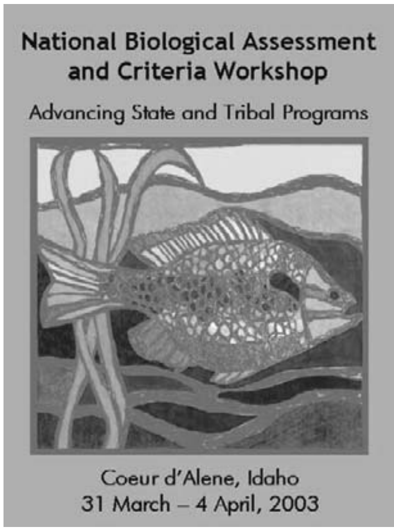
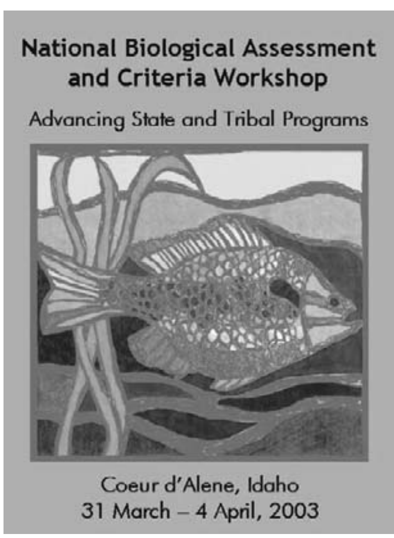


Index 101

BIOLOGICAL INDEX DEVELOPMENT METHOD: BASIC CONCEPTS

Course Presenters and Contributors
Jeroen Gerritsen, Michael Paul, Mick Micacchion, Russ Frydenborg, Chuck Hawkins, Rick Hafele, Tom Danielson, Dave Courtemanch, and Susan Cormier



Index 101

Biological Index Uses, Types, and Development

Presented by
Mick Micacchion,
Ohio EPA

Index 101 Course Outline

1. Overview of uses, types and development of indices
2. Steps in developing a multimetric index and Example from Florida
3. Steps in developing a multivariate predictive model (RIVPACS) index and Example from Oregon
4. Maine's approach to developing and using a biological index

Introduction to Index 101

- Regulatory basis of indices
- Why are indices used
- What do indices represent
- What data are needed
- What types of indices are there

Why Use Biological Indices?

- Clean Water Act Section 101(a) Purpose:

  - "To restore and maintain the chemical, physical and <u>biological integrity</u> of the Nation's waters."

Biological Integrity: Operational Definition

"The ability of an aquatic community to support and maintain a structural and functional performance comparable to the natural habits of a region."

As modified from Karr and Dudley (1981)

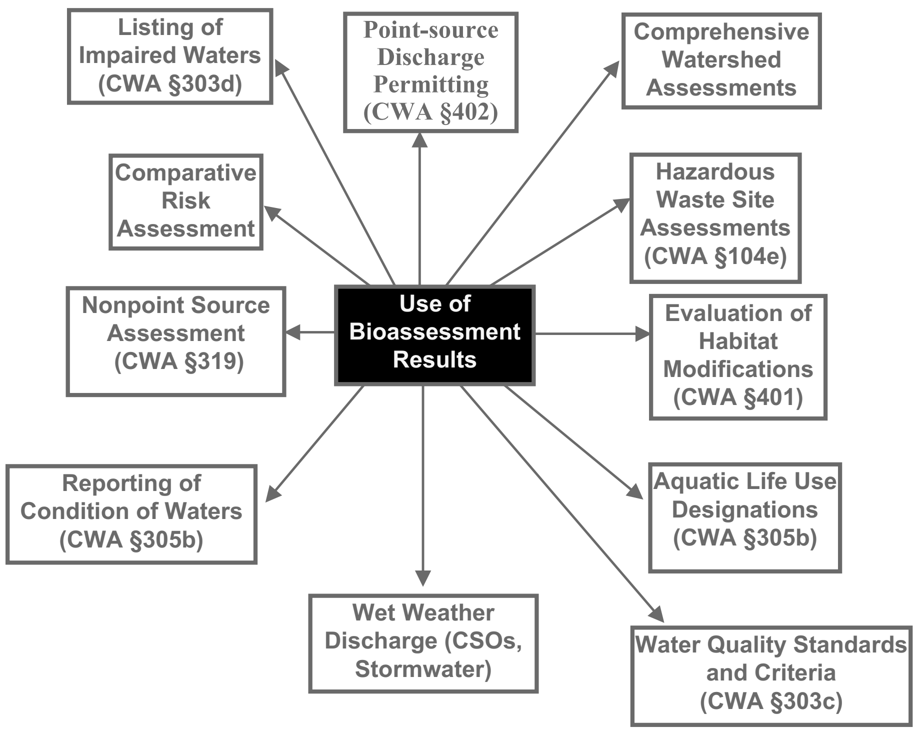
Water Quality Standards and the Use of Biological Indices

- Beneficial Use Designations
  - Aquatic Life Uses
- Numeric Criteria
  - Biological Criteria
- Narrative Criteria
  - Protection of aquatic life
- Antidegradation

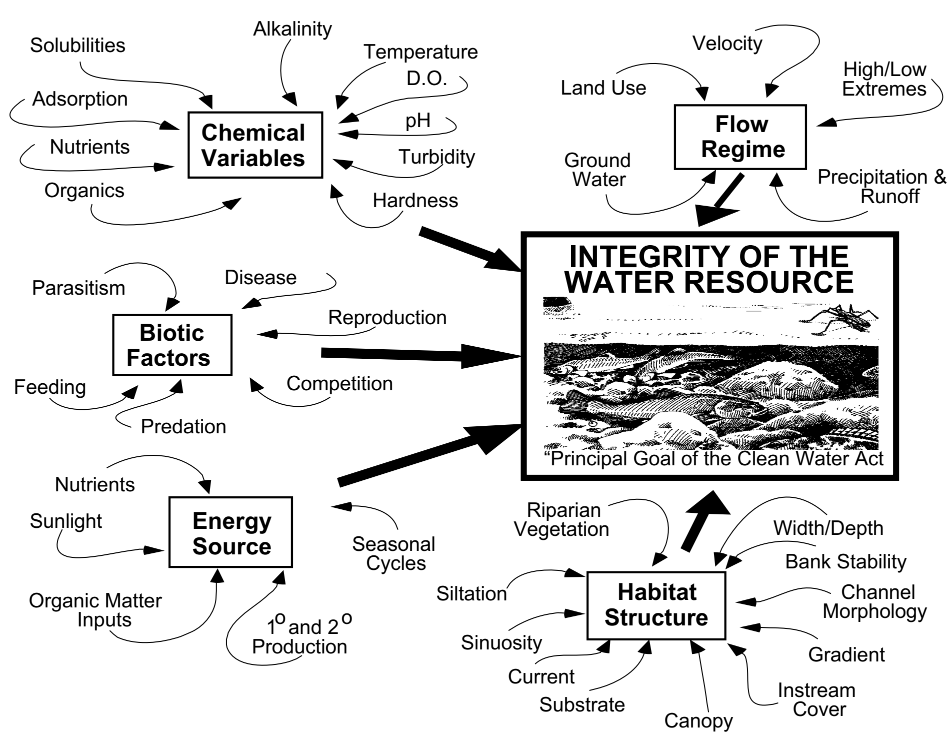
Use of Biological Indices for Other CWA Programs

- 305(b)
  - Water Body Condition Reports
- 303(d)
  - Impaired Waters Listings
- TMDL Process

Some Program Objectives



The Five Major Factors that Determine the Integrity of Aquatic Resources



Why Use Taxonomic Assemblages as Indicators ?

- Bioassessment provides indications of cumulative impacts of multiple stressors, not just chemical water quality.
- Biological community integrates past chemical, physical and biological events, both short- and long-term and directly evaluates the condition of the water resource.
- Properly developed methods, measures and reference conditions provide a tool that enables a direct reporting of the ecological condition of a water body.

Symptoms of Ecological Degradation

A Partial List:

- Reduced populations of native species.
- Fewer size (age) classes.
- Reduced number of intolerant species.
- Increased proportion of exotic species.
- Reduced proportion of ecological specialists.
- Simplified trophic web and interactions.
- Increased incidence of serious disease & anomalies.

Important Considerations for Biological Indices

- The measures used must be biological
- The measures must be interpretable at or extend to multiple trophic levels
- The measures must be sensitive to the condition being assessed
- The response range must be suitable for intended uses
- The measure must be reproducible and sufficiently precise
- The variability of the measures must be low enough to detect and quantify changes

Basic Premises of Biological Indices

- Least impacted biological systems have distinctive structural and functional attributes.
- Some attributes can be measured in the field and aggregated into an index.
- Departure of index scores from a reference condition is correlated with the degree (severity) of a perturbation.
- An index that measures many intrarelated factors of ecosystem structure and function best reflects the overall integrity of the community.

Important Steps in Biological Index Development

- Classify ecotypes - streams, rivers, lakes, wetlands, cold & warm water, etc.
- Develop cost-effective and reproducible sampling methods.
- Test and evaluate to select reliable and relevant measures
- Define analytical procedures to extract and display results on different spatial and temporal scales.
- Communicate results to different users and audiences.

Different Types of Indices

- Multimetric (IBI)
- Multivariate Predictive (RIVPACS)
- Others

Multimetrics (IBI)

Multimetrics (IBI)

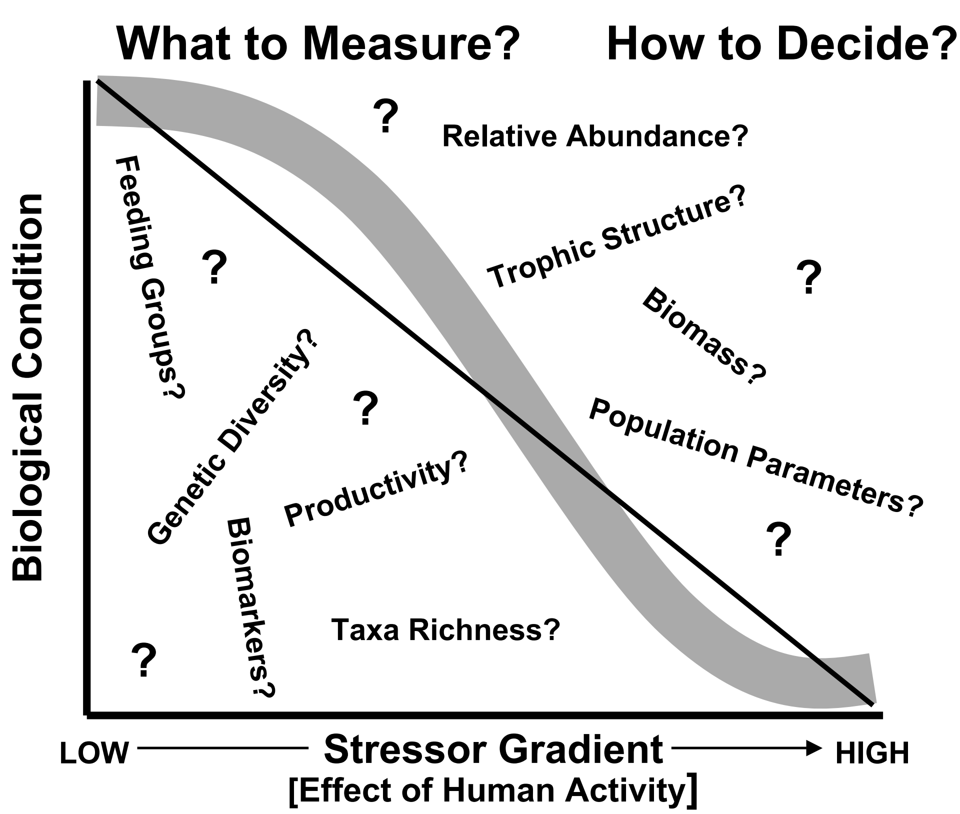
- Developed in 1980s
- Improvement on original single metrics (e.g. Hilsenhoff alone)
- Idea is to incorporate several attributes (metrics) reflecting 'biological integrity' into one synthetic multimetric score

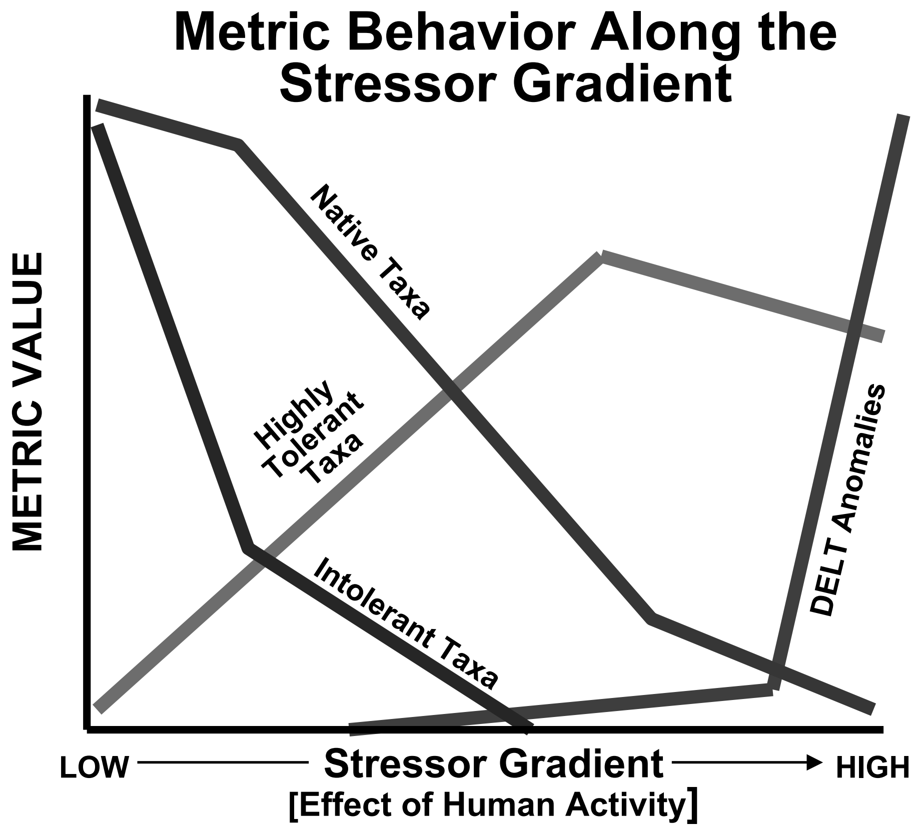
Multimetrics (IBI)

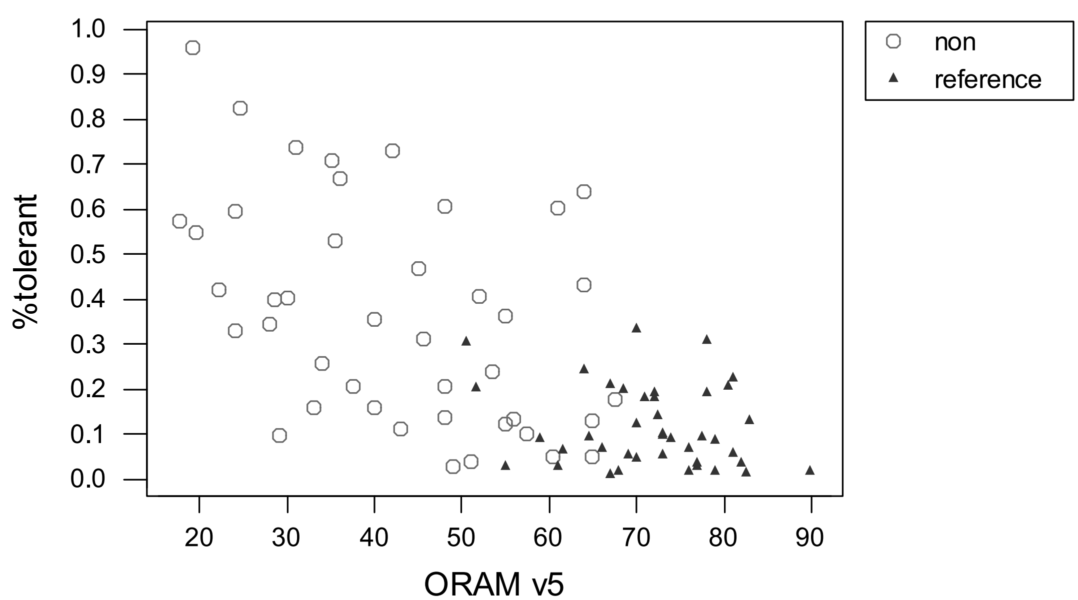
Definition

- A metric is a characteristic (attribute) of the biota that changes in some predictable way with increases in human disturbance

March 31 – April 4, 2003 National Biological Assessment and Criteria Workshop, INDEX 101_01




Metric Behavior Along the
Stressor Gradient
METRIC VALUE
Native Taxa
Highly
Tolerant
Taxa
Intolerant Taxa
DELT Anomalies
LOW
Stressor Gradient
HIGH
[Effect of Human Activity]


1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
%tolerant
20
30
40
50
60
70
80
90
ORAM v5
non
reference

Index of Biotic Integrity (Karr 1981)

12 Metrics

- Species richness
- #Darter species
- #Sunfish species
- #Sucker species
- %Intolerant species
- %Green sunfish
- %Omnivores
- %Insectivores
- %Top Carnivores
- %Hybrids
- %Diseased individuals
- Number of Fish

Community Composition

Environmental Tolerance

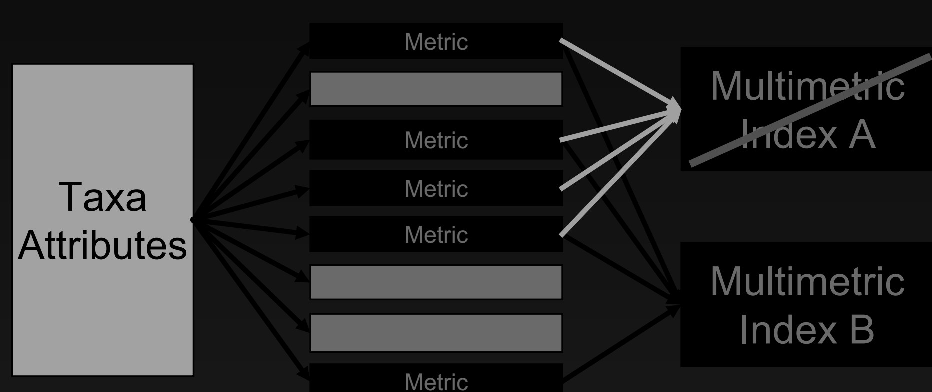
Community Function

Community Condition

- 5,3,1 metric scoring categories.
- 12 to 60 scoring range.
- Calibrated on a regional basis.
- Scoring adjust-ments needed for very low numbers.

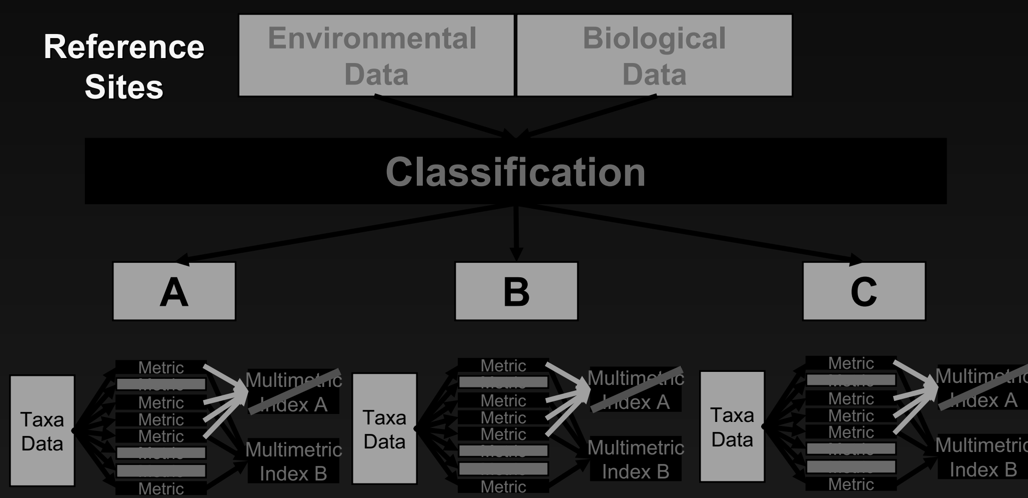
Multimetrics (IBI)

- Reference and degraded sites used to select metrics that discriminate
- Also used to test final multimetric combinations that discriminate



Multimetrics (IBI)

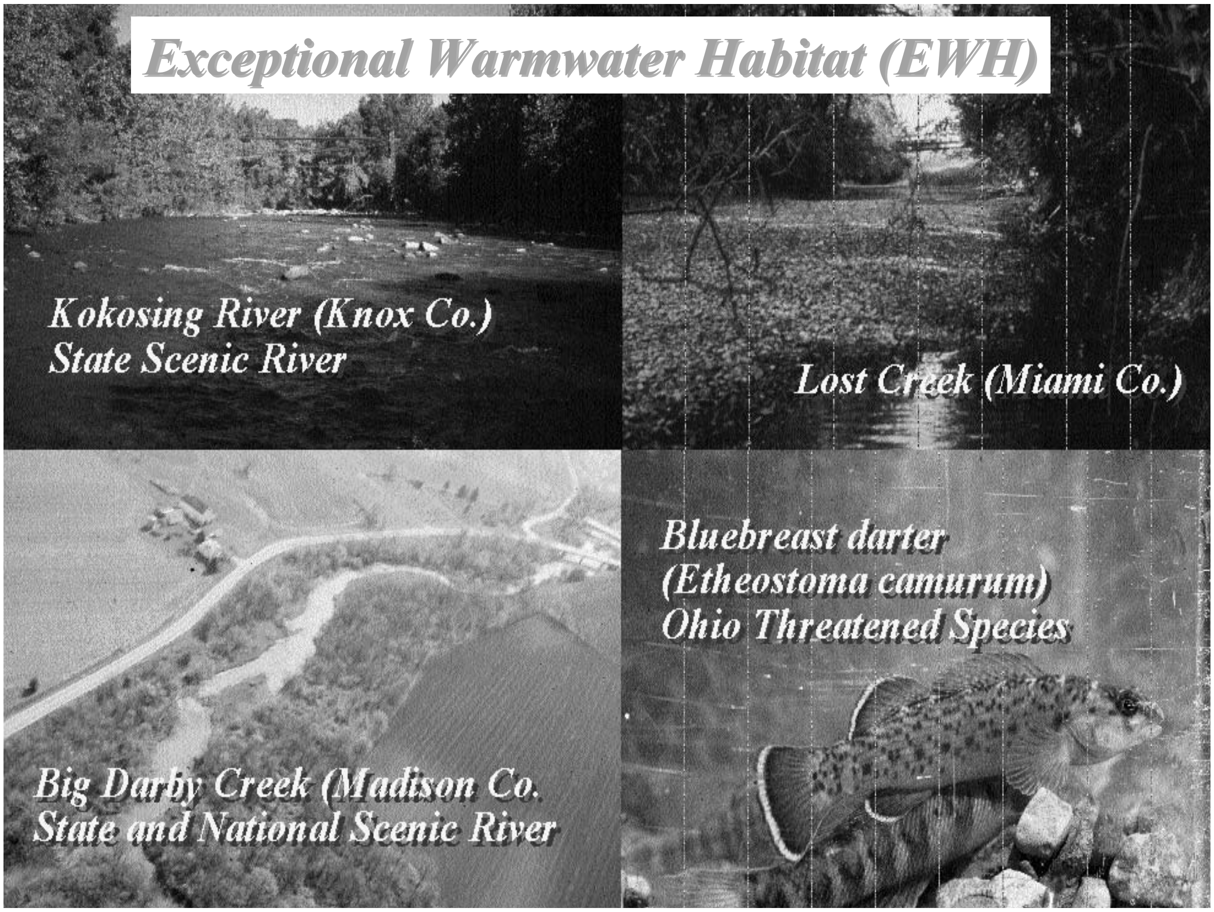
- Classification used to separate reference sites into similar biogeographic groups
- IBIs built for individual classes or groups of similar classes

