Report for 2002MN7B: BIODIVERSITY IN URBAN PONDS AND LAKES: HUMAN EFFECTS ON PLANKTON POPULATIONS

There are no reported publications resulting from this project.

Biodiversity in urban ponds and lakes: human effects on plankton populations

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Summary

The objectives of this project are to explore the diversity of planktonic algae and zooplankton in small inland lakes and to describe how planktonic diversity is affected by urban development. We employed stratified random sampling using GIS as a tool and identified 100 sampling sites within the seven-county Twin Cities metropolitan area. We then sampled each of these sites three times during the 2002 growing season for phytoplankton and zooplankton communities, as well as basic limnological parameters including chlorophyll and phosphorus. To date, almost all plankton samples have been processed (only 1/3 of the phytoplankton samples remain to be enumerated under the microscope). We have found differences in biodiversity between urbanized and non-urbanized regions, with lower summertime zooplankton and lower spring and summer phytoplankton biodiversity in the urban regions than in the outer regions. Based as they are on a rigorous, random, site selection process, we believe these to be the first results documenting an effect of urbanization on these organisms.

Introduction

This project is addressing two sorely neglected aspects of water resources research: 1) urban habitats and 2) biodiversity of small, inconspicuous species. There is wide recognition that biodiversity is an important aspect of water quality, yet on several critical fronts, we lack sufficient scientific underpinning to incorporate biodiversity into most assessments of water quality. First, there is little scientific data on effects of different environmental factors on biodiversity of small aquatic organisms. Second, there has been little attention paid to the water resources closest to the large proportion of today's society that lives in urban environments. By undertaking serious study of biodiversity in urban ponds and lakes, this project seeks to establish whether the combined influences of urbanization are deleteriously affecting the majority of the biodiversity within those habitats.

The sustainability and integrity and of our water resources are threatened by many human-induced factors. Twenty six percent of total terrestrial evapotranspiration and fifty four percent of runoff that is geographically and temporally accessible are used by humans (Postel et al. 1996). Important contributing factors to reduced water quality due to human effects – well known to all who have an interest in water quality – include

increased nutrient loading and sedimentation, acid rain, and contamination by heavy metals and other toxicants. Though much is left to learn about these factors, significant scientific advances have been made on all of these fronts. However, it is becoming increasingly clear that reduced biodiversity ranks among the most critical problems in management of aquatic ecosystems (Naiman et al. 1995), and here our knowledge base is much weaker.

Most discussions of biodiversity center on terrestrial habitats such as rain forests. However, biodiversity is even more threatened in aquatic ecosystems than in terrestrial ecosystems (Naiman et al. 1995). Approximately 20% of the world's species of freshwater fish have declining abundance or are already extinct (Moyle and Leidy 1992). The Environmental Defense Fund has estimated that 30-70% of several major aquatic groups, such as mollusks and fishes, are threatened. Maintenance of aquatic biodiversity has been identified as a freshwater research priority second only to restoration and rehabilitation of aquatic habitats (Naiman et al. 1995). Local and global extinction of aquatic species may come about through overt habitat change or loss, such as river impoundment, excessive nutrient loading, and drainage of aquatic ecosystems. Although habitat loss and degradation are probably most damaging to aquatic biodiversity, other potentially important threats include exploitation of commercial species and introduction of exotic species. Biodiversity loss may also be caused by chronic introduction of substances such as sediment or nutrients that alter the habitat. Further, it may occur due to introduction of novel predators, such as the Nile Perch in Lake Victoria, or due to highly successful exotic species that capitalize resources, such as Eurasian Water Milfoil or the zebra mussel.

