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OPTIMAL MACROINVERTEBRATE METRICS FOR THE ASSESSMENT OF A NORTHERN PRAIRIE STREAM

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ABSTRACT

This research was conducted to (1) determine an optimal suite of macroinvertebrate metrics and (2) test the effectiveness of standard EPA biological assessment methods for identification of stream degradation. Invertebrate samples were taken from 18 sites on Bachelor and Brookfield Creeks in Moody County, South Dakota once per month from April through September 1998 and 1999. Data were applied to 51 invertebrate metrics which were (1) randomly selected in sets of 10, (2) grouped as per Plafkin et al. (1989) (3) optimized by minimizing reference site variability and maximizing site discriminatory power (Barbour et al., 1999), and (4) optimized using principal components analysis (PCA). Plafkin and randomly selected metric sets resulted in 60% of stream sites classified as slightly impaired and 40% of sites as moderately impaired. Optimized metrics resulted in 20% of stream sites classified as unimpaired, 47% of sites as slightly impaired, and 33% of sites as moderately impaired. PCA metrics resulted in 47% of sites classified as unimpaired and 53% of sites as slightly impaired. Three sites categorized as slightly impaired using the Plafkin set were considered non-impaired using the optimized set. All sites categorized as slightly impaired using the Plafkin set were considered non-impaired using the PCA set. These results suggest that objective selection of core metrics is necessary to prevent type I errors from biomonitoring investigations.

INTRODUCTION

The use of multimetric community indices to evaluate impairment of aquatic biota is now used widely within the United States. Karr et al. (1986) first demonstrated the multimetric approach with the Index of Biotic Integrity (IBI) for fish communities in Illinois. This approach combines information on fish abundance, species composition, guild composition and condition to provide a single integrated index of biological integrity in surface waters. His protocol has served as a model for development of other multimetric approaches including the Benthic Index of Biotic Integrity (B-IBI) developed for rivers of the Tennessee Valley (Kerans and Karr, 1994), the Invertebrate Community Index (ICI) developed by the Ohio EPA (DeShon, 1995), and the USEPA Rapid Bioassessment Protocols (RBPs) (Plafkin et al., 1989). While originally developed for fish communities, this approach has now been applied to algal and invertebrate assemblages (Barbour and Yoder, 2000).

Numerous measures (metrics) of invertebrate community characteristics have been tested for use in water resource management. Although some require regional modifications, metrics are used over wide geographic areas (Barbour et al., 1999). From a large list of metrics, a suite of candidate metrics is chosen that is appropriate for regional settings. Candidate metrics are chosen based on knowledge of aquatic systems, flora and fauna, historical data, and literature reviews (Barbour et al., 1995).

From the candidate metrics, a set of core metrics is selected to be included within an index of biotic integrity. Most multimetric indices are comprised of eight to ten core metrics, which are selected because they reflect an aspect of the biological system (Karr and Chu, 1999). These core metrics are incorporated into an index that should provide an integrated picture of abundance, community composition, habitat utilization, functional organization, and tolerance to pollution (Barbour, 1999; Karr and Chu, 1999). This approach, using several types of measures, provides a more holistic assessment of community structure and function (Plafkin et al., 1989).

Application of the invertebrate multimetric approach requires knowledge of local and regional fauna and likely sources of degradation to surface waters. For example, invertebrate metrics developed for high gradient streams in the Black Hills of South Dakota are unlikely suitable for low-gradient ephemeral streams of eastern South Dakota. Thus, research efforts are needed to document the composition of regional invertebrate assemblages and select invertebrate community metrics suitable for different ecoregions.

This effort was conducted to determine an optimal suite of core macroinvertebrate metrics suited for detecting biological impairment in eastern South Dakota streams and test the usefulness of standard EPA biological assessment methods for identifying areas of impairment.

STUDY AREA AND METHODS

The Bachelor Creek watershed (Fig. 1) is located in the Northern Glaciated Plains Ecoregion of Eastern South Dakota (Omernik, 1987), extending across Moody and Lake counties within South Dakota. The watershed drains an area of 24,022 hectares, of which 633 hectares are considered highly erodible land. The landscape is characterized with low slopes and large numbers of prairie pothole wetlands. Land-use in the watershed area is primarily agricultural with approximately 83 percent cropland, 5 percent grassland, and 7 percent farms and shelterbelts (Moody County Conservation District, 1991).

