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ENVIRONMENTAL RESEARCH BRIEF

Evaluation of an Index of Biotic Integrity: Temporal Variability and Regional Application in the Midwest

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Background

Assessment of biotic integrity in water resource systems has been hampered by lack of indices suitable for evaluating biological conditions. (Biotic integrity is defined as presence of a balanced, integrated, adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of a natural habitat for the region.) Classical water quality assessments are usually based on chemical, bacterial, or thermal criteria. This approach neglects factors such as structural (habitat) characteristics, and patterns of temporal variation in environmental characteristics, both of which affect biological conditions and are subject to human alteration.

An Index of Biotic Integrity (IBI), based on analysis of fish communities in streams, was introduced by Karr (1981). The chief advantages of using fish communities to assess biological integrity are: fish integrate effects of watershed degradation; fish are typically present in all but the most ephemeral or polluted aquatic habitats; fish are comparatively easy to identify; fish communities include a range of species representing a variety of trophic levels; and statements about the condition of the fish community are better understood by the general public (Karr 1981). Furthermore, the fish community is a valued resource and, although the quality should be monitored and maintained for its own sake, the fish community is often overlooked by water quality managers. Although fish are routinely sampled by state and federal agencies, tools for analysis and interpretation of such data have been inadequate (Weber 1981) until now.

The IBI is designed to assess biotic integrity directly by evaluating twelve attributes of fish communities in streams. These attributes, called community metrics, fall into several categories, as listed in Table 1. They include: species richness and composition, trophic composition, and fish abundance and condition.

Ideally, criteria for scoring each metric should be adjusted to reflect changes in fish communities with stream size and region. However, some of the metrics change only slightly among stream fish communities while others vary substantially. Five species richness metrics are known to vary substantially with stream size and region. As listed in Table 1, the metrics are: total number of fish species, number of intolerant species, and numbers of darter (*Etheostomatinae*), sunfish (*Centrarchidae* including green sunfish but excluding *Micropterus*), and sucker (*Catostomidae*) species. Intolerant species were determined from regional ichthy-

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Table 1. Metrics Used in Assessment of Fish Communities (Modified from Karr 1981 and Fausch et al. 1984)

Category	Metric	Scoring Criteria 5 (best)	3	1 (worst)
Species Richness and Composition	*Total number of fish species*	*Varies with stream size and region*		
	Number and identity of darter species	*Varies with stream size and region*		
	Number and identity of sunfish species	*Varies with stream size and region*		
	Number and identity of sucker species	*Varies with stream size and region*		
	Number and identity of intolerant species	*Varies with stream size and region*		
	Proportion of individuals as green sunfish	<5%	5-20%	>20%
Trophic Composition	*Proportion of individuals as Omnivores*[a]	<20%	20-45%	>45%
	Proportion of individuals as insectivorous cyprinids	>45%	20-45%	<20%
	Proportion of individuals as top carnivores	>5%	1-5%	<1%
Fish Abundance and Condition	*Number of individuals in Sample*	*Varies with stream size*		
	Proportion of individuals as hybrids	0	0-1%	>1%
	Proportion of individuals with disease, tumors, fin damage and other anomalies	0	0-1%	>1%

[a]*Omnivores are species with diets composed of >25% plant material and the rest animal material (Schlosser 1982b).*

ology references such as those from Smith (1979) for Illinois.

In Table 1 the proportion of individuals as green sunfish (*Lepomis cyanellus*), the trophic composition metrics, and proportions of individuals that are hybrids or diseased seem to vary little and have been assigned fixed criteria for scoring. Number of individuals per sample was expressed as catch-per-unit-effort and relative criteria for scoring were determined for each watershed.

Each metric is evaluated against the standard conditions of an unimpacted site of similar size and regional location. Scores are determined for each metric under one of three headings: Deviates Strongly From (score of 1), Deviates Somewhat From (score of 3), or Approximates Expectations (score of 5). An overall site score, the IBI score, is the sum of the twelve individual metric scores with a range from 12 to 60.

Karr (1981) assigned total scores to five classes according to the following scale: Excellent 57-60; Good 48-52; Fair 39-44; Poor 28-35; Very Poor $\leq$23. When repeated sampling failed to produce any fish, sites were assigned to a sixth category: no fish. Fish communities receiving scores falling between these ranges must be assessed by informed biologists after careful consideration of individual criteria.

