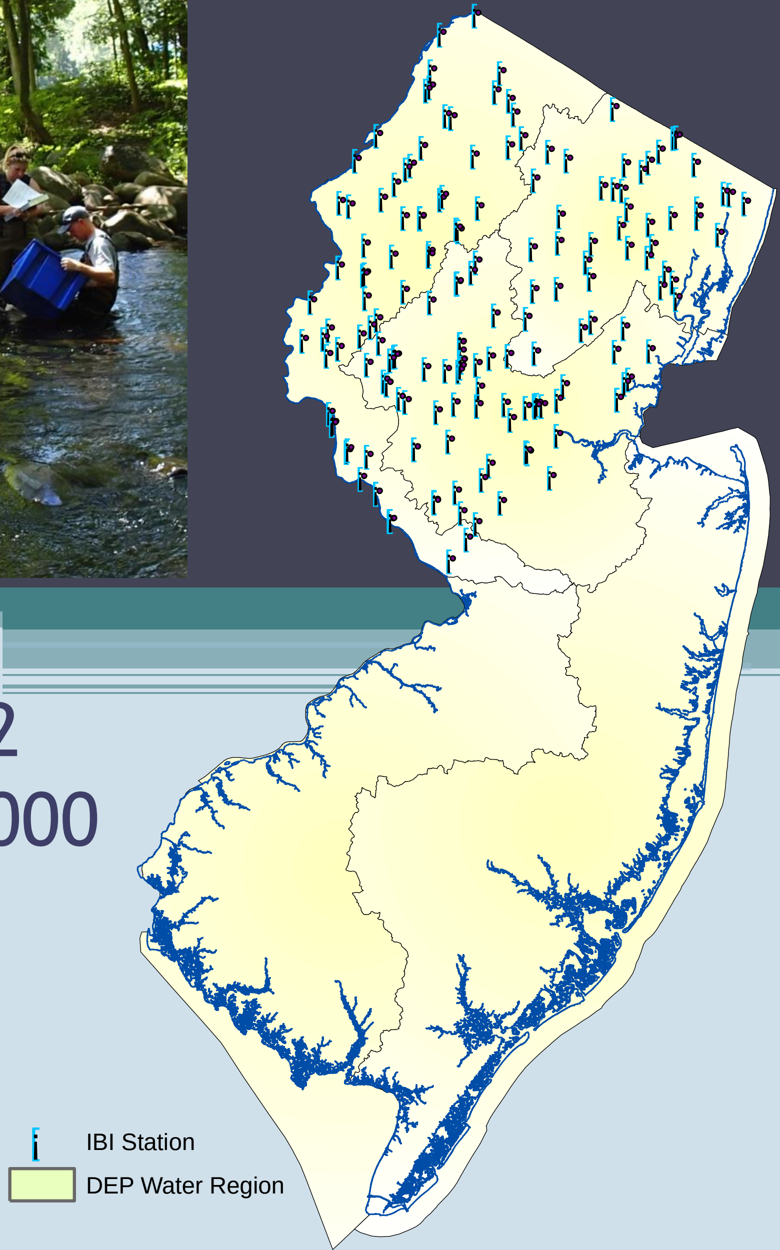
Development of indices of biotic integrity for high-gradient wadeable rivers and headwater streams in New Jersey

John Vile and Brian Henning

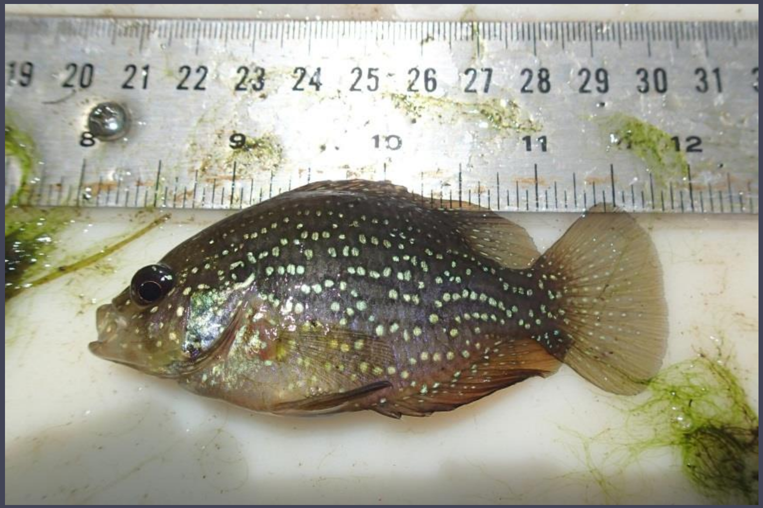
New Jersey Department of Environmental Protection
Bureau of Freshwater and Biological Monitoring

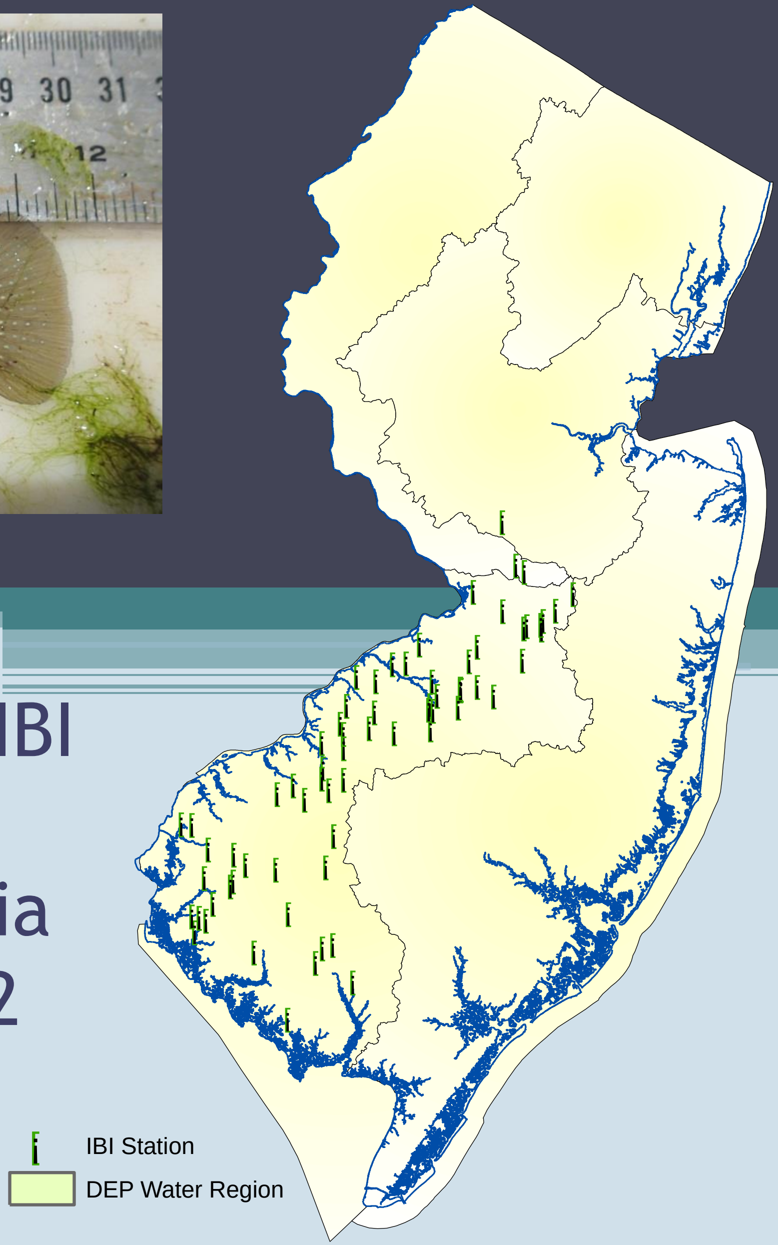
Northern Fish IBI



- Developed by U.S. EPA Region 2
- BFBM initiated monitoring in 2000
- BFBM completed metric refinement in 2005 & 2016
- Currently in 4th round of monitoring

Southern Fish IBI





- Pilot project to develop a fish IBI started by NJ Fish & Wildlife
- BFBM completed scoring criteria and validation finalized in 2012
- Currently evaluating Outer Coastal Plain

