A Multi-assemblage Index of Stream Integrity: What are the fish, bugs and algae telling us?

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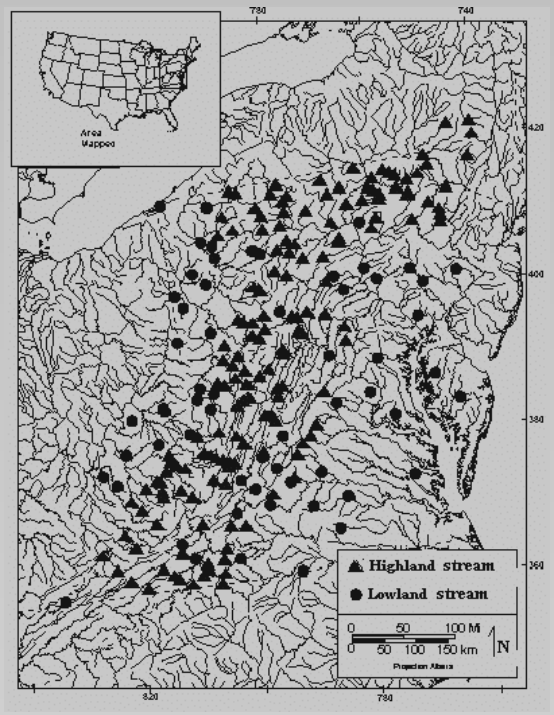
EMAP Stream Surveys

1993-1996

199 sites

233 site-visits

1st – 3rd order

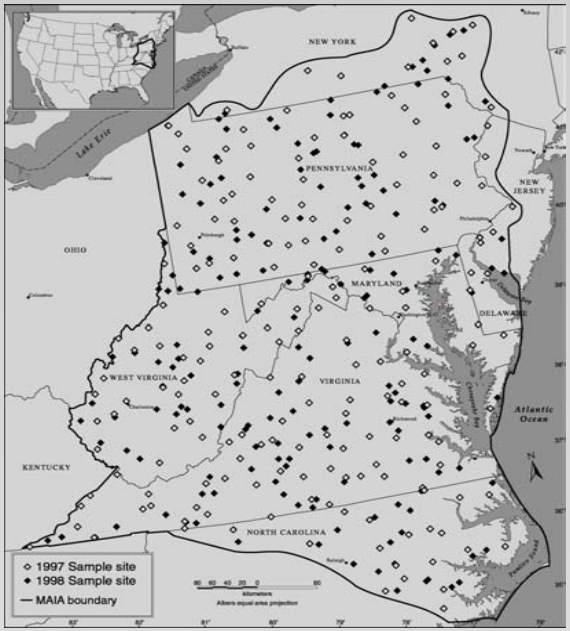


1997-1998

267 sites

295 site-visits

1st – 5th order



Other contributors:
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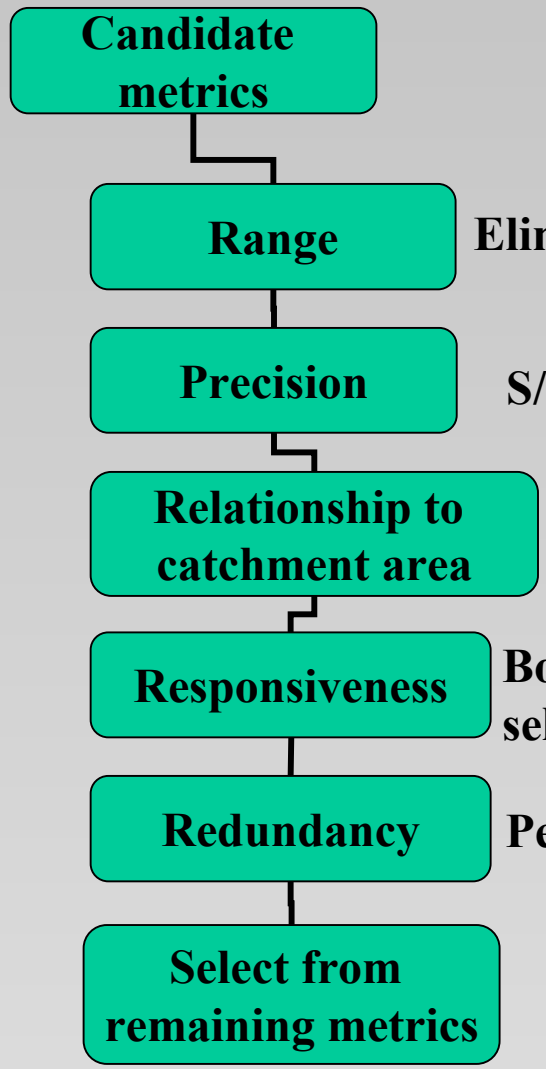
In past studies, we considered the stressor-response signals from—

- fish assemblage (> 50 attributes)
- macroinvertebrate assemblage (>100 attributes)
- algal assemblage (>200 attributes)

Stepwise metric evaluation



Range: Eliminate if percentage range <10%, or 90% of values=0

Precision: S/N ratio: Eliminate if S/N < 1.50

Relationship to catchment area: Use residuals of regression + a constant if significant correlation (p <0.01) with $\log_{10}$ of catchment area

Responsiveness: Box and scatter plots, Spearman rank correlations with selected chemical and habitat disturbance gradients

