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Development of indices of biotic integrity for high-gradient wadeable rivers and headwater streams in New Jersey

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ABSTRACT

The New Jersey Bureau of Freshwater and Biological Monitoring (BFBM) has been conducting Fish Index of Biotic Integrity (FIBI) monitoring on rivers and streams (with drainage area > 12.95 km^2) in the Northern part of the state since 2000 using Karr's original IBI format with several regional modifications. In an effort to increase the overall performance of the IBI and to assess smaller headwater streams, a new design and approach to metric development was evaluated on approximately 230 high gradient streams. This design, developed by Thomas Whittier and Robert Hughes, has been implemented for numerous Western U.S. studies, as well as the Connecticut multi-metric indices (MMI). Analysis resulted in two distinct stream classes; a coldwater community (Headwaters IBI) with drainage area < 10.36 km^2 consisting of brook trout, sensitive salamanders, and native crayfish and cool/warmwater fish communities (Northern FIBI) with drainage area > 10.36 km^2. Over 140 metrics from ten ecological classes were tested for signal to noise, range, responsiveness, and redundancy. A total of eight metrics representing seven ecological classes were selected for the Northern FIBI and six metrics representing five ecological classes were selected for the Headwaters IBI. These two indices provide the Bureau with an effective and sensitive biological tool to monitor and assess all non-tidal, wadeable streams in the Piedmont, Highlands, and Ridge and Valley physiographic ecoregions.

1. Introduction

One of the primary goals of the Clean Water Act is to maintain and restore biological integrity of all water bodies within the United States. Water resource managers commonly use biological assessments to evaluate water quality and to assess whether water bodies are meeting the goals of the Clean Water Act (Simon, 1999). The advantages of using biological monitoring over chemical monitoring have been well documented (Karr, 1981; Barbour et al., 1999) and the use of fish as biological indicators has grown in popularity since the inception of Karr's Index of Biotic Integrity (IBI) in 1981. Karr's IBI was a multimetric index designed to assess water quality conditions in warm midwestern streams using fish assemblages (Karr, 1981; Karr et al., 1986). Karr's IBI has since been regionally modified to account for differences in assemblage structure and function (Miller et al., 1988) and has been applied by water resource managers worldwide (Roset et al., 2007; Ruaro and Gubiani, 2013). In the United States, it is common for water resource managers to have one or several biomonitoring programs focused on differing trophic levels of aquatic organisms (i.e., algae, macroinvertebrates, fish), as the United States Environmental Protection Agency (U.S. EPA) recommends the use of at least two assemblages to provide information on aquatic life use; the health of streams for aquatic organisms (U.S. EPA, 2003).

The New Jersey Department of Environmental Protection (DEP) has been conducting biological monitoring using aquatic macroinvertebrates since 1992. In an effort to further enhance the Department's biological monitoring program and to supplement existing benthic macroinvertebrate monitoring, the New Jersey Fish Index of Biotic Integrity (FIBI) was established in 2000. The FIBI was developed by the U.S. EPA Region 2 (Kurtenbach, 1994) and was based on Karr et al. (1986) original design with regional modifications. The index was then implemented by the DEP Bureau of Freshwater and Biological Monitoring (BFBM) on high gradient streams greater than 12.95 km^2 in contributing watershed drainage size. The FIBI was later recalibrated by BFBM in 2005 to increase the overall sensitivity and performance. This process involved replacing unresponsive metrics, altering feeding and tolerance guild designations for species, and modifying scoring criteria within Karr's rapid bioassessment framework. Although the recalibrated design greatly increased the sensitivity of the index, several metrics remained unresponsive to anthropogenic stressors. In addition, small first and second order headwater streams less than 12.95 km^2 remained largely unassessed for vertebrates and an index was

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warranted to support and describe aquatic life use in headwater streams of New Jersey.

Several states in New England including Vermont (Langdon, 2001), New Hampshire (Neils, 2007), and Connecticut (Kanno et al., 2010) have developed coldwater IBIs for these small headwater streams, typically dominated by brook trout *Salvelinus fontinalis* and slimy sculpin *Cottus cognatus*. Additionally, Lyons (2006) created a cool/warmwater headwater IBI to assess water quality in Wisconsin, but found too few fish to accurately assess streams less than 4 km^2 in watershed area or 4–10 km^2, if stream slope exceeded 1%. As a result of depauperate fish assemblages in very small streams, biologists began supplementing fish data with other vertebrate and invertebrate taxa, most notably streamside salamanders, to accurately assess the biological integrity of headwater streams. The Maryland Biological Stream Survey developed a streamside salamander IBI (Southerland et al., 2004), while others (Ohio Environmental Protection Agency, 2002; Whittier et al., 2007; Pont et al., 2009) have included multiple vertebrate taxa groups such as fish and amphibians into a composite IBI.

In 2004, the Academy of Natural Sciences of Drexel University was contracted by NJDEP and EPA to pilot a project aimed to develop bioassessment criteria for headwater streams using fish, salamanders, crayfish, and frogs as bio- indicators (Keller et al., 2012). In 2013, NJDEP completed the validation of the Headwaters IBI sampling protocol and began monitoring a fixed network of sites in 2014, thus enabling the Department to monitor all wadeable, non-tidal streams north of the fall line for aquatic life use.

