TOWN OF HUDSON
LAKE LAY MONITORING PROGRAM
1983

Freshwater Biology Group (FBG)
University of New Hampshire
Durham

by
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PREFACE

A non-technical, comprehensive summary begins the report. The summary is intended to provide a quick reference to the main findings of the study. The reader is referred to Appendix B and the glossary for a clarification of technical terms and concepts.
ACKNOWLEDGEMENTS

1983 is the second year the town of Hudson has been a participant in the Lake Lay Monitoring Program. Mostly through the organization and direction of Mr. Ted Roome, the program has continued in the town of Hudson. Lay monitors on Robinson Pond included: David Robbins, J. and Anita Beaumont, Jeff and Ted Roome, and Glenn Bowles.

We congratulate the lay monitors on the quality of their work, and anticipate that they will continue with the program next year. We also express our appreciation to Mr. Roome and all the other members of the Hudson Conservation Commission for their time and effort. Also, we thank everyone who provided boats for our visiting team.

Members of our Freshwater Biology Group field team included Kim Babbitt, Dan Hayes, Wayne Boisselle, Tom Balf, and Mike Martin. Dan was team leader, and was responsible for coordinating all data analysis and interpretation. He and Tom were the zooplankton experts. Mike was the phytoplankton expert. Kim and Wayne specialized in phosphorus and chlorophyll a analysis. All members of the team helped in data organization and filing. Also, all team members participated in field trips throughout the summer.
This report has been produced in large part with data management and word processing programs on the UNH DEC-10 computer. Graphics were produced with program UFLCT and the CALCOMP drum plotter available on the DEC-10 system. The Office of Computer Services kindly provided computer time and data storage space for the Lake Lay Monitoring Program.
INTRODUCTION

This report presents the findings of the 1983 summer study of Robinson and Ottarnic Ponds in the Town of Hudson, New Hampshire. The study was conducted jointly by the Freshwater Ecology Group (FBG), University of New Hampshire, and by the Town of Hudson as part of the Lake Lay Monitoring Program (LLMP). The LLMP is a long-term water quality monitoring program that relies heavily on the efforts of lay persons. In Durham, the LLMP is conducted by Dr. Alan L. Baker (Associate Prof. of Botany) and Dr. James F. Haney (Associate Prof. of Zoology), who direct a team of trained graduate and undergraduate students. Space and research facilities were provided by the Departments of Botany and Zoology at the University of New Hampshire. Secretarial services were provided by the Department of Zoology.

The LLMP is a cooperative effort between the FBG and cooperating lake associations, conservation commissions, and municipalities. Funding for the program is derived solely by contributions from the participating groups. During 1983, the participating groups included: Walker Pond Protection Association, Town of Hudson, Town of Salem, Town of Merrimack, Town of Amherst, Lake Chocorua Conservation Federation, Winona Lake Association, Lake Winnipesaukee Association, Squam Lake Association, Merrymeeting Lake Association, Pleasant Lake Association, Bow Lake
Association, and Kanasatka Lake Association.

The LLMP has two major goals: first, to carry out scientific investigations on participating lakes in order to provide a data-base on lake biology, physics, and chemistry; and second, to educate people about lakes and their management. A broad data-base on lakes is necessary for their proper management, but is often lacking. Through the efforts of lay monitors and FRG members, such a data base can be provided. This commitment is long-term due to the long period of time it may require a lake to exhibit signs of disturbance. Continued monitoring from year to year is essential for the early detection of changes in lake conditions.

Education is also an important goal of the LLMP. Through education, people's awareness of lakes and human activities that may influence lakes is heightened. Perhaps the saddest occurrence is when a lake's quality is severely degraded without anyone aware of the fact, or worse yet, not caring.
Key to Figure 1: Lakes previously or presently in the LLMP of New Hampshire.

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Brief Non-technical Summary

1) The water quality in Robinson and Ottarnic Ponds is 'poor' as indicated by the low water transparency, large amounts of algae, potential for phytoplankton blooms, and widespread growth of macrophytes.

2) Water quality in Robinson and Ottarnic Ponds improved in 1983, based on increased water transparency, and smaller amounts of algae. This may be normal variation between years.

4) At the present time, acidification is not a serious problem for the Hudson Lakes. Loading of nutrients in the watersheds provides a buffer against the effects of acid rain.

5) The primary source of phosphorus for Ottarnic Pond appears to be Merrill Brock. Very high concentrations (1220 micrograms per liter) were measured just above Route 711.

6) Metallimnetic blooms of blue-green bacteria were observed in both Ottarnic and Robinson Ponds. The occurrence of such blooms is a strong indication of eutrophication in these ponds, and should be closely monitored in the future.
Comments and Recommendations for the Town of Hudson 1983

1) Data collection on Robinson Pond was sufficient during July and August. More data during June would be helpful in making comparisons between years. Apparently no lay monitors were available for Ottar nic Pond. This is unfortunate, as the strength of the program lies in the weekly monitoring of the pond by lay persons. Every effort should be made to reactivate monitoring on Ottar nic Pond in 1984.

2) Since lakewater transparency appears to be affected by water 'color' we suggest that lay monitors save filtrate samples as part of their regular routine. This filtrate is the water that has passed through the chlorophyll filter, and requires little additional effort to obtain.

3) We recommend that an expanded program of phosphorus sampling be initiated to identify point sources of loading of this nutrient into the lakes. This is a first step toward development of a program for water quality improvement in the Hudson lakes.
Executive Summary for the Town of Hudson 1983

1) Robinson Pond is mesotrophic to eutrophic based on its low Secchi disk depth (3.5 meters), moderate chlorophyll a concentration (1.7 mg/cubic meter), and high total phosphorus concentration (21.3 micrograms per liter). Other indications of eutrophy include rapid depletion of oxygen in the hypolimnion and metalimnion, formation of metalimnetic blooms of Blue-green bacteria, and high density of zooplankton (15-24 animals per liter). Ottarnic Pond is more eutrophic, with lower water transparency (2.5 meters), higher chlorophyll a (8.1 mg per cubic meter), and higher total phosphorus (42.6 micrograms per liter). Phytoplankton blooms were more intense, and zooplankton densities were higher (76-976 animals per liter) than in Robinson Pond.