To facilitate an adequate assessment and to comply with standard methods, a reference drainage was defined for comparison. Hughes (1995) defines reference conditions as those approximating presettlement physical, chemical, and biological conditions, or those areas believed to have high ecological integrity. However, due to the difficulty of determining what conditions would be like prior to European settlement, minimal disturbance is often used as a reference condition. In this study, Brookfield Creek, a nearby tributary of the

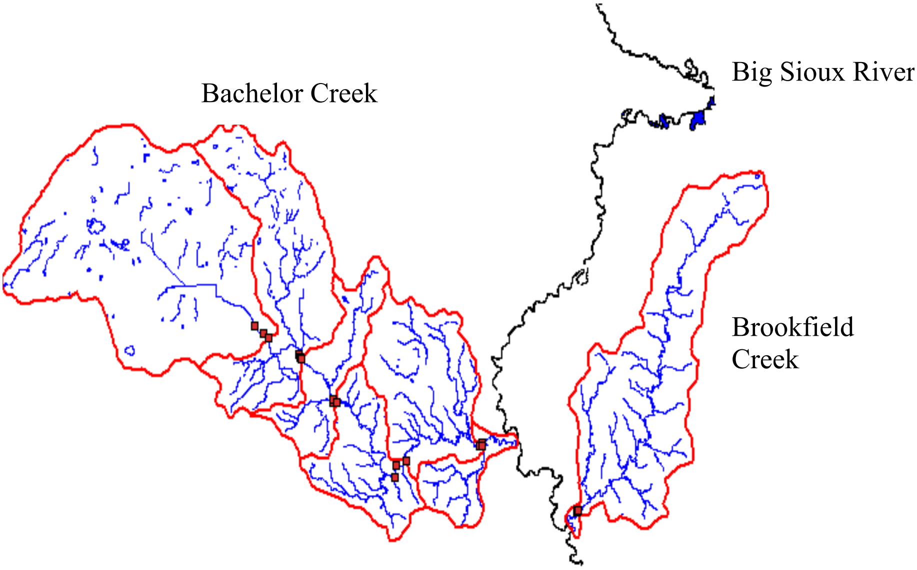

Figure 1. Location of sampling sites and reaches within Bachelor and Brookfield Creeks, Moody County, SD. Numbers indicate Bachelor Creek reaches (sub-watersheds). Dots represent sampling sites (Note: three sites per reach).

Big Sioux River, was selected as a reference stream for comparison to Bachelor Creek biological and habitat data.

Benthic macroinvertebrate samples were collected monthly from April through September in 1998 and 1999 from 5 reaches along the mainstem of Bachelor Creek (Fig. 1). Three riffle sites were sampled on each reach of Bachelor Creek (15 sites) and along the mainstem of Brookfield Creek (3 sites). Three standard one-minute kicknet samples were collected from each riffle site and combined to make one composite sample.

Invertebrate samples were subsampled and sorted within the laboratory. A fixed count (100-organism minimum subsample) was sorted from the matrix of detritus, sand, and mud (Newman, 1987). Major taxa were placed in separate vials and were identified to the genus/species level, excluding the phylum Annelida (Merritt and Cummins, 1996; Thorp and Covich, 1991).

Resulting invertebrate counts were applied to 51 candidate metrics (Table 1). These metrics were divided into five categories reflecting abundance, community composition, habitat utilization, functional organization, and tolerance to pollution (Barbour et al., 1999).

Four different core metric selection procedures were evaluated after metric scoring. Random sets of 10 candidate metrics were selected from the larger candidate set. These random sets become our null core set. The eight metric EPA Rapid Bioassessment core set was selected as our second core set. The third core set was selected following the metric optimization procedure of Barbour et al. (1999), producing a core metric set with high discriminatory power and low reference site variability. The final core set was derived using principal components analysis (PCA) applied to metric data.

