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A limnological assessment of Russell Pond, Woodstock, New Hampshire

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Abstract

A limnological survey was conducted during 17-18 September, 1998 to characterize the trophic state of Russell Pond, a 15.8 Ha natural Lake located in Woodstock, Grafton County, New Hampshire. Physical, biological and chemical parameters were measured to assess the health of the lake and changes from previous studies. Russell Pond is oligotrophic with high Secchi disk depths (13.8 m), low phosphorus levels (3.8 μg L^{-1}) and low Chlorophyll *a* concentration (0.5 μg L^{-1}). *Peridinium* (Dinophyceae) dominated (64%) the net phytoplankton. Calanoid copepods (Diaptomidae) constituted 87.5% of the crustacean zooplankton. The lake is at risk for acidification because of low acid neutralizing capacity (1.2 mg $CaCO_3$ L^{-1}) and low pH (5.6) in the deep water. Russell Pond has exceptionally high water clarity due to the low phytoplankton density and low water color (6.9 CPU). Water quality of the lake has been stable over the past few years. Compared to data from four other New Hampshire lakes, Russell Pond is the most oligotrophic of the lakes, followed by Pleasant Lake and Stonehouse Pond. Great Pond and Townhouse Pond were the most mesotrophic of the lakes.

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Introduction

Increasing awareness of pollution and of the long-range effects humans have on inland waters has lead to the development of programs to monitor the health of lakes and rivers. The goal of limnologists and managers is to prevent a decline in lake health before it reaches problematic levels. Gathering baseline data on lakes that have a variety of environmental qualities and human uses will help us understand the best way to manage these lakes to prevent resource degradation. Changes seen in the data collected over time can lead communities, scientists or governing associations to determine whether the trends are caused by natural or anthropogenic influences.

Several indices are commonly used to describe the trophic condition of a lake. The lack of universal agreement on these however, often leads to misinterpretation. In this study, Russell Pond is described using several classification schemes and indices to obtain an accurate description of its trophic state.

The most common terms used to describe the trophic state of a lake are oligotrophic, mesotrophic and eutrophic. A very general definition of these terms is as follows: an oligotrophic lake is typified by low nutrients and low productivity, a eutrophic lake usually has a high concentration of nutrients and high productivity, a mesotrophic lake lies in between these trophic states, with a moderate amount of nutrients and moderate productivity (Lampert and Sommer 1997). Various classification systems use different criteria to define these terms more specifically.

For instance, Forsberg and Ryding (1980) proposed a trophic state classification system based on four states: oligotrophic, mesotrophic, eutrophic and hypertrophic. Specific values for total nitrogen concentration, total phosphorous concentration, chlorophyll concentration and transparency (collected during summer stratification) fall into a range that denotes the trophic state. The index

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Requests for this report should be directed to Drs. A.L. Baker or J.F. Haney, University of New Hampshire, Center for Fresh Water Biology, Spaulding Hall, Durham, NH 03824. Copies can also be downloaded at the UNH Center for Freshwater Biology website: http://cfb.unh.edu.

itself is based on observations that suggest that there are correlations between these parameters over long periods of study. In other words, the measure of one parameter can allow for inferences regarding the values of other parameters (ex. high transparency indicates low chlorophyll *a* values). The accuracy of this index increases by using more than one parameter to make the final classification since individual parameters are influenced by many factors (Forsberg and Ryding 1980).

Another way to classify lakes is the trophic state index or TSI (Carlson 1977). This index is based on a scale of 0 to 100 and can be determined using one of several parameters including Secchi disk depth, total phosphorus and chlorophyll concentration. Each increment of 10 on the scale represents a doubling of the algal biomass. Only one parameter needs to be measured, although care must be taken to choose a parameter that best represents the system. The advantage of this index is that it is based on a numerical scale that provides more than three or four classifications, allowing detection of smaller changes in the trophic state of a lake over time, as well as more precisely comparing different lake systems (Carlson 1977).

Ecological models describing interactions among the different trophic levels of a particular lake can be used in addition to characterizing lakes using the trophic state indices. One model known as "cascading trophic interactions", uses predator population characters to explain differences in primary productivity among lakes with similar nutrients. This is known as a "top-down" concept in which increasing numbers of piscivores (large gamefish) leads to decreasing numbers of zooplanktivores (smaller zooplankton-eating fish), an increasing population of invertebrate planktivores, increasing zooplankton populations and finally a decrease in phytoplankton and primary production (Carpenter et al. 1985).

Other models describe lake ecosystems as having "bottom-up" controls. This means that lower trophic levels affect production of organisms at higher levels. The Morphoedaphic Index (MEI) suggests that fish production is ultimately controlled by the concentration of nutrients in a lake as well as other abiotic factors (Ryder 1982). An increase in nutrients leads to an increase in phytoplankton production and hence to an increase in both zooplankton and fish populations.

The objective of our limnological survey of Russell Pond was to collect data on the physical, chemical and biological parameters of the lake, to use the models presented to explain how these parameters interact, and finally to characterize the trophic state of the lake. Data from prior surveys of Russell Pond were also compared with the latest results to find trends. Russell Pond was compared to other lakes in the New Hampshire area in order to understand the differences and similarities of lakes in this region.

Study Site

Russell Pond is located in Woodstock, Grafton County, New Hampshire in the White Mountain National Forest. It is a glacial lake at an elevation of 494 m ASL. Russell Pond has an area of 15.8 Ha and a shore length of 1600 m. It has a volume of approximately 129.6 Ha-m and a maximum depth of 23.7 m with a mean depth of 8.2 m (New Hampshire Department of Environmental Services Lakes Inventory Database). Russell Pond's watershed is 147.9 Ha. There is a single inlet located on the northern side of the lake that was not flowing at the time of this study. A single outlet marked by a beaver dam is located on the southwestern shore. At the time of study discharge was approximated at 10 to 14 L min^{-1}. The outlet leads into Russell Pond Brook and continues to the Pemigewasset River.

