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CREATION AND ASSESSMENT OF AN INDEX OF BIOTIC INTEGRITY FOR COLDWATER, SOUTHEASTERN MINNESOTA STREAMS

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Abstract

Based upon fish collections from 50 stream locations (40 coldwater sites) in southeastern Minnesota, a coldwater Index of Biotic Integrity (IBI) was developed to assess water and habitat quality within streams of this region. Eight fish community characteristics or metrics were determined to be useful in assessing water and habitat quality at the sites examined, and were used to determine an IBI score for each stream site. These metrics included: 1) proportion of individuals as trout and sculpin, 2) proportion of individuals as tolerant, 3) proportion of Individuals as Intolerant, 4) proportion of individuals as creek chubs and blacknose dace, 5) proportion of individuals as generalist feeders, 6) proportion of individuals as insectivores, 7) coldwater fish per 150 m, and 8) proportion of individuals with anomalies. Based upon this coldwater IBI, 24 of the coldwater sites examined were rated as "good" or "fair", whereas the remaining 16 coldwater sites were rated as either "poor" or "very poor". No stream site was rated "excellent", although one location was borderline "good/excellent". The coldwater IBI developed during this project appeared to be successful in evaluating stream water and habitat quality at the coldwater sites examined. Further validation, refinement, and expanded use of this index is suggested within coldwater streams in Minnesota to improve its usefulness as a biomonitoring tool within the state.

Introduction

The Index of Biotic Integrity (IBI) was created by Karr (1981) as a device to quantify "biotic quality" of lotic environments using fish community attributes. The IBI was designed not only to measure water quality parameters, but also instream habitat quality and availability (Karr et al. 1986). Fish communities have been considered excellent indicators of the biotic health of lotic systems because they are relatively long-lived organisms, which may reflect both long and short-term stream quality (Karr et al. 1986). Also, fish occupy higher trophic levels, and are thus indicative of conditions of lower trophic levels (Karr et al. 1986). Furthermore, fish are relatively easy to collect, identify, and have life histories which are generally well-known (Karr et al. 1986).

Karr (1981) originally designed the IBI for midwestern warmwater streams and rivers. However, regional application of the IBI has often required considerable modification of Karr's (1981) original metrics (Miller et al. 1988). In regions with low species richness, the IBI especially has required extensive modification, but those modifications "underscore the flexibility of IBI rather than undermine it" (Miller et al. 1988). The objective of the present study was to create a regional IBI for southeastern Minnesota coldwater streams. Several authors have addressed the difficulty of applying the IBI to coldwater streams due to their relatively depauperate nature (Miller et al. 1988; Kwak 1993). However, as in warmwater systems, fish community assemblages should exhibit general and predictable tendencies with increasing environmental degradation and habitat destruction in coldwater streams (Miller et al. 1988).

Southeastern Minnesota is a region with karst topography. The streams of this heterogeneous region are derived primarily from groundwater resources, via coldwater springs (Mundahl 1992). Often, contaminated groundwater inflow and abusive watershed land practices (primarily agricultural) have degraded streams within the region (Troelstup and Perry 1989). The coldwater IBI was created with the intent of providing a general measure of the biotic health of area streams, enabling fish managers to better understand how riparian watershed changes influence the biotic health of a stream.

Methods

Fish assemblages were sampled at 51 sites in Winona, southern Wabasha, and eastern Olmsted counties, in southeastern Minnesota. Sites generally were sampled near bridges, or areas which made access to the stream easier. Emphasis was placed on sampling a variety of tributaries of the Whitewater River, and streams within Winona County. At each site, a 150-m segment was measured and marked. Beginning at the downstream end of each site, fish were collected using a Smith-Root Type VII backpack electrofisher and dipnets. Fish were identified, counted, examined for abnormalities, and then returned alive to the stream. Voucher specimens of all species collected at a site, except trout, were preserved in 10% formalin for laboratory confirmation of field identifications using the taxonomic key by Eddy and Underhill (1978). Voucher specimens were stored in the Winona State University Museum of Natural History. Watershed area above each site was determined using a 1:253,440 scale topographic map, and a Dietzgen Model D1806 polar planimeter.

The 51 sites sampled were used in creation of the coldwater IBI. The procedure outlined by Karr et al. (1986) was used in creating the coldwater IBI. Then, the index was applied to the sites used to create the model to determine if the scores each stream received correlated with field observations and data from Boxrud and Gallagher (1992). In addition, the coldwater index was tested on 15 independent sites studied by Quinn (1994), and 18 independent data sets obtained from Dr. Neal Mundahl at Winona State University, to assess the effectiveness of the coldwater IBI. However, Quinn (1994) used a 50-meter, three-pass removal sampling procedure; therefore, only the first-pass data were adjusted (by multiplying by three) to 150-m sampling segments. Quinn (1994) sampled stream reaches with and without artificial habitat structures (rehabilitated and unrehabilitated sites). The 18 data sets obtained from Dr. Mundahl include two sites on Gilmore Creek (13 sampling occasions), one I site from Pleasant Valley Creek, and four sites on the South Branch of the Whitewater River. Those sites were sampled using a single-pass procedure, with sampling reaches ranging from 150-250 meters in length. Data from the eighteen sampling occasions were adjusted to 150-meters stream length. Fish were assigned to their perspective fish groupings (examples are trophic guilds, tolerance rankings) using information from Eddy and Underhill (1978), Ohio EPA (1988), Bailey et al. (1992), Steedman (1988), Leonard and Orth (1986), Miller et al. (1988), Lee et al. (1980), range distribution maps, and personal observation.

Results and Discussion

From the 51 sites sampled, 9588 fish, representing 27 species, and eight families were captured (Table 1). On average, 188 fish were captured within a 150-m site, with each stream reach averaging five species. Individuals collected at a 150-m site ranged from 0 to 726 fish, with species richness per site ranging from 0 to 12. The family represented by the highest number of species was Cyprinidae, with nine species. Furthermore, the family Percidae was represented by seven species. Both Ictaluridae and Salmonidae were represented by three species, and Cottidae was represented by two species. The families Catostomidae, Gasterosteidae, and Petromyzontidae were represented by only one species.

Blacknose dace was the nongame fish captured at the greatest number of sites, being present at 32 of the 51 sites sampled. Nongame species found at 20 sites or more included white sucker (28 sites), creek chub (24 sites), longnose dace (21 sites), and johnny darter (20 sites). Nongame species present at one site only include logperch, mud darter, bigmouth shiner, black bullhead, and tadpole madtom. American brook lamprey, a state "special concern" species was present at three sites, totaling 11 individuals. A total of 87 fish with anomalies (including spinal curvature, missing fins and operculum, tumors and missing eyes), were collected from the 51 sites, of which blacknose dace, white sucker, and longnose dace had 92% of the anomalies.

Trout (brook, brown, or rainbow) were present at 40 of the 51 sites sampled. A total of 1775 trout was captured, comprising 18.5% of the fish community sampled. Brown trout were present at 93% of the sites where a trout species was captured, accounting for 85% of individual trout sampled. Brook trout accounted for 15% of the total trout population, and were captured in 9 of the 40 sites where trout were present. A single rainbow trout was captured in the South Branch of the Whitewater River, where they are stocked (Minnesota Department of Natural Resources-Lake City Personnel).

Sites were divided into two general categories, those with and without trout. Only sites with trout present were categorized as coldwater, and used in creating the coldwater IBI. Streams are commonly categorized as coldwater based on presence of trout (Kwak 1993). The sites without trout were categorized as warmwater, and used only for comparative reasons in testing several metrics.

Creation of the Cold water IBI.

The IBI as created by Karr (1981) utilized 12 metrics which fall into three generalized categories of species richness and composition, trophic composition, and fish abundance and condition (Table 2). The southeastern Minnesota coldwater IBI utilizes eight metrics, representing the general categories in roughly the same proportion as the original IBI (Table 3). Eight of the original 12 metrics used by Karr (1981) were considered inappropriate for use in southeastern Minnesota's coldwater streams. Metrics modified or used from Karr (1981) include proportion of individuals as intolerant, proportion of individuals as generalist feeders, proportion of individuals as insectivores, and proportion of individuals having anomalies. Proportion of individuals as tolerant was modified from Mundahl et al. (1992). Metrics created for the coldwater IBI include proportion of individuals as trout and sculpin, proportion of individuals as creek chub and blacknose dace, and coldwater fish per 150 meters. Other metrics tested, but determined inappropriate for use, included proportion as simple lithophilic spawners, number of darter and sculpin species, and number of minnow species.

Modifying the IBI for cold water streams

Karr (1981) stated that increased species richness is indicative of good habitat and water quality in warmwater midwestern streams. However, species richness was not considered a metric valuable for determining water quality of small, coldwater southeastern Minnesota streams. Vannote et al. (1980) noted that fish communities show a shift from low diversity in coldwater streams to more diverse communities at warmwater steams. Pristine coldwater streams in southeastern Minnesota generally have climax communities of trout and sculpin, with few other associated species (N. Mundahl, personal communication). As coldwater streams are degraded, removal of riparian vegetation and other agricultural practices tend to increase water temperature. Troelstrup and Perry (1989) found that stream temperature, turbidity, and percent occurrence of sediment on substrate were highest at sites adjacent to agricultural lands in watersheds of the Root River basin, southeastern Minnesota. Temperature increases from stream degradation appear to become progressively disadvantageous to trout and sculpin, thus allowing warmwater species to invade the degraded system. Therefore, high species richness was not a characteristic of coldwater streams that was considered indicative of good water quality and habitat availability, thus the metric was deleted.

Number and identity of darter species, sunfish species, and sucker species were not used as metrics. Those metrics utilize the relative intolerant nature of each family grouping to detect increasing stream degradation. However, in the context of depauperate, coldwater streams, limited number of species within those families were present. Therefore, proportion as trout and sculpin was used as a replacement metric which is sensitive to environmental degradation. Trout and sculpin tend to dominate coldwater, southeastern Minnesota streams. In addition, Kwak (1993) found that the best single predictor of trout production in southeastern

Minnesota was percent eroded bank. Thus, as streams in southeastern Minnesota are degraded by agricultural usage (which includes temperature degradation), proportion of individuals as trout and sculpin tends to decrease.

