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A depth-adjusted ambient distribution approach for setting numeric removal targets for a Great Lakes Area of Concern beneficial use impairment: Degraded benthos

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ABSTRACT

We compiled macroinvertebrate data collected from 1995 to 2014 from the St. Louis River Area of Concern (AOC) of Lake Superior. Our objective was to define depth-adjusted cutoff values for benthos condition classes to provide an analytical tool for quantifying progress toward achieving removal targets for the degraded benthos beneficial use impairment. We used quantile regression to model the limiting effect of depth on selected benthos metrics, including taxa richness, percent non-oligochaete individuals, combined percent Ephemeroptera, Trichoptera, and Odonata individuals, and density of ephemerid mayfly nymphs (*Hexagenia*). We created a scaled trimetric index from the first three metrics. Metric values above the 75th percentile quantile regression model prediction were defined as being in relatively excellent condition in the context of the degraded beneficial use impairment for that depth. We set the cutoff between good and fair condition as the 50th percentile model prediction, and we set the cutoff between fair and poor condition as the 25th percentile model prediction. We examined sampler type, geographic zone, and substrate type for confounding effects. Based on these analyses we combined data across sampler types and created separate models for each of three geographic zones. We used the resulting condition-class cutoff values to determine the relative benthic condition for three adjacent habitat restoration project areas. The depth-limited pattern of ephemerid abundance we observed in the St. Louis River AOC also occurred elsewhere in the Great Lakes. We provide tabulated model predictions for application of our depth-adjusted condition class cutoff values to new sample data.

Introduction

Great Lakes Areas of Concern (AOC) were listed by the signatories of the United States-Canada Great Lakes Water quality Agreement (GLWQA, ammendment of 1987; http://binational.net/annexes/a1/; accessed 6 October 2016) as places where significant impairment of beneficial uses of the Laurentian Great Lakes or their tributaries has occurred due to local human activities (https://www.epa.gov/great-lakes-aocs; accessed 6 October 2016). Beneficial use impairments (BUIs) result from changes in the chemical, physical, or biological integrity of the system sufficient to cause impairment in structural or functional attributes directly or indirectly important to humans. Among the 14 established BUIs are restrictions on fish and wildlife consumption, degradation of aesthetics, degraded fish and wildlife populations, and degradation of benthos.

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For an AOC in the U.S. to be "delisted," all local BUIs must be removed through the achievement of local removal targets created by states, tribes, and local stakeholder groups in a manner consistent with guidance provided by the U.S. Environmental Protection Agency (United States Environmental Protection Agency [USEPA], 2001). BUI removal targets should be premised on local goals and be consistent with applicable federal and state regulations. Targets should be based on measurable indicators, be realistic and achievable (https://www.epa.gov/great-lakes-aocs/beneficial-use-impairments; accessed 6 October 2016).

Degradation of benthos (i.e., benthic macroinvertebrate assemblages) is a BUI at twenty-three of the remaining twenty-seven AOCs in the US Great Lakes, including the St. Louis River (SLR), a tributary of western Lake Superior. The rationale for the degraded benthos BUI for the SLR AOC was evidence that benthic abundance and diversity were "reduced" in areas of known habitat alteration or in proximity to known sediment contamination in the lower SLR (Minnesota Pollution Control Agency [MPCA], 2013). Assemblages in these areas were dominated by pollution-tolerant taxa and lacked diversity (MPCA, 2013). The

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narrative removal target for the SLR AOC specifies that this BUI may be considered for removal when:

"*The benthic community in historically degraded areas (e.g., chemically, biologically, or physically) of the AOC does not significantly differ from unimpacted sites of comparable characteristics within the AOC. Benthic communities' characteristics including native species richness, diversity, and functional groups will be considered when comparing sites*" (MPCA, 2013).

"Comparable characteristics" means that physical habitat characteristics (e.g., depth, substrate), that are largely unrelated to the source of the impairment, are similar between historically degraded sites and restored sites or sites away from known historical degradation.

The wording "unimpacted sites" implies a reference expectation against which to assess the condition of sites. The reference condition approach for aquatic bioassessment is well developed (Baily et al., 2004; Grapentine, 2009; Yates and Bailey, 2010). However, defining reference is challenging in historically and extensively impacted contiguous ecosystems where sites are not independent, comparable unimpacted sites are rare, and reliable and sufficiently fine-scaled stressor gradient data are not available (Angradi et al., 2009b). Such is the case for the lower SLR. Other Great Lakes ecosystems with similar assessment challenges include the Lake Erie-Lake Huron Corridor (McPhedran and Drouillard, 2013) and the Upper St. Marys River. Because we could not define reference sites in the lower estuarine part of the SLR using stressor gradient data, we used an ambient distribution approach to define numeric condition-cutoff values (e.g., between impaired for the beneficial use and unimpaired for the beneficial use). In this approach, *a priori* percentiles are chosen representing particular condition cutoffs (e.g., poor, fair, good) which are applied to the distribution of available data for the resource (USEPA, 2000; Stoddard et al., 2006). We use the term "cutoff" instead of "threshold" to define condition classes to avoid confusion with the concept of ecological thresholds (Dodds et al., 2010).

There are problems with using the ambient distribution to define reference expectations, especially with respect to assessing the condition of a population of sites, which are discussed below. However, the ambient approach allows the *relative* impairment of sites to be compared among sites with similar characteristics. The relative condition of a site can thus be quantified and cutoff values derived. BUI removal and AOC delisting decisions must occur despite the lack of ecological reference as traditionally defined for data rich systems. Our view is that numeric BUI criteria based on an imperfect method for deriving relative condition are an improvement on the narrative removal target.

