ALTON BAY
LAKE LAY MONITORING PROGRAM
1983

Freshwater Biology Group (FBC)
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.
Acknowledgement

The data summarized and analyzed in this report would not have been available without the support of a number of Alton/Alton Bay residents. Many individuals expressed their enthusiastic support through financial contributions which defrayed the cost of the equipment and the chemical and data analysis as well as the training and advice by the Fresh Water Biology Group at UNH.

The following persons, businesses and organizations became "Charter Sponsors" by donating $100.00 each to make it possible on short notice to start the monitoring project in June of 1983:

Edith Y. Babson
Klaus and Vera Biemann
Sean and Dan Callahan
Warren and Vera Center
Steven Chandler
Lance and Ethel Dockray
Lee and Shirley Joyal
Dorothy Kellogg
Charles G. Newell
Juliet Peverley
Jim and Ruth Reider
Eldon and June Swim
Dick and Priscilla Williams
Frank and Ruth Youngblood

Alton Home Center
Farmington National & Savings Bank
Parker Marine & Sons
Sandy Point Beach Resort, Inc.
The William Tell Inn
Black Point (Derby Side) Association
Echo Point Association
Mt. Major Park Association
Peggy's Cove Association
United Associations of Alton
Woodland Waters Association
Camp Kehonka

The contributions of many others provided for the continuous support of the program during the summer and for the start of the next year's.

Even more important for the success of the first monitoring season was the dedication of those who conscientiously went out to one of the seven spots on the lake week after week to make the measurements, take the samples, record their findings, and forward them to UNH for compilation:

Site 21 Bruce Ballentine
Tom Chapman
Joe Dellano

Site 22 Lee Joyal
Everett Lawton
Cliff Chandler

Site 23 Lance Dockray
Victor Cardosi
John Nottleman

Site 24 Peter Whittemore
Charles Griffin

Site 25 Paul Todd
Tom Todd

Site 26 Ernie Rivers
Joe Sloan
Sid Merrill
Tom Bishop

Site 27 Elmer Locke
Rodney Powers
Harold Smethurst
The community can be proud of these individuals, almost all of them lake shore residents, fishermen or boating enthusiasts who provided a valuable service. We can hope that they enjoyed it and that many of them will be back out there during 1984.

Organizational support was provided by the Fresh Water Biology Group at UNH, the Lake Winnipesaukee Association, the United Associations of Alton and Klaus Biemann who coordinated the effort.

1983 is the first year Alton Bay has been a participant in the Lake Lay Monitoring Program. Through the direction and leadership of Dr. Claus Biemann, the program has developed strongly on Alton Bay.

We congratulate the lay monitors on the quality of their work, and anticipate that they will continue with the program next year. We thank Dr. Biemann, and the other members of the Alton Bay group for their time and efforts in coordinating and managing the LLMP at Alton Bay. 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 UPLOR, written by Professor Baker, 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 finding of the 1983 summer study of Alton Bay. The study was conducted jointly by the Freshwater Biology Group (FBG), University of New Hampshire, and the Alton Bay Association 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 at 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, Silver 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 PBG 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.
Key to Figure 1: Lakes previously or presently in the LLMP of New Hampshire.

<table>
<thead>
<tr>
<th>Map Location</th>
<th>Lake Name</th>
<th>Number of FBG Observations</th>
<th>Number of Lay Observations</th>
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<tr>
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<td>12</td>
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<td>Lake Chocorua</td>
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<td>27</td>
<td>Conway Lake</td>
<td>5</td>
<td>28</td>
</tr>
</tbody>
</table>
Brief Non-technical Summary

1) The water quality in Alton Bay is "good" because of the high water clarity (Secchi disk depth), and low amount of algae (chlorophyll a).

2) pH in Alton Bay was moderate. This represents only one point in time however, and more information is needed.

3) The phosphorus concentration in lakewater samples indicates moderate loading of phosphorus into Alton Bay. We recommend that a phosphorus sampling program be initiated next year to locate point sources of this nutrient.