Shifts in human demographics affect water resource pressures. The human population is becoming increasingly urbanized. Approximately 41% of the world's human population now lives in urban areas. There are 411 cities worldwide with over 1 million human inhabitants. However, until recently ecologists have avoided urban areas for research (McDonnell and Pickett 1991), and only recently have they begun serious examination of urban habitats as unique, important ecosystems. Examining species relationships along rural to urban gradients can be extremely useful, because doing so address practical, applied questions while also providing insight on basic questions regarding the structure and function of ecosystems (McDonnell and Pickett 1991). Although limnologists have not shied away from addressing important practical problems, the bulk of their research has been conducted on non-urban sites. As the human population continues to encroach on and urbanize habitats, the importance of understanding the effects of human disturbance on aquatic species and ecosystems will increase.

Methods

For site selection previous to any sampling, we split the seven-county Twin Cities metro area into three zones: an urban core, a surrounding, less urban ring, and the nonurban outskirts; these zones were based on land use and percent impervious surface. For the present report, the two urban zones have been combined into a single zone, and we will contrast the inner urbanized zone with the surrounding zone (Fig. 1). To choose sites, we randomly distributed points within each zone and then we used a combination of GIS and ground searching to identify the nearest permanent (containing water year-

round) pond or lake to those random points. The urban area is centered between St. Paul and Minneapolis while the nonurban area contains some of the outer-ring suburbs and the agricultural land up to the seven-county boundary. Fifty ponds or lakes are located within both the urban habitat and the nonurban habitat (total = 100 sites). These lakes range from small to large (0.003 – 5667 ha) and from oligotrophic to hyper-eutrophic (0.126 – 21.4 µM TP), yet lake size and TP does not differ significantly with urbanization (Fig. 1B,C). Some of these lakes are surrounded by parking lots while others are in protected areas. During the 2002 ice-free season we sampled each lake 3 times: in the early spring, mid summer, and late fall. At each sampling we took standard limnological measurements such as chl a, total phosphorus, dissolved phosphorus, seston phosphorus, and seechi depth. We also preserved composite algal and zooplankton samples.