Methods for deriving condition-class cutoff values that account for variation associated with natural factors improve the sensitivity and reliability of the indicator (Davis and Simon, 1995; Reynoldson et al., 1997; Baily et al., 2004). One version of this idea, illustrated in Fig. 1a, is that while there are multiple natural and anthropogenic sources of variation in the ambient distribution of benthos metrics, and assuming that not every sampled site is significantly impacted, a natural factor limits the maximum value of the metric (Terrell et al., 1996; Scharf et al., 1998). Values below the upper bound of the ambient distribution are limited by other factors, including anthropogenic disturbance. The upper bound of the distribution represents the extant least disturbed benthic conditions over the range of the limiting factor. A quantile function describing some upper bound of the data either as a straight line or as a peaked distribution can be used to define the reference condition for the metric in the local setting.

Preliminary analyses of selected benthos metrics from SLR samples showed that depth had a significant relationship with metric values (Fig. 2). This corroborates earlier studies in the lower SLR that showed an effect of depth on diversity and the relative abundance of many taxa (Swanson, 1999; Breneman et al., 2000; Trebitz et al., 2009). The distribution of the metrics was wedge-shaped with respect to depth (Fig. 2), suggesting a limiting effect of depth. Data included in Edsall et al. (2004) provide independent support for the existence of a depth-limited distribution for benthos in the lower SLR. In those data, there was a strongly wedge-shaped relationship between depth and the density of *Hexagenia* nymphs (Fig. 1b). Samples with visible evidence of pollution were not near the upper limit of nymph density for any depth at which they collected nymphs.

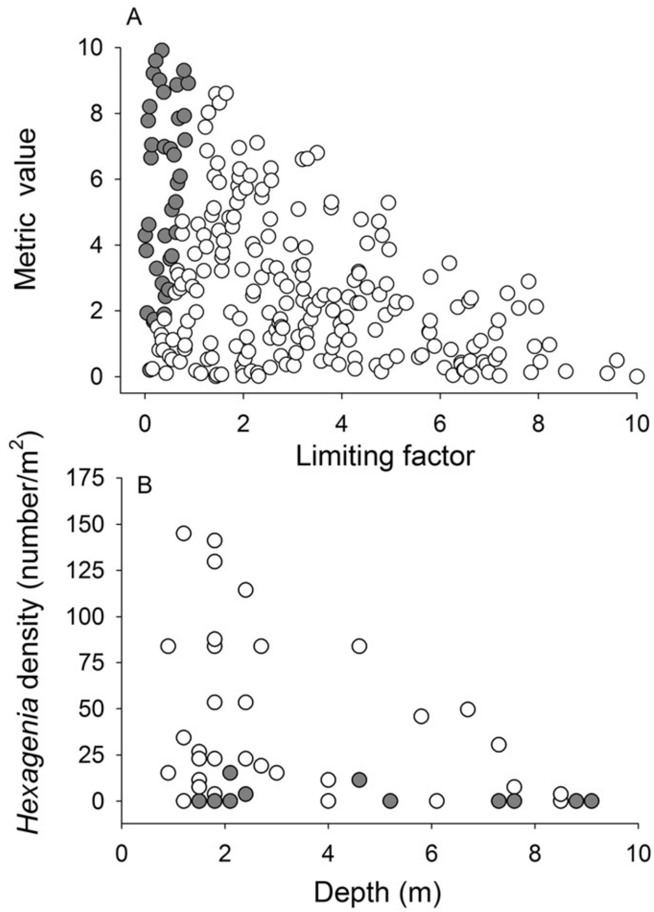

Fig. 1. Plot A: Hypothetical distribution of an indicator metric when a natural limiting factor is present. The population represented by all the points has a wedge-shaped distribution implying a linear limiting relationship wherein the maximum value of the metric occurs at a limiting factor value near 0. The population represented by the open symbols has a non-linear peaked relationship. In this case, the maximum value for the metric occurs at a factor value between 1 and 2. Plot B: Wedge-shaped distribution for the density of *Hexagenia* nymphs in the lower St. Louis River from data in Edsall et al. (2004). Filled symbols in plot B are samples that had visible evidence of pollution (e.g., sheen, coal, coal waste).

There are several potential explanations for the association between depth and the benthos in the SLR. Because of the geomorphology of the lower river, there is an association between depth and exposure or fetch (Fig. 3a), a correlate of natural physical disturbance, especially over the shallow 0 to 4 m depth range. Exposure increases with depth up to a depth of 2 to 3 m, which is the dominant depth outside of navigation channels. Other Great Lakes studies have shown an effect of fetch on benthos (e.g., Cardinale et al., 1998; Burton et al., 2002, 2004). There is a strong relationship between depth and the probability of occurrence of submerged aquatic vegetation (SAV; Fig. 3b). The occurrence of SAV, which has a significant effect on benthos diversity in the lower SLR (Trebitz et al., 2009), declines rapidly with depth and is rarely present deeper than 2 m (Angradi et al., 2013). The maximum organic matter content of the substrate, which also influences benthic assemblage composition (Cole and Weigmann, 1983), declines an order of magnitude over the depth range of the lower SLR (Fig. 3c). At the shallow end of the depth range, breaking wave-induced water velocity, which is a function of depth (Fig. 3d), has an effect on aquatic vegetation, sediment transport (Silander and Hall, 1997), and the littoral benthos