Clean Water is Not Enough: The Scientific Foundations of Biological Monitoring and Assessment



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Historically, water managers emphasized quality and quantity of water – the fluid

Growing concern about

the biology of waters

is changing that

perspective.

Foundation 1 Shifting Indicators

Administrative: permits, grants (bean counts)

Stressor: land-use change, effluent reduced

Exposure: pollutant conc., physical habitat

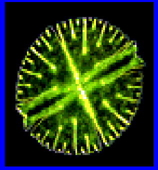
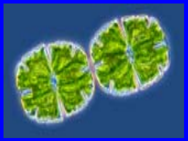
Response: biological measures, indexes (IBI)

New ENDPOINT:

biological condition as primary indicator "no civilization can wage relentless war on life without destroying itself, and without losing the right to be called civilized."

Rachel Carson, 1963






Pioneers – Biological Assessment

Stephen Forbes, 1880s
Illinois

Dr. Ruth Patrick, a pioneer in assessing the health of water bodies.

R. Kolkwitz & K. Marsson.
Ökologie der tierischen Saprobien.
1909

Ruth Patrick, 1940s
Pennsylvania

Despite those insights, chemical pollutant focus dominated 20th century

"... the various forms of life in a river are purely incidental, compared with the main task of a river, which is to conduct water runoff from an area toward the oceans."

H. A. Einstein, 1972

River Ecology

Resurgence of Bioassessment – 1980s

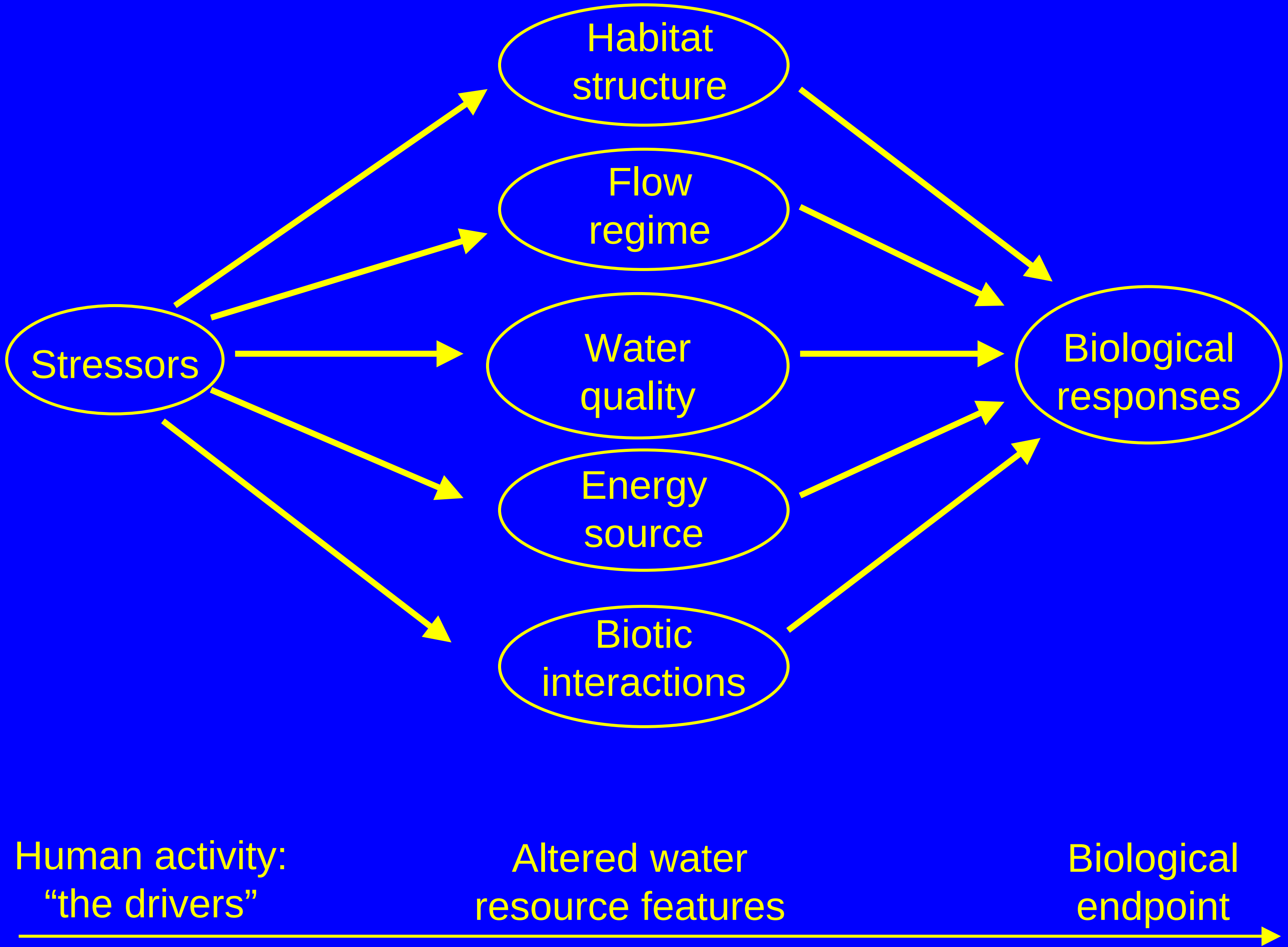
"Few events can transform the nature of a discipline as has the development and application of the original index of biotic integrity"

W. Davis, US EPA, 1999

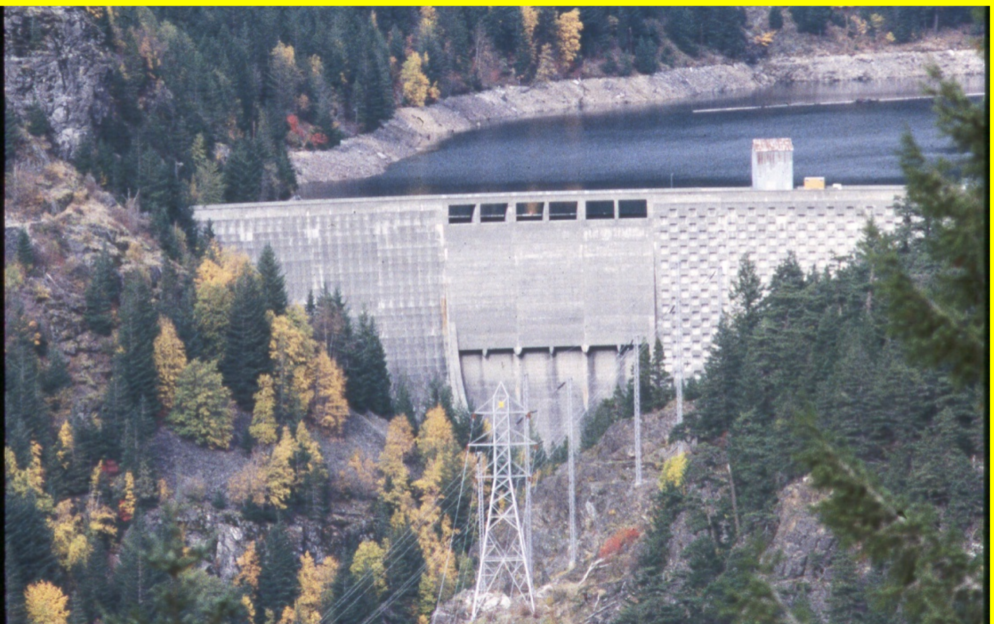
Foundation 2

Clean Water is Not Enough

We can no longer ignore
the “five factors”


