Presented at

Great Rivers Reference Condition Workshop

January 10-11, Cincinnati, OH

Sponsored by

The U.S. Environmental Protection Agency and The Council of State Governments

U.S. EPA Office of Research and Development

Environmental Monitoring and Assessment Program

THE DEVELOPMENT AND APPLICATION OF BIOLOGICAL ASSESSMENT TOOLS AND BIOCRITERIA FOR THE ASSESSMENT OF IMPACTS TO AQUATIC ASSEMBLAGES IN LARGE, NON-WADEABLE RIVERS

EMAP GRE Reference Condition Workshop
January 11, 2006

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Cooperative Agreements With U.S. EPA

- Cooperative agreements between MBI & CABB and U.S. EPA – initiated Oct. 2000 and Aug. 2001.
- Promote and demonstrate the role of biological assessment and criteria in WQ management.
- Examine relationships between biological criteria and biotic and abiotic stressors.
- Regional biocriteria development in streams and large rivers.

US EPA Science Forum

May 5 - 7, 2003

Washington DC

30 Years of Progress Through Partnerships:

Biological Indicators

Susan Jackson, US EPA Biological Criteria Program

What Is *Adequate* Monitoring & Assessment (M&A)?

- Biological, chemical, & physical indicators.
- Adherence to stressor, exposure, response roles – *avoid use of surrogates*.
- Data Quality Objectives – adequate for the intended purpose (should be defined by WQS).
- Design (scale, sequence, intensity) meets *multiple* management issues and needs.
- The product of M&A is the assessment, not just the data (avoid data rich, information poor syndrome).
- Professionalism – expertise in key disciplines

COST-EFFECTIVE

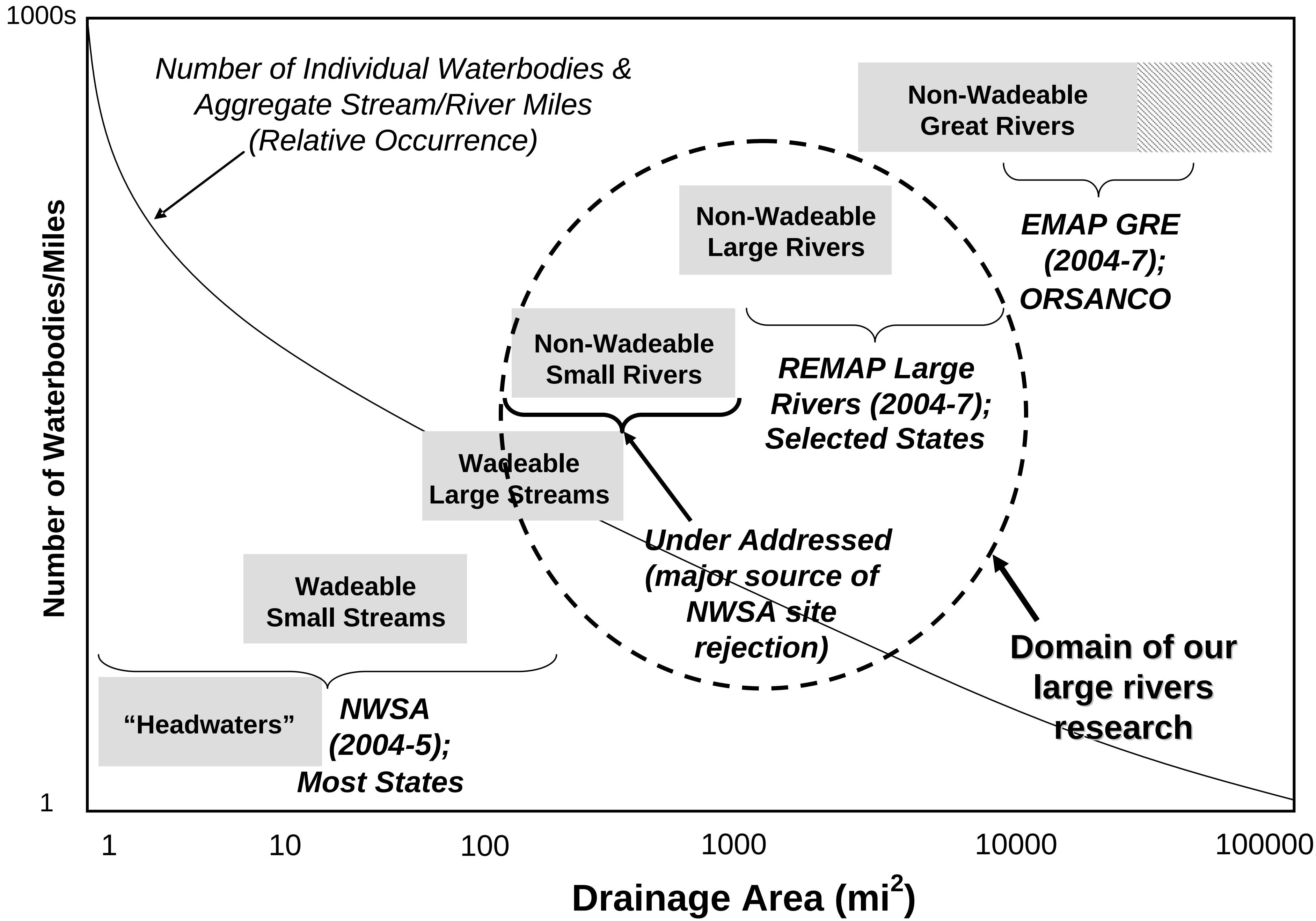
A Systematic Process

Three Principal Objectives of Systematic Bioassessment

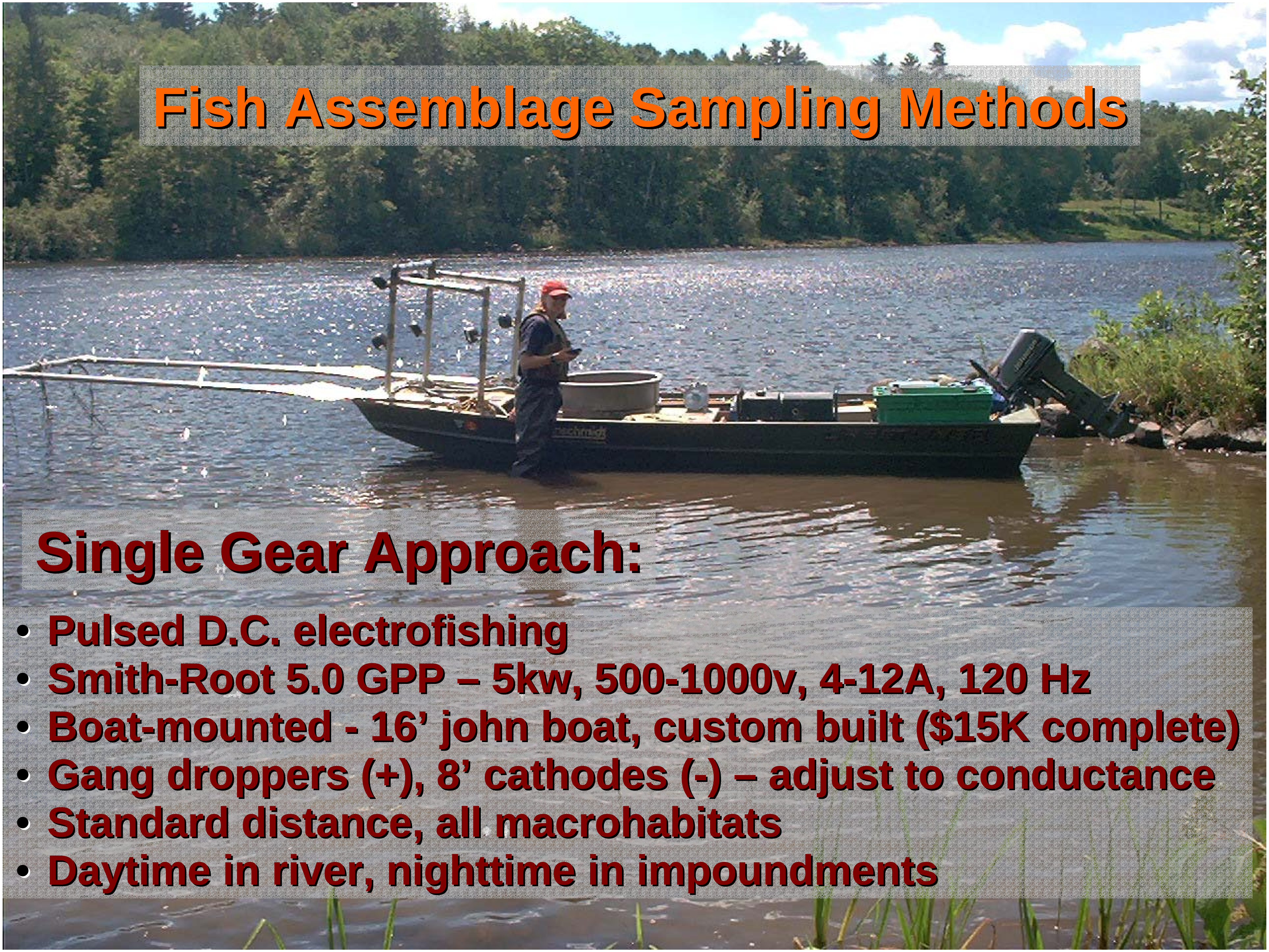
- Determine if use designations are appropriate and attainable
- Determine condition and status of the resource (including causal associations)
- Are changes taking place over time?

Issues of Large River Bioassessment

- Methods Issues – comparability, accuracy
- Bioassessment – calibration, validation
- Status and trends – sites, reaches, segments
- Scale issues – how much of a large river needs to be assessed?
- Local vs. reach scale issues.
- Support of multiple water quality & resource management objectives – will require consideration of multiple sampling designs.



1000s
1
Number of Waterbodies/Miles
Number of Individual Waterbodies & Aggregate Stream/River Miles (Relative Occurrence)
Non-Wadeable Great Rivers
EMAP GRE (2004-7); ORSANCO
Non-Wadeable Large Rivers
REMAP Large Rivers (2004-7); Selected States
Non-Wadeable Small Rivers
Wadeable Large Streams
Under Addressed (major source of NWSA site rejection)
Domain of our large rivers research
Wadeable Small Streams
"Headwaters"
NWSA (2004-5); Most States
1
10
100
1000
10000
100000
Drainage Area (mi2)

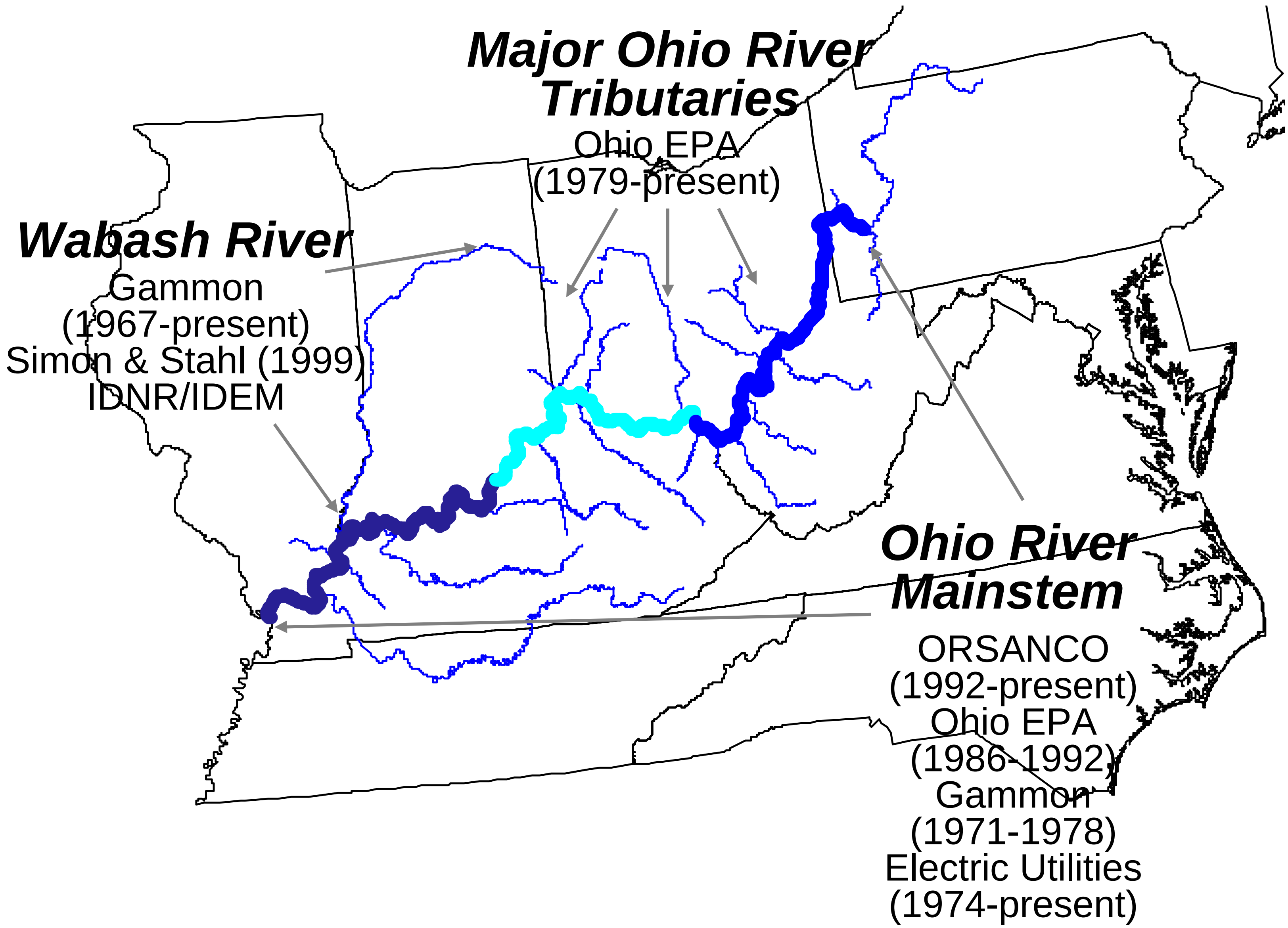


Fish Assemblage Sampling Methods

Single Gear Approach:

- Pulsed D.C. electrofishing
- Smith-Root 5.0 GPP – 5kw, 500-1000v, 4-12A, 120 Hz
- Boat-mounted - 16’ john boat, custom built ($15K complete)
- Gang droppers (+), 8’ cathodes (-) – adjust to conductance
- Standard distance, all macrohabitats
- Daytime in river, nighttime in impoundments

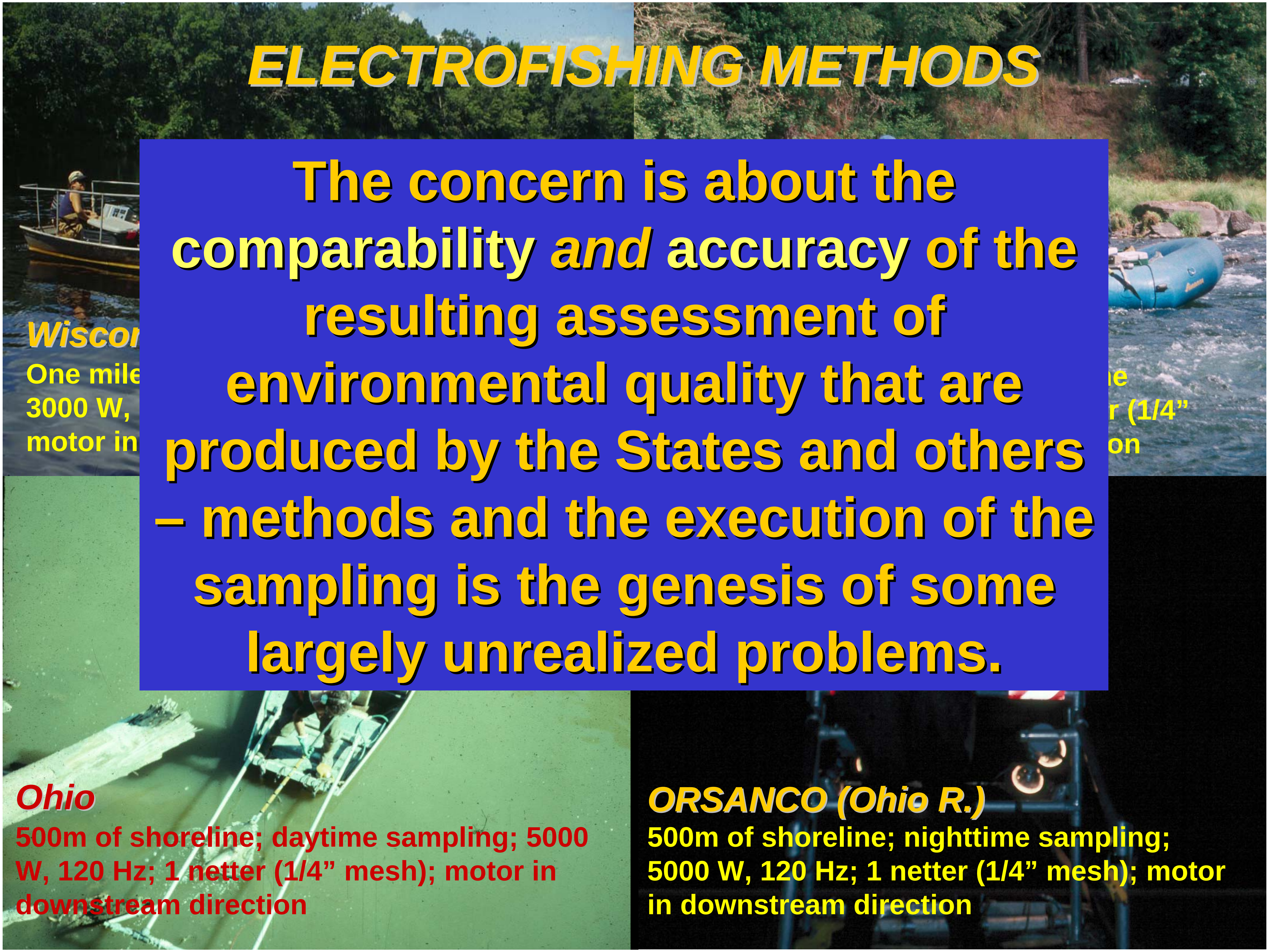
Fish Assemblage Assessments of Large and Great Rivers in the Upper Ohio Basin



Midwest Large River Programs:

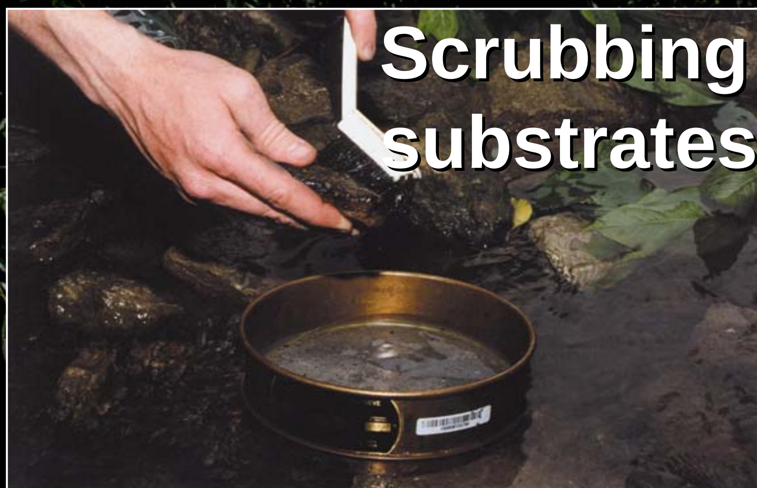
- ORSANCO – night electrofishing, IBI developed; macroinvertebrate method in development; in process of adopting in standards.
- Wisconsin – daytime electrofishing, IBI developed; exploring macroinvertebrate methods; not in WQS.
- Ohio EPA – daytime electrofishing, IBI developed; macroinvertebrate method and index established; adopted in WQS.
- Other Region V States – most have developmental projects underway; some conduct assessments.


