

4-2014

Using Zooplankton as Indicators of Environmental Quality to Inform Management of Small Lakes of Eastern New York

James P. Tucci

Follow this and additional works at: <http://digitalcommons.esf.edu/honors>

 Part of the [Aquaculture and Fisheries Commons](#), and the [Other Animal Sciences Commons](#)

Recommended Citation

Tucci, James P., "Using Zooplankton as Indicators of Environmental Quality to Inform Management of Small Lakes of Eastern New York" (2014). *Honors Theses*. Paper 48.

Using Zooplankton as Indicators of Environmental Quality to Inform Management of Small
Lakes of Eastern New York

by

James P. Tucci
Candidate for Bachelor of Science
Environmental Forest Biology
With Honors

April 2014

APPROVED

Thesis Project Advisor: _____
John M. Farrell

Second Reader: _____
Brandeis Brown

Honors Director: _____
William M. Shields, Ph.D.

Date: _____

Abstract

Zooplankton play an integral role in the function of aquatic food webs and may serve as indicators of productivity, biodiversity and ecosystem health. The objective of this study was to determine if zooplankton quality (based on total lipid content) and community structure are associated with physical and chemical variables that can be used as indicators of environmental quality among small lakes in eastern New York State. A diversity of small lakes in eastern New York State (n=25) were sampled for zooplankton with vertical tows (153um mesh nylon) and 50 individuals were identified, enumerated and total lipid was determined for each lake. Lake physical variables were also collected including: dissolved oxygen, pH, conductivity, shoreline development, secchi depth, nutrients (i.e. total dissolved phosphorous, silica), residential density, and percent forest cover. Highly correlated environmental variables were identified using a Pearson correlation matrix. Significant correlations ($p < 0.0001$) included, depth and temperature, percent forest cover and conductivity, and residential density and conductivity. Canonical Correspondence Analysis (CCA) showed that particular zooplankton species exhibited associations to percent forest cover, residential density, and overall size of body of water (Monte Carlo Test, 998 permutations; $p = 0.02$). Specific lakes were identified with associations based on their zooplankton community composition suggesting linkages to the environmental variables. Lake associations with environmental variables were then related to zooplankton quality (total lipid) with no observable trends. Based on associations of zooplankton with percent forest cover, lake managers should consider buffer zones and limiting anthropogenic inputs directly adjacent to water resources.

Table of Contents

	Page
Acknowledgments.....	I
Introduction.....	1
Materials and Methods.....	2
Results.....	5
Discussion.....	8
Lake Management Recommendations.....	12
References.....	14
	Appendix
Study Region (Figure 1).....	16
Zooplankton CCA (Figure 2).....	17
Lake CCA (Figure 3).....	18
Zooplankton Presence in Lakes (Table 1).....	19
Zooplankton Diversity Indices (Table 2).....	20
Zooplankton Subsample Data (Table 3).....	21
Pearson Correlation Matrix for Variables (Table 4).....	22
Monte Carlo Test Results (Table 5).....	23

Acknowledgements

I would like to thank my research advisor Dr. John Farrell for all of his assistance with this project. In addition I would like to thank Brandy Brown for all of her guidance and hours dedicated to this research. Furthermore, Dr. Kim Schulz and Dr. Mark Teece for their input and access to laboratories, Dr. Kevin Kapuscinski for statistical aid, Jesse Crandall and Ceili Bachman for their assistance with laboratory analysis and Gillian AvRuskin for her GIS expertise. Finally I'd like to extend my gratitude to all the lake associations and parks that allowed me to sample their respective lakes.

Introduction

Zooplankton play an integral role in the function of aquatic food webs and may serve as indicators of productivity, biodiversity and ecosystem health (Attayde & Bozelli 1998). It has been shown that zooplankton can be used to determine the planktivore to piscivore ratio within a water body (Mills et al. 1987). They have also been used as indicators of acidic or saline conditions (Derry et al. 2003) and for elucidating area of anthropogenic impact (Dodson et al. 2005). Through increased human development there is an expected nutrient influx which has been shown to elicit changes in zooplankton community responses (Dodson et al. 2005). Additionally, zooplankton lipid content can serve as an indicator of algal food source quality (Art et al. 1992). The quality of this food has been the subject of studies with the goal of using lipid to determine zooplankton condition (Gulati & Demott 1997).

Habitat variables such as lake stratification establish a density difference that inhibits some zooplankton species from vertical movements (Klumb et al. 2004). Lakes that do not stratify with an epilimnion and hypolimnion would be expected to have differing communities than those that do. For this reason it is an important variable to note in the analysis.

The objective of this study was to determine if zooplankton quality (based on total lipid content) and community structure are associated with physical and chemical variables that can be used as indicators of environmental quality among small lakes in eastern New York State.

The analysis of the zooplankton community structure and the relationship to local environmental variables will serve as an important baseline for residents in the study region. Other parameters such as chemical, nutrients, and morphological features serve as potential candidate variables for lake monitoring by resource managers and residents. Most of the lakes on this region have not been adequately sampled. The identification of important variables that structure zooplankton communities as proposed in this research will aid in a better understanding of these systems and serve as a baseline for assessing their future condition.

Materials & Methods

Zooplankton Collecting and Processing

A total of 25 small lakes of a variety of types acceptable for the study based on size and access were sampled in the Rensselaer county region (Figure 1). Lakes were sampled late morning to mid-day between mid-June and mid-July. Sampling was completed in non-rainy and relatively calm conditions. Zooplankton were collected using a conical nylon 153um mesh net. Within each lake three vertical hauls were completed in the deepest region, composited and then split-half for identification and enumeration and half for total lipid analysis. For identification, the zooplankton were immediately narcotized with Alka-Seltzer and then preserved with 70% EtOH. For total lipid analysis zooplankton were sieved through 100um micron mesh and frozen.

In the lab, 50 preserved zooplankton per lake were identified to lowest taxonomic level possible through the use of a compound microscope using University of New Hampshire online key (Haney et al 2013). Cyclopoid copepods and cladocerans were identified to the species level, calanoid copepods were taken no further than calanoid, and rotifers were not included in this study. The first 50 organisms found in a 1 mL homogenized subsample in a depression slide were chosen for identification (additional 1mL aliquots were used if 50 organisms were not reached in the first). For lipid analysis, frozen zooplankton were desiccated under a stream of liquid nitrogen. They were then analyzed using a modified Folch method for total lipid percentage. This involved using a DCM and methanol solvent to extract lipids which were centrifuged. The solvent was then extracted and placed in a corresponding vial to each sample. This procedure was repeated 3 times at which point the solvent was evaporated with compressed nitrogen gas and the remaining lipid in the vial measured (Folch et al. 1957).