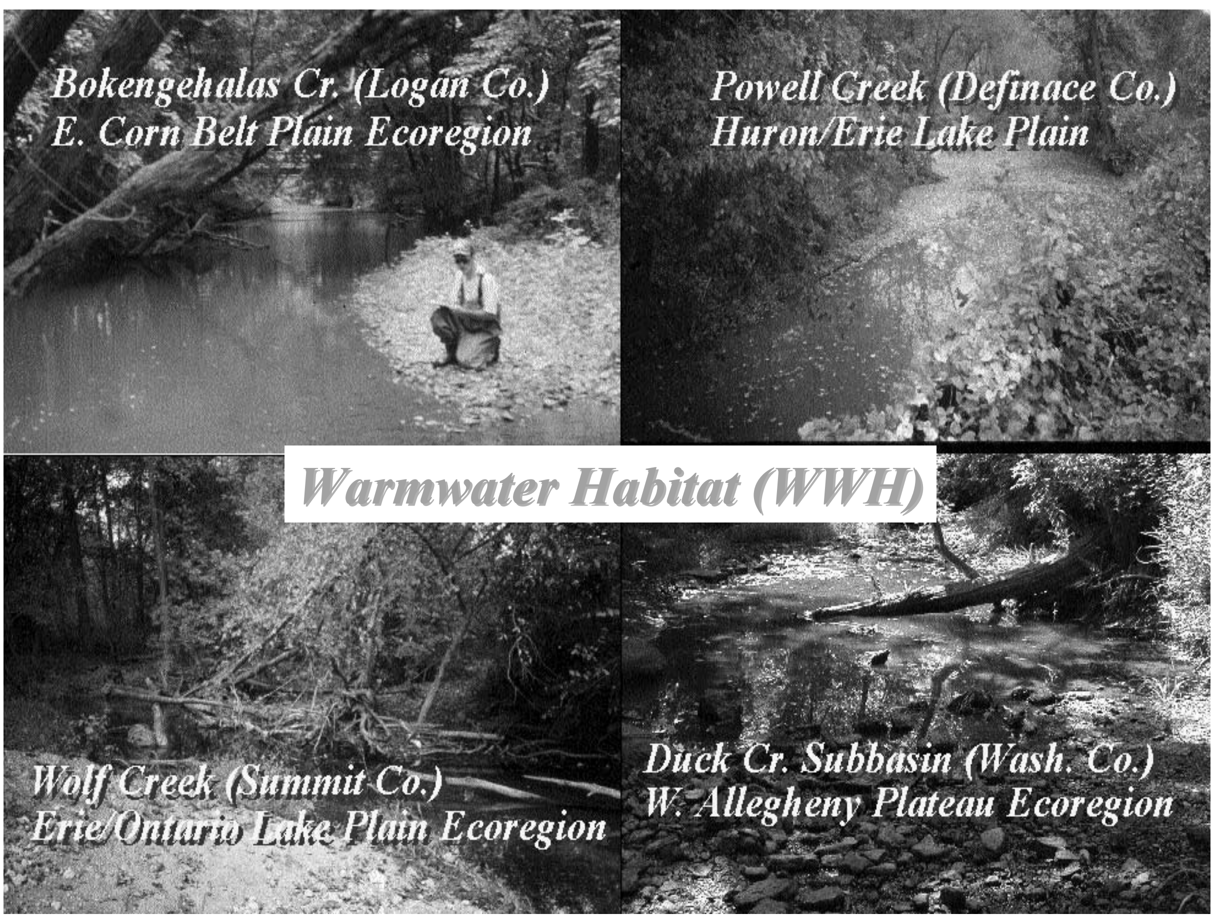


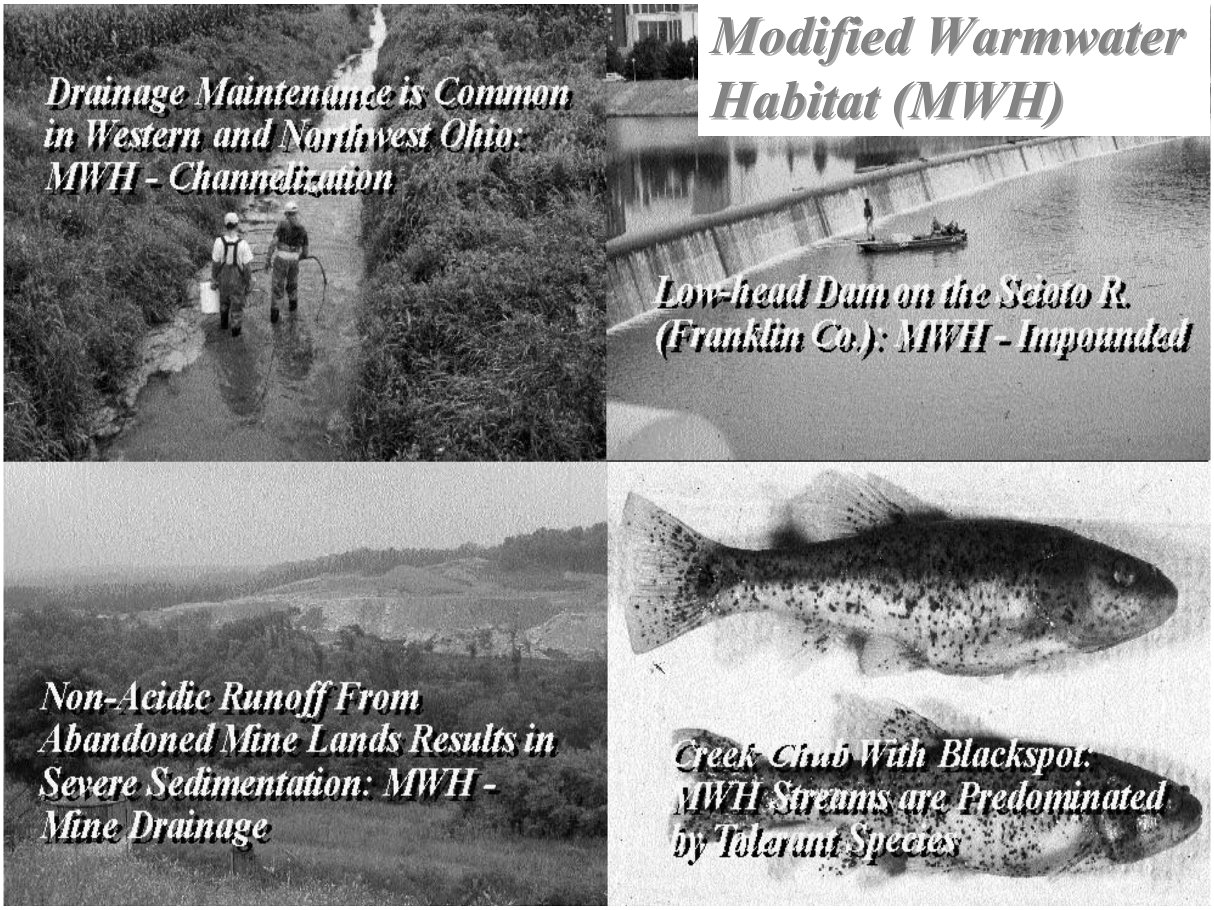
Aquatic Life Use Designations Ohio WQS

Based on Biological Community Attributes

- Exceptional Warmwater Habitat (EWH): Preserve & maintain existing HQ
- Warmwater Habitat (WWH): basic restoration goal for most streams
- Modified Warmwater Habitat (MWH): attainable condition for streams under drainage maintenance or other essentially permanent hydromodifications (e.g. dams)
- Limited Resource Waters (LRW): essentially irretrievable, human induced (e.g. widespread watershed modifications) or naturally occurring conditions (e.g. ephemeral flow)


Exceptional Warmwater Habitat (EWH)
Kokosing River (Knox Co.)
State Scenic River
Lost Creek (Miami Co.)
Big Darby Creek (Madison Co.
State and National Scenic River
Bluebreast darter
(Etheostoma camurum)
Ohio Threatened Species


Bokengehalas Cr. (Logan Co.)
E. Corn Belt Plain Ecoregion
Powell Creek (Definace Co.)
Huron/Erie Lake Plain
Warmwater Habitat (WWH)
Wolf Creek (Summit Co.)
Erie/Ontario Lake Plain Ecoregion
Duck Cr. Subbasin (Wash. Co.)
W. Allegheny Plateau Ecoregion

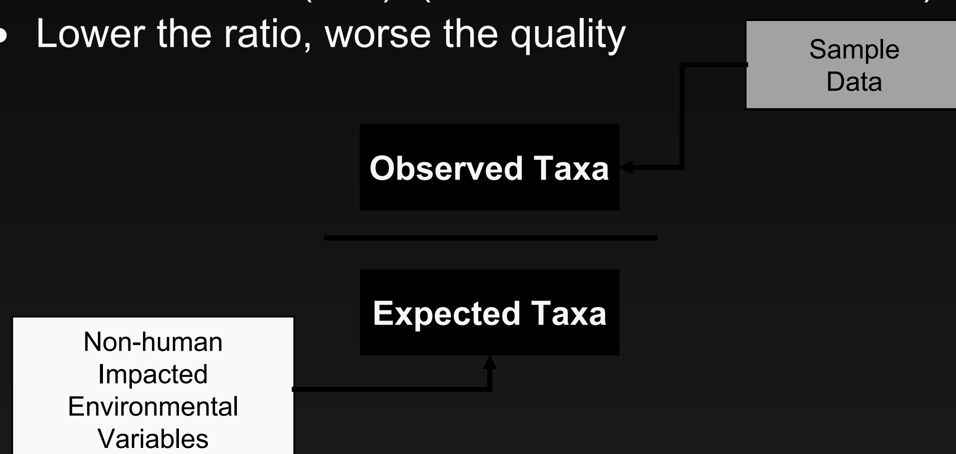

Modified Warmwater Habitat (MWH)
Drainage Maintenance is Common in Western and Northwest Ohio: MWH - Channelization
Low-head Dam on the Scioto R. (Franklin Co.): MWH - Impounded
Non-Acidic Runoff From Abandoned Mine Lands Results in Severe Sedimentation: MWH - Mine Drainage
Creek Chub With Blackspot: MWH Streams are Predominated by Tolerant Species


E. Fk. Duck Cr. - Hamilton Co.; LRW - Small Drainageway Maintenance
Hurford Run - Stark Co.; LRW - Small Drainageway Maintenance
Limited Resource Waters (LRW)
Cuyahoga River Navigation Channel; Cuyahoga Co. LRW - Other
Moxahala Cr. - Perry Co.; LRW - Acid Mine Drainage

Multivariate Predictive (RIVPACS)

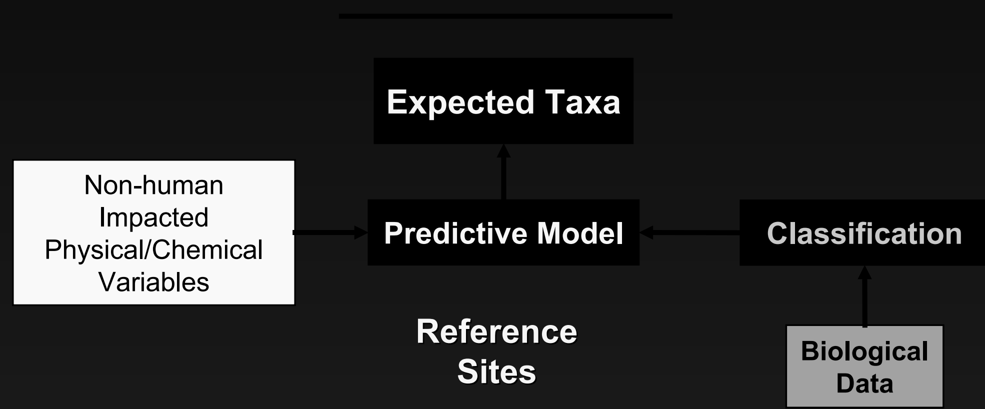
Multivariate Predictive (RIVPACS)

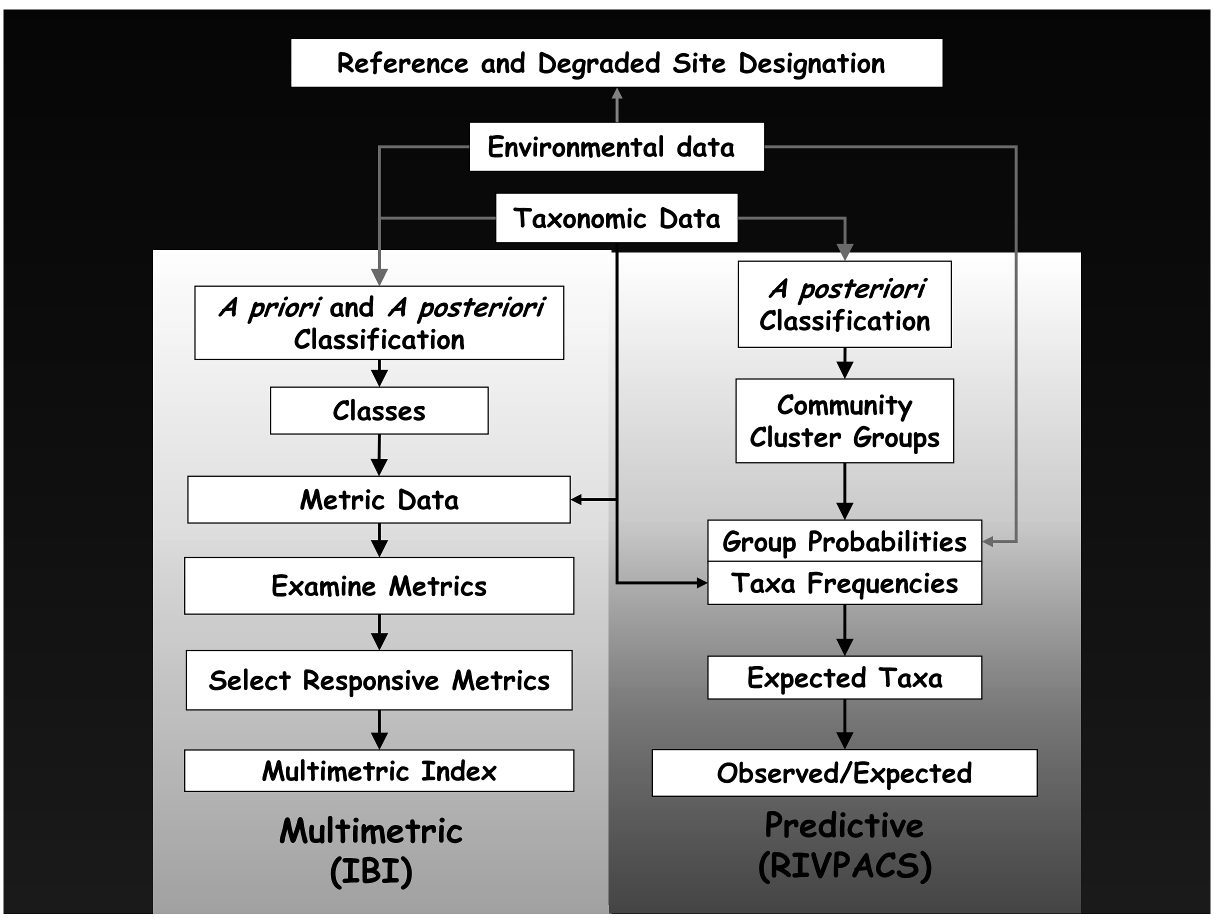
- Developed in late 1980s-1990s (RIVPACS)
- Started as a method for classifying unpolluted streams
- Predict the expected taxa at a site and compare to observed taxa (O/E) (1.00 = Reference Condition)
- Lower the ratio, worse the quality



Multivariate Predictive (RIVPACS)

- Reference sites used to build model for predicting expected taxa
- Classification used to approximate continuous gradient
- Results in a predicted “reference” for each test site = expected taxa



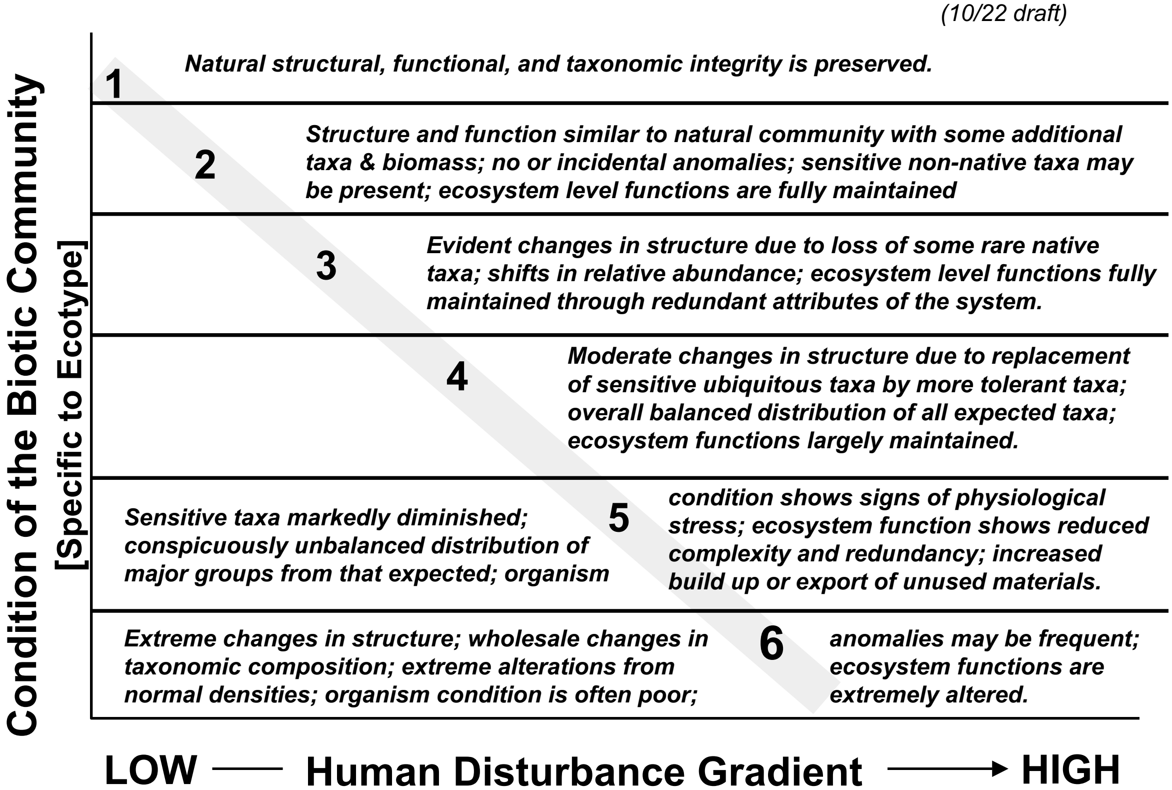


Other Biological Indices

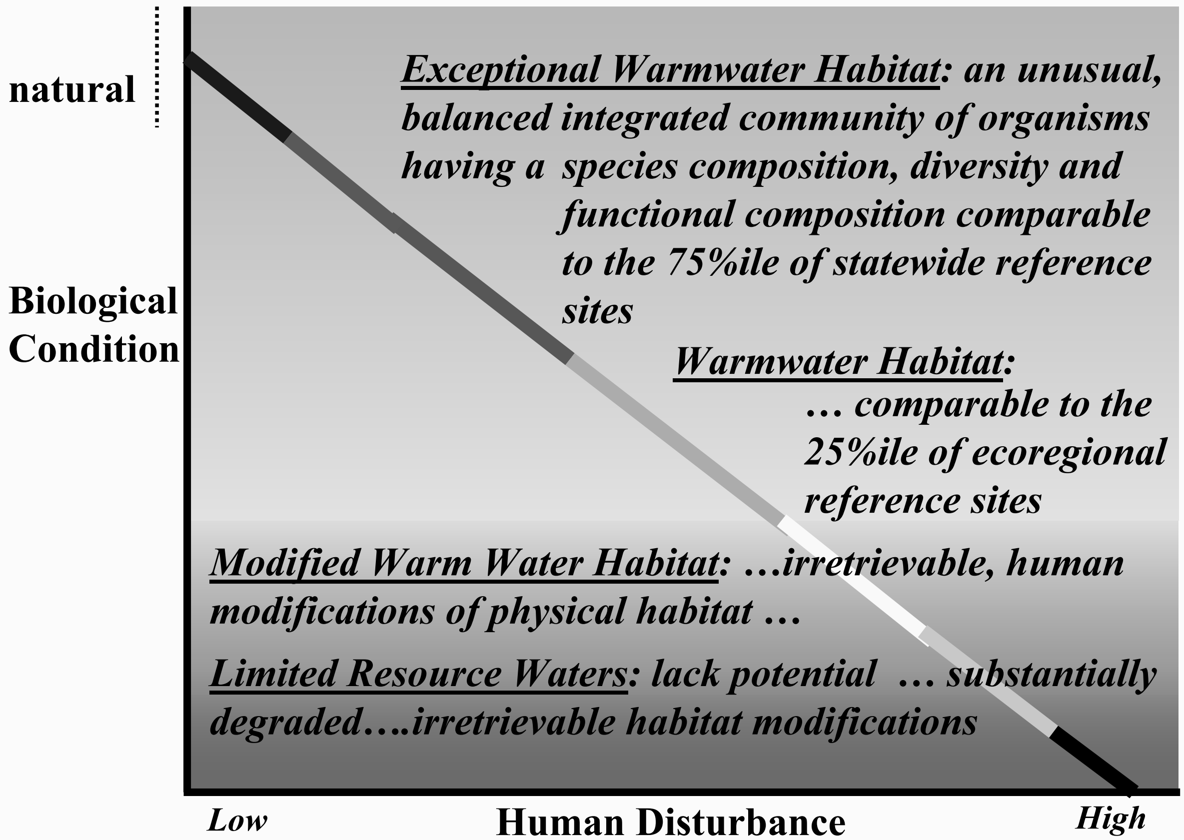
- Maine Approach
- Floristic Quality Assessment Index
- Amphibian Quality Assessment Index
- Hilsenhoff Index
- Many Others (Got any ideas?)

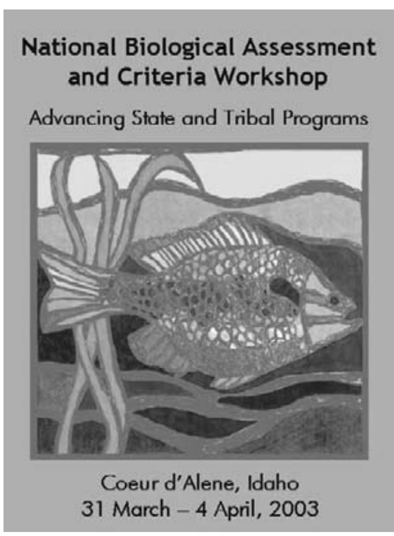
Tiered Aquatic Life Use Conceptual Model: Draft Biological Tiers

(10/22 draft)



Designated Aquatic Life Uses: Ohio/Streams & Rivers

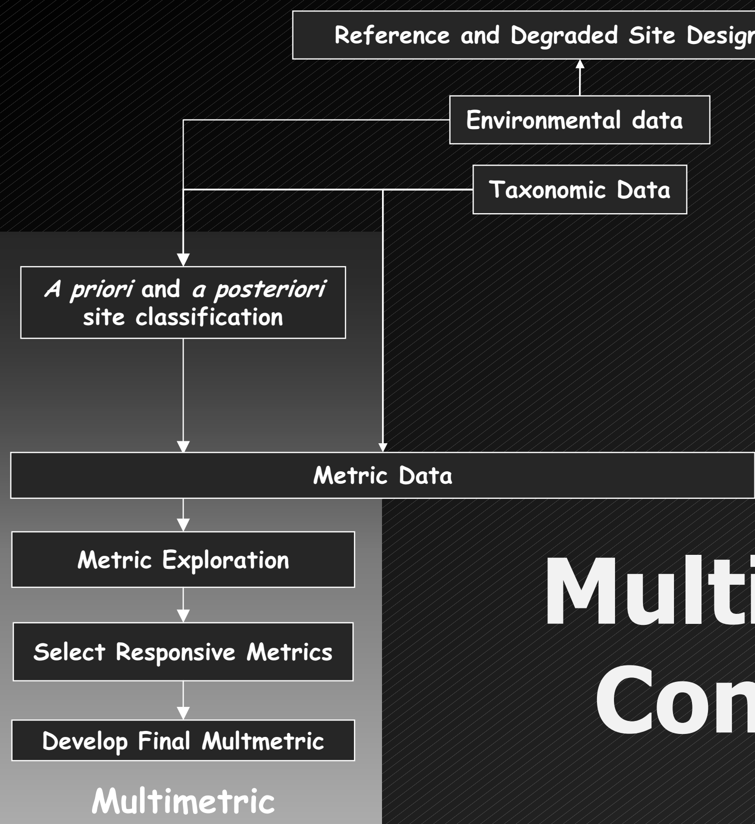




Index 101

Multimetric Concepts

Michael Paul; Jeroen Gerritsen
Tetra Tech, Inc.



Multimetric Concepts

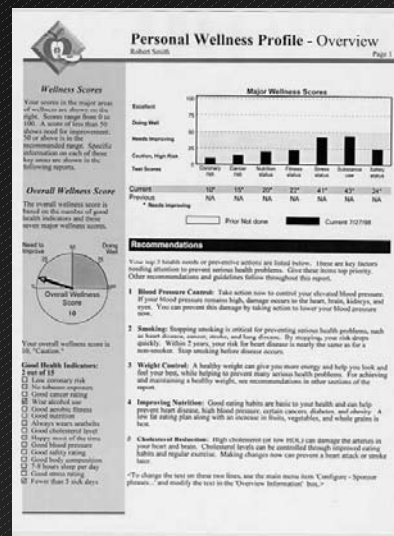
Basic Steps

- Reference/Degraded Criteria
- Classification
  - Reducing variability
- Metric Exploration
  - Incorporating broad ecological information
  - Identifying discriminatory metrics
  - Avoiding redundancy
- Developing the "multi"-metric
  - Testing combinations of metrics

A medical metaphor

- Have you ever taken a "wellness" test?

- **They ask a lot of questions based on common "indicators" = "metrics"**



Reference/Degraded Criteria

- What is healthy?
- Need two groups for building models

HEALTHY REFERENCE	UNHEALTHY DEGRADED
Non-smoker	2 packs/day
Low Stress	High Stress
Exercise 5d/week	No exercise
Healthy Diet	High Fat Diet

Classification

- The first few questions always deal with age, gender, etc.
- Expectations differ for different groups.

Metric Exploration

- One indicator doesn't get it done…
- Likely explored a lot of indicators
- Explored relationship of indicators to illness – developed those that were good at discriminating healthy from unhealthy folks.