Headwaters IBI

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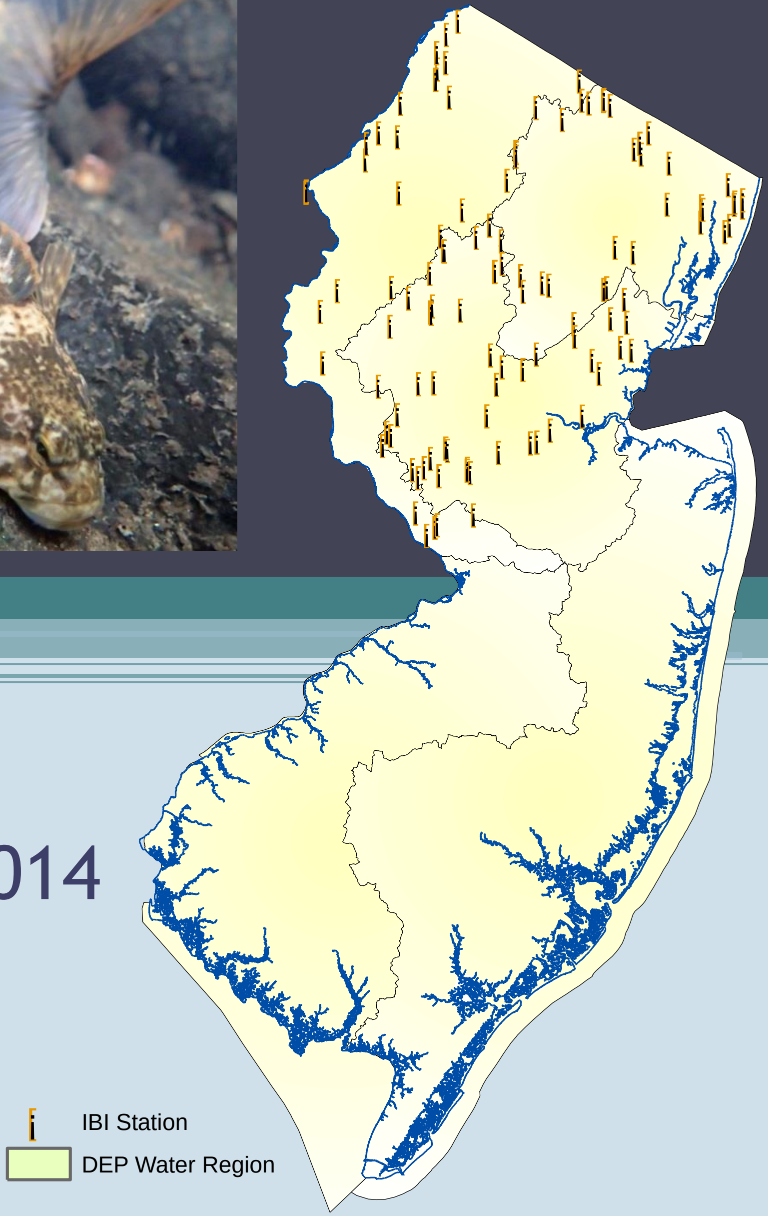


- Pilot study completed by ANS
- BFBM initiated monitoring in 2014
- BFBM completed metric refinement in 2016

Fish IBI Monitoring Network

Fixed Sites N=210

- Revisit every 5 years, track long-term trends.

Sentinel Sites N=21

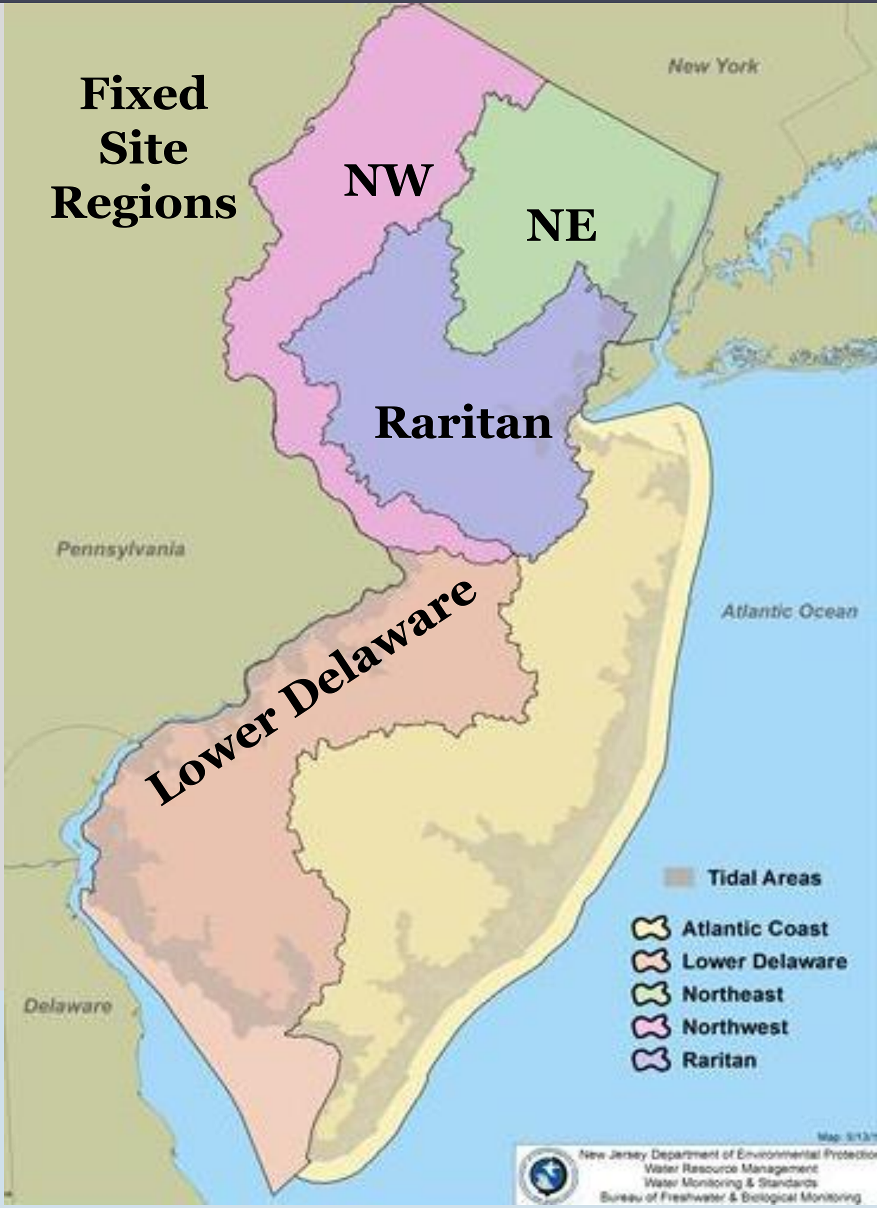
- Sentinel sites are sampled routinely to assess natural variability and environmental change.

Probabilistic Sites N=50

- Probabilistic sites were generated using a Generalized Random Tessellation Stratified (GRTS) survey design to provide a statistical Statewide survey of the Fish Index of Biotic Integrity Network.

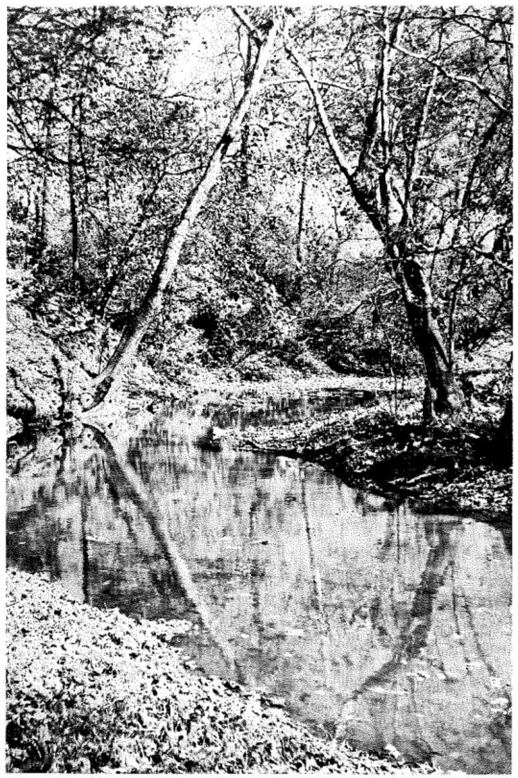
U.S. EPA Regional Monitoring Network N=3

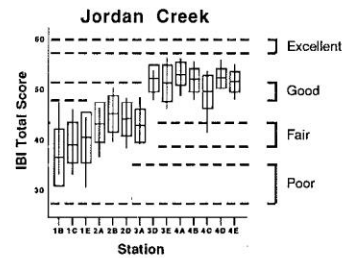
- RMN sites have minimal or low levels of upstream human-related disturbance
- Biological, thermal, and hydrologic data are collected to quantify and monitor changes in baseline conditions, including climate change effects.

