COMPLETION REPORT

for the

Investigation Entitled

"Water Quality Assessment of Hayden Lake, Idaho"

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Per Contract with Save Hayden Lake, Inc.,
for Research Initiated January 1, 1985

Date: July 1, 1986

ACKNOWLEDGMENTS

The funding for this research was granted solely by Save Hayden Lake, Inc. We appreciate the opportunity and cooperation provided by the homeowners, especially Maxwell Drever and Dwight Damon, in performing this study and helping to further the public's knowledge of a unique resource. Special thanks are extended to Kim McKee for his work throughout the sampling and analysis phase of the study and to Scott Andrews for his assistance in the field and laboratory during the summer months.

We also thank the Sandpoint office of the U.S. Geological Survey for Hayden Creek discharge data and the Turnbull Laboratory for Ecological Studies for temporary use of their facilities to analyze some of the phytoplankton and phosphorus samples. Thanks to the Idaho Division of Environment who made literature and data files available, and to the E.W.U. Graphics Department for the illustrations in this report.

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ABSTRACT

A study of Hayden Lake, Idaho and its tributaries was undertaken from April through December 1986. Limnological data were collected to establish a baseline of information identify changes in the water quality from previous investigations and determine the impact of future watershed activities on the present water quality.

The calcium bicarbonate waters of Hayden Lake had good clarity, little conductivity and low nutrient concentrations. Temperature profiles revealed well defined thermal stratification occurring in the mid-summer, resulting in a large, cool hypolimnion with some oxygen depletion occurring to a minimum concentration of 4.4 mg l^{-1}. The mean chlorophyll a concentration was also low (2.04 mg m^{-3}), as was the calculated mean primary productivity (0.202 g C m^{-2} day^{-1}). The lake was classified as oligotrophic bordering on mesotrophy.

Zooplankton, mainly rotifers and copepods, were most numerous in Hayden Lake in the spring. Cladocerans, primary grazers of algae, were a minor constituent of the zooplankton standing crop. Low zooplankton density also indicated that Hayden Lake is oligotrophic, but a high percentage of copepods could signify a trend towards mesotrophy.

In-lake nutrient calculations showed phosphorus (P) to be the major limiting factor for algal growth. Tributaries contributed approximately 69 percent of the total annual phosphorus load to the lake while septic systems accounted for five percent. Increase in total annual P load to the lake from the proposed Yellow-Stacel, Deerfoot-Shamrock and B.P.A. timber harvests was calculated to be 3-4 percent.

CONCLUSIONS AND RECOMMENDATIONS

The water quality of Hayden Lake is remarkably good. Two major factors are probably responsible for this:

1) A deep lake basin with a large volume that dilutes nutrient loads from various sources and maintains a large, cool hypolimnion.
2) Most of the watershed is mountainous, old growth, forest which has a low nutrient export coefficient per unit area of land.

However, Hayden Lake is susceptible to, and probably experiencing, accelerated eutrophication (nutrient enrichment) as a result of man's activities within the drainage basin. Preservation of Hayden Lake water quality will require that nutrients (phosphorus and nitrogen) which increase primary production (aquatic plants) be minimized. In order to achieve this goal, nutrient loads from near-shore septic systems should be eliminated, where possible, through the development of public sewer systems that do not allow nutrient rich leachate to enter the lake. Also, nutrient export from the upper watershed should not be allowed to increase. Proposed timber harvest in the Yellowstacel, Deerfoot-Shamrock, and B.P.A. timber sales will probably negate any progress in nutrient load reduction accomplished through the development of public sewer systems. The cumulative impact of continued timber harvests of approximately 1.2 km^2 (300 ac) per year as required by the U.S. Forest Service, if their goal of a 100 year rotation plan is to be met, poses the greatest threat to Hayden Lake water quality even when "best management practices" are employed. Past environmental assessments prepared by the U.S. Forest Service have tended to ignore the cumulative impacts of road building and logging on receiving water bodies from concurrent or consecutive timber harvests in the same watershed over a period of time. This management policy must be changed.

Several watershed management strategies should be initiated to prevent future degradation of Hayden Lake. They include:

1) Establish a watershed zone which promotes well planned development and limits the density of development unless special sewage disposal and erosion prevention measures are taken.
2) Create an inter-agency watershed committee that would review all potential activities in the watershed impacting the water quality of Hayden lake. The committee would have representation from Hayden Lake homeowners, U.S. Forest Service, State Division of the Environment, State Department of Fish and Game, Panhandle

Health District and any other individuals or agencies deemed appropriate.

3) Develop and implement special timber harvest procedures (more strict than best management practices). These procedures should allow for the exclusion of certain areas from timber harvest if present lake quality is at risk.

4) Maintain a monitoring program to identify any deterioration of water quality in the lake and its tributaries before a major problem develops.

5) Promote educational programs to increase public knowledge and concern toward Hayden Lake and its environs with emphasis on the impacts of human activities and water quality. Suggested protective measures that individual homeowners can implement are:

   - Update and inspect septic systems to maintain optimal effectiveness and minimize septic system effluent through water use conservation.
   - Design landscape to use as much natural vegetation as possible. This will lessen maintenance and the need for extra watering and fertilizer, both of which can increase nutrient load to the lake.

- Build road and parking surfaces to reduce erosion and runoff and remove organic debris (i.e., grass clippings, leaves, etc.) from the shoreline and parking surfaces so it will not be carried into the lake.
- Restrict boat travel to established channels in weedy areas to minimize the cropping of aquatic plants, reducing nutrient input from decaying plant parts. Also, limit wake size near the shoreline by slowing boat speed, thus decreasing shoreline erosion and the resuspension of bottom sediments.
- Use aquatic weed harvesting methods that remove plants from the water as opposed to the use of herbicides which can be harmful to other biota and results in a residual of decaying vegetation in the water.

Hayden Lake homeowners are to be commended for their active participation in the preservation of this exceptional waterbody. In order for this initial concern to have a permanent effect, the education and involvement of homeowners must continue. Interactive participation by homeowners in local policy and planning decisions should be preferred and is usually more productive than a reactive policy to past decisions. Homeowners should encourage changes in regulatory programs of the State of Idaho and the Panhandle Health District to strengthen and fund adequate water quality protection, thereby providing a means to enforce the use of sound environmental practices by industry and other agencies.

INTRODUCTION

Hayden Lake is one of a limited number of high quality lakes that represents a valuable natural resource to Northern Idaho. The Idaho Department of Health and Welfare (1980) has designated Hayden Lake a "special resource" and such waters are to receive "intensive protection . . . to preserve outstanding or unique characteristics" (Meckel 1983). In 1983, the Classification of Idaho's Freshwater Lakes by Milligan *et al*. assigned Hayden Lake the highest priority of all Idaho lakes to "receive immediate consideration for protective or corrective measures". The reasons for this high priority were because of Hayden Lake's high use potential, a nutrient load approaching the lake's capacity to handle such a load, and the potential for successful management through both effective and economic corrective measures (Milligan *et al*. 1983).

The first known data on Hayden Lake water quality was reported by Kemmerer *et al*. (1924). They found a distinct thermocline and a large, cool, hypolimnion with relatively high dissolved oxygen concentrations to a depth of 50 meters. The Idaho Department of Fish and Game (IDFG) also conducted studies in 1948 and 1953. The goals of these studies were to characterize the lake and improve the declining fisheries. They found the lake to have good clarity with relatively high dissolved oxygen concentrations even at lower depths with some oxygen depletion near the bottom (Vaughan 1949, Mauser 1958). More recently, sampling by state and federal agencies has been infrequent.

The Idaho Department of Health and Welfare (IDHW) in 1972 initiated a water quality survey on mostly surface waters of Hayden Lake at various sites, with some sampling to a depth of 26 m (85 ft)(Johann 1974). Site location was often inconsistent and emphasis was placed on bacterial analysis along shorelines. High total coliform counts tended to be found in intensively used areas but seldom were any fecal coliform found.

In 1975, an algal growth potential study was performed by the U.S. Environmental Protection Agency as part of the National Eutrophication Survey (USEPA 1977). The report classified Hayden Lake as early mesotrophic. Two algal assays determined that phosphorus was probably the limiting nutrient for primary productivity; although, a calculated nitrogen to phosphorus ratio on 23 July, 1975 suggested that nitrogen may periodically limit algal growth.

The Panhandle Health District (1977) conducted a shoreline survey with an update in 1985 (Beckwith 1986). Survey results showed there are 653 individual sewage disposal systems within 95 m (300 ft) of Hayden Lake. Since 1975, the average distance of sewage systems from the lakeshore has increased from 35 m (115 ft) to 38 m (125 ft) due to newly constructed or repaired septic systems (109 units) which averaged 80 m (262 ft) from the water's edge.

Increased public awareness and concerns have been directed toward ongoing and proposed watershed management practices that can directly or indirectly impact Hayden Lake water quality. These concerns are more specifically the results of proposed silvicultural practices in the Panhandle National Forest and development of multiple dwelling complexes within the lake's drainage basin. In order to develop a strategy for future lake management this study was undertaken to:

1) establish existing baseline water quality and identify any trends in water quality from previous data;
2) determine nutrient loading to Hayden Lake and predict potential impacts from future watershed management practices; and
3) make recommendations to maintain and/or improve the present water quality of Hayden Lake.

DESCRIPTION OF STUDY AREA

Hayden Lake is located 8.0 km (5 mi) north of Coeur d' Alene, Idaho (Fig. 1) at latitude 47°56'00" and longitude 116°42'00" and at an elevation of 682.1 m (2238 ft). The lake lies along the easterly edge of the Rathdrum Prairie and was probably formed, like many of the lakes in this valley, from the damming of a secondary valley by glacial outwash (Conners 1976). Groundwater from Hayden Lake represents a major contribution to the Spokane Valley-Rathdrum Prairie aquifer in the Spokane River drainage basin (Drost and Seitz 1977).

The Hayden Lake drainage basin encompasses approximately 166 sq km (64 sq mi), 80 percent of which is forested and administered, almost exclusively, by the U.S. Forest Service (USFS) through the Panhandle National Forest headquarters in Coeur d' Alene, Idaho. Lakefront property on Hayden Lake is considered 85 percent developed by seasonal and year-around residents and is zoned "restricted residential", which permits up to four dwellings per acre (Meckel 1983). Other property, away from the shoreline is zoned suburban agricultural, rural and agricultural. Three communities, Hayden, Hayden Lake and Dalton Gardens, are located along the lake's southern and westerly shores, and collectively

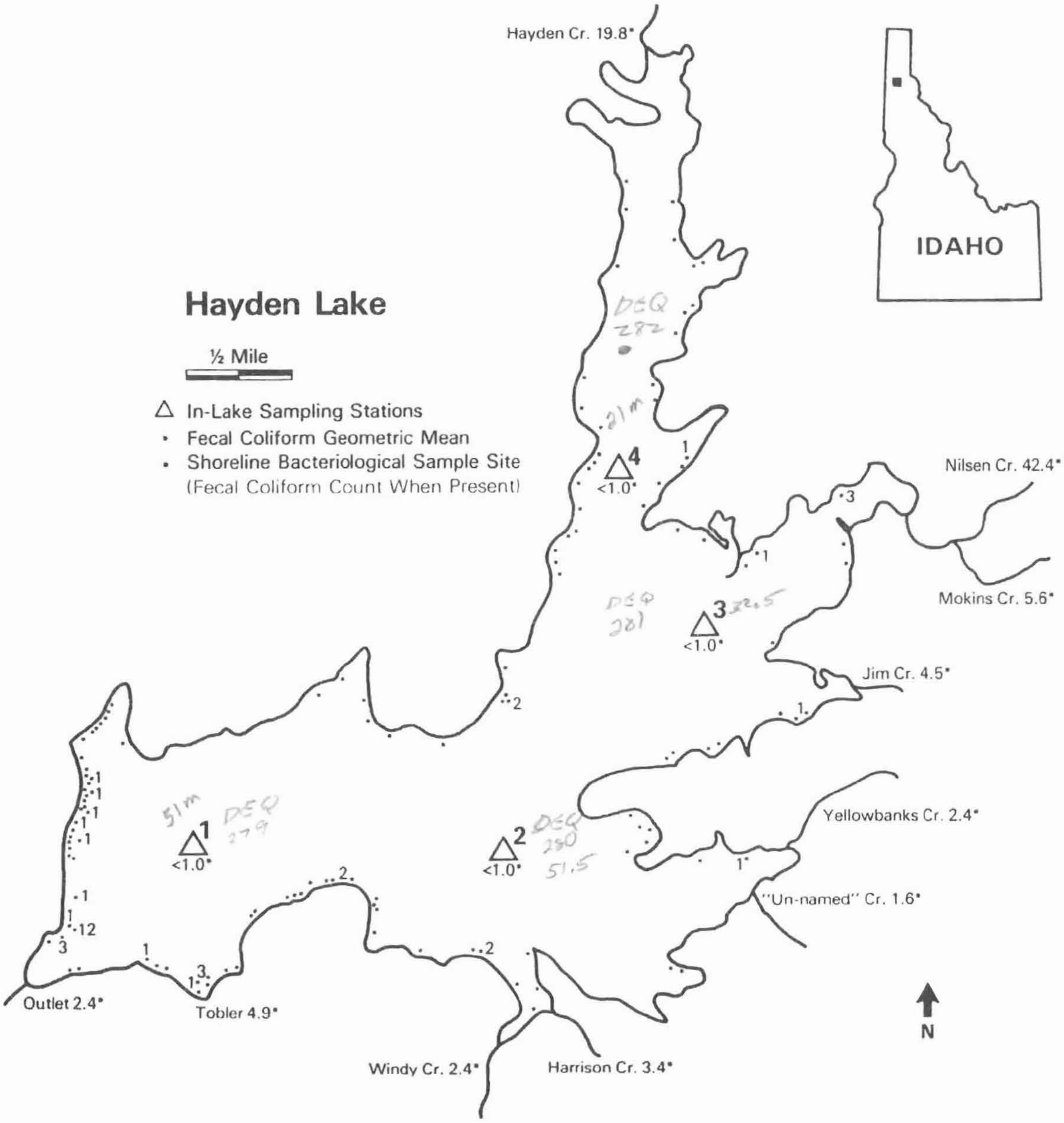


Figure 1. Location map for Hayden Lake, ID, indicating sampling sites (1985).

have a population of approximately 5000.

The surface area of Hayden Lake is 1581 ha (3907 ac) with a mean depth of 28.2 m (93 ft) and a maximum depth of 54.3 m (178 ft)(Table 1). The shallow northern end of the lake and most of the shallow bays contain dense submergent and emergent macrophyte growth, predominately Potamogeton species. Twenty small, and mostly seasonal, water courses empty into Hayden Lake. The majority of water entering the lake originates in the forested mountain sides to the south and east (Fig. 1) and is primarily transported by three tributaries: Hayden Creek, Mokins Creek and Yellowbanks Creek. Hayden Creek and Mokins Creek are the only tributaries that maintain substantial flows throughout the year. Land in the Mokins and Hayden Creek watersheds is used for logging, cattle grazing and limited agriculture (hay production) (Meckel 1983).

Water leaves Hayden Lake by subsurface seepage and one surface outlet at the southwestern end of the lake. Groundwater discharge into the Rathdrum Prairie aquifer from the Hayden Lake drainage has been estimated at 2.27 $m^3 sec^{-1}$ (80cfs)(Drost and Seitz 1977). The surface outlet flows only after the lake has filled to capacity from spring runoff and usually ceases in May. Spring spilling floods neighboring meadow land where it eventually disappears

Table 1. Morphometric data for Hayden Lake, ID (1985).

Maximum length	10.0 km (6.2 mi)
Maximum width	2.9 km (1.8 mi)
Maximum depth	54.3 m (178 ft)
Mean depth	28.2 m (93 ft)
Mean width	1.6 km (1.0 mi)
Surface area	1581 ha (3907 ac)
Volume	4.46×10^8 m^3 (3.62×10^5 ac-ft)
Shoreline development	3.1
Shoreline length	43.4 km (27.0 mi)

through percolation and evaporation. Irrigation and domestic water supplies are also pumped from the lake (Wuest 1986).

The shoreline has a diverse geomorphology. Most of the southern and eastern shorelines have slopes greater than 30 percent. These areas have high erosion potential with soil types varying from clay along the south shore to decomposing granite along most of the east shore. Northern shorelines from Berven Bay to English Point range from 7-15 percent slope and have shallow, silty clay soils on top of fractured basalt bedrock with moderate erosion potential. Western shorelines begin a transition to more shallow slopes of up to 7 percent and have sandy-gravel soil types with high permeability (Meckel 1983).

METHODS AND MATERIALS

Hayden Lake Tributaries and Outlet

Sampling

Sampling was performed monthly from 15 April through 2 December, 1985. Eight tributaries (Windy Creek, Harrison Creek, "Un-named" Creek, Yellowbanks Creek, Jim Creek, Mokins Creek, Nilsen Creek and Hayden Creek) and the Outlet were sampled when flowing (Fig. 1). Grab samples were taken at the tributary's intersection with Hayden Lake Road except for Mokins and Nilsen creeks which were sampled about 0.5 km upstream from their confluence. Jim Creek was sampled about 0.25 km upstream from Hayden Lake Road where the channel was more defined.