Habitat structure
Flow regime
Stressors
Water quality
Biological responses
Energy source
Biotic interactions
Human activity: “the drivers”
Altered water resource features
Biological endpoint

Pollutants and Pollution



Pollutants and Pollution

Pollutant: substance or material added to waters by human activity.   CWA 502(6); 33 U.S.C. § 1362(6).

Pollution: human-induced "alteration of chemical, physical, biological and radiological integrity of water."   CWA 502(19); 33 U.S.C. § 1362(19).

Effects on Aquatic Ecosystem

Direct effects
- channel modifications
- riparian clearing
- water withdrawal
- addition of alien taxa

Indirect effects
- changing land use
- appropriation of water
- stormwater runoff
- pollutant generation

Habitat structure

Flow regime

Water quality

Energy sources

Biotic interactions

Biological responses

Human activities (stressors)

Altered water resource features

Biological endpoint

General Trends

1. Physical variables → Biological variables

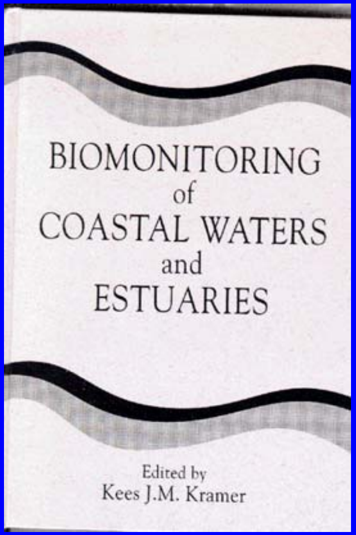
2. Chemical stressors → All stressors

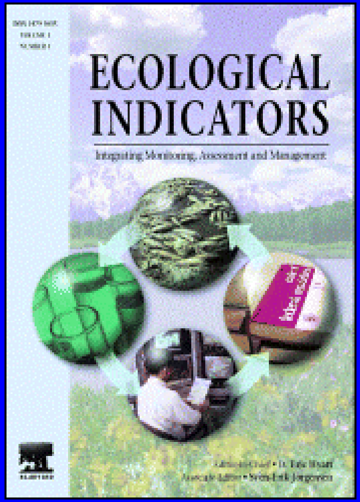
3. Narrow view → Integrative view

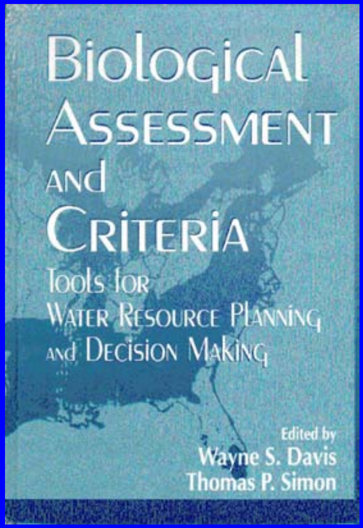
4. Single indicators → Multimetric IBI*

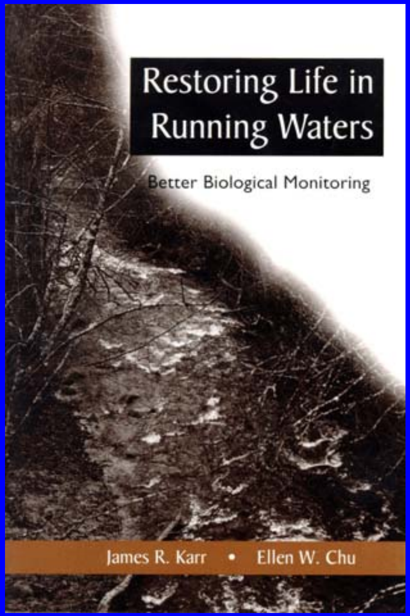
* Index of biological integrity (fish, inverts, algae, etc.)