Surrounding vegetation varies at Russell Pond with the northern half of the lake dominated by mixed deciduous trees and with ~5% conifers. The southern half consists of more dense stands of conifers with a small section dominated by ~80% conifers. Aquatic emergent vegetation consisted of a 50 by 80 m mat of mixed grasses in the shallow waters on the north eastern shore. *Eriocaulon septangulare* (pipe wort) also grew sparsely in the shallows along the perimeter of the lake. Most of the substrate in these areas was sand covered with

Table 1. The location and sampling dates of the five lakes surveyed in this study.

Lake	Location	Sampling Date
Pleasant Lake	Deerfield, New Hampshire	14 September 1998
Russell Pond	Woodstock, New Hampshire	17-18 September 1998
Stonehouse Pond	Barrington, New Hampshire	23 September 1998
Great Pond	Kingston, New Hampshire	28 September 1998
Townhouse Pond	Milton, New Hampshire	5 October 1998

leaves and decomposing plant matter.

Russell Pond has become a popular camping destination with approximately 50 tent and/or RV sites on the eastern side of the lake. There is a small beach and concrete boat ramp utilized by canoes only. Fly fishing is permitted and in 1998 the pond was stocked with 2500 fingerling brook trout, 2000 one year old and 210 two year old brook trout (*Salvelinus fontinalis*) (NH Fish and Game pers. comm.).

The other lakes discussed in this study included Pleasant Lake (Deerfield), Great Pond (Kingston), Stonehouse Pond (Barrington) and Townhouse Pond (Milton) (Table 1).

Methods

Physical and Chemical Parameters - The YSI 600 XL Multi-Parameter Water Quality Monitor measured temperature recorded profile depth, dissolved oxygen, pH, specific conductance and oxidation-reduction potential (ORP). The probe was lowered into the water at ~0.5 m min^{-1}. The depth of the epilimnion was determined from these temperature readings. Data were recorded with a Gateway Handbook 486 computer.

The Orion Dissolved Oxygen Meter (model 840) and the DO electrode (model 084050) also recorded temperature. This instrument measured temperature at increments of 0.5 m and was left at each specific depth until the reading stabilized.

Transparency of the lake water was determined using a view scope and a 20 cm Secchi disk. The disk was lowered over the unshaded side of the canoe until it could not be seen and then it was slowly raised until in view. The average depth was recorded to the nearest 0.1 m and the measurement was repeated three times.

The LI-COR Datalogger LI-1000 and the Underwater Quantum Sensor LI-192SA, recorded the intensity of light over a range of depths at the deepest part of the lake. An additional light photosensor recorded of the surface incident light intensity to correct for that moving cloud cover. The natural log of the light intensity was plotted against depth and the slope of the resulting line was the coefficient of attenuation (k_{ext}).

Alkalinity samples were taken with an integrated tube sampler, lowered to the lower boundary of the epilimnion. Alkalinity titrations followed the method described by Lind (1985), except for the use of 0.002 N sulfuric acid as the titrant and bromcresol green – methyl red as the indicator. The gray and pink endpoints were recorded for each titration indicating the 5.1 and 4.6 pH of the solution, respectively. The gray endpoint represents the alkalinity or acid neutralizing capacity (ANC) while the pink endpoint is useful only for comparison with historic data using the methyl orange indicator technique.

Water samples from the epilimnion, collected by the integrated tube sampler, were used to determine the dissolved color. These samples were passed through a Millipore Filtration System with a Millipore type HA 0.45 µm cellulose filter to remove phytoplankton and other particles. Dissolved color in the filtrate was determined from light absorption at 440 nm ($A_{440} - A_{750}$), multiplied by 859 to convert to chloroplatinate units (CPU).

Samples used to determine the phosphorus concentration were also taken from the epilimnion by the integrated tube sampler and placed in 250-mL bottles containing concentrated sulfuric acid. Total phosphorous was determined via the persulfate digestion method and ascorbic acid colorimetry described by Lind (1985).

Biological Parameters – Chlorophyll *a* concentration was determined from the integrated tube water samples filtered through a Millipore type HA 0.45 cellulose filter (see methods under dissolved color). Chlorophyll *a* was extracted from the phytoplankton by following Lind (1985), except that each of the three filters was placed in a grinder with 95% acetone containing Mg CO_3 until the filter was fully dissolved.

Samples from the integrated tube sampler were used to determine relative chlorophyll fluorescence (RFU). The samples were injected into a Turner Designs Fluorometer, model 10, to obtain the whole lake water (WLW) relative fluorescence units. Three additional water samples from the epilimnion were filtered through a 30 µm ring net and then run through the fluorometer to determine the RFU of the <30 µm fractions that represent the edible component of the phytoplankton to zooplankton. The <30 µm readings were subtracted from the WLW readings to determine the >30 µm RFU.

A vertical profile of net plankton was sampled using a 2.5 L clear acrylic water sampler (Aquatic Research Instruments, Inc.). Ten samples were taken at regular intervals from the surface to the deepest point of the basin and they were filtered through a funnel with 50 µm Nitex mesh. The mesh was placed in a jar and preserved in 4% formalin/sucrose solution.

