State of Ohio
Environmental Protection Agency

Ecological Assessment Section
Division of Water Quality
Planning & Assessment

The Qualitative Habitat Evaluation Index [QHEI]: Rationale, Methods, and Application

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Introduction

The presence and abundance of stream fishes is strongly related to the physical and chemical characteristics of a stream (Gorman and Karr 1978; Schlosser 1982). With changes in nutrients and habitat, changes such as those that occur with increasing stream size, obvious shifts in fish community structure and function occur (e.g., River continuum concept: Vannote et al. 1980; Minshall et al. 1985) . Although these changes in stream systems are often viewed as gradual or forming a "continuum", in reality there can often be much variability in local lithology and stream morphology that can affect fish communities (Minshall et al. 1985). Such variability has been increased by human activities; channel dredging and agricultural modification of watersheds can alter nutrient cycling patterns, and, in turn, fish community structure. If such altered streams enter more natural watersheds (e.g., wooded) they often regain more natural habitat and chemical characteristics (Marsh and Luey 1982). Much of the degradation observed in fish communities related to habitat disturbance is strongly influenced by the extent of modifications. As the extent of modifications increase the probability of local extinctions increase and a more disturbed community results.

Regulatory activities under the Federal Water Pollution Control Act of 1972 and its 1977 and 1987 amendments require knowledge of the potential fish or biological community that can be supported in a stream or river (termed aquatic life "use designations") for setting "benchmarks" of community expectations to compare against actual instream performance.[1] A procedure for relating stream potential to habitat quality would provide some insight into how habitat might affect biological expectations in a given waterbody.

To help with this problem we have developed an index of macro-habitat quality, the Qualitative Habitat Evaluation Index (QHEI). This index is designed to provide a measure of habitat that generally corresponds to those physical factors that affect fish communities and which are generally important to other aquatic life (e.g., invertebrates). The QHEI was developed within several constraints associated with the practicalities of conducting a large-scale monitoring program, i.e., we desired to construct an index that would work reliably for our purposes yet require few additional resources to use. Specifically, (1) the index needed to be easy to record in a minimal amount of time and with a minimum of field measurements, (2) the index should take advantage of the field experience of our field biologists (indeed, it was the realization that the subjective habitat evaluations of our

[1]In actual practice few States measure aquatic community performance directly but rely on chemical surrogates to measure performance. See OhioEPA (1987a) for shortfalls of this approach *alone*.

staff were often quite accurate which spurred development of this index), (3) the index should include all of the important variables that could influence fish communities (maximize explanatory power of index), (4) the index should have acceptable reproducibility among different workers, and 5) obviously, the index needed to be useful enough to separate the relative effects of habitat vs water quality on fish community structure or at a minimum determine the baseline community that could be expected in a particular habitat. The index is based on six interrelated metrics: substrate, instream cover, channel morphology, riparian and bank condition, pool and riffle quality, and gradient. These attributes have been shown to be correlated with stream fish communities (Table 1).

This document discusses (1) the relationship between the QHEI and its metrics with the IBI in minimally impacted (by chemical water quality) stream reaches in Ohio, (2) the importance of basin and subbasin landuse and stream modification and the limiting effects of "average" habitat conditions on the QHEI as a predictive tool, (3) guidelines for use of the QHEI for determining aquatic life use designations of flowing waters, and (4) the variability that can be expected in the calculation of the QHEI by different biologists.

Table 1. Literature citations describing correlations between fish communities or populations and the physical factors used as metrics in the QHEI.

Metric	Citation
General	Gorman and Karr (1978), Schlosser (1982a), Platts *et al.* (1983), Karr et al. (1983a)
Substrate	Lyons *et al.* (1988), Berkman and Rabeni (1987)
Cover	Angermeier and Karr (1984), Benke *et al.* (1984, 1985), Marzolf (1978)
Stream Channel	Griswold *et al.* (1978), Portt *et al.* (1986), Trautman (1939), Trautman and Gartman (1974), Schlosser (1982a,b)
Riparian Quality	Schlosser and Karr (1981), Dudley and Karr (1977), Karr and Schlosser (1977)
Pool/Riffle Quality	Schlosser (1982a; 1987),
Gradient	Trautman (1941; 1981), Hocutt and Stauffer (1975),

Background

Physical habitat in streams has been measured and quantified by a multitude of workers; however, for our purposes the methodologies are either too time consuming and costly (e.g. Habitat Suitability Indices; Terrell 1984 or Habitat Quality Index; Binns and Eiserman 1979) or do not encompass a wide enough range of physical attributes (Habitat Diversity Index; Karr and Gorman 1979). The QHEI is composed of an array of metrics that describe attributes of physical habitat that may be important in explaining the species presence, absence, and composition of fish communities in a stream. We envision the QHEI filling a gap between completely subjective habitat descriptions and more labor intensive Habitat Suitability Indices developed for each species in a fish community. Although it may not have the resolution to predict the abundance of each individual species in a stream, it should be useful in explaining shifts in the general composition and ecological function of lotic fish communities. This paper will primarily present data on the most recent form of the QHEI (OhioEPA 1989). Some reference will be made to an older form of the QHEI which is compared to the current form in Table 2 (see Ohio EPA 1989a); these references will generally explain the rationale for changes to the original structure of the QHEI. For convenience sake the current index will be referred to as the QHEI and the past effort the "Old" QHEI.

Scale

The influence of habitat on biological organisms and communities can be examined from several scales depending on an investigators purpose. The QHEI is a macro-scale approach that measures emergent properties of habitat (sinuosity, pool/riffle development) rather than the individual factors that shape these characters (current velocity, depth, substrate size).

Scoring

The field procedures and scoring criteria for the QHEI are described in Ohio EPA (1989). The field sheet for the QHEI consists of lists of qualitative descriptors that are checked as appropriate. Highest scores were assigned to the habitat parameters that have been shown to be correlated with streams that have high biological diversity and biological integrity with progressively lower scores assigned to less desirable habitat features. For example, the widest riparian width, > 50m, was assigned a 4 and narrower categories of riparian width were assigned progressively lower scores down to a score of zero for no riparian vegetation.

Table 2. Metrics and scoring ranges for the old version and the new version of the QHEI.

"Old " QHEI		"New" QHEI	
Substrate	15 pts	*Substrate*	20 pts
1) Type	2-14	1) Type	0-20
2) Quality	-2-2	2) Quality	-5-3
Instream Cover	15 pts	*Instream Cover*	20 pts
1) Type	0-8	1) Type	0-9
2) Amount	1-7	2) Amount	1-11
Channel Quality	15 pts	*Channel Quality*	20 pts
1) Sinuosity	1-4	1) Sinuosity	1-4
2) Development	1-4	2) Development	1-7
3) Channelization	1-4	3) Channelization	1-6
4) Stability	1-3	4) Stability	1-3
Riparian/Erosion	15 pts	*Riparian/Erosion*	10 pts
1) Width	0-5	1) Width	0-4
2) Floodplain Quality	1-5	2) Floodplain Quality	0-3
3) Bank Erosion	1-5	3) Bank Erosion	1-3
Pool/Riffle	15 pts	*Pool Riffle*	20 pts
1) Max. Depth	0-3	1) Max Depth	0-6
2) Cover Quality	0-3	2) --	- -
3) Current Available	-2-4	3) Current Available	-2-4
4) Pool Morphology	0-2	4) Pool Morphology	0-2
5) Riffle/Run Depth	1-3	5) Riffle/Run Depth	0-4
6) Riffle Substrate Stability	0-1	6) Riffle Substrate Stab.	0-2
7) Riffle Embeddedness	0-1	7) Riffle Embeddedness	-1-2
Drainage Area	0-15 pts	*Drainage Area*	*Not included*
Gradient	0-10 pts	*Gradient*	0-10 pts
Total Score	0-100 pts.	Total Score	0-100 pts.

Methods

Three groups of data were used to examine the behavior of the QHEI, (1) data from streams throughout Ohio that represent sites minimally impacted by chemical water quality or habitat ["warmwater" reference sites], (2) sites from streams that contain areas that have relatively unimpacted chemical water quality but have documented habitat impacts ["modified" reference sites], and (3) examples from within stream basins where we have used the QHEI in some water quality management decision. Data in groups one and two are the same that were used to generate Ohio's biocriteria; their selection and use is described in OhioEPA (1987b). All sites were sampled with one of three electrofishing methods (see OhioEPA 1989) which is based on the size and characteristics of the stream or river[2]. Data here are analyzed by site types: headwater sites (< 20 sq mi drainage area), wading sites (20-554 sq mi drainage area), and boat sites (90-6471 sq miles drainage area). A QHEI was calculated over the exact length of stream that was sampled by electrofishing: 150-200 m for headwater and wading sites and 500 m for boat sites. Calculation of the Index of Biotic Integrity (IBI) is explained in detail in Karr (1981), Karr *et al.* (1986), and OhioEPA(1987b). Some analyses were done by ecoregion. Descriptions of Ohio ecoregions and the rationale for their influence in Ohio is found in Whittier *et al.* (1987) and Ohio EPA (1989b,c).

Statistical Analysis

The influence of habitat data on stream fish communities was examined with simple linear and exponential regressions and frequency analyses of combined and individual components of QHEI metrics in relation to the IBI. Chi-square was used, by site type, to determine whether the frequency of sites with a given habitat characteristic in an IBI range differed substantially from the hypothetical population frequency based on the IBI distribution at all sites. Where expected frequencies were less than 5 for an IBI range they were combined with the adjacent IBI range. Data was insufficient to calculate chi-square by ecoregion within site types, however, ecoregions are distinguished on frequency plots. All tests were considered statistically significant at $P > 0.05$.

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[2]Boat and wading sites overlap somewhat in drainage area range because stream depth and other habitat features dictate the type of equipment that can be used. These features vary with physiography in Ohio (e.g., very deep streams with small drainage areas.that must be sampled with boats in WAP).

Results and Discussion

Relationship between the QHEI and the
Index of Biotic Integrity [IBI]

Statewide Trends

To examine the relationship between the IBI and QHEI, linear and exponential models were fit to the data. Linear regression indicated, for all data combined statewide and for all sampler types, that the QHEI is significantly correlated with the IBI (r^2=0.45). An exponential model provided a slightly better fit to the data (r^2= 0.47) than the linear model (Figure 1).

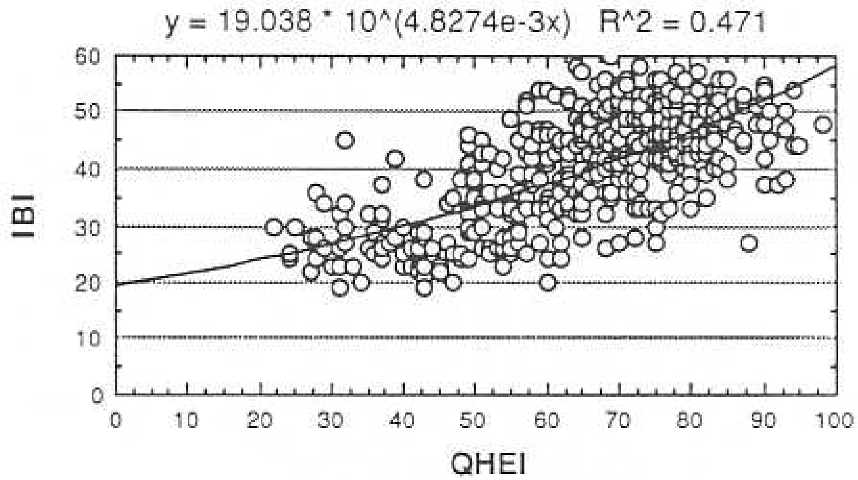


Figure 1. Least squares exponential regression analysis of the QHEI and IBI for 471 warmwater and modified reference sites (all site types and all ecoregions)

Significant linear regressions were also obtained for each sampler type (headwater sites - r^2=0.42, wading sites - r^2=0.40, boat sites - r^2=0.59) and in each case an exponential model provide a slightly better fit (Figure 2). The exponential models are also more consistent with the theoretical relationship between habitat and the structure of fish communities. The slope of the exponential models decreases at the lower IBI scores and the lines do not descend below an IBI of 20. In contrast, the linear models have Y-intercepts (IBI) of between 9 and 14.

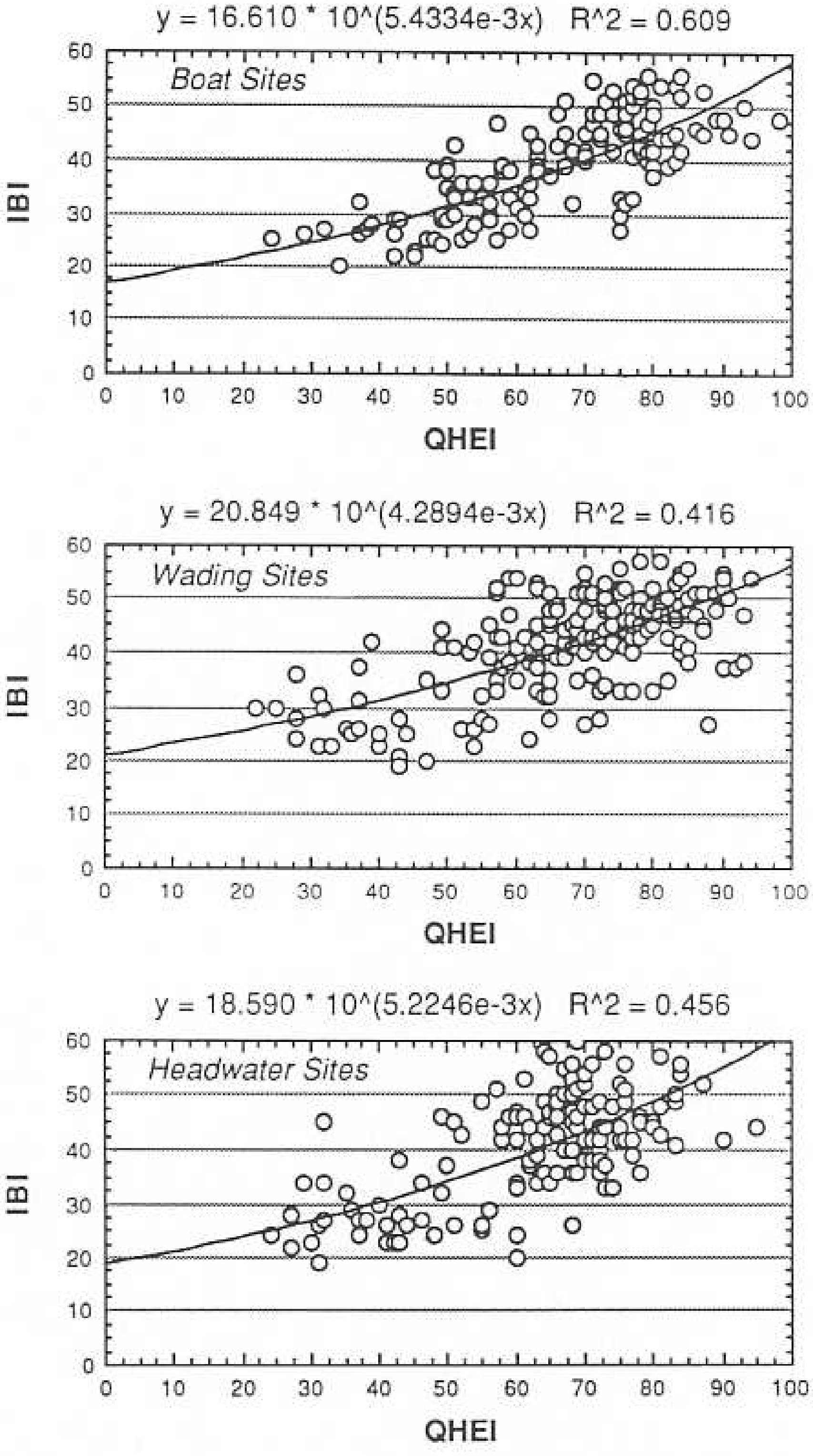


Figure 2. Least squares exponential regression analysis of the QHEI and IBI for warmwater and modified reference sites (all ecoregions) for headwater sites (top panel), wading sites (middle panel), and boat sites (bottom panel).

IBI scores of less than 20 are usually associated with "toxic" impacts where large components of the community are lost or disrupted and the abundance and biomass of the community is greatly reduced. In contrast, impacts that are predominantly due to habitat modification result in a shift of community function (e.g., omnivores increase relative to insectivores) with correspondingly less marked changes in structure. For impacts solely attributable to habitat modification IBI scores rarely descend below an IBI of 20 regardless of the QHEI score. Combinant analyses that includes individual IBI metrics and the modified index on well-being (Iwb) further separates the community response characteristics between habitat and toxic impacts

Some of the variation observed in the relationship between IBI and QHEI is related to factors "external" to the form of the QHEI or IBI. Two of the sub-categories of the modified reference site data include modifications that do not have commensurate effects on the QHEI, as they do on the IBI (impoundment, mine drainage). Also, some of the variation in the models discussed above is related to regionally varying factors other than habitat including background concentrations of the chemical constituents of streams (Whittier et al. 1987). There are significant differences in the QHEI by ecoregion (Figure 3) that are similar to the ecoregion patterns observed for the IBI (Figure 3). These factors account for the substantial variability of the QHEI/IBI relationship around the regression line. To reduce the effects of factors other than habitat that vary by ecoregion further analyses were done by ecoregion where data was sufficient.

QHEI by Ecoregion

The QHEI was significantly correlated with the IBI in all ecoregions of Ohio where data included a sufficient range of QHEI and IBI values (Table 3). Non-significant correlations were probably related to limited ranges of the available data. For example, in the HELP ecoregion at headwater sites the QHEI only ranged from 24-68 and the IBI from 19-26; in the IP the QHEI ranged from 58-73 and the IBI from 36-58. Either the QHEI or IBI range in each was insufficient to demonstrate a meaningful relationship.

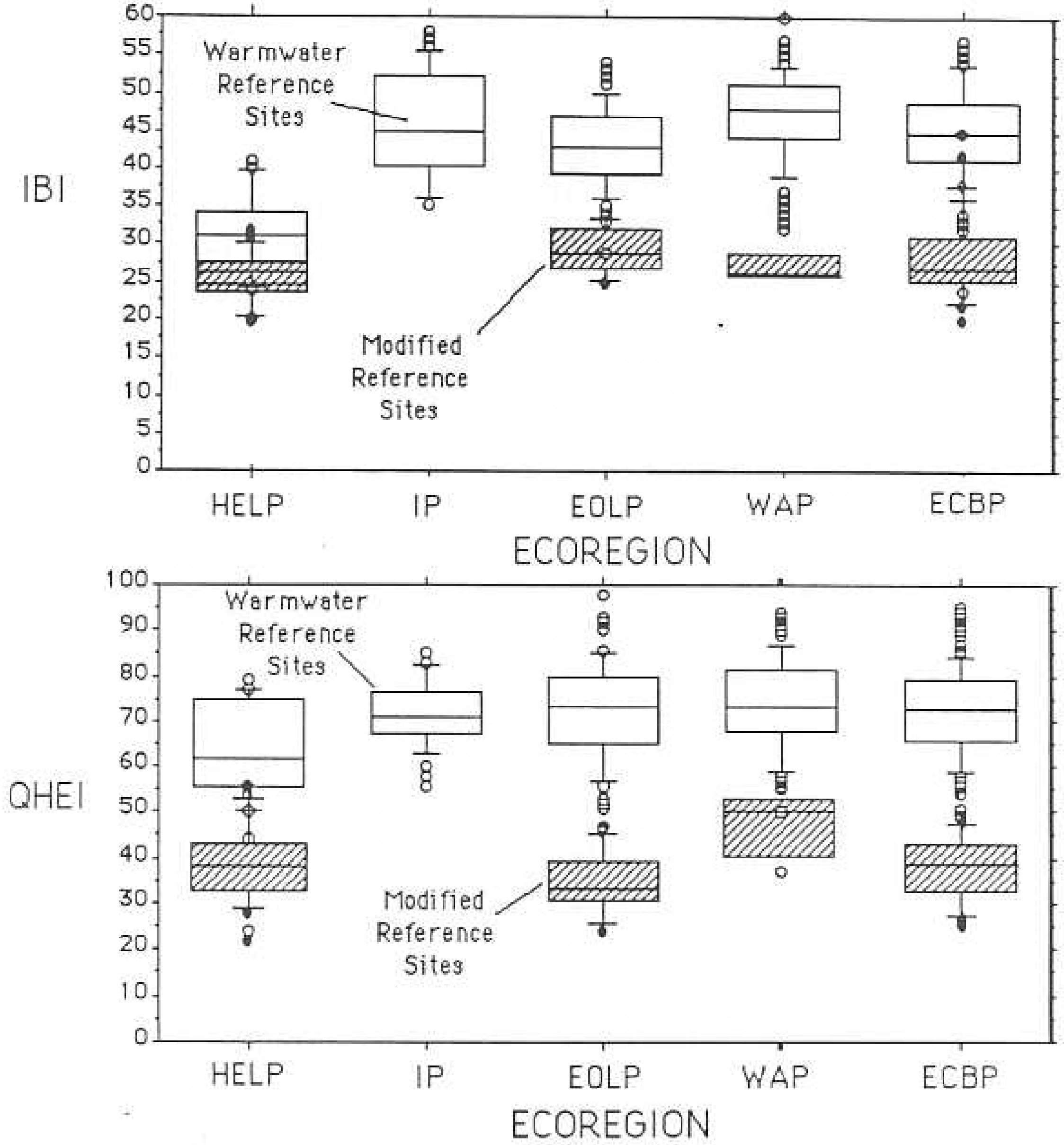


Figure 3. Box and Whisker Plots (medians, 25th and 75th percentiles, maximum value, minimum value, and outliers > two interquartile ranges from the median) for warmwater (open boxes) and modified (shaded boxes) reference sites for the IBI (top panel) and QHEI (bottom panel).