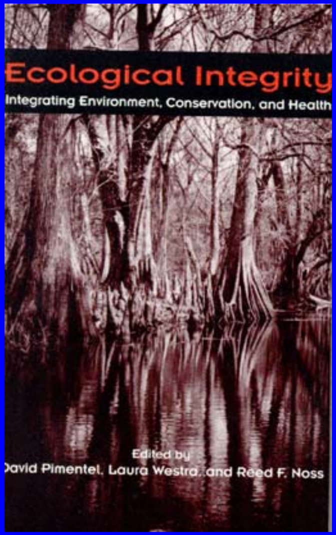
Recent Publications

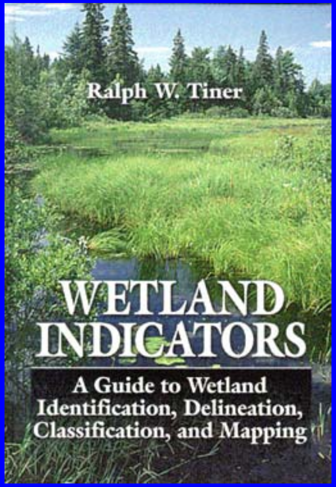


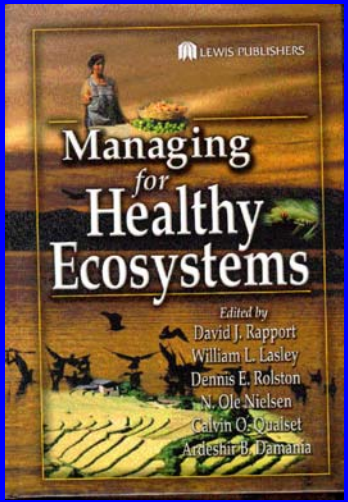


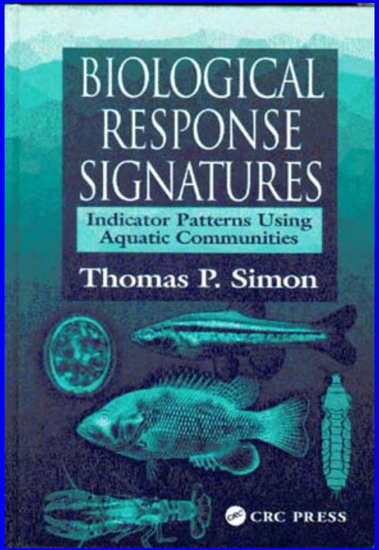


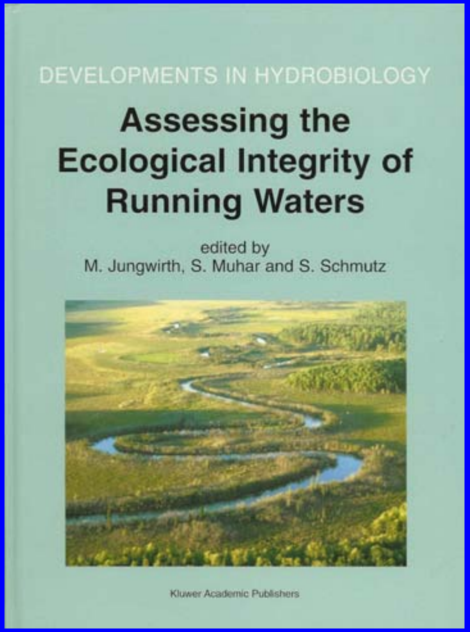












- Human activities (e.g., grazing, logging, point-source effluent, agriculture, transportation corridors, urbanization)

alter

- Five factors (HS, WQ, FR, ES, BI)

with

- Numerous biological consequences

that

- Degrade biological condition

The goal is to establish monitoring and assessment protocols to measure biological condition and protect biological integrity

Central Question:

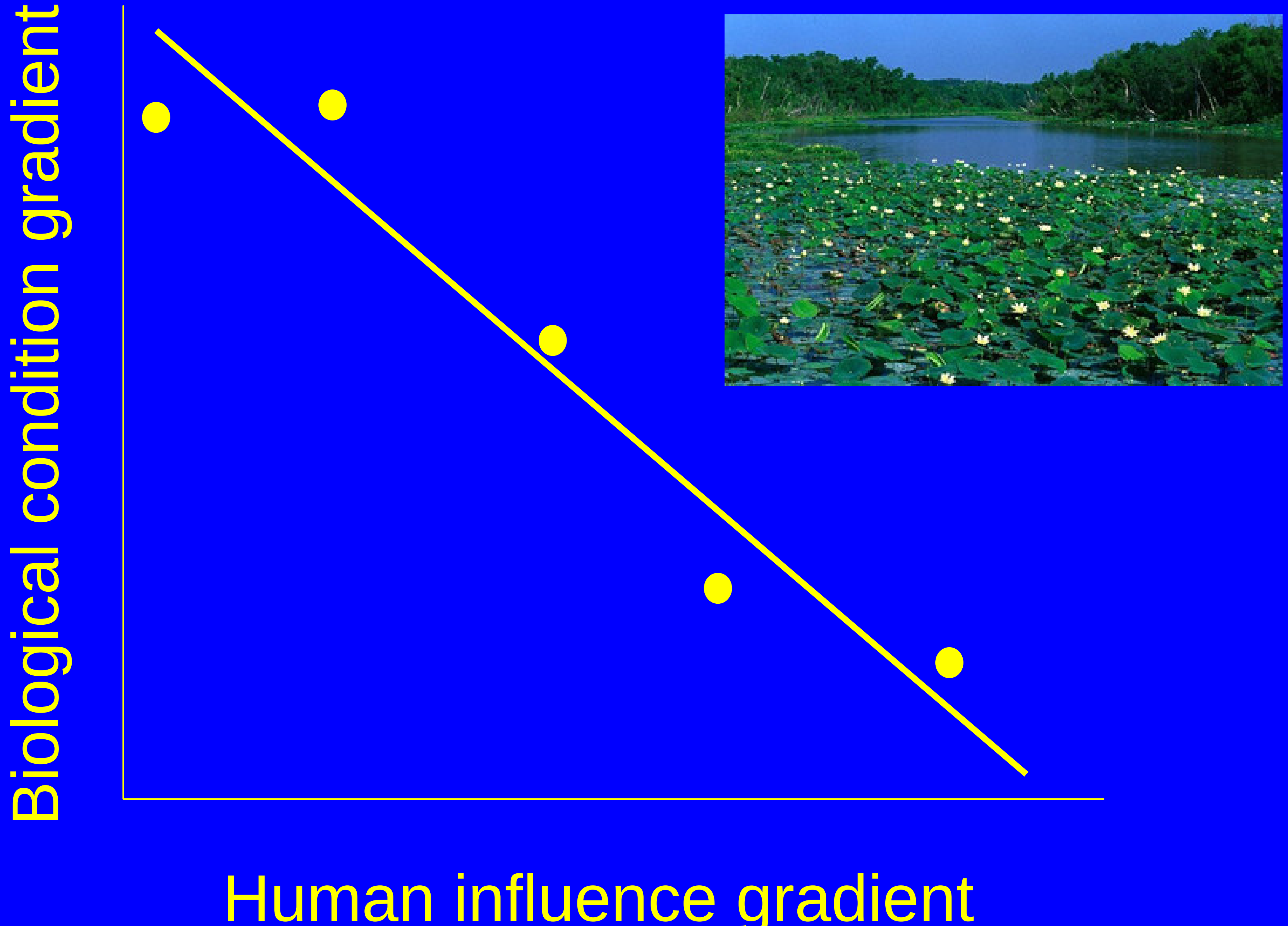
How do we measure biological condition?