The IBI distills data in progressive steps (Figure 1) allowing more complete use of information obtained in the original labor-intensive and cost-intensive collection stage, and also permits easier identification of community aspects that may have resulted in an overall unsatisfactory IBI value. Thus, the metric(s) causing a low IBI value can be pinpointed. Depending on study objectives, this information can lead to further investigations and/or to actions for mitigation.

Activities during the project reported here were restricted to applications of IBI in Midwestern U.S. This restriction is reflected in some of the taxa used for certain metrics (darters, suckers, sunfish). Application of the index to other geographical regions requires some alteration of metrics. Recommendations for those modifications are being developed.

Fish Community
↓
Collection
↓
Summarization by Species & Numbers
↓
Summarization by Metrics
↓
Rating of Metrics
↓
IBI

Figure 1. *The stepwise calculation of IBI.*

The Current Project

This research brief concentrates on discussion of the assessment and application of the IBI. First, evaluations were made of seasonal and year-to-year variations in the IBI at locations which were sampled over an extended period. The goals of this analysis were to determine, using the IBI, the extent to which the season of sample collection affects site evaluations. Also examined was the year-to-year variability in IBI values at a number of sites with and without intervening perturbations.

Second, evaluations were made of the reliability of the IBI for assessing biotic integrity in regions of North-Central United States outside the immediate Illinois-Indiana streams for which the index was originally developed. This phase of the study developed more precise ways to set criteria for scoring metrics, and also examined the agreement of IBI inferences about sites and regions with opinions from other researchers.

Temporal Variability

Evaluation of temporal variability in stream communities requires an extensive series of data from many sampling sites. During the past decade, data were collected by J. R. Karr and associates with support from the U.S. Environmental Protection Agency. These data reveal both the rigor of sampling protocols and the conditions of the stream environments. Data from three streams were analyzed: Black Creek, Allen County, Indiana (sampled from 1973-82); Big Ditch, Champaign County, Illinois (1978-80); and Jordan Creek, Vermilion County, Illinois (1978-80).

Big Ditch and Jordan Creek. Analyses of data from these two streams addressed the following questions: Does IBI rank sites similarly during each sampling period (assuming no major changes in channel, wate quality, etc.)? Do these rankings reflect prior assessments of site qualities, based on known effluent/habitat conditions? How much variability occurs within a site among sampling dates, and is this variability related to site quality? Does site assessment vary predictably with season? Within Big Ditch, can we discover differences among metrics in response to effluent vs. habitat degradation?

Big Ditch is a channelized tributary Sangamon River. Near its headwaters, it receives municipal effluent from Rantoul, IL (Schlosser and Karr 1981, Schlosser 1982a). Big Ditch was sampled at ten locations along its length, during early and late summer, in 1978, 1979, and 1980. Jordan Creek has been channelized upstream but not downstream (Schlosser and Karr 1981, Schlosser 1982a, b). Part of the channelized section passes through a woodlot and, consequently, has better habitat quality. Jordan Creek does not receive any significant point effluent. This stream was sampled at 5 to 14 locations, three or four times each year from early summer to autumn in 1978, 1979, and 1980.

