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Development of new indices of Great Lakes water quality based on profundal benthic communities

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ABSTRACT

Benthic invertebrate biomonitoring has long been a tool of choice for assessing the impacts of anthropogenic stress in aquatic systems. The Oligochaete Trophic Index (OTI) is used by the U.S. EPA Great Lakes National Program Office to assess Great Lakes trophic status for *State of the Great Lakes* reporting under the Great Lakes Water Quality Agreement. OTI scores are based on pollution tolerances of ubiquitous profundal oligochaetes. OTI limitations include the fact that the index is based on a limited number of species belonging to a single oligochaete class, species assignment to trophic groups in the index were determined by best professional judgment and cannot be tested independently, and the index's correlation with lake productivity has not been evaluated. To address these concerns, we developed two new indices of Great Lakes water quality based on the OTI equation by: (1) expanding the number of oligochaete species included in the index and reassigning previous classifications of oligochaete species to trophic groups (improved OTI, or iOTI); and (2) adding non-oligochaete species to the OTI (modified Trophic Index, or mTI). Finally, we tested a modeling approach using Modern Analogue Technique (MAT) transfer functions based on species responses to a surface chlorophyll gradient to derive assessment of site trophic status and an independent assignment of species to trophic categories. We found that both iOTI and mTI had a stronger relationship with surface remote-sensed spring chlorophyll than did OTI, but MAT models had stronger correlations with chlorophyll than did any of the indices.
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Introduction

The Clean Water Act (1972) and the Great Lakes Water Quality Agreement (GLWQA, 2012) stress the importance of monitoring the Great Lakes water quality to report on status and trends over time and guide the development and implementation of environmental programs to address existing and emerging issues. Benthic invertebrate biomonitoring has long been a tool of choice in assessing and monitoring the impacts of anthropogenic stress in aquatic systems, satisfying many of the criteria characterizing the ideal biomonitoring tool (Abbasi and Abbasi, 2012). Benthic macroinvertebrates can serve as long-term environmental indicators due to their relative longevity, range of biological traits, and well-established responses to different stressors (i.e., Barbour et al., 1999; Hilsenhoff, 1988; Howmiller and Scott, 1977; Karr and Chu, 1999; Milbrink, 1973; Resh et al., 1995; Wiederholm, 1980). As most persistent toxic contaminants ultimately become associated with bottom sediments due to their strong affinity for particulate material (Nalepa and Landrum, 1988), organisms living in these habitats integrate water and sediment quality (Rosenberg et al., 2004). The benthic community also closely reflects shifts in the overall system productivity and may be more sensitive to environmental changes than the pelagic community (Karatayev et al., 2013; Reynoldson and Metcalfe-Smith, 1992; Wiederholm, 1980). Benthic community structure integrates and reflects the cumulative effects of the factors impacting that habitat or ecosystem over time – an attribute not shared by indices based predominantly on physico-chemical variables (Abbasi and Abbasi, 2012).

In contrast to lotic and littoral benthic communities, profundal benthic communities of large deep lakes are often low in species richness and are primarily dominated by oligochaetes (Cook and Johnson, 1974; Henson, 1966). Pollution tolerance of aquatic oligochaetes has been used for water quality monitoring since the early 1930s (Brinkhurst, 1965; reviewed in Rodriguez and Reynoldson, 2011;

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Wright and Tidd, 1933). Unlike insects, oligochaetes do not emerge; they spend all their life within the sediment. As a result, a number of classification systems have been developed in different systems, including the Great Lakes, to quantify the association of oligochaetes with organic enrichment. Initially, these systems used total oligochaete numbers to reflect trophic conditions (e.g., Carr and Hiltunen, 1965; Wright, 1955), but much information is lost with this "bulk" approach since different species within the Oligochaeta class have widely differing sensitivities to organic enrichment. The availability of multiple species with different tolerances to organic pollution renders this class a useful indicator group across a full range of habitats from oligotrophic to heavily eutrophic (reviewed in Rodriguez and Reynoldson, 2011). As pollution increases, species with different physiological tolerances to water and sediment pollution replace each other and the community composition shifts (Lauritsen et al., 1985).

Multiple approaches have been developed to assess water quality based on benthic macroinvertebrates, from using indicator taxa to multimetric indices, many of which use taxa specific to lotic waters (Abbasi and Abbasi, 2012; Hilsenhoff, 1988). Benthic indices that involve ranking taxa (typically genus or species) on a scale from pollution intolerant to pollution tolerant are among the most common approaches to water quality monitoring (Abbasi and Abbasi, 2012; Birk et al., 2012). These indices are calculated as abundance-weighted averages of integer tolerance scores of taxa. For the Great Lakes, Brinkhurst et al. (1968) and Mozley and Howmiller (1977) used densities and tolerances of chironomid species to calculate a "trophic condition" index to facilitate comparison of trophic status among or within lakes using three tolerance groups. Howmiller and Scott (1977) adapted this index using species of Oligochaeta, and Milbrink (1983) later modified it, increasing the number of tolerance groups to four and introducing a coefficient dependent on the abundance of oligochaetes in the sample. A similar approach was used by Wiederholm (1980) to calculate the Benthic Quality Index (BQI) for lakes based on Chironomidae and Oligochaeta species. Recently, Jyväsjärvi et al. (2014) improved this index by deriving indicator scores for additional taxa using detrended correspondence analysis and weighted averaging in an extended BQI for profundal communities of northern European lakes.