Comparison of Zooplankton Assemblages

Zooplankton assemblage at each lake was compared on the basis of species richness, dominance, evenness, and diversity. Dominance was determined by the percentage of organisms

in each subsample that were represented by the three most abundant species within each lake (Dom3). Evenness was quantified using the Simpson's index and the Shannon-Weiner index was used to determine diversity. In Simpson's, D is Simpson's measure of concentration and P_i is the proportion of the total sample represented by the i th species. Both indices were calculated using the PAST program (Paleontological Statistics, 2001, version 2.1). Finally the percent of each community represented by the class Cladocera versus the class Copepoda was calculated.

$$\text{Evenness} = E_D = \frac{D}{D_{max}} = \frac{1}{\sum_{i=1}^S p_i^2} \times \frac{1}{S} \quad \text{Shannon} = H' = - \sum_{i=1}^R p_i \ln p_i$$

Environmental Variables

Using a YSI multi-probe, the vertical profile of each lake at 1 meter intervals was obtained in the deepest region of each lake. Environmental variables collected included; conductivity (S/cm), pH, temperature (C), Dissolved oxygen (D.O., mg/L), D.O. percent saturation, and depth. For each lake and variable the average of all 1 meter measurements were computed as an overall mean (e.g. all measurements of pH in the water column were averaged together). A Secchi depth (0.1m) was obtained within each lake at this point as well.

Additionally, a 500mL sample bottle was filled with water at 1 m depth in the center of the lake and then frozen for total phosphorous and total silica analysis. Total phosphorous and total silica concentration for all lakes was analyzed using a spectrometer and a standard curve (Strickland & Parsons 1972). Various physical parameters for each lake were also collected to aid in the grouping of lakes. Using images collected from Google earth with an overlaid 1 km marker the following variable were determined in ImageJ (Image J; 1.46r); shoreline development (how convoluted or circular the lake is), size (acres), residential density (roofs within 100 meters of shoreline/acre) and percent forest cover (each lake assigned into a category, 0-33%, 34-66%, 67-100% forested).

All environmental variables collected (n=13; total phosphorous, total silica, maximum depth, size, residential density, shoreline development, Secchi depth, temperature, conductivity, pH, D.O., percent forest cover, stratification) were imported into SAS (Statistical Analysis Software, version 9.4) where a Pearson correlation matrix was used to determine if any of the variables were significantly correlated to one another (Steiger 1980). This was necessary for further analysis of the communities to eliminate potentially redundant data.

Relationship of Zooplankton to Environmental Variables

A Canonical Correspondence Analysis (CCA) was performed using the abundance data from each lake's 50 organismal subsample and the 13 environmental variables. This served to identify possible associations between zooplankton species and the sampled variables (Ter Braak & Verdonschot 1995). Length of vectors in the ordination indicates the strength of the variable. How closely the vector parallels the axis indicates how well the axis represents the vectors (Ter Braak & Verdonschot 1995). For analysis, percent forest cover was assigned a 1, 2, or 3 depending on which of the afore mentioned categories the lake fell into, lake stratification was indicated with either a 1 for stratified or a 0 for not stratified. In addition to the CCA, a Monte Carlo randomization test was run with 998 iterations to test the significance of the species environment correlation and the significance of eigenvalues associated with the primary axis ($\alpha=0.10$). The CCA (row and column scores standardized by centering and normalizing, scaling of ordination scores = optimize columns: Response, scores for graphing = SmplUnit scores are linear combinations of Response) and randomization test were conducted in PC-ORD 6.0 (Kapusinski & Farrell 2013; methods). In addition to an ordination of the zooplankton and environmental variables, an ordination of the lakes was also produced. This second ordination included lipid content in the lake code to view how various lipid percentages associated by each zooplankton community.

Results

Comparison of Zooplankton Assemblage

In total, 24 zooplankton species were found across all the lakes. The presence or absence and the abundance of each species varied from lake to lake (Table 1). *Microcylops rubellus* was by far the dominant species sampled and was present in 23 of the lakes and composed approximately a quarter of all the individuals counted (Table 1). In Mill pond, for example, *M. rubellus* was highly prevalent and represented 98% of the subsample. This high prevalence reduced Mill pond's diversity, evenness and richness estimates relative to other lakes (Table 2). In contrast to Mill pond, Glass Lake represented the most diverse lake in terms of Shannon diversity, species richness, and it also exhibited high evenness. Glass Lake had a high proportion of large cladocerans such as species from the genus *Daphnia* and a relatively lower proportion of copepods (Table 2).

Seven species appear to be endemic based on their presence in only one of the lakes throughout the region. Each endemic species and the lake it was found in are; *Alona spp.* (Hampton Manor Lake), *Leydigia spp.* (Forest Lake), family Macrothricidae (Forest Lake), *Diaphanosoma brachyurum* (No Name One), *Eubosmina spp.* (Dyken Pond), *Daphnia parvula* (Dead Lake), and suborder Harpacticoeda copepod (Hedges Lake) (Table 3).

Environmental Variables

The Pearson's correlation matrix indicated strong correlations between; depth and temperature, percent forest cover and conductivity, and residential density and conductivity (Pearson correlation matrix, n=25, p<0.0001). Other select variables that were strongly correlated were; pH and secchi depth, size and shoreline development and pH and % forest cover (Pearson correlation matrix, n=25, p <0.002) (Table 4).

The CCA showed the four variables with the greatest zooplankton sorting power were percent forest cover, residential density, mean temperature, and whether or not the lake was

stratified (Figure 2). Residential density and stratification vectors opposed one another along the primary axis (horizontal). Mean temperature and forest cover vectors opposed one another along the secondary axis (vertical) (Figure 2). A Monte Carlo randomization test for the eigenvalues of the vectors showed significant correlation between the vectors and axis arrangement (998 permutations, $p < 0.092$) (Table 5).

Relationship of Zooplankton to Environmental Variables

The first ordination of the CCA places the zooplankton along the two axis based on associations with the 13 environmental variables. The proximity of the species labels indicates their environmental association similarities (Figure 2.) Various species group out together. The deep mesotrophic, intermediate forest cover and intermediate residential development species are represented by; *Daphnia mendotae*, *Daphnia pulex*, and *Diacyclops thomasi*. The forested, low density, cooler environmental associated species are represented by; *Daphnia ambigua*, *Holopedium gibberum*, and *Eubosmina spp.* The highly dense, warmer, low forested environmental associated species are; *Alona spp*, *Daphnia parvula*, both *Ceriodaphnia spp.*, and both *Diaphanosoma spp.* (Figure 2). A Monte Carlo randomization test outputted a significant correlation between the zooplankton species grouping and the environmental variables (< 0.023) (Table 5). *Microcyclops rubellus* as mentioned earlier was found in the majority of the lakes. On the CCA ordination this specie's label is located towards the middle of the vectors. This demonstrates a lack of preference towards the environmental variables.

