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Response of aquatic macrophytes to human land use perturbations in the watersheds of Wisconsin lakes, U.S.A.

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ABSTRACT

Aquatic macrophyte communities were assessed in 53 lakes in Wisconsin, U.S.A. along environmental and land use development gradients to determine effects human land use perturbations have on aquatic macrophytes at the watershed and riparian development scales. Species richness and relative frequency were surveyed in lakes from two ecoregions: the Northern Lakes and Forests Ecoregion and the Southeastern Wisconsin Till Plain Ecoregion. Lakes were selected along a gradient of watershed development ranging from undeveloped (i.e., forested), to agricultural to urban development. Land uses occurring in the watershed and in perimeters of different width (0–100, 0–200, 0–500, and 0–1000 m from shore, in the watershed) were used to assess effects on macrophyte communities. Snorkel and SCUBA were used to survey aquatic macrophyte species in 18 quadrats of 0.25 m^2 along 14 transects placed perpendicular to shore in each lake. Effects of watershed development (e.g., agriculture and/or urban) were tested at whole-lake (entire littoral zone) and near-shore (within 7 m of shore) scales using canonical correspondence analysis (CCA) and linear regression. Overall, species richness was negatively related to watershed development, while frequencies of individual species and groups differed in level of response to different land use perturbations. Effects of land use in the perimeters on macrophytes, with a few exceptions, did not provide higher correlations compared to land use at the watershed scale. In lakes with higher total watershed development levels, introduced species, particularly *Myriophyllum spicatum*, increased in abundance and native species, especially potamids, isoetids, and floating-leaved plants, declined in abundance. Correlations within the northern and southeastern ecoregions separately were not significant. Multivariate analyses suggested species composition is driven by environmental responses as well as human development pressures. Both water chemistry and land use variables loaded positively with the first CCA axis indicating that these factors are correlated. Land use pressures in Wisconsin are greater in the southeastern portion of the state where lakes have higher concentrations of water chemistry variables including alkalinity, conductivity, pH, calcium, magnesium, and nitrogen. This creates a complex gradient that influences species composition of macrophyte communities from lake to lake.

1. Introduction

Previous analyses of regional distributions of aquatic macrophytes suggest that shifts, declines and complete loss of species in aquatic macrophyte communities can be attributed to eutrophication, acidification and alkalinisation, and that those can be driven by human land use perturbations (Bowen and Valiela, 2001; Heegaard et al., 2001; Lougheed et al., 2001; Virola et al., 2001; Arts, 2002; Hauxwell et al., 2003; Moore et al., 2003; Dodson et al., 2005). Aquatic plant community composition is constrained by the environmental factors specific to a water body and physiological requirements of the species living therein (Moyle, 1945; Spence, 1967; Rørslett, 1991; Vestergaard and Sand-Jensen, 2000). For instance, increasing nutrient concentrations often result in a loss of isoetids; an initial increase in elodeid species is usually followed by a loss of the elodeids as turbidity increases and precludes growth (Rørslett, 1991; Toivonen and Huttunen, 1995; Egertson et al., 2004). This transition from oligotrophic to mesotrophic to eutrophic lakes results in a unimodal response in species rich-

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ness (Toivonen and Huttunen, 1995; Vestergaard and Sand-Jensen, 2000; Lougheed et al., 2001).

Shifts in aquatic environments (often nutrient loading) have been linked to agriculture (Crosbie and Chow-Fraser, 1999; Heegaard et al., 2001; Virola et al., 2001; Gleason et al., 2003; Egertson et al., 2004; Dodson et al., 2005; Rasmussen and Anderson, 2005) and urban land use practices (Nichols and Lathrop, 1994; Bowen and Valiela, 2001; Arts, 2002; Hauxwell et al., 2003; Alexander et al., 2008). Sediment and nutrients in runoff from agricultural land use cause eutrophication resulting in concomitant declines in submersed aquatic plants (Crosbie and Chow-Fraser, 1999; Gleason et al., 2003; Egertson et al., 2004; Rasmussen and Anderson, 2005). Negative effects can range from a shift in the aquatic plants toward predominantly floating and emergent species (e.g., Egertson et al., 2004) to a complete collapse of the macrophyte community (e.g., Philips et al., 1978; Rasmussen and Anderson, 2005). Urban perturbations include a suite of impacts that vary much more than from agricultural land use such as sewage leakage, road salts and other contaminants in run off, and nutrient pollution from landscaping and sewage treatment facilities (Findlay and Houlahan, 1997; Moore et al., 2003; Wang et al., 2003; Rasmussen and Anderson, 2005). And additional negative effects to aquatic plant communities have been directly linked to land development near the shoreline ecotone (Radomski and Goeman, 2001; Moore et al., 2003; Hrabik et al., 2005; Houlahan et al., 2006; Alexander et al., 2008). Due to the large disparity in urban development types and impacts, many studies mention urban impacts as a possible cause, but have found it difficult to link urban land use to specific causal impact on aquatic macrophyte communities (Toivonen and Huttunen, 1995; Virola et al., 2001; Dodson et al., 2005; Rasmussen and Anderson, 2005).

