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A comparison of survey methods to evaluate macrophyte index of biotic integrity performance in Minnesota lakes

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ABSTRACT

Aquatic macrophytes shape trophic web dynamics, provide food and refuge for macroinvertebrates and fish, and increase nutrient retention, sediment stabilization, and water clarity. Macrophytes are well-suited as indicators of ecological health because they are immobile, relatively easy to sample and identify, and respond to anthropogenic disturbance on an ecological time scale. Aquatic plant monitoring programs can provide valuable information to water resource managers, especially in conjunction with macrophyte-based indices of biotic integrity (IBI). However, there are several current sampling designs and the precision of IBI scores has not been evaluated across different surveys. We evaluated the performance of the Minnesota macrophyte-based IBI for two survey designs; a point intercept (PI) survey and a belt transect (BT) survey. PI surveys are time intensive, especially on large lakes, whereas BT are less time intensive and have been used historically in Minnesota. Our objectives were to compare the PI surveys with BT surveys on the same lakes, and to modify the BT survey (MT survey) to improve information obtained from BT surveys. BT surveys consistently overestimated IBI scores compared to the PI method ($t = 6.268$, df = 60, $p < 0.001$). Overall IBI scores calculated from MT surveys differed significantly from PI scores, but on average, MT surveys predicted scores only 3% lower than PI scores. Implementation of the Minnesota macrophyte-based IBI through the adoption of the MT survey approach would improve sampling efficiency and enable widespread documentation of the effects of landscape change, shifts in hydrologic regimes, and other anthropogenic activities on the integrity of lacustrine systems.

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1. Introduction

Aquatic plants, or macrophytes, are important components of aquatic ecosystems. Macrophyte communities intricately shape trophic web dynamics by providing oxygen, food, and shelter to macroinvertebrates, fish, and waterfowl. Additionally, aquatic vegetation contributes substantially to nutrient retention, sediment stabilization, and water clarity (Valley et al., 2004). Given the influence of macrophytes on the structure and function of aquatic ecosystems, aquatic plant monitoring programs can provide valuable information to water resource managers.

In the United States, the restoration and maintenance of the chemical, physical, and biological integrity of the nation's waters is mandated by the Clean Water Act of 1972 (formally, amendments to the 1948 Federal Water Pollution Control Act, 33USC1251). The specific legal requirement to maintain the biological integrity of aquatic systems cannot be fulfilled without directly assessing biotic condition. Conventional methods of ecosystem health assessment can be expanded to include direct biological assessment through the incorporation of indices of biotic integrity (IBIs), which integrate several indicators of ecosystem condition into a single index (Karr, 1991). Individual metrics of an IBI reflect biotic condition by measuring aspects of the structure or function of an ecosystem that respond to anthropogenic disturbance in a predictable manner. In Minnesota, the utility of such standardized multimetric measurements has been recognized and the implementation of IBIs in water resources management has been mandated by law (Minn. R. 7050.0150, subp 6). Beck et al. (2010) developed a preliminary macrophyte-based IBI that exhibited predictable changes across gradients of anthropogenic disturbance. Additionally, over two million US dollars has been proposed for the specific purpose of developing and implementing a macrophyte-based IBI

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in Minnesota (Minn. H.F. 656, subp 5.b). Similar and complementary methods have been developed across the Great Lakes region (Nichols et al., 2000; Rothrock et al., 2008; Radomski and Perleberg, 2012), which suggest macrophyte indices have potential for widespread application across broad geographic areas.

A fundamental research challenge is evaluating IBI performance between disparate survey methods. Integration of the Minnesota macrophyte-based IBI (Beck et al., 2010) into existing macrophyte survey protocols could facilitate statewide adoption of the index to enable widespread and systematic assessment of macrophyte assemblages. Currently, macrophytes are surveyed by the divisions of Ecological and Water Resources and Fish and Wildlife within the Minnesota Department of Natural Resources (DNR). DNR Ecological and Water Resources staff have completed over 250 surveys since 1999 using a grid-based point intercept (PI) method, whereas DNR Fisheries staff have completed over 2200 surveys since 1993 primarily using a belt transect (BT) method (Perleberg, Personal communication; Radomski and Perleberg, 2012). Similar aquatic plant survey methods used to survey aquatic plants in Minnesota are used by other state agencies (e.g., Wisconsin; Hauxwell et al., 2010) and in federal assessment programs for lakes under the National Lakes Assessment Program (USEPA, 2011).

Ecologists often face a tradeoff between data quality and the practical limitations of sampling effort when quantifying biotic characteristics of an ecosystem (Martinez et al., 1999; Cao et al., 2002; Kennard et al., 2006). PI survey methods provide quantitative and spatially explicit data, but are more time intensive than BT surveys and may be better suited for specific objectives, such as assessing macrophyte communities to address water quality related to the Clean Water Act of 1972 (Beck et al., 2010); changes in macrophyte communities over time in response to eutrophication, development, climate change; surveys for invasive species; and surveys for rare species. Alternatively, BT surveys do not represent whole-lake macrophyte communities as comprehensively, but do require less sampling effort. The Minnesota macrophyte-based IBI of Beck et al. (2010) was developed from PI surveys and its performance has not been evaluated using BT surveys.

