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ARTICLE

Applicability and Interpretation of Fish Indices of Biotic Integrity (IBI) for Bioassessment in the Upper Midwest

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Abstract
Multiple fish-based indices of biotic integrity (IBIs) and biological condition gradient models have been developed and validated to assess ecological integrity in the Laurentian Great Lakes region. We evaluated the applicability and effectiveness of using fish community indices for assessing site integrity in central Great Lakes streams, which have diverse temperature regimes and can be classified as warmwater, coolwater, or coldwater. Sites with different thermal regimes require different assessment tools to ensure comparability. Streams in the Big Manistee River watershed, Michigan, are near thermal thresholds for classification as coolwater or coldwater. We evaluated two coolwater and three coldwater indices developed for Upper Midwest streams. Output from coolwater indices were not correlated with coldwater index outputs and did not discriminate among the stream systems we evaluated. In monitoring temporal patterns over time (2002–2010), we found that coldwater indices showed similar patterns and agreed in relative scoring of sites from high to low. The three coldwater indices also similarly discriminated among stream systems; however, when the coldwater indices were used for specific site assessments, they produced differential results. Depending on which index was applied, a single site could be classified into three different levels of quality. This highlights the importance of index selection for management actions. An understanding of the factors that drive the indices and an understanding of reference conditions are imperative for effective use of fish-based IBIs in the Upper Midwest.

Biotic integrity has been defined as the ability to support an integrated, adaptive community of organisms, with species composition, diversity, and functional organization conforming to those expected for a natural assemblage in the region (Frey 1977; Karr and Dudley1981; Karr et al. 1986). As such, a system with intact biotic integrity supports a complex of native biodiversity with natural processes and services (Karr and Chu 1999). For the past several decades, assessment of the ecological condition of aquatic systems has routinely been accomplished using various modified and regionally calibrated indices of biotic integrity (IBIs; Karr 1981; USEPA 2002). Although criticisms of IBIs have been noted (e.g., Suter 1993), these indices are a commonly used approach for assessing biotic condition. After the multimetric concept's first application by Karr (1981) was published, the number of papers that cited it reached over 700 by 2007 (Ruaro and Gubiani 2013). Indices of biotic integrity can be effective monitoring tools for communicating quantitative and qualitative assessment information to the public and policy makers as well as providing quantitative data for hypothesis testing (Fore et al. 1994).

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Fish assemblages can be ideal indicators of ecological integrity given that different species can have unique responses to environmental conditions, as reflected by their relative abundances in a community (Karr et al. 1986; Barbour et al. 1999). Indices of stream condition based on fish community composition provide an approach for classifying stream reaches from a continuum of biological condition that integrates multiple influences over time, thus making the indices particularly useful for assessing overall stream integrity (Allan 2004). Multiple fish-based IBIs (Lyons et al. 1996; Mundahl and Simon 1999; Lyons 2012) and biological condition gradient (BCG) models (Gerritsen and Stamp 2012) have been developed and validated to assess ecological integrity in the Laurentian Great Lakes region. With multiple options for biomonitoring in the Upper Midwest, the sustained usefulness of fish-based IBIs and BCG models in research and management (i.e., by producing accurate and biologically meaningful assessments of stream condition) requires critical examination of their relative applicability and interpretation. For example, a range of conditions is used in the development of IBIs; however, assessment practitioners often do not have the luxury of a full range of conditions to assess. Sites in a given area may only have a restricted range of conditions represented, and practitioners must be able to determine which IBI to use for assessment.

A primary goal of bioassessment is to characterize a site and determine where it falls along a continuum of impairment; however, natural variation in small-and large-scale physical drivers also influences the biota within the regional range, and this must be considered when choosing the appropriate index for site assessment. Biotic and abiotic factors interact in complex ways at multiple spatial scales to influence organism abundance and distribution in fluvial systems (Hynes 1975; Vannote et al. 1980; Poff and Allan 1995; Fausch et al. 2002). At larger scales, drivers such as climate and surficial geology influence stream hydrology and thermal regime (Roth et al. 1996; Allan et al. 1997; Wang et al. 1997). Although large-scale influences (e.g., geology) provide a template for the range of potential habitat conditions, smaller-scale local factors (e.g., groundwater input) are important site-specific drivers of local habitat quality (sensu Tonn et al. 1990). Climatic variation, predation and competition (Moyle and Cech 1996), and the availability and quality of thermal habitat (Magnuson et al. 1979; Connor et al. 2003; Sloat et al. 2005) also modify the resulting fish community and therefore the resulting IBI score. The combination of large-scale landscape conditions and small-scale local conditions thus produces a hierarchical filter that influences or limits the assemblage composition (Frissell et al. 1986; Tonn et al. 1990; Gregory et al. 1991; Jackson et al. 2001) and sets the baseline for assessment of relative system degradation.

In Upper Midwest streams, flow pattern and thermal regime are strong predictors of local fish assemblages (Lyons 1996; Zorn et al. 2002, 2008; Wang et al. 2003; Wehrly et al. 2003). Thermal regimes of streams in this region fall along a gradient from coldwater to warmwater, with some uncertainty about the bounds of the coolwater classifications between the two extremes (Wehrly et al. 2003; Lyons et al. 2009). Coldwater stream fish communities are generally dominated by a small number of species, often within the families Salmonidae and Cottidae, which are restricted by thermal thresholds (Lyons 1996; Lyons et al. 1996; Wehrly et al. 2007). Warmwater systems are generally more diverse, and fish assemblages may be dominated by individuals in the families Centrarchidae, Catostomidae, Ictaluridae, and Cyprinidae (Lyons 1996).

Streams with different thermal and flow regimes require different assessment tools (Karr and Chu 1999), and interannual temperature variation in streams with mean temperatures near the upper or lower threshold for thermal classifications can lead to difficulty or error in determining their thermal classification; therefore, an ideal classification system would be based on a long-term record (Wehrly et al. 2003). Lyons (2012) indicated that modeling of temperature regimes at larger landscape scales may also be an appropriate predictor of a stream's true potential as a coolwater or coldwater system. Furthermore, indices that give higher scores for greater diversity in warmwater systems can result in misleading assessments if applied to cooler systems with naturally low diversity, where degradation is generally marked by an increase in diversity (Karr 1999; Lyons et al. 2009). Application of inappropriate indices can alter estimates of biotic integrity (Wang et al. 2003; Baker et al. 2005); therefore, an appropriate index must be selected and the index must be correctly applied if it is to serve as an effective indicator and be of use to managers, decision makers, and community members.

In the present study, the performance of five indices (Table 1) developed for the Upper Midwest was assessed using data from sites in the Big Manistee River watershed within Michigan's Lower Peninsula. The original Wisconsin coldwater IBI (Lyons et al. 1996) uses five metrics and was developed for use in coldwater Wisconsin streams (maximum daily mean temperature $<22°C$); the authors cautioned that the low number of metrics may limit the index's ability to detect small differences in biotic integrity. Mundahl and Simon (1999) used data from coldwater streams ($<22°C$) in Michigan, Minnesota, and Wisconsin to develop and validate an Upper Midwest IBI that uses 12 metrics. During initial validation by Mundahl and Simon (1999), the index was compared with the Wisconsin coldwater IBI of Lyons et al. (1996), and some discrepancies in classification were noted. Lyons (2012) developed an index based on fish assemblages in coolwater Wisconsin streams that were cool–cold transitional (maximum daily mean temperature = 20.7–22.5°C). Lastly, BCG models were developed for use in coolwater (July mean temperature = 17.5–19.0°C) and coldwater (July mean temperature $< 17.5°C$) stream systems of the Upper Midwest (Davies and Jackson 2006; Gerritsen and Stamp 2012). The BCG models

TABLE 1. Description of metrics that make up each evaluated index, indicating areas of overlap (M&S = coldwater index from Mundahl and Simon 1999; Lyons96 = coldwater index from Lyons et al. 1996; Lyons–cool = coolwater–coldwater transitional index from Lyons 2012; BCG–cool and BCG–cold = coolwater and coldwater biological condition gradient models from Gerritsen and Stamp 2012).