2) The surface pH of Ottarnic and Robinson Ponds was moderate, in the range 5.7-6.5. Alkalinites were high for New Hampshire lakewater, and averaged 17.8 mg per liter (356 microequivalents per liter) in Robinson Pond, and 36.9 mg (738 microequivalents per liter) calcium carbonate per liter in Ottarnic Pond. Acid rain does not appear to pose a threat to these lakes in the immediate future.

3) Dissolved oxygen concentrations in the hypolimnion fell below the tolerance range for cold-water fish. Severe oxygen depletion indicates eutrophy in both lakes.

4) Specific conductivity was high, (185.9 micromhos per cm in
Ottarnic Pond and 95.2 micromhos per cm in Robinson Pond) as was the chloride ion concentration, (23.1 parts per million in Ottarnic Pond and 13.3 parts per million in Robinson Pond). Local pollution is probably the source of these salts.

5) High concentration of phosphorus (maximum of 1220 micrograms per liter) were found in Merrill Brook at sites B and "Below". Specific conductivities were also high (maximum 686.1 micromhos per cm.) at these sites.

6) We propose that the Town of Hudson begin the first phase of a water quality improvement program for Robinson and Ottarnic Ponds. This would begin by the initiation of an expanded phosphorus sampling program.

METHODS OF LAY MONITORS

Lay monitors collected data on three parameters: thermal stratification, water clarity, and chlorophyll a concentration. Data were collected at weekly intervals whenever possible.

Thermal profiles were obtained by collecting lakewater samples at several depths with a modified Meyer bottle (Lind, 1979). Samples were obtained by lowering the empty but weighted bottle and sampling (by pulling out the stopper) at 1-meter intervals. The temperature of the
samples was measured with Taylor pocket thermometers, and recorded in degrees Celsius.

Water clarity was measured while lowering an 8-inch (20 cm) Secchi disk and holding a view-scope just below the surface to eliminate the effects of surface reflection and wave-action. When the Secchi Disk disappeared the depth mark on the plastic suspension line was noted. The disk was raised until it just came into sight, and again the depth on the line was noted. The process was repeated two to three times, and an average between the two marks on the line (the point of disappearance and the point of re-appearance) was considered to be the Secchi Disk Depth (SDD), measured to the nearest one-tenth meter (0.1 meter) -- as for example, 5.2 meters. Readings were generally taken between 9 a.m. and 3 p.m., the period of maximum light penetration.

Chlorophyll a concentration was used as an estimator of algal biomass. A weighted tube 33 feet (10 meters) in length was used to collect an integrated water sample from the 'upper-lake' (epilimnion). The weighted end of the tube was slowly lowered to the interface of the epilimnion and the 'middle-lake' (metalimnion). The end of the tube was then bent double to shut off flow of air and water, and the weighted end of the tube (presently at the base of the epilimnion) was pulled up to the surface with a plastic line attached to it. The water in the tube (epilimnetic lakewater sample) was poured into a plastic bottle by
placing the weighted end of the tube into the neck of the bottle and, while keeping the bent-off end above the weighted end, unbending the upper end (allowing the sample to discharge into the bottle).

Water samples were filtered through a membrane filter with a porosity of 0.45 microns. The damp filters containing chlorophyll-bearing algae were air dried for at least 15 minutes to prevent decomposition. Filtration and drying were done in the shade to minimize destruction (by bleaching) of chlorophyll. The dried filters were then sent to UNH for analysis. [In Durham, members of the Freshwater Biology Group extracted chlorophyll in 90% acetone saturated with magnesium carbonate, and read the absorbance of the sample at standard wavelengths (663 and 750 nanometers). If sufficient pigment was present, the sample was acidified and reread to enable estimation of the percentage of active chlorophyll relative to the sum of the pigment plus all of its breakdown products that were present.]

METHODS OF FRESHWATER BIOLOGY GROUP (FBG) TEAM

The same as well as additional parameters were investigated by the FBG research team. The additional factors were primarily measurements of sunlight penetration into the lakewater, and water chemistry. The latter included dissolved oxygen, 'free' (unbound) carbon dioxide, pH, specific conductivity, chloride ion, and total
phosphorus. In addition, the microscopic plants (phytoplanktonic algae) and animals (zooplanktonic invertebrates) were identified. Relative or absolute counts were made.

Dissolved oxygen and temperature were measured with a Yellow Springs Instruments Model 54A Oxygen/Temperature meter with a submersible probe. Readings were taken at 1-meter intervals throughout the 'upper-lake' (epilimnion) and 'lower-lake' (hypolimnion), and at half-meter intervals through the 'middle-lake' (metalimnion).

Sun- and skylight penetration into the lakewater was measured at 1-meter intervals with a Whitney submersible photometer model LMA-94, and the relative light intensity was recorded. Measurements were taken on the sunny side of the boat.

Dissolved water color was measured by reading the absorbance of filtered lakewater (0.45 micron) at 440 and 493 nanometers, in a Baech and Lomb Spectronic 710 with a path length of 15 cm.

Water chemistry (alkalinity, free carbon dioxide, pH, and specific conductivity) samples were collected with a 3-liter Van Dorn bottle. Samples to be analyzed for alkalinity, free carbon dioxide, specific conductivity, and pH were stored on ice in 250 ml polyethylene bottles.
Alkalinity, free carbon dioxide and pH were determined in the field, within 1 to 2 hours of sampling.

Alkalinity was determined titrimetrically with 0.002 M sulfuric acid to a final pH of 4.5, with a combination solution of the two dyes bromocresol green and methyl red as the end-point indicator (E.P.A., 1979). Alkalinity is expressed as equivalents of calcium carbonate.

'Free' (unbound) carbon dioxide concentration was determined by titrating the fresh lakewater samples with 0.0027 M NaOH to a final pH of 8.3, and with the dye phenolphthalein as the end-point indicator.

pH was measured with a pH meter (Corning Model 10) equipped with a combination probe (Orion Co.).

