APPENDIX C:

Modified Index of Well-Being (I_{wb})

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Appendix C-1: Modified Index of Well-Being (Iwb)

A Modification of the Index of Well-Being for Evaluating Fish Communities

Chris Yoder

Ohio EPA, Division of Water Quality Monitoring and Assessment
Surface Water Section
1030 King Avenue
Columbus, Ohio 43212

Introduction

The index of well-being (Iwb), or composite index, was developed by Gammon (1976) to evaluate the response of riverine fish communities to environmental stress. This index was first tested using data from the Wabash River in Indiana (Gammon 1976; Gammon et al. 1981) and subsequently from other rivers in Indiana, Ohio (Yoder et al. 1981; Gammon 1980), and Oregon (Hughes and Gammon 1987). Since 1979 the Ohio EPA has used the composite index to evaluate electrofishing data from nearly 2000 locations throughout Ohio. These included a wide range of stream and river types from the smaller headwater streams to the Ohio River. Study areas included a wide range of chemical and physical perturbations. Sampling methods used are described in more detail elsewhere (Ohio EPA 1987a).

Index of Well-Being

The Iwb incorporates four measures of fish communities that have traditionally been used separately: numbers of individuals, biomass, and the Shannon diversity index (H) based on numbers and weight. The computational formulas for the Iwb and Shannon index are given in Table 1. Relative abundance (numbers and weight) data are derived from pulsed D.C. electrofishing catches where sampling effort is based on distance rather than time (Gammon 1976). Ohio EPA bases relative abundance on a per kilometer basis for boat methods and on a 0.3 kilometer basis for wading methods (Ohio EPA 1987a).

The individual performance of numbers, biomass, and the Shannon index as consistent indicators of environmental stress in fish communities has been disappointing. However, when combined in the Iwb these individual community attributes work in a complimentary manner. For example an increase in total numbers and/or biomass caused by one or two predominant species is usually offset by a corresponding decline in the Shannon index. In addition the $\log_e$ transformation of the numbers and biomass components acts to reduce much of their inherent variability. Gammon (1976) found the individual variability of each of the four Iwb components to range from 20-50%, yet the variability for the Iwb was approximately 7%.

High numbers and/or biomass is usually perceived as a positive attribute of a fish community. This should result in a high Iwb provided a relative

Table 1. Computational formula for the index of well-being and the Shannon diversity index.

Composite Index

$$I_{WB} = 0.5 \ln N + 0.5 \ln B + \bar{H} \text{ (no.)} + H \bar{(wt.)}$$

where;
N = relative numbers of all species
B = relative weight of all species
$\bar{H}$ (no.) = Shannon index based on relative numbers
$\bar{H}$ (wt.) = Shannon index based on relative weight

Shannon Diversity Index

$$\bar{H} = -\sum \frac{(n_i)}{N} \log_e \frac{(n_i)}{N}$$

where;
n_i = relative numbers or weight of the ith species
N = total number or weight of the sample

"evenness" is maintained between the abundance of the common species. However, this is not invariable, particularly with environmental perturbations which tend to restructure fish communities without large decreases in diversity (e.g. nutrient enrichment, habitat modification). For example, we have observed fish communities in highly modified streams that have very high numbers, biomass, and moderate species richness. Such communities are predominated by species tolerant to these disturbances. Species that are intolerant to such disturbances either decline in abundance or are eliminated altogether. The net increase in the relative abundance of the tolerant species with only modest declines in species richness yields a high Iwb value. The increased abundance of tolerant species is not sufficiently offset by the Shannon indices because species richness is not equally influenced. The overall result is an Iwb evaluation that is not reflective of the actual response of the community to these types of degradation. In fact Iwb values at some disturbed sites equaled or exceeded those measured at reference or least impacted sites.

Modified Index of Well-Being

Several modifications of the Iwb were attempted to correct the problem of relatively high scores at degraded sites. These included the complete elimination of predominant species from the index calculation, selective elimination of species based on their predominance, and a different weighting of the numbers component of the Iwb. None of these modifications worked in a consistent manner. The problem with a total elimination of predominant species is that their presence is not considered and it is difficult to apply consistently.

Ecologically the problem is that of a predominance and high abundance of species tolerant to the environmental degradation that we are attempting to measure. Tolerant species are the last to disappear under the influence of increased environmental degradation or those that respond favorably to a radical change in the physical or chemical quality of the environment. Thus their uniform elimination from the numbers and biomass components of the Iwb was attempted. Ohio EPA has designated all fish species known to occur in Ohio as highly tolerant, moderately tolerant, intermediate, moderately intolerant, or highly intolerant (Thoma et al. 1987). This was accomplished by examining a large, statewide data base that includes data from nearly 2000 sites and a wide range of environmental conditions. While most attempts to designate species tolerance rely mostly on the existing technical literature and regional fish reference texts, the Ohio EPA method is based on direct observations of species response in the field. This requires a comprehensive data base and should be supplemented by information from the technical literature when necessary.