Lake grouping based on Zooplankton Community

The second CCA ordination (Figure 3) places the lakes sampled between the axis in locations determined by their zooplankton communities. The closer the lakes are to each other the more similar the communities are to one another. Environmental variables are still included for convenience in viewing how the lakes are indirectly being grouped by the variables, directly through the zooplankton.

Lake labels in the ordination include total percent lipid content. The lipid content is viewed to determine if any patterns are seen between variables or zooplankton communities and a high or low lipid percentage. No noticeable pattern is observed from this data (Figure 3).

Discussion

Zooplankton Assemblage

Zooplankton species are shown to be highly reflective of the grazing pressures on them and the environment within which they are found (Vanni 1987, Dodson et al. 2005). In this study we see the larger species such as genus *Daphnia* (specifically *Daphnia pulex*), and larger copepods such as *Diacyclops thomasi* are predominantly found in the larger deeper bodied mesotrophic lakes. This gives these larger pelagic species refugia from young of year fish predation. No lakes in the study contain populations of super filter-feeder fish such as alewives otherwise it would be expected that the larger cladocerans would be in lesser abundance or not present (Mills & Schiavone 1982). The *Daphnia spp.* are seen in the deep mesotrophic lakes and not the more forested lower nutrient lakes most likely due to lower productivity of the water body. The lower nutrient and thus in turn lower phytoplankton production make it more difficult as a filter feeding zooplankton. Thus we can use the daphnids as relative indicators between our deep mesotrophic and partially oligotrophic lakes in this study.

The genus *Alona* has been affiliated with more anthropogenic impacted eutrophied bodies of water as is the case within our study (Van Egeren et al. 2011). *Alona spp.* was found in Hampton Manor Lake which is essentially a catchment pond for a residential area. The small lake sits in a valley and all the runoff from the region is directed into it. It is also a central gathering point for summer Canada goose (*Branta Canadensis*) populations which input a large amount of nutrients through fecal matter. These two factors may be the cause of large algal blooms in addition to dense beds of invasive Eurasian milfoil (*Myriophyllum spicatum*). The other smaller, eutrophic lakes including Dead Lake and No Name One both exhibited similar zooplankton communities to Hampton Lake. All three lakes were predominately composed of communities typified by small sized zooplankton likely due to the lack of deep pelagic refugia from fish predation. Even in the deepest portions of these lakes, aquatic plants reach the surface.

The two species *Holopedium gibberum* and *Daphnia ambigua* both were associated with highly forested lakes with low sources of anthropogenic impact. More specifically they both appear to prefer the more dystrophic (low nutrients, stained), tannic lakes such as Dyken Pond, Cranberry Pond, Dunham Reservoir and Hicks Pond. *Daphnia ambigua* is the smallest of the daphnids and has been noted to prefer the lower, cooler levels of the thermocline (Haney et al 2013). *Holopedium gibberum* is known to rely on allochthonous carbon sources such as terrestrial plant matter from tree leaves (Matthews & Mazumder 2006) and it was expected that *Holopedium* would dominate forested lakes in this study region.

Microcyclops rubellus was ubiquitous and found in nearly every lake. This species appears to be a generalist, capable of existing in all studied lake groups. Unfortunately, lack of available literature on this species makes understanding its life history difficult. However, it also could show that this study is valuable in establishing evidence of the generalist nature of the species. The other generalist species found in this study was *Mesocyclops edax*, which is another cyclopoid copepod species.

Collectively, the species found in this study are all typical of the environments with which they were found (Dodson et al. 2005). Notably, there were no invasive zooplankton species discovered in any of the lakes. Most of the smaller lakes included in the study are isolated, privately owned and lack public access. The larger lakes are also further away from potential sources of invasive species such as the Hudson River or St. Lawrence Seaway. This small private ownership and distance from sources has likely helped to maintain the natural species composition.

Relationship of Zooplankton to Environmental Variables

As observed by the first CCA ordination (Figure 2), the zooplankton species significantly related to the environmental variables. The Monte Carlo test showed that the 998 random runs with the species and variables were significantly different from random. This provides support to

the ecological differences between the species mentioned earlier. The species do in fact differ in abundance and presence depending on the conditions of the water body they are in.

Percent forest cover maintains cooler temperatures in the lake through shading, carbon input via leaf litter, and serves as a buffer to absorb excess nutrients into the lake (Teels et al. 2006). Thus it is not particularly surprising that it was a significant variable in this study. Residential density was inversely correlated to percent forest cover which is also not surprising as typically the more residents around the lake the more trees that are cut down. But in addition to this, conductivity was positively correlated to residential density. It could be assumed that the increased building of structures around the lake contribute to runoff during rain events and thus heighten the conductivity (charged ions from erosion, households, salts) from anthropogenic sources.

The other significant variable in the study, stratification, is mostly correlated with lake depths. The formation of the cooler, lower, hypolimnion and warmer upper, epilimnion is impacted by circulation associated with wind energy and water column depth. Deep and sheltered lakes are prone to more stable stratification patterns. The study shows that zooplankton respond to this stratification. Some species (*Daphnia ambigua*) reside in the cooler lower levels of the thermocline. Lakes that are not stratified do not possess as strong of a thermocline. The non-stratified lakes are also able to cycle nutrients from the bottom to surface waters all summer along, increasing productivity which we have shown changes the community.

Lipid Content as a Quality Indicator

Total lipid % of zooplankton was more variable than expected. The total lipid % did not associate well with any lake grouping or environmental variable (Figure 2). This suggests that use of total lipid from the whole zooplankton community in a lake does not effectively distinguish lake types. The high variability could be due to algal food source selection between cladocerans and copepods. The different preferences may result in varying high lipid content

seasonality (Art et al. 1992, Wainman et al. 1993). Since total lipids were measured across the community, species specific patterns could not be discerned and this could explain why communities with fewer cladocerans seemed to have relatively lower lipid percent.

Future studies should focus on a specific type of lipid such as fatty acids (DHA, ARA, or EPA) or on one particular zooplankton species found in most lakes (potentially *Microcyclops rubellus* as it was found in most lakes and in relatively high abundance). Specific fatty acids are more indicative of the food source for the zooplankton and would better incorporate that algal food base than total lipid (Ohman 1997). Phosphorous has been shown to correlate with lipid content indirectly through increased lake productivity (Berglund 2001). Therefore it is suggested that a greater emphasis be placed on phosphorous data for future studies in addition with the other suggestions.