Metric	M&S	Lyons96	Lyons–cool	BCG–cold	BCG–cool
Number of species	x				
Number of coldwater species	x		x		
Number of minnow species	x				
Number of benthic species	x				
Number of tolerant species	x				
Salmonids as Brook Trout (%)	x	x			
Intolerant individuals (%)	x				
Coldwater individuals (%)	x				
White Suckers (%)	x				
Top carnivores (%)	x	x			
Number of coldwater individuals	x				
Number of warmwater individuals	x				
Number of intolerant species		x	x		
Individuals of tolerant species (%)		x			
Individuals of stenothermal coldwater or coolwater species (%)		x			
Number of coolwater species			x		
Invertivores (%)			x		
Omnivores (%)			x		
Overall species composition				x	x
Expert opinion				x	x

differ from traditional IBIs in that they (1) aim to provide a consistent assessment of ecological integrity that can be applied across regions and (2) are based not on reference sites but on a theoretical pristine condition, with expert judgment determining the base models (Davies and Jackson 2006). Each of the above indices assesses ecosystem integrity based either on reference conditions or on a defined condition, and each index places current sites on a continuum of ecological condition. We evaluated index performance, including annual trends, index drivers, correlation and concordance of assessments based on index scores, and potential biases that might result from each index.

METHODS

Four streams within the Big Manistee River watershed in the northern Lower Peninsula of Michigan were assessed for this study (Figure 1). The watershed has an area of approximately 490,000 ha and spans 11 counties and the exterior boundary of the 1836 Treaty Reservation of the Little River Band of Ottawa Indians. This watershed is typical of many Michigan systems, having low-gradient streams that are sand and gravel dominated and hydrologically stable, with temperatures influenced by groundwater inputs (Seelbach et al. 1997; Wehrly et al. 2006). Hendrickson and Doonan (1972) estimated that 90% of the annual discharge of the Big Manistee River watershed is from groundwater sources, which are common in the outwash plain drained by the watershed. The Big Manistee River watershed is primarily forested (56%), with scrub/shrub and grassland constituting 16% of land cover and wetlands comprising an additional 13% (NLCD 2006). There is minor agricultural use in the form of grazing and row crops (9%), and developed land covers 6% of the watershed (NLCD 2006). Sampling sites were located in two large subwatersheds (Bear and Pine creeks) and in two main-stem tributaries (Sickle and Oldhouse creeks; Figure 1). The lower portion of the Big Manistee River is federally recognized as a National Wild and Scenic River, and upper portions of the main stem and sections of tributaries were designated as Natural Rivers and Blue Ribbon Trout Streams by the State of Michigan.

Data collection.—The biological assessment program of the Little River Band of Ottawa Indians collected fish assemblage data annually (2002–2010) at four long-term monitoring sites in separate subwatersheds (Figure 1). Sampling station lengths were set as 40× the stream wetted width if greater than a minimum length of 120 m and less than a maximum length of 400 m. Backpack electrofishing was conducted using a Smith–Root LR-14 unit at summer base flow between June and August. Community composition was assessed by identifying, measuring, and counting all sampled fish. For broader spatial coverage, 26 additional sites throughout the watershed were also sampled during summer base flow in 2007. These sites were located in Bear Creek ($n = 8$), Pine Creek ($n = 12$),

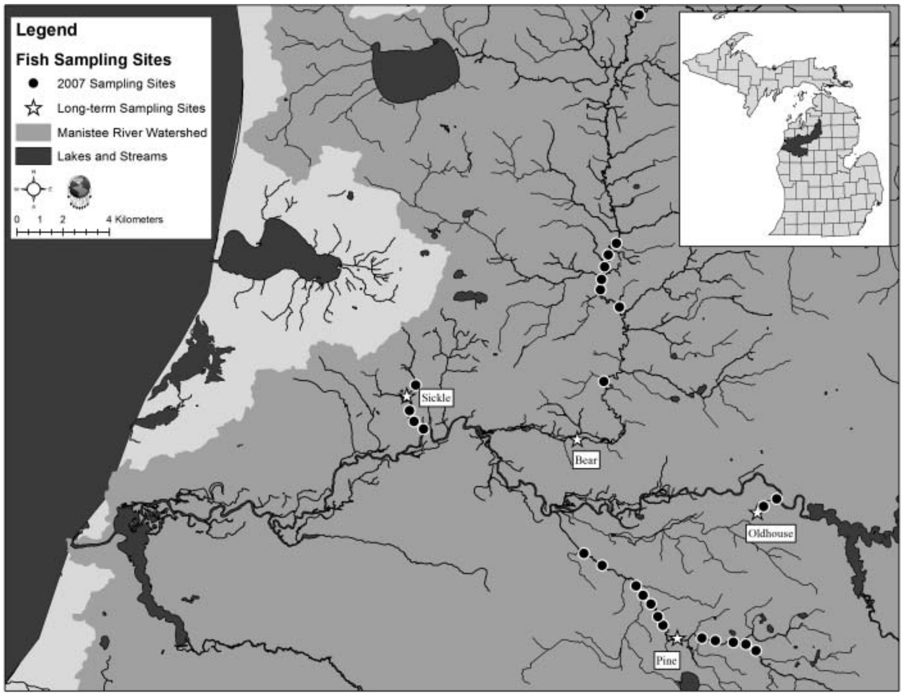

FIGURE 1. Locations of fish sampling sites within the Big Manistee River watershed, Michigan, USA. Sampling was conducted in the subwatersheds of Bear, Pine, Sickle, and Oldhouse creeks. Stars represent long-term sampling reaches; circles represent reaches sampled only in 2007.

Sickle Creek ($n = 4$), and Oldhouse Creek ($n = 2$; Figure 1). Bear Creek has a watershed of 52,912 km^2, with approximately 15% of the land use as agricultural (NLCD 2006). The Pine Creek watershed (124.05 km^2) is 75% forested, with 11% of land cover classified as wetlands and less than 1% classified as agriculture (NLCD 2006). The Sickle Creek watershed (8.95 km^2) is approximately 41% forested, with 11% wetland and 25% agricultural land cover (NLCD 2006). The Oldhouse Creek watershed (3.45 km^2) is approximately 71% forested, 25% wetland, and 4% agricultural land use (NLCD 2006). All sample locations were below the first barrier dam on the Big Manistee River and upstream of major road crossings, and all had generally intact forested riparian vegetation. Tributary locations were open to the Big Manistee River, where Brown Trout *Salmo trutta* and Rainbow Trout *Oncorhynchus mykiss* are stocked; sites were also open to Lake Michigan and therefore had migratory species present. Onset HOBO Water Temp Pro loggers were set to record hourly temperature measurements during May–September and were deployed periodically in 2002–2012 at the long-term monitoring stations. Mean daily and monthly temperatures (°C) were calculated for July of each year sampled. Habitat data were collected by using a rapid bioassessment protocol (Barbour et al. 1999). Scores reflected the overall condition of the local riparian and instream habitat.