The modified Iwb retains the same computational formula as the conventional Iwb developed by Gammon (1976). The difference is that any of 13 highly tolerant species, exotics, and hybrids are eliminated from the numbers and biomass components of the Iwb. However, the tolerant and exotic species are included in the two Shannon index calculations. This modification eliminates the "undesired" effect caused by high abundance of tolerant species, but

retains their "desired" influence on the Shannon indices. To illustrate the effect of this modification several comparisons were made between key fish community attributes, the modified Iwb, and the conventional Iwb. In addition results from different streams and rivers subjected to different types and varying levels of environmental degradation (both chemical and physical) demonstrate the influence that this modification has on an evaluation of fish community health and well-being. The comparisons were made separately for boat electrofishing and wading methods.

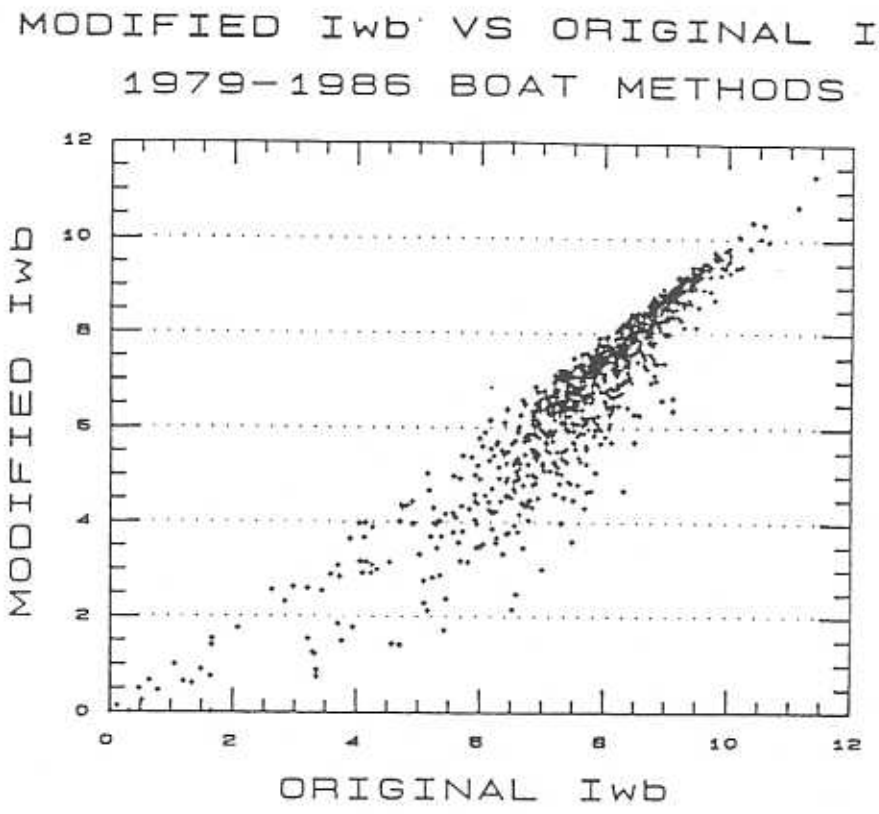
Modified Iwb and Original Iwb

Comparisons of the behavior of the modified Iwb and original Iwb were made using data from 912 boat electrofishing locations sampled between 1979-1986 and more than 972 locations sampled with wading methods between 1983-1986. These data sets were used to compare the modified Iwb with the original Iwb (Fig. 1), the difference between the modified Iwb and original Iwb with the modified Iwb (Fig. 2), the percent by number of tolerant species with the modified Iwb and the original Iwb for boat (Fig. 3) and wading (Fig. 4) methods. The Iwb is an "open ended" index in that it has no real upper limit. However, actual observations from over 2000 sites in Ohio show that Iwb values rarely exceed 10. Values above 8 and certainly 9 are generally regarded as being representative of healthy, unimpacted fish communities. The comparison of the modified and original Iwb shows a close agreement at the sites which score above 10, but an increasing departure as Iwb scores decline (Fig. 1). The patterns are similar for boat and wading methods. This relationship is also demonstrated in the comparison of the Iwb difference with the modified Iwb (Fig. 2). The difference between the original and modified Iwb values increases as the modified Iwb decreases.

The relationship of the percent by numbers of tolerant species with the modified and original Iwb was also examined (Figs. 3 and 4). A curve of best fit that approximates a 95% line was drawn on the comparisons with the modified Iwb. As the percent of tolerant species increases the modified Iwb decreases. This relationship is lacking with the original Iwb, a result of the previously described problem of high numbers of tolerant species inflating the original Iwb values. The 95% curve was superimposed on the comparisons with the original Iwb. The result is that many points lie above and to the right of the 95% line in the comparisons with the original Iwb. This means that the original Iwb can score high when the environment is adversely affected by certain types of physical and chemical degradation that result in a predominance of tolerant species. The result can be an incorrect evaluation of fish community condition. The treatment of tolerant species in the modified Iwb greatly reduces this problem and results in a consistently more accurate evaluation.

