United States
Department of
Agriculture

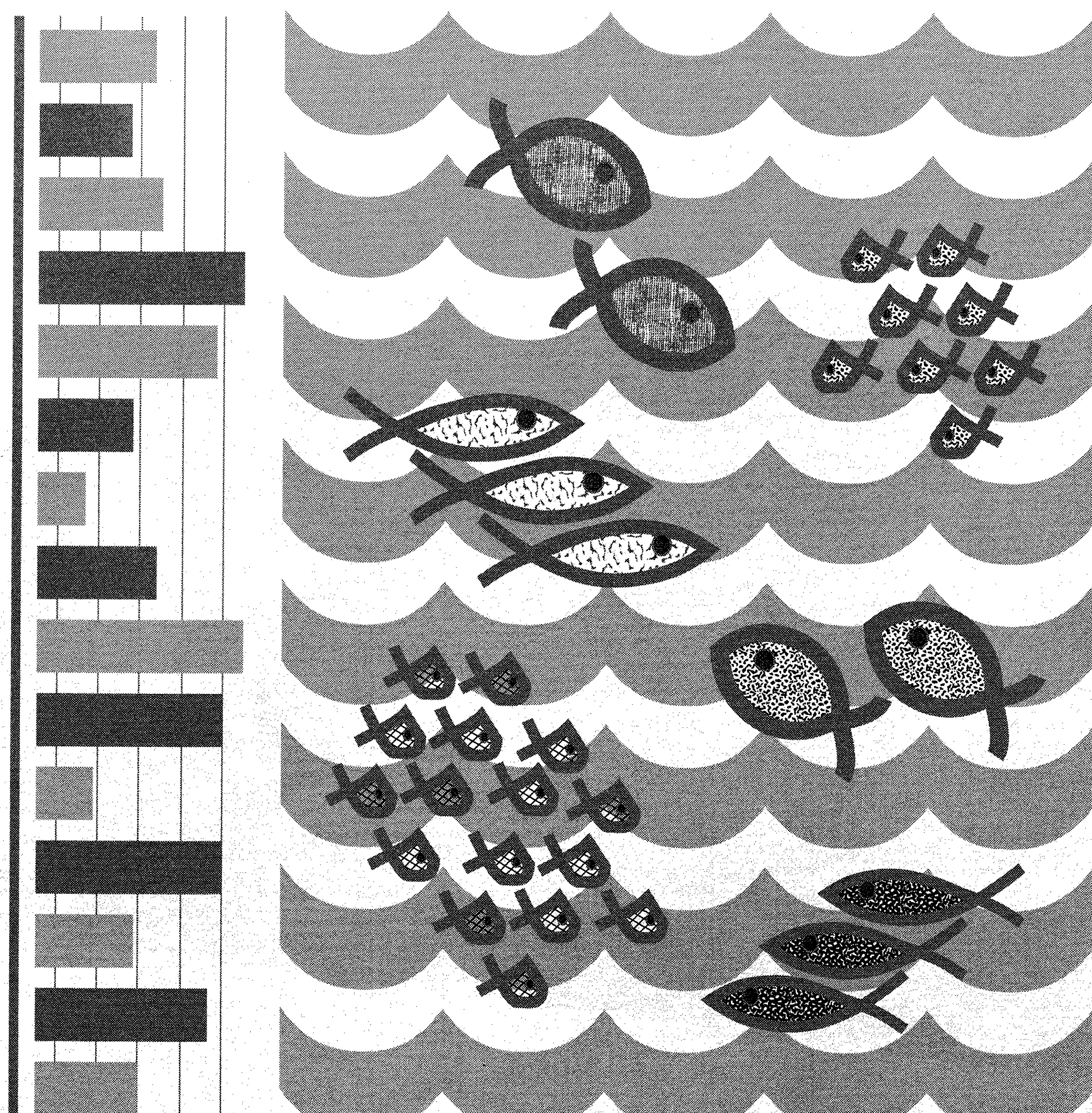
Forest
Service

North Central
Forest Experiment
Station

General Technical
Report NC-149

Using The Index Of Biotic Integrity (IBI) To Measure Environmental Quality In Warmwater Streams of Wisconsin

John Lyons



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North Central Forest Experiment Station
Forest Service - U.S. Department of Agriculture
1992 Folwell Avenue
St. Paul, Minnesota 55108
Manuscript approved for publication April 6, 1992
1992

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PART 1: GENERAL CONSIDERATIONS

Many varied and complex environmental problems affect the surface waters of North America. To better address some of these problems, a new approach to field monitoring and evaluation has recently emerged. This approach, generally termed "bioassessment" or "biomonitoring," uses data on biological populations or communities to assess and monitor environmental quality (Plafkin *et al.* 1989). Bioassessment and biomonitoring techniques have proven valuable in detecting and quantifying many types of environmental degradation in aquatic systems (Berkman and Rabeni 1987, Ohio EPA 1988, Fausch *et al.* 1990, Karr 1991).

Although many types of biota have been used in bioassessment and biomonitoring, benthic macroinvertebrates and fish have been found to be particularly effective (Berkman and Rabeni 1987, Plafkin *et al.* 1989). Wisconsin pioneered the development of bioassessment and biomonitoring techniques based on benthic macroinvertebrate community data during the 1970's and early 1980's (Hilsenhoff 1977, 1982). However, use of fish community data in bioassessment/biomonitoring of the State's waters lagged behind until recently. In 1984, the Wisconsin Department of Natural Resources (WDNR) began a pilot study to identify suitable bioassessment/biomonitoring techniques for Wisconsin based on fish. The pilot study concluded that an existing technique, the Index of Biotic Integrity, had excellent potential (Forbes and Lyons, WDNR, unpublished data). The Index of Biotic Integrity, commonly known as the IBI, is a bioassessment/biomonitoring technique that allows attributes of fish communities to be used to assess biotic integrity and environmental quality of streams and rivers (Karr 1981, Karr *et al.* 1986).

From 1987 through 1990, my colleagues and I from the WDNR collected and analyzed fish community data with the aim of developing a version of the IBI for use in warmwater streams of Wisconsin. This paper summarizes the results of this effort and presents a detailed description of how the IBI should be applied and interpreted in Wisconsin. Because of similarities in stream characteristics and fish fauna between Wisconsin and parts of adjacent States (Page and Burr 1986, Underhill 1986, Omernik and Gallant 1988), the Wisconsin version of the IBI described here should also be useful in southeastern and northeastern Minnesota, the entire Upper Peninsula and the northern Lower Peninsula of Michigan, extreme northwestern Illinois, and extreme northeastern Iowa. This paper is designed primarily as a "how to" manual, and as such contains little discussion of the underlying principles of the IBI. Readers interested in a more theoretical treatment of the IBI, including a comparison of the IBI with other

John Lyons is a Fisheries Research Biologist, Fish Research Section, Bureau of Research, Wisconsin Department of Natural Resources, 1350 Femrite Drive, Monona, Wisconsin 53716.

environmental indices that are based on fish communities, should refer to Berkman *et al.* (1986), Karr *et al.* (1986), Angermeier and Schlosser (1987), Hughes and Gammon (1987), Fausch *et al.* (1990), Karr (1991), and references therein. Appendix 1 describes in more technical detail the data and procedures used to develop and validate the Wisconsin version.

BACKGROUND

The IBI was originally developed by Dr. James Karr during the late 1970's and early 1980's to assess biotic integrity and environmental quality in small streams in Indiana and Illinois (Karr 1981, Karr *et al.* 1986). Karr and Dudley (1981) defined biotic integrity as "a balanced, integrated, adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of natural habitat of the region." Although the specific attributes and expectations of the original version of the IBI apply only to Indiana and Illinois, the general principles underlying the IBI concept apply to many streams throughout North America. Karr recognized this, and he and his colleagues at the University of Illinois developed procedures for adapting the IBI for use in different regions (Fausch *et al.* 1984, Karr *et al.* 1986). Biologists and managers in other States and Canadian provinces have since modified the IBI to fit the physical and biological characteristics of streams in their areas. They have generally found the IBI to be a useful assessment and evaluation tool (Miller *et al.* 1988, Fausch *et al.* 1990).

One of the most thorough modifications of the IBI has been done by the Division of Water Quality Monitoring and Assessment of the Ohio Environmental Protection Agency (Ohio EPA 1988). The Ohio EPA developed several versions of the IBI based on hundreds of fish community, habitat, and water quality samples from a wide variety of Ohio streams and rivers. The Ohio EPA uses the IBI extensively, and IBI scores have been incorporated into Ohio water quality standards. The Wisconsin version of the IBI that I present here is largely derived from the Ohio EPA "wading sites" version.

STRUCTURE OF THE IBI

The IBI consists of a series of fish community attributes, termed **metrics**, that reflect basic structural and functional characteristics of biotic assemblages: species richness and composition, trophic and reproductive function, and individual abundance and condition. The number and identity of metrics differ among different versions of the IBI, but all versions have metrics that measure both structural and functional characteristics of fish communities.

The Wisconsin version of the IBI described here consists of 10 basic metrics, plus 2 additional metrics (termed "correction factors" later in the text) that affect the index only when they have extreme values. These 12 metrics, described in detail in Part 2, are:

Species Richness and Composition
- Total number of native species
- Number of darter species
- Number of sucker species
- Number of sunfish species
- Number of intolerant species
- Percent (by number of individuals) that are tolerant species

Trophic and Reproductive Function
- Percent that are omnivores
- Percent that are insectivores
- Percent that are top carnivores
- Percent that are simple lithophilous spawners

Fish Abundance and Condition
- Number of individuals (excluding tolerant species) per 300 m sampled
- Percent with deformities, eroded fins, lesions, or tumors (DELT)

The last two metrics are not normally included in the calculation of the IBI, but they can lower the overall IBI score if they have extreme values (very low number of individuals or high percent DELT fish).

WHERE TO USE THE IBI

The Wisconsin IBI described in this paper is appropriate for use only in warmwater (*i.e.*, non-trout) streams. Many Wisconsin coldwater streams have too few species for a community-level index such as the IBI, although the IBI has been successfully adapted for trout streams in the western U.S. (Miller *et al.* 1988). More importantly, the response of many Wisconsin coldwater streams to changes in environmental quality violates one of the key assumptions underlying the Wisconsin IBI. The Index is predicated on the assumption that the number of species in a community declines with increasing environmental degradation. This assumption seems to be valid in warmwater streams in Wisconsin, but in coldwater streams, the number of species sometimes increases after limited or moderate degradation. Appendix 2 gives a more complete analysis of why the Wisconsin IBI is inappropriate for use in coldwater streams.

The Wisconsin IBI is appropriate only for permanent warmwater streams and rivers of intermediate size. Small headwater or intermittent streams and streams and rivers that are too deep or wide to be effectively sampled by wading require different versions of the IBI. The Ohio EPA (1988) has developed versions of the IBI for these two types of habitat, but these versions have not been evaluated in Wisconsin. Appendix 2 describes in more detail why different versions of the IBI are needed for headwater streams, "wadable" streams and rivers, and larger rivers.

Although the Wisconsin IBI is useful for assessing environmental quality and biotic integrity in intermediate-sized, warmwater streams, it is not meant to be a substitute for other proven environmental indices. Additional data on physical habitat, water quality, macroinvertebrates, and other biota are always desirable when evaluating a site. The Wisconsin IBI will be most useful when it complements rather than replaces other measures of environmental quality and biotic integrity.

USING AND INTERPRETING THE IBI

The IBI is calculated for a stream site by comparing the observed values of each metric with values expected in comparable streams of high environmental quality (Karr *et al.* 1986). If the observed values are close to the expected, then the stream in question probably has good environmental quality. If observed and expected values are far apart, then the stream is probably degraded. Thus, to calculate the IBI, it is necessary to know the characteristics of fish communities in streams of high environmental quality.

In Wisconsin, high quality warmwater streams have many native species, darters, suckers, sunfish, and intolerant species (species that are particularly sensitive to water pollution and habitat degradation) (Lyons *et al.* 1988, Lyons 1989). Tolerant species (species capable of persisting under a wide range of degraded conditions) are present, but do not dominate. Most fish are insectivores (species that feed primarily on insects or other small macroinvertebrates), and top carnivores (species that feed primarily on other vertebrates or large macroinvertebrates such as crayfish) are common. Omnivores (species that have at least 25 percent of their diet as plants and at least 25 percent as animal matter) are also common but do not dominate. Simple lithophilous spawners (species that lay their eggs on clean gravel or cobble without building a nest or providing parental care; Balon 1975) are common. Fish abundance is moderate to high (catch per 300 m (excluding tolerant species) greater than 150), and few or no individuals have deformities, eroded fins, lesions, or tumors (DELT).

As environmental degradation increases, the number of species declines; intolerant species decline the fastest and sunfish or suckers the slowest (Karr *et al.* 1986, Ohio EPA 1988). Tolerant species and omnivores become more common, and top carnivores, insectivores, and simple lithophilous spawners decrease, with top carnivores tending to decline the fastest. Fish abundance does not decline and proportion of DELT fish does not increase substantially until degradation is severe. In severely degraded streams, few species and individuals (or no fish at all) are present, and those present tend to be tolerant omnivores in poor physical condition.

ACCOUNTING FOR NATURAL DIFFERENCES AMONG STREAM FISH COMMUNITIES

Although it is fairly easy to qualitatively describe the characteristics of warmwater stream fish communities at different levels of environmental degradation, quantitative descriptions are much more difficult to generate. Much of the research required to modify the IBI for use in Wisconsin has focused on determining precisely how fish community structure and function are related to degradation. This research has been complicated by the fact that several environmental factors unrelated to degradation also influence community structure and function. These "natural" factors need to be taken into account in the development of quantitative expectations for IBI metrics.

Two important natural factors that influence community structure and function in Wisconsin warmwater streams are stream location and size (Lyons *et al.* 1988, Lyons 1989). These factors primarily influence the species richness metrics. Generally, species richness tends to be lower the farther north in Wisconsin a stream is located. For some taxa, especially sunfish, the proximity of a stream to a lake or large river also influences species richness. Sunfish are common inhabitants of lakes and large rivers, and may frequent streams that they normally would not occupy had those streams not been near a lake or large river. Thus, different numbers of sunfish species would be expected in streams located in different parts of the State and at different distances from lakes and large rivers.

My research suggests that Wisconsin should be divided into three geographic areas for scoring the species richness metrics: central/southern Wisconsin, northern Wisconsin, and the Lake Superior Basin (fig. 1). The boundary between the northern Wisconsin and central/southern Wisconsin areas approximates the boundary between the Northern Lakes and Forests Ecoregion and the North Central Hardwood Forest Ecoregion of the U.S. Environmental Protection Agency (Lyons 1989). Within the central/southern Wisconsin area, streams less than 8 km and streams more than 8 km (via a stream channel) from a lake or large river should be treated separately for the number of sunfish species metric.

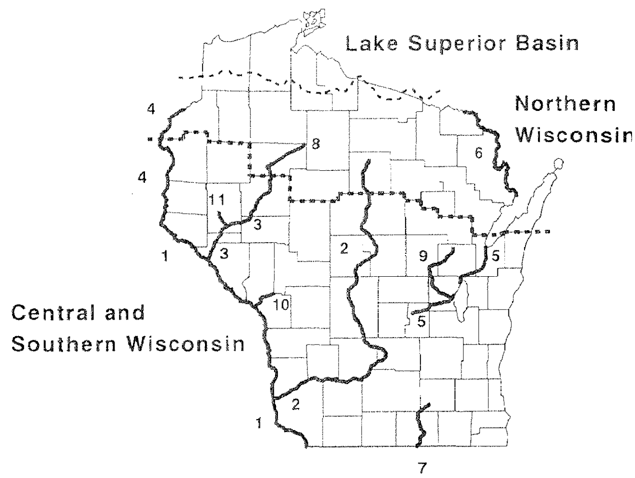

Figure 1.—*Map of Wisconsin, showing the boundaries of the three geographic areas used in determining scores for the species richness metrics. Large rivers (>40 m³ per second mean annual flow) are portrayed and identified by number. These, in order of size, are:*

1. *Mississippi River*
2. *Wisconsin River below Tomahawk (Lincoln Co.)*
3. *Chippewa River below mouth of Flambeau River (Rusk Co.)*
4. *St. Croix River below mouth of Clam River (Burnett Co.)*
5. *Fox River below mouth of Puchyan River (Green Lake Co.)*
6. *Menominee River below Highway 2/141 Crossing (Florence Co.)*
7. *Rock River below Lake Koshkonong (Rock Co.)*
8. *Flambeau River below confluence of North and South Forks of the Flambeau River (Sawyer Co.)*
9. *Wolf River below village of Shiocton (Outagamie Co.)*
10. *Black River along LaCrosse-Trempealeau County border*
11. *Red Cedar River below the city of Menomonie (Dunn Co.)*

The Lake Superior Basin-Northern Wisconsin boundary (- - -) is biologically precise; the northern Wisconsin-central/southern Wisconsin boundary (- - -) is not.

The boundary between the Lake Superior Basin and northern Wisconsin areas is biologically precise, delineating the northern range boundary for several fish species in Wisconsin. Streams in the Lake Superior Basin tend to have fish communities with fewer species than those of northern Wisconsin streams.

However, the boundary between the northern Wisconsin and central/southern Wisconsin areas is biologically imprecise. Generally, northern Wisconsin fish communities are more depauperate in species than central/southern Wisconsin fish communities, but the transition between these two areas is not as sharp as indicated on figure 1. In fact, the boundary is fairly diffuse; streams north of the border may have attributes of central/southern Wisconsin fish communities, and streams south of the border may have attributes of northern Wisconsin fish communities.

In Wisconsin, species richness tends to increase with increasing stream size. The rate at which species richness increases differs depending on the taxa considered. To account for this increase, Maximum Species Richness (MSR) plots have been developed (see Appendix 3) for each species richness metric. MSR plots predict the maximum number of species that undegraded streams of different sizes should have (Karr *et al.* 1986). The actual number of species in a stream is compared with the prediction from the MSR plot as part of the IBI calculation (see Part 2). Different MSR plots are used for the Lake Superior Basin, northern Wisconsin, and central/southern Wisconsin.

