Using Associations Between Biological Field Data and Ambient Water Chemistry Data to Derive Water Quality Targets

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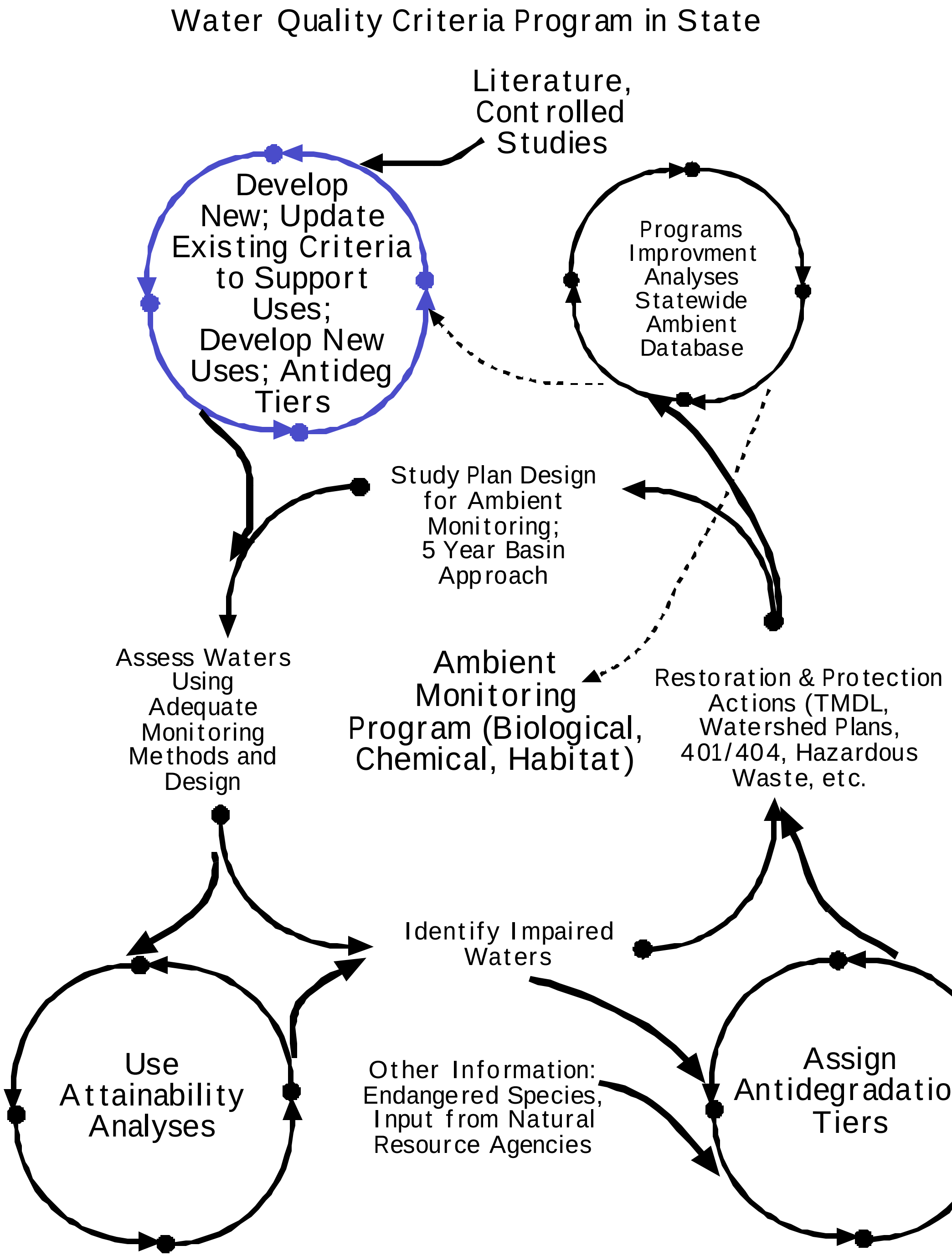
CABB

Important Goals of This Session

- Identifying the role of monitoring in the establishment of water quality goals and the “criteria” to protect those goals
- Cross-fertilization of management and research ideas concerning different approaches to environmental resource monitoring

Ohio Ambient Biological, Chemistry, Habitat Database

- Ohio has a dataset that extends back 25+ years with consistently collected water chemistry data, habitat data, and fish and macroinvertebrate community data.
- In this presentation I will provide examples of how this data set was used to:
  - Derive tiered ammonia and dissolved oxygen criteria for
  - Develop targets for effects of nutrients on aquatic life,
  - Create risk assessment “triggers” on dissolved metals translators
  - Derive background concentrations for commonly monitored chemicals in Ohio to aid in interpreting cause/source assessments in watershed intensive surveys.
  - Explore relationships between sulfates, chlorides and macroinvertebrate taxa abundance.

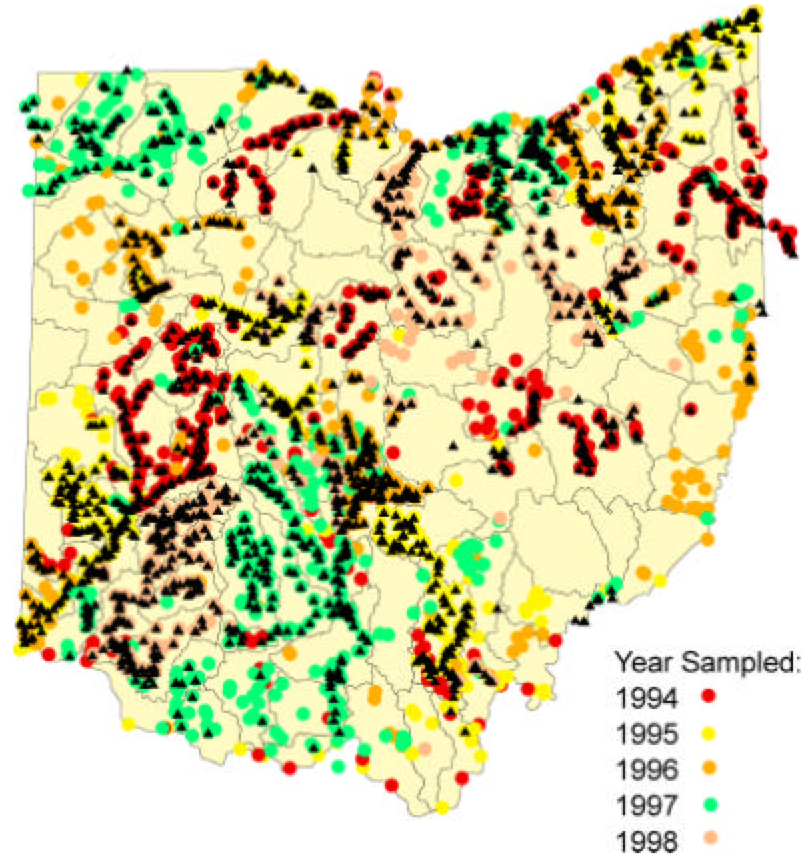


Critical to Cross-Fertilize Management with Research Results:

- Monitoring is a driving force for deriving strategic planning
- Monitoring helped drive the implementation ot TIERED AQUATIC LIFE USES
- Strong links between WQS program (criteria efforts) and monitoring data – Some criteria/targets derived wholly or partly with ambient data
- Monitoring data has help to define approach for new Anti-degradation tiers, TMDL program, and strategic goals
- Monitoring data key to active UAA program

Fish Community Data

- Late 1970s to present
- Approximately 20,000 samples
- Nearly 8,000 unique stations
- 162 species collected
- 7.9 million fish processed



Macroinvertebrate Community Data

- Early 1970s to present
- Over 7,100 samples (nearly 4200 with quantitative methods; Hester-Dendy)
- Over 5200 unique stations
- Over 1,180 taxa collected
- 22.6 million macroinvertebrates processed

Water Column Chemistry

- 1960s to present
- Over 100,000 samples
- Over 7,000 unique stations
- Conventionals (D.O., hardness, conductivity, nutrients, BOD, bacteria, etc)
- Metals (mostly total recoverable, recently dissolved forms)
- Other parameters (organics, etc, not all computerized)
- Other chemical databases: sediment, fish tissue