Ohio EPA Non-Wadeable Methods
Electrofishing Gear Array: Wadeable to Non-Wadeable
Effort: Distance Sampled
Logistics: Equipment & Access Issues
Multiple Habitats Sampled


ELECTROFISHING METHODS
The concern is about the comparability *and* accuracy of the resulting assessment of environmental quality that are produced by the States and others – methods and the execution of the sampling is the genesis of some largely unrealized problems.
Wiscon
One mile
3000 W,
motor in
Ohio
500m of shoreline; daytime sampling; 5000 W, 120 Hz; 1 netter (1/4” mesh); motor in downstream direction
ORSANCO (Ohio R.)
500m of shoreline; nighttime sampling; 5000 W, 120 Hz; 1 netter (1/4” mesh); motor in downstream direction

Benthic Macroinvertebrates

Active Sampling Methods Examples



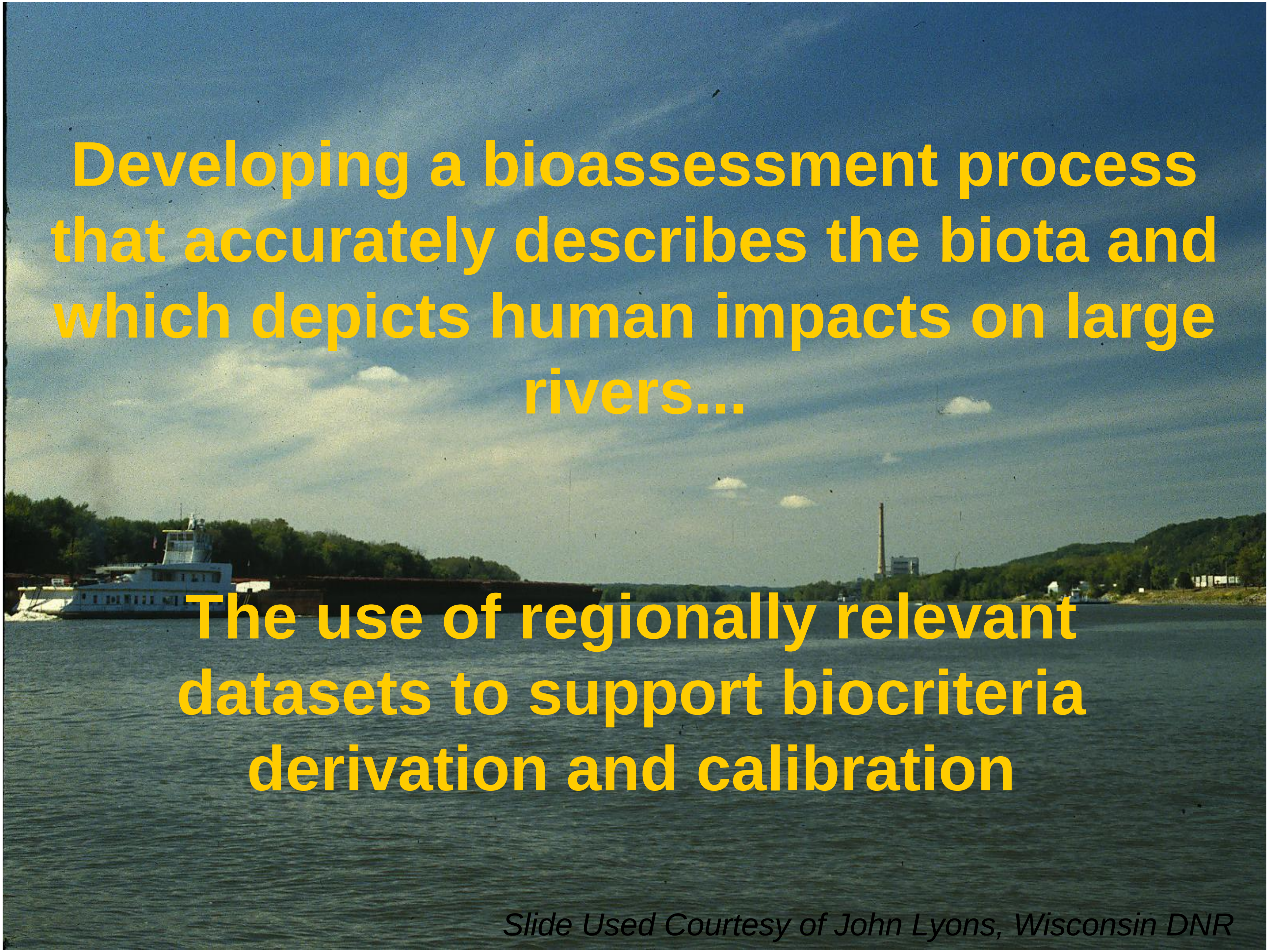
Dome Sampler

Net-based methods (including kicks, dips, jabs, sweeps, & picks)

Benthic Macroinvertebrates

Passive Sampling Methods Examples

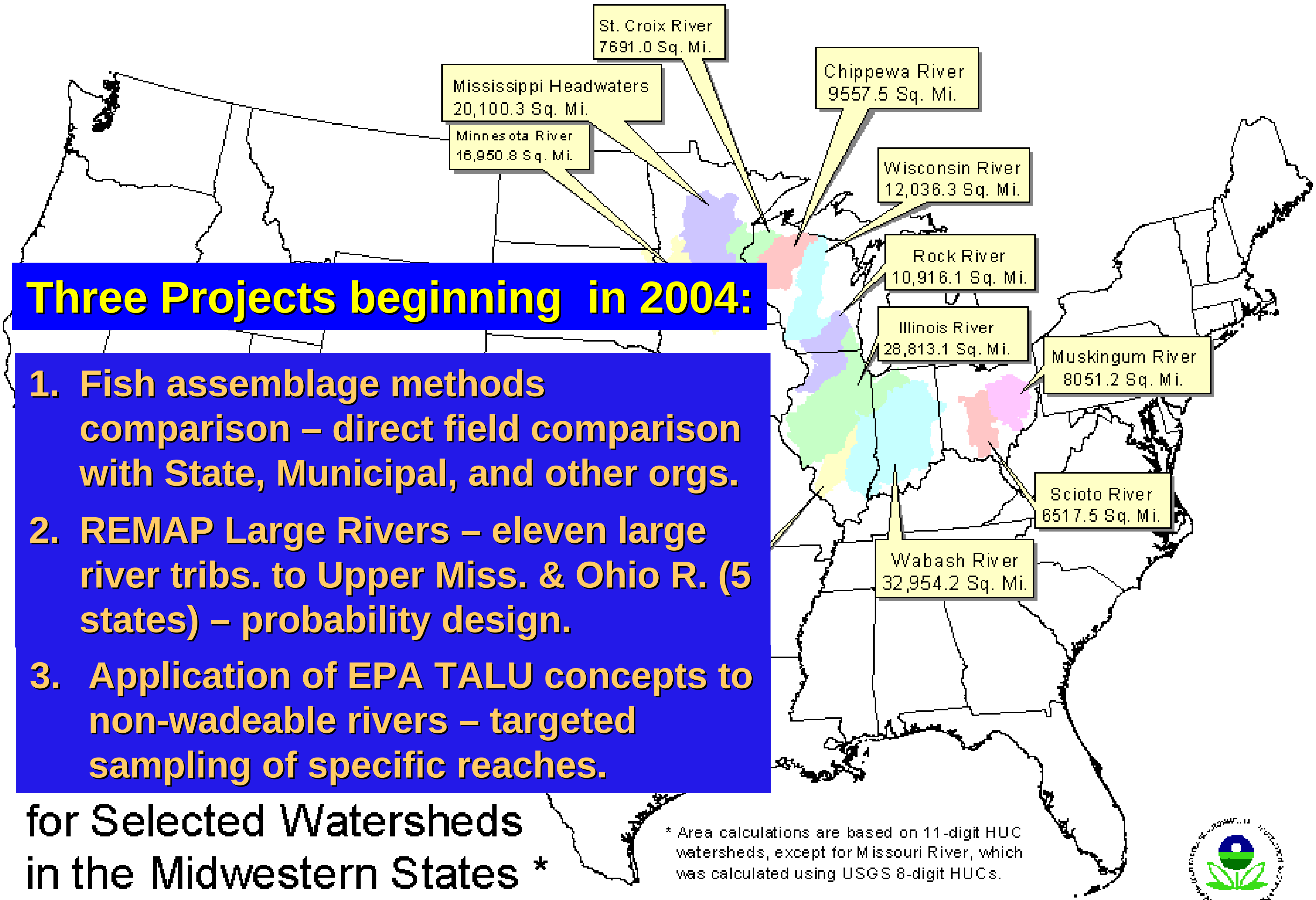
- Quantitative
  - Ohio-EPA
    artificial substrates
  - Maine DEP
    rock baskets
  - **Each state has sampled large rivers for >25 years**


Developing a bioassessment process that accurately describes the biota and which depicts human impacts on large rivers...
The use of regionally relevant datasets to support biocriteria derivation and calibration
Slide Used Courtesy of John Lyons, Wisconsin DNR

Three Projects beginning in 2004:

1. **Fish assemblage methods comparison – direct field comparison with State, Municipal, and other orgs.**
2. **REMAP Large Rivers – eleven large river tribs. to Upper Miss. & Ohio R. (5 states) – probability design.**
3. **Application of EPA TALU concepts to non-wadeable rivers – targeted sampling of specific reaches.**

for Selected Watersheds in the Midwestern States *



* Area calculations are based on 11-digit HUC watersheds, except for Missouri River, which was calculated using USGS 8-digit HUCs.

Kennebec River (2002-5)

- Wyman Dam to Merrymeeting Bay (30 sites, 2 test areas)
- Follow-up Waterville to Augusta (2002-5)
- Atl. salmon nursery habitat survey (2003)

Androscoggin River (2003)

- Errol, NH to Merrymeeting Bay (51 sites)

Sebasticook River (2003)

- Douglas Pond to Winslow (9 sites)

Penobscot River (2004)

- N. Br. To Hamden (40 sites); included W. ... tributaries

...gash (5 sites), ... Croix (12 sites)

Example of a project that started from “scratch”

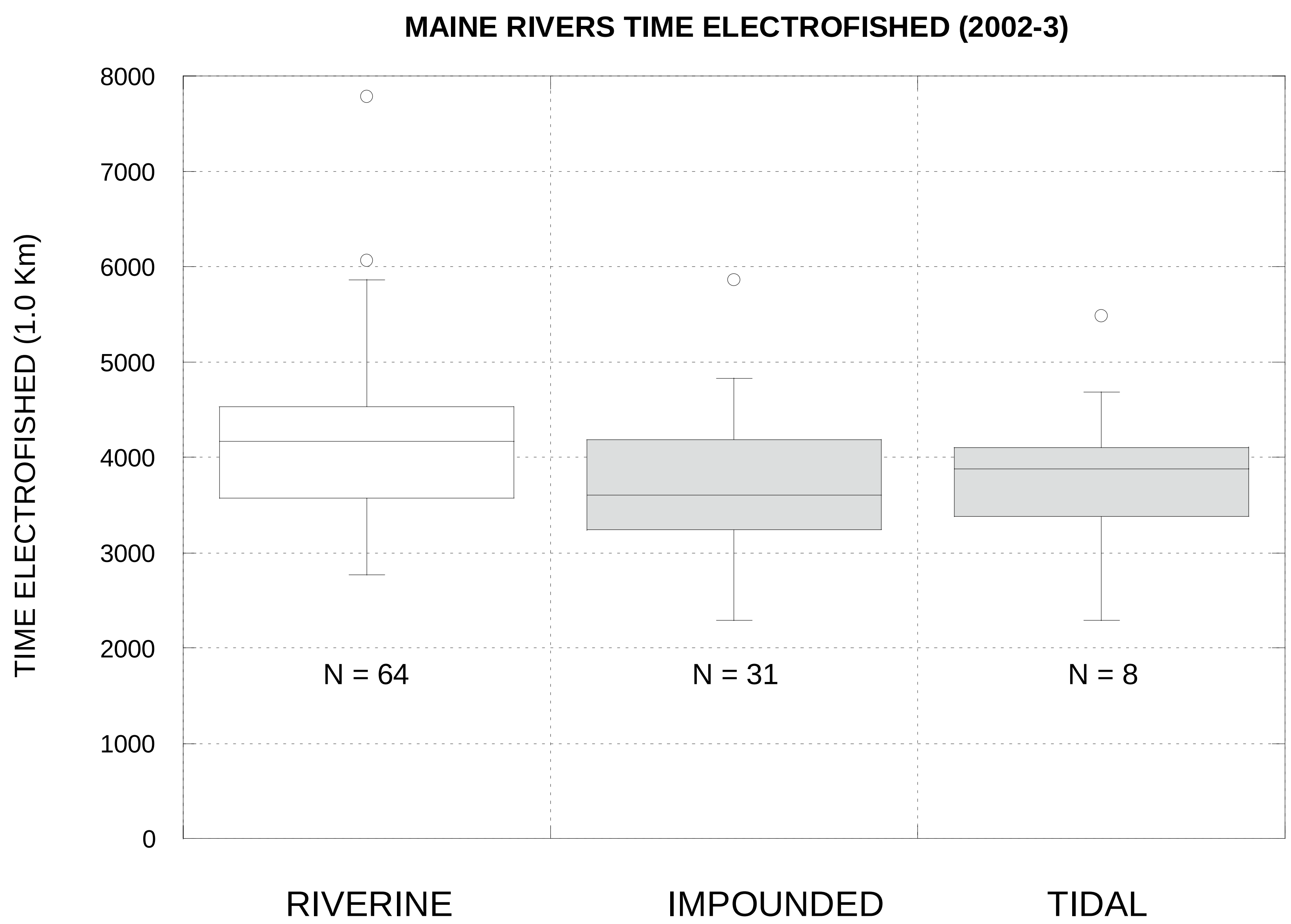
Cooperators

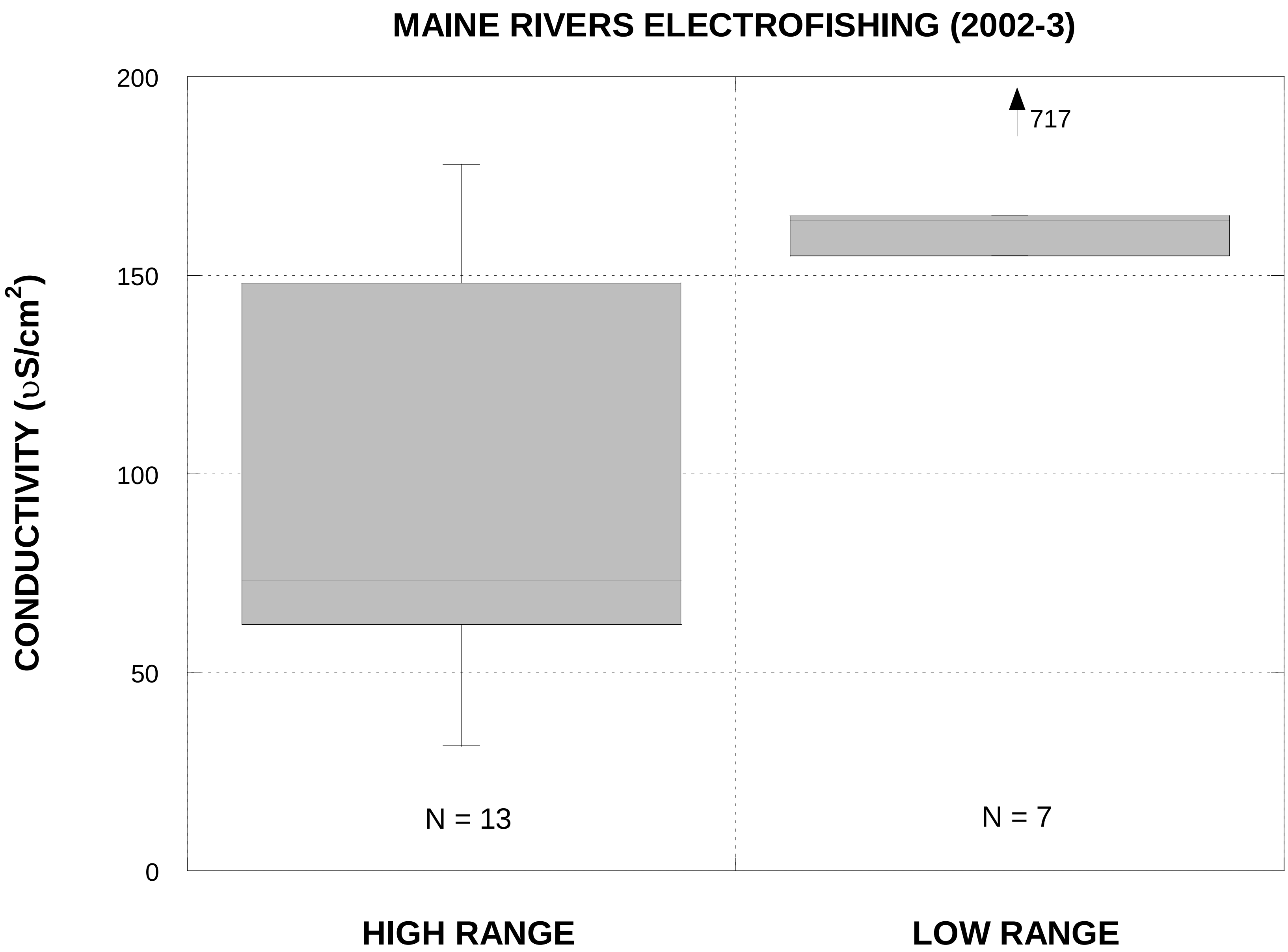
- U.S. EPA, Region I
- U.S. EPA, HECD
- Maine DEP
- Maine DIFW
- Maine DMR
- Maine ASC
- U.S. F&WS
- Penobscot Indian Nation
- Trout Unlimited
- St. Croix IWC
- Maine DOC
- NFWF
- GOMCME
- SRWA

Table 1. Key characteristics of a boat electrofishing protocol applicable to Maine and New England large river habitats.