An integrated vertical plankton tow was taken with triplicate samples using a 30 cm diameter, 50 µm mesh closing net. The net was lowered to just above the sediments (except in Russell Pond where the depth was 20 m). The net was rinsed and the contents the cod end were poured through

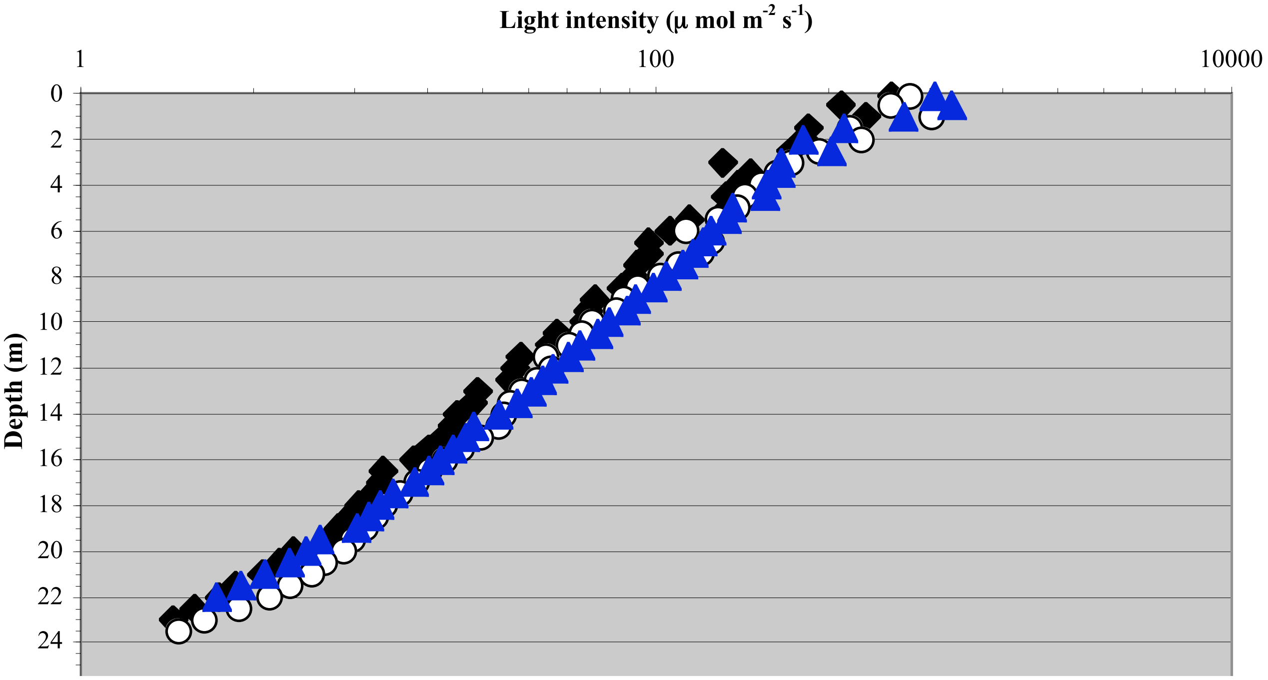

Fig. 1. Triplicate samples of light intensity profile at Russell Pond for 09-17-98.

a 50 µm ring net. Plankton in the ring net were rinsed into a jar and preserved with 4% formalin/sucrose solution. This procedure was repeated a total of three times.

Samples from the integrated plankton tow were analyzed to estimate densities of net phytoplankton and zooplankton. Of the 17 mL sample 50 µL were placed on a slide and analyzed at 100X to count the net phytoplankton. Density of the phytoplankton was determined from the volume of slide transect.

Zooplankton were counted with a dissecting microscope and the entire sample was counted. The density was determined by dividing the number counted by the volume of the water sampler. To determine the total biomass for each taxon, average dry weight for each taxon (Dumont et al. 1975) was multiplied by the total number counted in the sample. Body lengths of 30 randomly selected individuals were measured by capturing digital images using NIH Image Software.

An ANOVA was done on selected parameters to determine if lakes differed significantly. A Bonferroni post-hoc analysis was also run to determine the probability of each individual lake being similar to Russell Pond with regards to a specific parameter.

Results

Physical Parameters - The temperature profile of Russell Pond exhibited strong thermal stratification. Temperatures remained relatively constant in the epilimnion at approximately 18^{o}C . The metalimnion began at 7.5 m and the temperature steadily decreased to 7.1^{o}C. The hypolimnion began at 15 m and temperature changes occurred slowly to the sediment at 24 m (Fig. 2).

The mean Secchi disk depth was 13.8 m (± 0.07 SE). The intensity of light decreased continuously with increasing depth. The k_{ext} was 0.23 (Fig. 1).

Chemical Parameters - Specific conductance was relatively stable at 18 µS from the surface to approximately 8 m. At this point it slowly increased with depth to 27 µS at the deepest point of the basin of Russell Pond.

The oxygen profile at Russell Pond represented a negative heterograde oxygen curve indicating that the concentration of dissolved oxygen decreased slowly from the surface (10 mg L^{-1}), but had minima in the metalimnion between 8 to 10 m and in the hypolimnion at 16 m. At 23 m dissolved oxygen was still present at 4.9 mg L^{-1} (Fig. 2).

ORP readings at the surface were 355.6 mV and remained stable until 8 m. Below 8 m the ORP increased steadily reaching a maximum of 389.5 mV at the sediments. The hypolimnion remained an oxidizing environment (Fig. 2).

The pH at Russell Pond declined with depth from 7.1 at the surface to a more acidic 5.6 at 22.7 m. A small increase to 5.67 was recorded at the bottom of the lake, probably within the bottom sediments.

Mean alkalinity in the epilimnion was 1.2 (± 0.12 SE) mg $CaCO_3$ L^{-1}. The mean pink endpoint was 1.6 (± 0.12 SE) mg $CaCO_3$ L^{-1}.

Dissolved color (CDOM) was 6.9 CPU for all three samples analyzed.

The mean total phosphorus in the epilimnion of Russell Pond was 3.8 (± 0.24 SE) ppb.