Developing a 'multi'-metric

- Finally identified those indicators that consistently discriminated healthy individuals from unhealthy.
- Doctors now use an array of these to measure your "wellness"
- Individual indicators used for diagnosing particular problem areas

How it works – reference criteria

- Reference/Degraded Criteria
  - Reference sites are used to build classifications
  - Reference and Degraded used to select metrics and test final index
  - Abiotic variables are used
  - Likely need to test a few approaches
  - May need to stratify later

Reference Sites

- The primary function of reference conditions is as a measurement standard
- To be useful, a measurement standard must account for natural variability
  - undisturbed, natural
  - best of available
  - representative of class

Reference and Degraded Criteria

- Reference sites (must meet all)
  - No discharges within prescribed distance
  - Better than state water quality standards
  - Land use: no direct disturbances
  - Habitat typical for region; good riparian zone
- Stressed sites (meets one or more)
  - Fails water quality or sediment standards
  - Severe habitat impairment
  - Severe nonpoint sources; erosion

Maryland Reference Criteria (must meet all)

- pH • •6.0
- ANC • •50• eq/l
- dissolved oxygen • •4.0 ppm
- Nitrate-N • •4.2 mg/l
- Urban land use • •20% of catchment
- Forested land cover • 25% of catchment
- Remoteness rating "optimal" or suboptimal"
- Aesthetics rating "optimal" or "suboptimal"
- Instream habitat rating "optimal" or "suboptimal"
- Riparian buffer width • •15m
- No channelization
- No point source discharges

Maryland Stressed Criteria (meets any one)

- pH • •5.0 *and* ANC • •0 • eq/l
- dissolved oxygen • •2.0 ppm
- Nitrate-N • •7.0 mg/l and DO • •2.0 ppm
- Urban land use > 50% of catchment area and instream habitat rating "poor"
- Instream habitat rating "poor" and bank stability rating "poor"
- Channel alteration rating "poor" and instream habitat rating "poor"

Classification

- Classification
  - Comparing like to like
  - Way of apportioning variability
  - Models calibrated to each "class"
- *A priori* - existing
- *A posteriori* – derive from your data

A priori classification

- Ecoregions

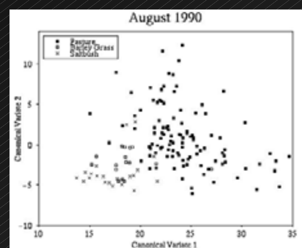
- Physiographic provinces

A posteriori classification

Physical and Chemical Data

STRM_ID	ALTD	ANC	ANSUM	CA	CATSUM	CL
MD507S	10	154	478.73	272	456.54	79
MD510S	5	153	531.45	237.5	521.98	102
MD511S	8	286	1037.49	367.3	1071.28	429
MD512S	6	391	830.06	409.2	842.59	54
MD751S	30	412	1439.38	588.8	1487.97	663
MD755S	12	246	654.72	327.3	665.57	166
MD756S	19	895	1275.91	728.5	1377.81	242
MDR02S	8	789	1310.7	903.2	1248.12	84
MDR03S	3	149	570.95	252	556.72	60
MDT02S	30	968	1477.49	658.7	1398.36	290
PA003S	3	353.4	703.05	356.8	686.86	149
PA018S	28	2370.6	2880.08	1801.4	2858.34	325
PA505S	9	1740	2340.86	1791.4	2384.73	150
PA508S	10	195	412.99	242.5	397.07	21
PA509S	151	164	163.11	107.3	191.17	19
PA510S	12	194	849.48	323.4	885.29	363
PA516S	5	96.8	410.48	190.1	417.4	151
PA517S	8	315	635.79	265	643.16	50
PA518S	22	66.2	249.29	128.7	255.86	32
PA519S	6	531	1214.6	493.5	1306.03	563
PA523S	9	773	1101.8	568.9	1104.61	116
PA528S	21	118	569.78	176.6	602.58	274
PA531S	14	240	614.21	405.2	594.08	91

Ordination
Cluster Analysis
Etc.



Classes or Groups

Highlands

Piedmont

Plains

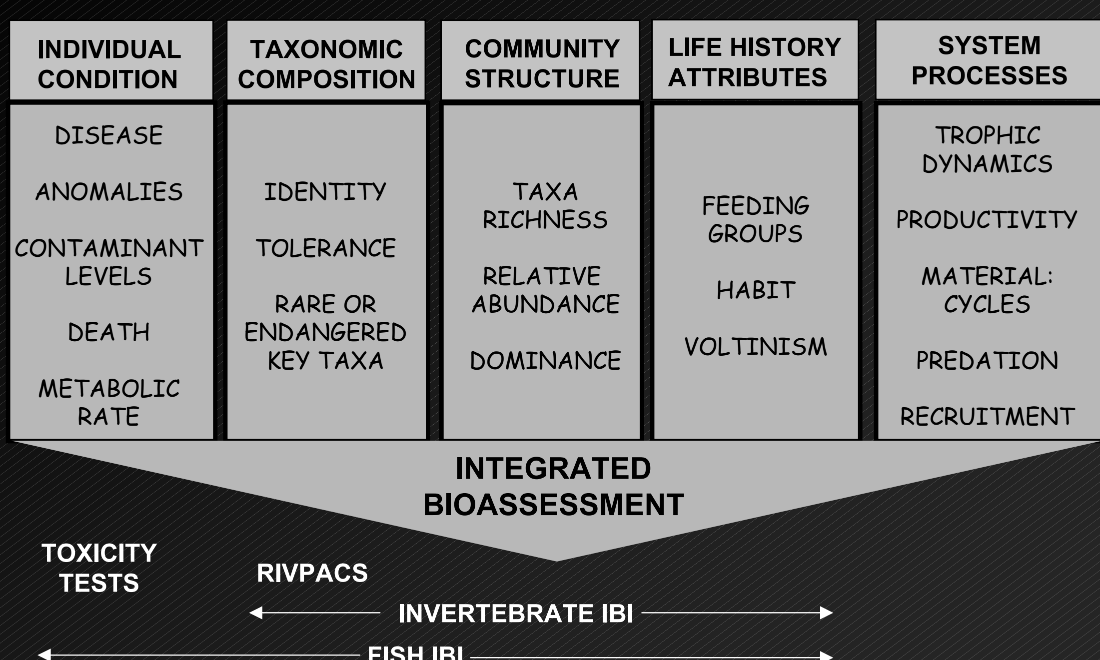
Confirmation

- Univariate tests
- MANOVA
- Other Ordination
- Similarity analysis

Metric Exploration

- Incorporating broad ecological information
- Identifying discriminatory metrics
- Avoiding redundancy

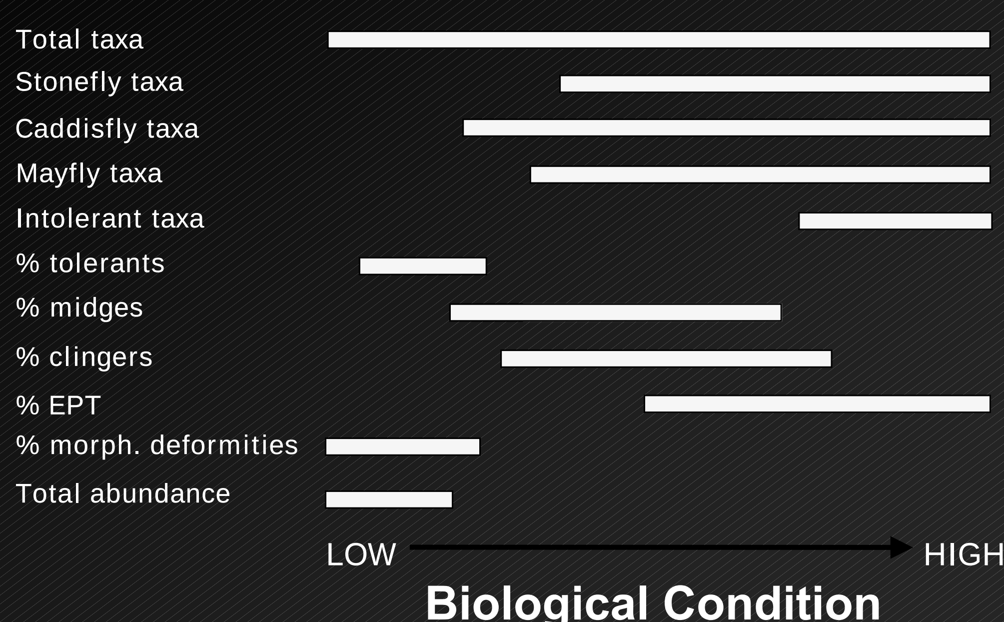
Metric Exploration



Ideal Multimetric Composite

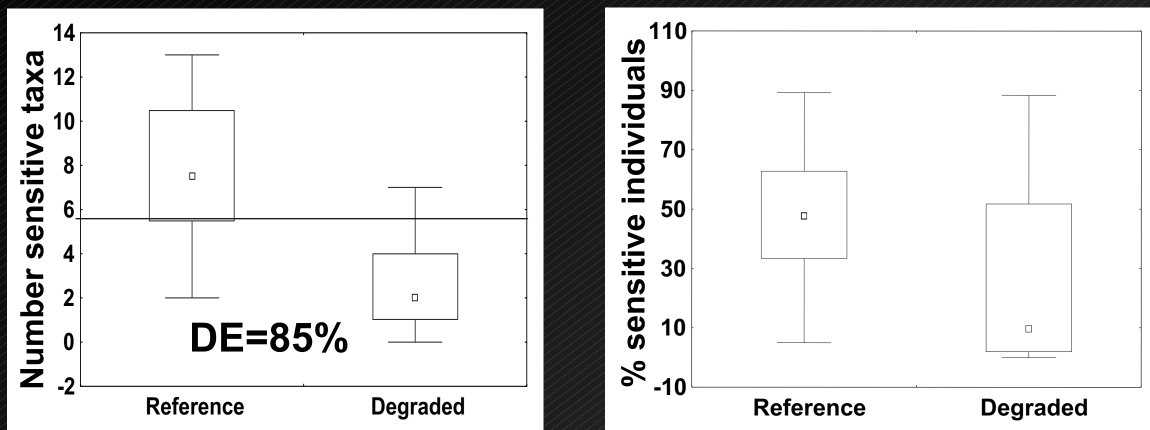
- Multiple organizational levels
- Addresses structure and function
- Broad sensitivity
- Broad range of habitats, niches
- Metric characteristics
  - Responsive to stressors
  - Low natural variability
  - Interpretable (understanding of ecology)
  - Cost-effective to measure

Different responsiveness



Testing metrics – reference vs degraded approach

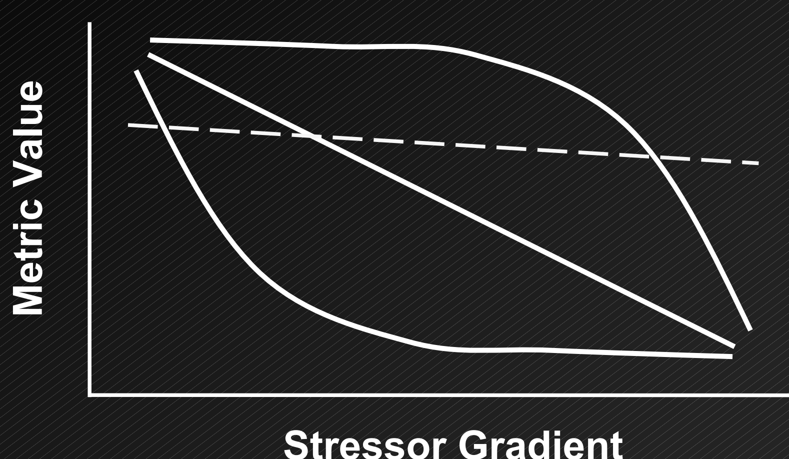
Metric Responses



Strong **Weak**

Discrimination Efficiency = percent degraded < 25th percentile reference

Testing metrics – gradient approach



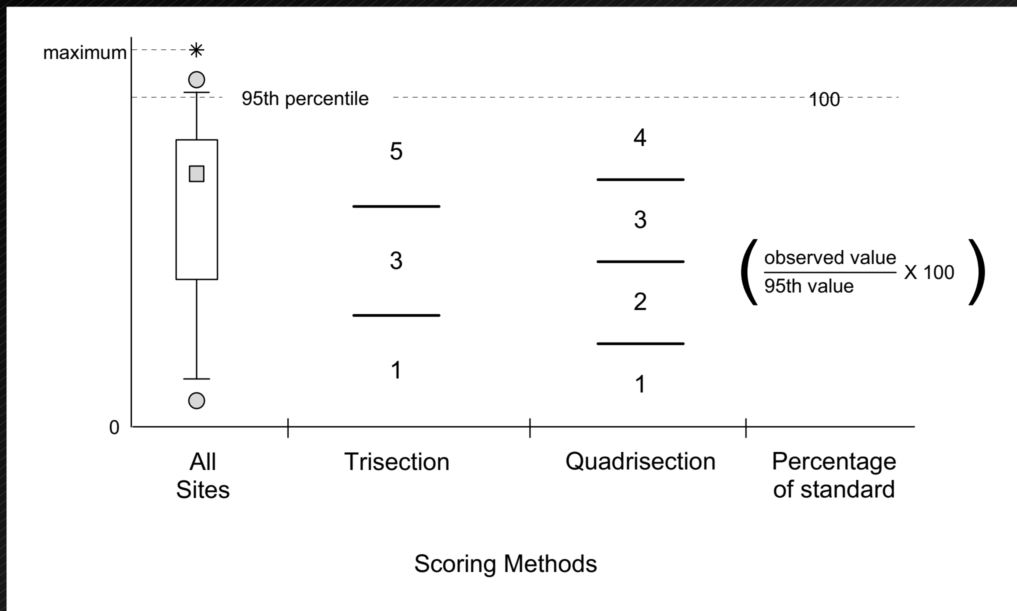
Avoid redundancy

- Avoid metrics that are components of others
  - E.g. % EPT and % Ephemeroptera
- Correlation analysis – avoid highly correlated metrics in same multimetric
  - r>0.7 is a good start

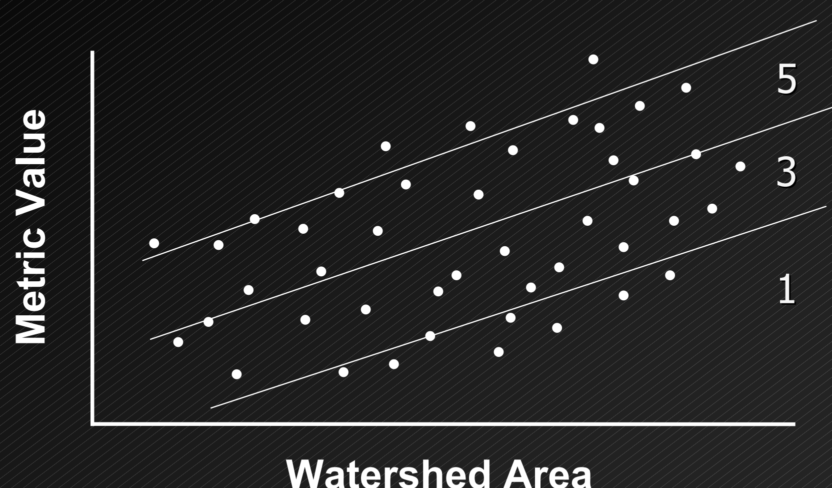
Delete Metrics

- Obscure ecological meaning
- Weak response to stressors
- Limited ecosystem relevance
- Redundancy to other metrics

Metric Standardization



Metric Standardization



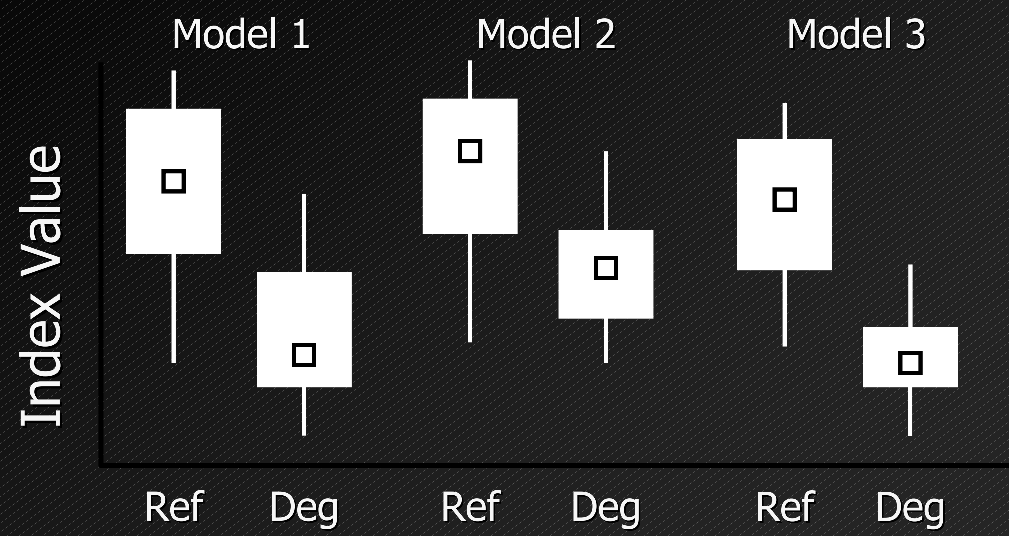
Assembling Metrics

- Use sum or average of standard scores of metrics to get final multimetric score
- Test several combinations for overall discrimination efficiency

Assembling multimetrics

Metric	Model 1	Model 2	Model 3
Ephemeroptera taxa	X	X	X
Plecoptera Taxa		X	X
Trichoptera Taxa		X	X
Insect taxa	X		
Non-insect taxa	X		
% Ephemeroptera	X		
% Ephemeroptera less Baetid		X	
% Trichoptera Less Hydropsyche		X	X
%Oligochaeta	X		
% scrapers	X	X	X
BCI CTQA		X	X
HBI	X	X	
% 5 dominant	X	X	

Compare Discrimination Efficiencies



DE = 80% 74% 98%

Different classes may have different indexes

- **Coastal Plain metrics**
  - Total taxa
  - EPT taxa
  - % mayflies
  - % Tanytarsini
  - Beck's Biotic Index
  - Scraper taxa
  - % clingers
- **Non-Coastal Plain metrics**
  - Total taxa
  - EPT taxa
  - % mayflies
  - % Tanytarsini
  - Ephemeroptera taxa
  - Diptera taxa
  - Intolerant taxa
  - % tolerant individuals
  - % collectors

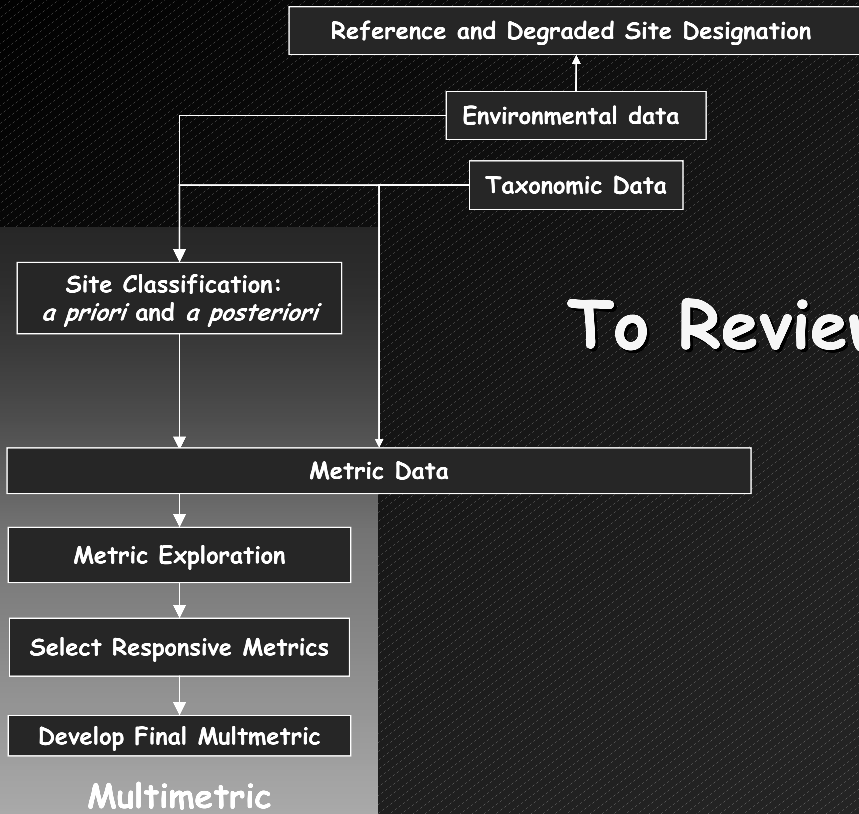
Or may be the same, but use different standardized scores or threshold values

95th Percentile of Reference Site Values

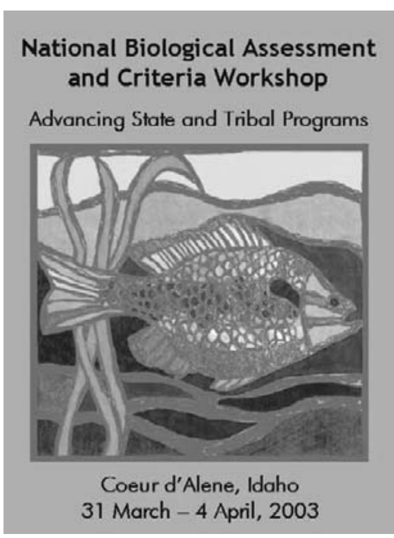
Metric	Class I	II	III	IV
Total Taxa	20	34	32	36
EPT Taxa	6	10	12	15
Diptera Taxa	8	12	12	15
% Tolerant	19	9	8	6
% Scrapers	12	20	23	20
% Clingers	55	60	63	65

Always test any model

- Use an independent dataset with reference and degraded sites
  - Same year set aside
  - Newly collected data
  - Test discrimination efficiency
  - Should match model building DE
  - No strict rule



To Review...



Index 101

Recalibrating Florida's Stream Condition Index

Russ Frydenborg, FL DEP;
Leska Fore, Statistical Design

Florida's Stream Condition Index: 1990's Multimetric Approach

- Established reference condition in various sub-ecoregions
  - Best professional judgment
    - Surrounding land use, in-stream habitat
- Sampled known impaired sites
  - Point source discharge studies
    - Toxicity, low DO, poor habitat

Florida's Stream Condition Index: 1990's Multimetric Approach (cont.)

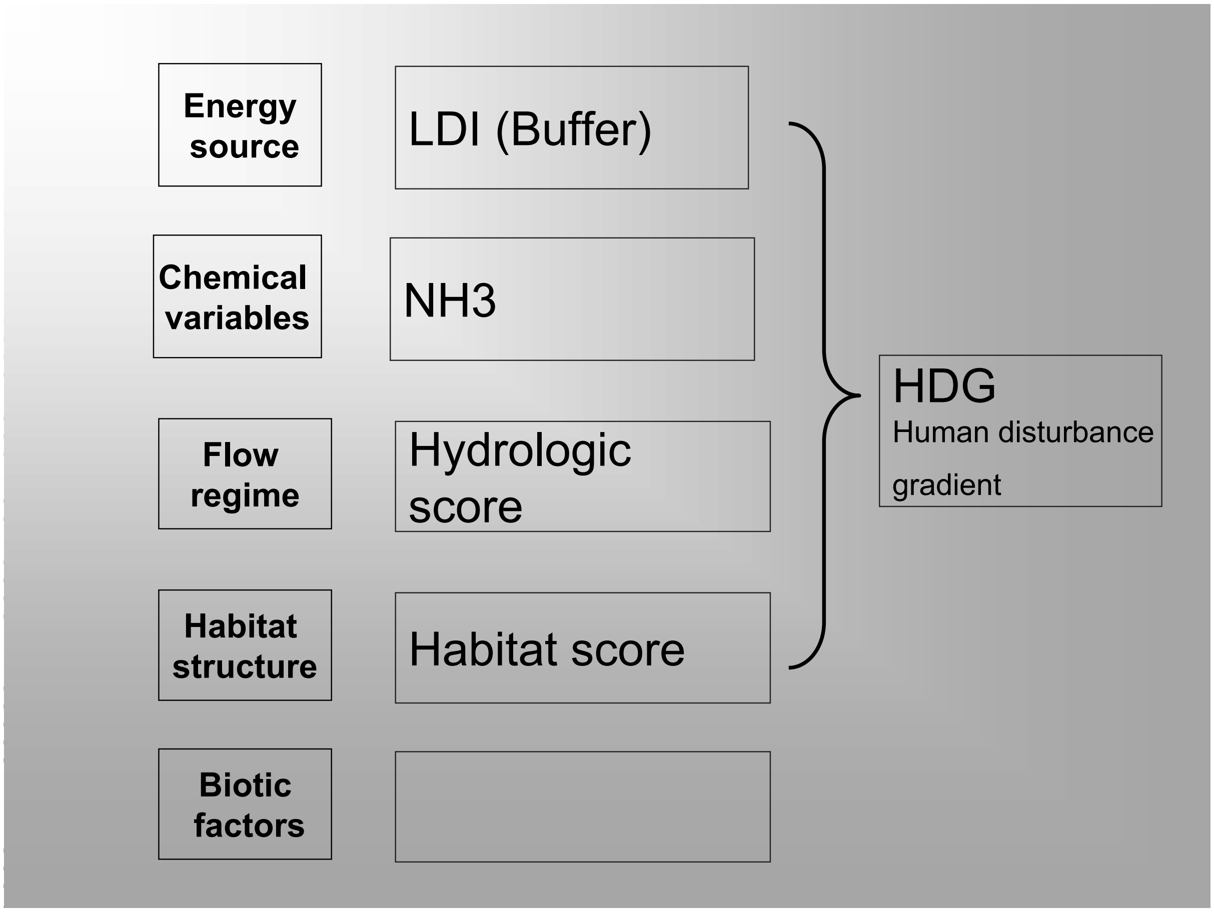
- Selected 7 metrics
  - Box and whisker plots determined discrimination power
- Aggregated by summing metrics
  - 5, 3, 1 point, depending on departure from reference condition

Florida's SCI Index Re-calibration

- Develop human disturbance gradient
  - Test disturbance gradient for each Bioregion
  - Evaluate metric response to disturbance gradient (new thresholds, new metrics)
- Determination of metric variability
- Power analysis for trend detection
- Develop consistency with EPA Tiered Aquatic Life Use Support guidance (TALUS)

Human Disturbance Factor Analysis

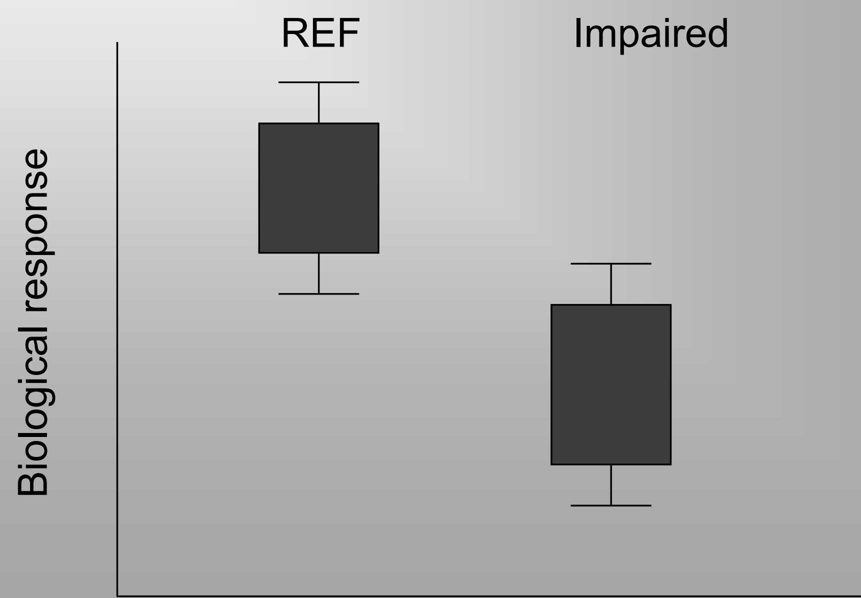
- Landscape level
  - Landscape Development Intensity Index
- Habitat alteration
  - Habitat assessment data
- Hydrologic modification
  - Hydrologic scoring process
- Chemical Pollution
  - Ammonia, etc.



