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A fish index of biotic integrity for South Dakota's Northern Glaciated Plains Ecoregion

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ABSTRACT

Ecosystem goods and services in streams are impaired when their biotic communities are degraded by anthropogenic stressors. An index of biotic integrity (IBI) translates community structure into a standardized ecoregion-specific stream health score. Documenting stream health is especially important in the Northern Glaciated Plains (NGP) Ecoregion, which is undergoing rapid landscape alterations through increased agriculture production. Our objectives were to develop a fish IBI and validate candidate reference sites for NGP wadeable perennial streams. Fish were sampled from 54 sites (consisting of reference sites, known-condition least and most disturbed sites, and random sites) during summers 2006–2011. Candidate metrics were sorted into nine metric classes based on attributes of fish assemblage form and function. Metric values were screened using metric range, signal-to-noise ratios, responsiveness to disturbance, and redundancy tests until each metric class contained only those metrics most responsive to anthropogenic stressors. The final IBI consisted of six metrics that were reflective of prairie stream fish assemblages, and differentiated between known-condition least and most disturbed sites. The mean reference sampling site IBI scores were found to be similar to both least and most disturbed sites (Mann–Whitney *U*-test; $P < 0.05$). Twelve reference site scores were below the NGP's median (69), whereas the other 11 sites were above the median and were representative of least disturbed conditions. We now have developed a standardized bioassessment tool for evaluating stream health, as well as a baseline for long-term monitoring in a dynamic ecoregion.

1. Introduction

Stream biota perform critical ecosystem services at the interface of terrestrial and aquatic systems. Streams process organic and inorganic terrestrial subsidies to mediate water quality, provide fish and wildlife habitat, and provide recreational opportunities for people (Loomis et al., 2000). The intensification of agricultural activities can lead to loss of wetlands, increased stream bank erosion, eutrophication of water systems, increased flooding, and dewatering of streams (Karr and Chu, 2000; Malmqvist and Rundle, 2002). Agricultural landuse affects a stream's energy source inputs, water quality, flow regime, habitat quality, and biotic interactions (Karr and Dudley, 1981; Karr et al., 1986). In turn, landuse influences biotic integrity, which is characterized by a balanced, integrated, adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of the natural habitat of the region (Frey, 1977; Karr and Dudley, 1981).

Bioassessments are often used to gauge biotic integrity (a surrogate for stream health) because they provide a time-integrated measure of the chemical, physical, and biotic dimensions of a stream (Rankin and Yoder, 1990). Although periphyton and macroinvertebrates can be used in biological monitoring programs, fish are sensitive to many forms of human disturbance, fish typically occupy multiple trophic levels that represent a greater fraction of stream processes, and the economic and esthetic benefit-to-cost ratio is greater for fish assessments (Harris, 1995; Oberdorff et al., 2001). The need to understand a stream's biotic integrity through a fish bioassessment is important in South Dakota, where the landscape is rapidly changing (e.g. domination of monoculture crops, groundwater withdrawals, tiling of wetlands, and loss of Conservation Reserve Program land; Claassen et al., 2011; Higgins et al., 2002). A long-term fish biological monitoring program is needed to guide the South Dakota Department of Environment and Natural Resources (SD DENR) in maintaining and restoring the biotic integrity of South Dakota streams, as these landuse changes are predicted to continue in order to sustain the demand for increased row crop production (Mehaffey et al., 2011; Sohl et al., 2012).

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One widely accepted bioassessment tool that gauges biotic integrity is the index of biotic integrity (IBI). The index compares a site of unknown condition with reference sites that have been validated as representing a region's least disturbed conditions through comparison with known condition sites (Barbour et al., 1999; Hughes, 1995; Stoddard et al., 2006). An IBI combines multiple metrics in a hypothesis of biological response to human influence. Successful metrics discriminate among sites by identifying the attributes of the fish assemblage most responsive to anthropogenic effects and least influenced by temporal variation and non-anthropogenic effects (Hughes et al., 1998; Karr and Chu, 1999). Metrics must be selected for specific regions, such as the Northern Glaciated Plains (NGP) Ecoregion, to account for differences in regional fish assemblages and regional anthropogenic stressors. Therefore, our first goal was to develop a fish IBI for the NGP, which we hypothesize would be reflective of Great Plains fish assemblages that are dominated by generalists tolerant of harsh hydrologic regimes and physicochemical conditions (Dodds et al., 2004; Matthews, 1988; Poff et al., 1997). The second goal was to use the IBI to evaluate candidate reference sites selected by SD DENR relative to known- condition least disturbed sites, which we hypothesized, would score similarly.

2. Methods

2.1. Study area

Level III Ecoregion 46, the Northern Glaciated Plains, extends from the Canadian provinces of Saskatchewan and Manitoba in the north to eastern South Dakota and southwest Minnesota to the south (Omernik and Gallant, 1988). The climate is subhumid with annual precipitation ranging from approximately 432 to 559 mm in an average year. Natural vegetation is primarily mixed and tallgrass prairie species. Grassland streams dominate the landscape with intermittent streams and linear wetlands providing drainage to prairie pothole basins (Bryce et al., 1998).