Biological Parameters – The average concentration of chlorophyll *a* in three samples was 0.5 ($\pm$ 0 SE) µg L^{-1}. The fluorometry samples had WLW readings of 7.4 ($\pm$ .2 SE) RFU and a <30 µm of 7.85 ($\pm$ .05 SE) RFU. Both <30 µm readings (edible forms of phytoplankton) were greater than the WLW readings resulting in negative values for the >30 fraction of the sample. This is probably an artifact due to a "shading" by the large particles >30 µm reducing the total fluorescence.

Phytoplankton observed in the vertical tow samples included *Peridinium* sp. (Dinophyceae), *Synura* sp. (Chrysophyceae), *Sphaerocystis* sp. (Chlorophyceae), *Dinobryon* sp. (Chrysophyceae) and *Melosira* sp. (Bacillariophceae). The dominant genus was *Peridinium* sp. accounting for 64% of all net phytoplankton counted in the sample.

The zooplankton identified in the vertical tow samples included *Daphnia pulex*, *Bosmina longirostris*, *Diaphanosoma* sp., *Holopedium gibberum*, *Polyphemus pediculus*, Cyclopoids, and Calanoid copepodids. *Keratella* sp. and nauplii were observed but not counted. Numerically calanoids comprised 87.5% of all crustacean zooplankton counted and many were identified as the herbivorous *Diaptomus* sp. (Fig. 3). In terms of biomass, the calanoids comprised 90 % of the total crustacean zooplankton. Average body lengths for zooplankton in this sample were 0.63 (± 0.01 SE) mm for *Diaptomus*, 1.15 (± 0.06 SE) mm for *Daphnia*, 0.61 (± 0.03 SE) mm for *Diaphanosoma* sp., 0.43 (± 0.08 SE) mm for *Bosmina longirostris*, and 0.73 (± 0.14 SE) mm for *Holopedium gibberum*.

Calanoid copepods dominated the discrete samples from the surface to the bottom. Highest densities were found in the deeper waters, 28.6 L^{-1} at 22.5 m and 31.35 L^{-1} at 24 m. The density of *Holopedium gibberum* was greatest at 7.5 m (1.6 L^{-1}), while *Daphnia* sp. had its highest density of 1.6 individuals L^{-1} at 15 m.

Discussion

Physical Parameters – On the date of sampling Russell Pond was still thermally stratified (Fig. 2). The high Secchi disk depth (13.77 m ± 0.03 SE) and the low coefficient of attenuation (k_{ext} = 0.23) indicate the extreme clarity of the lake (Fig. 1). Light penetrated deeply into the lake due to the combined effects of a low concentration of dissolved humic substances (6.9 CPU), and sparse amounts of algae in the water column (0.5 µg L^{-1} chlorophyll *a*). The small watershed may limit the importation of nutrients and sediments

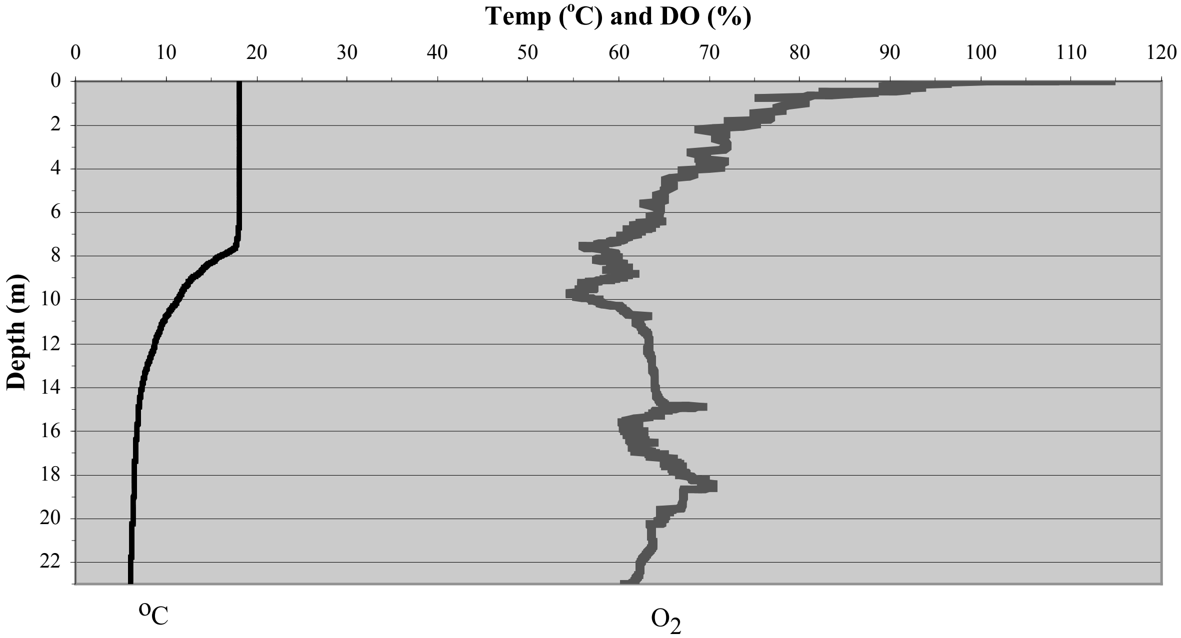

Fig. 2 Temperature, dissolved oxygen, and ORP profiles at Russell Pond 17 September, 1998.

