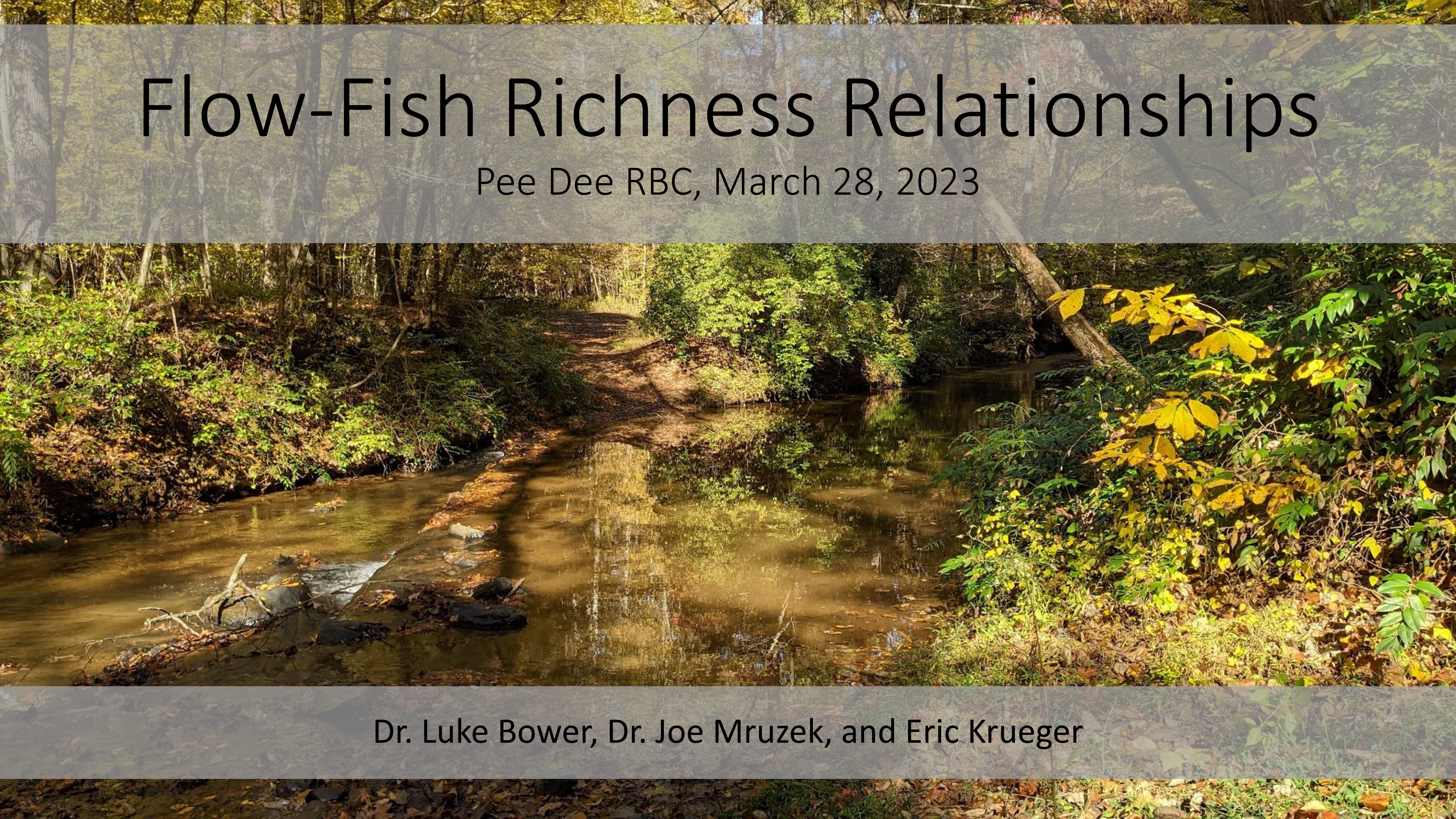
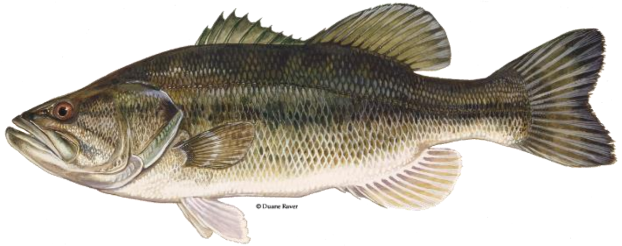
Flow-Fish Richness Relationships

Pee Dee RBC, March 28, 2023

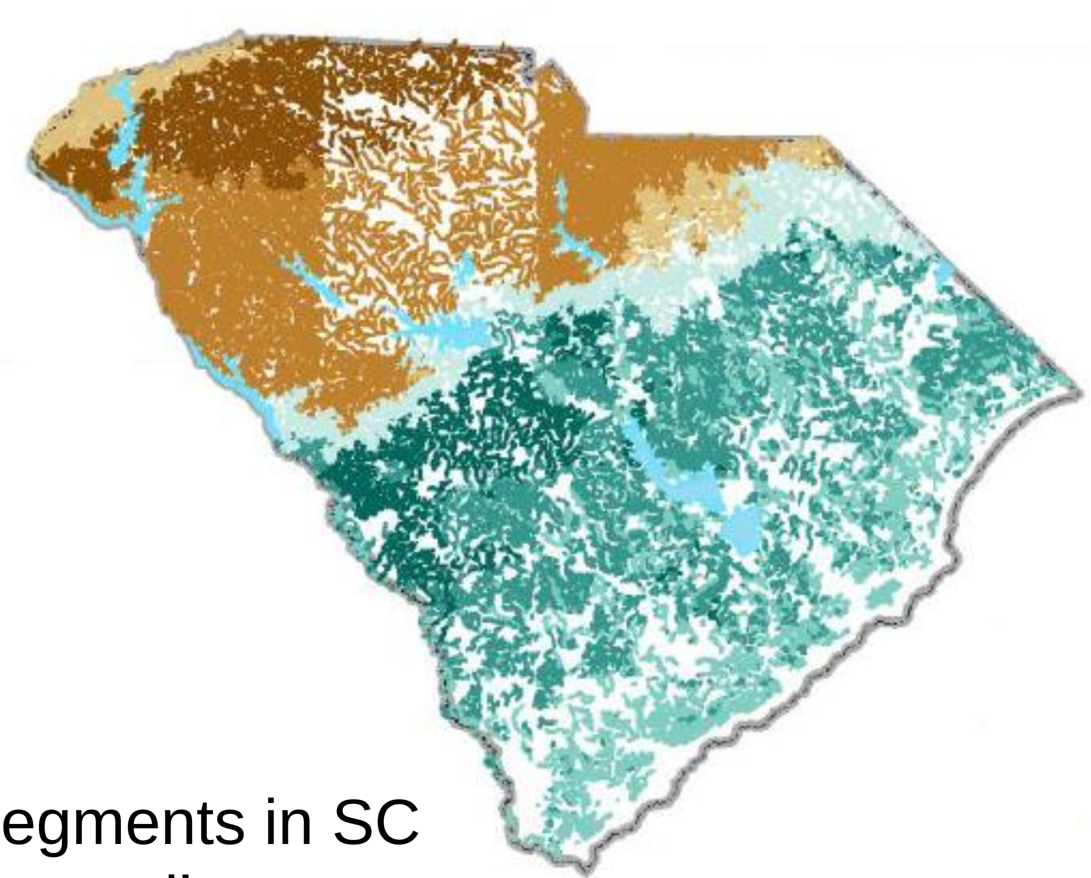


Dr. Luke Bower, Dr. Joe Mruzek, and Eric Krueger

Monitoring helps sustain designated uses



Too much water to monitor!