Table 1. Metrics used to categorize invertebrate communities in Brookfield and Bachelor Creeks, Moody County, SD (sorted by metric category).

Metric Category	Metric	Change Due to Impairment Relative to Reference
Abundance	Estimated Total Abundance	Increase or Decrease
	Taxonomic Richness	Decrease
Community Composition	Coefficient of Community Loss Index	Increase
	% Contribution of Dominant Taxon	Increase
	% Ephemeroptera (E)	Decrease
	% Plecoptera (P)	Decrease
	% Trichoptera (T)	Decrease
	% EPT (together)	Decrease
	% Elmidae	Decrease
	% Diptera	Increase
	% Chironomidae	Increase
	% Other Diptera and Non-Insect Taxa	Increase
	% Oligochaeta	Increase
	% Tanytarsini	Decrease
	% Rheotanytarsus	Decrease
	% Glyptotendipes	Increase
	% Hyallela azteca	Increase
	Tanytarsini:Chironomidae Ratio	Decrease
	EPT:Chironomidae Ratio	Decrease
	EPT Richness	Decrease
	Ephemeroptera Richness	Decrease
	Plecoptera Richness	Decrease
	Trichoptera Richness	Decrease
	Diptera Richness	Decrease
	Chironomidae Richness	Decrease
	Tanytarsini Richness	Decrease
	Tanytarsini Richness:Total Richness	Decrease
	Tanytarsini Richness:Chironomidae Richness	Decrease
	Rheotanytarsus Richness	Decrease
	Glyptotendipes Richness	Increase
	Hyallela azteca Richness	Increase
Habitat Utilization	% Burrowers	Increase
	% Climbers	Decrease
	% Clingers	Decrease
	% Gliders	Increase
	% Skaters	Increase
	% Sprawlers	Decrease
	% Swimmers	Increase
	% Preferring Depositional Habitat	Increase
	% Preferring Erosional Habitat	Decrease
Functional Organization	% Filtering Collectors	Decrease
	% Gathering Collectors	Increase
	% Piercers	Decrease
	% Predator Engulfers	Increase
	% Scrapers	Increase
	% Shredders	Decrease
	% Filtering + Gathering Collectors	Decrease
	Scraper:Filtering Collector Ratio	Increase
Tolerance to Pollution	% Intolerant Invertebrates (HTV < 3.0)	Decrease
	% Tolerant Invertebrates (HTV > 7.0)	Increase
	Modified Hilsenhoff Biotic Index	Increase

Each of the core metric sets was scored relative to reference Brookfield Creek data using a modification of the EPA Rapid Bioassessment protocol (Plafkin et al., 1989). Metrics of each Bachelor site were assigned a score of 0, 2, 4 or 6 based upon comparisons with reference stream conditions. Low scores indicate large deviation while high scores indicate similarity with reference conditions (Table 2). The sum of metric scores was divided by the maximum possible score to derive a percent comparability (IBI score) for each Bachelor site. Impairment classes (unimpaired, slightly impaired, moderately impaired and severely impaired) were assigned based upon quartile deviations from average reference stream conditions (Table 3).

RESULTS

Of the 51 candidate metrics examined, ten metrics were included in the optimized IBI based upon two conditions: 1) large differences in metric values between paired reference and test samples (discriminatory power) and 2) low reference site variability (Table 4). All candidate metrics were ranked based on

Table 2. Optimized set of metrics and scoring criteria selected for the Bachelor Creek study, Moody County, SD.

	OPTIMIZED INVERTEBRATE METRIC SCORES AND CRITERIA			
Metric	**6**	**4**	**2**	**0**
% Burrowers [b]	>75%	50-75%	25-50%	<25%
Community Loss Index [a]	<0.5	0.5-1.5	1.5-4.0	>4.0
% EPT [b]	>75%	50-75%	25-50%	<25%
% Filtering Collectors [c]	>75%	50-75%	25-50%	<25%
% Gathering Collectors [b]	>75%	50-75%	25-50%	<25%
% Preferring Erosional Habitat [c]	>75%	50-75%	25-50%	<25%
% Clingers [c]	>75%	50-75%	25-50%	<25%
EPT Taxa Richness [a, c]	>90%	80-90%	70-80%	<70%
Modified Hilsenhoff Biotic Index [a, b]	>85%	70-85%	50-75%	<50%
% Tolerant Invertebrates [b]	>75%	50-75%	25-50%	<25%

[a] Scores calculated based upon original RBP III criteria (Plafkin et al. 1989)
[b] Scores calculated based upon ratio of reference site to study site x 100
[c] Scores calculated based upon ratio of study site to reference site x 100

Table 3. Stream condition categories based upon percent accumulated point totals derived from invertebrate metric scores (modified from Plafkin et al. 1989).