Specific Applications

The utility of any index, biological or otherwise, is in how consistently it reacts to change either positive or negative. A significant shortcoming of the original Iwb is in its inability to adequately characterize degraded communities where an environmental stress results in a restructured community



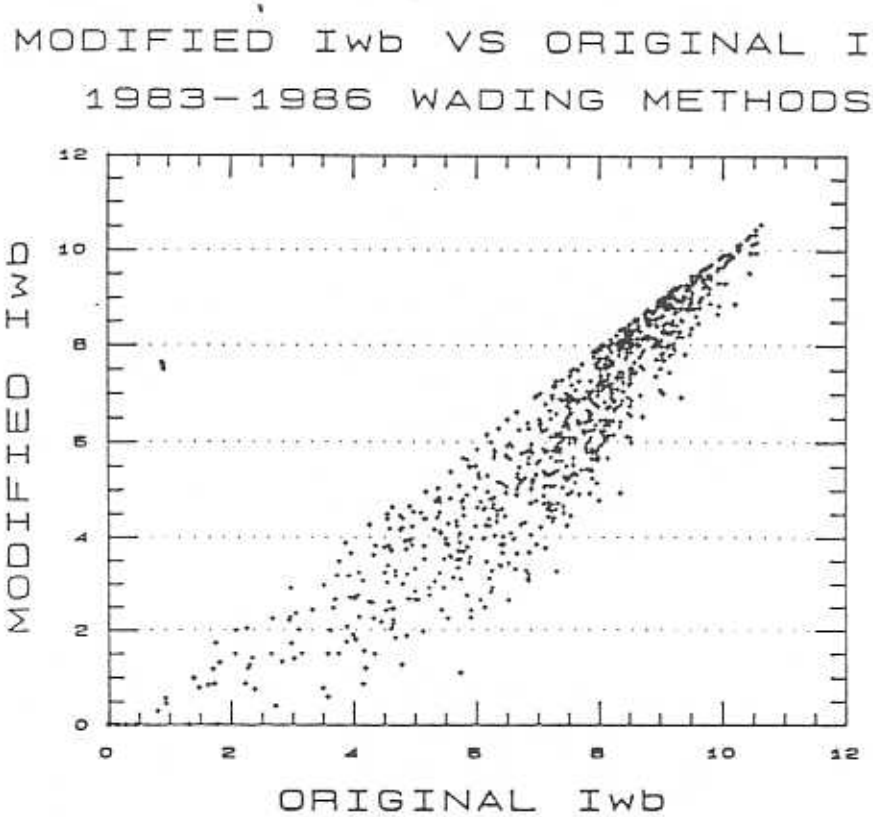


Figure 1. Comparison of the original Iwb with the modified Iwb at boat electrofishing locations sampled between 1979-1986 (top) and locations sampled with wading methods between 1983-1986 (bottom).