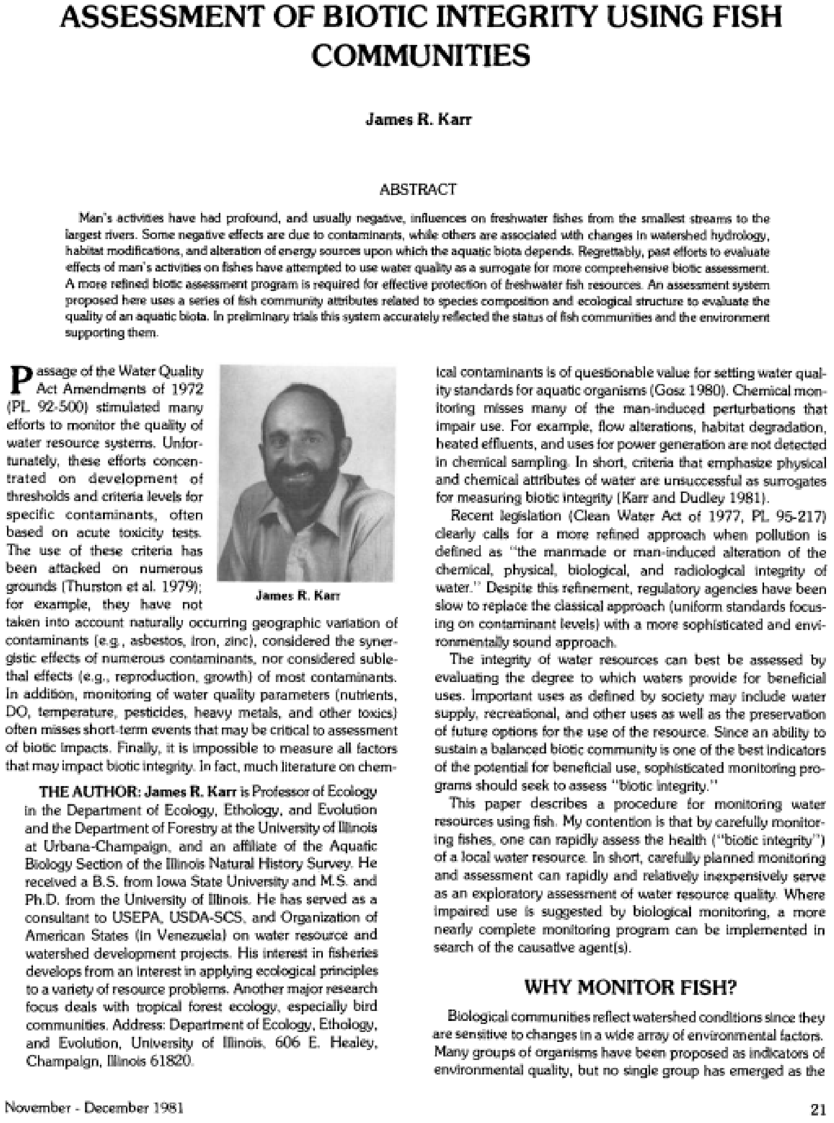


- >28,000 segments in SC
- >15,000 river miles
- And that’s just wadeable streams (~84% of surface water in SC)

Too much water to monitor!

for people to

Bio-assessment: using aquatic organisms to learn about river health



ASSESSMENT OF BIOTIC INTEGRITY USING FISH COMMUNITIES

James R. Karr

ABSTRACT

Man's activities have had profound, and usually negative, influences on freshwater fishes from the smallest streams to the largest rivers. Some negative effects are due to contaminants, while others are associated with changes in watershed hydrology, habitat modifications, and alteration of energy sources upon which the aquatic biota depends. Regrettably, past efforts to evaluate effects of man's activities on fishes have attempted to use water quality as a surrogate for more comprehensive biotic assessment. A more refined biotic assessment program is required for effective protection of freshwater fish resources. An assessment system proposed here uses a series of fish community attributes related to species composition and ecological structure to evaluate the quality of an aquatic biota. In preliminary trials this system accurately reflected the status of fish communities and the environment supporting them.

James R. Karr

Passage of the Water Quality Act Amendments of 1972 (PL 92-500) stimulated many efforts to monitor the quality of water resource systems. Unfortunately, these efforts concentrated on development of thresholds and criteria levels for specific contaminants, often based on acute toxicity tests. The use of these criteria has been attacked on numerous grounds (Thurston et al. 1979); for example, they have not taken into account naturally occurring geographic variation of contaminants (e.g., asbestos, iron, zinc), considered the synergistic effects of numerous contaminants, nor considered sublethal effects (e.g., reproduction, growth) of most contaminants. In addition, monitoring of water quality parameters (nutrients, DO, temperature, pesticides, heavy metals, and other toxics) often misses short-term events that may be critical to assessment of biotic impacts. Finally, it is impossible to measure all factors that may impact biotic integrity. In fact, much literature on chemical contaminants is of questionable value for setting water quality standards for aquatic organisms (Gosz 1980). Chemical monitoring misses many of the man-induced perturbations that impair use. For example, flow alterations, habitat degradation, heated effluents, and uses for power generation are not detected in chemical sampling. In short, criteria that emphasize physical and chemical attributes of water are unsuccessful as surrogates for measuring biotic integrity (Karr and Dudley 1981).

THE AUTHOR: James R. Karr is Professor of Ecology in the Department of Ecology, Ethology, and Evolution and the Department of Forestry at the University of Illinois at Urbana-Champaign, and an affiliate of the Aquatic Biology Section of the Illinois Natural History Survey. He received a B.S. from Iowa State University and M.S. and Ph.D. from the University of Illinois. He has served as a consultant to USEPA, USDA-SCS, and Organization of American States (in Venezuela) on water resource and watershed development projects. His interest in fisheries develops from an interest in applying ecological principles to a variety of resource problems. Another major research focus deals with tropical forest ecology, especially bird communities. Address: Department of Ecology, Ethology, and Evolution, University of Illinois, 606 E. Healey, Champaign, Illinois 61820.

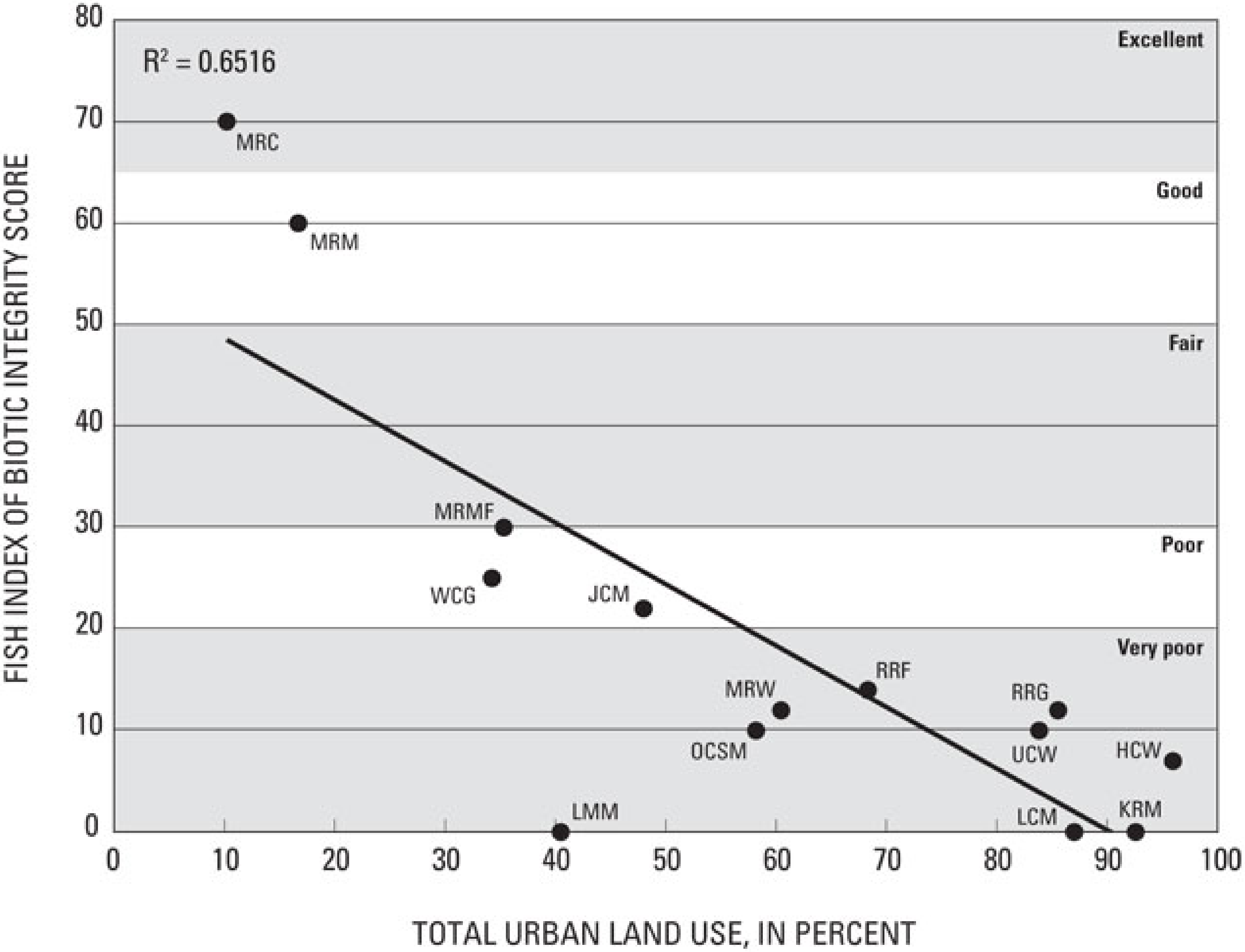
Recent legislation (Clean Water Act of 1977, PL 95-217) clearly calls for a more refined approach when pollution is defined as "the manmade or man-induced alteration of the chemical, physical, biological, and radiological integrity of water." Despite this refinement, regulatory agencies have been slow to replace the classical approach (uniform standards focusing on contaminant levels) with a more sophisticated and environmentally sound approach.

The integrity of water resources can best be assessed by evaluating the degree to which waters provide for beneficial uses. Important uses as defined by society may include water supply, recreational, and other uses as well as the preservation of future options for the use of the resource. Since an ability to sustain a balanced biotic community is one of the best indicators of the potential for beneficial use, sophisticated monitoring programs should seek to assess "biotic integrity."

This paper describes a procedure for monitoring water resources using fish. My contention is that by carefully monitoring fishes, one can rapidly assess the health ("biotic integrity") of a local water resource. In short, carefully planned monitoring and assessment can rapidly and relatively inexpensively serve as an exploratory assessment of water resource quality. Where impaired use is suggested by biological monitoring, a more nearly complete monitoring program can be implemented in search of the causative agent(s).

WHY MONITOR FISH?