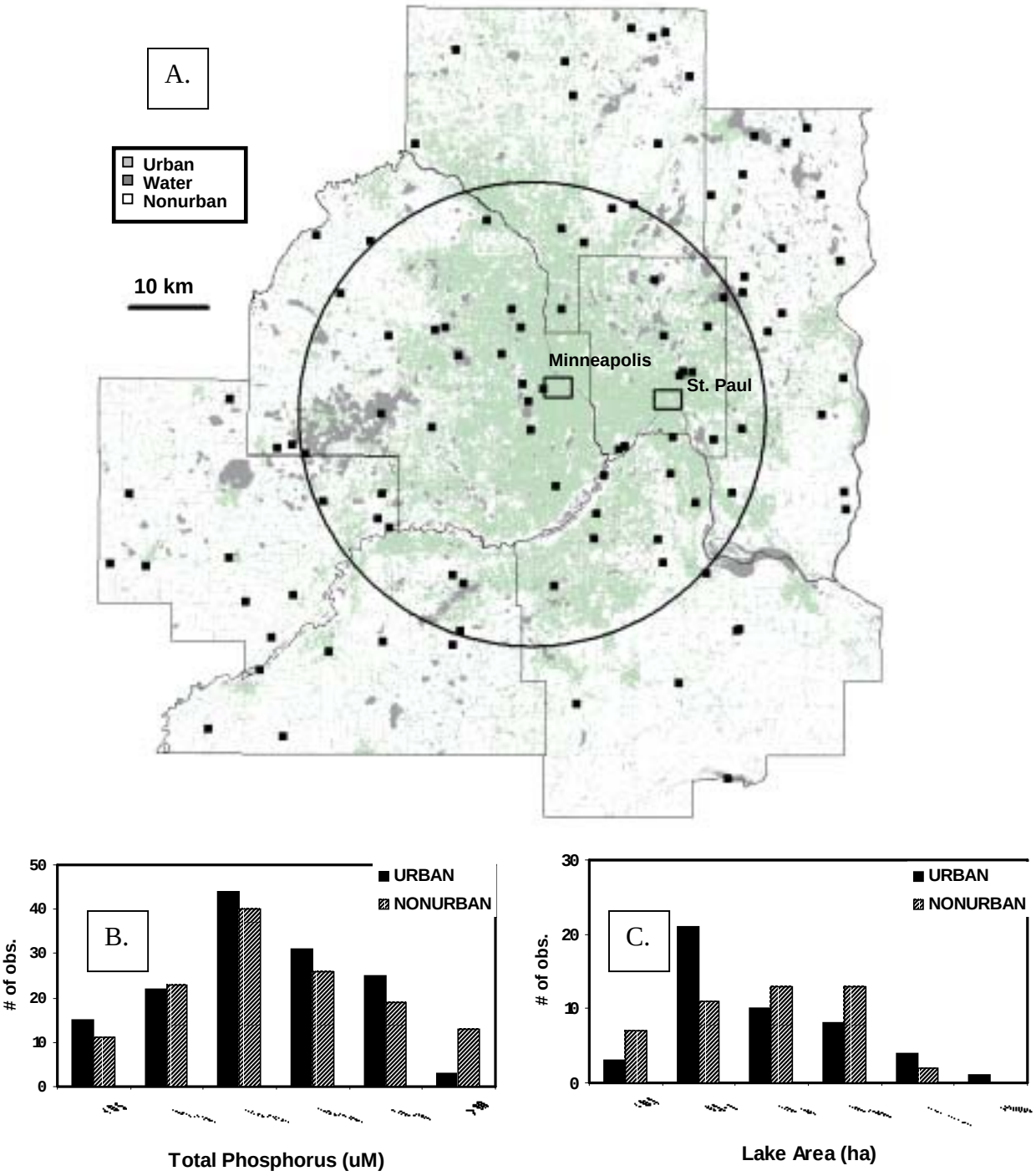

Fig. 1. A. Map of study sites. County boundaries are indicated. The heavy black circle demarks our division of “urban” and “non-urban” zones. This boundary does correspond to a fairly steep gradient in land use (“urban” land use is indicated by gray). There are fifty sites, selected randomly, within each of these two zones. B. Differences in lake fertility, as measured by total phosphorus, were minor between the two

regions. There were more lakes with very high phosphorus levels in the non-urban region. C. There were somewhat more sites in the 0.1-1 ha size classification in the urban region than the non urban. Other differences in lake size between the two zones were minor.

Phytoplankton samples were preserved with Lugol's iodine and stored at 4 °C in the laboratory. For species identification, we took a 10 ml subsample from each of the preserved samples and let the phytoplankton cells settle overnight in a 10 ml settling chamber. The samples were then observed under an inverted light microscope at x 400. Magnification of 1000x was also used when further details were needed for species identification. Phytoplankton cells larger than 5 microns in any dimensions were identified at least to the genus level and to the species whenever possible, and their counts were recorded for each of the six 250 μm x 250 μm fields of view, which were randomly selected. Filamentous algae, however, were counted if a trichome was longer than 5 μm, and the number of cells within a trichome was estimated by dividing the length of the trichome by the representative length of each cell. Some of the samples had a large number of cells and/or debris of algal or macrophytic origin, making accurate cell counts difficult. In those cases, the subsamples were diluted tenfold with deionized water before settling. We enumerated the zooplankton samples to species. To avoid bias associated with sampling effort we invested a similar quantity of effort in each sample. One 1 mL Sedgwick-grafter cell was counted per lake.

For both phytoplankton and zooplankton, we calculated the Shannon diversity index to evaluate species diversity for each sample.

To look for differences in diversity between regions, we tested frequency distributions using a Komolgorov-Smirnov test or using simple t-tests. For more detailed multivariate analyses, we used the Indicator test of Dufrene and Legendre (1997) to assess the influence of urban versus non urban watersheds on individual species. This test compares the frequency of occurrence and abundance of species between lakes in the urban and non urban categories, and identifies species that vary more between the two groups of lakes than would be expected by chance. We tested significance of each species as an Indicator of either lake group using permutation tests (1,000 permutations) (Dufrene and Legendre 1997). Because *P*-values associated with Indicator tests are based on data-dependent permutation procedures, there are no requirements for underlying data distributions. Indicator tests were performed using PC-ORD for Windows (McCune and Mefford 1997).