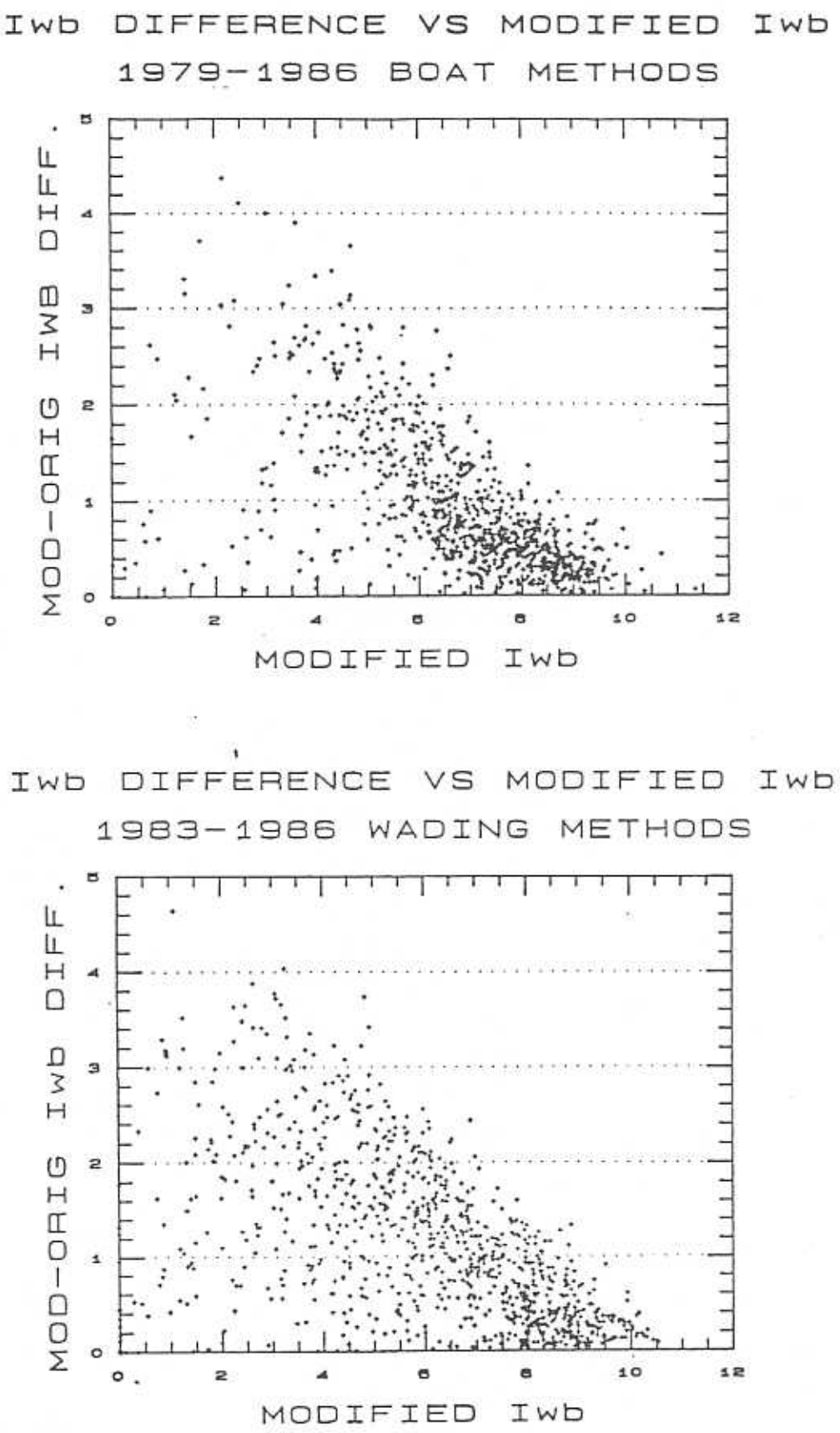
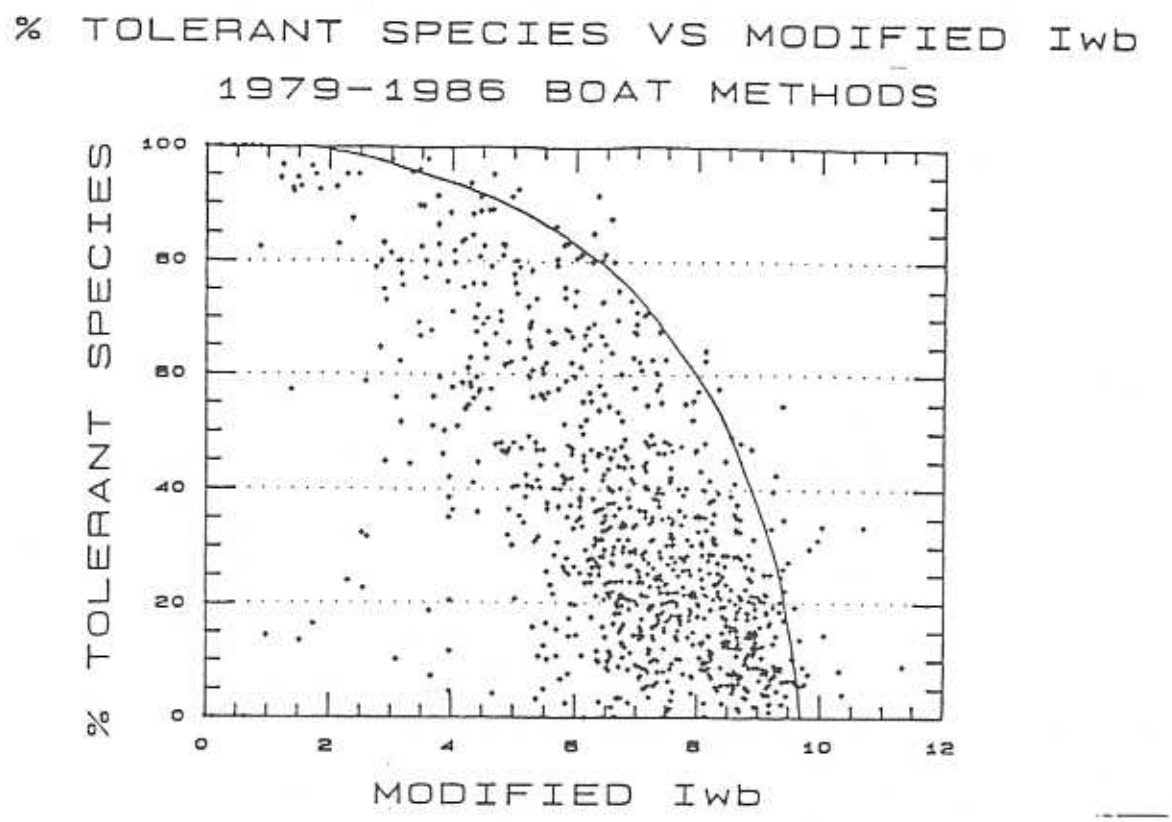


Figure 2. Relationship between the difference between the original Iwb and modified Iwb at boat electrofishing locations sampled between 1979-1986 (top) and locations sampled with wading methods between 1983-1986 (bottom).