In South Dakota, the NGP consists of eight Level IV Ecoregions that are separated by their geology, physiography, vegetation, climate, soils, land use, wildlife, and hydrology. For the purposes of this study, we grouped the Level IV Ecoregions 46k, 46l, 46m, and 46o into the coarser Coteau plateau region and ecoregions 46c, 46d, 46i, and 46n into the James River valley (Fig. 1). The study area consists of four major river basins: the James, Vermillion, Big Sioux, and Minnesota (Fig. 1). Land use is dominated by row crop agriculture and cattle grazing. Urban development is minimal across the entire study area.

2.2. Site selection

We needed to select similar numbers of replicate sites within least and most disturbed and random site classes, totaling at least 25 to approximate a balanced design between reference sites and targeted and random sites. We thus selected 16 known condition sites (8 least- and 8 most-disturbed site classes) and 16 random condition sites to exceed the minimum of 7 replicate least- and most-disturbed sites needed for regression analyses. We were able to increase the number of replicates of known condition sites to 8, within the limits of the budget and sampling period.

2.2.1. Reference sites

The SD DENR selected candidate reference sites to represent the least disturbed biotic and abiotic conditions in the NGP. Wadeable perennial streams were identified using Strahler stream order and flow permanency data from the National Hydrography Dataset (NHD plus). The result was a target population of 2546 first through fourth order stream segments. Candidate reference sites were screened from the target stream segment population based on watershed scores generated by the Analytical Tools Interface for Landscape Assessments (ATtILA) extension in ArcView 3.3. The extension ATtILA calculated 105 metrics from four groups: (1) landscape characteristics (e.g. land cover proportions), (2) riparian characteristics (e.g. land cover adjacent to streams), (3) human stressors (e.g. measures of population and roads), and (4) physical characteristics (e.g. elevation, precipitation and slope). Metrics with narrow variance distributions (Coefficient of Variation; CV < 1) were excluded from the candidate list. Principal Components Analysis (PCA) was used to reduce the dimensionality of the remaining metrics to five principle components that explained 75% of the variation in watershed scores within each Level IV Ecoregion (PC1 = eigenvalue 15.9, percent variance 33.1; PC2 = 6.32, 13.2; PC3 = 4.9, 10; PC4 = 4.6, 9.6; PC5 = 4.1, 8.6). Next, correlation analysis identified the metric explaining the most variation in each principle component. Selected metrics were scaled from 0 to 100, with increasing scores indicating a stream segment affected by relatively fewer disturbances than the population average. Metric values were summed and rescaled to fall between 0 and 100, resulting in a single index score for each stream segment (Larson, 2010).

Top ranking sites (based on the least disturbed watershed scores) became candidate reference sites after passing a series of screening tests. Candidate reference sites were excluded if stream channel alterations were present or feedlots, lakes/impoundments, or point-source pollution occurred within a 5-km radius of the sites on Geospatial Information Systems National Hydrography Dataset (NHD) layers and National Agriculture Imagery Program aerial photographs. Sites were subsequently excluded if landowner permission was not granted or contact could not be established (45 of 58 reference sites passed). Sites then had to pass the Environmental Protection Agency's Rapid Bioassessment Protocol (RBP) for Use in Wadeable Streams and Rivers which qualitatively evaluated the onsite stream and riparian habitat condition (Barbour et al., 1999). After the screening process, 25 unique candidate reference sites remained (Fig. 1). Reference streams ranged in mean wetted width from 2.0 to 19.4 m ($\bar{x}$ = 4.9 m; SD = 4.2 m), elevation from 348 to 565 m ($\bar{x}$ = 463; SD = 74 m), and discharge from 0 to 6.1 $m^3 s^{-1}$ ($\bar{x}$ = 0.3 SD = 1.1 $m^3 s^{-1}$).

2.2.2. Least disturbed

Eight sites with minimal anthropogenic disturbance were selected and sampled by South Dakota State University (SDSU; Fig. 1). The process for screening least disturbed sites was similar to reference site selection, with a few exceptions. The sum of violation parameters used to determine SD DENR surface water beneficial use violations were used to select least disturbed stream segments from the population of sites in the SD DENR water quality monitoring network. Violation parameters included dissolved oxygen, fecal coliform, *Escherichia coli*, nitrate, pH, sodium adsorption ratio, specific conductivity, total dissolved solids, total suspended solids, and temperature and were sampled a minimum of once per year. Those in the lower 5th percentiles of water quality standards violations were categorized as least disturbed. The watershed scores were used as a second-level screening tool within the lower 5th percentile of stream segment violations to find the eight least disturbed sites with the fewest violations and highest watershed scores. Site access was granted by landowners at 8 of 12 least disturbed sites. On-site, stream segments with acute disturbances present (i.e. feedlot) were rejected, and the RBP was not performed. Least disturbed streams ranged in mean wetted width from 2.8 to 10.6 m ($\bar{x}$ = 5.4 SD = 2.1 m), elevation from 367 to 522 m ($\bar{x}$ = 423 SD = 58 m), and discharge from 0 to 1.1 $m^3 s^{-1}$ ($\bar{x}$ = 0.3 SD = 0.3 $m^3 s^{-1}$).