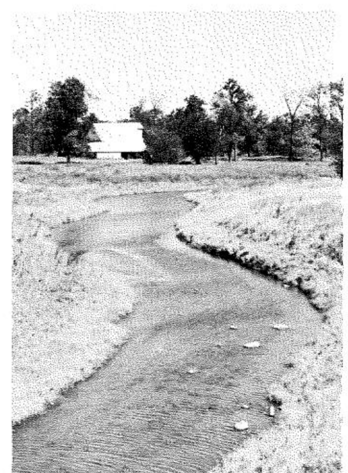


Assessing Biological Integrity in Running Waters A Method and Its Rationale

James R. Karr
Kurt D. Fausch
Paul L. Angermeier
Philip R. Yant
Isaac J. Schlosser







Illinois Natural History Survey
Special Publication 5 September 1986

Rapid Bioassessment Metrics

I. Species richness and composition metrics

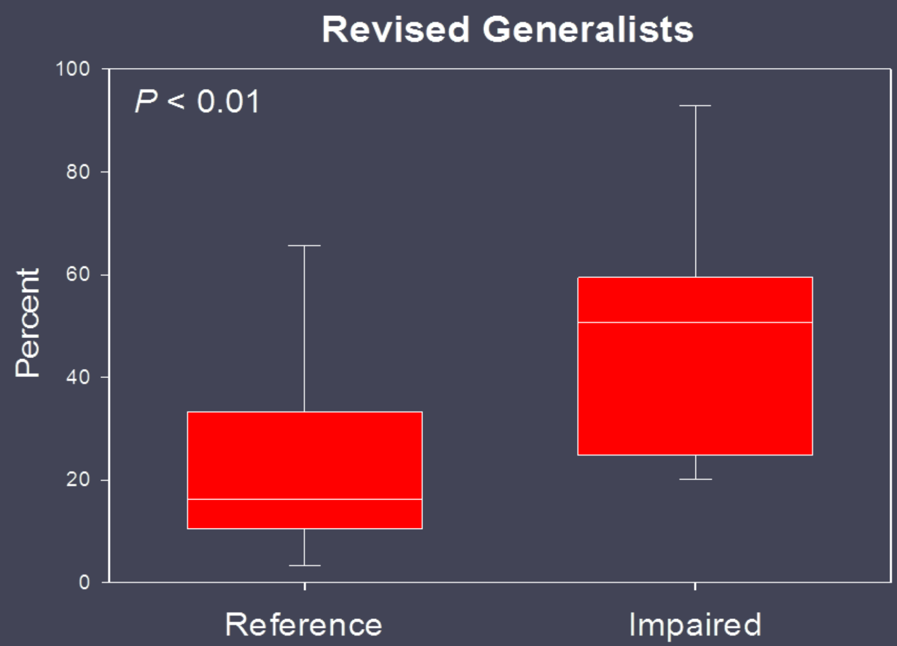
No. Fish Species
No. Benthic Insectivores
No. Trout & Centrarchid Species
No. Intolerant Species
Proportion of White Suckers

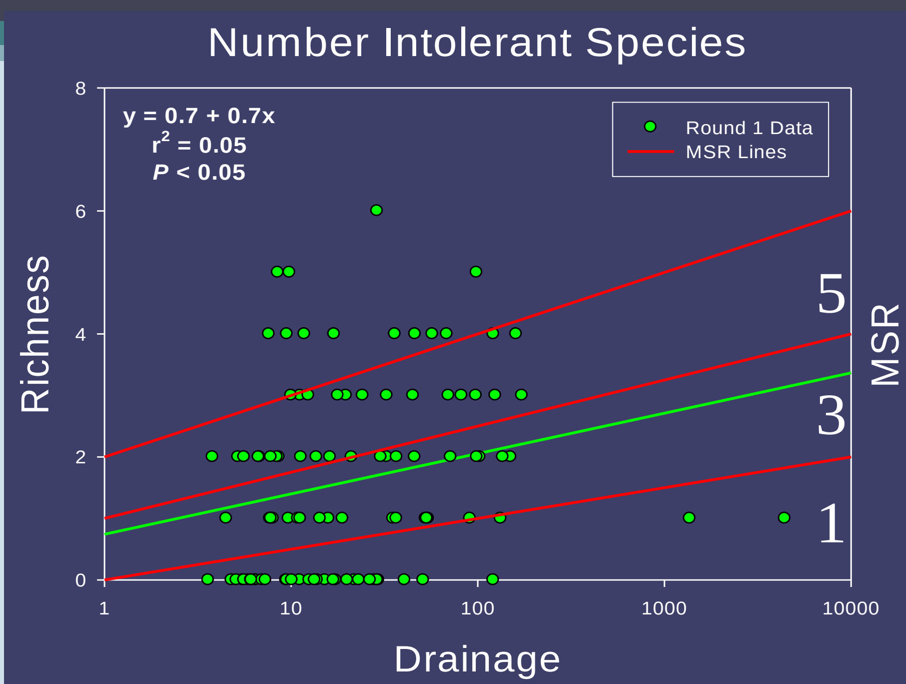
II. Trophic composition metrics

Proportion of Generalists
Proportion of Insectivorous Cyprinids
Proportion of Trout or Piscivores

III. Fish abundance and condition metrics

No. Specimens
Proportion with Anomalies





FIBI059 - Pascack River @ Emerson Rd
Date Sampled - 7/30/2003

Excellent | Good | **Fair** | Poor

	Score
# of Fish Species	5
# of Benthic Insectivorous Species (BI)	3
# of Trout and Centrarchid Species (trout, bass, sunfish, crappie)	5
# of Intolerant Species (IS)	1
Proportion of Individuals as White Suckers	5
Proportion of Individuals as Generalists (carp, creek chub, banded killifish, goldfish, fathead minnow, green sunfish)	5
Proportion of Individuals as Insectivorous **Cyprinids** (I and BI)	1
Proportion of Individuals as Trout *whichever gives better score OR Proportion of Individuals as Piscivores (Excluding American Eel)*	3
Number of Individuals in Sample	3
Proportion of Individuals w/disease/anomalies (excluding blackspot)	5
Total	**36**

Stream Rating

45-50	**Excellent**
37-44	**Good**
29-36	**Fair**
10-28	**Poor**

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[Article]

A Structured Approach for Developing Indices of Biotic Integrity: Three Examples from Streams and Rivers in the Western USA

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Abstract.—In the late 1990s the Environmental Monitoring and Assessment Program of the U.S. Environmental Protection Agency developed a structured set of tests to evaluate and facilitate selection of metrics for indices of biotic integrity (IBIs). These IBIs were designed to be applicable across multistate regions as part of a national assessment of all U.S. waters. Here, we present additional steps in, and refinements to, that IBI development process. We used fish and amphibian assemblage data from 932 stream and river sites in 12 western U.S. states to develop IBIs for Mountains, Xeric, and Plains ecoregions. We divided 237 candidate metrics into nine metric classes representing different attributes of assemblage structure and function. For each ecoregion we sequentially eliminated metrics by testing metric range, signal-to-noise ratios, responsiveness to disturbance, and redundancy to select the best metric in each class. The IBIs for the Mountains and Plains each had seven metrics and the Xeric IBI had five. In the Mountains, half of the estimated stream length that could be assessed had IBI scores greater than 62 (out of 100). In the Xeric and Plains, half the stream length had scores no greater than 50 and no greater than 37, respectively. An estimated 16% of Xeric stream length had scores greater than 62 (the median for the Mountains), while 5% of Plains stream length had scores that exceeded 62. This IBI development process is less subjective and more streamlined and has more clearly defined criteria for metric selection and scoring than those used in the past, while maintaining a strong ecological foundation.