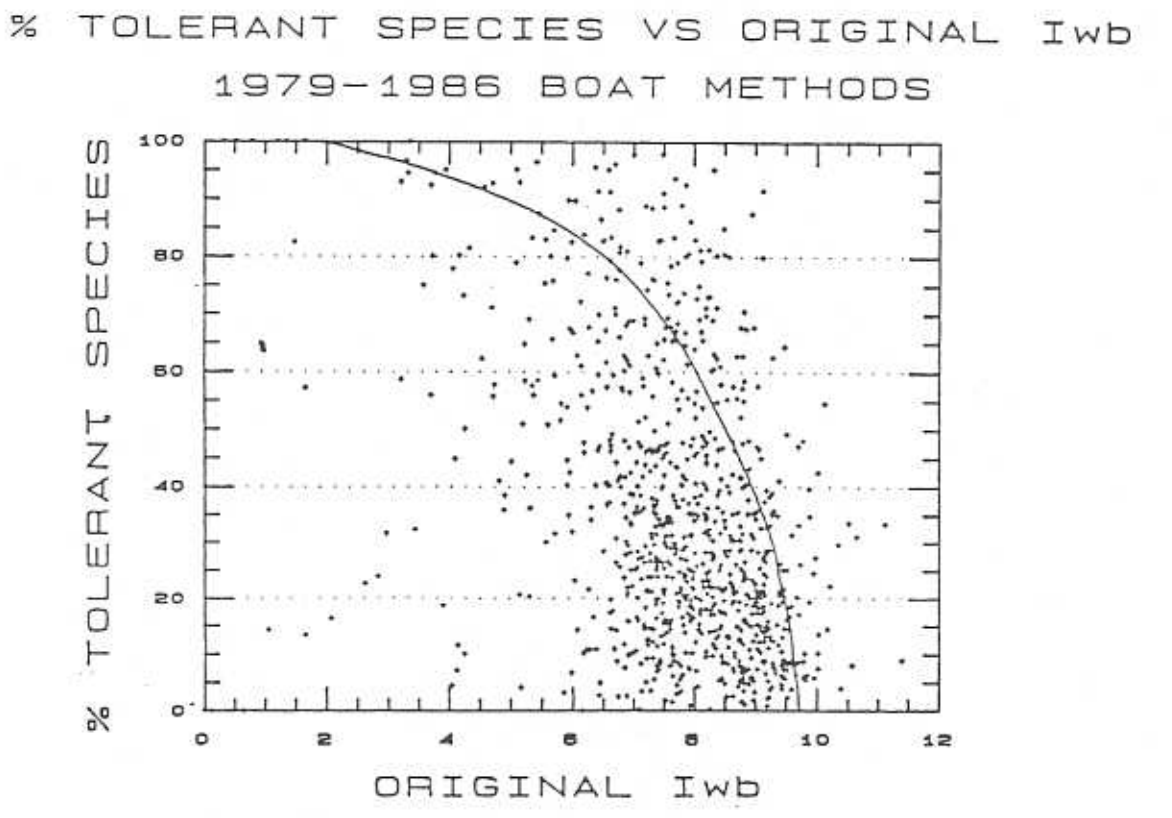
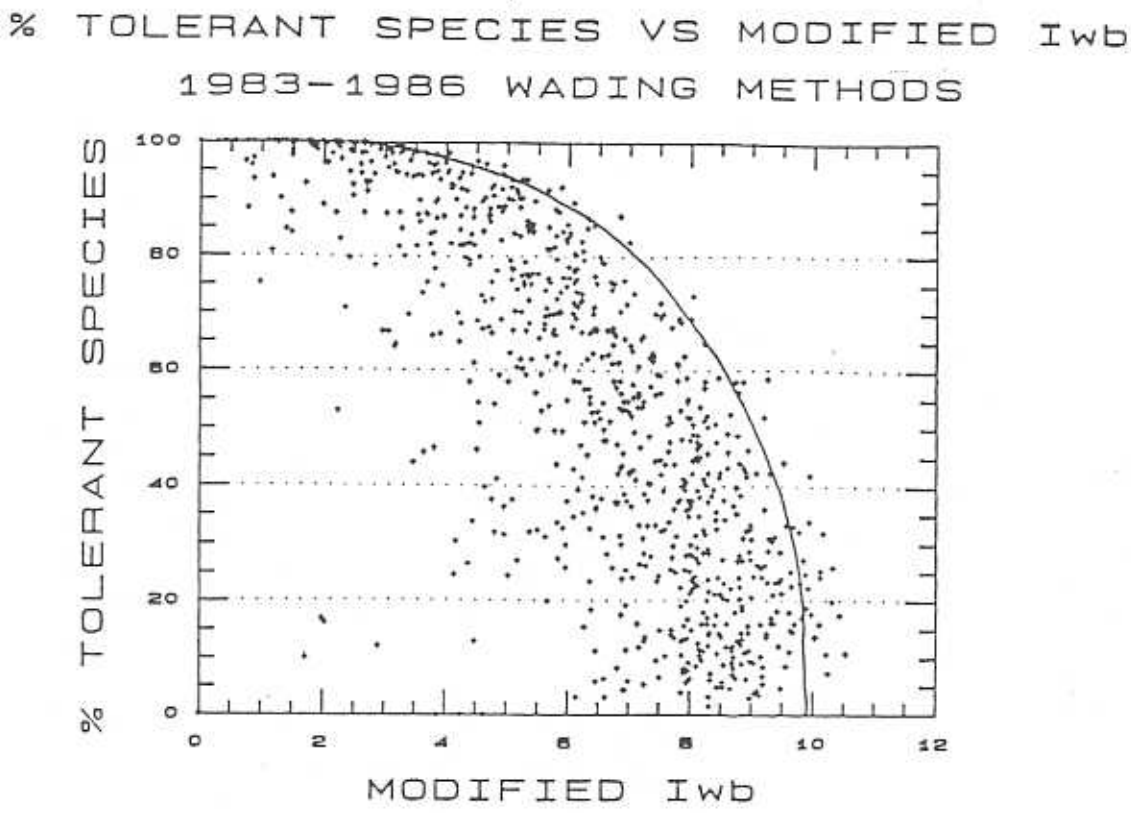