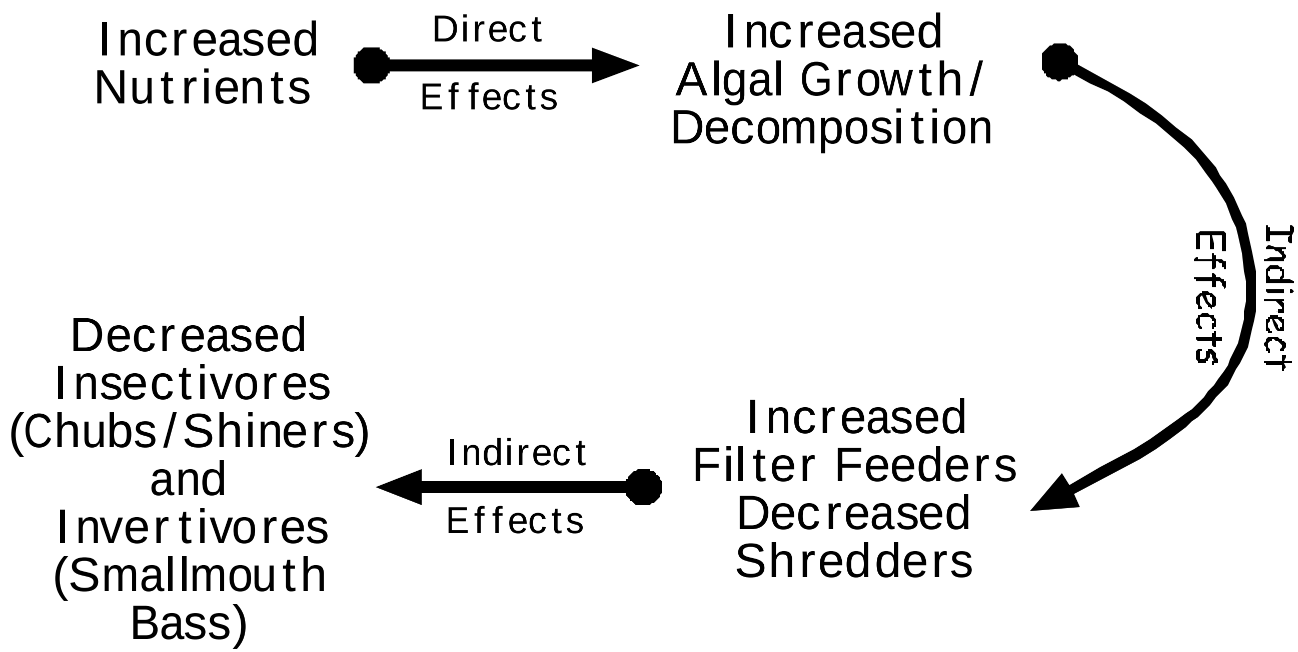
Major Approaches for Exploring Ambient Database

- Correlation Analyses
  - Examining relationships between ambient water chemistry data (water column and sediment) and IBI, ICI, and metrics – "Wedge" or Threshold analyses
  - Examining relationships between water chemistry and individual taxa or taxa groups
- Dividing Data into exploratory and testing databases
- Using more complex statistical methodologies such as recent WERF methods such as pattern recognition
- Site specific case studies
- Causation difficult to obtain (e.g., indirect effects); strength in multiple lines of evidence

Indirect Effects of Stressors

Toxicant/Stressor --Direct Effects--> Species A --Indirect Effects--> Species B

from Preston 2002

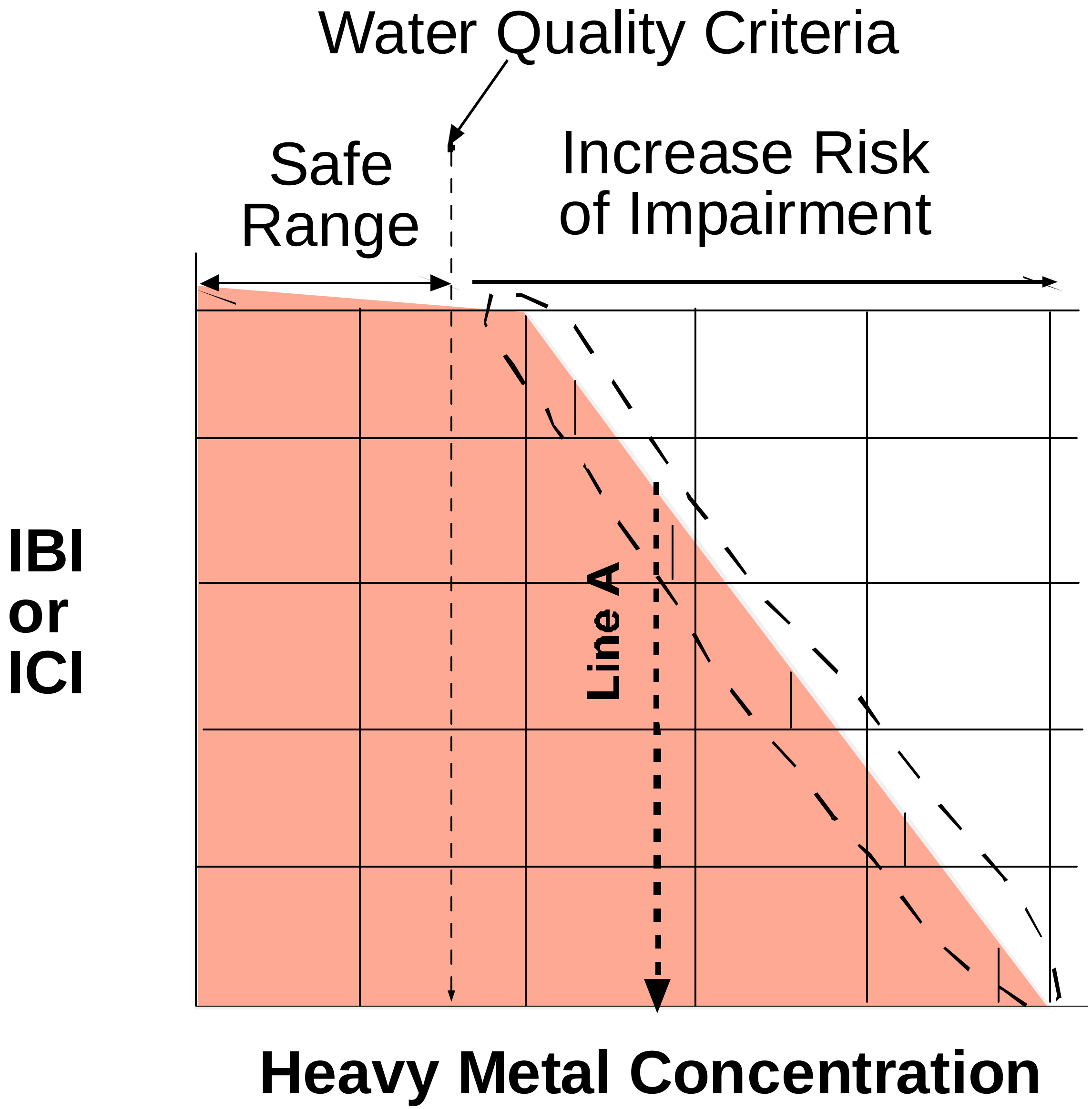


Interpreting Wedges of Data

- 95th Percentile Line represents the typically occurring maximum concentrations of a stressor at which a corresponding IBI, ICI, or some other valued parameter exists in the statewide database.