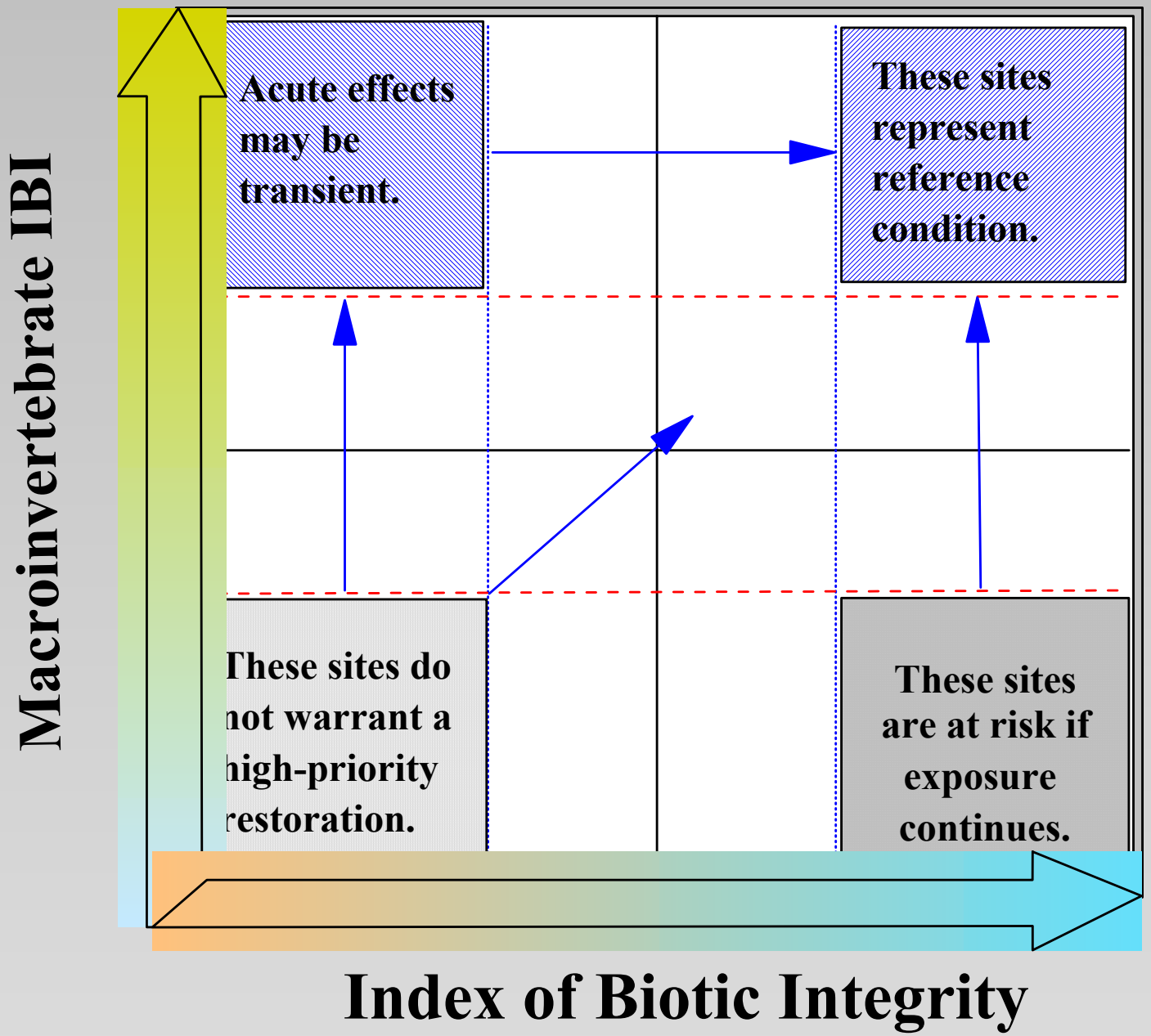
Redundancy: Pearson correlation of 0.7 or larger, choose one of pair

Previous Studies

You say to-may-to, I say to-mah-to: comparisons of diatom, macroinvertebrate, and fish species richness in Appalachian streams ***(NABS, Kalispell, MT, 1996)***

You say po-tay-to, I say po-tah-to: comparisons of fish, macroinvertebrate, and periphyton assemblage attributes and indices in Appalachian Mountain streams ***(NABS, La Crosse, WI, 2001)***

...inconsistent responses among indices to environmental variables...

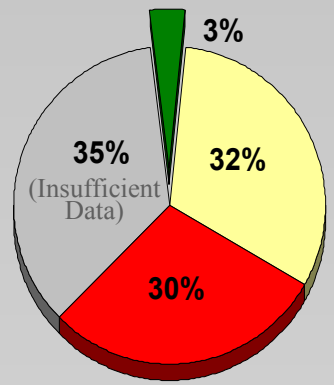

Acute effects may be transient.
These sites represent reference condition.
These sites do not warrant a high-priority restoration.
These sites are at risk if exposure continues.
Macroinvertebrate IBI
Index of Biotic Integrity

Development of an index of biotic integrity for the Mid-Atlantic Highlands Region. McCormick et al. Transactions of the American Fisheries Society 130:857-877 (2001)