Figure 3. Comparison of percent by numbers of tolerant species with the modified and original Iwb for boat electrofishing locations sampled between 1979-1986. The line of best fit approximates the 95% line based on the comparison with the modified Iwb.



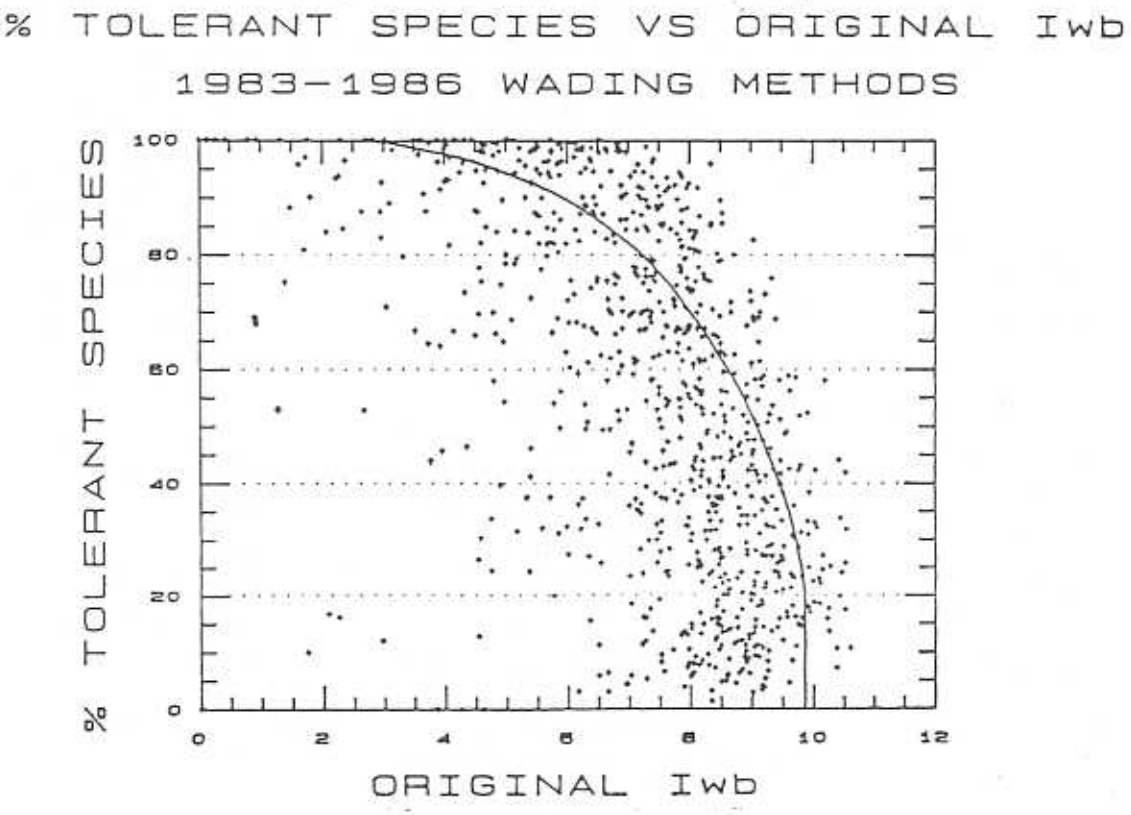


Figure 4. Comparison of percent by numbers of tolerant species with the modified and original Iwb for locations sampled with wading methods between 1983-1986. The line of best fit approximates the 95% line based on the comparison with the modified Iwb.

with high numbers and/or weight of tolerant species. Table 2 shows the results of fish sampling at selected sites that are affected by a variety of environmental stresses including habitat modification, organic enrichment, and toxic chemicals. Sites that represent relatively unimpacted situations are included for comparison. The differences between the modified and original Iwb are impressive, ranging from 1.0 to more than 3.0 Iwb units at the degraded sites. The difference at the relatively unimpacted sites is negligible being less than 0.1-0.5 Iwb units.