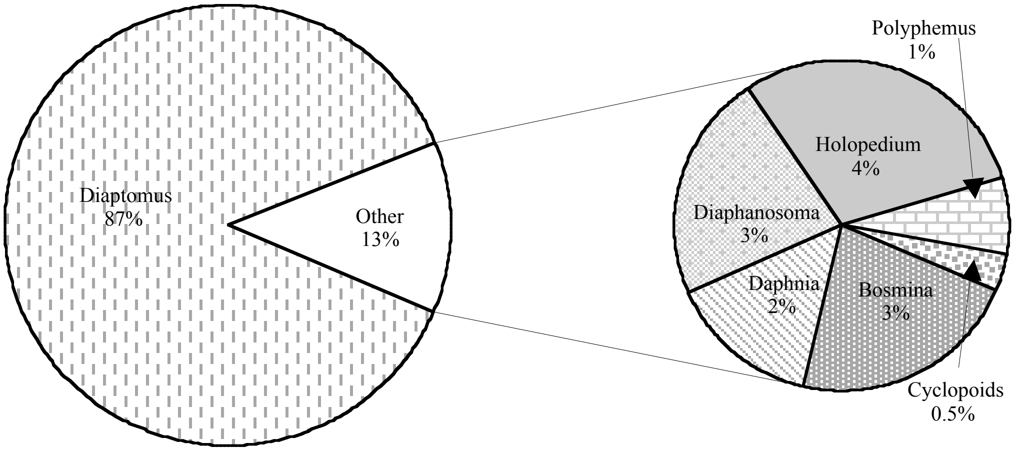

Fig. 3. Percent composition of crustacean zooplankton in Russell Pond.

into the system. The ratio of lake volume to watershed is 0.88. Most of the volume of the lake appears to be from direct precipitation and ground water, contributing to the low productivity of the lake.

Chemical Parameters - The negative heterograde oxygen profile is typical of a summer-stratified lake where oxygen concentrations in the metalimnion and hypolimnion depleted can not be replenished by respiring organism such as bacteria, phytoplankton and zooplankton. In Russell Pond however, oxygen was still present in the hypolimnion, but at reduced levels (4.9 mg L^{-1} at 23 m), suggesting Russell Pond was not sufficiently productive to create anoxic conditions in the hypolimnion.

The minima in the dissolved oxygen curve may be explained by a high density of bacteria and zooplankton at these depths (Fig. 2). Herbivorous calanoid copepods were dominated and present in high concentrations at 10 and 15 m (21.4 L^{-1} and 24.6 L^{-1}). They feed on phytoplankton and consume oxygen at these depths. Quite likely, the high transparency of this lake may have also permitted limited photosynthesis at these depths.

The Oxidation Reduction Potential (ORP) profile from Russell Pond supports the finding of oxygen in the hypolimnion. ORP levels were highest in the hypolimnion at 389.5 mV indicating an oxidizing environment (Fig. 2). At levels below 300 mV, phosphorus is resolubilized from the sediment (Lampert and Sommer 1997). The ORP levels in Russell Pond indicate that phosphorus should remain bound in the sediments. As a result, it may well be the limiting factor for primary production in this system. The low total phosphorus concentrations in this lake (3.8 ± 0.2 ppb) support this conclusion.

Russell Pond also had low specific conductivity that increased with depth. The low conductivity and dissolved color results indicates low concentrations of dissolved salts and organic residues in the water. The highest conductivity readings at 23 m (27 μS) could be attributed to bacteria decomposing deposits in the sediments freeing electrolytes.

The lowest pH in Russell Pond was 5.6 at 22.7m. The acidic condition in the deeper waters could be attributed to a build up of carbon dioxide from respiring organisms in the water column. It appears that respiration exceeded the production of oxygen by primary producers at these depths. The acidic pH also suggests that the ANC in Russell Pond was too low to adequately buffer the system. Typically in New Hampshire lakes the watershed supplies little calcium bicarbonate to buffer the lake waters. Acid rain could greatly affect the pH and survival of fish and plankton populations in Russell Pond since aquatic organisms can be negatively affected by a pH of 6.0 or less (Estabrook 1996).

Biological Parameters - Chlorophyll *a* concentrations in a lake are often used as an indicator of primary productivity. The low values in Russell Pond (0.5 μg L^{-1}) suggests there were extremely sparse phytoplankton populations in this lake (Lampert and Sommer 1997). This contention is also supported by the low chlorophyll fluorescence values (7.4 ± 0.2 SE).

The low primary production in most oligotrophic lakes can be explained by “bottom-up” controls. The “bottom-up” concept suggests that the lack of nutrients in Russell Pond limit phytoplankton. The scarcity of phytoplankton may result in lower production of herbivorous zooplankton. Surprisingly, calanoids had a relatively high average density of 19 individuals L^{-1}. Such high concentrations of herbivourus copepods could result in grazing that also exerts significant "top-down" control of the phytoplankton.

A survey of the fish population was not conducted at Russell Pond, but it is known to be stocked with brook trout (NHF&G per. comm.). The lack of information on the higher trophic levels makes it difficult to describe the "top-down" processes in the lake. However, it is possible to make some predictions about the trophic level using a model predicting the predator to panfish ratio from zooplankton lengths. This is described by the equation [ratio of predator to panfish = -0.46 + 0.99(mean length of crustacean zooplankton)] (Mills et al. 1987). Using this equation the average length of zooplankton in Russell Pond was 0.71 mm (± 0.12 SE) predicting a predator to panfish ratio of 0.24 predators per planktivorous fish. This predicted low number of piscivores in Russell Pond allows populations of planktivorous fish to increase. The planktivores consume the larger zooplankton first as catching a few large prey is more energy efficient than capturing many smaller zooplankton (Brooks and Dodson 1965). The result is a population of smaller sized zooplankton. This was evident in the low concentrations of larger zooplankton like *Daphnia sp.* (0.44 individuals L^{-1}). Instead the zooplankton populations were dominated by the calanoid copepods with a mean length of 0.62 (± 0.01 SE).

It is important to note that this model is most accurate when zooplankton are sampled once in the spring and once in midsummer as young-of-the-year fish may bias the results (Mills et al. 1987).

Trophic State of Russell Pond - The synthesis of the data collected in this survey makes it possible to characterize the trophic state of Russell Pond. According to the Forsberg and Ryding trophic classification (1980) Russell Pond is oligotrophic. Values of total phosphorus and chlorophyll for this site were well below the maximum values suggested for oligotrophic lakes by classification scheme. Transparency readings were also above the oligotrophic minimum of 4 m suggested by Forsberg and Ryding.