Table 3. Correlation coefficients (r) between the QHEI and the Index of Biotic Integrity, by Ecoregion and sample type (sample type is related to stream size). Asterisks denote significance at $P < 0.05$ (*) or $P < 0.01$ (**).

Statistic	HELP	IP	Ecoregion EOLP	WAP	ECBP
			Headwater		
r	.27NS	.24NS	.56**	.62**	.69**
N	8	13	35	31	52
			Wading		
r	.28NS	.16NS	.49**	.59**	.61**
N	16	20	28	47	73
			Boat		
r	.60**	.44NS	.90**	.81**	.76**
N	28	7	22	26	56

Correlation coefficients were generally highest for boat sites and lower for wading and headwater sites. Smaller streams are more likely to be affected by riparian conditions and modification than larger streams (Karr and Schlosser 1977). Riparian modifications may affect streams on a basin or subbasin scale that may be less evident in site specific measures of habitat. For example, removal of riparian vegetation in headwater streams may lead to a 6-9°C increase in temperature and a disruption of the allocthonous energy inputs (Karr and Schlosser 1977). Site specific habitat measures could underestimate such effects and the existing community could be of a lower integrity than that predicted by site specific habitat alone. Some of this variation in biological communities is explainable within the framework of ecoregion differences, but is also related to anthropogenic basin or subbasin modifications of stream systems.

Basin Averages of Habitat Quality

Although QHEI attempts to explain site-specific variation in the IBI due to habitat, the predominance and proximity of nearby, higher or lower quality habitat can result in IBI's greater or less than expected based on a single site-specific QHEI. Similarly, a predominance of poor land use practices and habitat modifications throughout a basin can result in IBI scores lower than expected based on a single site–specific QHEI. Recent ecological work has examined the influence of "sinks" and "sources" of individuals on populations (Pulliam 1988; also see Levin 1989); such a phenomenon also is likely at work in stream ecosystems. Streams that have a large proportion of their basin with natural habitats generally intact will be able to support good fish communities in short stretches of degraded habitat.

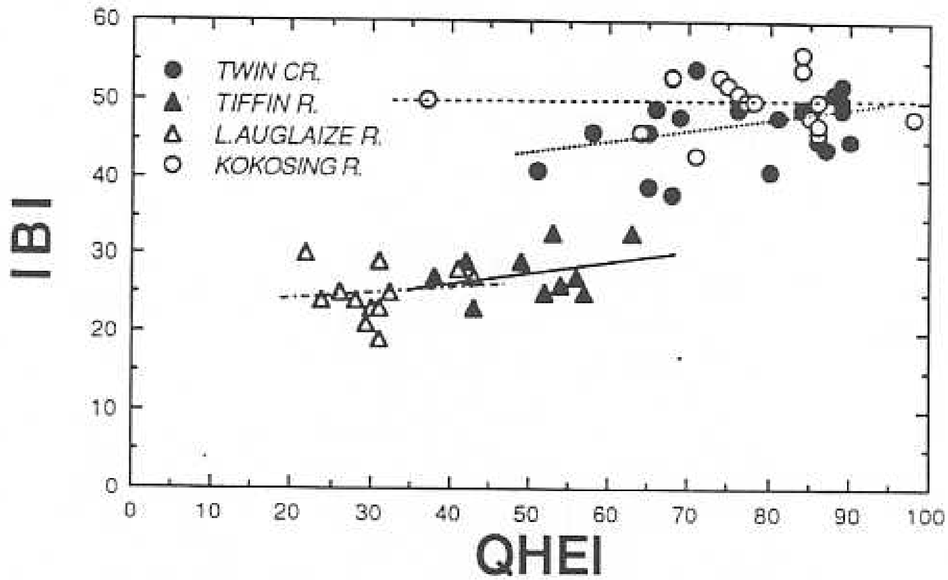


Figure 5. Linear regression models of QHEI versus IBI for four Ohio streams. Triangles represent stream basins with generally poor habitat quality and circles represent stream basins with good-excellent habitat quality.

Figure 4 illustrates stream basins with high quality stream habitat and basins with low quality stream habitat and their associated IBI values. Sites represented by triangles are stream systems with generally intact, high quality, habitat, Twin Creek (average QHEI= 77) and the Kokosing River (average QHEI= 77); sites represented by boxes are two stream systems with widespread modification resulting in generally degraded habitat, the Little Auglaize River (average QHEI= 31) and the Tiffin River (average QHEI= 51). A site specific QHEI of 50 would result in an IBI of about 25 in the Tiffin River or the Little Auglaize River and an IBI of about 45-50 in Twin Creek or the Kokosing River. Thus using the QHEI as a site specific predictor of IBI can vary vary widely depending on the predominant character of the habitat in a basin or reach.

Thus, it is evident that general basin characteristics and overall habitat quality influence stream fish communities more so than does site specific habitat. Such influences may also act through temperature modifications or disruptions of the energy flow through the biotic system and may not be evident in habitat measures. Some proportion of ecoregion variation in the biota is also explained by patterns of nutrient and chemical constituents of streams that arise because of differing soil types, parent materials, and natural vegetation.

The implication of these other sources of variation in the biota is that the QHEI (or any site specific habitat measure) not inclusive enough to be an *absolute site-specific* predictor of fish communities without further consideration of basin-wide or reach-wide influences on fish communities. This is incorporated into the protocols for assigning aquatic life use designations (discussed later).

Importance on Individual Metrics

The effects of QHEI metrics on the IBI were examined with correlation coefficients and metric subcomponent effects with chi-square goodness of fit tests. Although significant correlation coefficients do not imply causality there are some general trends that are consistent and that make ecological sense. Three metrics are consistently correlated with the IBI: pool quality, channel quality, and substrate quality (Tables 4 and 5). In contrast, the riparian zone quality is less often correlated with the IBI. This may be related to riparian effects being more important on a basin wide than site specific basis. Analysis of the frequency of occurrence of QHEI metric subcomponents among IBI ranges indicates that "negative" habitat characteristics generally (but not universally) contribute more to the explanation of deviations from a random distribution with IBI range than "positive" habitat characteristics (Table 6). The following sections examine the frequency distributions for important habitat characteristics and patterns of correlation for each metric and provides ecological explanations for these trends.

Table 4. Correlations coefficients (r values) between individual components of the QHEI and the Index of Biotic Integrity, by Ecoregion and sampling type. An asterisk denots significance at $P < 0.05$.

QHEI Metric	HELP	IP	Ecoregion EOLP	WAP	ECBP
			Boat Methods		
N	28	8	22	26	56
Substrate	.71*	.02NS	.84*	.86*	.47*
Cover	.19NS	-.22NS	.46*	.55*	.38*
Channel	.63*	-.47NS	.86*	.62*	.61*
Riparian	.02NS	-.28NS	.55*	.51*	.26NS
Pool	.16NS	-.31NS	.84*	.40*	.65*
Riffle	.41*	-.31NS	.86*	.50*	.46*
Gradient	.01NS	-.54NS	.69*	.83*	.52*
QHEI	.60*	-.44NS	.90*	.81*	.76*
			Wading Methods		
N	16	20	28	47	73
Substrate	.43NS	-.03NS	.36*	.62*	.40*
Cover	-.07NS	.17NS	.22NS	.49*	.60*
Channel	-.08NS	-.14NS	.41*	.39*	.58*
Riparian	-.36NS	-.39NS	.09NS	.10NS	.32*
Pool	.38NS	-.14NS	.38*	.15NS	.52*
Riffle	.18NS	-.11NS	.45*	.26NS	.36*
Gradient	.29NS	.47*	.56*	.31*	.44*
QHEI	.23NS	-.02NS	.49*	.59*	.61*
			Headwater Methods		
N	8	13	35	31	52
Substrate	.05NS	-.39NS	.38*	.67*	.51*
Cover	.37NS	-.36NS	.42*	.61*	.64*
Channel	.48NS	-.45NS	.57*	.63*	.65*
Riparian	.29NS	.36NS	.13NS	-.02NS	.45*
Pool	.11NS	.61*	.33*	.11*	.53*
Riffle	.14NS	.24NS	.08NS	.02*	.46*
Gradient	-.14NS	-.45NS	.27NS	-.06NS	.34*
QHEI	.27NS	-.24NS	.56*	.62*	.69*

Tables 5. Relative ranking by the magnitude of significant ($P < 0.05$) correlation coefficients (r) between the QHEI and IBI for Ohio ecoregions and sampling methods

Ecoregion	N	Metric ranking
		Boat methods
HELP	28	Substrate > Channel > Riffle
IP	7	*No significant correlations*
EOLP	22	Channel > Riffle > Substrate > Pool > Gradient > Riparian > Cover
WAP	26	Substrate > Gradient > Channel > Cover > Riparian > Riffle > Pool
ECBP	56	Pool > Channel > Gradient > Substrate > Riffle > Cover
		Wading Methods
HELP	16	*No significant correlations*
IP	20	Gradient
EOLP	28	Gradient > Riffle > Channel > Pool > Substrate
WAP	47	Substrate > Cover > Channel > Gradient
ECBP	73	Cover > Channel > Pool > Gradient > Substrate > Riffle > Riparian
		Headwater Methods
HELP	8	*No significant correlations*
IP	13	Pool
EOLP	35	Channel > Cover > Substrate > Pool
WAP	31	Substrate > Channel > Cover
ECBP	52	Channel > Cover > Pool > Substrate > Riffle > Riparian > Gradient

Table 6. Chi-square values for distribution of reference sites among IBI ranges for habitat subcomponents of the QHEI. Asterisks indicate significance level (*P < 0.05, **P < 0.01, ***P < 0.005).

QHEI Subcomponent	Headwater sites	Wading sites	Boat sites
Substrate			
Silt Covering			
Heavy/Moderate	20.2***	15.3**	27.4***
Normal/Low	10.4 NS	8.4 NS	12.8*
Embeddedness			
Severe/Moderate	14.4**	31.0***	22.2***
Low/None	5.5 NS	8.9 NS	6.6 NS
Type			
Boulders	—[1]	9.3*	2.8 NS
Cobble	4.3 NS	11.6*	23.0***
Gravel	7.5 NS	0.7 NS	12.8*
Sand	4.4 NS	3.0 NS	5.4 NS
Silt/Muck	21.2***	25.8***	30.9***
Origin			
Tills	6.7 NS	3.4 NS	8.9 NS
Limestone	2.8 NS	8.1*	—[1]
Pool/Riffle Quality			
Maximum Depth			
> 70 cm	6.5 NS	5.6 NS	0.2 NS
< 70 cm	6.9 NS	17.0***	—[1]
Morphology			
Wide	8.4 NS	11.9 NS	26.2***
Narrow/Equal	12.9*	25.3***	23.9***
Riffle Depth			
> 10 cm	2.6 NS	6.6 NS	27.9***
< 10 cm	1.3 NS	6.9 NS	—[1]
Current Types			
Fast	8.5*	16.5**	15.5**
Eddies	—[1]	7.0 NS	6.4 NS
Riffle Substrate Stability			
Stable	8.9 NS	14.9*	27.5***
Unstable	10.6***	20.4***	—[1]
Riffle Substrate Embeddedness			
Extensive/Moderate	9.2**	13.1**	—[1]
Low/None	8.7 NS	13.0 NS	27.1***
Cover			
Cover Amount			
Extensive/Moderate	9.9 NS	13.2 NS	8.3 NS
Sparse/Nearly Absent	34.5***	39.0***	28.4***
Cover Type			
Deep Pools	6.8 NS	7.0 NS	0.4 NS

Channel Characteristics			
Sinuosity			
High/Moderate	15.9*	9.1 NS	16.7**
Low/None	38.6***	18.6***	15.8**
Development			
Excellent/Good	20.8***	15.0*	31.9***
Fair/Poor	39.5***	36.6***	36.3***
Channel Modifications			
None/Recovered	12.9 NS	9.3 NS	4.0 NS
Recent/Recovering	41.7***	42.3***	10.4**
Stability			
High	11.3 NS	15.1**	12.8*
Moderate/Low	13.1*	15.6**	12.3*
Riparian Quality/Erosion			
Riparian Width			
Wide/Moderate	12.0 NS	12.7 NS	4.7 NS
Narrow/None	17.8**	7.3 NS	3.8 NS
Adjacent Landuse			
Agriculture	3.2 NS	3.9 NS	3.6 NS
Forest/Shrub	10.8 NS	4.1 NS	9.4 NS
Urban/Park/Mining	—[1]	3.9 NS	10.2 NS
Bank Erosion			
None/Little	4.6 NS	6.2 NS	6.5 NS
Moderate/Severe	—[1]	38.3***	10.2 NS

[1]Insufficient data for statistical test.

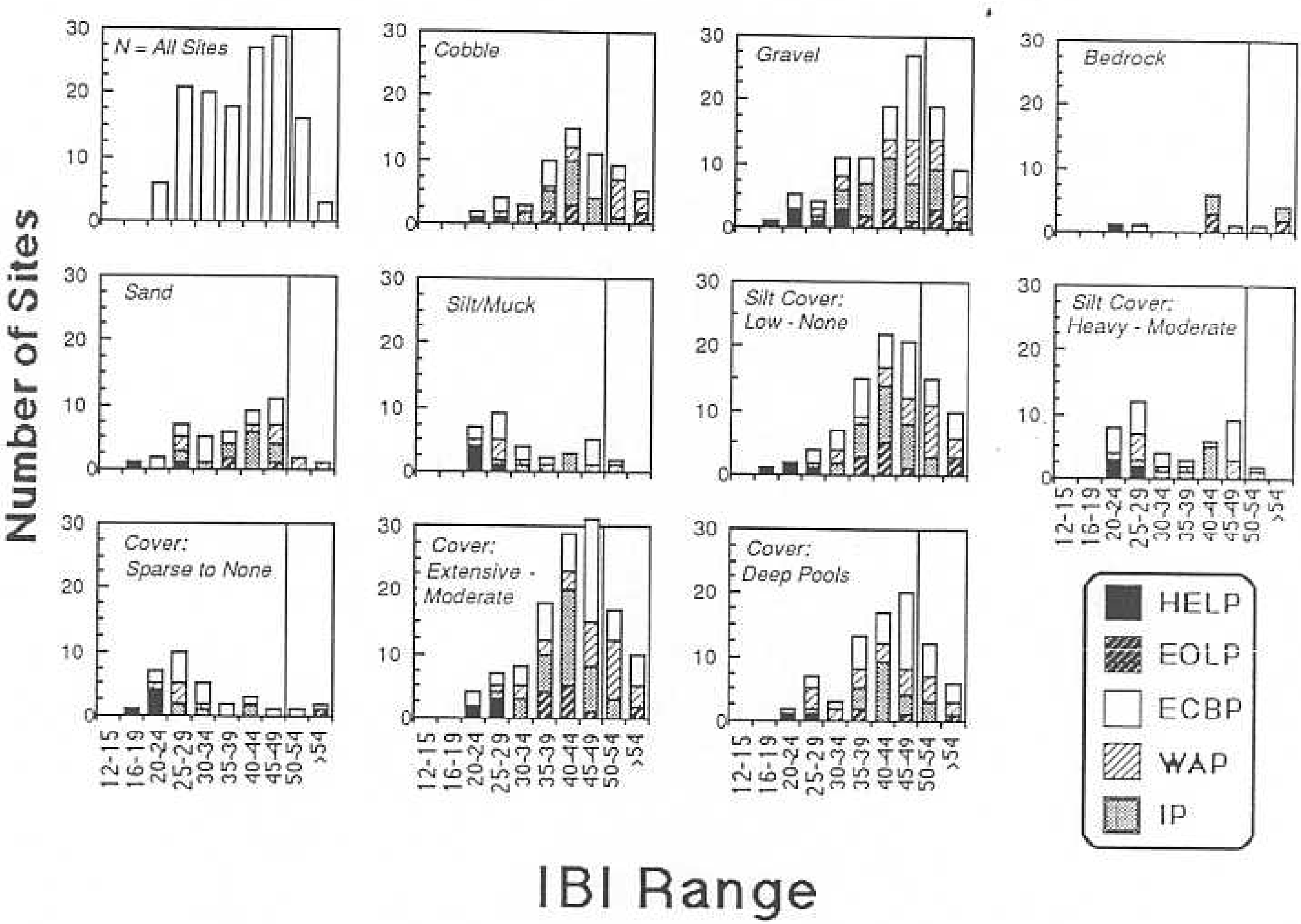


Figure 5. Frequency histogram of the occurrence of important substrate and cover attributes by IBI range for Ohio "Warmater" and "Modified" headwater refererence sites. Shading on bars denotes ecoregions except where noted differently. Vertical line of left side of charts represents an IBI of 50. The upper-right most chart represents the total frequency distribution of sites and, by percentage, would represent a random distribution of a habitat characters by IBI range.

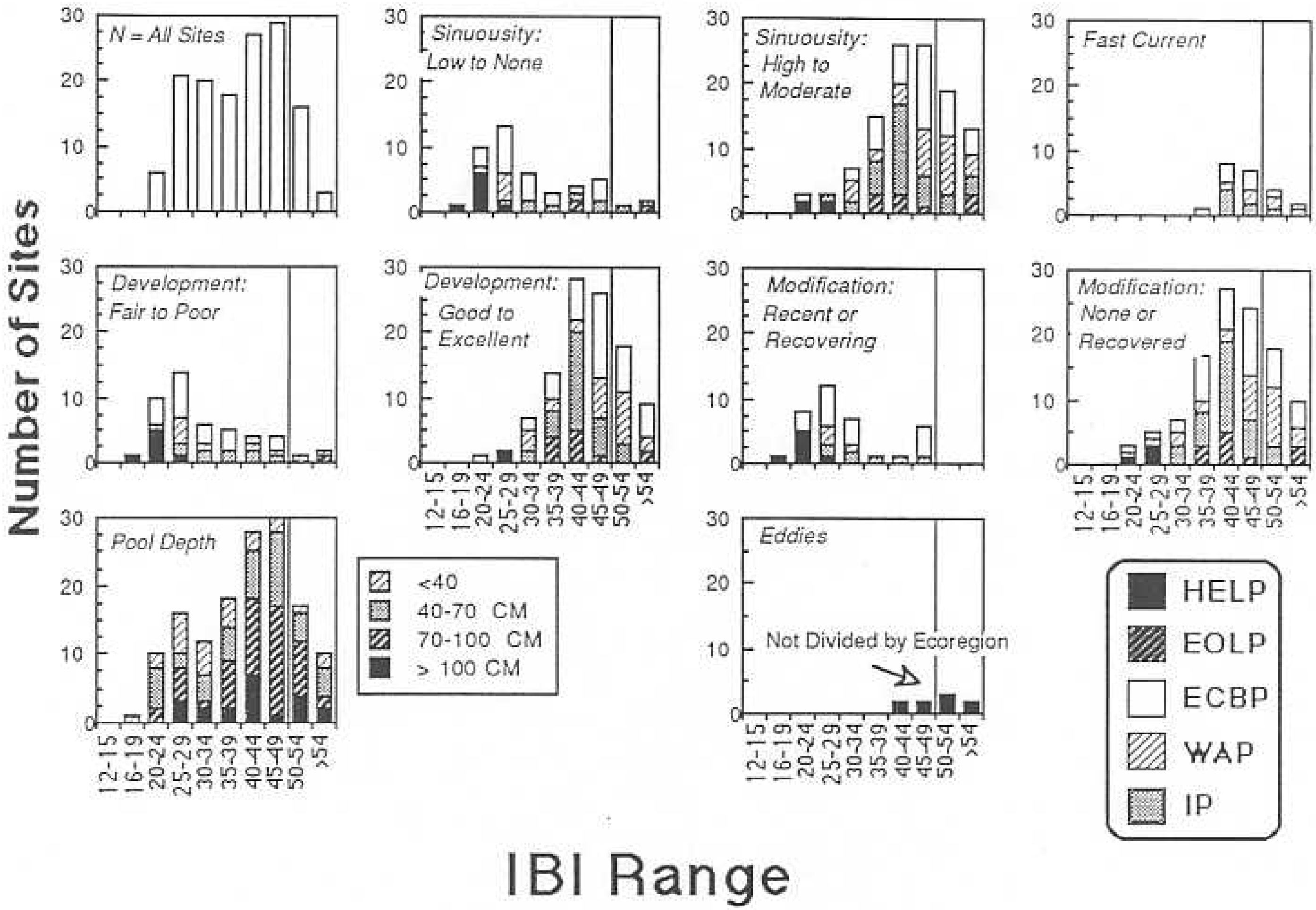


Figure 6. Frequency histogram of the occurrence of important channel and pool/riffle attributes by IBI range for Ohio "Warmater" and "Modified" headwater refererence sites. Shading on bars denotes ecoregions except where noted differently. Vertical line of left side of charts represents an IBI of 50. The upper-right most chart represents the total frequency distribution of sites and, by percentage, would represent a random distribution of a habitat characters by IBI range.