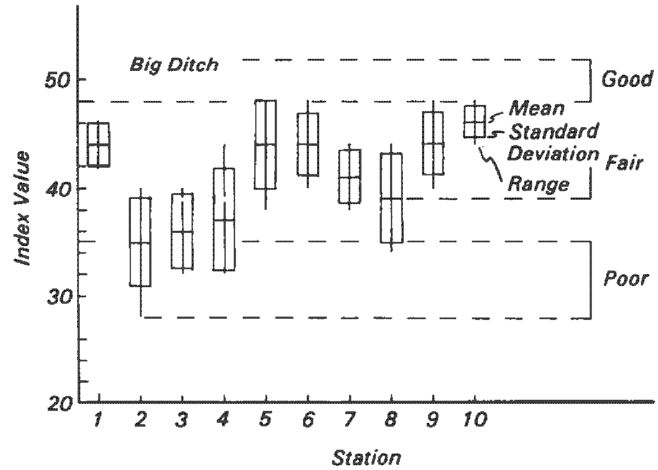

Figure 2. *IBI values for 10 sample stations in Big Ditch, IL.*

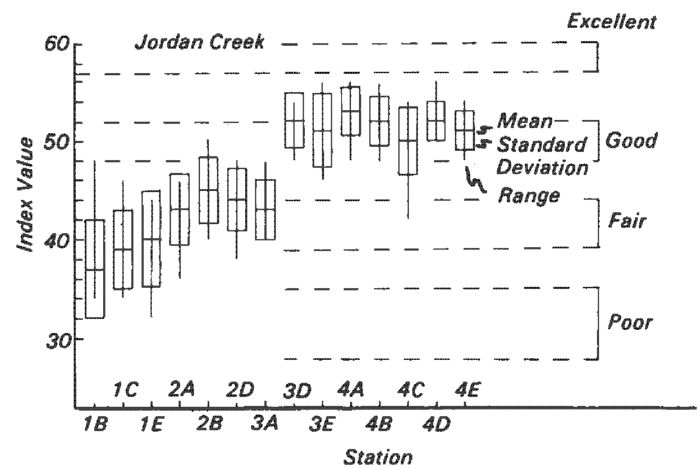

Figure 3. *IBI values for 14 sample stations in Jordan Creek, IL.*

Although IBI values are not invariant among seasons and years, site ranks are concordant (Friedman Test) over time within each stream (Figures 2 and 3). Furthermore, these rankings accord with prior assessments of site quality based on water quality and physical habitat measurements (documented in Schlosser and Karr 1981, Schlosser 1982a, b). For example, in Big Ditch (Figure 2), quality declines below the effluent discharge (site 2) and increases progressively downstream until reaching the section (sites 7 and 8) with lower habitat quality, where the IBI indicates lower fish quality. IBI values increase below these sites, where habitat quality improves.

In Jordan Creek (Figure 3), IBI values are low in the severely channelized section (sites 1B, 1C, 1E) but do not increase where the stream passes through a woodlot (sites 2A, 2B, and 2D). The increase in IBI values is more dramatic, however, where the stream passes through a well-established pasture (sites 3D and 3E) and then on through a more heavily forested area (sites 4A-4E).

In both of these streams, the IBI gave similar rankings of sites among time periods and these rankings agreed with water quality and habitat quality conditions, both within each stream and between the two streams.

Variability in IBI values at each site was related to the quality of the site and also to the quality of the entire stream. Higher quality sites within each stream were less variable among dates than were lower quality sites (Figure 4). Paradoxically, sites in higher quality Jordan Creek had more variable IBI values than did sites of similar average quality in Big Ditch.

This latter pattern of between-stream differences in variability as a function of quality is due to the mobility of fish. In streams with a broader range of suitable environments, movement among high and low quality areas is possibly due to proximity of higher quality areas that serve as refuges. The perceived quality of a poorer site can increase at times, thereby increasing variability in assessments.

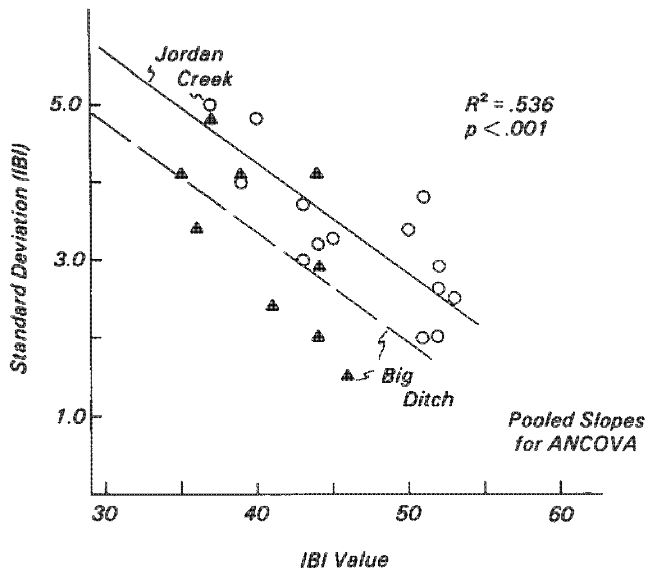

Figure 4. *Relationship between means and standard deviations of IBI values in Jordan Creek and Big Ditch, IL.*

Jordan Creek has a more extensive high quality area than does Big Ditch (Figures 2, 3). Therefore, poor sites in Jordan Creek have a greater potential for temporary increases in quality.

