Limnological study of Zealand Pond, White Mountains, New Hampshire

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Abstract

Zealand Pond, New Hampshire, was chosen as the site of a remote lake study. Data were collected between July 18 and August 29,1997. Zealand Pond had a relatively high pH (6.3-6.9) and alkalinity (2.3-3.1 mg $CaCO_3$ /liter), considering its small size and elevation (752 m). The lake was not thermally stratified, presumably due to its shallow depth and exposure to wind. Zealand Pond had a diverse zooplankton community, with two calanoid copepod species (*Hesperodiaptomus wilsonae* and *Leptodiaptomus ashlandi*), two cyclopoid copepods (*Mesocyclops edax* and *Ectocyclops phaleratus*), six cladoceran species (*Daphnia ambigua, Daphnia pulex, Ceriodaphnia reticulata, Bosmina longirostris, Alona costata, and Polyphemus pediculus*), and two rotifer species (*Keratella taurocephala and Conochilus* sp.). Densities of zooplankton ranged from 57.6 (*Hesperodiaptomus*) to 0.04 (*Alona*) animals per liter. Zooplankton species were documented with photographs and key identifying features. Low densities of fish were also present in the lake. Features of Zealand Pond are compared to other high altitude lakes.

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Introduction

Zealand Pond is a shallow, clear, high altitude (752 m, 2480 ft. ASL) lake located off route 302 in the White Mountains of New Hampshire. It was selected as a lake of interest for two reasons: little is known about its limnology, and there is a scarcity of data on lakes which are considered high altitude and remote in New Hampshire. The goal of this study was to collect baseline data on the physical and biological parameters of Zealand Pond. Data were collected so they could later be used to document lake changes, and be compared with other high altitude and remote lakes.

Acknowledgements

I wish to thank the Kathryn Staley, U.S. Forest Service, for granting permission to conduct this study on Zealand Pond. I also wish to thank Dr. James Haney for his guidance of this project and everyone who helped tote equipment. Outside reviewers provided useful suggestions for manuscript improvement.

Study site

Access to Zealand Pond was gained by entering near the Zealand campground and picnic area (Forest route 16 off Rt 302). Both these locations and the lake itself can be found in the AMC White Mountain hiking guide. An 11.3 km road ends at the Zealand Pond trailhead and from there it is an easy 4.0 km walk to the lake.

Much of the lakeshore is inaccessible because of swampy conditions. However, the edge along which the trail runs affords several observation points. The lake has no visible inlet but two small outlets, one on either end. The northern end of the lake drains into a broad swampy area that gradually narrows to a small stream forming the headwaters of the Zealand River. At the southern end a small stream flows directly from the lake forming Whitewall Brook. This stream joins the North Fork of the Pemigewasset River. Based on USGS maps, Zealand Pond is approximately 0.6 hectares (1.48 acres) (Figure 11).

About half of the lake is bordered by fairly steep hills. The forest surrounding the lake is a mix of deciduous and coniferous species while the immediate shore supports a wide variety of plant species, amongst others; alders and leather bush were plentiful. Sphagnum moss carpeted areas of the shore, providing shelter to small clusters of sundew plants (*Drosera*). Although no fish were seen in the lake they were spotted in the broad swampy area and its continuing outlet stream. On the early collection dates salamanders were seen in the lake and very large leeches were continually milling about. The black fly and mosquito populations were significantly less prominent than at similar lakes, such as Nancy Pond, which was visited at the same time. Data were collected in July and August when the lake would be assumed to be in its most active period.

Materials and Methods

All equipment used was backpacked in allowing measurements to be taken while at the study site. The lake was visited approximately once every two weeks between July 18, 1997 and August 29, 1997.

All samples were collected from an inflatable rubber raft. This type of boat was advantageous because it allowed access into shallow areas as well as being light enough to carry in.

Depth of the lake was determined by lowering a weighted, marked line to the bottom of the lake and then noting depth demarcations on the line. Samples were collected at the deepest part of the lake, which was between 1.25 and 1.50 meters in depth (Figure 11).

On one occasion a YSI model 54 oxygen probe with a thermistor temperature sensor was used to take a vertical profile. The probe readings indicated that the lake was well mixed. Since the lake is shallow and unstratified most of the samples were collected from a mid-depth. These mid-depth samples were assumed to be representative of the lake. Water clarity was measured using a secchi disk. After the original visit to the lake there was no need to use the disk since clarity exceeded the full depth each time.

Temperature was taken using a hand held thermometer. Water from a depth of about 0.75 meters was collected along with the water being used for dissolved oxygen titrations. The thermometer was allowed time to adjust before temperature readings were taken.

pH was measured with a pH wand (Oakton pHTestr 2). The probe was allowed to acclimate for at least 15 minutes before readings were taken. This was done once per visit unless there was reason for replication. The probe was calibrated using two standard buffer solutions at pH 4 and 10. On August 18 the water for pH was carried back to the lab, refrigerated and pH was not taken until the following day.

Dissolved oxygen in the lake was measured by the Winkler titration method (Lind, 1985). Water samples for the titrations were collected at 0.75 meters using a collection device that housed the titration bottle. This device was made for the New Hampshire Lakes Lay Monitoring Program by Aquatic Research Instruments. Two standard BOD bottles were filled and titrations were conducted on shore. Two 50 ml samples were processed using sodium thiosulfate (0.0125 N) as the titrant.

