Ecological Indicators 23 (2012) 176–188

Contents lists available at SciVerse ScienceDirect

Ecological Indicators

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

Application of multiple index development approaches to benthic invertebrate data from the Virginian Biogeographic Province, USA

Marguerite C. Pelletier[a,b,*], Arthur J. Gold[b], Liliana Gonzalez[c], Candace Oviatt[d]

[a] U.S. Environmental Protection Agency, Office of Research and Development, National Health and Environmental Effects Laboratory, Atlantic Ecology Division, Narragansett, RI 02882, United States
[b] University of Rhode Island, Department of Natural Resources Science, Kingston, RI 02881, United States
[c] University of Rhode Island, Department of Computer Science and Statistics, Kingston, RI 02881, United States
[d] University of Rhode Island, Graduate School of Oceanography, Narragansett, RI 02882, United States

ARTICLE INFO

Article history:
Received 23 December 2010
Received in revised form 15 March 2012
Accepted 18 March 2012

Keywords:
Benthic indices
Method comparison
Invertebrates
Estuarine

ABSTRACT

Previous work had indicated that the Virginian Province Index did not perform well in a smaller estuarine complex. While it was hoped that the existing Chesapeake Bay Benthic Index of Biotic Integrity, with its greater number of metrics and habitat separation would be more adaptable, this index also did not perform well outside of Chesapeake Bay. In this study we assembled additional metrics and applied different methods of index compilation to explore the indices relative strengths and weaknesses. Three different approaches were utilized – two multimetric indices (Chesapeake Bay IBI and the Mebane IBI) and a statistical logistic regression technique. The data were subdivided by habitat (salinity and grain size), and indices compiled using the same initial group of benthic metrics. Each approach was examined for its classification accuracy for both reference and impaired sites for the entire Virginian Province. The Chesapeake Bay IBI approach did not perform well in this study. In contrast, another multimetric approach, the Mebane IBI approach, performed well, as did the statistical logistic regression approach. Both techniques have promise for index development and could be useful in applying a biological condition gradient to estuaries.

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1. Introduction

Macroinvertebrates have commonly been used to detect pollution impacts in estuaries (Pinto et al., 2009; Dauvin et al., 2010). They are abundant, easy to collect and their communities are very diverse, with representatives from many different phyla (Snelgrove, 1998) utilizing many different habitats and feeding strategies (Rhoads, 1974; Weisberg et al., 1997; Little, 2000). Macroinvertebrate assemblages also respond predictably to pollution (Pearson and Rosenberg, 1978; Hart and Fuller, 1979), are relatively sedentary, and act as integrators of stress over months to years (Weisberg et al., 1997; Paul et al., 2001).

Benthic communities can be assessed using multivariate, univariate and multimetric approaches. Multivariate analysis is generally more sensitive (Warwick and Clarke, 1993; Clarke and Warwick, 2001). Less information is lost, and more complicated environmental gradients may be detected. Unfortunately, these analyses may be more difficult to interpret by non-experts. Given the potential difficulty of interpretation and the requirement for advanced statistical packages, many environmental managers prefer to use univariate (e.g., Shannon's H′) or multivariate indices (Weisberg et al., 1997; Paul et al., 2001) in estuaries to assess benthic community response. Benthic indices based on macroinvertebrates have been developed and used for assessing estuarine condition (Marques et al., 2009). In the United States, it has been suggested that biomonitoring and indices be used in marine and estuarine waters much as they are currently used in streams to address water quality standards (Gibson et al., 2000).

Benthic indices summarize aspects of the invertebrate community into a single number that can be used by environmental managers (Engle and Summers, 1999; Pinto et al., 2009). These indices can be related to various environmental factors which can help to diagnose identified impairment. Both multimetric and multivariate indices generally are composed of metrics representing different aspects of the benthic community including diversity, productivity, pollution tolerance-sensitivity, trophic composition and species composition, which are expected to change in response to environmental stressors such as sediment contamination or estuarine eutrophication. If chosen well, these metrics, and indices,

* Corresponding author at: U.S. Environmental Protection Agency, Office of Research and Development, National Health and Environmental Effects Laboratory, Atlantic Ecology Division, Narragansett, RI 02882, United States.
Tel.: +1 401 782 3131; fax: +1 401 782 3030.
E-mail address: pelletier.peg@epa.gov (M.C. Pelletier).

1470-160X/$ – see front matter. Published by Elsevier Ltd.
doi:10.1016/j.ecolind.2012.03.019