Data from Big Ditch and Jordan Creek provide less definitive answers to questions concerning the best season to sample and the implications of individual metrics. However, some inferences can be drawn. Within each stream, late summer collections usually produced higher IBI values than did samples from earlier in summer. This tendency varied among years, was more noticeable at poorer sites and is apparently related to the overall cause of site variability, i.e., movement of fish to the best available refuge sites and short-term effects of seasonal recruitment. These factors may inflate estimates of species richness and abundance at poor sites by including individuals that presumably cannot persist at that site. Predictably, this effect is variable among years, probably reflecting variability in recruitment.

Although Big Ditch has been completely channelized, two sites (7 and 8) had lower habitat quality, and two sites (2 and 3) were degraded by municipal sewage. Values of individual metrics at those four sites were examined to determine if each type of degradation was associated with changes in certain metrics. Conclusions from these comparisons must be evaluated with consideration of the small sample size and with recognition that each group of sites was affected to some degree by both types of degradation.

When compared to the two sites with exceptionally poor habitat quality, the two sites affected by municipal effluent had lower overall abundances, fewer insectivorous cyprinids, but more green sunfish and more species of darters. Conversely, sites with poor habitat had higher abundances with more insectivorous cyprinids but fewer darter species and few green sunfish. These conditions were noted in conjunction with toxic or hypoxic environments around the effluent, resulting in fewer individuals and greater prevalence of the very tolerant green sunfish. Where habitat is poorer, overall fish abundance is high but the more silty benthic habitat precludes some species of microhabitat-specialized darters.

In summary, examination of two streams in East-Central Illinois revealed that the IBI provided consistent evaluations of site quality in agreement with prior assessments. The evaluation of poor sites was more variable than that of good sites; there was greater likelihood of over-assessment of poor sites than of under-assessment of good sites. Over-assessment of poor sites was more likely in the late summer of certain years. Finally, behavior of individual metrics did tend to coincide with the nature of degradation.

Black Creek. Fish community data were collected in the Black Creek, Indiana watershed as part of a USEPA-supported study of the impact of agricultural land use on water quality (Morrison 1981). Many collections were made at several sites between 1973 and 1982. During this period, habitat and water quality varied in such complex ways, that interpretations of IBI values are not as straightforward as they were in Big Ditch and Jordan Creek. However, data from Black Creek were used to address several specific questions: Could impact of known habitat perturbations be assessed with the IBI? Was post-perturbation recovery observable with the IBI? Did the IBI show other patterns of seasonal or year-to-year variation?

Taken over the whole project period, IBI values increased from upstream to downstream, probably reflecting both greater project-related impact upstream and the effect of better riparian habitat downstream. The latter effect was made clearer by reference to a tributary that passes through a woodlot (Wertz Woods) where higher IBI values reflected better habitat quality (sinuous channel, pools and riffles, trees shading channel) than that found in sites on the unforested main channel.

Two notable periods of project impact occurred. First, early channel modifications resulted in sharp decreases in quality at most sites. After this impact, downstream sites showed rapid recovery and upstream sites, slower recovery. The second impact involved the Wertz Woods site (Figure 5). Although this site was not intentionally modified, project

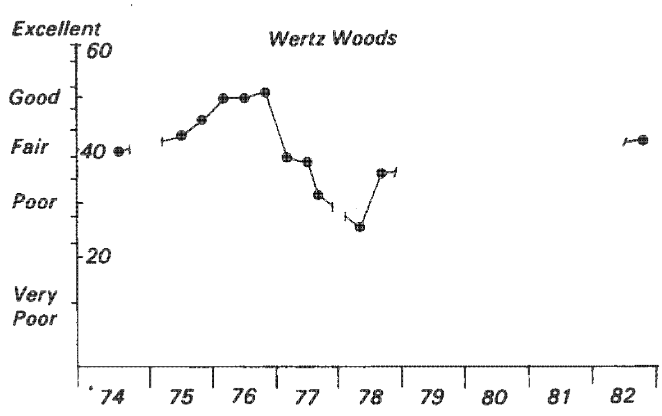

Figure 5. *Project impact and recovery of Wertz Woods site, Black Creek watershed, as shown by IBI.*

activities upstream (a poorly executed effort at bank stabilization) during 1976 resulted in transport of sediment into this site and deterioration of habitat quality. In turn, IBI values declined markedly, becoming similar to those of poorer sites in the watershed. A slow recovery towards pre-disturbance conditions began but has not yet returned this site to its former, relatively high quality state.