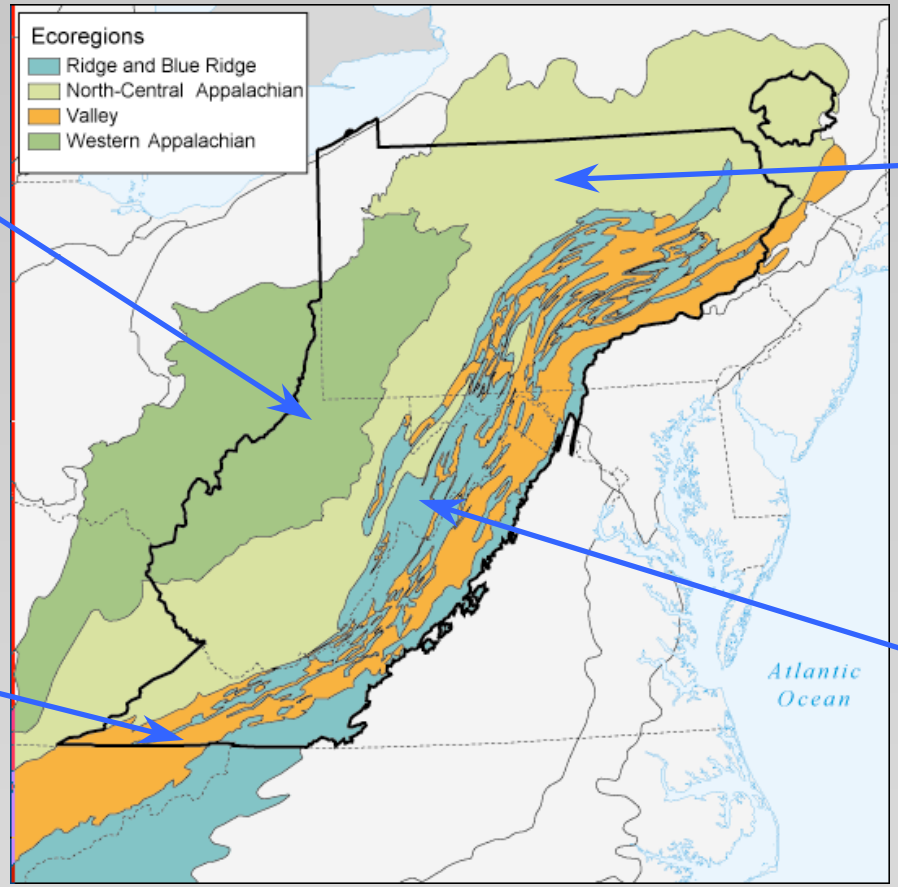
Fish Attributes

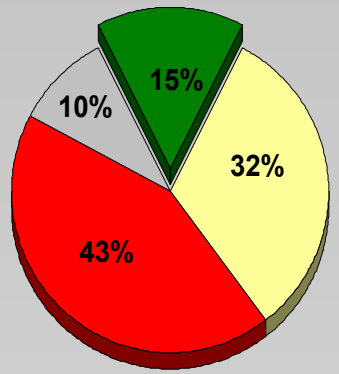
- % Cottid individuals
- % intolerant, clean gravel spawners
- % individuals as large omnivores
- % tolerant individuals
- % non-native individuals
- number of intolerant benthic species
- number of intolerant species
- number of intolerant Cyprinid species
- number of intolerant piscivore/insectivore species

Fish Assessment of the Condition of Appalachian Streams

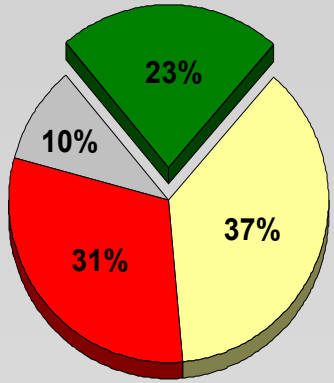


Western Appalachians

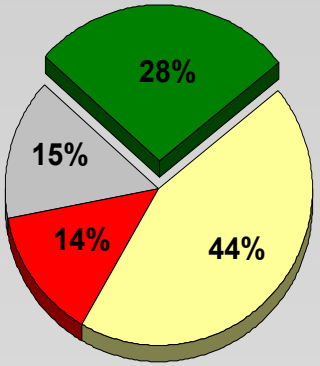




North-Central Appalachians



Valleys



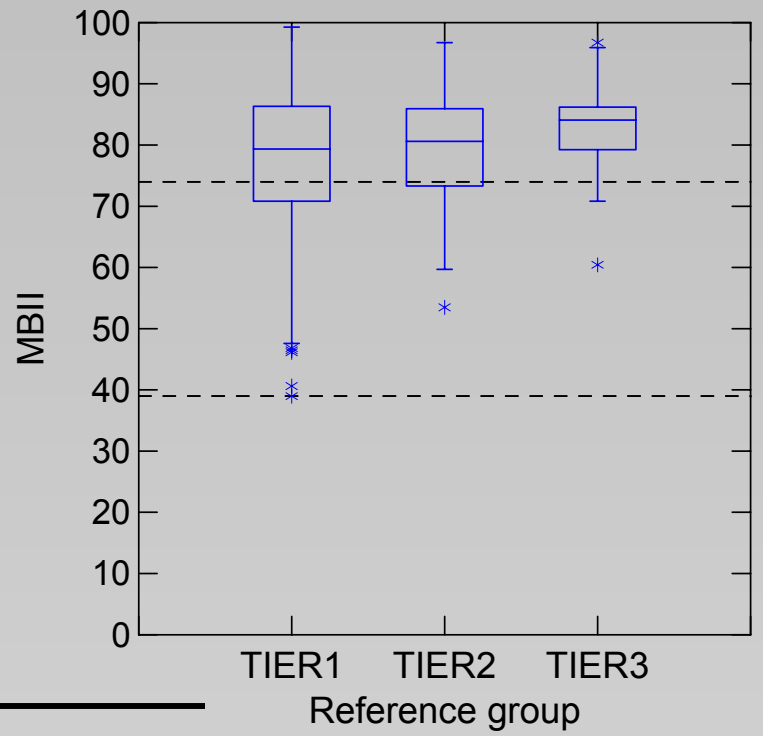
Ridge and Blue Ridge

*Development and evaluation of a macroinvertebrate biotic integrity index (*MBII*) for regionally assessing Mid-Atlantic highland streams.*
Klemm et al. Environmental Management 31:656-669 (2003)

Macroinvertebrate attributes

- collector-filterer richness
- % dominance of top 5 species
- macroinvertebrate tolerance index
- % non-insect individuals
- Ephemeroptera richness
- Plecoptera richness
- Trichoptera richness

Macroinvertebrate Assessment of the Condition of Appalachian Streams



Condition category	% of stream km (90% CI bounds)	Length of stream km
Good	16.8 ± 6.6	28192
Fair	57.2 ± 9.3	96043
Poor	26.0 ± 8.1	43562

Use of periphyton assemblage data as an index of biotic integrity. Hill et al. Journal of the North American Benthological Society 19:50-67 (2000)