We also used indirect gradient analysis to summarize relationships among abundance and occurrence of individual species, urban and non urban lakes, lake size and depth, and species diversity and richness. We used correspondence analysis (CA) because preliminary ordinations with detrended correspondence analysis showed gradient lengths of 4 standard deviations, indicating a unimodal response model was most appropriate (ter Braak 1995). Following ordination of site and species scores, we developed a triplot using the ordination results and lake size, lake depth, species richness, and species diversity of individual lakes. Finally, we used canonical correspondence analysis (CCA) to test the statistical significance of relationships between community composition of zooplankton and urban/non urban watersheds, lake maximum depth, and lake surface area (ter Braak 1986). We used step-wise forward selection to determine whether watershed type, lake depth, and lake area (independent variables) were related to zooplankton community structure, and the significance of each variable was assessed

using permutation tests (1,000 permutations) (ter Braak and Verdonshot 1995). We maintained an overall error rate of $P < 0.05$ by applying sequential Bonferroni corrections to the results of the significance tests (Rice 1990), and restricted our final analysis to independent variables with significant marginal and conditional effects. We then developed a triplot using species scores, lakes scores, and vectors for significant independent variables. Vectors for species richness and species diversity were developed post CCA to assess relationships of these variables with the variables listed above. CA and CCA were performed using CANOCO (ter Braak and Smilauer 1998). So far, we have utilized multivariate analyses only on the zooplankton data.

Results to date

We have observed land-use effects on biodiversity both for phytoplankton and for zooplankton. For phytoplankton, both the spring and summer communities showed noticeably lower biodiversity in the urban zones (Figs. 2 and 3). Fall samples are not yet enumerated. We have not yet performed more detailed species-level analyses on the phytoplankton data.

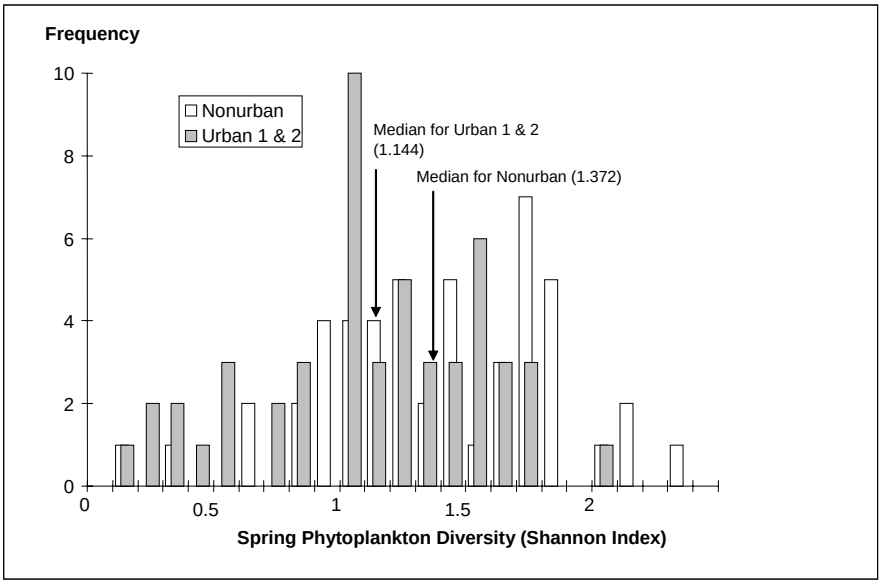

Figure 2. Spring phytoplankton biodiversity in the two regions. The differences were statistically significant.