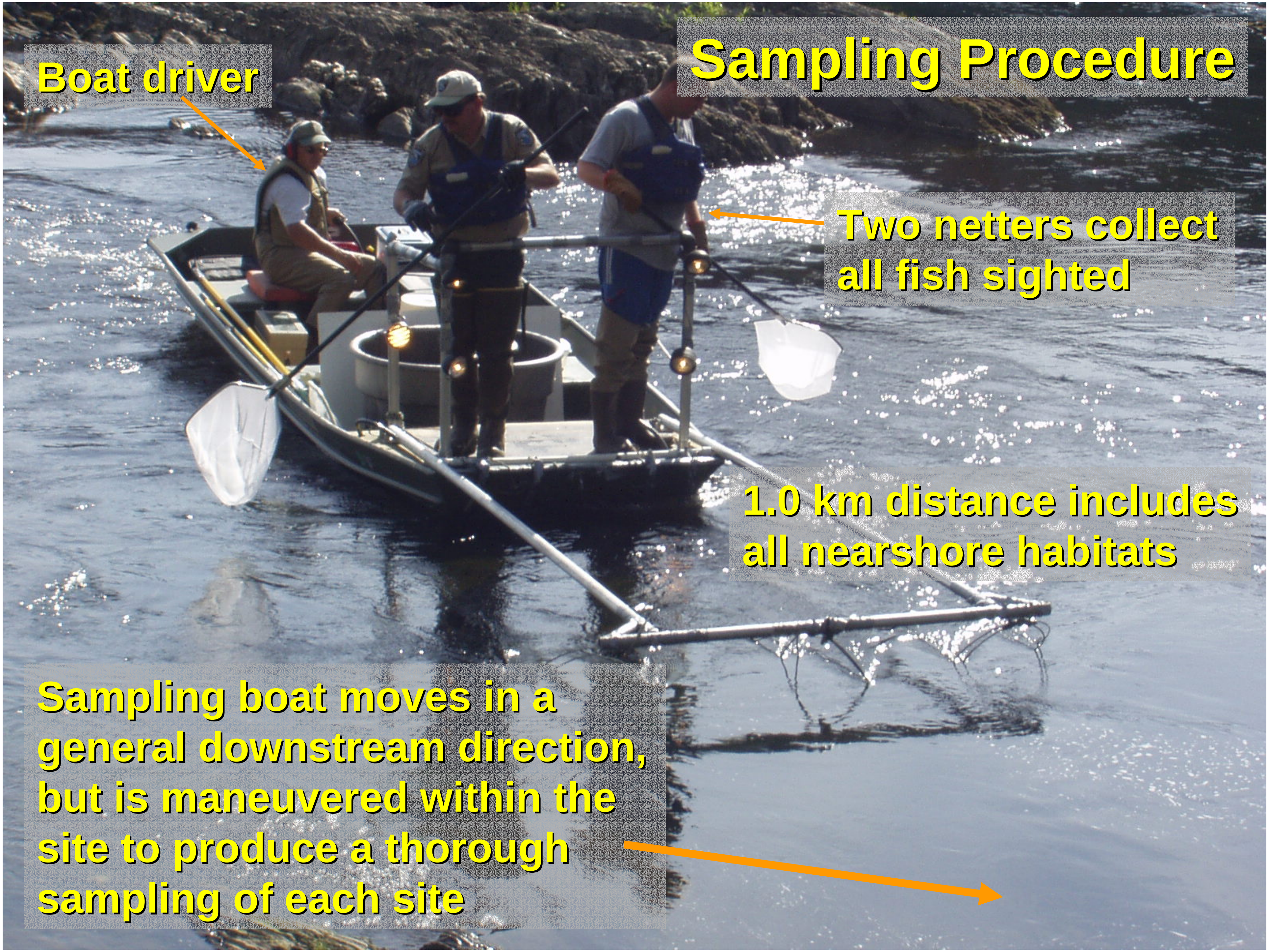
Category/Attribute	Riverine Wadeable[a] (Low-Mod. Cond.[b])	Riverine High Gradient (Low Cond.)	Riverine Mod. Gradient (Low Cond.)	Riverine Low Gradient (Mod. Cond.)	Impounded (Mod. Cond.)	Impounded (Mod. Cond.)	Tidal (High Cond.)
1. Drainage Area	<500 mi^2	<500 mi^2	>500-1000 mi^2	>1000 mi^2	NA	NA	NA
2. Platform	Georator[c] (bank set/towboat)	14' raft[d] or 12' johnboat	16' johnboat or 16' raft[e]	16' johnboat	16' johnboat	16' johnboat	16' johnboat
3. Crew Size	3 persons (2 netters)	2 persons (1 netter)	3 persons (2 netters)	3 persons (2 netters)	3 persons (2 netters)	3 persons (2 netters)	3 persons (2 netters)
4. Electrofishing Unit	GPP 2.5, 5.0[e] or equivalent	GPP 2.5, 5.0 or equivalent	GPP 5.0 or equivalent	GPP 5.0 or equivalent	GPP 5.0 or equivalent	GPP 5.0 or equivalent	GPP 5.0 or
5. Power Source	2500-5000 Watt Alternator	5000 Watt Alternator	5000 Watt Alternator	5000 Watt Alternator	5000 Watt Alternator	5000 Watt Alternator	5000 Watt Alternator
6. Unit Settings[f]	High 120 Hz	High 120 Hz 2-4 Amperes	High 120 Hz 2-4 Amperes	Low or High 120 Hz 4-8 Amperes	High 120 Hz 2-4 Amperes	Low or High 120 Hz 4-8 Amperes	Low 120 Hz >8-15 Amperes
(% of Low or High Range)	NA	(100%)	(100%)	(60-100%)	(100%)	(60-100%)	(50-80%)
7. Anodes[g]	Net Ring	2 gangs	3 gangs	3 gangs	3 gangs	3 gangs	2 gangs
8. Cathodes	rat tail	6'	8'	8'	8'	8'	8'
9. Sampling Direction & Distance	Upstream 0.2-0.5 Km	Downstream 0.5-1.0 Km	Downstream 1.0 Km	Downstream 1.0 Km	Downstream 1.0 Km	Downstream 1.0 Km	Downstream 1.0Km
10. CPUE[h] Basis	Per 0.5 Km	Per Km	Per Km	Per Km	Per Km	Per Km	Per Km
11. Time Sampled[i]	Not tested	3500-4500 s	4000-5500 s	3500-4500 s	3000-4000 s	3000-4000 s	3500-4500 s
12. Time of Day	Day	Day	Day	Day	Day or Night	Day or Night	Day

[a] Wadeable defined as sites where a raft or boat mounted apparatus cannot be used due to shallowness of depth – accessibility is not a criterion.
[b] Typical relative conductivity ranges: Low (15-40 µs/m^2); Moderate (40 – 200 µs/m^2); High (>200 µs/m^2).
[c] Employs a primary net ring as the anode that is operated by the primary netter backed by an assist netter - the unit is either bank set or towed on a small skiff (towboat).
[d] This platform was extensively tested in 2005.
[e] This platform has not been tested in Maine, but it has worked well elsewhere and in similar conditions.
[f] This does not constitute an endorsement of a particular brand or product name and is for methodological identification only.
[g] Unit settings are selected to produce the highest voltage and amperage output; these are what typically worked in each conductivity range and habitat type.
[h] Anodes consist of gangs or multiple strands of wire as described under Equipment Specifications.

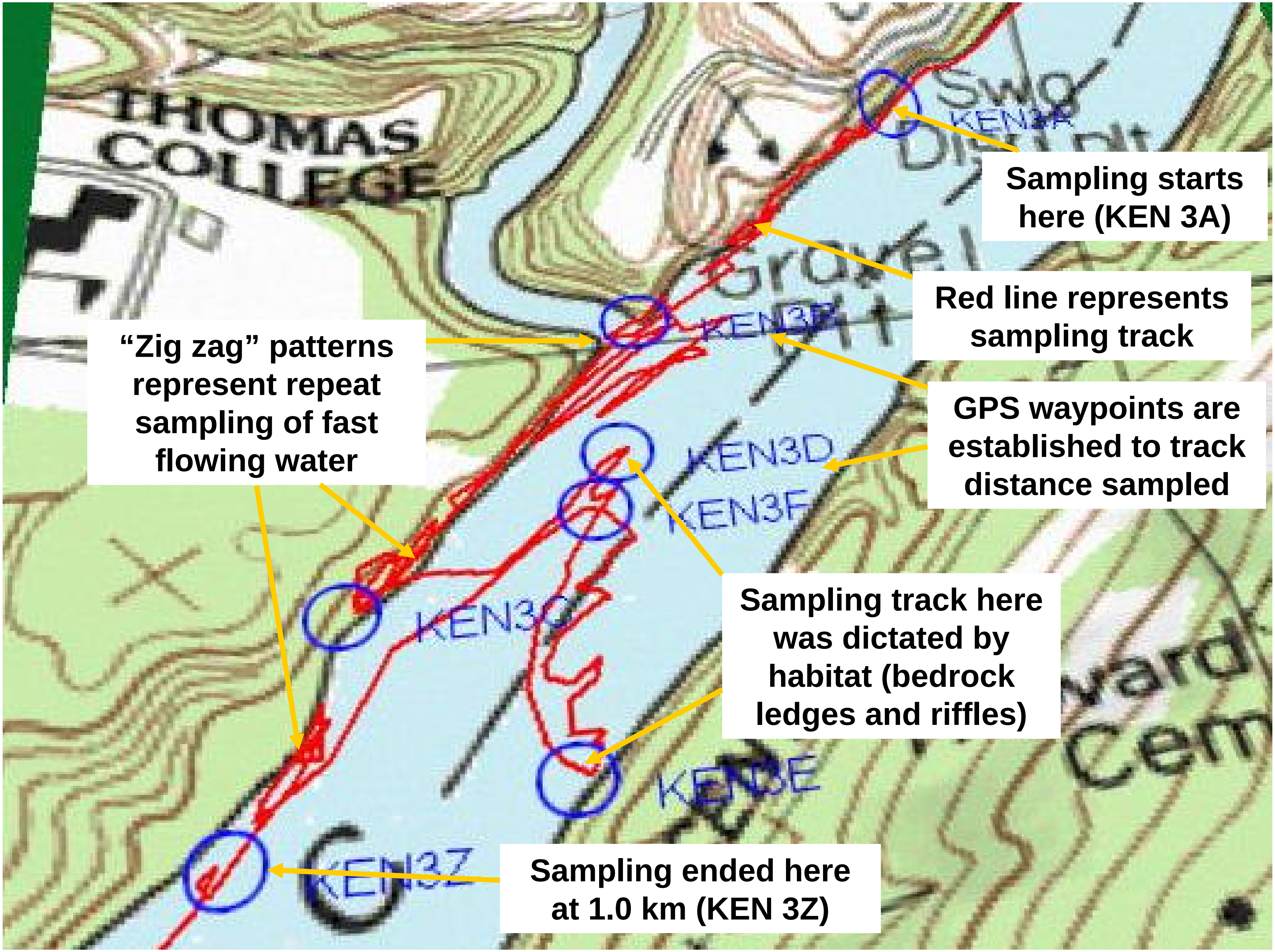

MAINE RIVERS TIME ELECTROFISHED (2002-3)
TIME ELECTROFISHED (1.0 Km)
8000
7000
6000
5000
4000
3000
2000
1000
0
N = 64
N = 31
N = 8
RIVERINE
IMPOUNDED
TIDAL



MAINE RIVERS ELECTROFISHING (2002-3)
CONDUCTIVITY (υS/cm2)
200
150
100
50
0
717
N = 13
N = 7
HIGH RANGE
LOW RANGE



Sampling Procedure
Boat driver
Two netters collect all fish sighted
1.0 km distance includes all nearshore habitats
Sampling boat moves in a general downstream direction, but is maneuvered within the site to produce a thorough sampling of each site


THOMAS COLLEGE
KEN3A
KEN3B
KEN3D
KEN3F
KEN3C
KEN3E
KEN3Z
Sampling starts here (KEN 3A)
Red line represents sampling track
“Zig zag” patterns represent repeat sampling of fast flowing water
GPS waypoints are established to track distance sampled
Sampling track here was dictated by habitat (bedrock ledges and riffles)
Sampling ended here at 1.0 km (KEN 3Z)

“Intermediate” Size River Equipment

14 ft. Electrofishing Raft

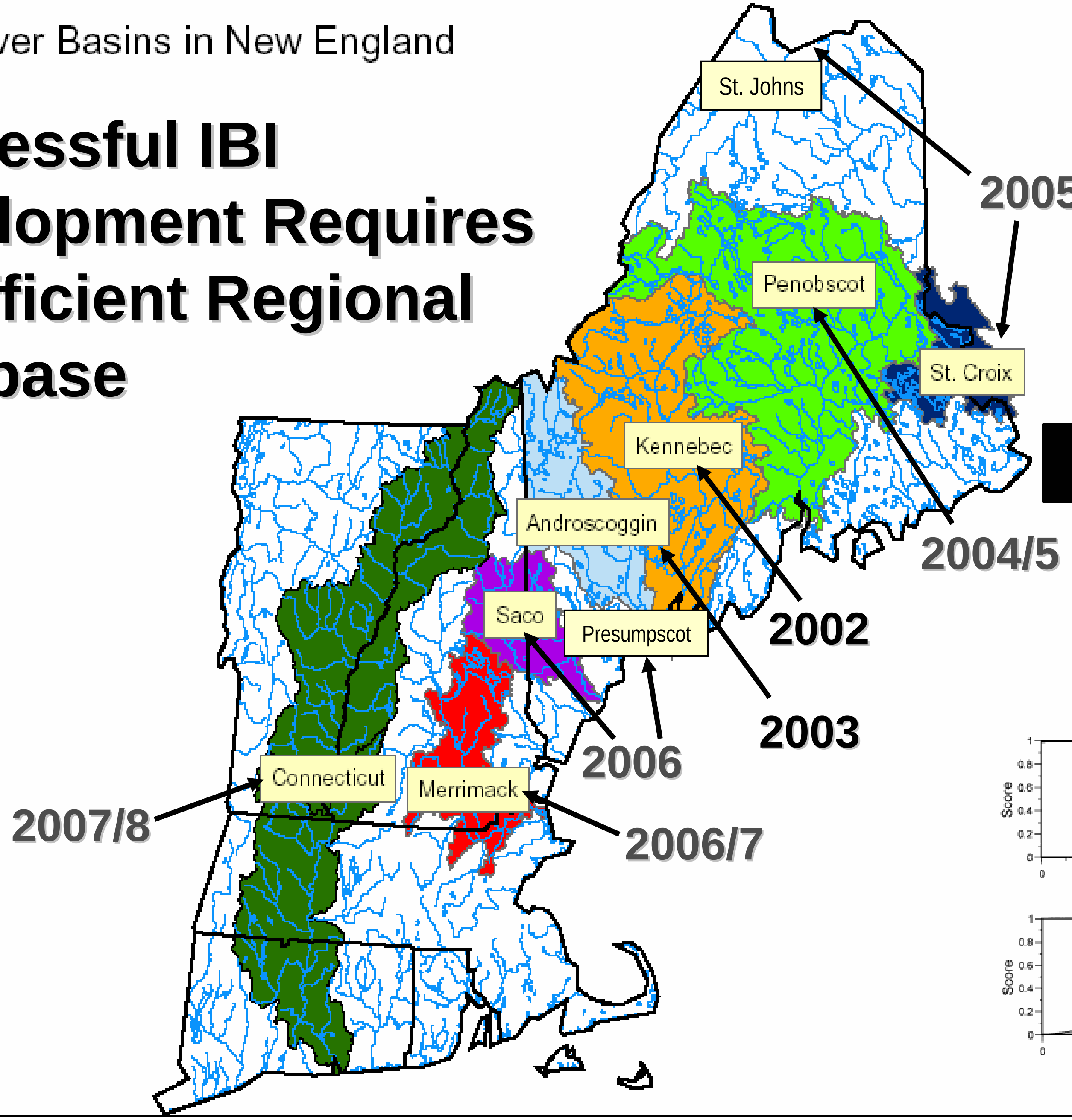
Two Person Crew

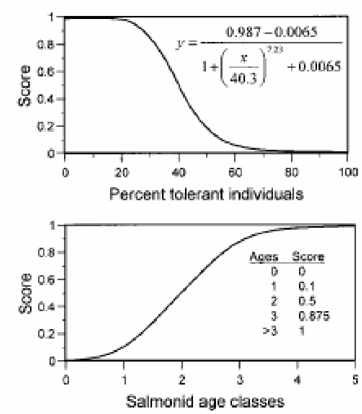
Launching & Retrieving

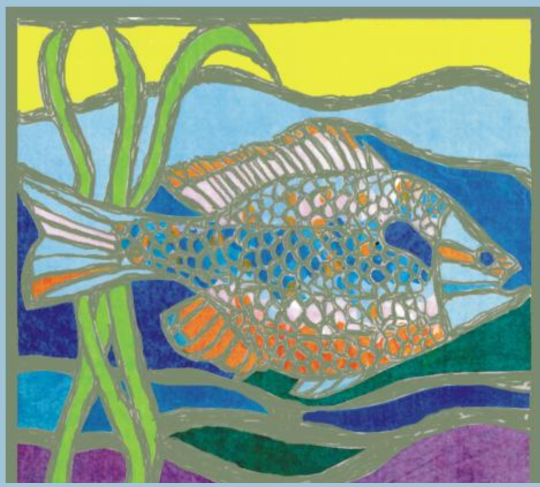
Smith-Root 2.5 GPP Unit

Major River Basins in New England

Successful IBI Development Requires a Sufficient Regional Database







Tiered Aquatic Life Uses: A Tool for Ecosystem Management

Hydrologic Alteration and Ecological Communities in the East

Amherst, MA, UMASS and TNC

October 20, 2005

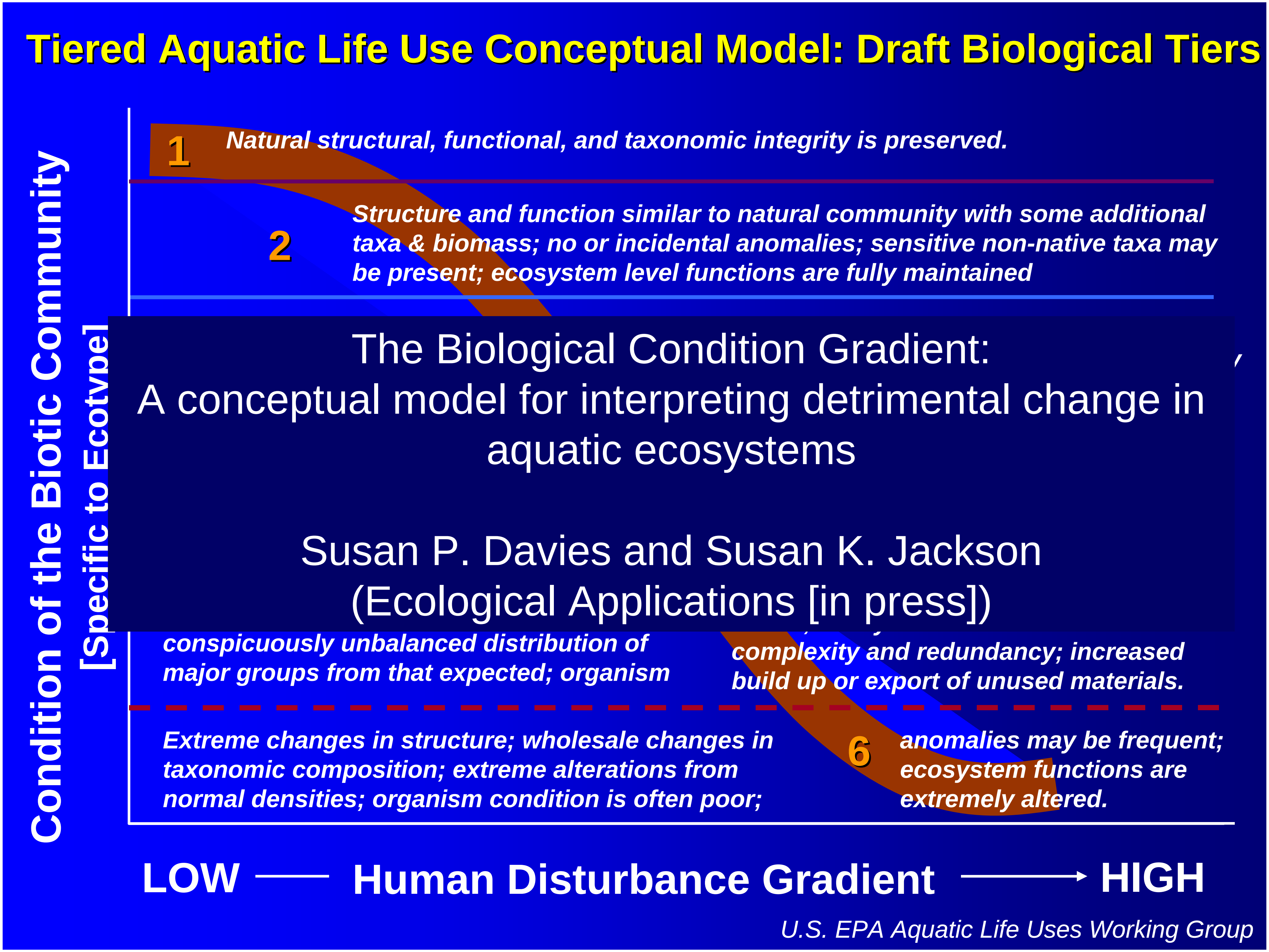
Susan Davies, State of Maine, and Susan Jackson, U.S. EPA

United States
Environmental Protection
Agency

Use of Biological Information to Tier Designated Aquatic Life Uses in State and Tribal Water Quality Standards

REVIEW DRAFT

August 2005



Tiered Aquatic Life Use Conceptual Model: Draft Biological Tiers
1
Natural structural, functional, and taxonomic integrity is preserved.
2
Structure and function similar to natural community with some additional taxa & biomass; no or incidental anomalies; sensitive non-native taxa may be present; ecosystem level functions are fully maintained
The Biological Condition Gradient:
A conceptual model for interpreting detrimental change in aquatic ecosystems
Susan P. Davies and Susan K. Jackson
(Ecological Applications [in press])
conspicuously unbalanced distribution of major groups from that expected; organism
complexity and redundancy; increased build up or export of unused materials.
Extreme changes in structure; wholesale changes in taxonomic composition; extreme alterations from normal densities; organism condition is often poor;
6
anomalies may be frequent; ecosystem functions are extremely altered.
Condition of the Biotic Community
[Specific to Ecotype]
LOW
Human Disturbance Gradient
HIGH
U.S. EPA Aquatic Life Uses Working Group

Biological Criteria: I

- Narrative ratings or numerical values which are based on the numbers and kinds of aquatic organisms (i.e., assemblage) which are found to inhabit a particular stream or river sampling location.