Metrics related to species composition, trophic and reproductive function, and fish abundance and condition are not strongly influenced by stream location and size; for these metrics, the same expectations are used for all areas of the State and all sizes of streams (see Part 2).

PART 2: APPLYING THE IBI IN WISCONSIN WARMWATER STREAMS

Application of the Wisconsin IBI is a sequential process, involving a series of discrete steps. These steps are summarized in table 1 and discussed in detail below.

COLLECTING AND PROCESSING THE FIELD DATA

Selecting and Delineating Sites for Data Collection

An appropriate choice of sampling sites is critical for the successful application of the IBI. The Wisconsin IBI presented here should be used only on Wisconsin warmwater streams of intermediate size. More specifically, the Wisconsin IBI should be applied only to reaches of permanent streams that are not designated as trout water and that are between 2.5 and 50 m wide with few areas deeper than 1.25 m. It must be possible to effectively sample these stream reaches by wading. The general concept of the IBI is valid for stream reaches that do not meet these criteria, but the Wisconsin IBI presented here has not been tested on them and may not be appropriate. Note that some sites with relatively cool water but degraded environmental conditions have the potential to become trout water if environmental conditions are improved. The Wisconsin IBI should probably not be applied to these sites (see Appendix 2).

Sites chosen for sampling should be representative of the overall habitat of the stream reach. Sampling areas should not normally include bridges, dams, mouths of tributaries, or other atypical habitat features, unless the goal of the sampling is to characterize the influence of these atypical features on local environmental quality. Fish assemblages in the vicinity of atypical habitat features are often not representative of the overall fish community of a stream reach.

Table 1.—*An outline of the steps involved in applying the Wisconsin IBI*

I. COLLECTING AND PROCESSING THE FIELD DATA

A. *Selecting and Delineating Sites for Data Collection*
Choose sites on warmwater streams that are 2.5 to 50 m wide and shallow enough to be effectively sampled by wading. Choose sites representative of the stream reach that is to be characterized. Delineate sites with a length of approximately 35 times the average width of the stream.

B. *Determining When to Sample*
Sample sites between mid-June and mid-September in central and southern Wisconsin, and during July or August in northern Wisconsin. Sample during daylight hours when streams are at baseflow.

C. *Determining Stream Size*
Use mean stream width within each site as the measure of stream size. Calculate mean stream widths from at least 10 field measurements per site. Make measurements at baseflow.

D. *Sampling the Fish Community*
Sample each site thoroughly in an upstream direction with a towed electroshocker. Carefully sample all major habitats within each site, and attempt to capture all fish observed that are greater than 25 mm total length.

E. *Processing the Fish Sample*
Accurately identify all fish to species and count the number of each species captured for each site. Also count the number of fish with obvious external deformities, eroded fins, lesions, and tumors (DELT).

II. ANALYZING THE DATA

A. *Determining Stream Location*
Locate each site with the three IBI regions of Wisconsin (Lake Superior Basin, northern Wisconsin, and central/southern Wisconsin), and measure the distance (via stream channels) from each site to the nearest lake (greater than 4 ha) or large river (see fig. 1).

B. *Classifying Fish Species*
For each site, classify each fish species that was caught into the appropriate IBI metric groupings using tables 2, 3, and 13.

C. *Dealing With Very Low Catch Rates*
Determine if sufficient fish have been captured to calculate the IBI. If fewer than 50 fish (including tolerant species) have been captured from a site, do not calculate an overall IBI score; rate the biotic integrity/environmental quality of that site as very poor.

D. *Using MSR Plots for Scoring*
Determine the number of species captured at each site for each of the five species richness metrics (native species, darters, suckers, sunfish, and intolerants). Use the appropriate MSR plots and guidelines for scoring each metric. For sites in the Lake Superior Basin, use table 4. For sites in northern Wisconsin, use figures 2-6. For sites in central/southern Wisconsin, use figures 7-12.

(table 1 continued on next page)

(table 1 continued)

E. *Scoring Metrics Based on Percentages*
Calculate the remaining five metrics (tolerant species, omnivores, insectivores, top carnivores, simple lithophils) as percentages (to the nearest 1 percent) of the total number of fish caught at each site. Use the guidelines in table 5 to score these metrics.

F. *Scoring Correction Factors*
For each site, calculate the number of individuals per 300 m correction factor as the total number of fish caught, excluding tolerant species, per 300 m of stream sampled, and the percent DELT fish correction factor as the total number of DELT fish captured divided by the total number of all fish (including tolerant species) captured. Score these two correction factors using guidelines in table 5.

G. *Calculating the Overall IBI Score*
Determine the overall IBI score at each site by summing the scores for the 10 metrics and the 2 correction factors. If the overall score is less than zero, round the score up to zero.

III. INTERPRETING IBI SCORES

A. *Interpreting the Overall IBI Score*
Use the guidelines in table 6 to interpret the overall IBI score for each site. If the overall score is close to 100, then infer that the biotic integrity/environmental quality of the site is high. If the score is near 0, then infer that biotic integrity/environmental quality is low. If the score is intermediate, then infer that biotic integrity/environmental quality is intermediate.

B. *Identifying Specific Environmental Problems*
Use scores for individual metrics to suggest specific environmental problems at sites where biotic integrity/ environmental quality is intermediate or low.

C. *Accounting for Differences Among Samples in IBI Scores*
In comparisons of overall IBI scores from different sites or from the same site over time, assume that differences in scores of 10 points or less are not significant and probably represent the combined effects of sampling error and natural variation in biotic integrity. Assume that differences of 25 points or more represent clear differences in biotic integrity/environmental quality. Collect further data to indicate whether differences of 10 to 25 points are significant.

D. *Incorporating Other Types of Information*
Do not rely solely on IBI scores when assessing the biotic integrity/environmental quality of sites. Whenever possible, also incorporate data on the other biota and the physical and chemical attributes of each site.

The total length of the site is very important, and it will vary depending on the size and nature of the stream. If the site is too short, certain uncommon or difficult-to-catch species are likely to be missed. If the site is too long, the amount of effort necessary to complete the sampling becomes prohibitive. Ideally, the site should be long enough to encompass several examples of all the major macrohabitat types within the reach (*i.e.*, pools, runs, riffles, bends, backwaters, side channels, islands, log jams). A minimum distance of 35 times the mean channel width at normal flow should be sampled to obtain an accurate picture of the fish community (Lyons 1992). In other words, if the stream reach averages 5 m wide at normal flow, then at least 175 m of stream should be sampled. If the reach has well-developed, regularly spaced pools, riffles, and runs, then an alternative sampling distance is three complete adjacent pool-riffle-run sequences. Whichever criterion is used, the sampling distance should be accurately measured and recorded.

For small (*i.e.*, narrow) streams, the above sampling distance guidelines can be easily met in less than 3 hours of sampling, and should always be followed. However, the amount of time required to meet these guidelines for some larger streams may be prohibitive (*i.e.*, more than 5 hours), especially if fish density is high. In such cases, site length can be shortened, but under no circumstances should site length for larger streams be less than 150 m nor should sampling time be less than 1 hour.

At sites that are wider than 16 m, it is usually impossible to simultaneously sample the entire width of the channel. At such sites, sampling should proceed in a zigzag pattern, moving from one bank to the other. All areas of hiding cover should be sampled thoroughly, as well as representative examples of all the major macrohabitats present, but the entire surface area of the site need not be sampled.

Determining When to Sample

Sampling should take place between mid-June and mid-September in central/southern Wisconsin, and during July or August in northern Wisconsin and the Lake Superior Basin (fig. 1). Sampling during summer maximizes sampling ease and minimizes disturbance of spring spawning gamefish. Additionally, summer sampling avoids the potential inclusion of transient species that may occur during spring or fall sampling. Many species of fish, including minnows (family Cyprinidae), suckers (family Catostomidae), smallmouth bass (*Micropterus dolomieu*), sauger (*Stizostedion canadense*), and walleye (*Stizostedion vitreum*), undertake large-scale movement or migration during spring and fall (Hall 1972, Curry and Spacie 1979, Schlosser and Ebel 1989, Langhurst and Schoenike 1990), but appear to stay within a limited home range during the summer (Larimore 1952, Gerking 1953, Funk 1955). Angermeier and Karr (1986), Angermeier and Schlosser (1987), and Karr *et al.* (1987) analyzed several years of data from Illinois streams and concluded that early summer to midsummer was the best time to sample for calculation of the IBI.

Sampling should always occur during the daytime. Although night sampling may be more effective for some nocturnal species such as bullheads and catfish (family Ictaluridae) and for top carnivores such as smallmouth bass (Paragamian 1989), expectations for all the metrics in the Wisconsin IBI have been developed from daytime data, so use of nighttime data may bias results. Additionally, electroshocking by wading is far easier and safer during the day than at night.

Sampling should take place when the stream is at baseflow (stable flow in the absence of runoff from precipitation). Electroshocking at higher flows is more difficult and less effective because of greater water volume, stronger currents, and decreased water clarity. Sampling should also be avoided for at least 2 weeks after a major flood, even if water levels quickly return to normal. Many fish probably vacate their usual habitat during floods, and it may take them several days to return to this habitat after the flood has ended.

Determining Stream Size

In the Wisconsin version of the IBI, mean stream width at normal flow is used as the measure of stream size for calculation of species richness metrics. This differs from other versions of the IBI in which stream order (Karr 1981, Karr *et al.* 1986) or drainage basin area (Ohio EPA 1988) is used. I have chosen to use mean width in the Wisconsin version for four reasons: (1) stream width is a measure of stream size more familiar to WDNR managers and biologists than either stream order or basin area; (2) stream width is a more accurate and precise measure of stream size than stream order in Wisconsin; (3) stream width was available in the Fish Distribution Survey data base, whereas stream order and basin area were not; (4) stream width is a more consistent measure of stream size between glaciated and unglaciated regions of Wisconsin than either stream order or basin area. In examining streams from regions with different glacial histories, the best measure of stream size is probably mean annual discharge (Hughes and Omernik 1981, 1983). However, discharge data are available for only a small fraction of Wisconsin streams. When I compared streams of similar discharge between the unglaciated Driftless Area of Wisconsin and the glaciated portions of the State, mean width differed less than either stream order or basin area. Revak (1989) found that Driftless Area streams had higher stream orders but smaller basin areas than similarly sized streams from glaciated areas of Wisconsin.

For use in the IBI, mean stream width should be calculated from at least 10 widely spaced field measurements at the site. These measurements should be made with a tape measure, and must have a minimum precision of $\pm$ 0.3 m. Measurements must encompass the range of widths present at a site, as well as the major main channel macrohabitats that are present (*i.e.*, pools, riffles, runs). Side channels should be part of width meaurements, but islands and sand or gravel bars should not, unless they have been exposed by drought and would be underwater at normal flow (see below). Backwaters, sloughs, and adjacent wetlands should also not be included in width measurements. Width measurements should be made at baseflow. If flow is reduced below normal baseflow because of drought, then width measurements should be based on an estimate of width at normal flow rather than the actual current channel width. Usually, the edges of the normal baseflow channel can be easily determined from an examination of channel shape and the distribution of terrestrial vegetation along the banks.

Sampling the Fish Community

Fish sampling should be done with a single WDNR-type "stream" electroshocker (generator towed in a small boat, with two or three operators who wade with hand-held electrodes). In streams less than 4 m wide that are very shallow or have numerous obstacles to boat movement (*e.g.*, large rocks or woody debris, thick overhanging vegetation), a backpack electroshocker can be used. Usually, a DC or pulsed-DC output electroshocker is preferred because it is safer, more effective in turbid or deep water, and less harmful to fish, but in low conductivity water (less than 75 umhos/cm) it may be necessary to use an AC unit. Shocking should be done in an upstream direction for safety reasons. All habitats within the site should be carefully and thoroughly shocked, and attempts should be made to capture **all** fish observed greater than 25 mm in total length. Fish smaller than this are not effectively sampled by electrofishing and should not be used in calculation of the IBI. It is particularly important to expend the same effort to capture nongame species as to capture gamefish species. The goal is to obtain a representative sample of the total fish community.

Processing the Fish Sample

Proper identification of all fish species is **essential** to accurately determine the IBI. Identification of many nongame fish species and juvenile game species is difficult in the field, so unless identification is certain, captured fish should be preserved for later examination and identification with keys. For specimens too large to preserve, good quality photographs are an option, but it is important that these photographs clearly show the features necessary for accurate identification. The best keys for identification of Wisconsin fishes are in Becker (1983); other useful keys are Eddy and Underhill (1974), Pflieger (1975), Smith (1979), and Trautman (1981). Even with good keys, identification of many species, especially minnows, is not easy and requires patience and practice.

During identification, the total number of fish with obvious external deformities, eroded fins, lesions, and tumors should be counted for calculating the percent DELT fish correction factor. It is important to distinguish between damage to fish caused by poor environmental quality and damage to fish caused by electroshocking or preservation, which should not be included in the count. Electroshocking, especially with AC current, sometimes causes large gashes or burns on fish, and may break bones, leading to apparent deformities (personal observations). Poor or incomplete preservation can lead to sloughing of scales and breakage of fins. Some parasites that occur just under the skin surface on fish may expand upon preservation, and the bump on the skin that results may superficially resemble a tumor. All of these electroshocking and preservation artifacts can be distinguished from true deformities, eroded fins, lesions, and tumors with careful observation and dissection. Note also that during and immediately after the spawning season, breeding individuals of many species may appear "beat up" as a result of spawning activities; such individuals should not be included in the count of DELT fish.

ANALYZING THE DATA

Determining Stream Location

Information about stream location is necessary for the calculation of species richness metrics. The location of each sampling site should be precisely described, including drainage basin, county, legal description (township, range, section), and distance from permanent landmarks, such as bridges, roads, or towns. It is often useful to prepare a map of the sampling site and surrounding area. Each site should be assigned to the appropriate geographic area: Lake Superior Basin, northern Wisconsin, or central/southern Wisconsin (fig. 1). Different criteria are used for each area in scoring species richness metrics.

The boundary between the northern Wisconsin and central/southern Wisconsin areas, which corresponds to county boundaries, represents a relatively broad transition zone rather than a sharp border. In analyzing species richness metrics for sites within 40 km of this boundary (via stream channels), I recommend calculating two IBI scores, one using the expectations for northern Wisconsin and the other using expectations for central/southern Wisconsin. The score and rating that seem most reasonable based on overall fish community attributes (see Interpreting IBI Scores on page 23) should be used.

In the central/southern Wisconsin area, the scoring criteria for the sunfish species richness metric depend on the distance of the sampling site (via stream channels) from a lake greater than 4 ha or a river with a mean annual discharge of 40 m^3 per second (see fig. 1). This distance should be determined from 7.5 minute (1:24000 scale) topographic maps using a map wheel. If the distance is less than or equal to 8 km, then one MSR plot is used to score the metric; if the distance is greater than 8 km, then another MSR plot is used.

Classifying Fish Species

To score the IBI metrics, all fish in a sample from a site must be classified into the appropriate structural and functional groups. Each metric consists of the fish that belong to a single structural or functional group. Individual fish species may be part of more than one group and hence contribute to more than one metric. A complete classification of all fish species in Wisconsin can be found in Appendix 4. The metrics and groups are as follows:

Species Richness and Composition Metrics

Total number of native species—The total number of species collected at a site, excluding hybrids (which can be common among sunfish and certain species of minnows) and exotic species (table 2). Exotic species are species that are present in Wisconsin waters only because of direct introduction by humans (*e.g.*, carp, salmon) or because of recent invasions that would not have been possible without human intervention (*e.g.*, the sea lamprey and alewife invaded Lake Michigan and Lake Superior after the construction of the Welland Canal, which bypassed Niagara Falls, a barrier to fish movement).

Number of darter species—The total number of darter species (family Percidae, table 2) collected, excluding hybrids. Darters are small benthic species that tend to be intolerant of many types of environmental degradation. They are mainly insectivorous, and for many of them, riffles or runs are preferred habitat. In the Lake Superior Basin, where darter species richness is naturally low, sculpins (*Cottus* species) and madtoms (*Noturus* species) are included in this metric. Sculpins and madtoms are commonly encountered in warmwater streams of this area, and occupy an ecological niche generally similar to that of the darters (see also Steedman 1988).

Number of sucker species—The total number of sucker species (family Catostomidae, table 2) collected, excluding hybrids. Suckers are large benthic species that generally live in pools or runs, although a few species are common in riffles. Some species are intolerant of environmental degradation, whereas others are tolerant. Most species feed on insects, although a few will also eat large quantities of detritus or plankton.

Number of sunfish species—The total number of sunfish species (family Centrarchidae, table 2), including rock bass (*Ambloplites rupestris*) and crappies (*Pomoxis* species), but excluding hybrids and smallmouth and largemouth bass (*Micropterus salmoides*). Sunfish are medium-sized, midwater species, which tend to occur in pools or other areas of slow-moving water. Most, but not all, are moderately tolerant of environmental degradation. All feed on a variety of invertebrates, although after some sunfish reach a certain size, they will eat fish. In the Lake Superior Basin, where sunfish species richness is naturally low, yellow perch (*Perca flavescens*) are included in this metric. Yellow perch are widespread in this area, and occupy an ecological niche generally similar to that of sunfish.

Number of intolerant species—The total number of species, excluding hybrids, that are intolerant of environmental degradation, particularly poor water quality, siltation and increased turbidity, and reduced habitat heterogeneity (*e.g.*, channelization). Intolerant species exist in a wide variety of fish families (table 2). However, delineation of intolerant species is a somewhat subjective process, and the criteria used in delineation are not easily quantified. I used three qualitative criteria, listed in order of priority, to classify species as intolerant: (1) a known high degree of sensitivity to the types of environmental degradation listed above, as documented in Becker (1983) and other regional fish publications; (2) an observed major decline in distribution and abundance in regions of Wisconsin where environmental problems are known to be severe (urban and industrial areas, agricultural areas with serious nonpoint source pollution problems); (3) designation as intolerant in other versions of the IBI used in central North America.