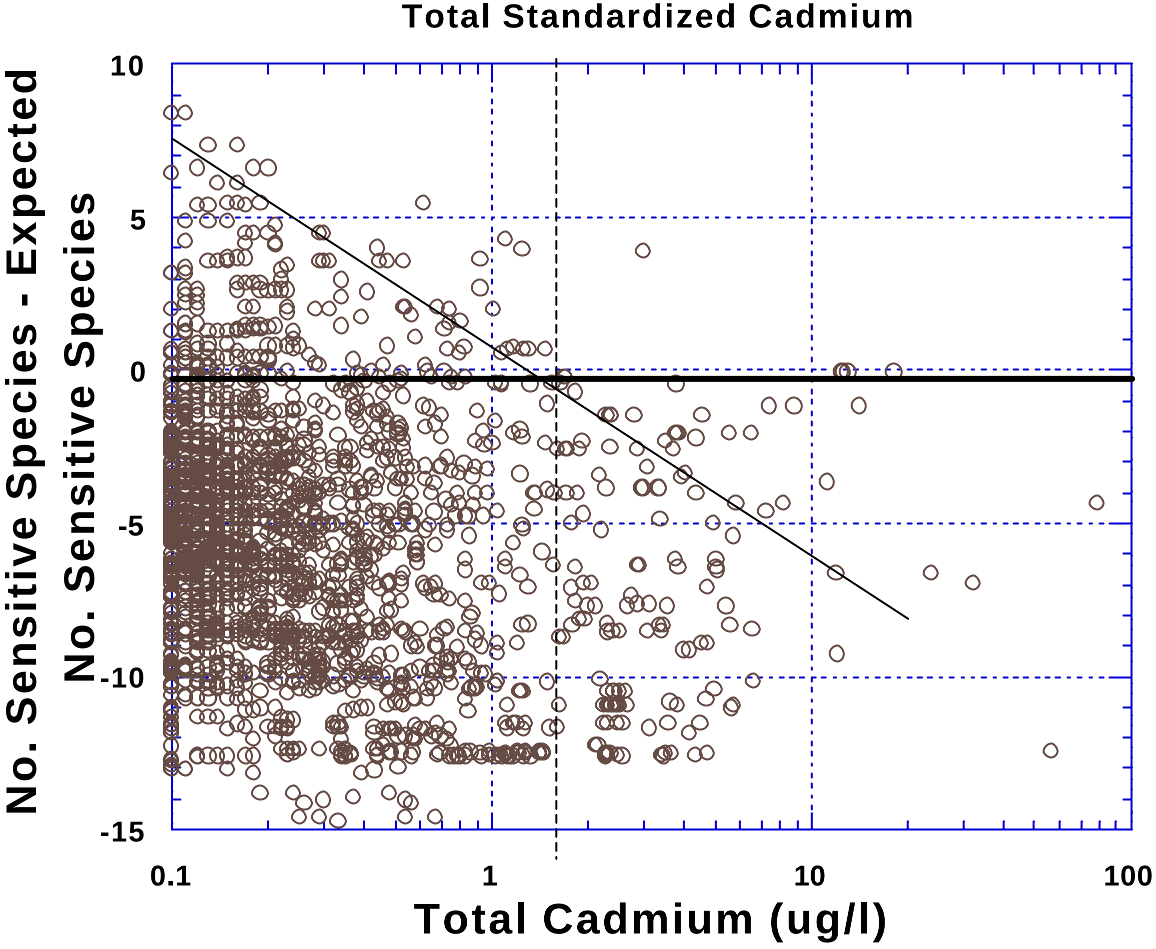
- Lines drawn perpendicular to the X-axis that intersect the IBI biocriterion for an aquatic life use designation define the maximum concentrations above which there is an increasing risk of non-attainment (empirically derived).

- Usefulness of ambient data for developing targets – Habitat/Sediment > Nutrients > D.O., pH > Ammonia > Toxicants

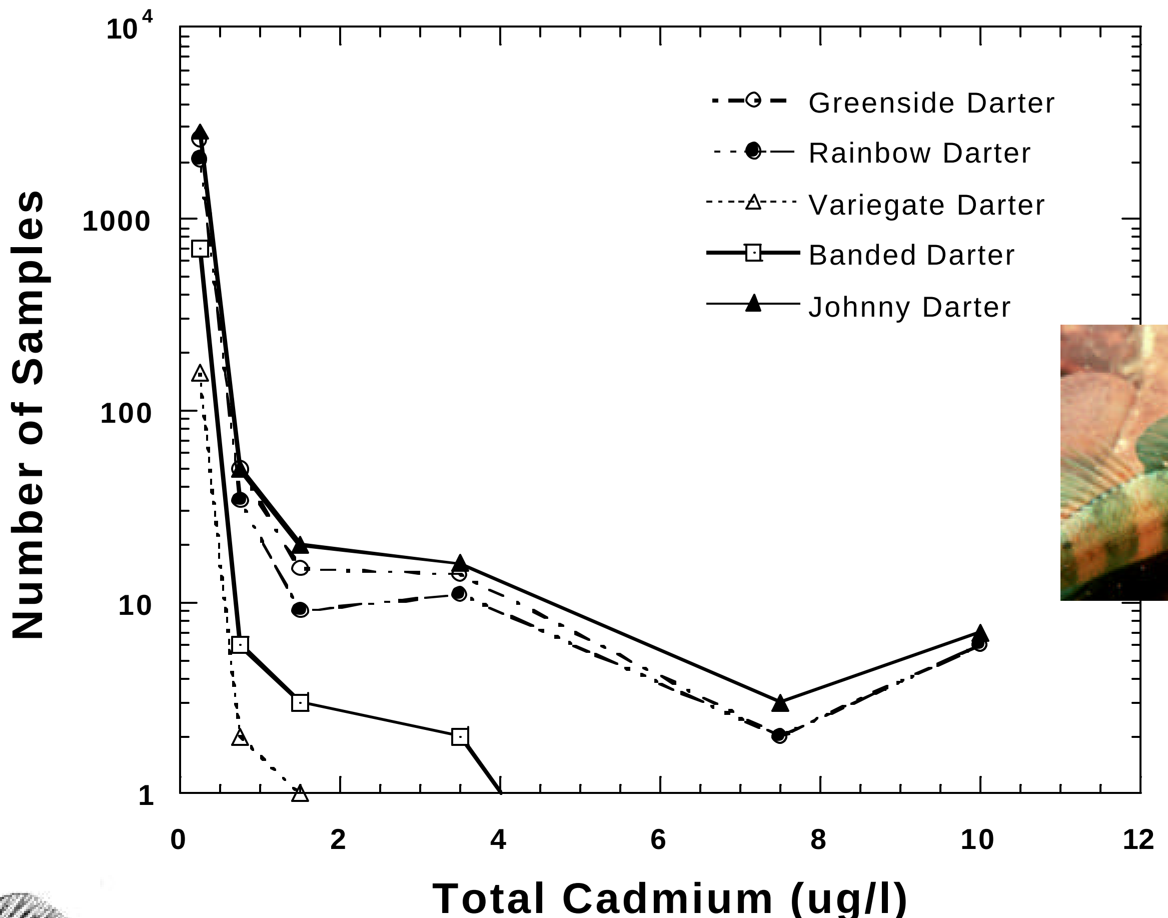

Water Quality Criteria
Safe Range
Increase Risk of Impairment
IBI or ICI
Line A
Heavy Metal Concentration

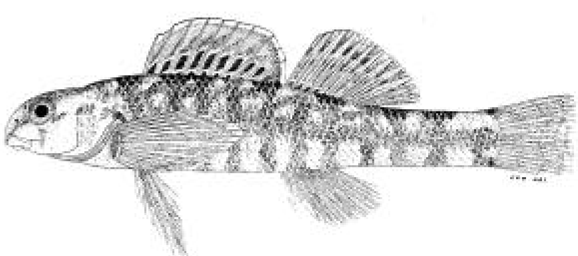
Advantages/Disadvantages to Wedge Analysis

- Advantages
  - Large, existing robust data bases with up to 10,000 points
  - Real world conditions
  - Can examine multiple response variables (e.g., IBI to individual taxa)
  - Real world risk management
  - Can provide support for application of toxicity-derived criteria
  - May integrate additive effects of metals and other pollutants
- Disadvantages
  - Does not isolate cause-effect relationship in same way that experimental analyses would; instead rely on statistical inference via ecological epidemeological approach
  - Multiple stressors almost universal
  - Many parameters do not have sufficient "hits" or resolution to analyze (e.g., nickel)
  - Need to understand strong habitat affects on biota and take into account via tiered uses, etc
  - Need large, spatially broad database to overcome shortcomings of small chemistry sample sizes at individual sites


Total Standardized Cadmium
No. Sensitive Species - Expected
No. Sensitive Species
10
5
0
-5
-10
-15
0.1
1
10
100
Total Cadmium (ug/l)

