WINNIPESAUKEE-CENTER HARBOR
1990
LAKES LAY MONITORING PROGRAM

by
Jeffrey A. Schloss

edited by
A.L. Baker and J.F. Haney

NEW HAMPSHIRE LAKES LAY MONITORING PROGRAM

NH LLMP

FRESHWATER BIOLOGY GROUP
University of New Hampshire
Durham

UNIVERSITY OF NEW HAMPSHIRE
COOPERATIVE EXTENSION

Helping You To Put Knowledge And Research To Work

To obtain more information about the NH Lakes Lay Monitoring Program (NH LLMP) contact the Coordinator (J. Schloss) at (603) 862-3848
Dr. Baker at 862-3845 or Dr. Haney at 862-2106
PARAMETERS SAMPLED
NH LAKES LAY MONITORING PROGRAM

LAY MONITORS

BASIC PROGRAM
- Secchi
- Disk Depth
- Temperature Profile
- Chlorophyll a
- Dissolved Color

ADVANCED OPTIONS
- Total Phosphorus
- Total Alkalinity
- pH
- Metallimnetic Chl a
- Fish Condition
- Aquatic Vegetation
- Rainfall & pH
- Motorboat Effects
- Bacteria

STREAM MONITORING
- Obs.
- Survey
- Temperature
- Conductivity
- Total
- Alkalinity
- Total Phosphorus
- Stream Flow
- Macro-Invertebrates
- Storm Events
- Bacteria

FBG Team corroborate tests above and sample plankton
PREFACE

This report contains the findings of a water quality survey of Center Harbor-Lake Winnipesaukee, New Hampshire, conducted in the summer of 1990 by the Freshwater Biology Group (FBG) of the University of New Hampshire and the Center Harbor Conservation Commission.

The report is written with the concerned lake resident in mind and contains a brief, non-technical summary of 1990 results as well as more detailed "Introduction" and "Discussion" sections. Graphic display of data is included, in addition to listings of data in appendices, to aid visual perspective.
TABLE OF CONTENTS

PREFACE.................................................1
ACKNOWLEDGEMENTS.................................5
CENTER HARBOR 1990 NON-TECHNICAL SUMMARY............7
COMMENTS AND RECOMMENDATIONS........................9
INTRODUCTION.........................................11
   The New Hampshire Lakes Lay Monitoring Program.......11
   Importance of Long-term Monitoring..................12
   Purpose and Scope of This Study....................14
DISCUSSION OF LAKE MONITORING MEASUREMENTS............15
   Thermal Stratification in the Deep Water Sites.......15
   Water Transparency..................................15
   Chlorophyll a.......................................16
   Dissolved Color.....................................17
   Total Phosphorus....................................18
   pH *................................................18
   Alkalinity..........................................19
   Specific Conductivity *..............................20
   Dissolved Oxygen and Free Carbon Dioxide *...........20
   Underwater Light *..................................21
   Indicator Bacteria *................................22
   Phytoplankton *.....................................23
   Zooplankton *.......................................24
   Fish Condition.....................................25
REFERENCES...........................................27
FIGURES...............................................31
DATA..................................................A-1
LAKE DIAGRAMS.......................................B-1
GLOSSARY.............................................C-1
ACKNOWLEDGEMENTS

This was the fifth year of participation in the Lakes Lay Monitoring Program (LLMP) for the Center Harbor monitors. The Lay Monitors were Duke Kline (Site 1 Deep) and Ingrid Smith (Site 2 Bay). Duke Kline was once again the coordinator for the Center Harbor lay monitoring program. The Freshwater Biology Group (FBG) congratulates the Lay Monitors on the quality of their work, and the time and effort put forth. We encourage other interested members of the Center Harbor Conservation Commission to continue monitoring during the 1991 season. Funding for the monitoring was provided by the Center Harbor Conservation Commission.

The Freshwater Biology Group is a not-for-profit research program co-supervised by Dr. Alan Baker and Dr. James Haney and coordinated by Jeffrey Schloss. Members of the FBG summer field team included Jeffrey Schloss, Kathleen Maroney, Robert Craycraft, Carol Young, John Marrette and John Ferraro. Other FBG staff assisting in the fall were: Sandy Weiss, Eric Betke and John Hodsdon.

The FBG acknowledges the University of New Hampshire Cooperative Extension for funding and furnishing office, laboratory and storage space. The College of Life Sciences and Agriculture provided accounting support and the UNH Office of Computer Services provided computer time and data storage allocations.

Participating groups in the LLMP include: The New Hampshire Audubon Society, Derry Conservation Commission, Dublin Garden Club, Nashua Regional Planning Commission, Center Harbor Bay Conservation Commission, Governor's Island Club Inc., Little Island Pond Rod and Gun Club, Walker's Pond Conservation Society, United Associations of Alton, the Pemaquid Watershed Study Group, the associations of Baboosic Lake, Beaver Lake, Berry Bay, Big Island Pond, Bow Lake Camp Owners, Lake Chocorua, Crystal Lake, Dublin Lake, Glines Island, Goose Pond, Great East Lake, Lake Kanasatka Watershed, Langdon Cove, Long Island Landowners, Lovell Lake, Mascoma
CENTER HARBOR
1990 NON-TECHNICAL SUMMARY

Monitoring was undertaken at Center Harbor by the volunteer monitors from June 27 to August 31. In-depth analysis of Center Harbor were conducted on June 20 and again on August 22 by the FBG.