Indices.—Regional fish indices were considered applicable for this study because they were appropriate for use with coolwater to coldwater streams in the Upper Midwest and the Northern Lakes and Forests Ecoregion (Omernik 1987) and because their sampling protocols matched the collection method and time frame of the available data. Regional indices calculated from community composition included (1) Lyons et al.'s (1996) IBI for coldwater streams in Wisconsin (hereafter, Lyons96 index); (2) Mundahl and Simon's (1999) IBI for coldwater streams in the Upper Midwest (M&S index); (3) Lyons' (2012) coolwater–coldwater transitional IBI (Lyons–cool index); and (4) Gerritsen and Stamp's (2012) coolwater and coldwater BCG models for the Northern Lakes and Forests Ecoregion (BCG–cool and BCG–cold models, respectively). All indices were calculated as directed by the original publications. The ability to make direct comparisons of scores (i.e., assessments of condition) across indices was evaluated by comparing the indices' numeric scale, thresholds, and classification systems. The indices vary in the range of possible numeric scores, in thresholds for classification groupings, and in how they were designed to be categorically interpreted (Table 1). Although the three IBIs (Lyons96, M&S, and Lyons–cool indices) have similar categories, the numeric thresholds that apply to these categories are not uniform. The BCG models function using six numeric categories that refer to certain biological conditions associated with a particular score (tier). The highest condition (tier 1) in the BCG model calibrated for the Upper Midwest includes the presence of native Brook Trout *Salvelinus fontinalis* and the absence of nonnative salmonids. Low numbers of other highly sensitive taxa, such as the Slimy Sculpin *Cottus cognatus*, may be present, with any other tolerant taxa occurring in very low numbers. Species composition changes take place along an expected gradient, with changes in the presence of tolerant and sensitive taxa occurring throughout each tier. For example, a tier-4 stream is described as possessing moderate changes in biotic community structure and minimal changes in ecosystem function (Davies and Jackson 2006). In a tier-4 stream, native salmonids are present but in very low numbers, taxa that have intermediate tolerance (e.g., White Sucker *Catostomus commersonii*, Blacknose Dace *Rhinichthys atratulus*, and Creek Chub *Semotilus atromaculatus*) dominate the community, and tolerant taxa (e.g., Green Sunfish *Lepomis cyanellus* and Fathead Minnow *Pimephales promelas*) are present but in low numbers (Gerritsen and Stamp 2012).

Index performance analysis.—Site scores from the 30 sites sampled throughout the Big Manistee River watershed in 2007 (Oldhouse Creek: $n = 3$ sites; Sickle Creek: $n = 5$; Pine Creek: $n = 13$; Bear Creek: $n = 9$) were plotted and regressed against habitat scores to assess whether index scores were related to habitat assessment across the overall watershed sites. The site scores were also analyzed using the Kruskal–Wallis H-test (Kruskal–Wallis ANOVA) with Dunn's post hoc multiple comparison procedure to determine whether mean index scores differed among streams. Index scores from the four long-term monitoring sites were plotted and regressed against date to evaluate temporal trends within each site, and slopes were compared to zero (Mazor et al. 2009) to determine whether significant trends could be identified. The significance level α was subjected to Bonferroni correction ($\alpha = 0.01$) so as to account for multiple comparisons across indices. Spearman's rank correlation (coefficient ρ) was used to assess the relationship between coldwater index scores and species richness for the 30 sites sampled in 2007. Additionally, Spearman's rank correlations between calculated scores resulting from each index were performed using data from all sites sampled in 2007 ($n = 30$). Correlation analysis was conducted in SigmaPlot version 12.2 (Systat Software).

RESULTS

Index Applicability

We detected interannual and daily variation in mean daily water temperatures during July at long-term monitoring stations (2002–2012) in the four tributary streams of the Big Manistee River (Figure 2). Mean (±SD) July temperature was 17.8 ± 1.70°C for Oldhouse Creek, 14.03 ± 1.30°C for Sickle Creek, 17.84 ± 1.85°C for Pine Creek, and 18.73 ± 1.90°C for Bear Creek. In one stream (Sickle Creek; Figure 2b), temperature was consistently below all five maximum thresholds for designation as a coldwater stream based on classifications by Lyons et al. (1996, 2009), Wehrly et al. (2003), Gerritsen and Stamp (2012), and Lyons (2012). Daily mean temperatures in the other three streams were periodically above the coldwater thresholds depending on the year. Because daily mean temperatures were variable and close to the thresholds for coolwater and coldwater designations (depending on the reference used), we assessed the data by using both coolwater and coldwater indices developed for the region, doing so under the hypothesis that the coolwater indices would not function properly.

Index Performance

Spatial trends.—The overall assessment of the stream sites sampled in 2007 ($n = 30$) indicated that the different indices produced disparate site classifications. The number of sites classified in the top levels of condition varied by index such that 100% were classified as "excellent" using the Lyons–cool index and 70% were classified as being within tier 1, 2, or 3 based on the BCG–cool index, whereas only 40% of the sites were classified as being within tier 1, 2, or 3 based on the BCG–cold index. The M&S index classified 24% of sites as "good" or better, whereas the Lyons96 index classified 30% of sites as "good" or better. Sites scores were not related to general habitat assessments (Figure 3). Regression analysis and plots indicated no significant relationship between the coldwater index scores and the habitat assessment scores for the 30 sites monitored in 2007 (M&S index: $r^2 < 0.002$, $P = 0.806$, Figure 3a; Lyons96 index: $r^2 < 0.003$, $P = 0.8763$, Figure 3b; BCG–cold model: $r^2 < 0.001$, $P = 0.868$, Figure 3c). However, sites were more similar based on subwatershed. General patterns of relative similarity among sites were supported by differences in mean index scores between the streams as assessed with the three coldwater indices (Figure 4). The Lyons96 index (Kruskal–Wallis H-test: $H = 15.217$, df = 3, $P = 0.002$), the M&S index ($H = 15.265$, df = 3, $P = 0.002$), and the BCG–cold model ($H = 11.299$, df = 3, $P = 0.010$) distinguished Sickle and Oldhouse creeks from each other as well as from Pine and Bear creeks (Dunn's post hoc test: $P < 0.05$). Pine and Bear creeks did not significantly differ in their mean scores. There was no significant discrimination among streams based on the BCG–cool model ($H = 5.285$, df = 3, $P = 0.152$) or the Lyons–cool index ($H = 5.903$, df = 3, $P = 0.190$). Spearman's rank correlations between coldwater index scores and species richness at the 30 sites sampled in 2007 indicated that the relationship with richness differed depending on the index used (Figure 5). Scores from the Lyons96 index were not significantly correlated with species richness ($\rho = 0.071$, $P = 0.707$), whereas the M&S index and the BCG–cold model both had significant relationships with richness (M&S index: $\rho = 0.623$, $P = 0.000246$; BCG–cold model: $\rho = 0.782$, $P = 0.000002$).