Percent that are tolerant species—The number of individuals that are members of species classified as tolerant of environmental degradation (table 2), expressed as a percentage of the total number of fish captured. As is the case for intolerant species, the delineation of tolerant species is somewhat subjective. I used three qualitative criteria, listed in order of priority, to classify species as tolerant: (1) a known ability to withstand poor water quality, particularly low dissolved oxygen levels, high levels of ammonia and other toxic substances, and high turbidity, as documented in Becker (1983) and other regional fish publications; (2) an observed ability to persist in good numbers in Wisconsin streams with poor environmental quality; (3) designation as tolerant in other versions of the IBI used in central North America. Hybrids are included in this metric if one or both parental species are considered tolerant species.

Table 2.—*Species assignments for species richness and composition metrics*[1]

Group	Species
Exotic species	Sea Lamprey, Alewife, Pink Salmon, Coho Salmon, Chinook Salmon, Atlantic Salmon, Rainbow Trout, Brown Trout, Rainbow Smelt, Goldfish, Common Carp, Grass Carp, Rudd, Threespine Stickleback, White Perch, Ruffe
Darters	Crystal Darter, Western Sand Darter, Mud Darter, Rainbow Darter, Bluntnose Darter, Iowa Darter, Least Darter, Johnny Darter, Banded Darter, Logperch, Gilt Darter, Blackside Darter, Slenderhead Darter, River Darter
Suckers	Highfin Carpsucker, Quillback, River Carpsucker, Longnose Sucker, White Sucker, Blue Sucker, Creek Chubsucker, Lake Chubsucker, Northern Hog Sucker, Spotted Sucker, Smallmouth Buffalo, Bigmouth Buffalo, Black Buffalo, Silver Redhorse, River Redhorse, Black Redhorse, Golden Redhorse, Shorthead Redhorse, Greater Redhorse
Sunfish	Rock Bass, Green Sunfish, Pumpkinseed, Bluegill, Warmouth, Orangespotted Sunfish, Longear Sunfish, White Crappie, Black Crappie
Intolerant species	Chestnut Lamprey (ammocoete only), Northern Brook Lamprey, Southern Brook Lamprey, Silver Lamprey (ammocoete only), American Brook Lamprey, Sea Lamprey (ammocoete only), Brook Trout, Muskellunge, Redside Dace, Mississippi Silvery Minnow, Speckled Chub, Gravel Chub, Pallid Shiner, Pugnose Shiner, Ghost Shiner, Blackchin Shiner, Blacknose Shiner, Spottail Shiner, Rosyface Shiner, Weed Shiner, Ozark Minnow, Highfin Carpsucker, Blue Sucker, Northern Hog Sucker, Black Buffalo, Spotted Sucker, Greater Redhorse, Slender Madtom, Rock Bass, Longear Sunfish, Smallmouth Bass, Crystal Darter, Rainbow Darter, Iowa Darter, Least Darter, Gilt Darter, Slenderhead Darter, Mottled Sculpin, Slimy Sculpin, Spoonhead Sculpin, Deepwater Sculpin
Tolerant species	Central Mudminnow, Goldfish, Common Carp, Golden Shiner, Red Shiner, Bluntnose Minnow, Fathead Minnow, Blacknose Dace, Rudd, Creek Chub, White Sucker, Yellow Bullhead, Green Sunfish

[1] Scientific names for this and table 3 are given in Appendix 4 table 13.

Table 3.—*Species assignments for trophic and reproductive function metrics*

Group	Species
Omnivores	Goldfish, Common Carp, Golden Shiner, Red Shiner, Bluntnose Minnow, Fathead Minnow, Bullhead Minnow, Rudd, River Carpsucker, Quillback, Highfin Carpsucker, White Sucker
Insectivores	Lake Sturgeon, Shovelnose Sturgeon, Goldeye, Mooneye, Lake Whitefish, Round Whitefish, Pygmy Whitefish, Central Mudminnow, Redside Dace, Lake Chub, Speckled Chub, Silver Chub, Gravel Chub, Hornyhead Chub, Pallid Shiner, Emerald Shiner, River Shiner, Ghost Shiner, Ironcolor Shiner, Striped Shiner, Common Shiner, Bigmouth Shiner, Pugnose Minnow, Blackchin Shiner, Blacknose Shiner, Spottail Shiner, Rosyface Shiner, Spotfin Shiner, Sand Shiner, Redfin Shiner, Mimic Shiner, Suckermouth Minnow, Finescale Dace, Longnose Dace, Pearl Dace, Longnose Sucker, Blue Sucker, Creek Chubsucker, Lake Chubsucker, Northern Hog Sucker, Smallmouth Buffalo, Bigmouth Buffalo, Black Buffalo, Spotted Sucker, Silver Redhorse, River Redhorse, Black Redhorse, Golden Redhorse, Shorthead Redhorse, Greater Redhorse, Black Bullhead, Yellow Bullhead, Brown Bullhead, Stonecat, Slender Madtom, Tadpole Madtom, Pirate Perch, Troutperch, Banded Killifish, Blackstripe Topminnow, Starhead Topminnow, Brook Silverside, Brook Stickleback, Ninespine Stickleback, Threespine Stickleback, White Perch, Green Sunfish, Pumpkinseed, Bluegill, Orangespotted Sunfish, Longear Sunfish, Crystal Darter, Western Sand Darter, Mud Darter, Rainbow Darter, Bluntnose Darter, Iowa Darter, Fantail Darter, Least Darter, Johnny Darter, Banded Darter, Ruffe, Yellow Perch, Logperch, Gilt Darter, Blackside Darter, Slenderhead Darter, River Darter, Freshwater Drum, Mottled Sculpin, Slimy Sculpin, Spoonhead Sculpin, Deepwater Sculpin
Top carnivores	Longnose Gar, Shortnose Gar, Bowfin, American Eel, Skipjack Herring, Pink Salmon, Coho Salmon, Chinook Salmon, Atlantic Salmon, Rainbow Trout, Brown Trout, Brook Trout, Lake Trout, Northern Pike, Grass Pickerel, Muskellunge, Channel Catfish, Flathead Catfish, Burbot, White Bass, Yellow Bass, Rock Bass, Warmouth, Smallmouth Bass, Largemouth Bass, White Crappie, Black Crappie, Walleye, Sauger
Simple lithophilous spawners	Lake Sturgeon, Shovelnose Sturgeon, Paddlefish, Redside Dace, Lake Chub, Gravel Chub, Emerald Shiner, River Shiner, Striped Shiner, Common Shiner, Ozark Minnow, Rosyface Shiner, Suckermouth Minnow, Southern Redbelly Dace, Blacknose Dace, Longnose Dace, Longnose Sucker, White Sucker, Blue Sucker, Northern Hog Sucker, Silver Redhorse, River Redhorse, Black Redhorse, Golden Redhorse, Shorthead Redhorse, Greater Redhorse, Burbot, Crystal Darter, Rainbow Darter, Banded Darter, Logperch, Gilt Darter, Blackside Darter, Slenderhead Darter, River Darter, Walleye, Sauger

Trophic and Reproductive Function Metrics

Percent that are omnivores—The number of individuals that belong to species with an adult diet consisting of at least 25 percent (by volume) plant material or detritus **and** at least 25 percent live animal matter (table 3), expressed as a percentage of the total number of fish captured. By definition, omnivores can subsist on a broad range of food items, and they are relatively insensitive to changes in the food base of a stream caused by environmental degradation. Primarily herbivorous species that occasionally ingest significant proportions of animal matter (*e.g.*, stonerollers [*Campostoma* species]) are not considered omnivores for this metric. Trophic classifications for this and the two other trophic function metrics are based upon personal observations, data in Becker (1983), and trophic classifications in Karr *et al.* (1986) and Ohio EPA (1988). Hybrids are included as omnivores if one or both parental species are omnivores.

Percent that are insectivores—The number of individuals that belong to species with an adult diet that is normally dominated by aquatic or terrestrial insects (table 3), expressed as a percentage of the total number of fish captured. Species classified as omnivores are not considered insectivores even if they eat large numbers of insects, nor are obligate filter feeders that may eat drifting insects (*e.g.*, gizzard shad [*Dorosoma cepedianum*]). However, species that may be primarily insectivorous under some circumstances, and planktivorous (*e.g.*, bluegill [*Lepomis macrochirus*]) or molluscivorous (*e.g.*, pumpkinseed [*Lepomis gibbosus*], freshwater drum [*Aplodinotus grunniens*]) under others, are considered insectivores for this metric. The creek chub (*Semotilus atromaculatus*) and blacknose dace (*Rhinichthys atratulus*) are considered generalized invertivores rather than insectivores, and they are not included in this metric. Although their diet is often dominated by insects and they rarely consume plant material, these two species eat a very broad range of animal matter, and they respond to changes in the food base of a stream more as an omnivore than an insectivore (Ohio EPA 1988). Hybrids are counted as insectivores only if both parental species are insectivores.

Percent that are top carnivores—the number of individuals that belong to species with an adult diet dominated by vertebrates (especially fish) or decapod crustacea (*e.g.*, crayfish, shrimp) (table 3), expressed as a percentage of the total number of fish captured. Species that have a predominantly piscivorous diet only when they reach very large size (*e.g.*, creek chub) are not considered top carnivores for this metric. Hybrids are considered top carnivores only if both parental species are top carnivores.

Percent that are simple lithophilous spawners—The number of individuals that belong to species that lay their eggs on clean gravel or cobble and do not build a nest or provide parental care (table 3), expressed as a percentage of the total number of fish captured. Simple lithophilous species need clean substrates for spawning and are particularly sensitive to sedimentation of rocky substrates. Classification of species as simple lithophilous spawners is based on Balon (1975), Berkman and Rabeni (1987), and Ohio EPA (1988). Hybrids are considered simple lithophilous spawners only if both parental species are simple lithophilous species.

Fish Abundance and Condition Correction Factors

Number of individuals—The number of individual fish, **excluding individuals of tolerant species**, captured per 300 m of stream sampled. To calculate this value, multiply the number of individuals captured (minus the tolerant individuals) times 300 and then divide by the distance sampled in meters. The number of individuals per 300 m is consistently very low at highly degraded sites, but may be either high or low at moderately or lightly degraded sites (see Appendix 1).

Percent with deformities, eroded fins, lesions, or tumors (DELT)—The number of individual fish with skeletal or scale deformities, heavily frayed or eroded fins, open skin lesions, or tumors, that are apparent from an external examination, expressed as a percentage of the total number of fish captured. Fish with heavy parasite burdens (*e.g.*, infestations of black spot

[*Neascus* sp.] or anchor hookworm [*Lernea* sp.]) are not included as DELT fish unless the parasites have caused deformities or lesions. Fish with DELT anomalies that are only visible after dissection are also not included. DELT fish are normally rare except at highly degraded sites (see Appendix 1).

Dealing With Very Low Catch Rates

If the total number of fish captured from a site (**including** tolerant species) is very low, IBI scores may be biased and not representative of the true biotic integrity and environmental quality of the site. When a sample contains only a few fish, IBI metrics and correction factors (especially those that are based on percentages) may be unduly influenced by the presence or absence of a few individuals. As a rule of thumb, the IBI should not be calculated for sites where the total sample consists of less than 50 individuals. At sites where fish abundance is very low, it may be worthwhile to extend the sampling distance to the point where at least 50 individuals have been captured. If this is not possible or desirable, then the IBI should not be calculated, and instead, the low fish abundance itself should be used to assess biotic integrity (see section on Interpreting IBI Scores).

Using MSR Plots For Scoring

The five species richness metrics are scored using Maximum Species Richness (MSR) plots given in figures 2 to 12. These MSR plots relate expected numbers of species to stream size at different levels of environmental quality. Different MSR expectations have been developed for each of the three geographic areas of Wisconsin, and within these areas, for each of the five metrics. As a rule, at any given stream size, the better the environmental quality, the greater the number of species expected. Additionally, for a given level of environmental quality, the larger the stream size, the greater the number of species expected. Thus, large, high-quality streams should have large numbers of species, whereas small, poor-quality streams should have few species.

The first step in using MSR plots is to convert stream size to the proper unit of measure. MSR plots are based on the natural logarithm (base e) of the mean stream width of a site in meters. Most calculators have a function key that directly determines natural logarithms; alternatively, log tables are available in many math and statistics textbooks.

Once the natural logarithm of stream width for a site is determined, the number of species at that site should be calculated for each of the five species richness metrics. Then, for each metric, the point that represents the intersection of the natural logarithm of stream width (x axis) and the number of species (y axis) should be located on the appropriate MSR plot. Figures 2 to 6 give the five MSR plots for sites in northern Wisconsin, and figures 7 to 12 give the six MSR plots for sites in central and southern Wisconsin (there are two plots for the number of sunfish species, one for sites within 8 km of a lake or large river, and one for sites more than 8 km from a lake or large river). Plots are not given for sites in the Lake Superior Basin. Rather, because of the simplicity of the relationship between stream size and expected number of species, table 4 gives scoring criteria for three size classes of streams.

Once the species richness for a particular metric has been located on the appropriate MSR plot, that metric can be scored. Note that each MSR plot has three diagonal or diagonal/horizontal lines. The uppermost of these lines is the Maximum Species Richness Line, the line below it is the First Trisection Line, and the line below that is the Second Trisection Line. The position of the Maximum Species Richness Line determines the positions of the two Trisection Lines (see Appendix 3 for information on how these lines are generated). If species richness falls on or above the Maximum Species Richness Line, or between the Maximum Species Richness Line and the First Trisection Line, then species richness is similar to that of a high-quality, relatively undegraded stream, and the metric is scored a 10. If species richness

Table 4.—*Scoring criteria for species richness metrics for sites in the Lake Superior Basin (i.e., number of species needed to achieve a certain score for each of three stream size classes for each metric)*

Metric[1]	Stream width[2]	Scoring criteria		
		10	5	0
	m			
Total number of native species	2.5-6.1	>6	3-6	<3
	6.2-12.1	>10	6-10	<6
	≥12.2	>14	9-14	<9
Number of darter plus sculpin & madtom species	2.5-6.1	>1	1	0
	6.2-12.1	>1	1	0
	≥12.2	>1	1	0
Number of sucker species	2.5-6.1	>1	1	0
	6.2-12.1	>1	1	0
	≥12.2	>1	1	0
Number of sunfish plus yellow perch species	2.5-6.1	1	0	-
	6.2-12.1	2	1	0
	≥12.2	>2	1-2	0
Number of intolerant species	2.5-6.1	1	0	-
	6.2-12.1	>1	1	0
	≥12.2	>2	1-2	0

[1] For sites in this basin **only**, the Darters metric includes all darters plus any sculpin and madtom species, and the Sunfish metric includes all sunfish plus yellow perch.

[2] Note that stream widths are given directly in meters, rather than the natural log of meters as is used in MSR plots.

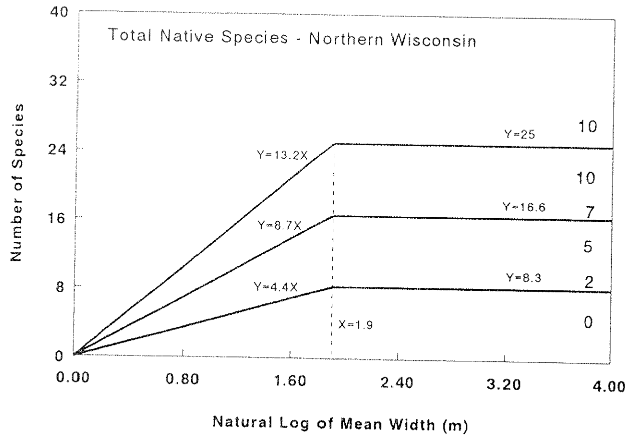

Figure 2.—*Maximum Species Richness (MSR) plot of total number of native species versus the natural log of mean stream width for the northern Wisconsin area. For this figure and figures 3 through 6, the plot is based on 26 sites sampled during the WDNR Fish Distribution Survey, 1976-1979. Lines on the plot are derived from the data for these 26 sites (see Appendix 3); for clarity, actual data points are not shown. The upper diagonal/horizontal line is the Maximum Species Richness (MSR) Line, the middle line is the First Trisection Line, and the lower line is the Second Trisection Line. The perpendicular dashed line indicates the point on the x axis where the MSR and Trisection lines switch from diagonal to horizontal. The equations shown describe mathematically each segment of each line; y = number of species and x = natural log of mean stream width. The numbers along the right margin of the plot give scoring criteria. If a site falls on or above the MSR Line or between the MSR Line and the First Trisection Line, it scores a 10. If a site falls on the First Trisection Line, it scores a 7. If a site falls between the First and Second Trisection Lines, it scores a 5. If a site falls on the Second Trisection Line, it scores a 2. If a site falls below the Second Trisection Line, it scores a 0.*

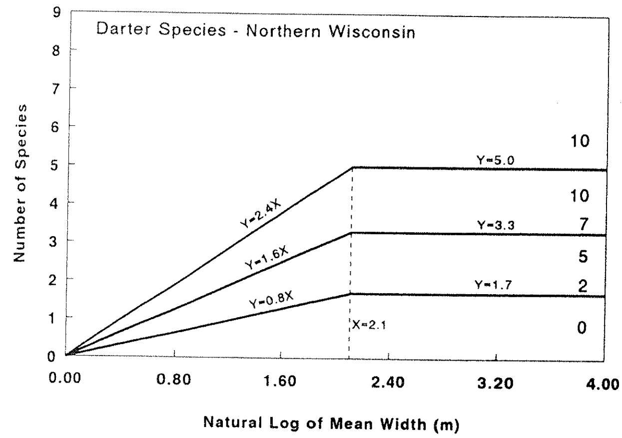

Figure 3.—*Maximum Species Richness (MSR) plot of number of darter species versus the natural log of mean stream width for the northern Wisconsin area. See legend of figure 2 for more explanation.*