1) Water transparency at Center Harbor was high, the sign of a clear and unproductive lake. The secchi disk was visible as far down as 7.7 meters (25.4 feet) and the transparency average was 7.5 meters at site 1 Deep and 6.0 meters at site 2 Bay. This indicates the deepwater site (1 Deep) on the lake is low in dissolved color and suspended matter such as algae and particulates. Lower transparency levels at the shallow site (Site 2 Bay) indicate the chlorophyll and color concentrations are slightly higher at the site. The 1990 average transparency of Site 1 Deep was the same as the 1989 average (the lake is as clear).

2) Chlorophyll a concentrations for the surface waters of Center Harbor were low through most of the season but reached moderate levels at Site 2 Bay in late August. Chlorophyll levels indicate the extent of algae growth in the water. Concentrations in the mixed layer of water averaged 2.1 milligrams per cubic meter (mg m⁻³, equivalent to about 2.1 parts chlorophyll per billion parts water) at site 1 Deep and 2.6 mg m⁻³ at site 2 Bay. Generally, concentrations below 3 mg m⁻³ are common to less productive, clear lakes and values above 7 mg m⁻³ are common in productive lakes. The 1990 average chlorophyll was higher than the 1989 average at both sampling stations and a new chlorophyll high of 4.8 mg m⁻³ was set at Site 2 Bay in August.

4) Total phosphorus (nutrient) samples, collected by the FBG at site 1 Deep, were at low levels. The deeper waters displayed no great accumulation of phosphorus as summer progressed. All samples were in the range of 2.2 to 8.8 parts per billion (ppb)
phosphorus which remains below the concentration of 15 ppb commonly thought of as the boundary between less productive and more productive lakes.

5) The pH of the surface waters of the lake, measured by the FBG and the volunteer monitors, remains within the optimum range for most aquatic organisms. The alkalinity of the lake is low, but about 1 unit higher than the average alkalinity of 6 units for LLMP program lakes. The pH and alkalinity data indicate that Center Harbor seems to have a low, but adequate, buffering capacity at this time to resist fluctuations in pH due to acid loadings.

6) The specific conductivity of the Center Harbor deep site was low on June 20 but reached moderate levels on August 28. High conductivity values can indicate the presence of septic leachate or deicing salt runoff.

7) In-depth analysis at Site 1 Deep disclosed the typical temperature stratification patterns for northern temperate lakes. With the depth of the upper mixed layer of water extending to 7.0 meters. Oxygen content of the bottom waters was high on June 20 but became depleted by August 22. Bottom water oxygen concentration remained above 5 milligrams per liter (the minimum concentration required for successful reproduction and growth of most coldwater fish) only to about 10 meters on August 22. Low oxygen and elevated CO2 levels in the bottom waters late in the season suggests accumulation of organic matter from lake algal production and possibly watershed run-off.

8) For all measurements considered and averaged for the season, Center Harbor would be classified as having low productivity, a clear, oligotrophic lake.

9) Comparisons between lay monitor and FBG data indicate the volunteer monitors of Center Harbor are doing an excellent job of measuring water quality.
COMMENTS AND RECOMMENDATIONS

1) We recommend that each association, including the Center Harbor Conservation Commission continue to develop their data base on lake water quality through continuation of the long term monitoring program. The data base will provide information on the short and long-term cyclic variability that occurs in the lake and eventually will enable more reliable predictions of water quality trends.

2) Since boat traffic on the lake is a concern for some, we recommend that the monitors initiate a boat effect study. All that would be required is sampling in the morning and then the same day late in the afternoon on a "quiet day" followed by the same sampling approach on a day of heavy boat traffic. A discount for sample processing will be offered to try to minimize costs of additional testing. Contact the LLMP coordinator for further information.

3) As a general addition to our Lakes Lay Monitoring Program, we recommend that each lake in the program begin monitoring the condition of the fish taken from the lake. The "Fish Monitoring" will require at least one lay monitor to record the species, length and weight and collect a sample of fish scales for each fish examined. In most lakes this will involve periodic creel census of sport fishermen on the lake.

Length-to-weight ratios give a measure of the nutritional condition of the fish. Age analysis of the fish scales (to be done at UNH) will tell how old each fish is. Together, these variables can help to track changes in the condition of the fish populations in the lake, and, of course, the "health" of the lake.

This study is currently being partially underwritten by the NH Fish and Game Department. As future funding is not guaranteed, participants should take advantage of this service while there is no processing charge.
INTRODUCTION

The New Hampshire Lakes Lay Monitoring Program

In this thirteenth year of operation, the NH Lakes Lay Monitoring Program has grown from a university class project on Chocorua Lake and pilot study on the Squam Lakes to a comprehensive state-wide program with over 500 volunteer monitors and more than 100 lakes participating. Originally developed to establish a data-base for determining long-term trends of lake water quality for science and management, the program has expanded by taking advantage of the many resources that citizen monitors can provide. The NH LLMP has an international reputation as a successful cooperative monitoring, education and research program. Current projects include: use of volunteer generated data for non-point pollution studies using high tech analysis system (Geographic Information Systems and Satellite Remote Sensing), intensive watershed monitoring for the development of lake nutrient budgets, and investigations of water quality and indicator organisms (food web analysis, fish condition, and stream invertebrates). The key ingredients responsible for the success of the program include innovative funding and cost reduction, assurance of credible data, practical sampling protocols and, most importantly, the interest and motivation of our volunteer monitors.