% of Possible Point Total	Stream Condition Category
>75% (>45 points)	Non-impaired
51-75% (31-45 points)	Slightly Impaired
25-50% (15-30 points)	Moderately Impaired
<25% (<15 points)	Severely Impaired

Table 4. Optimized set of invertebrate metrics and optimization rank for Bachelor Creek study, Moody County, SD.

Metric	Discriminatory Power	Rank	Reference C.V. (%)	Rank	Total Rank	Class
Modified Hilsenhoff Biotic Index	1.24	7	10.7	1	1	Tolerance
% Filtering Collectors	1.77	2	36.6	7	2	Feeding
% Preferring Erosional Habitat	1.10	9	27.4	3	3	Habit
% Clingers	0.91	12	30.7	5	4	Habit
Community Loss Index	1.37	4	60.7	16	5	Composition
% Tolerant Invertebrates (HTV>7)	1.25	6	58.7	15	6	Tolerance
EPT Taxa Richness	0.77	14	46.2	10	7	Richness
% Gathering Collectors	1.34	5	62.1	19	8	Feeding
% Burrowers	1.57	3	79.4	24	9	Habit
% EPT	1.00	12	70.6	22	10	Composition

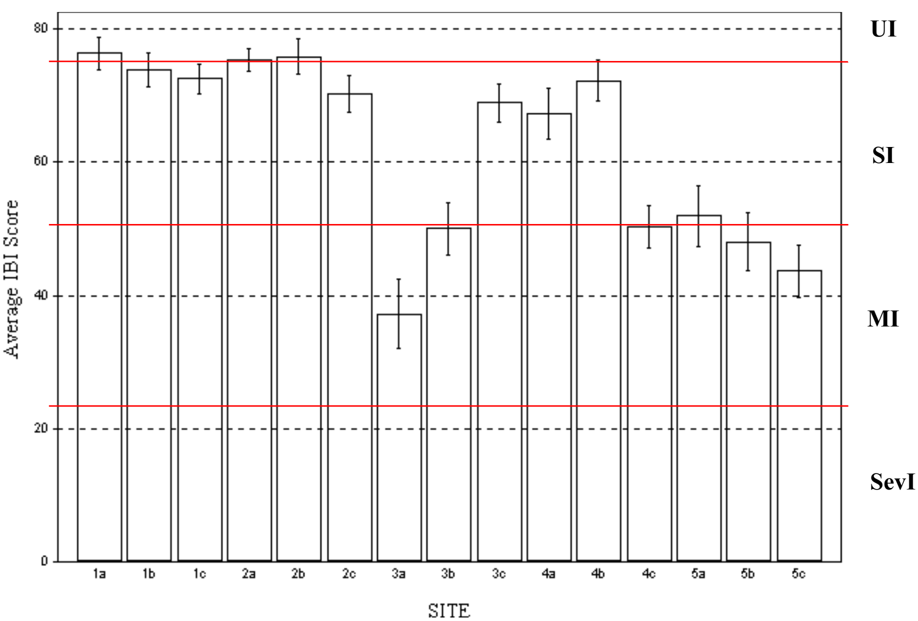

Figure 2. Average IBI scores for all sites using the optimized metric set. Solid horizontal lines indicate impairment category thresholds (UI=unimpaired, SI=slightly impaired, MI=moderately impaired, and SevI=severely impaired).

the above criteria and those that ranked in the top ten were retained (Fig.2). These qualities make this set most optimal for use in the Bachelor Creek assessment and applicable across the ecoregion.