Long-term monitoring.—Twenty-nine fish species representing 12 families were observed at the long-term monitoring sites (2002–2010; Table 2); the families included typical coldwater taxa, such as Salmonidae and Cottidae. Many species—predominantly in the families Catostomidae, Centrarchidae, and Cyprinidae—were only observed during a single sampling event. Output from coldwater indices indicated that Sickle

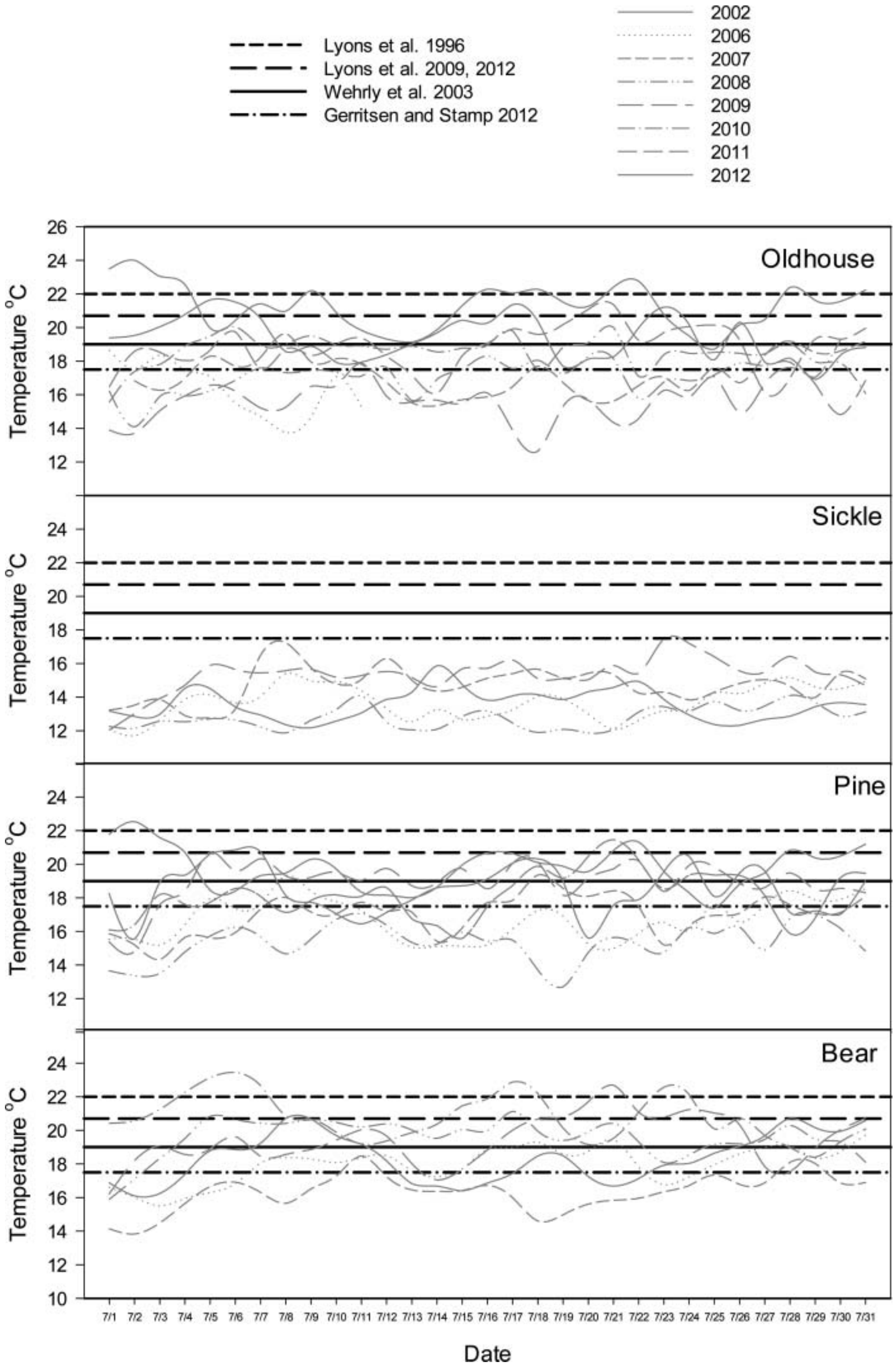

FIGURE 2. Daily mean temperatures (°C) in July at four long-term monitoring stations in the Big Manistee River watershed. Data were collected periodically from 2002 to 2012 depending on site location (e.g., there are only 5 years of data for Sickle Creek). Four different maximum thresholds for coldwater classification systems are depicted: (1) maximum daily mean less than 22°C (Lyons et al. 1996); (2) July weekly mean less than 19°C (Wehrly et al. 2003); (3) maximum daily mean less than 20.7°C (Lyons et al. 2009; Lyons 2012); and (4) average July temperature less than 17.5°C (Gerritsen and Stamp 2012).

Creek received the highest scores, whereas the scores for Bear and Pine creeks indicated the poorest quality; however, all sites scored well based on the coolwater indices. Bear Creek ($n = 8$ years) had the highest mean species richness (15 species), followed by Pine Creek (10 species), while both Sickle and Oldhouse creeks had an average annual richness of seven species. Low species richness was not consistently indicative of improvements in metric scoring across indices. For example, Oldhouse Creek generally had low richness, but it was scored as poor quality by the Lyons96 and M&S coldwater

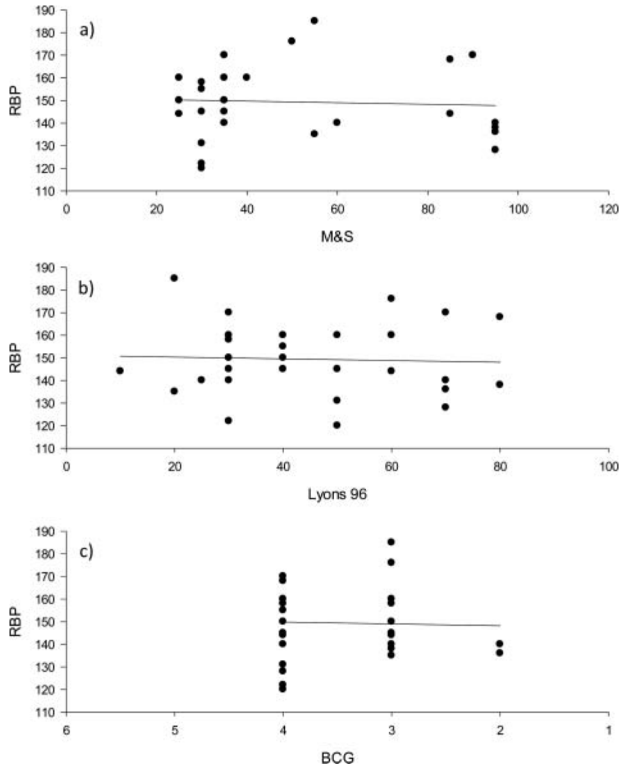

FIGURE 3. Regression analysis of rapid bioassessment protocol scores (RBP) against three coldwater indices of biotic integrity at 30 monitoring sites sampled in the Big Manistee River watershed during 2007: **(a)** Mundahl and Simon's (1999) index (M&S; $r^2 < 0.002$, $P = 0.806$); **(b)** Lyons et al.'s (1996) index (Lyons 96; $r^2 < 0.003$, $P = 0.8763$); and **(c)** Gerritsen and Stamp's (2012) coldwater biological condition gradient model (BCG; $r^2 < 0.001$, $P = 0.868$).