The NH LLMP was awarded the Robert Rodale Environmental Achievement Award from Renew America, a non-profit clearinghouse that promotes models of environmental initiative and dedication through its "Searching for Success - Environmental Success index" (ESI). As one of the programs that made the index under the Clean Water category, the NH LLMP stood up to a thorough screening and evaluation process that took into consideration program effectiveness, program replicability, economic feasibility and sustainability, and meeting of community needs.
In 1990 the NH LLMP was highlighted in an Environmental Protection Agency publication on volunteer monitoring as an example of a citizen based program collecting high quality data useful in the protection and management of New Hampshire Lakes. In the national newsletter "The Volunteer Monitor" the NH LLMP "home-made" equipment plans were published so other monitoring groups could benefit from our experience.

**Importance of Long-term Monitoring**

A major goal of a monitoring program is to identify any short or long-term changes in the water quality of the lake. Of major concern is the detection of cultural eutrophication: increases in the productivity of the lake, the amount of algae and plant growth, due to the addition of nutrients from human activities. Changes in the natural buffering capacity of the lakes in the program is also a topic of great concern, as New Hampshire receives large amounts of acid precipitation, yet most of our lakes contain little mineral content to neutralize this type of pollution.

For over a decade, data collected weekly from lakes participating in the New Hampshire Lakes Lay Monitoring Program have indicated there is quite a variation in water quality indicators through the open water season on the majority of lakes. Short-term differences may be due to variations in weather, lake use, or other chance events. Monthly sampling of a lake during a single summer provides some useful information, but there is a greater chance that important short-term events such as algal blooms or the lake response to storm run-off will be missed. These short-term fluctuations may be unrelated to the actual long-term trend of a lake or they may be indicative of the changing status or "health" of a lake.

To determine if a change in water quality is occurring, a lake must be sampled on a frequent basis over a substantial amount of time. A poorly designed sampling program may even mislead the investigator away from the actual trend: Consider the hypothetical lake in
Figure 1. Sampling only once a year during August from 1982 to 1986 would produce a plot (Fig. 2) suggesting a decrease in eutrophication. The actual long-term trend of the lake, increasing eutrophy, can only be clearly discerned by sampling additional times a year for a ten year period (Fig. 1). Frequent monitoring carried out over the course of many summers can provide the information required to distinguish between short-term fluctuation ("noise") and long-term trends ("signal"). To that end, the lake must establish a long-term data base.

The number of seasons it takes to distinguish between the noise and the signal is not the same for each lake. Evaluation and interpretation of a long-term data base will indicate that the water quality of the lake has worsened, improved, or remained the same. In addition, different areas of a lake may show a different response. As more data is collected, prediction of current and future trends can be made. No matter what the outcome, this information is essential for the intelligent management of the lake.

There are also short-term uses for lay monitoring data. The examination of different stations in a lake can disclose the location of specific problems and corrective action can be initiated to handle the situation before it becomes more serious. On a lighter note, some associations post their weekly data for use in determining the best depths for finding fish!

It takes a considerable amount of effort as well as a deep concern for one’s lake to be a lay monitor in the NH Lakes Lay Monitoring Program. Many times a monitor has to brave inclement weather or heavy boat traffic to collect samples. Sometimes it even may seem that one week’s data is just the same as the next. Yet every sampling provides important information on the variability of the lake.

We are pleased with the interest and commitment of our lay monitors and are proud that their work is what makes the NH LLMP the most extensive, and we believe, the best volunteer program of its kind.
Purpose and Scope of This Study

This was the fifth year that monitoring of Center Harbor was undertaken by the Freshwater Biology Group and the Center Harbor Conservation Commission. The program of sampling was designed to continue adding data to the long-term data base established. Sampling emphasis was placed on two open water stations: site 1 Deep and site 2 Bay. A more in-depth study of the deep lake site was undertaken by the FBG on June 20 and again on August 22.

The primary purpose of this report is to discuss results of the 1990 monitoring with emphasis on current conditions of Center Harbor including the extent of eutrophication and the lake's susceptibility to increasing acid precipitation. This information is part of a large data base of historical and more recent data compiled and entered onto computer files for New Hampshire lakes that include New Hampshire Fish and Game surveys of the 1930's, the surveys by the New Hampshire Water Supply and Pollution Control Commission and the FBG surveys. Care must be taken when comparing current results with early studies. Many complications arise due to methodological differences of the various testing facilities and technological improvements in testing.
DISCUSSION OF LAKE MONITORING MEASUREMENTS

The section below details the important concepts involved for the various testing procedures used in the New Hampshire Lakes Lay Monitoring Program. Where appropriate, summary statistics of 1990 results from all participating lakes are included. Certain tests or sampling performed at the time of the Freshwater Biology Group field trip are indicated by an asterisk (*).

**Thermal Stratification in the Deep Water Sites**

Lakes in New Hampshire display distinct patterns of temperature stratification, that develop as the summer months progress, where a layer of warmer water (epilimnion) overlies a deeper layer of cold water (hypolimnion). The layer that separates the two regions characterized by a sharp drop in temperature with depth is called the thermocline or metalimnion. Some shallow lakes may be continually mixed by wind action and will never stratify. Other lakes may only contain a developed epilimnion and metalimnion.