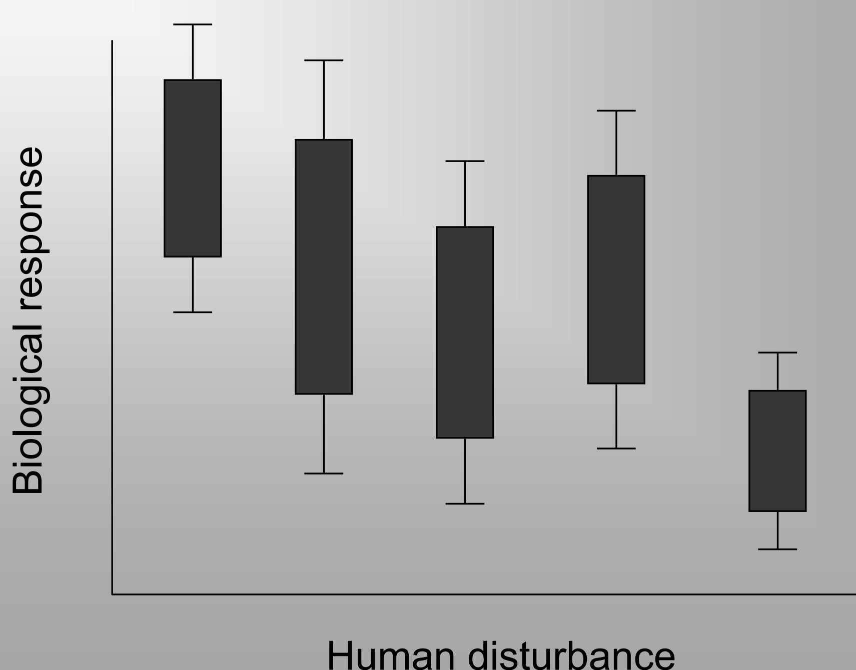
Two Approaches to Assessing Metrics

- Compare extremes
  - reference vs. impaired
- Compare across continuum of disturbance
  - Human Disturbance Gradient

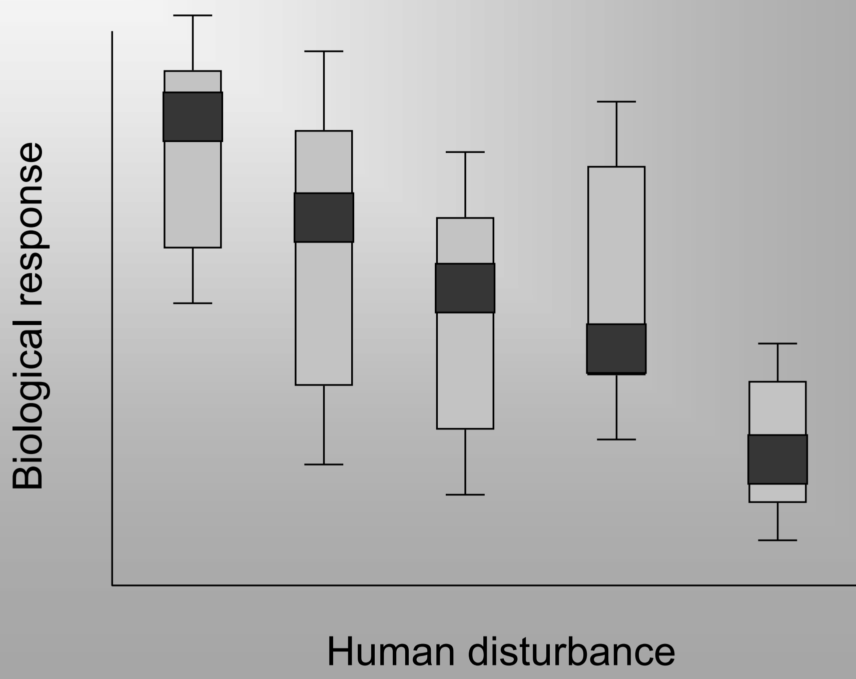
Works for extremes, but what about TALUS axis?



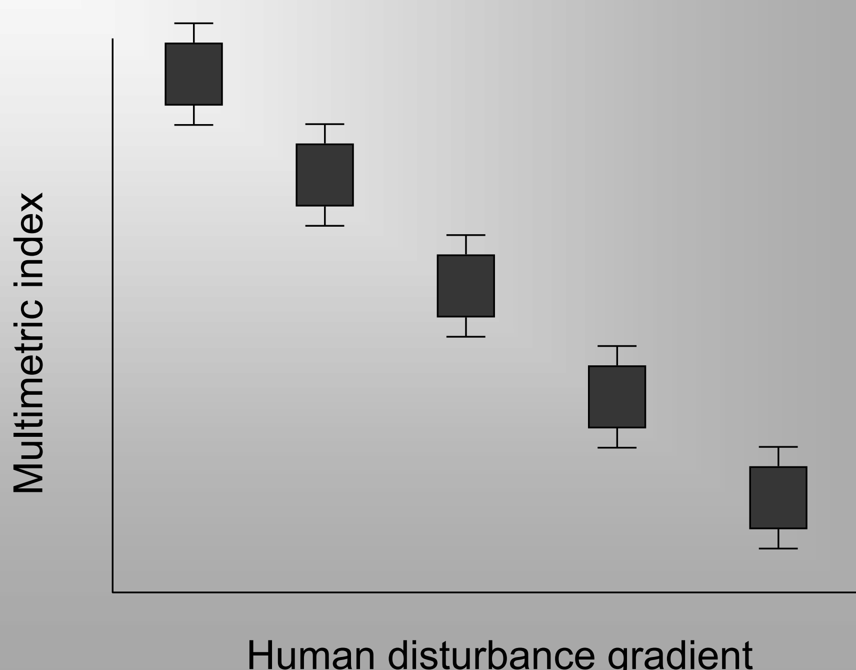
Noise on both axes!



Refine human disturbance scale
(find strongest predictors),
Select only the most robust biological metrics



The (unattainable?) Ideal



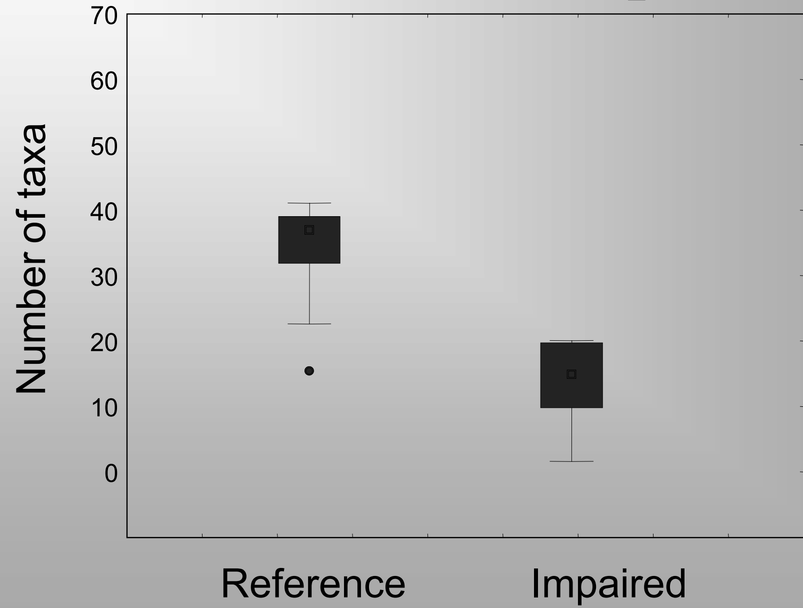
Metric Selection Criteria

- Meaningful measure of ecological structure or function
- Strong and consistent correlation with human disturbance
- Statistically robust, low measurement error
- Represent multiple categories of biological organization
- Not redundant with other metrics
  - Exception: "response signature" metrics

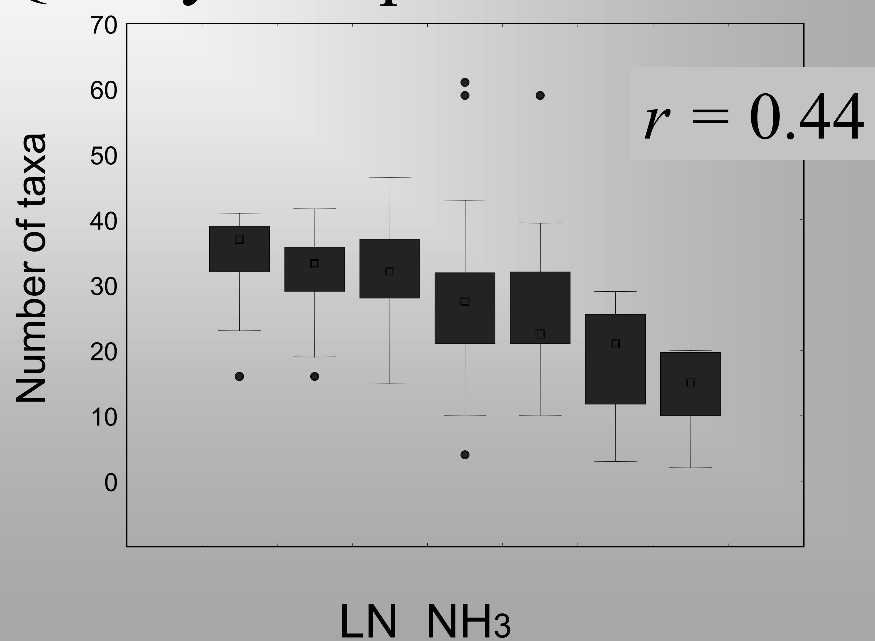
Metric Testing

1. Taxonomic richness & composition
2. Functional feeding groups
3. Life history
4. Tolerance and intolerance

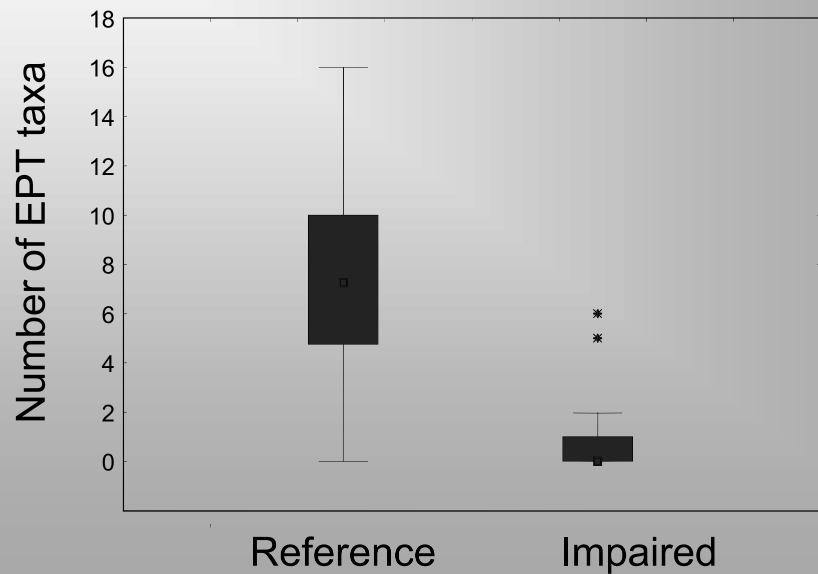
Taxa Richness: Reference vs. Impaired



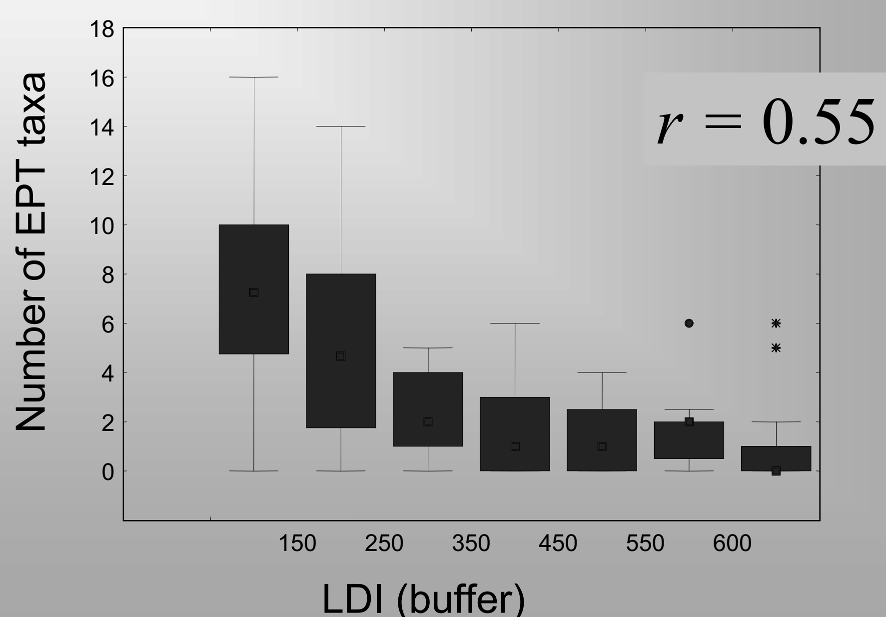
Taxa Richness vs. Water Quality Component of HDG



EPT: Reference vs. Impaired



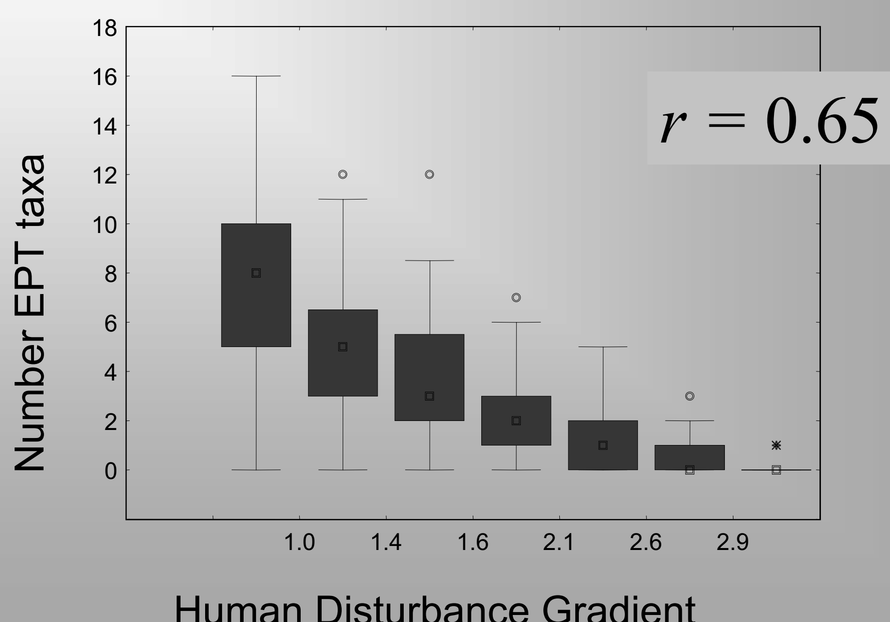
EPT vs. Landscape Development Intensity Index



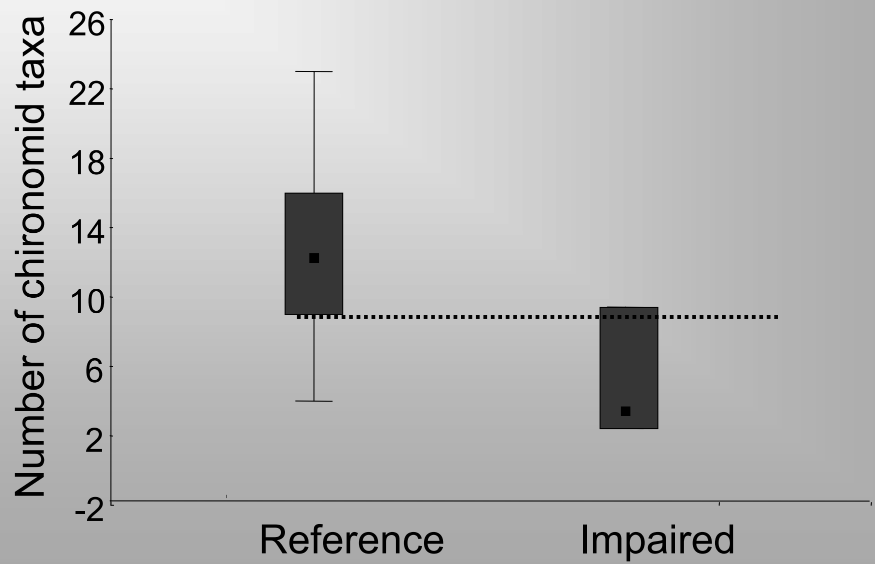
HDG is a combination of other disturbance measures

Scores **Measure**	**1**	**2**	**3**	**4**
NH3	<0.1	>0.1	>2	
Habitat	>65	>50 and <65	<50	
Hydro	<6	6-7	8-9	10
LDI (buffer)	<200	200-350	>350	
LDI (ws)	<200	200-350	>350	