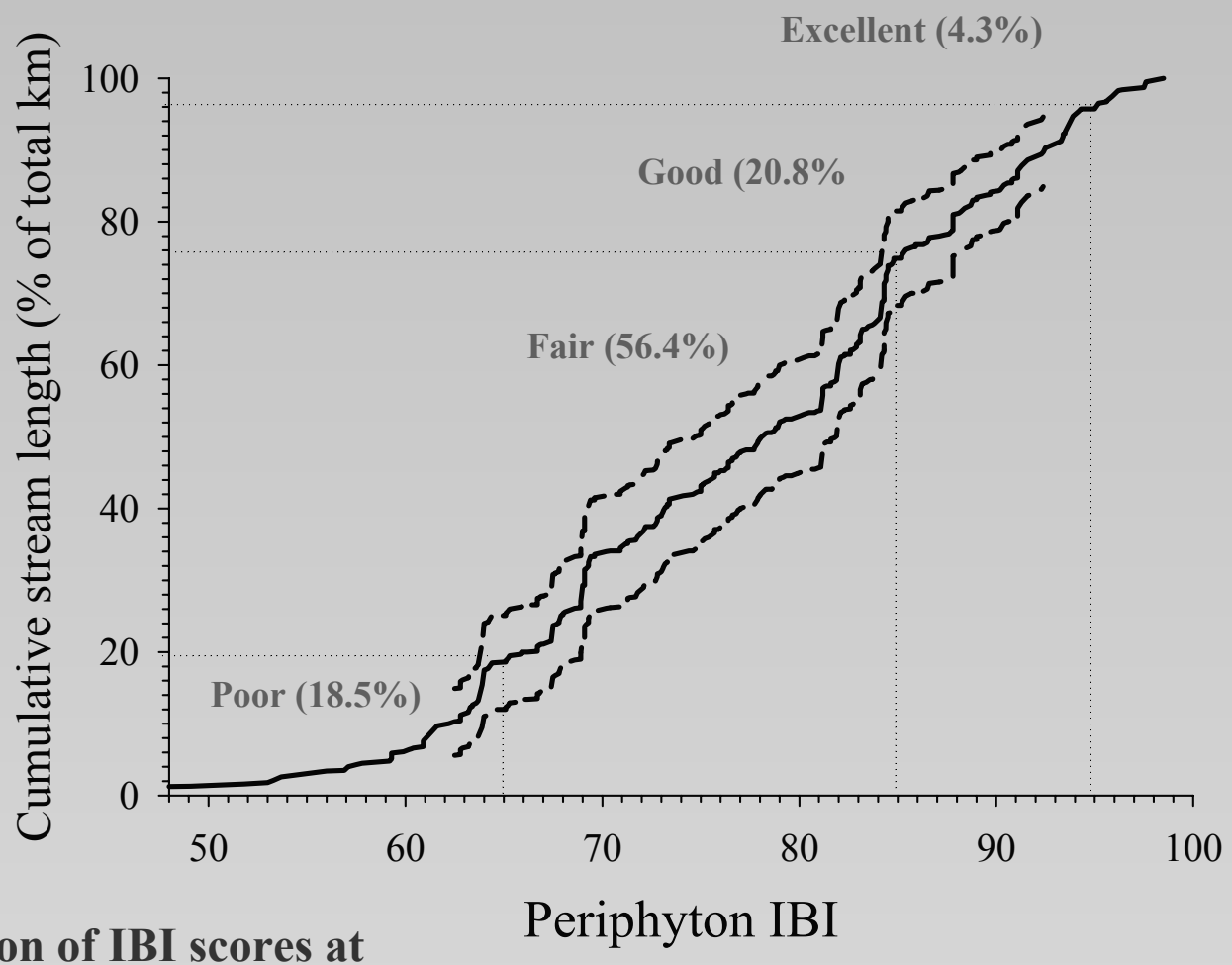
Assessment of streams of the eastern United States using a periphyton index of biotic integrity. Hill et al. Ecological Indicators 2:325-338 (2003)

Plus other modifications—Stoddard et al (*in prep*)

Algal attributes

- % eutraphentic individuals
- number of salt tolerant species
- % motile species
- % *Nitzschia* sp.
- % nitrogen metabolizing individuals
- number of low O_2 tolerant species
- % dominance by top 5 species
- number of tolerant species
- % *Eunotia* sp.

Periphyton Assessment of the Condition of Appalachian Streams



EMAP uses the distribution of IBI scores at *reference sites* to set thresholds:

- **Excellent**: IBI > 25th reference percentile
- **Good**: 10th < IBI < 25th reference percentile
- **Fair**: 5th < IBI < 10th reference percentile
- **Poor**: IBI < 5th reference percentile

So, what are the fish, bugs and algae telling us?

Our approach—

- Canonical correlation analysis of the suite of environmental with the suite of biological variables;

- Select attributes of fish, macroinvertebrate, and algal assemblages that are most responsive to the canonical gradient of environmental variables;

- Principal component analysis of environmental variables to identify environmental gradients;

- Correlation of environmental and biological variables with PCA axes;

- Eliminate redundant variables; and

- Construct multi-assemblage IBI

Environmental variables—the short list

Chemistry—

- Cl^-
- Total N
- Total P
- pH
- SO_4^{-2}

Habitat—

- Stream temp
- Median substrate size
- Mean thalweg depth
- Channel slope
- Riparian disturbance index
- Mean channel embeddedness
- mean channel width

Landscape—

- % watershed barren
- % watershed in forests
- % watershed in mines
- % watershed urbanized
- % watershed in wetlands
- road density
- watershed area
- stream order

PCA Gradients and their Correlates

	PCA 1	PCA 2	PCA 3
Variance Explained	0.62	0.30	0.06
Cl	0.55	0.51	----
Total N	----	0.99	----
Total P	----	0.50	----
SO_4	0.98	----	----
Substr.	----	-0.31	----
Depth	----	----	0.36
Slope	----	-0.30	----
Width	----	----	0.72
% Forest	----	-0.66	----
% Mine	0.60	----	----
% Urban	0.41	----	----
% Wetland	----	----	0.46
WS area	----	----	0.75
Roads	0.30	0.39	----
Order	----	----	0.64