Analysis of Bachelor Creek metric values resulted in 10 principle components explaining 83% of the variability in invertebrate community characteristics. The metric weighing most heavily on each principle component was selected to represent that component of ordinate space within the data set. This method resulted in ten metrics, which were collectively referred to as the PCA metric set (Table 5).

Table 5. Metrics included in the optimized, PCA and USEPA core metric sets for the Bachelor Creek study, Moody County, SD.

Optimized	PCA	USEPA
Hilsenhoff Biotic Index	% Preferring Depositional Habitat	Taxonomic Richness
% Filtering Collectors	% Chironomidae	Hilsenhoff Biotic Index
% Preferring Erosional Habitat	% Diptera	Scrapers:Filtering Collectors
% Clingers	% Burrower	EPT:Chironomidae
Community Loss Index	% Oligochaeta	% Dominant Taxon
% Tolerant Invertebrates	% Elmidae	EPT richness
% Gathering Collectors	Taxonomic Richness	Community Loss Index
EPT richness	Hilsenhoff Biotic Index	% Shredders
% Burrowers	Chironomidae richness	
% EPT	EPT richness	

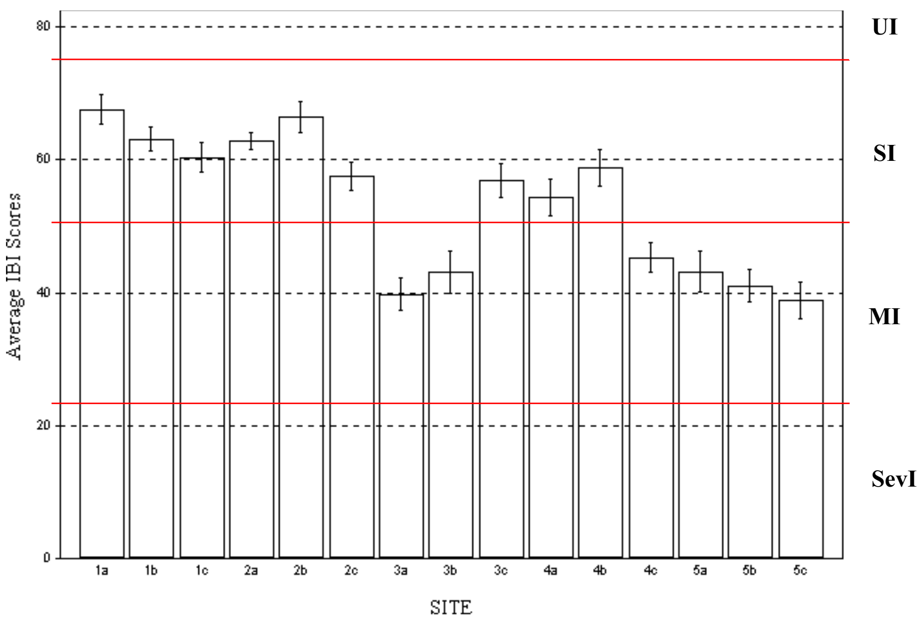

Figure 3. Average IBI scores for all sites using random (null) metric sets. Solid horizontal lines indicate impairment category thresholds (UI=unimpaired, SI=slightly impaired, MI=moderately impaired, and SevI=severely impaired).

Stream site impairment assignments varied among core metric sets. Random and Plafkin sets provided similar scorings with 60% of sites classified as slightly impaired and 40% as moderately impaired relative to reference Brookfield Creek communities (Figs. 3 and 4). In contrast, optimized core scorings suggest that 20% of Bachelor sites were unimpaired, 47% were slightly impaired and 33% were moderately impaired (Fig. 2). PCA metric set analysis deemed all sites either unimpaired (47%) or slightly impaired (53%) (Fig. 5).

