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Development of dual fish multi-metric indices of biological condition for streams with characteristic thermal gradients and low species richness

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ABSTRACT

Biological indicators based on fish assemblage characteristics are used to assess stream condition worldwide. Fish-based bioassessment poses challenges in Southern New England, the USA, due to the effects of within-watershed thermal gradients on fish assemblage types, low regional species richness, and lack of minimally disturbed sites. Dual multi-metric indices (MMI) of biological condition were developed for wadeable streams based on fish assemblage characteristics sampled across watershed landscapes with varying levels of human disturbance. A coldwater MMI was developed using streams with drainage area of $\leq$15 km^2, and a mixed-water MMI for streams with drainage areas of >15 km^2. For each MMI development, candidate metrics represented by ecological classes were sequentially tested by metric range, within-year precision, correlation with stream size, responsiveness to landscape-level human disturbances, and redundancy. Resultant coldwater and mixed-water MMI were composed of 5 and 7 metrics, respectively. Stream sites tended to score similarly when the two MMI were applied to transitional sites, i.e., drainage areas of 5–40 km^2. However, some sites received high scores from the mixed-water MMI and intermediate scores from the coldwater MMI. It was thus difficult to ascertain high-quality mixed-water streams from potential coldwater streams which currently support mixed-water assemblages due to ecological degradation. High-quality coldwater streams were restricted to stream sites with drainage areas $\leq$15 km^2. The newly developed fish-based MMI will serve as a useful management tool and the dual-MMI development approach may be applicable to other regions with thermal gradients that transition from coldwater to warmwater within watersheds.

1. Introduction

Bioassessment has become a standard tool used by resource management agencies worldwide to monitor and assess environmental conditions of many freshwater ecosystems (USEPA, 2006; Roset et al., 2007). Since an index of biotic integrity (IBI) was proposed to assess biological condition of warmwater streams in the Midwestern USA based on fish assemblage characteristics (Karr, 1981), multi-metric indices (MMI) have been developed for other regions and other lotic and lentic systems (Miller et al., 1988; Simon, 1999; Stoddard et al., 2008). The multi-metric approach has also been expanded to other taxa such as benthic macroinvertebrates (Kerans and Karr, 1994; Klemm et al., 2003) and periphyton (Fore, 2003).

The Southern New England region, located in the Northeastern USA, encompasses a dense network of wadeable streams, but the fish-based MMI approach has faced several challenges in this region (Jacobson, 1994). First, because the region was recently glaciated, it is characterized by low freshwater species richness (Whitworth, 1996). Previous MMI developed in depauperate regions often resulted in fewer metrics than those from more speciose regions (Langdon, 2001; Whittier et al., 2007; Akre Matzen and Berge, 2008). Second, data on "pristine" stream conditions are lacking in this extensively modified landscape. In addition to current land development, extensive deforestation occurred in late 1800s across the region (Foster, 1992). Past landuse activities probably have lasting effects on contemporary lotic environments (Maloney et al., 2008; Wenger et al., 2008), but the magnitude of these legacies is unknown. Finally, the region harbors a mixture of coldwater, coolwater, and warmwater streams, characteristically occurring along an upstream-downstream gradient within a watershed. Kanno and Vokoun (2008) characterized the fish assemblages across the Southern New England watersheds and documented that stream size was an important factor (with temperature) describing the distributions among three fluvial assemblages.

Despite these challenges, recent work on MMI indicates promise for Southern New England. More MMI have been

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developed and applied in depauperate systems (Lyons et al., 1996; Mundahl and Simon, 1999; Langdon, 2001; Hughes et al., 2004; Kanno and MacMillan, 2004; Bramblett et al., 2005; Whittier et al., 2007; Akre Matzen and Berge, 2008). The MMI approach taken in the State of Vermont (Northern New England) is particularly relevant (Langdon, 2001; VTDEC, 2004). Vermont employs a coldwater IBI for streams with 2–5 species and a mixed-water IBI for streams containing ≥5 species. This classification resembles that identified by Kanno and Vokoun (2008), where fluvial assemblages transitioned from headwater brook trout *Salvelinus fontinalis* dominated streams to blacknose dace *Rhinichthys atratulus*—creek chub *Semotilus atromaculatus* dominated streams, and finally to more diverse assemblages including species such as white sucker *Catostomus commersonii* and fallfish *Semotilus corporalis* in larger wadeable streams. Since Vermont is located in a different ecoregion than Southern New England (i.e., Northeastern Highlands/Northern Appalachian Plateau and Uplands vs. Northeastern Coastal Zone; Omernik, 1987), we believed it was necessary to develop new MMI for the region.

