Report as of FY2007 for 2006ND136B: "Top-down and Bottom-up Effects on the Abundance of Periphyton in Shallow Lakes"

Publications

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Report Follows

Top-down and Bottom-up Effects on the Abundance of Periphyton in Shallow Lakes

Regional Water Problem

Shallow lakes are the most common lake type in North America, yet our ecological understanding of these systems is poor relative to deeper "sport fish" lakes. Throughout the Prairie Pothole Region (PPR), landscape alterations have directly and indirectly altered the character and quality of regional waterbodies. The ecological value of these shallow aquatic ecosystems decreases as conditions favor a turbid, phytoplankton-dominated condition with low abundance and diversity of invertebrates and submerged aquatic plants (Scheffer 1998). Waterbodies in the turbid state are considerably less valuable to migrating waterfowl than clearwater, plant-dominated systems. Much evidence points to nutrients as a cause of high periphyton biomass, just as utrient loading enhances planktonic algae. Fish presence in a shallow basin ay also favor increased algae, both planktonic and periphytic. Periphyton is detrimental to acrophytes, and ultimately may contribute to a basin shifting from the clear-water state to the ess valuable turbid state. We need to better understand what controls periphyton, and the role it ay play in shifts from the clear-water state to the turbid-water state in shallow lakes within the PPR.

Literature Review

Shallow lakes can exist in two alternative stable states: a clear-water state dominated by macrophytes and a turbid-water state dominated by algae. Macrophytes play an important role in maintaining water clarity by tying up available nutrients and reducing the amount of sediment resuspension. They also protect invertebrates from predation, host periphyton communities, serve as spawning habitat and shelter for small fish, and provide habitat and food for waterfowl. Many previous studies have implicated increased phytoplankton in concurrent loss of macrophytes, favoring the view that phytoplankton induce shifts to the turbid state. Recently, more attention has been given to the role periphyton, specifically epiphyton, or algae growing attached to dead or living aquatic plants. The littoral zone of shallow lakes is typically extensive, and plants can often be found growing on up to 100 percent of the lake bottom.

The amount of periphyton growing on macrophytes is directly affected by grazing invertebrates (Allen 1971, Brönmark 1989, Hann 1991, Rosemond et al. 1993, McCollum et al. 1998, Hann et al. 2001), availability of nutrients (Cattaneo and Kalff 1980, Fairchild et al. 1985) and light (Wetzel 1983, Goldsborough and Brown 1991), as well as indirectly by the presence of fish (Brönmark 1989, Walker et al. 1998, Marklund et al. 2002) through a cascading effect within the food web. Therefore, periphyton biomass may be controlled from the “top down” by a fish-grazer interaction, and/or from the “bottom-up” by nutrient and light availability. Each lake is unique, differing in the presence, types, and abundance of fish, grazing invertebrates, periphyton, and macrophytes, the available nutrients, and the clarity of the water. Few researchers have observed the complete fish-invertebrate-periphyton-macrophyte trophic cascade

(Jones and Sayer 2003), as most studies have focused on just one of the top-down or the bottomup interactions.

Predatory fish directly reduce the abundance of grazing invertebrates (Walker et al. 1998, Karjalainen et al. 1999, Marklund et al. 2002, Ruetz et al. 2004) and indirectly affect algal biomass through changes in the abundance and behavior of invertebrate grazers (Power 1990, McIntosh and Townsend 1996). When fish are present and/or abundant, periphyton biomass will be higher, and when fish are absent periphyton will be suppressed by higher invertebrate grazing pressure.

Grazing invertebrates have been reported to be negatively correlated with periphyton biomass (Hillebrand 2002, Jones et al. 2002). Controlled experiments have utilized enclosures and exclosures to manipulate the presence or absence of invertebrates interacting with the plants and algae (Ruetz et al. 2004). Cattaneo (1983) conducted a similar experiment and found that periphyton biomass decreased significantly with the presence of oligochaetes and chironomids. Gastropods can also greatly suppress periphyton abundance, particularly the larger (>200μm^3), loosely attached cells (Martin et al. 1992).

Nutrient availability in a wetland can have important influences on the biomass of periphyton. Some studies have reported that an increase in available nutrients correlates with an increase in periphyton biomass (Cattaneo and Kalff 1980, Fairchild et al. 1985, Carrick and Lowe 1988), while others have found no such correlation (Jones et al. 2002, Jones and Sayer 2003). An increase in nutrients also tends to increase the turbidity of a shallow lake (Scheffer et al. 1993). This increase in turbidity causes a decrease in light penetration. When light is limited, periphyton biomass is limited as well (Goldsborough and Brown 1991). In shallow, clear lakes, where light can penetrate deeply into the water column, periphyton production can make a substantial contribution to total production by the primary trophic level (Wetzel 1983).