Biological Criteria: II

- Biological criteria are indexed to the reference assemblage of aquatic organisms within a particular geographical region (i.e., ecoregion) and with respect to stream and river size.

Establishing Reference Condition

I. Reference Sites

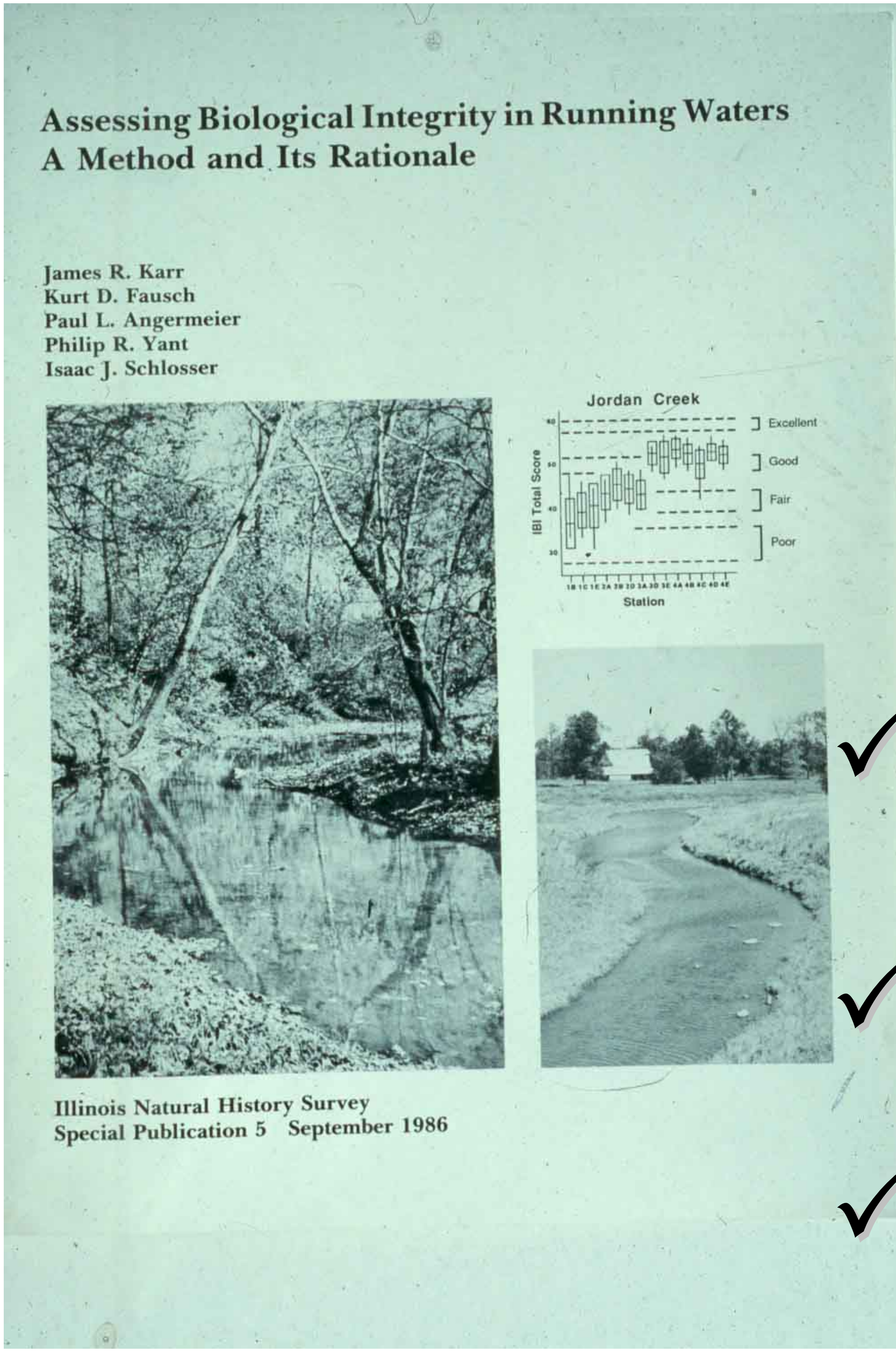
- Minimally to least impacted sites.
- Cultural setting & abiotic criteria – qualitative process used in 1980s.
- Subsets of sites needed for different ecotypes, water body types, and regions.
- Part of routine monitoring – ***resampling over a 10 yr. time interval********)*.*

*** - a complete set of re-sampled reference data (1990-1999) is now available for Ohio.**

Establishing Reference Condition

II. Reference Condition

- Data collected at reference sites.
- A distribution of data, not a single fixed data point.
- Should include upper tiers of Biological Condition Gradient.
- Alternative approaches can be used when empirical data is lacking (historical archives, expert panels).
- Used first to *calibrate* metrics, then to *set biocriteria*.


Assessing Biological Integrity in Running Waters
A Method and Its Rationale

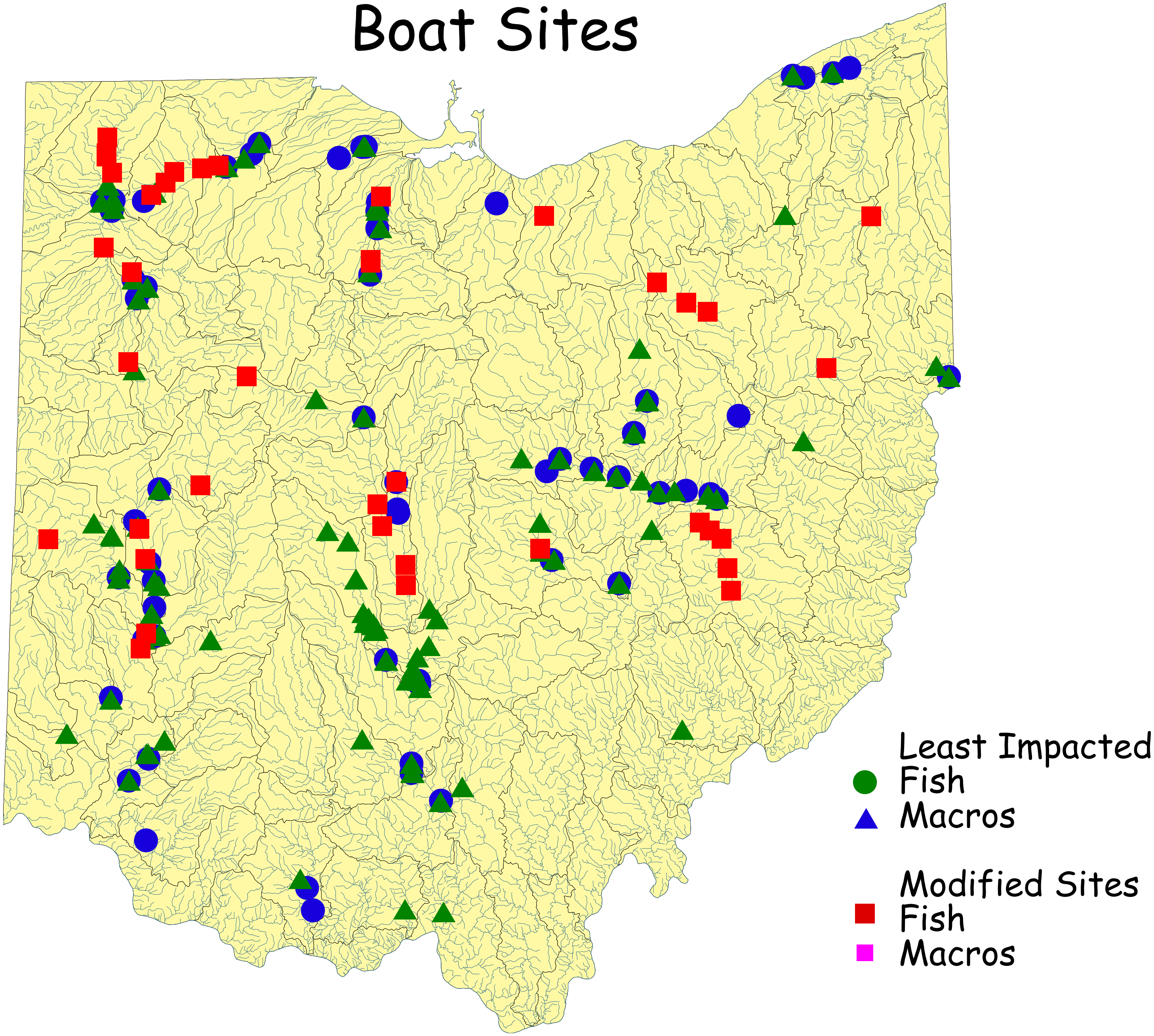
James R. Karr
Kurt D. Fausch
Paul L. Angermeier
Philip R. Yant
Isaac J. Schlosser

Illinois Natural History Survey
Special Publication 5 September 1986

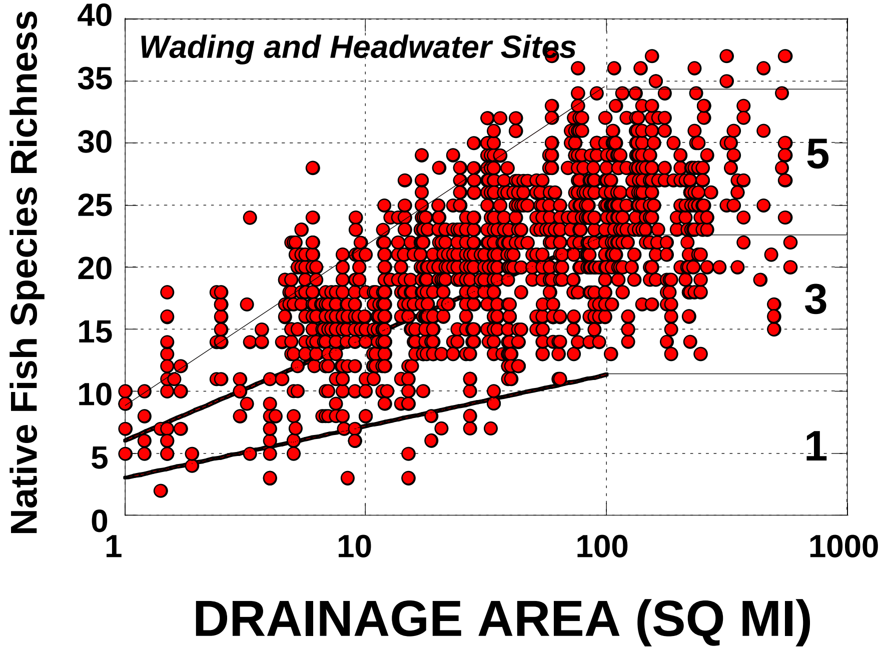
Guidelines for Deriving Regionally Relevant "IBI Type" Assessment Tools

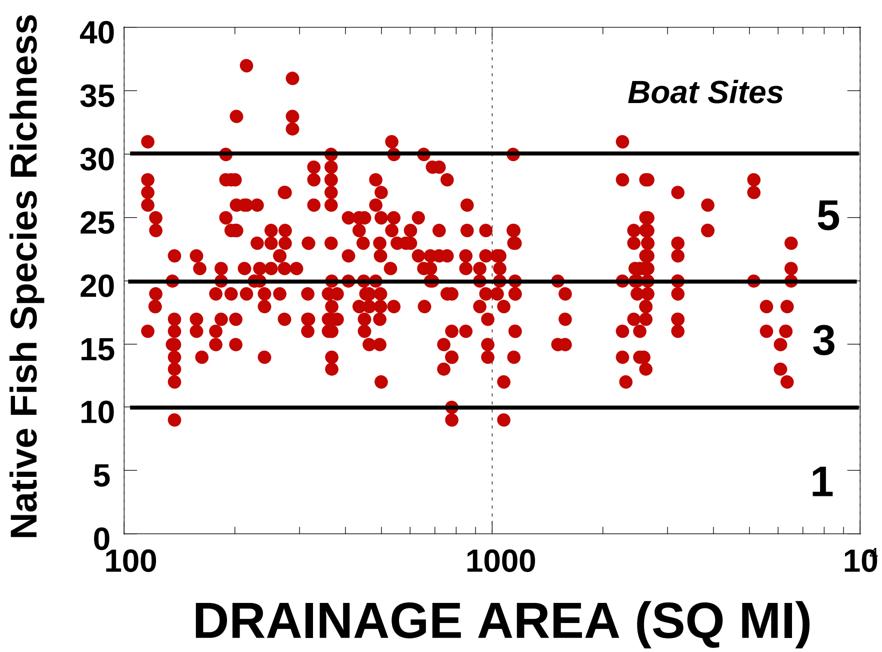
- **Karr et al. (1986) provides guidance for metric development, substitution, and modification.**
- **Requires detailed knowledge of the regional fauna including life history, taxonomy, zoogeography, and natural history.**
- **Requires an extensive database from consistent sampling of both reference condition and a gradient of human disturbance.**
- **Requires extensive testing of candidate metrics and aggregate indices.**

Ohio Biocriteria Reference Sites
Boat Sites




REFERENCE CONDITION
Wisconsin – N. Lakes/Forests
Ohio – Allegheny Plateau
Ohio River – Ohio/Ky.
Ohio/Indiana/Illinois – E. and Central Corn Belt

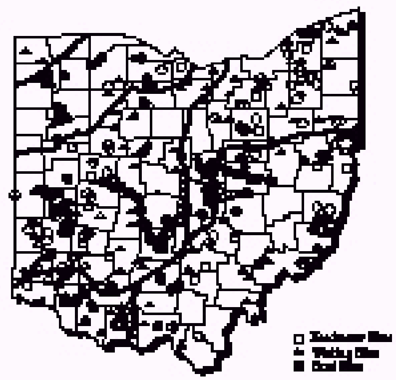




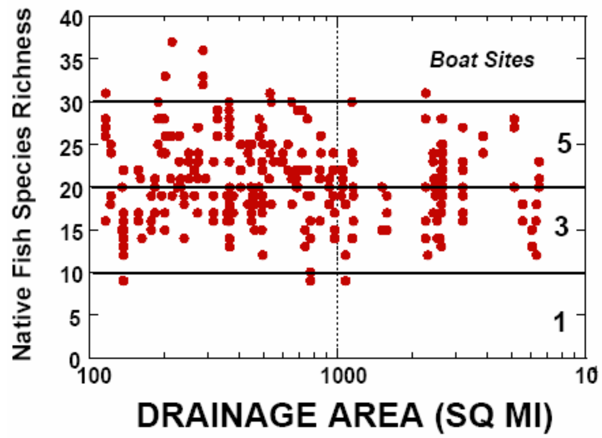
Calibration of Metrics Using Regional Reference Sites

- Scatter plot of metric value by appropriate calibration vector (e.g., watershed area).
- Determine 95% maximum line of best fit across surface of scatterplot; *driven by best reference sites.*
- Area beneath 95% line is subdivided (e.g., trisection) to determine metric scores - most data points should occur in upper ranges.
- This method reduces the influence of slightly degraded sites that may not biologically reflect the intent of reference condition.
- Slope of 95% line conservatively assumed to be zero for boat sites.