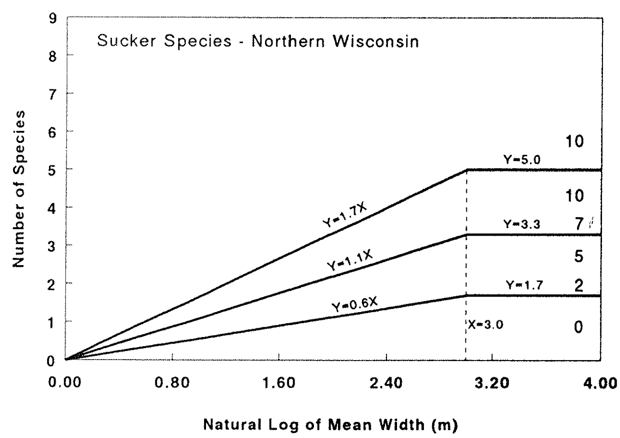

Figure 4.—*Maximum Species Richness (MSR) plot of number of sucker species versus the natural log of mean stream width for the northern Wisconsin area. See legend of figure 2 for more explanation.*

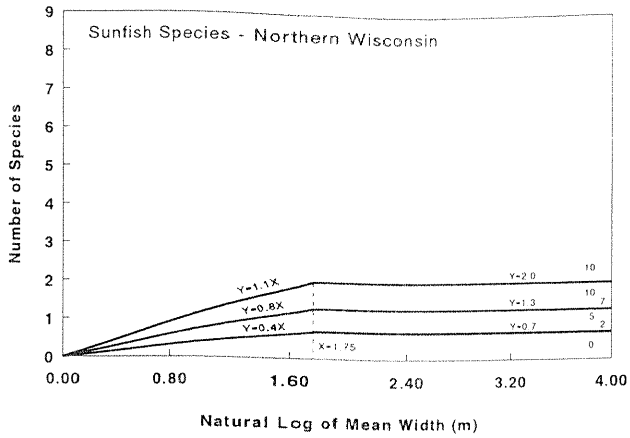

Figure 5.—*Maximum Species Richness (MSR) plot of number of sunfish species versus the natural log of mean stream width for the northern Wisconsin area. See legend of figure 2 for more explanation.*

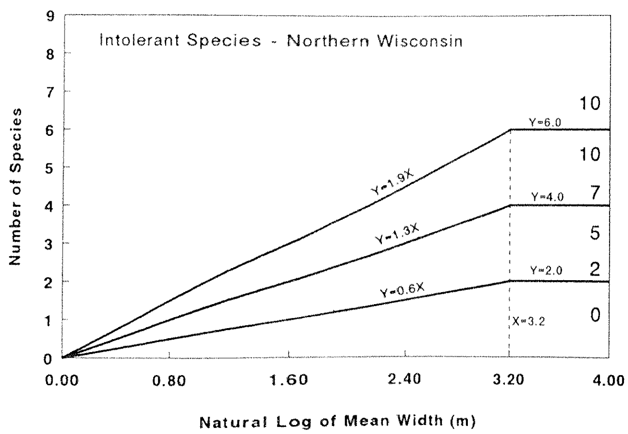

Figure 6.—*Maximum Species Richness (MSR) plot of number of intolerant species versus the natural log of mean stream width for the northern Wisconsin area. See legend of figure 2 for more explanation.*

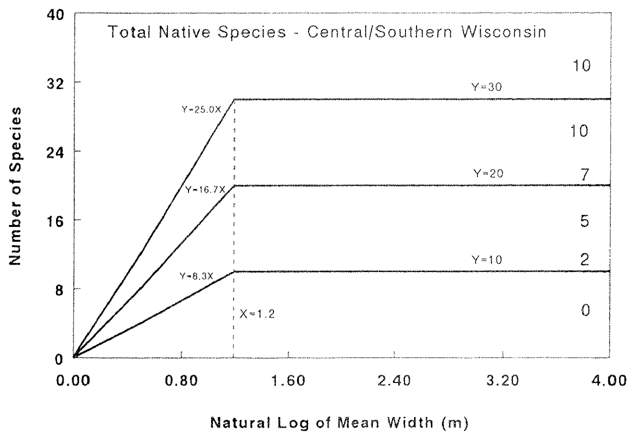

Figure 7.—*Maximum Species Richness (MSR) plot of total number of native species versus the natural log of mean stream width for the central/southern Wisconsin area. For this figure and figures 8, 9, and 12, the plot is based on 435 sites sampled during the WDNR Fish Distribution Survey, 1976-1979. Lines on the plot are derived from the data for these 435 sites (see Appendix 3); for clarity, actual data points are not shown. See legend of figure 2 for more explanation.*

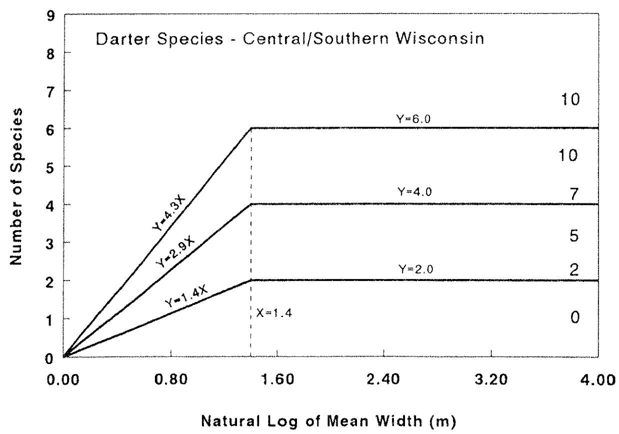

Figure 8.—*Maximum Species Richness (MSR) plot of number of darter species versus the natural log of mean stream width for the central/southern Wisconsin area. See legends of figures 2 and 7 for more explanation.*

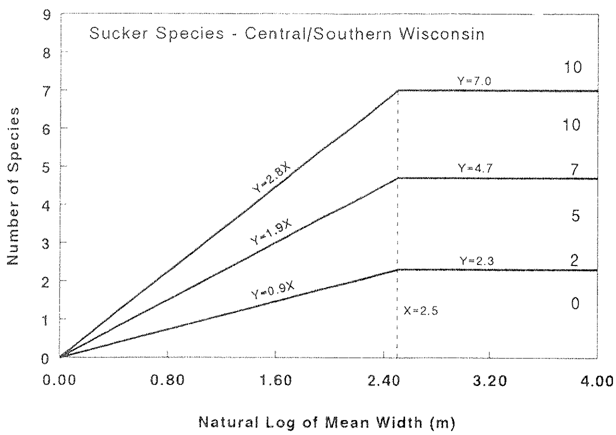

Figure 9.—*Maximum Species Richness (MSR) plot of number of sucker species versus the natural log of mean stream width for the central/southern Wisconsin area. See legends of figures 2 and 7 for more explanation.*

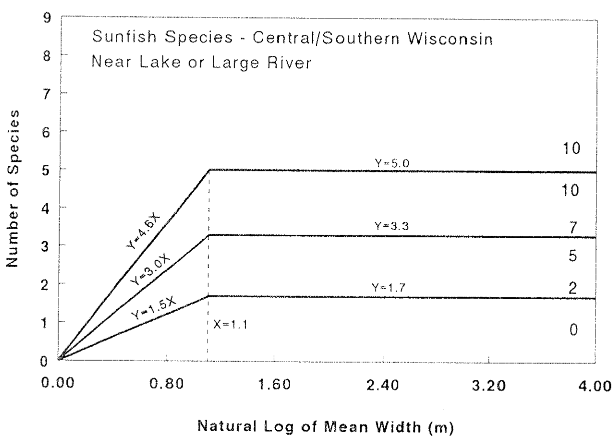

Figure 10.—*Maximum Species Richness (MSR) plot of number of sunfish species versus the natural log of mean stream width for sites less than or equal to 8 km (via stream channels) from a lake (> 4 ha surface area) or large river (≥ 40 m*^{3} *per second mean annual discharge) in the central/southern Wisconsin area. Lines on the plot are derived from the data from 157 sites; for clarity, these actual data points are not shown. See legend of figure 2 for more explanation.*

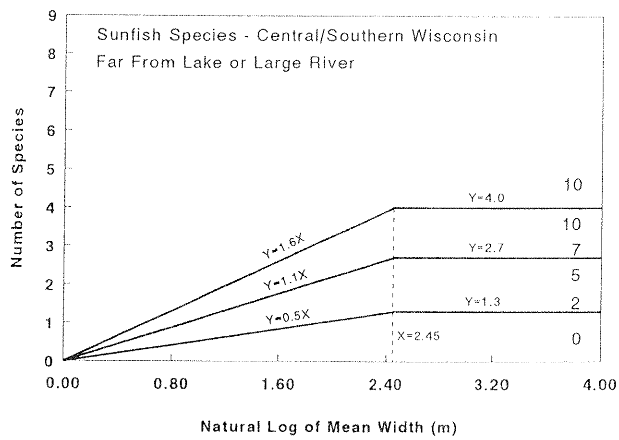

Figure 11.—*Maximum Species Richness (MSR) plot of number of sunfish species versus the natural log of mean stream width for sites more than 8 km (via stream channels) from a lake (> 4 ha surface area) or large river (≥ 40 m*^{3} *per second mean annual discharge) in the central/southern Wisconsin area. Lines on the plot are derived from the data from 278 sites; for clarity, these actual data points are not shown. See legend of figure 2 for more explanation.*

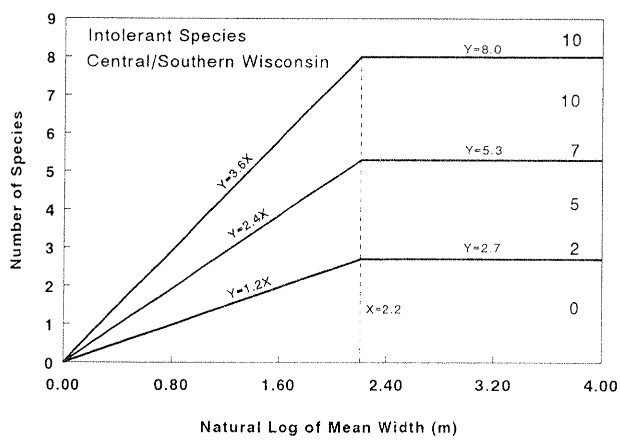

Figure 12.—*Maximum Species Richness (MSR) plot of number of intolerant species versus the natural log of mean stream width for the central/southern Wisconsin area. See legends of figures 2 and 7 for more explanation.*

falls directly on the First Trisection Line, then species richness is similar to that of a slightly degraded stream, and the metric is scored a 7. If species richness falls between the First and Second Trisection Lines, then species richness is similar to that of a moderately degraded stream, and the metric is scored a 5. If species richness falls directly on the Second Trisection Line, then species richness is similar to that of a degraded stream, and the metric is scored a 2. If species richness falls below the Second Trisection Line, then species richness is similar to that of a highly degraded stream, and the metric is scored a 0.

As a brief example, consider a site in the central/southern Wisconsin area with a mean width of 5 m (natural log = 1.61) that is located within 8 km of a 80-ha lake. The site has 21 total native species, including 2 darter species, and 1 sunfish species. The appropriate MSR plots for this site are found in figure 7 for the total number of native species metric, figure 8 for the number of darter species metric, and figure 10 for the number of sunfish species metric. The total number of native species falls just above the First Trisection Line in figure 7. Thus, the total number of native species metric is scored a 10 for this site. The number of darter species falls on the Second Trisection Line in figure 8, so the number of darter species metric scores a 2. The number of sunfish species falls below the Second Trisection Line in figure 10, so the number of sunfish species metric is scored a 0. A more complete set of examples of scoring of all metrics is given in Appendix 5.

Scoring Metrics Based on Percentages

The remaining five metrics, dealing with species composition and trophic and reproductive function, are based on percentages of individual fish captured rather than number of species. These metrics are not strongly influenced by stream size or site location either within Wisconsin or relative to lakes and large rivers. Thus, the same scoring criteria are used for all sites in Wisconsin.

Percentages are calculated by dividing the number of fish within a particular metric group by the total number of fish (including tolerant species) captured from a site. All percentages should be rounded to the nearest 1 percent. Scoring is based on criteria given in table 5.

Scoring Correction Factors

The number of individuals captured per 300 m of stream sampled and the percentage of DELT fish correction factors only influence the overall IBI score when they have extreme values (table 4). These two correction factors can lower the overall IBI score, but not improve it. The number of individuals captured correction factor includes all fish **except tolerant species**. Thus, it is possible to catch a large number of tolerant fish from a site and still calculate a very low or zero value for number of individuals captured (see Appendix 5). If the number of individuals captured per 300 m of stream is less than 50, the score for this correction factor is -10; if it is 50 or greater, the score is 0.

The percentage of DELT fish is calculated using all fish captured, including tolerant species. To determine this percentage, the number of DELT fish captured is divided by the total number of fish captured. If the percentage is greater than or equal to 4 percent, the score for this correction factor is -10; if it is less than 4 percent, the score is 0.

Calculating the Overall IBI Score

The overall IBI score is the sum of the scores for the 10 metrics and the 2 correction factors. If this sum is less than 0 (*i.e.*, if the sum of the 2 correction factors is greater than the sum of the 10 metrics, yielding a negative overall sum), then it is rounded up to 0. Thus, the minimum possible overall IBI score is 0, representing very poor biotic integrity, and the maximum is 100, representing excellent biotic integrity.

Table 5.—*Scoring criteria for the 10 metrics and 2 correction factors used to calculate the Wisconsin version of the IBI*[1]

Metric or correction factor	Scoring criteria 10	7	5	2	0
Species Richness and Composition Metrics					
Total number of native species	Scoring for species richness metrics depends on stream size and location. For sites in the Lake Superior Basin, see table 4. For sites in Northern Wisconsin, see figs. 2-6. For sites in Central/Southern Wisconsin, see figs. 7-12.				
Number of darter species					
Number of sucker species					
Number of sunfish species					
Number of intolerant species					
Percent tolerant species	0-19	20	21-49	50	51-100
Trophic and Reproductive Function Metrics					
Percent omnivores	0-19	20	21-39	40	41-100
Percent insectivores	100-61	60	59-31	30	29-0
Percent top carnivores	100-15	14	13-8	7	6-0
Percent simple lithophils	100-51	50	49-21	20	19-0
Fish Abundance and Condition Correction Factors					
Number of individuals per 300 m^2	If < 50 fish, subtract 10 from overall IBI score				
Percent DELT fish[3]	If ≥ 4 percent, subtract 10 from overall IBI score				

[1] All percents are in terms of total number of fish (including tolerant species); in calculating, round all percentages to the nearest 1 percent.
[2] The number of individuals correction factor does not include tolerant species.
[3] Percent DELT fish refers to fish with deformities, eroded fins, lesions, or tumors.

INTERPRETING IBI SCORES

Interpreting the Overall IBI Score

The higher the overall IBI score, the better the biotic integrity and, by inference, the environmental quality of a site. Sites with IBI scores close to the maximum possible value of 100 presumably have excellent environmental quality, whereas sites with IBI scores close to the minimum possible value of 0 presumably have very poor environmental quality. Sites with intermediate scores presumably have intermediate environmental quality. Table 6 provides integrity ratings for different ranges of overall IBI scores.

The overall IBI score is a useful summary of a wide and complex range of fish community attributes at a site. However, like all summaries of complex situations, the overall IBI score sometimes oversimplifies or misrepresents reality. Therefore, it is important not to rely too heavily on the overall IBI score when assessing biotic integrity. Of more value are the integrity rating derived from the IBI score and the actual nature of the fish community (Karr *et al.* 1986). Attributes of fish communities that are representative of very poor to excellent biotic integrity are given in table 6, and have been described in the section "Using and Interpreting the IBI." These attributes should be used to check the validity of biotic integrity ratings derived from overall IBI scores.

At some sites, the catch of fish (including tolerant species) may be too low (fewer than 50 individuals) to permit calculation of the IBI. Assuming that sampling procedures and performance have been adequate, an extremely low catch rate in a permanent, intermediate-sized, Wisconsin warmwater stream is always an indication of a serious environmental problem. If catch rates at a site are too low to allow the IBI to be calculated, then the biotic integrity rating of that site should be very poor.

Identifying Specific Environmental Problems

The overall IBI score is a measure of the overall environmental quality of a stream site, and a low score indicates that environmental problems exist. By itself, the overall IBI score cannot reveal what these problems are. However, the scores of individual metrics often provide insight into the specific causes of environmental degradation. For instance, low numbers of simple lithophilous species and benthic species such as darters and suckers are often caused by siltation and loss of coarse substrate. Sunfish and top carnivores do best in deeper pool habitats and areas of extensive cover, so if their species richness and abundance are low, deep water and instream cover habitat may have been lost. High numbers of DELT individuals invariably indicate major water quality problems. Highly skewed relative abundances of feeding groups can reflect disruptions of food webs. Karr *et al.* (1985, 1986), Berkman *et al.* (1986), Leonard and Orth (1986), Ohio EPA (1988), and Steedman (1988) provide examples of how metric scores can be used to infer specific types of environmental degradation.

Accounting for Differences Among Samples in IBI Scores

Even when true biotic integrity and environmental quality of a site remain constant over a time period, multiple fish community samples from that site made over that time period will rarely all have the same overall IBI score. This temporal variation among samples in IBI scores is caused by two factors: sampling error and natural variations in fish community attributes. Sampling error represents the failure to accurately and precisely characterize the fish community because of sampling difficulties or limitations. Natural variations are real fluctuations in fish community attributes that result from something other than human activities (*e.g.*, climatic fluctuations). Both sampling error and natural variation are unavoidable, but proper sampling design can minimize their effects on overall IBI scores (see section Collecting and Processing the Field Data; see also Angermeier and Karr 1986, Karr *et al.* 1987, Ohio EPA 1988).

