Aquatic Botany 108 (2013) 16–25

Contents lists available at SciVerse ScienceDirect

Aquatic Botany

journal homepage: www.elsevier.com/locate/aquabot

Environmental clustering of lakes to evaluate performance of a macrophyte index of biotic integrity

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ARTICLE INFO

Article history:
Received 21 November 2011
Received in revised form 5 February 2013
Accepted 15 February 2013
Available online 1 March 2013

Keywords:
Biological assessment
Clustering
Lake monitoring
Macrophyte IBI
Ordination
Variance partitioning

ABSTRACT

Proper classification of sites is critical for the use of biological indices that can distinguish between natural and human-induced variation in biological response. The macrophyte-based index of biotic integrity was developed to assess the condition of Minnesota lakes in relation to anthropogenic stressors, but macrophyte community composition varies naturally across the state. The goal of the study was to identify environmental characteristics that naturally influence macrophyte index response and establish a preliminary lake classification scheme for biological assessment (bioassessment). Using a comprehensive set of environmental variables, we identified similar groups of lakes by clustering using flexible beta classification. Variance partitioning analysis of IBI response indicated that evaluating similar lake clusters could improve the ability of the macrophyte index to identify community change to anthropogenic stressors, although lake groups did not fully account for the natural variation in macrophyte composition. Diagnostic capabilities of the index could be improved when evaluating lakes with similar environmental characteristics, suggesting the index has potential for accurate bioassessment provided comparable groups of lakes are evaluated.

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1. Introduction

Biological assessment (bioassessment) is the use of living organisms to evaluate the condition or health of an aquatic environment for the purpose of guiding resource management (Karr and Chu, 1999). A popular method for bioassessment is a multimetric approach using an index of biotic integrity (IBI) (Karr et al., 1986). A recent summary of bioassessment programs in the United States indicated that 68% of states, tribes, territories, and interstate commissions utilize or are developing multimetric indices (US Environmental Protection Agency, (USEPA, 2002)). Initiatives under the European Union Water Framework Directive have similarly focused on the development of multimetric indices for bioassessment (Stelzer et al., 2005; Penning et al., 2008). Multimetric indices provide information about biological condition by integrating ecological, functional, and structural aspects of aquatic systems. These indices are composed of metrics that respond in a predictable manner to human-induced stress. Higher IBI scores are considered indicative of systems with less environmental degradation and higher biotic integrity. Useful biological indices clearly identify biological response to anthropogenic stressors and exhibit minimal variation attributed to environmental characteristics, such as lake depth or watershed size (Karr and Chu, 1999).

Aquatic macrophytes are particularly well-suited for bioassessment because of documented changes in response to environmental condition (Genkai-Cato and Carpenter, 2005; Penning et al., 2008; Mackay et al., 2010) and roles in structuring the biological, chemical, and physical characteristics of lakes (Jeppesen et al., 1998; Cross and McInerny, 2006). An aquatic macrophyte-based IBI has recently been developed for lakes in Minnesota, USA (Beck et al., 2010). The macrophyte-based IBI has shown predictable responses to cultural eutrophication, although IBI response attributed to habitat variation among non-impacted or reference sites is unclear. A challenge to evaluating index response to habitat variation is possible covariance among natural lake characteristics and anthropogenic stressors (Cheruvelil and Soranno, 2008). However, a useful approach in bioassessment is the identification of comparable groups of waterbodies with similar biological communities (Hawkins et al., 2000; Newall and Wells, 2000; Karr

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[3] The Minnesota Cooperative Fish and Wildlife Research Unit is sponsored by the U.S. Geological Survey, the University of Minnesota, the Minnesota Department of Natural Resources, the U.S. Fish and Wildlife Service, and the Wildlife Management Institute.

0304-3770/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.aquabot.2013.02.003

and Chu, 1999). The identification of lake groups based on characteristics that naturally influence macrophyte communities would enable an evaluation of index response to habitat variation. More confident interpretation of the effects of anthropogenic stressors on biotic integrity could be achieved using comparable lake groups.

The goal of the study was to identify environmental characteristics that influence macrophyte IBI response as a basis for establishing a preliminary lake classification to improve bioassessment. The objectives were to (1) quantify major sources of natural variation in macrophyte communities in Minnesota glacial lakes, (2) use the quantified environmental variables to identify similar groups of lakes that minimize natural variability in macrophyte response, and (3) evaluate the effectiveness of using similar groups of lakes for improving bioassessment. Throughout, a distinction between environmental and anthropogenic variables is made such that natural variation in macrophyte communities is observed across environmental gradients, whereas macrophyte communities also respond to stressors attributed to anthropogenic variables. To achieve the objectives, we quantify 25 environmental variables that influence natural variability of macrophyte communities. These variables are then used in a clustering analysis to identify similar groups of lakes, followed by ordination to illustrate the relative influence of the environmental variables on the clusters. Lastly, we use both environmental and anthropogenic variables to quantify the proportion of macrophyte response attributed to both types of variables before and after clustering. We hypothesized that anthropogenic stressors would exhibit a larger influence on the macrophyte IBI when evaluating comparable lake groups, suggesting improved capabilities of the index to diagnose biological impairment. Information from the analyses provides a framework for lake classification that has relevance for implementation of macrophyte indices in Minnesota and other regions with comparable data.