Carlson's TSI (1977) also predicts that the lake is oligotrophic. The mean Secchi disk reading for Russell Pond was applied to the TSI equation [TSI =10 (6-lnSD/ln2) resulting in a TSI of 22.1.

In addition, Lampert and Sommer (1997) suggest characteristics commonly encountered in oligotrophic lakes. These include low levels of primary production, low levels of nutrients, and high concentrations of oxygen in the hypolimnion. Russell Pond exemplified all of these characteristics and should be considered oligotrophic.

Trends - An increasing trend was noted in fluorescence over the past two years in Russell Pond. Increases have occurred in both WLW fractions and <30 µm fractions suggesting there was increasing phytoplankton in the water (Fig. 5). Yet values of 7.4 (± 0.2 SE) RFU-WLW and 7.9 (± 0.005 SE) RFU-<30 are still quite low and this small increase did not appear to greatly affect the SDD or the attenuation of light.

Past data on the alkalinity and pH of Russell Pond are available from studies conducted by the New Hampshire Department of Environmental Services (DES) from 1984-1995 (Fig. 6). Alkalinity and pH of the lake are of concern because it lies at a high elevation. Most of Russell Pond's water input is probably from precipitation and water quality will quickly reflect the quality of

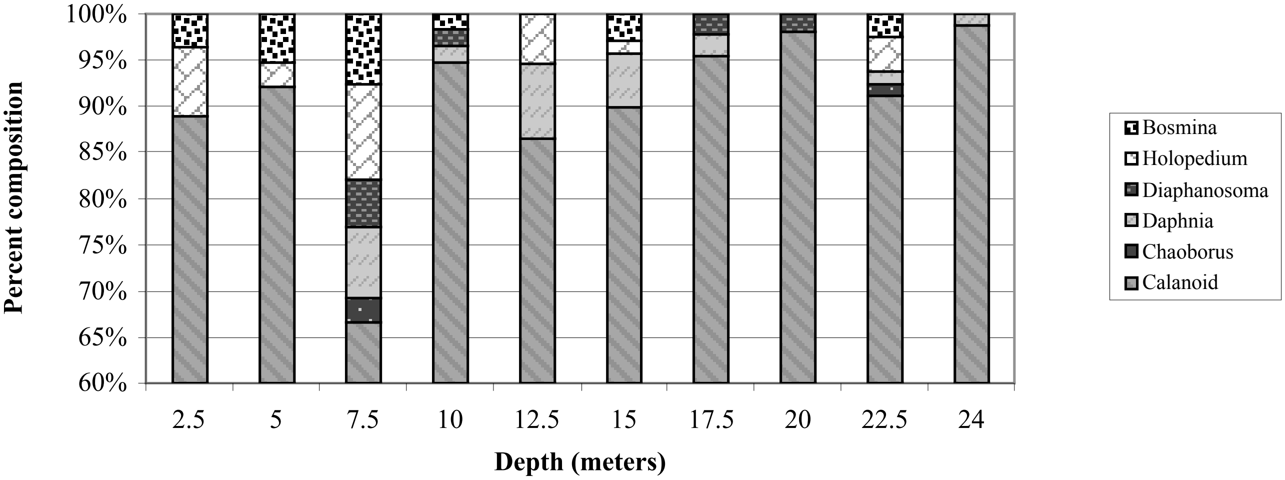

Fig. 4. Relative abundance of zooplankton from 2.5 to 24 meters in Russell Pond.

the rain especially if it is acidic (Estabrook 1996).

The results from Estabrook (1996) indicate an increasing trend in alkalinity, but no change in pH in Russell Pond. This year there was a decrease in alkalinity and an increase in pH (Fig. 6). It is important to note periods of high sunlight may give an elevated pH as photosynthesis utilizes carbon dioxide. However, alkalinity levels were at 1.2 mg L^{-1} $CaCO_3$. DES considers a lake vulnerable to acid rain if it has an alkalinity of less than 10 mg L^{-1} of calcium carbonate (Estabrook 1996). The vulnerability of the lake is evident from the data of 1997 that showed a significant decrease in both alkalinity and pH (Avila and Wemouth unpublished). Whether or not acid rain caused this decline, Russell Pond was not capable of buffering additional acid because of its low ANC. The recovery to this year's values could have been due in part to watershed construction and use by the campsite adding minerals to the water and increasing the buffering capacity.

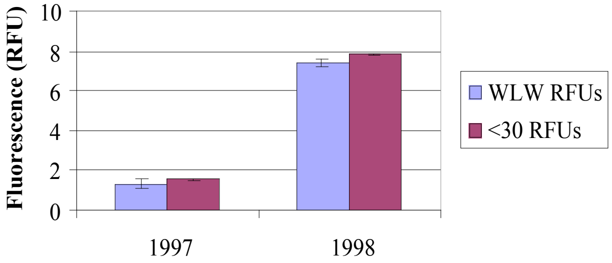

Fig. 5. Fluorescence (RFU) from 1997 and 1998 at Russell Pond (±1 SE).

General Discussion

The University of New Hampshire Field Liminology class surveyed four additional lakes in the fall of 1998, utilizing similar methods. The ANOVA p-values were $p<0.05$ for all of these parameters.

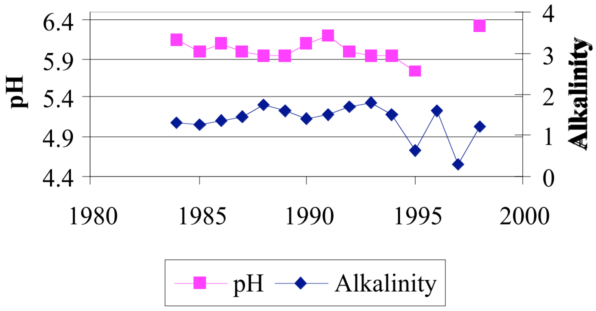

Fig. 6. Alkalinity and pH trends from 1980 to 1998 at Russell Pond (Estabrook 1996).