Table 6.—*Guidelines for interpreting overall IBI scores (modified from Karr* et al. *1986)*

Overall IBI score	Biotic integrity rating	Fish community attributes
100-65	Excellent	Comparable to the best situations with minimal human disturbance; all regionally expected species for habitat and stream size, including the most intolerant forms, are present with a full array of age and size classes; balanced trophic structure.
64-50	Good	Species richness somewhat below expectation, especially due to the loss of the most intolerant forms; some species, especially top carnivores, are present with less than optimal abundances or size/age distributions; trophic structure shows some signs of imbalance.
49-30	Fair	Signs of additional deterioration include decreased species richness, loss of intolerant forms, reduction in simple lithophils, increased abundance of tolerant species, and/or highly skewed trophic structure (*e.g.*, increasing frequency of omnivores and decreased frequency of more specialized feeders); older age classes of top carnivores rare or absent.
29-20	Poor	Relatively few species; dominated by omnivores, tolerant forms, and habitat generalists; few or no top carnivores or simple lithophilous spawners; growth rates and condition factors sometimes depressed; hybrids sometimes common.
19-0	Very poor	Very few species present, mostly exotics or tolerant forms or hybrids; few large or old fish; DELT fish (fish with deformities, eroded fins, lesions, or tumors) sometimes common.
No score	Very poor	Thorough sampling finds few or no fish; impossible to calculate IBI.

To determine whether observed differences among IBI scores actually represent true differences in biotic integrity and environmental quality, it is necessary to understand the magnitude of the influence of sampling error and natural variation in fish community attributes on IBI scores. Because the influences of sampling error and natural variation are difficult to separate from each other, their effects are best estimated jointly. The most straightforward way to do this is by analyzing fluctuations in IBI scores over time at individual sites where environmental quality has remained constant.

Using this approach, sampling error and natural variation together are estimated to cause fluctuations of 0 to 17 points (mean = 9 points; 9 percent of overall 100-point range) in the overall IBI score for the Wisconsin IBI (table 7). This estimate is based on data from six sites in the 1987-1990 data set that were sampled more than once during the 3 years. At each site, environmental quality ratings were similar between samples. Five of the six sites had good to excellent biotic integrity (IBI scores above 50), and the remaining site had fair biotic integrity (IBI score of 35 to 37).

Table 7.—*Overall IBI scores from sites that were sampled more than once during the 1987-1990 sampling and that had no change in environmental quality between samplings*

		Year				
Stream	**Mile**[1]	**1987**	**1988**	**1989**	**1990**	**Difference**
Little Platte	19.4	35	-[2]	-	37	2
Milwaukee	66.8	-	62	55	50	12
Mineral Point	12.6	64	-	-	80	16
North Branch Milwaukee	4.4	72	-	77	60	17
South Fork Flambeau	59.4	-	90	90	-	0
South Fork Flambeau	66.8	-	65	70	-	5

[1] *"Mile" refers to the distance (via the channel) from the mouth of the stream to the downstream end of the site, and is used to indicate site location on the stream.*
[2] *A "-" indicates that the site was not sampled that year.*

The 9-percent mean difference between samples for the Wisconsin IBI is similar to values for other versions of the IBI. For his Ontario version of the IBI, Steedman (1988) found that the maximum within-year difference at a single site was 10 percent (4 points; overall IBI range of 40 points), with most sites having differences of 5 percent or less. Between-year differences were greater, with a maximum value of 30 percent and most values at 13 percent or less. For the original version of the IBI, Karr *et al.* (1987; table 2, p. 4) found within-year differences in IBI scores to range from 4 to 25 percent, with a mean of 15 percent (7 points; overall IBI range of 48 points), and among-year differences (for August samples only) to range from 0 to 25 percent with a mean of 11 percent.

Several studies indicate that variation in IBI scores may be influenced by the level of biotic integrity and by stream size. For the Ohio EPA (1988) version of the IBI, Rankin and Yoder (1990) found that within-year coefficients of variation at individual sites were negatively correlated with biotic integrity; high biotic integrity sites had lower coefficients of variation than low integrity sites. Rankin and Yoder (1990) also found that coefficients of variation tended to increase slightly as stream size increased; they attributed this to greater sampling error in larger streams. Schlosser (1990) argued that studies of fish community structure and function predict that IBI scores should vary more in small streams than in larger streams. For the original version of the IBI, Karr *et al.* (1987) found that both within- and among-year variation in IBI scores were greater at sites with low biotic integrity than at sites with high biotic integrity.

From my analyses, coupled with results from previous studies, I conclude that for the Wisconsin version of the IBI, differences among IBI scores of 10 points or less (10 percent) are not significant. Observed differences of this magnitude probably represent the combined effects of sampling error and natural variation in fish community attributes rather than true changes in biotic integrity or environmental quality. Differences of 10 to 25 points (10 to 25 percent) may or may not represent true changes in biotic integrity; additional samples or supplementary data may be needed to determine if such differences are meaningful. Differences of 10 to 25 points may be more likely to indicate real differences in biotic integrity among sites with high IBI scores than among sites with low IBI scores. Differences of 25 points or more (25 percent) probably indicate real differences in biotic integrity and environmental quality, no matter what the values of the IBI scores for the samples or sites being compared.

When a particular site is sampled several times over a relatively short time period (*e.g.*, less than 1 year), one additional factor that might cause variation in IBI scores is the effect of the sampling itself on the fish community. Particularly in small streams, repeated electrofishing may cause substantial mortality or emigration of fish, as well as skeletal deformities among those fish that remain (personal observations). These effects of electrofishing will tend to lower the overall IBI score, especially if the intervals between samplings are too short to allow recolonization and recruitment processes to replace fish that have died or left the site. To minimize sampling effects on overall IBI scores during repeated monitoring of a site, I recommend that no more than three IBI samples be taken per year from each individual site, and that the interval between samplings at each site be at least 6 weeks.

Incorporating Other Types of Information

Relying solely on the IBI to assess the biotic integrity and environmental quality of a stream can be a risky strategy. The IBI is a useful tool for evaluating and monitoring streams, and may in fact be the best tool under many circumstances, but it is by no means foolproof or all encompassing (Fausch *et al.* 1990). The IBI is designed to complement rather than replace other measures of environmental quality (Karr *et al.* 1986, Angermeier and Schlosser 1987, Karr 1991). Whenever possible during stream surveys, information on other biota and on physical habitat and water quality should be gathered in addition to fish community data. Often, data on other biota, such as macroinvertebrates or algae, can indicate environmental problems that the IBI has missed, or shed light on the specific causes of low biotic integrity at a site (Berkman *et al.* 1986, Plafkin *et al.* 1989). Water quality and physical habitat deficiencies are almost always among the causes of reduced biotic integrity, so obviously habitat and water quality data are essential in the evaluation of streams (Plafkin *et al.* 1989, Fausch *et al.* 1990).

The IBI cannot successfully replace these other measures of biotic integrity and environmental quality, but it can definitely enhance their value. Like all widely used and proven environmental assessment tools, the IBI has attributes and strengths that other environmental indices or measures lack (Karr 1981, 1991). Many difficulties remain in the evaluation and protection of stream resources, and the IBI is certainly not a panacea. However, used in concert with data on physical habitat, water quality, and other biota, the IBI can greatly enhance efforts to quantify and protect biotic integrity and environmental quality of Wisconsin streams.

ACKNOWLEDGMENTS

I thank Don Fago and the other members of the Wisconsin Department of Natural Resources Fish Distribution Survey for collecting the data that I used to develop MSR plots. I also thank the many people, especially Paul Kanehl, who helped collect and manage the 1987-1990 data. Anne Forbes provided the initial impetus for the Wisconsin IBI work and deserves credit for helping get this project off the ground. Paul Rasmussen provided much helpful advice on statistics and computer programming. Earlier drafts of this paper benefited from reviews by Lyle Christenson, Dave Day, Clay Edwards, Paul Kanehl, Ed Rankin, and Tim Simonson. This research was funded in part by the WDNR, Bureau of Research; Sport Fish Restoration Program, Project F-83-R, Study 043; and the U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station, Wildlife and Fish Habitat Research Unit NC-4202.

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DEVELOPMENT AND VALIDATION OF THE WISCONSIN VERSION

Development

The Wisconsin IBI was developed using a large amount of fish community data, in some cases coupled with habitat and water quality information, from streams and rivers throughout the State. Species richness metrics and MSR plots were based on data from the WDNR Fish Distribution Survey (Fago 1988). From 1974 through 1979, the Fish Distribution Survey sampled fish communities at more than 4,500 discrete stations on more than 1,700 lakes, rivers, and streams throughout the southern and western thirds of Wisconsin. From the survey data base, I chose 490 stations on 290 warmwater streams and rivers for development of MSR lines. At all of these stations, survey personnel had attempted to completely sample the entire fish community, and all captured fish were accurately identified to species. However, counts of fish within each species stopped at 99, so the data did not always adequately represent relative abundance of species. All stations had been sampled by wading with either a standard WDNR DC backpack electroshocker or stream shocker during June, July, or August. An estimate of mean stream width, which I used as my measure of stream size, was available for each station.

To develop MSR plots, I graphed the number of species versus the natural log of the mean stream width in meters. I made separate plots for each of the three geographic areas and each of the five species richness metrics (totals of native species, darters, sunfish, suckers, and intolerant species) for a total of 15 plots. For each plot I then drew the MSR line and derived scoring criteria (see Appendix 3). Stations with a species richness near or above the MSR line for a particular metric received a score of 10 for that metric. Stations with a species richness far below the MSR line received a score of 0, and stations with intermediate species richness received intermediate scores.

I evaluated and developed scoring criteria for fish community composition and relative abundance metrics (metrics based on counts of individual fish; *i.e.*, species composition, trophic and reproductive function, and fish abundance and condition metrics) with data collected during 1987 through 1989 as part of a WDNR research study that I directed. This study explored relationships between fish communities and physical habitat characteristics in warmwater streams throughout Wisconsin, and encompassed streams ranging from very poor to excellent in environmental quality. Complete fish community data, including counts of all fish captured, were collected from 70 stations on 39 streams. All fish data were collected by wading with a standard WDNR DC stream shocker during June, July, or August.

Additionally, detailed physical habitat measurements (stream widths, depths, and discharge; water velocity, temperature, conductivity, and turbidity; bottom substrate composition; hiding cover for adult fish; pool-riffle development, channel gradient, and sinuosity; and bank stability, riparian vegetation, and land use) were made at each station during fish sampling. Some of these measurements were used to develop a 100-point rating scale for physical habitat quality (fig. 13). Water quality was rated on a four-point scale (table 8), using qualitative observations made at the station coupled with qualitative and quantitative water quality information from WDNR stream files.

I considered 15 possible fish community composition, trophic and reproductive function, and relative abundance and condition metrics for inclusion in the IBI (see Appendix IV). These 15 included all of those from Karr's original version (Karr 1981, Karr *et al.* 1986) and the Ohio EPA "wading sites" version (Ohio EPA 1988), plus a few from other versions of the IBI (Leonard and Orth 1986, Miller *et al.* 1988, Steedman 1988). For each potential metric, I correlated station values for that metric with station ratings for habitat quality, water quality, and overall environmental quality (a composite index obtained by multiplying the water quality rating by the habitat quality rating and dividing by four).

WISCONSIN WARMWATER STREAM PHYSICAL HABITAT RATING FORM

Stream: ______________________ Water Body ID: ______________

Year: ________ Month: ________ Day: ________ Entire Stream Mile: ______________

Evaluators: ______________________________ Total Score: ________

CATEGORY

Rating Item	Excellent	Good	Fair	Poor	Score
Bank erosion, failure and bank protection.	No significant bank erosion, failure. ≥ 90% of bank protected by plants or stable rock. 12	Limited amount of bank erosion, failure. 80% of bank protected by plants or stable rock. 8	Intermediate amount of bank erosion, failure. 60% of bank protected by plants or stable rock. 4	Extensive amount of bank erosion, failure. ≤ 50% of bank protected by plants or stable rock. 0	___
Main channel rocky substrate (% of area).	≥ 65% of the bottom covered by rocky substrate (BE + BO + RC + GR). 25	45% of the bottom covered by rocky substrate. 16	25% of the bottom covered by rocky substrate. 8	≤ 5% of bottom covered by rocky substrate. 0	___
Available cover for adult gamefish.	Extensive cover, (woody debris, rocks, or macrophyte beds) ≥ 12% of total surface area. 25	Adequate cover, 8% of the total surface area. 16	Cover limited, 4 % of the total surface area. 8	Little or no cover, 0% of the total surface area. 0	___
Average maximum Thalweg depth (4 deepest depths).	≥ 1.5 meters. 25	1.2 meters. 16	0.9 meters. 8	≤ 0.6 meters. 0	___
BB or RR Ratio (distance between bends or riffles/avg. main channel width).	BB or RR Ratio ≤ 12. 12	BB or RR ratio = 18. 8	BB or RR ratio = 24. 4	BB or RR Ratio ≥ 30. 0	___
99 = Excellent 66 = Good 33 = Fair 0 = Poor				Total Score:	___

Figure 13.—*Criteria and example of data sheet used to rate physical habitat quality at sites sampled during 1987-1990. The four categories (Excellent, Good, Fair, Poor) are provided as guidelines; the actual scores for each rating item can be inbetween the scores given for two adjacent categories. Terms and abbreviations used on the form include:*

Water Body ID—*a unique seven-digit identification code assigned to each stream, river, and lake in Wisconsin.*

Entire Stream Mile—*The distance in miles (via the stream channel) between the mouth of the stream and the downstream end of the site. Used to indicate site location on the stream.*

Main Channel Rocky Substrate—*BE = Bedrock, BO = Boulder, RC = Rubble/Cobble, GR = Gravel.*

BB or RR Ratio—*Bend to Bend or Riffle to Riffle Ratio.*

Table 8.—*Criteria for assigning water quality ratings to sites sampled in 1987-1990*

Score	Rating	Criteria
1	Very poor	Major fish kill within 1 year, or a history of regular fish kills, or chronic (more than once per year) severe violations of Wisconsin standards for key water quality characteristics (*e.g.*, dissolved oxygen, pH, suspended solids, ammonia, nitrates, pesticides, heavy metals).
2	Poor	Major fish kill within 5 years, or occasional (less than once per year) severe violations of Wisconsin standards for key water quality characteristics.
3	Fair	No known fish kills within 5 years, but site either is located in critical non-point source pollution watershed or highly developed urban or suburban area where poor quality runoff is possible, or occasionally suffers from minor violations of Wisconsin standards for key water quality characteristics.
4	Good	No evidence of fish kills or violations of Wisconsin standards for key water quality characteristics. Site located in an area where poor quality runoff is unlikely.

ASSESSMENT OF POTENTIAL METRICS

I selected metrics for the Wisconsin version of the IBI based on the magnitude of their correlation with environmental quality and their appropriateness for use in all parts of the State. Using these criteria, I chose to retain the following metrics, all of which are also used in the Ohio EPA (1988) "wading sites" version of the IBI:

- Percent tolerant species
- Percent omnivores
- Percent insectivores
- Percent top carnivores
- Percent simple lithophilous spawners

I also retained two other metrics as correction factors:

- Number of individuals (excluding tolerant species) per 300 m sampled
- Percent DELT (deformed, eroded fins, lesions, tumors) fish

Number of individuals, or its equivalent, has been used in most other versions of the IBI (Karr *et al.* 1986, Miller *et al.* 1988, Ohio EPA 1988). I did not find a strong relationship between **number of individuals** and environmental quality (table 9), although the lowest

Table 9.—*Correlations (Spearman's Rank Correlation Coefficient) between potential metrics and an independent measure of environmental quality for the 70 sites sampled during 1987-1989*

Potential metric	Correlation coefficient (r)	Significance value (p)
Percent green sunfish	-0.50	0.0001
Percent tolerant species	-0.57	0.0001
Percent common carp	-0.45	0.0001
Percent creek chub	0.16	0.1934
Percent white sucker	-0.32	0.0070
Percent omnivores	-0.50	0.0001
Percent facultative omnivores	-0.01	0.9476
Percent generalist feeders	0.16	0.1921
Percent insectivorous Cyprinids	0.17	0.1543
Percent insectivores	0.32	0.0064
Percent top carnivores	0.58	0.0001
Percent hybrids	-0.29	0.0157
Percent simple lithophilous spawners	0.25	0.0372
Number of individuals per 300 m sampled	0.15	0.2096
Percent DELT fish	-0.15	0.2084

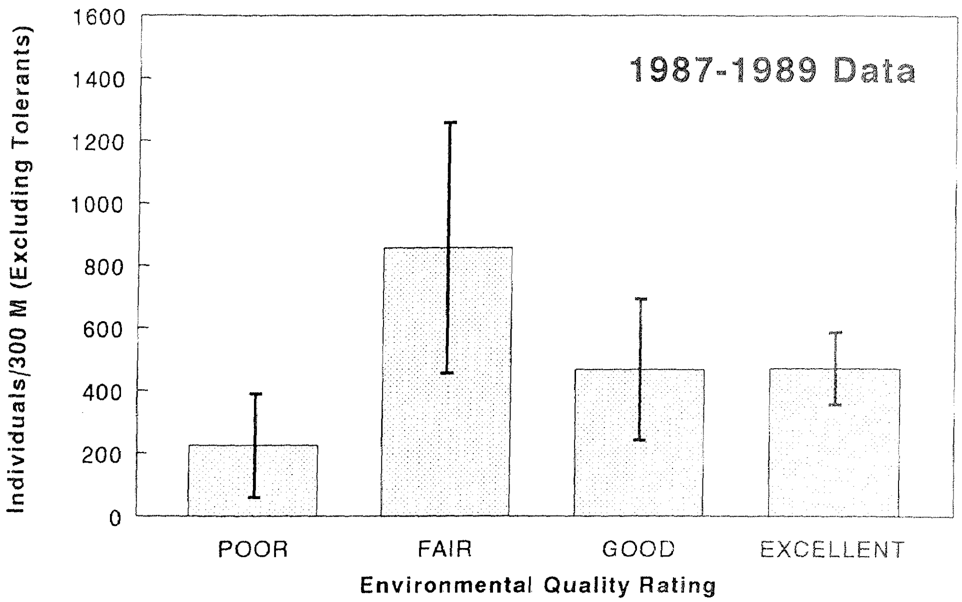

Figure 14.—*Plot of mean catch of individuals per 300 m sampled (excluding tolerant species) for four levels of the Environmental Quality Rating. The Poor rating was given to sites with environmental quality scores from 0 to 24, the Fair rating was given to sites with scores from 25 to 49, the Good rating was given to sites with scores from 50 to 74, and the Excellent rating was given to sites with scores from 75 to 100. Lines bisecting the bars indicate the 95 percent confidence limits of the mean.*

numbers occurred at the sites with the worst environmental quality (fig 14; ANOVA and Bonferroni Multiple Comparisons Test of log(Catch + 1); $F = 7.15$, $p = 0.0003$). The highest numbers occurred at sites with fair environmental quality. Therefore, the **number of individuals correction factor** only influences the overall IBI score when the **number of individuals** is very low.