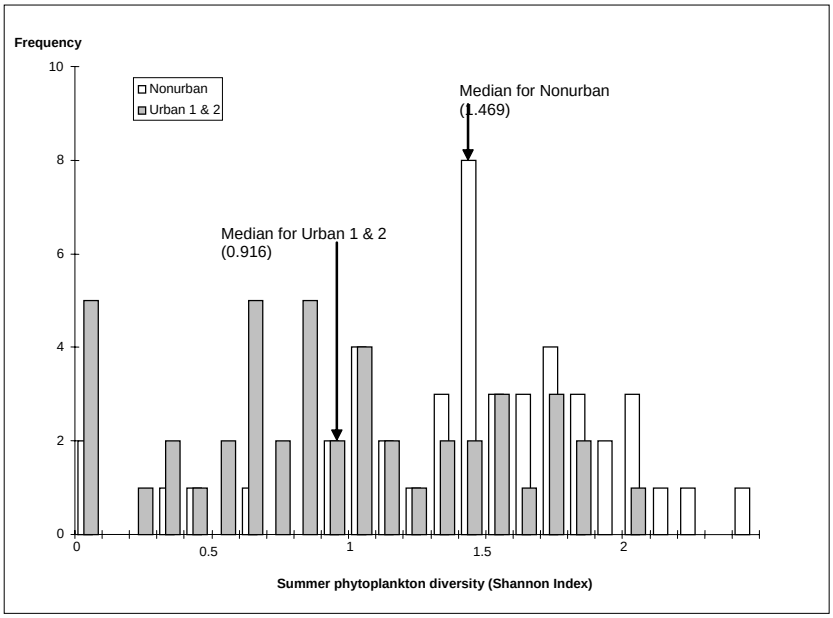

Figure 3. Summer phytoplankton biodiversity in the two regions. The differences were statistically significant.

For zooplankton, our results indicate that urbanization does decrease zooplankton diversity during the summer (K-S test: $p < 0.05$, Fig. 4). However, our urban and nonurban categories do not explain the variance in spring or fall zooplankton diversity.

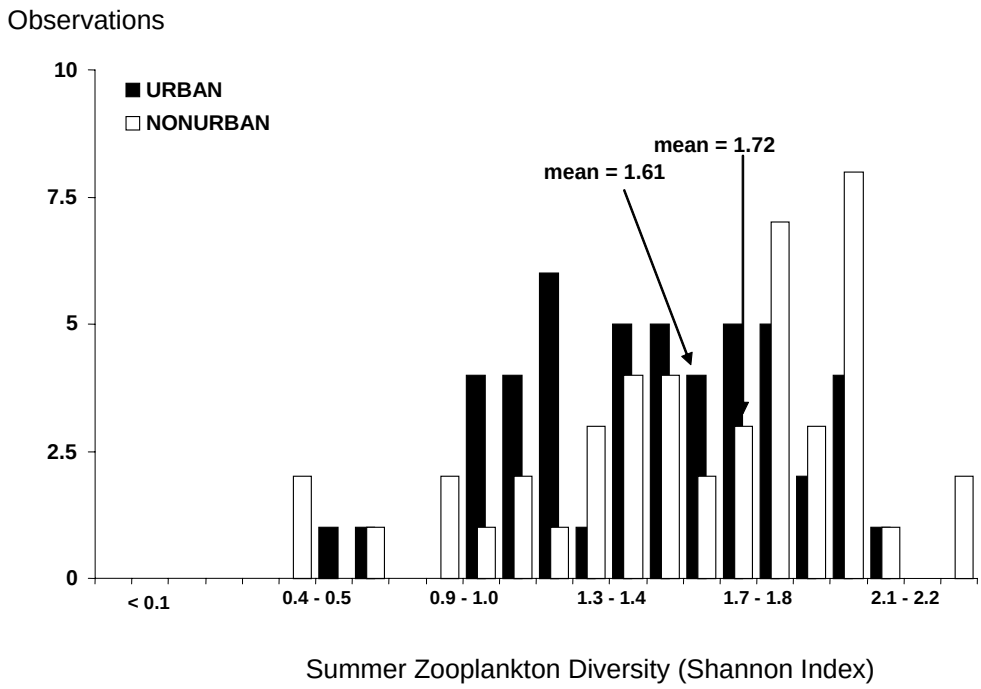

Figure 4. Summer zooplankton biodiversity in the two regions. The differences were statistically significant.