Hydrology

Discharge of each tributary was determined by taking the product of the stream cross-sectional area at the time of sampling and the average water velocity measured with a Price® flow meter. Discharge of Hayden Creek was also supplied by the USGS from the gaging station located just below the confluence of the North and East forks of Hayden Creek. Direct "bucketing" of water was also used on some of the smaller tributaries as water discharges decreased in late summer. The Outlet discharge was measured at the earthen dam when it was flowing in April and May by monitoring cross-sectional area and average channel velocity.

Physical and Chemical Parameters

In situ measurements at the eight tributary stations (Fig. 1) were made for temperature, conductivity, pH and dissolved oxygen with a Hydrolab® System 8000. Laboratory analyses included turbidity (nephelometric method), nitrate nitrogen (chromotropic acid method), nitrite nitrogen (diazotization method), ammonia nitrogen (phenate method), orthophosphate (stannous chloride method), and total phosphate (persulfate digestion - stannous chloride method), total alkalinity (potentiometric method), sulfate (turbidimetric method), chloride (mercuric nitrate method), total and calcium hardness (EDTA titration method), total Kjeldahl nitrogen (Kjeldahl digestion - electrode method) and silica (molybdosilicate method) as described by the American Public Health Association (APHA 1985). Combined sodium and potassium ion concentration (me/l) was estimated by subtracting the sum of calcium and magnesium ion concentrations (me l^{-1}) from one percent of the sample conductance.

Bacteriological Sampling

Surface grab samples were taken for each of the tributaries, and the Outlet when flowing, on each sample date. Samples were iced and analyzed for fecal coliform using the membrane filter technique (APHA 1985). Following incubation, colonies were counted and geometric means were calculated over all sample dates.

Hayden Lake

Sampling

Sampling was performed monthly at four in-lake stations from 15 April through 11 November 1985 (Fig. 1). Water samples were collected with a 2-liter Kemmerer bottle at 3-meter intervals from the surface to 15 m and at 6-meter intervals from 15 m to 51 m. An euphotic zone composite was also collected from the surface to the lower depth of the euphotic zone at 3-meter intervals.

Lake Morphometry and Hydrology

Morphometric features of the lake's basin were calculated from a bathymetrical map incorporated as part of the Kootenai County Lakes Master Plan (Meckel 1983). Changes in lake elevation were obtained from Hayden Lake Irrigation District. Inflow to Hayden Lake was determined as the sum discharges from eight tributaries: Windy Creek, Harrison Creek, "Un-named" Creek, Yellowbanks Creek, Jim Creek, Mokins Creek, Nilsen Creek and Hayden Creek. Direct contribution by rainfall was calculated using National Weather Service (1985) data from Coeur d' Alene, ID. Water retention time for the lake, expressed in years, was calculated by dividing the mean lake volume (m^3) by the mean daily inflow (m^3 day^{-1}) for the month. Storage change was calculated using the difference between the volume of inflow and the volume of outflow.

Physical and Chemical Parameters

In situ measurements at the four in-lake stations were made for temperature, conductivity, pH and dissolved oxygen with a Hydrolab® System 8000. Vertical profiles of light transmission through the water column were made using a Protomatic® underwater photometer at 1-meter intervals to a depth of one percent of surface incident light. This depth determined the lower limit of the euphotic zone (Verduin 1964). An extinction coefficient, a measure of light attenuation, was calculated according to Hutchinson (1957). In addition, Secchi disk measurements were made at each station for a general indication of water transparency (Welch 1948).

All lake samples were analyzed for turbidity, nitrate nitrogen, nitrite nitrogen, ammonia nitrogen, orthophosphate and total phosphate. In addition, euphotic zone composite samples were also analyzed for total alkalinity, sulfate, chloride, total and calcium hardness, total Kjeldahl nitrogen, silica, and sodium plus potassium as described in the "Tributaries and Outlet" section.

Phytoplankton Standing Crop, Chlorophyll a and Primary Productivity

Phytoplankton sub-samples were taken from euphotic zone composites and preserved with 1.0 ml of Lugol's iodine (APHA 1985). All phytoplankton biovolume counts per unit volume of water were determined using the sedimentation method as described by Schwoerbel (1970). Phytoplankton were identified with the aid of taxonomic keys by Hustedt (1930), Smith (1950), Prescott (1962, 1978), Patrick and Reimer (1966, 1975) and Weber (1971).

Chlorophyll a concentrations in the euphotic zone were determined using acetone extraction and the trichromatic method as prescribed in APHA (1985). Optical densities were measured at wavelengths of 630, 645, 663 and 750 nm on a Beckman DU-8 Spectrophotometer with a 1 cm cuvette and a 0.5 nm slit width (pheophytin a concentrations were not determined).

The method of Ryther and Yentsch (1957) as modified by Martin (1967) was used to estimate primary productivity. Monthly mean solar radiation data required for the calculation of primary productivity were obtained from the National Weather Service (1976) at Spokane International Airport.

Zooplankton Standing Crop

Zooplankton samples were collected at each of the four in-lake stations by taking oblique tows from the bottom to the surface using a Clarke-Bumpus quantitative sampler equipped with a no. 20 (76 micron aperture) silk net and cup. Samples were preserved in a three percent formalin solution and stained with 1.0 ml of Lugol's iodine and 1.0 ml of saturated eosin y-ethanol solutions (APHA 1985). Zooplankton were identified using the taxonomic keys of Edmondson (1959), Ruttner-Kolisko (1974) and Stemberger (1979).

Bacteriological Sampling

Grab samples were collected at the four permanent in-lake stations and at varying shoreline sampling sites (Fig. 1). Fecal coliform determination was performed using the methods previously outlined in the "Tributaries and Outlet" section.

Nutrient Loading

Phosphorus (P) and nitrogen (N) are generally considered to be the major elements limiting aquatic plant production. Of these two elements, phosphorus is usually the least in supply, and thus, the key element limiting primary productivity (Vollenweider 1968, Vollenweider and Dillon 1974). Increased phosphorus loading in many instances has been the direct result of point sources such as domestic wastewater and, therefore, more easily managed (Vollenweider and Dillon 1974). Nitrogen, on the other hand, is contributed by many diffuse sources in a watershed and is more difficult to control.

Nutrient Sources

Nutrient contributions from tributaries, atmospheric fallout (precipitation and dry), shoreline septic systems and proposed timber harvest were all treated as potentially significant sources. Total P loads from the tributaries were determined by calculating the product of the total monthly discharge and average P concentration. The phosphorus load of 0.04 g P m^{-2} yr^{-1} for atmospheric fallout (dry and precipitation) on the lake surface used in this study was taken from data collected at Twin Lakes, Idaho (Hallock 1986).

The P load estimate for shoreline septic systems was determined using an average concentration of 10 mg P l^{-1} for domestic wastewater. The total volume of wastewater entering the lake from septic systems was calculated using a value of 946.3 liters (250 gal) of wastewater per household per day (Panhandle Health District 1977) multiplied by the sum of the estimated seasonal household days (444 seasonal residents x 120 days) and the permanent household days (209 permanent x 365 days). This figure was then multiplied by the average P concentration to give an initial P load leaving all shoreline septic systems. As sewage leachate moves toward a lake, 90-99 percent attenuation of the P load can take place depending on soil type and shoreline slope (Fetter 1974, Gilliam and Patmont 1982). The average of 95 percent attenuation was applied in this study to the calculated P load leaving shoreline septic systems for the final P load entering the lake. It was assumed that leachate from drainfields was constant throughout the year.

An estimated P load from timber harvest was calculated by using all areas in the Deerfoot-Shamrock, Yellow-Stacel and BPA timber sales scheduled to receive burning as a form of slash treatment and, also, areas to receive new road construction (2.23 km^2, 550 ac; Lider 1986). A two-fold increase over background loading (0.017 metric tons of P

km^{-2} yr^{-1}) was used to predict increased P load from each square kilometer harvested and treated. The multiplication factor of three was derived from the mean increase over background P concentrations from nutrient loss studies following clearcutting and burning of slash (Fredricksen 1971) and following wildfire (Wright 1976). The P load from all sources was used in a predictive model developed by Vollenweider (1976) in an attempt to characterize Hayden Lake's response.

Nitrogen loading was calculated using the same general procedures as mentioned above for P loading. Nitrogen loading from atmospheric fallout was estimated as the product of the lake's surface area and an areal concentration of 0.6 g N m^{-2} yr^{-1} (USEPA 1974). The total contribution from septic systems was determined from a value of 30.5 g of N per household per day (Olsson et al. 1968) multiplied by the estimated permanent and seasonal resident days. The effects of timber harvest on N-loading was estimated by calculating a ten-fold increase in background levels from burned and new road construction (2.23 km^2, 550 ac) and a three-fold increase in background N from all other logged areas (3.32 km^2, 820 ac)(Fredricksen 1971, Brown et al. 1973 Tiedemann et al. 1978).

RESULTS

Hayden Lake Tributaries and Outlet

Hydrology

Maximum discharge for Hayden Creek, the largest tributary, occurred in April (6.99 m^3 sec^{-1}; Table 2). Mokins Creek (1.30 m^3 sec^{-1}) and Yellowbanks Creek (1.27 m^3 sec^{-1}) contributed the next highest flows to the lake in April. Discharges from the Outlet were recorded in April (0.07 m^3 sec^{-1}) and May (1.00 m^3 sec^{-1}) with no flow occurring the remainder of the study period. Both Yellowbanks and Jim creeks also "dried up" at the sample sites by mid-summer.

Water Chemistry

Calcium was the primary cation and bicarbonate the main anion in all the tributary streams of Hayden Lake (Table 3). Mean calcium concentrations varied from 0.09 me l^{-1} in Yellowbanks Creek to 1.33 me l^{-1} in Nilsen Creek. Bicarbonate was lowest in mean concentration for Yellowbanks Creek (0.16 me l^{-1}) and highest in Nilsen Creek (1.82 me l^{-1}). The Outlet, however, had a slightly higher concentration of magnesium than calcium. Mean sulfate concentrations were higher than chloride values for all

Table 2. Discharges (m^3 sec^{-1}) for the tributaries of Hayden Lake, ID (1985).

Tributary	4/15	5/13	Date 6/17	7/16	8/12
Windy Creek	0.32	0.07	0.01	<0.01	<0.01
Harrison Creek	0.06	0.02	0.01	<0.01	<0.01
"Un-named" Creek	0.26	0.04	0.01	<0.01	<0.01
Yellowbanks Creek	1.27	0.23	0.08	*	*
Jim Creek	0.29	0.03	0.03	0.01	*
Mokins Creek	1.30	0.35	0.11	0.06	0.05
Nilsen Creek	0.16	0.10	0.05	0.04	0.02
Hayden Creek**	6.99	1.13	0.59	0.20	0.20

Tributary	9/9	Date 10/7	11/4	12/2
Windy Creek	<0.01	<0.01	<0.01	*
Harrison Creek	<0.01	*	*	*
"Un-named" Creek	<0.01	<0.01	<0.01	*
Yellowbanks Creek	*	*	*	*
Jim Creek	*	*	*	*
Mokins Creek	0.04	0.04	0.05	0.09
Nilsen Creek	0.04	0.06	0.08	*
Hayden Creek**	0.18	0.14	0.31	0.11

* No flow

** USGS data

Table 3. Range and mean of the determined water quality parameters for the Outlet and tributary waters of Hayden Lake, ID (4/15/85 - 12/2/85).

Parameter	Outlet	Windy Creek	Harrison Creek	"Un-named" Creek	Yellowbanks Creek
Ca^{+2} (me l^{-1})	0.12-0.30 0.21	0.08-0.24 0.18	0.10-0.20 0.15	0.09-0.32 0.24	0.04-0.13 0.09
Mg^{+2} (me l^{-1})	0.15-0.33 0.24	0.05-0.17 0.12	0.03-0.16 0.09	0.06-0.19 0.12	0.03-0.10 0.06
Na^{+} + K^{+} (me l^{-1})	0.05-0.06 0.06	<0.01-0.16 0.09	0.05-0.16 0.11	0.06-0.14 0.11	0.04-0.08 0.06
HCO_3^{-} (me l^{-1})	0.48-0.49 0.49	0.16-0.43 0.32	0.15-0.42 0.29	0.15-0.55 0.41	0.12-0.20 0.16
SO_4^{-2} (me l^{-1})	0.04-0.07 0.05	0.05-0.14 0.09	0.09-0.14 0.10	0.05-0.10 0.08	0.04-0.07 0.06
Cl^{-} (me l^{-1})	0.02-0.02 0.02	0.01-0.03 0.02	0.02-0.02 0.02	0.01-0.03 0.02	0.01-0.02 0.02
Temperature (^{o}C)	8.5-10.1 9.3	5.9-17.7 9.4	5.3-11.7 8.6	5.2-13.1 8.6	5.8-9.0 7.0
Conductance (umhos cm^{-1})	50-51 51	30-51 40	24-50 34	25-60 47	18-25 21
pH Range	7.21-7.33	6.08-7.06	6.55-6.88	6.55-7.01	6.42-6.95
Dissolved Oxygen (mg l^{-1})	10.4-11.3 10.9	9.4-11.4 10.1	9.7-11.5 10.2	8.9-11.5 10.1	9.8-11.4 10.4
NO_3^{-}-N (mg l^{-1})	<0.01-0.04 0.02	0.02-0.27 0.09	0.02-0.09 0.06	0.04-0.25 0.13	0.01-0.04 0.02
NO_2^{-}-N (mg l^{-1})	<0.001-0.001 0.001	<0.001-0.001 <0.001	<0.001-0.001 0.001	<0.001-0.001 <0.001	<0.001-0.001 <0.001
NH_3-N (mg l^{-1})	<0.01-<0.01 <0.01	<0.01-0.04 0.01	<0.01-0.02 <0.01	<0.01-<0.01 <0.01	<0.01-<0.01 <0.01
Total Organic NH_3-N (mg l^{-1})	0.28-0.40 0.34	0.13-0.32 0.21	0.13-0.61 0.25	0.09-0.44 0.20	0.10-0.19 0.16

Table 3. (Continued)

Parameter	Outlet	Windy Creek	Harrison Creek	"Un-named" Creek	Yellowbanks Creek
Ortho-PO_4^{-3} (mg l^{-1})	0.01-0.02 0.01	0.03-0.11 0.06	0.06-0.12 0.08	0.03-0.09 0.07	0.02-0.07 0.04
Total-PO_4^{-3} (mg l^{-1})	0.04-0.07 0.05	0.05-0.12 0.07	0.07-0.18 0.10	0.06-0.13 0.08	0.03-0.09 0.06
Turbidity (NTU)	0.4-1.3 0.8	1.2-6.1 2.2	1.5-7.6 3.2	0.4-3.9 1.3	0.5-3.6 1.7
Silica (mg l^{-1})	8.2-9.2 8.7	20.1-23.8 22.2	23.3-25.5 24.4	18.6-22.7 20.8	14.0-15.2 14.8

Table 3. (Continued)

Parameter	Jim Creek	Mokins Creek	Nilsen Creek	Hayden Creek
Ca^{+2} (me l^{-1})	0.08-0.21 0.13	0.24-0.65 0.53	0.69-1.58 1.33	0.20-0.44 0.37
Mg^{+2} (me l^{-1})	<0.01-0.13 0.06	0.13-0.34 0.27	0.20-0.54 0.41	0.08-0.24 0.20
Na^{+} + K^{+} (me l^{-1})	0.06-0.17 0.12	<0.01-0.06 0.02	<0.01-0.06 0.02	<0.01-0.07 0.04
HCO_3^{-} (me l^{-1})	0.14-0.55 0.31	0.38-1.04 0.81	0.94-2.25 1.82	0.31-0.75 0.62
SO_4^{-2} (me l^{-1})	0.05-0.09 0.07	0.04-0.07 0.05	0.09-0.17 0.12	0.04-0.09 0.05
Cl^{-} (me l^{-1})	0.02-0.02 0.02	<0.01-0.02 0.01	0.01-0.10 0.04	0.01-0.03 0.02
Temperature (^{o}C)	5.5-11.5 8.0	0.9-13.1 7.6	5.3-13.1 9.7	0.0-14.5 8.9
Conductance (umhos cm^{-1})	21-40 31	42-99 81	96-206 170	35-72 59
pH Range	6.10-6.96	6.66-7.51	7.10-7.80	7.00-7.50
Dissolved Oxygen (mg l^{-1})	8.5-10.9 9.6	9.3-12.5 10.4	9.0-10.7 9.6	9.1-12.8 10.3
NO_3^{-}-N (mg l^{-1})	0.03-0.12 0.07	0.03-0.14 0.08	0.07-0.28 0.12	0.01-0.19 0.06
NO_2^{-}-N (mg l^{-1})	<0.001-0.001 <0.001	<0.001-0.001 <0.001	<0.001-0.003 0.001	<0.001-0.003 0.001
NH_3-N (mg l^{-1})	<0.01-<0.01 <0.01	<0.01-<0.01 <0.01	<0.01-0.04 0.01	<0.01-0.04 <0.01
Total Organic NH_3-N (mg l^{-1})	0.16-0.25 0.20	0.15-0.35 0.24	0.25-0.51 0.39	0.14-0.38 0.21

Table 3. (Continued)

Parameter	Jim Creek	Mokins Creek	Nilsen Creek	Hayden Creek
Ortho-PO_4^{-3} ($mg\ l^{-1}$)	0.02-0.08 0.05	0.02-0.06 0.03	0.09-0.12 0.10	<0.01-0.04 0.01 (.003) P
Total-PO_4^{-3} ($mg\ l^{-1}$)	0.04-0.08 0.07	0.04-0.12 0.06	0.12-0.27 0.15	0.01-0.14 0.04 (.013) P
Turbidity (NTU)	1.5-4.0 2.9	0.6-6.1 1.6	1.2-15.0 3.8	0.3-9.0 1.7
Silica ($mg\ l^{-1}$)	18.0-22.3 20.1	12.4-16.6 15.2	24.5-29.5 27.3	11.2-14.2 13.2

tributaries. Average temperatures for the study period ranged from 7.0°C in Yellowbanks Creek to 9.7°C in Nilsen Creek. Conductivity values were low for most of the tributaries, averaging only 21 µmhos cm^{-1} in Yellowbanks Creek. A maximum conductance of 206 µmhos cm^{-1} was measured in Nilsen Creek with an average of 170 µmhos cm^{-1} for the sampling period. Conductance of the Outlet was approximately 51 µmhos cm^{-1} for all the samples taken. The pH ranged from a low of 6.08 for Windy Creek to a high of 7.80 for Nilsen Creek. Mean dissolved oxygen (D.O.) concentrations were always greater than 9.0 mg l^{-1} for all tributaries. Turbidity values were low for all streams, except for the maximum of 15 NTU measured for Nilsen Creek in April. Mean turbidity was less than 4 NTU for all tributaries. Average silica concentrations ranged from 8.7 mg l^{-1} at the Outlet to 27.3 mg l^{-1} for Nilsen Creek.