Specific conductivity was measured with a Barnstead Conductivity Bridge Model PM-70CB equipped with model B-10 probe (cell constant = 1.0). Correction for sample temperature was made with a standard curve.

Chloride ion concentration was measured with a pH meter (Corning Model 10) equipped with a chloride electrode (Orion model 94-17B) and a double junction reference electrode (Orion Model 90-02). Standard curves were prepared every 2 hours during laboratory analysis.
Samples to be analyzed for total phosphorus, phytoplankton, and chlorophyll a were collected with a vertical 'tube' sampler. Chlorophyll a samples were filtered, dried and analysed in the same manner as those collected by lay monitors.

Total phosphorus samples were stored in acid-washed 250 ml polyethylene bottles, and were fixed within 1 to 2 hours with 1.0 ml concentrated sulfuric acid. In their Durham laboratory, the FBG members digested the total-phosphorus by adding ammonium persulfate and autoclaving the samples for at least 45 minutes. Finally, the phosphorus content of the samples was analyzed with the single-reagent method that included a fresh solution of ascorbic acid and potassium antimony tartrate (E.P.A., 1979). Absorbance of the blue phosphorus complex was measured spectrophotometrically at 650 nm.

Phytoplankton samples were fixed with iodine (Lugol's Solution) in the field, within 1 to 2 hours after collection. Phytoplankton were counted with a Unitron 'inverted' microscope after settling the samples for 24 hours in counting chambers. At least 200 individual algal 'units' were counted with a modified scan technique (Baker 1973).

Zooplankton density was estimated in samples collected by towing up a plankton net (30 cm diameter, 150 micron porosity) through the oxygenated (>0.5 ppm) portion of the
lake. Samples were fixed after collection with a 4% formalin-sucrose solution (Haney and Hall, 1973), and subsampled with a 1-ml Hensen-Stemple pipet. Sufficient subsamples were taken to insure that at least 100 microcrustaceans were counted.
RESULTS AND DISCUSSION OF LAY MONITOR DATA

Lay monitor research was conducted separately from Freshwater Ecology Group (FBG) research, thus the results are presented separately. Four sampling sites were active on Robinson Pond (Fig 2). No lay monitor teams were active on Ottaunic Pond. The lay monitor raw data for summer 1983 are presented in Appendix A.

Lay monitors collected information on three parameters: water transparency (Secchi disk depth), productivity (chlorophyll a), and thermal stratification (temperature profile). Information on thermal stratification is used primarily to determine the depth of the chlorophyll a sample. The lake was stratified during the entire sampling period (late June-August), with the epilimnion being 2.5 to 4.5 meters deep.

Figure 2. Robinson Pond, Town of Hudson, New Hampshire. Outline map and location of 1983 sampling sites.
Secchi Disk Depth (transparency)

Lakewater transparency on the average was shallow (3.5 meters) in Robinson Pond. Transparency was at a minimum (2.3 meters) in June, and increased over the summer (Fig. 3). Patterns at all sites were essentially the same, and differences between sites small (Table 1).

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Table 1. Monthly mean Secchi disk depth.

Figure 3. Seasonal variation of Secchi disk depth. (o site 1; A site 2; x site 3; + site 4).
Figure 4. Seasonal variation of chlorophyll a concentration. (O site 1; A site 2; X site 3; + site 4)

Chlorophyll a

Chlorophyll a concentrations in Robinson Pond were in the range 0.7 to 4.0 milligrams per cubic meter. Chlorophyll a concentrations were at a minimum during late June, and tended to increase as the season progressed (Fig. 4). Seasonal patterns between sites were not as parallel as Secchi disk depths, but for the most part chlorophyll a concentrations were similar at all sites. The occurrence of metalimnetic blooms of blue-green bacteria is a possible source of the increase in chlorophyll a observed over the summer. As the sampling depth varies, so does the amount of
this bloom that is sampled. This is one of the primary reasons for sampling only the epilimnion with the tube sampler.

<table>
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Table 2. Monthly mean chlorophyll a concentration.

Discussion

Relative to other lakes in the LLMP, Robinson Pond has a low lakewater transparency (Fig. 5). Chlorophyll a concentrations were moderate compared to other lakes in the program (Fig. 6). Based on Secchi disk depth, Robinson Pond would be classed as mesotrophic, but the average chlorophyll a concentration classes it as oligotrophic. The large seasonal variation in transparency indicates eutrophication in Robinson Pond.
Figure 5. Frequency distribution of Secchi Disk depth. Arrow indicates mean and bar indicates range of values from Robinson Pond.

Figure 6. Frequency distribution of chlorophyll a. Arrow indicates mean and bar indicates range of values from Robinson Pond.
Comparisons between 1982 and 1983 suggest differences due to weather. During 1982, the average Secchi disk depth was shallower than in 1983, but not consistently so (Fig. 7). Early in the summer, the transparency was greater during 1982 than 1983, but less after the middle of July. This may be explained by the wet period in Spring 1983, with high stream input of humic substances, followed by a prolonged period of calm sunny weather. Chlorophyll a concentrations were consistently lower in 1983 than in 1982 (Fig. 7). Weather may have affected the phytoplankton growth by reducing the nutrient supply from the hypolimnion. This would be the result of reduced mixing of the lake during a prolonged calm period, as in Summer 1983, is due to non-chlorophyllous material. Whether this is dissolved color or suspended particulates is unknown.
Figure 7. Comparison of Secchi disk depth and Chlorophyll a 1982-1983.
In 1938, the New Hampshire Fish and Game Department measured a transparency of 1.8 meters, and in 1953, a transparency of 2.1 meters. The New Hampshire Water Supply and Pollution Control Commission measured a transparency of 2.9 meters in 1979. On August 15, 1979, they also measured a chlorophyll a concentration of 11.59 milligrams per cubic meter. This value is higher than any observed by lay monitors or FBG team trips during 1983, but may represent contribution to the surface waters from the metalimnetic layer of phytoplankton observed both in 1982 and 1983. The water transparency was 0.5 meters less in 1938 than the shallowest transparency measured during 1983, and may indicate a reduction in humic substances since that time. Other parameters suggest little change in trophic state.