Biological communities reflect watershed conditions since they are sensitive to changes in a wide array of environmental factors. Many groups of organisms have been proposed as indicators of environmental quality, but no single group has emerged as the


R² = 0.6516
Excellent
Good
Fair
Poor
Very poor
MRC
MRM
MRMF
WCG
JCM
MRW
OCSM
RRF
RRG
UCW
HCW
LMM
LCM
KRM
FISH INDEX OF BIOTIC INTEGRITY SCORE
TOTAL URBAN LAND USE, IN PERCENT
0
10
20
30
40
50
60
70
80
90
100

Characterizing aquatic diversity

- Diverse biota = healthy ecosystem
- **Species richness:** number of species
- **Shannon's Diversity:** Accounts for <u>percentages</u>

Negative relationship with flow alteration

Bio-assessment: using aquatic organisms to learn about river health

1. Identify which environmental attribute you want to evaluate

2. Hypothesize relationships between organisms and environmental attributes

3. Identify key relationships between organisms and environment

4. Use those results to inform management

Rivers face many threats

Impoundment

Urbanization

Nonpoint pollution

Flow alteration

Stormwater runoff

Bio-assessment: using aquatic organisms to learn about river health

1. Identify which environmental attribute you want to evaluate
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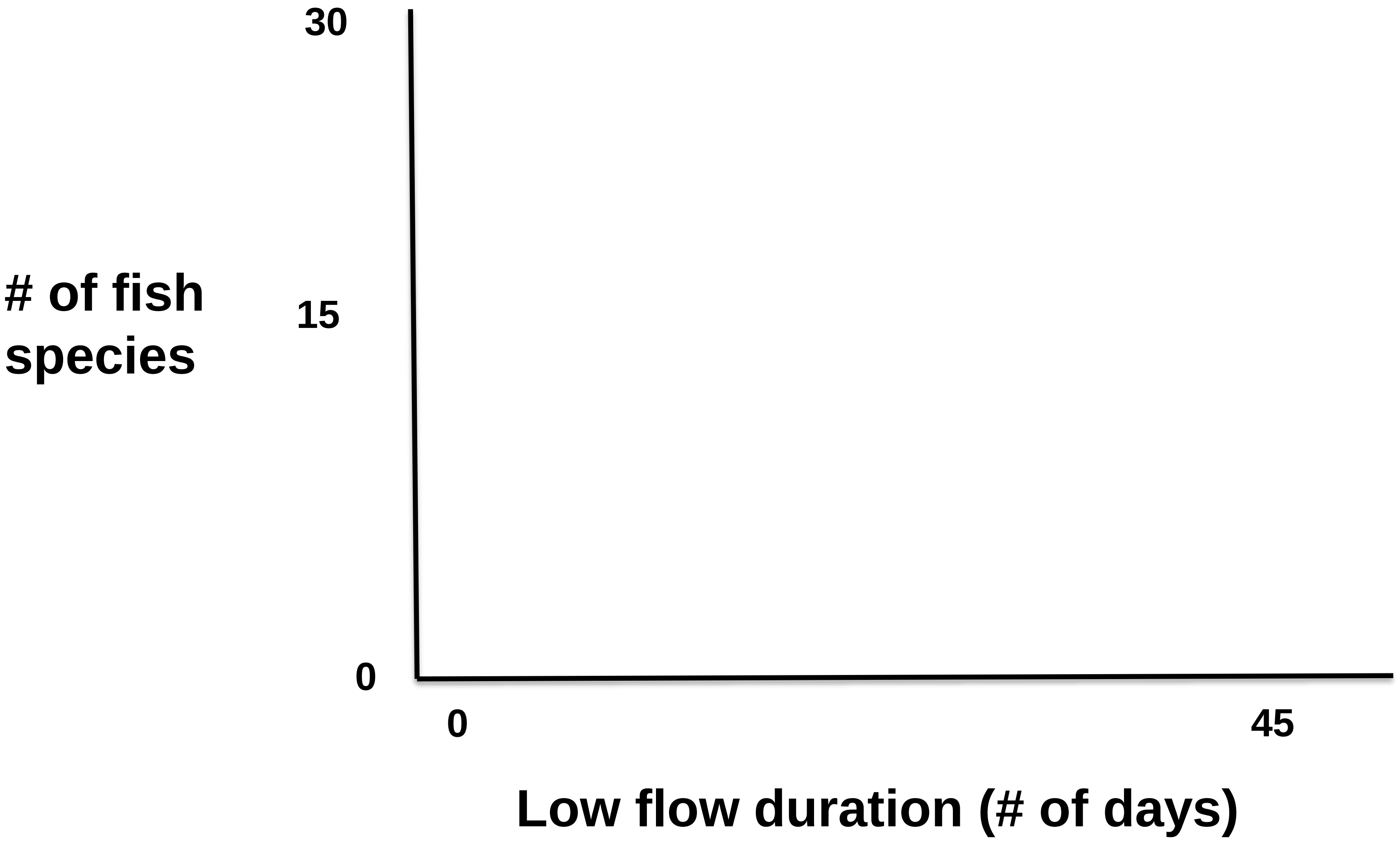
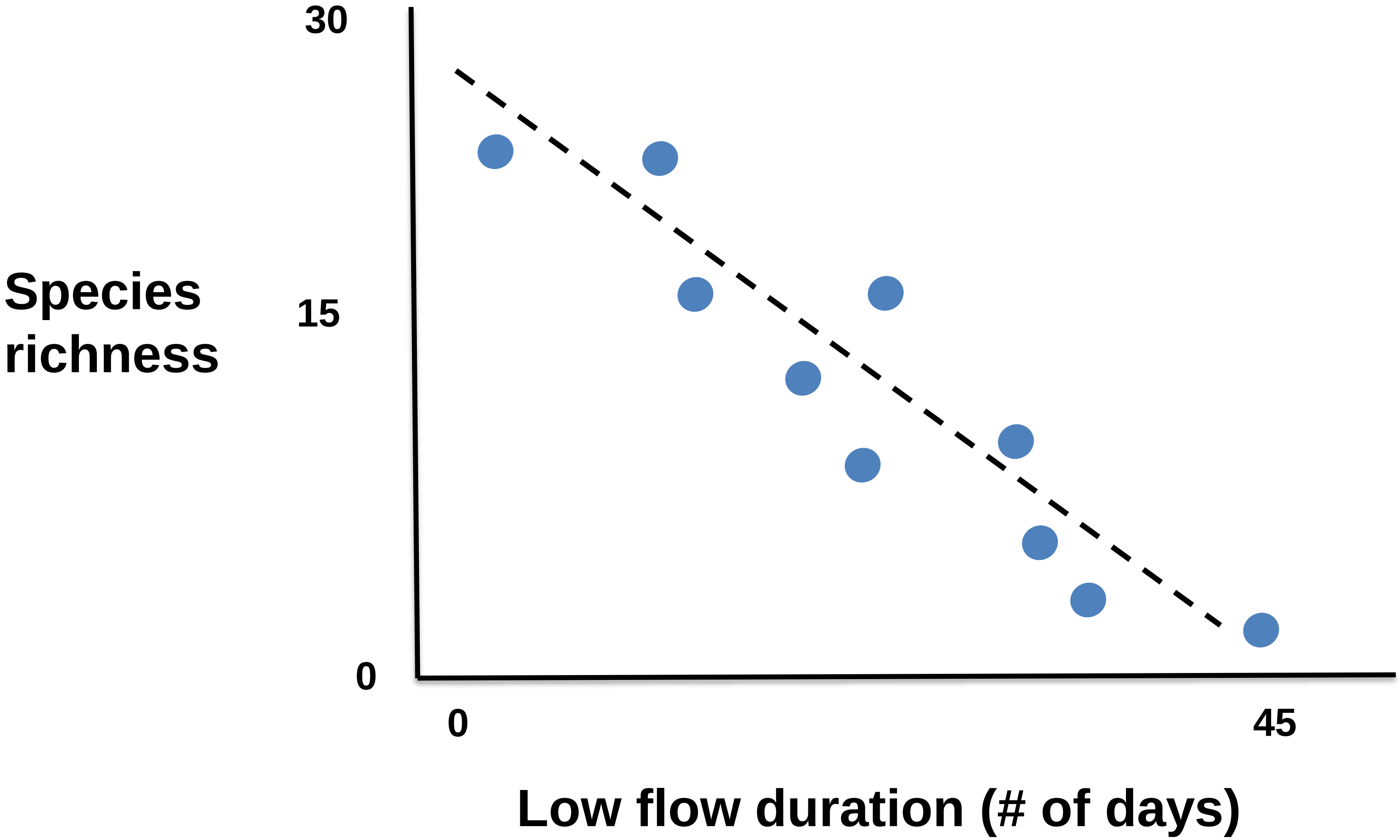

30
# of fish species
15
0
0
45
Low flow duration (# of days)