Iwb results from a recent electrofishing survey of the Ottawa River in northwestern Ohio are depicted in Figure 5. The original Iwb, modified Iwb, and the difference between each show that the largest differences occur downstream from the variety of environmental stresses that exist in this study area. Influences include raw sewage and urban runoff from combined sewer overflows, domestic wastewater from a sewage treatment plant with industrial contributors, effluent from an oil refinery, and effluent from an agricultural chemicals plant, and habitat modification resulting from several small impoundments. Ohio EPA uses a tiered classification system based on the Iwb to rate sites as exceptional, good, fair, poor, and very poor (Table 3). The exceptional and good ratings reflect full attainment of the Clean Water Act goal of biological integrity. Evaluation of impacted sites on the Ottawa River (Fig. 5) change from good to fair, fair to poor, or poor to very poor when the modified Iwb is used. Although the rating of the relatively unimpacted upstream site and the downstream recovery site appear to change from exceptional to good their original ratings were good because they did not meet all of the criteria for exceptional. In addition the difference between the original and modified Iwb at these two sites was the smallest in the study area.

Modified Iwb

The examples and analyses presented show that the modified Iwb is a consistent and sensitive index to a wide range of environmental stresses. The elimination of any of 14 highly tolerant species from the numbers and biomass components of the Iwb achieves this desired result and resolves a significant shortcoming of the original Iwb. Biological indices are most useful when they score consistently and are sensitive to a wide variety of environmental stresses, both chemical and physical. The modified Iwb achieves these objectives.

Table 2. Results of electrofishing at selected sits in Ohio that are subjected to different types and levels of environmental degradation showing the different ratings assigned by the original IWB compared to the modified Iwb.

Stream/River (RM[a])	Sample Type[b]	% No./Wt. Tolerant	Original Iwb	"Old" Rating[c]	Modified Iwb	"New" Rating[c]	Characterization of Degradation
Swan Creek (2.6)	W	45/90	4.10	Poor - V. Poor	2.92	V. Poor	Combined sewers, urban
L. Auglaize R. (17.6)	W	63/73	8.96	Good	7.73	Good - Fair	Channelization
L. Auglaize R. (37.4)	W	80/97	7.21	Fair	4.55	Poor	Sewage, channelization
L. Auglaize R. (41.1)	W	72/83	9.01	Good	7.51	Fair	Channelization
Blue Jacket Cr. (5.4)	2	90/98	7.29	Fair	4.58	Poor	Sewage, heavy metals
E. Br. Nimishillen C. (4.2)	W	95/99+	7.11	Fair	3.77	V. Poor	Toxic wastes, sewage
Mahoning R. (7.1)	B	82/45	1.49	V. Poor	0.88	V. Poor	Toxic wastes
Mahoning R. (46.3)	B	15/56	8.45	Good	7.94	Good	Impounded river
Cuyahoga R. (36.5)	B	90/96	6.05	Poor	3.54	V. Poor	Toxic wastes
Cuyahoga R. (40.4)	B	45/90	8.01	Good	6.58	Fair	Combined sewers, urban
Black R. (9.3)	B	88/98	6.76	Fair	4.34	Poor	Sewage, toxic wastes
L. Darby Cr. (15.2)	W	8/3	9.26	Good - Exceptional	9.20	Good - Exceptional	Unimpacted
Captina Cr. (14.5)	W	17/3	10.53	Exceptional	10.43	Exceptional	Unimpacted
Stillwater R. (16.0)	B	21/26	9.41	Good - Exceptional	9.13	Good - Exceptional	Unimpacted
Ottawa R. (1.2)	B	49/70	9.52	Exceptional	8.54	Good	Recovery site
Ottawa R. (34.7)	B	95/99	5.09	Poor	2.28	V. Poor	Toxic wastes, sewage
Ottawa R. (37.7)	B	80/96	9.12	Good	6.63	Fair-Poor	Combined sewers, urban
Ottawa R. (38.9)	B	85/92	8.49	Good	6.29	Fair-Poor	Com. sewers, impoundment
Gr. Miami R. (98.5)	B	13/24	9.45	Exceptional	9.25	Good - Exceptional	Unimpacted
Gr. Miami R. (77.1)	B	38/81	7.69	Good-Fair	6.54	Fair	Urban, impounded river
Gr. Miami R. (70.4)	B	76/97	6.55	Fair	3.93	V. Poor	Sewage wastes
Gr. Miami R. (65.9)	B	82/98	6.78	Fair	4.04	V. Poor	Sewage, impoundment

[a] River Mile Index - Ohio EPA PEMSO system.

[b] W - wading methods; B - boat electrofishing.

[c] Based on Ohio EPA classification system developed November 1980; revised January 1987.

Table 3. Conceptual response of fish community structural and functional attributes as portrayed by modified Index of Well-Being (Iwb). Narrative descriptions of fish community condition for good, fair, poor, and very poor ranges are indicated.