Ohio IBI Calibration & Biocriteria Derivation Process



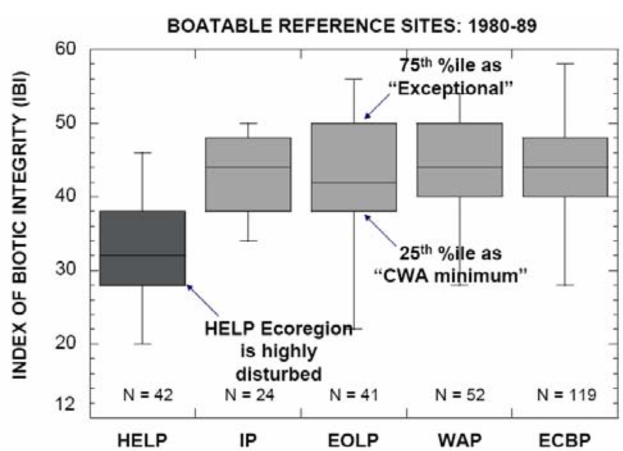
I. Select & sample reference sites



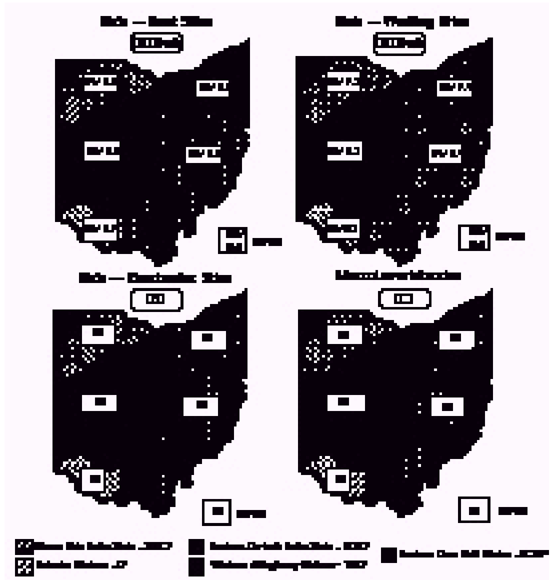
II. Calibration of IBI metrics

Metric	5	3	1
Number of Species	>20	10-20	<10
%Rnd-bodied sucker	>38	19-38	<19
No. of Sunfish Spp.	>3	2-3	<2
No. of Sucker Spp.	>5	3-5	<3
Intolerant Species	>3	2-3	<2
%Tolerant Species	<15	15-27	>27
%Omnivores	<16	16-28	>28
%Insectivores	>54	27-54	<27
%Top Carnivores	>10	5-10	<5
%Simple Lithophils			
<600 sq. mi.	>50	25-50	<50
>600 sq. mi.	Varies x Drainage Area		
%DELT Anomalies	<0.5	0.5-3.0	>3.0
Relative Abundance	>450	200-450	<200

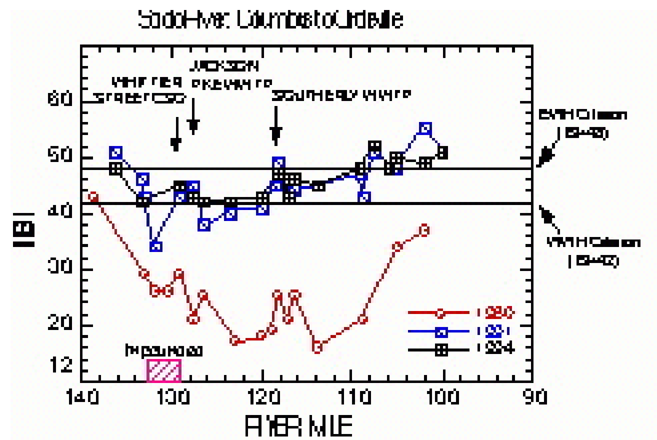
III. Calibrated IBI modified for Ohio waters



IV. Establish ecoregional patterns/expectations



V. Derive numeric bio-criteria: Codify in WQS



VI. Numeric biocriteria are used in bioassessments

Ohio Biological Criteria: Adopted May 1990 (OAC 3745-1-07; Table 7-14)

Huron Erie Lake Plain (HELP)

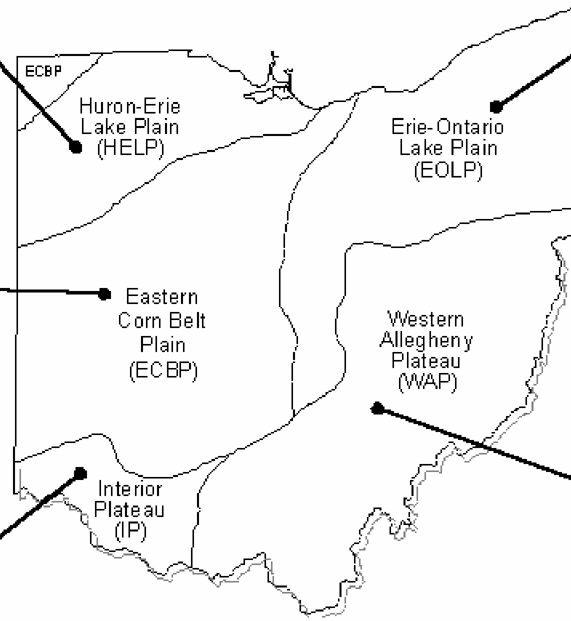
Use	Size	IBI	MIwb	ICI
WWH	H	28	NA	34
	W	32	7.3	34
	B	34	8.6	34
MWH-C	H	20	NA	22
	W	22	5.6	22
	B	20	5.7	22
MWH-I	B	30	5.7	NA

Erie Ontario Lake Plain (EOLP)

Use	Size	IBI	MIwb	ICI
WWH	H	40	NA	34
	W	38	7.9	34
	B	40	8.7	34
MWH-C	H	24	NA	22
	W	24	6.2	22
	B	24	5.8	22
MWH-I	B	30	6.6	NA

Eastern Corn Belt Plains (ECBP)

Use	Size	IBI	MIwb	ICI
WWH	H	40	NA	36
	W	40	8.3	36
	B	42	8.5	36
MWH-C	H	24	NA	22
	W	24	6.2	22
	B	24	5.8	22
MWH-I	B	30	6.6	NA



Western Allegheny Plateau (WAP)

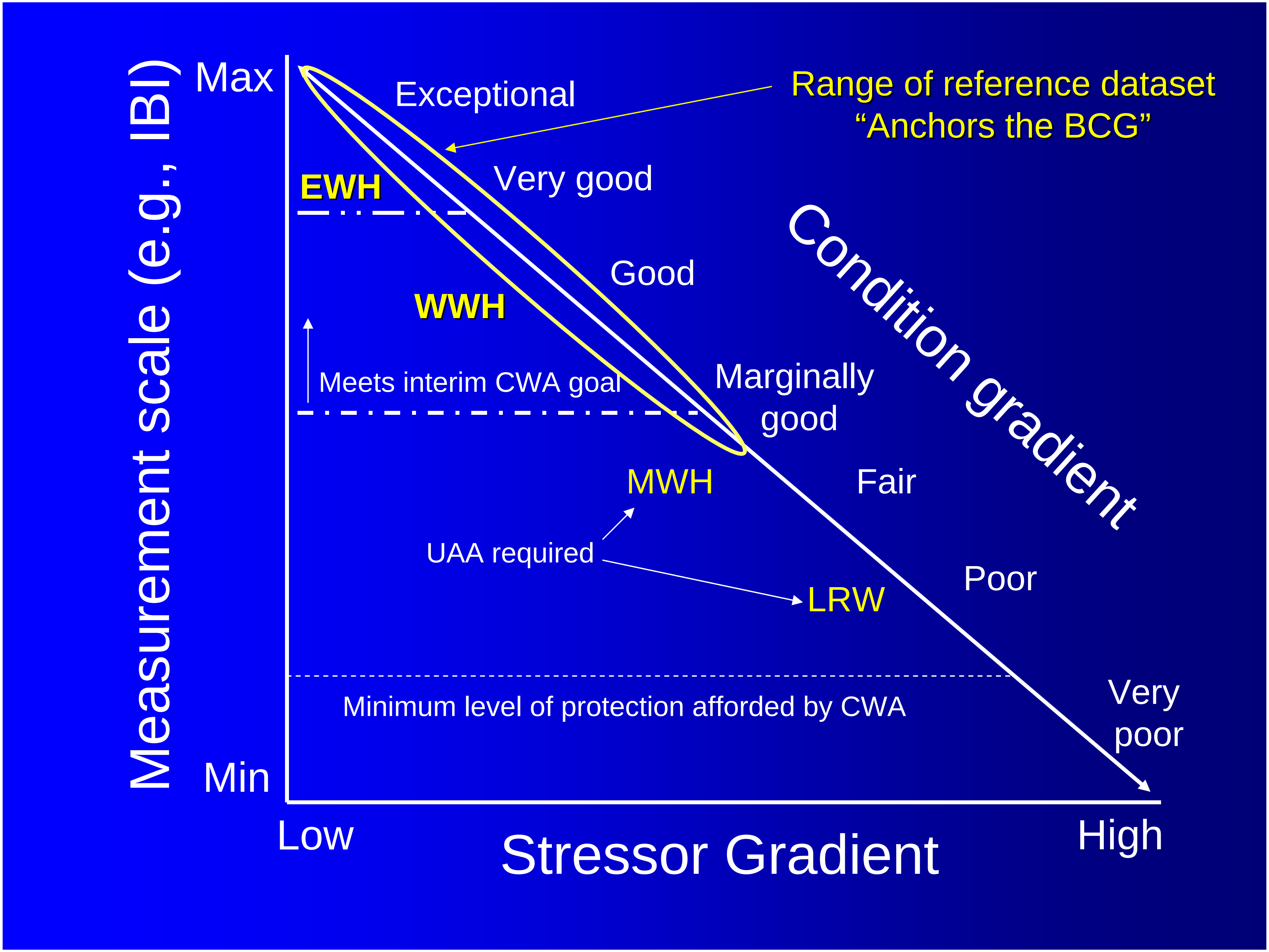
Use	Size	IBI	MIwb	ICI
WWH	H	44	NA	34
	W	44	8.4	34
	B	40	8.6	34
MWH-C	H	24	NA	22
	W	24	6.2	22
	B	24	5.8	22
MWH-A	H	24	NA	30
	W	24	5.5	30
	B	24	5.5	30
MWH-I	B	30	6.6	NA

Interior Plateau (IP)

Use	Size	IBI	MIwb	ICI
WWH	H	40	NA	30
	W	40	8.1	30
	B	38	8.7	30
MWH-C	H	24	NA	22
	W	24	6.2	22
	B	24	5.8	22
MWH-I	B	30	6.6	NA

Statewide Exceptional Criteria

Use	Size	IBI	MIwb	ICI
EWH	H	50	NA	46
	W	50	9.4	46
	B	48	9.6	46

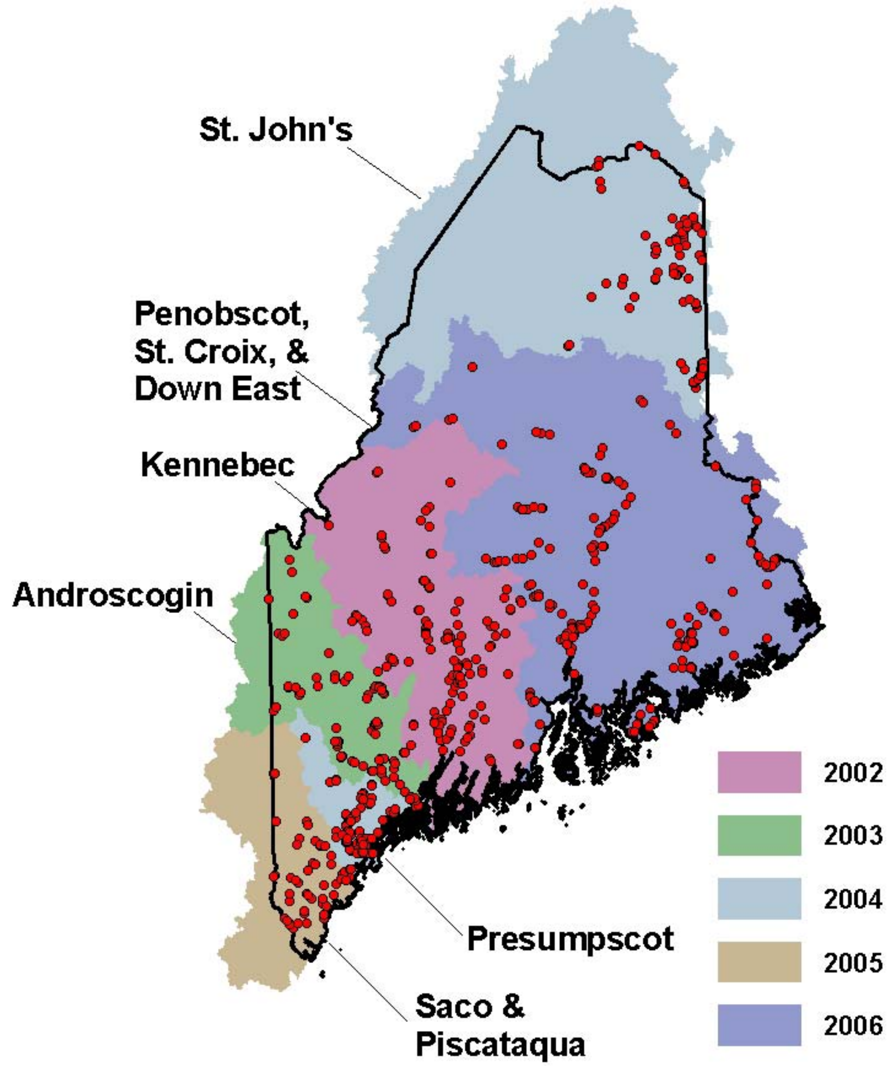


Measurement scale (e.g., IBI)
Max
Min
Exceptional
Range of reference dataset
"Anchors the BCG"
Very good
EWH
Good
WWH
Condition gradient
Meets interim CWA goal
Marginally
good
MWH
Fair
UAA required
LRW
Poor
Minimum level of protection afforded by CWA
Very
poor
Low
Stressor Gradient
High

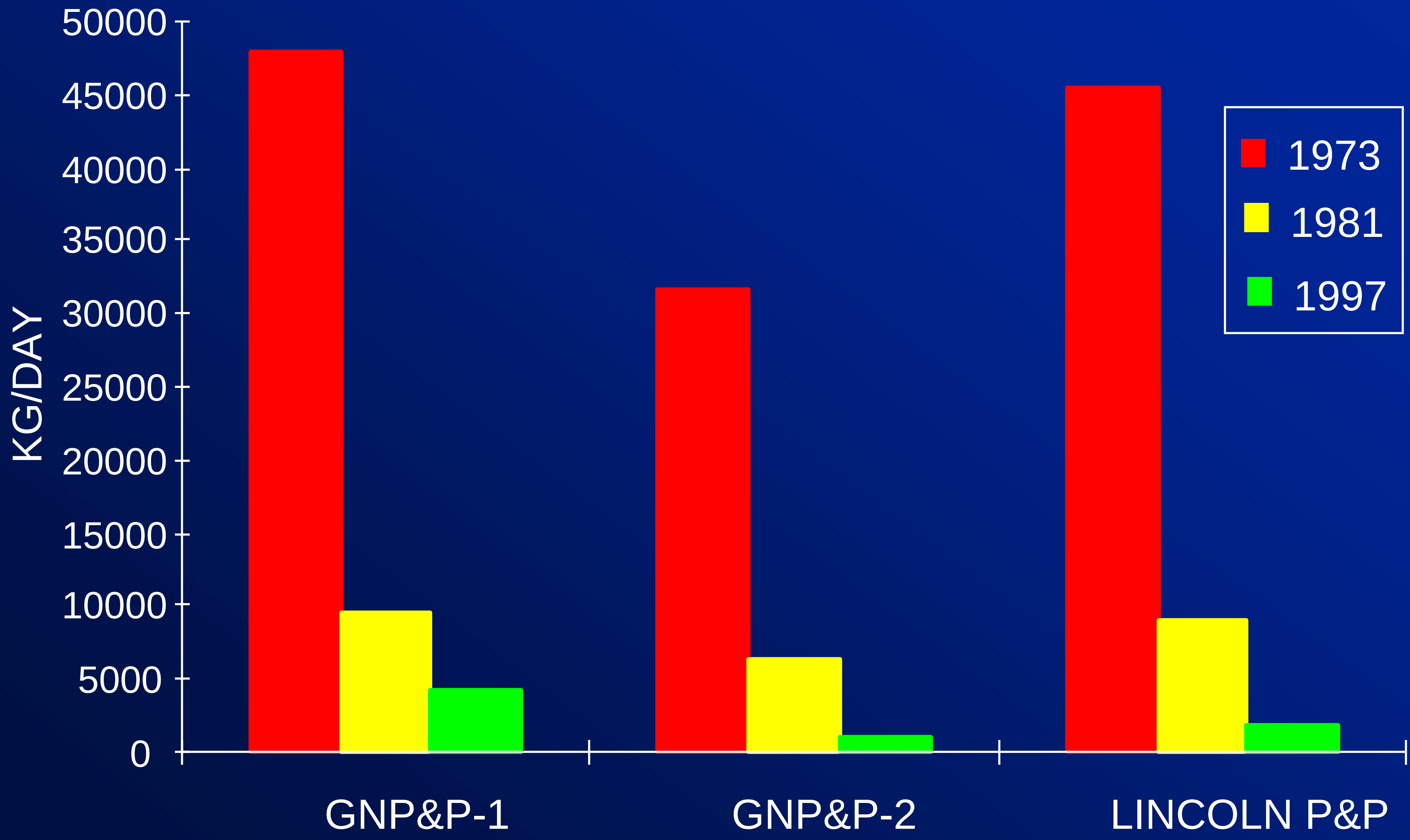
Biological Criteria: III

- Biological criteria represent a calibrated assessment tool which fosters an organized goal setting process in an effort to reconcile human impacts and guide restoration efforts.