Proportion of individuals as intolerant was retained as a metric for use in coldwater, southeastern Minnesota streams. Karr et al. (1986) used decreasing proportion as intolerant fish as indicative of increasing stream degradation. Two species, American brook lamprey and longnose dace, were species classified as intolerant that are present in southeastern Minnesota streams (Table 4). The Ohio EPA (1988) classified both species as rare intolerants.

Karr et al. (1986) concluded that midwestern streams with high proportions of green sunfish were indicative of poor water quality conditions due to their exceptional tolerance to a variety of environmental impairments. However, green sunfish were absent from the majority of watersheds in southeastern Minnesota. Both creek chubs and blacknose dace were species that appeared exceptionally tolerant to poor water quality and habitat conditions. Proportion of individuals as creek chub and blacknose dace were combined as an indicator of exceptionally tolerant species after range distributions indicated that, collectively, both species cover the vast majority of southeastern streams watersheds, whereas each species separately did not occur in all major watersheds. In addition, Leonard and Orth (1986) and Steedman (1985) used proportion of creek chubs and *Rhinichthys* in their respective studies of the Central Appalachian Mountains and Central Ontario streams.

Proportion of individuals as omnivores was retained as a metric. However, the definition of an omnivore (Karr et al. 1986) requires that a species consume at least 25% plant and 25% animal matter. Precise information on the diets of southeastern Minnesota fish species were not available. Therefore, the metric was used as proportion as generalist feeders.

Proportion of individuals as insectivorous cyprinids was modified to simply proportion of individuals as insectivores because of the depauperate nature of coldwater streams.

Adult trout are the only piscivores in coldwater, southeastern Minnesota streams. Since trout were not measured or aged, proportion of individuals as piscivores was deleted.

Number of individuals in a sample was modified to coldwater fish per 150 m. Fish were classified as coldwater based on field observations and range distributions (Lee et al. 1980). Fish classified as coldwater include slimy sculpin, mottled sculpin, American brook lamprey, brown trout, brook trout, rainbow trout, longnose dace and brook stickleback (Table 4). Creek chub and blacknose dace are coldwater fish which were not included in the metric due to their exceptional tolerance to degradation. Both white sucker and johnny darter were species found in greater than 20 sites in southeastern Minnesota streams. However, both species were observed in highest abundance in streams which were not coldwater. In addition, white sucker is a tolerant species. Therefore, neither species was included in the scoring of the metric.

Proportion of individuals as hybrids was not used as a metric due to difficulty in recognizing non-centrarchid hybrid species in the field.

Proportion of individuals with anomalies was retained as used by Karr (1981).

Scoring the metrics

Metrics were scored using the procedure outlined by Karr (1991). All metrics were plotted against the log transformation of watershed area, and if any correlation was apparent, a maximum expected value line was drawn to include 90% of the reference data points. The area under the line was then subdivided into three equal areas. The areas were assigned numerical values of 5 (good), 3 (fair), or 1 (poor). During instances in which no correlation with watershed area was apparent, the alternate trisection method was used. A horizontal line containing approximately 95% of the points was drawn, and the area under the line was then trisected. Numerous possibilities occurred in placing the lines drawn during scoring of the metrics. Therefore, best professional judgment and other literature values were referenced.

Metric 1 (proportion of individuals as trout and sculpin) appeared negatively correlated with watershed areas greater than 17 square miles (Figure 1). Below 17square miles, scoring was held constant. Metrics 2-5 (proportion of individuals as tolerant, proportion of individuals as creek chub and blacknose dace, proportion of individuals as generalist feeders, and proportion of individuals as insectivores) did not appear correlated with watershed area (Figures 2, 4-6). Therefore, those metrics were scored using the alternative trisection method. Metric 6 (proportion of individuals as intolerant) appeared positively correlated with watershed area (Figure 3). Metric 7 (coldwater fishes per 150 m) appeared negatively correlated with watershed areas greater than 11 square miles (Figure 7). Metric 8 (proportion of individuals with anomalies) was scored using proportions determined by Leonard and Orth (1986) (Figure 8).

The coldwater, southeastern Minnesota IBI utilized eight metrics, thus the range of possible IBI scores was from 8 to 40. IBI scores of the sites were categorized into their respective integrity classes based upon the percentages that Karr et al. (1986) used for the 12-metric, midwestern U.S. warmwater IBI. Therefore, a score of 40-39 was assigned the integrity class of "excellent" (Table 5). The integrity class of "good" ranged from 38-32, and "fair" ranged from 31 to 27. IBI scores assigned to the integrity class of "poor" and "very poor" ranged from 26-19 and 18-8, respectively.

Scoring of sites used in creation of the coldwater IBI

IBI scores of the 40 sites used in creating the coldwater IBI ranged from 12 to 38 (Figures 9-10, Table 6). Warmwater sites, not used in creation of the index, received coldwater IBI scores ranging from 12 to 31 (Table 6). IBI scores of the 40 sites, with and without the warmwater sites, were plotted against watershed area on Figures 11 and 12. Based on visual observations and invertebrate studies from Boxrud and Gallagher (1992), sites chosen as being representative of the best streams in the area included Garvin Brook (sites 6,13,40), and Beaver Creek (site 45). Furthermore, sites assumed to be representative of non-degraded waters had

IBI scores of 32 or higher, which is characteristic of "good" water quality. Based on visual observations, sites assumed to be extremely degraded included a stream which runs through Latsch State Park (site 36), Big Trout Creek (site 20), and West Burns Valley Creek (site 37). These sites all had IBI scores of less than 18, which is characteristic of streams with very poor biotic health. The scoring of sites on the Whitewater River system was supported by the findings of Boxrud and Gallagher's (1992) invertebrate studies. In the best professional judgment of the author of the present study, the coldwater IBI appeared to assign sites used in creation of the index to appropriate integrity classes.

IBI scores of the sites from Quinn (1994) ranged from 16 to 34 (Table 7). Little variability was apparent between rehabilitated (improved) and unrehabilitated (reference) sites within four of the five streams. However, in the improvement project at the Middle Branch of the Whitewater River, 1131 scores were higher at rehabilitated sites than at unrehabilitated sites. The two unrehabilitated sites were upstream from the two rehabilitated sites. Both upstream, unrehabilitated sites scored "poor" on the IBI ratings (scores of 24 and 26). The downstream rehabilitated sites had IBI scores of 32 and 34, which are indicative of "good" water quality and habitat availability.

Boxrud and Gallagher (1992) found a rehabilitated stream section of the Middle Branch of the Whitewater River contained better habitat for stream invertebrates than an upstream, unrehabilitated site. In addition, Boxrud and Gallagher (1992) found stream quality for invertebrates at a downstream, unrehabilitated site was like that of the rehabilitated section. That downstream site (site 16) scored the highest IBI (IBI = 38) value of any stream in southeastern Minnesota that was examined.

The coldwater IBI was applied to 13 data sets, collected at two sites on Gilmore Creek during the months of June and October, between 1991 and 1993 (Table 8). Scores from the upstream Wildwood Road sites ranged from 28 to 30, and the scores from the downstream St. Mary's site ranged from 26 to 30. Comparatively, the site used in creation of the IBI at Wildwood

Road sampled during July 1992 scored 32 (Figure 13). Gilmore Creek endured no major visually obvious changes between the time period from 1991 to present, thus it was expected that IBI scores of the two sites would remain relatively constant over time. The Wildwood Road site varied little over seven differing sampling occasions between June 13, 1991 to October 5, 1993. In addition, IBI scores of the site near St. Mary's College varied little between five independent samplings during 1991.

The coldwater IBI was applied to four independent sites on the South Branch of the Whitewater River, which were sampled on September 25 and October 2, 1990 (Table 8). All sites lacked trout, so the sites served as warmwater references. The site furthest downstream, scored the highest value of the four sites (IBI = 26). Both sites in the middle reaches of the stream had calculated IBI scores of 14. The furthest upstream site scored the lowest of the South Branch independent sites, having an IBI score of 10. Streams, under normal circumstances, should exhibit a continuum of decreasing IBI scores from upstream to downstream. However, the independent sites on the South Branch of the Whitewater River exhibited higher IBI scores downstream and lower scores upstream. The stream's headwaters are located on an agricultural plain, and as the stream proceeds downstream, it enters the forested Whitewater Wildlife Management Area. As the stream enters the management area, it appeared that effects from increased shading and small, coldwater tributaries provided better coldwater habitat downstream. Also, the furthest downstream site contained trout during a later sampling occasion used in creation of the coldwater IBI. Furthermore, the banks of the stream within Whitewater Wildlife Management Area are not continually degraded by the immediate activities of cattle. Thus, biotic conditions of the stream appeared better for coldwater fish communities downstream.

The coldwater IBI was applied to one independent site on Pleasant Valley Creek (Table 8). The site scored an IBI of 26 (poor). A separate sampling occasion used in creation of the coldwater IBI (site 4) at the same locality, which was sampled before the independent occasion, received an IBI score of 28 (fair). The decreased IBI score of the second sampling occasion was expected because the riparian corridor of the stream experienced increased housing development during the time period between the two samplings (N. Mundahl, personal communication). In addition, the stream bed was observed as having higher quantities of sand and silt during the second sampling occasion (N. Mundahl, personal communication).

IBI scores of the 40 coldwater sites used in creation of the index were plotted against each metric (Table 9; Figures 13-20). Proportion of individuals as tolerant (metric 2) and proportion of individuals as generalist feeders (metric 5) individually explained 77% and 76% of the variability in the coldwater IBI, respectively (Figures 14, 17). Metrics created for the coldwater IBI, metrics 1(proportion of individuals as trout and sculpin), 4 (proportion of individuals as creek chubs and blacknose dace), and 7 (coldwater fish per 150 m), individually explained 49%, 62%, and 37% of the variability in the coldwater IBI, respectively (Figures 1,16,19). Therefore, all metrics created during the present study appear to contribute to the IBI. Proportion of individuals as insectivores explained 28% of the variability in the coldwater IBI (Figure 18). Both proportion of individuals as intolerant and proportion of individuals with anomalies explained little variability in the coldwater IBI (Figures 15, 20). The present study proposes a basis for stream managers to assess changes in the biotic health of southeastern Minnesota's coldwater streams. However, since the index was created and applied to a limited number of sites, further validation of the metrics proposed during the present study is needed. In particular, proportion of individuals as intolerant should be scrutinized. Karr et al. (1986) listed mottled sculpin as an intolerant species. However, during the present study sculpin were not used as intolerant fish because other literature did not list sculpin as intolerant, and they were prominent in the scoring of three other metrics. Also, the intolerant metric should be further examined during future studies to determine if higher-gradient streams are more likely to contain coldwater, intolerant fish. Both intolerant species used in the present study, longnose dace and American brook lamprey, were observed most frequently in streams with higher-gradients . Only further study will elucidate the true value of the metrics used during the course of the present study. Furthermore, the southeastern Minnesota coldwater IBI should only be tested by experienced aquatic biologists, because no management device can "substitute for the knowledge and expertise of an experienced, well informed stream ecologist when it comes to stewardship of our flowing waters" (Kwak 1993).