Lake Management Recommendations

Fish stocking is commonly used as a tool used by lake managers theoretically to better the fishing experience. Many things should be considered prior to stocking a lake so as to ensure the integrity of the lake is retained and so as to not waste homeowner's funds. For example, residents wishing to stock their lake with fish should consider if there is a sufficient food base for fish being stocked and for their offspring. Some lakes in this study had extremely small zooplankton that clearly indicates heavy fish predation. Such lakes should not be further stocked. It is recommended fish community data be added to future analyses to better understand the relationships to zooplankton community patterns and lake environmental variables.

Hedges Lake was the only lake in this study with zebra mussels (*Dreissena polymorpha*). This species filters out the water column at comparatively high rates and as such results in clearer waters and benthification (concentration of nutrients towards the bottom of the lake where the mussels reside) (Zhu et al. 2006). Due to this Hedges had the greatest visibility of all the lakes in the study. Species composition within the lake would be expectedly different and probably more similar to the neighboring lake, Lake Lauderdale had these invasives not been introduced. Should residents seek to implement a management plan for the reduction or removal of zebra mussels they could use zooplankton community analysis as in this study to determine the relative success.

The most important implication from this project is the maintenance of a sufficient riparian buffer for lake ecosystems. Percent forest cover is shown to be a strong driver of the zooplankton community structure as such residents should consider a forested buffer for shoreline landscaping. Other options could include shrubs or flora that exhibit high nutrient retention and erosion control while still being aesthetically pleasing to the homeowner. The retention of nutrients terrestrially keeps algal blooms at a low and allows for more lucid waters. Fertilized lawns adjacent to water bodies provide a direct source of eutrophication and would be

better utilized further away or again with some form of buffer region (Teels et al. 2006). Having trees along the shoreline also aids in keeping lake temperatures cooler which in turn allows for a higher dissolved oxygen content and a less stressful environment for those aquatic organisms.

Lake residents and managers have a variety of goals in mind when it comes to their water bodies. Often it is sought to establish healthy, large sport fish, some wish for pristine waters for recreation, and still others seek to preserve native species and rich biodiversity. Regardless of what the end goal is zooplankton abundance and diversity contribute to the wellbeing of the lake.

References

- Arts, M., Evans, M., & Robarts, R. (1992). Seasonal patterns of total and energy reserve lipids of dominant zooplanktonic crustaceans from a hyper-eutrophic lake. *Oecologia*. Retrieved from <http://www.springerlink.com/index/X4227655P22T13G0.pdf>
- Attayde, J., & Bozelli, R. (1998). Assessing the indicator properties of zooplankton assemblages to disturbance gradients by canonical correspondence analysis. *Canadian Journal of Fisheries and ...*. Retrieved from <http://www.nrcresearchpress.com/doi/abs/10.1139/f98-033>
- Derry, a. M., Prepas, E. E., & Hebert, P. D. N. (2003). A comparison of zooplankton communities in saline lakewater with variable anion composition. *Hydrobiologia*, 505(1-3), 199–215. doi:10.1023/B:HYDR.0000007414.12566.19
- Dodson, S., Lillie, R., & Will-Wolf, S. (2005). Land use, water chemistry, aquatic vegetation, and zooplankton community structure of shallow lakes. *Ecological Applications*, 15(4), 1191–1198. Retrieved from <http://www.esajournals.org/doi/pdf/10.1890/04-1494>
- Folch, J., Lees, M., & Sloane-Stanley, G. (1957). A simple method for the isolation and purification of total lipids from animal tissues. *J. Biol. Chem.* Retrieved from <http://www.aufsi.auburn.edu/recommendedmethods/05B01c03a.pdf>
- Gulati, R., & Demott, W. (1997). The role of food quality for zooplankton: remarks on the state-of-the-art, perspectives and priorities. *Freshwater Biology*, 753–768. Retrieved from <http://onlinelibrary.wiley.com/doi/10.1046/j.1365-2427.1997.00275.x/abstract>
- Hammer, O., Harper, D.A.T. and Ryan, P.D. 2001. PAST: Paleontological Statistics software package for education and data analysis. *Paleontologia Electronica* 4(1):9 pp.
- Haney, J.F. *et al.* "An-Image-based Key to the Zooplankton of North America" version 5.0 released 2013. University of New Hampshire Center for Freshwater Biology <cfb.unh.edu> 29 Apr 2014
- Kapuscinski, K. L., & Farrell, J. M. (2013). Habitat factors influencing fish assemblages at muskellunge nursery sites. *Journal of Great Lakes Research*. doi:10.1016/j.jglr.2012.11.007
- Klumb, R., Bunch, K., & Mills, E. (2004). Establishment of a metalimnetic oxygen refuge for zooplankton in a productive Lake Ontario embayment. *Ecological*, 14(1), 113–131. Retrieved from <http://www.esajournals.org/doi/pdf/10.1890/02-5054>
- Matthews, B., & Mazumder, A. (2006). Habitat specialization and the exploitation of allochthonous carbon by zooplankton. *Ecology*, 87(11), 2800–12. Retrieved from <http://www.ncbi.nlm.nih.gov/pubmed/17168024>
- Mills, E., Green, D., & Jr, A. S. (1987). Use of zooplankton size to assess the community structure of fish populations in freshwater lakes. *North American Journal of Fisheries Management*. Retrieved from [http://www.tandfonline.com/doi/full/10.1577/1548-8659\(1987\)7%3C369%3AUOZSTA%3E2.0.CO%3B2](http://www.tandfonline.com/doi/full/10.1577/1548-8659(1987)7%3C369%3AUOZSTA%3E2.0.CO%3B2)
- Mills, E., & JR, A. S. (1982). Evaluation of fish communities through assessment of zooplankton populations and measures of lake productivity. *North American Journal of Fisheries* Retrieved from [http://www.tandfonline.com/doi/full/10.1577/1548-8659\(1982\)2%3C14%3AEOFCTA%3E2.0.CO%3B2](http://www.tandfonline.com/doi/full/10.1577/1548-8659(1982)2%3C14%3AEOFCTA%3E2.0.CO%3B2)
- Ohman, M. (1997). On the determination of zooplankton lipid content and the occurrence of gelatinous copepods. *Journal of Plankton Research*, 19(9), 1235–1250. Retrieved from <http://plankt.oxfordjournals.org/cgi/doi/10.1093/plankt/19.9.1235>