Foundation 3

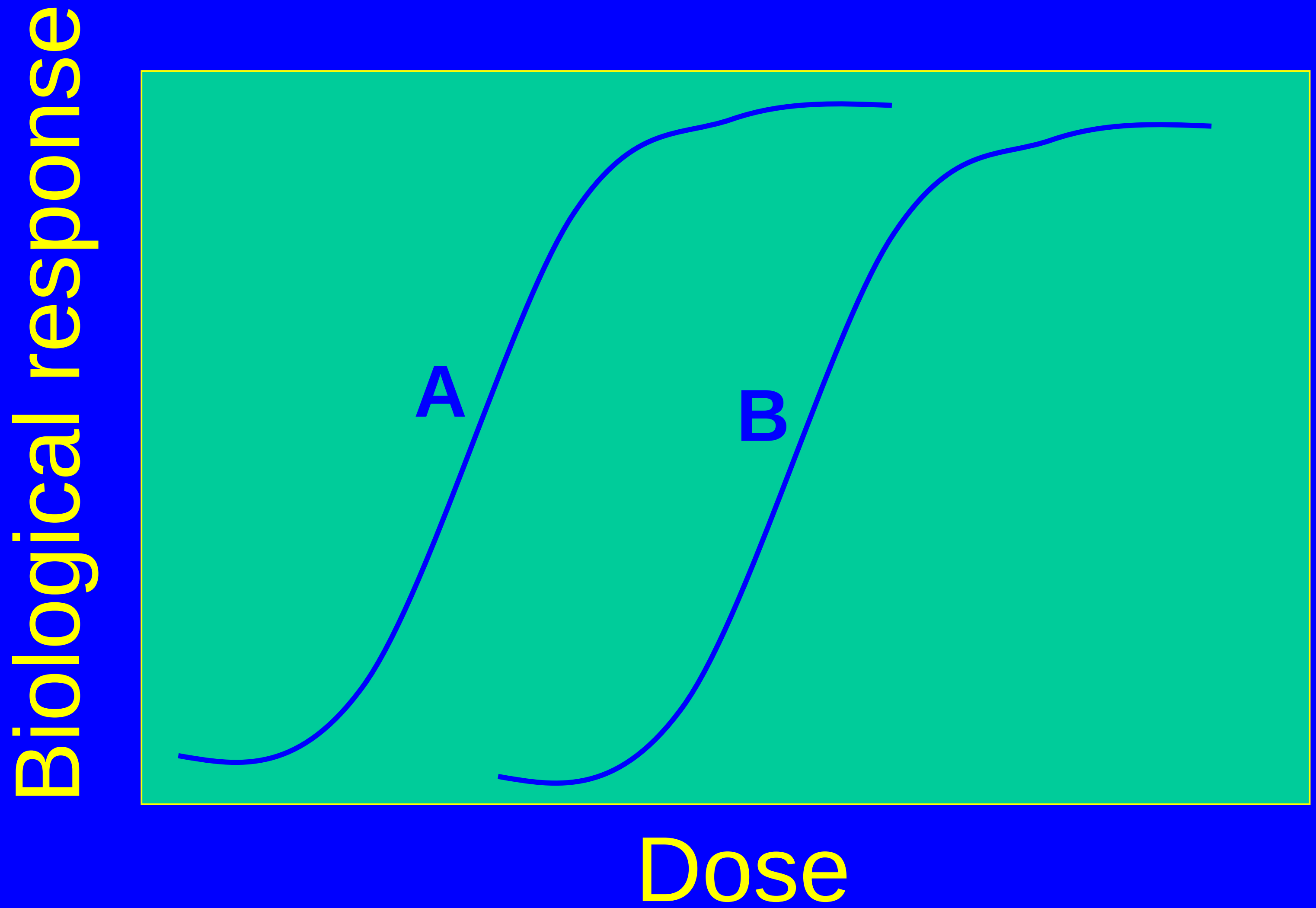
Ecological dose-response curves.

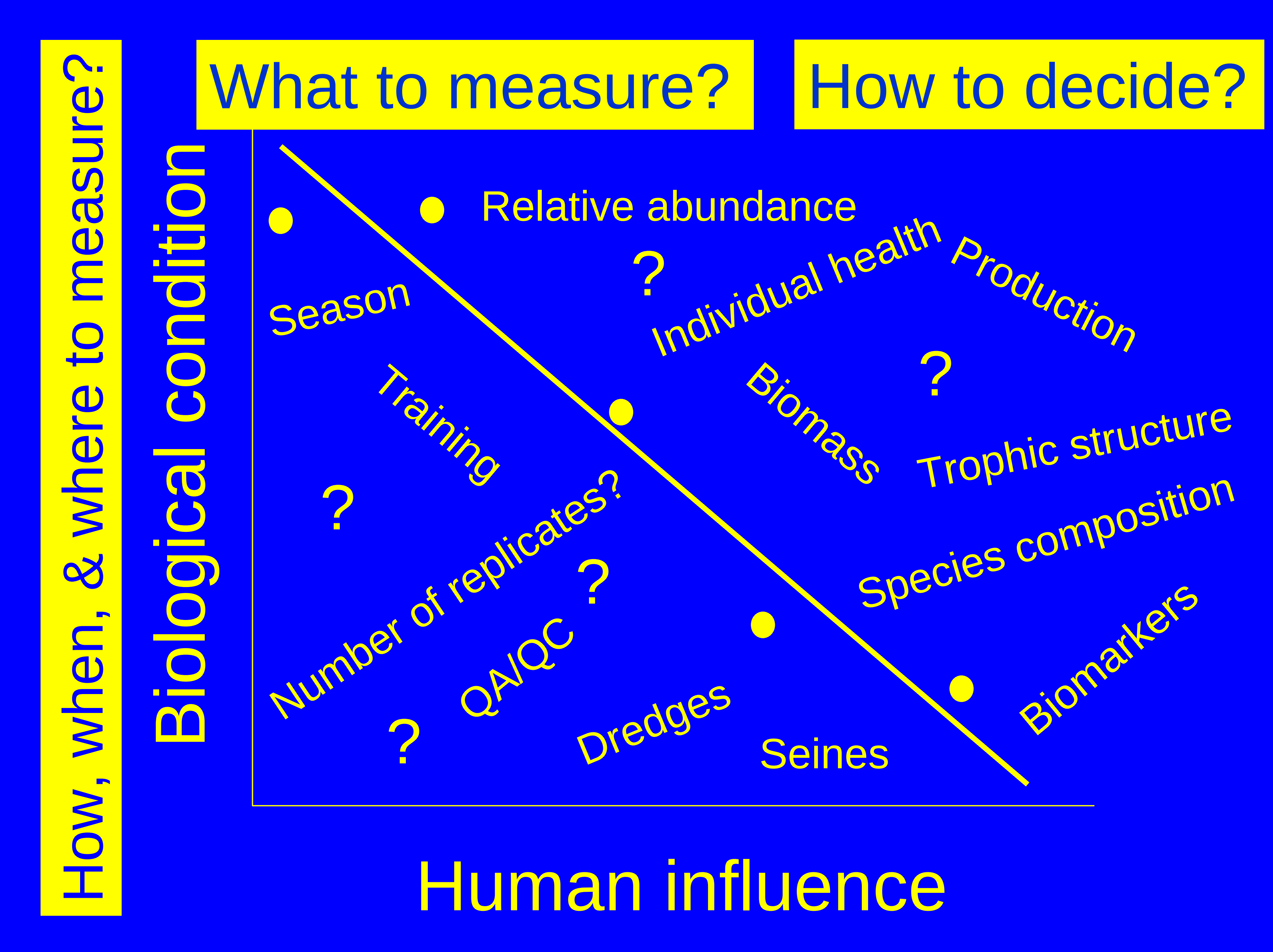
Relationship between human influence gradient and biological condition gradient