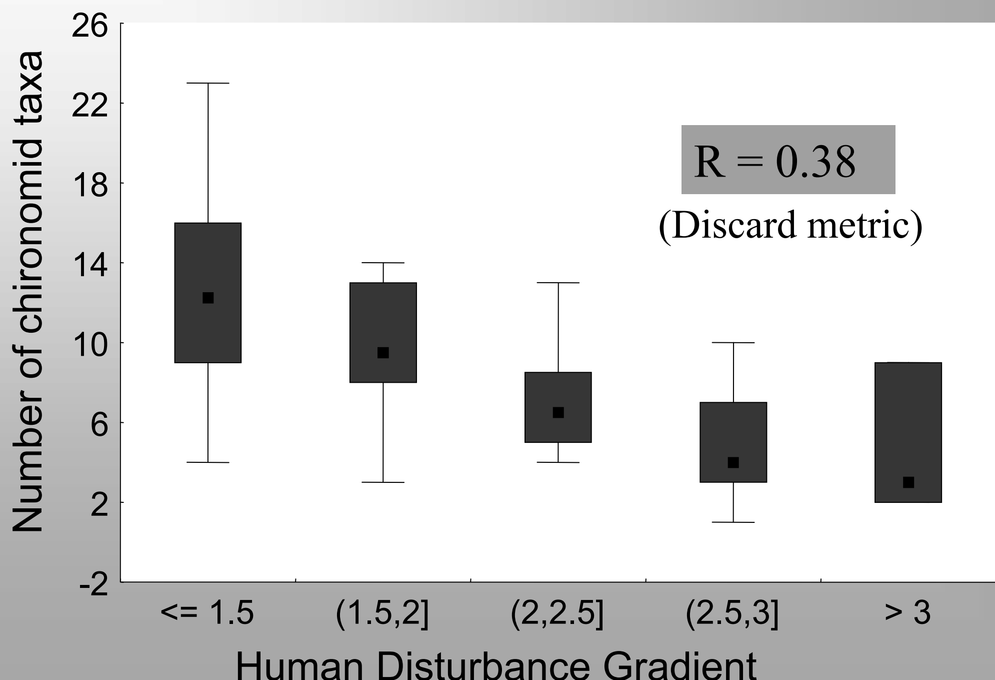
EPT vs. Human Disturbance Gradient



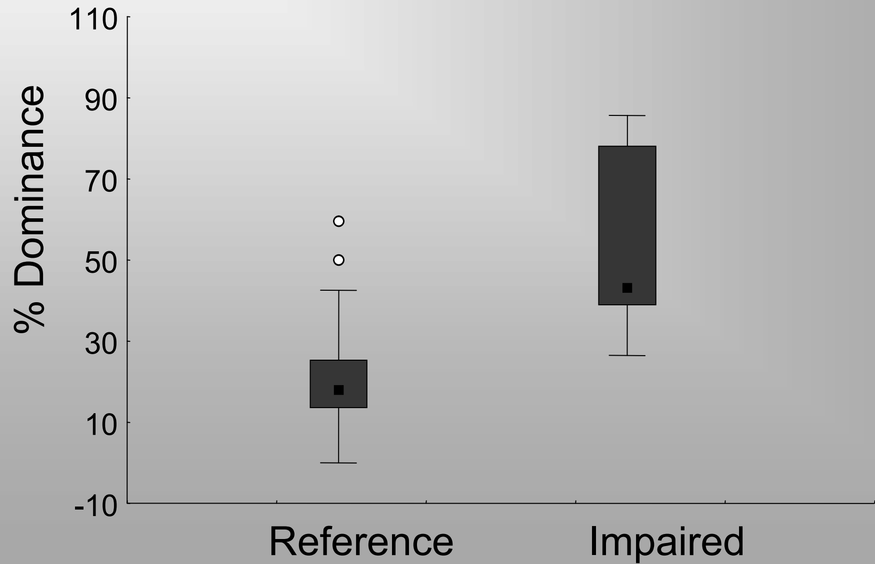
Chironomid taxa: Reference vs. Impaired



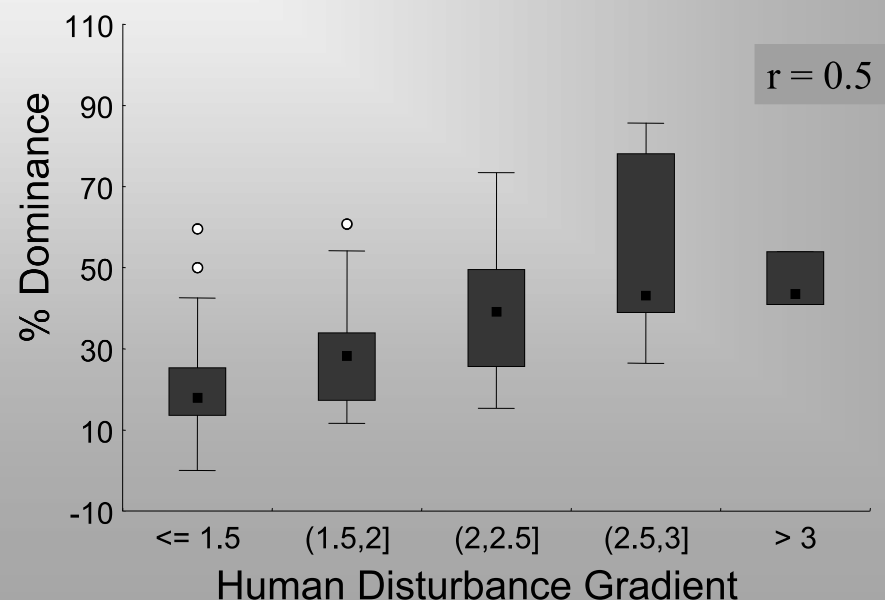
Chironomid taxa vs. HDG



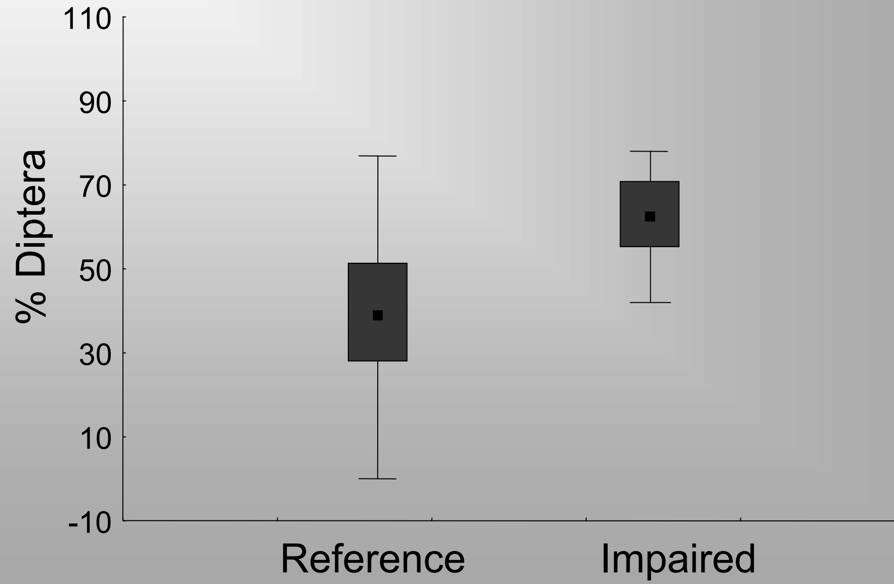
% Dominance: Reference vs. Impaired



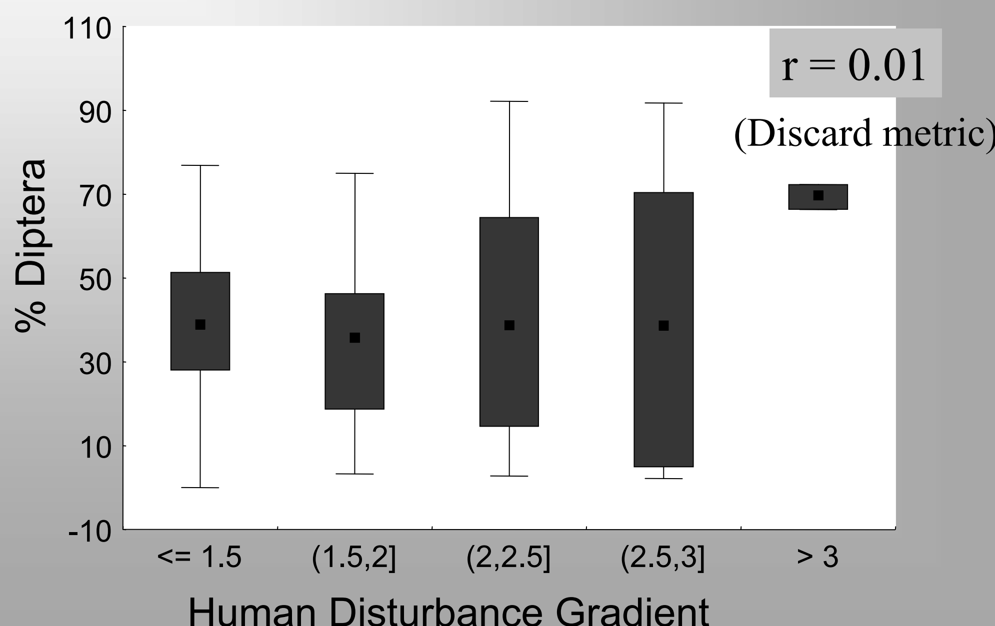
% Dominance vs. HDG



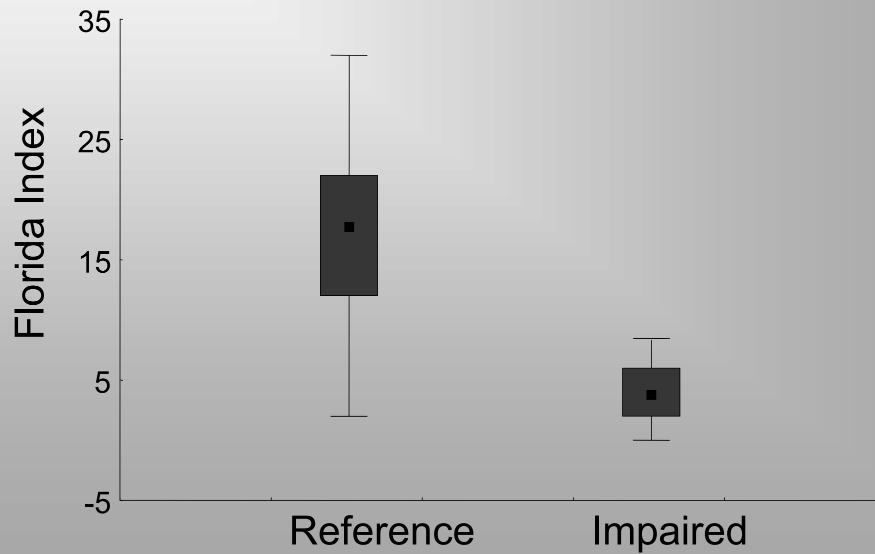
% Diptera : Reference vs. Impaired



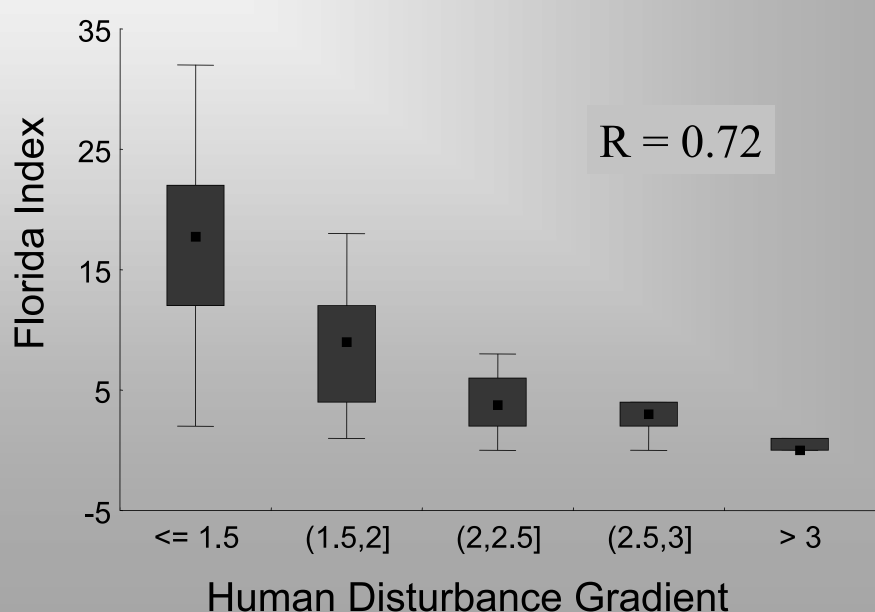
% Diptera vs. HDG



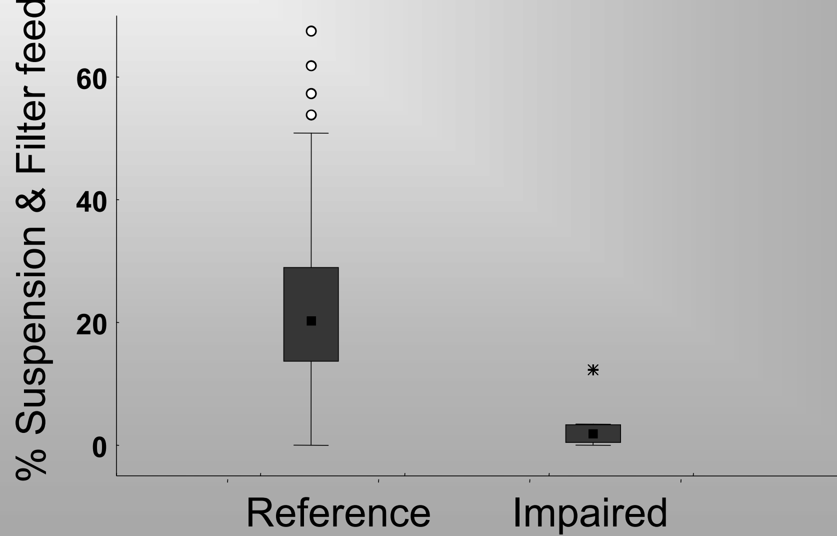
Florida Index: Reference vs. Impaired



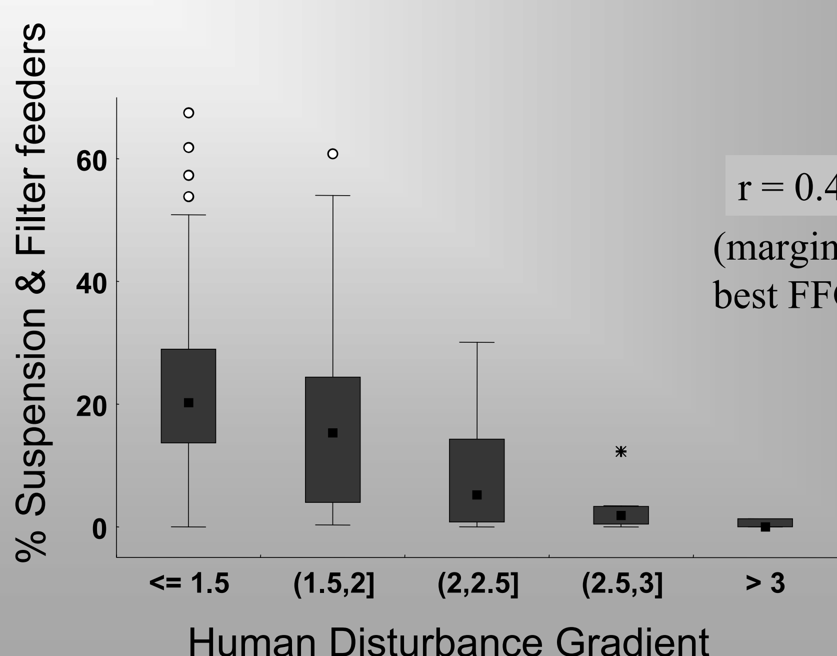
Florida Index vs. HDG



Filter-feeders: Reference vs. Impaired



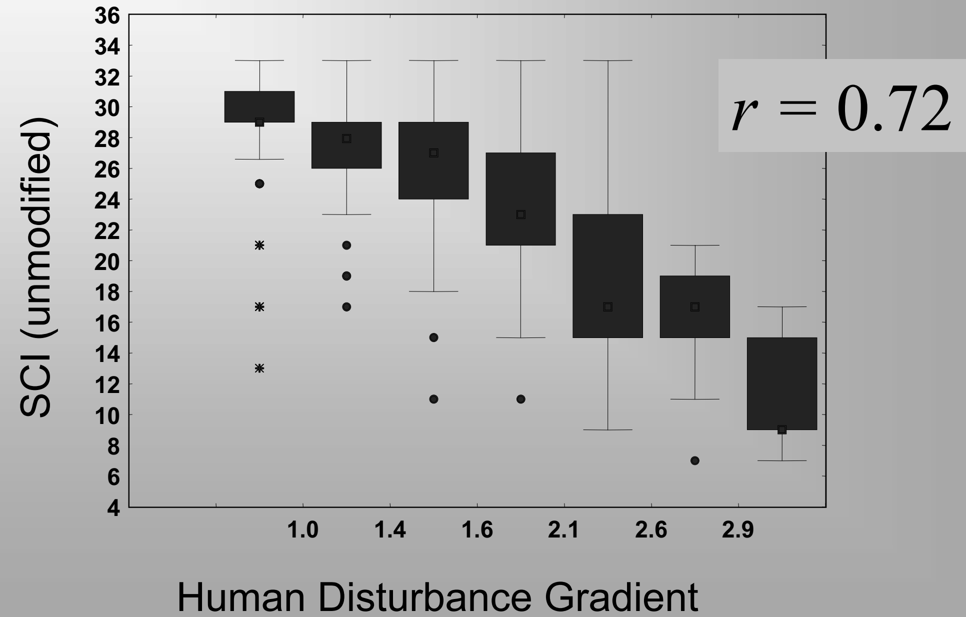
Filter-feeders vs. HDG



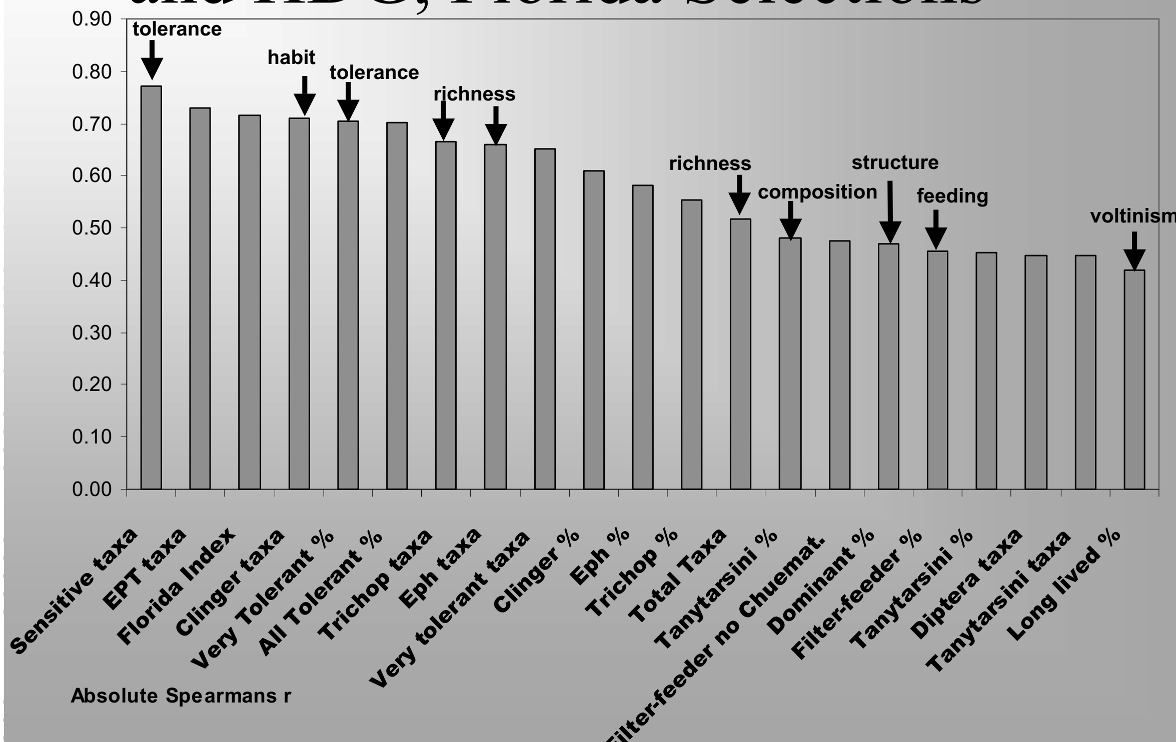
r = 0.47

(marginal, but best FFG metric)

Unmodified SCI vs. Human Disturbance Gradient



Correlation Values for Metrics and HDG, Florida Selections



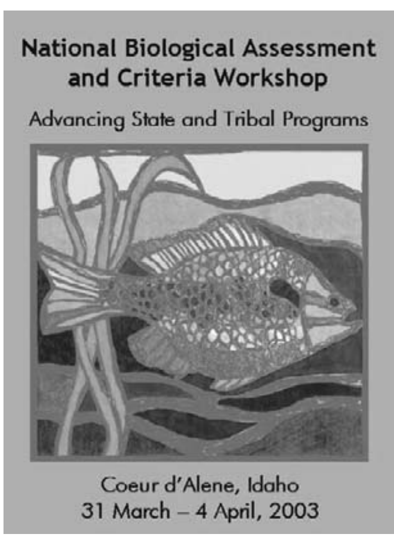
	SCI	New Index
Taxonomic richness	Total taxa	Total taxa
	EPT taxa	Mayfly taxa
		Caddisfly taxa
	Chironomid taxa	% Tanytarsini
Feeding group	Collector-filterers	Collector-filterers
Life history		% Long-lived
		Clinger taxa
Community structure	% Dominance	% Dominance
	% Diptera	
Tolerance & Intolerance	Florida Index	Intolerant taxa
		% Very tolerant

Existing Applications of SCI

- Ambient Monitoring
- Impaired Waters Rule (TMDLs)
- Point Source Permitting
- Watershed (NPS) Studies
- BMP Effectiveness Studies

Conclusions

- Multimetric Indexes are effective in a regulatory sense
- Discriminatory power of metrics
  - Comparing extremes identifies strong metrics, but includes some “noisy” metrics
  - Human Disturbance Gradient improves metric selection and provides an independent measure for comparing biological response



Index 101

Use of RIVPACS-type Predictive Models in Aquatic Biological Assessment: Theory and Application

Chuck Hawkins, Utah State University;
Rick Hafele, Oregon Dept. of Environmental Quality

The Concept:
O versus E as a Measure of Biological Integrity

$$\frac{O}{E} = \frac{\text{the } \textbf{\textit{set}} \text{ of native taxa expected at a site that are actually observed.}}{\text{the } \textbf{\textit{set}} \text{ of native taxa expected to occur at a site in the absence of human-caused stress.}}$$

The deviation of O from E is a measure of compositional similarity and thus a community-level measure of biological integrity.

O/E has some useful properties as an index of biological condition.

- It has an intuitive biological meaning (taxa are the ecological capital on which all ecosystem processes depend) and is interpretable by researchers, managers, the public, and policy makers.

O/E has some useful properties as an index of biological condition.

- It means the same thing everywhere, which allows direct and meaningful comparisons across regions and states.

O/E has some useful properties as an index of biological condition.

- Its derivation and interpretation are independent of type and knowledge of stressors in the region.

O/E has some useful properties as an index of biological condition.

- It is quantitative.

O/E has some useful properties as an index of biological condition.

Major Issues for the 101 Course

- Understanding the units of measure.
- Predicting the expected taxa.
- Calculating O/E, the biological condition value.
- Determining if an assessed site is impaired.

Basic Concepts

- Predictive models base assessments on the compositional similarity between observed and expected biota.

The Unit of Measure

- The deviation of O from E is difficult to express in a simple way given the multivariate nature of both terms.
- We need a simple currency that also retains the information content of compositional similarity.
- We also need a way of dealing with the fact that we ***sample*** the biota and thus deal with probabilities not absolutes.

O/E: A Simplified Expression of a Multivariate World

- Define E as the ***number*** of native taxa expected to occur at a site in the absence of human-caused stress.
- Define O as the ***number*** of taxa that are predicted to occur that are actually present.
- The ratio O/E is the ***proportion*** of taxa observed that should have been collected.
- O/E is not based on raw taxa richness; O is constrained to include only those taxa with a probability of capture greater than a stated threshold.

Basic Concepts
(Units of Measure & the Expected Taxa)

Species	Replicate Sample Number 1	2	3	4	5	6	7	8	9	10	Freq (P_c)
A	*	*	*	*	*	*	*	*	*	*	1.0
B	*	*		*	*	*		*	*	*	0.8
C	*		*		*	*			*		0.5
D		*	*				*		*	*	0.5
E					*						0.1
Sp Count	3	3	3	2	4	3	2	2	4	3	2.9

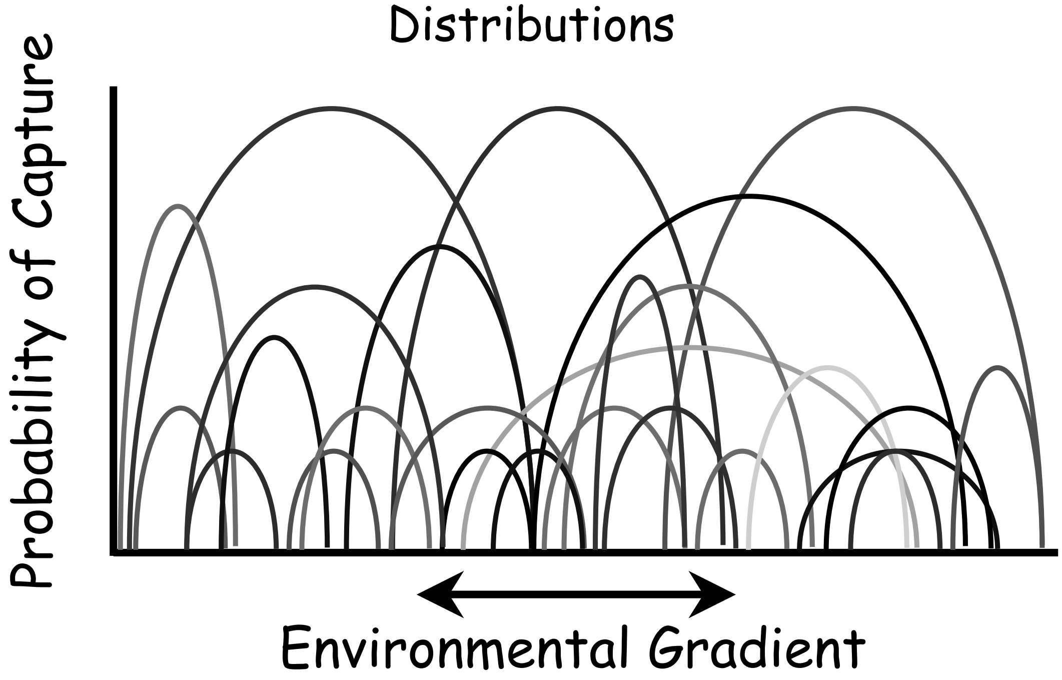
Species Richness is the Currency.

$E = \sum P_c =$ • •number of species / sample = 2.9.

O/E as a Measure of Impairment

Expected Biota		Observed Biota			
Species	Pc	O_1	O_2	O_3	O_4
A	1.0	*	*	*	*
B	0.8	*		*	
C	0.5		*		
D	0.5	*			
E	0.1				
F	0				*
Expected Sp Count	2.9	3	2	2	1
	O/E	1.03	0.69	0.69	0.34

This is the Challenge:
Estimating the Probabilities of Capture of Many Different Taxa that Exhibit Individualistic Distributions



The basic approach to modeling pc's and estimating E was worked out by Moss et al.*

River InVertebrate Prediction and Classification System (RIVPACS)

*Moss, D., M. T. Furse, J. F. Wright, and P. D. Armitage. 1987. The prediction of the macro-invertebrate fauna of unpolluted running-water sites in Great Britain using environmental data. Freshwater Biology 17:41-52.

RIVPACS-type Models: 8 Basic Steps

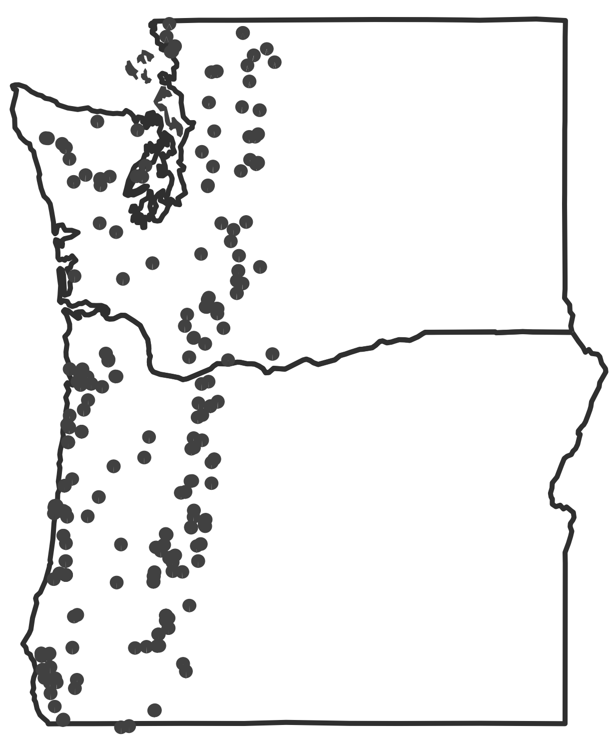
1. Establish a network of reference sites.
2. Establish standard sampling protocols.
3. Classify sites based on their biological similarity.
4. Estimate individual probabilities of capture by relating environmental setting to the biological classification (multivariate statistics).

For each assessed site:

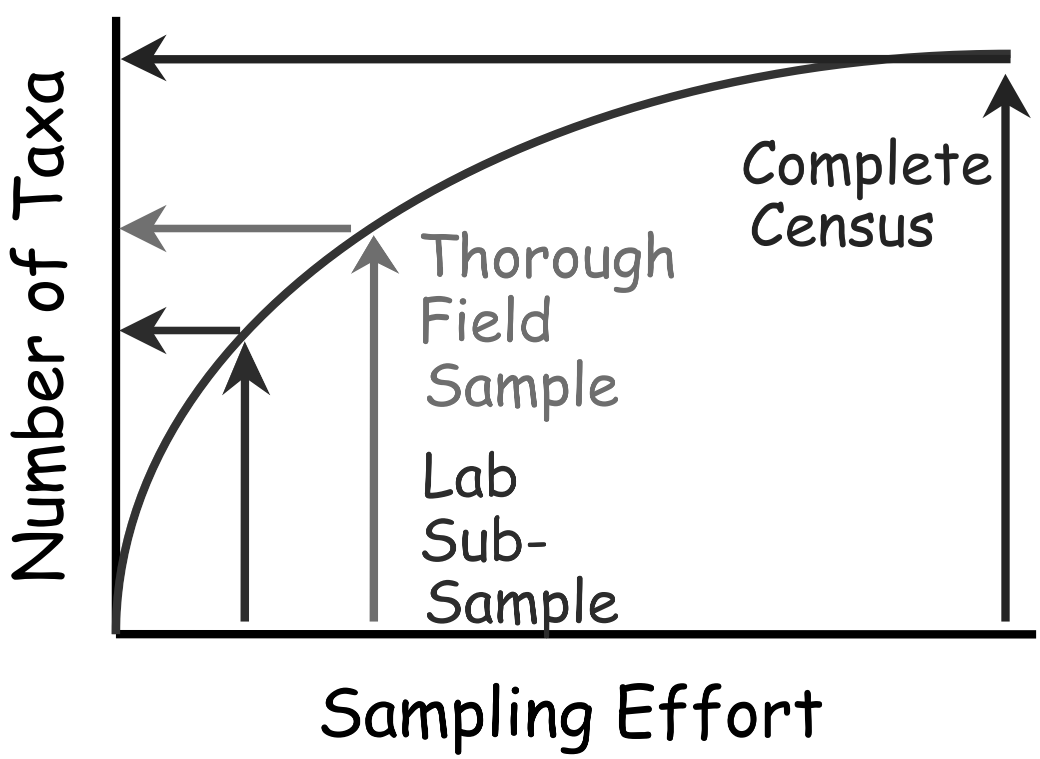
5. Sum p_c's to estimate E.
6. Count O
7. Calculate O/E.
8. Determine if observed O/E is different from reference?