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Table 1. Species collected at 51 sites in Winona, Wabasha, and Olmsted counties, MN, during the summers of 1992-1993. Fish were sampled using a 150-m, single-pass electrofishing procedure.

Scientific name	Common name	Family name	Number of sites captured
Ameiurus melas	Black bullhead	Ictaluridae	1
Ameiurus natalis	Yellow bullhead	Ictaluridae	2
Campostoma anomalum	Central stoneroller	Cyprinidae	7
Catostomus commersoni	White sucker	Catostomidae	28
Cottus bairdl	Mottled sculpin	Cottidae	5
Cottus cognatus	Slimy sculpin	Cottidae	6
Culaea inconstans	Brook stickleback	Gasterosteidae	13
Etheostoma asprigene	Mud darter	Percidae	1
Etheostoma caeruleum	Rainbow darter	Percidae	2
Etheostoma flabellare	Fantail darter	Percidae	11
Etheostoma nigrum	Johnny darter	Percidae	20
Lampetra appendix	American brook lamprey	Petromyzontidae	3
Lepomis cyanellus	Green sunfish	Percidae	4
Lepomis macrochirus	Bluegill sunfish	Percidae	2
Luxilus cornutus	Common shiner	Cyprinidae	4
Notropis dorsalis	Bigmouth shiner	Cyprinidae	1
Noturus gyrinus	Tadpole madtom	Ictaluridae	1
Oncorhynchus mykiss	Rainbow trout	Salmonidae	1
Percina caprodes	Logperch	Percidae	1
Phoxinus erythrogaster	Southern redbelly dace	Cyprinidae	3
Pimephales notatus	Bluntnose minnow	Cyprinidae	6
Rhinichthys atratulus	Blacknose dace	Cyprinidae	32
Rhinichthys cataractae	Longnose dace	Cyprinidae	21
Salmo trutta	Brown trout	Salmonidae	37
Salvelinus fontinalis	Brook trout	Salmonidae	9
Semotilus atromaculatus	Creek chub	Cypdnidae	24
Umbra limi	Central mudminnow	Cyprinidae	6

Table 2. Metrics used by Karr (1986) to assess fish communities in the midwestern United States.

Category	Metric
Species richness and composition	
	1. Total number of fish species.
	2. Number and identity of darter species.
	3. Number and identity of sunfish species.
	4. Number and identity of sucker species.
	5. Proportion of individuals as intolerant.
	6. Proportion of individuals as green sunfish.
Trophic composition	
	7. Proportion of individuals as omnivores.
	8. Proportion of individuals as insectivorous cyprinids.
	9. Proportion of individuals as piscivores.
Fish abundance and condition	
	10. Number of individuals in a sample.
	11. Proportion of individuals as hybrids.
	12. Proportion of individuals with anomalies.

Table 3. IBI metrics used to assess stream fish communities in cold water, southeastern Minnesota streams.

Category	Metric	Scoring criteria 5	3	1
Species composition:				
	1. Proportion of individuals as trout and sculpin	see Figure 1		
	2. Proportion of individuals as tolerant.	<30%	30-60%	>60%
	3. Proportion of individuals as intolerant.	see Figure 3		
	4. Proportion of individuals as creek chubs and blacknose dace.	<20%	20-40%	>40%
Trophic composition:				
	5. Proportion of individuals as generalist feeders.	<20%	20-40%	>40%
	6. Proportion of individuals as insectivores.	>50%	25-50%	<25%
Fish abundance and condition:				
	7. Coldwater fish per 150 m.	see Figure 7		
	8. Proportion of individuals with anomalies.	<0.5%	0.5-1 %	<1

Table 4. Classification of fishes captured in southeastern Minnesota during summer 1992,1993.

1- Insectivore G - Generalist T - Tolerant R - Intolerant C - Coldwater fish
* not used in calculations due to exceptionally tolerant status.

Scientific name	Common name	Trophic guild	Tolerance	Cold water fish
Ameiurus melas	Black bullhead	I	T	
Ameiurus natalis	Yellow bullhead	I	T	
Campostoma anomalum	Central stoneroller			
Catostomus commersoni	White sucker	G	T	
Cottus bairdi	Mottled sculpin	I		C
Cottus cognatus	Slimy sculpin	I		C
Culaea inconstans	Brook stickleback	I		C
Etheostoma asprigene	Mud darter			
Etheostoma caeruleum	Rainbow darter	I		
Etheostoma flabellare	Fantail darter	I		
Etheostoma nigrum	Johnny darter	I		
Lampetra appendix	American brook lamprey		R	C
Lepomis cyanellus	Green sunfish	G	T	
Lepomis macrochirus	Bluegill sunfish	I		
Luxilus comutus	Common shiner	I		
Notropis dorsalis	Bigmouth shiner	I		
Noturus gydnus	Tadpole madtom			
Oncorhynchus mykiss	Rainbow trout			C
Percina caprodes	Logperch	I		
Phoxinus erythrogasfer	Southern redbelly dace			
Pimephales notatus	Bluntnose minnow	G		
Rhinichthys atratulus	Blacknose dace	G	T	C*
Rhinichthys cataractae	Longnose dace	I	T	C
Salmo trutta	Brown trout	R		C
Salvelinus fontinalis	Brook trout			C
Semotilus atromaculatus	Creek chub	G	T	C*
Umbra limi	Central mudminnow	I	T	

Table 5. Description of integrity classes. Modified from Karr et al. (1986)

Total IBI score	Integrity class	Attributes
39-40	Excellent	- Comparable to the best situations without human disturbance. The most intolerant forms are present; balanced trophic structure.
32-38	Good	- Partial or complete loss of most intolerant forms; trophic structure shows signs of stress; coldwater fish abundance less than optimal.
27-31	Fair	- Intolerant forms absent. Increasing proportions of warmwater species; highly skewed trophic structure
19-26	Poor	- Dominated by generalist feeders and tolerant forms; severe reduction in abundance of nontolerant coldwater fish; anomalies may by present
8-18	Very poor	- Few fish present, mostly generalist feeders tolerant forms; anomalies common

Table 6. IBI scoring of the 51 sites used in creation of the coldwater IBI. Sites were sampled using a 150-m, single pass electrofishing procedure during the summers of 1992 and 1993. Metric used in scoring are listed on Table 3. Location of the sites are shown on Figure 10. Sites with an asterisk are warmwater, and were only used as references.

Site	ml	m2	m3	m4	m5	m6	m7	m8	Total
1*	1	1	1	1	1	1	1	5	12
2	5	5	1	5	5	5	3	1	30
3*	1	5	1	5	3	5	1	5	26
4	5	5	1	5	5	1	1	5	28
5	5	5	1	5	5	1	3	5	30
6	5	5	1	5	5	5	5	5	36
7	1	1	1	1	1	1	1	5	12
8	5	5	1	5	5	1	1	5	28
9	1	1	1	1	1	3	1	5	14
10	5	5	1	5	5	1	5	5	32
11	5	5	1	5	5	1	1	5	28
12	5	5	1	5	5	5	3	5	34
13	5	5	3	5	5	5	3	5	36
14	5	5	1	5	5	5	5	5	36
15	1	3	1	3	1	1	1	5	16
16	3	5	5	5	5	5	5	5	38
17	1	1	1	1	1	1	1	3	20
18	1	1	1	5	1	1	1	5	16
19*	1	1	1	1	1	1	1	5	12
20	5	3	1	5	3	1	1	5	24
21	5	5	1	5	5	3	5	5	34
22	5	5	3	5	5	3	5	5	36
23	3	1	1	1	1	1	3	5	16
24	1	5	3	5	5	5	3	5	32
25*	1	1	1	5	3	5	1	5	22
26	1	3	5	3	3	1	5	3	28
27*	1	3	3	3	1	3	1	3	18
28	5	5	1	5	5	1	1	5	28
29	1	3	5	1	1	5	1	3	20
30	3	3	5	5	3	5	5	3	32
31	5	5	1	5	5	1	1	5	28
32	3	5	1	5	3	5	1	5	28
33	5	5	1	5	5	5	3	5	34
34	5	5	3	5	5	1	1	5	30
35	-	-	-	-	-	-	-	-	-
36*	1	1	1	1	1	5	1	5	16
37	1	1	1	1	1	1	1	5	12
38*	1	5	5	5	5	5	3	3	31
39	3	3	1	1	1	1	1	5	16
40	5	5	1	5	5	5	5	5	36
41	1	3	1	3	3	5	1	1	18
42	1	1	1	1	1	3	1	5	14
43*	1	3	1	1	1	3	1	5	16
44	1	1	1	1	1	1	1	5	12
45	3	5	1	5	5	5	5	5	34
46*	1	5	3	3	3	5	1	5	26
47*	1	1	1	3	3	3	1	3	16
48	1	3	1	3	1	3	1	5	19
49*	1	1	5	3	5	5	1	5	26
50	5	5	1	5	3	1	5	5	30
51	3	3	1	5	1	1	3	5	22

Table 7. IBI scores of independent sites studied by Quinn (1994). All sites were sampled during summer 1993. Metrics used in scoring the sites are listed on Table 3.