4) The data collected by lay monitors and the Freshwater Biology Group represents a good beginning on a long-term data base for Alton Bay. Continued monitoring will serve to add to this data base, and provide a valuable record of water quality from year to year.
Comments and Recommendations for Alton Bay 1983

1) The consistency of data collection from the lay monitors has been excellent throughout the 1983 season. We hope that the lay monitors will continue at this level of intensity, and even expand their monitoring into the early spring.

2) A phosphorus sampling program should be initiated during 1984. The goal of this program would be to locate point sources of this nutrient.

3) To examine the effect of seasonal changes in water color on Secchi disk depth, water samples for dissolved lakewater color should be collected. These samples consist of the filtrate from the chlorophyll sample.
Executive Summary for Alton Bay 1983

1) Alton Bay is oligotrophic based on Secchi disk depth, chlorophyll a concentration, and total phosphorus. Chlorophyll a concentrations were low, with a summer average for lay data of 0.7 milligrams per cubic meter. The average summer transparency was 8.2 meters. Total phosphorus was moderate, with an average of 14.9 micrograms per liter measured on June 15.

2) Phytoplankton densities were low (676 – 7198 cells per milliliter). Chrysophytes and Diatoms dominated on June 15. Crustacean zooplankton densities were low (3-4 animals per liter), with calanoid copepods, Holopedium, Bosminia, and Daphnia dominating.

3) The pH on June 15, 1983 was in the range 6.5 to 6.7. Earlier (April-May) measurements of pH are necessary, however, to evaluate the acid rain effects during the critical period following spring thaw. The alkalinity averaged 8.1 mg per liter. According to EPA standards, lakes with less than 10 mg per liter are "highly sensitive" to acid rain.

4) Dissolved oxygen in the cold, deep water was high on June 15, but without another test date, the rate of oxygen depletion can not be determined.

5) The salt and chloride ion content of lakewater in Alton Bay was low to moderate, indicating inputs of salts such as
through road salting, sewage, or watershed runoff.

6) Relative to other lakes in the LLMP, Alton Bay is lightly stained with humic acids. The high water clarity in the bay is related to the low dissolved color.
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 twice 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 (PBG) TEAM**

The same as well as additional parameters were investigated by the PBG 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-8A, 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 Bausch 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 N 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 N 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 PH-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 analyzed 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 FGG 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 Biology Group (FBG) research, thus the results are presented separately. Seven sampling sites were established on Alton Bay (Fig 2). The raw lay monitor 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 mostly to determine the depth of the chlorophyll a sample. The lake was stratified during most of the entire sampling period (late July to mid-September).
Figure 2. Alton Bay, Town of Alton, New Hampshire.

**Secchi Disk Depth (transparency):**

Site 23 had the deepest average water transparency (9.3 meters). Site 27 also had greater clarity than the other sites, with an average transparency of 9.2 meters. Sites 22, 24, 25, and 26 had similar transparencies or a seasonal
basis, and differences between sites are probably insignificant (Table 1). Coverage at site 21 was insufficient to be directly comparable to other sites, but it appears that it was similar to the second set of sites.

Table 1. Monthly Average Secchi Disk Depth.

<table>
<thead>
<tr>
<th>Site</th>
<th>21</th>
<th>22</th>
<th>23</th>
<th>24</th>
<th>25</th>
<th>26</th>
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</thead>
<tbody>
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<td>---</td>
<td>---</td>
<td>9.0</td>
<td>7.3</td>
<td>8.2</td>
<td>8.0</td>
<td>---</td>
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<tr>
<td>August</td>
<td>---</td>
<td>8.6</td>
<td>9.8</td>
<td>8.6</td>
<td>8.4</td>
<td>8.3</td>
<td>9.3</td>
</tr>
<tr>
<td>September</td>
<td>---</td>
<td>---</td>
<td>9.6</td>
<td>8.4</td>
<td>8.4</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>October</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>7.0</td>
<td>6.0</td>
<td>---</td>
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</tr>
</tbody>
</table>

Transparency was at a minimum at all sites during April and early June. The transparency fluctuated little over July, August, and early September, and decreased during late September and October (Fig. 3).
Figure 3. Seasonal variation of Secchi disk depth.