Creating RIVPACS Models

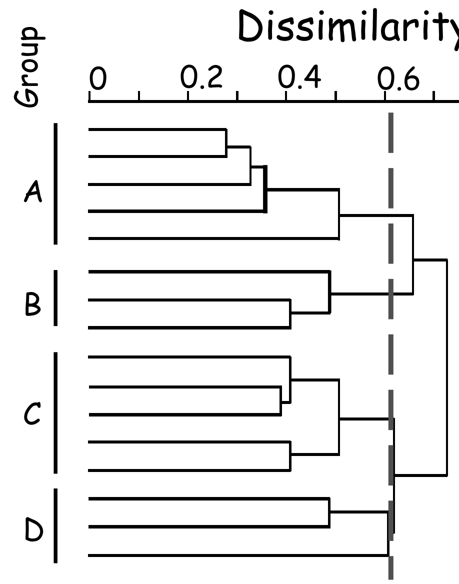
1. Establish a network of reference sites that span the range of environmental conditions in the region of interest.



2. Use standard protocols to sample biota and habitat features.



3. Classify sites in terms of their compositional similarity.



This cluster analysis shows 4 'groups' of sites

4. Derive a multivariate model to predict from environmental features the probabilities of sites belonging to biologically-defined groups and the probabilities of capturing each taxon.

P_c = f(elevation, watershed area, geology)

The Discriminant Model

Biologically Defined
Reference Sites:

Group A
Group B
Group C
Group D

Reference Site
Predictor Variables:
Catchment Area
Geology
Latitude
Longitude
Elevation
etc.

Discriminant Analysis → Discriminant Model

Combining the Discriminant Model + Frequencies of Occurrence Provides Estimates of Probabilities of Capture

Test Site
Predictor
Variables

Discriminant Model

Group Probabilities		Taxon 1 Reference Site Frequencies	
50% Group A	*	60% Group A	= 0.30
40% Group B	*	20% Group B	= 0.08
10% Group C	*	0% Group C	= 0.00
0% Group D	*	0% Group D	= 0.00

$P_c = 0.38$

5. Sum p_c's to estimate the number of taxa (E) that should be observed at the site based on standard sampling.

Species	P_c
1	0.70
2	0.92
3	0.86
4	0.63
5	0.51
6	0.32
7	0.07
8	0.00
E	4.01

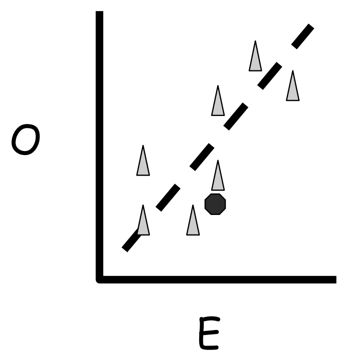
6. Determine O, the number of predicted taxa that were collected (O).

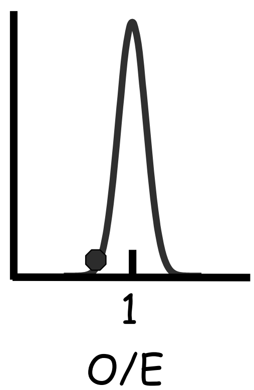
7. Calculate O/E.

Species	P_c	O
1	0.70	*
2	0.92	*
3	0.86	
4	0.63	
5	0.51	*
6	0.32	
7	0.07	
8	0.00	
E	4.01	3

$O/E = 3 / 4.01 = 0.75$

8. Determine if the O/E value is significantly different from the reference condition by comparing against model predictions and error.

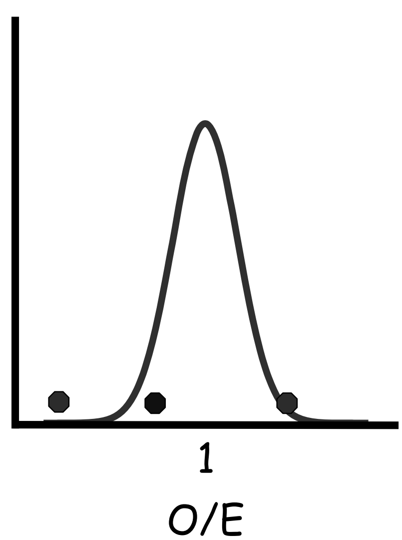




Statistical Issues Regarding Inferences of Impairment

Single Sites/Samples

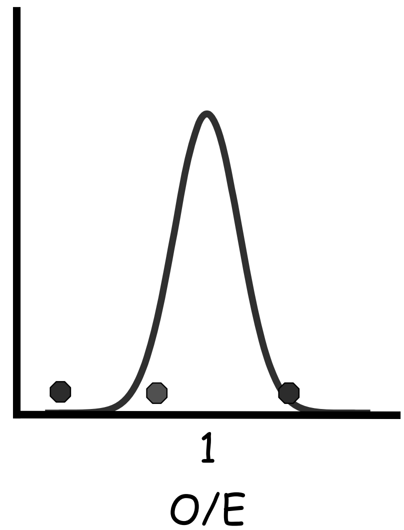
Hypothesis: the observed O/E value is from the same distribution of values estimated for reference sites, i.e., the site is equivalent to reference.



Statistical Issues Regarding Inferences of Impairment

Multiple Sites or Replicated Samples at a Site

Hypothesis: the observed mean is different from 1 (the reference mean).



RIVPACS-type Models: 8 Basic Steps

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For each assessed site:

5. Sum p_c's to estimate E.
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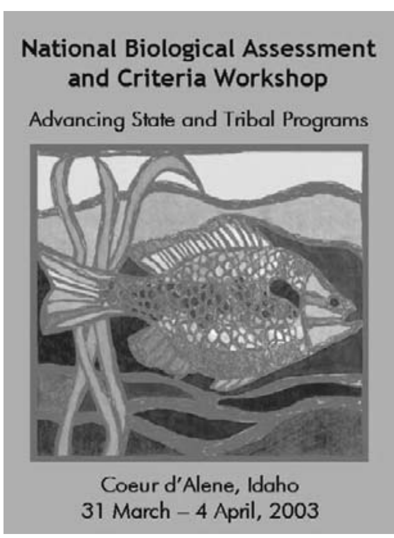
8. Determine if observed O/E is different from reference?

RIVPACS Outputs Can Also Be Used to Identify Sensitive and Tolerant Taxa

Sensitivity Index:

$$\frac{\#\text{ sites taxon was observed}}{\#\text{ sites taxon was expected}}$$



Index 101

Oregon's Experience with Multimetric and Multivariate Approaches

Presented by
Rick Hafele, Oregon DEQ

Index Tools and Uses?

- Oregon has been using both multi-metric and multivariate analysis tools since mid 1990's
- Two primary uses of indexes
  - Evaluate biological condition and set criteria for impairment.
  - Characterize biological assemblages and identify environmental factors affecting them.

Evaluating Indexes?

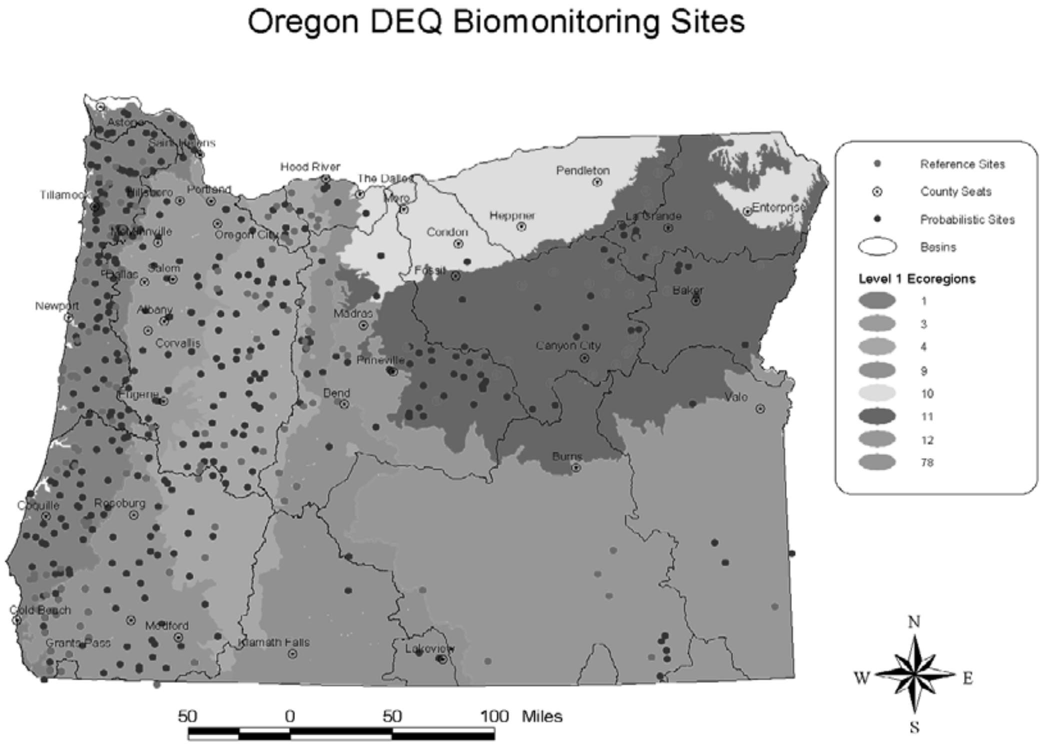
Sensitivity: How well do they distinguish changes from expected conditions?

Precision: How much within site variability is there for index scores?

Stressor ID: Can the index help determine environmental stressors?

Reference site requirements: What kind of reference site network is necessary to develop the index?

Oregon's Monitoring Sites



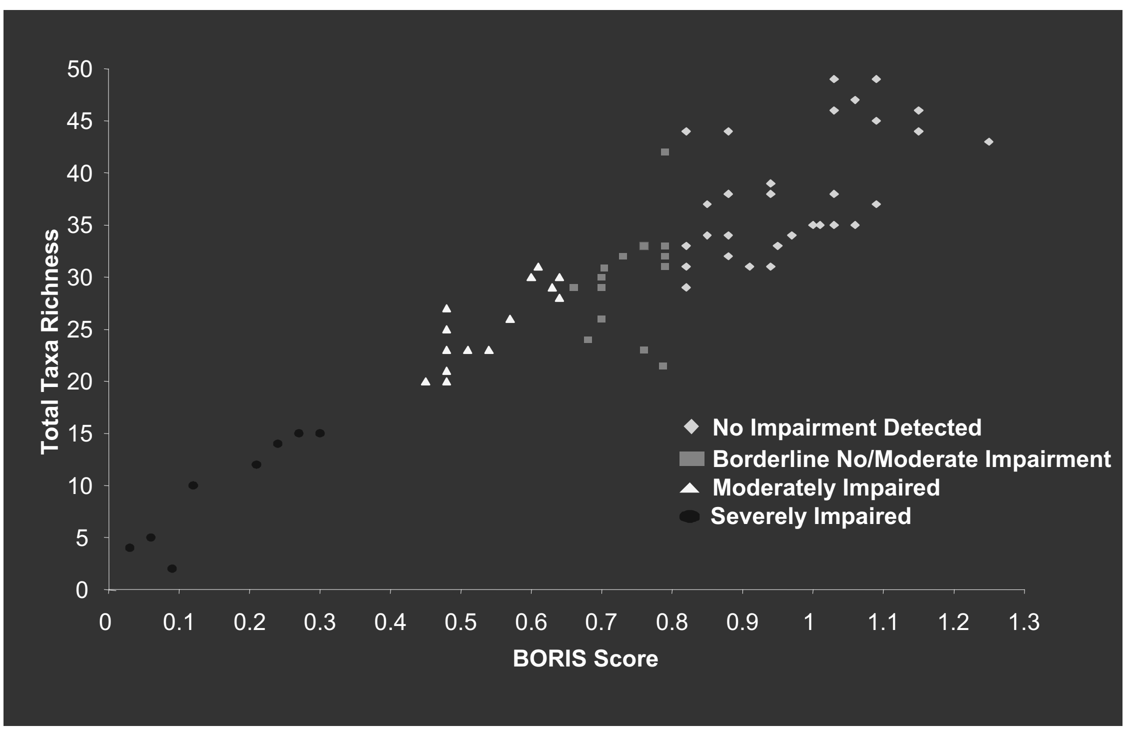
Example Project Sites

Grande Ronde Study

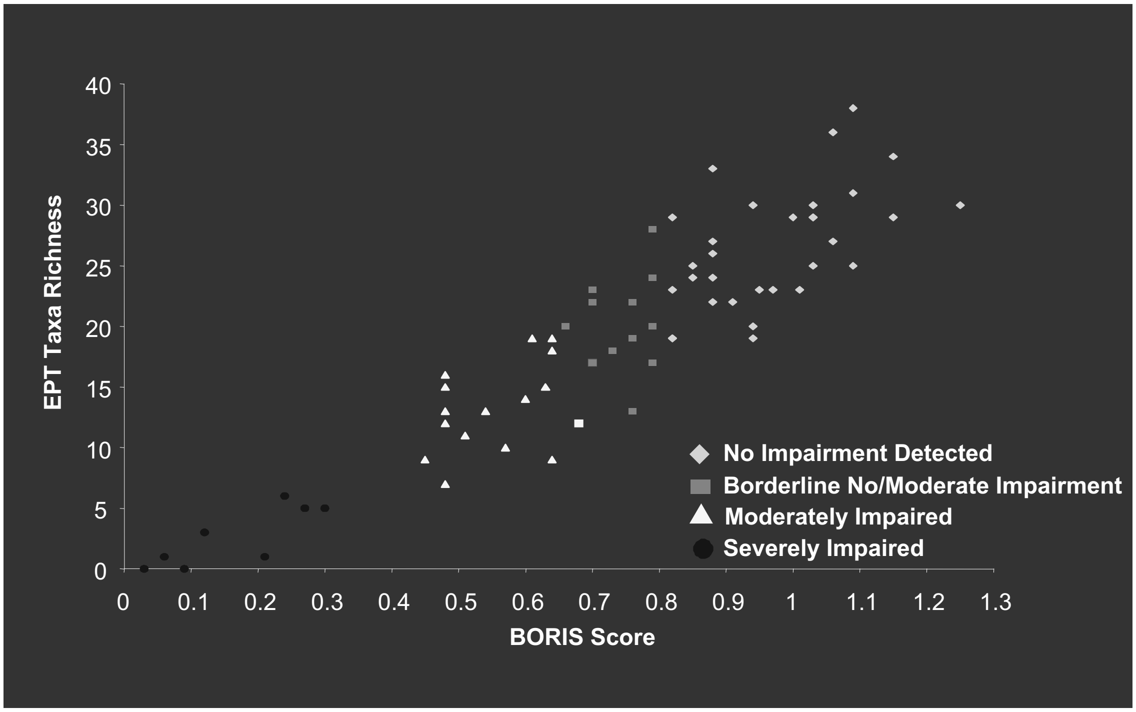
Factors Influencing Choice of Indexes in Oregon

- Range of disturbance between reference and impacted sites often small, especially in forested regions of the state.
- Small range of disturbance requires more intensive field and lab protocols and sensitive biological index.
  - 8 square feet composite sample from multiple riffles
  - 500 minimum count subsamples
  - Identification level - Genus/species for most families.
  - Multi-metric and multivariate models evaluated.
  - BORIS Multivariate Model – **"B**enthic evaluation of **OR**egon r**I**ver**S"**

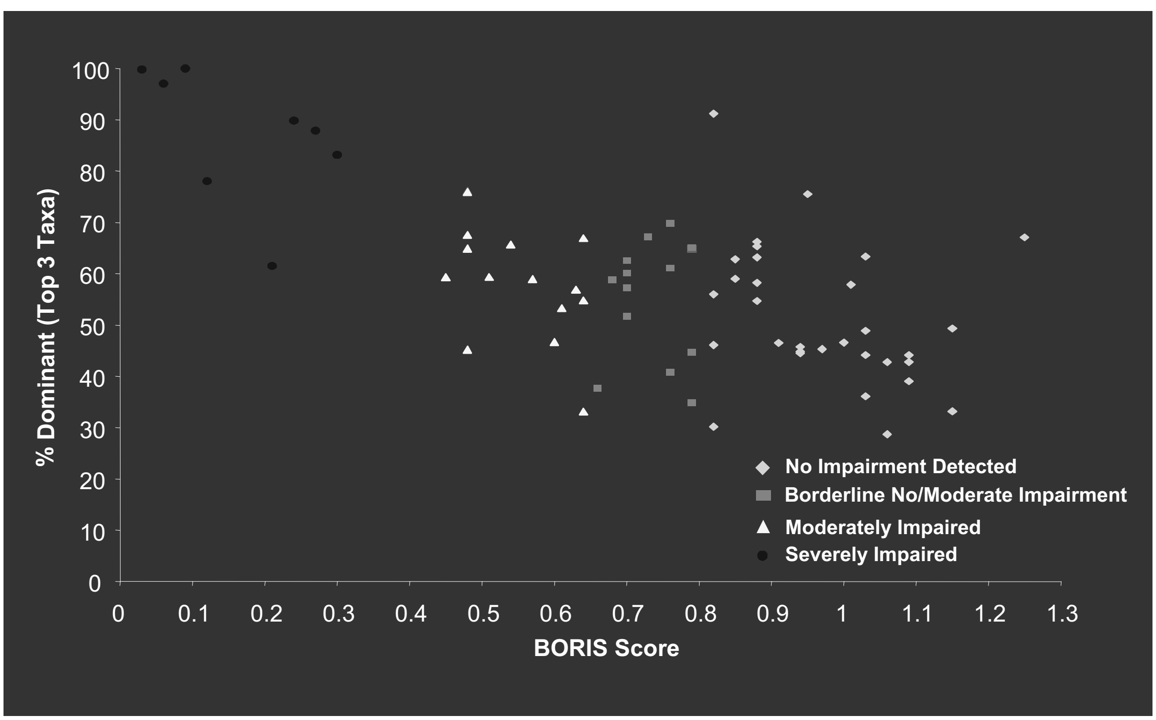
Metric & Multivariate Results



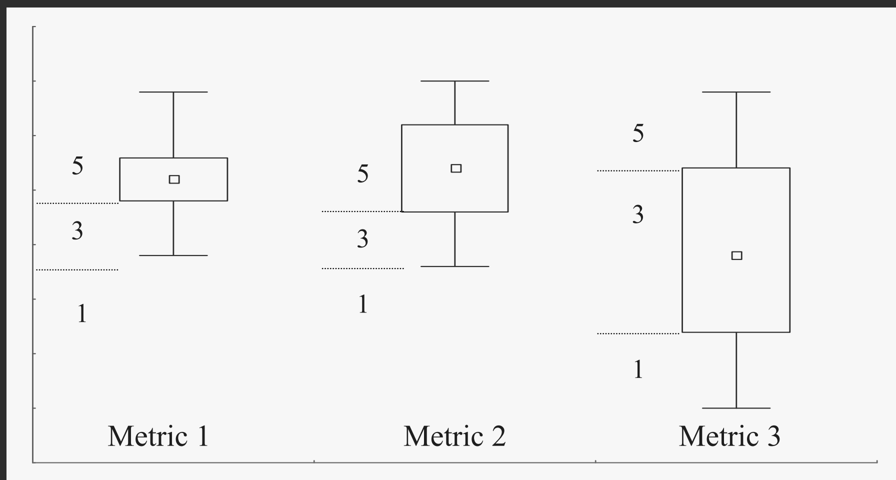
Metric & Multivariate Results



Metric & Multivariate Results



Multi-metrics



Metric 1 = 25th & 10th percentile of reference condition
Metric 2 = X1 & X2 Std. Dev. from reference mean
Metric 3 = 20th & 70th percentile of population range

Multi-metric Scoring Criteria

April

	TotTaxa	EphTaxa	PleTaxa	TriTaxa	SenTaxa	SedInt	%Dom	%Tol	%SedTol	HBI
5pts	>29	>7	>6	>4	>4	>1	<60	<11	<10	<3.2
3pts	24-29	6-7	5-6	3-4	3-4	1	60-71	11-16	10-15	3.2-3.5
1pt	<24	<6	<5	<3	<3	0	>71	>16	>15	>3.5

July

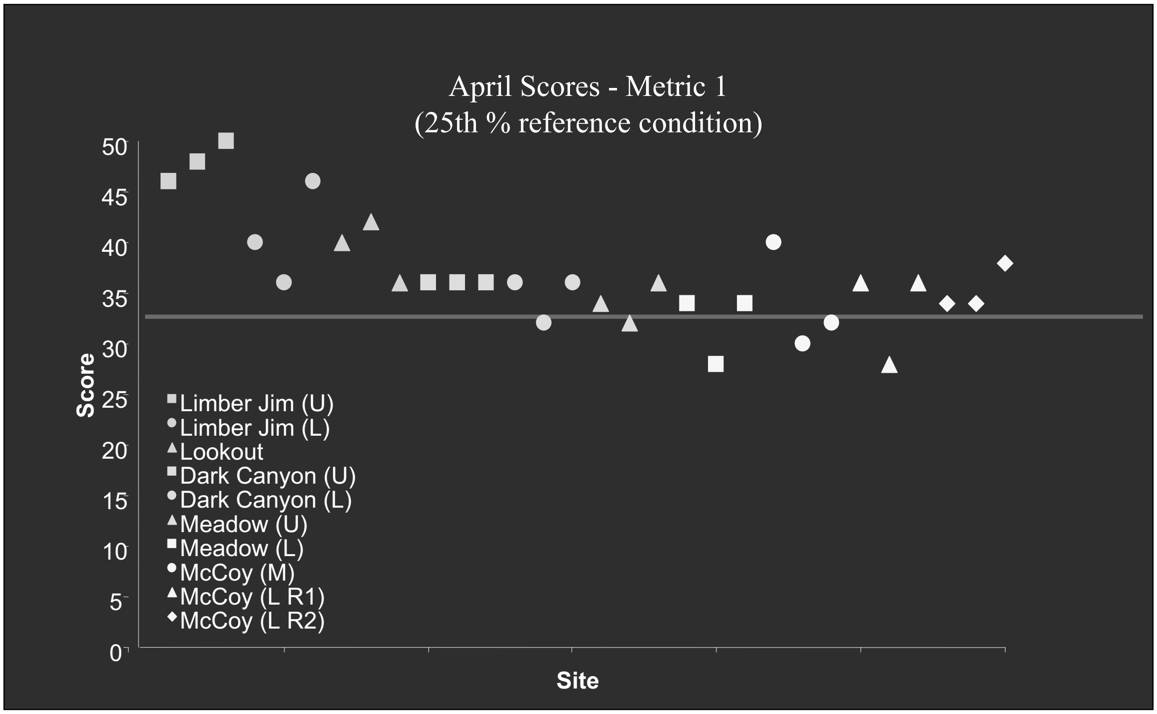
	TotTaxa	EphTaxa	PleTaxa	TriTaxa	SenTaxa	SedInt	%Dom	%Tol	%SedTol	HBI
5pts	>31	>7	>6	>3	>4	>1	<38	<24	<10	<3.9
3pts	24-31	6-7	5-6	1-2	3-4	1	39-42	24-36	10-15	3.9-4.3
1pt	<24	<6	<5	<3	<3	0	>42	>36	>15	>4.3

September

	TotTaxa	EphTaxa	PleTaxa	TriTaxa	SenTaxa	SedInt	%Dom	%Tol	%SedTol	HBI
5pts	>37	>7	>7	>5	>5	>1	<53	<11	<7	<4.0
3pts	33-37	6-7	6-7	4-5	2-5	1	53-62	11-16	7-10	4.0-4.6
1pt	<33	<6	<6	<4	<2	0	>62	>16	>10	>4.6

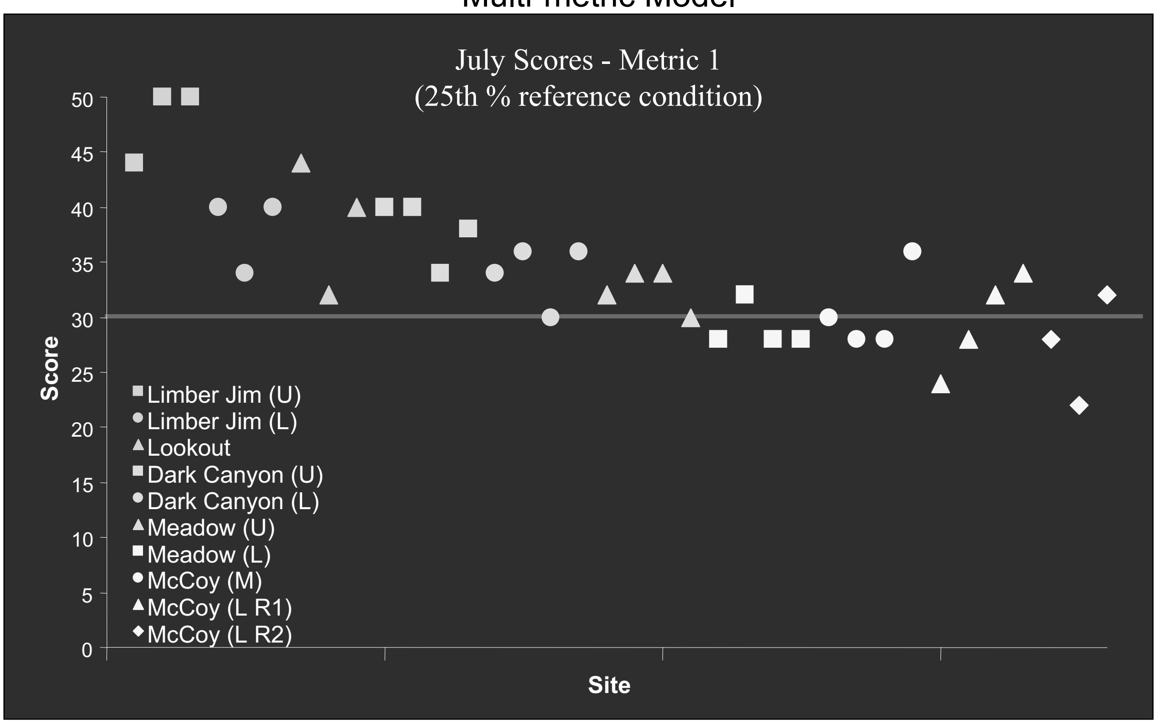
Sensitivity?