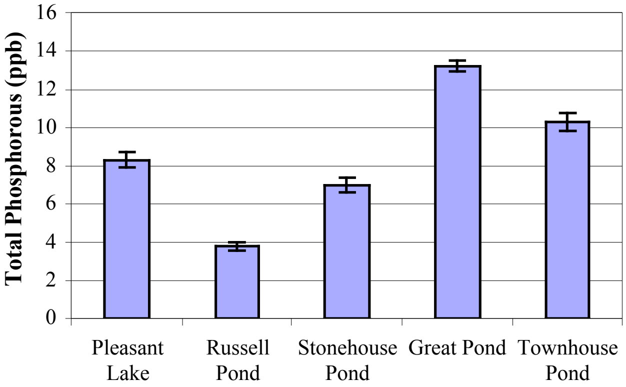

Fig. 7. Total phosphorus concentrations in all five lakes, Fall 1998 (± 1 SE).

The concentration of total phosphorus in Russell Pond was significantly lower than the other lakes ($p<0.05$) and it appears to be the limiting nutrient in this lake (Fig. 7). Likely sources of phosphorus in Russell Pond were leaf litter, the introduced fish and runoff from the camping area. Chlorophyll *a* concentrations in Russell Pond did not differ significantly from to those in Pleasant Lake ($p=0.81$) and Stonehouse Pond ($p=0.38$) (Fig. 8). Primary production in these ponds may therefore be limited by other factors. Pleasant Lake primary production may be limited by an increased number of grazers while Stonehouse Pond may have low primary production due to the low pH of the water. On the other hand, there was a significantly greater concentration of chlorophyll *a* in Townhouse Pond ($p<0.05$) and in Great Pond ($p<0.05$) (Fig. 8).

Russell Pond also had significantly less CDOM than all the other lakes ($p<0.05$) except for Pleasant Lake (Figure 9). Although Secchi disk depths were not statistically compared, Pleasant Lake had the next highest SDD (6.43 m ± 0.03 SE) and low levels of chlorophyll *a* (1.7 µg L^{-1} ± 0.1 SE) (Fig. 8). Reduced levels of nutrients in both

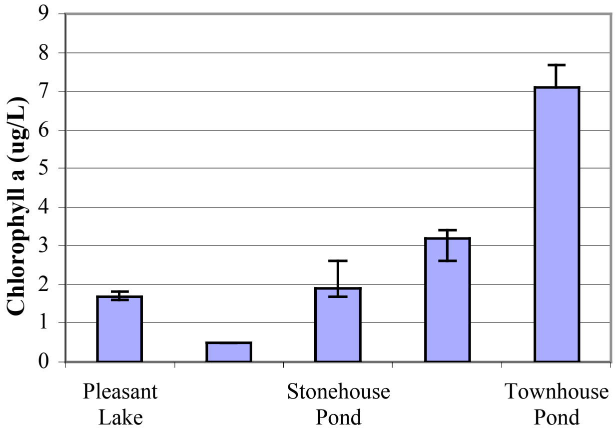

Fig. 8. Chlorophyll *a* concentrations in all five lakes, Fall 1998 (± 1 SE).

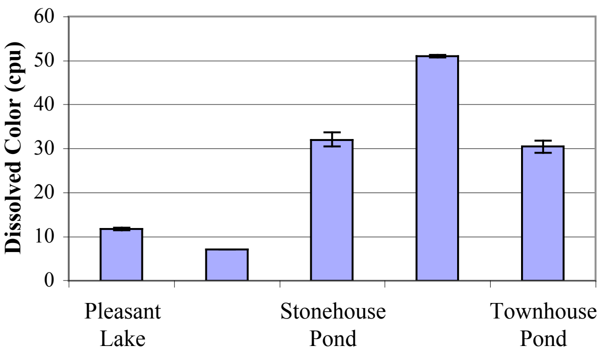

Fig. 9. CDOM data in all five lakes, Fall 1998 (± 1 SE).

lakes, leads to low primary production and high transparency readings.

The pH in Russell, Pleasant and Townhouse Ponds did not differ significantly ($p < 0.05$). They were all in the low 6.0 range and therefore should be monitored for decreasing pH. Stonehouse Pond ($p<0.05$) had the lowest pH of 5.77 and is at great risk as a pH below 6.0 can lead to many problems within the food web (Estabrook 1996). Russell pond had ANC very similar to Pleasant Lake (Fig. 10). The low buffering capacity again suggests these ponds may be at risk of severe acidification. Great Pond was significantly different from Russell Pond ($p<0.05$) as it had a relatively high pH of 6.7 (± 0.01 SE) and a high ANC of 9.7 (± 0.7 SE).

Trophic State of Five Lakes - Using Carlson's Trophic State Index (1977), Russell Pond was the most oligotrophic of all the lakes in the study with a TSI of 22.1 followed by Pleasant Lake (33.2) and Stonehouse Pond (37.4). Great Pond and Townhouse Pond were the most eutrophic of the lakes with a TSI of 44.6. However, a TSI of 50 is considered mesotrophic. Thus, the lakes in our study range from oligotrophic to mesotrophic.