Nitrate nitrogen concentrations averaged the highest for "Un-named" (0.13 mg l^{-1}) and Nilsen (0.12 mg l^{-1}) creeks. Nitrate nitrogen values were lowest for the Outlet and Yellowbanks Creek, averaging 0.02 mg l^{-1}. Nitrite and ammonia nitrogen concentrations were low for all tributaries with means of approximately 0.001 mg l^{-1} and 0.01 mg l^{-1}, respectively. Total organic nitrogen averaged a minimum of 0.16 mg l^{-1} in Yellowbanks Creek to a maximum of 0.39 mg l^{-1} in Nilsen Creek.

Orthophosphate (OP) and total phosphate (TP) levels were at a maximum in Harrison Creek (0.08 and 0.10 mg l^{-1}, respectively) and Nilsen Creek (0.10 and 0.15 mg l^{-1}, respectively). Minimum OP and TP concentrations were measured at the Outlet and Hayden Creek.

Bacteriological Sampling

The highest levels of fecal coliform (FC) were consistently found in Nilsen Creek with a geometric mean of 42.4 FC 100 ml^{-1} (Fig. 1). Actual FC values (see Appendix F) from Nilsen Creek ranged from a minimum of 10 on 16 July to a maximum of 170 on 17 June.

Hayden Creek had the second highest FC counts with a GM of 19.8 FC 100 ml^{-1}. The remainder of the tributaries had GMs of less than 10 FC 100 ml^{-1} (Fig. 1). Two samples also collected from the culvert discharge near Tobler's Marina representing runoff from the Cooper's Bay development had FC counts less than 10 FC 100 ml^{-1}.

Hayden Lake

Hydrology

A maximum inflow of 27.61 x 10^6 m^3 to Hayden Lake occurred in April, while minimum inflow (0.54 x 10^6 m^3) was estimated for December (Table 4). Discharge at the Outlet occurred only in April and May with a maximum total discharge of 2.68 x 10^6 m^3 in May. A subsurface flow from the lake to the Rathdrum Prairie-Spokane Valley aquifer has been established by U.S. Geological Survey (Drost and Seitz 1977) and shown in Table 4. Minimum inflow to the lake in December and no discharge at the Outlet resulted in a calculated maximum water retention time of 71.9 years in December (Table 5). Approximately ~~1.1~~ 0.1 exchanges of the lake's volume occurred during the April to December study period.

Error - personal communication Ken Merrill 4/21/88

Temperature

A minimum temperature of 4.1°C occurred at the 27-meter depth of station 1 in April, while a maximum temperature of 20.4°C occurred at the surface of station 4 in August. Homothermal conditions typical of spring turnover were not apparent when sampling commenced in April (Fig. 2). Thermal stratification became well established in June when a maximum differential of 12.2°C was measured between the surface and bottom waters of station 3. Homothermal conditions were evident at station 3 and 4 again in November when fall turnover occurred. Turnover was probably delayed at the deeper stations, 1 and 2.

Table 4. Total monthly inflow, discharge and storage change ($m^3 \times 10^6$) for Hayden Lake, ID (1985).

Month	Inflow	Discharge		Storage Change
		Outlet	Subsurface	
April	27.61	0.18	5.88	+21.55
May	5.28	2.68	6.08	-3.48
June	2.28	*	5.88	-3.60
July	0.86	*	6.08	-5.22
August	0.75	*	6.08	-5.33
September	0.70	*	5.88	-5.18
October	0.64	*	6.08	-5.44
November	1.17	*	5.88	-4.71
December	0.54	*	6.08	-5.54

* No flow

Table 5. Monthly mean storage, daily inflow, retention time and exchange rate, Hayden Lake, ID (1985).

Month	Mean Storage $m^3 x10^6$	Mean Inflow $m^3\ day^{-1} x10^3$	Retention Time Years	Exchange Rate
April	446	920	1.33	0.75
May	446	170	7.19	0.14
June	446	76	16.08	0.06
July	446	28	43.67	0.02
August	446	24	51.02	0.02
September	446	23	53.19	0.02
October	446	21	58.14	0.02
November	446	39	31.35	0.03
December	446	17	71.94	0.01

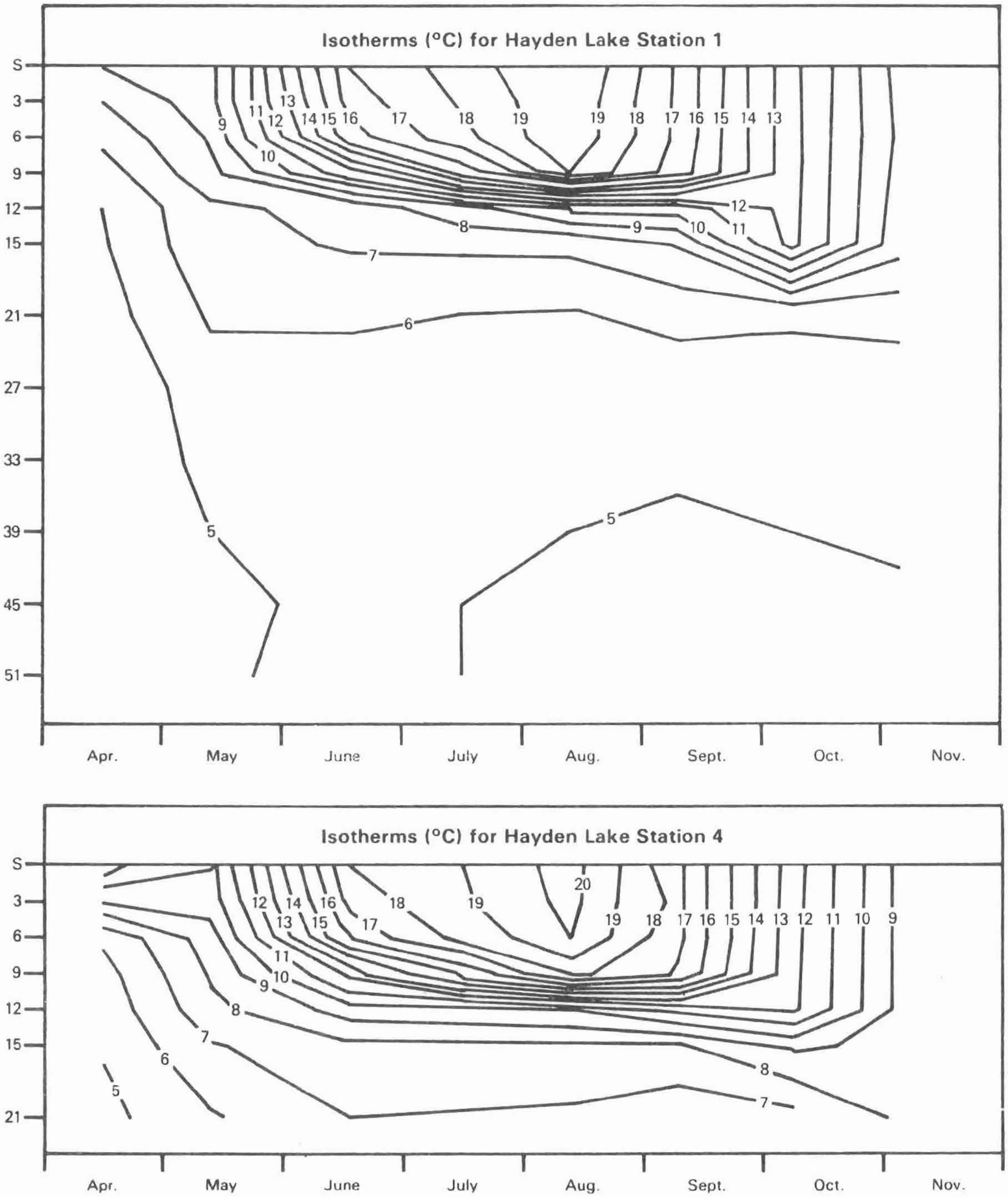


Figure 2. Isotherms (^{o}C) at stations 1 and 4, Hayden Lake, ID (1985).

Water Chemistry

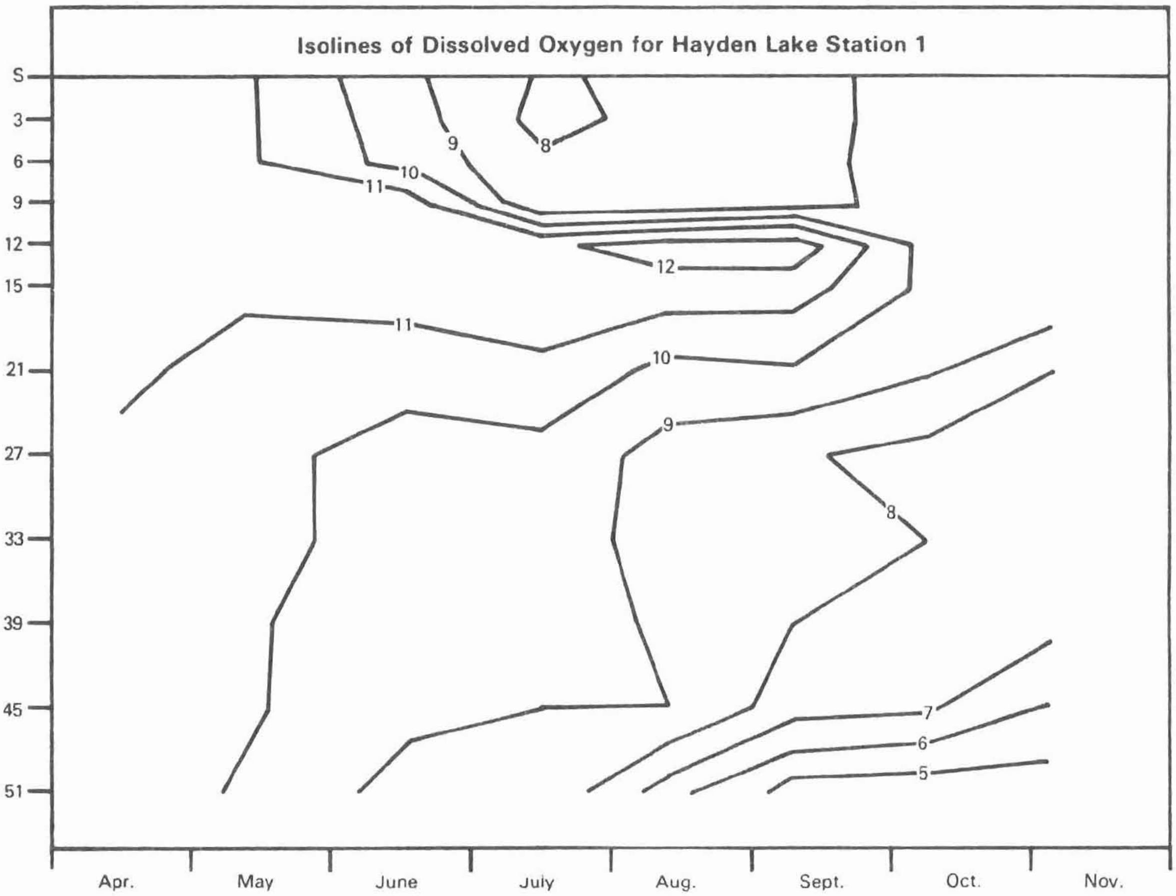
Conductivity values were relatively constant (41-55 µmhos cm^{-1}; Table 6) throughout the study with little evidence of chemical stratification. Minimum values occurred at the 21-meter depth of station 1 in July, while maximum values were determined at the surface to the 6- and 9-meter depths in August and September. Dissolved oxygen concentrations reached a maximum of 12.5 mg l^{-1} at the 12-meter depth of station 1 in August (Fig. 3). A minimum value of 4.4 mg l^{-1} was measured at the 51-meter depth of station 1 in October. An absence of oxygen was not evident during the study. Mean D.O. concentrations exceeded 10.0 mg l^{-1} at stations 3 and 4 during the study (Table 6).

Nitrate nitrogen concentrations averaged 0.03 mg l^{-1} at stations 1, 2 and 4 and 0.04 mg l^{-1} at station 3 (Table 6). Nitrite nitrogen values were usually 0.001 mg l^{-1} and ammonia nitrogen values less than 0.01 mg l^{-1} at all stations. Mean OP levels were less than 0.01 mg l^{-1} at stations 1 and 2, and 0.01 mg l^{-1} at stations 3 and 4 (Fig. 4; Table 6). Total phosphate concentrations ranged from less than 0.01 mg l^{-1} in August and October to 0.08 mg l^{-1} in April and May. Turbidity values were higher at station 4 (2.8 NTU) than at the other stations with mean values of 0.4 NTU at stations 1, 2 and 3 and 0.5 NTU at station 4.

Table 6. Range and mean of the determined water quality parameters at each Hayden Lake sampling station (4/15/85 - 11/4/85).

Parameter	Station 1	Station 2	Station 3	Station 4
Temperature (°C)	4.1-20.0 8.3	4.3-20.2 8.5	4.7-20.3 10.3	4.7-20.4 11.1
Conductance (umhos cm^{-1})	41-54 50	41-55 50	43-55 51	45-55 51
pH Range	5.62-8.17	5.24-8.33	5.74-8.24	6.01-8.04
Dissolved Oxygen (mg l^{-1})	4.4-12.7 9.5	4.9-12.7 9.6	7.7-12.3 10.1	7.9-12.4 10.1
NO_3^--N (mg l^{-1})	0.01-0.07 0.03	<0.01-0.07 0.03	0.02-0.08 0.04	0.01-0.06 0.03
NO_2^--N (mg l^{-1})	<0.001-0.003 0.001	<0.001-0.003 <0.001	<0.001-0.002 <0.001	<0.001-0.002 <0.001
NH_3-N (mg l^{-1})	<0.01-0.04 <0.01	<0.01-0.02 <0.01	<0.01-<0.01 <0.01	<0.01-<0.01 <0.01
Ortho-PO_4^{-3} (mg l^{-1})	<0.01-0.03 <0.01	<0.01-0.02 <0.01	<0.01-0.03 0.01	<0.01-0.04 0.01
*0.326 Total-PO_4^{-3} (mg l^{-1})	<0.01-0.07 (0.023) 0.02 (0.0065)	<0.01-0.08 (0.026) 0.02	<0.01-0.07 0.03 (0.010)	<0.01-0.08 0.03
Turbidity (NTU)	0.2-0.9 0.4	0.1-1.3 0.4	0.3-0.8 0.4	0.3-2.8 0.5

P/O4 = 0.326



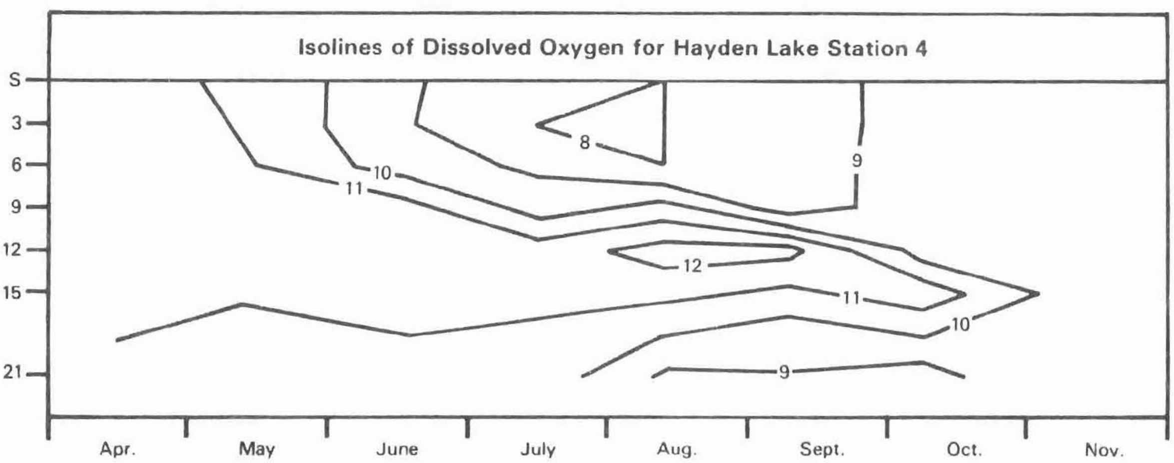


Figure 3. Isolines of dissolved oxygen (mg l^{-1}) at stations 1 and 4, Hayden Lake, ID (1985).