Twenty-five years ago, when the condition of streams and rivers was largely assessed by water quality criteria, Karr (1981) proposed an index of biotic integrity (IBI). It was designed to quantify characteristics of stream fish assemblages to assess biotic integrity, which is defined by Frey (1977) and Karr and Dudley (1981) as the "capability of supporting and maintaining a balanced, integrated, adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of the natural habitat of the region." Since that time, IBIs have become fairly standard tools for assessment of stream condition, particularly to address aquatic life uses (Davis and Simon 1995; Simon 1999a). The original IBI, which was developed for fish assemblages in Midwestern warmwater streams, has been modified for other regions and continents (Miller et al. 1988; Hughes and Oberdorff 1999; Karr 2006), coldwater streams (Lyons et al. 1996; Hughes et al. 2004), plains streams (Bramblett and Fausch 1991; Shearer and Berry 2002; Bramblett et al. 2005), large rivers (Hughes and Gammon 1987; Lyons et al. 2001; Emery et al. 2003; Mebane et al. 2003; Yoder et al. 2005) and lakes (Minns et al. 1994; Drake and Pereira 2003). Others have used IBI concepts to develop multi-

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Structured Approach to IBIs

Whittier, T.R., Hughes, R.M., Stoddard, J.L., Lomnicky, G.A., Peck, D.V., Herlihy, A.T.,2007. A structured approach for developing indices of biotic integrity: three examples from western USA streams and rivers. Trans. Am. Fish. Soc. 136, 718-735.

- Developed set of tests to evaluate and select metrics in a streamlined manner that is less subjective
- When a metric fails a test, it is eliminated

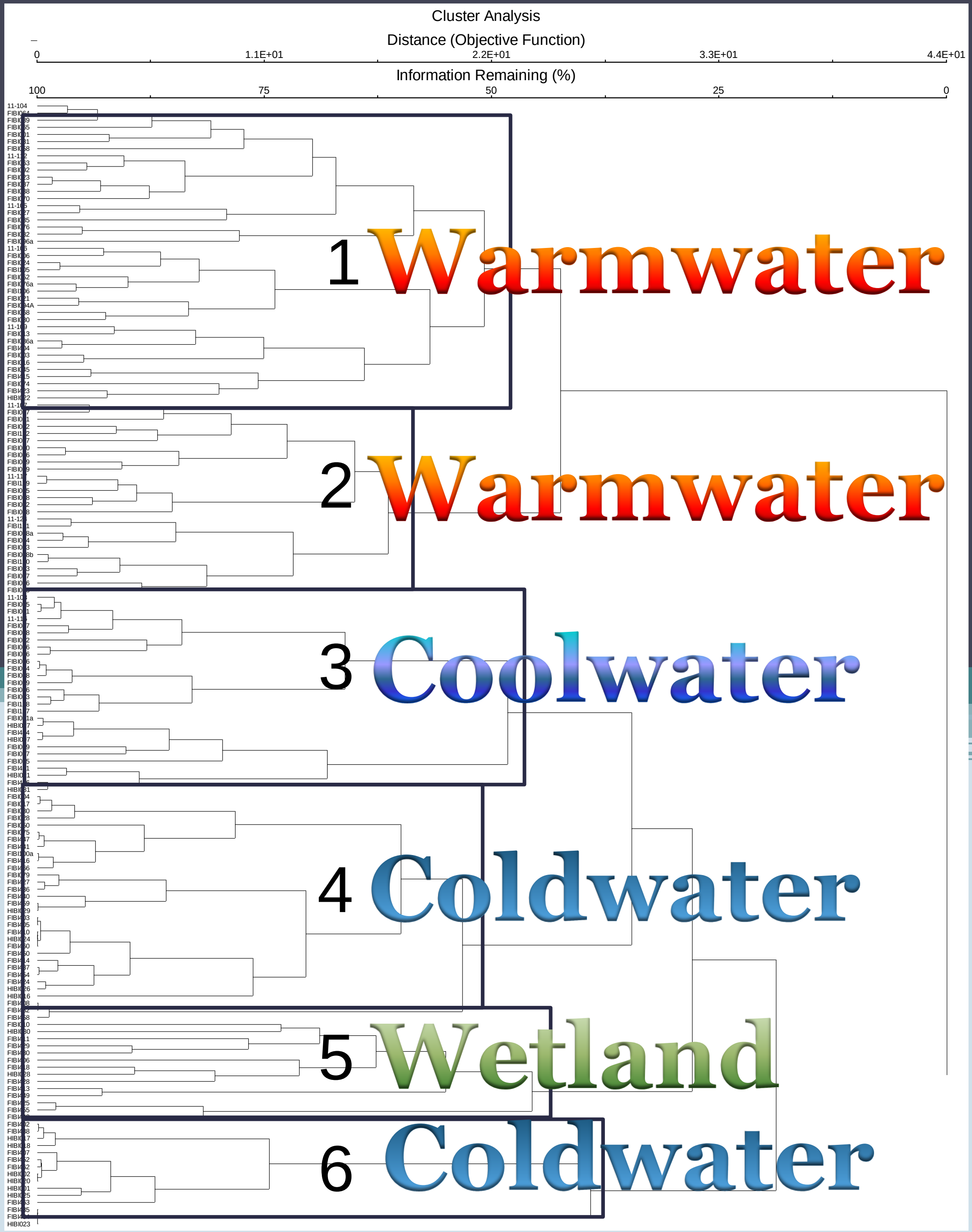
1. Range Test
2. Signal to noise
3. Correlation with natural gradients (drainage size, gradient)
4. Responsiveness test
5. Redundancy
6. Range test for metric scores
7. Metric scoring and evaluation

TABLE 1.—Metric classes used to develop indices of biotic integrity in the western USA.

Class	Description
Habitat	Preferred habitat for each vertebrate species (e.g., benthic, water column, or hider)
Tolerance	General tolerance to common anthropogenic, physical, and chemical stressors (sensitive, intermediate, tolerant, or very tolerant)
Trophic	Primary source of nutrition for each vertebrate species as an adult (herbivore, invertivore, invertivore–piscivore, piscivore, or omnivore)
Reproductive	Reproductive habit for each vertebrate species (e.g., lithophil, nest builder, or crevice spawner)
Composition	The representation of different taxonomic groups (e.g., family) in the assemblage
Richness	The number of different kinds of taxa
Life history	The general life history strategy for each vertebrate species (e.g., migrating [vagile], long-lived, etc.)
Aliens	Whether each vertebrate species is native or introduced in the region where it was collected
Abundance	The number of individuals of an assemblage, taxonomic group, or guild collected

Ecological Designations

Species name		Origin	Temperature	Tolerance	Trophic	Reproduction	Stream Flow
Fish							
A. brook lamprey	Lampetra appendix	N	C-W	I	FF	Litho	Rheo
American eel	Anguilla rostrata	N	W	T	TC		
Banded killifish	Fundulus diaphanus	N	W	T	GF		
Black crappie	Pomoxis nigromaculatus	A	W	M	TC		
Blacknose dace	Rhinichthys atratulus	N	C-W	M	GF	Litho	Rheo
Bluegill	Lepomis macrochirus	A	W	M	GF		
Bluespotted Sunfish	Enneacanthus gloriosus	N	W		I		
Bluntnose minnow	Pimephales notatus	A	W	T	GF		
Bridle shiner	Notropis bifrenatus	N	W	M	I		
Brook trout	Salvelinus fontinalis	N	C	I	TC	Litho	Rheo
Brown bullhead	Ameiurus nebulosus	N	W	M	GF		
Brown trout	Salmo trutta	A	C	I	TC	Litho	
Chain pickerel	Esox niger	N	W	M	TC		
Comely Shiner	Notropis amoenus	N	W	M	I	Litho	
Common carp	Cyprinus carpio	A	W	T	GF		
Common shiner	Luxilis cornutus	N	C-W	M	I	Litho	
Creek chub	Semotilus atromaculatus	N	C-W	M	GF	Litho	
Creek chubsucker	Erimyzon oblongus	N	W	M	BI		
Cutlips minnow	Exoglossum maxillingua	N	W	I	BI	Litho	
Eastern mudminnow	Umbra pygmaea	N	W	M	GF		
Eastern silvery minnow	Hybognathus regius	N	W	M	H		