The Forsberg and Ryding index (1980) also classifies Russell, Pleasant, and Stonehouse Ponds as oligotrophic. Townhouse Pond on the other hand, has a transparency that is mesotrophic, a phosphorous concentration that is oligotrophic and a chlorophyll *a* concentration that is eutrophic. In this lake, there was a population of planktivorous fish, or Alewife (*Alosa*) may be consuming the zooplankton grazers and therefore allowing the phytoplankton in Townhouse Pond to increase and the transparency to decrease (Brown 1996). The dense population of phytoplankton was also reflected in the high RFU-WLW results of 75.3 RFU. Great Pond also had water transparency that was mesotrophic and an oligotrophic phosphorous concentration. Although the Carlson and Forsberg and Ryding indices are modeled differently, they classified the five lakes into similar trophic states.

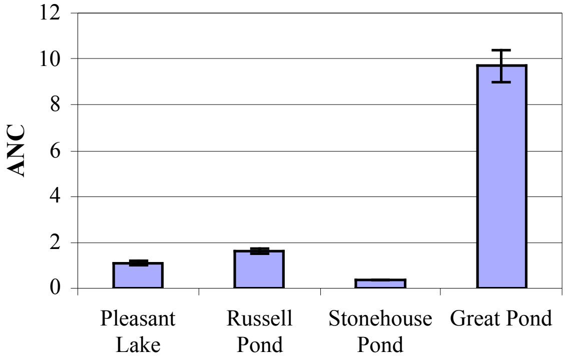

Fig. 10. Alkalinity data in four lakes, Fall 1998 (± 1 SE).

Water Quality Relationships - The public is often concerned with eutrophication because it decreases the aesthetic qualities of the lake such as water clarity. In our study there were linear relationships between the log chlorophyll *a* and SDD ($p<0.05$ $r^2=0.83$), indicating as chlorophyll *a* concentrations increase, the transparency decreases (Fig. 11). There was also a significant negative relationship between dissolved color and the Secchi disk depth ($p<0.05$ $r^2=0.86$) (Fig. 12).

There was also a significant positive relationship between phosphorous and chlorophyll *a* concentration ($p<0.05$ $r^2=0.76$) (Fig. 13), indicating as phosphorous concentrations increased the concentration of phytoplankton also increased. This relationship suggests phosphorous is likely be a limiting nutrient in a system.

Summary

Russell Pond is an oligotrophic lake with high transparency, low nutrients and low phytoplankton density. The Trophic State Index (Carlson 1977) and Forsberg and Ryding's index (1980) both indicated the oligotrophic status of Russell Pond.

Water quality in Russell Pond has remained relatively stable over the past few years. The greatest

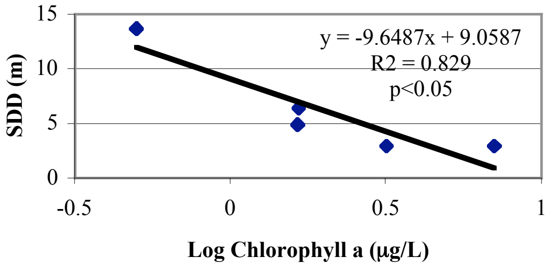

Fig. 11. Regression analysis on the relationship of the log 10 chlorophyll and Secchi disk disk depth for all five lakes, fall 1998.

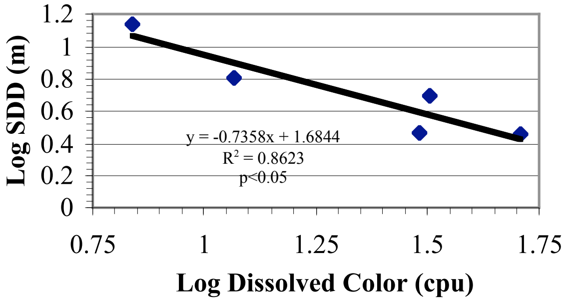

Fig. 12. Regression analysis on he relationship between the log of dissolved color and he log Secchi disk depth for all five lakes, fall 1998.

concern for this lake is acid rain because of Russell Pond's elevation and its low alkalinity (ANC). The lower pH in 1997 demonstrates this lake's susceptibility (Fig. 6). The lakes should be monitored carefully to detect further change. Most of the lakes in the Lakes and Ponds survey including Russell Pond however, have shown no significant increase in pH over the past 15 years (Estabrook 1996). The US EPA Clean Air Act amendments have reduced sulfur emissions into the atmosphere and the result has been a decline in acidic precipitation (Estabrook 1996). These protective measures will hopefully prevent further decline in the acid neutralizing capacity of Russell Pond.

Surveys should probably be conducted at least twice a year, once in the late summer and once in the winter. Readings of pH for example, are more stable during the winter as plants remove carbon dioxide from the water for photosynthesis during the summer (Estabrook 1996). If a particular lake is vulnerable or at risk, focused surveys should be conducted at more regular intervals between the two main surveys. Other lakes in the northern region of the state with higher elevation could also benefit from these studies.

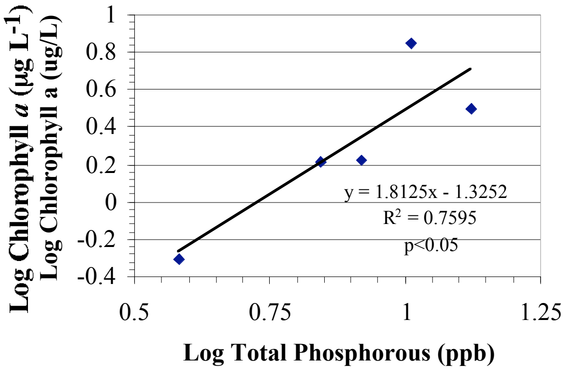

Fig. 13. Regression analysis on the relationship between the log of chlorophyll a and log of total phosphorus for all five lakes, fall 1998.

The water quality at Russell Pond seems stable and the camping facility does not appear to have caused any obvious damage to the lake ecosystem. The modern rest areas and limited seasonal use help maintain the trophic state. Russell Pond is one of New Hampshire's cleanest and clearest lakes and care should be taken to preserve its unique qualities.

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