Darter Species Occurrence vs Total Cadmium

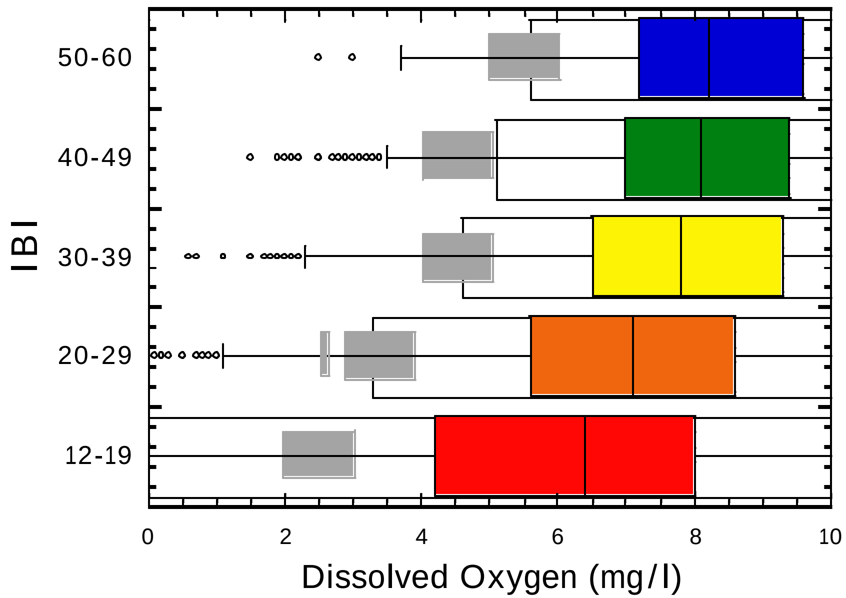


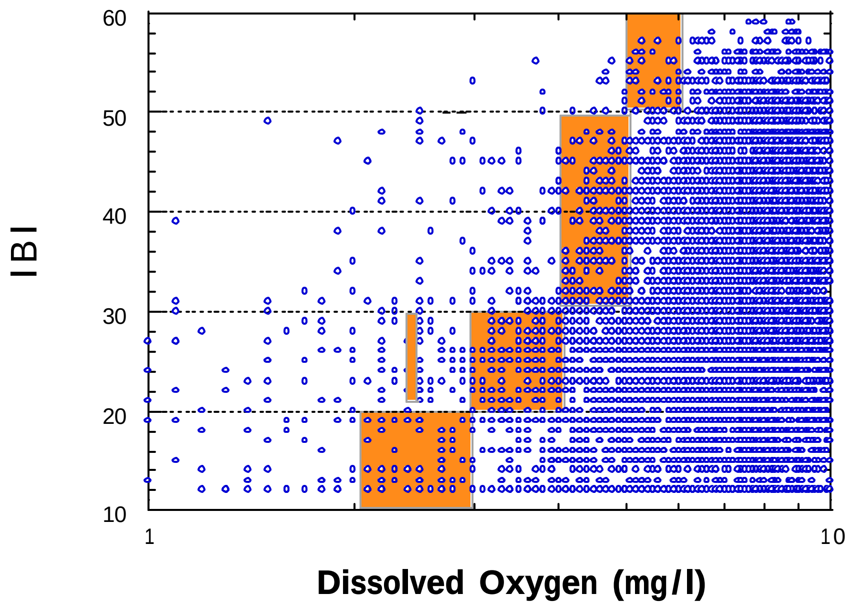


Methods for Developing Refined Targets or Criteria from Ambient Data

- Examination of reference site ranges of stressor
  - U. S. EPA approach for nutrient criteria
  - Defining reference reaches for sediment delivery and geomorphic functioning of streams (e.g., Rosgen, Simon)
- Examining threshold relationships in data by identifying upper thresholds of relationships between stressor and response variables. This threshold has been interpreted as typically occurring maximum concentrations of a stressor at which a response variable value is still found
  - quantile regression method for total iron
  - Ohio EPA use of 95th percentile regression for stressors
  - maximum species richness lines of IBI and other multimetric indices

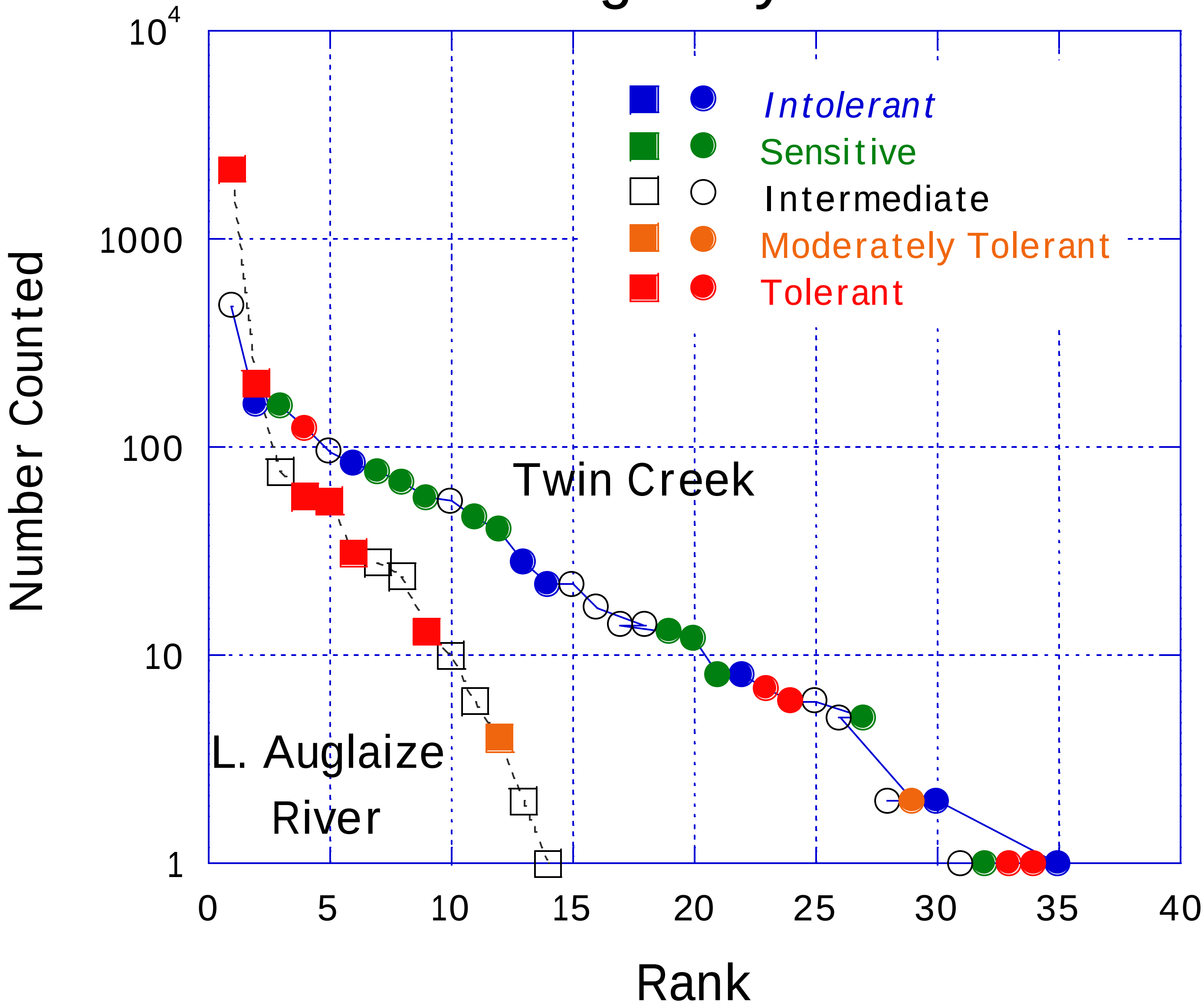
Ohio D.O. Criteria

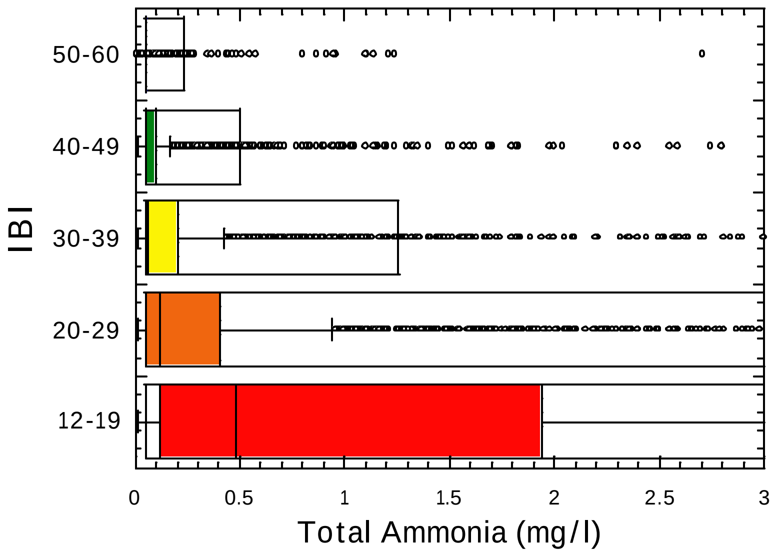


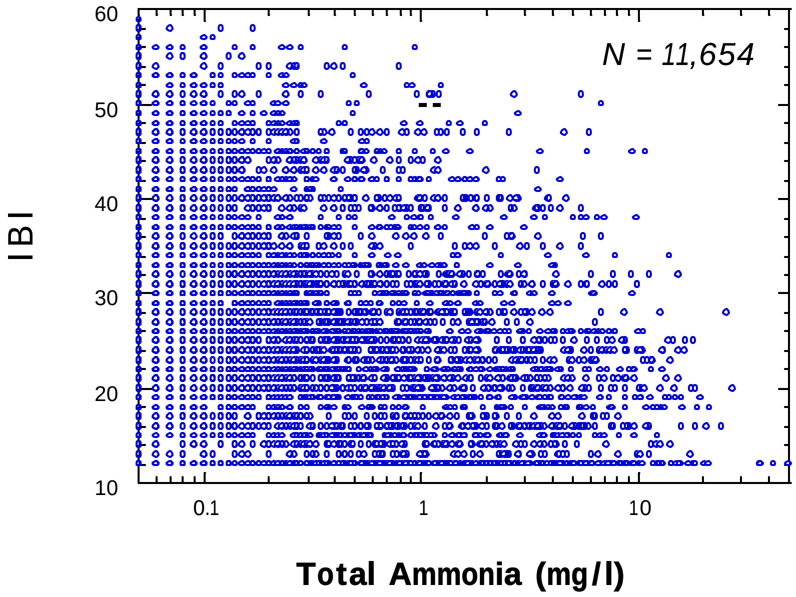


- Modification of Toxicity Approach
- Basic WWH numbers originally derived by species approach
- Tiered criteria adjusted using threshold approach
- Water quality criteria represented by shade boxes (minimum and average criteria)
- Criteria vary by aquatic life and in one case by ecoregion

Are Aq Life Use Tiers Really Different Biologically?