We also examined the appropriate number of metrics to include in our optimal core set. Using one of the more degraded sites (site 5B) and the top ten optimized metrics, we evaluated the response of site IBI score upon adding one

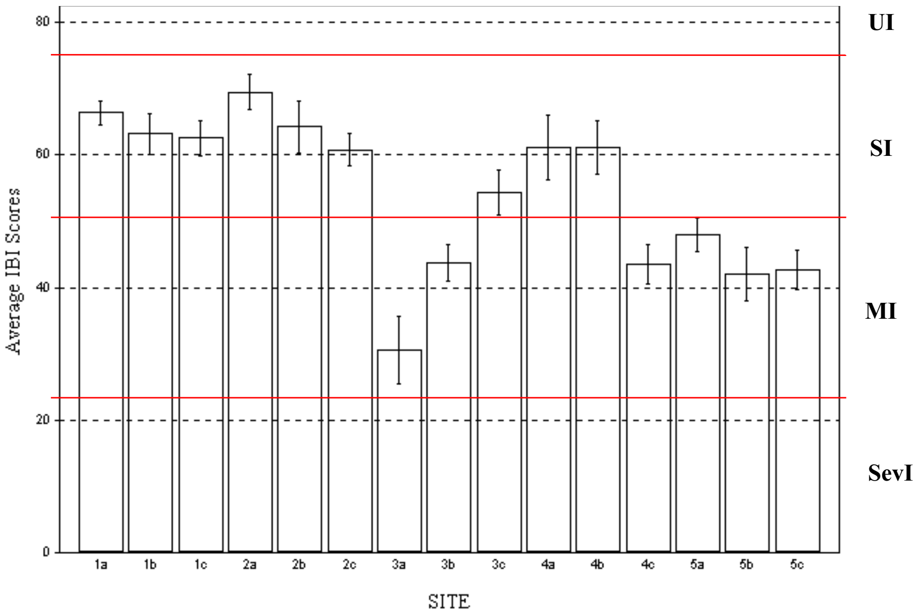

Figure 4. Average IBI scores for all sites using the Plafkin et al (1989) metric set. Solid horizontal lines indicate impairment category thresholds (UI=unimpaired, SI=slightly impaired, MI=moderately impaired, and SevI=severely impaired).

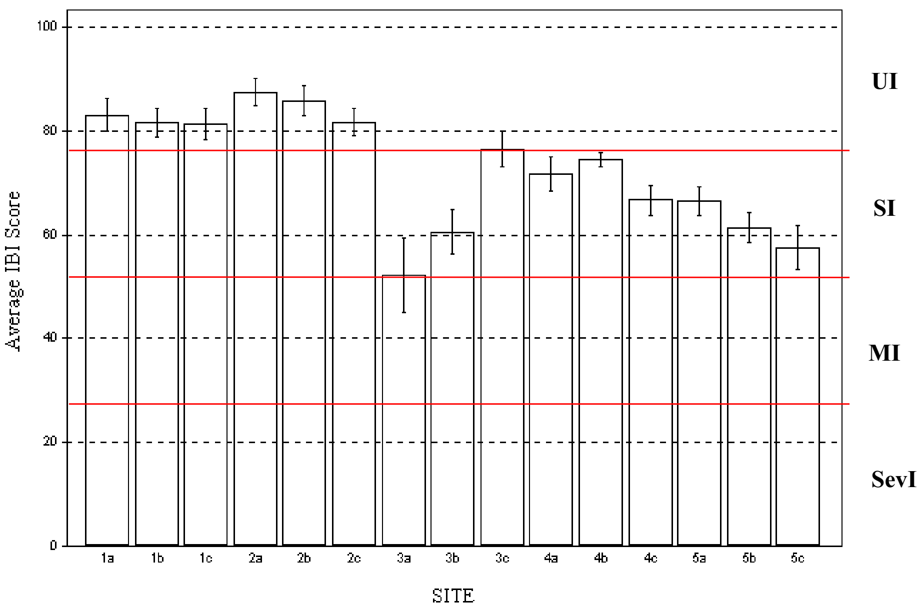

Figure 5. Average IBI scores for all sites using the PCA metric set. Solid horizontal lines indicate impairment category thresholds (UI=unimpaired, SI=slightly impaired, MI=moderately impaired, and SevI=severely impaired).