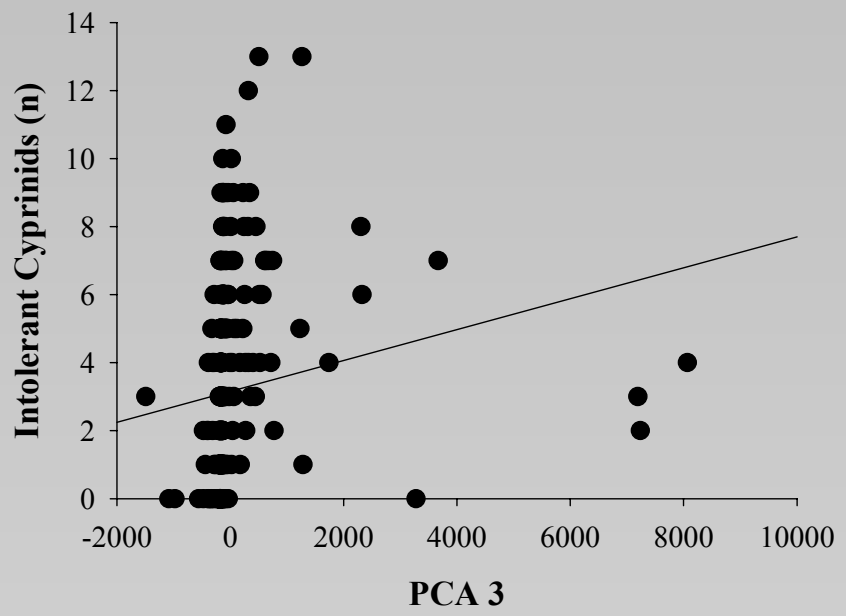
	PCA 1	PCA 2	PCA 3
Fish IBI	-0.32	-0.23	0.15
Bug IBI	-0.17	-0.17	0.21
Algal IBI	-0.27	-0.35	-0.06
MABI	-0.27	-0.41	0.06

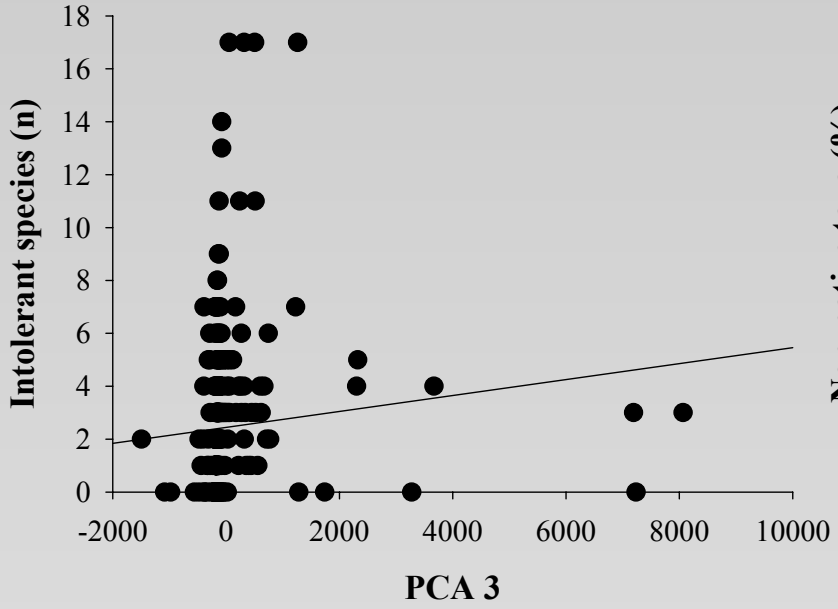
	PCA 1	PCA 2	PCA 3
No. Intol. Benthics	----	----	0.52
No. Intol. Cyprinid	----	----	0.54
No. Intol. Individuals	----	----	0.41
% Non-native spp.	----	----	0.39
% Large Omnivores	----	----	0.30
% Intol. Pisc./Insect.	----	----	0.31
% Tolerant Individ.	----	----	-0.35
Col.-Filt. Richness	----	----	0.33
Plecopt. Richness	-0.34	-0.32	----
% Tol. Individ.	----	0.26	----
No. Eutra. Diatoms	0.33	0.42	----
No. Salt-tolerant spp.	----	0.32	----
% N-metabol. Indiv.	----	0.31	----
No. Low O_2 Tol. spp.	----	0.35	----
% *Nitzschia* sp.	----	0.32	----
No. Tolerant spp.	----	0.31	----
% Dominance-5 spp.	----	-0.31	----

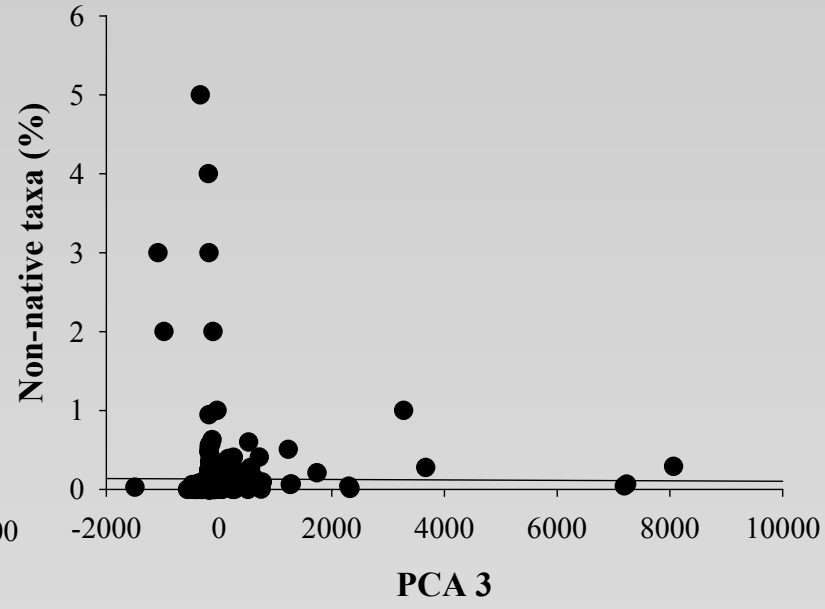
PCA 1=mining/industrial disturbance
PCA 2=agriculture/nutrient enrichment
PCA 3=stream size