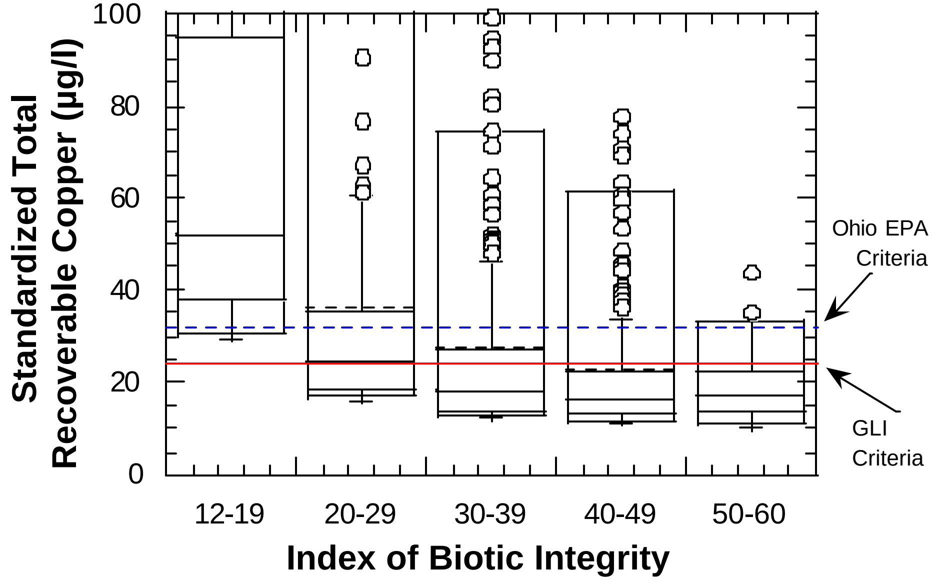


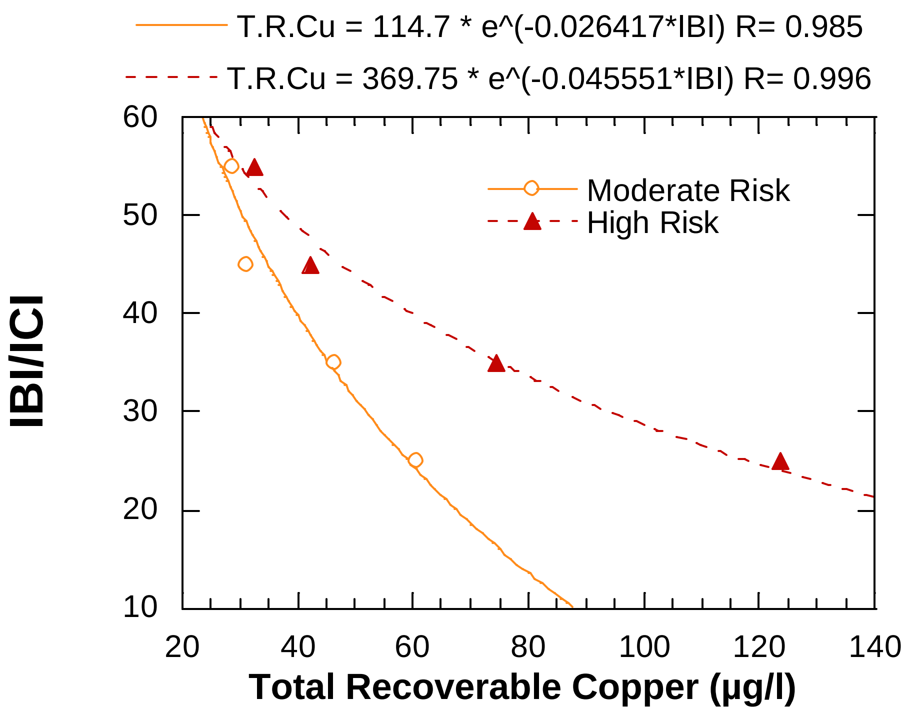


Ohio Total Ammonia Criteria

- Same data illustrated as box plots and scatter plot
- Criteria derived from both toxicity data and field data; anchored with tox data adjusted with field data (insufficient lab data for many important species)
- Criteria vary with aquatic life use, temperature and pH
- e.g., at 20C and pH 8:

Aq. Life Use	Average	Maximum
EWH	1.3	5.6
WWH	1.4	9.1
MWH	2.0	9.1





Total Metals Triggers

- Initial concern that dissolved metals translators could result in high total metals loading to stream
- Could total metals cause impairment because of transformation or other mode of toxicity (e.g., ingestion?)
- Thus for four common metals (Cu, Cd, Pb, Zn) Ohio create “caps” depending on likelihood of impairment
- Depends on condition of the biology and existing load to sediments

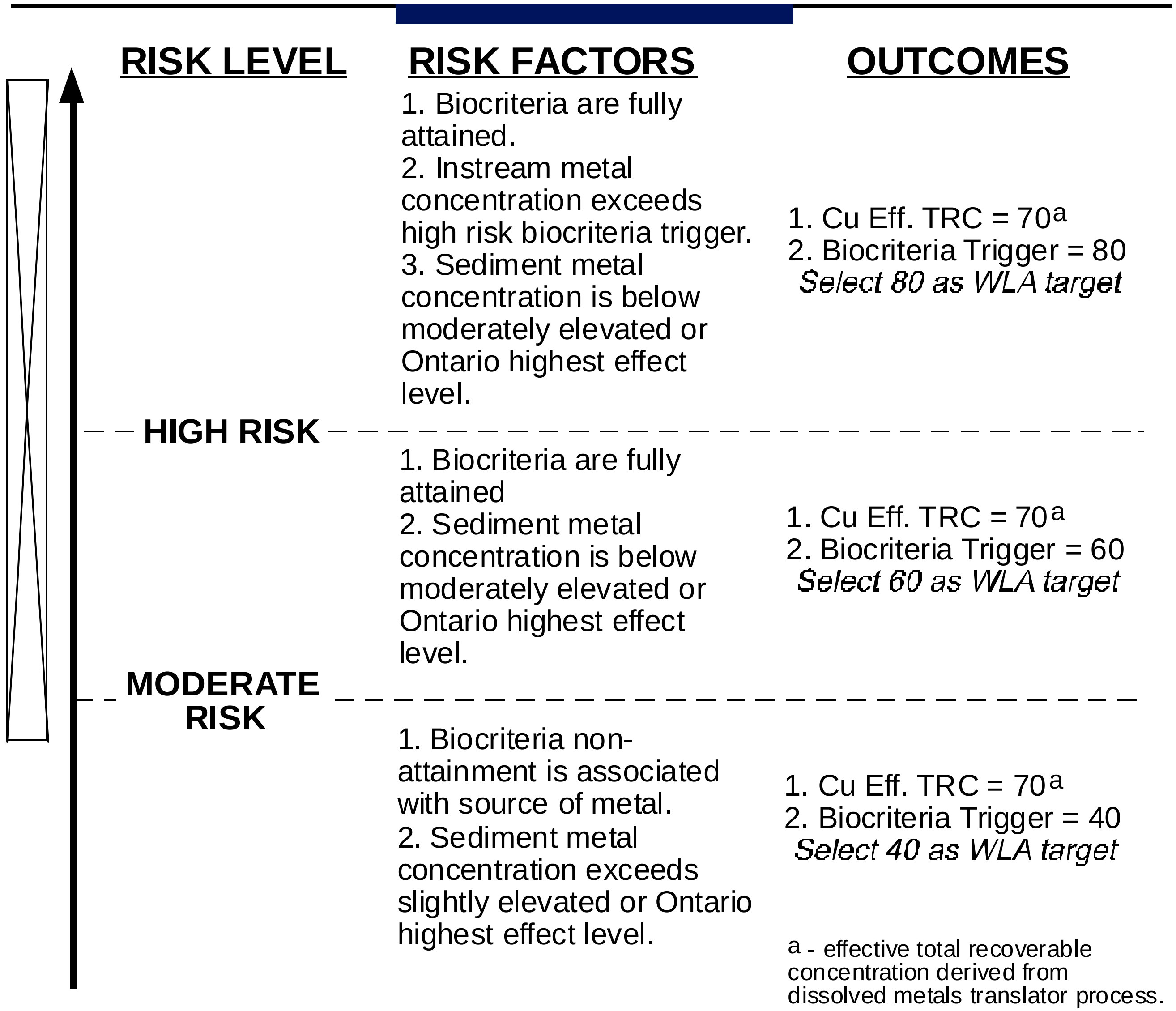


Figure 4. Flow chart illustrating how the moderate and high risk biocriteria derived total recoverable "trigger" concentrations of heavy metals should be used in developing wasteload allocations.