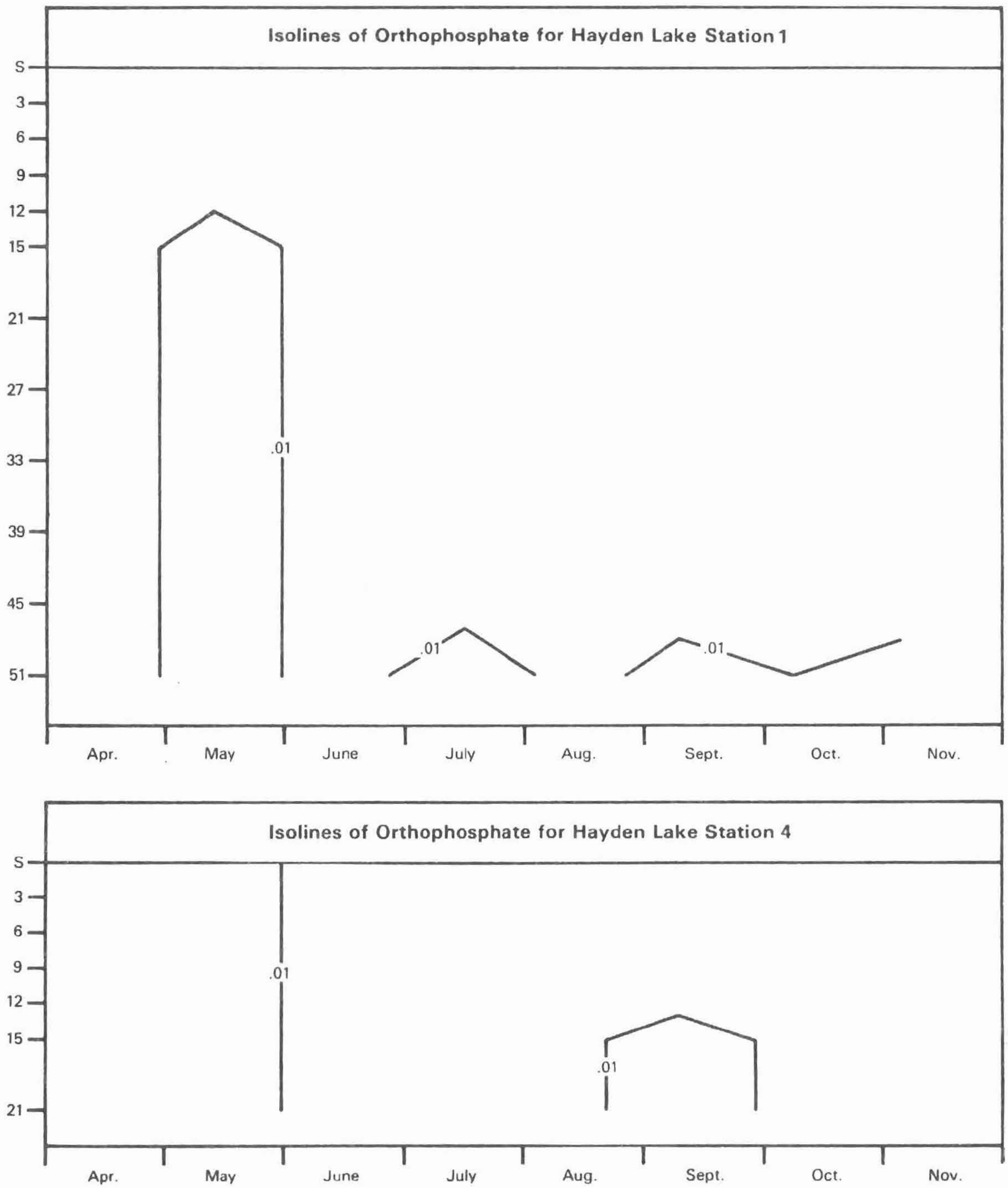


Figure 4. Isolines of orthophosphate (mg l^{-1}) at stations 1 and 4, Hayden Lake, ID (1985).

The euphotic zone range and mean for each of the determined water quality parameters are shown in Table 7. Mean temperature values ranged from 11.0°C at station 1 to 11.8°C at station 4. Conductance averaged 51 µmhos cm^{-1} at all stations. Mean D.O. concentrations were slightly higher in the euphotic zone (10.2 mg l^{-1}) than in the water column (9.8 mg l^{-1}). All inorganic nitrogen parameters (nitrate, nitrite and ammonia) were generally the same values in the euphotic zone as in the water column. Total phosphate concentrations in the euphotic zone averaged 0.03 mg l^{-1} at station 2, compared to 0.02 mg l^{-1} in the water column. The remaining stations had mean TP concentrations the same as those calculated for the water column. Mean turbidity levels in the euphotic zone (0.8 NTU) were double those in the water column (0.4 NTU) at all stations. Silica ranged from 6.3 mg l^{-1} at station 1 to 9.5 mg l^{-1} at station 4, with an overall lake average of 8.2 mg l^{-1}. Euphotic zone depth was greatest at station 1 (21 m) and the least at station 4 (18 m).

Light

Secchi disk depth, a measure of water clarity, was highest in September when turbidity levels were lowest in the lake. Water clarity was at a minimum in April and May

Table 7. Range and mean of the determined water quality parameters for the euphotic zone at each Hayden Lake sampling station (4/15/85 - 11/4/85).

Parameter	Station 1	Station 2	Station 3	Station 4
DEQ	279	280	281	282
Ca^{+2} (me l^{-1})	0.27-0.30 0.29	0.28-0.38 0.30	0.28-0.30 0.29	0.27-0.31 0.29
Mg^{+2} (me l^{-1})	0.14-0.19 0.17	0.09-0.18 0.15	0.14-0.21 0.16	0.12-0.18 0.16
Na^{+} + K^{+} (me l^{-1})	<0.01-0.08 0.06	<0.01-0.10 0.06	0.03-0.09 0.06	<0.01-0.09 0.06
HCO_3^{-} (me l^{-1})	0.46-0.76 0.53	0.47-0.51 0.50	0.48-0.52 0.50	0.48-0.53 0.49
SO_4^{-2} (me l^{-1})	0.05-0.10 0.07	0.05-0.11 0.06	0.05-0.10 0.07	0.05-0.11 0.07
Cl^{-} (me l^{-1})	0.02-0.03 0.02	0.02-0.03 0.02	0.02-0.03 0.02	0.02-0.03 0.02
Temperature (^{o}C)	5.9-16.0 11.0	6.4-15.7 11.1	6.4-15.8 11.3	7.5-16.2 11.8
Conductance (umhos cm^{-1})	46-54 51	46-53 51	46-54 51	46-54 51
pH Range	6.60-7.62	6.47-7.86	6.59-7.81	6.82-7.60
Dissolved Oxygen (mg l^{-1})	9.4-11.4 10.1	9.5-11.5 10.3	9.4-11.4 10.2	9.4-11.6 10.2
NO_3^{-}-N (mg l^{-1})	0.01-0.06 0.03	0.01-0.05 0.03	<0.01-0.07 0.03	0.01-0.08 0.03
NO_2^{-}-N (mg l^{-1})	<0.001-0.001 0.001	<0.001-0.001 <0.001	<0.001-0.003 0.001	<0.001-0.001 0.001
NH_3-N (mg l^{-1})	<0.01-0.01 <0.01	<0.01-<0.01 <0.01	<0.01-<0.01 <0.01	<0.01-<0.01 <0.01
Total Organic NH_3-N (mg l^{-1})	0.18-0.46 0.34	0.17-0.37 0.29	0.16-0.54 0.32	0.13-0.58 0.31

Table 7. (Continued)

Parameter	Station 1	Station 2	Station 3	Station 4
Ortho-PO_4^{-3} ($mg\ l^{-1}$)	<0.01-0.01 < 0.01	<0.01-0.02 <0.01	<0.01-0.02 0.01	<0.01-0.02 0.01
Total-PO_4^{-3} ($mg\ l^{-1}$)	0.01-0.04 0.02	<0.01-0.07 0.03	0.01-0.08 0.03	0.01-0.07 0.03
Turbidity (NTU)	0.5-0.9 0.7	0.4-1.8 1.0	0.4-0.6 0.5	0.3-1.2 0.8
Silica ($mg\ l^{-1}$)	6.3-9.0 8.1	6.6-8.7 8.1	6.6-8.9 8.2	7.1-9.5 8.3
Euphotic Zone Depth (m)	12-21 17	13-19 17	11-19 16	12-18 15
Extinction Coefficient ($k\ m^{-1}$) Range	0.21-0.38	0.24-0.32	0.22-0.41	0.26-0.38
Secchi disk (m)	5.9-9.2 7.3	6.5-9.6 7.7	6.4-9.3 7.7	3.1-8.6 6.7
Chlorophyll *a* ($mg\ m^{-3}$)	1.15-2.59 2.10	1.31-2.59 1.97	1.46-2.40 1.93	1.46-3.72 2.16
Chlorophyll *b* ($mg\ m^{-3}$)	<0.01-1.44 0.44	<0.01-1.44 0.31	<0.01-0.45 0.16	0.01-2.87 0.55
Chlorophyll *c* ($mg\ m^{-3}$)	0.13-5.93 1.97	0.02-5.93 1.57	<0.01-2.14 0.95	0.70-10.65 2.52

when turbidity was highest because of spring runoff. Secchi disk depth ranged from 3.1 m at station 4 in April when turbidity was 1.2 NTU to 9.6 m at station 2 in September when turbidity was 0.4 NTU. Extinction coefficients varied from a minimum of 0.21 k m^{-1} at station 1 in September to a maximum of 0.41 k m^{-1} at station 3 in October.

Phytoplankton Standing Crop, Chlorophyll a and Primary Productivity

A total of 62 species in 51 genera were identified in the Hayden Lake phytoplankton community during the sampling period (Table 8). The algal class Chlorophyceae had the greatest diversity with 22 species identified, while the class Euglenophyceae had only one member identified.

The mean phytoplankton biovolume for the study period was 0.529 mm^3 l^{-1} on a volumetric basis. The major phytoplankton species were ranked according to absolute mean biovolume (Table 9). *Oscillatoria limnetica* (a blue-green algae) had the largest mean biovolume at 0.143 mm^3 l^{-1} which was approximately 27 percent of the total estimated mean mean biovolume. Microplankton (unidentified cells less than five microns in size) ranked second in mean biovolume and accounted for 13 percent of the total mean biovolume. *Cryptomonas* sp., *Gymnodinium* sp. and *Mallomonas* sp. ranked

Table 8. Phytoplankton species identified from euphotic zone composite samples, Hayden Lake, ID (1985).

DIVISION: CHLOROPHYTA

Class: Chlorophyceae

Acanthosphaera Zachariasi Lemmermann
Ankistrodesmus falcatus (Corda) Ralfs
Carteria sp. Diesing
Chlamydomonas sp. Ehrenberg
Chlorogonium elongatum (Dang.) Franze
Closterium sp. Nitzsch
Coccomonas sp. Stein
Cosmarium sp. Corda
Crucigenia irregularis Wille
Echinosphaerella sp. G.M. Smith
Franceia Droescheri (Lemm.) G.M. Smith
Gloeocystis sp. Naegeli
Golenkinia radiata (Chod.) Wille
Lagerheimia subsalsa Lemmermann
Mesotaenium sp. Naegeli
Oocystis parva West & West
Oocystis sp. Naegeli
Pandorina morum Bory
Roya obtusa (Berb.) West & West
Scenedesmus sp. Meyen
Schroederia setigera (Schroed.) Lemmerman
Tetraedron arthrodesmiforme (G.S. West) Woloszynska
Tetraedron minimum (A. Braun) Hansgirg
Treubaria sp. Bernard

DIVISION: CHRYSOPHYTA

Class: Bacillariophyceae

Asterionella formosa Hassall
Cyclotella glomerata Bachmann
Cyclotella sp. Kuetz
Cymbella sp. Agardh
Fragilaria contruens (Ehr.) Grun.
Fragilaria crotonensis Kitton
Fragilaria sp. (Lyngb.) Rabenhorst
Stephanodiscus sp. Ehrenberg
Synedra actinastroides Lemmermann
Synedra acus Kuetz
Synedra cyclopum Brutschy
Synedra rumpens Kuetz

Table 8. (Continued)

Synedra sp. Ehrenberg
Synedra ulna (Nitz.) Ehrenberg
Tabellaria fenestrata (Lyngb.) Kuetz

Class: Chrysophyceae

Amphichrysis sp. Korshikov
Chromulina sp. Cienkowski
Chrysapsis sp. Pascher
Chrysochromulina sp. Lackey
Diceras phaseolus Fott
Dinobryon bavaricum Imhof
Mallomonas sp. Perty
Ochromonas sp. Wystozki

DIVISION: CRYPTOPHYTA

Class: Cryptophyceae

Chroomonas sp. Hansgirg
Cryptomonas sp. Ehrenberg
Rhodomonas sp. Karsten

DIVISION: CYANOPHYTA

Class: Cyanophyceae

Anabaena sp. Bory
Aphanocapsa delicatissima West & West
Aphanothece nidulans P. Richter
Chroococcus limneticus Lemmermann
Microcystis aeruginosa Kuetz
Oscillatoria limnetica Lemmermann
Spirulina laxissima G.S. West

DIVISION: PYRROPHYTA

Class: Dinophyceae

Glenodinium sp. (Ehrenb.) Stein
Gymnodinium sp. Stein
Hypnodinium sp. Klebs

Table 8. (Continued)

DIVISION: EUGLENOPHYTA

Class: Euglenophyceae

Trachelomonas sp. Ehrenberg
Trachelomonas volvocina Ehrenberg

Table 9. Rank of the predominant phytoplankton species according to absolute mean biovolume* ($mm^3\ l^{-1}$) based on euphotic zone collections from all stations over all dates, Hayden Lake, ID (1985).

Rank	Taxon	Biovolume
1	*Oscillatoria limnetica*	0.143
2	Microplankton	0.069
3	*Cryptomonas* sp.	0.034
4	*Gymnodinium* sp.	0.032
5	*Mallomonas* sp.	0.031
6	*Rhodomonas* sp.	0.029
7	*Glenodinium* sp.	0.020
8	*Chroomonas* sp.	0.017
9	*Asterionella formosa*	0.015
10	*Aphanocapsa delicatissima* *Hypnodinium* sp.	0.014

* Absolute biovolume is the total biovolume contributed by each respective alga divided by the number of sample dates.

Table 10. Rank of the predominant phytoplankton species according to occurrence (%) based upon euphotic zone collections from all stations over all dates, Hayden Lake, ID (1985).

Rank	Taxon	Occurrence
1	Microplankton	100
2	Chroomonas sp. Rhodomonas sp.	96.9
3	Oscillatoria limnetica	90.6
4	Ankistrodesmus falcatus	87.5
5	Gymnodinium sp.	81.3
6	Cryptomonas sp.	75
7	Dinobryon bavaricum	71.9
8	Mallomonas sp.	65.6
9	Glenodinium sp.	53.1
10	Gloeocystis	50

third, fourth and fifth in mean biovolume, respectively.