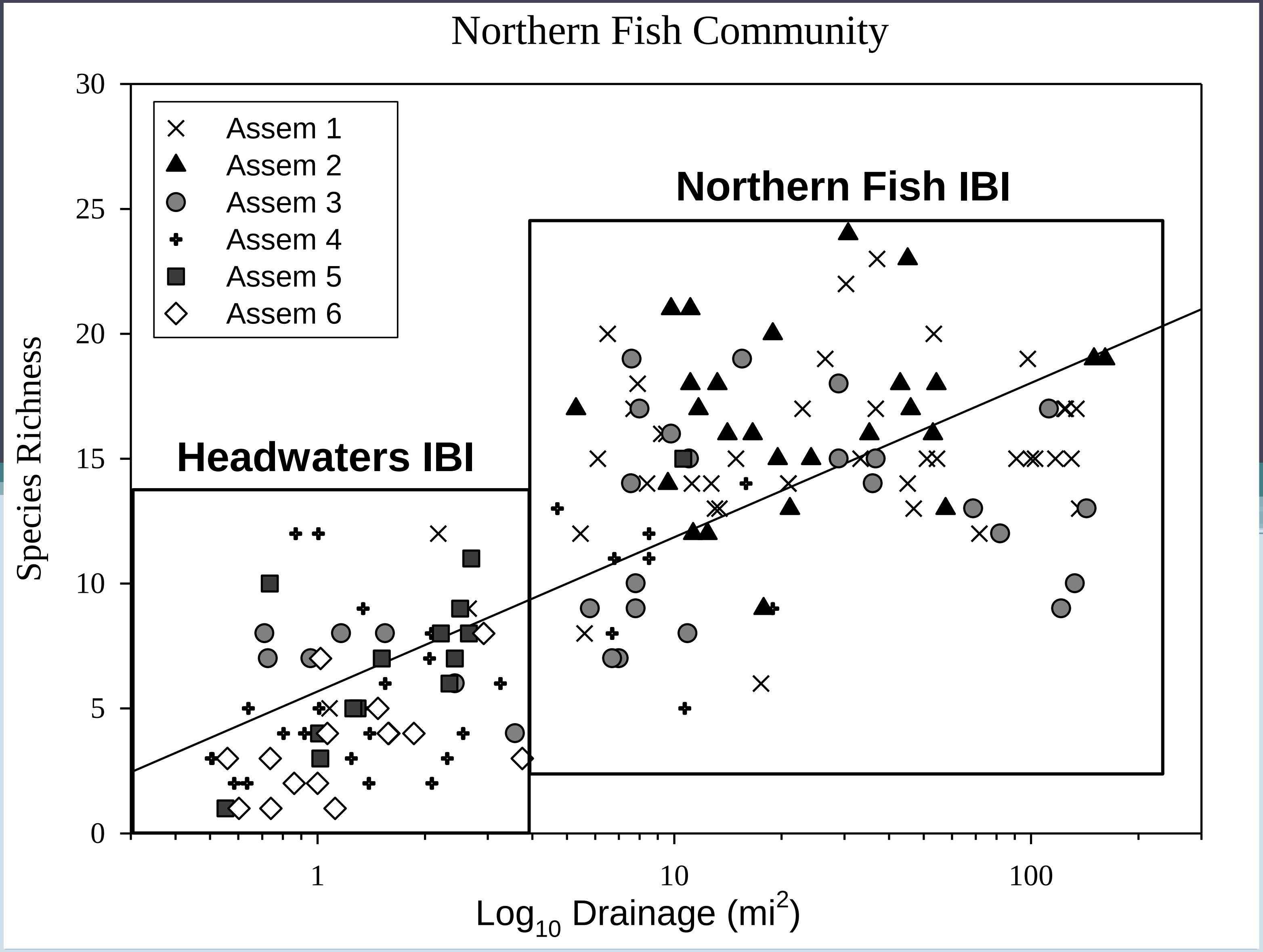


Cluster Analysis
Distance (Objective Function)
0
1.1E+01
2.2E+01
3.3E+01
4.4E+01
Information Remaining (%)
100
75
50
25
0
1 Warmwater
2 Warmwater
3 Coolwater
4 Coldwater
5 Wetland
6 Coldwater

Fish Assemblages

1. *Redbreast Sunfish, *Tessellated Darter, *Green Sunfish, Rock Bass, Spottail Shiner, Yellow Bullhead, Bluegill, Banded Killifish, Redfin Pickerel
2. *Longnose Dace, *Fallfish, *Margined Madtom, *Smallmouth Bass, *White Sucker, Shield Darter, American Brook Lamprey, Largemouth Bass
3. *Brown Trout, Cutlips Minnow, American Eel
4. *Blacknose Dace, *Creek Chub
5. *Creek Chubsucker, *Eastern Mudminnow, *Brown Bullhead, *Golden Shiner, Chain Pickerel, Pumpkinseed
6. *Brook Trout, Slimy Sculpin

Coldwater vs Cool/Warmwater



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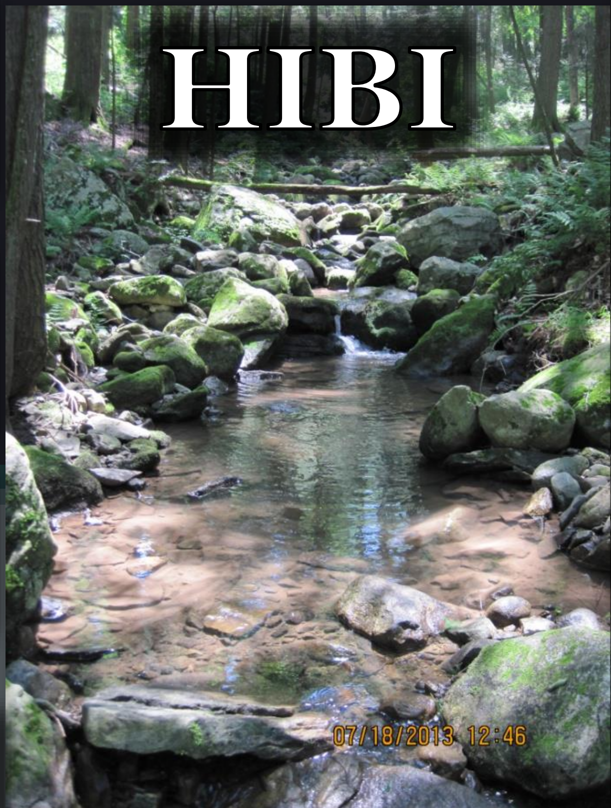

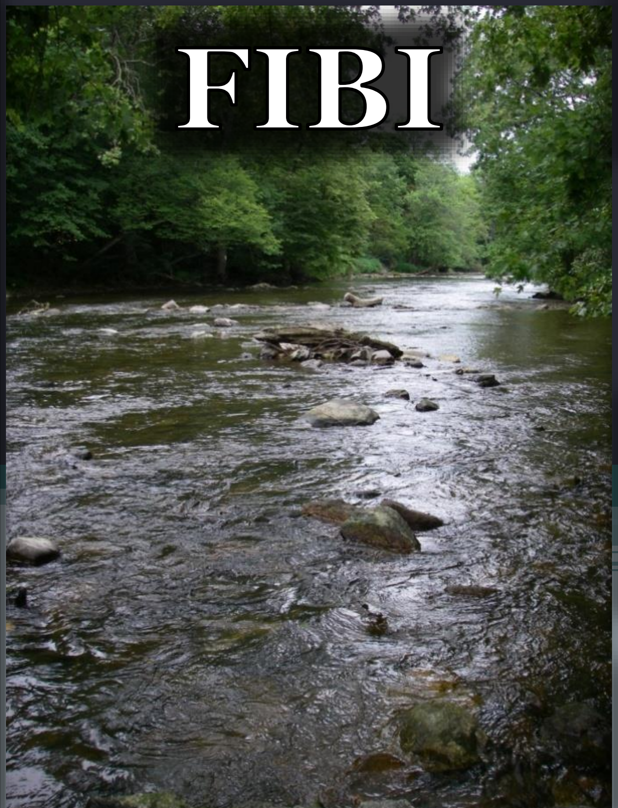

DEPARTMENT OF ENVIRONMENTAL PROTECTION NEW JERSEY

John Vile and Brian Henning
Water Monitoring & Standards
Bureau of Freshwater and Biological Monitoring