This study is designed to sample the abundance and composition of species involved in the fish-invertebrate-periphyton-macrophyte trophic cascade, along with other variables (nutrients, turbidity, and phytoplankton) to identify factors influencing periphyton biomass in shallow prairie lakes. Most controlled experiments have involved enclosures and exclosures, placed in a single body of water, to manipulate the presence or absence of fish and/or invertebrates interacting with the plants and algae. These experimental studies have also used from one to only a few species per trophic level (i.e. fish, invertebrates, etc.) and very few studies have evaluated more than two trophic levels. Observational studies typically involve around ten lakes, which limits the amount of variation within treatments as well as the number of study lakes in either the clear- or turbid-water state. Grazing and nutrient effects on periphyton biomass in streams have been widely studied, but little is known about periphyton levels in shallow lakes, or the influence various trophic levels can have on macrophyte abundance and water clarity. We hypothesize that grazing invertebrates will have stronger impacts on periphyton abundance, relative to available nutrients, but that nutrients will still play a role in determining periphyton abundance. We are sampling 75 lakes in two different study areas in Minnesota to test this littoral cascade hypothesis.

Scope and objectives

This study will provide better understanding of interactions contolling to periphyton within shallow lake ecosystems, by accomplishing these objectives:

1. Sample the epiphyton, invertebrate, fish, macrophyte, phytoplankton, and nutrient/light interactions within 75 shallow lakes in Minnesota.
2. Sample shallow lakes of varying water clarity (clear- vs turbid-water state) and nutrient input (LO & HI impact landscapes).
3. Test various combinations of explanatory variables in models to determine if periphyton is controlled from the top-down, from the bottom-up, or by a combination of both.
4. Determine which variables best predict periphyton biomass (nutrients, light, fish, invertebrates).
5. Determine how periphyton biomass and its predictor variables differ between study landscapes, among lakes within each landscape, and with depth in each lake.

Methods

Two areas in western Minnesota have been chosen for study. The northern area is located in eastern Polk County, while the southern area spans the region from southern Grant County to the northern edge of Stevens County. Each study area comprises approximately 560 km^2. Study sites were selected by randomly choosing from groups of candidate lakes conforming to criteria identified as part of a broader study. While compiling candidate lakes, surface area, depth, distance to roads, adjacent upland cover and other criteria were taken into account. A total of 75 wetlands were chosen using this method, roughly half within the northern study area and remaining sites in the southern study area. All sites selected are semipermanent or permanent (type IV or V) with regard to duration of flooding (Stewart and Kantrud 1971). Periphyton, invertebrate, macrophyte, and fish abundance, plus nutrient and light availability were sampled throughout the 2005 and 2006 summers.

Periphyton biomass (Chl *a*) is determined by deploying artificial substrates for five weeks. Sampling devices were set out in mid-June and collected in late-July each year (average time in water is 5 weeks). These devices consisted of a polyester braided rope (¼" thick, 1½ m long) with a brick anchor attached to one end and a float on the other, with three vinyl microscope slides attached using zip-ties at individual depths along the rope (10, 50, and 90cm from surface). The total height of the sampling device was approximately 1.5m. Using artificial substrata instead of collecting living plants permits a uniform surface type, area, and orientation, and therefore less variation in the sampling of periphyton biomass. Some species of plants may be able to alter the periphyton community, so by using an artificial substrate the species of macrophytes present will not be a factor. Cattaneo and Kalff (1979) concluded that periphyton production did not differ between natural and artificial plants. Substrates were placed vertically in the water column at a depth of ~1.5 m. Since periphyton and grazer biomass varies with depth (James et al. 2000), deploying substrates at specific depths controlled for this influence. Three devices were deployed in each lake, near the same locations

where invertebrates were sampled. Upon collection, each sample was removed from the lake with care to limit disturbance to the periphyton, placed in a container with tap water, and stored in a dark cooler until be processed in the lab within 12 hours.

Periphyton biomass will be estimated from chlorophyll *a* analyses (APHA 1989). Periphyton is scraped off slides into a dish with a razor blade, and a sub-sample was filtered onto a glass fiber filter (Whatman GF/C). Filters were frozen until processing in the lab. Each sample is allowed to steep for 24 hours in a separate tube with 90% acetone. Fluorometry is used for determining chlorophyll *a*, since it is more sensitive than spectrophotometry and thus requires fewer samples. Fluorescence is measured at 430 nm and 663 nm, and calibration factors are derived to convert fluorometric readings to concentrations of chlorophyll *a*.