The purpose of this study was to develop coldwater and mixed-water MMI using an extensive dataset collected in the State of Connecticut, located in Southern New England. First, we determined a threshold drainage area size to divide the data into coldwater (smaller stream) and mixed-water (larger stream) sub-datasets. Second, stream sites were classified along a human disturbance gradient created with watershed-level landscape variables known to affect biotic condition. Third, candidate MMI metrics were tested to develop coldwater and mixed-water MMI. Finally, we explored the performance of the two MMI at transitional sites near the cutoff criteria between coldwater and mixed-water.

2. Materials and methods

2.1. Data sources and field methods

Fish assemblage data were collected from wadeable streams across the entire state of Connecticut between 1999 and 2007. Collection locations were selected to support aquatic life use support assessments required under section 305(b) of the Federal Clean Water Act and Connecticut's water quality standards (CTDEP, 2002a). Fish were sampled during base-flow periods (June-September) from stream segments primarily characterized as high to moderate gradient riffle/run habitat. Backpack or tote-barge electrofishers were used depending on stream size. Stream lengths sampled differed among sites; sampling effort was approximately 10 times the average stream width for 3rd and 4th order streams, and between 100 and 150 m for 1st and 2nd order streams. The field crew conducted single-pass electrofishing, proceeding upstream by sampling all available habitats. Fish were enumerated, identified to species, measured for total length, and released (CTDEP, 2002b).

Fish data were screened prior to the MMI development process. Stocked salmonids, hybrid, and unidentified individuals were deleted from the dataset. Stocked salmonids were typically recognizable in the field due to size and external characteristics. Although natural reproduction is common in the study area, brown trout *Salmo trutta* were removed from the dataset in entirety because the state augments natural reproduction with a fry stocking program (CTDEP, 2007). Stream sites with ≥30 fish individuals and ≥2 native species were retained in the dataset after initial screening was completed. As a result, the dataset included fish assemblage data collected from 348 stream reaches across Connecticut spanning drainage areas of 1.16–347.20 km^2.

2.2. Division of dataset for developing coldwater and mixed-water MMI

The dataset contained fish assemblages represented by more than one thermal guild. Using another, larger dataset (collected by three-pass depletion sampling), Kanno and Vokoun (2008) identified four assemblage types; a brook trout-dominated assemblage (Assemblage A), a blacknose dace-creek chub dominated assemblage (Assemblage B), a relatively diverse fluvial-species assemblage characterized by species such as fallfish, white sucker, and longnose dace *Rhinichthys cataractae* (Assemblage C), and a relatively diverse assemblage containing macro-habitat generalists including pumpkinseed *Lepomis gibbosus*, brown bullhead *Ameiurus nebulosus*, and golden shiner *Notemigonus crysoleucas* (Assemblage D). Slight taxonomic differences for Assemblages B, C and D were observed between the eastern and western portions of the study area, but ecological similarities were obvious. A discriminant function based on proportional abundance of species at sites in the larger dataset (Kanno and Vokoun, 2008) was applied to the current dataset to classify stream sites as one of the four assemblage types. Discriminant function analysis was run with arc-sign square root transformed data in program SAS (version 9.1, SAS Institute Inc., Cary, NC). The distribution of assemblage types was then plotted against drainage area to identify a threshold value for division of the parent dataset into coldwater and mixed-water subsets.

2.3. Landscape-level human disturbance and reference condition

The magnitude of human disturbances at a stream site was quantified at the watershed scale. Land cover and use at the watershed scale has been repeatedly demonstrated to affect stream biota (Wang et al., 2001; Stanfield and Kilgour, 2006; Stranko et al., 2008; Wenger et al., 2008). For each stream site, upstream drainage area was delineated based on the 30-m resolution National Elevation Dataset using ArcGIS version 9.2 and Arc Hydro version 1.2 (ESRI, Redlands, CA). The land cover variables calculated for each drainage area included: (1) percent of impervious surface, (2) percent of forested land, (3) road density, (4) road crossing density, (5) population density, (6) dam density, and (7) density of known water quality issues (e.g., industrial discharge permits and leachate reports). Percent of impervious surface and forested land was based on the 2001 National Land Cover Dataset (Homer et al., 2007). Population density was calculated from the 2000 population census (http://www2.census.gov/census_2000/), and road density and road crossing density were derived from a 1:100,000-scale road atlas (http://seamless.usgs.gov/). Locations of dams and known water quality issues were obtained from the Connecticut Department of Environmental Protection records.

A synthetic human disturbance gradient was derived from the seven landscape variables using Principal Component Analysis (PCA) to reduce the dimensionality of the original variables (McCune and Grace, 2002). Percent of impervious surface and forested land were arcsine square root transformed, and dam density and density of known water quality issues were log transformed. The remaining variables were not transformed because data transformation did not improve data normality. PCA was executed on a correlation matrix among the landscape variables in program PC-ORD (version 5, MjM Software, Gleneden Beach, OR).

The resulting human disturbance gradient was then used to classify stream sites into three categories; least, moderately, and most disturbed sites. It was not possible to locate streams which had received minimal human disturbance in the extensively modified landscape, and our "reference condition" represented the