Both seasonal and year-to-year variations in IBI were observable in Black Creek as well as in another nearby stream unaffected by project activities. The amplitude of these variations was greater in poorer upstream sites. As in the Illinois streams, early summer IBI values were less variable among years than late summer values.

In summary, the IBI was useful in documenting effects of project activities, showing both initial reductions in quality and subsequent rate and extent of recovery. Both seasonal and year-to-year variation in IBI values were discernable, with early summer values often being lower, but less variable among years, than were late summer values.

Regional Application

In addition to evaluating behavior of the IBI over time at selected sites, this study evaluated the Index over a wider geographic area. That effort produced extensive data sets from seven additional rivers (Figure 6): three in Illinois and one each in Michigan, Kentucky, Nebraska, and the Dakotas. For each river one sample was obtained for each of 33 to 139 sample sites. In addition, some sites were replicated in the Nebraska watershed. For five of the seven rivers, both species lists and relative abundance data were available; for the other two (Rock River, IL and James River, ND and SD) only species lists were available (Fausch et al. 1984).

These data were used in two analyses. First, all data were used to develop expectations of species richness in each watershed as a function of stream size (stream order and watershed area). Second, for those rivers from which were obtained both species lists and relative abundances, each site was assessed using the IBI. Results from the IBI were then compared with other information about conditions among sites and rivers.

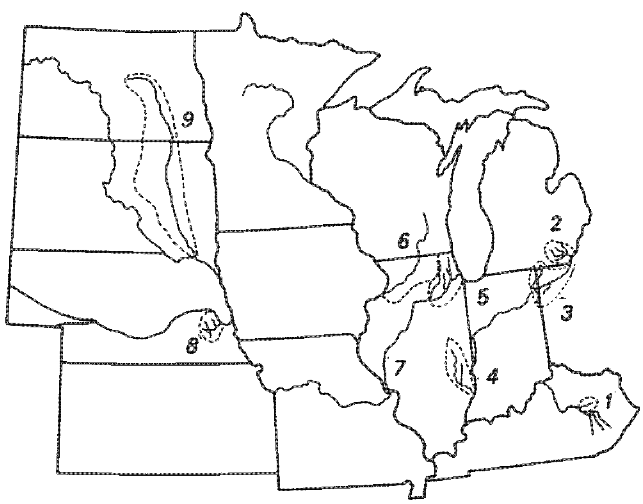

Figure 6. *Locations of Red (1), Raisin (2), Embarras (4), rivers, Chicago area (5), Rock River (6), Salt Creek (8), and James River (9).*

Expected values of certain metrics used in calculation of IBI vary with stream size and/or geographic region. Thus, the study sought to establish protocols to determine those expectations as well as to determine if rivers throughout the midwest exhibited similar stream size vs. species richness relationships. If generality could be demonstrated at some useful level, considerable time could be saved in application of IBI to other rivers.

Expectations for total species were generated using the concept (Fausch et al. 1984) of the Maximum Species Richness Line (MSRL). Plots of species richness versus stream order (or watershed area) at each collection site produce a right triangle of points bounded on the upper side by a hypothetical line representing the expected maximum number of species to be found at each stream size (Figure 7). A line with slope fit by eye that forms the upper bound for 95 percent of the sites is a better measure of true species