RESULTS AND DISCUSSION OF FRESHWATER BIOLOGY GROUP DATA

Temperature and Dissolved Oxygen

Robinson and Ottarnic Ponds were thermally stratified on all test dates. Due to their small size and protected placement in their watersheds, both ponds were well stratified even as early as June 8 (Fig. 8).
Figure 8. Temperature and Oxygen profiles.
(▲ temperature; ○ dissolved oxygen)
Peaks of oxygen concentration were found in the thermocline during July and August in both ponds (Fig. 9). These peaks are due to metalimnetic blooms of phytoplankton. The combination of shallow mixing depth, moderate water clarity, and nutrient-rich water are good conditions for the formation of metalimnetic blooms. In this case, these blooms are primarily composed of *Oscillatoria* (see Phytoplankton section).

![Dissolved Oxygen](image1)

![Dissolved Oxygen](image2)

**Figure 9.** Oxygen profiles comparing all test dates.
(Ottarnic • June 8; ▲ July 13; X July 28; • August 10; Robinson • June 8; ▲ July 13; X August 10.)
The rapid rate of oxygen depletion, and the development of metalimnetic oxygen peaks are two strong indications of eutrophic systems. The combination of low hypolimnetic and metalimnetic oxygen and high epilimnetic water temperature makes Robinson and Ottarnic best suited for warm-water fish such as bass, perch and pickerel.

**Water Clarity and Dissolved Color**

Lay monitor Secchi disk depths and FBG team Secchi disk depths were comparable for overlapping time periods.

Sunlight is quickly absorbed and scattered by dissolved coloring materials and suspended particles. A value describing the attenuation of light in lakes is the 'extinction coefficient of diffuse downwelling light (k)'. In Robinson Pond, k was in the range 0.796 to 1.000 and averaged 0.921. This relatively high value of k (Fig. 10) corresponds to the low lakewater transparency in Robinson Pond. In Ottarnic Pond, k was even greater, in the range 1.32-1.56 and averaging 1.42.
Figure 10. Frequency distribution of extinction coefficient of lakes in the LLMP. Arrow indicates mean and bar indicates range of values from the Hudson lakes.

Dissolved water color, primarily due to humic acids, decreased from 0.052 to 0.042 over the summer in Robinson, and from 0.078 to 0.056 in Ottamn Pond.
Figure 11. Frequency distribution of dissolved color of lakes in the LLMP. Arrow indicates change of the summer.

Associated with the relatively high dissolved color in June are lower Secchi disk depths than during July and August. The decrease in color may be due to bleaching of the humic acids by the sun and because of lower input of humic acids due to less precipitation during the summer.

Chlorophyll a

Chlorophyll a concentrations in Robinson Pond measured by the FBG were similar to those measured by the lay monitors. Concentrations were in the range 2.0 to 2.4 milligrams per cubic meter. In Ottmar Pond, chlorophyll a concentrations were in the range 4.4-16.0 milligrams per cubic meter, and averaged 8.1 milligrams per cubic meter. This is lower than last year's average (18.8 mg/cubic meter).
but may be merely due to the low number of samples, and the
great influence of single data points. Chlorophyll a
samples from the depth at which there was an oxygen peak in
Ottarnic Pond were very high, in the range 61.9-121.9
milligrams per cubic meter. In Robinson Pond, chlorophyll a
concentration at the oxygen peak was lower (37.2 milligrams
per cubic meter), and corresponds to the small peak observed.
These observations indicate the development of strata of
high densities of phytoplankton by mid to late summer.

Total Phosphorus

Total phosphorus is usually the most important nutrient
limiting algal growth in freshwater systems. Its
concentration can indicate the potential for algal growth.
In Robinson Pond, epilimnetic total phosphorus averaged 21.3
micrograms per liter. Ottarnic Pond had double Robinson's
average total phosphorus, with 56.7 micrograms per liter.
Based on total phosphorus concentrations, Robinson would be
classed as mesotrophic, and Ottarnic as eutrophic (Fig.
12). The concentrations of total phosphorus in Ottarnic
Pond would place it to the right of the distribution shown
in Figure 12. A sample was taken from the bloom area at its
greatest development. The total phosphorus in this sample
was 352.4 micrograms per liter. The high total phosphorus
in this area probably represents nutrients that were
released from the sediments during periods of anoxia, and
absorbed by phytoplankton.
Figure 12. Distribution of phosphorus values. Arrow indicates mean and bar range of values from Robinson Pond.

Alkalinity, pH, and Free Carbon Dioxide

The vertical pattern of pH, alkalinity, and free carbon dioxide found at Site 2 on August 10 is typical of the ponds (Fig. 13).
Figure 13. Profile of alkalinity, pH and free carbon dioxide.

The pH values of surface water in Robinson Pond were moderate, in the range 5.7-6.4. Alkalinity was high for New Hampshire lakes, averaging 17.8 milligrams calcium carbonate per liter, although according to EPA standards, 10-20 milligrams per liter indicate lakes "moderately sensitive" to acid rain. Alkalinity and pH were even higher in Ottarnic Pond. The pH was in the range 6.0-6.5, and the alkalinity averaged 36.9 milligrams calcium carbonate per
liter. Although these are relatively high alkalinitities for New Hampshire, they are still low on a nation-wide basis. Alkalinitities measured during previous surveys of Robinson Pond were in the range 9.0–90.6 milligrams per liter. The high value was measured in 1938 by the New Hampshire Fish and Game Department, and may be questionable. Alkalinitities from other surveys of Ottarnic Pond were in the range 19.0–35.0 milligrams per liter.

Free carbon dioxide accumulated in the thermocline and hypolimnion of Robinson and Ottarnic Pond. This lowers the pH of these layers of lakewater (Fig 13). The large amount of free carbon dioxide in the deep waters indicates high productivity in both ponds.