- Rasband, Wayne. National Institutes of Health USA. <http://imagej.nih.gov/ij> Java 1.6.0_20 (64 -bit)
- SAS Institute Inc. 2013. SAS®9.4 Guide to Software Updates. Cary, NC: SAS Institute Inc
- Strickland, J. D. H., & Parsons, T. R. (1972). A practical handbook of seawater analysis, 1972. *Fisheries Research Board of Canada, Ottawa, 167*. Retrieved from <http://scholar.google.com/scholar?hl=en&btnG=Search&q=intitle:A+PRACTICAL+HANDBOOK+of+Seawater+Analysis#0>
- Steiger, J. (1980). Tests for comparing elements of a correlation matrix. *Psychological Bulletin*. Retrieved from <http://psycnet.apa.org/journals/bul/87/2/245/>
- Teels, B. M., Rewa, C. A., & Myers, J. (2006). Aquatic Condition Response to Riparian Buffer Establishment. *Aquatic Condition Response to Riparian Buffer Establishment, 34(4)*, 927–935.
- TerBraak, C. J. F., & Verdonschot, P. F. M. (1995). Canonical correspondence analysis and related multivariate methods in aquatic ecology. *Aquatic Sciences, 57(3)*, 255–289. doi:10.1007/BF00877430
- Van Egeren, S. J., Dodson, S. I., Torke, B., & Maxted, J. T. (2011). The relative significance of environmental and anthropogenic factors affecting zooplankton community structure in Southeast Wisconsin Till Plain lakes. *Hydrobiologia, 668(1)*, 137–146. doi:10.1007/s10750-011-0636-3
- Vanni, M. (1987). Effects of food availability and fish predation on a zooplankton community. *Ecological Monographs, 57(1)*, 61–88. Retrieved from <http://www.jstor.org/stable/10.2307/1942639>
- Wainman, B. C., McQueen, D. J., & Lean, D. R. S. (1993). Seasonal trends in zooplankton lipid concentration and class in freshwater lakes. *Journal of Plankton Research, 15(11)*, 1319–1332. doi:10.1093/plankt/15.11.1319
- Zhu, A. B., Fitzgerald, D. G., Mayer, C. M., Rudstam, L. G., Mills, E. L. (2006). Alteration of Ecosystem function by Zebra mussels in Oneida Lake: Impacts on submerged macrophytes, *9(6)*, 1017–1028. doi:10.1007/s10021-005-0049-y

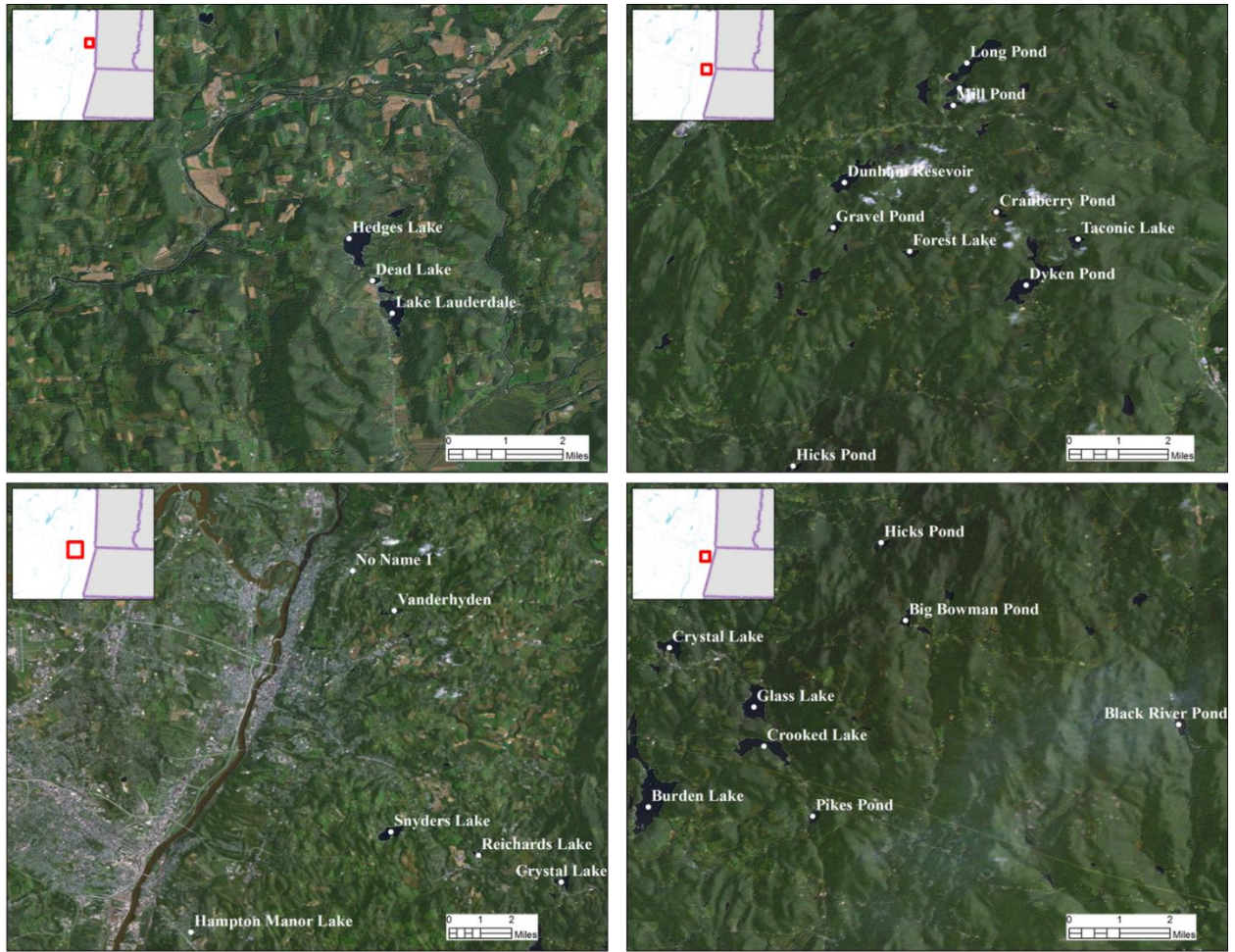


Figure 1. Study region of the Rensselaer county area and all 25 lakes sampled. Images from ArcGIS.