Category	--- MEETS CWA GOALS ---		------ DOES NOT MEET CWA GOALS ------		
	"Exceptional"	"Good"	"Fair"	"Poor"	"Very Poor"
1.[a]	Exceptional, or unusual assemblage of species	Usual association of expected species	Some expected species absent, or in low abundance	Many expected species absent, or in low abundance	Most expected species absent
2.	Sensitive species abundant	Sensitive species present	Sensitive species absent, or in very low abundance	Sensitive species absent,	Only most tolerant species remain
3.	Exceptionally high species richness	High species richness	Declining species richness	Low species richness	Very low species richness
4.[b]	Composite index Greater than 9.5	Composite index Greater than 7.4 - 8.6[b], Less than 9.4	Composite index Greater than 5.3 - 6.3[b], Less than 7.4-8.6[b]	Composite index Greater than 4.5 - 5.0[b], Less than 5.3-6.3[b]	Composite index Less than 4.5 or 5.0[b]
5.	Outstanding recreational fishery		Tolerant species increasing, beginning to predominate	Tolerant species predominate	Community organization lacking
6.	Species with an endangered, threatened, or special concern status are present				

[a] Conditions: Categories 1, 2, 3 and 4 (if data is available) must be met and 5 or 6 must also be met in order to be designated in that particular class.

[b] encompasses range of ecoregional values; area of insignificant departure is -0.5 from ecoregional criterion.

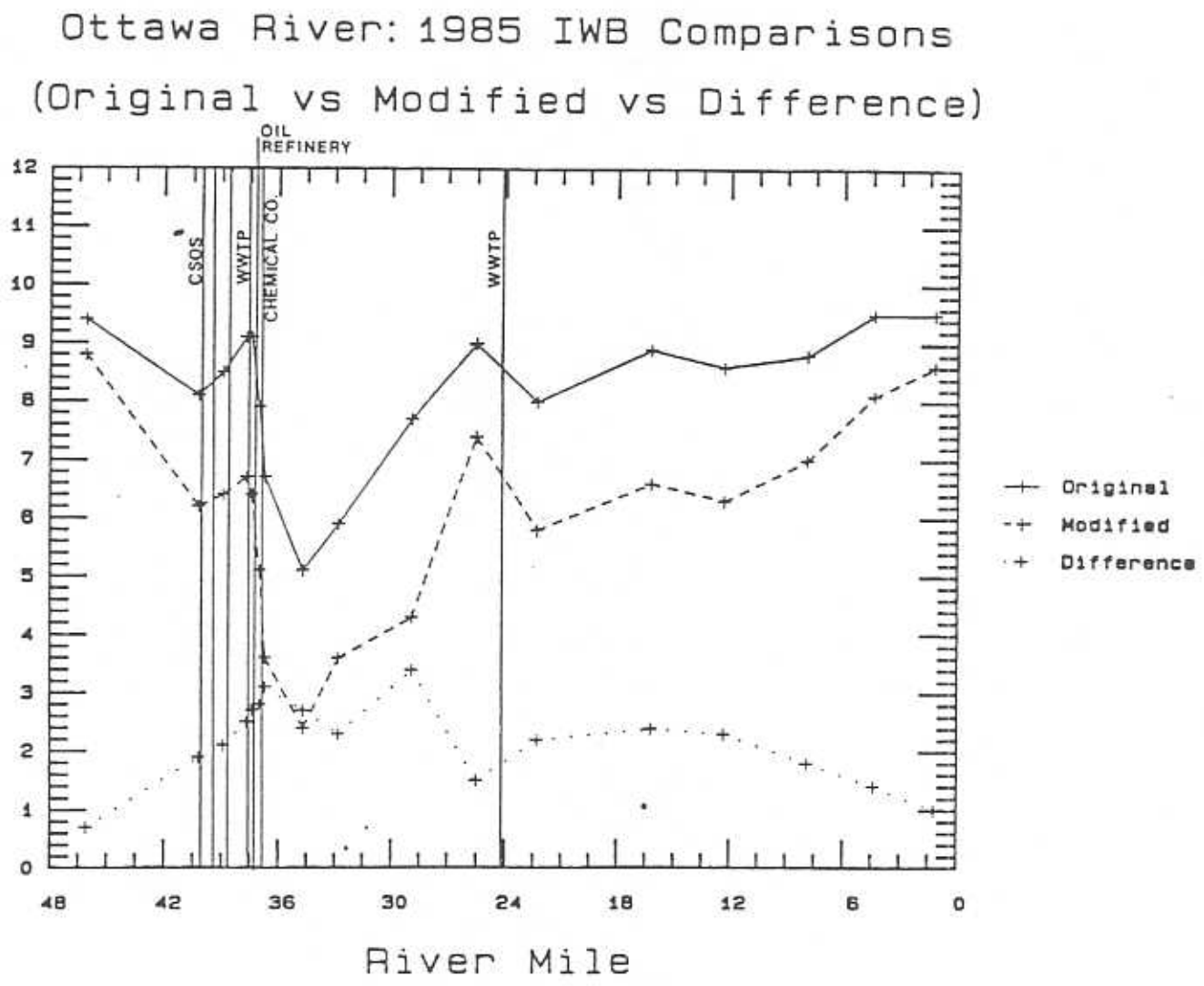


Figure 5. Original Iwb and modified Iwb results based on electrofishing samples from the Ottawa River during July-September 1985. The difference between the original Iwb and modified Iwb is included for comparison. Environmental influences are indicated.