Percent DELT fish has also been used in most other versions of the IBI (Karr *et al.* 1986, Miller *et al.* 1988, Ohio EPA 1988). However, very few DELT fish were encountered in Wisconsin during the 1987-1989 sampling. Of 70 sites, 24 had DELT fish, but no site had more than four, and the maximum percentage was 0.5 percent. There was not a significant relationship between relative abundance of DELT fish and environmental quality (table 9). However, other studies have found high numbers of DELT fish at grossly polluted sites (Karr *et al.* 1988, Ohio EPA 1988). Only a few such sites were sampled during 1987-1989, so I have retained **percent DELT fish** as a correction factor that only influences the overall IBI score when the proportion of DELT fish is high.

I rejected the following eight metrics:

Percent common carp—Common carp (*Cyprinus carpio*) relative abundance tends to increase with increasing environmental degradation (Karr *et al.* 1986, Miller *et al.* 1988). However, carp reach the northern edge of their range in Wisconsin and are rare in northern Wisconsin (Becker 1983). They also do not occur in high abundance in high gradient streams (Lyons 1989). Although **percent common carp** was negatively correlated with environmental quality, the **percent tolerant species metric** (of which carp form a part) had a better correlation (table 9).

Percent creek chub—Creek chub relative abundance is often high at degraded sites (Karr *et al.* 1986, Leonard and Orth 1986). However, creek chubs usually do best in small streams and tend to be uncommon in larger streams (Becker 1983). **Percent creek chub** was not correlated with environmental quality (table 9).

Percent green sunfish—Green sunfish relative abundance tends to increase with increasing environmental degradation (Karr *et al.* 1986). However, green sunfish reach the northern edge of their range in Wisconsin and are rare in northern Wisconsin (Becker 1983). They also do best in small streams and tend to be uncommon in larger streams (Ohio EPA 1988). Although, **percent green sunfish** was negatively correlated with environmental quality, the **percent tolerant species metric** (of which green sunfish form a part) had a better correlation (table 9).

Percent white sucker—White sucker (*Catostomus commersoni*) relative abundance is often high at degraded sites (Karr *et al.* 1986; Miller *et al.* 1988). Although, **percent white sucker** was negatively correlated with environmental quality, the **percent tolerant species metric** (of which white suckers form a part) had a better correlation (table 9).

Percent facultative omnivores—Under certain degraded conditions, normally insectivorous common shiners (*Luxilus cornutus*) and spotfin shiners (*Cyprinella spiloptera*) may have an omnivorous diet (Ohio EPA 1988). However, the combined relative abundance of these two species was not correlated with environmental quality (table 9).

Percent generalist feeders—Creek chubs and blacknose dace have varied, broad diets, and often respond positively to environmental degradation and food web disruption in the same manner as omnivores (Leonard and Orth 1986, Ohio EPA 1988, Steedman 1988). However, the combined relative abundance of these two species was not correlated with environmental quality (table 9).

Percent insectivorous cyprinids—Insectivorous cyprinids tend to decline as environmental degradation increases (Karr *et al.* 1986). However, they are naturally rare in very low gradient streams (Lyons, unpublished data). Additionally, the relative abundance of insectivorous cyprinids was not correlated with environmental quality (table 9).

Percent hybrids—Hybrids are often common at degraded sites. However, hybrids are difficult to identify, and they were rare in the 1987-1989 data set.

Scoring criteria for the five metrics chosen for inclusion in the Wisconsin IBI were based on the distribution of station values for each metric. The four stations (5.7 percent of total) with the best values for each metric (highest or lowest values, depending on the nature of the metric) determined the expected value for streams with good environmental quality. Stations with metric values near this expected value scored a 10 for that metric. Stations with metric values much worse than the expected value scored a 0, and stations with intermediate values received an intermediate score.

Other versions of the IBI rate metrics on a scoring scale from 1 (worst) to 5 (best) (Karr *et al.* 1986, Leonard and Orth 1986, Miller *et al.* 1988, Steedman 1988). Most of these other versions have 12 metrics, resulting in a possible range of IBI values from 12 (worst) to 60 (best). Wisconsin biologists unfamiliar with the IBI tend to not like this scoring range, and several of them requested that the Wisconsin version have a more easily interpretable scale (personal observations). Thus, I have scaled the Wisconsin IBI from 0 to 100, scoring each metric over a range of 0 to 10.

Validation

To validate whether the Wisconsin IBI truly reflected the environmental quality of a stream, I tested whether there was a significant positive relationship between the overall IBI score and independent measures of environmental quality.

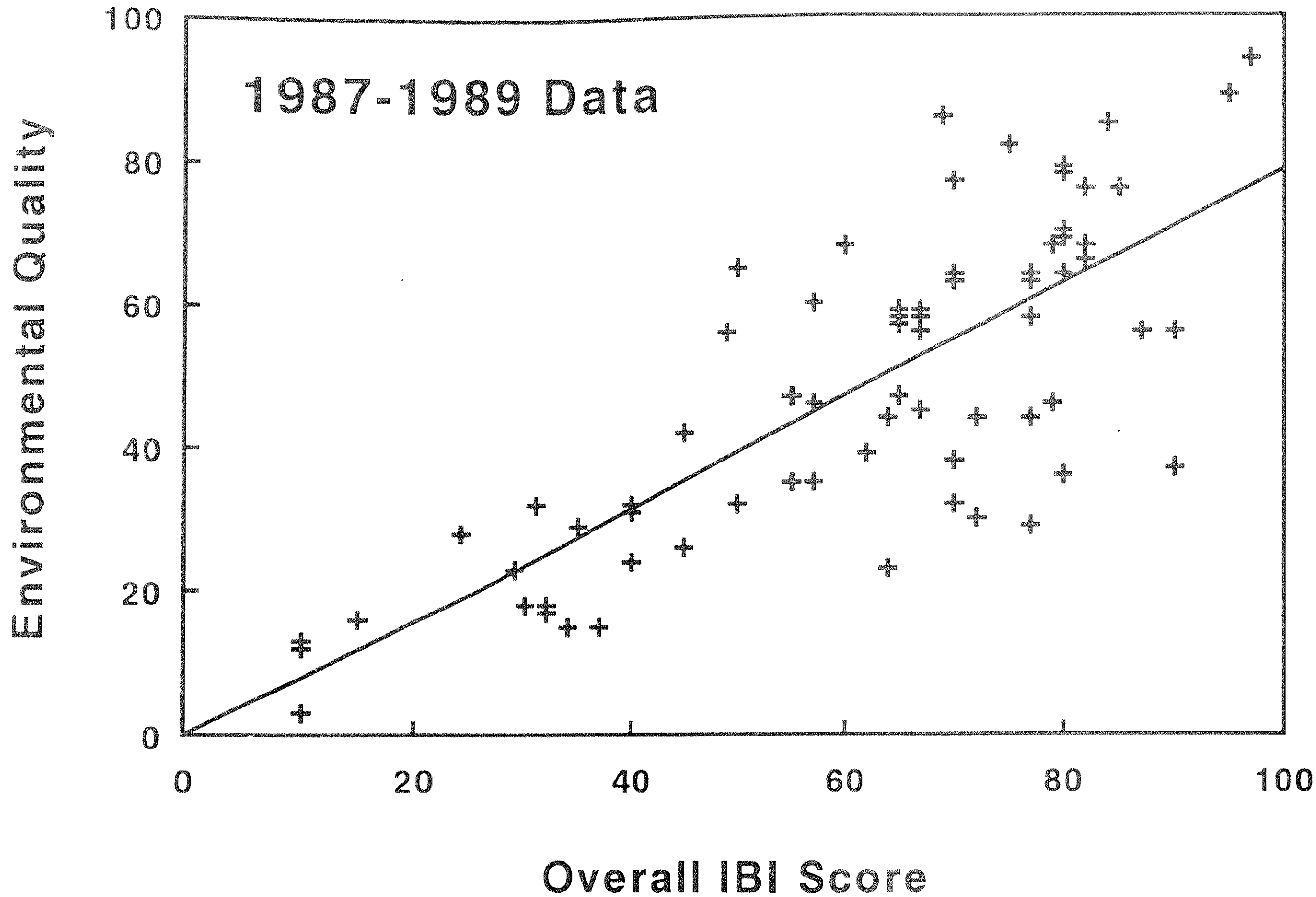

Figure 15.—*Plot of environmental quality versus overall IBI score for the 70 sites sampled during 1987-1989. Environmental quality and overall IBI score are significantly positively related (Spearman's* r = *0.74;* p < *0.0001), and the relationship is indicated by the solid line.*

The overall score for the Wisconsin IBI is the sum of the scores for all 10 metrics, minus any correction factors for extreme values for the number of individuals and percent DELT fish metrics. I calculated overall IBI scores for the 1987 through 1989 data and then compared these scores to the habitat quality rating, the water quality rating, and the overall environmental quality rating for each station (see Appendix 4 for actual values).

Overall IBI scores for the stations sampled in 1987 through 1989 were significantly related to independent measures of environmental quality. IBI scores were strongly positively correlated with overall environmental quality ratings (fig. 15; Spearman Rank Correlation Coefficient = 0.74, $p < 0.0001$). IBI scores were also positively correlated with the habitat quality rating (Spearman Rank Correlation Coefficient = 0.55, $p < 0.0001$). A one-way analysis of variance (ANOVA) and Bonferroni multiple comparisons test indicated that stations with higher IBI scores had better water quality ratings ($F = 42.50$, $p < 0.0001$).

The strong positive relationships between IBI scores and independent measures of environmental quality represent only a partial validation of the Wisconsin IBI. The species composition, trophic and reproductive function, and abundance and condition metrics were chosen and developed so that they reflected environmental conditions at each station. In a sense,

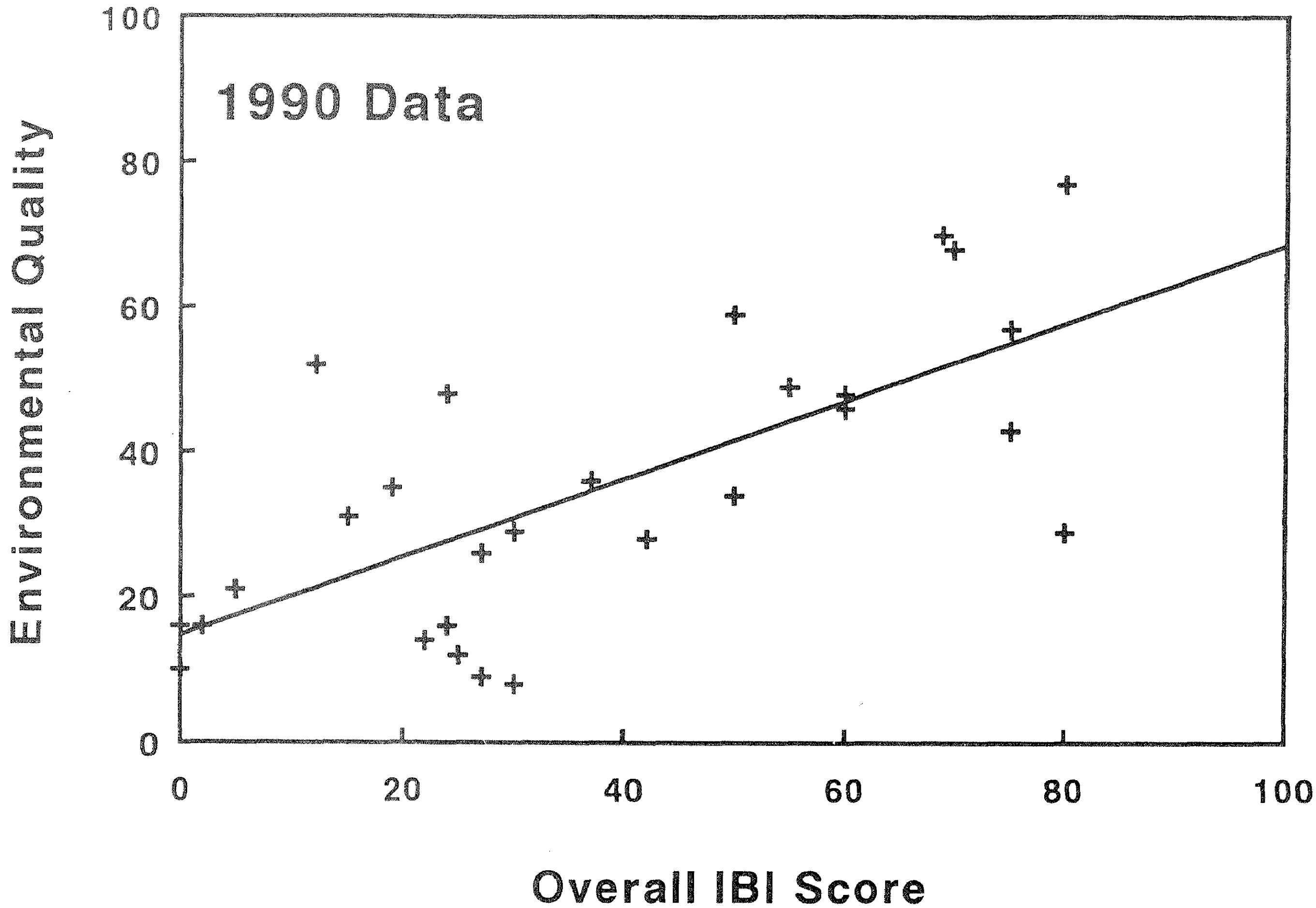

Figure 16.—*Plot of environmental quality versus overall IBI score for the 28 sites sampled during 1990. Environmental quality and overall IBI score are significantly positively related (Spearman's* r = *0.60;* p = *0.0007), and the relationship is indicated by the solid line.*

the IBI was developed to mimic patterns of environmental quality at a specific set of stations. Determining whether IBI scores were likely to reflect environmental quality at other stations required an independent test using data from a new set of stations.

I carried out this test with data from 1990. The research study that produced the 1987-1989 data continued into 1990, with data collected in the same manner as previously. In 1990, a total of 28 stations on 16 streams were sampled. Seven of these stations on four streams had also been sampled during 1987-1989, but the rest were sampled for the first time. I related IBI scores to environmental quality ratings for the 1990 set of stations.

Analysis of 1990 data validated the Wisconsin version of the IBI. Overall IBI scores were again strongly positively correlated with overall environmental quality ratings (fig. 16; Spearman Rank Correlation Coefficient = 0.60, p = 0.0007). IBI scores were also positively correlated with the habitat quality rating, although the correlation was only marginally significant (Spearman Rank Correlation Coefficient = 0.31, p = 0.1071). The weaker relationship between IBI scores and habitat ratings occurred because three of the 1990 stations had fair to good habitat but very poor water quality and hence very low IBI scores. A one-way ANOVA and Bonferroni multiple comparisons test again indicated that stations with higher IBI scores had better water quality ratings (F = 8.17, p = 0.0006).