Fish Attributes

PCA 3=stream size

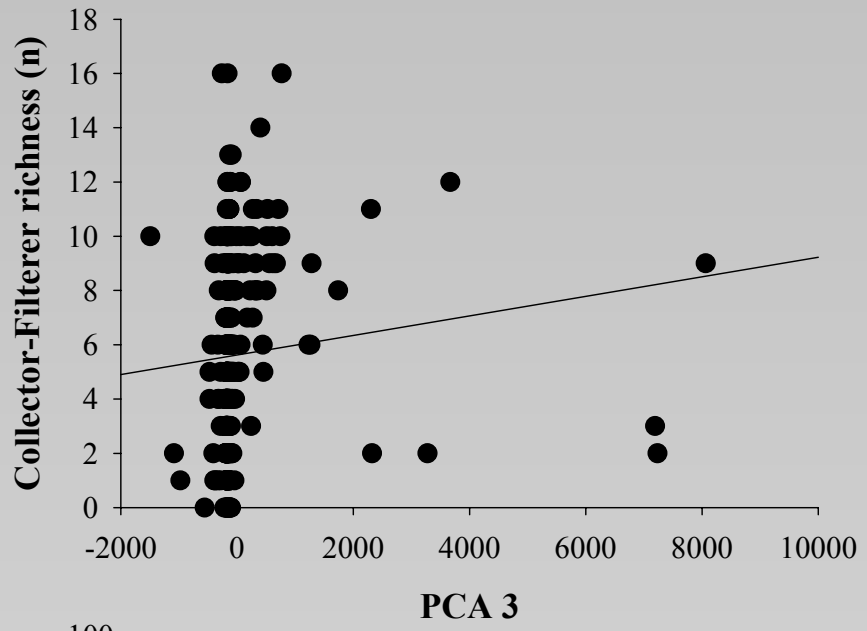


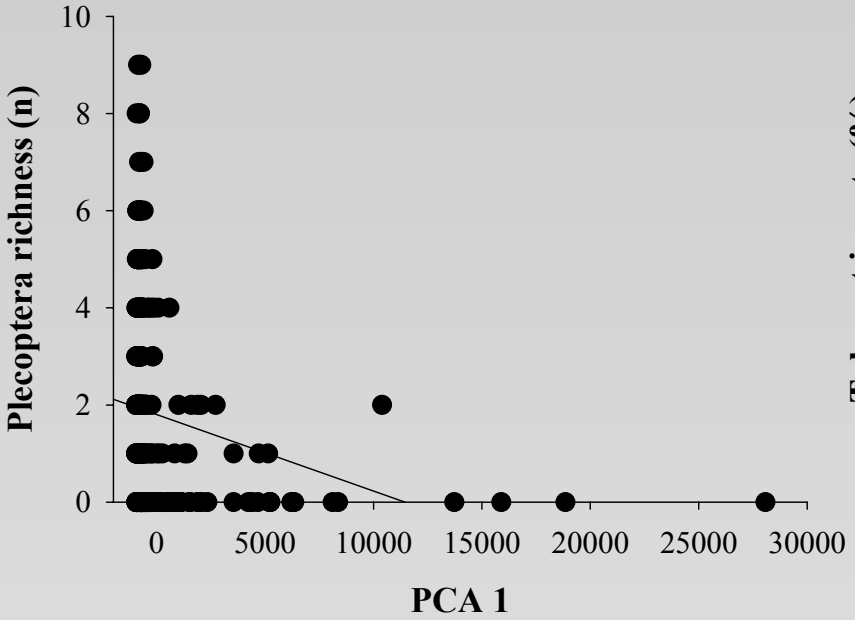


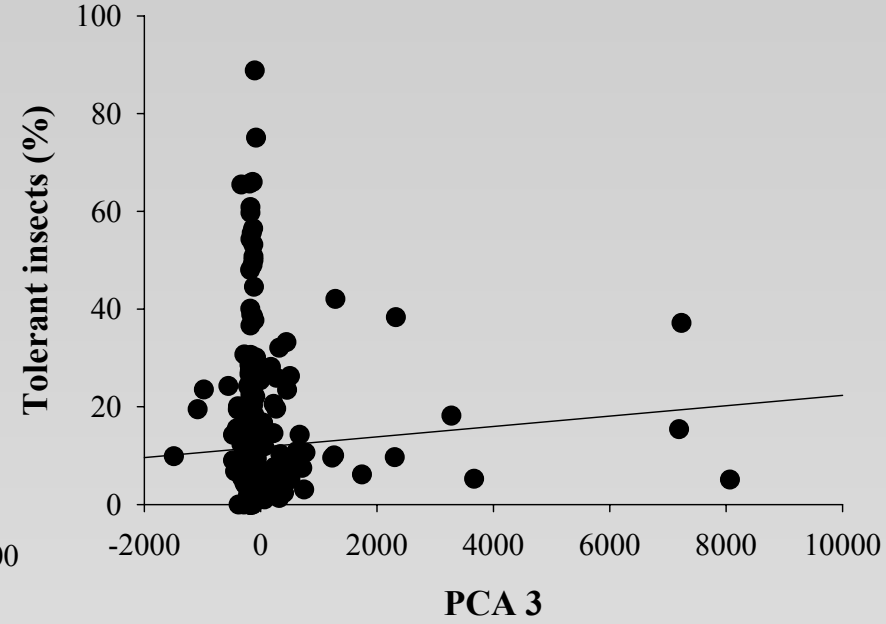


Macroinvertebrate Attributes

PCA 1=mining/industrial disturbance
PCA 3=stream size

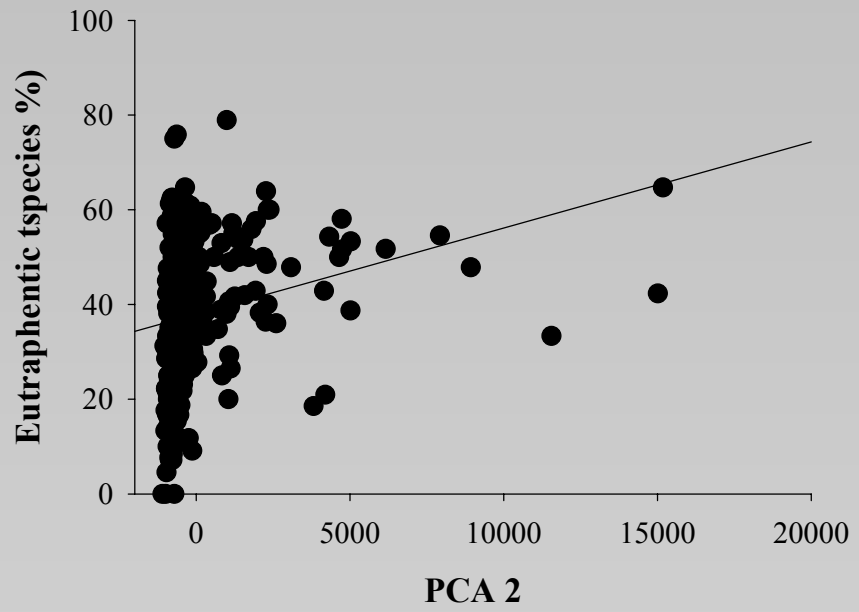


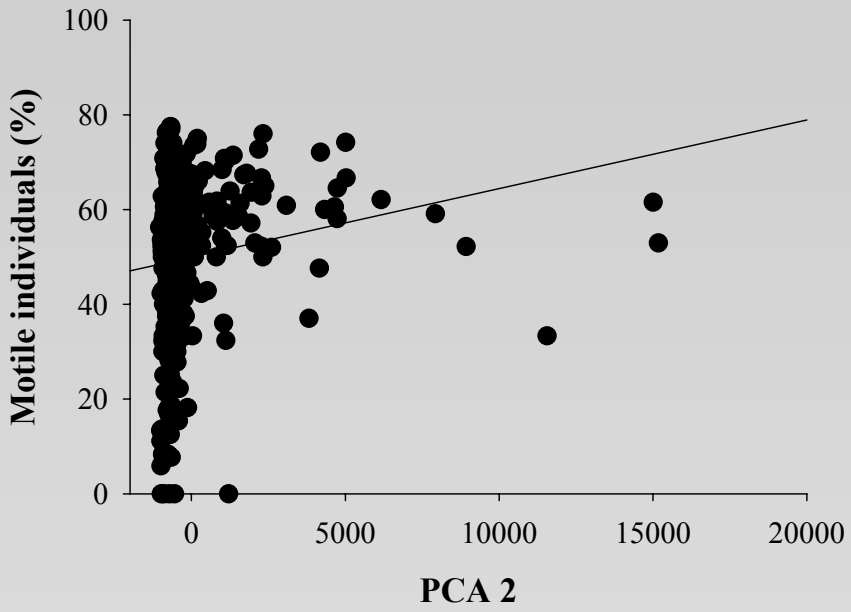


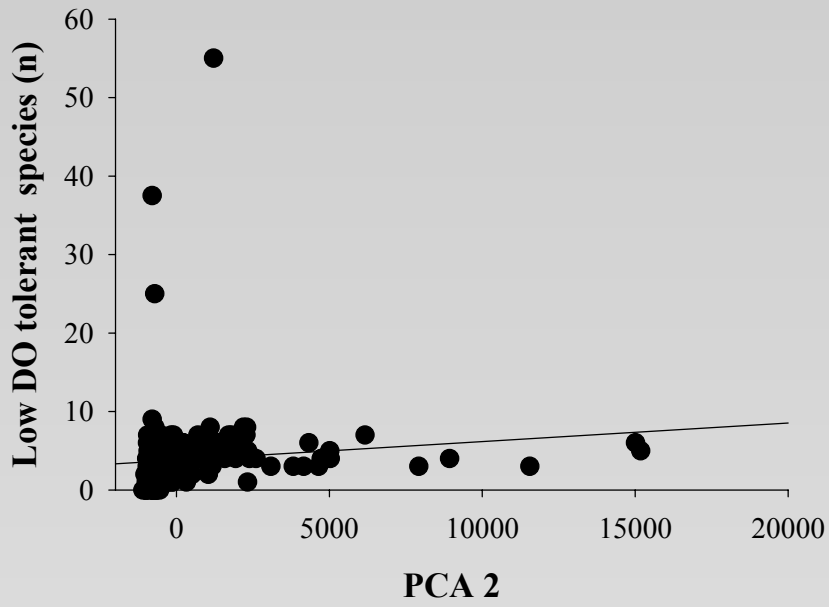


Algal Attributes

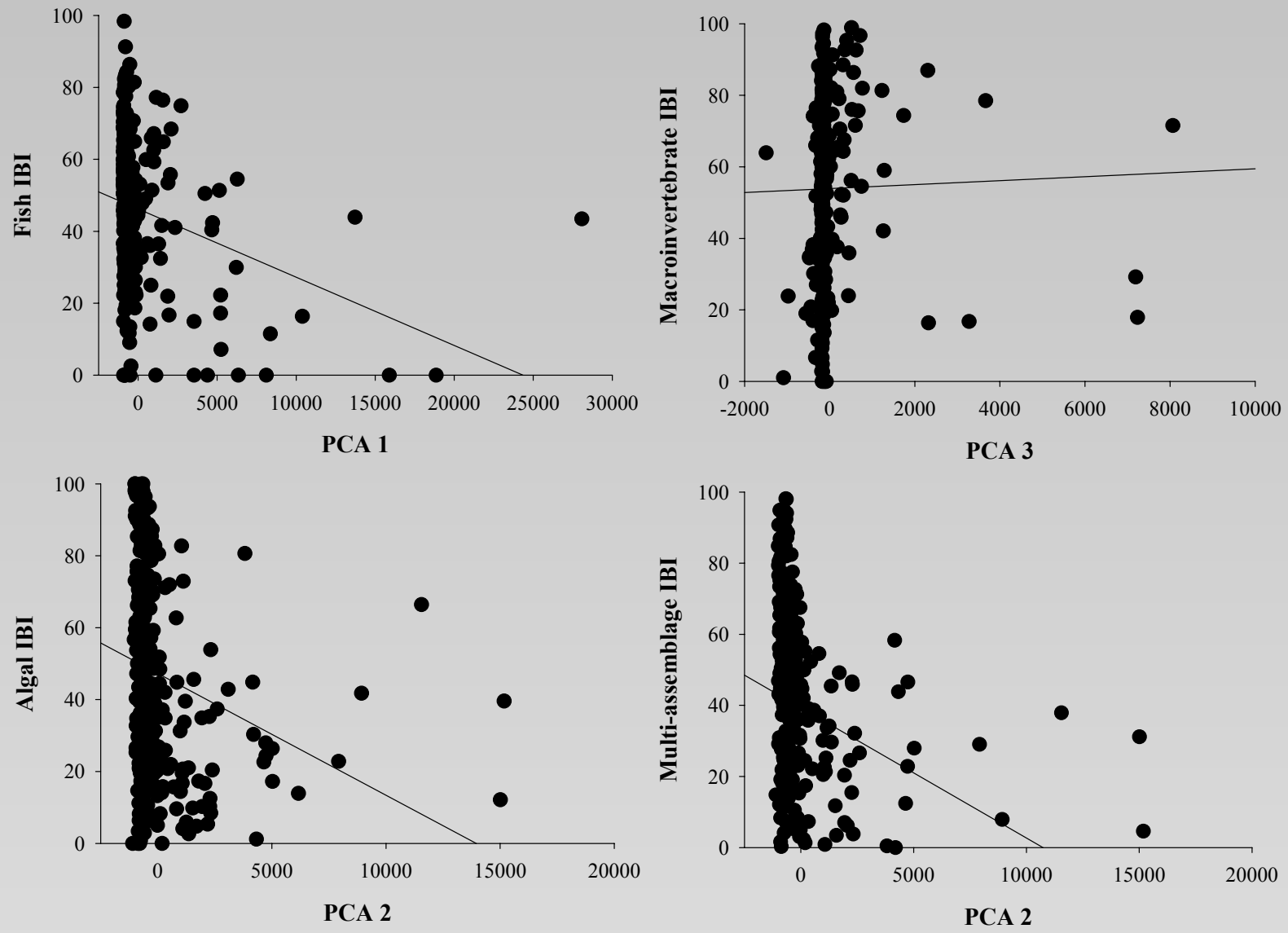
PCA 2=agriculture/nutrient enrichment







Comparison of Indices of Biotic Integrity



PCA 1=mining/industrial disturbance PCA 2=agriculture/nutrient enrichment PCA 3=stream size

Classification of Appalachian Streams based on Fish, Macroinvertebrate, Algal and Multi-assemblage Indices of Biotic Integrity

Class	Fish IBI	Bug IBI	Algal IBI	MABI
Excellent	16	14	7	8
Good	14	21	16	9
Fair	22	22	19	44
Poor	47	42	58	39
Minimum	0	0	0	3
Median	48	56	43	33
Maximum	98	99	100	96

Discriminant Function Analysis

Index	Classification Error Rate (%)		
	Condition Class[1]	Non-reference Condition[2]	Reference Condition[3]
Fish IBI	**30 (16)**	**29**	**30**
Bug IBI	**10 (0)**	**31**	**35**
