Abstract

Zooplankton biomass, distribution and abundance are of extreme importance in aquatic systems. They maintain a crucial role as the second trophic level of aquatic habitats in allowing energy to flow up the food web. Zooplankton are also very sensitive to changes therefore make ideal indicators of a healthy water system. Any disturbance, such as nutrient enrichment, fish introductions, thermal discharges, or toxic effluents that alters the composition of the zooplankton community could ultimately affect the rest of the system (Balcer 1984). This study surveys lakes and bogs for which records show no data regarding dominant zooplankton or were lacking basic water analysis. Results found Cyclopoid Copepods and Calanoid Copepods are the most common zooplankton species in the surveyed Lakes and Bogs. Ziesnis Bog and Cranberry Lake showed the most variance in zooplankton containing unique species not found in the other areas surveyed. Significant correlations of component loadings from a principal components analysis (PCA) of zooplankton distributions across locations with water analysis data revealed statistically significant trends of pH, temperature and dissolved oxygen (DO) in relation to location and zooplankton biomass. The data obtained in this study will be a useful aid for management of the studied aquatic systems and for future limnology researchers.

Introduction

Aquatic systems are best understood by identifying the individual components of an ecosystem and examining their relations (Balcer et al. 1984). Zooplankton are heterotrophic microscopic animal like protists that feed on phytoplankton, making them primary consumers. They are often overlooked but critical to maintaining aquatic food web foundations by being the second trophic level in most aquatic environments and given that some aquatic insects, larval fish and some adult fish feed on zooplankton, they play a very important role in transferring energy across the food web (Sladecek 1958).

Because of their short life cycle, zooplankton respond quickly to environmental changes in their aquatic environments and are therefore often used as indicators of overall health or condition of their habitats (Thorp *et al*. 1991). Not only are zooplankton influenced by their water quality, they have a profound influence on certain non-biological aspects of water quality, such as pH, color, odor, taste, etc. (Carrick *et al*. 1997). In complex ways, zooplankton can speak to the condition of the water and can be used to assess overall lake or bog health.

Zooplankton play a critical role in sustaining aquatic systems. They are widely studied in many bodies of water and their use as ecological indicators has become more important recently due to the increasing human population and industrial growth which have produced a trend of increasing eutrophication and raised concerns about declining water quality in lakes. As a result of these concerns, in 1972 the United States and Canada signed the Great Lakes Water Quality Agreement as an expression of each country's commitment to restore and maintain the chemical, physical and biological integrity of the Great Lakes Basin Ecosystem (Tuchman 2005).

Because abundance of zooplankton is an indicator of a healthy body of water determining the biomass, distribution and abundance of zooplankton will aid in managing each of the lakes and bogs on the University of Notre Dame Environmental Research Center (UNDERC) property. UNDERC is located in the Upper Peninsula of Michigan and Wisconsin. The lakes and bogs on UNDERC property were created after the final glacial recession (Laurentide or Wisconsin Glaciations) at the end of the Pleistocene, approximately 10,000 years ago (Balcer 1984)

Many of the lakes and bogs on the UNDERC property have been surveyed for dominant zooplankton types and assessed for basic water characters such as pH and dissolved oxygen

(DO). Few lakes on UNDERC property are among the most studied environmental systems in the world (Carpenter 2001) Other lakes, however, remain unstudied and basic zooplankton surveys have never been recorded.

This study surveyed lakes and bogs for which records show no data regarding dominant zooplankton types or were lacking basic water analysis, or both. This study recognized that zooplankton are microscopic aquatic life forms having little or no resistance to currents and are therefore free floating or suspended in open or pelagic waters (Thorp *et al.*, 1991). While some forms of zooplankton move by vertical migration, their horizontal position is mostly determined by current movements of the body of water they inhabit (Balcer et al. 1984).

Oligotrophic lakes (nutrient-poor and oxygen rich containing relatively little plant life or nutrients), eutrophic lakes (oxygen content depleted by organic nutrients) and dystrophic (acidic and supporting little biodiversity) bodies of water are all expected to vary in biomass, distribution and abundance of zooplankton communities. Outcomes of this survey add basic information on the aquatic communities located on the UNDERC property and may shed light on relationships between abiotic aquatic characters and the second trophic levels of those systems.