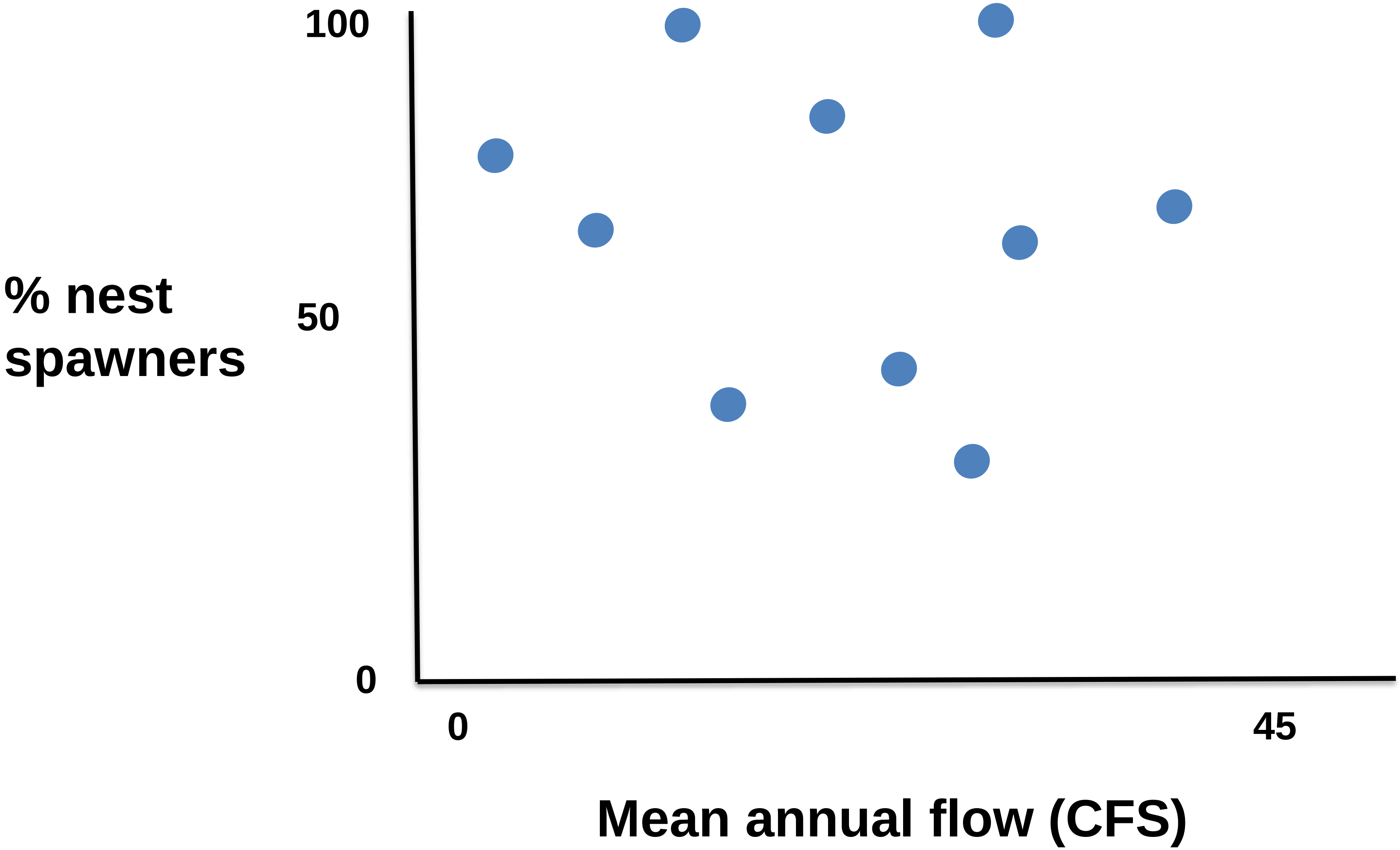
Bio-assessment: using aquatic organisms to learn about river health

1. Identify which environmental attribute you want to evaluate
2. Hypothesize relationships between organisms and environmental attributes
3. Identify key relationships between organisms and environment
4. Use those results to inform management

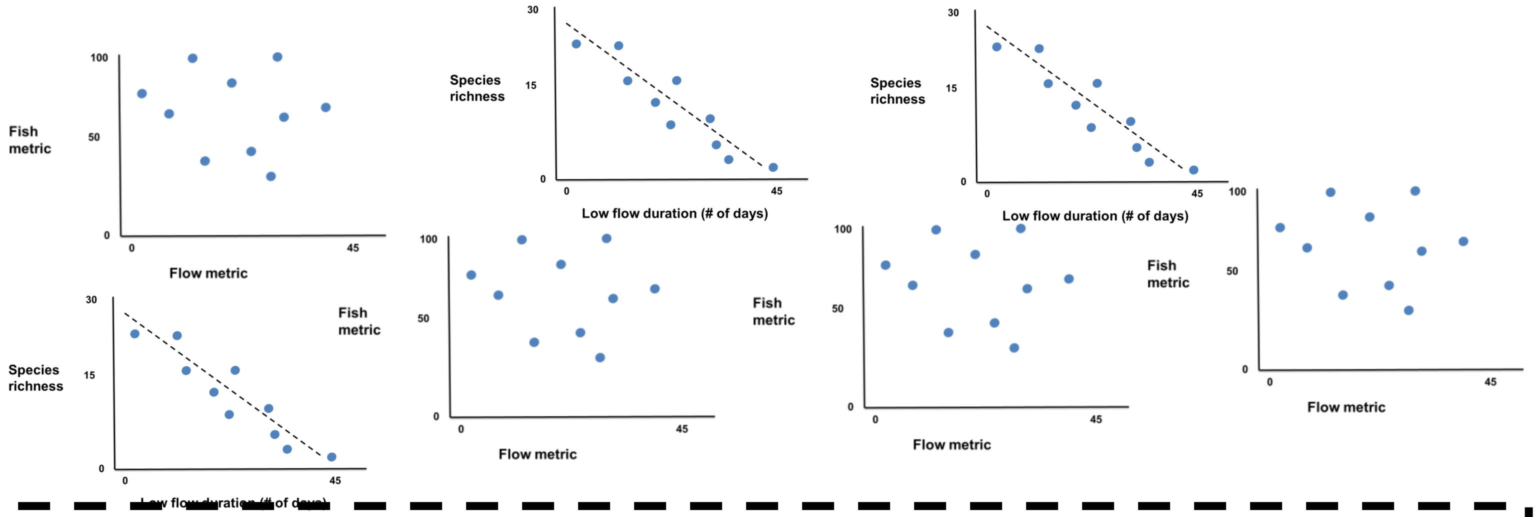
Identify relationships: some are informative



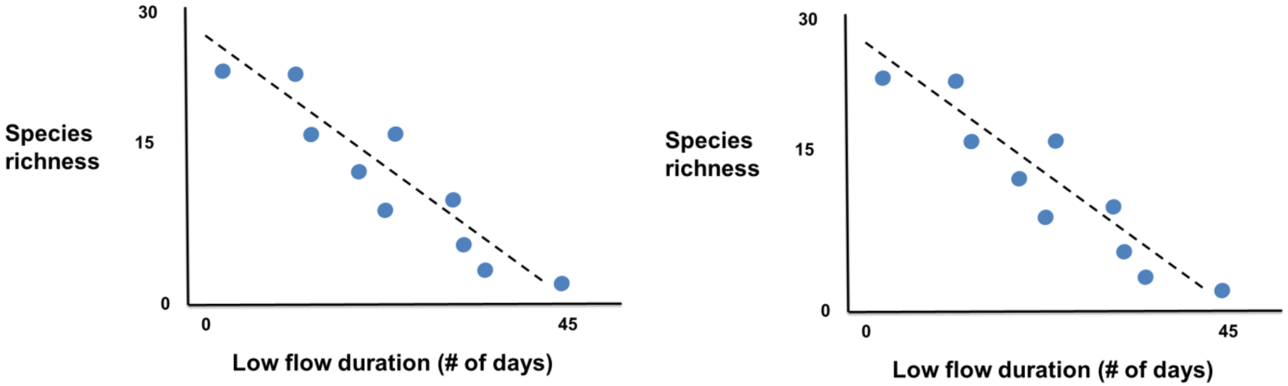
Identify relationships: some are not informative



Identify relationships: remove uninformative relationships



Filter: statistical modeling process



Bio-assessment: using aquatic organisms to learn about river health

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Contents lists available at ScienceDirect

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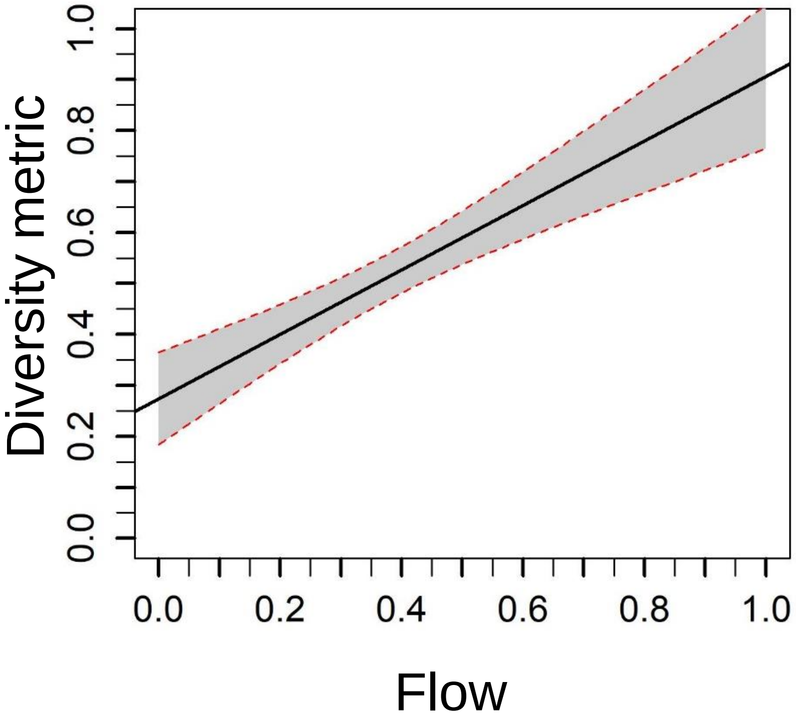
Quantifying flow–ecology relationships across flow regime class and ecoregions in South Carolina