In an effort to provide continuity between the Fish IBI and Headwaters IBI programs and to evaluate new analysis techniques, an innovative structured approach developed for western U.S. streams and rivers was reviewed (Whittier et al., 2007; Stoddard et al., 2008; MPCA, 2014). Several states have adopted this approach in the development or refinement of fish IBI’s including Connecticut (Kanno et al., 2010) which completed coldwater and mixed-water multi-metric indices (MMI) and Minnesota (MPCA, 2014) which developed several state indices. We followed this same approach in the development of two New Jersey specific multi-metric indices that will serve as more sensitive/responsive replacements to those previously developed indices for non-tidal high gradient wadeable streams and rivers in the northern part of the state.

The development of two new size specific IBIs in the state of New Jersey presented several challenges. New Jersey is the most densely populated state in the United States (United States Census Bureau, 2011) and its freshwaters are relatively deficient in fish species compared to other regions of the United States. New Jersey’s logging, agriculture, and industrial practices of the past and present day, coupled with rapid land development, have greatly altered aquatic systems throughout much of the state. As a result, natural conditions are scarce and the lack of reference streams further complicates the development of an IBI (Hughes et al., 1998). In addition, extensive stocking of nonnative sportfish, such as brown trout *Salmo trutta* and black basses *Micropterus* sp. has resulted in the naturalization of a number of species and has contributed to the declines of many native fishes (Rahel, 2000; Gozlan et al., 2010; McKenna et al., 2013).

The purpose of this study was to develop two indices of biotic integrity for the higher gradient streams of northern New Jersey that could be used to accurately assess water quality and aquatic life use across varying sizes of wadeable streams. A new northern Fish IBI for larger wadeable streams was developed which is more sensitive and responsive to anthropogenic stressors. Secondly, a new Headwaters IBI was developed to assess smaller order streams that are often low in fish richness and therefore cannot be accurately assessed solely with a fish based IBI. The development of these IBIs will allow all wadeable steams north of the fall line to be assessed for aquatic life use.

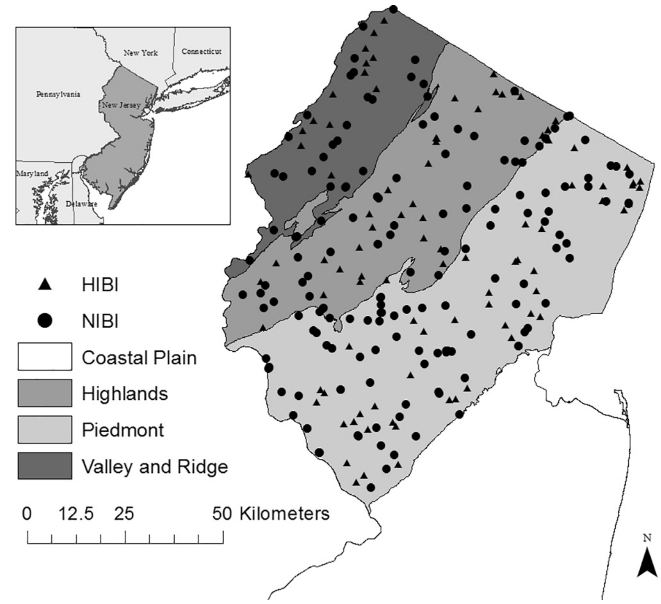

Fig. 1. Map of northern New Jersey depicting sampling locations for Headwaters IBI (triangle) and Northern Fish IBI (circle) development.

2. Materials and methods

2.1. Study area

Data were collected from wadeable streams north of the fall line which runs roughly south-east to north-west from Trenton, NJ to Raritan Bay. The fall line separates the Coastal Plain from the Piedmont ecoregions. Streams in the northern part of the state are characterized by high gradient, cobble/boulder streams in the Piedmont, Highlands, and Ridge and Valley ecoregions (Fig. 1).

2.2. Site selection

We used the least disturbed condition approach to select sites to evaluate both the Headwaters and Northern Fish IBI. The least disturbed condition approach uses the “best” available sites given the current conditions of aquatic resources in regards to landscape characteristics, EPA RBP habitat score for high gradient streams, chemistry, and biological communities (Stoddard et al., 2006). Sites were grouped in disturbance categories using criteria based on land-use characteristics and total habitat score (Table 1). The total habitat score is a visual based habitat assessment performed at each site using the format given in the Rapid Bioassessment Protocols (Barbour et al., 1999) for high gradient streams. Sites that did not fit the criteria of least impaired (LI) or most impaired (MI) were characterized as intermediate.

Table 1
Land use characteristics and total habitat score used to define least disturbed and most disturbed for each Index of Biotic Integrity.

Index	Condition	Least Impaired	Most Impaired
Fish IBI		N = 23	N = 25
	% Forest + %Wetland	≥60	< 40
	% Urban	≤20	> 60
	% Impervious cover	≤4	≥20
	Total Habitat Score	≥145	< 115
Headwater IBI		N = 35	N = 20
	% Forest + %Wetland	> 70%	< 30%
	% Urban	< 20%	> 70%
	% Impervious cover	< 5%	> 20%
	Total Habitat Score	Optimal or Suboptimal	Marginal or Poor