The Clean Water Act (1972) dictates "an identification and classification according to eutrophic condition" of all publicly owned freshwater lakes, including the Great Lakes, in order to access trends in lake quality and to aid environmental decision making. A modification of the Milbrink index, accepting the abundance-based coefficient and formula but retaining Howmiller and Scott's species classifications (Oligochaete Trophic Index, or OTI), is used by the U.S. Environmental Protection Agency's (EPA) Great Lakes National Program Office (GLNPO) to report benthic results from its long-term Great Lakes Biology Monitoring Program (Barbiero and Tuchman, 2002) and by EPA and Environment and Climate Change Canada to assess ecosystem condition for *State of the Great Lakes* reporting under the Great Lakes Water Quality Agreement. The assignment of oligochaete species to trophic categories by US EPA was based on Great Lakes species and has been subject to some modification over time (Barbiero et al., 2009; Riseng et al., 2014). While the OTI evaluates Great Lakes trophic state correctly, within-lake assessment (e.g., lake basins) using OTI is more problematic. For example, the amount of chlorophyll *a*, total and soluble phosphorus, as well as algal blooms in Lake Erie are the highest in the western and lowest in the eastern basin, but OTI scores are higher in the eastern than in the western basin (Riseng et al., 2014). There may be several reasons for this disagreement between OTI and pelagic measures of trophic state. First, OTI has not been specifically tested to evaluate its correlation with lake productivity. Second, assignment of taxa to trophic groups by researchers is an ongoing process, further complicated by the assignment of the same species to different groups by researchers working in lakes of different trophicity (Howmiller and Scott, 1977; Krieger, 1984; Milbrink, 1983), as relatively few oligochaete species have been the subject of toxicological and life-history studies (reviewed in Rodriguez and Reynoldson, 2011). The OTI index uses only a portion (27) of the species or higher taxa of all oligochaetes described for the Great Lakes (101 oligochaete taxa, Spencer and Hudson, 2003). Third, since the index is based on abundance of a single class (Oligochaeta), samples that do not contain Oligochaeta cannot be evaluated (US EPA, 2015). Finally, multiple additional factors in the Great Lakes (e.g., invasive species, regional climate trends) may have modified the responses of constituent species to productivity such that the OTI may not fully reflect changes in the trophic status of the ecosystem. Therefore, there is a need to evaluate the performance of the OTI, and possibly improve the index or develop a new method, to better assess the current trophic status of the Great Lakes and other large lakes, and to track changes through time.

In this study, we developed new water quality indices based on the OTI (Milbrink, 1983) by (1) adding more oligochaete species and reviewing previous classifications of oligochaete species to trophic groups and reassigning species as necessary (hereby called the improved Oligochaete Trophic Index, or iOTI) and (2) adding non-oligochaete species to OTI trophic groups (hereby called the modified Trophic Index, or mTI). We calculated and tested iOTI and mTI using the 1998–2013 U.S. EPA GLNPO benthic data set collected from all five Great Lakes, in conjunction with other chemical and biological data generated by the U.S. EPA GLNPO Limnology and Great Lakes Biology Monitoring programs and U.S. EPA GLNPO estimates of surface chlorophyll concentration derived from satellite observations. We then compared the performance of the OTI, iOTI, and mTI to measures of eutrophication and water quality variables to evaluate their sensitivity and to choose the best performing benthic index for estimation of water quality in the Great Lakes. Finally, to avoid potential bias of assigning species to a limited number of trophic groups (four) by relying solely on expert opinion, we used a modeling approach based on species responses to the surface chlorophyll gradient to derive assessment of the trophic status of sampling stations and an independent assignment of species to trophic categories.

Materials and methods

To test the OTI, iOTI, and mTI, we used benthic and water quality data collected from all five Laurentian Great Lakes by U.S. EPA GLNPO in annual summer (August) surveys from 1998 to 2013. Benthic invertebrate data were collected at 58 regular sampling stations (from 10 to 16 stations per lake) with depths that ranged from 9 to 250 m (details in Burlakova et al., in this issue). Triplicate samples for benthic invertebrates were collected at each station using a Ponar sampler. Samples were washed through a 500-μm mesh sieve, preserved with formaldehyde with Rose Bengal stain to a final concentration of 5–10% and then sorted and identified in the lab to the lowest practical taxonomic level. Sediment chemistry and granulomerty, important for the explanation of distributional patterns in benthic invertebrates (Brinkhurst, 1974; Cole and Weigmann, 1983), were unavailable for our analysis. Sediment grain size data were collected at a limited number of stations in 1998; sediment organic carbon, sediment phosphorus and sediment nitrogen was measured only in 1998 and 2002. These data, however, may not be applicable for analysis of recent benthic data because *Dreissena* spp. (both *D. polymorpha* and *D. rostriformis bugensis* invaded the Great Lakes in late 1980s–early 1990s and by 2014 had colonized the majority of GLNPO monitoring stations in all lakes except Lake Superior) are known to increase the amount of organic matter in the sediment (Stewart et al., 1998; Howell et al., 1996). Water quality (WQ) variables, including chlorophyll *a* (μg/L), total soluble phosphorus (TSP, μg/L), and total phosphorus (TP, μg/L), were measured near the bottom (1 m above the bottom in Lake Erie and 2 m in other lakes) once a year (during same summer cruise) and only at 34 of the 58 benthic stations. While multiple sources of organic matter (e.g., phytoplankton, periphyton and benthic algae, and allochthonous matter) are available for use by the littoral benthic community, most of our stations were located in the profundal zone (below thermocline, usually

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