Conductivity was measured using a YSI model 33 S-C-T conductivity meter. Profile readings at 0.25-meter increments were taken each time, although there was very little variation in the water column. The probe was red lined before each use and measurements were recorded by hand.

Data were corrected to 18^{o}C (assuming a slope of 2.5 percent per 1^{o}C).

Alkalinity was measured as the acid neutralizing capacity (ANC) using the standard titration method (Lind, 1985). Triplicate water samples were collected and brought to shore for processing. Fifty ml of water were measured using a graduated flask and then transferred into a clear plastic cup. Three to four drops of the indicator bromcresol green \ methyl red were added and thoroughly mixed. Dilute sulfuric acid (0.002N) was used to titrate the sample through two end points, first until it appeared gray, indicating a pH of 5.0 to 5.2, and then again to the final end point of pink, indicating a pH of 4.6 to 4.8 (Wetzel and Likens, 1979). The titration volume for the gray endpoint was converted to $CaCO_3$ equivalent in mg $CaCO_3$ per liter. The three samples were averaged to establish one value for the lake.

Zooplankton was collected by horizontal tows. A circular collection net (30 cm diam., 80 µm mesh) was towed behind the boat. At the end of the towing distance the net was quickly pulled into the boat to prevent it from settling into the bottom sediments or backwashing the collected zooplankton. The sample was concentrated through a 50 µm Nitex net and washed into a sample jar. The sample was preserved with sucrose/formalin (4% / 4%, Haney and Hall, 1973). Two tows were done on each date. Zooplankton were later identified and enumerated. Before being counted each sample was standardized to 100 mls and subsampled with a 1 ml Hensen-Stemple pipet. Each 1ml subsample used here provided between 300 and 800 total organisms.

The cyclinder formula, $V=\pi r^2 h$, was used to calculate the volume of lake water sampled, where r is 12.5 cm for the 30 cm net and h is the estimated distance towed. The estimated distance towed was 25 meters on July 18 and 19 meters on each of the other sampling dates.

Several assumptions were made when using this system. First it was assumed that the net equally sampled all zooplankton in the lake and no species avoided capture. When using an 80 µm net it is understood that some organisms such as small rotifers will pass thru the netting. There will also be a certain number of organisms that stick to the mesh. Finally, when subsampling there is the possibility that very low-density species will not be detected.

Results

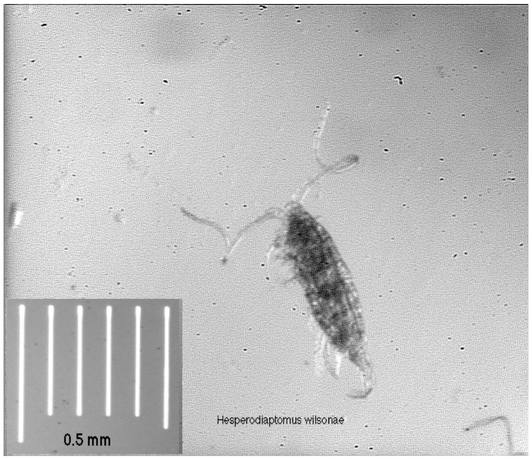
Species identification -The following keys were used for species identification: Ward and Wipple (1959), Pennak (1989) and K. Smith and C.H. Fernando, (1978).

Hesperodiaptomus wilsonae. By far the most abundant zooplankton species in Zealand Pond, this calanoid copepod was identified using Smith and Fernando (1978). The identifying characteristics of this species are:

Terminal setae of caudal ramus nearly equal in length, fourth not different from others……*Diaptomus*

Antennule of female (male left) with 2 setae on 11th segment

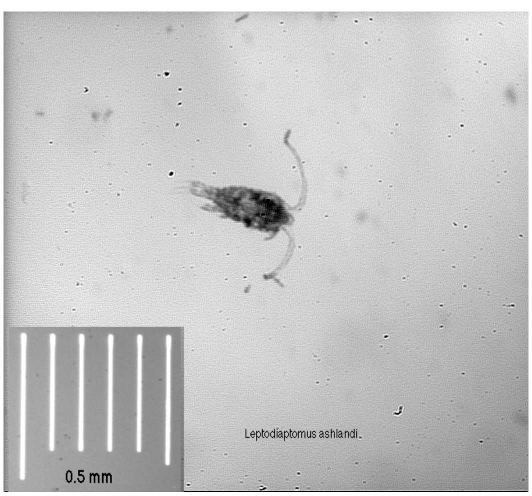
Setae on segments 17,19,20,22 of antennule not hooked…..
Hesperodiaptomus wilsonae



Hesperodiaptomus wilsonae
(scale=0.5mm)

Leptodiaptomus ashlandi. A small calanoid species that is fairly difficult to identify. Using Smith and Fernando (1978) these are the identifying characteristics:

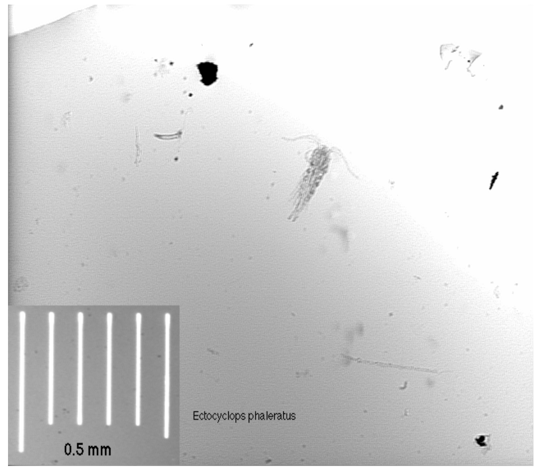
Antepenultimate segment (#23) of male right antennae with distal process
Process reaching to middle or beyond next segment
Process is slender in width and has a blunt or rounded apex
Right exopod of male 5th leg lacking hyaline process on inner distal face. Insertion of lateral spine about one third of the length of segment (difficult to see)



Leptodiaptomus ashlandi(scale=0.5mm)

Ectocyclops phaleratus. A cyclopoid species identified using Ward and Wipple (1959). Once identified as a cyclopoid the following characteristics will lead to species:

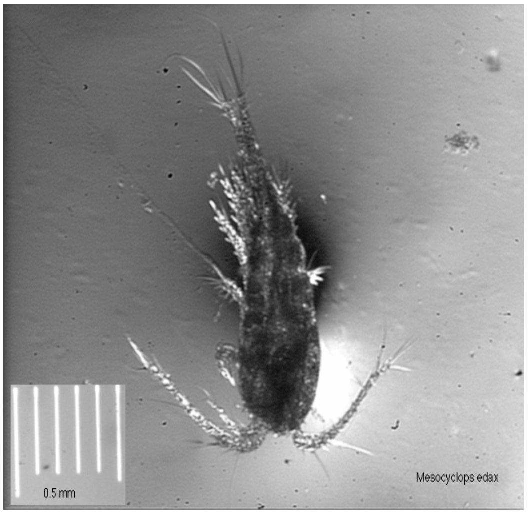
Leg five not distinct from 5th metasomal segment (very hard to see) and armed with 2 strong inner spines and an outer setae
First antennae usually of 11 segments, sometimes 9 or 10



Ectocyclops phaleratus (scale=0.5mm)

Mesocylops edax. A cyclopoid species identified using Smith and Fernando (1978). This species was very large, in comparison with the other zooplankton, but had a lower abundance. Identifying characteristics include:

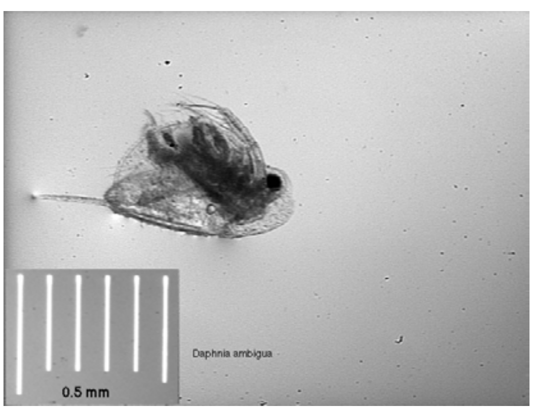
Antennule of 17 segments
Caudal ramus less than 4 times as long as broad (usually 2 to 3 times)
Antennule with hyaline membrane
Inner most terminal setae of caudal ramus usually long (more then 2 times) relative to outer most terminal setae
Lateral setae insert about half way to the apex of caudal ramus......*Mesocyclops*
Branches of caudal rami very divergent—inner margin usually hairy
Distal segment of antennule with sharply notched hyaline membrane
Connecting lamella of 4th leg with small rounded protuberances
Distal segment of 5th leg with spine on mesial border longer then terminal setae (hard to see).....*Mesocyclops edax*



Mesocyclops edax (scale=0.5mm)

Daphnia ambigua. A small, round headed, cladoceran species identified using Pennak (1989).

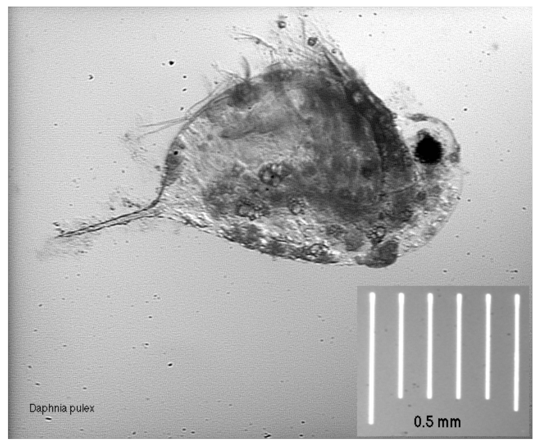
Rostrum present....DAPHNIDAE
Posterior spine usually present
Without cervical sinus....*Daphnia*
Median line of head shield continues along middorsal line onto carapace
Teeth of all 3 claw pectin about same size
Swimming hair at base of second of 3 segmented ramus extends beyond tip of ramus
Ocellus absent
Swimming hair of antennae not extending beyond posterior margin of valves.



Daphnia ambigua (scale=0.5mm)

Daphnia pulex. A cladoceran species identified using Pennak (1989).