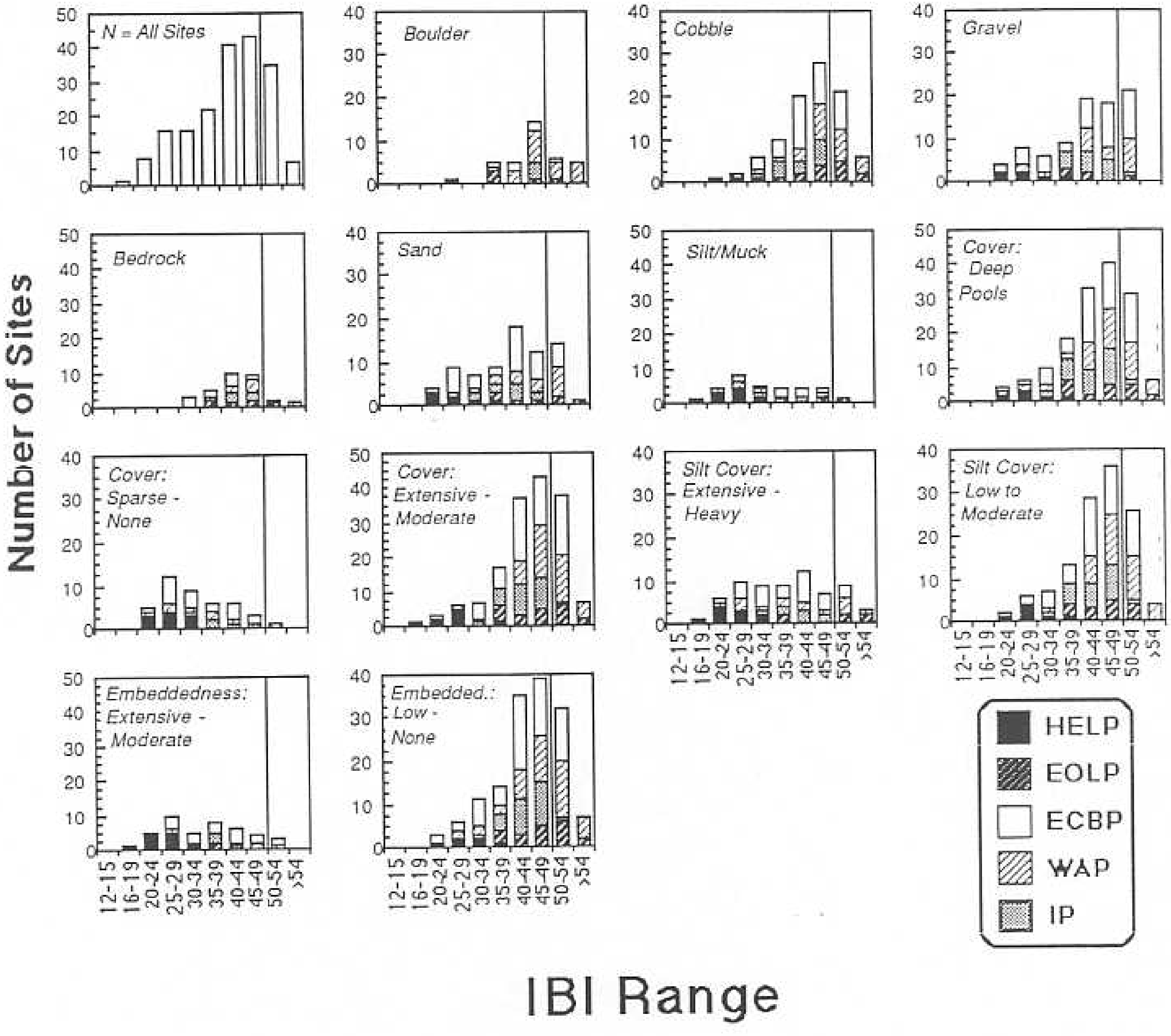


Figure 7. Frequency histogram of the occurrence of important substrate and cover attributes by IBI range for Ohio "Warmater" and "Modified" wading refererence sites. Shading on bars denotes ecoregions except where noted differently. Vertical line of left side of charts represents an IBI of 50. The upper-right most chart represents the total frequency distribution of sites and, by percentage, would represent a random distribution of a habitat characters by IBI range.

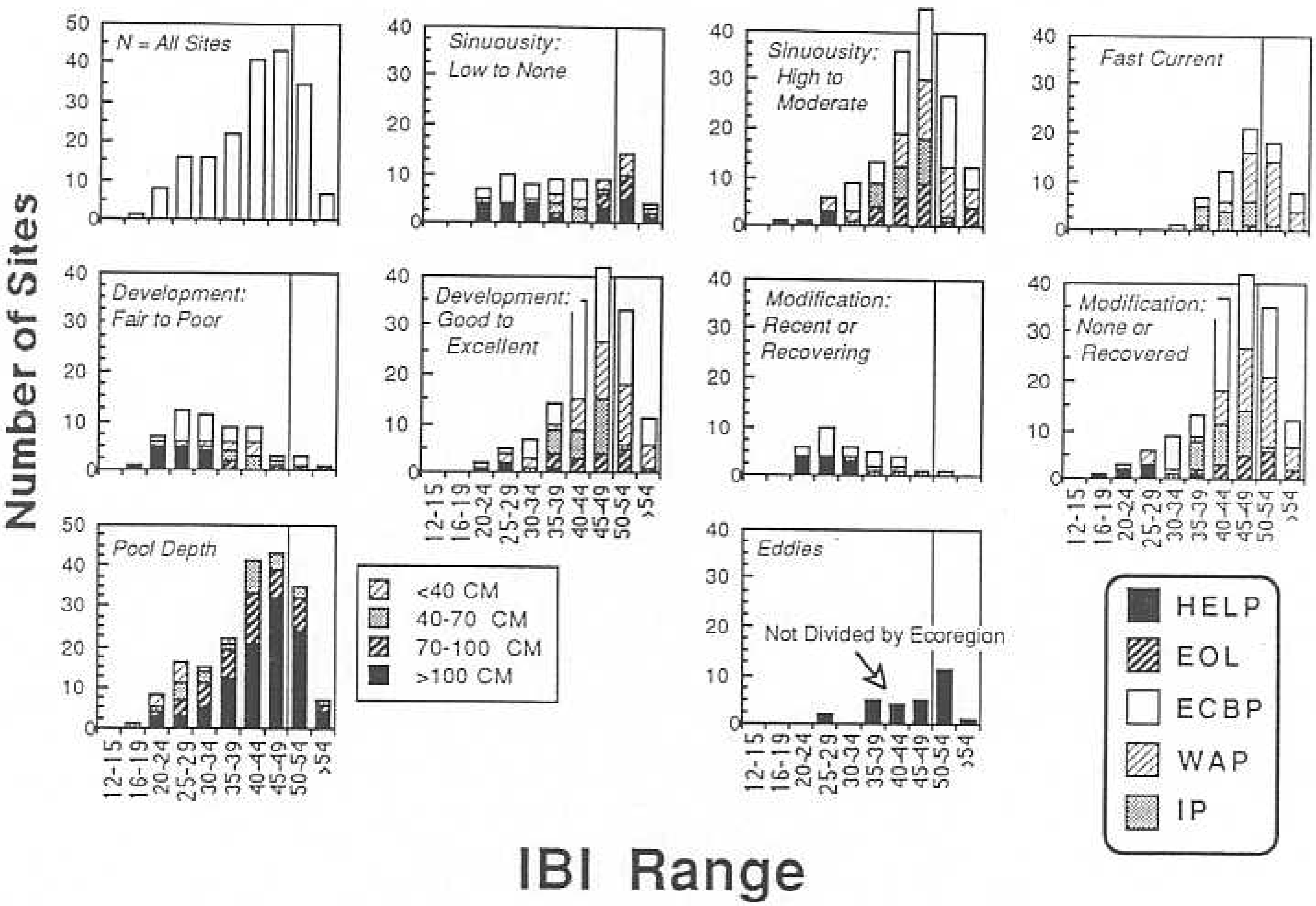


Figure 8. Frequency histogram of the occurrence of important channel and pool/riffle attributes by IBI range for Ohio "Warmater" and "Modified" wading refererence sites. Shading on bars denotes ecoregions except where noted differently. Vertical line of left side of charts represents an IBI of 50. The upper-right most chart represents the total frequency distribution of sites and, by percentage, would represent a random distribution of a habitat characters by IBI range.

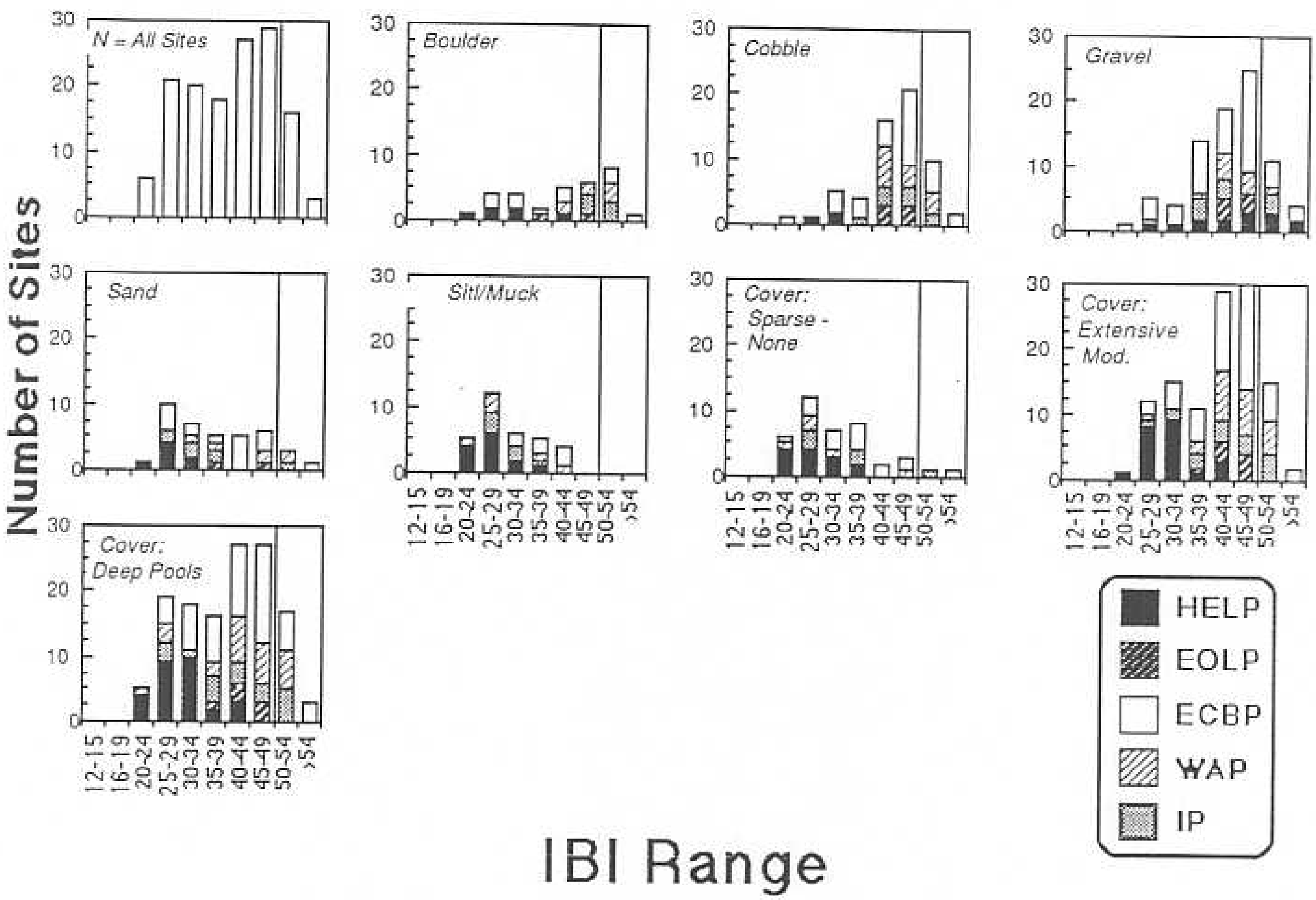


Figure 9. Frequency histogram of the occurrence of important substrate and cover attributes by IBI range for Ohio "Warmater" and "Modified" boat refererence sites. Shading on bars denotes ecoregions except where noted differently. Vertical line of left side of charts represents an IBI of 50. The upper-right most chart represents the total frequency distribution of sites and, by percentage, would represent a random distribution of a habitat characters by IBI range.

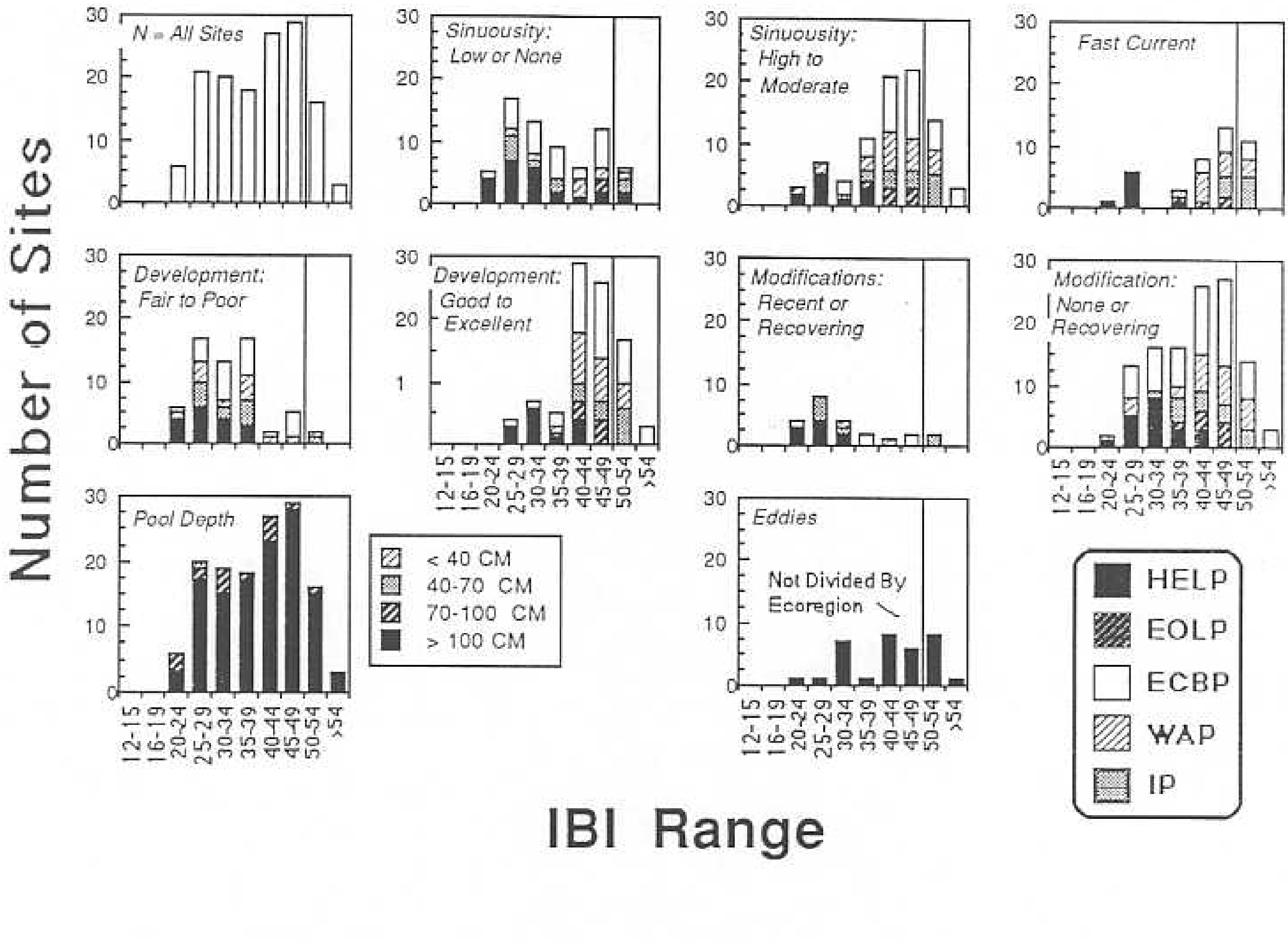


Figure 10. Frequency histogram of the occurrence of important channel and pool/riffle attributes by IBI range for Ohio "Warmater" and "Modified" boat refererence sites. Shading on bars denotes ecoregions except where noted differently. Vertical line of left side of charts represents an IBI of 50. The upper-right most chart represents the total frequency distribution of sites and, by percentage, would represent a random distribution of a habitat characters by IBI range.

Substrate

In most cases where there was sufficient data, substrate was significantly correlated with the IBI (Table 4 and 5). Substrate was consistently most highly correlated in the Western Allegheny Plateau (WAP) regardless of sampler type. This ecoregion has perhaps the widest range of substrate quality in Ohio from high gradient boulder, cobble streams to low gradient streams severely impacted by silt, sand, and mine generated fines. Of the metric subcomponents, boulder and cobble at wading sites and cobble and gravel at boat sites were more often associated with higher IBI scores (Table 6, Figures 5, 7, and 9). Silt or muck, in contrast was strongly associated with lower IBI scores for all sampler types (Table 6, Figures 5, 7, and 9). Sites that may have had better underlying substrates but had heavy-moderate coverings of silt or that had highly to moderately embedded substrates also had lower IBI scores across all sampler types (Table 6, Figures 5, 7, and 9).

Substrate has been long known to be of importance to stream fishes (Trautman 1981). The influence of high quality substrates is probably related to their importance in providing food organisms (macroinvertebrates) to the insectivores and benthivores that typify midwest streams . Larger substrates are more stable and produce larger and longer lived taxa of macroinvertebrates, which are preferable food items, than fine grain, unstable substrates such as sand (de March 1976). Large substrates may also function as escape or winter cover.

Pool/Glide Quality

The pool metric, like the substrate metric, was usually positively correlated with the IBI. This metric was most consistently correlated with the IBI in the Erie Ontario Lake Plain (EOLP) and Eastern Corn Belt Plains (ECBP) (Table 5). Subcomponents of this metric include diversity of current types, maximum depth of pools, and pool morpholgy. Sites with fast currents, for all sampler types, had higher IBI scores than expected by chance (Table 6, Figures 6, 8, and 10). Fast currents flush fine particles from the substrate and acts as a constructive force for increasing habitat heterogenity. Generally, sites with fast current also have a higher diversity of current types (e.g., moderate current, slow current, and eddies).

Stream depth explained little in large rivers (Table 6, Figure 10) probably because most larger rivers in Ohio have at least 70 cm maximum depths. For wading streams (Figure 8) sites < 40 cm in depth were not observed with IBI scores > 40. High IBI scores do occur in sites with < 40 cm maximum depth in headwater streams (Figure 6, also see depth as cover: Figure 5) however there is insufficient data to test if this was different from expected. In headwater streams the presence of good flow and riffles could ameliorate some of the effects of shallow pools. Although eddies were usually associated with higher

IBI scores in headwater streams (Figure 6) data is too limited to test for significance. Eddies generally are associated with good riffles and pools and good substrates and cover thus they should integrate many of the habitat characteristics found in good streams.

Channel Quality

Channel quality was usually positively correlated with the IBI (Table 4). This metric is comprised of measures of sinuosity, presence/absence of channel modification, pool/riffle development, and pool/riffle stability. Streams with little or no sinuosity were associated with lower IBI scores for all sampler types (Table 5 and 6, Figures 6, 8, and 10). Streams with little to no sinuosity often have higher levels of suspended sediments during low and moderate flow periods than more natural streams with higher sinuosity (Karr and Schlosser 1977). Further, streams with good sinuosity often have less erosion (Karr and Schlosser 1977) and are often associated with good pool/riffle development . As illustrated in Figures 6, 8, and 10 stream sites with only fair to poor riffle/pool development generally have lower IBI scores and sites with excellent to good development have higher IBI scores (Table 6). Streams with poor scores on the development subcomponent lack well developed pools or riffles and are often associated with stream channel modifications. Recently modified sites or sites that are still recovering from modification have lower IBI scores (Table 6, Figures 6, 8, and 10). However, in certain circumstances, where the stream in general has intact and diverse habitat, the effects of these modifications on the biota may be ameliorated. The fourth component of the channel quality metric, riffle/pool stability (not illustrated) shares similar negative trends with the other components: lower IBI scores with moderate to low channel stability (Table 6). The negative effects of channel modifications, which the components of this metric reflect, have been well documented in the fisheries literature (see Table 1). The magnitude of these activities, especially in headwater streams which serve as spawning areas, have been postulated as a major cause of a shift of many large river fish communities in the midwest from "dominance by insectivore and insectivore-piscivore fishes to omnivores and herbivore-detritivores" (Karr *et al.* 1983).