We have begun to explore whether lake or pond size or trophic status are predictors of biodiversity. For the zooplankton, we did not see any strong effects of size or productivity on biodiversity. We also performed a single preliminary comparison of zooplankton vs. phytoplankton diversity across sites and again did not see any relationships. These results are provisional and need to be repeated in more detail and with all the phytoplankton data once collected.

Indicator tests, which test whether certain species or groups of species are more sensitive to urbanization, showed that 7.5% of all species on the second sampling date were significant indicators for lakes with either an urban or non urban watershed (Table 1). Of the 12 significant species, 7 were more abundant and occurred more often in non urban sites, while 5 were observed in greater numbers and more frequently in urban sites.

CA results indicated variability in the average scores for urban and non urban lakes: non urban lakes scored higher on axis 1 and lower on axis 2, while urban lakes scored closer to the origin of both axes (Fig. 5). The difference in average lake scores reflects differing community composition between the two types of lakes; many species scored very high on axis 1 and very low on axis 2, indicating high affinity for non urban sites. In contrast, few species scored high on axis 2 and low on axis 1, which would have indicated high affinity for urban sites. Thus, the overall trend was a greater proportion of species showed higher abundance and occurrence in non urban sites than vice versa, while other species were equally common in both habitats. The vector for species diversity also indicated higher values in non urban lakes, while species richness showed a much weaker relationship with watershed type. Vectors for lake depth and area indicated a strong positive relationship between these two variables, but the opposing direction of these vectors with vectors for richness and diversity indicates strong negative relationships. A few species showed greater abundance and occurrence in larger, deeper lakes, but most species were more abundant and more common in shallower systems.

Forward selection in CCA indicated that urban/non urban watersheds ($P = 0.036$) and maximum depth ($P = 0.003$) both explained a significant amount of variation in the zooplankton data, while lake size did not ($P = 0.750$). The CCA triplot using watersheds and maximum depth supported the results of CA (Fig. 6). Some species scored between urban and non urban lake scores, indicating equal abundance and occurrence between lake types. However, more species had scores very close to site scores for non urban lakes compared to species scoring close to urban lakes, indicating many species are more abundant and more common in non urban sites. Scores for species diversity and richness (determined post CCA) were also closer to the scores for non urban sites, reflecting higher values compared to urban lakes. Finally, a few species showed a strong, positive relationship with lake depth, but the vast majority showed a strong negative relationship with depth. Overall, these results indicate that the abundance and occurrence of most species, as well as species richness and diversity, will be highest in shallow lakes in non urban watersheds.

Table 1. Significant indicator species for non-urban watershed (A) and urban watershed lakes (B). The difference in abundance and frequency of occurrence between urban and non urban lakes for these species is greater than expected by chance, and is higher in non urban and urban lakes for species in group A and B, respectively. P values represent the proportion of random permutations that generated differences in abundance and frequency of occurrence equal to or higher than the observed values.