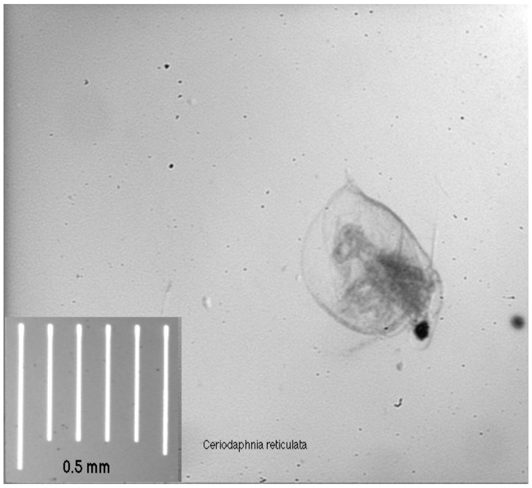
Rostrum present....DAPHNIDAE
Posterior spine usually present
Without cervical sinus....*Daphnia*
Teeth of proximal and middle pecten of postabdominal claw larger than teeth of distal pecten
Teeth of middle pecten of postabdominal claw stout, largest at least 3 times as long as teeth of distal pecten
Ocellus present
Ventral margin of head concave, optic vesicle touching margin of head
Without antennal mound
Spinules of ventral margin closely spaced
Tip area of rostrum with roughly polygonal markings
Marginal denticles of postabdomen extending slightly less than half of the length of the postabdomen



***Daphnia pulex* immat.** (scale=0.5mm)

Ceriodaphnia reticulata. A cladoceran species identified using Pennak (1989). Identifying characteristic are:

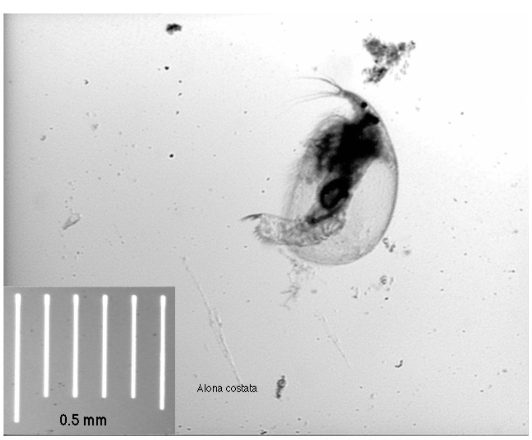
Rostrum absent
Antennules small, head small and depressed
Head without a spine....DAPHNIDAE, *Ceriodaphnia*
Claws with pecten



Ceriodaphnia reticulata (scale=0.5mm)

Alona costata. A littoral/benthic species of cladoceran identified using Pennak (1989).

Anus on dorsal side of abdomen
Compound eye present, eye and ocellus of usual size
Posterior margin of valves not greatly less than maximum height
Claws with out secondary tooth in middle
Rostrum not greatly exceeding antennules, narrow and pointed near tip
Ventroposterior angle with out teeth
Postabdomen with out clusters of large spines
Postabdomen with both marginal and lateral denticles, marginal denticles not markedly longer distally.....*Alona*
Less than 14 marginal denticles
Anal groove of post abdomen unarmed
Female postabdomen with about 12 subequal marginal denticles

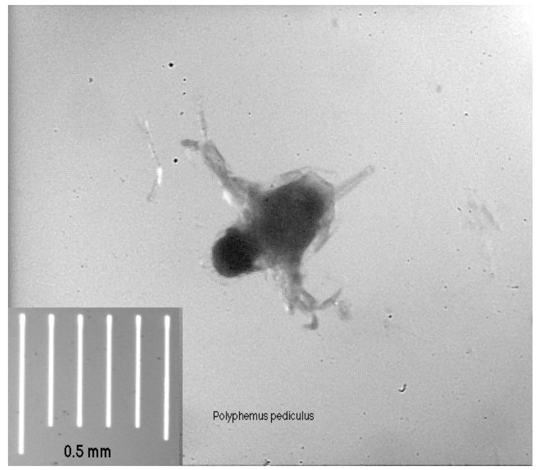


Alona costata (scale=0.5mm)

Polyphemus pediculus. A littoral cladoceran species keyed out using Pennak (1989).

Identifying characteristics are:

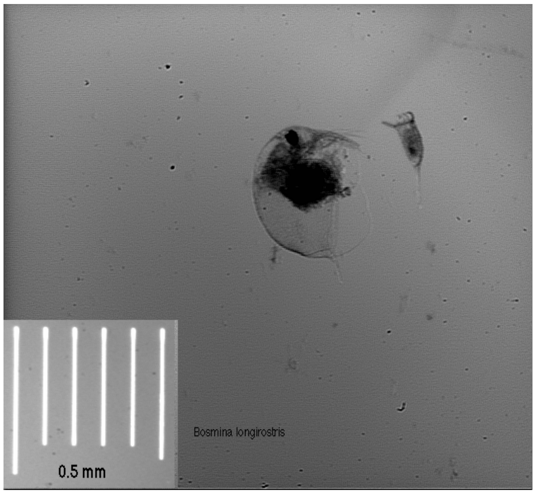
Body short, four pairs of stout legs bearing branchial appendages
These are easy to identify, usually larger then other zooplankton, brown in color and have a large brown eye....POLYPHEMIDAE, *Polyphemus pediculus*.