Table 10.—*IBI and environmental quality data for sites sampled during 1987-1989; higher scores indicate better quality*

Stream	County	Mile[1]	IBI[2]	EQ[3]	HQ[4]	WQ[5]
Amnicon R.	Douglas	5.7	80	69	69	4
Big Plover R.	Portage	7.4	80	70	70	4
Big Plover R.	Portage	8.8	80	64	64	4
Big Rib R.	Marathon	13.1	64	44	59	3
Big Rib R.	Marathon	14.7	82	66	66	4
Big Rib R.	Marathon	16.5	77	63	63	4
Big Rib R.	Marathon	17.9	50	32	32	4
Big Rib R.	Marathon	18.0	77	58	58	4
Big Rib R.	Marathon	19.0	79	68	68	4
Big Roche a Cri Cr.	Adams	2.0	77	64	64	4
Big Roche a Cri Cr.	Adams	6.8	50	65	65	4
Cedar Cr.	Washington	18.5	45	26	34	3
Cedar Cr.	Washington	19.4	37	15	20	3
Crawfish R.	Dodge	37.8	57	35	47	3
Crawfish R.	Dodge	38.7	45	42	56	3
Crawfish R.	Dodge	39.6	79	46	61	3
East Fork Chippewa R.	Ashland	24.1	80	79	79	4
East R.	Brown	10.6	10	12	24	2
Embarrass R.	Shawano	46.6	84	85	85	4
Galena R.	Lafayette	29.8	29	23	45	2
Goose Lake Canal	Racine	2.4	10	3	5	2
Hay R.	Dunn	16.6	67	59	78	3
Jump R.	Rusk	3.5	95	89	89	4
Jump R.	Rusk	7.2	82	76	76	4
Little Platte R.	Grant	19.4	35	29	57	2
Little Wolf R.	Waupaca	9.9	85	76	76	4
Livingston Br.	Iowa	2.5	32	18	36	2
Manitowish R.	Vilas	31.4	65	58	58	4
Mecan R.	Marquette	9.5	49	56	56	4
Menominee Cr.	Grant	7.7	40	31	62	2
Menomonee R.	Milwaukee	3.0	15	16	64	1
Menomonee R.	Milwaukee	5.7	10	13	50	1
Milwaukee R.	Ozaukee	53.4	65	47	63	3
Milwaukee R. (1988)	Washington	64.6	55	35	47	3
Milwaukee R. (1989)	Washington	64.6	57	46	61	3
Milwaukee R. (1988)	Washington	65.5	30	18	24	3
Milwaukee R. (1989)	Washington	65.5	40	32	42	3
Milwaukee R.	Washington	66.0	24	28	37	3
Milwaukee R. (1988)	Washington	66.8	62	39	52	3
Milwaukee R. (1989)	Washington	66.8	55	47	63	3
Mineral Point Br.	Iowa	12.6	64	23	30	3
Mineral Point Br.	Iowa	13.0	72	44	59	3
Moose R.	Douglas	1.0	70	63	63	4
Moose R.	Sawyer	2.5	67	58	58	4
Mukwonago R.	Waukesha	1.3	80	36	36	4

(Table 10 continued on next page)

(Table 10 continued)

Stream	County	Mile[1]	IBI[2]	EQ[3]	HQ[4]	WQ[5]
North Br. Milwaukee R. (1987)	Washington	4.4	72	30	40	3
North Br. Milwaukee R. (1989)	Washington	4.4	77	44	59	3
North Br. Milwaukee R.	Sheboygan	17.3	40	24	32	3
North Fork Bad Axe R.	Vernon	4.8	70	32	42	3
North Fork Bad Axe R.	Vernon	8.4	77	29	38	3
North Fork Bad Axe R.	Vernon	17.0	67	45	60	3
Oconto R.	Oconto	28.6	82	68	68	4
Pats Cr.	Lafayette	1.8	34	15	29	2
Rat R.	Forest	12.5	70	77	77	4
Rat R.	Forest	24.2	60	68	68	4
Rattlesnake Cr.	Grant	4.8	31	32	64	2
South Fork Flambeau R. (1988)	Price	59.4	90	37	37	4
South Fork Flambeau R. (1989)	Price	59.4	90	56	56	4
South Fork Flambeau R.	Price	62.8	75	82	82	4
South Fork Flambeau R. (1988)	Price	66.8	65	59	59	4
South Fork Flambeau R. (1989)	Price	66.8	70	64	64	4
Sinsinawa R.	Grant	14.7	32	17	34	2
Trout R.	Vilas	10.0	67	56	56	4
West Br. Milwaukee R.	Fond du Lac	0.7	70	38	50	3
West Fork Chippewa R.	Sawyer	14.8	97	94	94	4
West Fork Chippewa R.	Sawyer	20.7	87	56	56	4
West Twin R.	Manitowoc	17.1	69	86	86	4
White R.	Marquette	14.9	65	57	57	4
Willow R.	St. Croix	13.2	57	60	80	3
Yellow R.	Taylor	60.0	80	78	78	4

[1] Mile is the distance in miles from the mouth of the stream to the downstream edge of the site, via the stream channel, and is used to indicate site location.

[2] IBI is the overall IBI score (range 0 to 100; see table 6).

[3] EQ is the overall environmental quality score (range 0-100). The environmental quality score is the product of the habitat and water quality scores, divided by four and rounded to the nearest one point.

[4] HQ is the habitat quality score (range 0 to 99; see fig. 13).

[5] WQ is the water quality score (range 1 to 4; see table 8).

Table 11.—*IBI and environmental quality data for sites sampled during 1990. (See legend from table 10 for explanations of column headings).*

Stream	County	Mile	IBI	EQ	HQ	WQ
Beaver Dam R.	Dodge	18.9	0	10	41	1
Beaver Dam R.	Dodge	20.2	0	16	65	1
Beaver Dam R.	Dodge	26.5	24	16	65	1
Little Platte R.	Grant	19.4	37	36	71	2
Manitowish R.	Iron	11.3	80	77	77	4
Milwaukee R.	Washington	64.6	12	52	69	3
Milwaukee R.	Washington	65.5	24	48	64	3
Milwaukee R.	Washington	66.8	50	59	79	3
Mineral Point Br.	Iowa	12.6	80	29	39	3
North Br. Milwaukee R.	Washington	4.4	60	46	61	3
North Br. Pike R.	Kenosha	0.9	2	16	63	1
North Br. Pike R.	Racine	2.8	27	9	37	1
North Br. Pike R.	Racine	3.8	30	8	30	1
North Fork Eau Claire R.	Eau Claire	11.5	60	48	48	4
Otter Cr.	Lafayette	4.1	50	34	67	2
Otter Cr.	Lafayette	6.6	42	28	55	2
Pike R.	Kenosha	2.6	5	21	42	2
Pike R.	Kenosha	5.9	30	29	57	2
Pike R.	Kenosha	8.3	15	31	62	2
South Br. Pike R.	Kenosha	0.5	27	26	52	2
South Br. Pike R.	Kenosha	2.4	25	12	24	2
South Fork Eau Claire R.	Eau Claire	24.6	69	70	70	4
Squirrel R.	Oneida	6.7	55	49	65	3
Tomahawk R.	Oneida	43.6	75	57	76	3
Tomahawk R.	Oneida	53.6	75	43	57	3
Waumandee Cr.	Buffalo	17.1	19	35	47	3
Waumandee Cr.	Buffalo	21.0	22	14	19	3
Wisconsin R.	Vilas	406.6	70	68	68	4

WHERE NOT TO USE THIS VERSION OF THE IBI

Very Small Warmwater Streams

The nature of fish communities in very small warmwater streams (intermittent and/or <2.5 m wide) differs substantially from that of fish communities in larger warmwater streams, so versions of the IBI developed for intermediate-sized streams are inappropriate for very small streams. In Wisconsin, very small warmwater streams are often harsh, highly variable environments, even in the absence of human perturbation. As a result, their fish communities are usually dominated by a small number of small, mobile, generalist or tolerant species such as the bigmouth shiner (*Notropis dorsalis*), creek chub, fathead minnow (*Pimephales promelas*), blacknose dace, and green sunfish (*Lepomis cyanellus*) (Lyons *et al.* 1988, Lyons 1989). Because these opportunistic species move in and out of small warmwater streams as physical and chemical conditions change, natural variability in fish community structure and function tends to be high. This natural variability makes it difficult to develop an effective version of the IBI for very small warmwater streams. The Ohio EPA (1988) has developed a version of the IBI for very small warmwater streams in Ohio (their "headwater sites" version), but this version has not yet been tested in Wisconsin.

Large Warmwater Streams and Rivers

Warmwater streams and rivers too large to sample effectively by wading require a different version of the IBI than intermediate-sized warmwater streams. Electroshocking by wading cannot effectively sample all areas of large streams and rivers, so large streams and rivers require a more complex sampling scheme than intermediate-sized streams. Usually this scheme involves a combination of sampling techniques and gears (boat electrofishing, gill/trammel netting, trap netting, and/or trawling in deeper areas; wading electrofishing and/or seining in shallow areas) because no one technique alone can give a reasonably complete picture of the fish community in larger streams. The difficulty in applying the IBI lies in combining the sampling results from these different methods. Each sampling method has different biases and capture efficiencies, and simply adding together catches from different sampling techniques and gear types is usually inappropriate. It may be possible to formulate sampling protocols that involve standardized units of effort for combinations of methods, but this has not yet been done. The Ohio EPA (1988) has developed a version of the IBI for larger Ohio rivers (their "boat" sites version) based solely on boat electrofishing, but it is not known how this version will work on larger warmwater streams and rivers in Wisconsin.

Coldwater and Coolwater Streams

In Wisconsin, coldwater streams have maximum daily summer temperatures that rarely exceed 22°C, and coolwater streams have maximum daily summer temperatures that rarely exceed 24°C. Summer water temperatures in warmwater streams regularly surpass these levels. I do not believe that it will be possible to develop a version of the IBI that will be effective for coldwater and coolwater streams in Wisconsin without fundamental changes in the index. This is because the response of Wisconsin coldwater and coolwater streams to many types of degradation violates one of the key underlying assumptions of the Wisconsin IBI and all other versions of the IBI proposed thus far. All current versions of the IBI are based on the assumption that as environmental degradation increases and biotic integrity declines, the number of species declines. In Wisconsin coldwater and coolwater streams, moderate levels of environmental degradation often result in **increased** species richness, and species richness often declines as environmental quality and biotic integrity improve.

For example, consider the case of Timber Coulee Creek in west-central Wisconsin. During the 1960's, poor agricultural land use practices and bank erosion caused biotic integrity in the stream to decline. Once a good coldwater trout stream, habitat in the Timber Coulee Creek had been so degraded that only heavy stocking permitted trout to persist there. Beginning in the late 1960's, the WDNR undertook a massive habitat improvement project over several kilometers of the stream. Riparian land-use practices were improved, banks were stabilized, and instream habitat was greatly enhanced. Biotic integrity improved greatly, and the stream now supports a healthy trout population with many large individuals. Stocking is no longer needed to maintain this population. However, as a consequence of habitat improvement, species richness in Timber Coulee Creek declined by one to six species (8 to 67 percent) depending on location (fig. 17). Improved biotic integrity resulted in **reduced** species richness.

Why do cool/coldwater streams and warmwater streams respond differently to changes in biotic integrity? The answer to this question lies in the temperature preferences of Wisconsin fishes and the relationship between environmental degradation and water temperature in coolwater

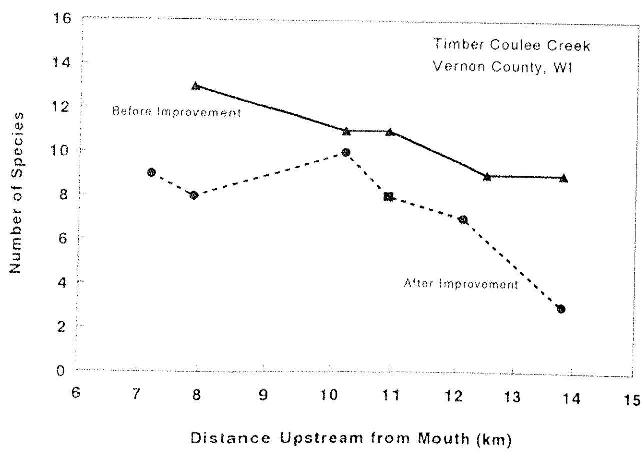

Figure 17.—*Total species richness at several sites in Timber Coulee Creek, west-central Wisconsin, during two time periods. The downstream-most sites are to the left of the plot, and the upstream-most are to the right. Sites sampled in 1966, before habitat and biotic integrity were improved, are indicated by triangles and a solid line. Sites sampled after habitat and biotic integrity were improved are indicated by circles (1976), a square (1980), and a dashed line.*

and coldwater streams. Relatively few Wisconsin fish species can persist in coolwater and coldwater streams, but many can persist in warmwater streams. Thus, high quality coolwater and coldwater streams tend to have lower species richness than comparably sized warmwater streams. Small coldwater streams sometimes contain only one or two species (a trout and a sculpin or a *Rhinichthys* species).

Most types of environmental degradation lead to increased maximum summer water temperatures. For example, poor land-use practices and increased erosion often result in a reduction of cold groundwater or spring inputs to streams, removal of riparian vegetation and decreased shading of streams, and wider, shallower stream channels that more effectively absorb solar radiation. As streams become degraded, summer water temperatures will often increase enough to permit colonization by warmwater species. Even if water temperatures increase to the point where coolwater or coldwater species are eliminated, a greater number of warmwater species will probably be able to take their place. Thus, species richness will increase even though environmental quality, and with it biotic integrity, have declined.

Some coolwater and coldwater streams are degraded to the point where they have become warmwater streams. With improvements in environmental quality, these streams might again become coolwater or coldwater and decline in species richness. As presently formulated, the IBI may not be the most appropriate tool for assessing biotic integrity in these streams. But how can potential coolwater and coldwater streams be identified?

Coolwater and coldwater streams have characteristic fish faunas. As these types of streams become degraded, their fish faunas are joined and ultimately replaced by generalist and tolerant warmwater species. Moderately degraded coolwater and coldwater streams usually have a mixed fish fauna, with some coldwater or coolwater species and some warmwater species. By examining species composition, it may be possible to identify potential coolwater or coldwater streams that have been converted to warmwater by environmental degradation.

Table 12 lists species generally restricted to coldwater and coolwater streams in Wisconsin. These "primary" coolwater and coldwater species tend to decline as environmental degradation increases and stream temperatures approach warmwater levels. Table 12 also lists a group of species that does well in both coolwater and warmwater streams, and in some cases even coldwater streams. These "secondary" coolwater species are usually among the first to invade coolwater or coldwater streams that have increased in temperature. Some of them (*e.g.*, fathead minnow, blacknose dace, creek chub, white sucker) are highly tolerant of degradation and can become quite abundant as environmental quality declines.

A good indication of whether or not a moderately degraded warmwater stream is a potential coolwater or coldwater stream is the number of primary coolwater and coldwater species coupled with the relative abundance of secondary coolwater species. A rule of thumb is that if at least three primary coolwater or coldwater species are present and most individuals are either primary or secondary coolwater species, a site is probably potentially coolwater or coldwater.

If the IBI is not a good measure of biotic integrity and environmental quality in actual or potential coolwater and coldwater streams, then what measure should be used? Little research has been done on this question, and any recommendations must be regarded as tentative. With this in mind, I suggest using the relative abundance, age/size structure, and condition of any primary coolwater and coldwater fishes present as indicators of environmental quality.

Table 12.—*Wisconsin fishes that are primarily found in coldwater streams (primary coldwater) or coolwater streams (primary coolwater) and that occur commonly in both coolwater and warmwater streams (secondary coolwater)*[1].

Classification	Species
Primary coldwater	Pink Salmon, Coho Salmon, Rainbow Trout, Chinook Salmon, Brown Trout, Brook Trout, Longnose Sucker, Mottled Sculpin, Slimy Sculpin
Primary coolwater	Northern Brook Lamprey, Southern Brook Lamprey, American Brook Lamprey, Sea Lamprey, Alewife, Rainbow Smelt, Muskellunge, Redside Dace, Lake Chub, Brassy Minnow, Northern Redbelly Dace, Finescale Dace, Pearl Dace, Burbot, Brook Stickleback, Threespine Stickleback, Ruffe
Secondary coolwater	Central Mudminnow, Northern Pike, Emerald Shiner, Spottail Shiner, Southern Redbelly Dace, Fathead Minnow, Blacknose Dace, Longnose Dace, Creek Chub, White Sucker, Troutperch, Rock Bass, Smallmouth Bass, Iowa Darter, Johnny Darter, Yellow Perch, Logperch, Walleye

[1]Scientific names are given in Appendix 4, Table 13.

CONSTRUCTING MSR PLOTS

Maximum Species Richness (MSR) plots are constructed as follows: For all appropriate sites (75 in this example) in the database, graph number of species (Y axis) versus the natural log of mean stream width in meters (X axis) (fig. 18). Place a ruler along the y axis. Pivot the ruler to the right, with the ruler anchored at the origin. When the pivoting ruler has passed 5 percent of the total data points (3.75 points in this example [0.05 X 75]), stop the ruler and draw a straight line from the origin to the height of the maximum number of species observed (9 in this example). Then continue the line horizontally to the right at this height, parallel to the X axis. This line is the Maximum Species Richness (MSR) Line. At the point where the MSR line shifts from ascending to horizontal, drop a perpendicular line to the X axis (X = 2.9 in this example). Divide this perpendicular line into three equal segments. Draw lines from the origin to each of the two points that divide the perpendicular line into segments. Continue these two lines horizontally to the right from the division points, parallel to the X axis. The upper of these two lines is the First Trisection Line, and the lower is the Second Trisection Line.