Center Harbor became partially stratified when the weather was calm.

**Water Transparency**

Secchi Disk depth is a measure of the water transparency. The deeper the depth of secchi disk disappearance, the more transparent the lake water; light penetrates deeper if there is little dissolved and/or particulate matter (which includes both living and non-living particles) to absorb and scatter it.

In the shallow areas of many lakes, the secchi disk will hit bottom before it is able to disappear from view (what is referred to as a "Bottom Out" condition). Thus, Secchi disk measurements are generally taken over the deepest sites of a lake. Transparency values of greater than 4 meters are typical of clear, less productive lakes. Values less than 2.5 meters are generally an indication of a very productive lake. In 1990 the average trans-
prenacy for lakes participating in the NH LLMP was 6.1 meters with a range of 1.8 to 13.7 meters.

**Chlorophyll a**

The chlorophyll a concentration is a measurement of the standing crop of phytoplankton and is often used to classify lakes into categories of productivity called trophic states. **Eutrophic** lakes are highly productive with large concentrations of algae and aquatic plants due to nutrient enrichment. Characteristics include accumulated organic matter in the lake basin and lower dissolved oxygen in the bottom waters. Summer chlorophyll a concentrations average above 7 mg m$^{-3}$ (7 milligrams per cubic meter; 7 parts per billion). **Oligotrophic** lakes have low productivity and low nutrient levels and average summer chlorophyll a concentrations are generally less than 3 mg m$^{-3}$. These lakes generally have cleaner bottoms and high dissolved oxygen levels throughout. **Mesotrophic** lakes are intermediate in productivity with concentrations of chlorophyll a generally between 3 mg m$^{-3}$ and 7 mg m$^{-3}$. In 1990 the average chlorophyll for lakes participating in the NH LLMP was 2.8 mg m$^{-3}$ with a range of 0.4 to 42.1 mg m$^{-3}$.

Center Harbor chlorophyll a levels averaged 2.1 mg m$^{-3}$ with a range of 1.7 to 2.6 mg m$^{-3}$ at site 1 Deep and 2.6 mg m$^{-3}$ with a range of 1.6 to 4.8 mg m$^{-3}$ at site 2 Bay. Chlorophyll levels remained low early in the season but reached more productive levels, above 3 units, in late August.

Testing is sometimes done to check for **metalinntetic algal populations**, algae that layer out at the thermocline and generally go undetected if only epilimnentic (point or integrated) sampling is undertaken. Chlorophyll concentrations of a water sample collected in the thermocline is compared to the integrated epilimnentic sample. Greater chlorophyll levels of the point sample, in conjunction with microscopic examination of the samples (see Phytoplankton section below), confirm the presence of such a population of algae.
Mid lake chlorophyll samples, collected by the FBG at Center Harbor, remained low early in the season but reached moderate to high levels by late August. Mid lake chlorophyll levels were more than three times higher than surface water levels, reaching 7.4 mg m$^{-3}$ on August 22. Higher mid lake chlorophyll levels late in the season were the result of the larger "golden algae", Synura, stratifying in the thermocline (see phytoplankton section).

**Dissolved Color**

The dissolved color of lakes is generally due to dissolved organic matter from humic substances, which are naturally-occurring polyphenolic compounds leached from decayed vegetation. Highly colored or "stained" lakes, have a "tea" color. Such substances generally do not threaten water quality except as they diminish sunlight penetration into deep waters. Increases in dissolved water color can be an indication of increased development within the watershed as many land clearing activities (construction, deforestation, and the resulting increased run-off) add additional organic material to lakes. Natural fluctuations of dissolved color occur when storm events increase drainage from wetlands areas within the watershed. As suspended sediment is a difficult and expensive test to undertake, both dissolved color and chlorophyll information is important when interpreting the secchi disk transparency.

Dissolved color is measured on a comparative scale that uses standard chloroplatinate dyes and is designated as a color unit or ptu. Lakes with color below 10 ptu are very clear, 10 to 20 ptu are slightly colored, 20 to 40 ptu are lightly tea colored, 40 to 80 ptu are tea colored and greater than 80 ptu indicates highly colored waters. Generally the majority of New Hampshire lakes have color between 20 to 30 ptu.
Total Phosphorus

Of the two "nutrients" most important to the growth of aquatic plants, nitrogen and phosphorus, it is generally observed that phosphorus is the more limiting to plant growth, and therefore the more important to monitor and control. Phosphorus is generally present in lower concentrations, and its sources arise primarily through human related activity in a watershed. Nitrogen can be fixed from the atmosphere by many bloom-forming blue-green bacteria, and thus it is difficult to control. The total phosphorus includes all dissolved phosphorus as well as phosphorus contained in or adhered to suspended particulates such as sediment and plankton. As little as 15 parts per billion of phosphorus in a lake can cause an algal bloom.

Generally, in the more pristine lakes, phosphorus values are higher after spring melt when the lake receives the majority of runoff from its surrounding watershed. The nutrient is used by the algae and plants which in turn die and sink to the lake bottom causing phosphorus to decrease as the summer progresses. Lakes with nutrient loading from human activities and sources (Agriculture, Sediment Erosion, Septic Systems, etc) will show greater concentrations of nutrients as the summer progresses or after major storm events. Circulation of nutrients from the bottom waters of more productive lakes in late fall can result in algal blooms.