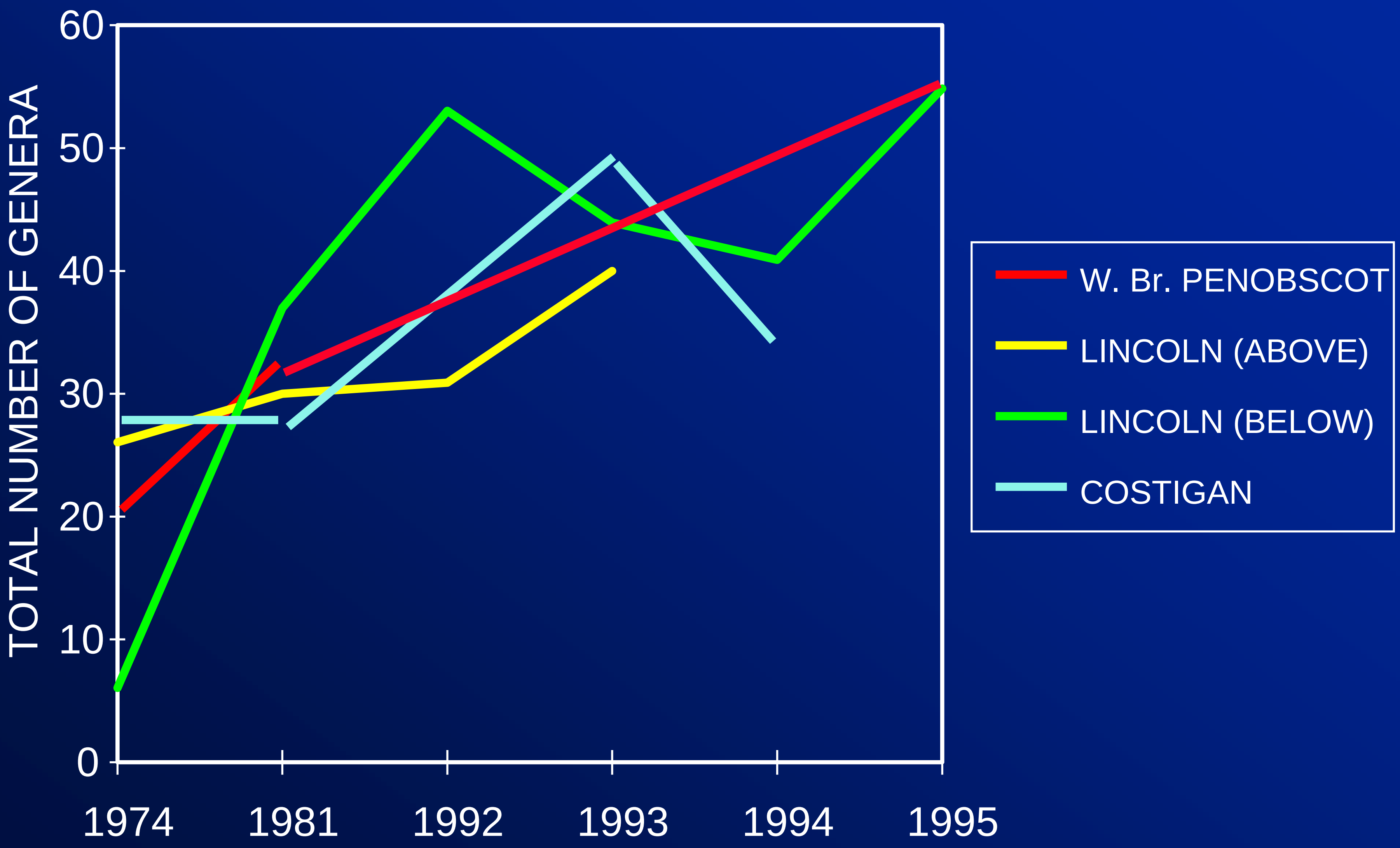
Maine DEP Bioassessments

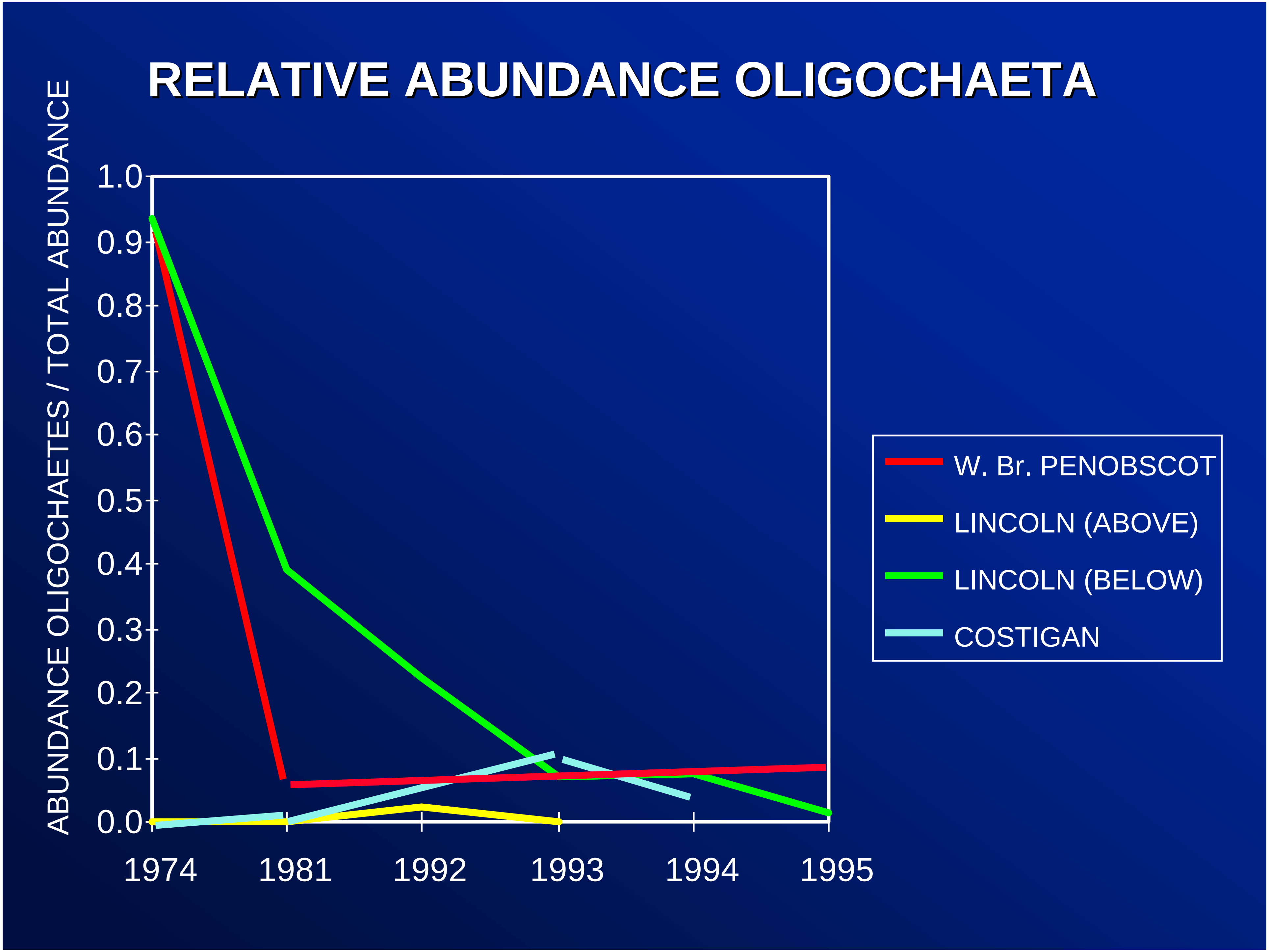


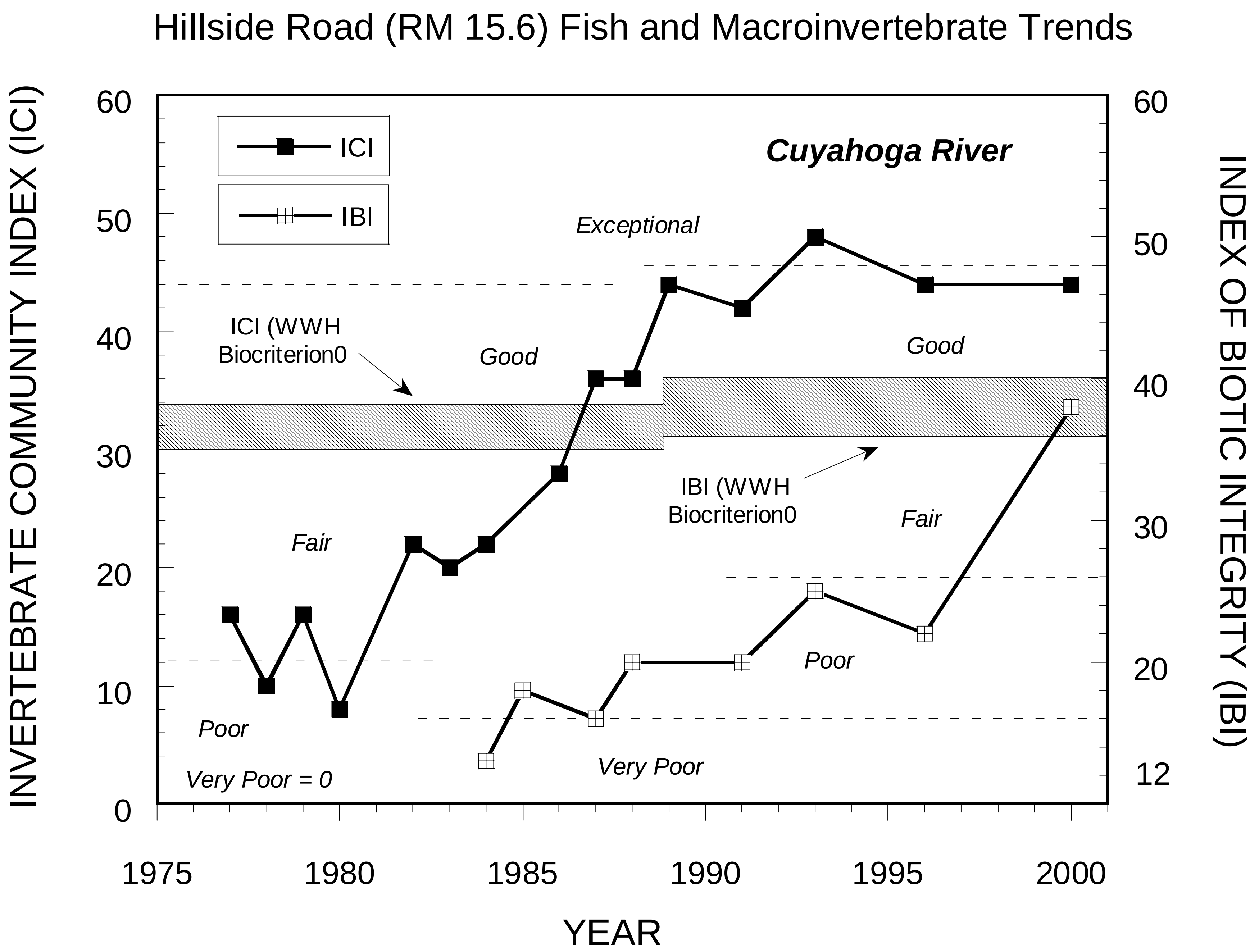
ESTIMATED TSS (KG/DAY) FOR THREE PULP AND PAPER MILLS ON THE PENOBSCOT RIVER



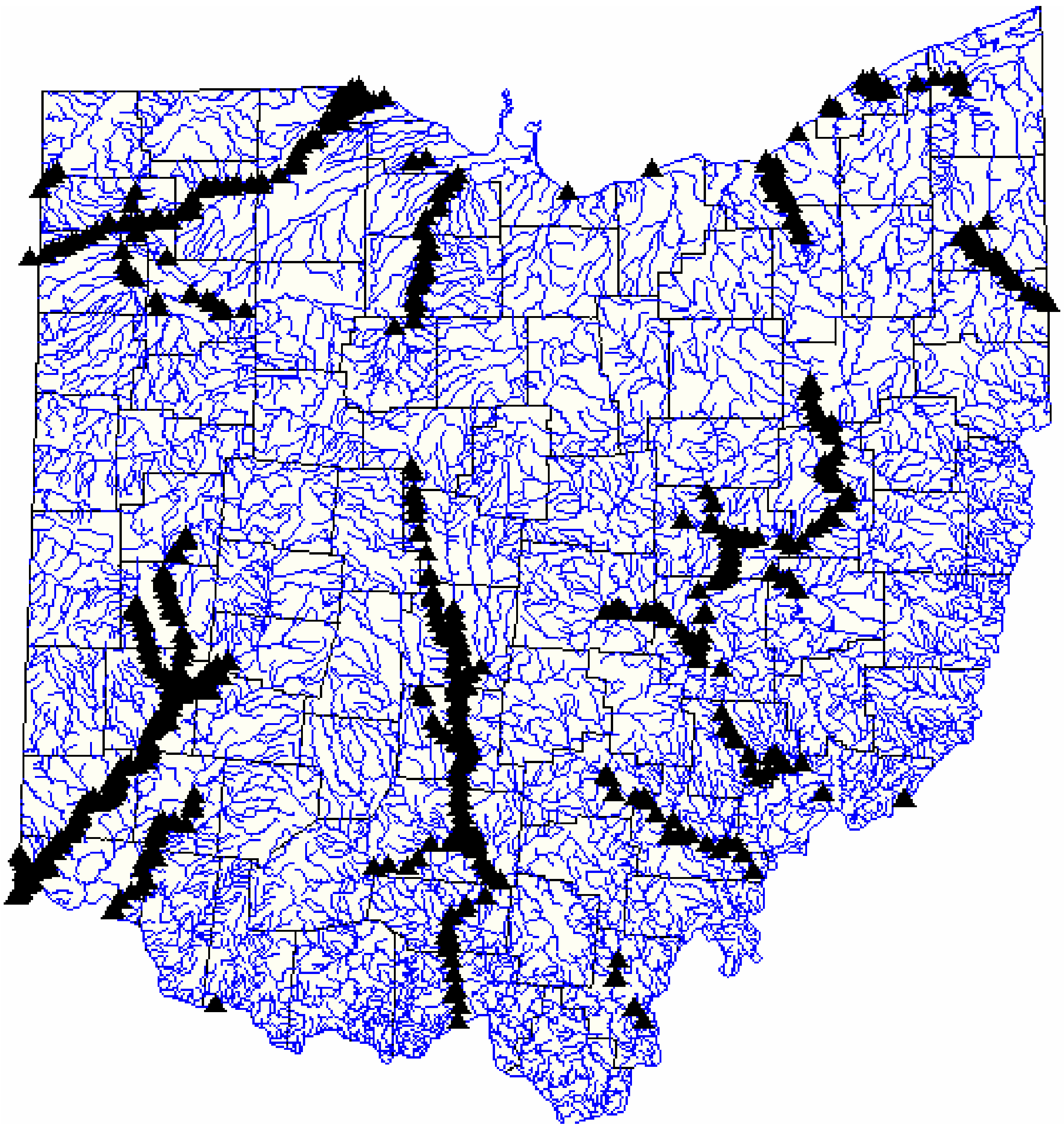
GENERIC RICHNESS




RELATIVE ABUNDANCE OLIGOCHAETA
ABUNDANCE OLIGOCHAETES / TOTAL ABUNDANCE
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
1974
1981
1992
1993
1994
1995
W. Br. PENOBSCOT
LINCOLN (ABOVE)
LINCOLN (BELOW)
COSTIGAN



Hillside Road (RM 15.6) Fish and Macroinvertebrate Trends
ICI
IBI
Cuyahoga River
Exceptional
Good
Good
ICI (WWH Biocriterion0
IBI (WWH Biocriterion0
Fair
Fair
Poor
Poor
Very Poor = 0
Very Poor
INVERTEBRATE COMMUNITY INDEX (ICI)
INDEX OF BIOTIC INTEGRITY (IBI)
YEAR
0
10
20
30
40
50
60
12
20
30
40
50
60
1975
1980
1985
1990
1995
2000



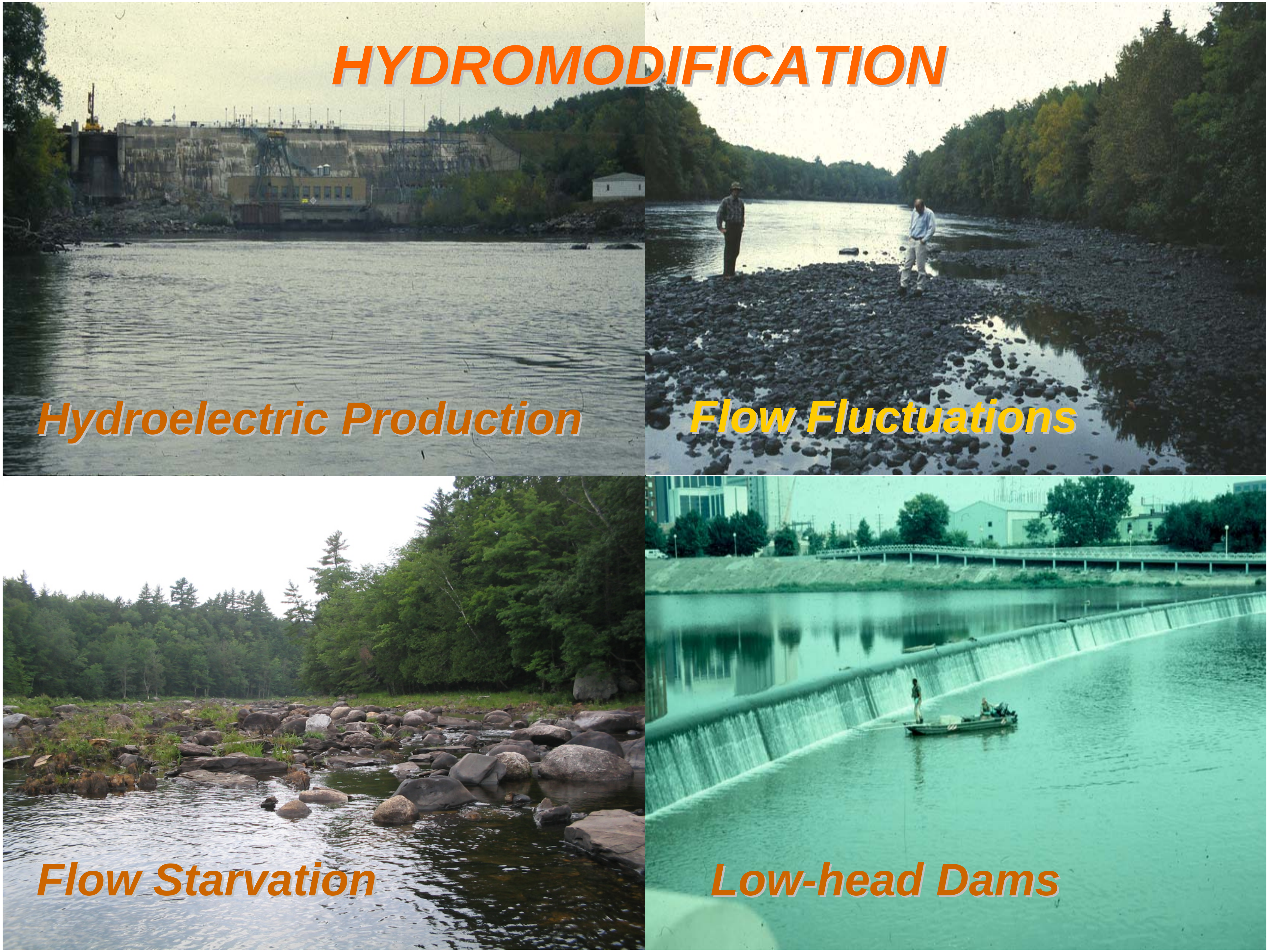
Ohio Large Rivers Bioassessment: 1979 - present

- Multiple stressors (point & nonpoint sources, habitat, hydromodification)
- Intensive survey design
- Repeat samplings >1 to 5-10 years; supports before & after assessments
- Aggregate assessment for waterbody subclass (>150-500 mi.^{2})

Mission Accomplished? Declarations of "total victory" – are they premature?