Effects of land uses on macrophyte communities in Wisconsin have been noted in both the northern, more meso-oligotrophic lakes by Jennings et al. (2003) and Alexander et al. (2008) and in the southeastern, eutrophic lakes by Dodson et al. (2005). The two ecoregions of this study provide a diverse array of macrophyte communities in lakes along a gradient of agricultural intensity as well as urbanization. The Northern Lakes and Forests Ecoregion (herein referred to as the northern ecoregion) is an area with historically low human development pressure, which is increasing. Most of the original vegetation has been cleared from watersheds in the Southeastern Wisconsin Till Plains Ecoregion (herein referred to as the southeastern ecoregion) and crop land is now in many areas being transitioned into urban development.

This study examines how species richness and relative frequencies of individual aquatic plant taxa and species groups are distributed among lakes relative to environmental, agricultural and urban development gradients in two ecological regions. Our research questions ask: (1) can a pattern of decline in species richness and diversity be linked (i.e., correlated) to agriculture and/or urban development and (2) is this pattern affected by the extent of the littoral ecotone positioned between aquatic vegetation in the lake and human land use? For instance, whereas lake succession (primarily eutrophication) causes a decline in isoetids, a unimodal response in elodeids, and a shift toward floating-leaved and emergent plants (Toivonen and Huttunen, 1995; Egertson et al., 2004), we suggest that anthropogenic development causes a decline in more species, especially those that are more visible such as floating-leaved and emergent species.

2. Study area

Lakes of the northern and southeastern ecoregions differed (Table 1). Lake size and corresponding watershed areas were slightly larger in the northern ecoregion. Lakes generally followed a gradient of increasing nutrient levels from the northern to the southeastern ecoregion. The northern ecoregion is an area of naturally low nutrient and calcium concentrations, having glacial soils and with mostly oligotrophic to mesotrophic lakes (Omernik et al., 2000). Human development pressure around northern lakes has been historically low (topography of this area discourages most agricultural practices), but urban development pressure is increasing as vacation homes and permanent residences are built, particularly around lakeshores. The southeastern ecoregion is dotted with lakes mostly with higher nutrient concentrations than northern lakes (Omernik et al., 2000). Most of the original vegetation has been cleared from southern watersheds and crop land in many areas is being transitioned into urban development. In study lakes, agricultural land use ranged from 0 to 16% in northern watersheds from 0 to 73% of the area in southeastern watersheds. Urban development covered more area than agricultural land in

Table 1
Catchment lake dimensions and limnology of the study lakes in the southeastern and northern ecoregions of Wisconsin. Reported are means ± S.E. and the level of significance of a Wilcoxon signed-rank test (p).

Variable	Southeastern ecoregion Mean	Northern ecoregion Mean	p
Watershed development (% of area)			
Urban	32 ± 4	13 ± 2	<0.001
Agriculture	32 ± 5	4 ± 1	<0.001
Total	64 ± 4	16 ± 3	<0.001
Lake-scale characteristics			
Lake area (hectares)	47 ± 5	67 ± 7	0.018
Watershed area (hectares)	260 ± 40	571 ± 98	0.004
Watershed area: lake area	6 ± 1	11 ± 3	0.297
Max depth of lake (m)	12 ± 1	9 ± 1	0.063
Lake perimeter (km)	3 ± 0.3	5 ± 0.3	0.001
Limnology			
Alkalinity (meq L^{-1})	2.8 ± 0.1	0.6 ± 0.1	<0.001
Conductivity (μmhos cm^{-1})	388.3 ± 24.4	83.0 ± 9.1	<0.001
pH (Su)	8.7 ± 0.1	7.8 ± 0.1	<0.001
Calcium (meq L^{-1})	1.3 ± 0.1	0.4 ± 0.05	<0.001
Magnesium (meq L^{-1})	2.1 ± 0.1	0.2 ± 0.02	<0.001
Chlorophyll-a (mg L^{-1})	5.7 ± 0.9	6.4 ± 1.2	0.656
Color (units)	7.8 ± 0.9	12.5 ± 1.4	0.002
Secchi (m)	2.7 ± 0.2	2.4 ± 0.2	0.383
Total phosphorous (mmol L^{-1})	2.1 ± 0.4	1.3 ± 0.2	0.068
Total nitrogen (mmol L^{-1})	31.6 ± 1.8	16.2 ± 1.2	<0.001

Land use variables are expressed as percent of the watershed.