Phosphorus samples collected by the FBG remained below the 15 ppb level for both the surface and the bottom waters during the June and August sampling dates.

pH

The pH is a way of expressing the acidic level of lake water, and is generally measured with an electrical probe sensitive to hydrogen ion activity. The pH scale has a range of 1 (very acidic) to 14 (very "basic" or alkaline) and is logarithmic (ie: changes in 1 pH unit reflect a ten times difference in hydrogen ion concentration). Most aquatic organisms
tolerate a limited range of pH and most fish species require a pH of 5.5 or higher for successful growth and reproduction.

The pH at Center Harbor was 5.8 on June 20 and 6.2 on August 22.

**Alkalinity**

Alkalinity is a measure of the buffering capacity of the lake water. The higher the value the more acid that can be neutralized. Typically lakes in New Hampshire have low alkalinitie due to the absence of carbonates and other natural buffering minerals in the bedrock and soils of lake watersheds.

Decreasing alkalinity over a period of a few years can have serious effects on the lake ecosystem. In a study on an experimental acidified lake in Canada by Schindler, gradual lowering of the pH from 6.8 to 5.0 in an 8-year period resulted in the disappearance of some aquatic species, an increase in nuisance species of algae and a decline in the condition and reproduction rate of fish. During the first year of Schindler's study, the pH remained unchanged while the alkalinity declined to 20 percent of the pre-treatment value. The decline in alkalinity was sufficient to trigger the disappearance of zooplankton species, which in turn caused a decline in the "condition" of fish species that fed on the zooplankton.

The analysis of alkalinity employed by the Freshwater Biology Group includes use of a dilute titrant allowing an order of magnitude greater sensitivity and precision than the standard method. Two endpoints are recorded during each analysis. The first endpoint (grey color of dye; pH endpoint of 5.1) approximates low level alkalinity values, while the second endpoint (pink dye color; pH endpoint of 4.6) approximates the alkalinity values recorded historically, such as NH Fish and Game data, with the methyl-orange endpoint method.

The average alkalinity of lakes throughout New Hampshire is low, approximately 7 mg per liter (calcium carbonate alkalinity), while the average alkalinity of the lakes studied
by the Freshwater Biology Group in the NH LLMP is approximately 6.0 mg per liter. When alkalinity falls below 2 mg per liter the pH of waters can greatly fluctuate. Alkalinity levels are most critical in the spring when acid loadings from snowmelt and runoff are high, and many aquatic species are in their early, and most susceptible, stages of their life cycle.

Center Harbor alkalinity was low, but slightly higher than levels found at NH LLMP lakes and about average for a New Hampshire Lake. It is sufficient enough to prohibit wide variations in pH and buffer any acid precipitation.

**Specific Conductivity** *

The specific conductance of a water sample indicates concentrations of dissolved salts. Leaking septic systems and deicing salt runoff from highways can cause high conductivity values. Fertilizers and other pollutants can also increase the conductivity of the water. Conductivity is measured in micromhos (the opposite of the measurement of resistance ohms) per centimeter, more commonly referred to as micro-Siemans.

Center Harbor had low conductivity levels at the deep site early in the season but reached moderate levels late in the summer. Conductivity levels ranged from 24.7 to 29.3 micro-Siemans on June 20 and from 47.0 to 68.4 micro-Siemans on August 22.

**Dissolved Oxygen and Free Carbon Dioxide** *

Oxygen is an essential component for the survival of aquatic life. Submergent plants and algae take in free carbon dioxide and create oxygen through photosynthesis by day. Respiration by both animals and plants uses up oxygen continually and creates carbon dioxide. Dissolved oxygen profiles determine the extent of declining oxygen concentrations in the lower waters. High carbon dioxide values are indicative of low oxygen conditions and accumulating organic matter. For both gases, as the temperature of the water decreases, more gas can be dissolved in the water.
The typical pattern of clear, unproductive lakes is a slight decline in hypolimnetic oxygen as the summer progresses. Oxygen in the lower waters is important for maintaining a fit, reproducing, cold water fishery. Trout and salmon generally require oxygen concentrations above 5 mg per liter (parts per million) in the cool deep waters. On the other hand, carp and catfish can survive very low oxygen conditions. Oxygen above the lake bottom is important in limiting the release of nutrients from the sediments and minimizing the collection of undecomposed organic matter.

Bacteria, fungi and other decomposers in the bottom waters break down organic matter originating from the watershed or generated by the lake. This process uses up oxygen and produces carbon dioxide. In lakes where organic matter accumulation is high, oxygen depletion can occur. In highly stratified eutrophic lakes the entire hypolimnion can remain unoxgenated or anaerobic until fall mixing occurs.

Oxygen was plentiful in the bottom waters of Center Harbor on July 20 but became depleted by August 22. The oxygen concentration remained above 5 mg per liter only to about 10 meters by August 22. Carbon Dioxide levels remained low throughout the sampling season.

**Underwater Light**

Underwater light available to photosynthetic organisms is measured with an underwater photometer which is much like the light meter of a camera (only waterproofed!). The photic zone of a lake is the volume of water capable of supporting photosynthesis. It is generally considered to be delineated by the water's surface and the level where light is reduced, by the absorption and scattering properties of the lake water, to one percent of the surface intensity. The one percent depth is sometimes termed the compensation depth. Knowledge of light penetration is important when considering lake productivity and in studies of submerged vegetation. Discontinuity (abrupt changes in the slope) of the profiles
could be due to metalimnetic layering of algae or other particulates (discussed above). The underwater photometer allows the investigator to measure light at depths below the Secchi disk depth to supplement the transparency information.