Luke M. Bower [a,*], Brandon K. Peoples [b], Michele C. Eddy [c], Mark C. Scott [d]



- Quantify relationships between key flow metrics and biotic response to better inform water flow standards throughout the state of South Carolina
  - Project changes in aquatic communities

- Provide a tool

Frame Work

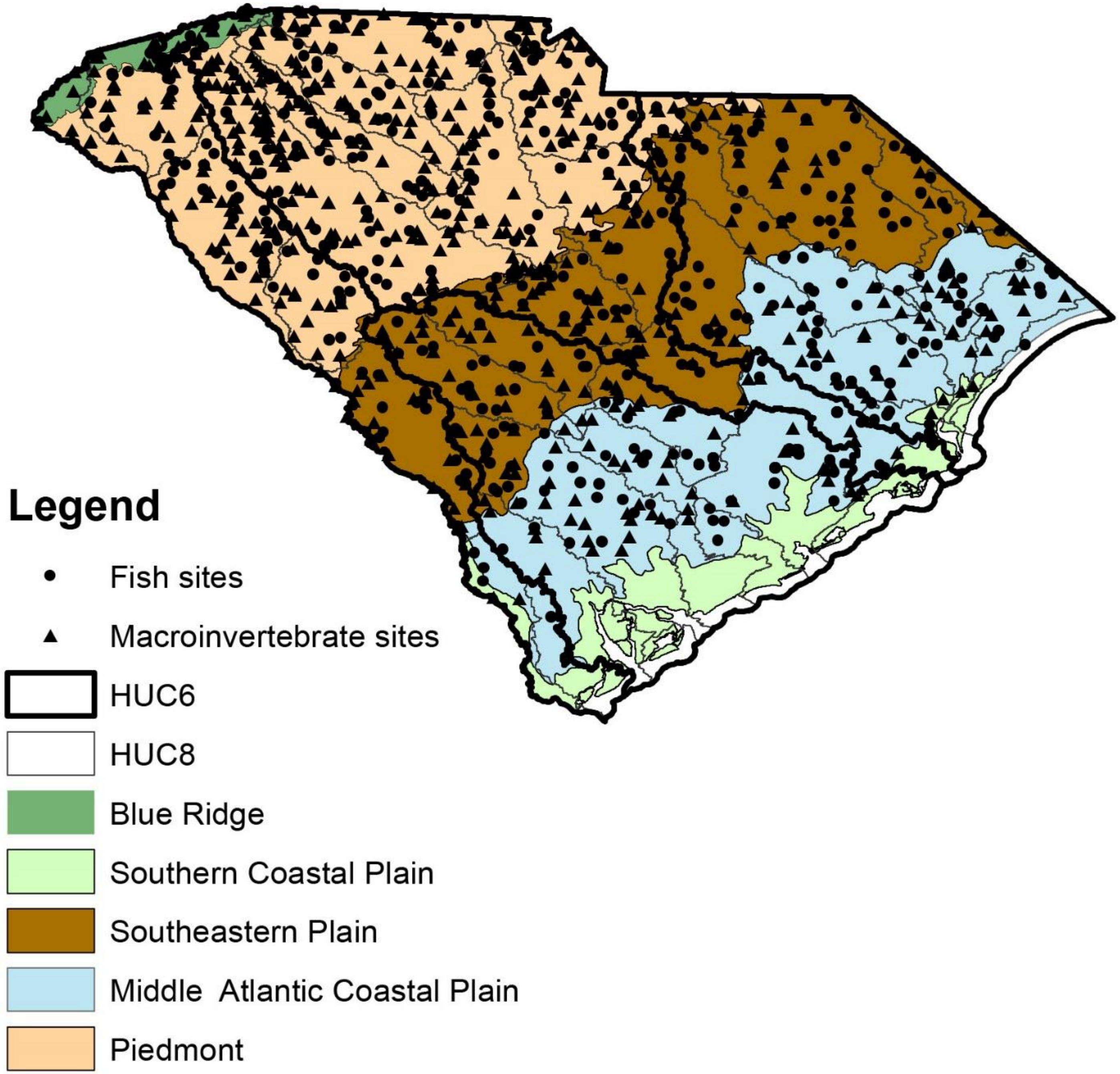
- The ecological limits of hydrologic alteration (ELOHA). Poff et al., 2010

Build a hydrologic foundation of streamflow and biological data

2. Classify natural river types

3. Determine flow-ecology relationships associated within each river type

4. Recommend water flow standards to achieve river condition goals

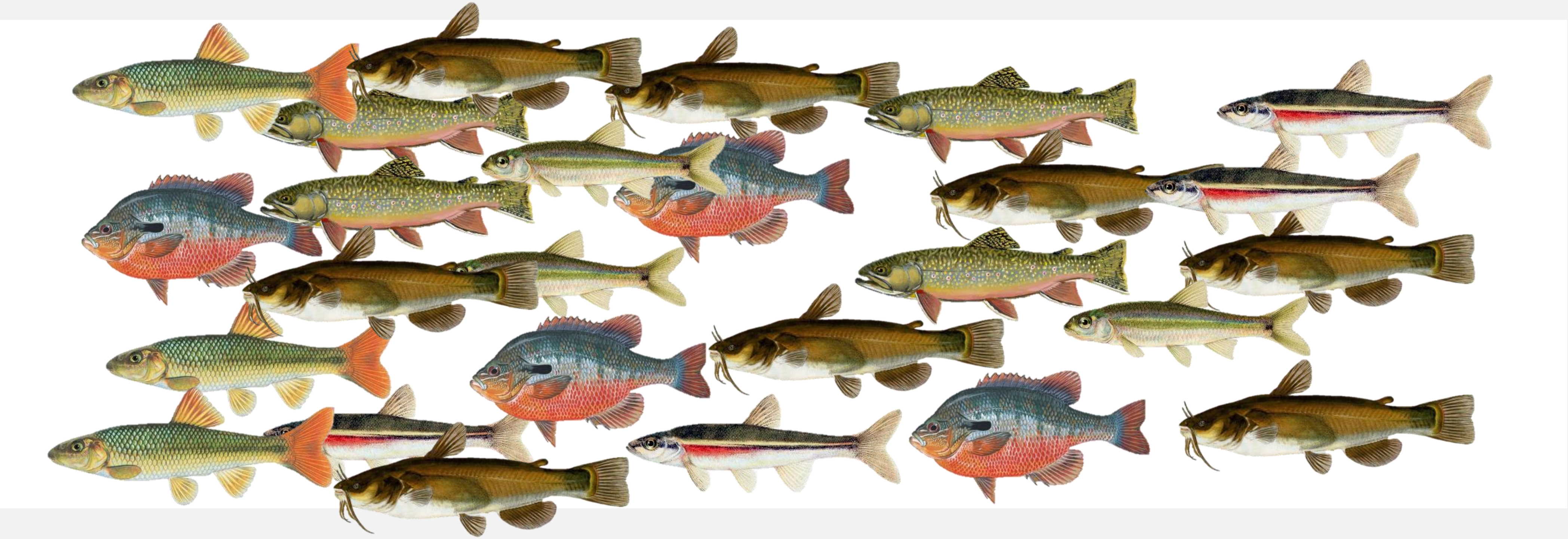


Biological Data:

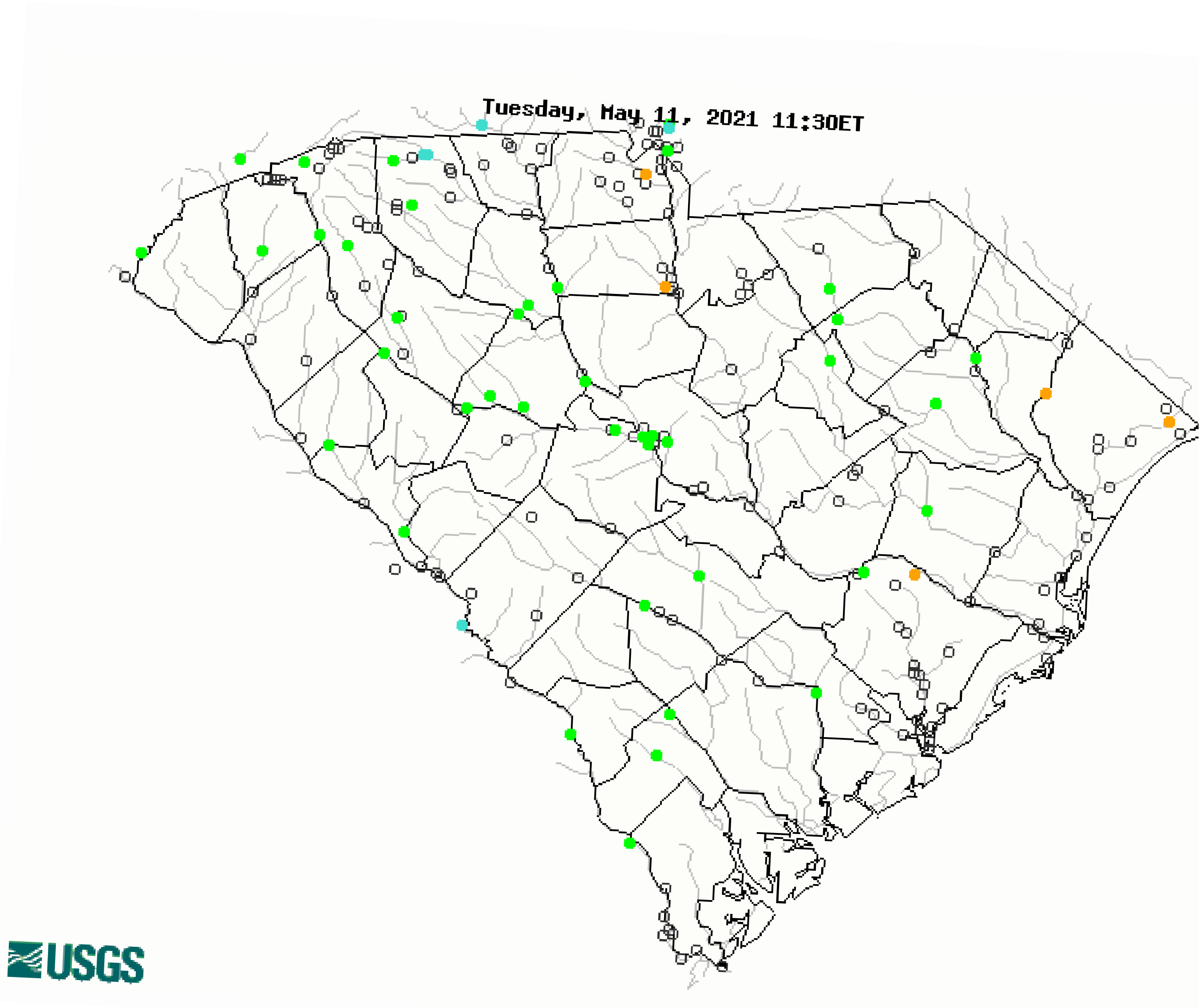
- 492 Fish sites (streams & rivers)
    - DNR
    - 8 biological response metrics
- 530 aquatic insects sites
    - DHEC
    - 6 biological response metrics