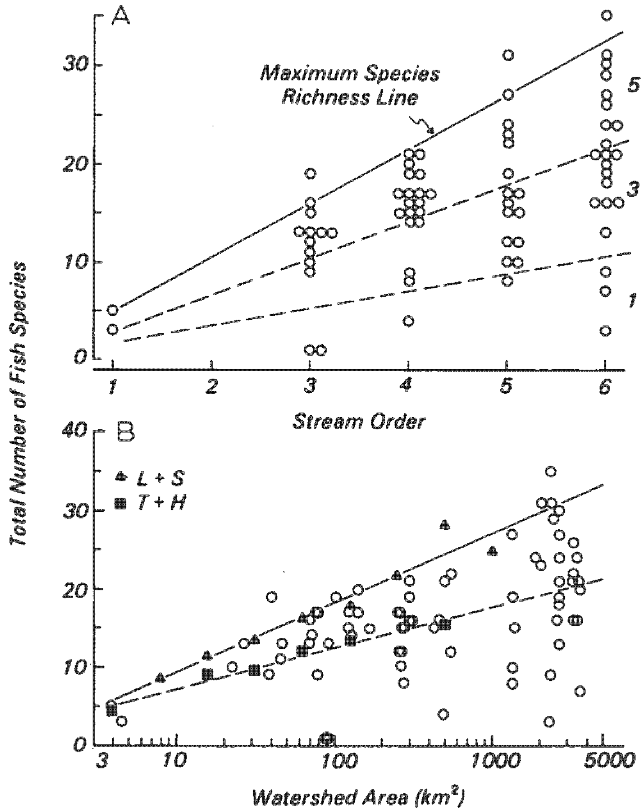

Figure 7. *Total number of fish species vs. stream order (A), and log_{10} watershed area (B) for 72 "least disturbed" sites from the Embarras River. See text for explanation of Maximum Species Richness lines. Dashed lines in (A) trisect the right triangle into regions used in scoring IBI metrics (see text). Linear regressions for data of Larimore and Smith (1963, triangles and solid line) and Thompson and Hunt (1930, squares and dashed line) are shown in B. Maximum Species Richness line (not shown) in B is nearly identical to Larimore and Smith (1963) regression.*

richness over stream orders than that provided by a linear regression. Points may lie far below this line due to sampling inadequacies or to site-degradation.

Although MSRLs for the seven rivers differed, they generally form two groups of similar lines (Figure 8). The uppermost group is a set of woodland streams in the eastern region of the midwest. These rivers generally have more species at any stream order than do Great Plains streams, the lower group. Within each group, maximum species richness tends to be similar, particularly at intermediate stream orders (e.g., 2-4).

Ideally, application of IBI to a river would be preceded by determination of its MSRL. However, if this information were not available, tentative IBI values were derived from expectations of rivers in the same geographical area (Figure 8).

This analysis of midwestern streams indicates that maximum species richness of higher order sites tends to decline in an east to west direction. Nearby streams tend to have similar maximum species richness; more distant streams toward the east tend to have more species at a similar order and distant streams toward the west, fewer species. Therefore, if information from a nearby river is unavailable, interpolation of information from two rivers on either side could be used as an acceptable first approximation.

Once the MSRL has been drawn, operational limits for scoring observed species richness can be determined. The right triangle defined by the MSRL is divided into three zones by radiating lines and scored accordingly.

Using this approach to determining expectations for species number and number of species in the darter, sunfish, and sucker groups, IBI values were calculated for five rivers. The goals of this analysis were to examine applicability of the IBI to rivers in Kentucky, Michigan, Illinois and Nebraska; to determine if IBI is dependent on stream order; and to compare IBI values with conditions within and between rivers based on knowledge of each river as well as on published and unpublished evaluations of researchers familiar with those areas.

The IBI was clearly applicable to each of these five rivers (Figure 9). Furthermore, overall assessments accorded with prior evaluations. The two least disturbed watersheds—Red River, KY and Embarras River, IL—had most sites ranked "Good" or above (92% and 83%, respectively). The two most disturbed watersheds—the Chicago area, IL and Salt Creek, NE—had most of their sites "Fair" or poorer (90% and 96%, respectively). Raisin River, MI, a watershed with a range of disturbance, had IBI values throughout the available range—"Excellent" to "No Fish."