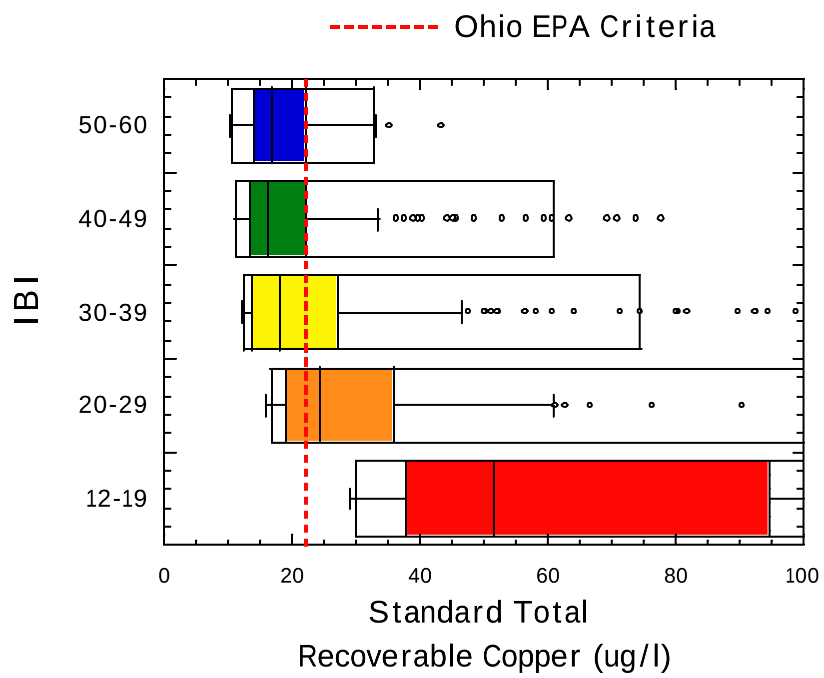
Table 1, continued.

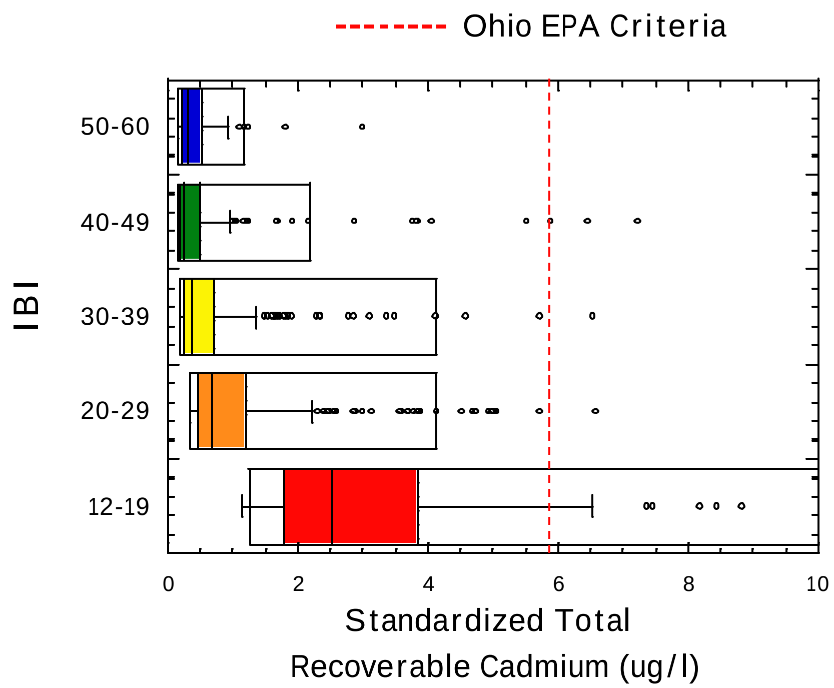
Equation for total recoverable copper Moderate or High Risk concentration including an adjustment for hardness :

$$TRCu_{IBI,H} = TRCu_{IBI,300} * [Cu\text{-}WQS_{300}/Cu\text{-}WQS_{H}]$$

where $TRCu_{IBI,300}$ is the moderate or high risk total recoverable copper concentration (µg/l) which corresponds to a specific IBI or ICI biocriterion at a hardness of 300 mg/l (see equations in Figure 2); $Cu\text{-}WQS_{300}$ is the existing total recoverable copper criterion at a hardness of 300 mg/l; $Cu\text{-}WQS_{H}$ is the existing total recoverable copper criterion at a specific hardness.

			Water Hardness (as mg/l CaCO3)						
ALUSE	Ecoregion	Type	100	150	200	250	300	350	400
Copper - Moderate Risk									
EWH (50)	ALL	HW, WD	11	16	21	26	31	35	40
EWH (48)	ALL	BT	12	17	22	27	32	37	42
46	-	-	12	18	23	29	34	39	44
WWH (44)	WAP	HW,WD	13	19	25	30	36	41	47
WWH (42)	ECBP	BT	14	20	26	32	38	44	49
WWH (40)	ECBP	HW,WD	14	21	27	34	40	46	52
WWH (40)	EOLP	HW, BT	14	21	27	34	40	46	52
WWH (40)	WAP	BT	14	21	27	34	40	46	52
WWH (40)	IP	HW,WD	14	21	27	34	40	46	52
WWH (38)	IP	BT	15	22	29	36	42	48	55
WWH (38)	EOLP	WD	15	22	29	36	42	48	55
36	-	-	16	23	30	37	44	51	58
WWH (34)	HELP	HW,WD,BT	17	25	32	39	47	54	61
32	-	-	18	26	34	42	49	57	64
MWH-I (30)	ALL	BT	19	27	36	44	52	60	68
MWH-A (30)	WAP	HW,WD,BT	19	27	36	44	52	60	68
28	-	-	20	29	38	46	55	63	71
26	-	-	21	30	40	49	58	67	75
MWH-C (24)	IP	HW,WD,BT	22	32	42	51	61	70	79
MWH-C (24)	EOLP	HW,WD,BT	22	32	42	51	61	70	79
MWH-C (24)	WAP	HW,WD,BT	22	32	42	51	61	70	79
MWH-C (24)	ECBP	HW,WD,BT	22	32	42	51	61	70	79
MWH-C (22)	HELP	HW,WD,BT	23	34	44	54	64	74	84
20	-	-	25	36	47	57	68	78	88
Copper - High Risk									
EWH (50)	ALL	HW, BT	14	20	26	32	38	44	49
EWH (48)	ALL	BT	15	22	29	35	42	48	54
46	-	-	16	24	31	38	45	52	59
WWH (44)	WAP	HW,WD	18	26	34	42	50	57	65
WWH (40)	ECBP	HW,WD	22	32	41	51	60	69	78
WWH (40)	EOLP	HW, BT	22	32	41	51	60	69	78





Complementary Nature of Field and Toxicity Data

- Newer U.S. EPA criteria document (2001) added chronic data for more taxa including threatened and endangered taxa which lowered CCC to 0.15 ug/l from 1.3 ug/l
- Field data indicated that existing cadmium criteria shown on graph may not be protective of higher aquatic life uses (in contrast to other metals)