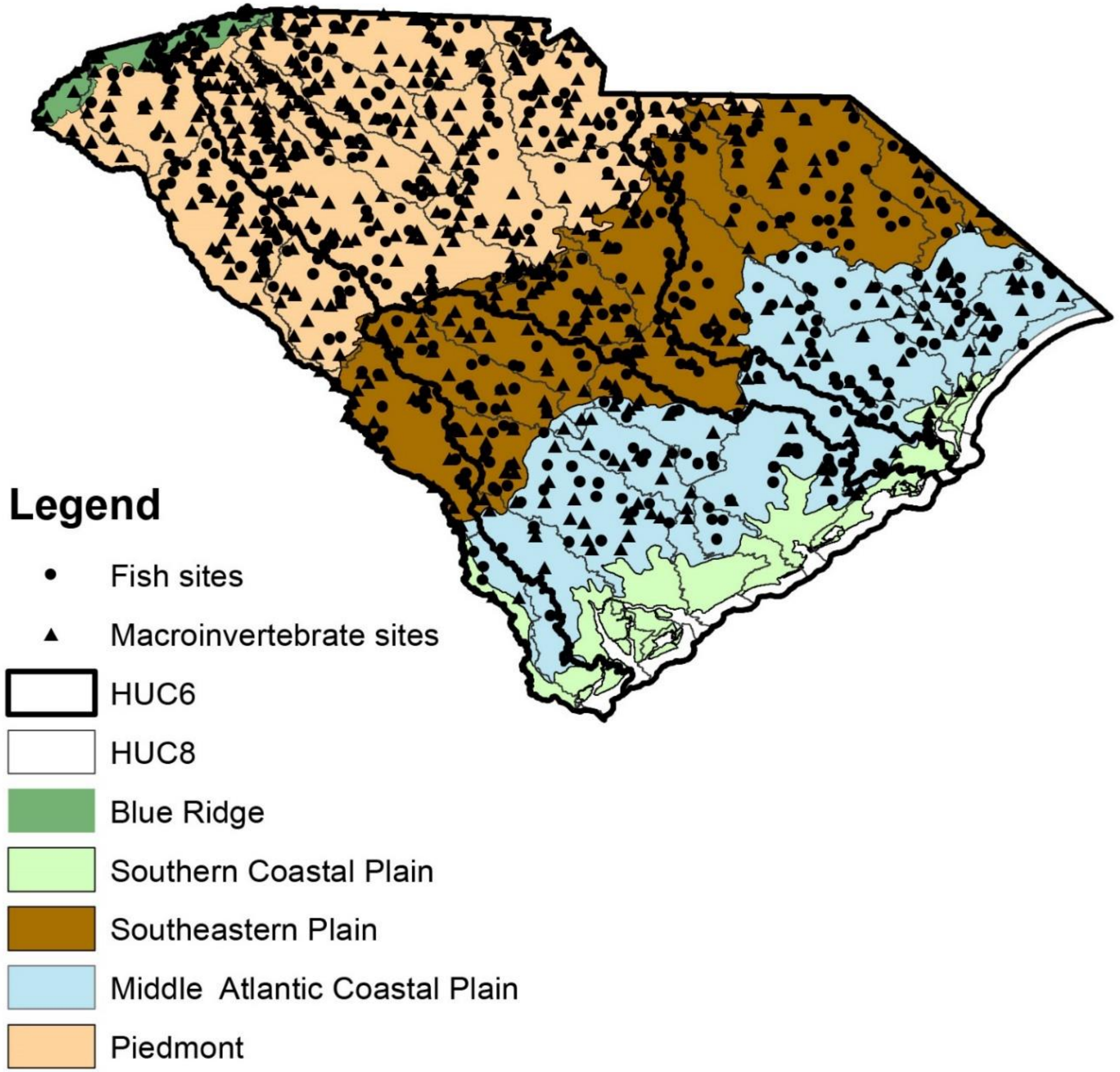
Fish and Aquatic insects Metrics

- **Richness:** number of species
- **Shannon's** diversity index: weights richness by abundance
- Proportional representation of **tolerant** individuals
- **Megaloptera-Odonata** index
    - Index of flow preference
    - Low values consistent flow



SC streamflow gauges





1. Build a hydrologic foundation of streamflow data

- WaterFALL model: 171 hydrologic metrics
  - rainfall-runoff model 30 year period
  - Flow regime: Timing, magnitude, frequency, rate of change, and duration