Zooplankton were sampled twice per year, once in early-June, and again in Late-July, by collecting two replicate vertical column samples (Swanson 1978a) at six open water locations in each wetland. Estimates will be made of density, biomass, and taxon richness of zooplankters. Relative abundance of free-swimming invertebrates was obtained with submerged activity traps (ATs) (Swanson 1978b, Murkin et al. 1983, Ross and Murkin 1989). Six ATs were deployed at the interface of open water and emergent macrophytes, and left in each wetland for 24 hours. Abundance (counts of dominant forms) and taxon richness of macroinvertebrates will be determined, paying special attention to identifying taxa considered to be grazers/scrappers.

Density and trends in abundance of submerged macrophytes were assessed using a modified technique of Jessen and Lound (1962) and Deppe and Lathrop (1992). In each wetland, submersed macrophytes were sampled at 20 stations in early August each year. Four transects were established perpendicular to the longest axis of the lake, with 5 stations established along each transect. Therefore, sampling stations were apportioned among 3 depth strata (open water, transition, nearshore). Two samples were collected from each station using a weighted plant rake, with frequency of occurrence calculated for each plant species and all taxa combined. The first sample was weighed to determine the relative abundance (mass) of macrophytes overall. Metaphyton (e.g. *Cladophora* spp.) and macroalgae (e.g. *Chara* spp.) were assessed along with vascular plant species during these surveys.

Three surface water samples were taken along the middle of each wetland during early- June, and again in late-July each year. These samples were stored on ice and transported immediately to the Minnesota Department of Agriculture chemistry lab (St. Paul, MN) for analysis of chlorophyll *a*, total and Kjeldahl nitrogen, and total phosphorus. Turbidity and specific conductance were measured in the field with a portable nephelometer and conductivity meter, respectively. Phytoplankton biomass were estimated from chlorophyll *a* (Strickland and Parsons 1972). Collection of samples for chlorophyll *a* simultaneously with measurement of turbidity allows assessment of the contribution of phytoplankton to turbidity, and ultimately to light attenuation. A secchi disk was also used to determine water clarity, by sampling the middle of each lake once in early-June, and again in late-July each year.

All fish sampling was conducted during late-July each year. Three mini-fyke nets (9.5 mm bar mesh with 4 hoops, 2 throats, 7.62 mm lead, and a 0.69 X 0.99 rectangular frame opening into the trap) were set overnight in each lake. One experimental gill net (76.2 m multifilament net with 19, 25, 32, 38, and 51-mm bar meshes) was set along the

deepest depth contour available in wetlands less than 2-m deep or parallel to shore along a 2-m contour in wetlands with sufficient depth. This protocol has been shown to be effective in sampling fish assemblages in small lakes from other regions (Tonn and Magnuson 1982, Rahel 1984, Jackson and Harvey 1989, Robinson and Tonn 1989). This should enable us to capture both small- and large-bodied fish, and species from all the major trophic guilds (e.g. planktivores, benthivores, and piscivores) potentially present in the study wetlands. All species of fish sampled were counted and returned alive to the wetlands if possible. Voucher specimens were retained for laboratory identification when field identification could not be made.

Multivariate techniques will be used to interpret the interactions between biotic and abiotic variables. Specifically, two types of gradient analysis, principle components analysis (PCA) or correspondence analysis (CA) will be used (ter Braak 1995). These techniques are able to identify and summarize major patterns in the data, and by considering all species and sites at once, they permit detection of patterns that univariate techniques are unable to identify. Such patterns include which species vary the most among sites, which species have positive/negative associations, which species are most abundant in specific sites, as well as which sites are most similar/dissimilar in terms of species abundance, and how much individual sites differ in community composition. Abundance and composition of fish, invertebrates, and macrophytes may be correlated with the various variables, such as nutrients, light, and periphyton biomass.

Finally an information-theoretic (IT) approach, a type of model selection, will be used to determine which variables are related to periphyton biomass. Models will be selected *a priori* to ensure inclusion of appropriate variables, and comprised of various combinations of the variables. This approach will then be used to select the model best supported by the data, and dismiss others that are less plausible. Model selection considers both problems associated with overfitting the data (using too many parameters) and underfitting the data (using an insufficient number of parameters).