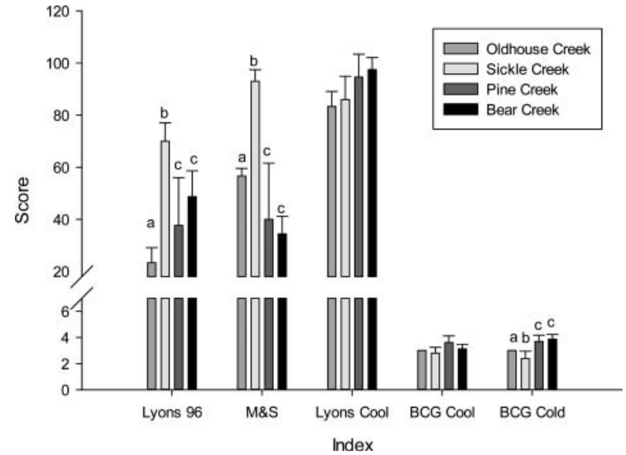

FIGURE 4. Index scores for each stream sampled in the Big Manistee River watershed during 2007 (Lyons 96 = coldwater index from Lyons et al. 1996; M&S = coldwater index from Mundahl and Simon 1999; Lyons cool = coolwater–coldwater transitional index from Lyons 2012; BCG cool and BCG cold = coolwater and coldwater biological condition gradient models from Gerritsen and Stamp 2012). Separate ANOVAs were completed for each index; for a given index, values with different letters are significantly different. The Lyons 96 index, M&S index, and BCG cold model all had similar patterns of significant differences in mean site scores. Scores for the Lyons cool index and the BCG cool model did not indicate these same patterns, and no significant differences were found among sites. Note that the relative condition of sites based on the BCG models is reversed such that a lower tier represents better condition.

indices (Figure 6). The presence of Brook Trout (or the percentage of salmonids that were Brook Trout) was a common parameter indicating high quality in the coldwater IBIs. None of the long-term monitoring sites had more than 1% of salmonids as Brook Trout, and the relatively low scores reflected this attribute.

Long-term (2002–2010) site scores varied over time and by index (Figures 6 and 7). Assessment based on the Lyons–cool index produced the highest scores for all sites, whereas the Lyons96 and M&S indices varied in ranking by site and over time (Figure 6). Overall long-term trend analysis of the scores for Oldhouse Creek showed a significant decline through time based on the M&S index ($r^2 = 0.867$, $P = 0.007$), but this decline was not reflected in the other index scores. The BCG models indicated relatively stable results for Pine and Bear creeks, while more pronounced temporal variation was observed in the BCG model scores for Oldhouse and Sickle creeks (Figure 7). Long-term monitoring sites were classified differently depending on the year and index examined. For example, within a single year, sites in both Oldhouse and Bear creeks could be classified as poor, fair, or excellent depending on the index (Figure 6).

Correlation of indices.—An evaluation of which indices are correlated may lead to better interpretation and the ability to choose the most appropriate index for the question being addressed. Spearman's rank correlations from the data collected at 30 sites throughout the watershed in 2007 indicated that scores calculated using the Lyons96 index were positively correlated with scores from the M&S index ($\rho = 0.715$, $P = 0.000033$; Figure 8a) and with scores from the BCG–cold model ($\rho = 0.517$, $P = 0.00595$; Figure 8b). Scores from the M&S index were also positively correlated with those of the BCG–cold model ($\rho = 0.477$, $P = 0.012$; Figure 8c). Neither the Lyons–cool index nor the BCG–cool model had scores that were significantly correlated with those from another index. However, both of the coolwater indices tended to rate the sites highly and with little variation.

DISCUSSION

The use of IBIs is common in the Upper Midwest, and their application can be an informative tool for tracking relative system condition over time or within a region; however, selection and interpretation of IBIs are complicated, potentially leading to conflicting results depending on the index used for assessment. We found that the coolwater indices consistently scored sites as being of high quality relative to the scoring from coldwater indices, thus confirming the importance of accurate thermal classification of a site. Inappropriate application of IBIs

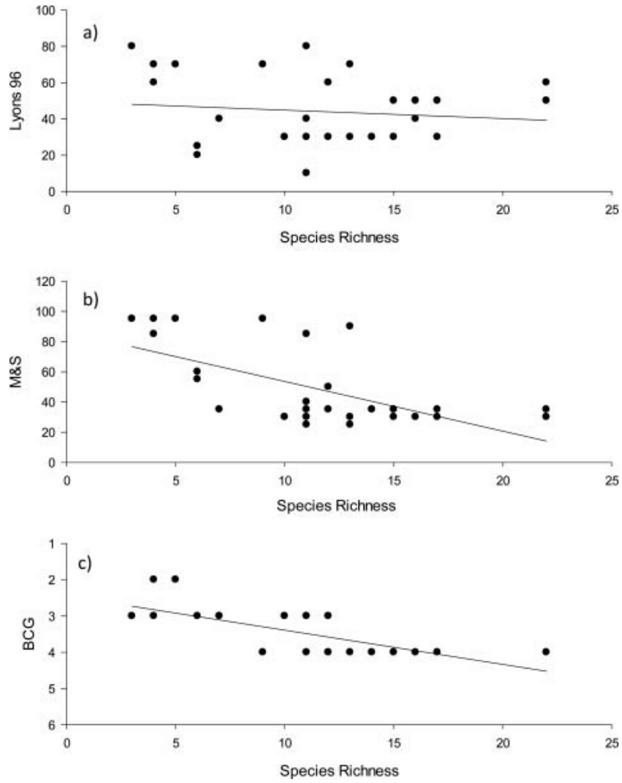

FIGURE 5. Spearman's rank correlations between coldwater index scores and species richness at 30 sites sampled throughout the Big Manistee River watershed during 2007: **(a)** Lyons et al.'s (1996) index (Lyons 96; Spearman's rank correlation coefficient $\rho = 0.071$, $P = 0.707$); **(b)** Mundahl and Simon's (1999) index (M&S; $\rho = 0.623$, $P = 0.000246$); and **(c)** Gerritsen and Stamp's (2012) coldwater biological condition gradient model (BCG; $\rho = 0.782$, $P = 0.000002$).

has been found to bias the scores (Wang et al. 2003; Baker et al. 2005) and thus their interpretation. All of the indices we evaluated were developed for the Upper Midwest region, but they resulted in significantly different assessments of our study sites in the Big Manistee River watershed. All sites were scored as being in better condition when assessed with coolwater indices than with coldwater indices. Although output scores from the coldwater indices were correlated, they varied in magnitude and in the classification of sites. An understanding of the primary factors driving index output and of the regional reference condition (or predicted natural condition) forming the basis of each index is important for guiding selection of the most appropriate assessment tools.

Index Applicability

Determining thermal classification of stream systems is imperative for accurate assessment and application of indices (Lyons 1992; Lyons et al. 1996). Our findings indicated that the thermal regimes of the streams we monitored were at the threshold between coolwater and coldwater classifications based on actual (not modeled) temperatures. All of the streams assessed in this study are listed as Michigan trout streams (Natural Resources and Environmental Protection Act, Section 48701[o], as amended in Section 324.48701 [o] of the Michigan Compiled Laws); as such, they are considered to be coldwater streams. Furthermore, our study streams were also classified as coldwater based on statewide modeled water temperature (Wehrly et al. 2009). The actual temperature measurements at our sites occasionally exceeded the coldwater thresholds, but when actual temperatures, modeled data, and the performance of the coolwater indices are collectively considered, there is support for using the coldwater classification and associated indices for these streams. When applied to data sets for the Big Manistee River watershed, the Lyons–cool index and BCG–cool model produced results that did not match those from the coldwater indices. Overall, the Lyons–cool index consistently scored sites as "excellent," with little variation; although the BCG–cool model displayed some sensitivity to temporal site trends, neither the BCG–cool model nor the Lyons–cool index was correlated with the other indices. However, all of the coldwater indices were correlated with each other.