Site	m1	m2	m3	m4	m5	m6	m7	m8	IBI Score
Garvin Brook:									
Improved	5	5	1	5	5	5	5	3	34
Reference	5	5	1	5	5	5	5	3	34
Reference #2	5	5	1	5	3	3	5	3	32
Little Trout Creek:									
Improved	1	3	1	3	3	3	1	3	18
Reference	1	3	1	1	1	5	3	3	18
Big Trout Creek:									
Improved	3	1	1	5	1	1	1	3	16
Reference	5	3	1	5	1	1	1	3	20
Reference	3	3	1	5	1	1	1	3	18
West Indian Creek:									
Improved	5	5	1	5	5	5	5	3	34
Reference	5	5	1	5	5	5	5	3	34
Middle Branch of the Whitewater River:									
Improved	5	5	1	5	5	5	3	3	32
Reference	5	3	1	5	3	5	1	3	26
Improved #2	5	5	3	5	5	5	3	3	34
Reference #2	5	5	1	5	5	1	1	3	24

Table 8. IBI scores from independent sites obtained from Dr. Neal Mundahl. The South Branch of the Whitewater River sites were sampled from September 25 and October 2, 1990. Metrics used in scoring the sites are listed on Table 3.

Site	Date sampled	m1	m2	m3	m4	m5	m6	m7	m8	IBI score
Pleasant Valley Creek	10-4-93	5	5	1	5	5	1	1	3	26
Gilmore Creek										
Wildwood road:										
	6-13-91	5	5	1	5	5	1	3	3	28
	6-17-91	5	5	1	5	5	1	5	3	30
	10-8-91	5	5	1	5	5	1	1	3	28
	10-10-91	5	5	1	5	5	1	3	3	28
	10-13-92	5	5	1	5	5	1	3	3	28
	10-15-92	5	5	1	5	5	1	3	3	28
	10-5-93									
St. Mary's:										
	6-19-91	5	5	1	5	5	1	3	3	28
	6-15-91	5	5	1	5	5	1	3	3	28
	6-21-91	5	5	1	5	5	1	3	3	28
	10-8-91	3	5	1	5	5	3	1	3	26
	10-13-91	3	5	1	5	5	3	3	3	26
South Branch of the Whitewater River										
	Site 1.	1	3	5	3	3	3	5	3	26
	Site 2.	1	3	1	3	1	1	1	3	14
	Site 3.	1	1	3	3	1	1	1	3	14
	Site 4.	1	1	1	1	1	1	1	3	10

Table 9. Percent variability in the coldwater IBI explained by each individual metric.

Metric	Percent explained
Metric 1: proportion of individuals as trout and sculpin	49.4
Metric 2: proportion of individuals as tolerant	76.9
Metric 3: proportion of individuals as intolerant	4.70
Metric 4: proportion of individuals as creek chub and blacknose dace	62.2
Metric 5: proportion of individuals as generalists	76.3
Metric 6: proportion of individuals as insectivores	27.7
Metric 7: coldwater fish per 150 m	37.4
Metric 8: proportion of individuals with anomalies	1.30

Figure 1. Scoring of Metric 1: Proportion of individuals as trout and sculpin. The 40 sites used in creation of the metric were sampled using a 150-m, single-pass electrofishing procedure during the summers of 1992 and 1993.

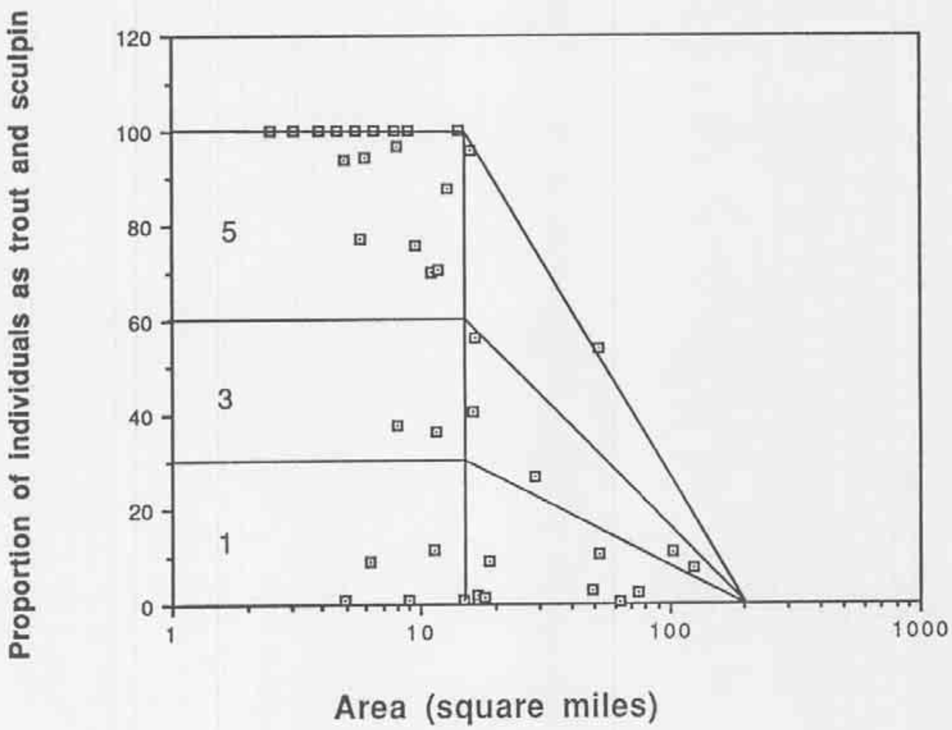


Figure 2. Scoring of Metric 2: Proportion of individuals as tolerant. The 40 sites used in creation of the metric were sampled using a 150-m, single-pass electrofishing procedure during the summers of 1992 and 1993.

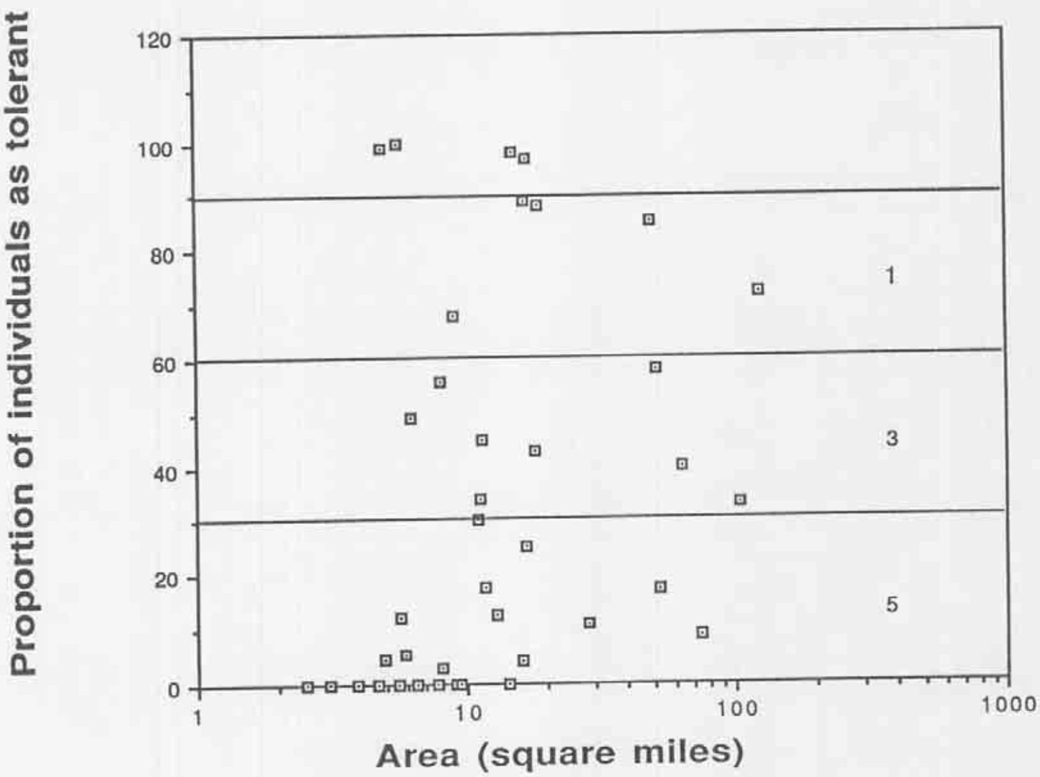


Figure 3. Scoring of Metric 3: Proportion of individuals as intolerant. The 40 sites used in creation of the metric were sampled using a 150-m, single-pass electrofishing procedure during the summers of 1992 and 1993.

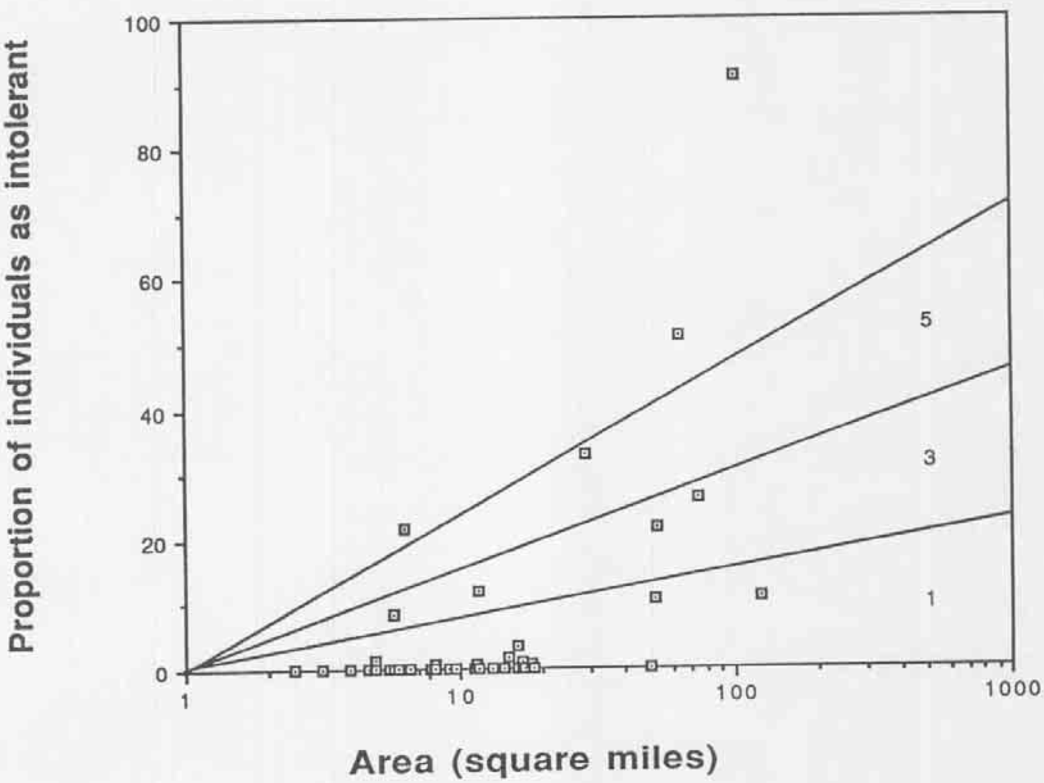


Figure 4. Scoring of Metric 4: Proportion of individuals as creek chub and blacknose dace. The 40 sites used in creation of the metric were sampled using a 150-m, single-pass electrofishing procedure during the summers of 1992 and 1993.