Deliverables

This study will improve understanding of the fish-invertebrate-periphyton macrophyte cascade, including direct impacts of nutrients and light on periphyton biomass, and the indirect impact of periphyton on macrophyte abundance. An understanding of which variables most influence periphyton abundance can help managers maintain these shallow lakes in the Clearwater state. Manuscripts will be prepared and submitted describing these findings.

Progress to date

Field data has already been collected for the full two years of the study. We sampled fish, macrophytes, nutrients, phytoplankton, periphyton, and invertebrates. Many invertebrate samples still need to be processed, but other lab work is well underway. I am currently in the early stages of analyzing data and writing manuscripts.

Financial Information

The research described in this proposal is a collaborative effort involving the University of St. Thomas (St. Paul, MN), North Dakota State University (Fargo, ND), and research scientists from both the Fisheries and Wildlife sections of the Minnesota Department of Natural Resources (MN DNR) (Bemidji, MN). The MN DNR has supported this project by covering many costs associated with travel, equipment purchase, and data collection. Funding from the NDWRRI will be used for graduate stipend, student assistance with invertebrate samples, lab supplies, and travel to meet with cooperators in the MN DNR about data analysis and publications.

Literature Cited

Allen, H. L. 1971. Primary production, chemoorganotrophy and nutritional interactions of epiphytic algae and bacteria on macrophytes in the littoral of a lake. Ecological Monographs **61**:97-127.

APHA. 1989. Standard Methods for the Examination of Waste and Wastewater, Seventeenth edition. American Public Health Association, Washington, DC

Attayde, J. L., and L. A. Hansson. 2001. Fish-mediated nutrient recycling and the trophic cascade in lakes. Canadian Journal of Fisheries and Aquatic Sciences **58**:1924-1931.

Brönmark, C. 1989. Interactions between epiphytes, macrophytes, and freshwater snails: a review. Journal of Molecular Studies **55**:299-311.

Carrick, H. J., and R. L. Lowe. 1988. Response of Lake Michigan benthic algae to an *in situ* enrichment with Si, N, and P. Canadian Journal of Fisheries and Aquatic Sciences **45**:271-279.

Cattaneo, A. 1983. Grazing on epiphytes. Limnology and Oceanography **28**:124-132.

Cattaneo, A., and J. Kalff. 1979. Primary production of algae growing on natural and artificial aquatic plants: A study of interactions between epiphytes and their substrate. Limnology and Oceanography **24**:1031-1037.

Cattaneo, A., and J. Kalff. 1980. The relative contribution of aquatic macrophytes and their epiphytes to the production of macrophyte beds. Limnology and Oceanography **25**:280-
289.

Deppe, E. R., and R. C. Lathrop. 1992. A comparison of two rake sampling techniques from sampling aquatic macrophytes. Wisconsin Bureau of Research Findings 32, Madison.

Dodds, W. K. 2002. Freshwater Ecology: Concepts and Environmental Applications. Academic Press, San Diego, CA, USA.

Fairchild, G. W., R. L. Lowe, and W. B. Richardson. 1985. Algal periphyton growth on nutrientdiffusing substrates: An *in situ* bioassay. Ecology **66**:465-472.

Goldsborough, L. G., and D. J. Brown. 1991. Periphyton production in a small, dystrophic pond on the Canadian Precambrian Shield. International Association of Limnology **24**:1497-1502.

Hann, B. J. 1991. Invertebrate grazer - periphyton interactions in a eutrophic marsh pond. Freshwater Biology **26**:87-96.

Hann, B. J., C. J. Mundy, and L. G. Goldsborough. 2001. Snail-periphyton interactions in a prairie lacustrine wetland. Hydrobiologia **457**:167-175.