Index Performance

The three coldwater indices differ in parameters that have the greatest influence on the score for a given site. Indices generally produce higher scores (or a lower tier for the BCG–cold model) when there are few total species in the sample and when native coldwater species are present and dominate the community. Scoring of the Lyons96 index is based on five metrics, resulting in a relatively large influence of each metric, including the percentage of salmonids that are Brook Trout. The low number of metrics has been identified as a limitation of some indices (Angermeier and Karr 1986; Miller et al. 1988; Lyons et al. 1996). Although all three coldwater indices include the presence of Brook Trout as a metric that leads to higher scores, the scoring of the M&S index is based on 12 metrics and therefore does not place as much weight on the percentage of Brook Trout, although that metric remains important in the scoring. Similarly, for the BCG–cold model, the Brook Trout is one of six coldwater species that improve site scores. The sensitivity in the Lyons96 index based on its lower number of metrics was exemplified by the Oldhouse Creek long-term monitoring site, where Brook Trout were not encountered. The overall scoring for that site was very low with the Lyons96 index but was generally higher (though variable) with the M&S index (Figure 6). Interestingly, the lack of Brook Trout and the presence of nonnative salmonids (Brown Trout and Rainbow Trout) at the Oldhouse Creek site also resulted in lower scores from the BCG–cold model until 2007–2009, when additional coldwater taxa (e.g., Cottidae) began to be represented in the samples.

TABLE 2. Occurrence of species over 8 years of sampling (2002–2010) at long-term monitoring sites in Bear, Pine, Oldhouse, and Sickle creeks (asterisks denote species that were found only in one sample).

Family	Species	Bear	Pine	Oldhouse	Sickle
Catostomidae	Golden Redhorse *Moxostoma erythrurum*	X			
	Shorthead Redhorse *Moxostoma macrolepidotum*	X			
	White Sucker *Catostomus commersonii*	X	X	X	
Centrarchidae	Bluegill *Lepomis macrochirus*	X	X	X	X
	Green Sunfish *Lepomis cyanellus*	X*	X	X	X
	Largemouth Bass *Micropterus salmoides*	X*	X*		
	Pumpkinseed *Lepomis gibbosus*	X	X		
	Rock Bass *Ambloplites rupestris*	X	X*		
Cottidae	Mottled Sculpin *Cottus bairdii*	X	X	X	X
Cyprinidae	Blacknose Dace *Rhinichthys atratulus*	X	X	X	X
	Bluntnose Minnow *Pimephales notatus*	X			
	Common Shiner *Luxilus cornutus*	X			
	Creek Chub *Semotilus atromaculatus*	X	X	X	X
	Emerald Shiner *Notropis atherinoides*	X			
	Golden Shiner *Notemigonus crysoleucas*	X			
	Longnose Dace *Rhinichthys cataractae*	X	X		
	Northern Redbelly Dace *Chrosomus eos*	X	X	X	X
Esocidae	Redfin Pickerel *Esox americanus*	X			
	Muskellunge *Esox masquinongy*	X			
	Northern Pike *Esox lucius*	X			
	Central Mudminnow *Umbra limi*	X	X	X	X
Gasterosteidae	Brook Stickleback *Culaea inconstans*			X	X
Ictaluridae	Black Bullhead *Ameiurus melas*			X*	
Lotidae	Burbot *Lota lota*	X			X
Percidae	Blackside Darter *Percina maculata*	X			
	Johnny Darter *Etheostoma nigrum*	X	X	X	X
	Logperch *Percina caprodes*	X*			
	Yellow Perch *Perca flavescens*				X
Petromyzontidae	American Brook Lamprey *Lethenteron appendix*				X
	Sea Lamprey *Petromyzon marinus*		X*	X*	X*
Salmonidae	Brook Trout *Salvelinus fontinalis*		X		X
	Brown Trout *Salmo trutta*	X	X	X	X
	Chinook Salmon *Oncorhynchus tshawytscha*	X	X	X	X
	Coho Salmon *O. kisutch*	X	X	X	X
	Rainbow Trout *O. mykiss*	X	X	X	X

Analysis of site scores for 2002–2010 indicated natural annual variability at the long-term monitoring sites. In previous analyses of IBI variability over time, more highly degraded sites were found to exhibit greater variability than less-degraded sites (Steedman 1988; DeShon 1994; Niemela and Feist 2000; Paller 2002). However, Hughes et al. (1998) cautioned that such results can be misleading if too few sites are included in the analysis. We observed mixed results from our long-term monitoring: three of the four sites were relatively degraded (scored as fair to poor) and had higher coefficients of variation than the site that was classified as having "good" biotic integrity based on the Lyons96 and M&S indices. As was noted by Mundahl and Simon (1999), the assessments of site condition by the M&S index and the Lyons96 index diverged as impairment of the sites increased. Mundahl and Simon (1999) described how their index includes seven metrics that are sensitive to low levels of biotic integrity and thus may be better able to differentiate sites with higher levels of degradation. Although both the M&S and Lyons96 indices scored the long-term monitoring site on Pine Creek as "poor" and the site on Sickle Creek as "good," they diverged in their assessments of the long-term monitoring sites on Oldhouse and Bear creeks. Oldhouse Creek monitoring indicated a significant trend of site degradation over time based on the