Materials and Methods

Initial research of the available University of Notre Dame Environmental Research Center records found no single resource or database of all lakes and bogs together with water chemistry characteristics and dominant zooplankton present in those water bodies. Another factor taken into consideration were values recorded for some lakes and bogs being an inconsistent collection having data collected in different years by different researchers with different tools (Elser 1987, Carpenter unpublished, UNDERC unpublished, Francl 2004).

Therefore, the available data on the basic water chemistry of lakes and bogs as well as a survey of the dominant zooplankton on which those lake and bog communities rely was found to be incomplete.

This study explored lakes and bogs for which dominant zooplankton communities remain unknown, each of which also needed basic water analysis performed or updated. Choice of lakes and bogs used in this proposed study was made by coupling the need for a current pH reading for the body of water with the need for a zooplankton survey on that lake or bog. There are other lakes and bogs still needing either water analysis or zooplankton surveys, but those included in this study needed both. The bodies of water included in this study were: Bergner Lake, Crampton Lake, Cranberry Lake, Firestone Lake, Moccasin Lake, Mullahy Lake, Nansen Lake, Plum Lake, Doughnut Bog and Ziesnis Bog (Figure 1).

Water analysis was conducted using portable instruments to measure pH, water temperature, conductivity, dissolved oxygen (DO) and a Secchi disk. All measurements were recorded at locations within each lake or bog and averaged for use in analysis. Exact location that were selected to best represent the body of water. For example, on Plum Lake, (area = 225.9 acres; Johnson, 1997), four measurements were taken in different corners of the lake (one in the East, West, North, South) and the fifth in the approximate center of the Lake (Figure 2).

All plankton were collected at approximately the same time of day in an attempt to minimize bias between locations and to maximize collection sampling using a plankton tow net at all locations. Thirty meters of surface water at each sub site was sampled allowing a volume of 2.121 m^3 to be sampled (volume of a cylinder = (3.14) (radius) 2(height or length of sample) to be tested: V = (3.14) (0.15)2(30 m), V = 2.121m^3). The zooplanktons from each sample (per water body) were preserved in a labeled jar containing an equal volume of 100 ml of ethanol as a control, until identification could be made.

Zooplankton identification was performed in a laboratory and individuals were identified as specifically as possible. Forty milliliters of each (well-mixed) original 5 samples from each water body samples were used for zooplankton assessment. A 2ml sample was then taken with a pipette and placed into a small Petri dish divided into 36 squares. Use of dishes allowed a greater surface area to volume ratio in order to identify all zooplankton in the 2 ml samples and provided a systematic way to count the sample, preventing recounting or miscounting zooplankton. This procedure was replicated five times to give a total volume of 10 ml sub sample and five replicates for each location. The abundance of each sample was then converted to number of organisms per 2 ml.

Numerical Taxonomic Systematics (NTSYS)-pc version 2.02i explained variance in zooplankton data by using Principal Components Analyses (PCA). Descriptive statistics and correlations were performed using SYSTAT 11 for each location in order to characterize the major groups of zooplankton present and their relative abundance in each system. Correlations were calculated by independent variables being water quality values for different lakes/bogs and dependant variables being presence of and density measures of zooplankton groups in those locations.

Results

Zooplankton Survey

PCA combined all factors and fit any extreme data points to explain the most variance in the data set by showing a linear relation when plotted. The first Component (best fit variance) explained 23% of the variance correlation in the data. Component 2 (second most variance) combined with Component 1 showed trends of 42% of the variance correlation in the data. Component 3 (third most variance) combined with Component 1 and 2 showed a correlation value of 58% trends.