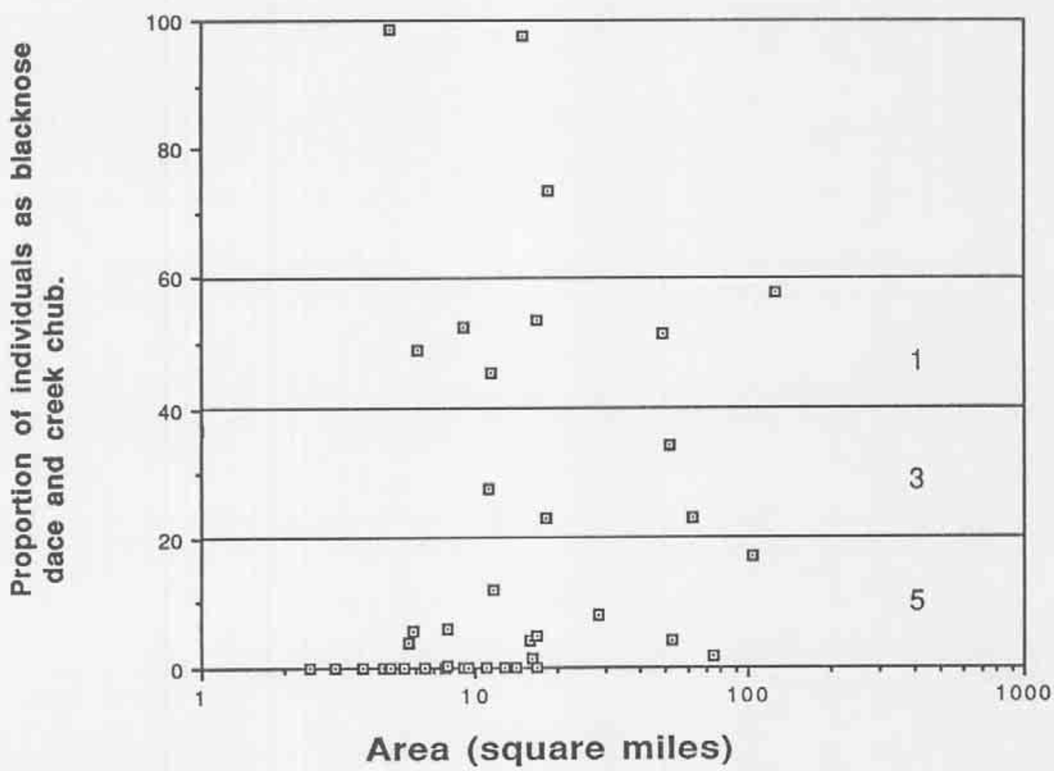


Figure 5. Scoring of Metric 5: Proportion of individuals as generalist feeders. The 40 sites used in creation of the metric were sampled using a 150-m, single-pass electrofishing procedure during the summers of 1992 and 1993.

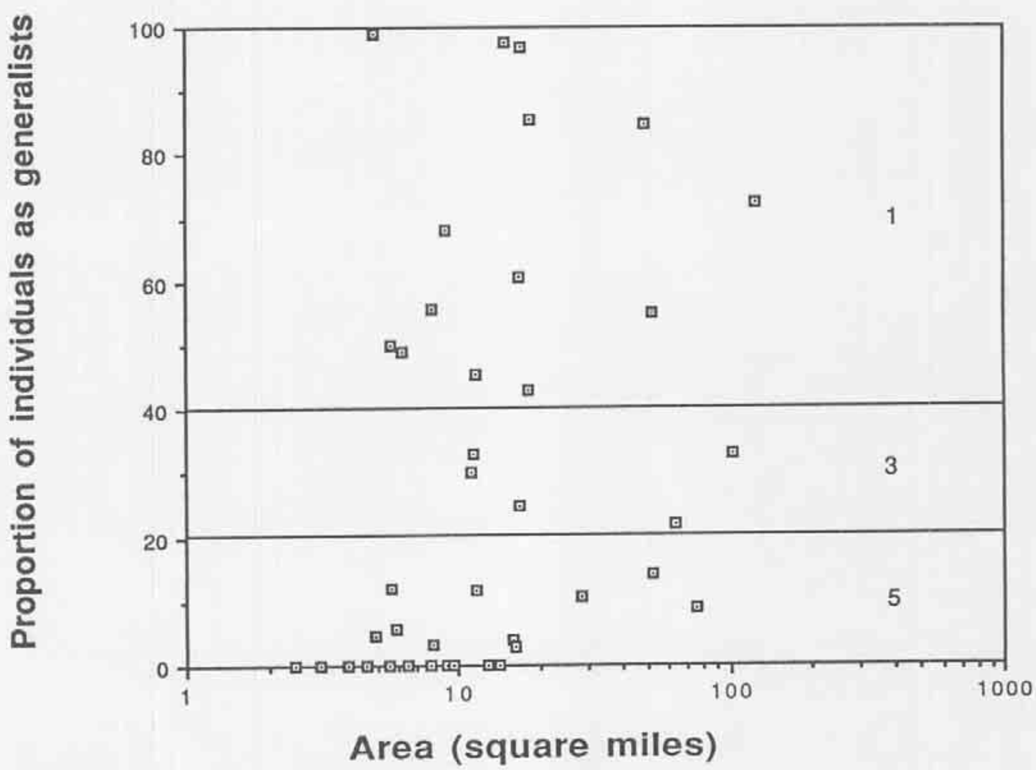


Figure 6. Scoring of Metric 6: Proportion of individuals as insectivores. The 40 sites used in creation of the metric were sampled using a 150-m, single-pass electrofishing procedure during the summers of 1992 and 1993.

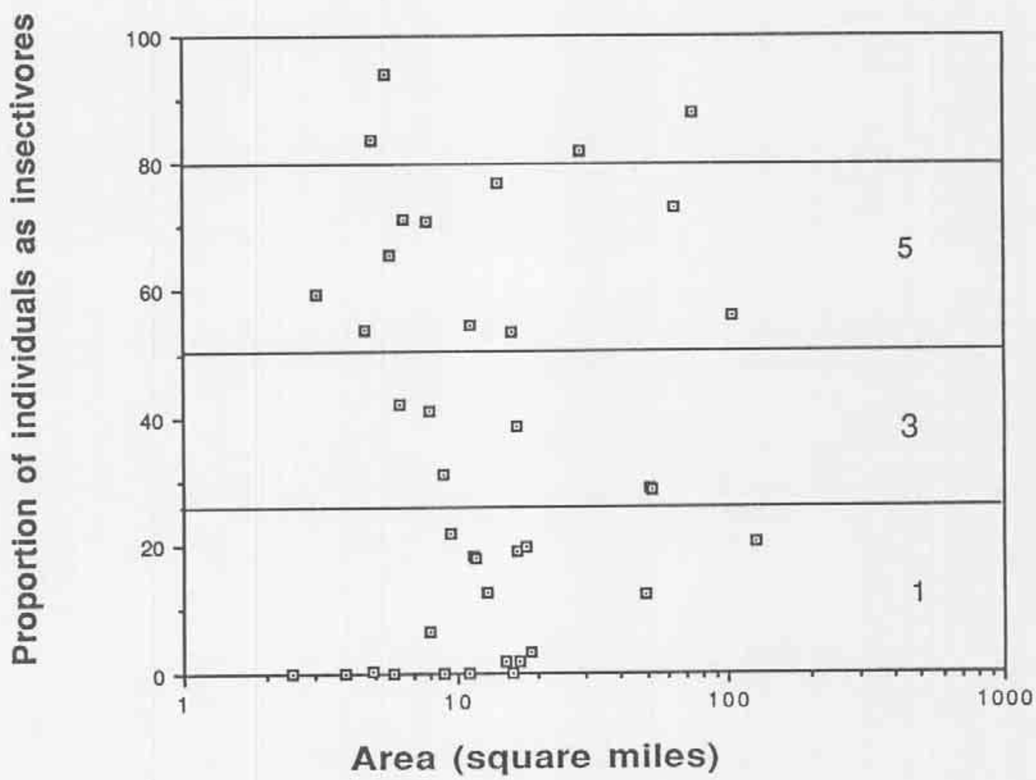


Figure 7. Scoring of Metric 7: Coldwater fish per 150 m. The 40 sites used in creation of the metric were sampled using a 150-m, single-pass electrofishing procedure during the summers of 1992 and 1993. Coldwater species are shown on Table 4.