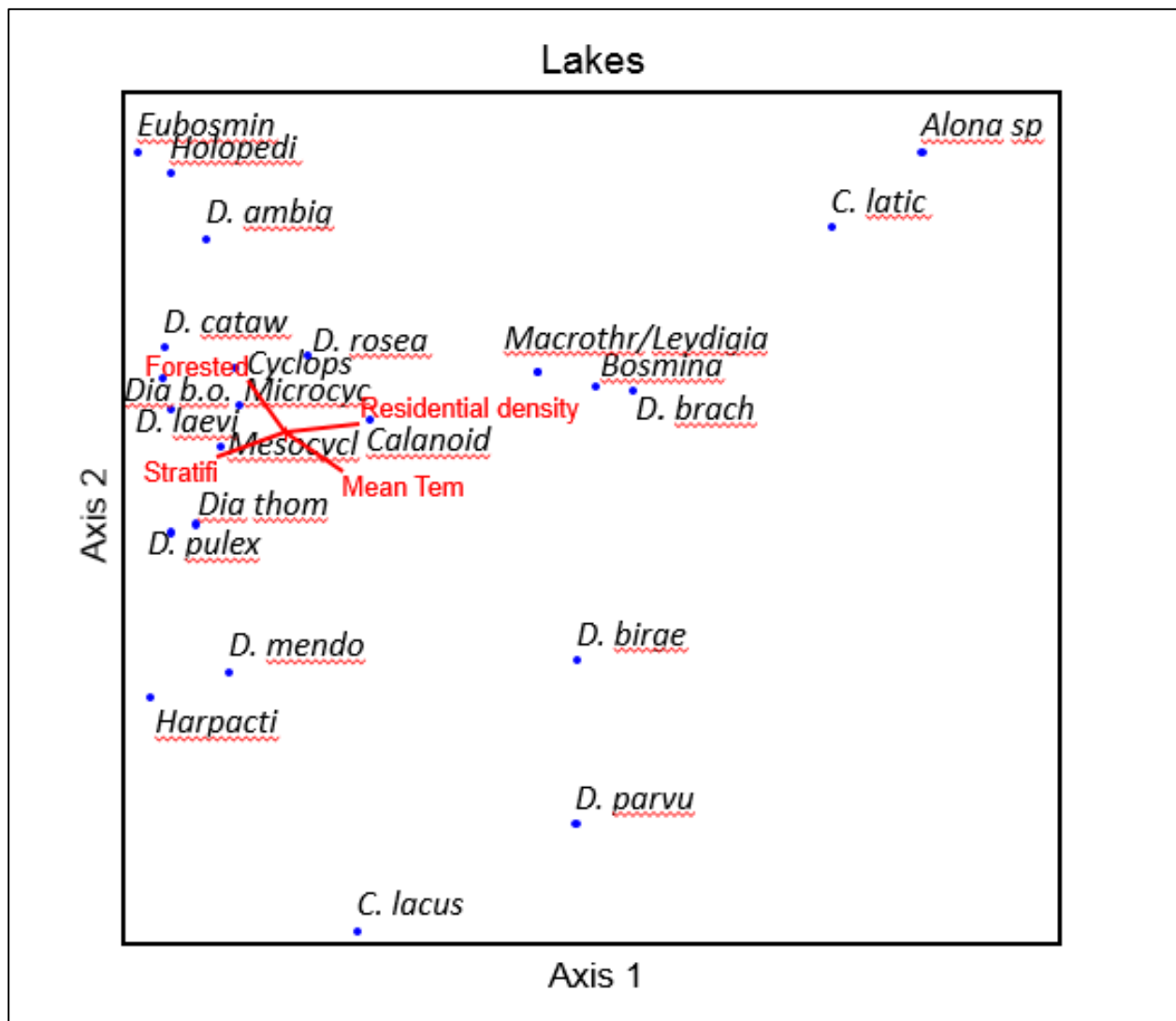


Figure 2. Canonical Correspondence Analysis of the zooplankton species along environmental variable gradients (pH, temperature, secchi depth, SDL, stratification, size, max depth, conductivity, residential density, percent forested, phosphorous, silica, dissolved oxygen). Percent variation explained by axis 1 =13.5, axis 2=10.9.

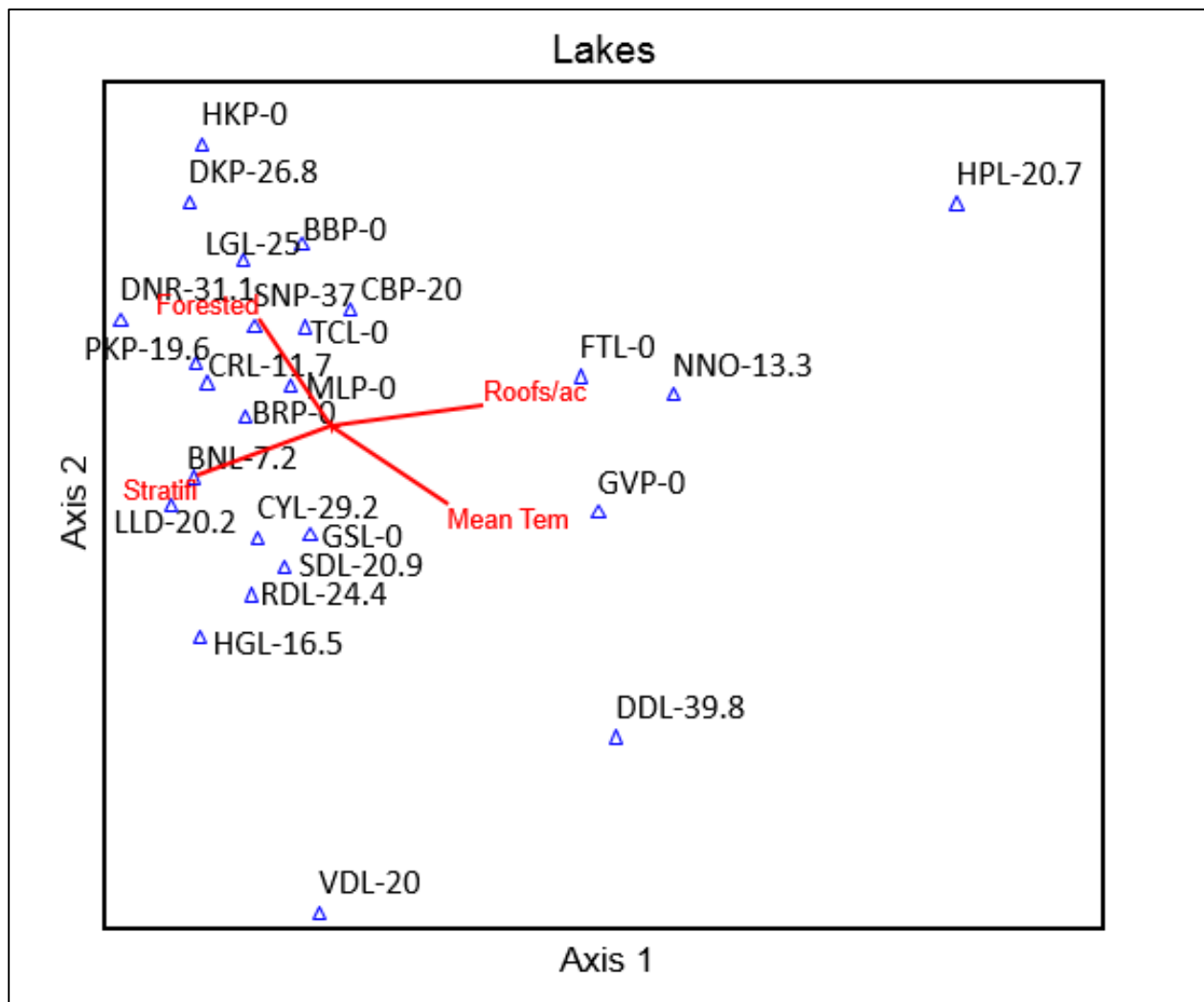


Figure 3. Ordination of lakes based on the zooplankton assemblages found within each body of water. Lake labels include lipid percentage. “0’s” account for lakes that were unable to be analyzed via lipids.