Underwater light measurements in mid June indicate the photic zone of Center Harbor existed to about 17.4 meters (the lake bottom). The photic zone was measured to about 10.4 meters on August 22. The reduction of light penetration late in the season may be the result of increasing algal levels in the thermocline.

**Indicator Bacteria**

Coliform bacteria in water indicate the possibility of fecal contamination. Although they are usually considered harmless to humans, they are much easier to test for than harmful pathogenic enteric bacteria (*Salmonella*, *Shigella* etc.) and viruses that may be present in fecal material. **Total coliform** includes all coliform bacteria which arise from the gut of animals or from vegetative materials. **Fecal coliform** are those specific organisms that inhabit the gut of warm blooded animals. Another indicator organism **Fecal streptococcus** (sometimes referred to as **enterococcus**) also can be monitored. The ratio of fecal coliform to fecal strep may be useful in suggesting the type of animal source responsible for the contamination. Desirable levels for a Class A water body is less than 50 total coliform organisms per 100 milliliters. If the coliform level rises above 150 organisms per 100ml swimming should be prohibited.

Ducks and geese are often a common cause of high concentrations of coliform at specific lake sites. While waterfowl are important components to the natural and aesthetic qualities of lakes that we all enjoy, it is poor management practice to encourage these birds by feeding them. The lake and surrounding area provides enough healthy and natural food for the birds and feeding them stale bread or crackers does nothing more than import additional nutrients into the lake and allows for increased plant growth. As birds also are a host
to the parasite that causes "swimmers itch" waterfowl roosting areas offer a greater chance for infestation to occur. Thus while leaving offerings for our feathered friends is enticing, the results can prove to be detrimental to the lake system and to human health.

No bacteriological analysis was done on Center Harbor.

**Phytoplankton**

The planktonic community includes microbial organisms that represent diverse life forms, containing photosynthetic as well as non-photosynthetic types, and including bacteria, algae, crustaceans and insect larvae (the zooplankton are discussed below in a separate section). Because planktonic algae or "phytoplankton" tend to undergo rapid seasonal cycles on a time scale of days and weeks, the levels of populations found should be considered to be most representative of the time of collection and not necessarily of other times during the ice-free season, especially the early spring and late fall periods.

The composition and concentration of phytoplankton can be indicative of the trophic status of a lake. Seasonal patterns do occur and must be considered. For example, diatoms, tend to be most abundant in April-June and October-November, in the surface or epilimnetic layers of New Hampshire lakes. As the summer progresses, the dominant types might shift to green algae or golden algae. By late season blue-green bacteria generally dominate. In nutrient rich lakes, nuisance green algae and/or bluegreen bacteria might dominate continually. After fall mixing diatoms might again be found to bloom.

Center Harbor phytoplankton samples from the upper mixed layer of water were low in number and showed a high diversity which is generally indicative of healthy lake conditions. The small flagellated Cryptomonas and Chroomonas were the dominant algae in the epilimnion for both the June and August sampling dates. A mid lake (thermocline) algal sample collected late in the season revealed an increase in the density of the larger
"golden algae", Synura. Higher densities of Synura late in the season resulted in the elevated metalimnetic chlorophyll levels observed on August 22 (see chlorophyll section).

Zooplankton *

There are three groups of zooplankton that are generally prevalent in lakes: the protozoa, rotifers and crustaceans. Most research has been devoted to the last two groups although protozoa may be found in substantial amounts. Of the rotifers and the crustaceans, time and budgetary constraints usually make it necessary to sample only the larger zooplankton (macrozooplankton; larger than 80 or 150 microns; 1 million microns make up a meter). Thus, zooplankton analysis is generally restricted only to the larger crustaceans. Crustacean zooplankton are very sensitive to pollutants and are commonly used to indicate the presence of toxic substances in water. The crustaceans can be divided into two groups, the cladocerans (which include the "water fleas") and the copepods.

Macrozooplankton are an important component in the lake system. The filter feeding of the herbivorous ("grazing") species may control the population size of selected species of phytoplankton. The larger zooplankton can be an important food source for juvenile and adult planktivorous fish. All zooplankton play a part in the recycling of nutrients within the lake.

As discussed above for phytoplankton, zooplankton undergo seasonal population cycles and the results discussed below are most representative of the collection dates and not necessarily of other times during the ice-free season, especially during the early spring and late fall.

The zooplankton population was low in June and dominated by the calanoid copepod, Diaptomus. The zooplankton density was considerably higher on August 22 at which time the cladoceran, Bosmina, was dominant. This filter feeding crustacean
zooplankton can control the population size of selected species of phytoplankton and also serve as an important food source for certain species of fish.

**Fish Condition**

As with the plankton discussed above, the health of the fish species of a lake will be indicative of the overall water quality. Condition is determined by comparing the length of the fish to its weight. As would be expected, the heavier the fish for its length, the better its condition will be. By also examining a scale collected from the fish under a microscope, the approximate age and growth history can also be determined. We encourage the Center Harbor monitors to add to our data base by participation in the volunteer fish condition program.
REFERENCES


Figure 1. The upper graph depicts weekly chlorophyll concentrations of a model lake measured weekly during ice-free conditions. The long-term trend is that of increased eutrophication (lake has become "greener"). Diamonds below the curve represent late summer (August) dates the data set was subsampled to create Figure 2.