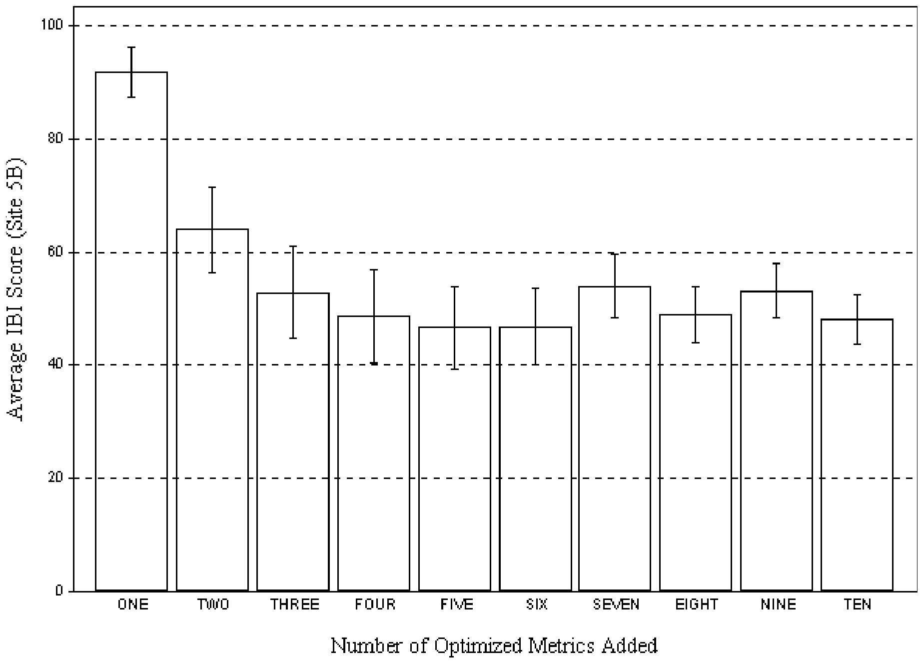

Figure 6. Average IBI score for site 5B adding one optimized metric in optimized order. Significant differences in scores result up through the addition of the thirdmetric.

metric at a time in optimized order. The IBI score using ten optimized metrics for site 5B was 48% (moderately impaired). With only one metric included in the index, site 5B IBI score was 92% (unimpaired). With two metrics included, the site score dropped to 64% (slightly impaired). The scores continue to significantly decrease ($p<0.017$; alpha level corrected using Bonferroni procedure) until after the addition of the third metric. An index incorporating the top three optimized metrics yielded an IBI score of 53% (slightly impaired). After the addition of the third metric, the IBI scores became stable (Fig. 6).

DISCUSSION

To account for the broad range of human impacts on aquatic systems, a multimetric approach has been found to be a successful assessment tool. Multimetric indices are now utilized by state agencies across the nation (Barbour and Yoder, 2000). More than 90% of state water agencies use a multimetric approach (Karr and Chu, 1999).

Core metrics are those that indicate various aspects of structure, composition, individual health or processes of the aquatic biota. When selecting a core set, representative metrics should be chosen from each of five primary categories: composition, richness, tolerance, feeding, and habit (Barbour et al., 1999). Accurate assessment of biological integrity requires a method that incorporates a biotic inspection of patterns and processes from individual to ecosystem levels (Barbour and Yoder, 2000).

Using an objective selection procedure, multimetric indices can be universally applied to a variety of waterbody and assemblage types. The multimetric approach has been applied to rivers, lakes, and wetlands and has been used to examine the health of fish, invertebrate and algal assemblages. Objectively chosen core metrics are also inherently adjusted for regional settings.

Traditionally, eight to ten metrics are used to form an integrated index (Karr and Chu, 1999). Based on our results, the IBI score stabilizes after the addition of three metrics, suggesting a need of only three metrics in an index. However, three metrics would not sufficiently represent all metric categories and may not accurately detect all disturbance types.

Accuracy, the ability of a measure to reflect actual conditions, can be weakened in two different ways. The measure could indicate that impairment has occurred when, in fact, it has not occurred (type I error). Conversely, the measure could indicate that impairment has not occurred when, in fact, it has (type II error) (Resh and Jackson, 1995). Our results indicate that objective selection of core metrics is necessary to prevent type I errors from biomonitoring investigations.

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