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Development, calibration, and validation of a littoral zone plant index of biotic integrity (PIBI) for lacustrine wetlands

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ARTICLE INFO

Article history:
Received 13 June 2006
Received in revised form
10 January 2007
Accepted 16 January 2007

Keywords:
Plant IBI
Metrics
Aquatic plant assemblage
Lake assessment
Biological assessment

ABSTRACT

We examine lacustrine wetland plant assemblages in the Central Corn Belt Plain portion of the Lake Michigan basin and developed a multimetric plant index of biotic integrity (PIBI). Our objectives were to determine the structural and functional attributes of littoral zone plant assemblages of least-impacted lacustrine wetlands, establish and test candidate metrics, statistically test and calibrate metrics, and finally validate a PIBI along a disturbance gradient. Of 35 candidate metrics, we chose 11 metrics that were grouped into four categories: species richness and composition, species tolerance, guild structure, and vegetation abundance. Based on Spearman correlations, we identified a suite of metrics, particularly those related to species richness and tolerance that had a strong response to human-induced habitat change. The overall PIBI correlated strongly with independent measures of habitat quality ($p < 0.001$) using a qualitative habitat index developed for lacustrine habitats. We validated the lacustrine PIBI by comparing index response to various landuse, landcover, and management types. Least impacted lakes and lakes classified as recreational or undergoing ecological restoration were not statistically separable and received the highest index scores, while the lowest scores were associated with industrial and residential land use. Least-impacted sites differ significantly ($p < 0.001$) from both industrial and residential lakes.

1. Introduction

Biological integrity is the ‘‘ability to support and maintain a balanced, integrated, adaptive assemblage of organisms having a species composition, diversity, and functional organization comparable to that of natural habitat of the region’’ (Karr and Dudley, 1981). The mission of the Clean Water Act (CWA) is to maintain and restore the physical, chemical, and biological integrity of the nation’s surface waters. At the same time, the Environmental Protection Agency (U.S. E.P.A.) has established a policy of no-net loss of wetlands. The combined goals of wetland quality under the CWA and wetland quantity under E.P.A. policy provide an opportunity to meld effective management objectives and prudent conservation measures.

Despite the national no net-loss policy, wetlands are disappearing at an alarming rate as a result of anthropogenic effects (Simon and Stewart, 2006). As wetlands are filled, drained, or tilled, in most cases, no idea of the comparative value of the destroyed wetland exists. In order to establish priorities for future wetland preservation and conservation, it would be desirable to rank wetlands according to relative ‘‘quality’’ or ‘‘value’’ at national (U.S.E.P.A., 2002; Ferreira et al., 2005), regional (Simon et al., 2001; DeKeyser et al., 2003;

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1470-160X/$ – see front matter © 2007 Elsevier Ltd. All rights reserved.
doi:10.1016/j.ecolind.2007.01.002

Rothrock and Simon, 2006), and state level (Gernes and Helgen, 1999; Mack, 2001) scales.

The U.S. E.P.A., Region 5, prescribed an Advanced Identification of Wetlands (AIDID) project to delineate quality of remaining wetlands in the Great Lakes portion of northwest Indiana. The AIDID process entailed selecting wetlands from aerial photographs and maps based on land use, land cover, and wetland heterogeneity. Wetlands that possessed intact riparian corridors as well as heterogeneous emergent and submergent aquatic plant assemblages were selected (the best remaining) for visual inspection. Once at the site, an observer inspected the wetlands, visually judging its integrity, noting the presence of exotics, determining the dominant plant forms, and if seen, noting threatened or endangered species (Stewart et al., 1999; Simon et al., 2001). The rationale was that once the very best wetlands were identified, then efforts could be made to protect them by either direct purchase or working with the property owner. As part of this process we determined that the visual inspection method was inadequate and that a more thorough method that still met the criteria of rapidity was needed. This approach became the hypotheses behind Simon et al. (2001), which developed a plant index of biotic integrity (PIBI) for aquatic plant assemblages in riverine and palustrine wetlands along the southern shore of Lake Michigan. This index used the same rationale as the original fish assemblage IBI (Simon, 1998), but modified 12 metrics to characterize and reflect attributes important to plant assemblages.