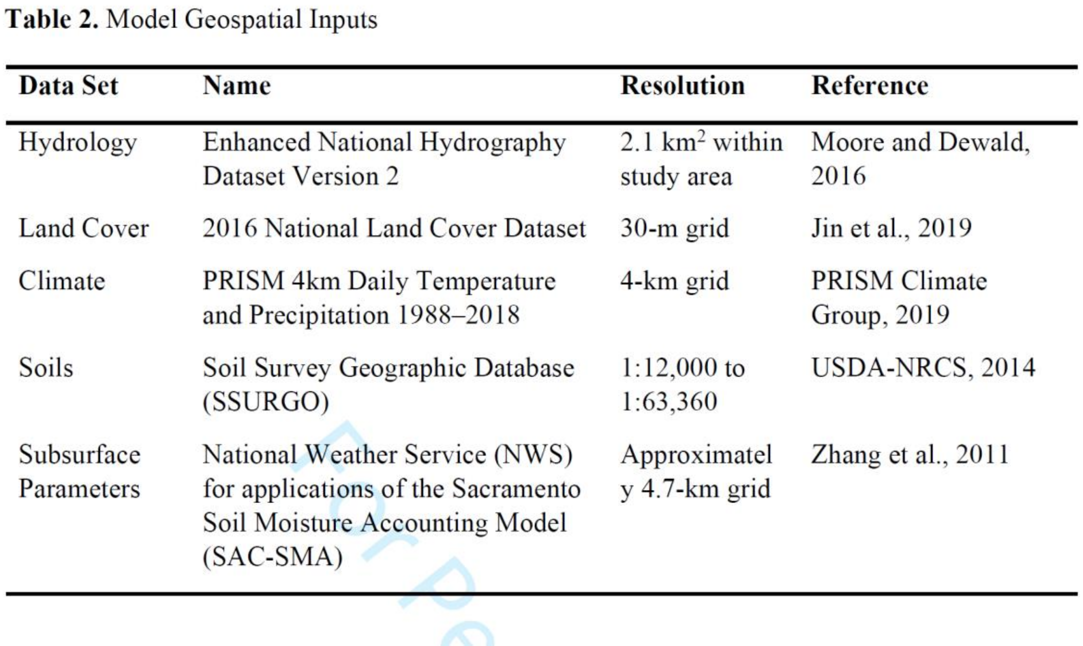


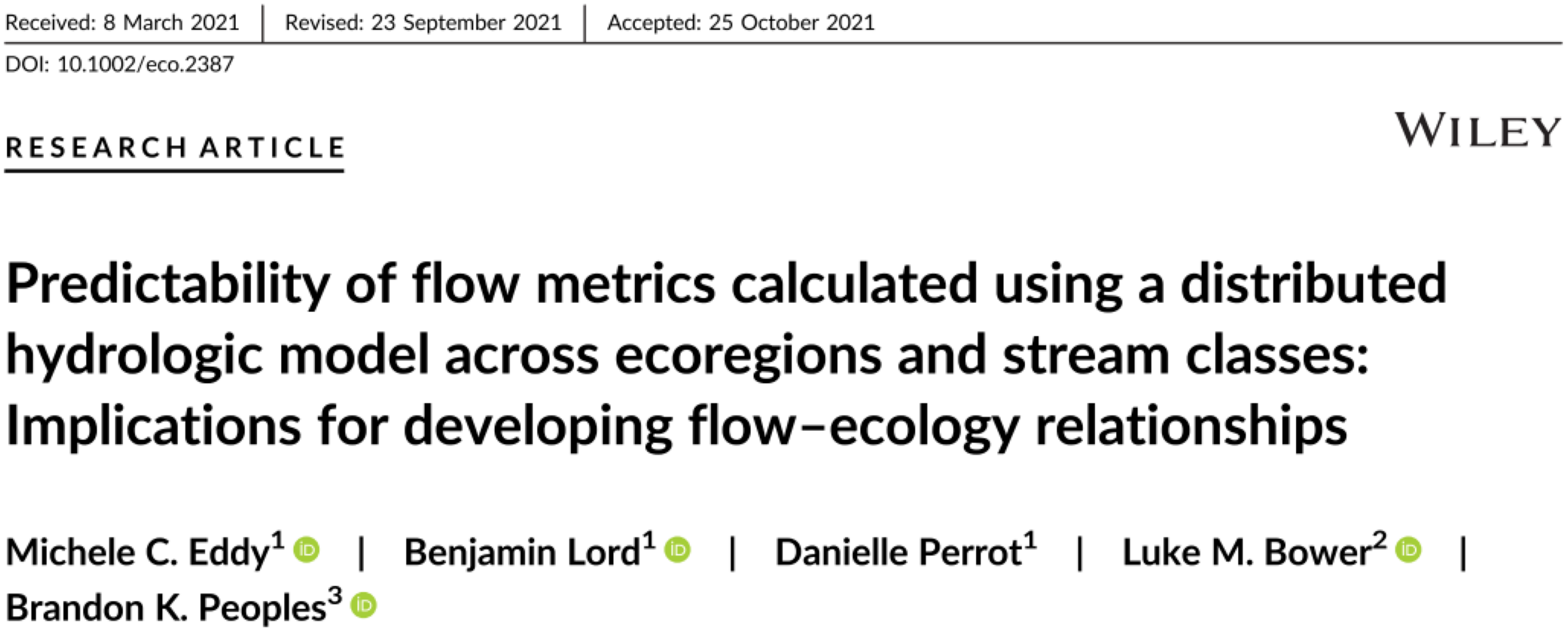
Table 2. Model Geospatial Inputs

Data Set	Name	Resolution	Reference
Hydrology	Enhanced National Hydrography Dataset Version 2	2.1 km^2 within study area	Moore and Dewald, 2016
Land Cover	2016 National Land Cover Dataset	30-m grid	Jin et al., 2019
Climate	PRISM 4km Daily Temperature and Precipitation 1988–2018	4-km grid	PRISM Climate Group, 2019
Soils	Soil Survey Geographic Database (SSURGO)	1:12,000 to 1:63,360	USDA-NRCS, 2014
Subsurface Parameters	National Weather Service (NWS) for applications of the Sacramento Soil Moisture Accounting Model (SAC-SMA)	Approximately 4.7-km grid	Zhang et al., 2011

Code	Flow regime	Description
MA1	Magnitude	Mean daily flow (cfs)
MA3	Magnitude	Mean of the coefficient of variation for each year
MA41	Magnitude	Annual runoff
MA42	Magnitude	Variability of MA41
ML17	Magnitude	Base flow index
ML18	Magnitude	Variability in ML17
ML22	Magnitude	Specific mean annual minimum flow
MH14	Magnitude	Median of annual maximum flows (dimensionless)
MH20	Magnitude	Specific mean annual maximum flow (cfs/mile)
FL1	Frequency	Low flow pulse count
FL2	Frequency	Variability in FL1
FH1	Frequency	High flood pulse count
FH2	Frequency	Variability in FH2
DL16	Duration	Low flow pulse duration (Days)
DL17	Duration	Variability in DL16
DL18	Duration	Number of zero-flow days
DH15	Duration	High flow pulse duration (Days)
DH16	Duration	Variability in DH15
TA1	Timing	Constancy
TL1	Timing	Julian date of annual minimum
TL2	Timing	Variability in TL1
TH1	Timing	Julian date of annual maximum starting at day 100
TH2	Timing	Variability in TH1
RA8	Rate	Number of reversals

M = Magnitude
D = Duration
F = Frequency
T = Timing
R = Rate

L = Low flow
H= High flow



Received: 8 March 2021 | Revised: 23 September 2021 | Accepted: 25 October 2021
DOI: 10.1002/eco.2387

RESEARCH ARTICLE

WILEY

Predictability of flow metrics calculated using a distributed hydrologic model across ecoregions and stream classes: Implications for developing flow–ecology relationships

Michele C. Eddy[1] | Benjamin Lord[1] | Danielle Perrot[1] | Luke M. Bower[2] | Brandon K. Peoples[3]

Framework

- The ecological limits of hydrologic alteration (ELOHA). Poff et al., 2010

1. Build a hydrologic foundation of streamflow and biological data

Classify natural river types

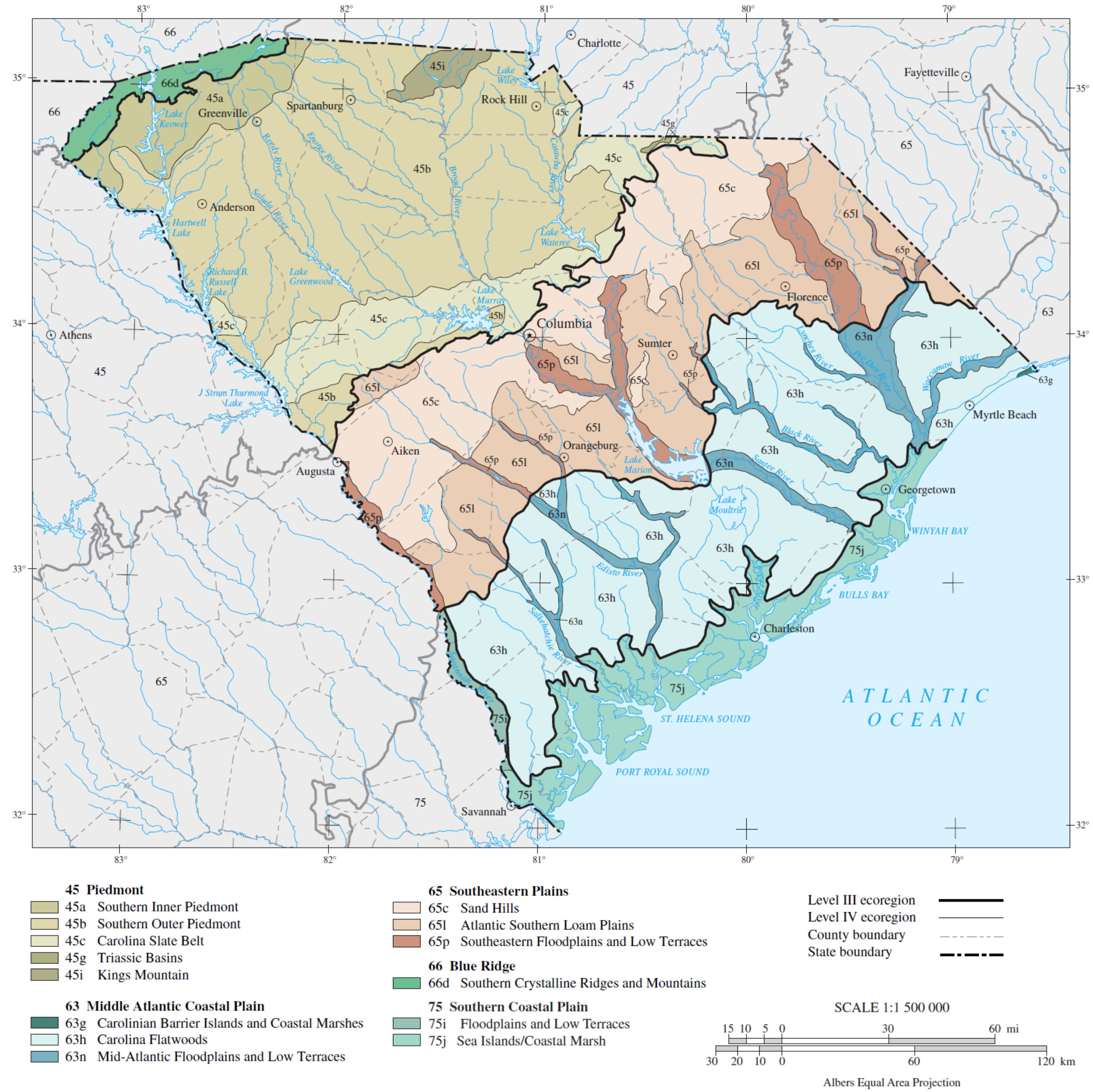
3. Determine flow-ecology relationships associated within each river type

4. Recommend water flow standards to achieve river condition goals

2. Classify natural river types

A. **Flow-ecology relationships may differ among stream classes**

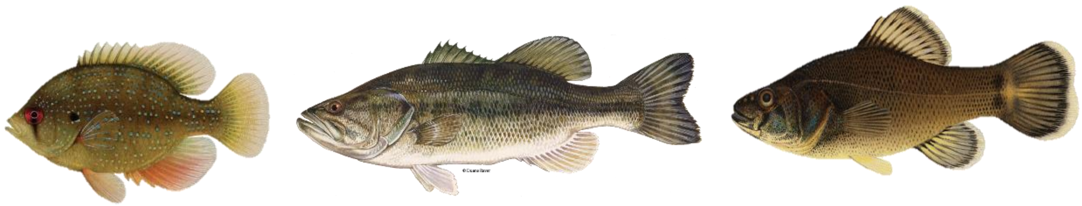
B. Relationship holds for these un-sampled streams