Many large rivers are effluent dominated by treated sewage flows – growth pressures are taxing existing infrastructure and assimilative capacity


NONPOINT SOURCES
Severe Bank Erosion
Urban Stormwater
Riparian Encroachment
Siltation of Substrates


HYDROMODIFICATION
Hydroelectric Production
Flow Fluctuations
Flow Starvation
Low-head Dams

American Fisheries Society Symposium 45:000–000, 2005

Changes in Fish Assemblage Status in Ohio's Nonwadeable Rivers and Streams over Two Decades

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Marc A. Smith, Brian C. Alsdorf, David J. Altfater, Charles E. Boucher,
Robert J. Miltner, Dennis E. Mishne, Randall E. Sanders, and
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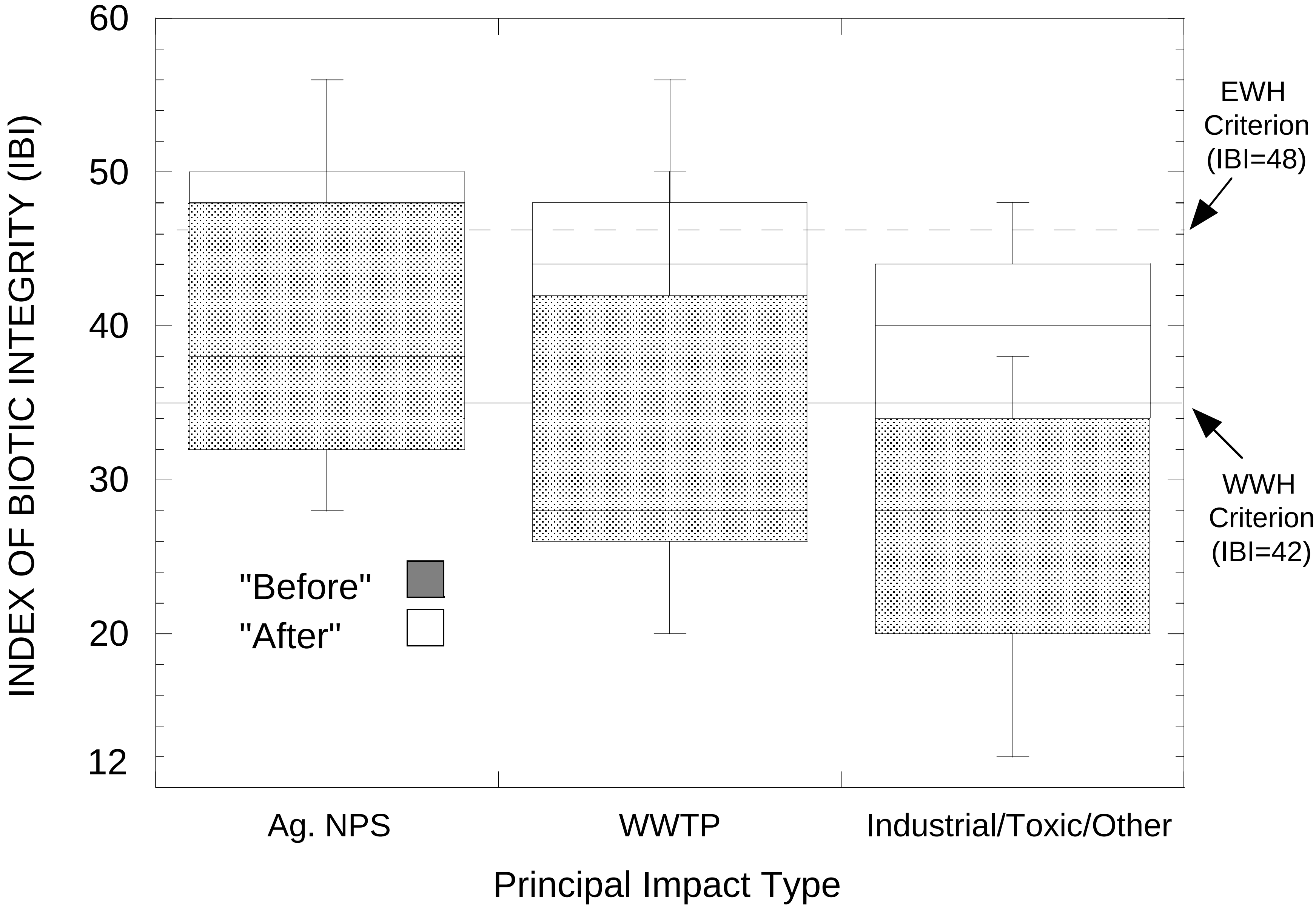
Abstract.—A systematic, standardized approach to monitor fish assemblages has been applied in Ohio's rivers since 1979. A primary objective is the assessment of changes in response to water pollution abatement and other water quality management programs. All major, nonwadeable rivers were intensively sampled using standardized electrofishing methods and a summer–early fall index period. Most rivers were sampled two or three times, before and after implementation of pollution controls at major point source discharges and best management practices for nonpoint sources. A modified and calibrated index of biotic integrity (IBI) was used to demonstrate and evaluate changes at multiple



INDEX OF BIOTIC INTEGRITY (IBI)
60
50
40
30
20
12
EWH
Criterion
(IBI=48)
WWH
Criterion
(IBI=42)
"Before"
"After"
Ag. NPS
WWTP
Industrial/Toxic/Other
Principal Impact Type

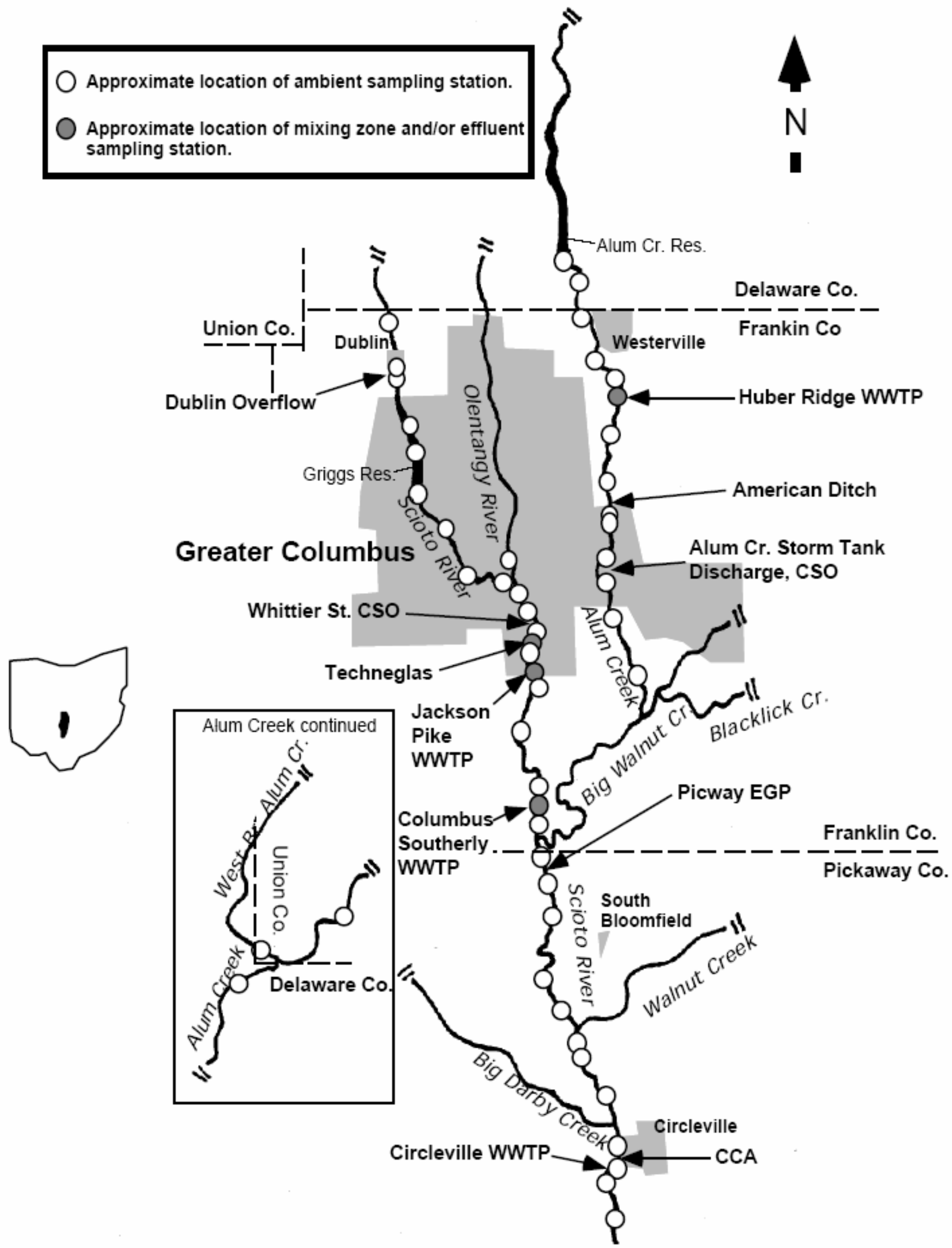


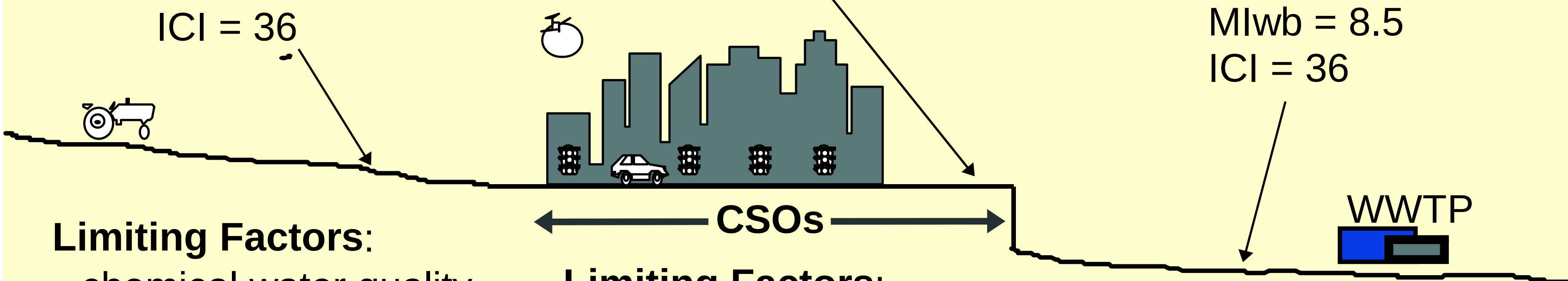
Figure 4.. The 1996 middle Scioto River study area showing principal streams and tributaries, population centers, major pollution sources and environmental monitoring stations.

Application of Biocriteria in Complex Settings

1. Free-flowing river (**WWH** use designation):
Upstream from urban area ECBP Ecoregion - Wading site type:
IBI = 40
MIwb = 8.3
ICI = 36

2. Impounded river (**MWH** use designation):
Within urban area ECBP Ecoregion - Boat site type:
IBI = 30
MIwb = 6.6
ICI = N/A

3. Free-flowing river (**WWH** use designation):
Downstream from urban area
ECBP Ecoregion - Boat site type:
IBI = 42
MIwb = 8.5
ICI = 36



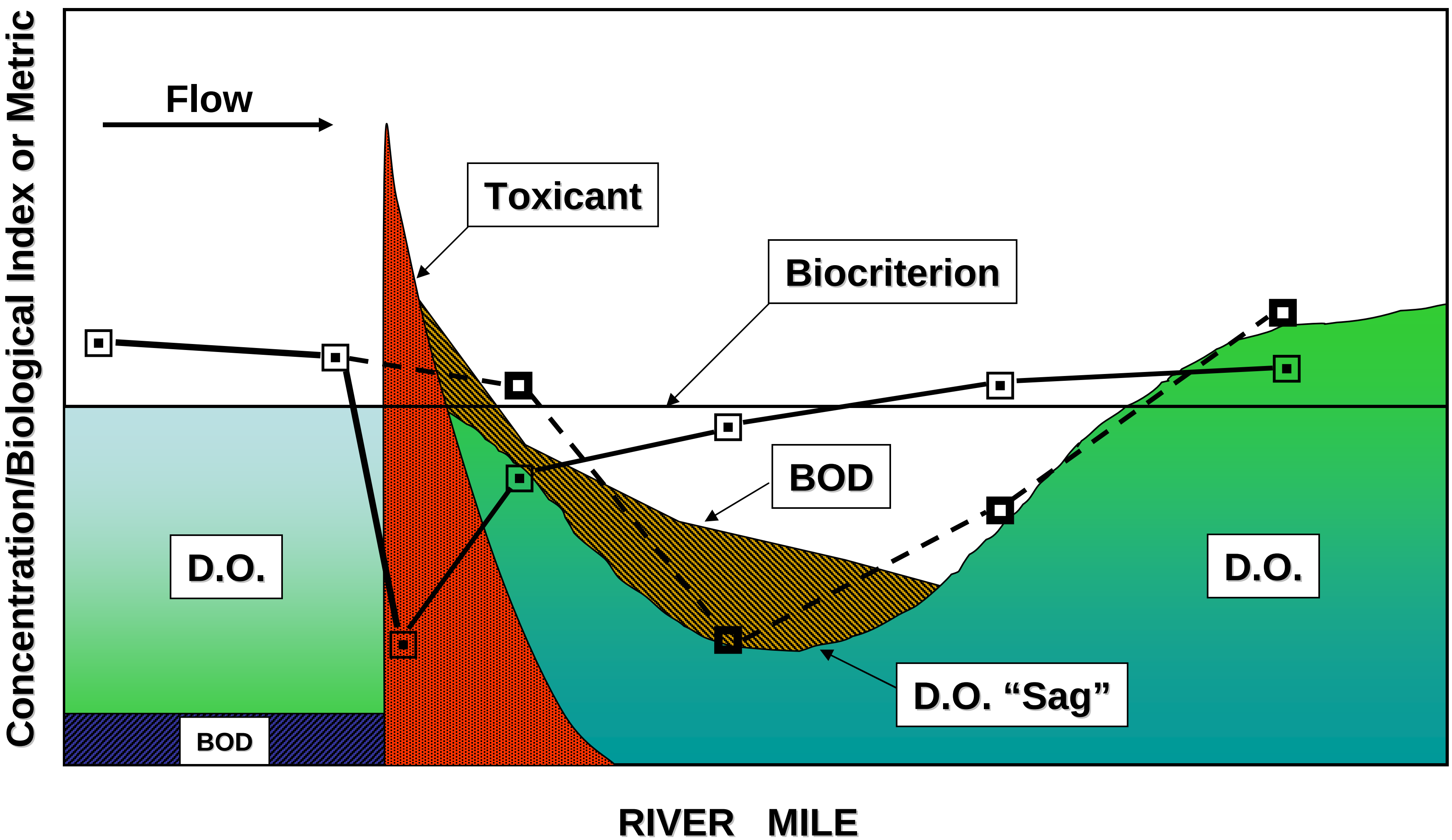
Limiting Factors:
- chemical water quality
- physical habitat
- flow/energy dynamics

Limiting Factors:
- physical habitat
- energy/flow dynamics
- chemical water quality

Limiting Factors:
- chemical water quality
- energy/flow dynamics
- physical habitat

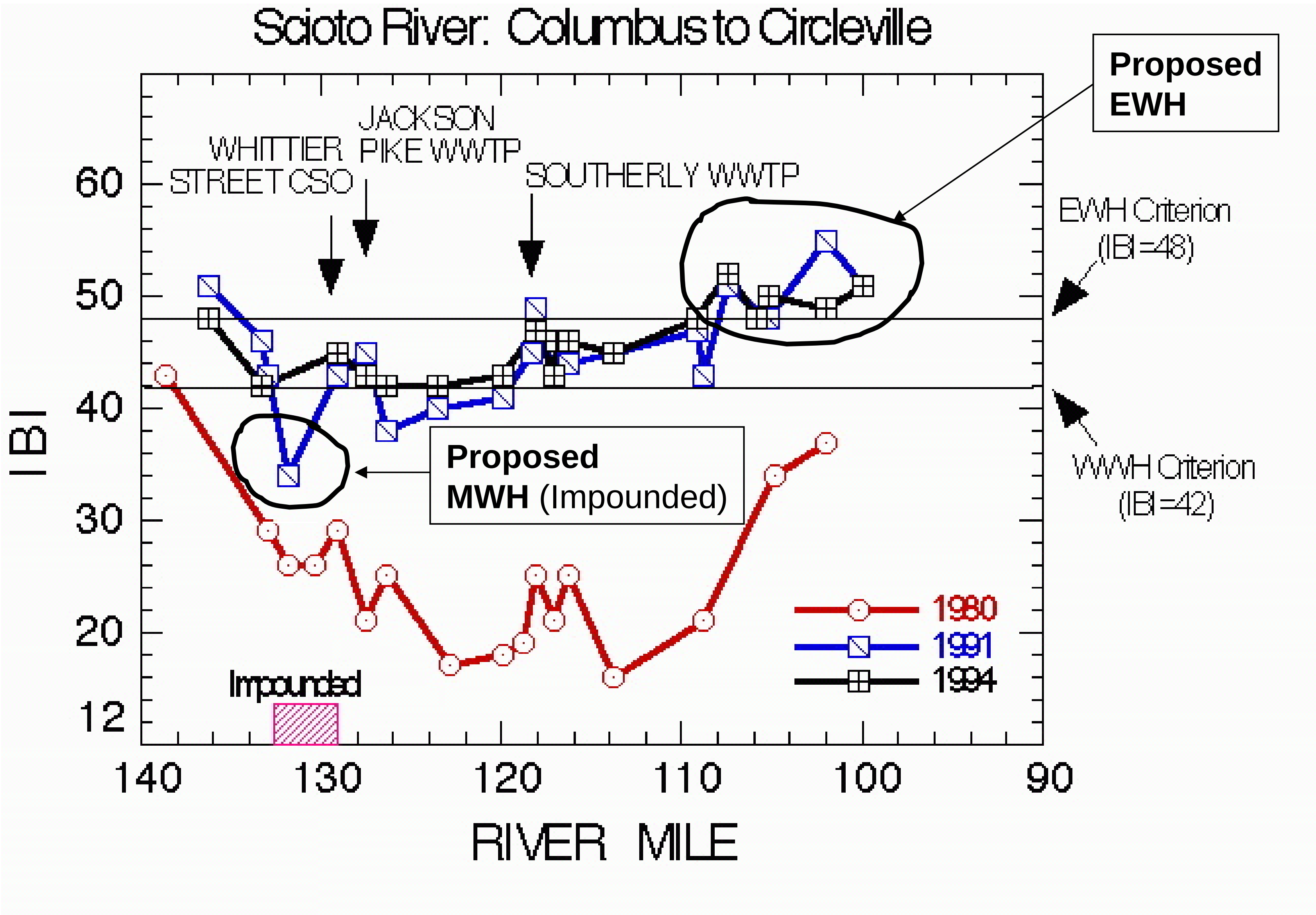
Flow Direction →

Resurrecting the Concept of the Pollution Impact Continuum in Rivers: It Still Exists