Table 1. Zooplankton species captured across all lakes, including total number of lakes each species were present and relative abundance across all lakes

Species	Total Lakes Present	% Abundance
<i>Alona spp.</i>	1	0.4
<i>Bosmina longirostris</i>	12	5.2
<i>Calanoid copepod</i>	17	16.08
<i>Ceriodaphnia lacustris</i>	3	1.6
<i>Ceriodaphnia laticaudata</i>	2	1.28
<i>Cyclops scutifer</i>	2	0.72
<i>Daphnia ambigua</i>	7	3.12
<i>Daphnia catawba</i>	12	10.8
<i>Daphnia laevis</i>	4	1.28
<i>Daphnia mendotae</i>	10	11.28
<i>Daphnia parvula</i>	1	0.08
<i>Daphnia pulex</i>	6	5.84
<i>Daphnia rosea</i>	14	4.8
<i>Diacyclops bicuspidatus</i>		
<i>odessanus</i>	3	0.8
<i>Diacyclops thomasi</i>	8	1.2
<i>Diaphanosoma birgei</i>	2	2.4
<i>Diaphanosoma brachyurum</i>	1	0.4
<i>Eubosmina spp.</i>	1	0.32
<i>Harpacticoida</i>	1	0.08
<i>Holopedium gibberum</i>	7	4
<i>Leydigia spp.</i>	1	0.08
<i>Macrothricidae</i>	1	0.32
<i>Mesocyclops edax</i>	12	2.96
<i>Microcyclops rubellus</i>	23	24.96

Table 2. Indices of zooplankton assemblage structure calculated from the 50-organism subsample including diversity (Shannon Index), evenness (Simpson), dominance (Dom3), richness (species), percent copepod species and percent cladoceran species. Lake code is lake name and date sampled.

Lake	Diversity	Evenness	Dominance	Richness	% copepod	% cladoceran
BNL-615	1.45	0.61	0.82	7	22	78
CRL-615	1.55	0.67	0.84	7	32	68
CYL-613	2.03	0.76	0.6	10	58	42
GSL-615	2.06	0.71	0.62	11	26	74
PKP-621	1.92	0.85	0.62	8	48	52
RDL-706	0.84	0.58	0.98	4	62	38
SDL-616	1.07	0.73	0.98	4	56	44
HKP-711	1.18	0.65	0.96	5	48	52
BBP-621	1.33	0.63	0.88	6	60	40
BRP-621	0.56	0.44	0.96	4	86	14
CBP-702	1.18	0.65	0.92	5	58	42
DNR-620	1.13	0.52	0.94	6	14	86
DKP-620	1.63	0.64	0.8	8	44	56
FTL-702	1.13	0.51	0.88	6	80	20
GVP-702	1.27	0.89	0.92	4	46	54
TCL-702	0.89	0.49	0.96	5	74	26
HPL-624	1.35	0.77	0.88	5	24	76
LGL-625	0.84	0.58	0.98	4	38	62
MLP-625	0.1	0.55	1	2	98	2
SNP-625	1.54	0.78	0.82	6	24	76
HGL-716	1.57	0.6	0.82	8	52	48
DDL-716	1.87	0.81	0.62	8	24	76
LLD-716	1.64	0.74	0.74	7	36	64
VDL-630	1.05	0.71	0.96	4	16	84
NNO-630	1.81	0.88	0.66	7	44	56

Table 3. Total species count in each lake's 50 organism subsample.

	Alona spp	Bosmina l	Calanoid c	C. lacustri	C. laticauc	Cyclops sc	D. ambigu	D. catawb	D. laevis	D. mendo	D. parvula	D. pulex	D. rosea	Dia b.o.	Dia thomaz	D. birgei	D. brachy	Eubosmin	Harpactic	Holopedi	Leydigia s	Macrothri	Mesocycl	Microcycl
BNL-615	0	0	4	0	0	0	0	15	0	1	0	22	1	0	3	0	0	0	0	0	0	0	0	4
CRL-615	0	0	0	0	0	0	0	1	12	19	0	0	2	0	2	0	0	0	0	0	0	0	3	11
CYL-613	0	1	6	0	0	4	0	2	0	12	0	6	0	3	2	0	0	0	0	0	0	0	2	12
GSL-615	0	4	3	0	0	0	3	2	3	16	0	7	2	0	1	0	0	0	0	0	0	0	1	8
PKP-621	0	0	11	0	0	0	0	10	0	10	0	4	2	5	2	0	0	0	0	0	0	0	0	6
RDL-706	0	0	1	0	0	0	0	0	0	19	0	0	0	0	0	0	0	0	0	0	0	0	1	29
SDL-616	0	0	27	0	0	0	0	9	0	0	0	13	0	0	0	0	0	0	0	0	0	0	0	1
HKP-711	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	24	0	9	15
BBP-621	0	3	0	0	0	5	16	0	0	0	0	0	0	0	2	0	0	0	0	0	1	0	0	23
BRP-621	0	3	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	43
CBP-702	0	5	3	0	0	0	1	0	0	0	0	0	15	0	0	0	0	0	0	0	0	0	0	26
DNR-620	0	0	0	0	0	0	1	30	1	0	0	0	11	0	0	0	0	0	0	0	0	0	1	6
DKP-620	0	0	0	0	0	0	13	2	0	0	0	0	1	2	0	0	0	4	0	8	0	0	1	19
FTL-702	0	3	33	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	1	4	0	7
GVP-702	0	12	19	0	0	0	0	0	0	0	0	0	0	0	0	15	0	0	0	0	0	0	0	4
TCL-702	0	0	34	0	0	0	0	12	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	2
HPL-624	5	21	12	0	11	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
LGL-625	0	0	19	0	0	0	0	29	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0
MLP-625	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	49
SNP-625	0	0	2	0	0	0	3	18	0	0	0	0	4	0	0	0	0	0	0	13	0	0	0	10
HGL-716	0	1	4	0	0	0	0	0	0	21	0	0	2	0	1	0	0	0	1	0	0	0	11	9
DDL-716	0	7	6	6	0	0	0	0	0	10	1	0	0	0	0	14	0	0	0	0	0	0	2	4
LLD-716	0	0	9	0	0	0	0	5	0	4	0	21	2	0	0	0	0	0	0	0	0	0	2	7
VDL-630	0	0	0	13	0	0	0	0	0	29	0	0	0	0	2	0	0	0	0	0	0	0	0	6
NNO-630	0	4	8	0	5	0	0	0	0	0	0	0	14	0	0	0	5	0	0	0	0	0	3	11

Table 4. Correlation coefficients for environmental variables from a Pearson Correlation matrix run in SAS.