A detailed assessment of the potential effects of different survey designs and reduced sampling effort on IBI behavior may be timely, as multiple researchers have indicated that survey methods affect data quality (Gotelli and Colwell, 2001; Perleberg, 2001; Beck et al., 2010; Mikulyuk et al., 2010). Mikulyuk et al. (2010) reported that species richness estimates decreased significantly in a predictable manner as sampling effort was reduced, but other attributes, such as the relative frequency of dominant species, maximum depth of plant growth, and percentage of vegetated littoral area, were less dependent on sampling intensity. Additionally, Perleberg (2001) cautioned against comparing frequency values from survey methods that employed different plot numbers and sizes because large plot sizes tended to falsely inflate frequency values.

The IBI consists of a variety of different types of metrics and responses of the metrics to sampling effort are unlikely to be uniform. If overall IBI and metric scores can be accurately predicted at a reduced sampling intensity, as in BT surveys, there is potential to increase the efficiency of widespread assessment of ecological health using macrophytes in Minnesota and other areas in the Great Lakes region.

Our goal was to evaluate the performance of the Minnesota macrophyte-based IBI across multiple survey types and levels of sampling effort to quantify index precision with different methods. We assumed that the time required for PI surveys on individual lakes is excessive and a more efficient sampling design can be used for statewide implementation of the IBI. Our objectives were to determine the utility of using the IBI with a modified transect (MT) design to improve information obtained from BT surveys while reducing overall sample effort for a comparable PI survey. For all analyses, existing PI surveys were used as a comparison for BT and MT surveys. A quantitative comparison of survey methods will inform monitoring in Minnesota and may be useful for other areas where similar methods are used.

2. Methods

Three analyses were conducted to achieve our goal. First, IBI and component metric scores were compared for 61 lakes with existing PI and BT data to evaluate comparability of existing survey methods. Second, the ability of the MT approach to reproduce IBI scores from PI surveys was evaluated using randomized MT surveys that contained survey points along hypothetical transects. MT surveys were used to sample simulated macrophyte communities in three lakes with smooth surfaces of lakewide macrophyte communities that were created by indicator kriging of existing species data. Third, the MT survey design was expanded to a dataset of 39 lakes to further quantify the utility of the approach to maximize data quality and minimize sample effort.

2.1. Belt transect surveys versus point intercept surveys

The first analysis evaluated the use of existing BT surveys to obtain IBI scores for comparison with scores using PI surveys. Of the 97 lakes used to develop the Minnesota macrophyte-based IBI (Beck et al., 2010), 61 lakes in which both PI and BT DNR surveys had been carried out were chosen for analysis (Supplement 1 and 2). These lakes span four level III ecoregions (Omernik, 1987) (Fig. 1.), represent many of the major lake classes in Minnesota (Schupp, 1992), and range widely in ecological characteristics as indicated by macrophyte IBI scores which ranged from 23 to 78.

A predefined grid of evenly spaced points is overlaid across the littoral zone (area of macrophyte growth) and each point is sampled with a double-headed rake in the PI method. Plant species are identified and their presence or absence is recorded (Madsen, 1999). Plants are visually assessed along 6 m wide transects and sampled with a double-headed rake when closer inspection is needed in the BT method (Anonymous, 1993). The number of transects ranges from 10 to 50 depending on lake surface area and each transect is considered an individual sample point. In contrast to the predetermined area of the PI surveys, BT surveys do not have a defined sample area and transects vary in length depending on slope of the lake bottom. PI surveys were performed in June through September of 2001–2008 with a mean sample density of 2.8 points/ha for each lake. BT surveys were performed in June through September of 1993–2003 with 10–50 transects per lake depending on surface area (Anonymous, 1993). Lake surveys contain species presence/absence and depth data for each sample unit. The sample units are individual points for PI surveys or whole transects for BT surveys.

IBI and component metric scores were calculated for PI and BT surveys using a program developed with R statistical software (RDCT, 2012). The program uses individual lake surveys to calculate metric scores for each of seven metrics from Beck et al. (2010). The metrics are: maximum depth of plant growth, 95% occurrence (MAXD), percentage of littoral zone vegetated (LITT), number of species with frequency over 10% (OVER), relative frequency of submersed species (SUBM), relative frequency of sensitive species (SENS), relative frequency of tolerant species (TOLR), and number of native taxa (TAXA). The SENS and TOLR metrics are based on the Coefficient of Conservatism (Milburn et al., 2007). The metrics are summed to obtain an IBI score.

Raw metric values are determined from the survey data, e.g., count of native species richness, and converted to a continuous