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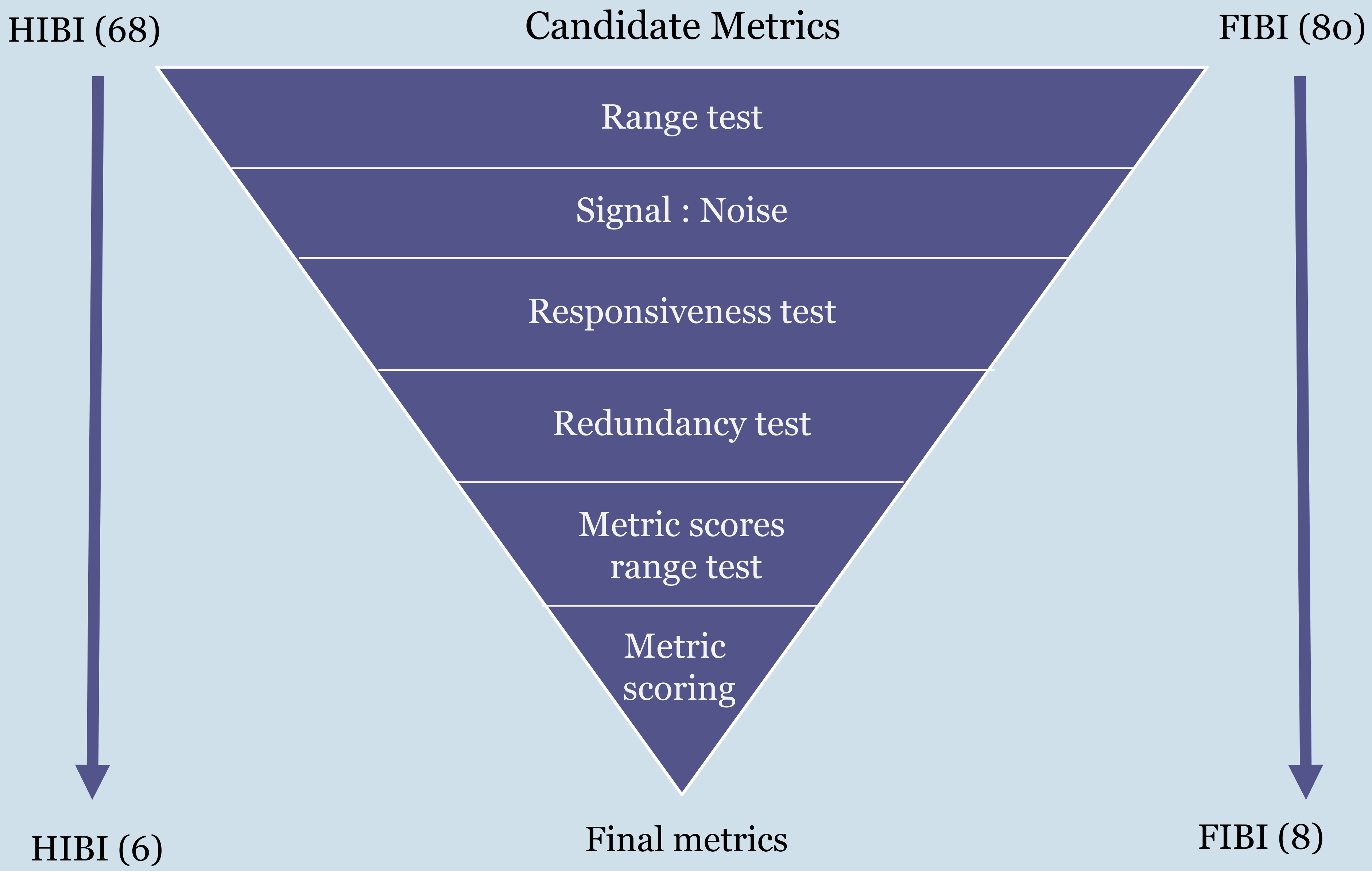
NJ Metric Evaluation Process



NJ Metric Evaluation Process

1. Range Test
    - Eliminated metrics with < 4 species (Richness metrics only)
    - Eliminated metrics with >75% zero values or identical values
2. Signal to noise - ratio of variance among sites (signal) to the variance of repeated visits to the same site (noise)
    - Eliminated metrics with S:N values less than 3
3. Correlation with natural gradients (drainage size, gradient)
    - Metrics with R^2 >.25 were adjusted
    - Predicted value = $m*\log_{10}$(drainage area)+b
    - Adjusted value = mean of reference + observed- predicted
4. Responsiveness test
    - Correlation coefficients with land use, habitat, water chemistry variables
    - One-way ANOVA (Least Impaired vs. Most Impaired) 3 disturbance categories (LU/habitat)
    - Highest F-statistic in each class used as the primary criteria for selecting the strongest metric within each ecological class
5. Redundancy
    - Correlation coefficients of $r = |0.75|$ was used as a cut-off for metric elimination
6. Range test for metric scores
    - Produced boxplots of Least Impaired vs. Most Impaired
7. Metric scoring and evaluation
    - Scored metrics scaled to range from 0-100 (continuous scoring)

Metric Testing

Metric	Signal/ Noise	Range	Max Identical Values	% Zero Values	Correlation w/ Pop Density n=114	Correlation w/ Forest n=127	Correlation w/ IC n=125	Correlation w/ Habitat n=127	F-Statisitic
Taxonomic Richness									
Richness	3.38	3-24	11%	0.0%	-0.35	0.03	-0.25	0.07	
Non-Native Sp	2.82	0-8	25%	0.8%	-0.28	0.09	-0.20	0.07	
Adj Non-Native Sp					-0.21	-0.01	-0.13	0.01	
Native Sp	3.00	2-20	14%	0.0%	-0.29	-0.01	-0.22	0.05	
Coldwater Sp	11.12	0-4	53%	53.0%	-0.31	0.40	-0.35	0.45	
Coolwater Sp	5.83	0-13	20%	0.8%	-0.58	0.32	-0.58	0.49	
Adj Coolwater Sp					-0.53	0.24	-0.53	0.46	21.94
Warmwater Sp	3.53	0-15	16%	0.8%	0.06	-0.32	0.18	-0.39	
Top Carnivore Sp	2.68	0-7	28%	1.6%	-0.42	0.31	-0.40	0.33	
Generalist Sp	2.97	2-12	21%	0.0%	0.13	-0.37	0.24	-0.44	
Benthic Insectivore Sp	5.87	0-6	30%	2.4%	-0.53	0.31	-0.52	0.46	
Intolerant Sp	14.43	0-6	29%	28.6%	-0.45	0.43	-0.50	0.57	35.98
Tolerant Sp	6.02	1-8	24%	0.0%	0.38	-0.61	0.48	-0.52	41.47
Intermediate Tolerant Sp	2.98	0-17	14%	0.8%	-0.37	0.10	-0.29	0.05	
Rheophilic Sp	7.94	0-7	27%	0.8%	-0.47	0.31	-0.46	0.55	29.16
Rheo-Bdace/Tdart Sp	7.36	0-5	31%	27.6%	-0.40	0.31	-0.40	0.56	31.04
Lithophilic Sp.	6.17	0-12	15%	0.8%	-0.57	0.42	-0.60	0.52	43.99
Native Lithophilic Sp.	3.36	0-9	28%	0.8%	-0.53	0.34	-0.53	0.48	33.36

Metrics failing for tests were eliminated

Final Selection

Metric	Correlation w/ Pop Density n=127	Correlation w/ Forest n=137	Correlation w/ IC n=137	Correlation w/ Habitat n=137	Ref Correlation w/ Drainage n=23	F Statistic	DE
Taxonomic Richness							
Intolerant Sp	-0.44	0.46	-0.50	0.57	0.10	35.6	90.5%
Rheo-Tdart Sp	-0.39	0.36	-0.41	0.56	0.19	39.7	76.2%
Rheo-Tdart % Rich	-0.35	0.46	-0.42	0.62	0.00	**45.9**	100 %
Rheo-Bdace/Tdart Sp	-0.37	0.33	-0.37	0.53	-0.12	37.1	76.2%
Thermal							
Adj%Coolwater Sp	-0.53	0.27	-0.51	0.46	-0.04	18.0	66.7%
Adj%NonTolerant Coolwater Sp	-0.48	0.46	-0.49	0.51	0.00	33.6	76.2%
Adj%Cold/NonTolerant Coolwater Sp	-0.50	0.51	-0.52	0.57	0.00	**43.6**	80.0%
Adj %Warmwater Sp	0.48	-0.44	0.49	-0.49	0.00	24.2	71.4%
Trophic							
Generalist % of Richness	0.69	-0.53	0.68	-0.61	-0.42	**56.2**	88.0%
%NonTolerant Generalist Sp	-0.35	0.35	-0.37	0.37	-0.35	27.3	85.7%
Tolerance							
%Tolerant Sp	0.56	-0.50	0.52	-0.51	0.34	32.0	81.0%
Tolerance Index	0.54	-0.54	0.53	-0.58		**56.4**	92.0%
Intolerant % of Richness	-0.46	0.54	-0.54	0.62		45.6	96.0%
Stream Flow							
%Lithophils-Wsucker	-0.44	0.48	-0.51	0.59	-0.48	**68.4**	96%
Non-native							
%Nonnative Top Carnivore Sp	-0.19	0.21	-0.19	0.23	0.25	5.8	66.7%
Composition							
%Dominant 3-Bdace	0.47	-0.32	0.44	-0.46	0.30	**33.7**	88%
Adj%Cyprinid	-0.49	0.51	-0.54	0.56	0.00	**62.0**	88%
Habitat							
Benthic Insectivore Sp	-0.52	0.38	-0.54	0.48	0.26	30.6	66.7%
Benthic Insectivore %Richness	-0.50	0.46	-0.54	0.52	0.24	**50.3**	96.0%
Benthic Insectivore Sp-TD	-0.58	0.41	-0.54	0.51	0.16	35.4	66.7%
NatNonTolBenthic Sp	-0.52	0.42	-0.56	0.55	0.11	37.9	76.2%
NatNonTolBenthic Sp-TD	-0.49	0.44	-0.55	0.58	0.02	42.4	76.2%