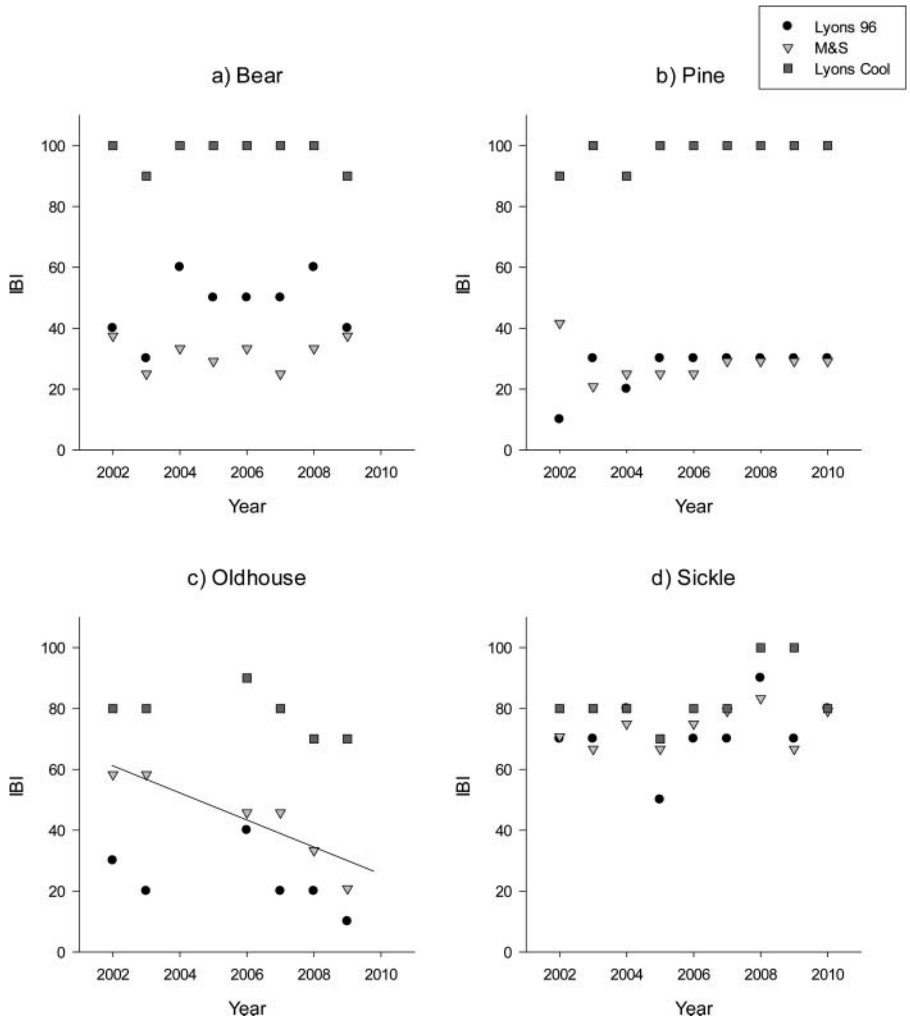

FIGURE 6. Analysis of trends in indices of biotic integrity (Lyons 96 = coldwater index from Lyons et al. 1996; M&S = coldwater index from Mundahl and Simon 1999; Lyons cool = coolwater–coldwater transitional index from Lyons 2012) from 2002 to 2010 at four long-term monitoring stations in the Big Manistee River watershed: **(a)** Bear Creek, **(b)** Pine Creek, **(c)** Oldhouse Creek (the only significant regression detected; $r^2 = 0.867$, $P = 0.007$), and **(d)** Sickle Creek.

M&S index. The BCG–cold model indicated that three of the long-term monitoring sites were relatively stable, whereas the Sickle Creek site ranged over three tiers of that index. These examples suggest that with continued long-term monitoring of sites, indices can be used to detect natural variability and to track trends in degradation or improvement. Trebitz et al. (2003) found that IBIs were insensitive to subtle changes in a simulated system, and they warned against using only IBIs as an early detection system for degradation; however, other authors have stressed the need for long-term data sets assessed by using IBIs as a tool to increase our understanding of variability and change in a system (Fore et al. 1994; Jackson and Fureder 2006; Kennen et al. 2012).

Although rapid bioassessment habitat scores were not indicative of IBI scoring, subwatersheds and overall species richness did show patterns in relation to mean IBI score. The coldwater indices discriminate among differing fish community compositions and can be used to rank and compare the stream systems. Sickle Creek had the highest average scores for all indices in 2007 because all sampled fish belonged to coldwater species, including the Burbot and Brook Trout. The Oldhouse Creek sites also had relatively low diversity (six species in 2007); however, those sites generally scored poorly due to the presence of tolerant species and the absence of Brook Trout. Sites in Pine and Bear creeks did not separate well due to the overlap in species and their general compositional similarities. The coldwater IBIs allow for differential assessment of stream fish assemblages and are sensitive to the types of species alterations that are commonly encountered in the Northern Lakes and Forests Ecoregion; this, coupled with long-term monitoring, facilitates the elucidation of patterns and trends over time.

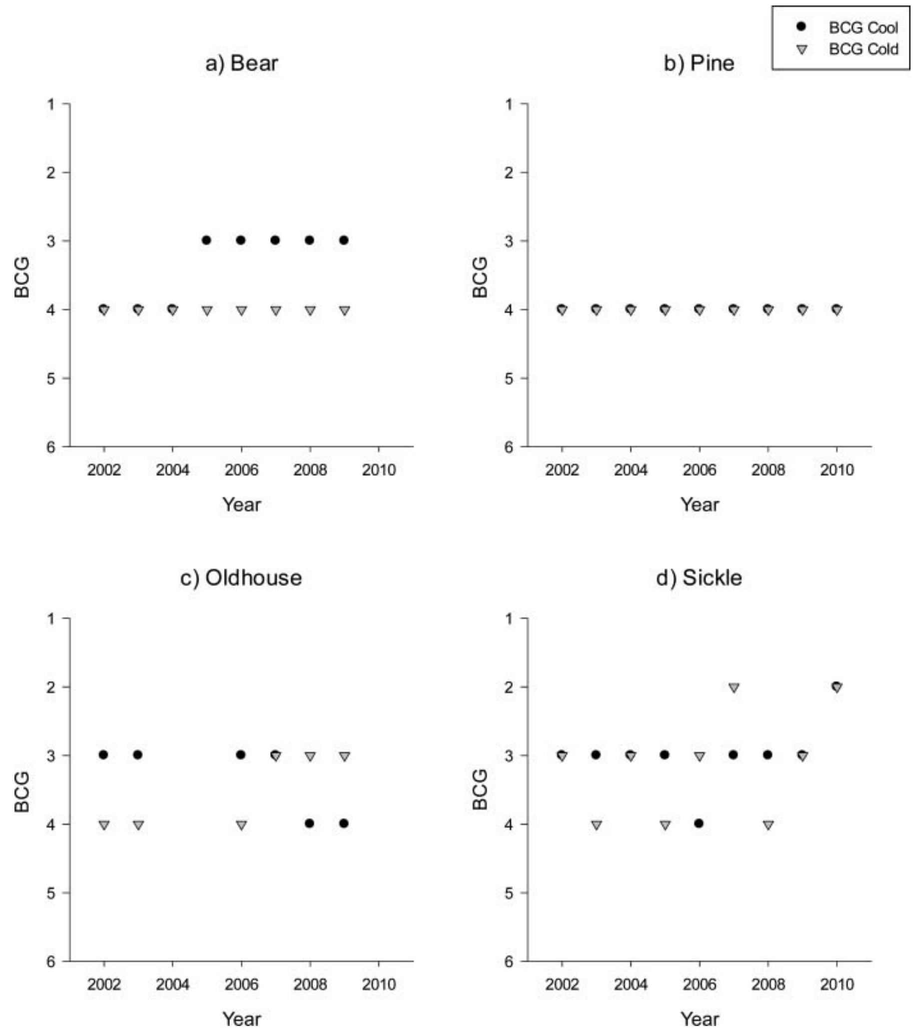

FIGURE 7. Analysis of trends in indices based on biological condition gradient models (coolwater [BCG cool] and coldwater [BCG cold]; Gerritsen and Stamp 2012) from 2002 to 2010 at four long-term monitoring stations in the Big Manistee River watershed: **(a)** Bear Creek, **(b)** Pine Creek, **(c)** Oldhouse Creek, and **(d)** Sickle Creek. No significant relationships were detected.

Interpretation of Index Scores

Interpretation of IBI scores should incorporate an understanding of the relative weighting of certain drivers in the index. Coldwater indices tended to assess trends similarly and to agree in their relative scoring of sites from high to low quality. However, when a specific site or year was analyzed with all three coldwater indices, it might be classified as fair, poor, or good depending on the index chosen (e.g., the Oldhouse Creek site; Figures 6c and 7c). Although the three coldwater indices were concordant and generally showed similar temporal trends, the magnitude of scoring was variable, which could lead to different conclusions regarding the general integrity of a given site. As the M&S and Lyons96 indices showed the strongest correlation, we would suggest that the next step is to analyze the index components and determine which drivers are most important for the question to be evaluated. Only two of the metrics in the Lyons96 index overlap with those of the M&S index (i.e., percentage of salmonids as Brook Trout; percentage of fish as top carnivores), but the remaining three metrics of the Lyons96 index do have similarities with metrics included in the M&S index, utilizing either the number or the percentage of intolerant, tolerant, and coldwater individuals. As noted in the development of the M&S index, the inclusion of additional metrics representing the overall number of species, number of benthic species, and number of warmwater species may facilitate the M&S index's ability to differentiate degraded sites (Mundahl and Simon 1999). This was demonstrated in the present study when we evaluated correlations between overall species richness and index scores. The M&S index and the BCG–cold model had high levels of correlation with species richness and thus may be better suited for application to areas with greater richness. Increased species richness in coldwater systems may act as a surrogate for degradation, and in such cases these two indices would be preferred.