Species	*P* value
(A) Indicator species for non-urban land use	
Belloid rotifer	0.004
Euchlanis dilatata	0.031
Filinia longiseta	0.013
Lecane signifera	0.023
Monostyla lunaris	0.011
Monostyla quadridentata	0.047
Mytilinia ventalis	0.004
(B) Indicator species for urban land use	
Kellicottia bostonienses	0.042
Keratella cochlearis	0.048
Keratella cochlearis faluta	0.020
Brachionus quadridentatus	0.046
Trichocerca lata	0.007

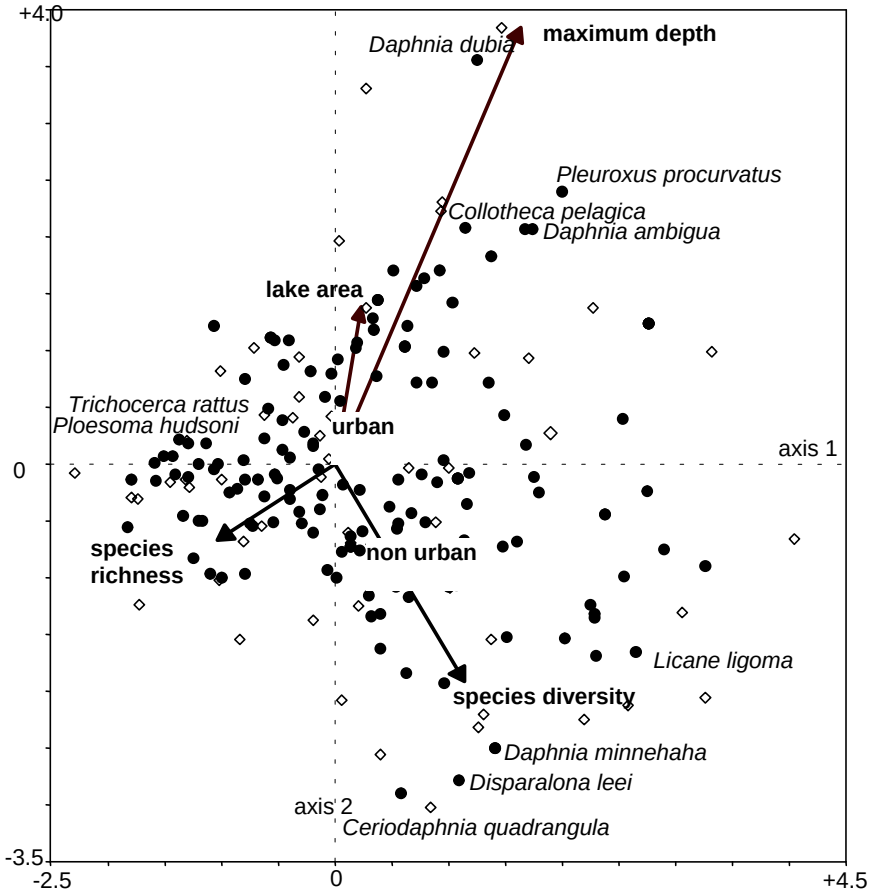

Figure 5. Triplot showing results of correspondence analysis of the second sampling date. Diamonds show scores for individual lakes and maximize the dispersion of the species scores. Average scores for urban and non urban lakes are indicated by text. Scores for individual species are shown as solid circles, and indicate the location of maximal abundance and frequency of occurrence across the lake scores. Arrows are vectors for the respective variables and point in the direction of increasing values; longer vectors indicate stronger relationships with the lake scores. Individual taxa represent examples of species associated with deep lakes with lower diversity (upper right), shallow lakes with lower diversity (middle left), and shallow lakes with higher diversity (lower right).