Ecological Dose-Response Curves



Dose-Response Curves (Toxicology)





How, when, & where to measure?
What to measure?
How to decide?
Biological condition
Relative abundance
?
Individual health
Production
Season
Training
Biomass
?
Trophic structure
?
Number of replicates?
?
Species composition
QA/QC
Biomarkers
?
Dredges
Seines
Human influence

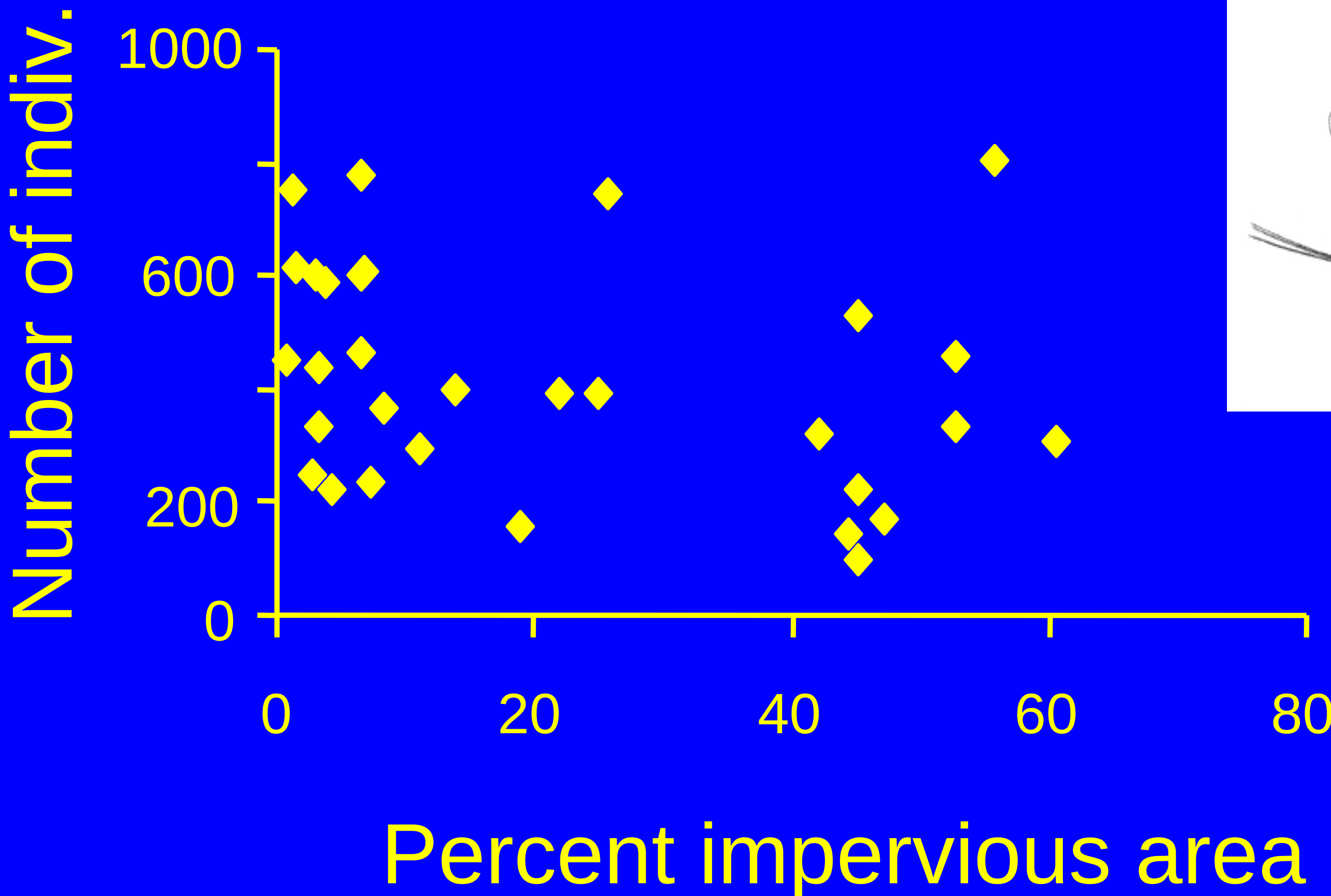
Five Crucial Activities

- Classify environment types
- Select reliable and relevant signals: metrics
- Develop appropriate sampling protocols and designs
- Define analytical procedures to extract and display patterns
- Communicate results to citizens and others