Instream Cover

Instream Cover was usually positively correlated with the IBI (Table 5). The amount of cover appeared to have more influence than the presence of any one cover type to attainment of higher IBI scores. Stream sites with sparse cover or cover nearly absent rarely had lower IBI scores for all sampler types (Table 6, Figures 5, 7, and 9). Lack of instream cover is often associated with channel modifications; in which cover is often regarded as an "impediment" to flow and removed. Removal of the riparian vegetation results in a decreased input of woody debris to the stream channel, perhaps the most

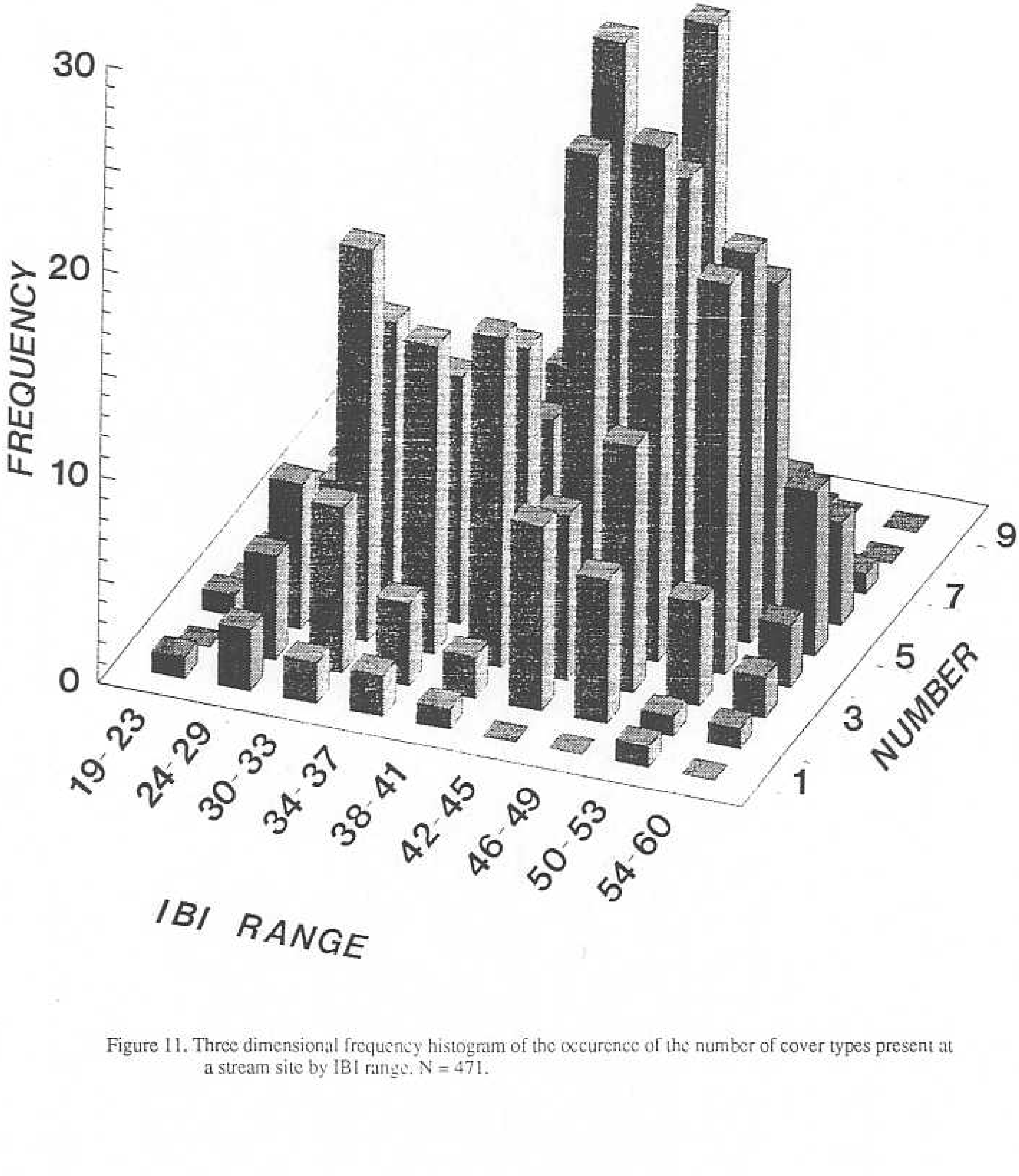


Figure 11. Three dimensional frequency histogram of the occurence of the number of cover types present at a stream site by IBI range. N = 471.

important source of cover in streams. Generally, sites with 3 or fewer cover types had lower IBI scores and sites with more than 3 were associated with higher IBI scores (Figure 11). Cover has been shown to be an important component of warmwater streams (Angermeier and Karr 1984) and may function as escape cover, a refuge from high flows, or may be important as a source of invertebrate production (Benke *et al.* 1984).

Riffle/Run Quality

Riffle/Run quality, as measured by QHEI, was less consistently correlated with the IBI than the above-mentioned metrics (Table 6). In headwater streams, the correlation was significant only in the ECBP ecoregion (Table 5). The occurrence of deep riffles (generally > 10 cm) was significantly associated with higher IBI scores in only boat sites (Table 6, Figure 10). Because boat sites may lack riffles the association of deep riffles with higher IBI scores may be related to the presence rather than the quality of the riffles *per se* (there are few shallow riffles at boat sites). Unstable and highly embedded substrates are associated with lower IBI values (Table 6) in wading and headwater sites (insufficient data for boat sites). Many of the attributes of high quality riffles are integrated in aspects of other metrics including such components as fast current, pool/riffle development, and eddies. Riffles function as critical habitat for rheophilic fish and macroinvertebrate species, however, even in modified streams some of the basic function and form of riffles exist to a limited degree in most Ohio streams.

Gradient

Stream gradient is an important influence on stream fish communities (see Table 1). For the ecoregions that occur in Ohio, stream gradient generally is not characterized by extreme values. In other areas of the country high gradients (up to 175 ft/mi) have much greater effects on fish species distributions (Leonard and Orth 1986; Miller *et al.* 1988). Very high gradients are largely limited to headwater streams. Low gradient streams or stream reaches, however, are found in all ecoregions with the Huron-Erie Lake Plain having, on average, the lowest gradient streams (Ohio DNR 1962). Scoring for stream gradient ranges was based on work done by Trautman (1942, 1981). Trautman (1981) classified Ohio streams as low, moderate, or high gradient on the basis of gradient in feet/mile and stream size measured as stream width. Because Ohio EPA relies on drainage area as a measurement of stream size we developed a relationship between stream width (m) and drainage area (sq mi) (Figure 12). Trautman's (1981) classifications were modified slightly and scores were assigned to categories of gradient and drainage area (Table 7) based on examination of plots of IBI versus stream gradient (Figure 13).

Table 7. Classification of stream gradients for Ohio, corrected for stream size. Modified from from Trautman (p 139, 1981). Scores were derived from plots of IBI versus the natural log of gradient for each stream size category.

Average Stream Width (m)	Drainage Area (sq mi)	Gradient (ft/mile)						
		Very Low	Low	Low-Moderate	Moderate	Moderate High	High	Very High[1]
0.3-4.7	0-9.2	0-1.0 **2**	1.1-5.0 **4**	5.1-10.0 **6**	10.1-15.0 **8**	15.1-20 **10**	20.1-30 **10**	30.1-40 **8**
4.8-9.2	9.2-41.6	0-1.0 **2**	1.1-3.0 **4**	3.1-6.0 **6**	6.1-12.0 **10**	12.1-18.0 **10**	18.0-30 **8**	30.1-40 **6**
9.2-13.8	41.6-103.7	0-1.0 **2**	1.1-.2.5 **4**	2.6-5.0 **6**	5.1-7.5 **8**	7.6-12.0 **10**	12.1-20 **8**	20.1-30 **6**
13.9-30.6	103.7-622.9	0-1.0 **4**	1.1-2.0 **6**	2.1-4.0 **8**	4.1-6.0 **10**	6.1-10.0 **10**	10.1-15 **8**	15.1-25 **6**
>30.6	>622.9	-	0-0.5 **6**	0.6-1.0 **8**	1.1-2.5 **10**	2.6-4.0 **10**	4.1-9.0 **10**	>9.0 **8**

[1]Any site with a gradient > than the upper bound of the "very high" gradient classification is assigned a score of 4.

Gradient 'quality' as measured by QHEI, was somewhat less consistently correlated with the IBI than the substrate, cover, channel, or pool/riffle metrics (Table 5). Headwater streams show the poorest correlation between gradient score and the IBI (Table 5). The relationship between raw gradient values (ft/mi) and the IBI is better fit by a logarithmic relationship than a linear one when the data is examined by site type (r^2 values: headwater, log - 0.34, linear - 0.12; wading, log - 0.12, linear - 0.05, boat, log - 0.37, linear - 0.36). This logarithmic relationship was incorporated into the actual scoring, which was based on a "fit-by-eye" curvilinear threshold response of the IBI to natural log of gradient illustrated in Figure 13

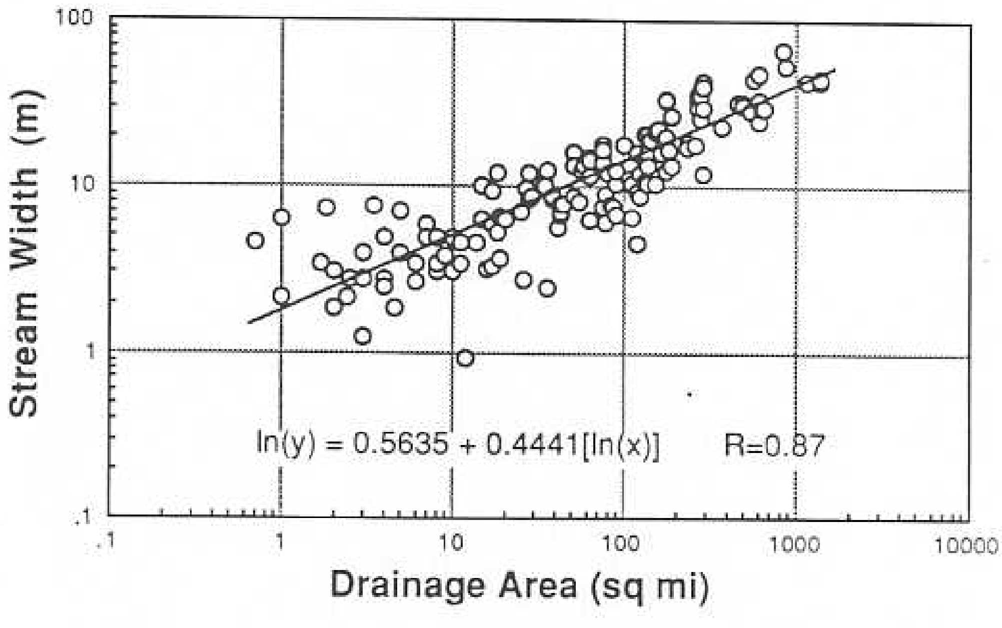
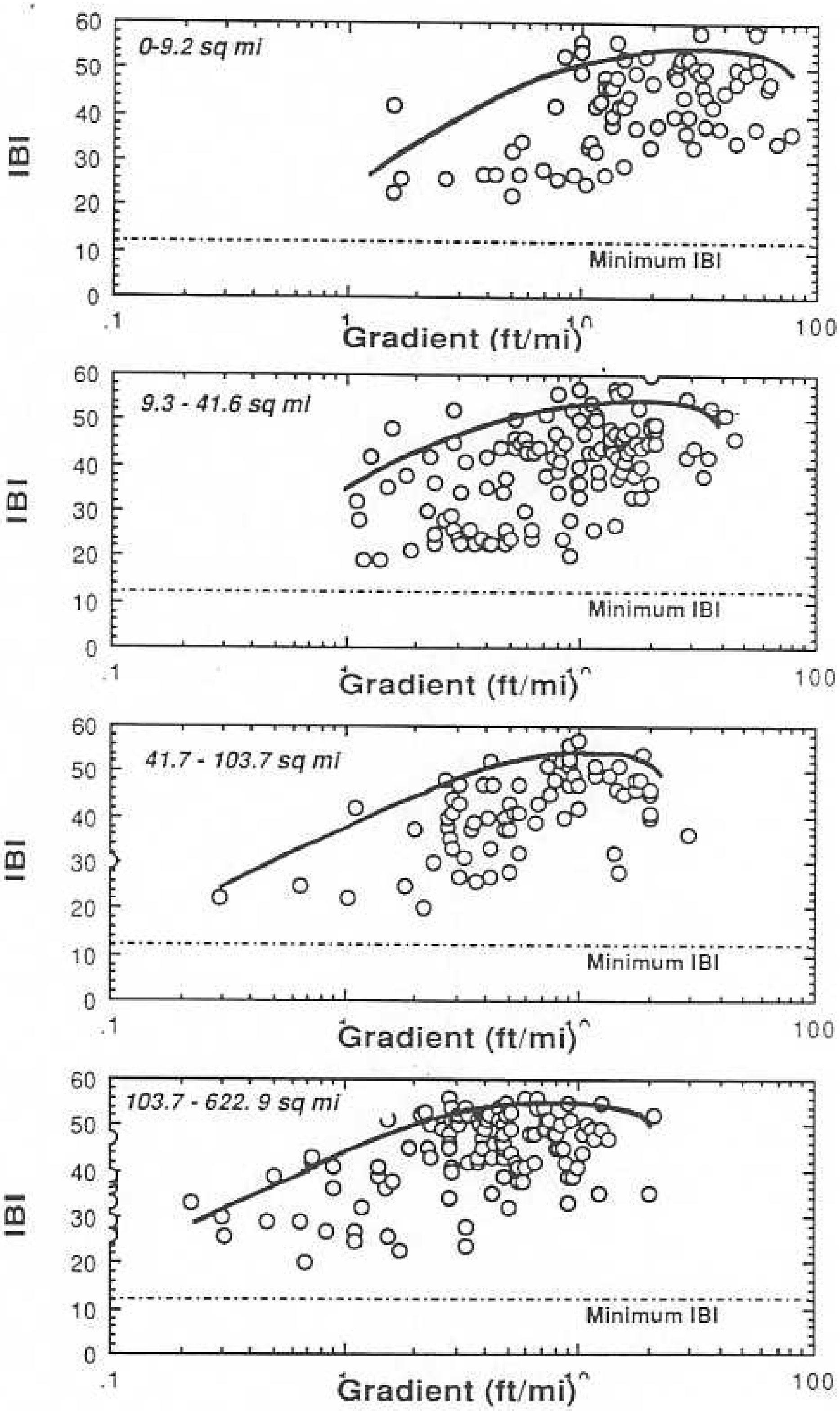


Figure 12. Average stream widths (ft/mi) versus drainage area (sq mi) for Ohio streams.

Larger streams have, on average, larger potential energy (to move sediments, etc.) and gradient may be less important for maintaining habitat features than a small stream with a similar gradient. A 4 X 7 Contingency table analysis (Gradient Score vs IBI Range) showed that the frequency of occurrence of gradient scores was not random with respect to IBI Range (G statistic = 118, P < 0.0001). This is illustrated in Figure 13 where lower gradients are generally, but not universally, associated with lower IBI values and higher gradient scores with higher IBI values.

The effects of nonpoint pollution can be exacerbated or ameliorated by habitat characteristics. The low gradient in HELP streams increases the retention time of fine sediments that are deposited in the stream bed and the resulting bedload degrades spawning substrate, reduces stream depth heterogeneity (through aggradation), and buries cover. The high gradient WAP streams, in contrast, are less susceptible to nonpoint pollution because of the high transport capacity and short retention time of fine sediments, especially in riffle/run areas. These trends are reflected in the generally poor fish communities of the HELP ecoregion and good-excellent communities characteristic of the WAP.



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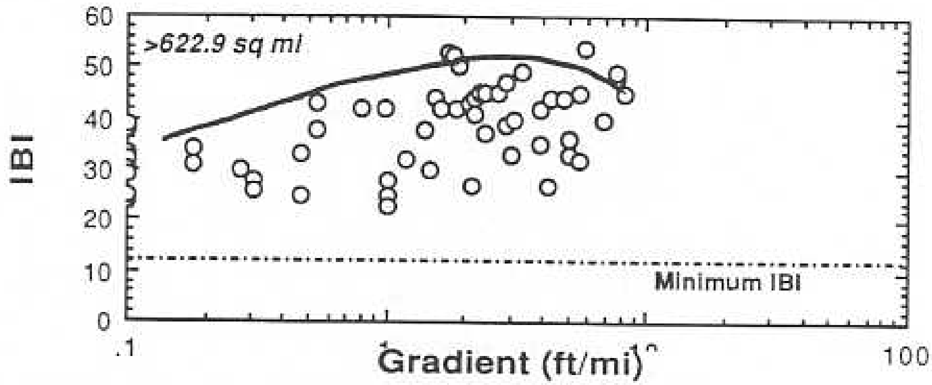

Figure 13. Scatter plots of stream gradient (ft/mi) by IBI for five different stream sizes as measured by drainage area. Lines superimposed on graphs were drawn by eye and represents an estimate of a threshold of the IBI for as given gradient.

Riparian Quality

Riparian quality was the metric least consistently correlated with the IBI of all the metrics examined (Table 4 & 5). The frequency occurrence of the subcomponents of this metric in relation to the IBI was not significantly different from random with the exception of the bank erosion submetric in wading sites (Table 6). The riparian component of the QHEI appears to have the weakest *direct* effect on the IBI. The indirect effects and the effects of the riparian zone at the scale of a basin or sub-basin is, however, likely to be large. The quality of the riparian zone has cumulative effects on cover availability (inputs of logs, woody debris), channel integrity, and direct effects of the energy dynamics of streams. Andrus *et al.* (1988) found that riparian trees must be left to grow longer than 50 years to ensure an adequate supply of woody debris for streams in Oregon. Because up to 70% of the pools in the study of Andrus *et al.*(1988) were formed by woody debris, poor management of the riparian forest can have far reaching effects on fish communities. Similar processes undoubtedly are important in Ohio streams.

On the basis of our analysis of average habitat quality discussed above and some of the important functions of riparian vegetation (stream temperature regulation and allocthonus energy inputs) this metric may be more important in its influence on general water quality conditions at a basin or sub-basin scale than in explaining site specific variation in the biota..

Using the QHEI to Assign Designated Uses

Figures 14-16 summarize the process used for assigning or changing designated aquatic life uses of Ohio streams. The ultimate arbiters of aquatic life use potential and attainment are the biocriteria (see Ohio EPA 1987b, c), which are direct measures of biotic integrity; if a stream achieves these criteria it, by definition, meets that specific use *regardless* of the QHEI performance. In many cases the biological data does not exist (especially for many unnamed small streams) or the biota is impaired so that the true potential has not been demonstrated. In these cases we must rely on a habitat evaluation and the QHEI to assign an aquatic life use.

Habitat data is collected from multiple sites in a stream when an aquatic life use is to be assigned or changed. For streams of > 3 square miles drainage area, the first step is to ascertain if there is extensive macro-habitat modification throughout major reaches of the stream (Figure 14). Uses are assigned by stream or stream segment and NOT by individual site. If there are no extensive modifications or other precluding factors (see below) the stream is usually classified Warmwater Habitat (WWH). Designation of a stream as Exceptional Warmwater Habitat (EWH) principally relies on direct evidence, from biosurvey data, that sufficient sites are attaining the EWH biocriteria. If biological data indicates that a stream cannot attain the Warmwater Habitat use because of natural conditions, alternative biocriteria can be developed (see Ohio EPA 1987b).

Types of Habitat Impacts

There are three broad classifications of habitat impacts that are commonly encountered in Ohio streams: channel modifications, impoundments, and non-acidic mine effects. Each of these habitat types is approached differently when designating aquatic life uses.