Development of Nutrient Targets

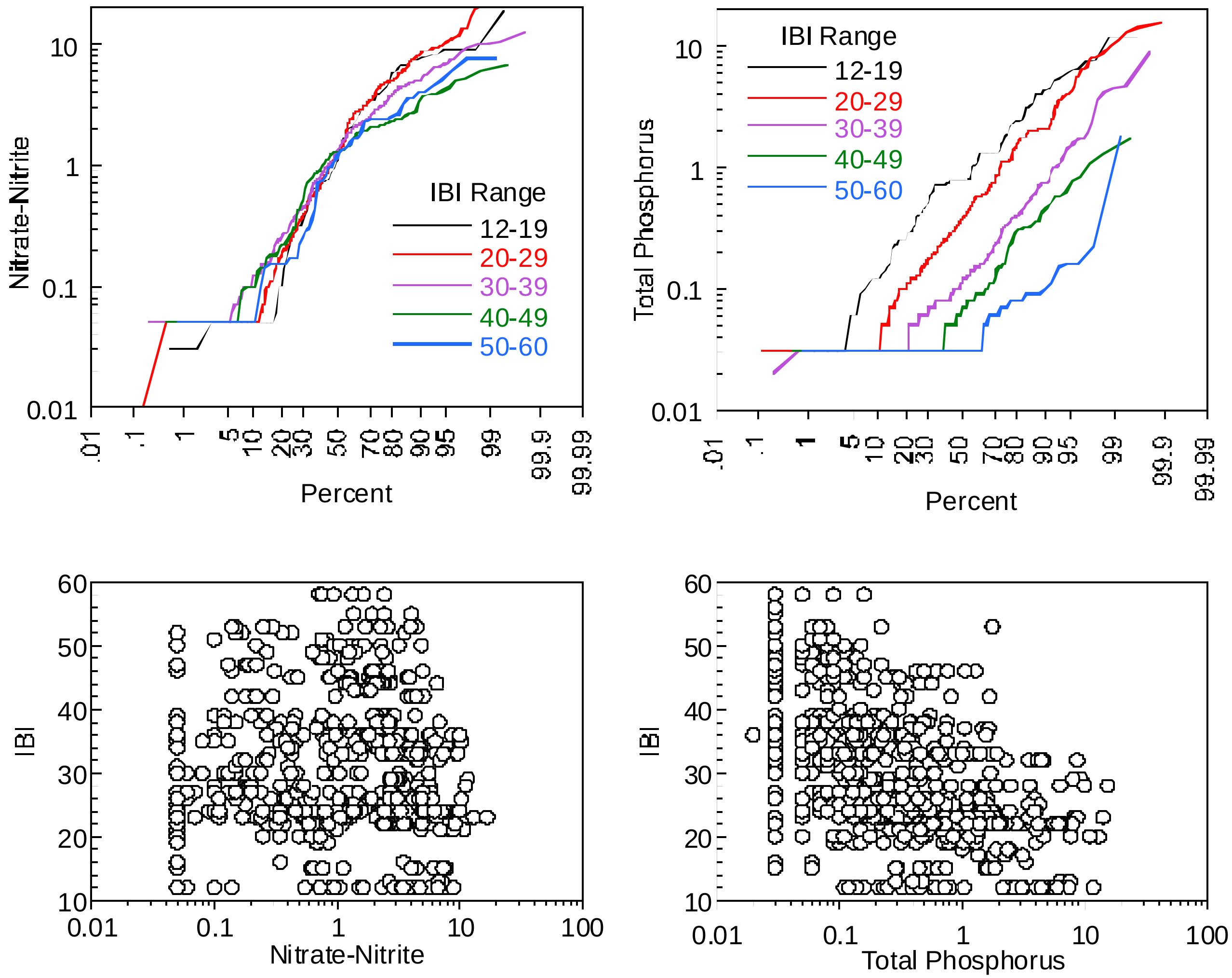


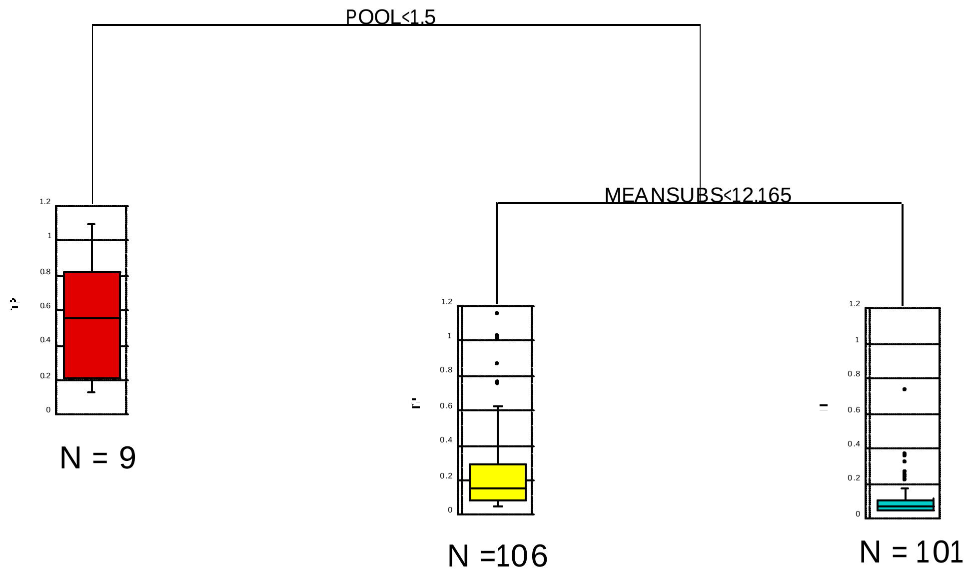
Figure 18. Cumulative frequency distributions by of IBI scores by IBI range and nitrate-N (upper left) and total phosphorus (upper right). Lower panel, scatter plots of IBI scores by nitrate-N and total phosphorus. All plots are for headwater streams in the ECBP ecoregion.

The Influence of Habitat On Nutrient Effects

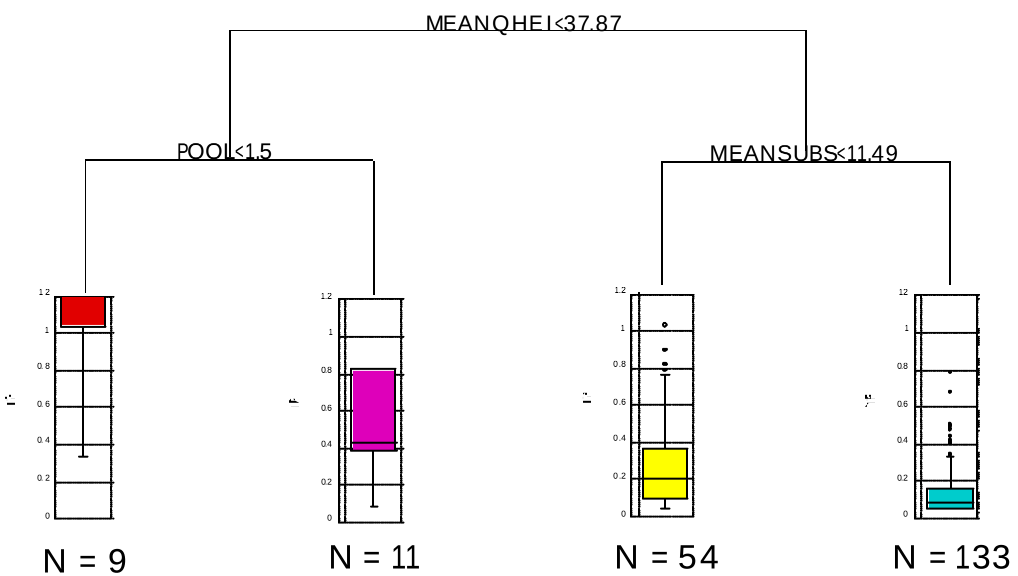
Table 5. Summary of two-three most important explanatory abiotic variables based on three different exploratory statistical analysis of the Ohio EXPLOR database for four different response variables and separately for headwater and larger wadeable streams. Variables in table ?? were use and re analyzed to select the two-most important variables for each response variable.