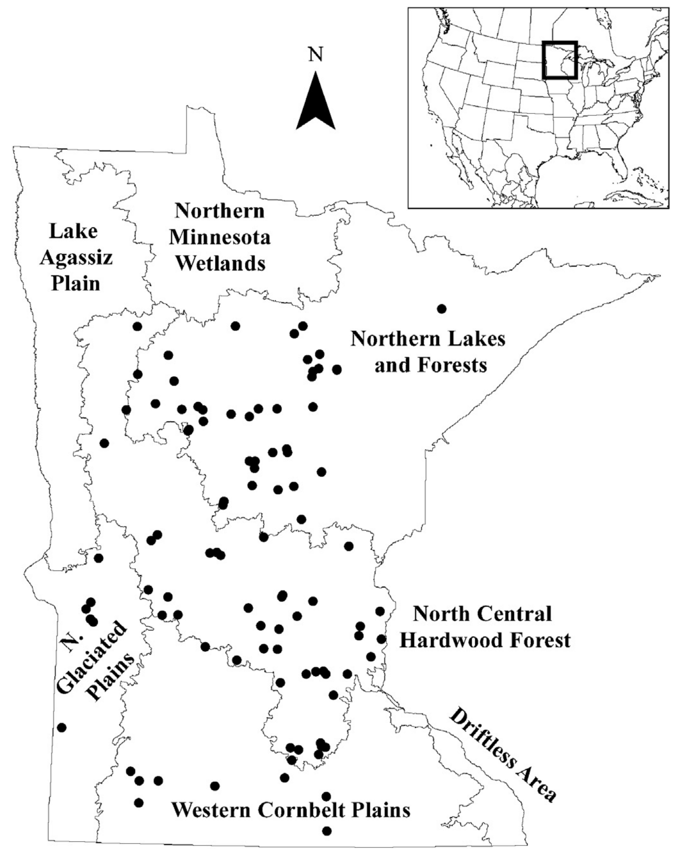

Fig. 1. Ninety-seven lakes used to evaluate performance of the macrophyte-based index of biotic integrity (Beck et al., 2010). Boundaries indicate ecoregions described in Omernik (1987).

2. Methods

2.1. Survey data and lake characteristics

A dataset of 97 lakes described in Beck et al. (2010) was used to evaluate the response of the macrophyte IBI. Each lake has information for IBI and metric scores obtained from point intercept vegetation surveys (Madsen, 1999). The dataset contains lakes in four ecoregions in Minnesota: the North Central Hardwood Forests ($n = 43$), Northern Glaciated Plains ($n = 6$), Northern Lakes and Forests ($n = 38$), and Western Cornbelt Plains ($n = 10$) (Omernik, 1987, Fig. 1). Lakes in the northeast are typically deep and dimictic, whereas lakes in the southwest are typically shallow and polymictic. Lakes in the southern and south-western regions of the state are also more nutrient rich, as a result of lake depth, land use, and soil characteristics of the watersheds. Temperature and precipitation rates decrease with latitude and also vary with regional topography. Climate patterns can affect lake characteristics through varying rates of evapotranspiration, runoff, and length of the growing season.

Twenty-five environmental variables were quantified based on their hypothesized effect on the distribution of aquatic plants across multiple spatial scales (Table 1). The macrophyte IBI was expected to exhibit variability associated with these environmental variables because comparable groups of lakes for bioassessment of macrophytes have not been identified. The selected environmental characteristics were grouped into three categories: lake, watershed, and climate. Finally, four anthropogenic variables were quantified for use in variance partitioning analyses described in Section 2.2.3 (Table 2).

2.1.1. Lake characteristics

Quantified lake characteristics were surface area, maximum depth, Shoreline Development Index (SDI), and lake elevation. Surface area and maximum depth were obtained from shapefiles provided by the Minnesota Department of Natural Resources (MNDNR, 2009). SDI was calculated as the ratio of shoreline length to the circumference of a circle of area equal to that of the lake (Wetzel, 2001) and serves as a proxy for habitat variability, i.e., lakes with $SDI \rightarrow 1$ become increasingly circular, whereas lakes with $SDI \gg 1$ have increasingly complex shorelines. Elevation is the height of the lake above sea level and was obtained from a Digital Elevation Model (DEM) for Minnesota (MNDNR, 2009).

2.1.2. Watershed characteristics

Quantified watershed characteristics were watershed area, ratio of watershed area to lake surface area, number of catchments upstream (flow network data from MNDNR, 2009), watershed elevation range, mean watershed slope, and soil and geological characteristics (see below). Lake watersheds were defined as the continuous area of land drained by the upstream hydrological network, including the land that drains directly into a lake. Watershed elevation range and mean slope were obtained from a statewide DEM (MNDNR, 2009).

Soil characteristics of lake watersheds can influence the physical and chemical properties of runoff entering a lake (D'Arcy and Carignan, 1997; Wetzel, 2001). Soil characteristics quantified for each watershed were available water capacity, percent clay, liquid limit of soil layer (required water content for mobility), percent organic material, permeability, depth of soil layer, and Crop Productivity Index (CPI) (from Natural Resource Conservation Service, NRCS, 2006, 2010). CPI values were obtained from county soil

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