Chlorophyll a

The chlorophyll a concentration was low at all sites, with yearly averages in the range 0.5 - 0.9 milligrams per liter. The seasonal pattern was variable between sites, and may be a reflection of the low chlorophyll a concentrations. Generally peaks in chlorophyll a were found in April, mid-September, and November (Fig. 4).

Table 2. Monthly Mean Chlorophyll a.

<table>
<thead>
<tr>
<th>Site</th>
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<th>22</th>
<th>23</th>
<th>24</th>
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<td>---</td>
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<td>0.82</td>
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<td>0.56</td>
<td>0.82</td>
<td>0.87</td>
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<tr>
<td>October</td>
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<td>---</td>
<td>0.71</td>
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</table>
Figure 4. Seasonal variation of chlorophyll a.

Discussion

Lakewater in Alton Bay is relatively transparent compared to other lakes in the LLMP. Also, based on Secchi disk depth and chlorophyll a concentration, Alton Bay is oligotrophic (Fig. 5, 6).

Although site 23 had the deepest lakewater transparency and the lowest chlorophyll a concentration, these two variables do not correspond with their respective values at other sites.
Figure 5. Frequency distribution of Secchi disk depth. Arrow indicates mean transparency during 1983; bar indicates range of values in Alton Bay.

LLMP Chlorophyll (1980-1983)

Figure 6. Frequency distribution of chlorophyll a. Arrow indicates mean chlorophyll concentration during 1983; bar indicates range of values in Alton Bay.

Chlorophyll in milligrams per cubic meter
RESULTS AND DISCUSSION OF FRESHWATER BIOLOGY GROUP DATA

Temperature and Dissolved Oxygen

Alton Bay was thermally stratified at both test sites on June 15, 1983. The epilimnion extended down to about 3 meters, and the thermocline (metalimnion) extended from this point down to approximately 10.5 meters (Fig. 7). At both sites, the hypolimnetic temperature was in the range 9-11 degrees Celsius. Also, at both sites, the hypolimnetic oxygen concentration was above 9 parts per million. These conditions are very well suited for cold-water fish such as lake trout and land-locked salmon, assuming that oxygen is not severely depleted over the summer. The degree of oxygen depletion indicates low production in Alton Bay. With such low productivity, growth of fish may be slower than in more mesotrophic systems.
Figure 7. Temperature and Oxygen profiles.

T in degrees Celsius - Dissolved oxygen
in parts per million
in depth per meters
Water Clarity and Dissolved Color

Lay monitors and FBG team members obtained similar Secchi disk depths on June 15, indicating that lay monitors are correctly obtaining their measurements.

Sunlight is quickly extinguished in lakewater due to absorbance and scattering by suspended particles and dissolved coloring material. A value describing the attenuation of light in lakewater is the 'extinction coefficient of diffuse downwelling light' \( k \). In Alton Bay, \( k \) was in the range 0.317 to 0.380, and averaged 0.376. Relative to other lakes in the LLMP, this is a low value (Fig. 8), and corresponds to the deep Secchi disk depth in Alton Bay.

Dissolved water color, primarily due to humic acids, averaged 0.032 on June 15. Compared to other lakes in the LLMP, this is a relatively low value. The result of having low color is to allow light to penetrate deeper into the water column (higher transparency).
Figure 8. Frequency distribution of extinction coefficient, of lakes in the LLMP, showing mean of Alton Bay.

Figure 9. Frequency distribution of dissolved color of lakes in the LLMP, showing mean of Alton Bay.
Chlorophyll a

Chlorophyll a concentrations measured by the FEG were similar to those measured by the lay monitors. Concentrations were 1.0 milligrams per cubic meter at both sites on June 15.