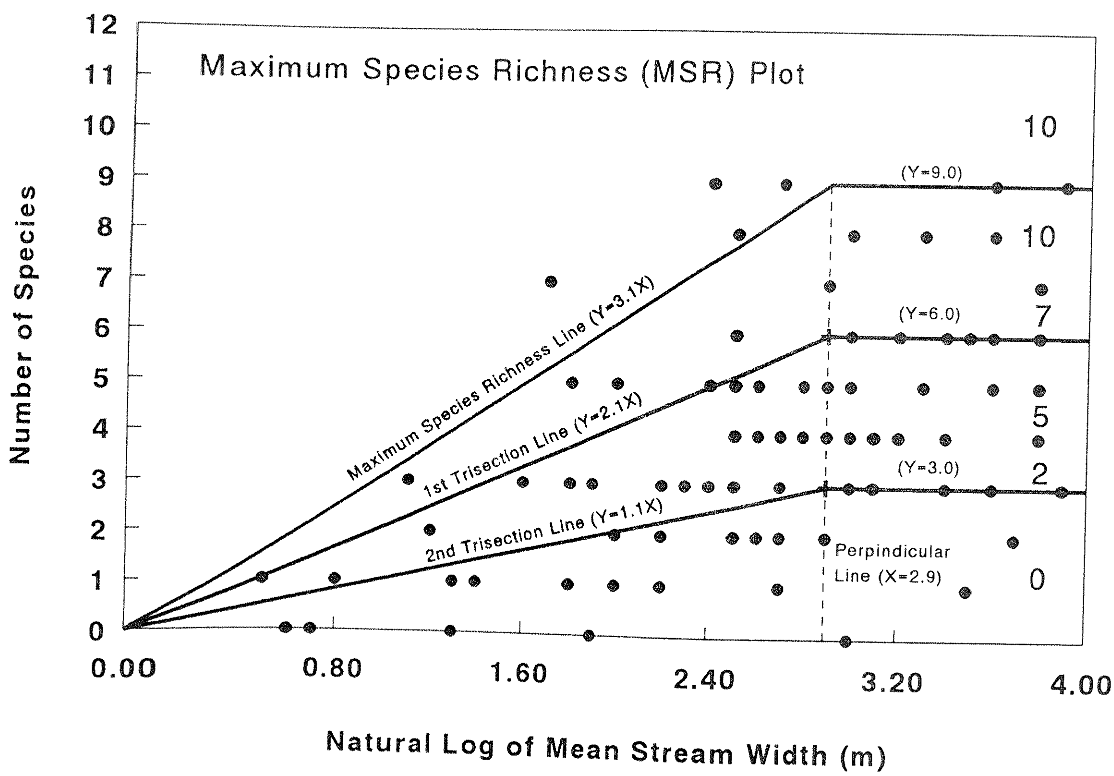

Figure 18.—*Example of a Maximum Species Richness (MSR) plot, which is used to generate scoring criteria for species richness metrics in streams of different sizes. Lines are positioned based on the distribution of points. Equations for each line segment are given in parentheses. Numbers along the right part of the figure denote scoring values for different regions of the plot.*

APPENDIX 4
IBI CLASSIFICATION OF WISCONSIN FISHES

Table 13.—*Classification of Wisconsin fishes into taxonomic, tolerance, feeding, and spawning groups for calculation of IBI metrics. Fish are listed in order of their* **Code**. *Common and scientific names follow Robins et al. (1991). For the lamprey common names: "N." = Northern; "Am." = American; "S." = Southern; "Brk." = Brook.*

Code: *the Wisconsin Department of Natural Resources fish species code (Fago 1988). The code is useful for identifying species in computer applications of the IBI. A code in parentheses indicates that the species has been extirpated from the State.*

Taxa: *the taxonomic groups used in species richness metrics. C = Catostomid (Sucker); D = Darter; E = Exotic; S = Sunfish.*

Tolerance: *the ability of a species to tolerate environmental degradation and severe environmental conditions. I = Intolerant; T = Tolerant.*

Feeding: *the feeding or trophic classification of a species. Fi = Filter Feeder (planktivore); Ge = Generalist Feeder; He = Herbivore; In = Insectivore; Om = Omnivore; Pa = Parasite; Tc = Top Carnivore (piscivore). The Fi, Ge, He, and Pa groups are not used in the calculation of metrics. A "-" after the three species of brook lampreys indicates that these species do not feed as adults.*

Spawning: *the spawning behavior and habitat of a species. SL = Simple Lithophilous.*

Common name	Scientific name	Code	IBI Classification			
			Taxa	Tolerance	Feeding	Spawning
LAMPREYS	PETROMYZONTIDAE					
Chestnut Lamprey (ammocoete)	*Ichthyomyzon castaneus*	A02	-	I	Fi	-
Chestnut Lamprey (adult)	*Ichthyomyzon castaneus*	A02	-	-	Pa	-
N. Brook Lamprey (ammocoete)	*Ichthyomyzon fossor*	A03	-	I	Fi	-
N. Brook Lamprey (adult)	*Ichthyomyzon fossor*	A03	-	I	-	-
Silver Lamprey (ammocoete)	*Ichthyomyzon unicuspis*	A04	-	I	Fi	-
Silver Lamprey (adult)	*Ichthyomyzon unicuspis*	A04	-	-	Pa	-
Am. Brk. Lamprey (ammocoete)	*Lampetra appendix*	A05	-	I	Fi	-
Am. Brk. Lamprey (adult)	*Lampetra appendix*	A05	-	I	-	-
Sea Lamprey (ammocoete)	*Petromyzon marinus*	A06	E	I	Fi	-
Sea Lamprey (adult)	*Petromyzon marinus*	A06	E	-	Pa	-
S. Brook Lamprey (ammocoete)	*Ichthyomyzon* cf. *gagei*	A07	-	I	Fi	-
S. Brook Lamprey (adult)	*Ichthyomyzon* cf. *gagei*	A07	-	I	-	-
STURGEONS	ACIPENSERIDAE					
Lake Sturgeon	*Acipenser fulvescens*	B01	-	-	In	SL
Shovelnose Sturgeon	*Scaphirhynchus platorynchus*	B02	-	-	In	SL
PADDLEFISHES	POLYODONTIDAE					
Paddlefish	*Polyodon spathula*	C01	-	-	Fi	SL

(Table 13 continued on next page)

(Table 13 continued)

Common name	Scientific name	Code	IBI Classification			
			Taxa	Tolerance	Feeding	Spawning
GARS	LEPISOSTEIDAE					
Longnose Gar	*Lepisosteus osseus*	D01	-	-	Tc	-
Shortnose Gar	*Lepisosteus platostomus*	D02	-	-	Tc	-
BOWFINS	AMIIDAE					
Bowfin	*Amia calva*	E01	-	-	Tc	-
FRESHWATER EELS	ANGUILLIDAE					
American Eel	*Anguilla rostrata*	F01	-	-	Tc	-
HERRINGS	CLUPEIDAE					
Alewife	*Alosa pseudoharengus*	G01	E	-	Fi	-
Gizzard Shad	*Dorosoma cepedianum*	G02	-	-	Fi	-
Skipjack Herring	*Alosa chrysochloris*	G03	-	-	Tc	-
MOONEYES	HIODONTIDAE					
Goldeye	*Hiodon alosoides*	H01	-	-	In	-
Mooneye	*Hiodon tergisus*	H02	-	-	In	-
TROUTS	SALMONIDAE					
Cisco (Lake Herring)	*Coregonus artedi*	I04	-	-	Fi	-
Lake Whitefish	*Coregonus clupeaformis*	I05	-	-	In	-
Bloater	*Coregonus hoyi*	I06	-	-	Fi	-
Deepwater Cisco	*Coregonus johannae*	(I07)	-	-	Fi?	-
Kiyi	*Coregonus kiyi*	I08	-	-	Fi	-
Blackfin Cisco	*Coregonus nigripinnis*	(I09)	-	-	Fi	-
Shortnose Cisco	*Coregonus reighardi*	(I10)	-	-	Fi?	-
Shortjaw Cisco	*Coregonus zenithicus*	I11	-	-	Fi	-
Pink Salmon	*Oncorhynchus gorbuscha*	I12	E	-	Tc	-
Coho Salmon	*Oncorhynchus kisutch*	I13	E	-	Tc	-
Chinook Salmon	*Oncorhynchus tshawytscha*	I16	E	-	Tc	-
Pygmy Whitefish	*Prosopium coulteri*	I17	-	-	In	-
Round Whitefish	*Prosopium cylindraceum*	I18	-	-	In	-
Rainbow Trout	*Oncorhynchus mykiss*	I19	E	-	Tc	-
Atlantic Salmon	*Salmo salar*	I20	E	-	Tc	-
Brown Trout	*Salmo trutta*	I21	E	-	Tc	-
Brook Trout	*Salvelinus fontinalis*	I22	-	I	Tc	-
Lake Trout	*Salvelinus namaycush*	I23	-	-	Tc	-
SMELTS	OSMERIDAE					
Rainbow Smelt	*Osmerus mordax*	J01	E	-	Fi	-
MUDMINNOWS	UMBRIDAE					
Central Mudminnow	*Umbra limi*	K01	-	T	In	-

(Table 13 continued on next page)

(Table 13 continued)

Common name	Scientific name	Code	IBI Classification Taxa	Tolerance	Feeding	Spawning
PIKES	ESOCIDAE					
Grass Pickerel	*Esox americanus vermiculatus*	L01	-	-	Tc	-
Northern Pike	*Esox lucius*	L02	-	-	Tc	-
Muskellunge	*Esox masquinongy*	L03	-	I	Tc	-
MINNOWS	CYPRINIDAE					
Central Stoneroller	*Campostoma anomalum*	M06	-	-	He	-
Largescale Stoneroller	*Campostoma oligolepis*	M07	-	-	He	-
Goldfish	*Carassius auratus*	M08	E	T	Om	-
Redside Dace	*Clinostomus elongatus*	M09	-	I	In	SL
Lake Chub	*Couesius plumbeus*	M10	-	-	In	SL
Grass Carp	*Ctenopharyngodon idella*	M11	E	-	He	-
Common Carp	*Cyprinus carpio*	M12	E	T	Om	-
Brassy Minnow	*Hybognathus hankinsoni*	M14	-	-	He	-
Mississippi Silvery Minnow	*Hybognathus nuchalis*	M15	-	I	He	-
Speckled Chub	*Macrhybopsis aestivalis*	M16	-	I	In	-
Silver Chub	*Macrhybopsis storeriana*	M17	-	-	In	-
Gravel Chub	*Erimystax x-punctatus*	M18	-	I	In	SL
Hornyhead Chub	*Nocomis biguttatus*	M19	-	-	In	-
Golden Shiner	*Notemigonus crysoleucas*	M20	-	T	Om	-
Pallid Shiner	*Notropis amnis*	M21	-	I	In	-
Pugnose Shiner	*Notropis anogenus*	M22	-	I	He	-
Emerald Shiner	*Notropis atherinoides*	M23	-	-	In	SL
River Shiner	*Notropis blennius*	M24	-	-	In	SL
Ghost Shiner	*Notropis buchanani*	(M25)	-	I	In	-
Ironcolor Shiner	*Notropis chalybaeus*	(M26)	-	-	In	-
Striped Shiner	*Luxilus chrysocephalus*	M27	-	-	In	SL
Common Shiner	*Luxilus cornutus*	M28	-	-	In	SL
Bigmouth Shiner	*Notropis dorsalis*	M29	-	-	In	-
Pugnose Minnow	*Opsopoeodus emiliae*	M30	-	-	In	-
Blackchin Shiner	*Notropis heterodon*	M31	-	I	In	-
Blacknose Shiner	*Notropis heterolepis*	M32	-	I	In	-
Spottail Shiner	*Notropis hudsonius*	M33	-	I	In	-
Ozark Minnow	*Notropis nubilus*	M34	-	I	He	SL
Rosyface Shiner	*Notropis rubellus*	M35	-	I	In	SL
Spotfin Shiner	*Cyprinella spiloptera*	M36	-	-	In	-
Sand Shiner	*Notropis stramineus*	M37	-	-	In	-
Weed Shiner	*Notropis texanus*	M38	-	I	He	-
Redfin Shiner	*Lythrurus umbratilis*	M39	-	-	In	-
Mimic Shiner	*Notropis volucellus*	M40	-	-	In	-
Suckermouth Minnow	*Phenacobius mirabilis*	M41	-	-	In	SL
Northern Redbelly Dace	*Phoxinus eos*	M42	-	-	He	-
Southern Redbelly Dace	*Phoxinus erythrogaster*	M43	-	-	He	SL
Finescale Dace	*Phoxinus neogaeus*	M44	-	-	In	-
Bluntnose Minnow	*Pimephales notatus*	M45	-	T	Om	-
Fathead Minnow	*Pimephales promelas*	M46	-	T	Om	-
Bullhead Minnow	*Pimephales vigilax*	M47	-	-	Om	-

(Table 13 continued on next page)

Common name	Scientific name	Code	IBI Classification			
			Taxa	Tolerance	Feeding	Spawning
Blacknose Dace	*Rhinichthys atratulus*	M48	-	T	Ge	SL
Longnose Dace	*Rhinichthys cataractae*	M49	-	-	In	SL
Creek Chub	*Semotilus atromaculatus*	M50	-	T	Ge	-
Pearl Dace	*Margariscus margarita*	M51	-	-	In	-
Red Shiner	*Cyprinella lutrensis*	(M52)	-	T	Om	-
Rudd	*Scardinius erythrophthalmus*	M53	E	T	Om	-
Channel Shiner	*Notropis wickliffi*	M54	-	-	In	-
SUCKERS	CATOSTOMIDAE					
River Carpsucker	*Carpiodes carpio*	N05	C	-	Om	-
Quillback	*Carpiodes cyprinus*	N06	C	-	Om	-
Highfin Carpsucker	*Carpiodes velifer*	N07	C	I	Om	-
Longnose Sucker	*Catostomus catostomus*	N08	C	-	In	SL
White Sucker	*Catostomus commersoni*	N09	C	T	Om	SL
Blue Sucker	*Cycleptus elongatus*	N10	C	I	In	SL
Creek Chubsucker	*Erimyzon oblongus*	(N11)	C	-	In	-
Lake Chubsucker	*Erimyzon sucetta*	N12	C	-	In	-
Northern Hog Sucker	*Hypentilium nigricans*	N13	C	I	In	SL
Smallmouth Buffalo	*Ictiobus bubalus*	N14	C	-	In	-
Bigmouth Buffalo	*Ictiobus cyprinellus*	N15	C	-	In	-
Black Buffalo	*Ictiobus niger*	N16	C	I	In	-
Spotted Sucker	*Minytrema melanops*	N17	C	I	In	SL
Silver Redhorse	*Moxostoma anisurum*	N18	C	-	In	SL
River Redhorse	*Moxostoma carinatum*	N19	C	-	In	SL
Black Redhorse	*Moxostoma duquesnei*	(N20)	C	-	In	SL
Golden Redhorse	*Moxostoma erythrurum*	N21	C	-	In	SL
Shorthead Redhorse	*Moxostoma macrolepidotum*	N22	C	-	In	SL
Greater Redhorse	*Moxostoma valenciennesi*	N23	C	I	In	SL
BULLHEAD CATFISHES	ICTALURIDAE					
Black Bullhead	*Ameiurus melas*	O05	-	-	In	-
Yellow Bullhead	*Ameiurus natalis*	O06	-	T	In	-
Brown Bullhead	*Ameiurus nebulosus*	O07	-	-	In	-
Channel Catfish	*Ictalurus punctatus*	O08	-	-	Tc	-
Slender Madtom	*Noturus exilis*	O09	-	I	In	-
Stonecat	*Noturus flavus*	O10	-	-	In	-
Tadpole Madtom	*Noturus gyrinus*	O11	-	-	In	-
Flathead Catfish	*Pylodictis olivaris*	O12	-	-	Tc	-
PIRATE PERCHES	APHREDODERIDAE					
Pirate Perch	*Aphredoderus sayanus*	P01	-	-	In	-
TROUTPERCHES	PERCOPSIDAE					
Troutperch	*Percopsis omiscomaycus*	Q01	-	-	In	-
CODFISHES	GADIDAE					
Burbot	*Lota lota*	R01	-	-	Tc	SL

(Table 13 continued on next page)

(Table 13 continued)

Common name	Scientific name	Code	IBI Classification			
			Taxa	Tolerance	Feeding	Spawning
KILLIFISHES	CYPRINODONTIDAE					
Banded Killifish	*Fundulus diaphanus*	S01	-	-	In	-
Blackstripe Topminnow	*Fundulus notatus*	S02	-	-	In	-
Starhead Topminnow	*Fundulus dispar*	S03	-	-	In	-
SILVERSIDES	ATHERINIDAE					
Brook Silverside	*Labidesthes sicculus*	T01	-	-	In	-
STICKLEBACKS	GASTEROSTEIDAE					
Brook Stickleback	*Culaea inconstans*	U01	-	-	In	-
Ninespine Stickleback	*Pungitius pungitius*	U02	-	-	In	-
Threespine Stickleback	*Gasterosteus aculeatus*	U03	E	-	In	-
TEMPERATE BASSES	PERCICHTHYIDAE					
White Bass	*Morone chrysops*	V01	-	-	Tc	-
Yellow Bass	*Morone mississipiensis*	V02	-	-	Tc	-
White Perch	*Morone americana*	V03	E	-	In	-
SUNFISHES	CENTRARCHIDAE					
Rock Bass	*Ambloplites rupestris*	W04	S	I	Tc	-
Green Sunfish	*Lepomis cyanellus*	W05	S	T	In	-
Pumpkinseed	*Lepomis gibbosus*	W06	S	-	In	-
Warmouth	*Lepomis gulosus*	W07	S	-	Tc	-
Orangespotted Sunfish	*Lepomis humilis*	W08	S	-	In	-
Bluegill	*Lepomis macrochirus*	W09	S	-	In	-
Longear Sunfish	*Lepomis megalotis*	W10	S	I	In	-
Smallmouth Bass	*Micropterus dolomieu*	W11	-	I	Tc	-
Largemouth Bass	*Micropterus salmoides*	W12	-	-	Tc	-
White Crappie	*Pomoxis annularis*	W13	S	-	Tc	-
Black Crappie	*Pomoxis nigromaculatus*	W14	S	-	Tc	-
PERCHES	PERCIDAE					
Crystal Darter	*Ammocrypta asprella*	X03	D	I	In	SL
Western Sand Darter	*Ammocrypta clara*	X04	D	-	In	-
Mud Darter	*Etheostoma asprigene*	X05	D	-	In	-
Rainbow Darter	*Etheostoma caeruleum*	X07	D	I	In	SL
Bluntnose Darter	*Etheostoma chlorosomum*	X08	D	-	In	-
Iowa Darter	*Etheostoma exile*	X09	D	I	In	-
Fantail Darter	*Etheostoma flabellare*	X10	D	-	In	-
Least Darter	*Etheostoma microperca*	X11	D	I	In	-
Johnny Darter	*Etheostoma nigrum*	X12	D	-	In	-
Banded Darter	*Etheostoma zonale*	X14	D	I	In	SL
Yellow Perch	*Perca flavescens*	X15	-	-	In	-
Logperch	*Percina caprodes*	X16	D	-	In	SL

(Table 13 continued on next page)

(*Table 13 continued*)

Common name	Scientific name	Code	IBI Classification			
			Taxa	Tolerance	Feeding	Spawning
Gilt Darter	*Percina evides*	X17	D	I	In	SL
Blackside Darter	*Percina maculata*	X18	D	-	In	SL
Slenderhead Darter	*Percina phoxocephala*	X19	D	I	In	SL
River Darter	*Percina shumardi*	X20	D	-	In	SL
Sauger	*Stizostedion canadense*	X21	-	-	Tc	SL
Walleye	*Stizostedion vitreum*	X22	-	-	Tc	SL
Ruffe	*Gymnocephalus cernuus*	X26	E	-	In	-
DRUMS	SCIAENIDAE					
Freshwater Drum	*Aplodinotus grunniens*	Y01	-	-	In	-
SCULPINS	COTTIDAE					
Mottled Sculpin	*Cottus bairdi*	Z01	-	I	In	-
Slimy Sculpin	*Cottus cognatus*	Z02	-	I	In	-
Spoonhead Sculpin	*Cottus ricei*	Z03	-	I	In	-
Deepwater Sculpin	*Myoxocephalus thompsoni*	Z04	-	I	In	-