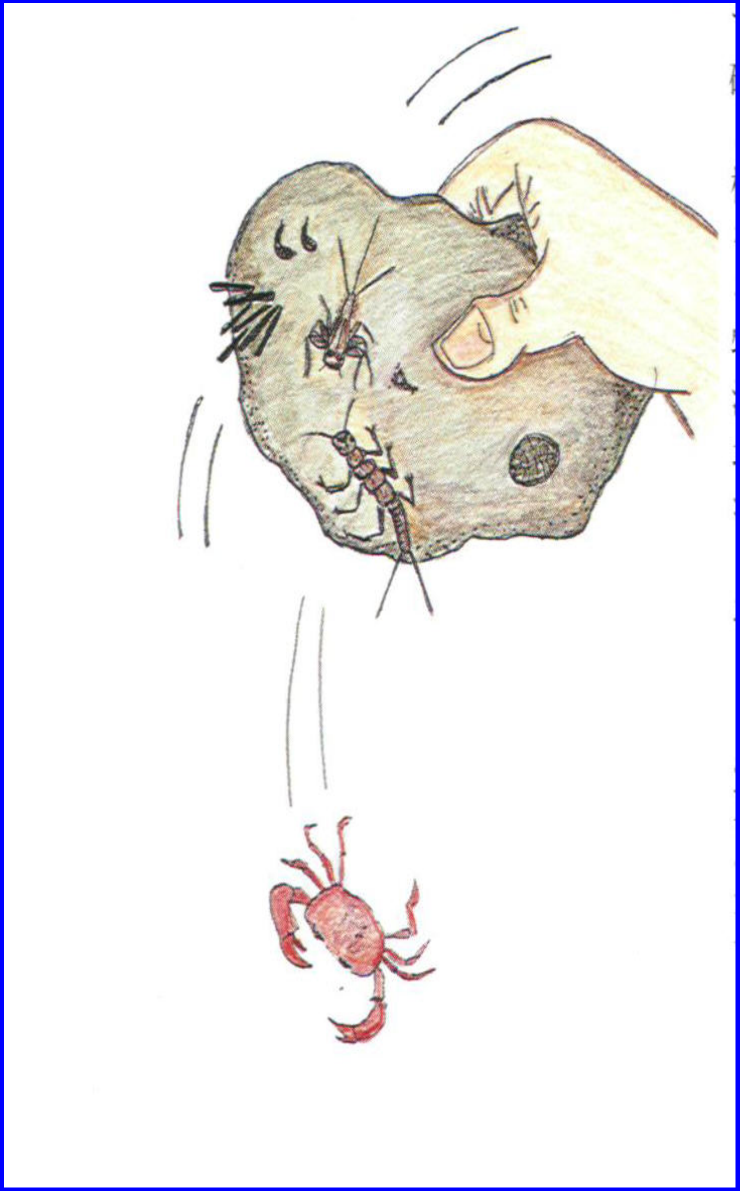
Foundation 4

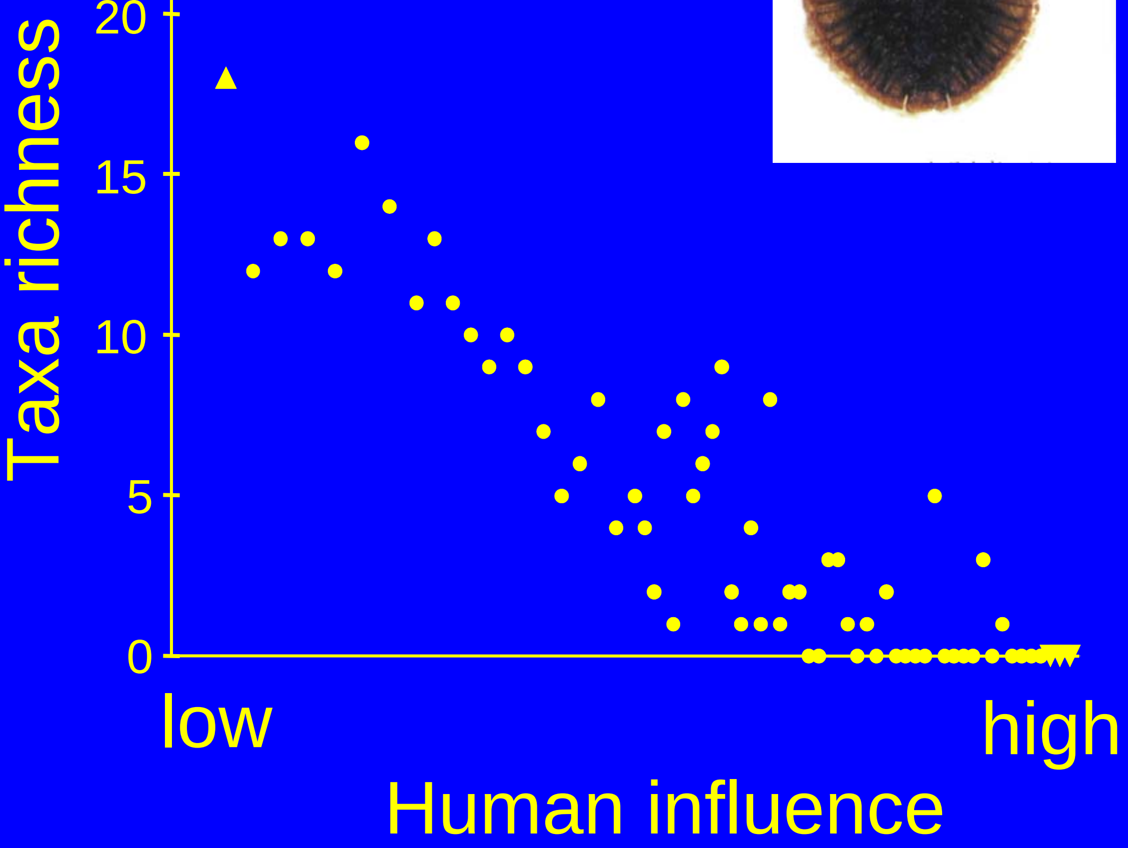
Identify metrics that provide clear,consistent, and easily interpreted signal.

Puget Sound Streams - 1994



Clinger taxa richness





Biological Assessment Process

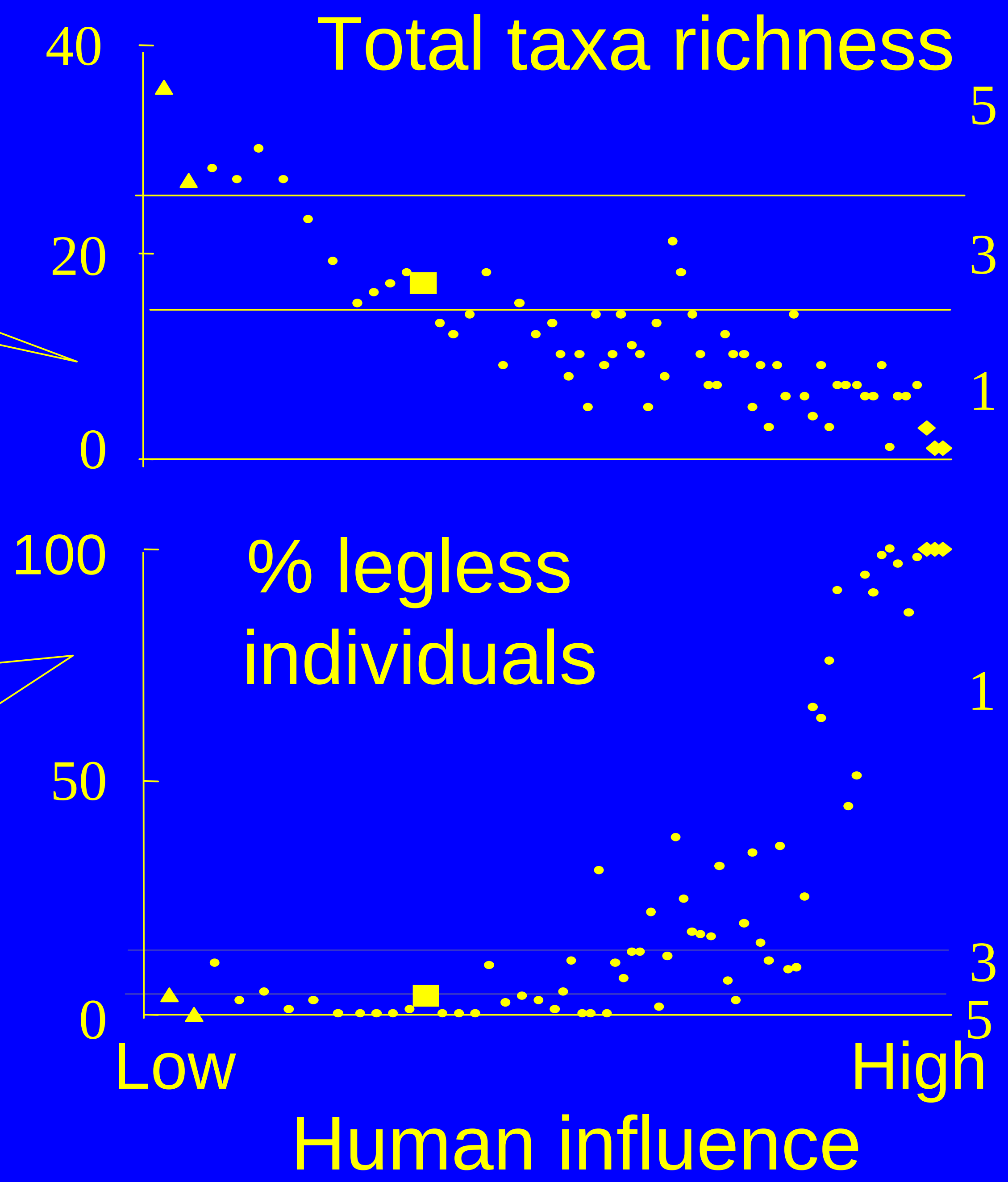
1. Collect samples of invertebrates, fish, or other organisms