Specific Conductivity and Chloride Ion Concentration

Both Robinson and Ottarnic Ponds had high salt contents based on specific conductivities. The average specific conductivity from Ottarnic was 185.9 micromhos per cm, and 95.2 micromhos per cm in Robinson. Chloride ion concentration is related to salt concentration as it is one of the major constituents of salts in New Hampshire lakewater. Concentrations were relatively high at both ponds, 13.3 parts per million at Robinson, and 23.1 parts per million in Ottarnic. Although the specific conductivities are higher than other lakes in the ILMP, some lakes had a higher chloride ion concentration than Ottarnic.
or Robinson. This suggests that the salts in Robinson and Ottarnic are different chemically than salts in the other lakes involved with the LLMP, and have a lower proportion of chloride ions. The chemical composition of the salts present was not measured.

**Phytoplankton**

Densities of epilimnetic phytoplankton in Robinson Pond were low to high, in the range 542-1803 cells per milliliter. Chlorophytes (small flagellated forms, *Ankistrodesmus* and *Schroederia*) and Cryptomonads (*Chroomonas*) were dominant over the summer. On July 13, Blue-green bacteria (*Chroococcus*, *Coelosphaerium*) were also of numerical importance. Epilimnetic phytoplankton populations were more dense in Ottarnic Pond than Robinson Pond. Numbers ranged from 1539 to 3550 cells per milliliter. Dominant groups over the season included: Chlorophytes (small flagellated forms, *Ankistrodesmus*, *Schroederia*, *Oocystis*, and *Pediasstrum*), Diatoms (*Rhizosolenia* and *Cyclotella*), Cryptomonads (*Chroomonas* and *Cryptomonas*), and Chrysophytes (*Dinobryon*, and *Mallomonas*). Euglenoids and other groups were also present in low densities. The density of epilimnetic phytoplankton, and the species composition of Robinson Pond indicates mesotrophic conditions, and in Ottarnic Pond eutrophic conditions.
Phytoplankton samples were obtained from bloom areas with a Van Dorn sampler. Densities in Robinson were lower (2580 per milliliter) than in Ottarnic (9150-14640 per milliliter), but both blooms were heavily dominated by Oscillatoria filaments (69-85%). In Robinson, other dominant species in the bloom include: small flagellated Chlorophytes, Cryptomonas, and Euglenoids (Euglena, Phacus, and Trachelomonas). Ottarnic Pond showed more Euglenoids (Trachelomonas), and Diatoms (Rhizosolenia) than Robinson. Also present in some of the Ottarnic samples were small coccoid blue-green bacteria. These were very small forms and were difficult to identify. Numerically, however, they formed an important part of the community, as their numbers may have reached 48,000 cells per milliliter.

Zooplankton

Herbivorous crustacean zooplankton density was moderate (15-24 animals per liter) in Robinson Pond. Calanoid copepods were dominant over the season as a whole, but seasonally Bosmina and Daphnia were also dominant. The density of predatory zooplanktors, mostly cyclopid copepods, was relatively high (7-10 animals per liter), and may lower the density of other zooplankton.

In Ottarnic Pond, density of herbivorous crustacean zooplankton was very high (76-976 animals per liter). The highest density occurred on August 10, during the decline of
the metalimnetic bloom. It is possible that the zooplankton contributed to the decrease in phytoplankton densities during the decline period of the bloom. Dominant groups included: *Daphnia, Bosmina, Ceriodaphnia*, and *Diaphanosoma*. The density of predatory crustacean zooplankton was also high, in the range 18-57 animals per liter. The density of zooplankton in Robinson Pond indicates a mesotrophic to eutrophic lake, and the density in Ottarnic indicates a eutrophic lake.

**Stream Samples**

Samples from the inlets to Ottarnic Pond were taken to locate potential areas of loading and absorption. Four sites were established on Merrill Brook (Fig. 14, A-D), and two sites on the north (unnamed) tributary (Fig. 14, E,F). Also, one site at the outlet was established (Fig. 14, G). Samples from the north inlet had relatively low total phosphorus (29.7 micrograms per liter average for sites E and F), and moderate specific conductivities and chloride ion concentrations (205.2-341.1 micromhos per cm; and 42.8-71.7 parts per million chloride). This tributary is apparently not the major source of nutrients for Ottarnic Pond. Conditions of the outlet were similar to the open lake, except the total phosphorus concentration were slightly lower than the lake (34.5 micrograms per liter). Merrill Brook appears to be the major source of nutrients for Ottarnic Pond. The average total phosphorus concentration
at site A, Benson's Animal Farm was 32.2 micrograms per liter. At the site located just above the culvert under Rt. 11, the average total phosphorus concentration had risen to 505.1 micrograms per liter. During periods of peak phosphorus concentration, however, the flow rate was greatly reduced. On July 28, at Site B, located near the upper limit of navigability of Merrill Brook from Ottarnic Pond, the total phosphorus concentration was still high, at 450.7 micrograms per liter. After passing through most of the wetland associated with Merrill Brook, at Site A, the phosphorus concentration had dropped to 44.9 micrograms per liter. This suggests that plants or sediments in the wetland may act as a phosphorus sink during this time period. The pattern of specific conductivities and chloride ion concentrations was similar to that of total phosphorus (Figure 16).
Figure 14. Map of Ottarnic Pond and watershed, Town of Hudson, New Hampshire.
Figure 15. Chemical profiles from Merrill Brook.
Figure 16. Chemical profiles from Merrill Brook.
REFERENCES


### APPENDIX A

#### LLMP 1983 -- Lay Monitor Data: Hudson

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APPENDIX B

CLARIFICATION OF SOME TERMS AND CONCEPTS

**Thermal Stratification**

Thermal stratification as a seasonal phenomenon is of prime importance in the lives of aquatic organisms. The formation of thermal layers affects many of the chemical and physical factors of their environment.