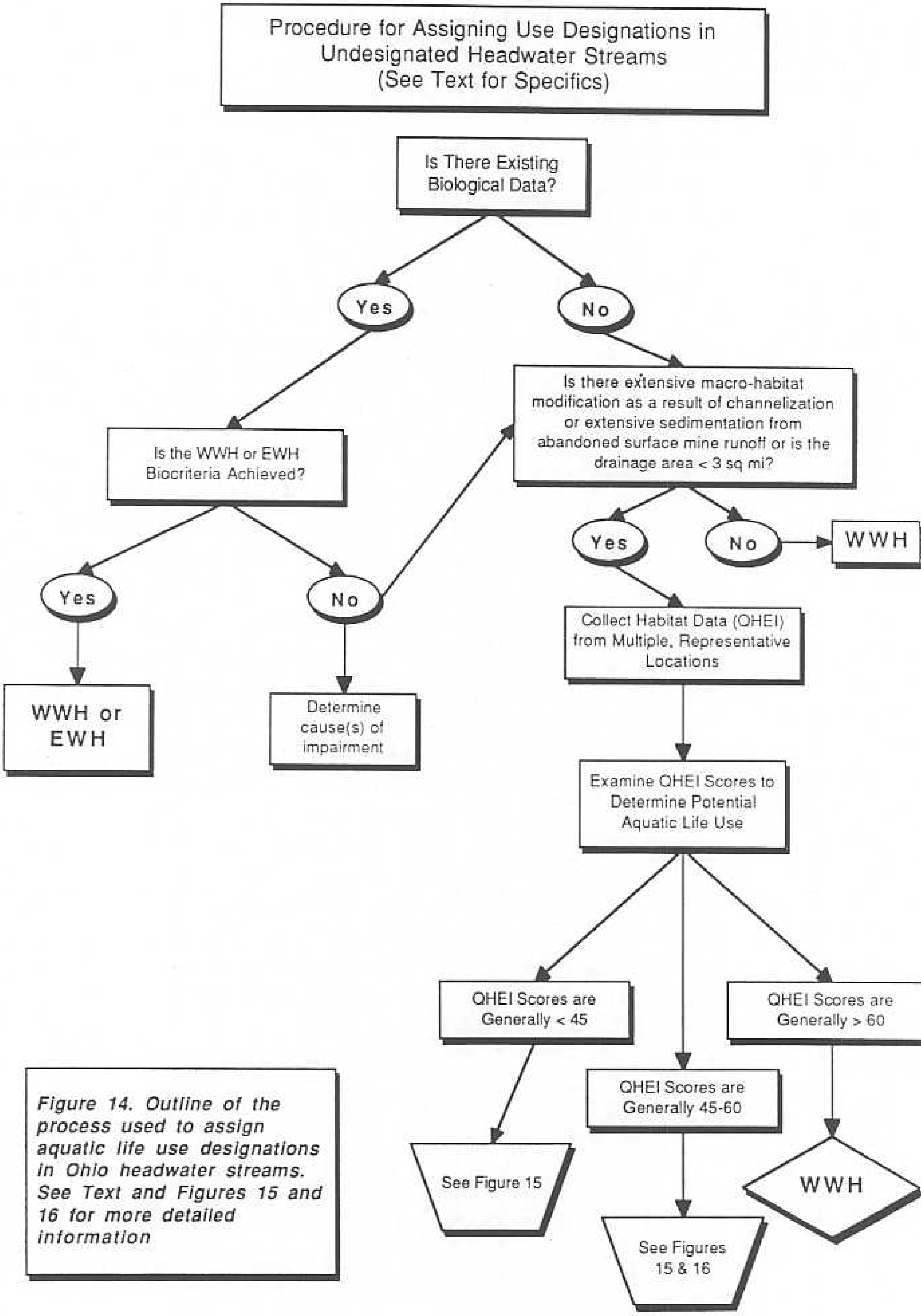

Figure 14. Outline of the process used to assign aquatic life use designations in Ohio headwater streams. See Text and Figures 15 and 16 for more detailed information

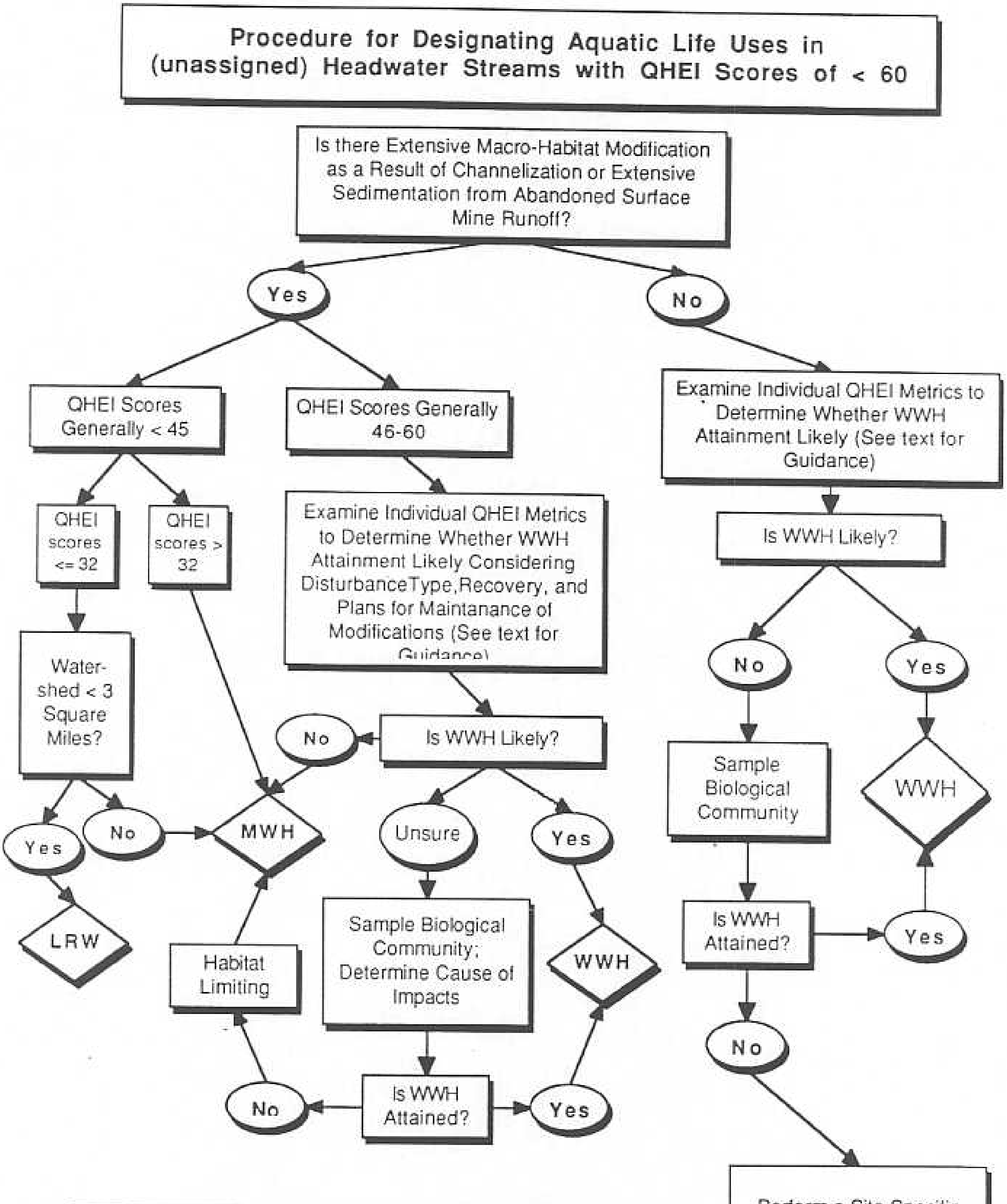

Figure 15. Flow Chart of the general procedures for assigning aquatic life uses in Ohio headwater streams (Drainage area <= 20 sq mi) that have QHEI scores < 60. See text for specifics and exceptions to general guidelines.

Procedure For Examining Individual QHEI Metrics to Determine Likelihood of Attaining WWH in Headwater Streams

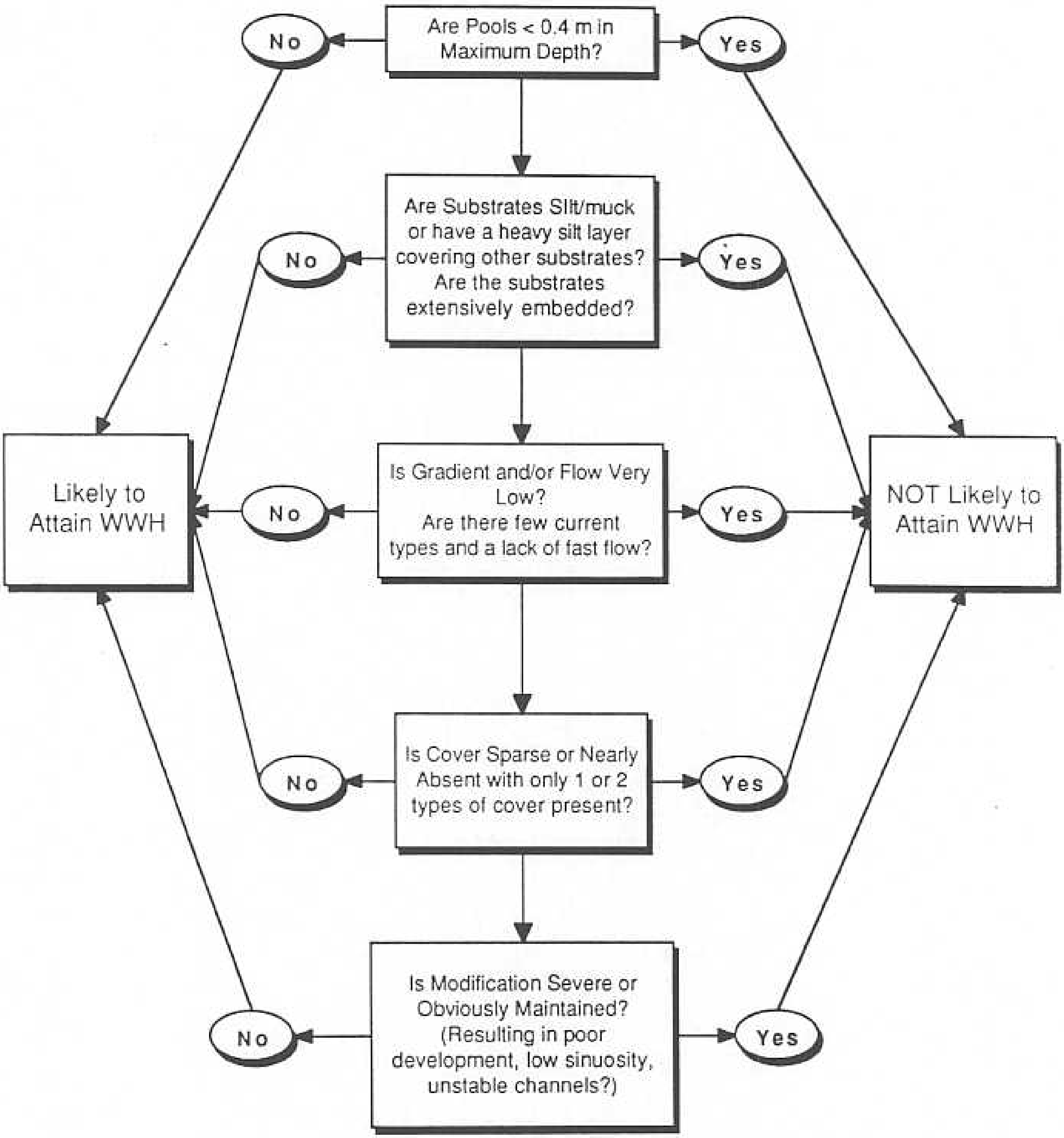

Figure 16. "Negative" habitat characteristics diagnostic of the MWH habitat use in Ohio streams. As stream reaches or stream basins accumulate these characters they are less able to support WWH fish communities. Conversely, the absence of these negative characters is diagnostic of WWH/EWH fish communiites. See text for a more detailed discussion.

MWH (Mine affected)

Mine sediment effects are the most distinct of the habitat impact types. Mine affected streams often have similar or lower IBI scores compared to channel modified streams and impounded streams; however, their QHEI scores often approach that of unmodified streams (Figure 17)[3]. In these streams the sediment effects are so severe that they alone can limit the community, even with a high QHEI score. Examination of the individual habitat metrics in mine affected streams provides a characteristic pattern of low substrate scores (often lower than those in channelized or impounded streams), but high scores in other metrics such as channel quality and pool quality (Figure 18). As such the designation of the mine affected modified warmwater habitat use relies heavily on direct sampling of the biota. Assignment of the MWH use for mine affected areas also relies heavily on the identification of the sources of the sediment, extent of mine activity in the basin, and the relative prospects for reclamation in the near future. This use is most often applied to streams impacted and impaired below WWH by non-acidic mine runoff from abandoned mine lands where no reclamation activities are imminent.

MWH (*Impoundments*)

Assignment of the MWH for the impoundment related modification type is made in conjunction with biosurvey data, and is not based on QHEI alone. Candidates for this aquatic life use are typically long reaches of impounded river, not brief impoundments on otherwise free-flowing rivers. Obviously, impounded areas are too deep to be sampled with wading methods, thus biocriteria only exists for the boat sampling site type.Consistent failure to fully attain the WWH biocriteria in an extensively impounded stream reach may warrant the MWH use. Such habitats, however, often occur in areas affected by urban impacts such as combined sewers and general urban runoff. These external factors must also be evaluated when the MWH use is being considered. Attainment or near-attainment of the WWH use in these areas may be sufficient reason to retain that use for impoundments.

MWH (Channel Modification)

Channel modifications are the most common and extensive habitat perturbations to Ohio streams. However, the mere presence of channel modification is insufficient reason for assigning the MWH use. The considerations prior to assigning the MWH aquatic life use are outlined below.

1) **The MWH designation is reserved for extensively modified stream segments or sub-basins.** The MWH use is not intended to be applied in patchwork

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[3]Note the outliers in the unmodified reference data (low IBI scores and low QHEI scores) in Figure 17. These outliers are largely HELP reference sites that have poor habitat and do not meet the definition of "relatively unimpacted" associated with the other ecoregions. See Ohio EPA (1987b) for more information.

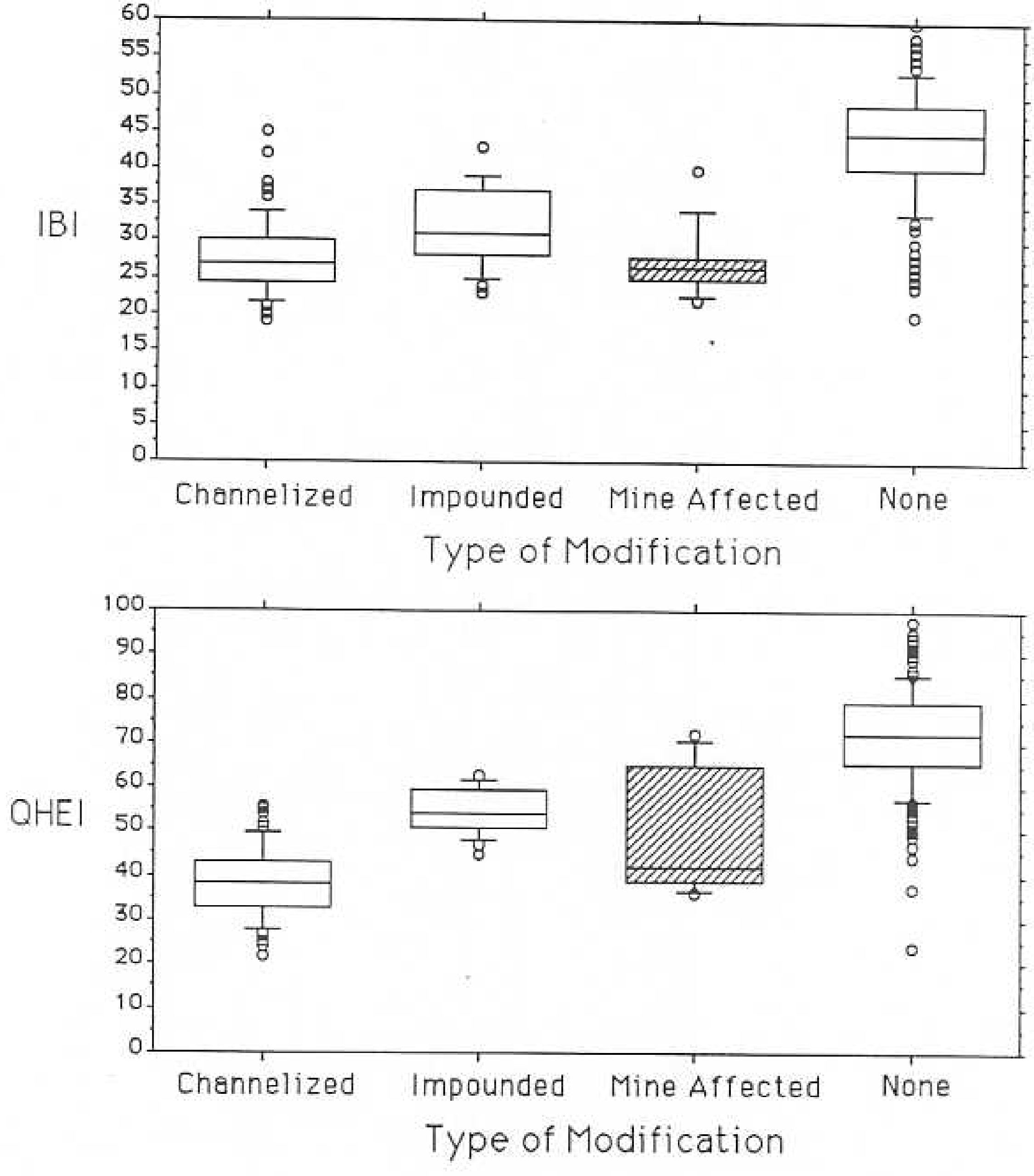

Figure 17. Box and Whisker Plots (medians, 25th and 75th percentiles, maximum value, minimum value, and outliers > two interquartile ranges from the median) from modified reference sites with channel modifications, impoundments, and mine affects (crosshatched) and warmwater reference sites for the IBI (top panel) and QHEI (bottom panel).

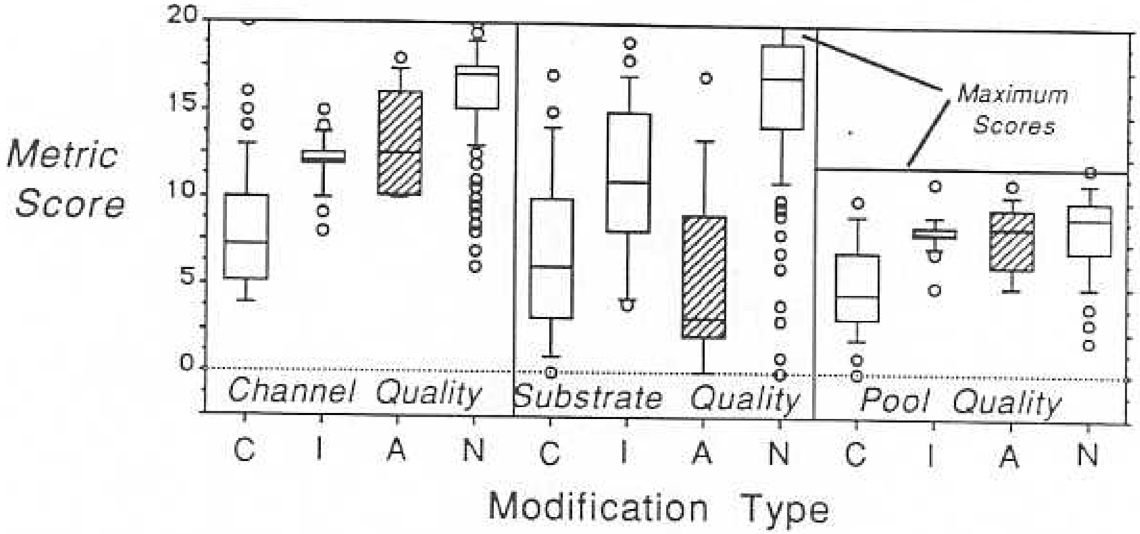

Figure 18. Box and Whisker Plots (medians, 25th and 75th percentiles, maximum value, minimum value, and outliers > two interquartile ranges from the median) for metric scores from modified reference sites with channel modifications (C), impoundments (I), and mine affects (A, crosshatched) and warmwater reference sites (N). The maximum score possible is 20 for channel and substrate quality and 12 for pool quality.

fashion in a stream or river. The previous analyses on the average habitat quality in a basin illustrated the ability for isolated areas of degraded habitat within a basin with generally good or high quality habitat to support a WWH or even EWH biological community. The MWH use is reserved for the converse of this situation: streams where average habitat quality is poor and unlikely to attain a WWH aquatic life use.

2) **The stream or basin must be under approved channel maintenance sanctioned by the Soil Conservation Service (SCS) or County Engineer and have 401/404 approval –OR– show no evidence of biological recovery over an extended period of time (i.e., 50-100 years).** Modified streams often have the ability to regain their natural habitat characteristics. Habitat characteristics of streams in a region (e.g., ecoregion) are the result of interacting variables such as gradient, lithology, rainfall, land use, etc.; such variables are modified, but not eliminated during channel modifications. With no further modifications the stream channel will progress through a physical "successional" process and eventually resemble the stream prior to modification. Where streams have been channelized, and flow and gradient is sufficient, channel characteristics can often recover some of their function within a few years. Other streams, especially those with low gradients, can take many years to regain the habitat functions lost

during modification; some may never recover their original habitat. Thus the MWH use is reserved for streams that are not likely to recover within 50-100 years, or, are kept in a habitat-poor "successional" stage by approved maintenance activities. These activities are generally overseen by a county engineer or SCS agent for flood control and agricultural purposes (drainage) and have received approval via the 401/404 process. In the process of determining an aquatic life use Ohio EPA will contact the county SWCD, county engineer, or other appropriate agency to ascertain the extent and history of existing channel modifications and to determine whether there are existing maintenance activities.

3) **Stream recovery potential must be considered, especially in relation to stream gradient, to determine if the MWH definition of "irretrievable anthropogenic modification" is met.** As discussed above, it is necessary to determine whether a stream can recover from modifications or is essentially "irretrievably modified". Such a classification is related to the intrinsic ability of a stream to reconstruct habitat naturally. Our experience suggests that streams with gradients of 5-6 ft/mi or greater are likely to recover habitat that would support a WWH community[4]; streams with gradients < 5 ft/mi will be very slow to recover, or may not recover at all , essentially resulting in an "irretrievable anthropogenic modification", a key criterion for changing a use to MWH.

It must be made clear that the above points refer to existing channelization in Ohio. *The MWH use is in no way to be used to permit the modification of a stream or river that is currently attaining the WWH (and certainly the EWH) use.* Ohio EPA's antidegradation policy prohibits activities that result in a reduction of a stream's ability to attain its current level of performance or, at a minimum, its current use..

LRW Aquatic Life Use.