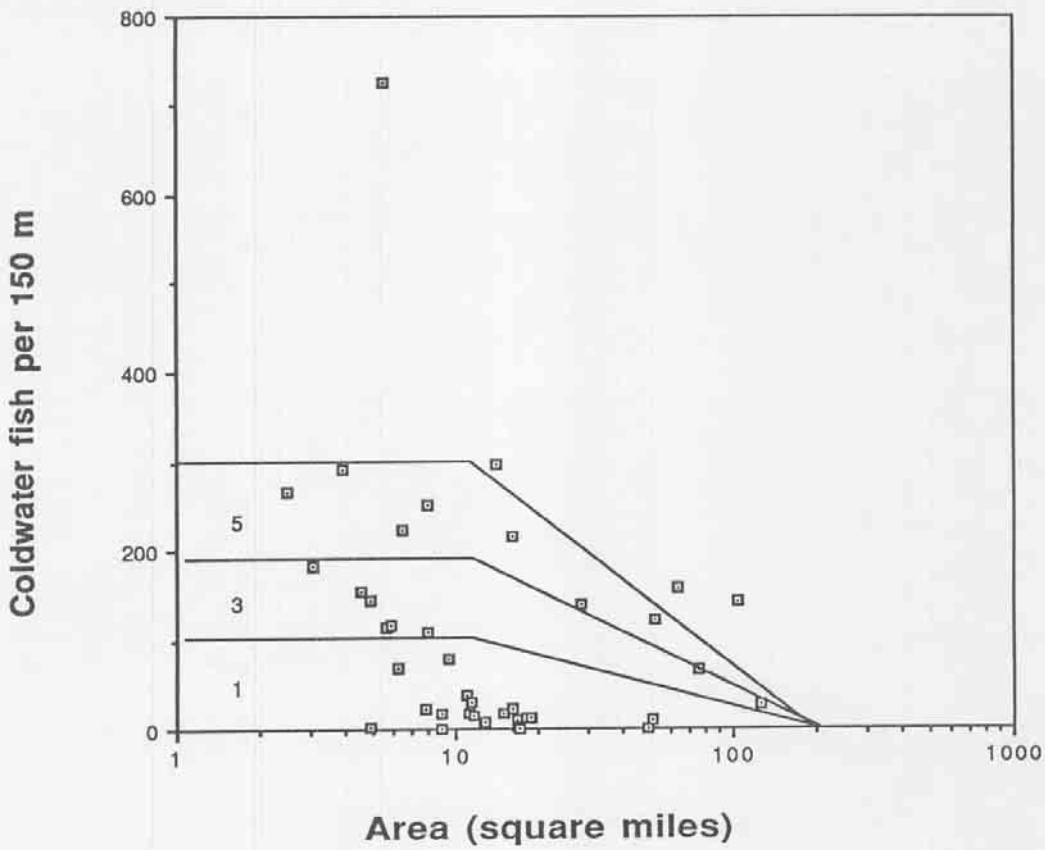


Figure 8. Scoring of Metric 8: Proportion of individuals with anomalies. The 40 sites used in creation of the metric were sampled using a 150-m, single-pass electrofishing procedure during the summers of 1992 and 1993.

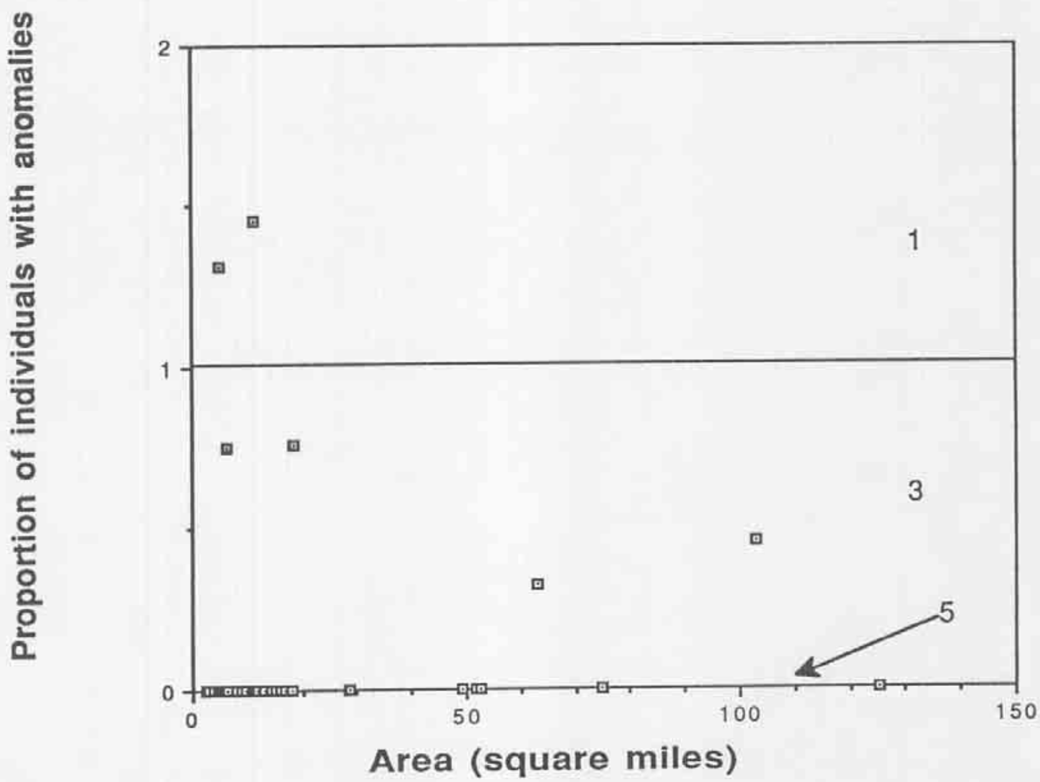


Figure 9. Distribution and assigment of integrity classes to IBI scores from sites used in creation of the index.

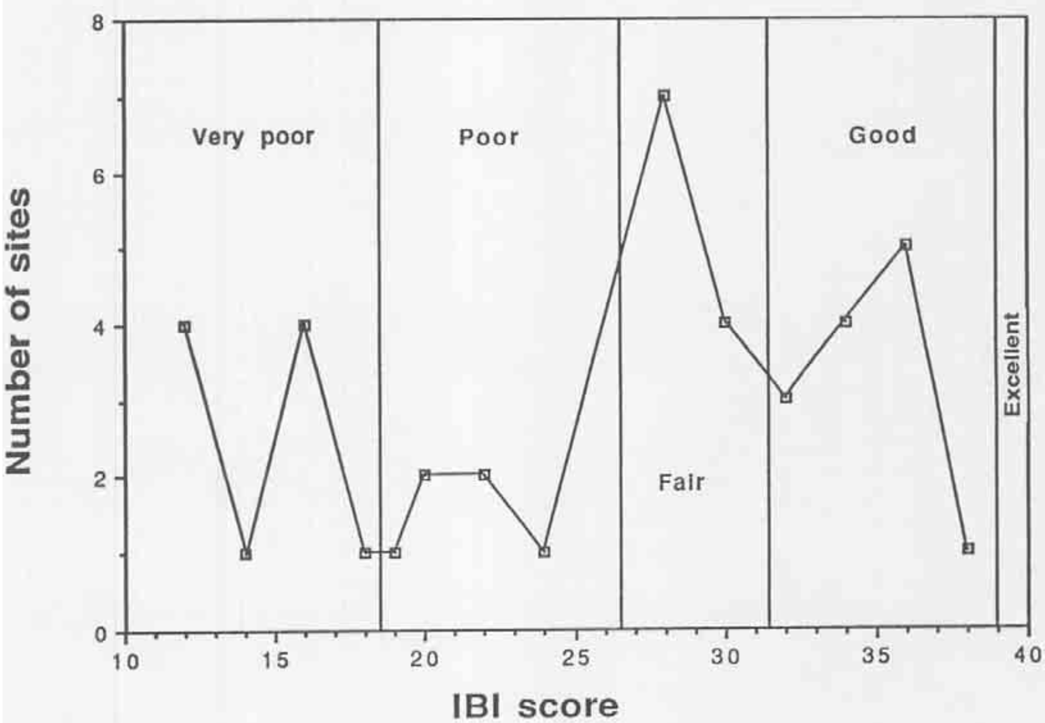


Figure 10. Map of the 50 sites sampled during the summers of 1992 and 1993. IBI score of each site is listed next to the site number. Scoring of each site is listed on Table 6. Map coordinates of each site are listed in the Appendix.

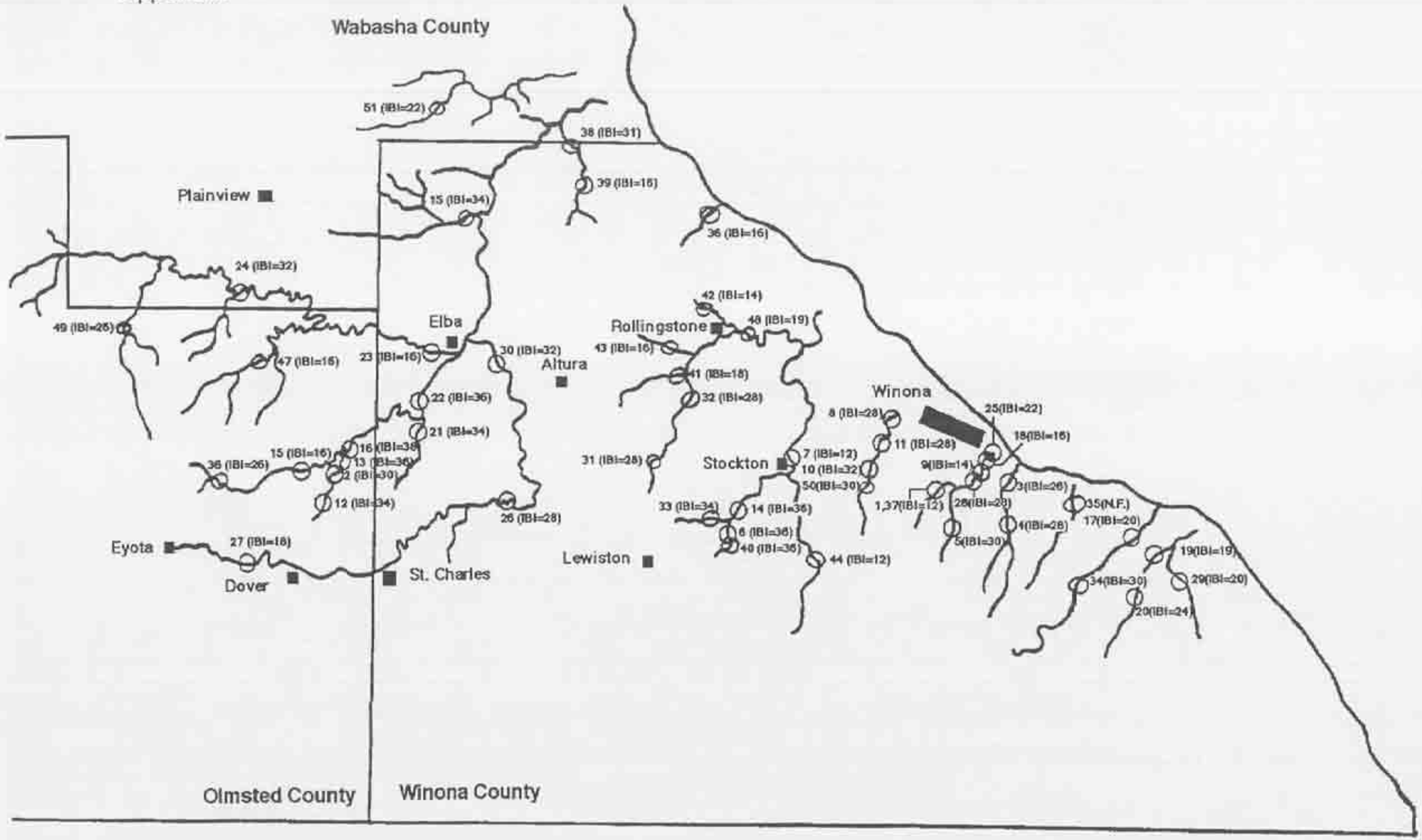


Figure 11. Plot of IBI scores from coldwater sites used to create the index vs. watershed area. Sites used are shown on Figure 10. Scoring of the sites is listed on Table 6. Metrics used in scoring are shown on Table 3.