High Gradient Fish IBI Metrics

Metric	Ecological Class	Response to stress	S:N	F Statistic	% DE
%Rheophilic Species-Tessellated Darter (drainage corrected)[a]	Taxonomic Richness	Decrease	12.52	99.5	100
%Cold/NonTolerant Coolwater Species (drainage corrected)[b]	Thermal	Decrease	12.07	43.6	80
%Generalist Species[a]	Trophic	Increase	6.49	56.2	88
Tolerance Index	Tolerance	Increase	16.38	56.4**	92
% Lithophilic Species-White Sucker[a]	Reproduction	Decrease	13.19	68.55+	96
% Cyprinidae (drainage corrected)[b]	Composition	Decrease	11.29	62.0	88
% Top 3 Dominant Species-Blacknose Dace[b]	Composition	Increase	7.50	33.7	88
% Benthic Insectivore Species[a]	Habitat	Decrease	15.95*	50.3	96

[a]Proportion of Species

[b]Proportion of Individuals

*Log_{10} +1 transformation

**Log_{10} transformation

+Arcsin square root transformation

Discrimination efficiency (DE) is the capacity of the biological metric or index to detect stressed conditions. It is measured as the percentage of stressed sites that have values lower than the 25th percentile of reference values (Stribling et al. 2000).

Headwaters IBI Metrics

Metric	Ecological Class	Response to stress	S:N	F statistic	% DE
Intolerant Vertebrate Richness	Taxonomic Richness	Decrease	14.3	38.8	95
Proportion of Vertebrate Richness as Top Carnivore	Trophic	Decrease	17.8	25.0	79
% Tolerant Fish Individuals	Tolerance	Increase	31.2	31.0	89
Proportion of Total Richness as Native	Non-Native	Decrease	3.1	30.4	89
% Native Crayfish	Composition	Decrease	3.2	43.1	100
Brook Trout Density (individuals/100m^2)	Indicator Species	Decrease	1.6	7.1	*

*The 25th percentile for least disturbed sites was 0.00 for metric

IBI Metric Scoring

Metrics which **decrease with an increase in stress**:

Score = 100 x Metric Value/95th Percentile*

Example: Intolerant Vertebrate Richness = (Metric ÷ 3) x 100

*least & most impaired data

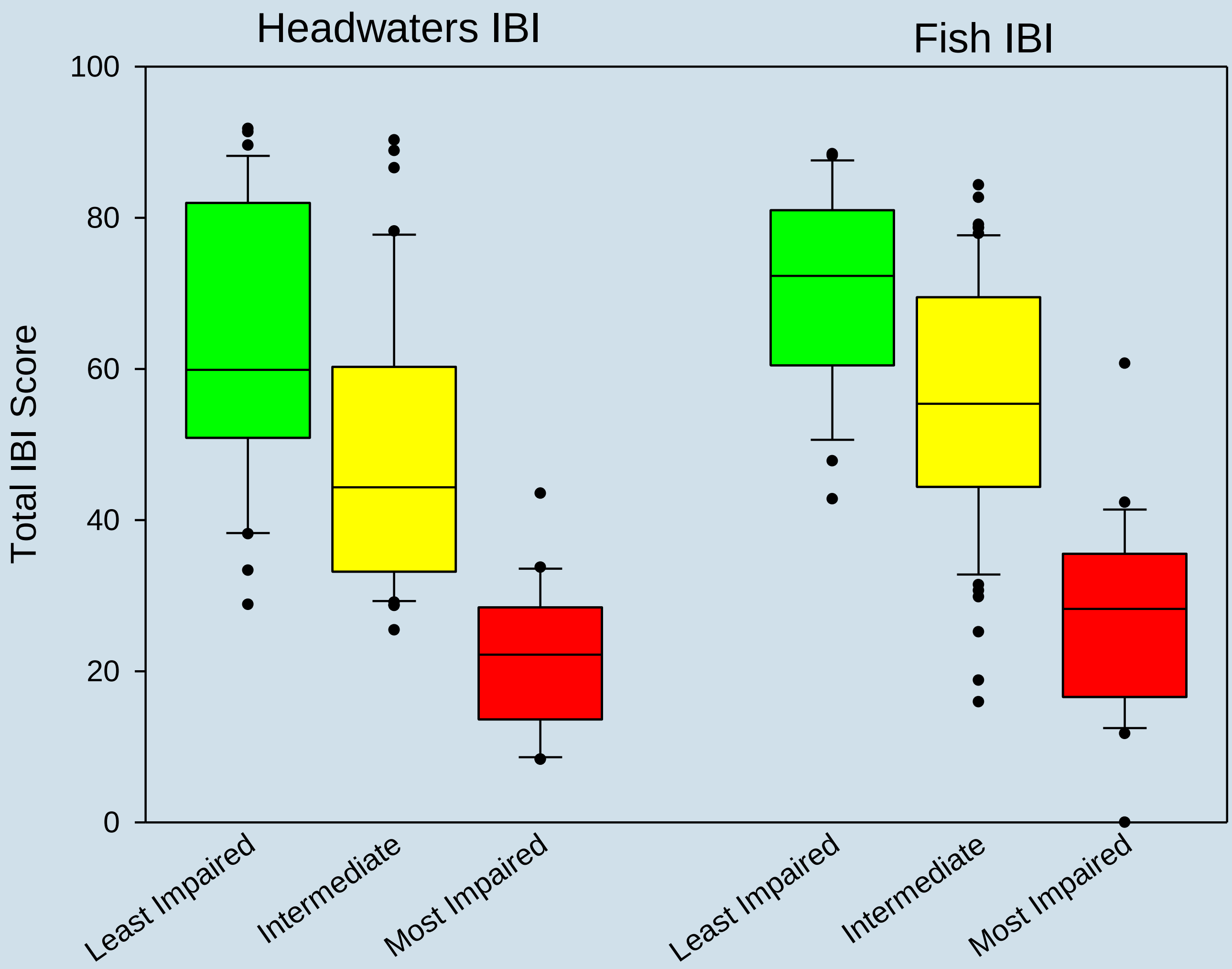
Metrics which **increase with an increase in stressor levels** were scored using the 5th percentile of least impaired as the upper limit using the formula:

Score = 100 x (95th Percentile – Metric Value)/(95th Percentile – 5th Percentile).