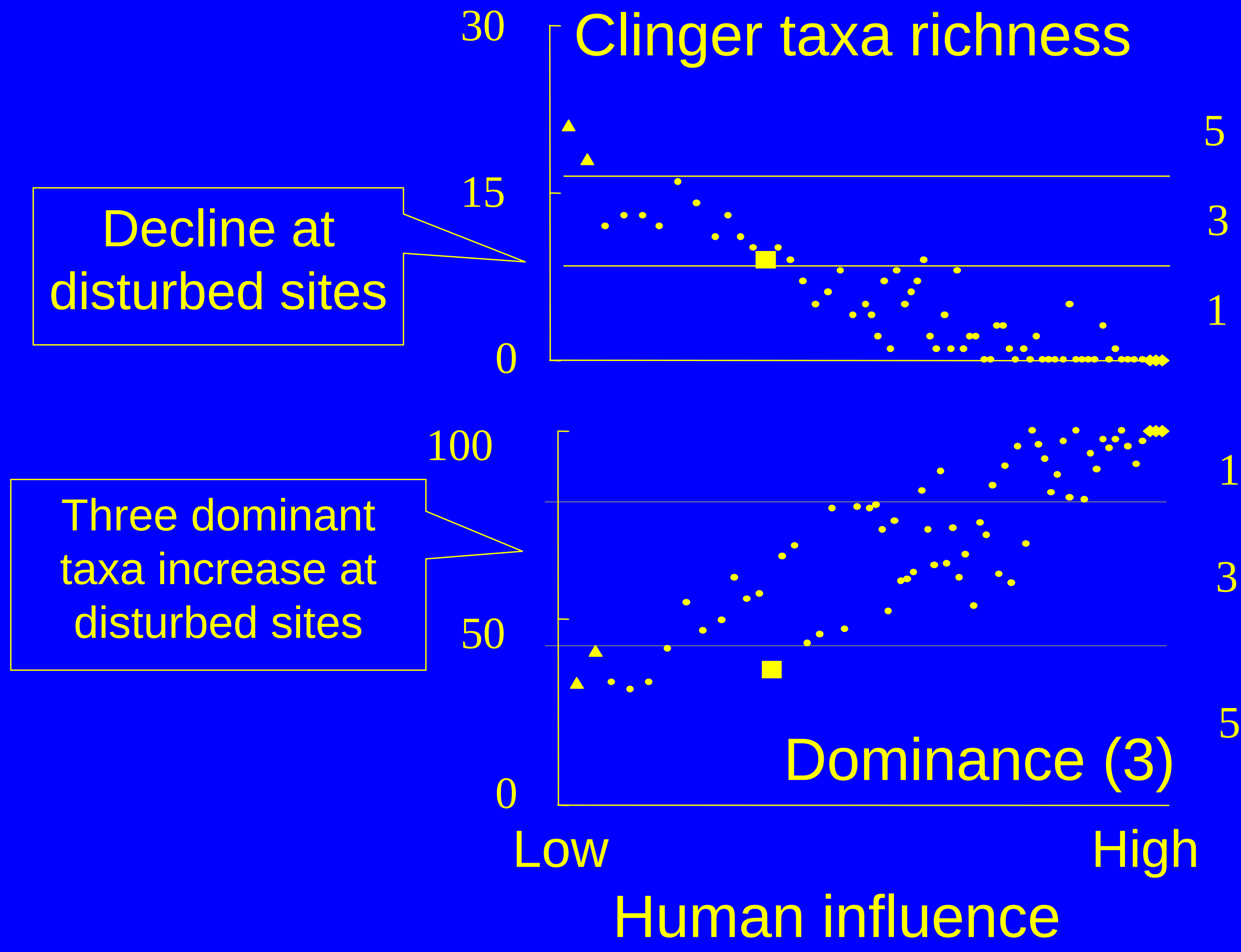
2. Sort, identify, and count by taxonomic and ecological characteristics

3. Score metrics based on divergence from expectation at undisturbed sites

Decline at disturbed sites

Increase at disturbed sites





Clinger taxa richness
30
15
0
5
3
1
Decline at disturbed sites
100
50
0
1
3
5
Dominance (3)
Three dominant taxa increase at disturbed sites
Low
High
Human influence

Biological Assessment Process

4. Add metric scores to produce IBI

IBI = S(tot) + S(legl) + S (cling) + S (dom)

= 3 + 5 + 3 + 5 = 16

5. Interpret IBI and other information to
   a. define condition
   b. identify likely causes of degradation
   c. evaluate management success

Index of Leading Economic Indicators

- real money supply
- index of consumer expectations
- stock prices
- unemployment insurance claims
- vendor performances
- building permits
- average weekly manufacturing hours
- manufacturing new orders for consumer goods
- interest rate spread
- manufacturing new orders for non-defense capital goods