Headwater Streams (≤ 20 sq mi)			Wadeable Streams (>20-200 sq mi)		
Factor Analysis [a]	Multiple Regression	Regression Tree Analyses	Factor Analysis	Multiple Regression	Regression Tree Analyses
IBI			IBI		
1. Huc-11 QHEI 2. TKN	1. Pool 2. TKN	1. Huc-11 Substr 2. TKN/Cover	1. Cover 2. TKN	1. Cover 2. Huc-11 QHEI	1. Huc-11 QHEI 2. Cover
1. Huc-11 QHEI 2. TKN	1. TKN 2. Huc-11 QHEI	1. Huc-11 Substr 2. TKN	1. Cover 2. TKN		1. Cover 2. Huc-11 QHEI
Sensitive Fish Species			Sensitive Fish Species		
1. Huc-11 Substr 2. Pool	1. Huc-11 QHEI 2. Pool	1. Huc-11 QHEI 2. Riffle	1. Cover 2. TKN	1. Huc-11 Substr 2. TKN	1. Huc-11 Substr 2. Huc-11 QHEI
1. Pool 2. Huc-11 Substr	1. Pool 2. Riffle	1. Huc-11 QHEI 2. Riffle	1. Pool/Cover 2. TKN	1. Cover 2. Huc-11 Substr 2. TKN	1. Pool 2. Huc-11 Substr
ICI			ICI		
1. D.O. 2. Pool	1. D.O. 2. Cover	1. Channel 2. Nitrate	1. Cover 2. TKN	1. TP 2. Nitrate	1. D.O.
1. Huc-11 Substr 2. D.O.	1. Huc-11 Substr 2. D.O.	1. Nitrate	1. Pool 2. TKN	1. Pool/TP 2. Nitrate	1. TKN 2. D.O.
Qual EPT Taxa			Qual EPT Taxa		
1. Huc-11 QHEI 2. TKN	1. Pool 2. TKN	1. Pool 2. Substrate	1. Cover 2. TKN	1. TKN 2. TP	1. TKN 2. Cover
1. TKN 2. Huc-11 QHEI	1. Substrate 2. Pool 3. TKN	1. Huc-11 Subs 2. Substrate/ Total Ammonia	1. TKN/TP 2. Pool	1. TKN 2. Nitrate	1. TKN 2. Nitrate

Headwater Exploratory Database
TP vs. Habitat Variables

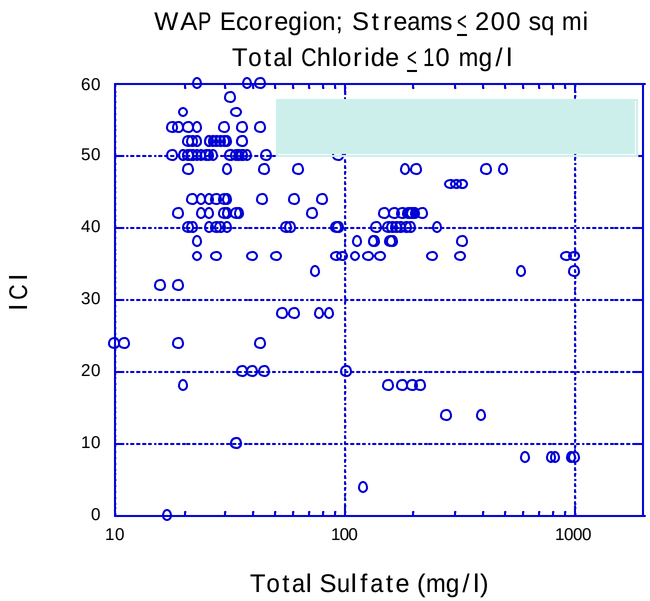


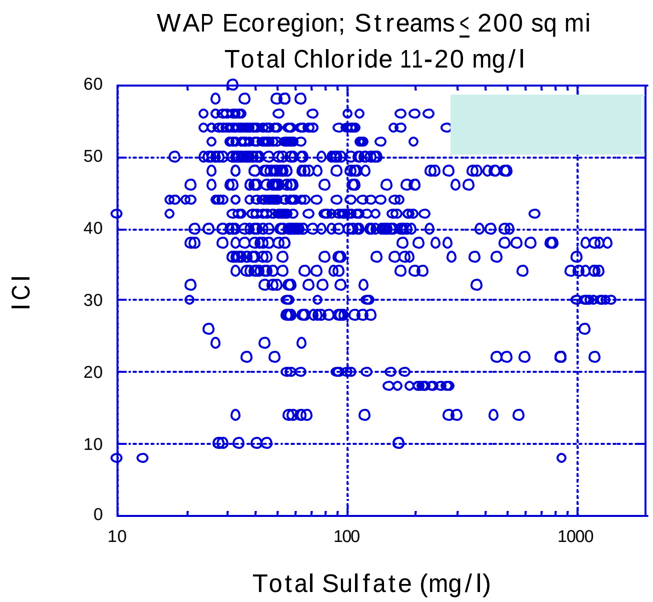
Headwater Verification Database
TP vs. Habitat Variables

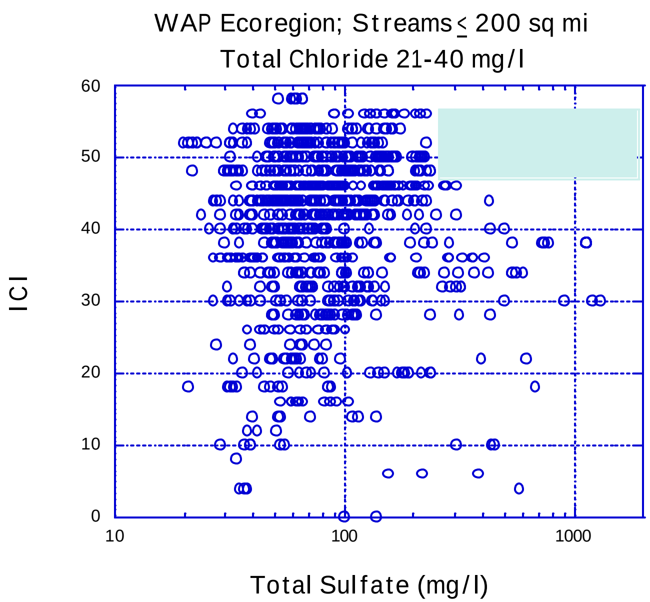


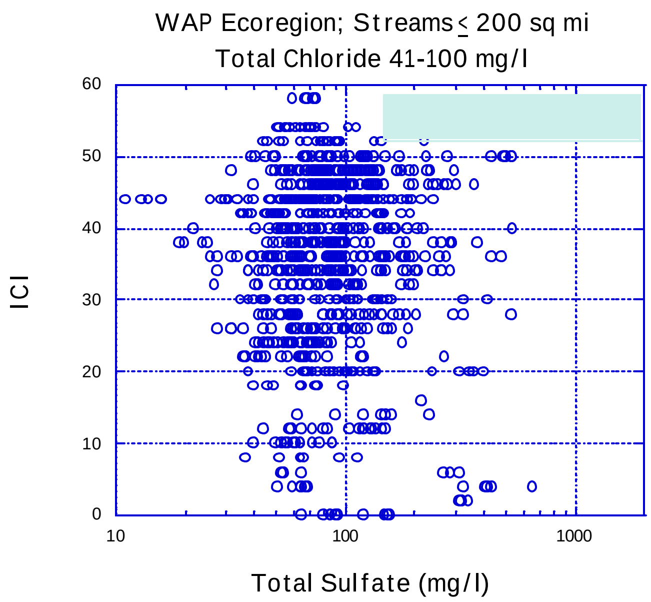
Sulfate and Chloride

- Recent toxicity testing on Hyallela found that mix water with low chlorides caused high levels of toxicity in Hyallela
  - Testing water using moderately hard constituted water (MHRW) can have low concentrations of chloride (~1.9 mg/l)
  - compared to reformulated moderately hard constituted water (RMHRW) which has about 33.9 mg/l (Smith et al. 1997). T
- Testing in these waters by Soucek (2004) found that the LC50 of Hyalella azteca was greatly affected by the water source


WAP Ecoregion; Streams ≤ 200 sq mi
Total Chloride ≤ 10 mg/l
ICI
60
50
40
30
20
10
0
10
100
1000
Total Sulfate (mg/l)


WAP Ecoregion; Streams ≤ 200 sq mi
Total Chloride 11-20 mg/l
ICI
60
50
40
30
20
10
0
10
100
1000
Total Sulfate (mg/l)


WAP Ecoregion; Streams ≤ 200 sq mi
Total Chloride 21-40 mg/l
ICI
60
50
40
30
20
10
0
10
100
1000
Total Sulfate (mg/l)


WAP Ecoregion; Streams ≤ 200 sq mi
Total Chloride 41-100 mg/l
ICI
60
50
40
30
20
10
0
10
100
1000
Total Sulfate (mg/l)

Sulfate, Chloride and Macros

- When we examined the association between sulfate and chlorides and invertebrate assemblages as measured by the ICI, we found
  - High ICIs $\geq$ 50 (Exceptional communities) were absent at relatively low sulfate concentrations when chlorides were low;
  - Where chlorides were higher, but not excessively so, ICIs in the 50s were found at higher sulfate levels
- This matched the results of toxicity testing

Conclusions:

- Water resource quality management can benefit from integrated standards and monitoring program with adequate biological, chemical, and physical collected concurrently
- For certain parameters ambient associations between biological and these stressors can be used to set targets and adjust criteria in a risk management framework
- States and other entities should have an active process for examining patterns in ambient data in relation to criteria and uses (above 305b/TMDL efforts)
- EMAP/REMAP datasets can serve a similar function and should be integrated with state efforts whenever possible.

Paddlefish in the Scioto River below Columbus