Multi-metric Model



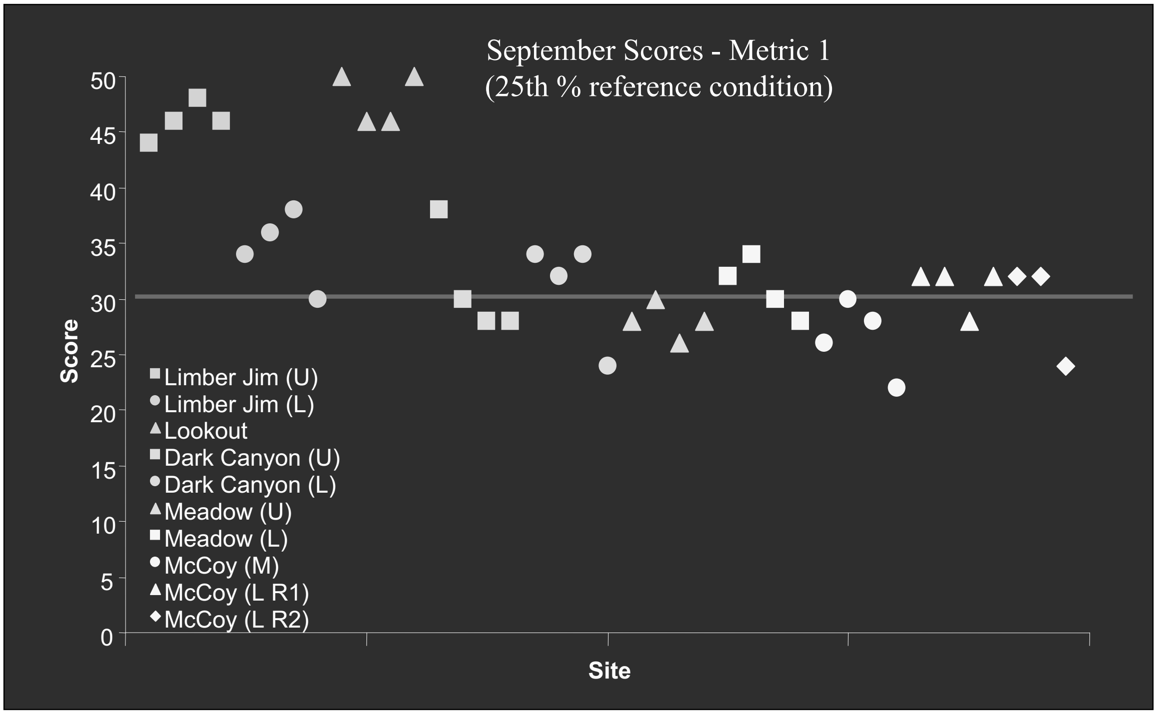
Sensitivity?

Multi-metric Model



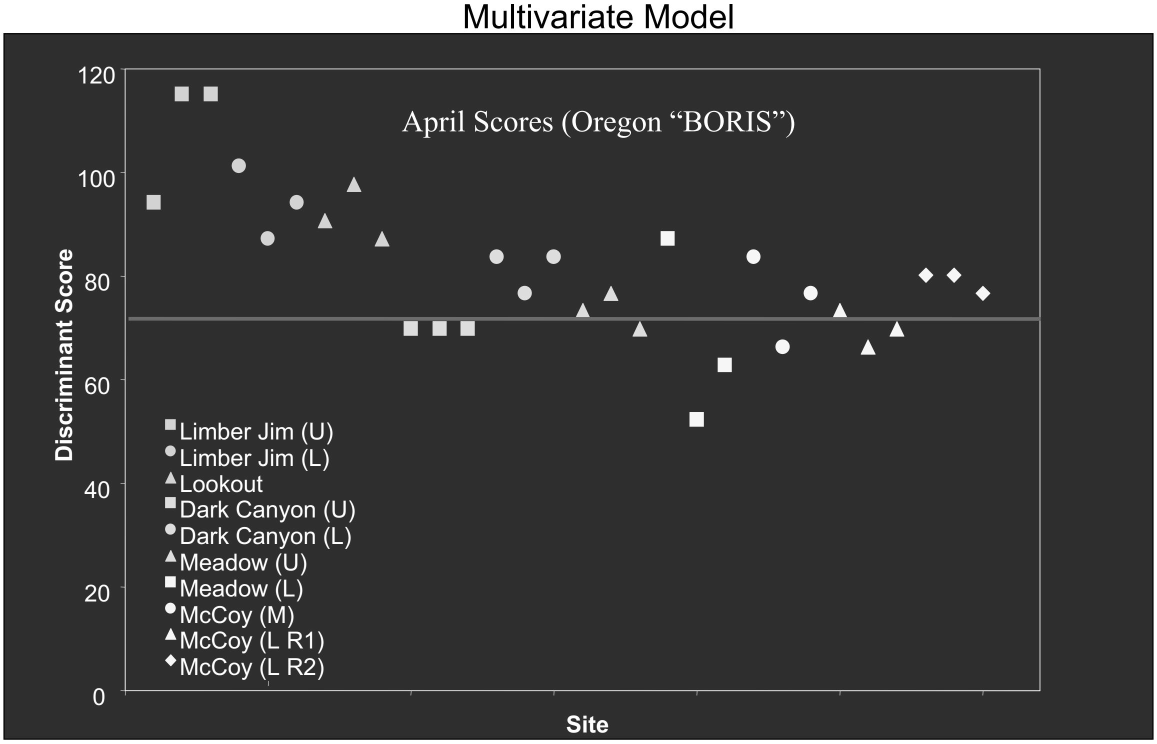
Sensitivity?

Multi-metric Model



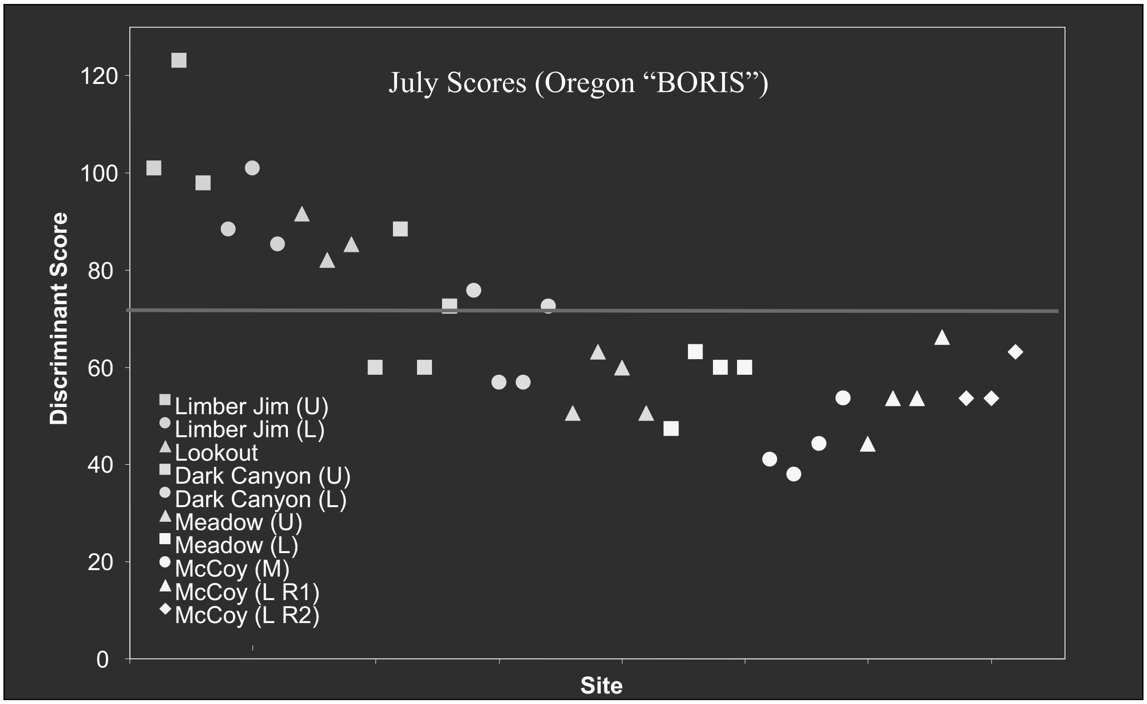
Sensitivity?

Multivariate Model



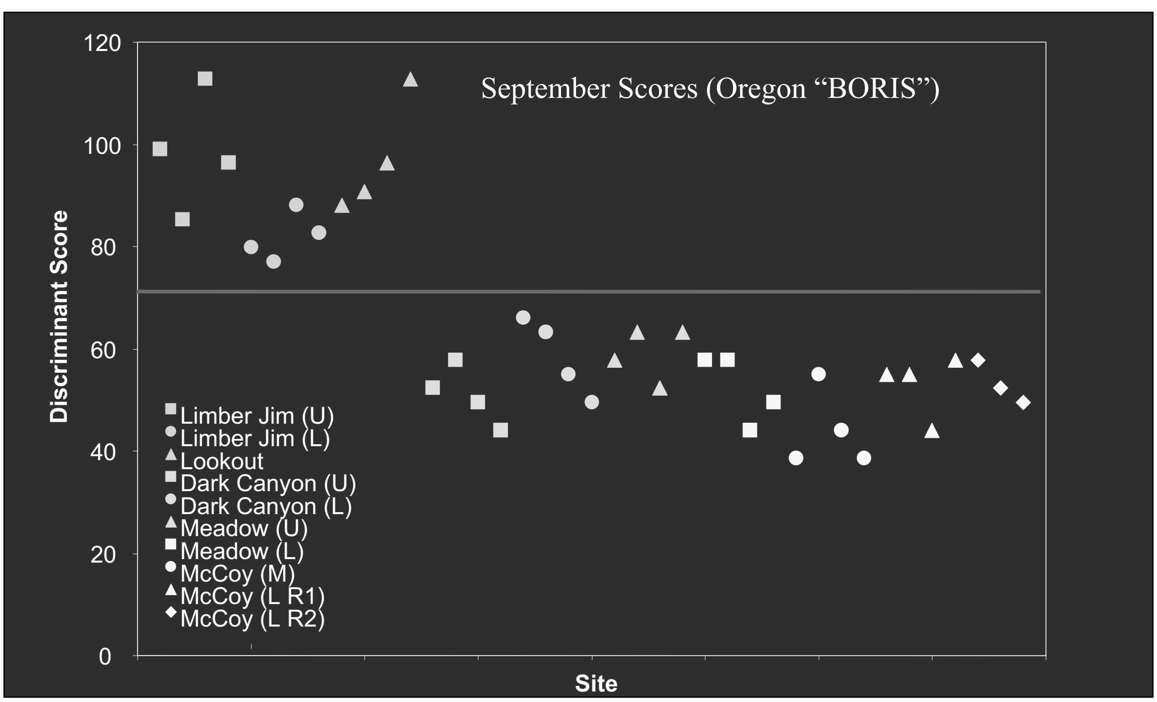
Sensitivity?

Multivariate Model



Sensitivity?

Multivariate Model



Precision

Replicate Site Data Comparison

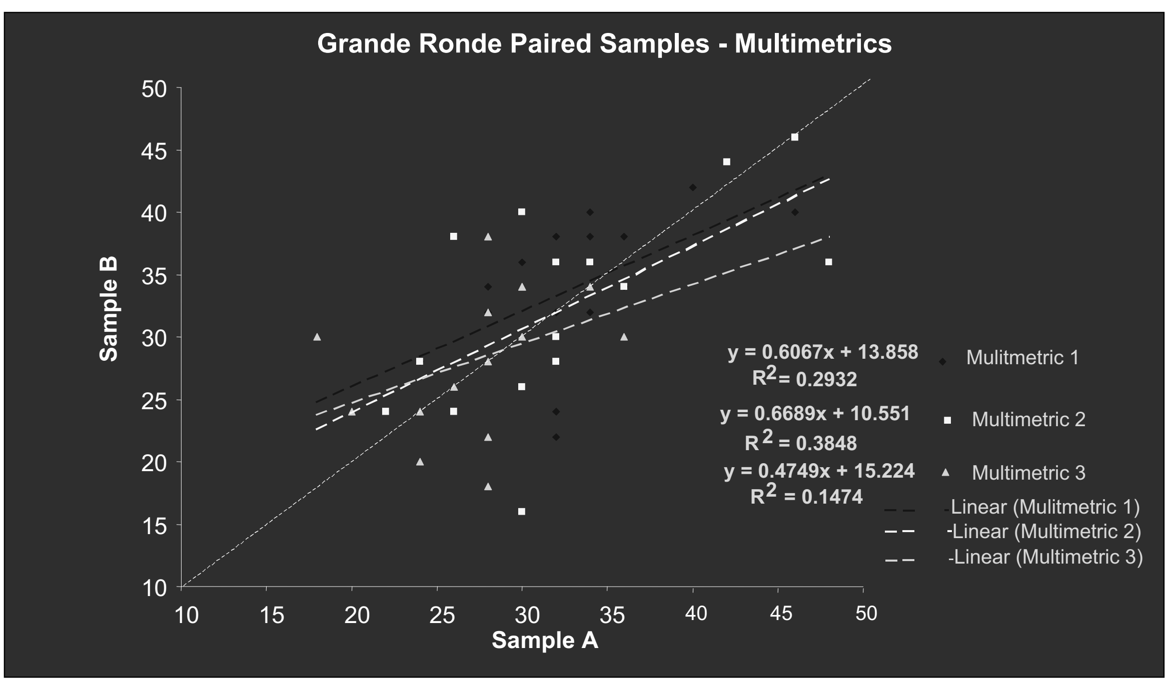
***15 same day duplicate samples compared**

	Range between Duplicate Samples	Mean Difference Between Duplicates
Metrics:		
25th Percentile	0-25	11.3
1 Std. Dev.	0-35	12.7
20th & 70 Percentile	0-30	12
BORIS Model	0-14	6.3

* Data standardized to a 100 point scale

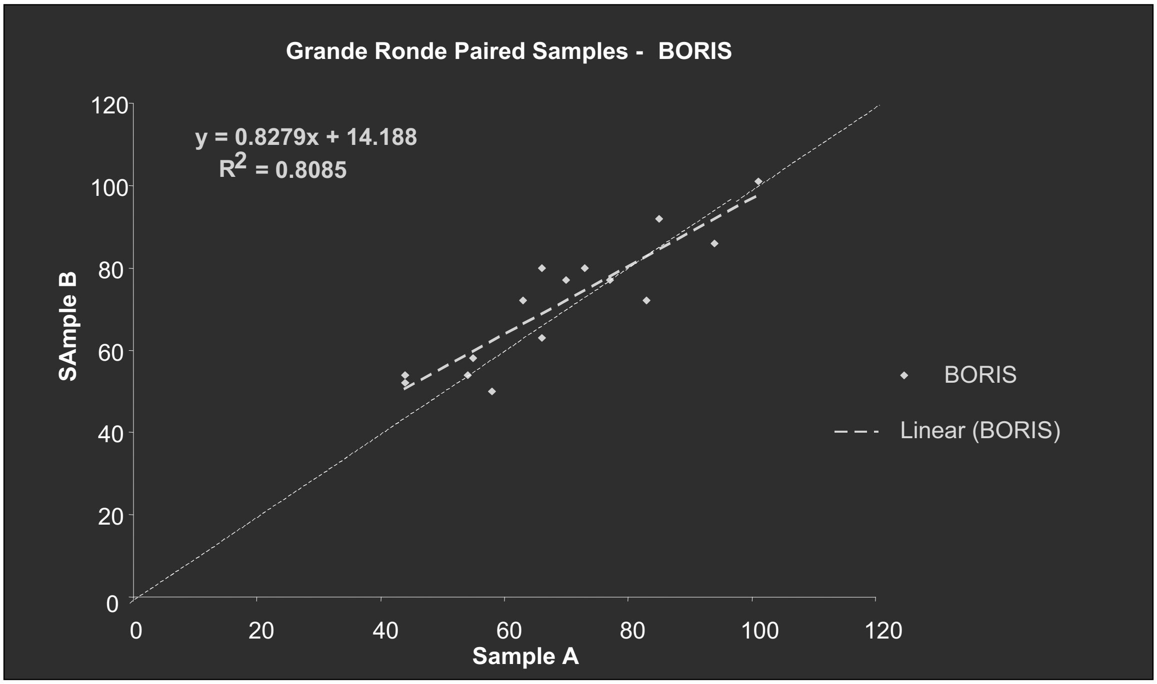
Precision

Replicate Site Data



Precision

Replicate Site Data

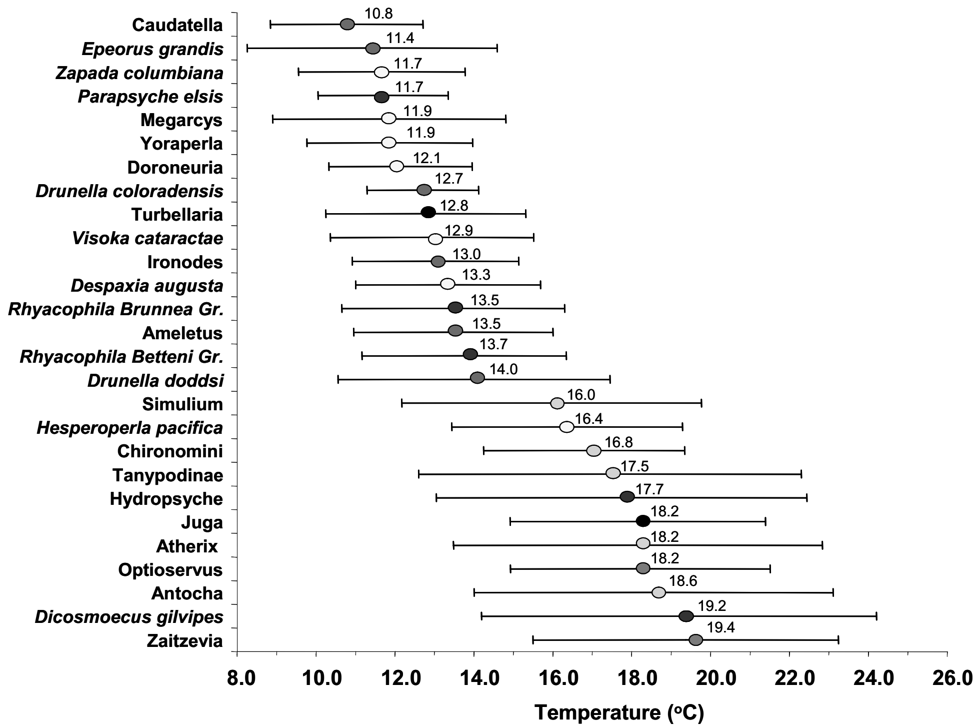


Characterizing Possible Stressors

Multivariate Analysis: List of missing and replacement taxa can be used to characterize some stressor variables.

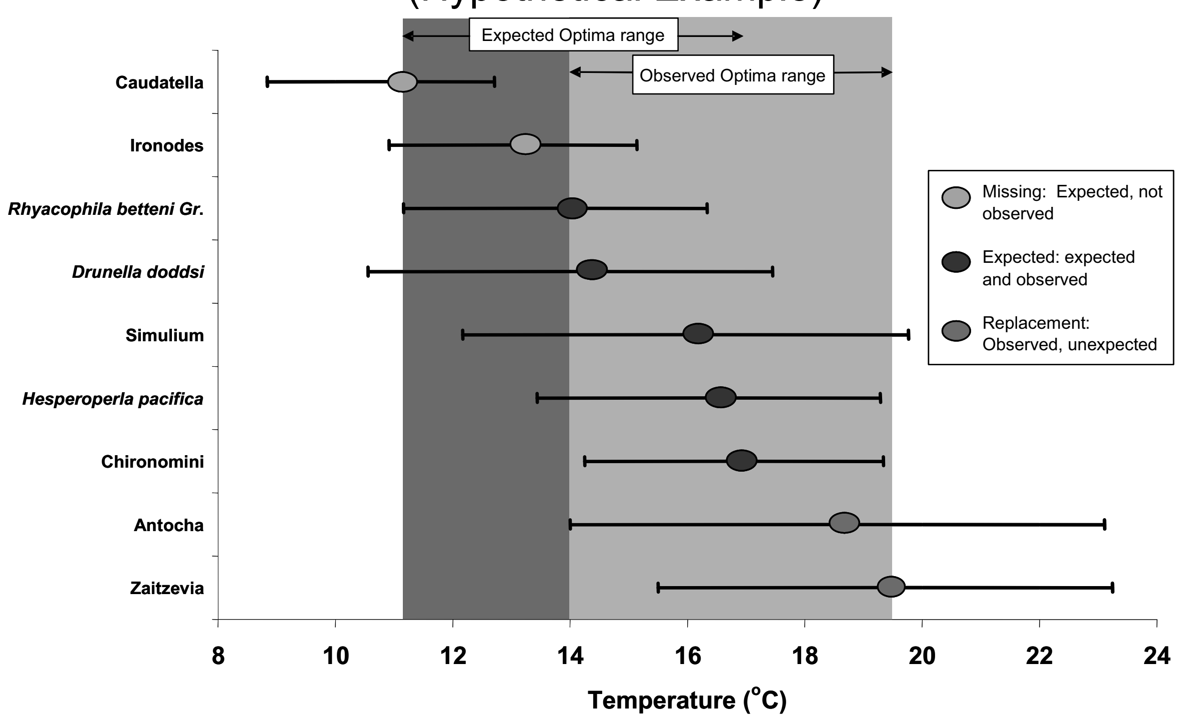
Multi-metric Analysis: Individual metrics provide useful information about different environmental stresses.

Stressor Indicators



Stressor Indicators

(Hypothetical Example)



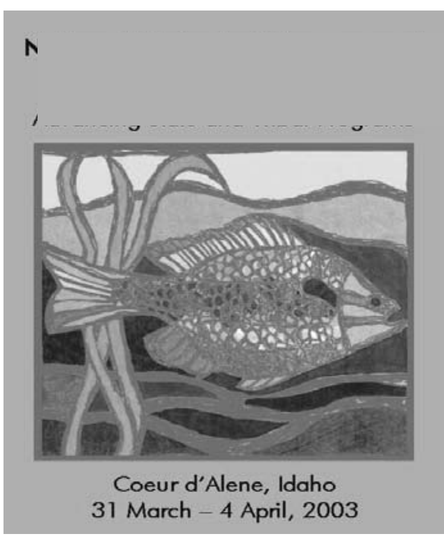
Evaluating Indexes?

Sensitivity: In Oregon multivariate models have shown a slightly higher level of sensitivity to detect changes from reference condition than multi-metric indexes.

Precision: Oregon replicate site data have shown less variability for multivariate models than multi-metric models.

Stressor ID: Both models used in combination probably provide best assessment of environmental stressors.

Reference site requirements: Both methods require reference site information, but multivariate models probably require more intensive reference site sampling than multi-metric indexes.