The Limited Resource Water (LRW) aquatic life use is reserved for streams with extremely limited physical habitat that cannot be expected to even attain the MWH biocriteria. Limited Resource Waters have:

> "extremely limited physical habitat due to natural limitations or extreme alterations of anthropogenic origin. An example of the former are small ephemeral streams with drainage areas less than three sq. mi. An example of the latter are streams affected by chronic acid runoff from surface mines with sustained pH values less than 4.1 S.U. or severe streambed sedimentation. As a result of severe habitat limitations LRW are not able to attain even the MWH biological criteria outside of areas of chemical pollution. QHEI alone may be sufficient to determine the appropriateness of the LRW designation if the score is less than the 25th percentile of the MWH headwater reference sites." (Ohio EPA 1987b).

[4]Streams with > 5-6 ft/mile are likely to recover enough habitat characteristics to achieve the baseline WWH biocriteria; less information is available on the time frame necessary to fully recover all past habitat characteristics.

The 25th percentile of the **QHEI** for modified reference sites is 32. Streams less than 3 sq mi that have **QHEI** scores less than 32 would be strong candidates to be classified as LRW. Streams with greater than 3 sq mi drainage area and without other factors severely limiting aquatic life (e.g., low pH) are generally able to attain a more protective use than LRW even with modifications. Extreme modifications, however, (e.g., concrete channels, etc.,) may warrant consideration of LRW in these streams.

Using the QHEI in the Use Designation Process

Plots of the IBI for ranges of the QHEI results in overlapping ranges of QHEI scores that are useful to the aquatic life use designation decision process: <45, 46-60, and > 60 (Figure 19). From figure 18 it is clear that QHEI scores < 45 are usually associated with streams that do not attain the WWH biocriteria and QHEI scores of > 60 usually do achieve the WWH or EWH biocriteria. QHEI scores intermediate to this may fall into the range of the MWH or WWH biocriteria depending on what habitat characteristics appear to be limiting to aquatic life. This intermediate range is wide because such sites are found both in basins with generally good and generally poor habitat; this increases the range in the observed IBI scores. In contrast sites with extreme QHEI scores (high or low) are less likely found in streams of the opposite range of habitat quality. Thus, the average habitat in a basin or homogeneous stream reach is important to the designation of aquatic life uses.

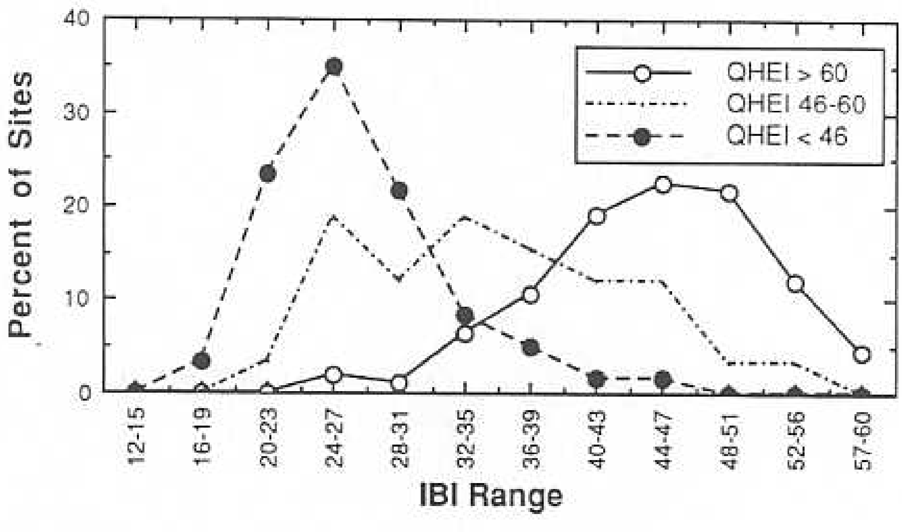

Figure 19. Frequency curves of the IBI for sites with QHEI scores > 60, 46-60, and ≤ 45.

Stream reaches with QHEI scores averaging > 60 will likely have the potential to attain the WWH use. With QHEI scores > 60 the effects of any stream modification are usually not severe and many of the natural characteristics of stream still exist. Also, it is likely that any past habitat degradation will recover with time in such areas. Streams with QHEI scores averaging < 45 have modifications that are generally severe and widespread. Often channel modifications are maintained or flow and stream gradient are very low so that more natural conditions do no readily reappear. Note that we are talking about stream-wide habitat conditions and *not a site-specific situation.* Average habitat quality in a homogeneous reach is most important to assigning and evaluating aquatic life uses. For example the Kokosing River had a mean QHEI of 77 among 16 sites. An outlier site had a QHEI of 37 but still had a near exceptional IBI score - this is why multiple locations and the general habitat quality must be considered (see Figure 4).

Designation of uses is most difficult for streams with QHEI values intermediate (45-60) to the low and high range scores discussed above and where direct estimates of biological performance is lacking or WWH use attainment is precluded by other factors. In these situations specific characteristics of the stream which may (or may not) limit a use are considered. Other information is also examined such as biological data from nearby streams with similar modifications if such information exists.

Table 8 summarizes some of the habitat characteristics of Modified Warmwater streams and Warmwater streams; superscripts and print style in Table 8 refer to the influence of the

Table 8. Habitat Characteristics of Modified Warmwater Streams and Warmwater Streams in Ohio. Superscripts for MWH streams refer to the influence of a particular characteristic in determining the use (1-high influence, 2-moderate influence) . Characteristics apply to all ecoregions and types unless otherwise noted.

Modified Warmwater Streams	Warmwater Streams
1. Recent channelization[1] or recovering[2]	1. No channelization or recovered
2. Silt/muck substrates[1] or heavy to mod. silt covering other substrates[2]	2. Boulder, cobble, or gravel
3.Sand subtrates[2-Boat], Hardpan origin[2]	3. Silt Free
4. Fair-Poor Development[2]	4. Good-Excellent Development
5. Low-No sinuosity[2,1-Headwater]	5. Moderate-High Sinuosity
6. Only 1-2 cover types[2], Cover sparse to none[1]	6. Cover extensive to moderate
7. Intermittent or interstitial[2-with poor pools]	7. Fast Current, Eddies
8. Lack of fast current[2]	8. Low-normal substrate embeddedness
9. Max. depth < 40[1-Wading,2-Headwater]	9. Max. depth > 40
10. High embeddedness of substrates[2]	10. Low/No embeddedness

characteristics to these streams (1-high influence (bold type), 2-moderate influence (normal type). Streams with QHEI scores between 45-60 should have several of the primary factors to be considered for MWH status.

As streams accumulate more of the negative characteristics listed in Table 8, especially those characterized as having a high influence on the biota, the biologist should be more likely to classify a stream as MWH. A stream with fewer of these characteristics, or with a number of the distinctive WWH characteristics will be more likely classified as at least WWH. Figure 16 summarizes this process.

Case Examples of the Use of the QHEI for assigning and evaluating aquatic life uses.

This section will discuss three case examples of how the QHEI has proved useful in assigning aquatic life uses or evaluating aquatic life use attainment.

Hurford Run

Hurford Run illustrates a situation where three aquatic life uses, LRW, MWH, and WWH, were designated within the same stream. Hurford Run (drainage area 7 sq mi at its confluence with Nimishillen Creek) flows through a heavily industrialized area in Canton, Ohio and its fish and macroinvertebrate communities are severely impaired by chemical and physical impacts. Major industrial point sources discharge directly to Hurford Run or its major tributary, Domer Ditch. The entire stream has been modified at some time with most of the middle section re-channelized within the past two years. The lower mile had been channelized, but has sufficient gradient and has recovered many of the channel characteristics of a more natural headwater stream. Figure 20 summarizes the important biological and physical characteristics of the stream. Table 9 summarizes important QHEI components by stream segment.

Table 9 - Habitat Characteristics of the three aquatic life use segments found in Hurford Run. Characteristics associated with MWH or LRW are boldface.

LRW Upper Segment RM 1.8-3.0	MWH Middle Segment RM 1.1-1.7	WWH Lower Segment RM 0.0-1.0
Drainage Area < 3 sq mi	Drainage Area > 3 sq mi	Drainage Area > 3 sq mi
Silt/Muck Substrates[1]	Sandy Substrates	Cobble Substrates
Poor Development[2]	**Poor/Fair Development**[2]	Good/Excellent Development
No Sinuosity[1]	**Low/No Sinuosity**[1]	**Low/Moderate Sinuosity**[1]
Cover Sparse to None[1]	**Cover Sparse**[1]	Cover Moderate
No fast current[2]	Fast Current	Fast Current
Recent Channelization[1]	**Recent Channelization**[1]	**Recovering from Channelization**[2]
Max Depth < 40 cm[2]	Max Depth > 40 cm	Max Depth > 40 cm
Substrates Highly Embedded[2]	**Substrates Highly Embedded**[2]	Substrates Moderate to Low Embeddedness

The extreme small size of Hurford Run in the upper segment, the industrialized nature of the land use, and the poor habitat that is periodically modified qualify this section of stream as a limited resource water aquatic life use.

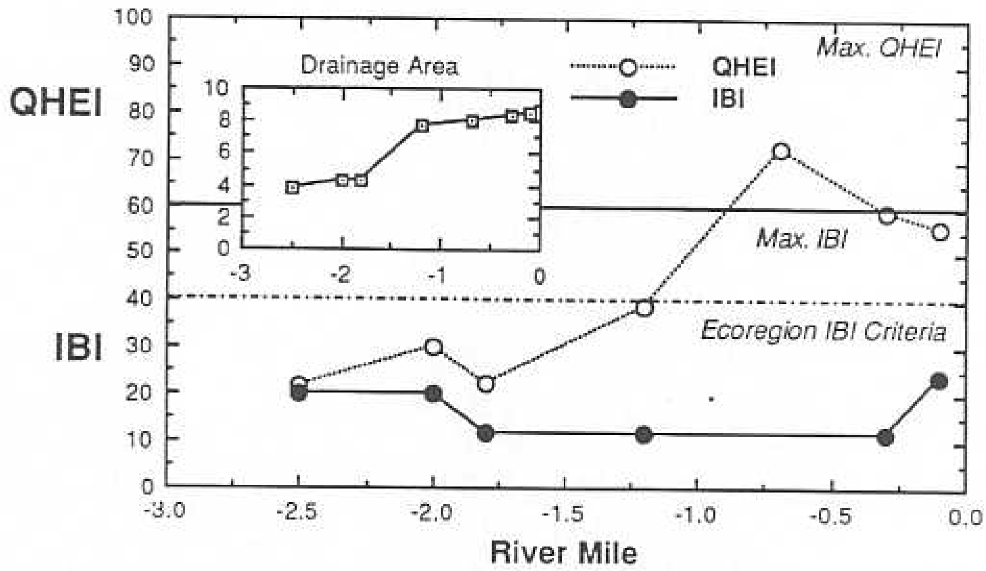

Figure 20. Longitudinal plot of the IBI (closed circles) and QHEI (open circles) versus river mile for Hurford Run, near Canton, Ohio. Graph of drainage area (sq mi) is inset on the plot for reference

The middle stretch although modified is larger, has adequate flow (Domer Ditch a WWH stream enters at the upstream end of this stretch) and sufficient habitat diversity to support a biological community characteristic of the MWH use. The periodic channel maintenance and relatively fine-particle substrates preclude a WWH biological community for the forseeable future. Maintenance of a modification and the likelihood of reverting to a WWH stream in the near future is critical to the designation of the MWH use. If this stretch had showed a tendency to recover quickly and would not be modified again a WWH aquatic life use may have been considered.

The downstream-most stretch, although modified at one time has good substrate, pool depth, pool/riffle development, and current diversity to support a warmwater community found in a headwater stream. It also has sufficient gradient to allow the recovery process to occur at a relatively rapid pace.

Twin Creek

Twin Creek is an example of where QHEI data was ancillary to biosurvey data in assigning an aquatic life use (EWH) but was used to interpret changes in the fish community in a longitudinal analysis of the data. Figure 21 summarizes the important biological and physical characteristics of the stream. The fish (IBI) and macroinvertebrate indices (ICI), clearly attain or nearly attain the exceptional range of the biocriteria (Figure 21). The QHEI scores (average QHEI = 77 ,range 51-90) indicate excellent habitat, the likely origin of the EWH attainment. . Several short sections, however had somewhat lower IBI and ICI scores than the average (Figure 21).

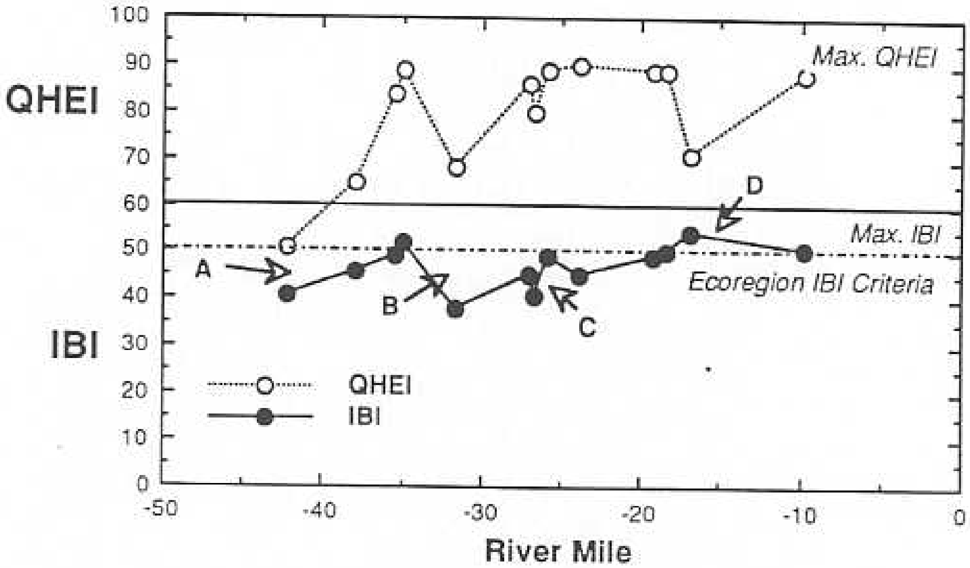

Figure 21. Longitudinal plot of the IBI (closed circles) and QHEI (open circles) versus river mile for Twin Creek from Lewisburg to Germantown, Ohio. Labeled segments are discussed in text.

The section labeled A in Figure 21 is the upstream most area sampled. Here the stream is much smaller (drainage area < 42 sq mi) and is impacted by agricultural nonpoint sources. Section B is a small stretch impacted by a combination of WWTP effluent and agricultural rowcrop encroachment on the riparian zone. An increased bedload of sand and silt resulting in some embedded substrates were obvious here. Section C was downstream of a WWTP, however most of the suppresion of the IBI was related to the impounded nature of this site and for 0.3 miles downstream. Section D showed no depression of the IBI even at a site with a relatively low QHEI. The lower twenty miles of Twin Creek however was nearly continuous good-excellent habitat and the community was not affected by a short stretch of habitat of somewhat lower quality.

West Branch Nimishillen Creek/Nimishillen Creek

This area illustrates the importance of considering aquatic life potential on the basis of habitat when examining attainment status in rivers. In Nimishillen Creek the QHEI data was critical in identifying and delineating a impaired section of the stream. The West Branch of Nimishillen Creek has poor habitat throughout the section we sampled (RM 0 to 5.8 Table 10, Figure 22). As it flows through urban Canton it is characterized by sandy substrates and broad shallow glides (Table 10). Nimishillen Creek in contrast has cobble substrates and excellent riffle/pool development with good variation in depth and current, especially as it leaves the urban area of Canton downstream of the confluence of the West Branch.

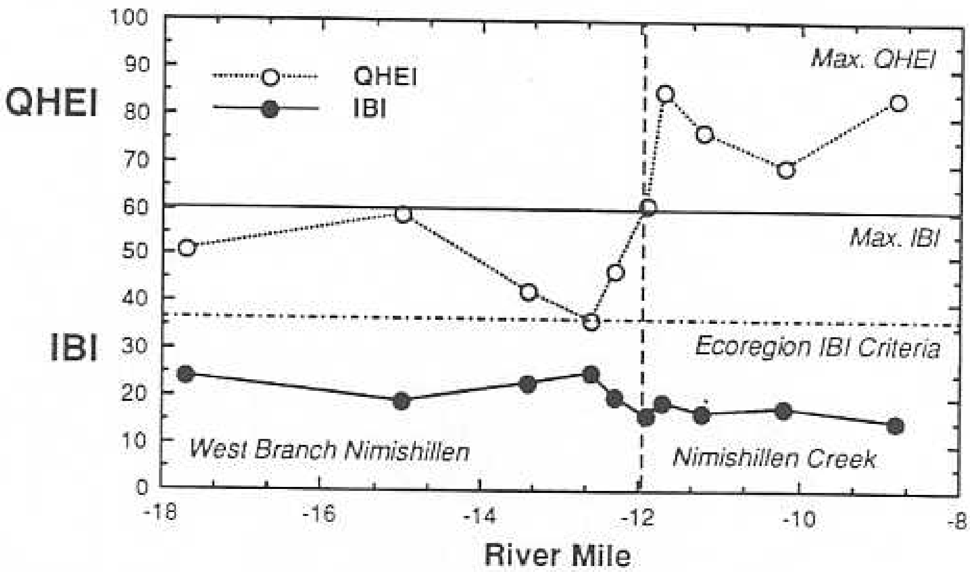

Figure 22. Longitudinal plot of the IBI (closed circles) and QHEI (open circles) versus river mile for Nimishillen Creek and the West Branch Nimishillen Creek at Canton, Ohio.

The IBI in Nimishillen Creek decreased downstream of the confluence of the West Branch (Figure 22) where it should have increased with the improvement in habitat and distance from urban impacts (storm sewers, runoff). This observation resulted in additional sampling in the West Branch were a galvanizing plant without a discharge permit was found to impair 16 miles of Nimishillen Creek with periodic leaching and/or discharge of acid, zinc, and lead. Table 10 summarizes the major shifts in habitat quality between the West Branch Nimishillen Creek and Nimishillen Creek.

Table 10. Major habitat characteristics of six sampling locations in the West Branch Nimishillen Creek and four sampling locations in Nimishillen Creek downstream of the West Branch confluence.

West Branch Nimishille Creek *RM's 5.8, 3.2, 1.6, 0.8, 0.5, 0.1*	*Nimishillen Creek* *RM's 11.7.11.1, 10.2, 8.9*
Recovering from Channelization[2]	No or Minor Channelization
Sand Substrates	Cobble Substrates
Poor-Fair Development[2]	Good-Excellent Development
No-Low Sinuosity[2]	Moderate Sinuosity
Sparse-Moderate Cover	Moderate Cover
Moderate Current-No Eddies	Moderate & Fast Current - Eddies
Substrate Extensively or Moderately Embedded[2]	Substrate No-Low Embeddedness
Maxiumum Depth < 70 cm	Maximum Depth > 100 cm

QHEI Variability

An estimate of investigator variability was obtained by having two different biologists independently score the QHEI for the same locations; temporal variability was estimated by having the same biologist score the QHEI on different occasions. In 1985 Twin Creek was scored (with the OLD QHEI) at 15 locations (each location at two different times) by two biologists from the Ohio EPA (Table 11). A two-tailed paired t-test showed no significant difference in the final QHEI scores or in 4 of the 6 individual metric scores on one occasion and 6 of 6 metrics on the second ocasion (Table 11) significance at P >0.05). The one metric that showed a difference was the riffle metric which in this form of the QHEI ranged in score from 0-5. The scoring difference averaged less than one point but one biologist accounted for the higher score in 9 of 10 locations. In general, even in those instances where investigator or temporal differences were statistically significant, the differences are minor in a biological sense (i.e., based on expected effects on fish communiites) and in the degree of resolution we expect from the index.

Table 11. Comparison of QHEI scoring (overall and individual metrics) between two biologists and between two different occasions for 15 locations on Twin Creek sampled during June-August of 1986. An asterisk denotes significance for a two-tailed paired t-test at $P < 0.05$)

Metric	df	Mean difference	P	Significance
		Comparison Between Sampling Dates		
		Biologist 1		
Substrate	14	0.13	0.73	NS
Cover	14	-0.40	0.36	NS
Channel	14	0.40	0.03	*
Riparian	14	0.37	0.30	NS
Pool	14	0.20	0.57	NS
Riffle	14	0.60	0.01	*
		Biologist 2		
Substrate	14	0.40	0.33	NS
Cover	14	-0.87	0.15	NS
Channel	14	0.00	—	NS
Riparian	14	0.93	0.01	*
Pool	14	-0.47	0.17	NS
Riffle	14	0.20	0.27	NS
		Comparison Between Biologists		
		Time Period 1		
Substrate	14	0.20	0.55	NS
Cover	14	-0.53	0.28	NS
Channel	14	0.80	0.02	*
Riparian	14	0.33	0.18	NS
Pool	14	0.20	0.53	NS
Riffle	14	0.53	0.01	*
		Time Period 2		
Substrate	14	0.07	0.90	NS
Cover	14	-1.00	0.07	NS
Channel	14	0.40	0.27	NS
Riparian	14	0.90	0.06	NS
Pool	14	0.47	0.09	NS
Riffle	14	0.13	0.33	NS

Utility of the QHEI and Some Cautions and Limitations

Habitat is of critical importance to understanding biological community processes in streams and a reliable method to assess its quality is essential to any water resource program. The QHEI is designed to fill a void between completely subjective habitat assessments and more intensive habitat assessment efforts that rely on more resource intensive, quantitative methods. It performs best when the objective of its use is assigning aquatic life use designations or examining aquatic life use attainment in conjuction with the IBI or other community level indices.