Figure 2. The lower graph depicts late summer chlorophyll data of the model lake in Figure 1. Note how limited sampling over a five year period suggests a much different trend, that of decreasing eutrophy. Thus, limited sampling can mislead the investigator of long-term trends.
**Figure 3** - Seasonal trends for secchi disk depth (water transparency) 1990 for Center Harbor, site 1 Deep. Dotted lines on the plot border the ranges common to oligotrophic, mesotrophic and eutrophic lakes.
Figure 4 - Center Harbor 1990. Seasonal trends for chlorophyll \( a \) concentration of lay monitor sites 1 Deep and 2 Bay. Chlorophyll \( a \) concentrations in parts per billion (mg per m\(^3\)) of chlorophyll \( a \). Dotted lines on the plots border the ranges common to oligotrophic, mesotrophic and eutrophic lakes.
LAKE WINNIPESAUKEE—CENTER HARBOR
CHLOROPHYL CONCENTRATION 1990

\[ ^\wedge \text{EUTROPHIC} \wedge \]

\[ ^\wedge \text{MESOTROPHIC} \wedge \]

\[ ^\wedge \text{OLIGOTROPHIC} \wedge \]

CHLOROPHYLL a (ppb)


\[ \square \text{SITE 1 DEEP} \quad + \quad \text{SITE 2 BAY} \]
**Figure 5** - Profiles of temperature (temp.) and dissolved oxygen ($O_2$) on (A) 20 June 1990 and (B) 22 August 1990 at Center Harbor Site 1 Deep. Units of measurement are as indicated. Oxygen and temperature were measured at one-half meter intervals. Note the decrease in oxygen at the lake bottom (see text).
Figure 6 - Pie diagrams of Phytoplankton Diversity at Center Harbor by Algal Class for site 1 Deep, 20 June 1990 and 22 August 1990.
LAKE WINNIPESAUKEE
(CENTER HARBOR)

SITE 1 DEEP
20 JUN 0-3m

DIATOMS 10%
EUGLENIIDS 4%
GREENS 15%
CRYPTOMONADS 48%
GOLDEN ALGAE 23%

SITE 1 DEEP
20 JUN 90 4.5m

DIATOMS 8%
GREENS 23%
CRYPTOMONADS 38%
GOLDEN ALGAE 32%

SITE 1 DEEP
22 AUG 90 0-7.5m

DIATOMS 9%
DESMIDS 1%
GREENS 22%
CRYPTOMONADS 55%
GOLDEN ALGAE 12%

SITE 1 DEEP
22 AUG 90 10.0m

DIATOMS 10%
GREENS 16%
CRYPTOMONADS 34%
BLUEGREENS 6%
GOLDEN ALGAE 32%

PHYTOPLANKTON ABUNDANCE % BY ALGAL GROUP
Figure 7 - Center Harbor 1990. Relative percent by zooplankton group (pie diagrams) for site 1 Deep on representative dates. Pie diagrams are labeled above with date and depth of tow.
ZOOPPLANKTON DATA
20 JUNE 1990
0-11.5 METERS

WINNI-CENTER HARBOR  1 DEEP

ZOOPPLANKTON DATA
22 AUGUST 1990
0-12.5 METERS

ZOOPPLANKTON DENSITY = # OF ORGANISMS PER LITER
Figure 8 - Center Harbor, Site 1 Deep. Comparison of 1990 Secchi Disk Transparencies to previous yearly data. The patterns of the bars display the minimum, mean and maximum values for each year sampled while the length of the bar represents the total range of values. The higher the secchi disk value, the clearer the pond.

Figure 9 - Center Harbor, Site 2 Bay. Comparison of 1990 Secchi Disk Transparencies with previous yearly data. The patterns of the bars display the minimum, mean and maximum values for each year sampled while the length of the bar represents the total range of values. The higher the secchi disk value, the clearer the pond.
COMPARISON: 1986-1990 DATA
CENTER HARBOR SITE 1 DEEP
SECCHI DISK

KEY: MIN MEAN MAX

1 Deep 1987
1988
1989
1990

EUTROPHIC MESO. OLIGOTROPHIC

Secchi Disk Depth (meters)

The higher number = clearer water

CENTER HARBOR SITE 2 BAY
SECCHI DISK

KEY: MIN MEAN MAX

2 Bay 1987
1989
1990

EUTROPHIC MESO. OLIGOTROPHIC

Secchi Disk Depth (meters)

The higher number = clearer water
Winnipesaukee-Center Harbor Data on file as of 03/16/1991

Lakes Lay Monitoring Program, U.N.H.