Hillebrand, H. 2002. Top-down versus bottom-up control of autotrophic biomass: a metaanalysis on experiments with periphyton. Journal of the North American Benthological
Society **21**:349-369.
Jackson, D. A., and H. H. Harvey. 1989. Biogeographic associations in fish assemblages: local vs. regional processes. Ecology **70**:1472-1484.
James, M. R., I. Hawes, and M. Weatherhead. 2000. Removal of settled sediments and periphyton from macrophytes by grazing invertebrates in the littoral zone of a large oligotrophic lake. Freshwater Biology **44**:311-326.
Jessen, R., and R. Lound. 1962. An evaluation of a survey technique for submerged aquatic plants. Minnesota Department of Conservation Game Investigational Report 6, St. Paul.
Jones, J. I., and C. D. Sayer. 2003. Does the fish-invertebrate periphyton cascade precipitate plant loss in shallow lakes? . Ecology **84**:2155-2167.
Jones, J. I., J. O. Young, J. W. Eaton, and B. Moss. 2002. The influence of nutrient loading, dissolved inorganic carbon and higher trophic levels on the interaction between submerged plants and periphyton. Ecology **90**:12-24.
Karjalainen, J., M. Leppa, M. Rahkola, and K. Tolonen. 1999. The role of benthivorous and planktivorous fish in a mesotrophic lake ecosystem. Hydrobiologia **408/409**:73-84.
Marklund, O., H. Sandsten, L.-A. Hansson, and I. Blindow. 2002. Effects of waterfowl and fish on submerged vegetation and macroinvertebrates. Freshwater Biology **47**:2049-2059.
Martin, T. H., L. B. Crowder, C. F. Dumas, and J. M. Burkholder. 1992. Indirect effects of fish on macrophytes in Bays Mountain Lake: evidence for a littoral trophic cascade. Oecologia **89**:476-481.
McCollum, E. W., L. B. Crowder, and S. A. McCollum. 1998. Complex interactions of fish, snails, and littoral zone periphyton. Ecology **79**:1980-1994.
McIntosh, A. R., and C. R. Townsend. 1996. Interactions between fish, grazing invertebrates and algae in a New Zealand stream: a trophic cascade mediated by fish-induced changes to grazer behavior? Oecologia (Berlin) **108**:174-181.
Murkin, H. R., P. G. Abbott, and J. A. Kadlec. 1983. A comparison of activity traps and sweep nets for sampling nektonic invertebrates in wetlands. Freshwater Invertebrate Biology**2**:99-106.
Power, M. E. 1990. Resource enhancement by indirect effects of grazers: armored catfish, algae, and sediment. Ecology **71**:897-904.
Rahel, F. J. 1984. Factors structuring fish assemblages along a bog lake successional gradient. Ecology **65**:1276-1289.
Robinson, C. L. K., and W. M. Tonn. 1989. Influence of environmental factors and piscivory in structuring fish assemblages of small Alberta lakes. Canadian Journal of Fisheries and Aquatic Sciences **46**:81-89.
Rosemond, A. D., P. J. Mullholland, and J. W. Elwood. 1993. Top-down and bottom-up control of stream periphyton: effects of nutrients and herbivores. Ecology **74**:1264-1280.
Ross, L. C., and H. R. Murkin. 1989. Invertebrates. Pages 35-38 *in* E. J. Murkin and H. R. Murkin, editors. Marsh Ecology Research Program: Long-term monitoring procedures manual, Delta Waterfowl and Wetlands Research Station, Portage la Prairie, Manitoba, Canada. Technical Bulletin 2.

Ruetz, C. R., III, B. Vondracek, and R. M. Newman. 2004. Weak top-down control of grazers and periphyton by slimy sculpins in a coldwater stream. Journal of the North American Benthological Society **23**:271-286.
Scheffer, M. H., S. H. Hosper, M.-L. Meijer, B. Moss, and E. Jeppesen. 1993. Alternative equilibria in shallow lakes. Trends in Ecology and Evolution **8**:275-279.
Stewart, R. E., and H. A. Kantrud. 1971. Classification of natural ponds and lakes in the glaciated prairie region. Bureau of Sport Fisheries and Wildlife Resources Publication No. 92, Washington, D. C.
Strickland, J., and T. R. Parsons. 1972. A practical handbook of seawater analysis. Bull. Fish. Res. Bd. Can. **167**.
Swanson, G. H. 1978a. A plankton sampling device for shallow wetlands. Journal of Wildlife Management **42**:670-672.
Swanson, G. H. 1978b. Funnel trap for collecting littoral aquatic macroinvertebrates. The Progressive Fish-Culturist **40**:73.
ter Braak, C. J. 1995. Ordination. *in* R. H. Jongman, C. J. ter Braak, and O. F. van Tongeren, editors. Data Analysis in Community and Landscape Ecology. Cambridge University Press, Cambridge, U.K.
Tonn, W. M., and J. J. Magnuson. 1982. Patterns in the species composition and richness of fishassemblages in northern Wisconsin lakes. Ecology **63**:1149-1166.
Walker, E., L. B. Crowder, and S. A. McCollum. 1998. Complex interactions of fish, snails, and littoral zone periphyton. Ecology **79**:1980-1994.
Wetzel, R. G. 1983. Periphyton in Freshwater Ecosystems. Dr W. Junk Publishers, The Hague.