Because of its qualitative format it may have less utility as a *predictor* of single species standing stocks (often the response variable of interest to resource managers) than more quantitative methods. For such purposes, however, it may prove a useful screening tool and a inexpensive measure of regional variation in habitat quality that is often not included in single species models (Layher and Maughan 1985). Another area where it might be useful is in the analyses of the habitat requirements of non-game species where little autoecological data is available but large scale survey databases exist or are being collected (Bond *et al.* 1988).

Recently, the U. S. Fish and Wildlife Service (USFWS) published guidelines for determining the effects of oil and hazardous substances on fish and wildlife habitat (Escherich and Rosenberger 1987) for use in conjunction with the natural resource damage assessment rules promulgated under section 301(c) of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). The USFWS (Escherich and Rosenberger 1987) outline the utility Habitat Evaluation Procedures and Habitat Suitability Indices in these procedures as :

> .."(1) establish that assessment and contol are habitats are similar to pre-release conditions in the assessment area and that observed species changes (e.g., diminished population numbers) are not likely due to habitat differences; (2) quantify changes in habitat resulting from a release of oil or hazardous subtances; (3) determine changes in habitat unit availability caused by a discharge or a release; (4) provide a replicable and quantitative basis for determining the cost of restoring sites to attain habitat conditions present prior to release of oil or hazardous substances; and (5) provide a replicable and quantitative basis for determining the cost of achieving appropriate replacement for the lost habitat value of affected areas that cannot be restored to acheive in-kind, equal or relative habitat replacement..."

Where biological community indices replace species specific measures as a basis of a resource damage claim the QHEI may have utility in many of the areas outlined above. Further testing needs to be done to assess the applicability and limitations of the QHEI in these circumstances.

QHEI scores should not be "reified" in a rigid framework of a "criteria"; this index was designed to be explanatory and not predictive *per se,* especially with regard to site-specific QHEI scores. Aquatic life use potential is determined by a combination of basin-wide and site-specific conditions including habitat structure, chemical and physical characteristics (e.g., temperature), energy dynamics, flow regime, and biotic interactions (see Figure 1 of Ohio EPA 1987a). The biota integrates all these factors, whereas, the QHEI only reflects one of these components directly. Any attempt to rely on a strictly predictive relationship between the QHEI and IBI is ignoring the power of an integrated approach to water resource management. In performing simple, low risk, water resource tasks such as designating uses in small headwater streams habitat data alone can be reliably used. An experienced biologist needs to carry out such an assessment, however, to recognize exceptions to typical conditions. Because the QHEI relies on specific definitions of habitat characteristics (see Appendix 1) regular training is a necessity to ensure comparability among biologist in assessments and decision making.

An important result of this study is the relationship between habitat and fish communities in streams with poor habitat. A hypothetical relationship between habitat quality and fish communities is a sigmoidal curve (Plafkin *et al.*1989). Such a hypothetical curve is superimposed on the data used in this study at boat sites (Figure 23) with the exponential relationship discussed earlier also illustrated. The axis have been standardized to the percent of the maximum IBI and percent of maximum QHEI to reflect the graph in Plafkin (1989). Overall, the sigmoidal relationship fits the data well. A major inconsistency, however, is at the lowest IBI and QHEI scores. The actual data descends below an IBI of 20 only once (Figure 23). The sigmoidal curve, however, predicts continued impact to the community, rather than the leveling off of the effects of habitat observed here. Some types of habitat impacs could result in continued degradation (e.g., dewatering), however for the typical modifications observed in Ohio (e.g., channelization) the effects of habitat level off. This has application for distinguishing types of impacts in Ohio; the most severe impacts (IBI scores < 20) are rarely caused by habitat alone.

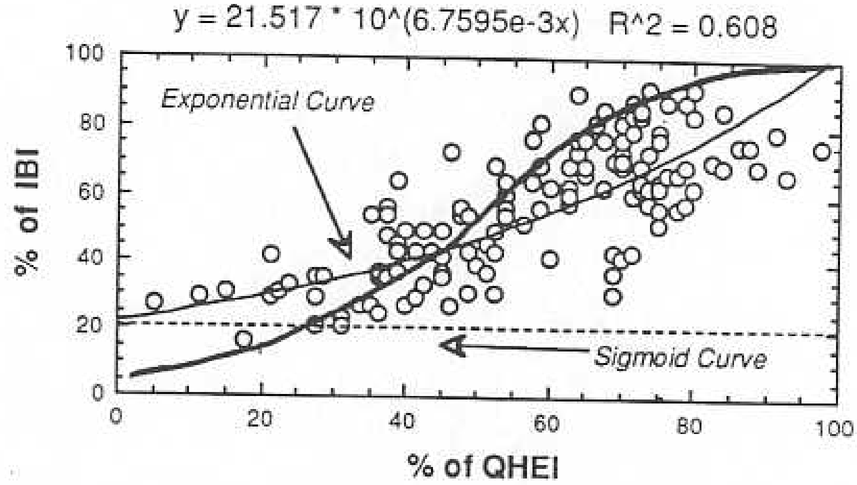

Figure 23. Standardized IBI versus standardized QHEI scores (% of maximum score) for boat data from Ohio warmwater reference and modified warmwater reference sites. Sigmoid curve superimposed on graph is based on Figure 8.1-1 of Plafkin et al. (1989). Expontial curve was calculated from the data.

Information generated by the analyses outlined here not only need to be incorporated into water resource management agencies but integrated into their regulatory decision making process. In water resource regulatory programs across the country traditional water quality chemistry approaches have dominated water resource programs and habitat problems have received little attention. It makes little sense to "protect" the biota by mandating multimillion dollar improvements to a point source discharge while the important biological uses are impaired by habitat modifications for reasons such as "flood-control", construction activities, or waterway improvements. Water resource management as well as water resource assessments need to be broad-based and integrated.

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Appendix 1a. Ohio headwater "warmwater" and "modified" reference sites used in analyses ofthe QHEI.

River Mile	QHEI	IBI	Species	Drainage Area (sq mi)	Modification
		Huron Erie Lake Plain			
04-114 - SOUTH POWELL CREEK					
14.1	42	23	8	4.0	Channelization
04-131 - PRAIRIE CREEK					
18.1	30	23	11	18.0	Channelization
04-137 - HAGERMAN CREEK					
0.8	31	19	5	14.0	Channelization
04-207 - LEATHERWOOD DITCH					
1.6	24	24	9	10.0	None
04-614 - BRUSH CREEK					
19.1	43	23	10	17.0	Channelization
05-053 - LITTLE RACCOON CREEK					
4.3	55	25	5	1.2	None
05-058 - CASWELL DITCH					
0.5	44	26	6	5.0	None
05-219 - MUDDY CREEK					
37.3	68	26	12	4.0	None
05-223 - GRIES DITCH					
0.9	60	20	9	15.0	None
		Interior Plateau			
02-530 - ROCKY FORK PAINT CREEK					
23.3	65	57	24	14.0	None
02-585 - MOBERLY BR. CLEAR CREEK					
0.9	64	49	15	2.5	None
10-211 - LICK CREEK					
4.1	73	44	12	8.0	None
10-212 - TREBOR RUN					
0.1	73	58	16	7.0	None
10-213 - CAVE RUN					
0.2	64	58	15	3.7	None
10-215 - LOUISE TRIBUTARY					
0.2	71	42	15	7.5	None
2.8	72	40	15	2.5	None
10-216 - LITTLE EAST FORK					
0.9	58	42	12	9.6	None
11-021 - TURTLE CREEK					
6.3	69	36	19	18.0	None
11-022 - DRY RUN					
1.8	67	40	10	5.0	None
11-138 - FIVEMILE CREEK					
0.4	72	36	16	10.0	None
23-005 - SHARON CREEK					
4.3	71	38	10	1.7	None

Appendix 1a. Ohio headwater "warmwater" and "modified" reference sites used in analyses ofthe QHEI.

River Mile	QHEI	IBI	Species	Drainage Area (sq mi)	Modification
		Erie Ontario Lake Plain			
01-420 - MUDDY PRAIRIE RUN					
0.7	83	41	12	11.0	None
03-022 - BAUGHMAN CREEK					
3.0	72	38	20	19.0	None
07-007 - COWLES CREEK					
7.2	60	42	12	6.0	None
08-118 - E. FK. STATELINE CREEK					
0.1	65	47	6	1.5	None
08-205 - STONE MILL RUN					
2.0	78	46	14	8.0	None
08-206 - E. BR. M. FK. LITTLE BEAVER CREE					
3.0	66	43	20	15.0	None
13-100 - E. BR. ROCKY RIVER					
26.7	66	48	17	12.0	None
13-104 - HEALY CREEK					
0.8	62	37	12	4.5	None
13-200 - W. BR. ROCKY RIVER					
33.6	67	40	21	8.0	None
15-012 - TRIB. TO CHAGRIN RIVER					
0.2	74	48	12	1.7	None
17-184 - LITTLE KILLBUCK CREEK					
0.8	66	36	10	20.0	None
17-190 - CAMEL CREEK					
3.8	72	44	15	9.5	None
17-210 - ROCKY FORK LICKING RIVER					
16.0	75	44	25	20.0	None
17-211 - LOST RUN					
4.1	69	44	20	10.0	None
17-215 - LONG RUN					
0.4	68	53	16	6.0	None
17-221 - RACCOON CREEK					
24.0	81	43	15	11.2	None
17-250 - N. FK. LICKING RIVER					
38.2	70	38	13	6.2	None
17-418 - LITTLE SUGAR CREEK					
4.2	73	33	13	9.0	None
17-463 - E. BR. NIMISHILLEN CREEK					
8.6	63	39	19	12.0	None
17-484 - SWARTZ DITCH					
0.2	46	34	20	13.0	Channelization
17-553 - RIVER STYX					
3.9	36	29	17	14.0	Channelization
17-556 - LITTLE CHIPPEWA CREEK					
11.4	35	32	10	0.8	Channelization
17-561 - TRIB. TO LITTLE CHIPPEWA CREEK					
0.1	60	34	6	1.0	None
17-655 - LITTLE JELLOWAY CREEK					
2.0	84	54	20	17.5	None

Appendix 1a. Ohio headwater "warmwater" and "modified" reference sites used in analyses ofthe QHEI.

River Mile	QHEI	IBI	Species	Drainage Area (sq mi)	Modification
17-656 - E. BR. JELLOWAY CREEK					
2.3	75	52	17	4.8	None
17-714 - MUDDY FORK MOHICAN RIVER					
18.5	51	45	22	20.0	None
17-725 - LANG CREEK					
3.2	68	47	17	14.0	None
18-040 - EAGLE CREEK					
22.5	52	43	15	5.5	None
18-043 - S. FK. EAGLE CREEK					
3.9	63	42	21	9.3	None
18-046 - SILVER CREEK					
0.8	74	48	16	11.0	None
2.3	73	44	14	9.0	None
18-504 - LITTLE YANKEE RUN					
9.5	75	42	13	9.0	None
18-505 - LITTLE DEER CREEK					
0.5	73	37	16	7.0	None
19-007 - TINKERS CREEK					
29.0	56	29	10	3.0	None
19-028 - BREAKNECK CREEK					
14.7	76	42	22	5.1	None
20-014 - E. FK. E. BR. BLACK RIVER					
2.7	64	44	12	16.0	None
			Western Allegheny Plateau		
01-037 - SCOTTS CREEK					
8.1	70	48	11	1.6	None
8.9	76	56	7	0.3	None
01-510 - DURBIN RUN					
0.4	31	26	8	2.5	Channelization
01-520 - TURKEY RUN					
1.4	65	34	9	8.0	None
02-611 - M. FK. SALT CREEK					
22.1	69	51	15	4.9	None
02-728 - MILL CREEK					
1.0	75	52	25	17.0	None
06-013 - LEITH RUN					
2.8	83	50	17	6.0	None
06-066 - WILLS CREEK					
4.0	68	36	3	4.0	None
06-101 - CAT RUN					
3.3	74	33	7	8.0	None
06-106 - BEND FORK					
12.3	50	37	7	1.2	None
06-203 - CEDAR LICK CREEK					
0.1	70	52	12	6.6	None
06-420 - ARCHERS FORK					
2.2	58	44	19	17.0	None
06-460 - WITTEN RUN					
2.4	66	50	15	8.0	None

Appendix 1a. Ohio headwater "warmwater" and "modified" reference sites used in analyses ofthe QHEI.

River Mile	QHEI	IBI	Species	Drainage Area (sq mi)	Modification
06-504 - WILLIAMS CREEK					
1.4	57	51	17	11.0	None
06-704 - PINEY FORK					
0.3	67	55	17	15.0	None
06-708 - BAKER FORK					
0.4	61	53	17	12.0	None
06-915 - NANCY RUN					
1.0	69	46	9	8.0	None
06-931 - ELKHORN CREEK					
6.6	83	49	9	3.0	None
06-932 - STRAWCAMP RUN					
0.4	75	52	15	5.0	None
06-933 - CENTER FORK					
0.1	69	60	19	12.0	None
06-934 - TRAIL RUN					
0.3	68	50	10	3.0	None
09-720 - COULLEY FORK					
0.2	55	49	16	4.6	None
17-120 - IRISH CREEK					
2.2	65	46	16	15.0	None
17-153 - DOUGHTY CREEK					
15.4	72	49	19	14.0	None
17-214 - PAINTER RUN					
0.3	60	47	18	6.0	None
17-308 - BLACK FORK					
2.5	55	26	12	9.6	Channelization
2.7	51	26	14	9.5	Channelization
3.5	90	42	18	8.4	None
17-325 - OGG CREEK					
1.5	49	32	11	5.5	Channelization
2.1	77	42	11	4.5	None
17-879 - MILLER CREEK					
0.2	37	24	11	11.6	Mine Affected
17-881 - RANNELS CREEK					
1.0	46	27	13	5.6	Mine Affected
		Eastern Corn Belt Plains			
02-085 - SYCAMORE CREEK					
4.7	61	46	18	19.0	None
02-181 - TAYLOR CREEK					
4.4	77	39	21	12.0	None
02-182 - SILVER CREEK					
2.4	68	40	21	13.0	None
02-200 - BIG DARBY CREEK					
79.2	66	46	15	5.0	None
79.2	66	46	15	5.0	None
79.3	71	48	19	5.0	None
02-221 - PLEASANT RUN					
0.5	68	56	20	9.4	None

Appendix 1a. Ohio headwater "warmwater" and "modified" reference sites used in analyses ofthe QHEI.

River Mile	QHEI	IBI	Species	Drainage Area (sq mi)	Modification
02-222 - SPAIN CREEK					
0.4	71	56	19	9.1	None
0.5	70	54	25	9.1	None
3.6	76	49	15	6.0	None
02-223 - FLAT BRANCH					
0.8	29	34	15	13.9	Channelization
0.9	27	28	14	13.9	Channelization
02-231 - TRIB. TO GEORGES CREEK					
6.0	63	34	5	1.5	None
02-237 - NORTH ROCKSWALE DITCH					
2.6	37	27	13	3.0	Channelization
02-251 - LITTLE DARBY CREEK					
0.5	87	52	19	5.4	None
3.7	62	44	13	2.4	None
02-540 - CLEAR CREEK					
6.8	76	51	26	19.0	None
8.5	81	57	22	13.0	None
02-562 - W. BR. RATTLESNAKE CREEK					
4.4	60	24	15	19.0	None
04-055 - M. FK. GORDON CREEK					
3.8	38	27	11	6.0	Channelization
04-240 - HUFFMAN CREEK					
1.7	49	46	14	1.5	None
04-518 - CENTER BRANCH					
3.2	40	30	10	15.5	Channelization
04-519 - CARTER CREEK					
2.1	48	24	12	10.0	Channelization
05-010 - SUGAR CREEK					
3.4	95	44	13	11.7	None
05-042 - PARAMOUR CREEK					
6.3	32	34	11	4.5	Channelization
05-059 - PPG TRIB. TO PARAMOUR CREEK					
3.7	32	45	9	1.0	Channelization
11-030 - NEWMAN RUN					
0.3	65	47	18	9.0	None
11-031 - MILL RUN					
0.4	59	46	17	8.0	None
11-032 - GLADY RUN					
5.8	60	33	6	4.0	None
11-401 - OLDTOWN CREEK					
0.1	68	45	14	10.0	None
14-006 - BLUEROCK CREEK					
1.4	78	36	7	1.4	None
14-029 - BEAR CREEK					
12.1	62	38	15	12.0	None
14-075 - MCKEES CREEK					
0.5	80	45	15	17.0	None
14-084 - CHEROKEE MANS RUN					
3.5	77	39	14	16.0	None
14-100 - MAD RIVER					
60.9	67	50	16	7.5	None

Appendix 1a. Ohio headwater "warmwater" and "modified" reference sites used in analyses ofthe QHEI.

River Mile	QHEI	IBI	Species	Drainage Area (sq mi)	Modification
14-120 - CHAPMAN CREEK					
4.0	78	45	14	17.0	None
14-130 - NETTLE CREEK					
4.5	66	36	10	15.0	None
8.2	72	42	11	8.0	None
14-139 - MACOCHEE CREEK					
2.8	80	44	11	14.0	None
14-203 - BRUSH CREEK					
0.1	60	46	16	17.0	None
14-208 - PAINTER CREEK					
16.2	46	27	14	3.5	Channelization
14-220 - GREENVILLE CREEK					
34.4	61	53	21	6.0	None
14-236 - INDIAN CREEK					
2.0	41	23	11	19.0	Channelization
14-238 - N. FK. STILLWATER RIVER					
0.4	41	26	14	18.0	Channelization
14-317 - WELKER LATERAL					
0.9	43	38	6	1.7	Channelization
14-501 - LITTLE TWIN CREEK					
6.3	66	49	20	4.0	None
14-505 - BANTAS FORK					
9.4	81	48	17	9.0	None
14-606 - NINEMILE CREEK					
4.2	43	28	12	9.2	Channelization
6.4	27	22	8	1.6	Channelization
14-802 - N. FK. GREAT MIAMI RIVER					
10.5	32	27	10	8.5	Channelization
17-220 - S. FK. LICKING RIVER					
28.5	70	42	17	15.0	None
31.5	64	36	14	12.0	None
17-650 - KOKOSING RIVER					
49.8	84	56	25	14.5	None

Appendix 1b. Ohio wading "warmwater" and "modified" reference sites used in analyses ofthe QHEI.

River Mile	QHEI	IBI	Species	Drainage Area (sq mi)	Modification
			Huron Erie Lake Plain		
04-038 - KONZEN DITCH					
0.7	40	25	12	24.0	Channelization
04-052 - GORDON CREEK					
6.8	33	23	18	37.0	Channelization
04-110 - POWELL CREEK					
4.3	62	24	21	112.0	None
4.4	55	28	19	112.0	None
04-112 - NORTH POWELL CREEK					
7.4	43	19	12	40.0	Channelization
04-120 - BLUE CREEK					
3.5	35	26	24	114.0	Channelization
04-130 - LITTLE AUGLAIZE RIVER					
18.8	37	31	17	90.0	Channelization
41.1	22	30	18	34.0	Channelization
04-132 - HOAGLIN CREEK					
5.8	31	23	13	41.0	Channelization
04-143 - TOWN CREEK					
19.8	28	24	10	22.0	Channelization
04-203 - SUGAR CREEK					
0.7	52	26	15	64.0	None
3.5	57	35	19	58.0	None
04-510 - TWELVEMILE CREEK					
1.7	43	21	11	35.0	Channelization
04-605 - MUD CREEK					
1.6	56	27	18	55.0	Channelization
04-609 - LICK CREEK					
11.0	54	26	14	36.0	Channelization
05-219 - MUDDY CREEK					
21.1	70	27	14	43.0	None
16-215 - TOUSSAINT CREEK					
20.0	55	32	17	60.0	None
			Interior Plateau		
02-530 - ROCKY FORK PAINT CREEK					
18.1	63	38	30	34.0	None
10-100 - EAGLE CREEK					
11.6	69	35	23	115.0	None
10-200 - OHIO BRUSH CREEK					
15.2	85	47	27	371.0	None
15.2	85	47	27	371.0	None
25.1	75	52	34	315.0	None
39.4	70	55	31	133.0	None
44.7	66	49	27	45.0	None
10-220 - W. FK. OHIO BRUSH CREEK					
1.1	70	48	28	140.0	None
12.7	63	53	27	28.2	None

Appendix 1b. Ohio wading "warmwater" and "modified" reference sites used in analyses ofthe QHEI.