Polyphemus pediculus (scale=0.5mm)

Bosmina longirostris. An cladoceran species identified using Pennak (1989). *Bosmina* have a body shape distinct from other cladoceran and once identified as *Bosmina* the following steps will identify this particular species:

Antennules of female fixed
Intestine simple....BOSMINIDAE
Female postabdominal claw with fine distal pecten (has proximal as well)
Front sensory bristle near mid point between eye and rostrum.



Bosmina longirostris
Keratella taurocephala (scale=0.5mm)

Diaphanosoma brachyurum. A cladoceran species identified using Pennak (1989). This species has an easily recognizable body form.

Having carapace
Antennae of female biramous and
flattened....SIDIDAE
Dorsal ramus of antennae two segmented
Without lateral expansions on antennae
Without spines on postabdomen
Ocellus absent....*Diaphanosoma*
Head not more than half valve length
Eye anterior.

Diaphanosoma brachyurum
(scale=0.5mm)

Keratella taurocephala. A rotifer species of the class monogonata and order Ploima, keyed out using Pennak (1989). The identifying characteristics of this organism are:

One or two or no posterior spines
With six short to medium anterior spines,
but highly variable
Dorsal surface of lorica with pattern of
polygonal facets
Cyclomorphic with 20 species (pictured with
Bosmina longirostris).

The rotifer *Conochilus* was occasionally seen but not enumerated

Physical and chemical data-All of the data collected are presented in Appendix 1. This information has been included so that precise numbers and data points can be referred back to if they are of interest for future research.

Alkalinity, pH, temperature, conductivity, and dissolved oxygen are each represented by bar graph which draws attention to any change which may have occurred over the sampling period (Figures 1-5).

Temperature fluctuations in the sampling period ranged from the greatest temperature of 21.5 ^{o}C in July to a low of 18 ^{o}C in August. The temperature decreased over the sampling period with the exception of August 1 and August 18 when the temperature remained the same

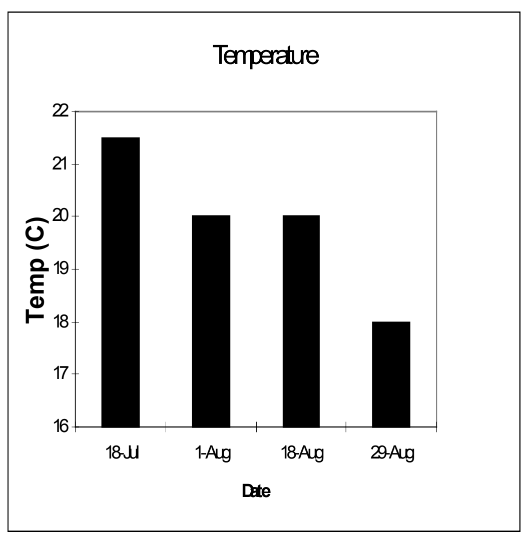


Figure. 1 Temperature of Zealand Pond, NH, July thru August 1997.

Dissolved Oxygen data were not collected on July 18. Titrations for the remaining dates yield results varying between a low of 6.5 mg/l on August 1 to a high of 8.6 mg/l on August 18.

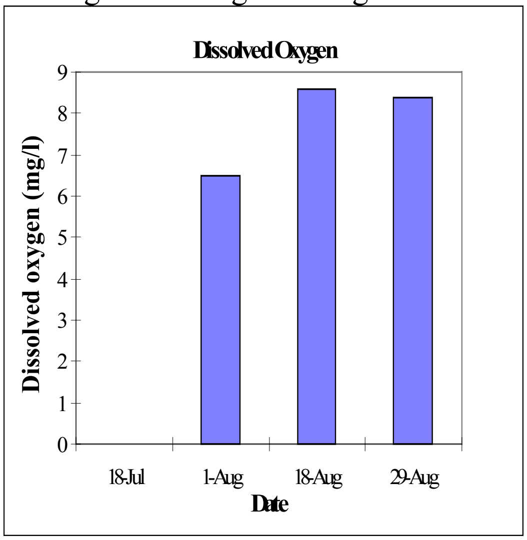


Figure 2. Dissolved Oxygen for Zealand Pond, NH, July thru August 1997.

ANC was quite low and varied slightly, ranging from a high value of 3.12 mg/l $CaCO_3$ on August 18 to a low of 2.34 mg/l $CaCO_3$ on July 18.

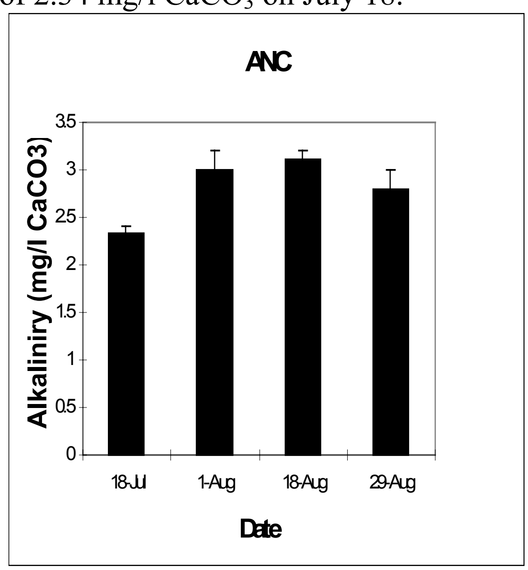


Figure 3. Acid Neutralizing Capacity for Zealand Pond, NH, July thru August 1997.