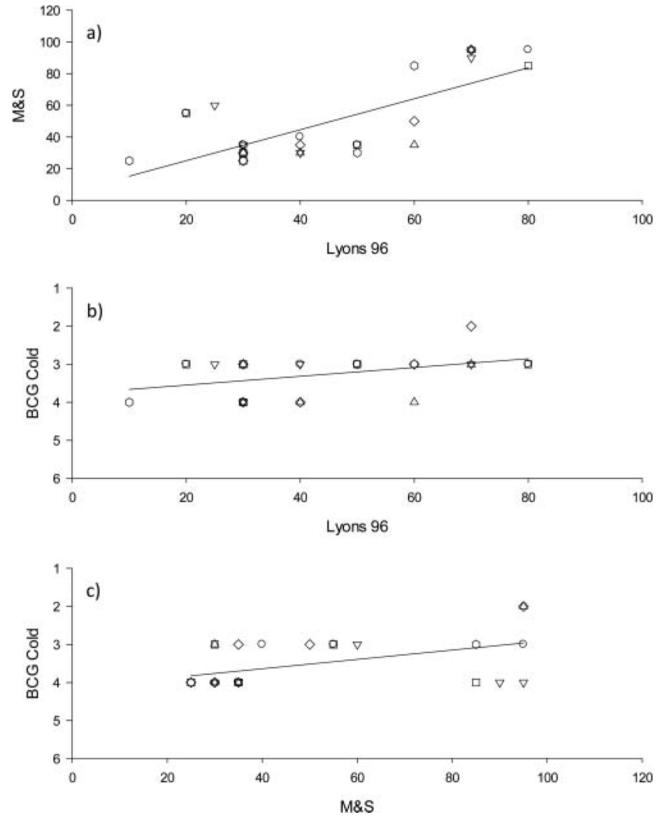

FIGURE 8. Spearman's rank correlations between coldwater index scores for 30 sites throughout the Big Manistee River watershed in 2007: **(a)** Mundahl and Simon's (1999) index (M&S) versus Lyons et al.'s (1996) index (Lyons 96; Spearman's rank correlation coefficient $\rho = 0.715$, $P = 0.000003$); **(b)** Gerritsen and Stamp's (2012) coldwater biological condition gradient (BCG cold) model versus the Lyons 96 index ($\rho = 0.517$, $P = 0.00595$); and **(c)** the BCG cold model versus the M&S index ($\rho = 0.477$, $P = 0.012$). All correlations were significant.

Spatial interpretations (landscape and local views) of fish communities can also lead to seemingly contradictory results if the relative temporal and spatial coverages are not adequately represented within the data (Wiley et al. 1997). Wang et al. (2003) found that IBI scores in the Northern Lakes and Forests Ecoregion suggested overall good biotic condition that was not strongly related to land use; they attributed this to misapplication of the IBI and the lack of a coolwater IBI, since many of the sites in the study lacked notable environmental degradation. Based on empirical validation of temperature regimes at our monitoring sites in the same ecoregion, data from long-term monitoring stations, and knowledge of historic and current land use, we believe that the sites monitored in the Big Manistee River watershed are coldwater streams with signs of degradation. Our habitat assessment also indicated highly variable riparian cover and little relationship between habitat scores and IBI scores. VanDusen et al. (2005) found that in the northern portion of the Northern Lakes and Forests Ecoregion, forestry management practices (i.e., selective logging) left historic land use signals in the biotic communities of streams that persisted for decades. In a companion study, Flaspohler et al. (2002) reported that indications of degradation in multiple biotic communities (birds, fish, and macroinvertebrates) could persist for up to 30 years after selective logging, even in areas where best management practices (i.e., a 30-m riparian management zone) were employed. Because much of the Big Manistee River watershed is dominated by forest, current land use activities and historic degradation may contribute to lower site scores. As was noted by Wiley et al. (1997), both spatially and temporally extensive sampling designs are needed to accurately assess biotic communities.

Assessment of fish communities has effectively conveyed information on the status and ecological quality of aquatic ecosystems (Roset et al. 2007). The scientific community should ensure that the interpretation of index scores is clear and well understood. This is exemplified by data from Pine and Bear creeks, which are considered "tier-1 trout streams" in Michigan (Tonello 2011) and yet scored in the "poor" category for biotic integrity. The occurrence of nonnative fish lowers the scores resulting from the BCG–cold model, Lyons96 index, and M&S index; therefore, each index includes explicit statements regarding how it was developed to assess the overall integrity of a fish community. In the Upper Midwest, coldwater systems are commonly managed for nonnative fish species, often through stocking, which can lower the overall index score and quality (Mundahl and Simon 1999). Biotic integrity is different than the status of a fishery; therefore, communicating a clear interpretation of scores is imperative to reduce confusion and ensure appropriate understanding of the assessment.

All of the indices were developed in relation to a regional reference condition or a predicted natural condition that serves as a reference point for score interpretation, thus exemplifying the need for a greater understanding of those reference conditions. For example, the Lyons96 index is based on Wisconsin coldwater streams as the reference condition, whereas the M&S index is based on streams from Wisconsin, Minnesota, and Michigan. The BCG–cold model was also calibrated for streams in these states; however, it was developed in relation to a presumed natural and undisturbed condition (tier 1). The M&S index scores represent how a site assessment ranks in relation to streams throughout Wisconsin, Minnesota, and Michigan, whereas the Lyons96 index scores represent how a site ranks in relation to Wisconsin coldwater streams. Scores from the BCG–cold model represent how a site ranks in relation to a presumed natural, undisturbed condition for the entire Upper Midwest. The BCG–cold model generally scored sites as mediocre for the region, whereas a larger gradient of condition was expressed in scores from the M&S and Lyons96 indices. The difference in scoring may be partially explained by differences in the reference condition among these indices.

CONCLUSIONS

Assessing and communicating the status of lotic systems are vital to their management, restoration, and protection. Although indices such as IBIs have been applied for over 30 years (Ruaro and Gubiani 2013), they have been refined and improved over time. Assessment of indices used in the Upper Midwest indicated that the proper classification of thermal regime is imperative for appropriate and accurate scoring. For the coldwater indices evaluated, site scores revealed long-term trends and natural variability. Indices were correlated, but the magnitude of site scores was variable due to differences among indices in the reference condition used and the relative weighting of metrics. Awareness and understanding of the drivers and development of each index will aid in interpretation of index scores. For example, if a stream community dominated by Brook Trout is the valued condition, then use of an index that is heavily influenced by Brook Trout abundance would be appropriate, and an explanation of the score should include a description of this bias. If comparison with a pristine natural condition is desired, then an index based on that reference would be more appropriate. The indices we used classified sites into groups that are all based on the value of particular biotic communities. Recognizing and incorporating index drivers into communication of the scores will assist in their interpretation and usefulness. The BCG–cold model ranks sites in comparison with a natural, undisturbed condition and indicated that most of our sites showed changes in community structure with the presence of tolerant taxa. Scores from the Lyons96 index were heavily weighted and influenced by Brook Trout; although this index can be used as an indicator of biotic integrity, there may be limitations for its use when streams are slightly degraded and have a low abundance of Brook Trout. For the Big Manistee River watershed, which exhibited some degradation and increased species richness, the metric-rich M&S index tracked trends over time, elucidated annual variation, and discriminated among sites. All three coldwater indices could be used for an assessment as long as the drivers of the index and the reference condition are articulated, understood, and included as critical features of the assessment's goals.

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