Numerical Taxonomic Systematics (NTSYS) ran principal components analysis (PCA) of the combined zooplankton and location data. In PCA of Component 1 (23% of the three total variance was explained) 3 locations were found with low loadings. Cranberry Lake (-0.4890), Moccasin Lake (-0.3647), and Plum Lake (-0.2898) these aquatic habitats support little variance in biodiversity of zooplankton. The zooplankton species that correspond to these locations share a loading on the negative end of the axes. The most significant zooplankton species are Cyclopoid Copepods (-0.4967), *Diaphanosoma birgei* (-0.4668) and Calanoid Copepods (-0.4152). Ziesnis Bog(1.2384) has a high correlation being the farthest right on a positive axis. Zooplankton species that share a trend of appearing on the positive end of the axis are *Holopedium gibberum* (0.9098), *Mesocyclops edax* (0.9074), Chydoridae Alona (0.9074), and *Daphinidae ceiodapnia* (0.9074) (Figure 3).

PCA of Component 2 explained 19.31% of the variance found significant trends in two locations found on the negative end of the axis. Moccasin Lake (-0.4403) and Plum Lake (-0.3786) share a biodiversity of zooplankton species such as Cyclopoid Copepods (-0.4544), Calanoid Copepods (-0.4580) and *Bosmina longirostris* (-0.3922). Cranberry Lake (1.1121) appeared on the far right of the axis. Zooplankton species sharing a high correlation with positive loadings include *Diaphanosoma birgei* (0.8023), *Latonopis occidentalis* (0.8891), *Limnocalanus macrurus* (0.8891) and *Epischura lacustris* (0.8891) (Figure 3).

PCA of Component 3 explained 16.11% of the variance and revealed no clear patterns.

Water Analysis

Eight lakes and two bogs were surveyed in five locations that best characterized the body of water. Of these lakes, Crampton , Moccasin, Plum and Bergner were found to be oligotrophic (nutrient-poor and oxygen rich containing relatively little plant life or nutrients). Donut Bog, Firestone Lake, Mullahy Lake and Nansen Lake were found to be eutrophic (oxygen content depleted by organic nutrients). Cranberry Lake is in transition to becoming eutrophic. Ziesnis Bog represented a dystrophic bog (acidic and supporting little biodiversity) (Table 1).

Correlation analysis (performed in SYSTAT 11) performed a Bartlett Chi-square using the averages of water chemistry data found Component 1 to have a statistically significant correlation between temperature (= 0.014) and DO (= 0.054). Component 2 was statistically correlated to pH (= 0.014). There were no significant correlations (all $p > .1$) between Component 3 and any of the water analysis data (Figure 3).

Discussion

The PCA percent values explain the most variance on the graph axis and are greater than expected showing that there are significant patterns in the data. The data supports trends in relative zooplankton biodiversity abundance. However more replicates would be needed to obtain comparisons that would fully statistically support or reject the data.

Cyclopoid and Calanoid Copepods are the zooplankton species that showed the least amount of variance in that they are the most abundant and common in the aquatic habitats surveyed. These species reproduce producing several generations each year this is a major contributing factor to their surveyed biomass.

Cranberry Lake and Ziesnis Bog have some zooplankton species that do not overlap with the other locations. Daphinidae Ceiodapnia are unique to Ziesnis Bog and are generally found only in the summer and fall, this species over winters as resting eggs and perform limited vertical migrations (Balcer *et al*. 1984). Zooplankton that are unique to Cranberry Lake *include Latoropsis occidentalis, Limnocalanus macrurus and Epischura lacustris*. *Latoropsis occidentalis* is rarely found in the Great Lakes region. Bioassays show that the copepod *Limnocalanus macrurus* is sensitive to high chlorine concentrations that are often found near the cooling water outflows of power plants (Balcer et al. 1984). This is a limiting factor for other zooplankton species, however chlorine concentrations were not tested in each aquatic habitat and further research would have to be performed to understand the relationship between this zooplankton species and their biomass to Cranberry Lake. *Epischura lacustris* is usually found in the upper waters of stratified lakes where food is most abundant (Balcer et al. 1984).

To fully understand why these zooplankton species are not found in the other aquatic habitats surveyed more replicates would need to be performed over a longer seasonal time frame as these zooplankton species have different breeding and life cycles. Knowing this, the zooplankton survey is bias towards those who are mature in early July.

Correlation analysis found that abiotic factors such as temperature, DO and pH were a limiting factor in the zooplankton species found in each surveyed lake and bog. Zooplankton are sensitive to these components and different species require different abiotic components. (figure 3)

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Figures