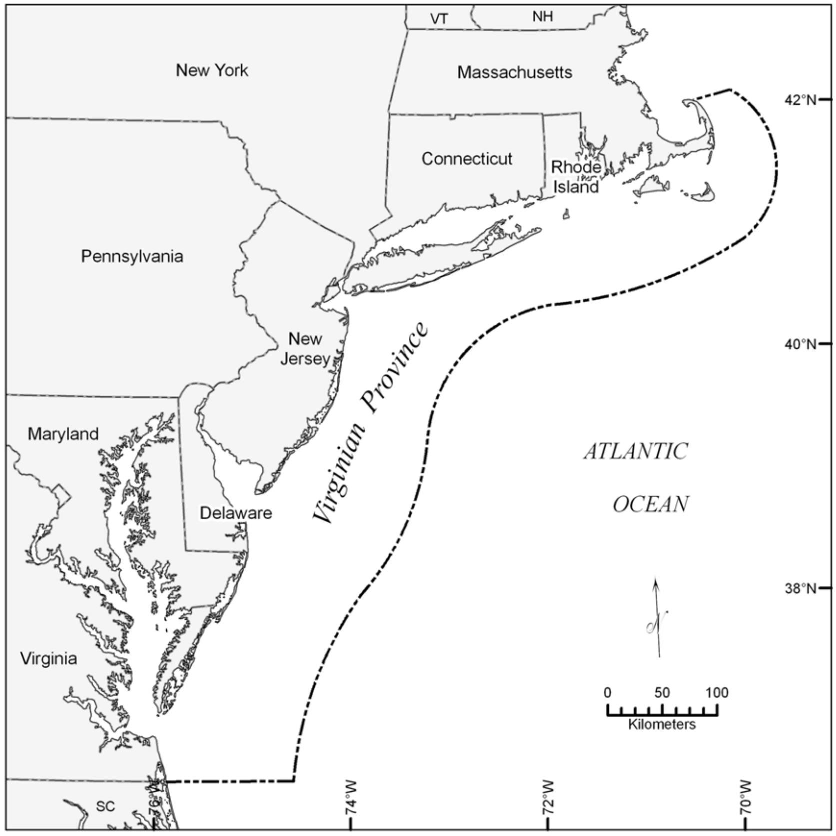

Fig. 1. Map of Virginian Biogeographic Province.

will be primarily responsive to the environmental gradient of concern (e.g., anthropogenic impairment) and minimize the impact of natural gradients. However, because these indices are community summaries, some information is lost; it is possible that they will be unresponsive to factors not accounted for during index development or that some undetected gradient could influence the index.

A variety of indices have been developed worldwide (Marques et al., 2009). In the United States, benthic indices comprised of multiple metrics are commonly utilized (Karr et al., 1986; Weisberg et al., 1997; Engle and Summers, 1999; Van Dolah et al., 1999; Paul et al., 2001; Llansó et al., 2002a,b; Hale and Heltshe, 2008), although the method of their construction varies. The Index of Biotic Integrity (IBI), an additive multimetric technique, was first developed for streams using fish communities (Karr et al., 1986). This approach was later applied to stream macroinvertebrate communities (Ohio EPA, 1987; Plafkin et al., 1989; Kerans and Karr, 1994), and then to estuarine macroinvertebrate communities (Weisberg et al., 1997; Van Dolah et al., 1999). This approach is now used in more than 80% of water quality programs in the United States (Norris and Hawkins, 2000). Although the traditional approach for developing IBIs advocated by Karr has been utilized in U.S. estuarine waters (Weisberg et al., 1997; Van Dolah et al., 1999), alternative IBI development practices have been utilized in freshwater. One modification uses continuous scoring, and it has been shown to be more effective than non-continuous scoring (i.e., 1, 3, 5) of traditional IBI approaches (Pinto et al., 2009; Blocksom, 2003). Continuous scoring was used to develop a fish index for Pacific Northwest rivers (Mebane et al., 2003), and macroinvertebrate indices in mid-Atlantic highland streams (Blocksom, 2003).

A variation on the traditional IBI approaches is to use statistical techniques to assemble multimetric indices. For example, Engle and Summers (1999) developed a benthic index comprised of five metrics for Gulf of Mexico estuaries using discriminant analysis. This index was scaled between zero and ten to aid in interpretation. Paul et al. (2001) also used discriminant analysis to develop a benthic index using three metrics for the Virginian Biogeographic Province (Fig. 1) located along the east coast of the United States. To account for habitat differences, some metrics were adjusted for salinity. Index values below zero are considered impaired while those above zero are considered unimpaired. Hale and Heltshe (2008) used logistic regression rather than discriminant analysis to develop a benthic index composed of three metrics for the Gulf of Maine. This index also ranges from 0 to 10.

Diaz et al. (2004) suggested that development of new indices should only proceed after examination of the appropriateness of existing indices. The Virginian Province Index (Paul et al., 2001) was developed using discriminant analysis. This index was well calibrated for the entire Province (Fig. 1), while also performing well when applied to the Chesapeake Bay (Ranasinghe et al., 2002). However, it was not particularly effective when applied to assessing benthic condition in the Hudson-Raritan estuary (D. Adams, personal communication). The better performance in the Chesapeake Bay was likely due to the fact that almost half of the stations used to develop the Virginian Province Index were from Chesapeake Bay. The Chesapeake Bay Benthic Index of Biotic Integrity (Weisberg et al., 1997; Llansó, 2002) is a multimetric index that is subdivided by habitat and contains many more metrics summarizing benthic community condition. Given the success in applying this index within Chesapeake Bay, the largest estuary in the United States, and its subestuaries, we hoped that it would be possible to directly apply the Index to the entire Virginian Province. However, our initial attempts to directly apply this index did not provide good classification accuracy, especially for impaired sites. Our results corresponded to other unsuccessful attempts to apply this index to