River Mile	QHEI	IBI	Species	Drainage Area (sq mi)	Modification
10-400 - WHITEOAK CREEK					
6.6	75	52	27	222.0	None
12.8	82	35	27	213.0	None
10-420 - E. FK. WHITEOAK CREEK					
3.2	70	52	32	73.0	None
10-430 - N. FK. WHITEOAK CREEK					
6.8	56	39	22	48.0	None
11-010 - O'BANNON CREEK					
0.3	71	36	25	58.0	None
11-100 - E. FK. LITTLE MIAMI RIVER					
35.6	75	56	33	236.0	None
41.2	70	52	27	216.0	None
54.2	71	43	28	159.0	None
11-107 - STONELICK CREEK					
1.2	71	42	22	76.0	None
3.1	60	54	32	71.0	None
11-150 - W. FK. E. FK. LITTLE MIAMI RIVER					
0.2	77	41	19	28.0	None
11-151 - DODSON CREEK					
0.2	63	45	25	32.0	None
			Erie Ontario Lake Plain		
03-001 - GRAND RIVER					
83.5	53	40	24	85.0	None
03-120 - MILL CREEK					
10.0	90	37	21	86.0	None
17.2	63	37	25	70.0	None
03-130 - ROCK CREEK					
0.8	74	48	30	57.6	None
07-001 - ASHTABULA RIVER					
27.2	73	40	21	65.0	None
07-004 - W. BR. ASHTABULA RIVER					
1.9	74	45	21	27.0	None
08-103 - BULL CREEK					
1.9	85	38	12	40.0	None
13-100 - E. BR. ROCKY RIVER					
21.9	79	47	23	24.0	None
13-205 - N. BR. ROCKY RIVER					
5.5	70	43	21	35.0	None
15-001 - CHAGRIN RIVER					
4.0	76	44	21	246.0	None
33.4	83	46	21	54.0	None
17-181 - APPLE CREEK					
6.4	75	33	14	24.0	None
17-211 - LOST RUN					
0.3	81	47	22	23.0	None
17-250 - N. FK. LICKING RIVER					
24.0	82	47	23	64.0	None
17-260 - LAKE FORK LICKING RIVER					
0.1	56	45	21	34.0	None

Appendix 1b. Ohio wading "warmwater" and "modified" reference sites used in analyses ofthe QHEI.

River Mile	QHEI	IBI	Species	Drainage Area (sq mi)	Modification
17-406 - M. FK. SUGAR CREEK					
1.7	59	38	12	63.0	None
17-462 - M. BR. NIMISHILLEN CREEK					
6.8	47	35	23	34.0	None
17-500 - TUSCARAWAS RIVER					
119.4	82	43	21	35.0	None
17-556 - LITTLE CHIPPEWA CREEK					
0.1	31	32	10	29.0	Channelization
17-654 - JELLOWAY CREEK					
4.4	78	50	26	37.5	None
17-662 - SCHENCK CREEK					
2.8	85	48	21	39.3	None
17-674 - N. BR. KOKOSING RIVER					
6.3	86	47	22	84.0	None
17-714 - MUDDY FORK MOHICAN RIVER					
12.8	65	40	27	42.0	None
17-718 - JEROME FORK					
13.0	60	35	24	38.0	None
18-001 - MAHONING RIVER					
91.5	57	43	22	44.0	None
19-028 - BREAKNECK CREEK					
6.8	67	42	18	40.0	None
20-010 - E. BR. BLACK RIVER					
11.1	63	42	21	185.0	None
21-001 - VERMILION RIVER					
44.5	93	47	23	78.0	None
21-006 - BUCK CREEK					
1.1	92	37	19	21.0	None
			Western Allegheny Plateau		
01-100 - FEDERAL CREEK					
1.3	71	50	37	138.0	None
01-170 - MCDOUGALL BRANCH					
2.4	63	42	30	29.0	None
01-400 - CLEAR CREEK					
2.0	84	40	22	89.0	None
02-600 - SALT CREEK					
25.9	69	51	29	175.0	None
02-611 - M. FK. SALT CREEK					
0.3	63	52	30	109.0	None
02-710 - S. FK. SCIOTO BRUSH CREEK					
0.6	85	50	24	112.0	None
02-800 - SUNFISH CREEK					
8.0	89	51	31	132.0	None
06-100 - CAPTINA CREEK					
6.7	73	50	26	154.0	None
14.5	84	55	31	134.0	None
20.5	81	57	32	91.0	None
06-106 - BEND FORK					
0.6	73	49	20	27.0	None

Appendix 1b. Ohio wading "warmwater" and "modified" reference sites used in analyses ofthe QHEI.

River Mile	QHEI	IBI	Species	Drainage Area (sq mi)	Modification
06-117 - S. FK. CAPTINA CREEK					
0.2	78	57	31	36.0	None
06-123 - N. FK. CAPTINA CREEK					
0.5	79	47	27	33.0	None
06-210 - MCINTYRE CREEK					
0.1	70	40	15	27.0	Mine Affected
06-400 - LITTLE MUSKINGUM RIVER					
17.3	73	53	34	234.0	None
06-440 - WITTEN FORK					
1.1	80	49	26	43.0	None
06-500 - MCMAHON CREEK					
2.3	65	28	21	85.0	Mine Affected
5.6	65	32	25	80.0	Mine Affected
06-700 - SUNFISH CREEK					
5.0	70	51	28	101.0	None
7.1	86	51	26	99.0	None
17.3	68	45	20	49.0	None
23.9	77	43	19	22.0	None
06-900 - YELLOW CREEK					
27.5	72	28	17	29.0	Mine Affected
06-910 - N. FK. YELLOW CREEK					
0.8	77	48	25	58.0	None
6.2	79	44	21	41.0	None
06-931 - ELKHORN CREEK					
0.5	73	34	25	33.0	None
08-001 - LITTLE BEAVER CREEK					
15.0	81	49	23	261.0	None
08-100 - N. FK. LITTLE BEAVER CREEK					
7.6	80	45	26	106.0	None
08-200 - M. FK. LITTLE BEAVER CREEK					
1.9	81	48	27	141.0	None
9.0	87	45	22	114.0	None
08-300 - W. FK. LITTLE BEAVER CREEK					
0.8	90	55	27	111.0	None
12.9	85	56	30	74.0	None
09-400 - PINE CREEK					
20.5	68	41	31	102.0	None
09-600 - SHADE RIVER					
16.4	58	43	27	131.0	None
17-035 - S. FK. WOLF CREEK					
4.9	59	47	23	73.0	None
17-044 - W. BR. WOLF CREEK					
3.5	81	47	24	140.0	None
17-070 - OLIVE GREEN CREEK					
2.7	83	47	30	79.0	None
17-153 - DOUGHTY CREEK					
0.7	61	43	22	59.0	None
17-210 - ROCKY FORK LICKING RIVER					
2.0	83	53	29	76.0	None
2.1	73	51	32	76.0	None

Appendix 1b. Ohio wading "warmwater" and "modified" reference sites used in analyses ofthe QHEI.

River Mile	QHEI	IBI	Species	Drainage Area (sq mi)	Modification
17-310 - JONATHAN CREEK					
12.3	65	35	19	105.0	None
17-400 - SUGAR CREEK					
3.8	73	48	29	337.0	None
17-502 - WHITE EYES CREEK					
0.3	56	39	25	53.0	None
17-870 - BUFFALO FORK					
7.2	40	23	11	32.0	Mine Affected
17-890 - BUFFALO CREEK					
0.8	36	25	15	49.0	Mine Affected
17-960 - WAKATOMIKA CREEK					
2.0	57	51	31	231.0	None
12.5	59	54	33	154.0	None
14.9	90	52	29	140.0	None
		Eastern Corn Belt Plains			
01-001 - HOCKING RIVER					
96.2	88	27	9	24.0	Channelization
02-079 - LITTLE WALNUT CREEK					
0.5	59	47	22	44.0	None
02-100 - BIG WALNUT CREEK					
61.9	74	42	16	35.0	None
02-109 - MILL CREEK					
28.1	66	48	21	64.0	None
02-145 - FULTON CREEK					
10.4	54	42	20	23.0	None
02-158 - LITTLE SCIOTO RIVER					
9.2	72	33	19	73.0	None
11.2	49	44	24	47.0	None
02-165 - RUSH CREEK					
4.2	49	41	25	85.0	None
02-200 - BIG DARBY CREEK					
3.2	84	54	37	554.0	None
3.3	85	41	27	554.0	None
13.4	90	54	29	534.0	None
41.8	94	54	25	240.0	None
54.2	82	50	25	136.0	None
55.1	76	52	30	135.0	None
63.7	65	51	27	119.0	None
76.6	75	51	28	32.0	None
02-210 - LITTLE DARBY CREEK					
15.2	87	51	25	162.0	None
02-300 - DEER CREEK					
51.4	77	45	25	82.0	None
02-302 - HAY RUN					
4.0	57	52	22	20.1	None
02-400 - OLENTANGY RIVER					
14.7	93	38	22	483.0	None
02-450 - WHETSTONE CREEK					
25.5	69	46	19	26.0	None

Appendix 1b. Ohio wading "warmwater" and "modified" reference sites used in analyses ofthe QHEI.

River Mile	QHEI	IBI	Species	Drainage Area (sq mi)	Modification
02-500 - PAINT CREEK					
79.9	65	48	22	39.0	None
02-522 - COMPTON CREEK					
1.4	80	52	34	59.0	None
02-550 - RATTLESNAKE CREEK					
15.0	80	33	17	123.0	None
02-579 - SUGAR CREEK					
26.8	28	36	11	30.0	Channelization
04-100 - AUGLAIZE RIVER					
96.8	37	37	22	65.0	Channelization
04-160 - BLANCHARD RIVER					
71.8	67	39	24	145.0	None
88.3	57	33	21	83.0	None
96.4	25	30	26	48.0	Channelization
97.5	32	30	23	43.0	Channelization
04-185 - EAGLE CREEK					
11.8	67	44	23	37.0	None
04-200 - OTTAWA RIVER					
46.1	76	41	20	98.3	None
04-617 - BEAVER CREEK					
2.8	63	33	25	43.0	None
05-200 - HONEY CREEK					
12.5	84	42	29	149.0	None
35.2	37	26	15	26.0	Channelization
05-300 - TYMOCHTEE CREEK					
6.1	64	32	19	232.0	None
8.6	62	38	23	229.0	None
11-001 - LITTLE MIAMI RIVER					
85.4	86	51	27	104.0	None
11-100 - E. FK. LITTLE MIAMI RIVER					
75.3	69	44	20	23.0	None
11-200 - TODD FORK					
20.3	78	45	25	54.0	None
11-306 - ANDERSON FORK					
5.0	71	51	30	77.0	None
12-001 - HURON RIVER					
14.5	60	41	23	350.0	None
12-200 - W. BR. HURON RIVER					
3.7	66	39	21	236.0	None
7.7	67	44	21	233.0	None
12-206 - SLATE RUN					
4.1	49	33	13	41.0	None
14-010 - INDIAN CREEK					
4.1	69	41	26	100.0	None
4.9	76	46	31	99.0	None
9.4	77	46	26	82.0	None
14-022 - ELK CREEK					
3.7	91	50	25	37.5	None
14-043 - HONEY CREEK					
3.2	83	48	19	86.0	None
10.0	72	43	19	34.0	None

Appendix 1b. Ohio wading "warmwater" and "modified" reference sites used in analyses ofthe QHEI.

River Mile	QHEI	IBI	Species	Drainage Area (sq mi)	Modification
14-048 - LOST CREEK					
2.5	69	41	20	58.0	None
8.2	77	40	15	44.0	None
9.7	79	48	21	31.0	None
14-050 - SPRING CREEK					
1.0	73	44	15	26.0	None
1.1	73	50	18	26.0	None
14-100 - MAD RIVER					
53.2	58	37	17	34.0	None
14-111 - BEAVER CREEK					
0.7	77	33	14	39.0	None
14-200 - STILLWATER RIVER					
47.8	78	43	22	112.0	None
51.2	65	45	31	106.0	None
63.0	28	28	16	29.0	Channelization
14-235 - SWAMP CREEK					
4.5	40	25	15	25.0	Channelization
14-500 - TWIN CREEK					
19.2	89	48	25	225.0	None
35.5	84	49	25	68.0	None
37.9	65	46	15	34.0	None
42.2	51	41	24	28.0	None
14-505 - BANTAS FORK					
1.3	87	44	21	34.0	None
14-700 - MUCHINIPPI CREEK					
2.3	39	42	15	85.0	Channelization
14-800 - S. FK. GREAT MIAMI RIVER					
1.5	70	43	27	51.0	None
14-999 - MIAMI-ERIE CANAL					
0.1	47	20	12	100.0	Channelization
21-001 - VERMILION RIVER					
10.7	78	48	26	251.0	None
22-001 - WABASH RIVER					
469.5	54	23	21	124.0	Channelization
476.2	44	25	20	102.0	Channelization
484.8	43	28	13	65.0	Channelization

Appendix 1c. Ohio boat "warmwater" and "modified" reference sites used in analyses ofthe QHEI.

River Mile	QHEI	IBI	Species	Drainage Area (sq mi)	Modification
			Huron Erie Lake Plain		
04-001 - MAUMEE RIVER					
19.8	75	27	17	6330.0	None
26.7	76	32	18	6258.0	None
31.5	75	33	15	6058.0	None
33.0	48	25	12	6052.0	Impounded
38.5	56	30	11	5697.0	Impounded
45.7	50	39	18	5655.0	Impounded
49.6	60	31	17	5581.0	Impounded
49.6	60	31	17	5581.0	Impounded
54.7	61	34	19	5559.0	None
69.8	54	28	13	2306.0	None
04-100 - AUGLAIZE RIVER					
3.2	68	32	23	2428.0	None
15.2	45	23	17	1932.0	Impounded
28.8	77	33	26	717.0	None
39.7	77	41	29	327.0	None
04-160 - BLANCHARD RIVER					
0.2	47	25	13	771.0	Impounded
04-200 - OTTAWA RIVER					
1.2	75	30	25	364.0	None
04-600 - TIFFIN RIVER					
1.0	57	25	15	777.0	None
6.5	53	33	15	737.0	None
14.1	49	29	10	556.0	Channelization
23.2	52	25	14	471.0	Channelization
26.0	38	27	12	422.0	Channelization
34.8	42	29	14	410.0	Channelization
04-999 - MIAMI-ERIE CANAL					
55.4	34	20	16	200.0	Channelization
55.4	34	20	16	200.0	Channelization
05-001 - SANDUSKY RIVER					
19.0	49	24	9	1253.0	Impounded
22.7	79	40	12	1073.0	None
23.0	50	38	19	1073.0	None
16-001 - PORTAGE RIVER					
17.3	62	36	20	494.0	None
17.6	63	41	24	435.0	None
			Interior Plateau		
10-220 - W. FK. OHIO BRUSH CREEK					
1.3	82	39	27	116.0	None
11-001 - LITTLE MIAMI RIVER					
24.2	78	42	21	1145.0	None
36.0	83	45	23	959.0	None
44.2	82	44	22	680.0	None
11-100 - E. FK. LITTLE MIAMI RIVER					
15.5	76	47	18	359.0	None

Appendix 1c. Ohio boat "warmwater" and "modified" reference sites used in analyses ofthe QHEI.

River Mile	QHEI	IBI	Species	Drainage Area (sq mi)	Modification
42.3	83	45	28	212.0	None
44.1	71	47	25	195.0	None
54.8	78	42	19	157.0	None
		Erie Ontario Lake Plain			
03-001 - GRAND RIVER					
6.1	81	54	25	687.0	None
13.4	90	48	24	630.0	None
13.4	90	48	24	630.0	None
22.1	84	52	23	581.0	None
17-150 - KILLBUCK CREEK					
35.6	70	40	17	367.0	None
50.4	51	34	19	137.0	None
17-200 - LICKING RIVER					
28.1	58	38	26	533.0	None
17-220 - S. FK. LICKING RIVER					
13.1	67	39	14	117.0	None
17-238 - BUCKEYE LAKE FEEDER CANAL					
0.6	43	29	12	200.0	Channelization
17-250 - N. FK. LICKING RIVER					
2.4	77	41	26	229.0	None
3.4	63	39	17	227.0	Impounded
17-470 - STILL FORK SANDY CREEK					
0.3	49	30	12	71.0	Impounded
17-550 - CHIPPEWA CREEK					
0.5	32	27	12	188.0	Channelization
6.5	24	25	12	146.0	Channelization
17.2	29	26	13	33.0	Channelization
17-650 - KOKOSING RIVER					
11.7	98	48	19	379.0	None
20.9	74	53	22	264.0	None
25.5	76	51	23	250.0	None
28.7	77	50	25	202.0	None
18-001 - MAHONING RIVER					
46.3	48	38	18	424.0	Impounded
19-001 - CUYAHOGA RIVER					
64.5	80	42	17	187.0	None
		Western Allegheny Plateau			
02-001 - SCIOTO RIVER					
9.0	80	39	22	6471.0	None
56.0	68	42	26	5131.0	None
70.4	80	43	26	3849.0	None
02-500 - PAINT CREEK					
5.0	93	50	28	1137.0	None
02-600 - SALT CREEK					
9.9	77	52	34	281.0	None
08-001 - LITTLE BEAVER CREEK					
4.5	87	45	20	496.0	None

Appendix 1c. Ohio boat "warmwater" and "modified" reference sites used in analyses ofthe QHEI.

River Mile	QHEI	IBI	Species	Drainage Area (sq mi)	Modification
8.0	80	50	22	294.0	None
09-300 - LITTLE SCIOTO RIVER					
12.6	67	51	27	200.0	None
17-044 - W. BR. WOLF CREEK					
13.3	75	46	25	116.0	None
17-100 - CONOTTON CREEK					
22.0	65	37	23	90.0	None
17-150 - KILLBUCK CREEK					
24.9	37	32	18	463.0	None
17-200 - LICKING RIVER					
3.6	83	40	25	753.0	None
17-500 - TUSCARAWAS RIVER					
6.9	67	45	19	2577.0	None
17.7	81	44	19	2473.0	None
21.1	87	53	22	2443.0	None
17-600 - WALHONDING RIVER					
1.2	94	44	23	2255.0	None
1.2	94	44	23	2255.0	None
8.0	91	45	18	1576.0	None
15.8	72	49	19	1505.0	None
17-650 - KOKOSING RIVER					
0.5	86	46	26	483.0	None
17-800 - WILLS CREEK					
0.3	72	44	26	853.0	None
27.0	37	26	12	738.0	Mine Affected
37.7	39	28	13	671.0	Mine Affected
46.6	42	26	11	554.0	Mine Affected
17-840 - LEATHERWOOD CREEK					
0.8	42	22	10	91.0	Mine Affected
			Eastern Corn Belt Plains		
02-001 - SCIOTO RIVER					
100.2	70	41	22	3197.0	None
102.0	79	47	24	2638.0	None
105.2	70	42	24	2610.0	None
133.0	63	38	18	1068.0	Impounded
140.0	56	29	9	1042.0	Impounded
142.8	51	30	12	1021.0	Impounded
150.0	50	29	13	977.0	Impounded
179.6	59	33	23	407.0	None
201.2	54	36	21	226.0	None
221.8	45	22	17	76.0	Channelization
02-078 - WALNUT CREEK					
3.8	78	53	26	273.0	None
9.3	76	49	25	212.0	None
18.9	66	43	20	183.0	None
02-100 - BIG WALNUT CREEK					
15.8	77	41	23	272.0	None
02-108 - EVERSOLE RUN					
0.3	56	32	13	979.0	Impounded

Appendix 1c. Ohio boat "warmwater" and "modified" reference sites used in analyses ofthe QHEI.

River Mile	QHEI	IBI	Species	Drainage Area (sq mi)	Modification
02-109 - MILL CREEK					
0.2	55	33	15	179.0	Impounded
02-200 - BIG DARBY CREEK					
3.7	89	48	24	553.0	None
24.0	83	54	22	498.0	None
25.0	81	54	23	496.0	None
26.7	84	56	20	457.0	None
29.3	78	45	20	449.0	None
30.1	79	56	21	448.0	None
31.8	76	46	23	446.0	None
42.0	80	49	18	240.0	None
55.3	84	42	19	135.0	None
62.5	76	45	19	121.0	None
02-400 - OLENTANGY RIVER					
5.5	58	39	21	529.0	Impounded
28.1	52	36	21	409.0	Impounded
02-510 - N. FK. PAINT CREEK					
17.6	77	54	22	160.0	None
04-100 - AUGLAIZE RIVER					
65.0	51	43	17	207.0	Impounded
67.0	80	42	34	202.0	None
05-001 - SANDUSKY RIVER					
31.0	63	43	22	1048.0	None
43.0	62	33	9	957.0	Impounded
46.9	79	42	14	774.0	None
05-200 - HONEY CREEK					
0.4	62	27	10	176.0	Impounded
11-001 - LITTLE MIAMI RIVER					
83.1	74	49	24	122.0	None
14-001 - GREAT MIAMI RIVER					
77.1	59	27	13	2591.0	Impounded
80.7	56	36	19	2512.0	None
83.3	61	30	14	1174.0	Impounded
91.0	80	37	21	1150.0	None
98.5	78	52	22	1030.0	None
100.7	74	42	16	972.0	None
106.8	70	45	21	911.0	None
107.6	50	35	14	904.0	Impounded
115.3	59	38	13	849.0	Impounded
116.9	62	45	21	845.0	None
130.0	71	49	25	540.0	None
143.6	53	26	10	410.0	Impounded
14-100 - MAD RIVER					
2.0	66	49	27	650.0	None
14-200 - STILLWATER RIVER					
18.0	73	51	25	599.0	None
21.2	71	55	21	528.0	None
32.9	72	45	22	233.0	None
41.4	78	43	29	189.0	None
14-220 - GREENVILLE CREEK					
0.1	57	47	17	201.0	None

Appendix 1c. Ohio boat "warmwater" and "modified" reference sites used in analyses ofthe QHEI.

River Mile	QHEI	IBI	Species	Drainage Area (sq mi)	Modification
22.6	51	33	14	106.0	Impounded
14-400 - FOURMILE CREEK					
0.3	76	49	19	315.0	None
14-500 - TWIN CREEK					
0.2	76	49	22	316.0	None