Conductivity (corrected for 18^{o}C) remained fairly constant over time with values between 19.9µS and 20.0µS. The exception to this was August 29 when conductivity increased to 22.0 µS.

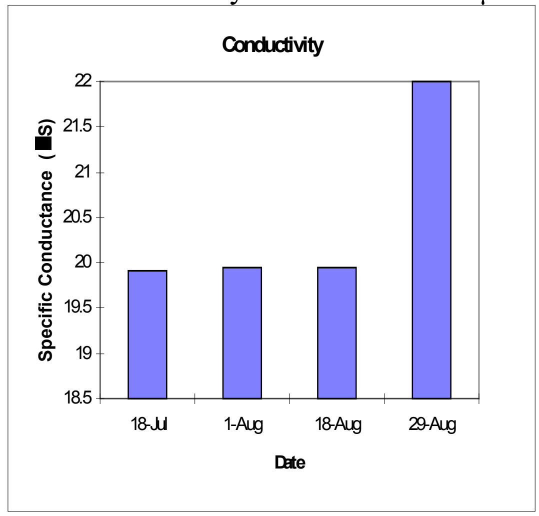


Figure 4. Specific Conductance for Zealand Pond, NH, July thru August, 1997.

The pH of this system ranged from 6.3 on July 18 to 6.9 on August 18.

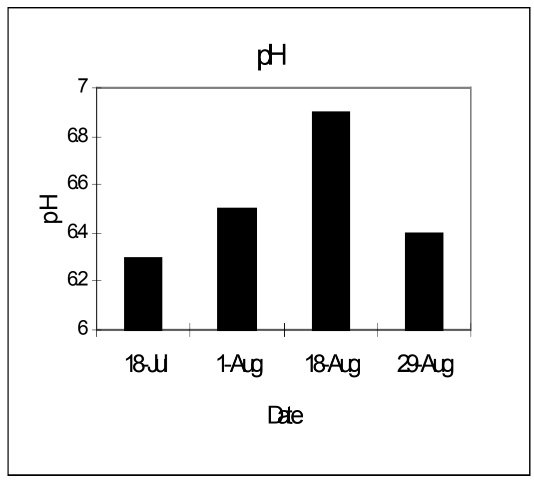


Figure 5. pH of Zealand Pond, NH, July thru August 1997.

Zooplankton graphs are included so that population dynamics can be observed over the sampling period. The lakes two cyclopoid species are represented by Figure 6. No *Mesocyclops edax* were detected on August 1; highest densities of this animal, 0.16 per liter, were recorded on July 18. *Ectocyclops phaleratus* were most numerous on July 18 as well with

0.29 per liter and least abundant on August 29 when none were dectected.

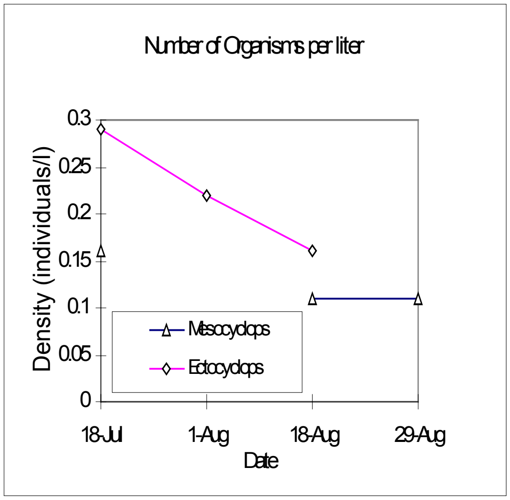


Figure 6a. Densities of *Mesocyclops edax* and *Ectocyclops phaleratus* in Zealand Pond, NH, July thru August 1997.

Leptodiaptomus ashlandi and *Hesperodiaptomus wilsonae* were the two calanoid species found in Zealand Pond. *Hesperodiaptomus* was clearly the dominant zooplankter in Zealand Pond with densities ranging between 57.6 per liter on August 1 to 27.1 per liter on July 18 (Figure 7). *Leptodiaptomus* was considerably less abundant, ranging from 4.2 per liter on August 1 to zero dectected on August 29.