	Pearson Correlation Coefficients												
	Prob > r under H0: Rho=0												
	Number of Observations												
	Size	Depth	SDL	Forested	silica	phosphorus	density	strat	temp	cond	DO	PH	secchi
Size	1.00000	0.50431	0.60799	-0.11127	0.07638	-0.30540	-0.25939	0.35349	-0.28336	-0.03200	0.22067	0.46357	0.59971
		0.0102	0.0013	0.5964	0.7167	0.1377	0.2105	0.0902	0.1797	0.8820	0.3001	0.0298	0.0015
	25	25	25	25	25	25	25	24	24	24	24	22	25
Depth	0.50431	1.00000	0.42512	-0.07453	0.12031	-0.28348	-0.25722	0.56429	-0.76190	-0.11267	0.12690	0.46010	0.46945
			0.0341	0.7233	0.5668	0.1697	0.2145	0.0041	<.0001	0.6002	0.5546	0.0312	0.0179
	25	25	25	25	25	25	25	24	24	24	24	22	25
SDL	0.60799	0.42512	1.00000	0.24649	0.02412	-0.29606	-0.24704	0.32317	-0.47798	-0.20646	-0.04977	0.00827	0.17300
				0.2349	0.9089	0.1507	0.2338	0.1235	0.0182	0.3331	0.8174	0.9709	0.4083
	25	25	25	25	25	25	25	24	24	24	24	22	25
Forested	-0.11127	-0.07453	0.24649	1.00000	-0.29578	0.09873	-0.58991	0.11426	-0.35246	-0.83362	0.06389	-0.66616	-0.35273
			0.2349		0.1511	0.6387	0.0019	0.5950	0.0912	<.0001	0.7668	0.0007	0.0837
	25	25	25	25	25	25	25	24	24	24	24	22	25
silica	0.07638	0.12031	0.02412	-0.29578	1.00000	-0.17620	0.16007	0.01516	0.01876	0.40154	-0.20619	0.37853	0.19215
			0.9089	0.1511		0.3995	0.4447	0.9440	0.9307	0.0518	0.3337	0.0824	0.3575
	25	25	25	25	25	25	25	24	24	24	24	22	25
phosphorus	-0.30540	-0.28348	-0.29606	0.09873	-0.17620	1.00000	0.08386	0.05452	0.11947	-0.05819	-0.34247	-0.25462	-0.25075
			0.1507	0.6387	0.3995		0.6902	0.8003	0.5782	0.7871	0.1014	0.2528	0.2267
	25	25	25	25	25	25	25	24	24	24	24	22	25
density	-0.25939	-0.25722	-0.24704	-0.58991	0.16007	0.08386	1.00000	-0.58912	0.31919	0.75812	-0.31817	0.20808	-0.13512
			0.2338	0.0019	0.4447	0.6902		0.0025	0.1284	<.0001	0.1297	0.3528	0.5196
	25	25	25	25	25	25	25	24	24	24	24	22	25
strat	0.35349	0.56429	0.32317	0.11426	0.01516	0.05452	-0.58912	1.00000	-0.62624	-0.25874	-0.00441	0.18397	0.23031
			0.1235	0.5950	0.9440	0.8003	0.0025		0.0011	0.2222	0.9837	0.4125	0.2789
	24	24	24	24	24	24	24	24	24	24	24	22	24
temp	-0.28336	-0.76190	-0.47798	-0.35246	0.01876	0.11947	0.31919	-0.62624	1.00000	0.33514	0.08767	-0.01543	-0.01936
			0.0182	0.0912	0.9307	0.5782	0.1284	0.0011		0.1094	0.6837	0.9457	0.9285
	24	24	24	24	24	24	24	24	24	24	24	22	24
cond	-0.03200	-0.11267	-0.20646	-0.83362	0.40154	-0.05819	0.75812	-0.25874	0.33514	1.00000	-0.21379	0.56863	0.11216
			0.3331	<.0001	0.0518	0.7871	<.0001	0.2222	0.1094		0.3158	0.0058	0.6018
	24	24	24	24	24	24	24	24	24	24	24	22	24
DO	0.22067	0.12690	-0.04977	0.06389	-0.20619	-0.34247	-0.31817	-0.00441	0.08767	-0.21379	1.00000	0.24682	0.44448
			0.8174	0.7668	0.3337	0.1014	0.1297	0.9837	0.6837	0.3158		0.2681	0.0295
	24	24	24	24	24	24	24	24	24	24	24	22	24
PH	0.46357	0.46010	0.00827	-0.66616	0.37853	-0.25462	0.20808	0.18397	-0.01543	0.56863	0.24682	1.00000	0.65036
			0.9709	0.0007	0.0824	0.2528	0.3528	0.4125	0.9457	0.0058	0.2681		0.0010
	22	22	22	22	22	22	22	22	22	22	22	22	22
secchi	0.59971	0.46945	0.17300	-0.35273	0.19215	-0.25075	-0.13512	0.23031	-0.01936	0.11216	0.44448	0.65036	1.00000
			0.4083	0.0837	0.3575	0.2267	0.5196	0.2789	0.9285	0.6018	0.0295	0.0010	
	25	25	25	25	25	25	25	24	24	24	24	22	25

Table 5. Monte Carlo test results for species-environment correlations and eigenvalues based on 998 runs with randomized data.

Axis	Real Data	Mean	Minimum	Maximum	<i>p</i>
Eigenvalue					
1	0.487	0.428	0.305	0.536	0.092
2	0.395	0.344	0.231	0.456	
3	0.303	0.273	0.195	0.409	
Spp-Envr corr.					
1	0.967	0.916	0.809	0.980	0.023
2	0.928	0.878	0.740	0.965	
3	0.800	0.862	0.696	0.974	