Example: % Tolerant Fish Individuals = (96.1- Metric)/ (96.1- 0) x 100

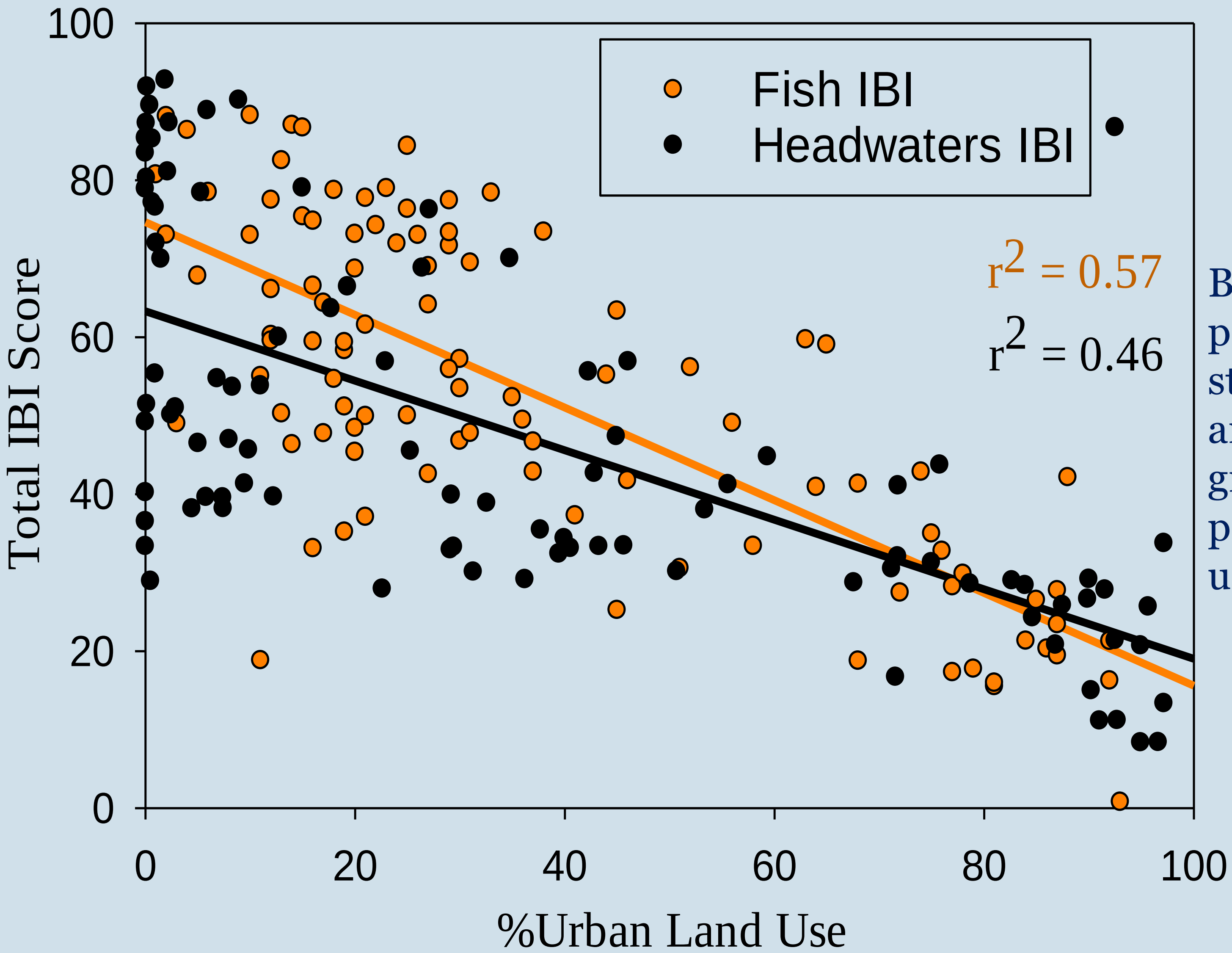
The total index score is derived from averaging all individual metric scores.

Final Headwater IBI and Fish IBI score for each disturbance gradient



Overall mean HIBI and FIBI scores for most impaired and least impaired sites were significantly different (ANOVA, $p \leq 0.001$)

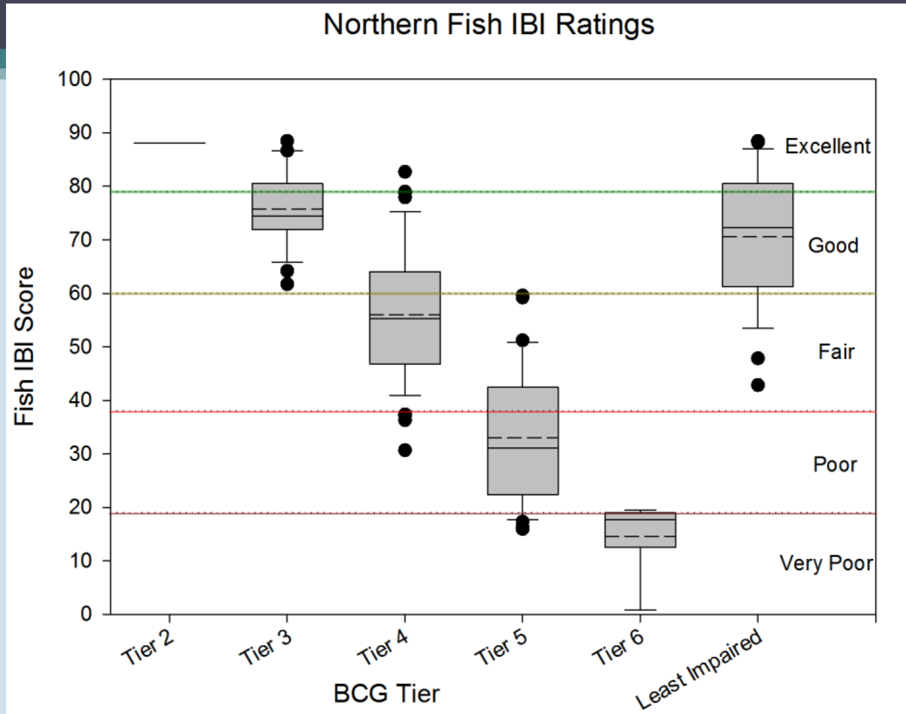
FIBI and HIBI relationship with urban landuse



Both IBI's responded positively to general stressor indicators and land use gradients, such as percent urban land use

FIBI Ratings

Assessment Rating	NIBI Score
Excellent	100-79
Good	78-60
Fair	59-38
Poor	37-19
Very poor	18-0



UB 95% CI Tier 3

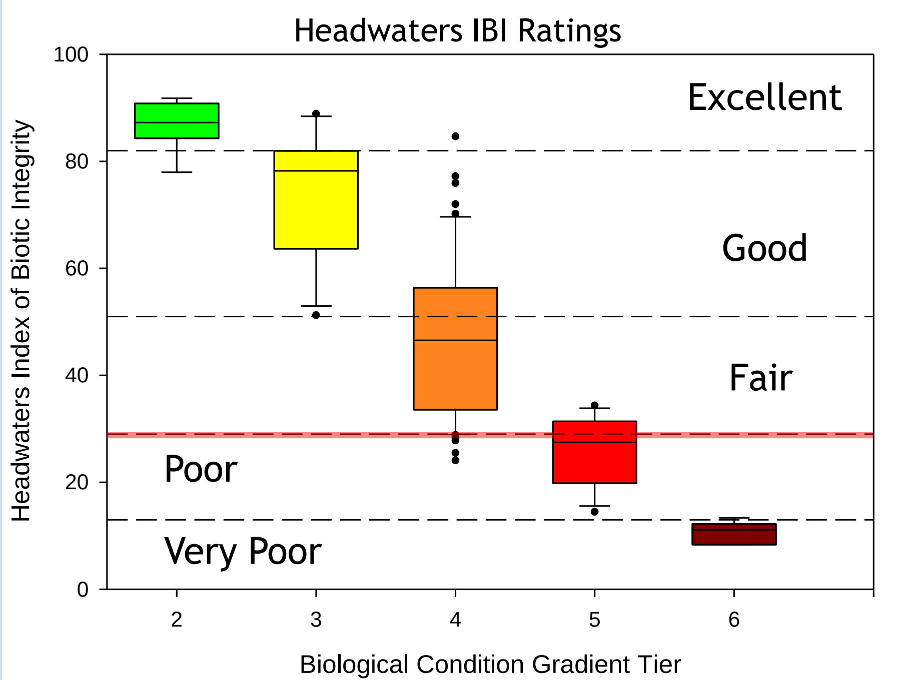
UB 95% CI Tier 4

UB 95% CI Tier 5

UB 95% CI Tier 6

HIBI Ratings

Assessment Rating	HIBI Score
Excellent	82-100
Good	51-81
Fair	29-50
Poor	13-28
Very poor	0-12



UB 95% CI Tier 3

UB 95% CI Tier 4

UB 95% CI Tier 5

UB 95% CI Tier 6

Summary

- A new northern Fish IBI for larger wadeable streams was developed which is more sensitive and responsive to anthropogenic stressors

- A new Headwaters IBI was developed to assess smaller order streams that are often low in fish richness and therefore cannot be accurately assessed solely with a fish based IBI

- All wadeable (non tidal) freshwater steams north of the fall line can now be assessed for aquatic life use

Article submission

Development of indices of biotic integrity for high-gradient wadeable rivers and headwater streams in New Jersey

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- Currently under peer review


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