Daphnia ambigua, *Daphnia pulex*, *Ceriodaphnia reticulata*, *Polyphemus pediculus* and *Alona costata* were graphed together because of their similarly low densities. *Daphnia* were observed in low densities, between

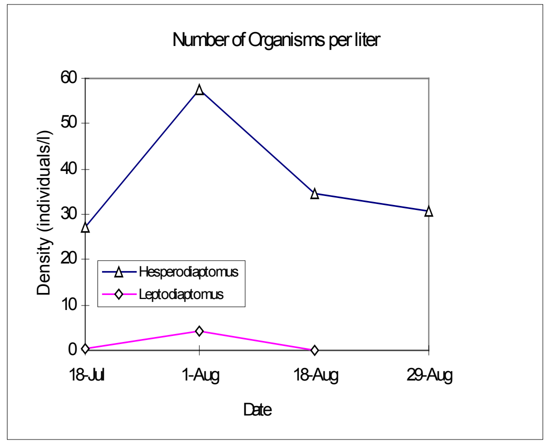


Figure 7. Densities of *Hesperodiaptomus wilsonae* and *Leptodiaptomus ashlandi* in Zealand Pond, NH, July thru August 1997

0.05 and 0.11 per liter, only on the final two sampling dates. Both species of Daphnia were combined in Figure 8. *Ceriodaphnia* were found only on August 18 with 0.05 individuals per liter. *Polyphemus* were present each sampling date except for August 18 and had densities ranging from 0.26 per liter on August 29 to 0.11 per liter on August 1. *Alona* was the least abundant cladoceran with densities of 0.04 per liter and 0.05 per liter on July 18 and August 1 respectively (Figure 8).

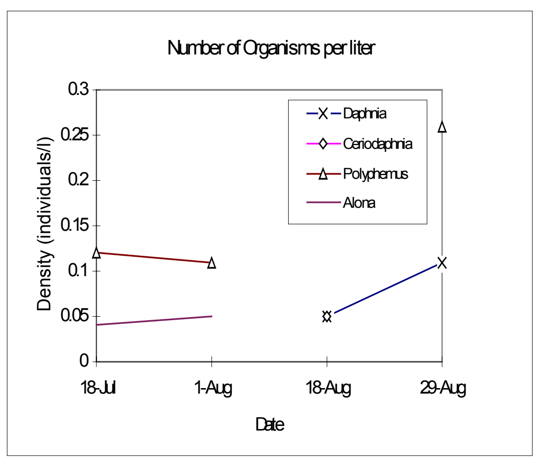


Figure 8. Densities of *Daphnia spp.*, *Ceriodaphnia reticulata*, *Polyphemus pediculus* and *Alona costata* in Zealand Pond, NH, July thru August 1997.

Diaphanosoma brachyurum densities ranged from 2.39 per liter on

July 18 to 0.16 per liter on August 29. *Bosmina longirostris* were most abundant on August 18, 4.14 per liter and least abundant on July 18, 0.89 per liter (Figure 9).

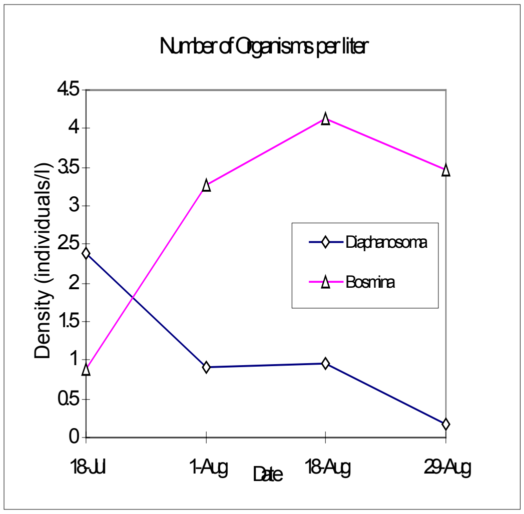


Figure 9. Densities of *Bosmina longirostris* and *Diaphanosoma brachyurum* in Zealand Pond, NH, July thru August 1997.

Discussion

Water Chemistry-Zealand Pond had extremely low concentrations of dissolved solutes, as indicated by the low specific conductivity (19.9-22 μS), typical of unpolluted lakes in the White Mountains. The lake does not seem to be highly sensitive to acidification and had surprisingly high pH (6.3-6.9) and alkalinity (2.3-3.1 mg/liter), considering its small size and elevation. This suggests that it receives some buffering from the watershed, such as runoff from the surrounding soil, an underlying bedrock or nutrient recycling from the sediments.

Variations in weather may explain some of the variability in water chemistry. Noticeable variations were seen for several of the physical parameters on August 18th. This day was particularly windy and may be the cause for increase in dissolved oxygen as well as the lower temperature. The wind was stirring the surface of the lake and may have introduced more oxygen into the water as well as cooling the water. August 29th was also a rainy, windy day and it had been rainy at least one day prior to sampling. The increase in conductivity on this date may have been due to an increase in hydrogen ions carried into the water by rainfall. Dissolved oxygen on this date was also high and may again be the result of the lake surface being stirred. Temperature decreased, probably from an influx of cold rain as well as the cooler air temperature..

Fluctuations in water level may have affected the physical and biological balance of Zealand Pond as well. In the short sampling period of this study there was a noticeable water level drop of approximately 6-8 cm between July 18 and August 1. Due to rain on August 29 the water level was again higher.