The 10 major phytoplankton species were also ranked by how often they occurred in the collected samples (Table 10). Microplankton was the only group found in every sample. Chroomonas sp. and Rhodomonas sp. were tied for second rank with an occurrence of 96.9 percent. Oscillatoria limnetica was ranked third (90.6 percent), Ankistrodesmus falcatus was fourth (87.5 percent) and Gymnodinium sp. was ranked fifth with an occurrence of 81.3 percent.

Seasonal trends in absolute mean biovolume for the various algal classes are shown in Figure 5. The Bacillariophyceae (diatoms) had their maximum mean biovolume of 0.118 $mm^3\ l^{-1}$ in April with a generally declining trend through the summer. Asterionella formosa was the most common species in this class with a mean biovolume of 0.015 $mm^3\ l^{-1}$.

The chlorophyceans (green algae) had a pulse of growth in the spring (0.064 $mm^3\ l^{-1}$) and then declined in the summer until an increase in biovolume was again observed in November. As previously mentioned, this class was the most diverse, but was usually dominated by Acanthosphaera Zachariasi, Ankistrodesmus falcatus and Chlamydomonas sp.

The Chrysophyceae had relatively low biovolumes throughout the study period with a mean of 0.045 $mm^3\ l^{-1}$.

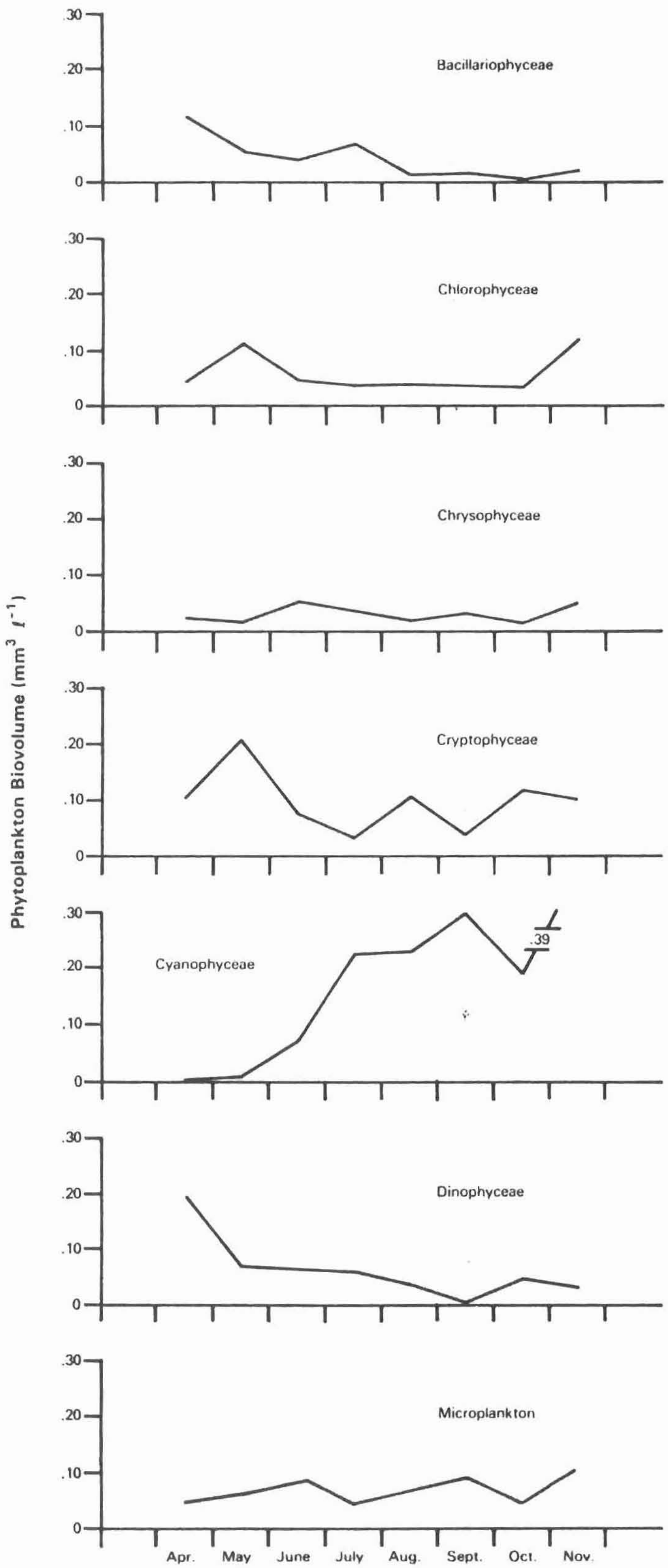


Figure 5. Mean phytoplankton biovolume ($mm^3\ l^{-1}$), for the seven major algal classes by date over all stations, Hayden Lake, ID (1985).

The most common species representing this class were Mallomonas sp., Dinobryon bavaricum and Diceras phaseolus.

The crytophyceans had some relatively large peaks as a class (Fig. 5) primarily species of Cryptomonas, Rhodomonas and Chroomonas.

The cyanophyceans (blue-green algae) began to appear in June and generally increased throughout the summer and fall to a maximum mean biovolume of 0.390 $mm^3\ l^{-1}$ on 11 November. The dominant species of the class was Oscillatoria limnetica but was joined later in the season by Microcystis aeruginosa, Anabaena sp. and Aphanocapsa delicatissima.

The Dinophyceae (dinoflagellates) declined from a relatively high mean biovolume in the early spring (0.194 $mm^3\ l^{-1}$) to lower mean biovolumes throughout the rest of the study (Fig. 5). This algal class was dominated by Gymnodinium sp. and Glenodinium sp. which ranked fourth and seventh in mean biovolume, respectively (Table 9).

Mean phytoplankton biovolume by station, over all dates, varied little with a range from a minimum of 0.497 $mm^3\ l^{-1}$ at station 4 to a maximum of 0.573 $mm^3\ l^{-1}$ at 2 (Fig. 6). Seasonal variations in mean biovolumes, over all stations by date, also varied only slightly with an overall mean of 0.531 $mm^3\ l^{-1}$. A slight increase was observed in the fall as Oscillatoria limnetica increased in abundance.

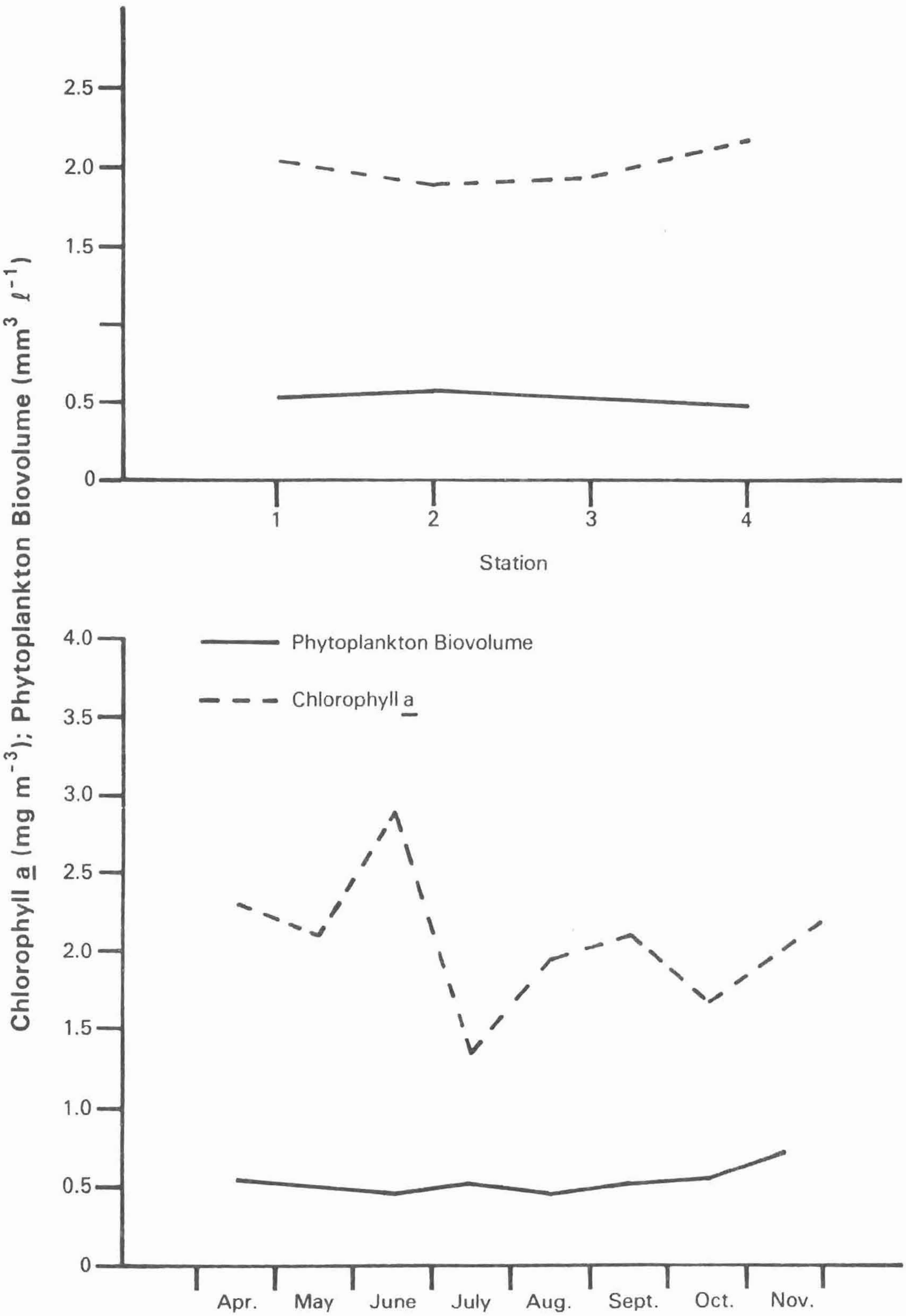


Figure 6. Mean phytoplankton biovolume ($mm^3\ l^{-1}$) and chlorophyll a concentrations ($mg\ m^{-3}$) by station over all dates and by date over all stations, Hayden Lake, ID (1985).

The mean chlorophyll *a* concentration for the study was 2.04 mg m^{-3} (Fig. 6). Station means, over all dates, ranged from a minimum of 1.93 mg m^{-3} at station 3 to a maximum of 2.16 mg m^{-3} at station 4. Mean monthly chlorophyll *a* concentrations over all stations varied from a minimum value occurring in July (1.35 mg m^{-3}) to a maximum mean observed in June (2.59 mg m^{-3}).

The estimated mean daily primary productivity, by station over all dates, ranged from a minimum of 0.206 g C m^{-2} day^{-1} at station 2 to a maximum of 0.255 g C m^{-2} day^{-1} at station 3 (Fig. 7). The overall mean productivity value for the study period was 0.202 g C m^{-2} day^{-1} with the highest value of 0.513 g C m^{-2} day^{-1} occurring at station 2 on 17 June (Fig. 7). Mean seasonal primary productivity, over all stations by date, quickly increased from 0.073 g C m^{-2} day^{-1} in April to a maximum mean value of 0.387 g C m^{-2} day^{-1} in June. Primary production gradually declined through late summer and fall to a minimum value of 0.040 g C m^{-2} day^{-1} in November.

Zooplankton Standing Crop

Fifteen species in 13 genera (8 Rotifera, 2 Eucopepoda and 5 Cladocera) were identified (Table 11). Mean zooplankton standing crop for the study was 2136.40 x 10^4

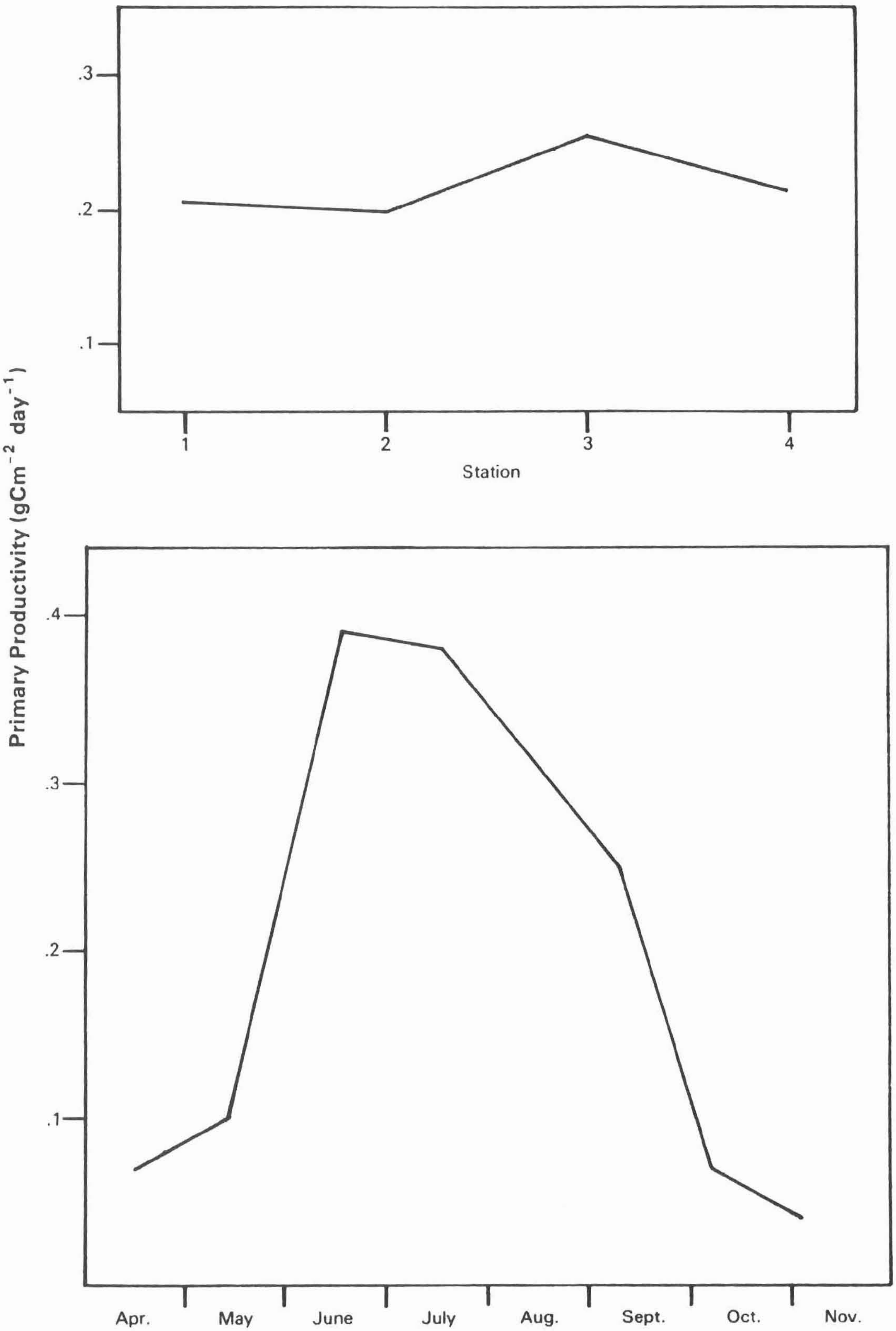


Figure 7. Mean primary productivity (g C m^{-2} day^{-1}) by station over all dates and by date over all stations, Hayden Lake, ID (1985).

Table 11. Zooplankton species identified during the study, Hayden Lake, ID (1985).

Phylum Arthropoda

Subphylum Mandibulata

Class Crustacea

Subclass Branchiopoda

Order Cladocera

Bosmina longirostris (Müller)
Ceriodaphnia lacustris (Jurine)
Daphnia laevis Birge
Daphnia pulex Leydig
Diaphanosoma leuchtenbergianum Fischer

Subclass Copepoda

Suborder Calanoida

Epischura nevadensis Lilljeborg

Suborder Cyclopoida

Cyclops bicuspidatus thomasi Forbes

Phylum Rotifera

Class Monogononta

Order Collothecacea

Collotheca balatonica Varga

Order Flosculariacea

Conochilus unicornis Rousselet

Order Ploima

Keratella cochlearis (Gosse)
Keratella quadrata (Müller)
Notholca squamula Müller
Polyarthra vulgaris Carlin
Synchaeta pectinata Ehrenberg
Trichocerca cylindrica (Imhof)

organisms m^{-2}.

Rotifer standing crop ranged from a minimum of 0.34 x 10^4 organisms m^{-2} at station 4 on 9 September to 1733.75 x 10^4 rotifers m^{-2} at station 2 on 13 May. The overall average density was 1143.07 x 10^4 rotifers m^{-2}, comprising 53.5 percent of the standing crop. Copepods were present in all samples averaging, 952.41 x 10^4 numbers m^{-2} and 44.6 percent of the standing crop. A low density of 7.99 x 10^4 copepods m^{-2} existed at station 4 on 7 October with a high of 561.72 x 10^4 copepods m^{-2} at station 2 on 13 May. Cladocerans were not present in 13 of the 32 samples collected and made up only 1.92 percent of the total zooplankton numbers. A maximum of 41.45 x 10^4 cladocerans m^{-2} was identified at station 4 on 16 July.