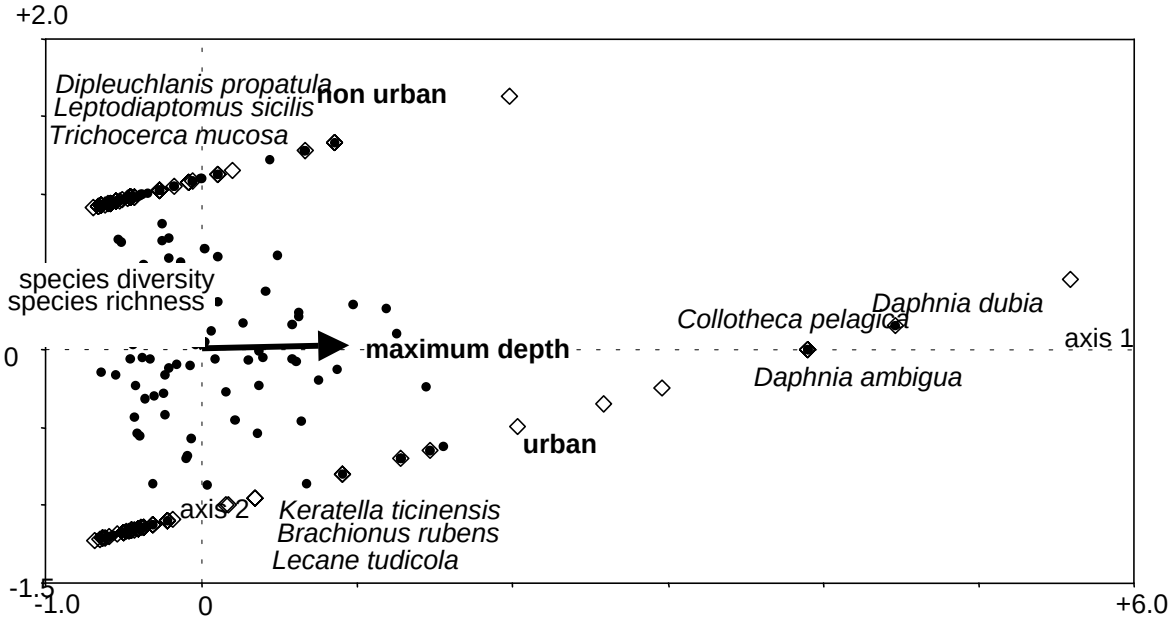

Figure 6. Triplot showing results of canonical correspondence analysis (CCA) of the second sampling date. Diamonds show scores for individual lakes and maximize the dispersion of the species scores, while also showing the relationships among species scores, lake type, and maximum depth. Scores for individual species are shown as solid circles, and indicate the location of maximal abundance and frequency of occurrence across the lake scores and in relationship to lake type and maximum depth. The arrow for maximum depth points in the direction of increasing values. Vectors for species richness and diversity were determined post CCA and also point in the direction of increasing values. Land use and maximum depth both explained a significant amount of variance in the zooplankton data.

Ongoing work

This project was designed to elucidate patterns in biodiversity in the Twin Cities metropolitan area. The patterns we've observed now naturally raise the question of what causes plankton biodiversity to tend to be lower in the central part of this region than in the outskirts?

The effects of human influence on diversity will very widely depending upon the type of human influence; while diversity also differs naturally according to factors such as large-deep lakes or small-shallow ponds. We have initiated two projects to tease apart the human effects on diversity from natural differences in diversity. First, we are determining the land use immediately surrounding each of the 100 study lakes, using GIS maps. With the land use surrounding each lake, we can investigate the effects of different types of human impact, such as urbanization and agriculture. In addition, land use information may help us understand high diversity urban lakes; for example, lakes protected in large urban parks. Second, we are collecting data on macrophyte abundance. This data will help us separate differences in diversity driven by human influence from those related to the habitat and cover provided by macrophytes.

Summary of findings

This study has demonstrated very rigorously that lakes and ponds with the central, more urbanized, portion of the Twin Cities metropolitan regions support a lower

planktonic biodiversity than sites within the more peripheral locations outside of the heavily urbanized core. Our preliminary analyses indicate that these differences cannot be ascribed to differences in habitat size (area) or productivity between the two regions.

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Publications and Presentations

None to date.

Statement of related grants submitted or funded as a result of this project

A proposal to the NSF Ecological Diversity competition is being prepared for the July 15, 2003 deadline.

Description of student training provided by projects

This project has provided salary and research support for Kiyoko Yokota, a Ph.D. student in Ecology, Evolution and Behavior at the University of Minnesota.