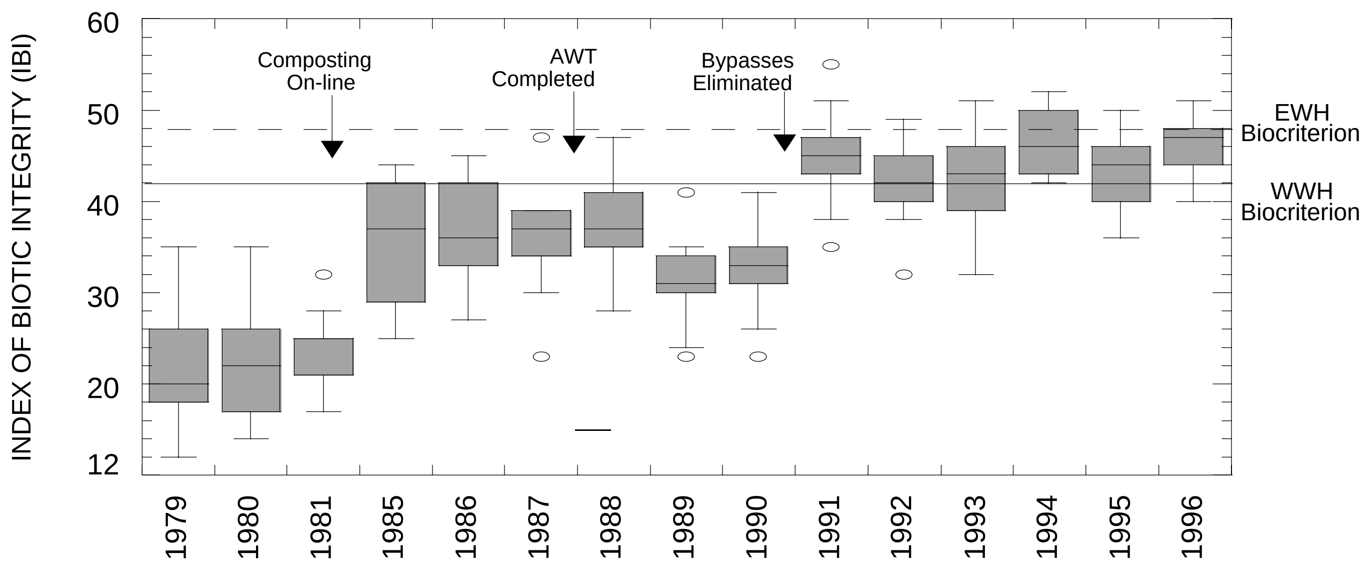


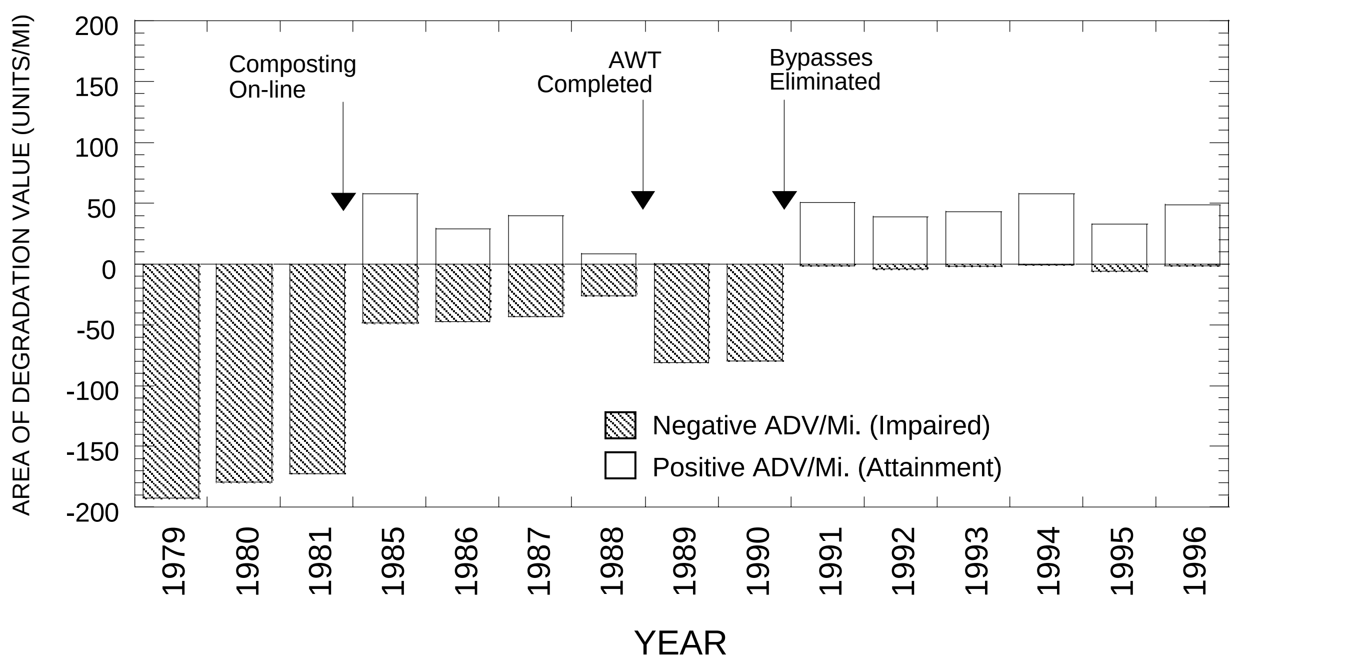
After Bartsch and Ingram (1967)

Demonstrating Changes Through Time: Scioto River 1980 - 1994

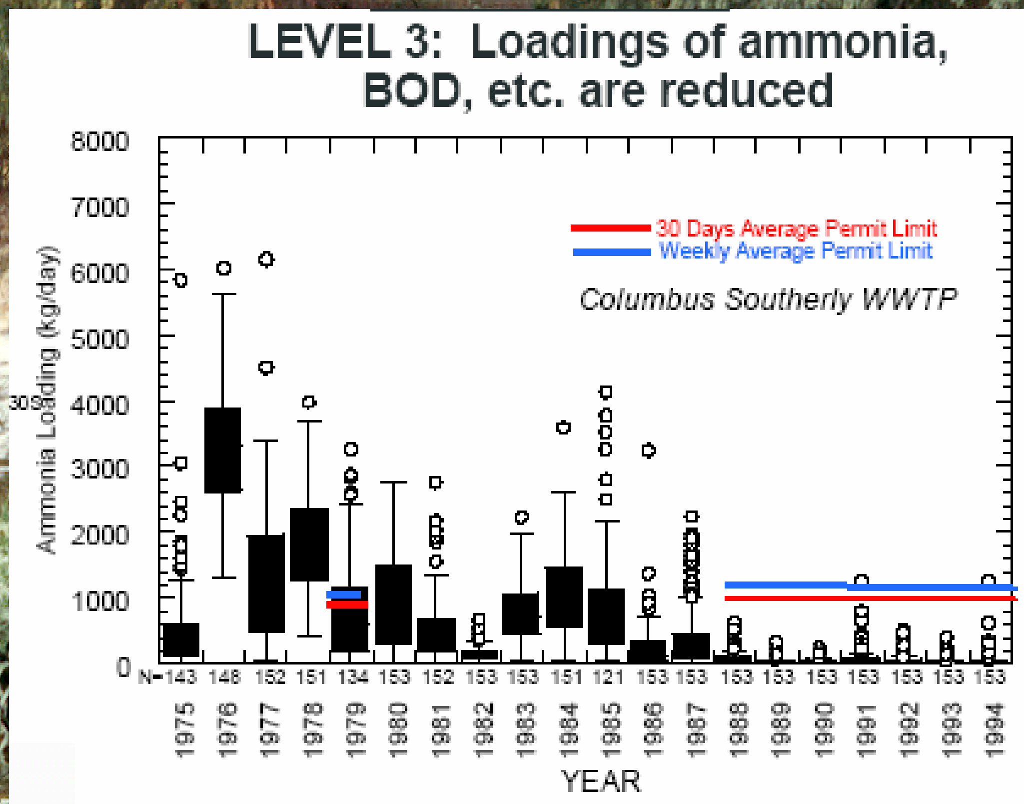


Demonstrating Changes Through Time: Scioto River (1979 – 1996)





Jackson Pike WWTP – 75 MGD
Columbus Southerly WWTP – 125 MGD
Combined 200 MGD = 90-95% of summer base flow



Measuring and Managing Environmental Progress: Hierarchy of Indicators

1. Management actions
2. Response to management

Administrative indicators
[permits, plans, grants, enforcement,
[technologies used, BMPs installed]

3. Stressor abatement

Stressor indicators
[effluent reduction, changes in land-use practices]

4. Ambient conditions
5. Direct exposure to effects of pollution

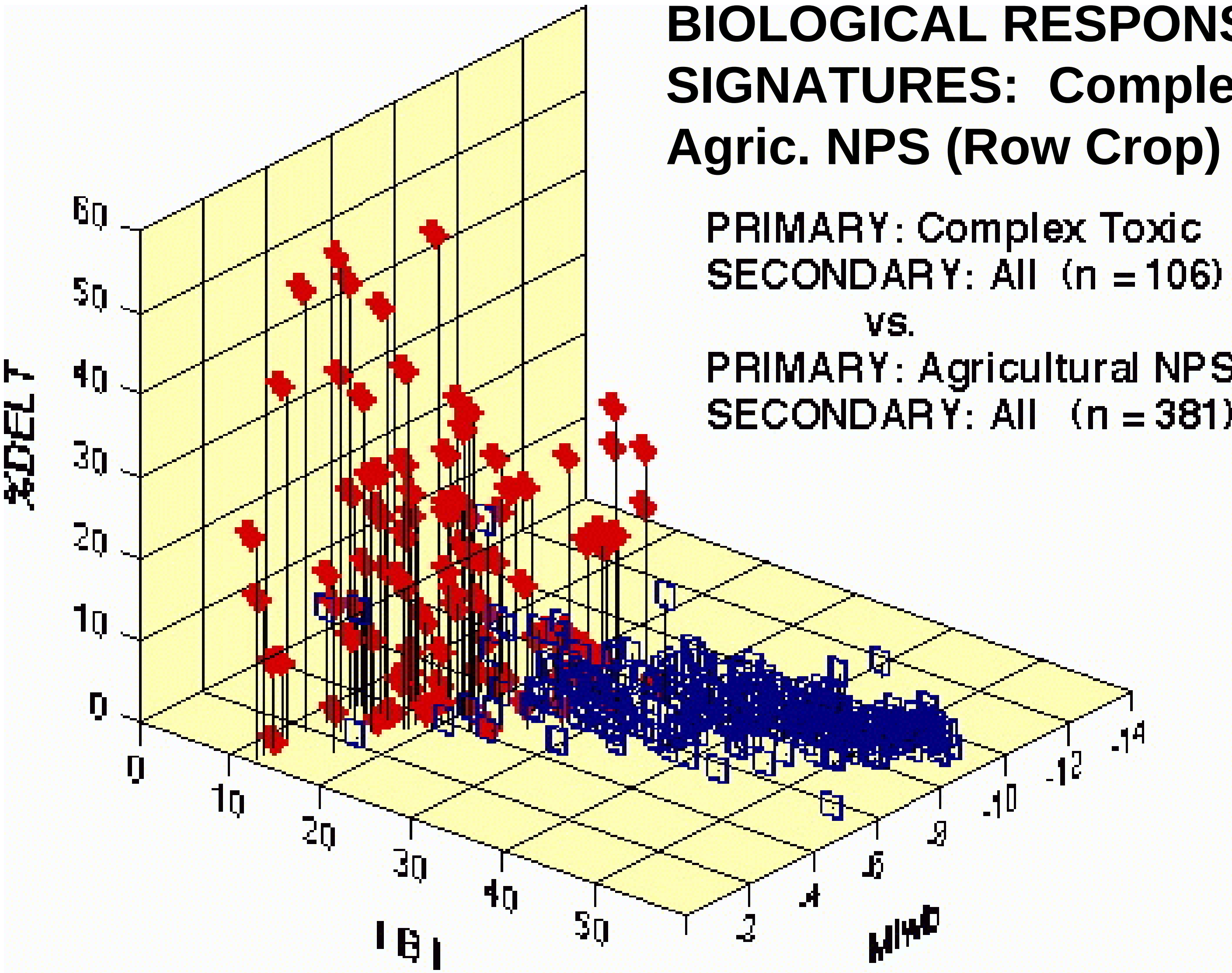
Exposure indicators
[pollutant conc., flow or physical habitat alteration, assimilation and uptake of pollutants, reduced spawning habitat, nutrient dynamics changes, sedimentation effects, etc.]

6. Biological response

Response indicators
[biological metrics, multimetric indexes, target species, other biological measures]

Endpoint of Concern: "ecological health"

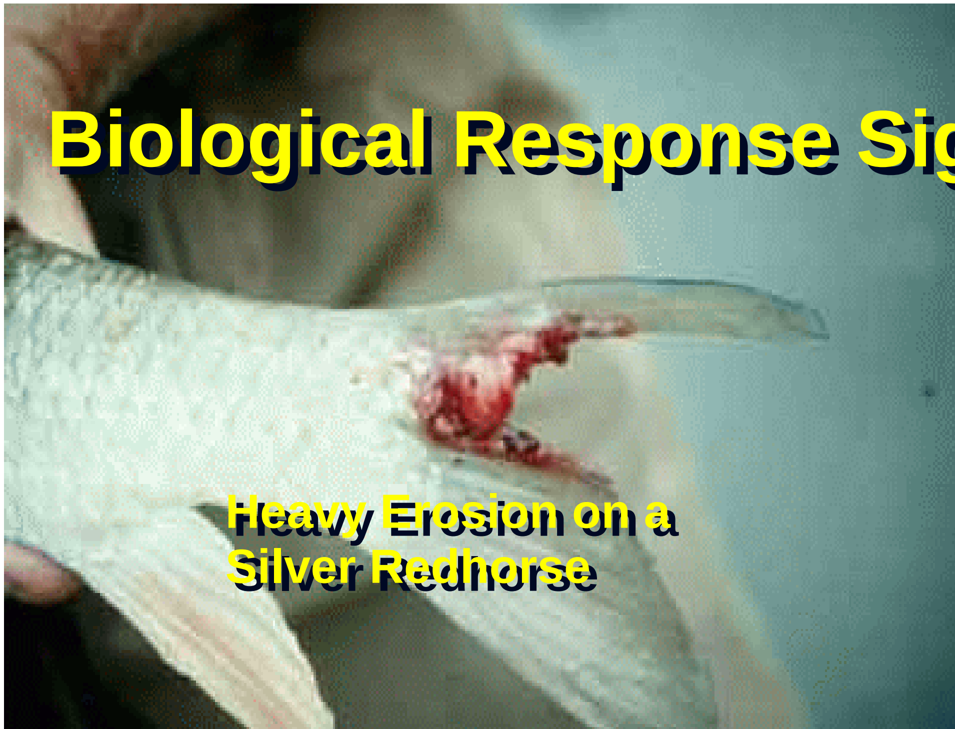
BIOLOGICAL RESPONSE SIGNATURES: Complex Toxic vs. Agric. NPS (Row Crop)

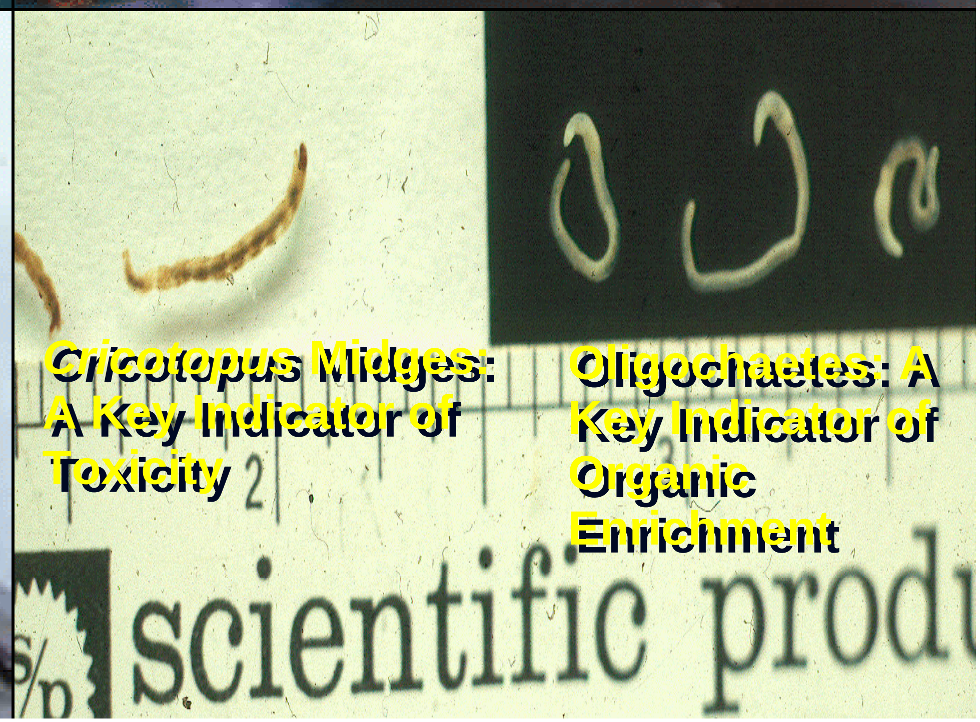


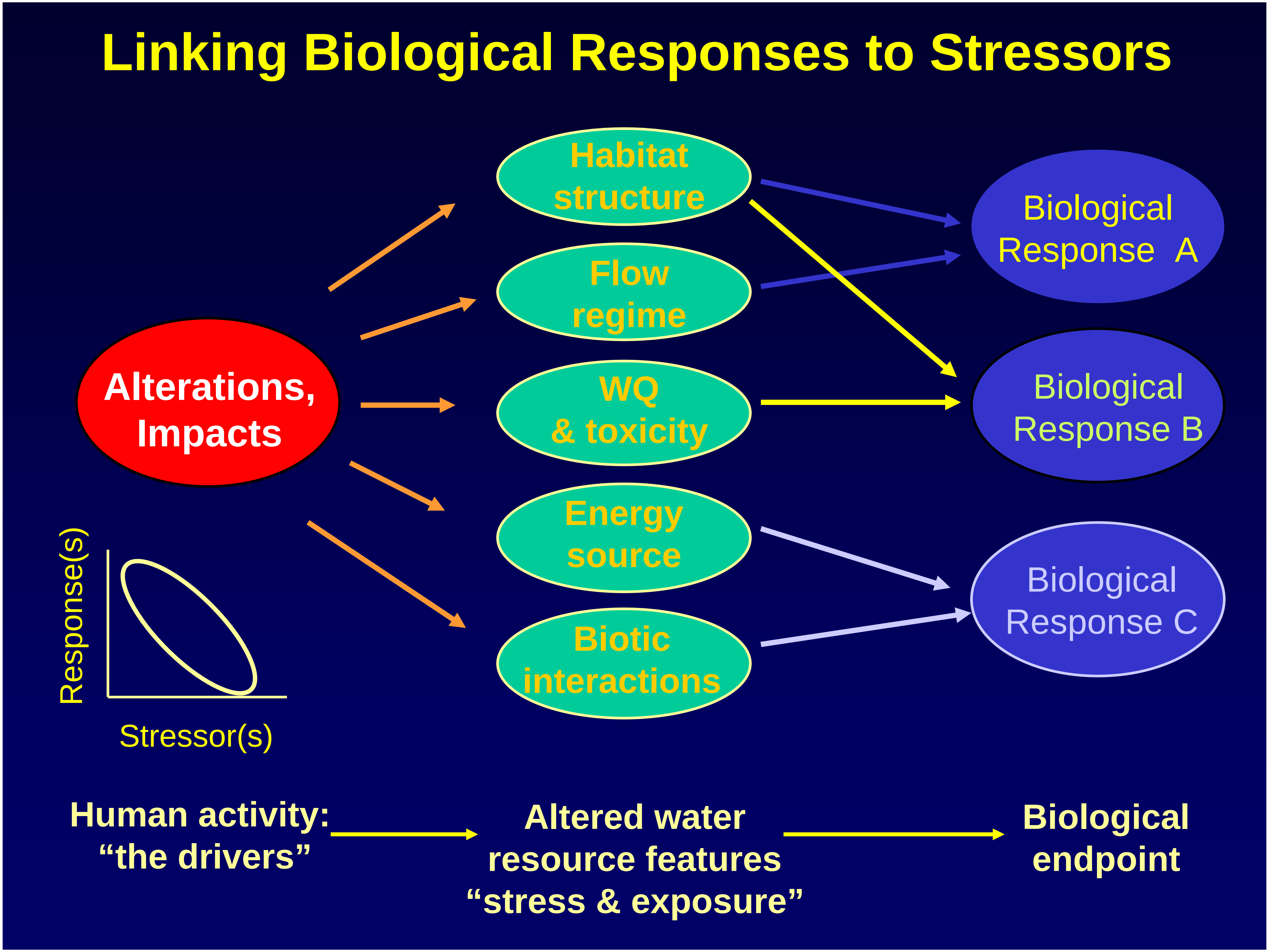
HELP/ECBP Ecoregions

after Yoder and Rankin (1995)

Biological Response Signatures: Key Attributes






Linking Biological Responses to Stressors
Habitat structure
Flow regime
WQ & toxicity
Energy source
Biotic interactions
Alterations, Impacts
Biological Response A
Biological Response B
Biological Response C
Response(s)
Stressor(s)
Human activity: "the drivers"
Altered water resource features "stress & exposure"
Biological endpoint

Good quality biological data *and a process for using it* is essential for improving the management of aquatic resources and bringing policy and legislation into the 21st Century