Zooplankton-The zooplankton community of Zealand Pond was diverse with six cladoceran species, four copepod species and two rotifer species. The number of cladoceran species found in Zealand Pond was considerably greater than that of other high altitude systems. For example Zealand Pond had 10.0 species, Lakes of the Clouds, NH, had 4.0 species (Buchanan, 1974), Montane ponds in the Colorado Rocky mountains averaged 4.75 species (Patalas,1964) and subalpine ponds in the Canadian Rocky Mountains averaged 3.94 species (Anderson, 1971). It should be noted, however, that the lakes and ponds listed above are located at much greater elevations then Zealand Pond. At 752 m ASL Zealand Pond could be considered a high elevation lake in New Hampshire, but this elevation is much lower than that of western alpine lakes. The relatively high species richness may be explained by the correlation between species diversity and elevation, with lakes at lower altitudes containing greater numbers of zooplankton species (Anderson 1971). It would be of significant interest to investigate other remote ponds in New Hampshire at altitudes similar to that of Zealand Pond to test whether this pattern generally holds. There have been few studies on remote lakes in the state and further data on similar systems would allow for more accurate comparisons between systems.

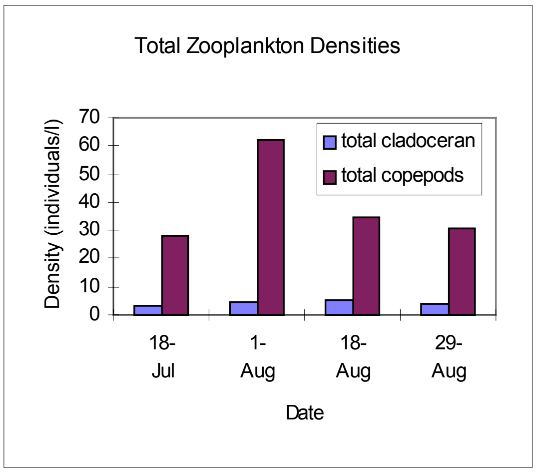


Figure 10. Total zooplankton densities, Zealand Pond, NH, July thru August, 1997

Zealand Pond had a greater number of cladoceran species, but the densities of copepods far out numbered all cladocerans combined. It should also be noted that the abundance of zooplankton species in Zealand Pond were not evenly represented since the dominant zooplankton, *Hesperodiaptomus wilsonae*, was approximately one hundred times more abundant then any other species.

Anderson (1971) found that in the high altitude lakes and ponds of Western Canada the number of copepod species was always greater than the number of cladoceran species (population densities were not reported). In two later studies (1972) he confirmed that, with regard to density, copepods dominated these systems. A similar dominance of copepod species was also observed in Zealand Pond (Figure 10). In a study of the Lakes of the Clouds, New Hampshire's highest altitude lakes at 1542 meters, (5059 feet ASL), the number of cladoceran species was higher than the number of copepod species and the density of cladocerans was greater than that of the copepods (Buchanan, 1974). The dominance of cladocerans in Lake of the Clouds may be due to the absence of fish. Since fish are visual feeders, larger zooplankton such as cladocerans are preferred prey items and their populations will be suppressed where fish are present. Also, copepods swim faster and are better adapted to avoid fish predation (Lampert and Sommer 1997). Thus, it is possible that the fish population of Zealand Pond has a strong influence on the composition of the zooplankton community. Although no fish were seen in the lake they were observed in the northern outlet stream and are assumed to have access to the lake. Also, New Hampshire Fish and Game Department occassionally stocks the lake with Eastern Brook Trout. According to Anderson (1980), large numbers of *Hesperodiaptomus* are rarely seen when there is heavy fish predation. Thus the fish populations in Zealand Pond are probably fairly low considering the high density of *Hesperodiaptomus* upon which they likely feed.

Based on general knowledge of the species present in Zealand Pond a preliminary model of the structure of the zooplankton community can be constructed (Figure 12). A more thorough study would be necessary to understand the precise food web interactions. *Hesperodiaptomus* are a predatory species known to feed on rotifers as well as on other small copepods and calanoids (Anderson 1980). Because they are predatory, *Hesperodiaptomus* may limit population growth and diversification of other zooplankton species in Zealand Pond. *Leptodiaptomus* are the major phytoplankton grazers in the lake. Cyclopoid species (*Ectocyclops* and *Mesocyclops*) are predatory or omnivorous, feeding on other crustaceans and organic debris. Cladoceran species present in Zealand Pond are filter feeders, consuming algae, protozoans, bacteria and organic detritus.

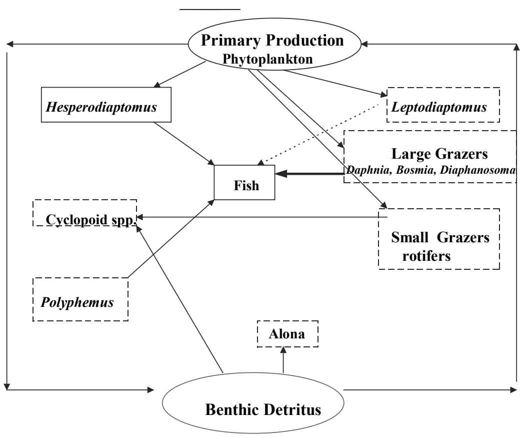


Figure 12. Model of Zealand pond foodweb interactions.

The study presented here was designed to provide baseline data on the biological and physical parameters of Zealand Pond. It is an initial study and more detailed investigations are needed to better understand the condition of the lake and it sensitivity to change.

Figure 11. View of Zealand Pond looking north, indicating sampling site (X).

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