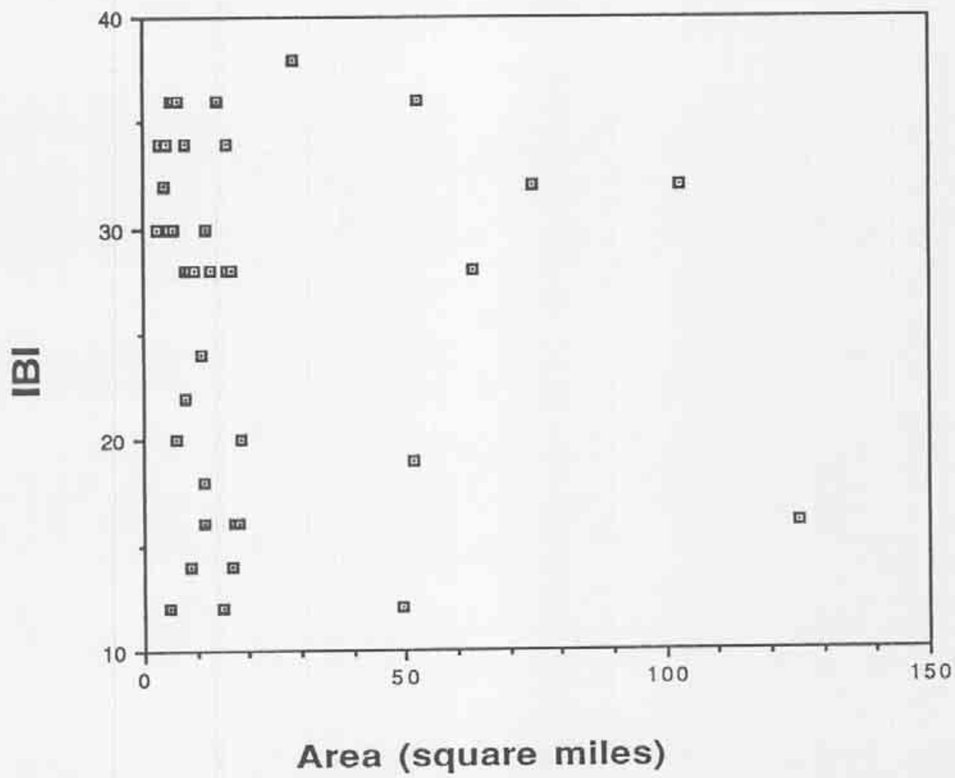


Figure 13. Correlation between metric 1 (proportion of individuals as trout and sculpin) and total IBI scores at each of the 40 coldwater sites. Metrics used in scoring are listed on Table 3.

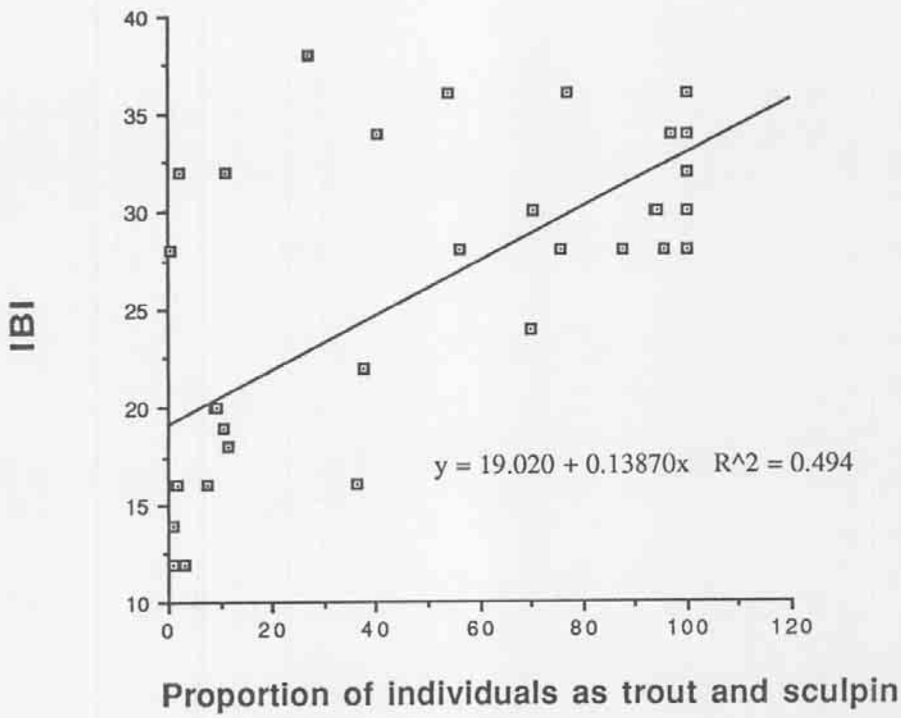


Figure 15. Correlation between metric 3 (proportion of individuals as intolerant) and total IBI scores at each of the 40 coldwater sites. Metrics used in scoring are listed on Table 3.

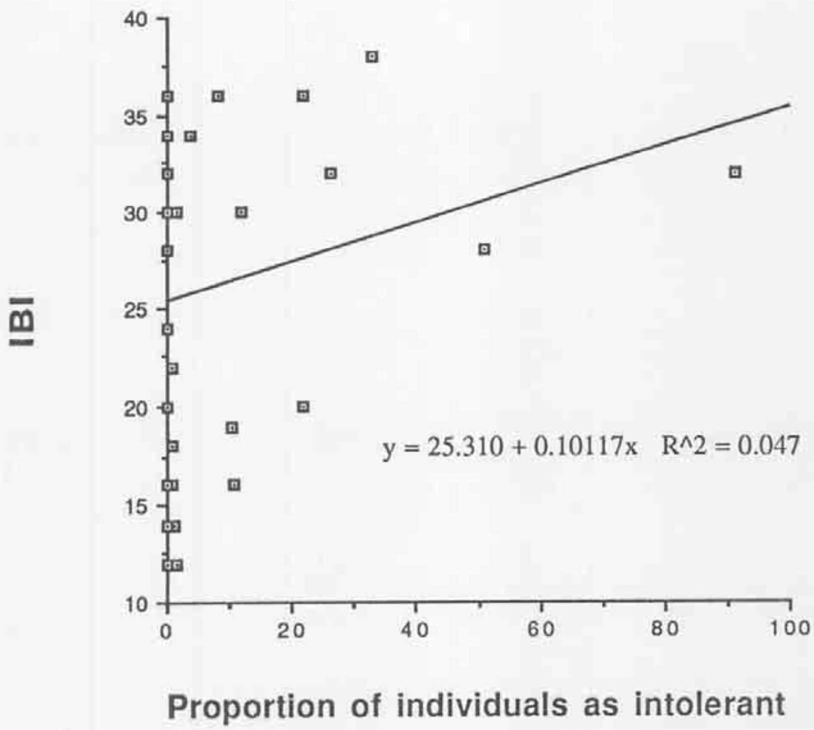


Figure 16. Correlation between metric 4 (proportion of individuals as creek chub and blacknose dace) and total IBI scores at each of the 40 coldwater sites. Metrics used in scoring are listed on Table 3.

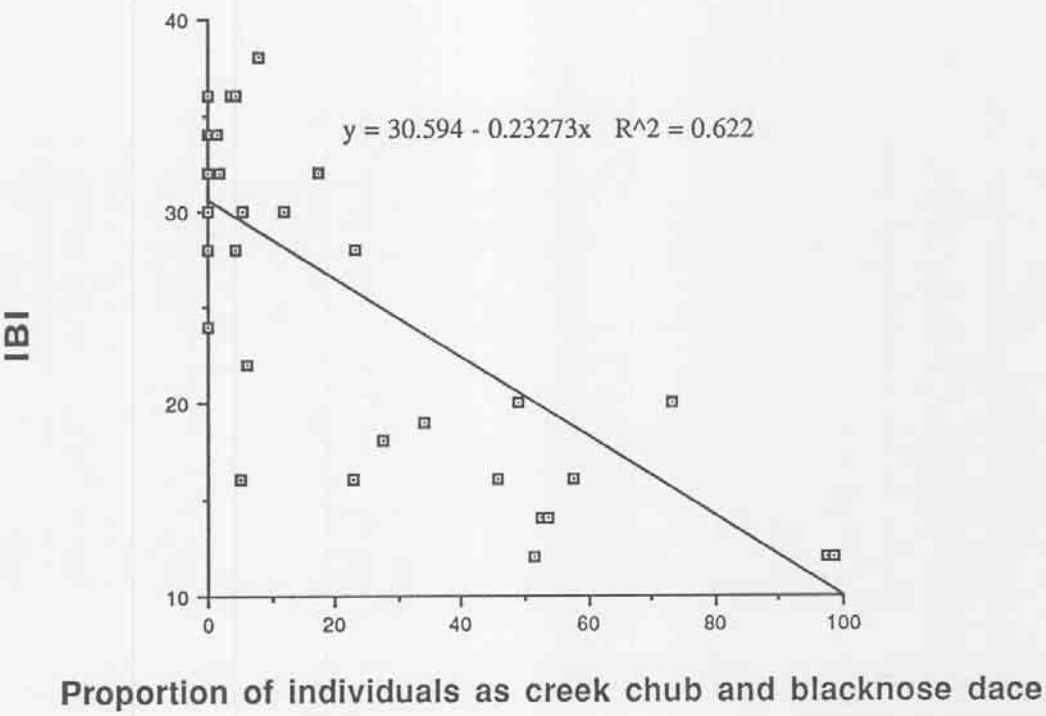


Figure 18. Correlation between metric 6 (proportion of individuals as insectivores) and total IBI scores at each of the 40 coldwater sites. Metrics used in scoring are listed on Table 3.