Immature copepods (nauplii) were present in all samples and comprised 29.5 percent of the zooplankton standing crop (Tables 12 and 13). Keratella cochlearis, the most numerous rotifer, occurred in 75 percent of the samples and contributed 28.3 percent of the total numbers. Keratella quadrata was identified in 88 percent of the samples, but contributed only 14.6 percent of the density. Cyclops bicuspidatus thomasi occurred 100 percent of the time. Only 8.3 percent of the zooplankton density could be attributed to this cyclopoid copepod. Synchaeta pectinata, a rotifer,

Table 12. Rank of the major zooplankton species of Hayden Lake, ID, according to occurrence (%) based upon collections from all stations (1985).

Rank	Taxon	Occurrence
1	Cyclopoid copepodid *Cyclops bicuspidatus thomasi* Nauplii *Polyarthra vulgaris*	100
2	*Keratella quadrata*	88
3	*Epischura nevadensis* *Keratella cochlearis*	75
4	*Diaphanosoma leuchtenbergianum* *Synchaeta pectinata*	63
5	*Bosmina longirostris* Calanoid copepodid *Ceriodaphnia lacustris* *Daphnia laevis*	38

Table 13. Rank of the major zooplankton species of Hayden Lake, ID, according to abundance (%) based upon collections from all stations (1985).

Rank	Taxon	Abundance
1	Nauplii	29.5
2	Keratella cochlearis	28.3
3	Keratella quadrata	14.6
4	Cyclops bicuspidatus thomasi	8.3
5	Polyarthra vulgaris	7.4
6	Cyclopoid copepodid	6.3
7	Synchaeta pectinata	2.8
8	Diaphanosoma leuchtenbergianum	1.0

and *Diaphanosoma leuchtenbergianum*, a cladoceran, were found in 63 percent of the samples, and represented 2.8 and one percent of the total numbers, respectively.

Rotifers, primarily *K. cochlearis*, *K. quadrata* and *P. vulgaris*, were responsible for the single rotifer peak of the sampling period, which occurred during April and May (Figs. 8 and 9). Numbers declined from a mean of 86.94 x 10^5 rotifers m^{-2} in May to a mean of 0.85 x 10^5 rotifers m^{-2} in June. *Polyarthra vulgaris* peaked again in July, September and October. Rotifer densities remained below the minimum June level through the remainder of the study.

Cyclops bicuspidatus thomasi was the main contributor to the Eucopepoda maximum peak (average 26.64 x 10^5 m^{-2}) in May and June (Figs. 8 and 10). *Epischura nevadensis*, a calanoid copepod, exhibited its only peak in August and September. Copepod numbers declined steadily after June reaching a minimum average of 2.65 x 10^5 copepods m^{-2} in October.

Cladocerans did not appear in the samples taken until June when numbers averaged only 0.02 x 10^5 m^{-2} (Fig. 8). The maximum peak (2.21 x 10^5 m^{-2}), primarily *D. leuchtenbergianum*, occurred in July, followed by a sharp decline in August. Another peak of cladocerans occurred in September (1.10 x 10^5 m^{-2}) when *Daphnia laevis* and *D. leuchtenbergianum* peaked (Fig. 10). Cladoceran density

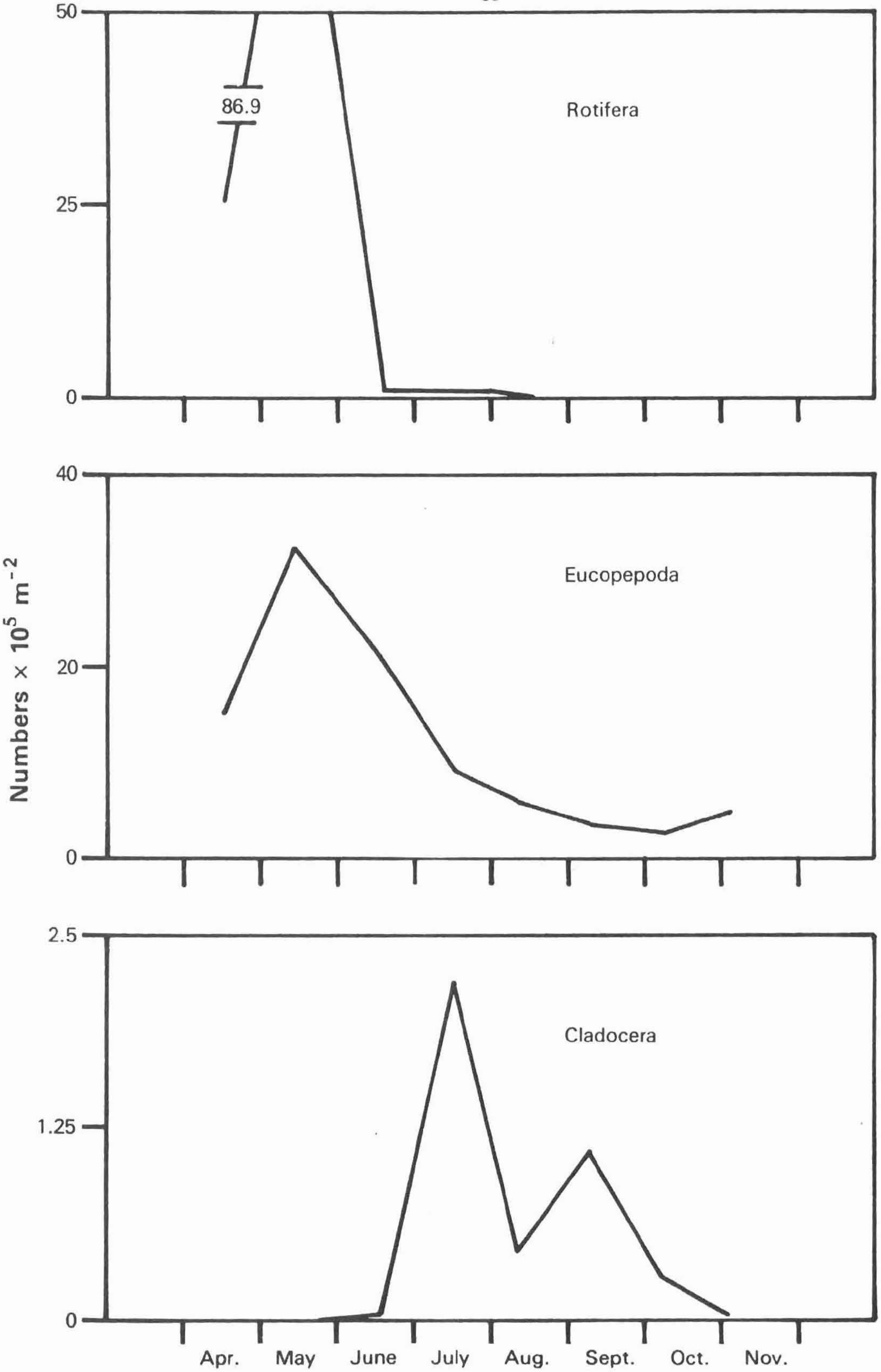


Figure 8. Mean zooplankton density (# x 10^5 m^{-2}) by order and date over all stations, Hayden Lake, ID (1985).

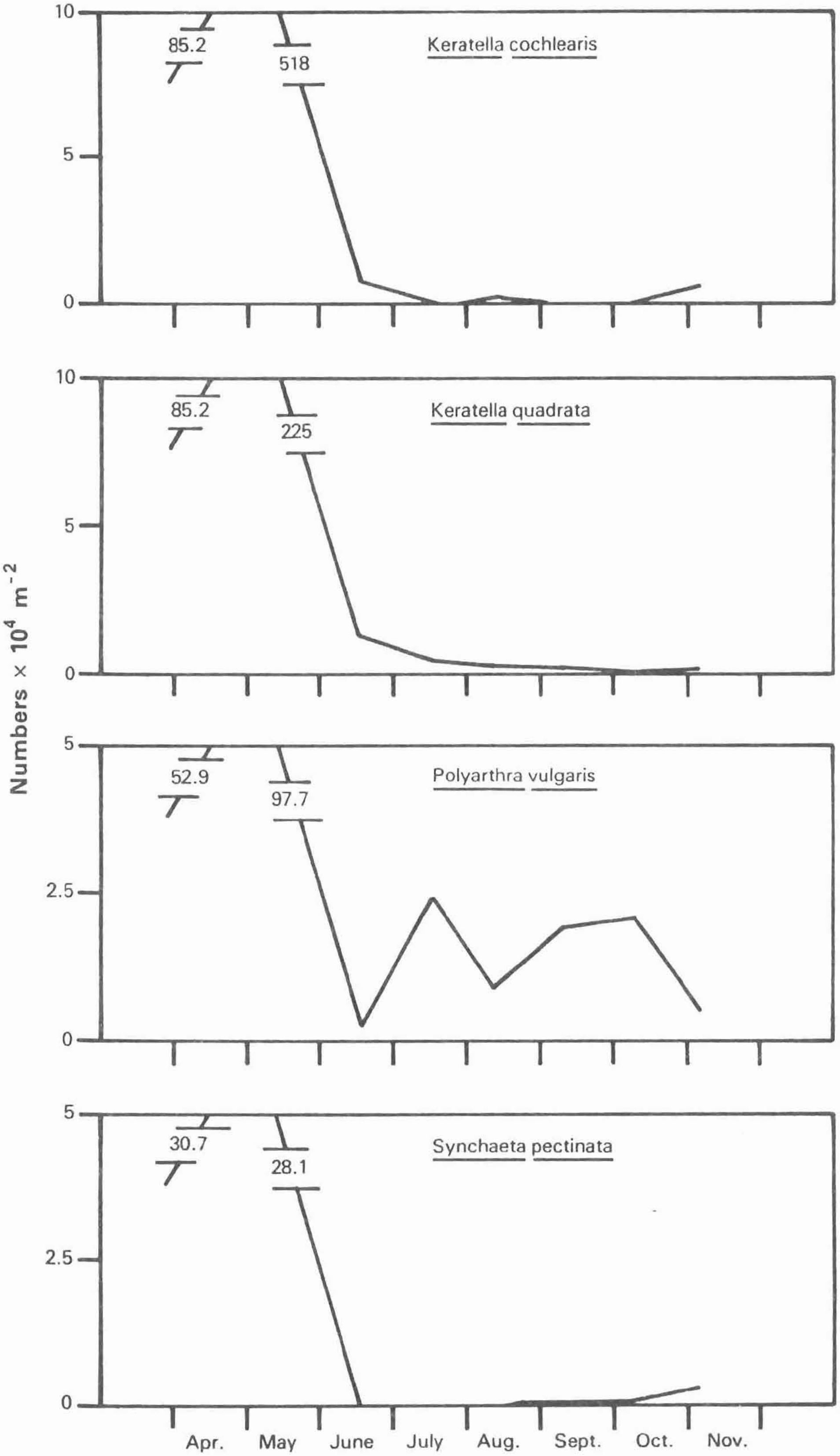


Figure 9. Successional trends of the predominant rotifers by date over all stations, Hayden Lake, ID (1985).

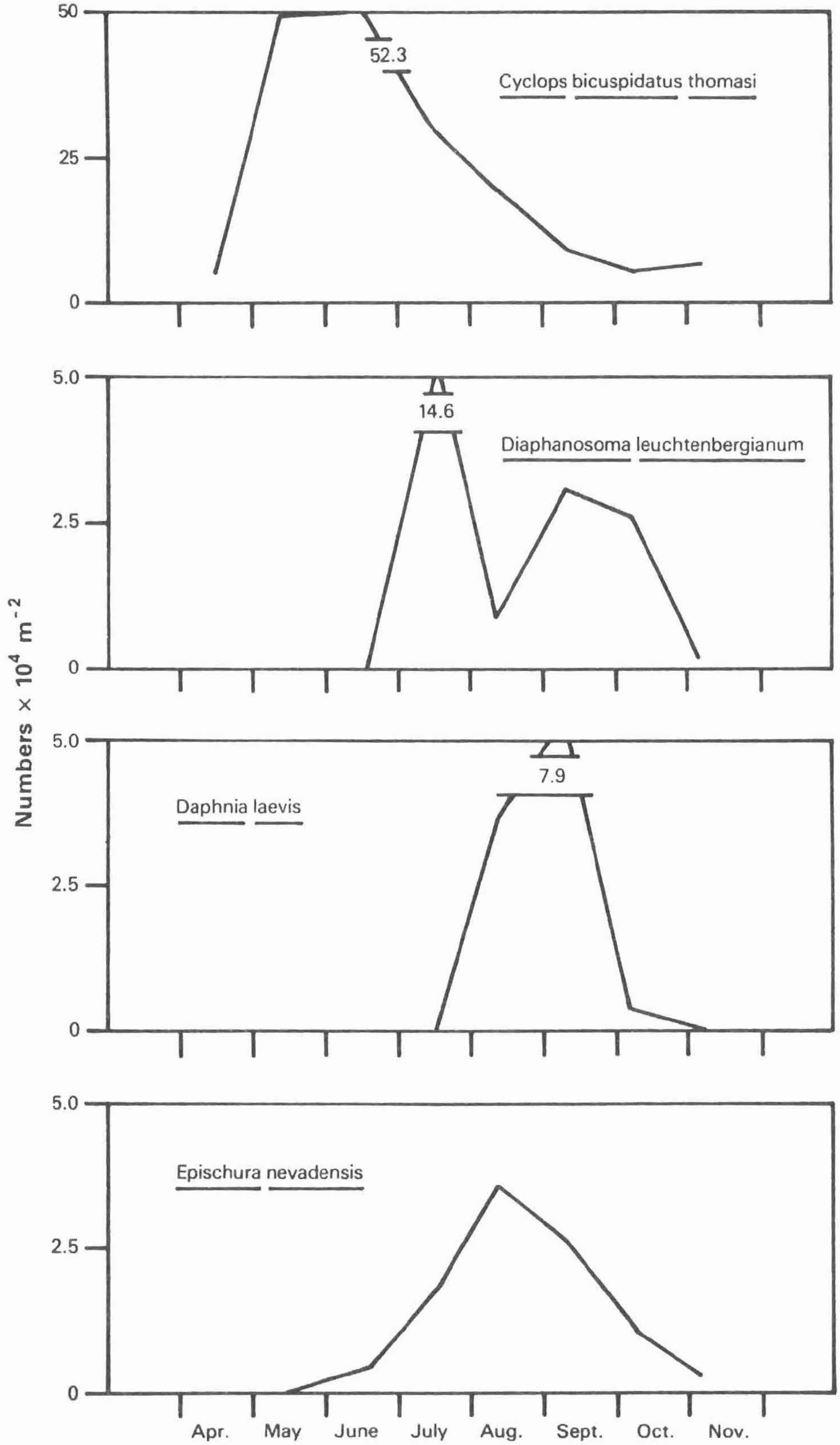


Figure 10. Successional trends of the predominant crustaceans by date over all stations, Hayden Lake, ID (1985).

decreased sharply in October, although D. leuchtenbergianum numbers remained relatively high. Standing crop declined further in November, reaching the low levels recorded in June.

Zooplankton standing crop ranged from an average of 31.60 x 10^4 individuals m^{-2} on 7 October to 1192.67 x 10^4 individuals m^{-2} on 13 May. Rotifer mean standing crop and percentage composition (57.6%) were highest at station 2. Copepods were most numerous at station 2, but contributed the majority (51.1%) of the zooplankton density at station 3. Cladocerans exhibited their highest standing crop and maximum percentage composition (4.8%) at station 4.

Zooplankton-Phytoplankton Relationships

Zooplankton abundance at the various stations generally followed the same trend as that of phytoplankton biovolume (Fig. 11). That is, densities of both communities increased from stations 1 to 2 then decreased to station 4. Numbers of zooplankton were highest at station 1 and 2 and lowest at the shallow stations, 3 and 4. However, phytoplankton maximum cell volume was determined for stations 2 and 3, and minimum volumes were recorded at stations 1 and 4.