New Hampshire lakes are generally dimictic, with mixing of the water column occurring in the spring and fall. During periods of mixing, sometimes called overturn, the entire water column tends to circulate (holomixis). That is, the bottom-most waters are refreshed with water recently in contact with the atmosphere. The surface waters are enriched with water recently in contact with the bottom sediments. Some lakes, especially those with a high salt content toward the bottom of the basin, may be monomictic and fail to mix (overturn) to the bottom.
During the spring, the entire water column circulates freely, resuspending and redissolving material from the bottom sediments. As the sun's intensity increases, the surface waters are heated so that they become buoyant and tend to float, creating a mixing-barrier with cooler water beneath. Eventually three layers are formed, called the upper-lake (epilimnion), middle-lake (metalimnion), and lower-lake (hypolimnion) (Fig. B-1). Characteristically, the epilimnion and hypolimnion are uniform in temperature, even though the upper lake is warm and the lower lake is usually very cold. In contrast, the temperature gradually or suddenly becomes cooler in the metalimnion (sometimes called the thermocline, or temperature gradient). The gradation in temperature corresponds to a gradient in other important characteristics of water, such as viscosity and specific gravity, that explain the presence of a mixing barrier between the epilimnion and the hypolimnion.

Depth of the metalimnion through the summer is variable, and is regulated to a large extent by the length of the wind-fetch on the lake (the length of lake aligned with the predominant axis of wind-storms). In the autumn, the sun's intensity decreases, the water in the epilimnion cools, and the mixing barrier weakens. Eventually the metalimnion disintegrates and the fall overturn occurs.
Ice and snow insulate the lakewater during winter, and the liquid lakewater cools to nearly freezing just under the ice layer, while it remains relatively warm further down in the water column (about 10 degrees Fahrenheit, or 4 degrees Celsius). Sometimes the overburden of snow after a heavy snowstorm in January or February may cause melt-holes to form in the ice, and the snow may turn to slush even while the air temperature is at its seasonal coldest (as low as 25 or 30 degrees below zero Fahrenheit)! This has caused some hysteria about 'radioactive things dropping from outer space' or 'radioactive substances dropping from jet planes' -- even though it is only the weight of snow! Some reverse stratification may occur, with a layer of colder water overlying the relatively warmer water below.

Two aspects of the seasonal thermal stratification cycle about which we are most concerned are vertical mixing (overtturn) and the formation of stratified temperature layers during the summer.

Periods of overturn are very important because of their effect of enriching the lakewater with material from the sediments. In eutrophic lakes, blooms of algae generally follow these periods in response to high concentrations of chemicals such as phosphorus, nitrogen, silica, and other essential nutrients -- those required for the growth of microscopic algae.
Effects of stratification will vary depending upon the depth of the lake or cove. In shallow areas, the epilimnion may extend to the bottom. If this is the case, the lakewater will constantly pick up material from the bottom usually resulting in a decrease in water transparency and an increase in algal growth.

One of the major consequences of a stratified lake system is reduced transportation of material between the bottom and surface. The effects of having a "barrier" within the water column are many but the most important include transport of nutrients from the epilimnion to the hypolimnion by sedimentation (enriching the hypolimnion at the expense of the epilimnion), and oxygen depletion in the hypolimnion.

Loss of nutrients from the epilimnion is due primarily to the sedimentation of plankton organisms such as algae and bacteria. The depletion of nutrients from the epilimnion is important for restricting the growth of algae during the summer, because the primary productivity of most lakes occurs only in the epilimnion. As a result of fall overturn the surface waters may become mixed with nutrient-rich bottom waters, and fall pulses of phytoplankton (freely-drifting microscopic algae) may develop.
Figure B-1. Typical summer thermal stratification of a temperate lake. The 'metalimnion' provides a mixing barrier between the 'epilimnion' and the 'hypolimnion'. The dashed line represents the thermal profile, with cold water in the hypolimnion.
Oxygen Depletion

Oxygen depletion in the hypolimnion occurs for two reasons -- respiration by plants, bacteria and animals, and absence of mixing of the water column (combined with respiration). The resultant loss of oxygen plays an important role in regulating the depth regions within which aerobic (requiring oxygen) and anaerobic (oxygen avoiding) organisms may thrive. The aerobic organisms include some bacteria, most algae, and all animals, and although they may have special adaptations to allow a tolerance to very low levels of dissolved oxygen, even for prolonged periods of time, they must occasionally obtain a supply of oxygen. The algae are the principal source of re-oxygenation by photosynthesis in the metalimnion, and the balance between oxygen production (by photosynthesis) and consumption (by respiration) is critical in determining the oxygen depletion in lakewater. The problem is minimal in surface waters, as the atmosphere overhead is a good source of oxygen.

Fishermen are acutely aware of the oxygen requirement of fish, and know that they can expect no lake trout fishing where oxygen has been depleted in the cool bottom waters of a lake. In fact, the lake trout, as well as related species of fish, are entirely eliminated from such lakes. Even though the surface waters are well oxygenated, the temperature is too high to support the salmonid-type fish.
Most people are unaware that important groups of micro-organisms thrive in the \textit{anoxic} (lacking oxygen, similar to \textit{anaerobic}) bottom waters of lakes. For the most part, these are the important groups of bacteria that regulate cycles of \textit{nutrients} at or near the bottom of such lakes. The bacteria are involved in crucial processes that may determine the chemical quality of the lake -- including modification of all \textit{nutrients} essential to growth of the \textit{microscopic algae} -- such as carbon, phosphorus nitrogen, and sulphur, by \textit{putrefaction} or break-down of dead organisms, and by \textit{fermentation}. The \textit{anaerobic} bacteria are also involved in processes such as nitrogen fixation that converts unavailable nitrogen to very-available ammonia, and in the formation of a large host of dissolved organic substances such as vitamins that promote the growth of \textit{microscopic algae}. In general, the \textit{anaerobic} bacteria can be viewed as the principal agents involved in promoting \textit{recycling} of essential \textit{nutrients} that otherwise would have been lost and locked up in the lake sediments.

\textbf{Water transparency}

Water \textit{transparency}, as indicated by \textit{Cecchi disk depth}, is influenced by many factors. Dissolved substances such as \textit{humic acids} (tea-colored coloring matter from plant decay) will frequently lend a yellow or brown color to the water, thus decreasing its \textit{transparency}. The \textit{humic acids} are especially prevalent in waters running through bogs or
coniferous forests.