Total Phosphorus

Total phosphorus is usually the nutrient limiting algal growth in freshwater systems. Its concentration can be used to indicate the potential for algal growth. Concentrations were moderate at both sites, averaging 14.9 micrograms per liter (Fig. 10). These values are higher than expected based on chlorophyll a concentrations. A high flushing rate may be the cause of lower chlorophyll a concentrations than expected, but no information is available on the flushing rate of Alton Bay in particular. Another possibility is that acid precipitation may be stressing the algal community, and lowering its growth rate relative to the phosphorus concentration. More data is needed before any solid conclusions can be drawn, suggesting the possibility of having lay monitors collect phosphorus samples during 1984 in order to increase the seasonal and spatial coverage of the lake.
Figure 10. Distribution of phosphorus values, showing mean from Alton Bay. (micrograms per liter)

Alkalinity, pH, and Free Carbon Dioxide

The vertical pattern of pH, alkalinity, and free carbon dioxide found at Site 1 on June 15 is typical of the lake (Figure 11).
Figure 11. Profile of alkalinity, pH and free carbon dioxide. (parts per million and pH units)

The pH values of surface water in Alton Bay were moderate, in the range 6.5-6.7. Measurements are needed earlier in the summer, however, to evaluate the effects of the spring runoff on alkalinity. Late-summer values of alkalinity were moderate, with a mean of 8.1 milligrams calcium carbonate per liter. According to the Environmental Protection Agency (U.S.E.P.A.) lakes with less than 10 milligrams calcium carbonate alkalinity per liter are
considered to be "highly sensitive" to acid rain.

Free carbon dioxide accumulated in the thermocline and hypolimnion of Alton Bay, lowering the pH of these layers of lakewater (Fig 11). The amount of free carbon dioxide in the deep waters indicates low productivity in Alton Bay.

**Specific Conductivity and Chloride Ion Concentration**

Alton Bay has a low to moderate salt content based on the average specific conductivity (56.2 micromhos per cm). The chloride ion concentration was also moderate, with 6.2 parts per million. These measures, along with the total phosphorus concentration Alton Bay may be receiving nutrients from the surrounding watershed and/or housing units.

**Phytoplankton**

The density of phytoplankton on June 15 was low at both sites, in the range 676-719 cells per milliliter. Site 22 had the lower density, and was dominated by Chrysophytes (*Dinobryon*). Diatoms (*Cyclotella, Tabellaria*), Cryptomonads (*Chroococcus*), and Chlorophytes (small flagellated forms). Site 24 had a slightly higher density, but diatoms were the most dominant, with Chlorophytes, Cryptomonads, and Chrysophytes following in dominance. Also present were Cyanophytes (*Gleocapsa*) in moderate densities. Often the presence of blue-green bacteria is an indication of
eutrophication, but in Alton Bay's case other parameters do not support this indicator.

**Zooplankton**

The density of herbivorous crustacean zooplankton was low (3-4 animals per liter) at both sites on June 15. Dominant groups included calanoid copepods, *Holopedium*, *Bosmina*, and *Daphnia*. The low density of zooplankton is an indication of the low productivity of Alton Bay.
REFERENCES


**APPENDIX A**

**LLMP 1983 -- Lay Monitor Data: Alton Bay Jan-24-84**

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APPENDIX E

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 meromictic and fail to mix (overtturn) 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 (overturn) 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.

Fisherman are acutely aware of the oxygen requirement of fish, and know that they can expect no laketrout fishing where oxygen has been depleted in the cool bottom waters of a lake. In fact, the laketrout, 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 *anoxic* (lacking oxygen, similar to *anaerobic*) bottom waters of lakes. For the most part, these are the important groups of bacteria that regulate cycles of *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 *nutrients* essential to growth of the *microscopic algae* -- such as carbon, phosphorus nitrogen, and sulphur, by *putrefaction* or break-down of dead organisms, and by *fermentation*. The *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 *microscopic algae*. In general, the *anaerobic* bacteria can be viewed as the principal agents involved in promoting *recycling* of essential *nutrients* that otherwise would have been lost and locked up in the lake sediments.

**Water transparency**

Water *transparency*, as indicated by secchi disk depth, is influenced by many factors. Dissolved substances such as *humic acids* (tea-colored coloring matter from plant decay) will frequently lend a yellow or brown color to the water, thus decreasing its *transparency*. The *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 many 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 plankton (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 planktorns, 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 circulates, 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).

**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.

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

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, tars, 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 holcimixis.)

**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.
Overtun  
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 if exposed sufficiently long to the atmosphere or another source of 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 form (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 *Kelllicottia*. 