Seasonally, over all stations by date, there was an inverse relationship between zooplankton and phytoplankton

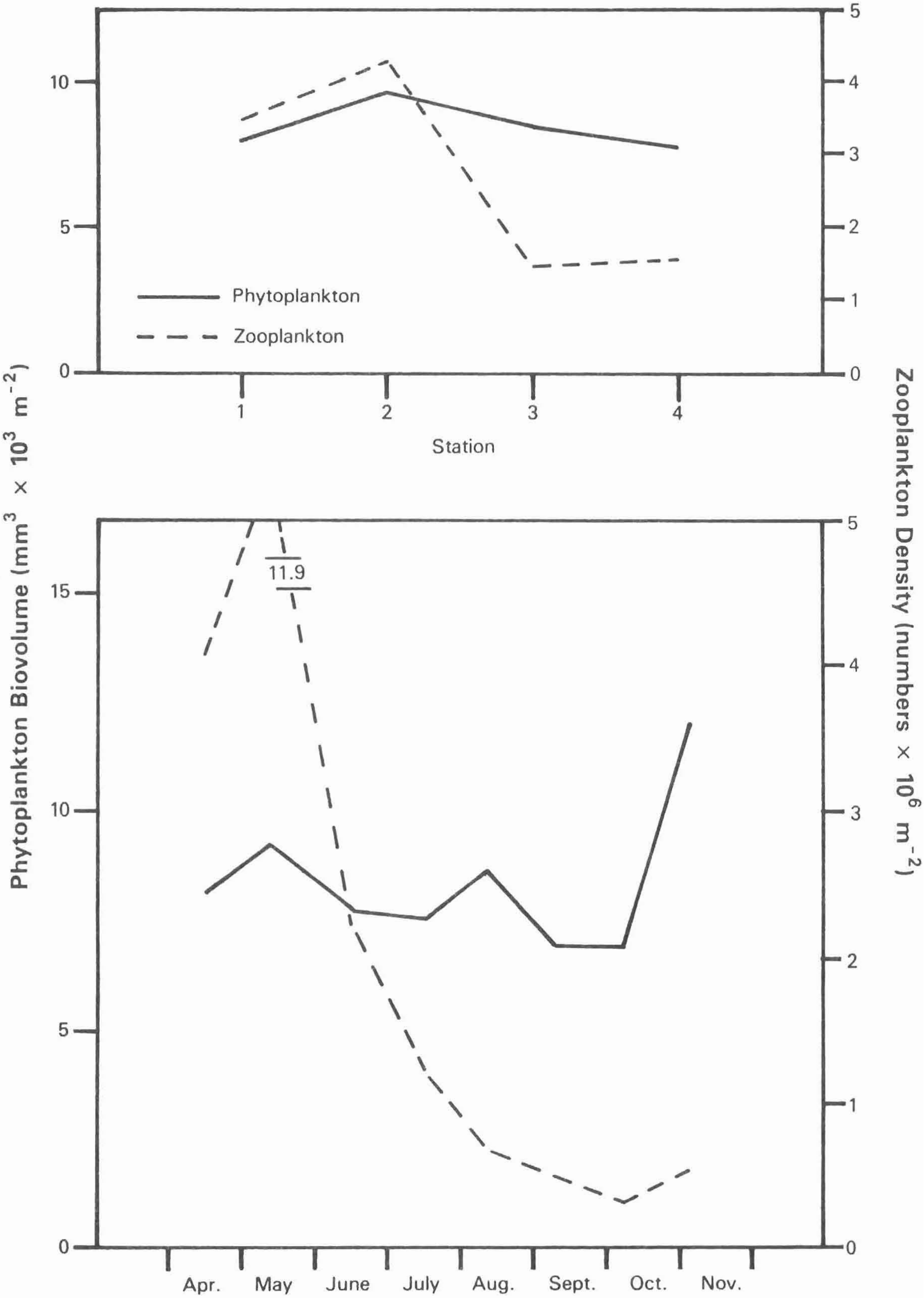


Figure 11. Total mean zooplankton density (# x 10^6 m^{-2}) and phytoplankton biovolume (mm^3 x 10^3 m^{-2}) by station over all dates and by date over all stations, Hayden Lake, ID (1985).

standing crops (Fig. 11). Zooplankton density was highest in the spring and lowest in the summer and fall. Phytoplankton biovolumes fluctuated less through the spring and summer with maximum cell volumes being calculated in the fall. Zooplankton (mainly rotifers) reached maximum density in May when phytoplankton peaked. Numbers of zooplankton declined sharply in June when phytoplankton cell volume decreased. Zooplankton density steadily decreased through the summer. Phytoplankton biovolume dropped in June and July and peaked again in August when zooplankton density was low. Algal standing crop then decreased in September, along with zooplankton. Both communities reached their minimum densities of the sampling period in October, but were on the rise again in November, particularly phytoplankton. Algal biovolume was highest in November, while zooplankton density was at one of its lowest levels of the sampling period.

Bacteriological Sampling

All geometric means calculated for the four in-lake stations were less than one (Fig. 1). Only three out of all in-lake water samples had FC present and no samples had more than 1 FC 100 ml^{-1}. Fecal coliform counts at the shoreline sites were also low (Fig. 1) with 83 percent of the samples taken having no evidence of fecal contamination. Of the 23 samples which had FC present, 22 had FC counts less than 5 100 ml^{-1} (see Appendix F). The highest shoreline FC count found during the study was 12 FC 100 ml^{-1} found at Honeysuckle Beach on 16 July.

Nutrient Loading

The total annual P load to Hayden Lake was calculated to be 2.44 metric tons per year. The tributaries collectively contributed 69 percent (1.69 metric tons) of the total P load entering the lake. Hayden Creek by itself accounted for 73 percent of the tributary P load. Mokins Creek represented a distant second with 14 percent of the P load contribution. Atmospheric fallout contributed an estimated 26 percent (0.63 metric tons per year) of the total P load. Shoreline septic systems were estimated to contribute 0.12 metric tons of P per year representing about five percent of the total annual P load.

The reasonableness of the calculated total P load entering Hayden Lake was checked using a relationship described by Vollenweider (1976) which uses a ratio of mean in-lake P concentrations to influent P concentrations and plotted against hydraulic residence time (Fig. 12). In Hayden Lake, mean in-lake P concentration (8 μg P l^{-1}) was

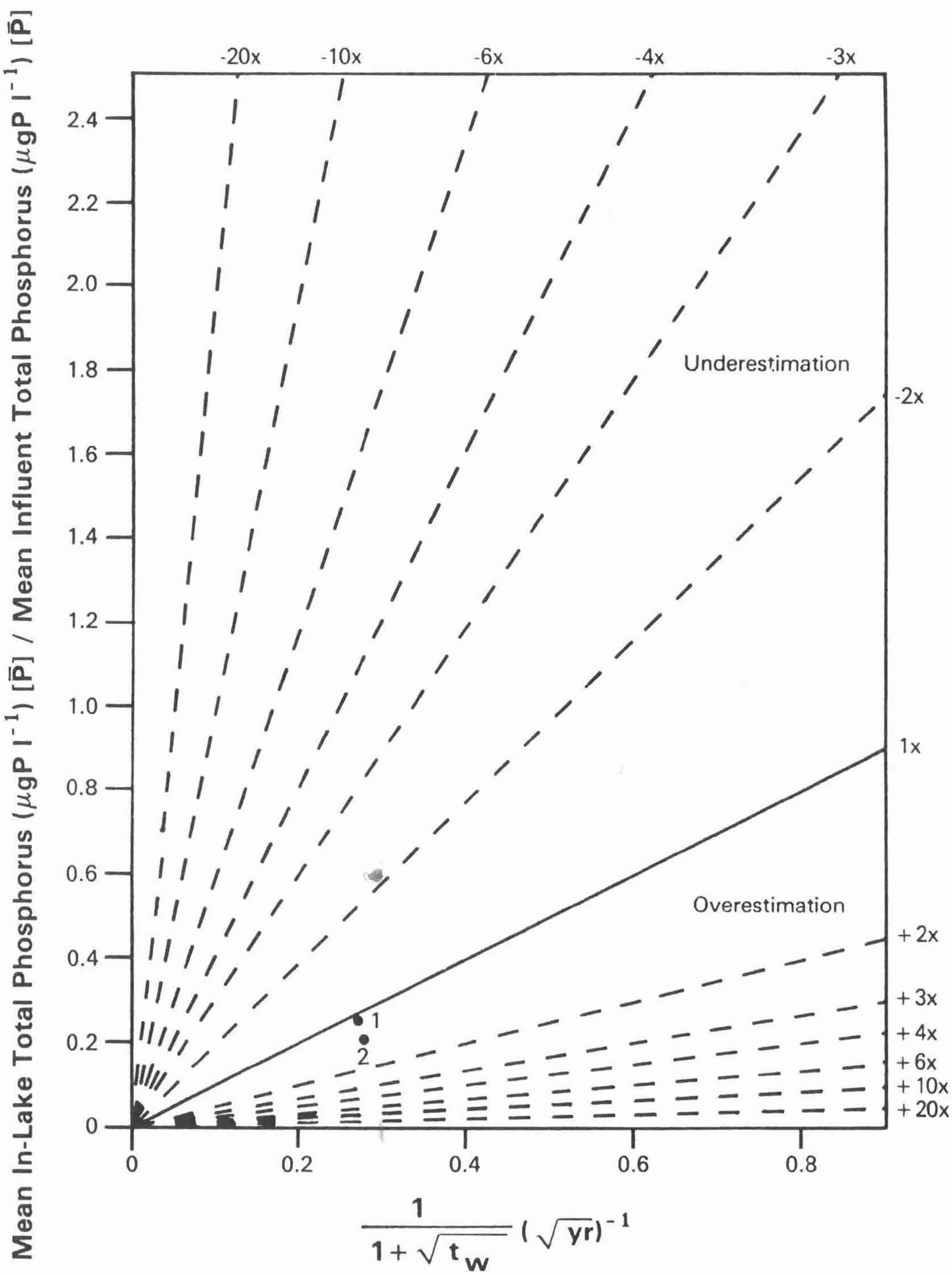


Figure 12. An evaluation of Hayden Lake, ID, TP loading estimate: Vollenweider mean in-lake TP/mean influent TP-hydraulic residence time (1985).

found to be smaller than the calculated influent P concentration from the tributaries (33 µg P l^{-1}). However, a plot of the P concentration ratio versus hydraulic residence time showed that the influent P load is a reasonable estimation of in-lake P concentration (Point #1). Point #2 on Figure 12 reflects the addition of other P loads also entering the lake from atmospheric fallout (dry and wet) and shoreline septic systems. This shift towards overestimation could be explained as the result of P becoming involved in the "metabolism" of the waterbody. Phosphorus is removed from the water column when dead plankton settle to the bottom as sediment. This storage of P in the sediments is common to oligotrophic lakes since dissolved oxygen concentrations are high enough in the hypolimnion to prevent P from being released back into the water column. This process effectively removes P from the water column resulting in lowered P concentrations and low primary productivity.

The total yearly N load to Hayden Lake was calculated to be 27.56 metric tons. The tributaries were the source of 51 percent of the total N load. Surface fallout and septic systems contributed an estimated 34 and 14 percent of the total N load, respectively. The overall mean ratio of biologically available forms of N (NH_4^++NO_3^-+NO_2^-) to P (orthophosphate) for Hayden Lake euphotic zone samples was approximately 40:1 indicating that P was the major limiting factor. Assuming P is the primary factor limiting algal growth, it is possible to compare P loading to primary productivity and also make some predictions about the trophic status of Hayden Lake.

Predictions of lake response is made possible using the model developed by Vollenweider (1976) as described in the U.S. portion of the Organization for Economic Cooperation and Development (OECD) study of nutrient loading (Rast and Lee 1978).

Vollenweider (1976) developed a relationship between in-lake P concentration and the hydraulic properties of a waterbody normalized load to chlorophyll a concentrations using data collected from 35 OECD study lakes. Hayden Lake data were plotted using the Vollenweider-OECD relationship (Fig. 13). Again, point #1 is using P load from the tributaries only, while point #2 also includes the P loads from the atmospheric fallout and septic systems. Both points 1 and 2 fall within the established 95 percent confidence interval, defined by the dashed lines. A more recent update of the chlorophyll a normalized P load relationship was made using more than 325 additional lakes (Jones and Lee 1985). The lakes represented a wide spectrum

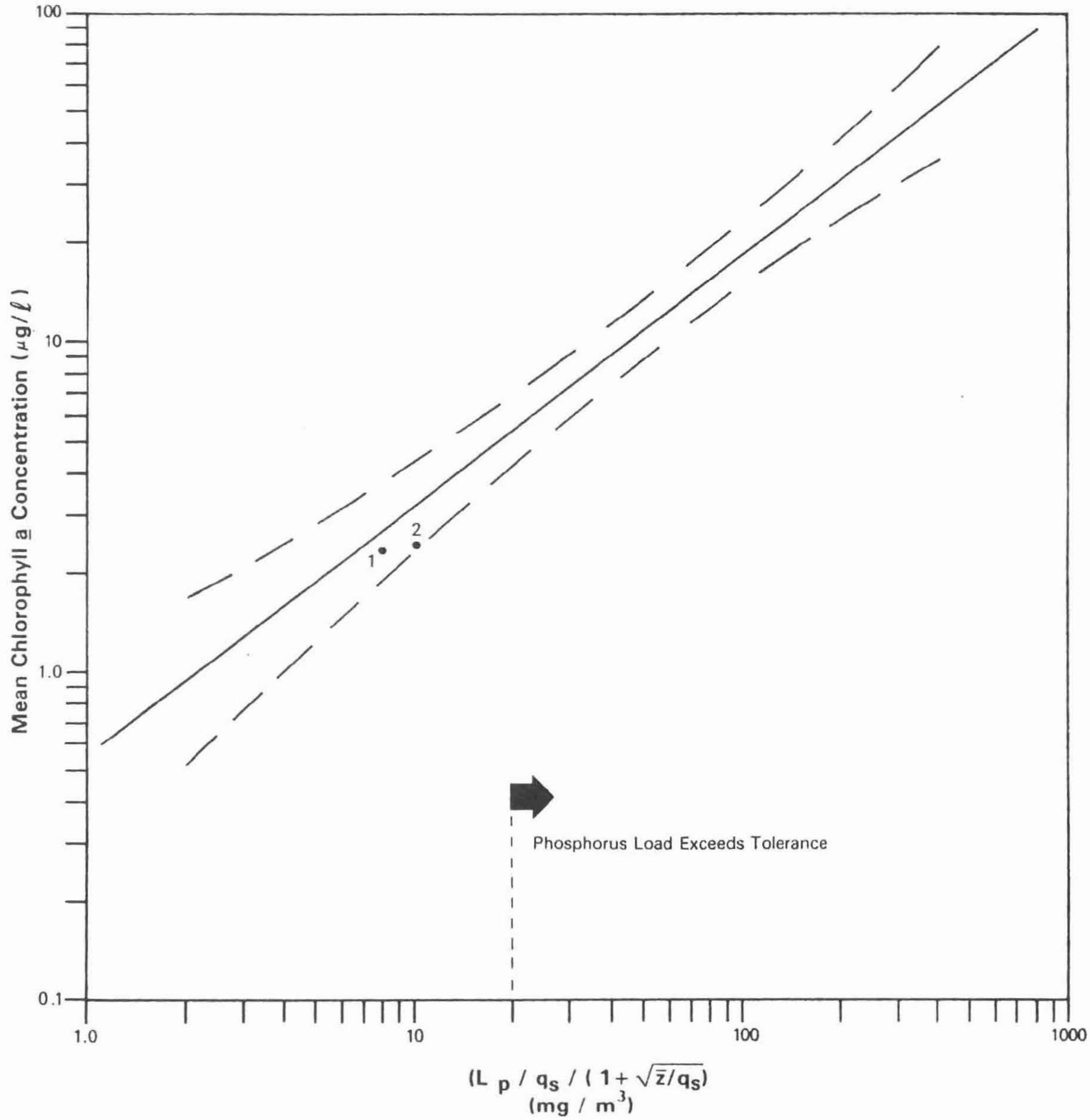


Figure 13. Phosphorus load, normalized by mean depth and hydraulic load, versus mean chlorophyll a concentration for Hayden Lake, ID (June through October). The dashed lines represent the 95 percent confidence interval.

of trophic states in different climates. The resulting regression line determined for the chlorophyll a normalized P load relationship was essentially the same as that of the original OECD report further verifying the validity of the model relating chlorophyll a concentration to P load in a waterbody.

Vollenweider (1976) also developed a P loading to mean depth/hydraulic residence time relationship to predict the trophic status of a lake (Fig. 14). The trophic zones are bordered by lines of critical nutrient concentrations as proposed by Sawyer (1947) and Sakamoto (1966). Waterbodies which fall below the 10 mg m^{-3} line are considered oligotrophic (low productivity) while waterbodies which plot above the 20 mg m^{-3} line are considered eutrophic (high productivity). A lake with moderate primary productivity would graph between the two lines (mesotrophic). A plot of the tributary P load into Hayden Lake would indicate that the lake is oligotrophic (Fig. 14). However, the addition of other possible sources of P load (atmospheric fallout and septic systems) cause the trophic status to shift from oligotrophic to mesotrophic (point #2).