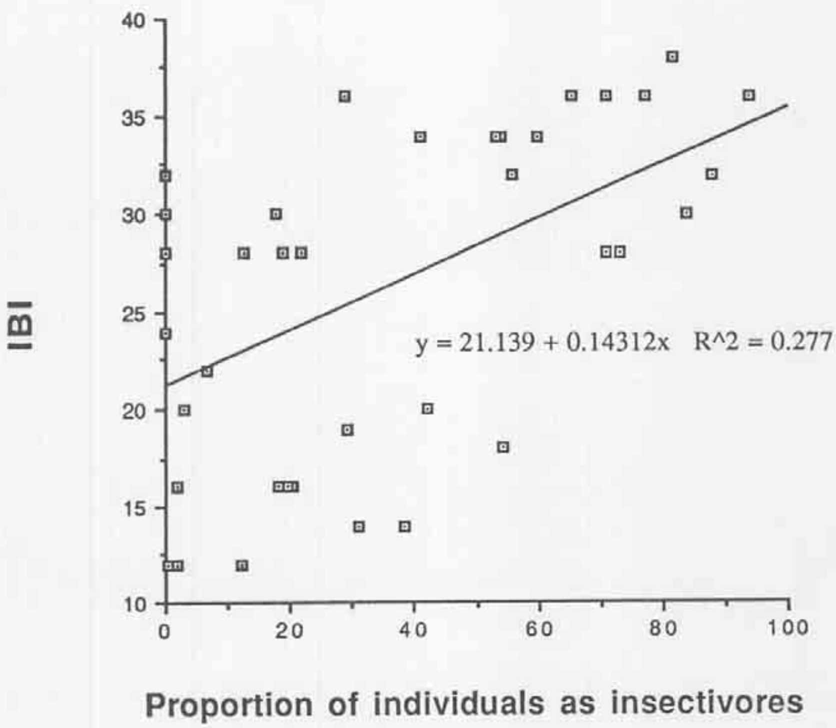


Figure 19. Correlation between metric 7 (coldwater fish per 150 m) and total IBI scores at each of the 40 coldwater sites. Metrics used in scoring are listed on Table 3.

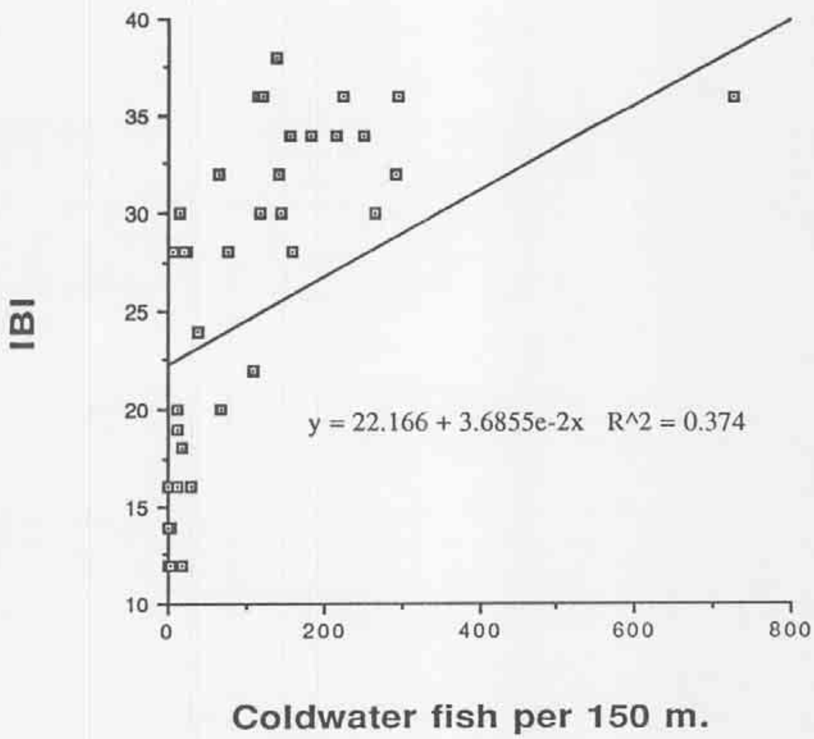
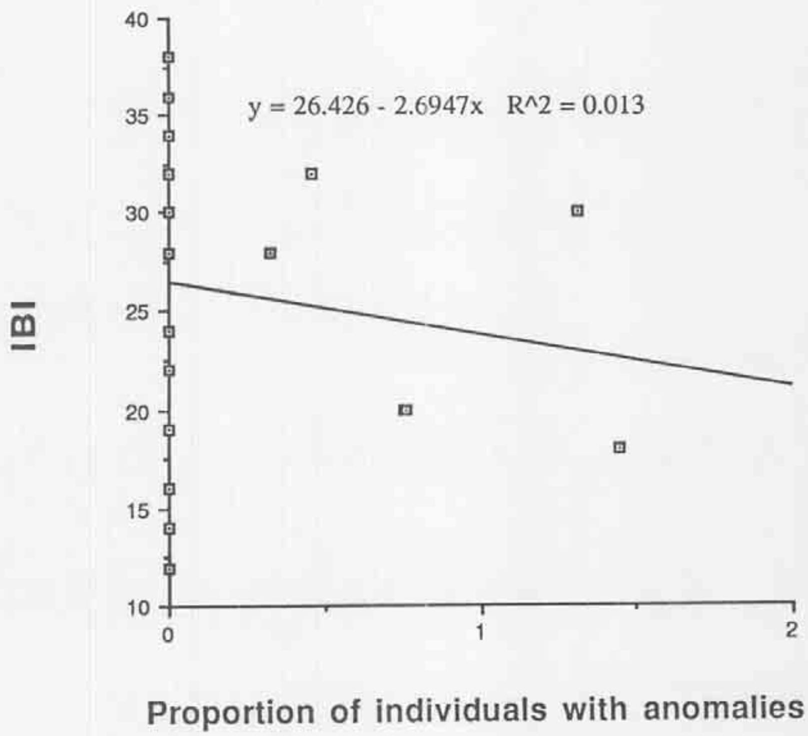


Figure 20. Correlation between metric 8 (proportion of individuals with anomalies) and total IBI scores at each of the 40 coldwater sites. Metrics used in scoring are listed on Table 3.



Appendix 1. Map coordinates of the sites used in creation of the coldwater, southeastern Minnesota IBI.

Site	Stream	Map Coordinates	Date sampled
1	West Burns Valley Creek	T1 06N RAW S3	6/25/92
2	Middle Branch of the Whitewater River	T1 07N R11 W S35	6/26/92
3	Pleasant Valley Creek	T106N R7W S1	7/1/92
4	Pleasant Valley Creek	TI 06N R7W S12	7/1/92
5	East Burns Valley Creek	T1 06N R7W S10	7/6/92
6	Garvin Brook	TI 06N R8W S8	7/7/92
7	Garvin Brook	TI 07N R8W S34	7/8/92
8	Gilmore Creek	T107N R7W S20	7/9/92
9	Main Burns Valley Creek	T107N R7W S36	7/10/92
10	Gilmore Creek	T107N R7W S31	7/15/92
11	Gilmore Creek	TI 07N R7W S29	7/16/92
12	Middle Branch of the Whitewater River	T106N R11 W S3	7/17/92
13	Middle Branch of the Whitewater River	T107N R11 W S35	7/17/92
14	Garvin Brook	T106N R8W S5	7/28/92
15	Warmwater Trib. of M.B.W.W. River	T107N R11W S32	7/29/92
16	Middle Branch of the Whitewater River	TI 07N R11 W S26	7/29/92
17	Cedar Creek	T1 06N R6W S11	7/30/92
18	Main Burns Valley Creek	T1 07N R7W S36	7/31/92
19	Big Trout Creek	T106N R6W S13	8/3/92
20	Big Trout Creek	T106N R6W S23	8/4/92
21	Trout Run Creek	Ti 07N R10W S29	8/5/92
22	Middle Branch of the Whitewater River	TI 07N R10W S20	8/5/92
23	North Branch of the Whitewater River	T107N R10W S8	8/10/92
24	North Branch of the Whitewater River	T1 08N R11 W S32	9/10/92
25	Main Burns Valley Creek	T107N R7W S36	8/11 /92
26	South Branch of the Whitewater River	T106N R10W S2	8/12/92
27	South Branch of the Whitewater River	T106N R11 W S20	8/12/92
28	Bums Valley Creek	T107N R7W S35	8/17/92
29	Little Trout Creek	TI 06N R5W S19	8/20/92
30	South Branch of the Whitewater River	T107N R10W S14	8/24/92
31	Rupprecht Creek	T1 07N R9W S35 NE 1/4	6/15/93
32	Rupprecht Creek	T1 07N R9W S24 NE 1/4	6/16/93
33	Peterson Creek	TI 06N R8W S7 NE 1/4	6/21/93
34	Cedar Creek	TI 06N R6W S28 NW 1/4	6/23/93
35	Homer Creek	T106N R6W S9 NW 1/4	6/24/93
36	Latsch State Park Creek	T108N R9W S12 NE 1/4	6/28/93
37	West Burns Valley Creek	T107 R5W S4 SE 1/4	6/28/93
38	Trout Creek	T108 R9W S5 NW 1/4	7/1/93
39	Trout Creek	T108 R9W S17 NW 1/4	7/1/93
40	Garvin Brook	T108 R5W S8 SW 1/4	7/6/93
41	Bear Creek	T108 R6W S13 NW 1/4	7/7/93
42	Speltz Creek	T108 R8W S31 SE 1/4	7/9/93
43	Straight Valley Creek	T108 R9W S11 NE 1/4	7/22/93
44	Stockton Creek	T106 R8W S14 NE 1/4	7/28/93
45	Beaver Creek	T108N R10W S15 SW 1/4	8/2/93
46	Warmwater Trib. MBWW River	T106 RI 2W S1 NE 1/4	8/5/93
47	Logan Creek	T107 RI 1W S8 SE 1/4	8/10/93
48	Rollingstone Creek	T107 R8W S4 SW 1/4	8/12/93
49	North Branch of the Whitewater River	T107 R1 2W S4 SW 1/4	8/13/93
50	Gilmore Creek	T107N R7W S31 SE 1/4	8/19/93
51	East Indian Creek	T109 R10W S29 SE 1/4	8/25/93