Current waterbody assessment practices focus on the development of environmental indicators that are rapid, cost-effective, precise, and repeatable (Herricks and Schaeffer, 1985). Since the development of multimetric indices, the original index of biotic integrity (IBI) has been repeatedly adapted and now is considered a family of indices (Simon, 2000). The development of lake assessment indices has remained one of the last resource types needing environmental indicator development (O'Connor et al., 2000).

Furthermore, despite the success of primary producers as indicators of water quality and hydrological modification (e.g., Seddon, 1972; Whitton, 1979; van Dam et al., 1994; Demars and Harper, 1998), development of rapid multimetric indices that emphasize primary producers lagged behind those for various animal groups. Recent efforts have begun to take advantage of a broad diversity of primary producers including algae (e.g., Hill et al., 2000; Tang et al., 2006) and bryophytes (Heino et al., 2005b), as well as vascular plants.

Vascular plants are currently the focus of rapid assessment indicators for wetlands in the United States (e.g., Davis and Simon, 1995; Stewart et al., 1999; Gernes and Helgen, 1999; Nichols et al., 2000; Simon et al., 2001; Mack, 2001; Cohen et al., 2005; Miller et al., 2006; Rothrock and Simon, 2006). These include both univariate approaches such as the floristic quality index (Swink and Wilhelm, 1994; Herman et al., 1997; Lopez and Fennessy, 2002) and multimetric approaches (Simon et al., 2001; DeKeyser et al., 2003; Miller et al., 2006). For example, Nichols et al. (2000) proposed an aquatic macrophyte community index that relies on morphoedaphic attributes, diversity indices, the relative frequencies of submersed, sensitive, and exotic species, and number of taxa. Mack (2001) tested vegetation IBIs suitable for emergent, shrub-carr, and wooded wetlands in Ohio. DeKeyser et al. (2003) developed an index for the prairie pothole region, while Miller et al. (2006) incorporated measures of floristic quality into a broader headwater index in Pennsylvania. Outside the United States plant assemblages have also proven useful in assessment of aquatic and wetland habitat (Heino et al., 2005a,b), especially those in riverine settings (Haury et al., 1996; Spencer et al., 1998; Ferreira et al., 2002; Iliopoulou-Georgudaki et al., 2003; Dodkins et al., 2005; Ferreira et al., 2005). Especially noteworthy among these studies was the ability of macrophytes to detect habitat degradation due to changes in land use (Heino et al., 2005a,b) and differences in index signatures attributable to elevated nitrate as opposed to siltation (Dodkins et al., 2005).

In the southern Great Lakes basin of the United States, only a small remnant of remaining wetlands persist in the Central Corn Belt Plain (Simon et al., 2001), yet they include a rich and varied flora along a measurable disturbance gradient. The high species diversity of wetland plant species (Choi, 2000; Simon et al., 2001) including the variety of life history strategies, sensitivities and tolerances (Swink and Wilhelm, 1994), and response to anthropogenic stressors (Stewart et al., 1999; Wilhelm et al., 2003) provide a strong foundation for development of wetland assessment tools (U.S.E.P.A., 2002).

The purpose of this paper is to further the development of the index of biotic integrity concept for plant assemblages. In this case we propose a PIBI suitable for lacustrine littoral zones based upon a large sample of natural lakes from the glaciated region of northwestern Indiana.

2. Methods

2.1. Study sites

Sixty-five natural lakes from northwest Indiana were chosen as study sites following the least-impacted criteria identification of the ADID project (Fig. 1). These lakes were randomly selected as a subset of the best lakes remaining in the area, but still covered a broad range of quality including industrial, residential, and recreational lakes, as well as, those undergoing ecological restoration or considered least impacted by human activity. Geologically the lakes have similar parent material since they are situated on a single massive depositional sequence composed of glacial till and outwash laid down 14–15,000 years ago by the Wisconsinan glaciation (Fleming et al., 1994). The lakes fall within several physiographic subdivisions of northwestern Indiana, including the Chicago Lake Plain, Valparaiso Moraine, and Kankakee Sand sections. Lake sizes varied from less than 1 ha to nearly 380 ha. Depending upon lake size and the number of vegetated areas available for sampling, study sites ranged from one to four sites per lake. The number of sites surveyed increased with increasing lake size. For example, lakes less than 100 ha had two sites sampled per lake, while lakes greater than 100 ha had three to four sites depending on the amount of natural vegetated shoreline available. A complete listing of lake sites included in this study is available at www.indiana.edu/~inbsarc/projects_files/projects_fish_files/projects_lakesofindiana.html.