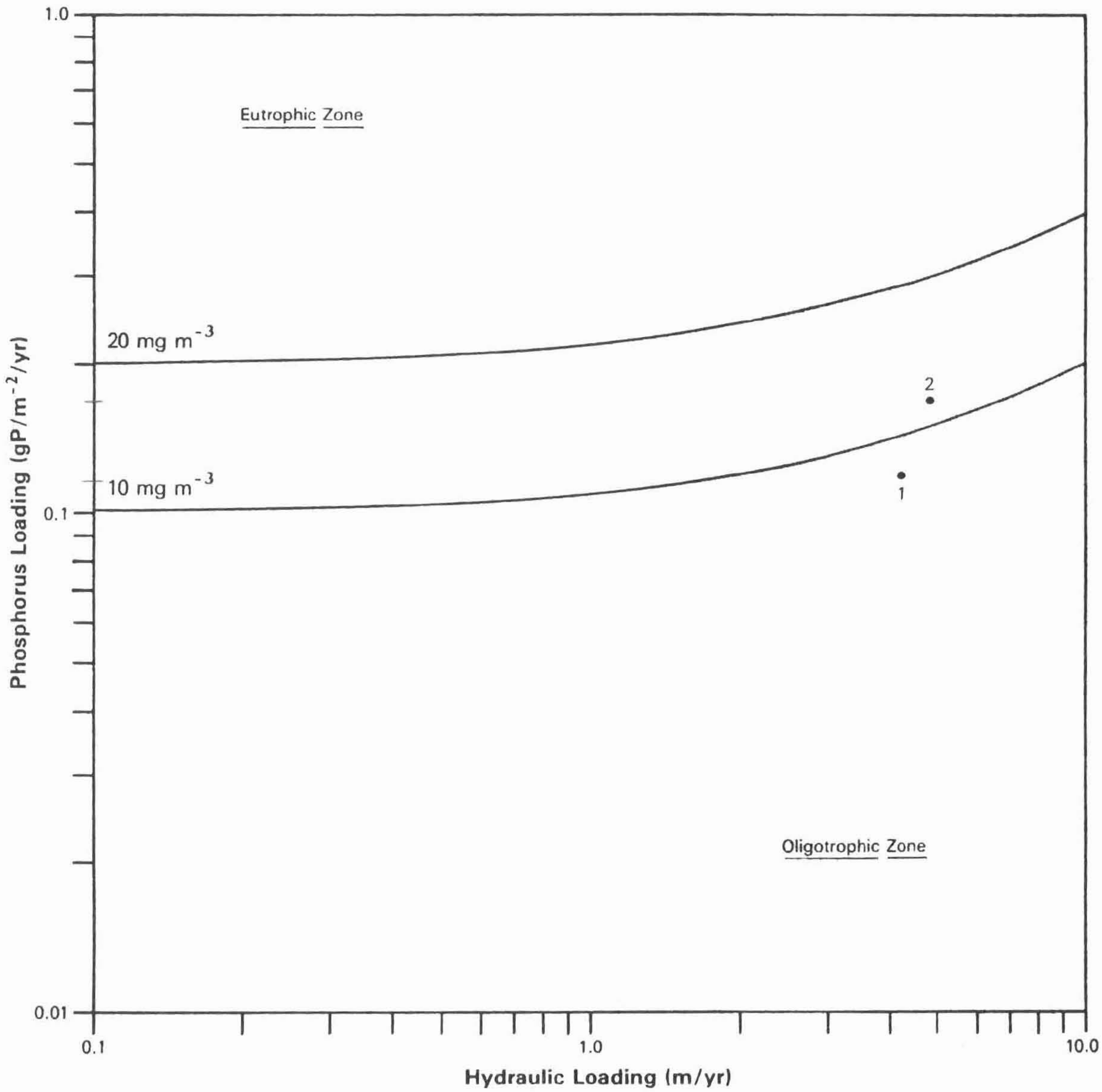


Figure 14. Vollenweider (1976) P loading curve for Hayden Lake, ID, indicating trophic status through analysis of point and non-point sources (1985).

DISCUSSION

Thermal stratification of Hayden Lake was well established from June through October with an average temperature of 16.4^{o}C in the epilimnion and 5.6^{o}C in the hypolimnion. Conductivity values were low and varied little with no evidence of chemical stratification. Maximum D.O. values tended to occur at the 9-21 meter depths during stratification. This metalimnetic oxygen maximum probably occurred as a result of the decreasing solubility of oxygen in the warmer waters of the epilimnion and reduced oxygen concentrations in the hypolimnion due to decomposition (Wetzel 1983). Hypolimnetic oxygen depletion can be used, along with other parameters, as an indicator of trophic status Lakes with low productivity (oligotrophic), like Hayden Lake, usually have a higher D.O. content in the hypolimnion than in the epilimnion in the summer due to the cooler temperatures in the deeper waters (Wetzel 1983). As productivity of a lake increases, oxygen is consumed in the hypolimnion in the summer during decomposition of organic matter from the sediments. Although anaerobic conditions did not develop in Hayden Lake, there was some oxygen depletion (D.O. concentration averaging <5.0 mg l^{-1}) at the 51-meter depth of station 1 (September-November) and station 2 (October), even when temperatures remained low indicating a possible shift towards mesotrophy. Vaughan (1949) also measured a lower oxygen concentration (4.7 mg l^{-1}) at a depth of 51 m.

Nitrate and nitrite nitrogen concentrations were low throughout the study and there was no accumulation of ammonia in the hypolimnion. Higher total phosphate concentrations were measured in April and May when P loads from the tributaries were larger as a result of high runoff. Total phosphorus concentrations in 1976 were 0.05 mg l^{-1} at one mid-lake station and 0.01 to 0.04 mg l^{-1} at all other stations sampled (Trial 1977). During this study lower concentrations of TP ($\bar{x}$ = 0.02 mg l^{-1}) became stabilized in the water column by June. There was no build-up of phosphorus in the hypolimnion during summer stratification. In more eutrophic lakes, a build-up of nutrients usually occurs in the hypolimnion, in part, due to the absence of oxygen. Under these conditions phosphorus, for example, can enter the overlying water from the sediments and accumulate in the lower depths (Wetzel 1983).

Water clarity of Hayden Lake during the summer and fall of 1985 was excellent, with Secchi disk measurements ranging from a mean of 7.1 m to 9.2 m at all stations. A Secchi disk transparency of 9.0 m was also measured at a deep water station in July (Johann 1974). In comparison, Spirit Lake, ID, a mesotrophic lake, had an average Secchi disk reading of 4.6 m (Soltero and Hall 1985).

Phytoplankton mean biovolume and chlorophyll *a* concentrations were relatively low and, in part, contributed to the excellent water transparency of Hayden Lake. The seasonal succession of the phytoplankton community in Hayden Lake resembled general trends described in other temperate lakes (Verduin 1959, Wright 1964, Soltero and Hall 1985). In early spring, the phytoplankton was dominated by small cryptophyceans, dinoflagellates and diatoms that can exist in cold water temperatures and low light intensity often found with ice cover. A slight decline in total mean biovolume was observed as the summer progressed and the earlier algal assemblage was gradually replaced by chrysophyceans and microplankton. The slightly lowered biovolume may be related to a reduction in biologically available nutrient in the euphotic zone (Wetzel 1983).

Blue-green algae, especially *Osillatoria limnetica*, became a significant part of the phytoplankton community in June and by late July had become the predominant species. The explanation for the large increase in *Oscillatoria limnetica* was uncertain, but similar species of *Oscillatoria* have been found near the lower limits of the metalimnion in other lakes (Hutchinson 1967, Reynolds 1984). It may be possible that this type of algae prefers cooler temperatures and decreased illumination found in the bottom of the thermocline, or that *Oscillatoria* utilizes nutrients liberated from decaying, epilimnetic plankton suspended in dense layers near the hypolimnion.

Relatively low chlorophyll a concentrations (study mean = 2.04 mg m^{-3}) reflect the decreased phytoplankton biovolume found in Hayden Lake and was similar to other oligo- and mesotrophic lakes (Sakamoto 1966). However, the seasonal fluctuations in chlorophyll a concentrations did not correlate with the seasonal fluctuations in algal biovolume. This may be a function of changing species composition in the phytoplankton with differing ratios of chlorophyll a contents to cell biovolumes (Reynolds 1984).

Estimated primary productivity was also relatively low (0.25 g C m^{-2} day^{-1}) which relates to the lower euphotic zone chlorophyll a concentrations and is another indication of the lake's intermediary trophic status. An oligotrophic lake usually has primary productivity of near 0.1 g C m^{-2} day^{-1} while a eutrophic lake typically has primary productivity exceeding 1.1 g C m^{-2} day^{-1} (Vollenweider 1968). The large increase in the estimated primary productivity occurring in June was likely a result of increased light, temperature and chlorophyll a concentrations in the euphotic zone. Light and temperature values continued to increase as the summer progressed, but chlorophyll a concentrations declined after the early summer algal pulse.

Hayden Lake average zooplankton standing crop was 2136.40 x 10^4 organisms m^{-2} in contrast to an average density of 4116.12 x 10^4 organisms m^{-2} for Spirit Lake, ID, a mesotrophic lake (Soltero and Hall 1985). Gannon and Stemberger (1978) postulate that oligotrophic lakes have a smaller biomass than more eutrophic lakes. Cladocerans, which are generally more abundant in eutrophic waters (Gannon and Stemberger 1978), comprised only 1.9 percent of the standing crop in Hayden Lake. Adult calanoid copepods and copepodids (nauplii were not identified as either calanoid or cyclopoid), although less than one percent of the total standing crop, apparently were able to compete for food at low (oligotrophic) food densities which usually occur in oligotrophic systems (McNaught 1975). However, the high percentage of cyclopoid copepods (44.6%) identified in Hayden Lake would indicate a trend towards mesotrophy (Patalas 1975, Gannon and Stemberger 1978, Chapman et al. 1985). Kemmerer et al. (1924) and Vaughan (1949) also determined that Cyclops, along with Diaptomus (Vaughan 1949), were the most abundant zooplankton species in Hayden Lake.

The two most abundant rotifers, K. cochlearis and K. quadrata, were probably able to escape predation by the cyclopoid, C. bicuspidatus thomasi, due to the spiny morphology of these rotifers (Stemberger and Evans 1984).

In addition, the third most abundant rotifer, P. vulgaris, probably escaped predation by Cyclops because of the evasive swimming techniques of this rotifer. Apparently, Cyclops was able to take advantage by feeding on the rotifer, S. pectinata (Brandl and Fernando 1981, Stemberger and Evans 1984), which was abundant in April and May when Cyclops was beginning to peak.

The availability of suitable food for herbivorous zooplankton on a percentage composition basis (green algae, chrysophytes, cryptomonads, euglenoids and Microplankton as determined by Porter (1973, 1977) was essentially the same at all stations. Seasonally, zooplankton were more abundant in the spring and phytoplankton biovolume highest in the fall when zooplankton reached its lowest density. There appeared to be effective grazing pressure on the algae by the zooplankton (Fig. 11), but an analysis of the percentage composition of the algae does not completely support this. Rotifers, which feed on smaller particles such as bacteria, fungi and nannoplankton (Ruttner-Kolisko 1974), constituted 70.3 percent of the April-May zooplankton peak. The smaller food items were not quantified in the phytoplankton data analysis, and therefore, not represented in Figure 11. However, copepod nauplii, which do graze on phytoplankton, were more abundant in the spring samples than at other times of the year (21.9% of standing crop).

As lake temperatures warmed in July, zooplankton numbers declined dramatically and blue-green algae began to dominate the algal biovolume. Cladocerans, primarily Daphnia, which are more efficient grazers than rotifers and copepods (Brooks and Dodson 1965), peaked in abundance in July. However, blue-green algae may have had an inhibitory effect on the cladoceran filtering apparatus (Porter 1977), which could explain the low percentage contribution (1.9%) of the cladocerans to the zooplankton standing crop. Fish predation could have also lowered the cladoceran population considerably (Brooks and Dodson 1965). They hypothesized that fish will selectively prey on the larger Daphnia allowing smaller, inefficient grazers to predominate (rotifers, small cladocerans). Also, some feeding inhibition may have occurred, since blue-green algae comprised 34.5 percent of the total phytoplankton biovolume, further lowering the cladoceran numbers in Hayden Lake. Maximum numbers of cladocerans occurred at station 4 where blue-green algal percentage composition was low.

When Daphnia peaked in September, phytoplankton biovolume decreased sharply. At this time smaller, more edible species of algae classified as microplankton were present (17.3% of biovolume), although blue-green algae were at a peak (56.2%). Cyclops, a predator, was the only crustacean to increase in November. As a result, phytoplankton (primarily blue-greens) attained the maximum biovolume of the sampling period, probably due to lack of grazing pressure.

Low zooplankton densities would indicate that Hayden Lake is oligotrophic bordering on mesotrophy. The low numbers of cladocerans and the high percentage of rotifers identified would support a trend towards mesotrophy. The presence of inefficient algal grazers and the relative absence of larger efficient consumers like Daphnia could result in an increased algal standing crop. An increase in algae due to lack of adequate grazing pressure could, in turn, accelerate eutrophication.

There was essentially no indication of fecal contamination in the sampled open water areas of Hayden Lake. Shoreline samples revealed only one sample exceeding 10 FC 100 ml^{-1} (Honeysuckle Beach) and was probably a result of the crowded conditions which existed there during warm summer days. An increase in FC in a high usage swim area was not surprising since some natural shedding of human bacteria is common and when it is confined to a small area may affect the water quality (Cabelli 1977).

The higher FC counts in Hayden and Nilsen creeks were attributed to the presence of cattle along their stream banks which invariably results in contamination of the stream. The low FC counts for the rest of the tributaries probably best reflects undisturbed forest lands.

Liebig's "Law of the Minimum" states that growth of an organism is limited by the substance or foodstuff which is found in the least quantity as related to the organism's minimal needs (Wetzel 1983). In the aquatic environment, P and N are generally the nutrients which limit primary productivity and of these two, P is usually the element in shortest supply (Rast and Lee 1978). A ratio of 16 nitrogen atoms to 1 phosphorus atom is considered to be the decisive point for assessing whether N or P is limiting algal growth (Rast and Lee 1978). If a ratio of N:P is greater than 16:1 in the euphotic zone then P is limiting; conversely, if the N:P ratio is less than 16:1 then N would be considered limiting. Since the N:P ratio in Hayden Lake was calculated at 40:1 and algal assays by the USEPA (1977) showed P to be limiting, it would appear that any attempts to slow the eutrophication process must be accomplished by reducing, or at least maintaining, the current in-lake P concentration. In order to control in-lake P concentration, steps must first be taken to manage the sources of P loading.

The Hayden Lake watershed has the potential for successful management of non-point and point nutrient sources because the majority of it has been relatively undisturbed and lies almost solely under administrative jurisdiction of the U.S. Forest Service. This jurisdiction should allow for efficient and consistent watershed management policies to preserve Hayden Lake water quality. The management of the upper watershed has the most potential for controlling critical impacts on the water quality since this part of the watershed represents the source of approximately two-thirds of the total P load to Hayden Lake. In order for any other nutrient source abatement project to be effective, the water quality from the watershed must be preserved.

Proposed timber harvest in the watershed will probably have detrimental effects on water quality of Hayden Lake even when "best management practices" are followed. Using only the forested areas that will receive burning as slash treatment and road construction (2.23 km^2; 550 ac) in the Yellow-Stacel, Deerfoot-Shamrock and B.P.A. timber sales, and assuming concurrent harvest of all three sales, resulted in an estimated 0.08 metric ton (3.3 percent) increase in P load to Hayden Lake. This is not a worst case scenario as it does not address the potential increase in P load from the remaining 3.04 km^2 (750 ac) that would receive selective timber harvest in the proposed sales. Selective harvest acres may also cause an increase in nutrient load but has not been shown in the limited research literature now available. The timing at which the increased P load will enter the lake due to changes in the hydrologic cycle is also not addressed. It may be that spring run-off will carry most of the new P load into the lake at an optimal time for algal growth. This has the potential to cause at least localized algal blooms in bays, or even large whole-lake increases in algae growth. Therefore, it may be inappropriate to use only increased P load without considering other ecological aspects influencing algal growth in Hayden Lake.

The cumulative impact of several separate timber harvest projects more than likely poses the greatest threat to Hayden Lake water quality. An average of about 1.21 km^2 (300 acres) per year will be harvested in the next 10 years (Lider 1986). This rate of timber harvesting will probably be continued throughout following decades to meet USFS long-term management plans for a 100 year harvest rotation. The combined effect of each timber harvest project allowing permissible degradation under "best management practices" will probably result in a significant long term decline in Hayden Lake water quality. It has been the policy of the USFS to file environmental assessments declaring "no significant impact" for individual timber sales while ignoring the cumulative effects of timber harvests. These cumulative effects must be addressed before progress in watershed management for lasting water quality in Hayden Lake can be achieved.

Phosphorus loading from near-shore sources also has the potential to be reduced through corrective measures. The major changes could be in the collection and central processing of domestic wastewaters from lake homes. Currently, septic tanks and drainfields are the most common form of sewage treatment. This type of sewage treatment allows leachate to enter the lake, especially when located in close proximity to the shoreline. Alternatives for sewage treatment that do not allow leachate to enter the lake should be promoted by all people concerned with preserving Hayden Lake water quality.

Poor watershed management practices in the past and sewage leachate entering the lake from shoreline homes may have accelerated the eutrophication process in Hayden Lake. The combination of conservative forest practices in the upper watershed and proper sewage disposal can slow this aging process and contribute to the maintenance of Hayden Lake water quality.

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