Foundation 5

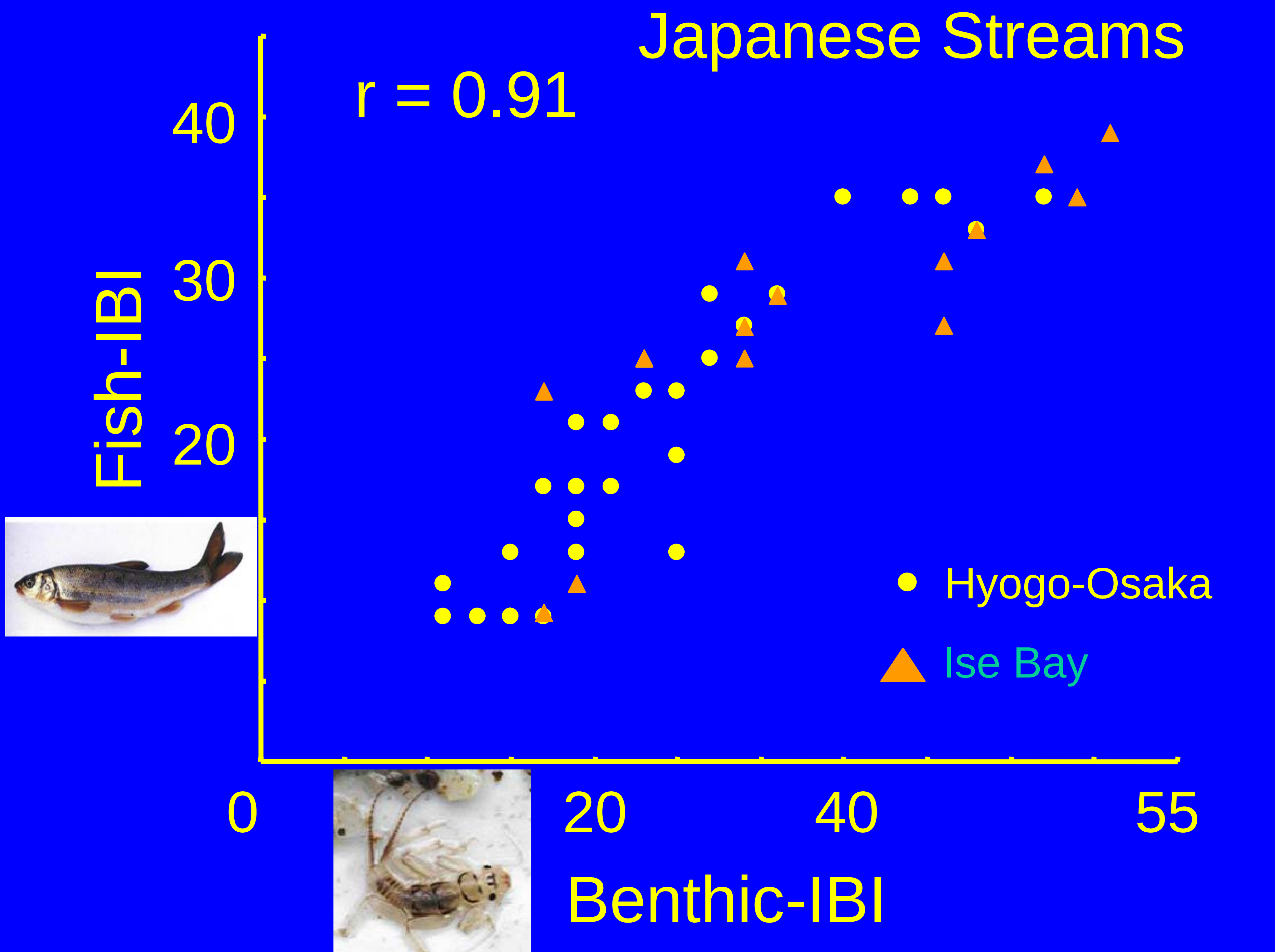
Employ rigorous sampling design and analytical procedures.

Statistics of Environmental Indicators

- standardized field and lab methods are crucial
- bootstrap analysis can evaluate variance
- important to understand:
  - power
  - statistical significance vs. biological consequence
- study design can minimize error variance
- IBI's are normally distributed
- field validation is essential
- validate with multiple data sets

Important Themes

- Focus on biological endpoints
- Employ concept of reference condition
- Organize sites into classes
- Assess change caused by human actions
- Require standard sampling, lab, analysis
- Score sites numerically to reflect site condition
- Define “bands” or condition levels


Japanese Streams
r = 0.91
Fish-IBI
40
30
20
0
20
40
55
Benthic-IBI
Hyogo-Osaka
Ise Bay

Thornton Creek, NE Seattle

Sub-basin TIA 51%

Local urban land cover 89%

B-IBI = 12 (“very poor”)

Miller Creek, SEA-TAC

Sub-basin TIA 54%

Local urban land cover 45%

B-IBI = 12 (“very poor”)

Despite a fully vegetated riparian zone in this reach of Miller Creek, biological condition is identical to that in Thornton Creek.

Why Bioassessment Is Useful - I

Ensemble of biological contexts always present

Objectively defined benchmark or baseline

Statistically and biologically rigorous

Assess change due to human actions

Diagnose causes of degradation

Why Bioassessment Is Useful - II

Standard methods - sampling, lab, analysis

Score resource condition numerically, describe narratively

Discriminate levels of degradation

Evaluate management and restoration programs

With strong empirical base, no need to resolve higher
order debates in theoretical ecology

Easily communicated to citizens and policy makers

Pitfalls to Avoid

Conceptual

Sampling

Analytical

Application

Sockeye Salmon

Photo by Tom Quinn

Pitfalls to Avoid - Conceptual

- Excessive dependence on theory
- Narrow conceptual framework
- Ignoring human-influence gradient
- Expecting simple chemical (or other) correlations
- Poor definition or misuse of reference condition
- Inappropriate classification of environment types

Pitfalls to Avoid - Sampling

- Inadequate sampling design
- Too many or too few data
  - (season, microhabitats, major taxa)
- Improper sampling protocols
- Misunderstanding of the sources of variability
- Failure to sample across a human-influence gradient
- Inappropriate use of probability-based sampling

Pitfalls to Avoid - Analytical

- Use of incompatible data sets
- Failure to keep track of sources of variability
- Failure to understand cumulative ecological dose-response curves
- Inattention to important signals (rare species)
- Failure to define/verify metrics

Pitfalls to Avoid - Application

- Analysis inappropriate to the situation
  - spatial and temporal scale
  - environmental context [stressor(s), resource]
  - legal
  - regulatory
- Solution that treats symptoms rather than disease
- Solution flawed by inaccurate problem identification
- Solution unlikely to have desired effect
- Solution that brings other problems (iatrogenesis)