Another factor affecting water transparency is the number of particles suspended in the water column. These particles are of two types: sediments and living organisms. Sediments are especially prevalent in areas where mixing occurs all the way to the bottom, as during overturn of holomictic lakes. Human activity such as boating or swimming can also resuspend sediments. Among living organisms, phytoplankton has the greatest effect on water transparency, due to its pigmentation and abundance. Chlorophyll a, the pigment common to all photosynthetic phytoplankton, is used as one measure of phytoplankton density.

Water transparency (measured as the Secchi Disk Depth), chlorophyll a and thermal stratification, along with other important physical, chemical and biological observations of study lakes, are the core of the lay monitoring program. Long- or short-term trends in these data can be used as indicators of changing trophic status of lakes.

Lake Trophic Status

Every classification scheme suffers from over-simplification! The very act of classifying requires the definition of classes within which study objects may be placed or pigeon-holed. Often the classes are defined by some arbitrary means, and the boundaries are subject to
change depending upon the definition that is used. The fundamental problem with the process of classification is that once boundaries are set and classes are defined, we tend to think of the classes as somehow isolated from each other. Instead they may blend into each other at the boundaries. As you consider the classification scheme, please think of a continual gradient of individual lake types, through which any lake may pass. The passage may require a long period of time, given changes in the landscape or climate by natural causes, or a relatively short time given human-induced changes in use of the lake or its shoreline and watershed. One may hope that the following five categories of trophic status will help to simplify what we know about lakes, yet leave us with a sense of the probable evolution of lakes between classes of trophic status.

Three major categories of trophic status include oligotrophy, mesotrophy, eutrophy. Oligotrophic lakes characteristically have high transparency and low concentrations of chlorophyll a and phosphorus. Therefore, a large fraction of the visible portion of sunlight radiation, including from blue through red light, can penetrate to great depths in the lakes. Mesotrophic lakes are intermediate, and eutrophic lakes have relatively low transparency and high concentrations of chlorophyll a and phosphorus. Due to the high chlorophyll concentration, restrictions are placed on the transmission of sunlight into
eutrophic lakes -- especially on blue and red light that are absorbed in the upper waters of the lakes by microscopic algae. Generally green light penetrates furthest into such lakes, and although it can be used in photosynthesis, it is less efficient than red or blue light. Thus photosynthesis is more restricted to upper layers in eutrophic lakes than in less-productive lakes. Two additional major categories of lakes are dystrophy and mixotrophy. Lakes in these two categories have a high concentration of humic acids, and thus are heavily stained. Light penetration is severely restricted by the tea-colored stain, and only the red portion of sunlight is transmitted beneath the surface. Therefore, microscopic algae can grow only near the surface, and even then are light-limited (little or no blue light is transmitted to them). If such a lake has a low concentration of microscopic algae -- indicated both by algal counts (with a microscope) and by a low chlorophyll a concentration, the lake is called dystrophic. It is probable that the lake has a low input (loading) of nutrients, so that the microscopic algae are limited both by low light level and by low nutrient levels. However, if the lake receives a large loading of fertilizer, supplying an abundance of phosphorus, nitrogen and other essential nutrients, the microscopic algae may form a relatively concentrated community, and thus the chlorophyll a concentration rises. Such a lake is called mixotrophic -- a 'mixture' of organisms produced within the lake with
imported organic material (mainly humic substances) from bogs or other sources outside the lake basin.

**Plankton**

Microscopic organisms found throughout the water column of lakes belong to the *plankton*, or *plankton community*. Members of the community are especially adapted for life in the open water where they must be able to resist gravity to stay in suspension, and to capture energy for survival. Important members of the *plankton community* are all microscopic, and belong to several different groups of bacteria, algae, fungi, and animals. In some cases the organisms spend their entire life in the open water, while in other cases only a fraction of their life (usually early stages, as in some and insects). Students of biology are often attracted to the *plankton community* because of the immense diversity of organisms and processes that occur within it, because of its relative importance to a body of water, and especially because much about life of larger organisms can be learned from these special *plankton* organisms.

Interactions between the *plankton community* and lakewater determine to a very large extent the *trophic status* of lakes. In addition, a firm foundation is laid for the long-term management of lakes when the characteristics of the *plankton community* and the lakewater are determined.
Seasonal changes in both the **planktors** (members of the **plankton community**) and in the water chemistry require that several observations be made each year in a lake. Annual changes are generally slower, and can be discerned only during the course of long-term monitoring of principal parameters of **plankton** and water chemistry.

It is beyond the scope of this section of the report to describe all of the important changes that occur in the **plankton** as a lake passes through various **trophic stages** (oligotrophy, mesotrophy, etc.). But foremost among these is the change in concentration of **plankton** organisms -- especially the **microscopic algae**. This change is usually regulated by chemical loading into lakes, but is also regulated by seasonal changes in weather, and by several biological processes that occur in lakes -- such as grazing by microscopic crustaceans (**water fleas** and their allies). A good monitoring program includes not only an analysis of numbers of planktors, but also of types. Predictions of trophic evolution in lakes may be discerned more quickly by observing such changes in the **plankton**.
APPENDIX C

GLOSSARY

Aerobe Organisms requiring oxygen for life. All animals, most algae and some bacteria require oxygen for respiration.

Algae See phytoplankton.

Alkalinity Total concentration of bicarbonate and hydroxide ions (in most lakes).

Anaerobe Organisms not requiring oxygen for life. Some algae and many bacteria are able to respire or ferment without using oxygen.

Anoxic Without oxygen. The hypolimnion of a lake may become anoxic if there are many organisms using oxygen for respiration and there is little replenishment from the atmosphere.

Benthic Referring to the bottom sediments.

Bacterioplankton Bacteria adapted to the "open water" or "planktonic" zone of lakes, adapted for many
specialized habitats and include groups that can use the sun's energy (phytoplankton), some that can use the energy locked in sulfur or iron, and others that gain energy by decomposing dead material.

**Bicarbonate**

The most important ion (chemical) involved in the buffering system of New Hampshire lakes.