[Lay Monitor Data]

Winnipesaukee-Center Harbor, NH
-- subset of trophic indicators, all sites, 1990

1990 SUMMARY
Average transparency: 6.6 (1990: 8 values; 5.0 - 7.7 range)
Average chlorophyll: 2.5 (1990: 8 values; 1.6 - 4.8 range)
Average alk (gray): 7.0 (1990: 8 values; 5.5 - 8.0 range)
Average alk (pink): 8.2 (1990: 8 values; 7.0 - 9.0 range)

<table>
<thead>
<tr>
<th>Site</th>
<th>Date</th>
<th>Transparency (m)</th>
<th>Chl a (ppb)</th>
<th>Total Phos (ppb)</th>
<th>Alk. (gray) ph 5.1</th>
<th>Alk. (pink) ph 4.6</th>
<th>Color Pt-Co units</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Deep</td>
<td>06/27/1990</td>
<td>7.7</td>
<td>1.7</td>
<td>---</td>
<td>7.4</td>
<td>8.5</td>
<td>---</td>
</tr>
<tr>
<td>1 Deep</td>
<td>07/18/1990</td>
<td>7.0</td>
<td>2.6</td>
<td>---</td>
<td>7.5</td>
<td>8.2</td>
<td>---</td>
</tr>
<tr>
<td>1 Deep</td>
<td>07/30/1990</td>
<td>7.7</td>
<td>2.1</td>
<td>---</td>
<td>7.1</td>
<td>8.0</td>
<td>---</td>
</tr>
<tr>
<td>2 Bay</td>
<td>07/26/1990</td>
<td>7.5</td>
<td>1.8</td>
<td>---</td>
<td>6.5</td>
<td>8.0</td>
<td>---</td>
</tr>
<tr>
<td>2 Bay</td>
<td>08/03/1990</td>
<td>5.0</td>
<td>1.6</td>
<td>---</td>
<td>5.5</td>
<td>7.0</td>
<td>---</td>
</tr>
<tr>
<td>2 Bay</td>
<td>08/16/1990</td>
<td>6.0</td>
<td>2.1</td>
<td>---</td>
<td>8.0</td>
<td>9.0</td>
<td>---</td>
</tr>
<tr>
<td>2 Bay</td>
<td>08/24/1990</td>
<td>6.0</td>
<td>4.8</td>
<td>---</td>
<td>6.8</td>
<td>9.0</td>
<td>---</td>
</tr>
<tr>
<td>2 Bay</td>
<td>08/31/1990</td>
<td>5.5</td>
<td>2.9</td>
<td>---</td>
<td>6.8</td>
<td>8.0</td>
<td>---</td>
</tr>
</tbody>
</table>

<< End of 1990 listing, 8 records >>
TYPICAL TEMPERATURE CONDITIONS: SUMMER NEW HAMPSHIRE - DEEP LAKE

DEPTH (meters)

0  2  4  6  8  10  12  14  16

EPILIMNION
UPPER - WARM WATER LAYER - WIND MIXED

METALIMNION
SHARP DROP IN TEMPERATURE (THERMOCLINE)

HYPOLIMNION
BOTTOM COLD WATER LAYER

TEMPERATURE (°C)
APPENDIX C

GLOSSARY OF LIMNOLOGICAL TERMS

**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**—A system lacking oxygen, therefore incapable of supporting the most common kind of biological respiration, or of supporting oxygen-demanding chemical reactions. The deeper waters of a lake may become anoxic if there are many organisms depleting oxygen via respiration, and there is little or no replenishment of oxygen from photosynthesis or 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 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
Eutrophy- The lake trophic state in which algal production is high. Associated with eutrophy is low Secchi disk depth, high chlorophyll a, and low 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 lake water 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 "acid" ion, present in small amounts even in distilled water, but contributed to rain-water by atmospheric processes, to ground-water by soils, and to lakewater by biological organisms and sediments. The active component of "acid rain". See also "pH" the symbolic value inversely and exponentially related to the hydrogen ion.

Hypolimnion- The deepest layer of lakewater during periods of thermal stratification.

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

Lake Morphology- The shape and size of a lake and its basin.

Littoral- The area of a lake shallow enough for submerged aquatic plants to grow.

Meromixis- The condition where the entire lake fails to circulate to its deepest points; 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 aesthetically "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 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. Aesthetically 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.
Overtur - 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. Symbolically, the pH value is the 'negative logarithm' of the hydrogen ion concentration. For example, a pH of 5 represents a hydrogen ion concentration of $10^{-5}$ molar. [Please thank the chemists for this lovely symbolism -- and ask them to explain it in lay terms!] In any event, the higher the pH value, the lower the hydrogen ion concentration. The range is 0 to 14, with 7 being neutral 1 denoting high acid condition and 14 denoting very basic condition.

Photosynthesis - The process by which plants convert the inorganic substances carbon dioxide and water into organic glucose (sugar) and oxygen using sunlight as the energy source. Glucose is an energy source for growth, reproduction, and maintenance of almost all life forms.

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. Domestic sewage usually contains from 2 to 10 ppm phosphorus.

Parts per billion - Also known as "ppb". This is only 1/1000 of ppm, therefore much less concentrated. As little as 1 ppb of phosphorus will sustain growth of algae. As little as 10 ppb phosphorus will cause algal blooms! Think of the ratio as 1 milligram (1/28000 of an ounce) of phosphorus in 25 barrels of water (55 gallon drums)! Or, 1 gallon of septic waste diluted into 10,000 gallons of lakewater. It adds up fast!

Plankton - Community of microorganisms that live suspended in the water column, not attached to the bottom sediments or aquatic plants. See also "bacterioplankton" (bacteria), "phytoplankton" (algae) and "zooplankton" (microcrustaceans and rotifers).

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 "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.

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)

**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 *Kellicottia*. 