Algal IBI	**12 (0)**	**21**	**26**
MABI	**35 (5)**	**13**	**44**

[1]numbers in parentheses are % of sites misclassified by 2 or more classes
[2]% of non-reference sites misclassified as reference sites
[3]% of reference sites misclassified as non-reference sites

Some Simple Conclusions

1. **Individual fish attributes were most responsive to habitat space variables, but collectively (IBI) they were most responsive to mining and urbanization gradients.**

2. **Macroinvertebrates attributes and IBI were most responsive to habitat space variables, with the exception of Plecoptera richness which responded to mining/urbanization.**

3. **Algal attributes and IBI were most responsive to nutrient gradients.**

4. **The MABI was more responsive to environmental gradients, especially agriculture/nutrients, than were the individual fish, macroinvertebrate or algal IBI.**

5. **Interestingly, despite the IBI being scored against reference conditions, none of the indices was able to separate reference sites from the rest of the sites.**

Lessons Learned/Things to Ponder

1. **Assessing condition, setting criteria, or determining use designations based on a single group of organisms is unlikely to result in the right answer--the myth of the most sensitive species, revisited.**

2. **The tendency of WQ monitoring programs nationwide to rely on single indicators may result in Type I Errors.**

3. **The approaches detailed in Hill et al., McCormick et al., Klemm et al., and Stoddard et al. represent significant, quantitative and quantifiable improvements over "BPJ" approaches.**

4. **Using biological condition to identify reference sites for scoring indices of biotic integrity is circular. Minimally disturbed sites should be independently identified (chemical, habitat or landscape criteria) and verified with biological indicators of condition.**

Ecological Indicators:

Prophet or Private Eye?

"…indicators must provide information relevant to specific assessment questions, which are developed to focus monitoring data on environmental management issues."

Evaluation Guidelines for Ecological Indicators
EPA/620/R-99/005 (May 2000)

When selecting biological indicators "*one size does not fit all*", in fact, "*one size may not fit any*."