IBI values did not correlate with stream order in streams that were considered of uniform quality—Salt Creek, which has generally "Fair" or "Poor" sites, and the least disturbed parts of the Embarras River, which had mostly "Good"

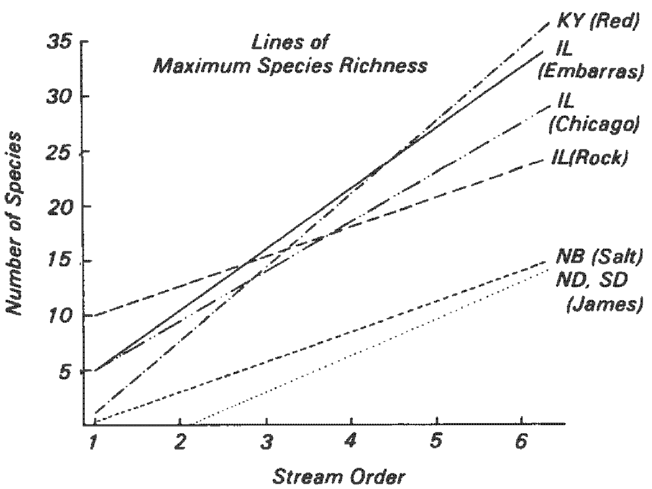

Figure 8. *Maximum species richness lines for six midwestern rivers.*

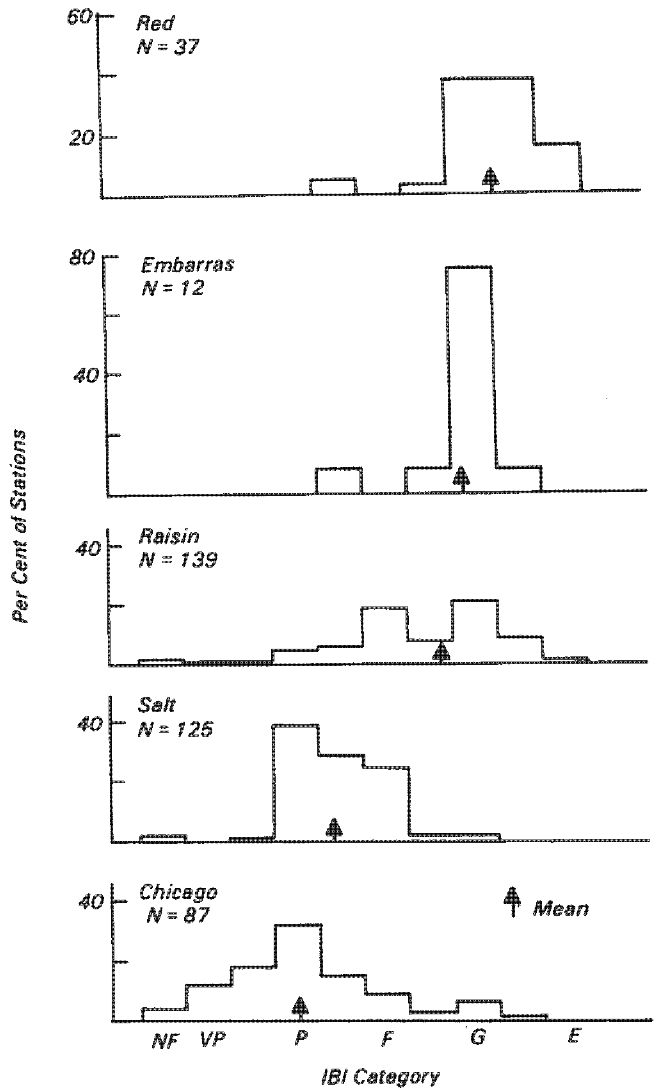

Figure 9. *Frequency distributions of IBI values in five watersheds with both species lists and relative abundance data available.*

sites. Exceptions were in the other three, in which first order sites often had somewhat higher scores than did most sites farther downstream. This pattern, apparently due to decreased disturbance in smaller streams, represented real differences and thus did not indicate a weakness of the Index.

Summary

The Index of Biotic Integrity (IBI) is a useful tool for evaluating fish community data. The IBI ranks sites according to relative quality. When environmental impacts have occurred which should reduce fish community quality, the IBI documents both the impact and subsequent recovery. The IBI does show systematic seasonal and year-to-year variations which may reflect actual short-term changes in quality.

The IBI can be used in areas of the Mississippi Valley outside of Illinois and Indiana. When expectations of species richness are not available from the user's experience, these expectations can be generated with data from the watershed of interest, or from other watersheds nearby. When used with fish community data from Kentucky, Michigan, Indiana, Illinois, and Nebraska, the IBI has given site assessments which agree with independent assessments of biologists familiar with the regions.

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