**Buffering**

The capacity of lakewater to absorb acid with a minimal change in the pH. In New Hampshire the main chemical responsible for buffering is the bicarbonate ion. (See pH.)

**Chloride**

One of the components of salts dissolved in lakewater. Generally the most abundant ion in New Hampshire lakewater, it may be used as an indicator of raw sewage or of road salt.

**Chlorophyll a**

The main green pigment in plants. The concentration of chlorophyll a in lakewater is often used as an indicator of algal abundance.

**Circulation**

The period during spring and fall when the combination of low water temperature and wind cause the water column to mix freely over its entire depth.

**Density**

The weight per volume of a substance. The more dense an object, the heavier it feels.
Low-density liquids will float on higher-density liquids.

**Dimictic**
The thermal pattern of lakes where the lake curculates, or mixes, twice a year. Other patterns such as polymictic (many periods of circulation per year) are uncommon in New Hampshire. (See also meromictic and holomictic).

**Dystrophy**
The lake trophic state in which the lakewater is highly stained with humic acids (reddish brown or yellow stain) and has low productivity. Chlorophyll a concentration may be low or high.

**Epilimnion**
The uppermost layer of water during periods of thermal stratification. (See lake diagram).

**Holomixis**
The condition where the entire lake is free to circulate during periods of overturn. (See meromixis.)

**Eutrophy**
The lake trophic state in which algal production is high. Associated with eutrophy is low Secchi disk depth, high chlorophyll a, and high total phosphorus. From an esthetic viewpoint these lakes are "bad" because water clarity is low, aquatic plants are often found in abundance, and cold-water fish such as trout and salmon are usually not present. A good aspect of eutrophic lakes is their high productivity in terms of
warm-water fish such as bass, pickerel, and perch.

Free CO₂ Carbon dioxide that is not combined chemically with lakewater or any other substances. It is produced by respiration, and is used by plants and bacteria for photosynthesis.

Humic acids Dissolved organic compounds released from decomposition of plant leaves and stems. Humic acids are red, brown, or yellow in color and are present in nearly all lakes in New Hampshire. Humic acids are consumed only by fungi, and thus are relatively resistant to biological decomposition.

Hydrogen ion The ion which is measured to indicate acidity. (See pH).

Hypolimnion The deepest layer of lakewater during periods of thermal stratification. (See lake diagram)

Lake Any "inland" body of relatively "standing" water. Includes many synonyms such as ponds, tarns, lochs, billabongs, bogs, marshes, etc.

Lake morphology The shape and size of a lake and its basin.

Meromixis The condition where the entire lake fails to circulate to its deepest point; caused by a high concentration of salt in the deeper waters, and by peculiar landscapes (small deep lakes surrounded
by hills and/or forests. (Contrast holomixis.)

**Mesotrophy**
The lake trophic state intermediate between oligotrophy and eutrophy. Algal production is moderate, and chlorophyll a, secchi disk depth, and total phosphorus are also moderate. These lakes are esthetically 'fair' but not as good as oligotrophic lakes.

**Metalimnion**
The 'middle' layer of the lake during periods of summer thermal stratification. Usually defined as the region where the water temperature changes at least one degree Celsius per meter depth. Also called the thermocline.

**Mixis**
Periods of lakewater mixing or circulation.

**Mixotrophy**
The lake condition where the water is highly stained with humic acids, but algal production and chlorophyll a values are also high.

**Oligotrophy**
The lake trophic state where algal production is low, Secchi disk depth is deep, and chlorophyll a and total phosphorus are low. Esthetically these lakes are the "best" because they are clear and have a minimum of algae and aquatic plants. Deep oligotrophic lakes can usually support cold-water fish such as lake trout and land-locked salmon.
Overturn  See circulation or mixis.

pH A measure of the hydrogen ion concentration of a liquid. For every decrease of 1 pH unit, the hydrogen ion concentration increases 10 times.

Photosynthesis The process by which plants convert carbon dioxide into glucose (sugar) using sunlight as the energy source. Glucose is an energy source for growth, reproduction, and maintenance.

Phytoplankton Microscopic algae which are suspended in the 'open water' zone of lakes and ponds. A major source of food for zooplankton. Common examples include: diatoms, euglenoids, dinoflagellates, and many others. Usually included are the blue-green bacteria.

Parts per million Also known as PPM. This is a method of expressing the amount of one substance (solute) dissolved in another (solvent). For example, a solution with 10 PPM of oxygen has 10 pounds of oxygen for every 999,990 pounds (500 tons) of water.

Plankton Community of microorganisms that live suspended in the water column, not attached to the bottom sediments or aquatic plants.
Saturated When a solute (such as water) has dissolved all of a substance that it can. For example, if you add table salt to water, a point is reached where any additional salt fails to dissolve. The water is then said to be saturated with table salt. In lakewater, gaseous oxygen can dissolve, but eventually the water becomes saturated with oxygen.

Specific conductivity A measure of the amount of salt present in lakewater. As the salt concentration increases, so does the specific conductivity (electrical conductivity).

Stratum A layer or a "blanket". Can be used to refer to one of the major layers of lakewater such as the epilimnion, or to any layers of organisms or chemicals that may be present in a lake.

Thermal Stratification The process by which layers are built up in the lake due to heating by the sun and partial mixing by wind. (See Appendix B.)

Thermocline Region of temperature change. (See metalimnion.)

Total Phosphorus A measure of the concentration of phosphorus in lakewater. Includes both free forms (dissolved), and chemically combined forms (as in living tissue, or in dead but suspended organisms).
Trophic status A classification system placing lakes into similar groups according to their amount of algal production. (See Oligotrophy, Mesotrophy, Eutrophy, Mixotrophy, and Dystrophy for definitions of the major categories, and Appendix B)

Z A symbol used by limnologists as an abbreviation for depth.

Zooplankton Microscopic animals in the planktonic community. Some are called 'water fleas', but most are known by their scientific names. Scientific names include: *Daphnia*, *Cyclops*, *Bosmina*, and *Kelliottia*. 