Index 101

Use of Linear Discriminant Models to Determine Life Use Attainment

Tom Danielson, Susan Davies, Leon Tsomides, and Dave Courtemanch; Maine DEP

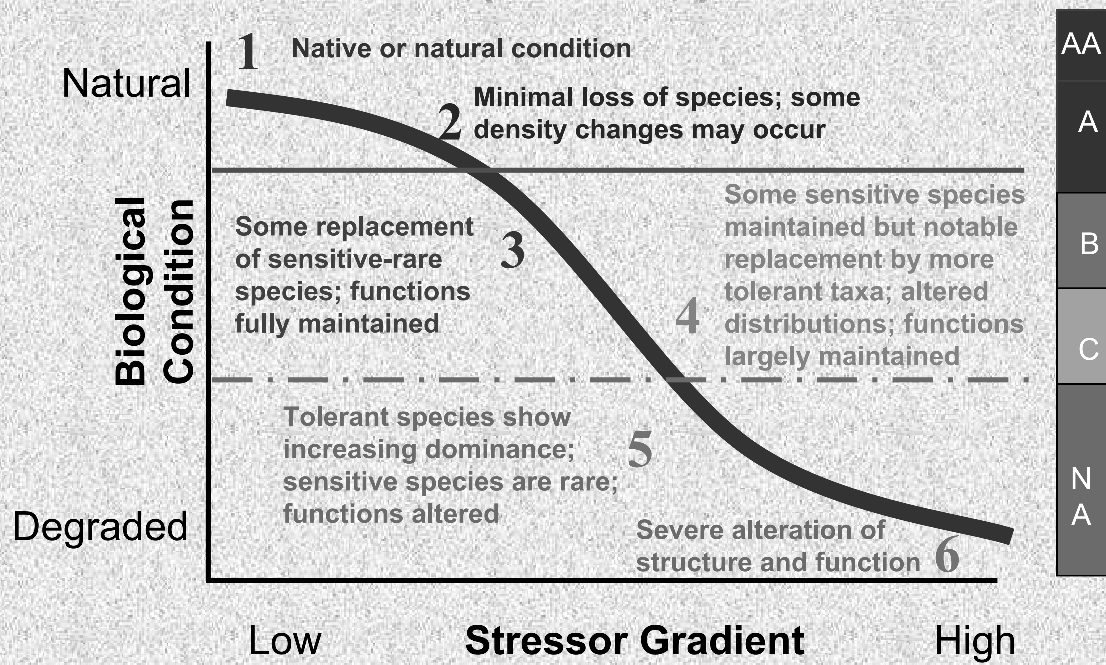
Outline

- Maine's Water Classification System
- Macroinvertebrate Sampling Methods
- Linear Discriminant Models
- Advantages and Considerations

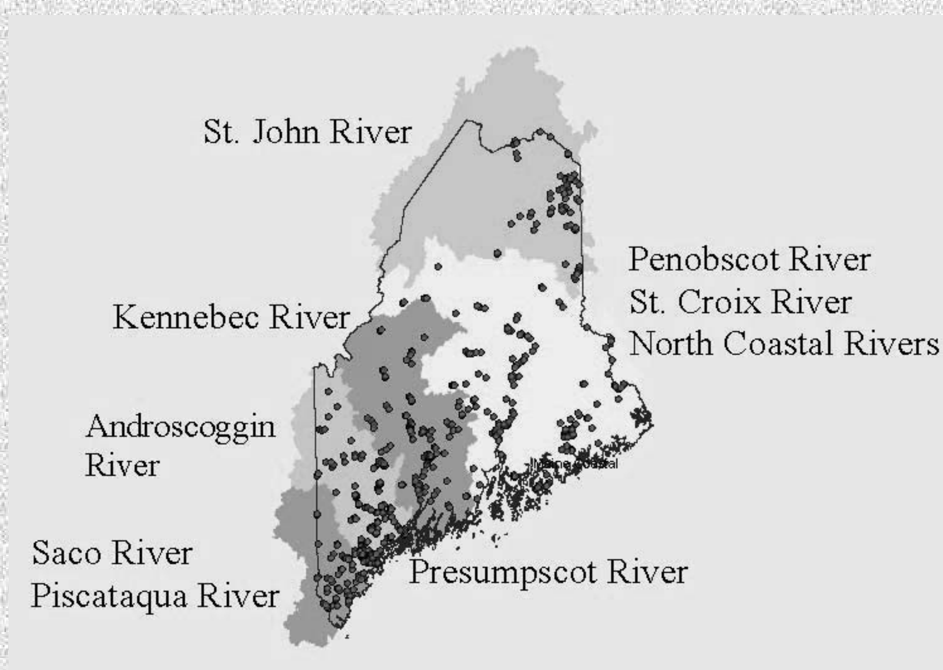
Maine's Water Classification System for Rivers and Streams

- Classes A and AA (treated same for aquatic life use)
  - Aquatic life shall be as naturally occurs.
- Class B
  - no detrimental changes in the resident biological community
  - maintain all indigenous species
- Class C
  - maintain structure and function of resident biological community
- Non-attainment (**NA**)
  - does not meet minimum criteria

Tiered Aquatic Life Use Support (TALUS)



Sampling Stations



Sampling Methods

- Rock bags or baskets
  - Standard volume of cobble
- Usually 3 replicates
- Placed in riffle or run of wadable stream or river
- Left in stream for 4 weeks to allow macroinvertebrates to colonize rocks
- Standard sampling window between July and September

Sampling Methods for Deep Rivers

- 3 or 4 cones filled with standard amount of rocks.
- Cones have attached rope and buoy to facilitate retrieval.
- During retrieval, staff slide a "hat" down the rope to cover cone during retrieval and minimize loss or organisms.
- Divers help retrieve cones if problems arise.

Sampler Retrieval

- Sampler collected with D-frame dipnet to avoid losing critters
- Sampler emptied into sieve bucket
- Sampler and rocks are cleaned inside bucket to remove macroinvertebrates and detritus
- Macroinvertebrates are picked from detritus in the lab

Data Manipulation

- Subsampling and identification
  - <500 individuals - all individuals identified
  - >500 individuals - subsampling is allowed (e.g., 1/2, 1/4)
- Level of taxonomic identification
  - 88% of taxa identifications have been to genus or species
  - 12% of taxa identifications have been to a higher taxonomic level because of early instar or damaged specimens.
  - Taxa counts from replicates are averaged
- Taxa counts are standardized to genus level before model variables are calculated

Development of Linear Discriminant Models

- In 1999, DEP biologists assigned 376 blind samples to one of four *a priori* groups -
  - Class A (n = 120)
  - Class B (n = 117)
  - Class C (n = 72)
  - Non-attainment (NA) of minimum criteria (n = 67)
- DEP biologists included Dave Courtemanch, Susan Davies, and Leon Tsomides
- Assignment of samples was based on abundance, richness, community structure, and ecological theory.

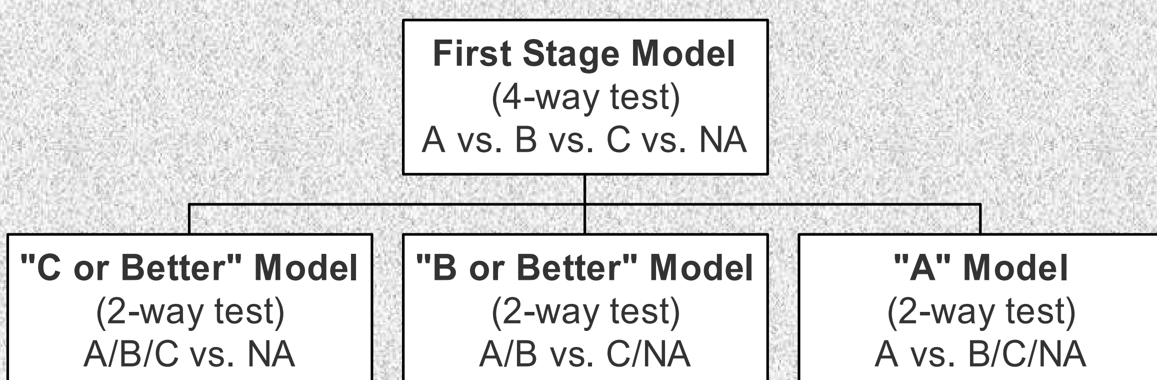
Consistency of *a priori* Assignments

- Consistency of MDEP biologists
  - 96% of independent assignments were unanimous OR majority agreement (2 out of 3)
- Three non-MDEP biologists independently assigned *a priori* classes to samples
  - 80% of independent assignments concurred with MDEP biologists' consensus assignments
- Interpretations did not differ by more than one class in either direction

Development of Linear Discriminant Models

- LDMs are multivariate predictive models that use biological variables to predict a new sample's probability of membership in the four *a priori* groups (A, B, C, & NA).
- For example,
  - Given a set of biological variable values, what is the probability that a sample belongs to the Class A group?

Series of Four Linear Discriminant Models



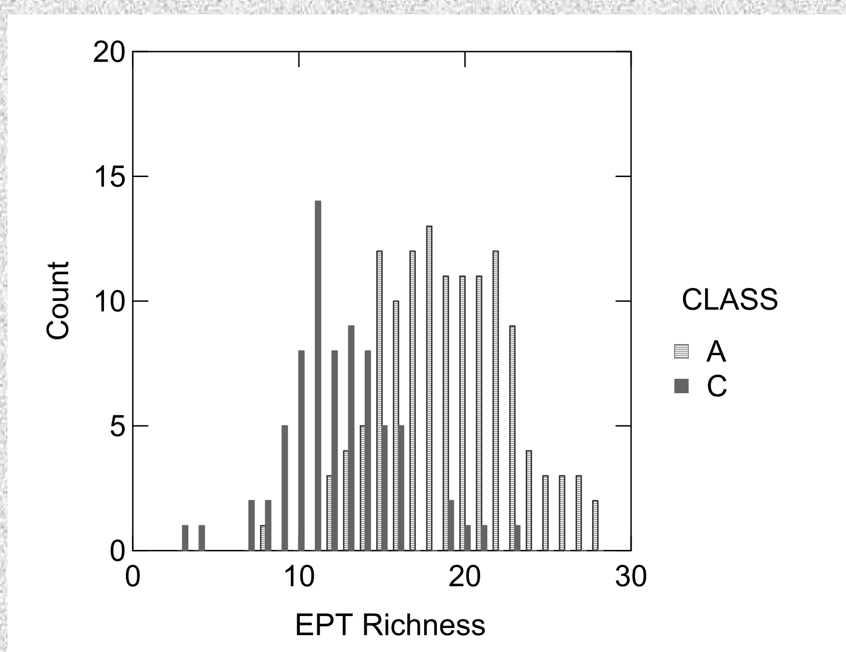
* Aquatic life use attainment decisions are based on the three 2-way tests.

First Stage Model (4-way test)

- Example: 0.30 A, 0.54 B, 0.16 C, 0.00 NA
  - Based on 9 variables
    - Total Abundance of Individuals
    - Generic Richness
    - Plecoptera Abundance
    - Ephemeroptera Abundance
    - Shannon-Weiner Diversity
    - Hilsenhoff Biotic Index
    - Relative Abundance of Chironomidae
    - Relative Generic Richness of Diptera
    - *Hydropsyche* Abundance

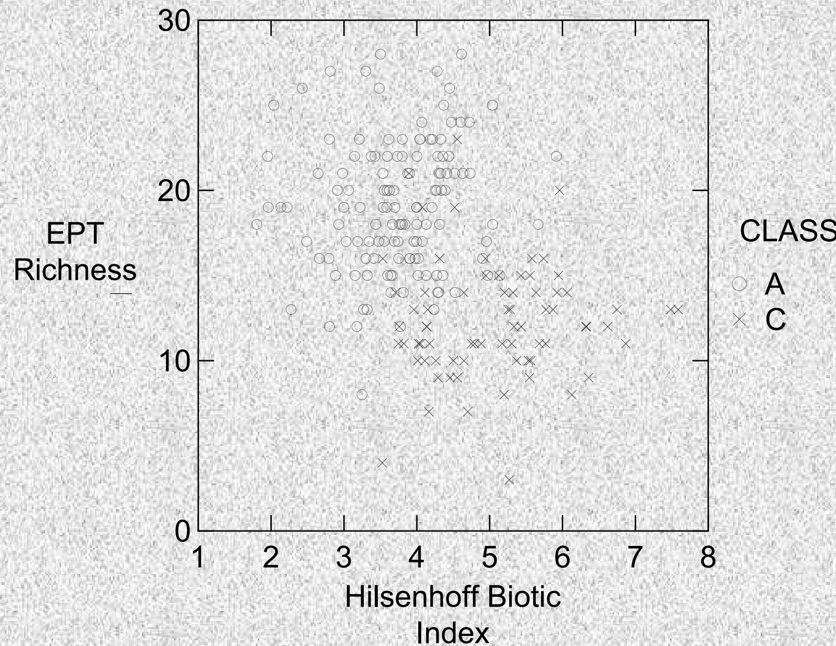
Advantages of Multivariate Analysis

Separation of Class A and Class C samples using 1 variable.



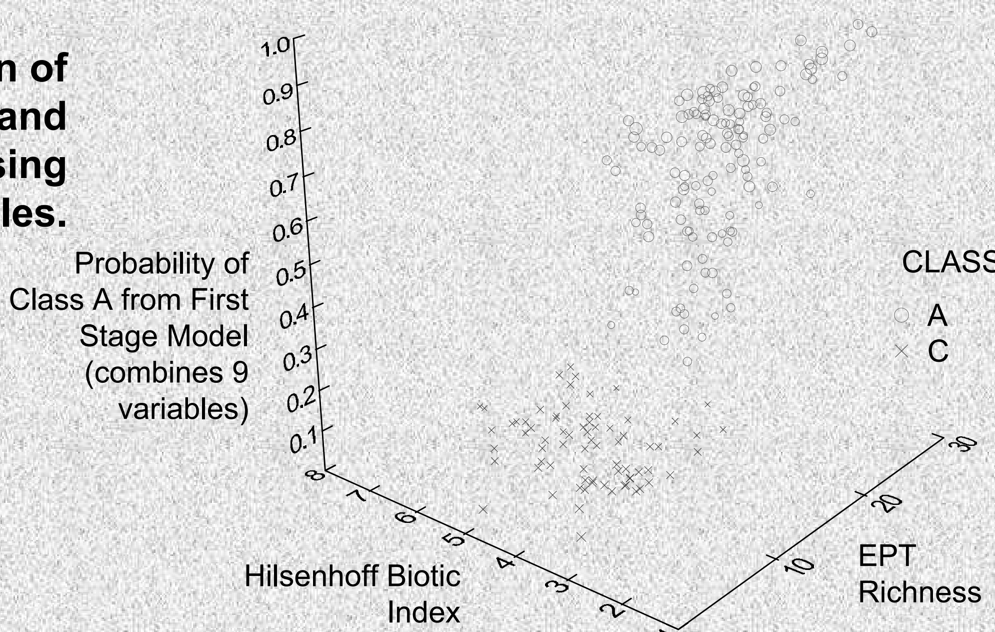
Advantages of Multivariate Analysis

Separation of Class A and Class C samples using 2 variables.



Advantages of Multivariate Analysis

Separation of Class A and Class C using 11 variables.



“C or Better” Model (2-way test)

- Example: 1.00 A/B/C 0.00 NA
  - Based on 4 variables
    - Probability A+B+C from First Stage Model
    - *Cheumatopsyche* Mean Abundance
    - EPT Richness / Diptera Richness
    - Relative Oligochaeta Abundance

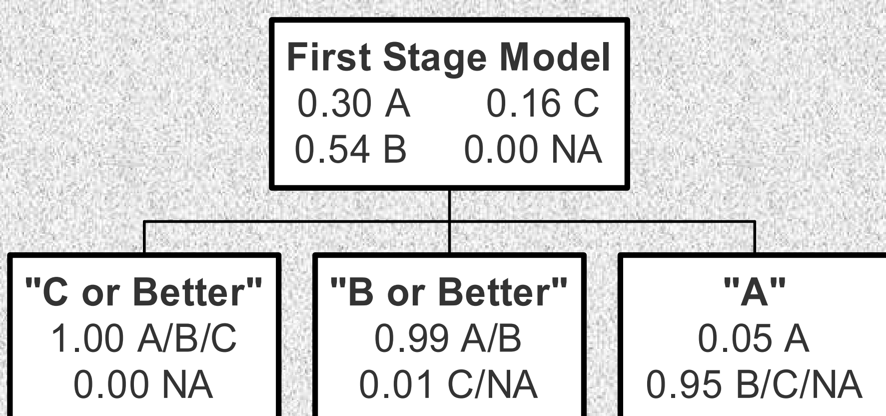
“B or Better” Model (2-way test)

- Example: 0.99 A/B 0.01 C/NA
  - Based on 7 variables
    - Probability A+B from First Stage Model
    - Perlidae Mean Abundance
    - Tanypodinae Mean Abundance
    - Chironomini Mean Abundance
    - Relative Ephemeroptera Abundance
    - EPT Generic Richness
    - Sum of Mean Abundances of *Dicrotendipes*, *Micropsectra*, *Parachironomus*, and *Helobdella*

"A" Model (2-way test)

- Example: 0.05 A 0.95 B/C/NA
  - Based on 6 variables
    - Probability A from First Stage Model
    - Relative Plecoptera Richness
    - Sum of Mean Abundances of *Cheumatopsyche*, *Cricotopus*, *Tanytarsus*, and *Ablabesmyia*
    - Sum of Mean Abundances of *Acroneuria* and *Stenonema*
    - Ratio EP Generic Richness
    - Ratio of Class A Indicator Taxa (*Brachycentrus*, *Serratella*, *Leucrocuta*, *Glossosoma*, *Paragnetina*, *Eurylophella*, and *Psilotreta*)

Results of Linear Discriminant Models



* Based on p=0.60 threshold, result is Class B.

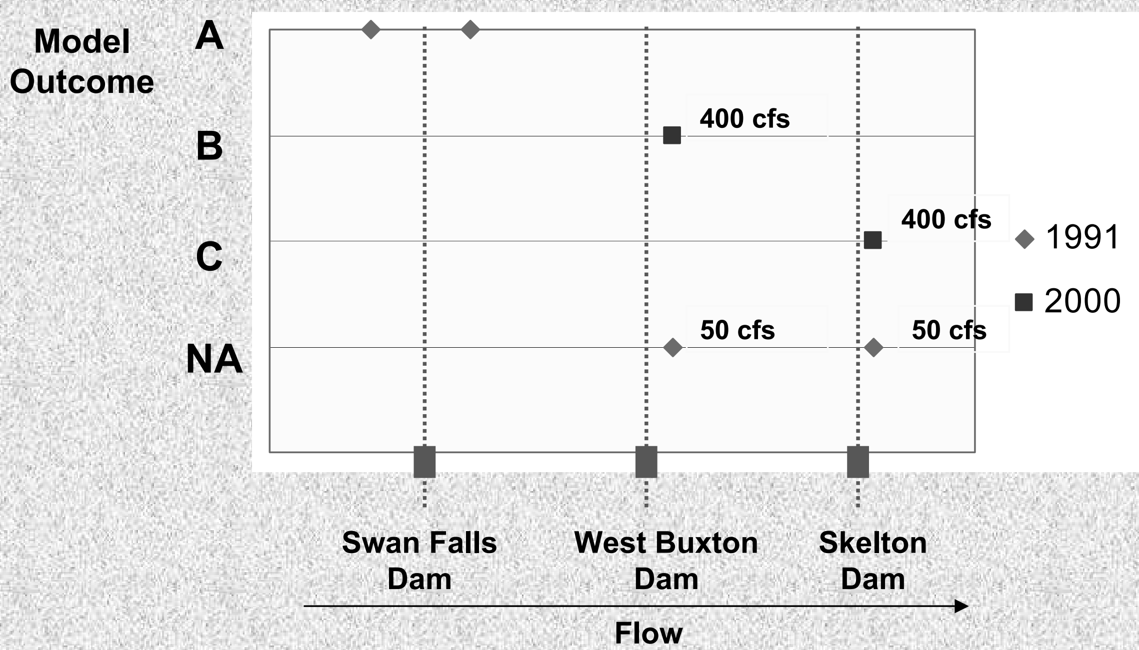
Model Performance

Class A Model				B or Better Model				C or Better Model			
		Model Prediction				Model Prediction				Model Prediction	
		A	B,C,NA			A,B	C,NA			A,B,C	NA
A Priori	A	**87%**	13%	A Priori	A,B	**94%**	6%	A Priori	A,B,C	**96%**	4%
	B,C,NA	9%	91%		C,NA	6%	94%		NA	12%	88%

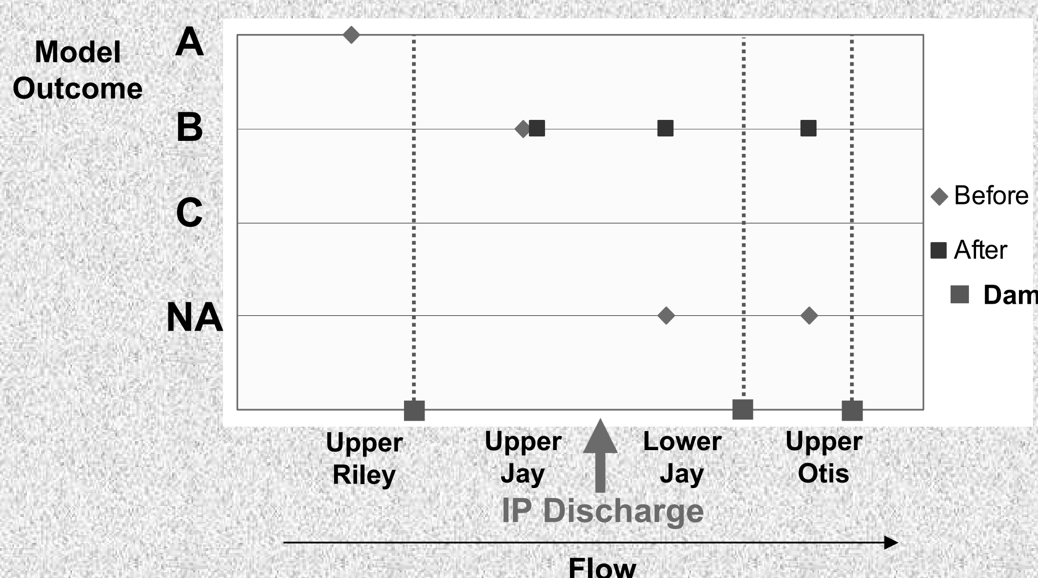
Advantages of Approach

- Direct relationship between model outcomes and aquatic life uses.
  - Translates broad resource goals and objectives to scientifically defensible, quantitative thresholds
- Based on ecological theory and demonstrated to reflect changes in resource condition.
- Statistically based with known probability of error.

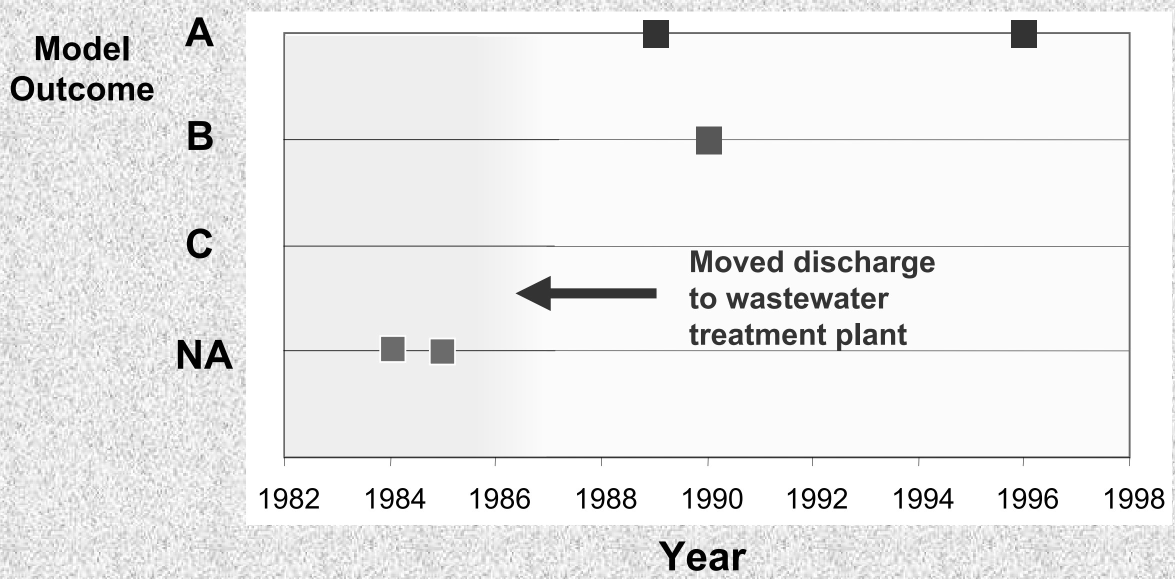
Effects of Increasing Flow below Dams on the Saco River



Effects of Removing TSS Discharge on Androscoggin River Impoundments



Reducing Discharges from Guilford Industries into Piscataquis River



Considerations of Approach

- Process of assigning *a priori* classes requires experienced biologists
  - but classification steps in developing multimetric indexes and predictive models also greatly benefit from having experienced biologists
- Requires periodic recalibration as number of samples in database increases.
- Possible circularity based on *a priori* classification
  - Do Class A model outcomes represent minimally-disturbed reference conditions?

Does the model accurately classify minimally disturbed streams?

- **27** samples were selected with following criteria:
  - not used to build the model
  - no known point sources
  - average % of upstream watershed
    - 94% forested
    - 3% logged
    - 2% crop
    - 1% residential
    - <1% urban/industrial/commercial
- **24 (89%)** of samples had model outcomes of class A

For More Information

- Biomonitoring Web Site
  - http://www.state.me.us/dep/blwq/docmonitoring/biomonitoring/index.htm
- Methods Manual
  - http://www.state.me.us/dep/blwq/docmonitoring/finlmeth1.pdf
- Fifteen Year Retrospective
  - http://www.state.me.us/dep/blwq/docmonitoring/biomonitoring/biorep2000.htm
- E-mail
  - biome@maine.gov