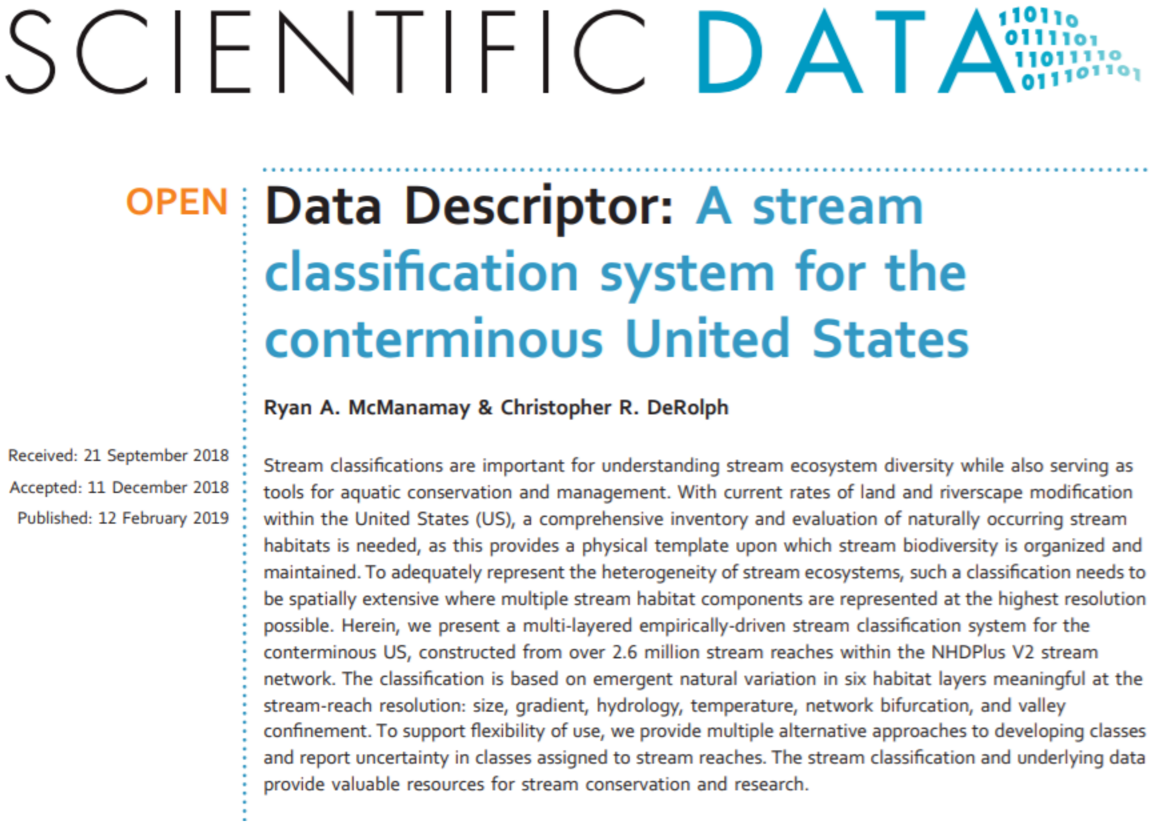
Ecoregions

- Organisms differ among ecoregions
- Piedmont

- Southeastern Plains



Existing classification framework



SCIENTIFIC DATA

OPEN

Data Descriptor: A stream classification system for the conterminous United States

Ryan A. McManamay & Christopher R. DeRolph

Received: 21 September 2018
Accepted: 11 December 2018
Published: 12 February 2019

Stream classifications are important for understanding stream ecosystem diversity while also serving as tools for aquatic conservation and management. With current rates of land and riverscape modification within the United States (US), a comprehensive inventory and evaluation of naturally occurring stream habitats is needed, as this provides a physical template upon which stream biodiversity is organized and maintained. To adequately represent the heterogeneity of stream ecosystems, such a classification needs to be spatially extensive where multiple stream habitat components are represented at the highest resolution possible. Herein, we present a multi-layered empirically-driven stream classification system for the conterminous US, constructed from over 2.6 million stream reaches within the NHDPlus V2 stream network. The classification is based on emergent natural variation in six habitat layers meaningful at the stream-reach resolution: size, gradient, hydrology, temperature, network bifurcation, and valley confinement. To support flexibility of use, we provide multiple alternative approaches to developing classes and report uncertainty in classes assigned to stream reaches. The stream classification and underlying data provide valuable resources for stream conservation and research.

2 to 3 classes per ecoregion, e.g.:

Piedmont:
-Perennial runoff
-Stable baseflow

Framework

- The ecological limits of hydrologic alteration (ELOHA). Poff et al., 2010

1. Build a hydrologic foundation of streamflow and biological data

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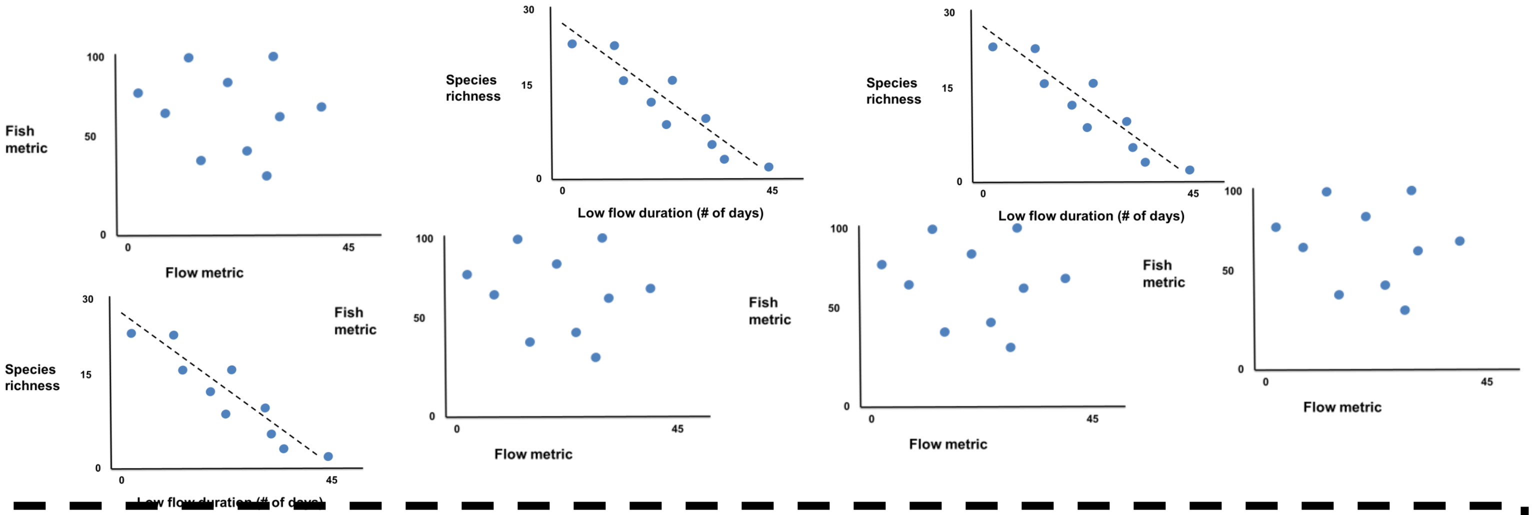
Determine flow-ecology relationships associated within each river type

4. Recommend water flow standards to achieve river condition goals

Identify relationships: remove uninformative relationships



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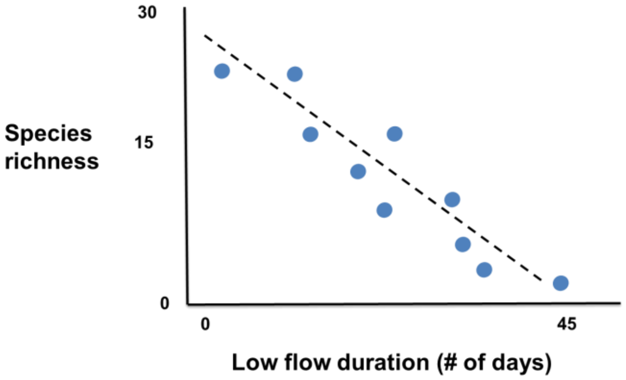
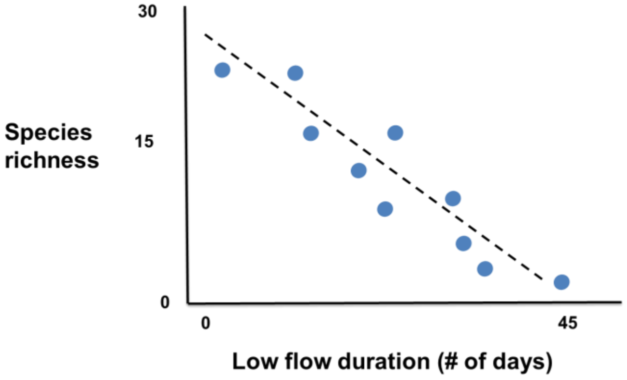
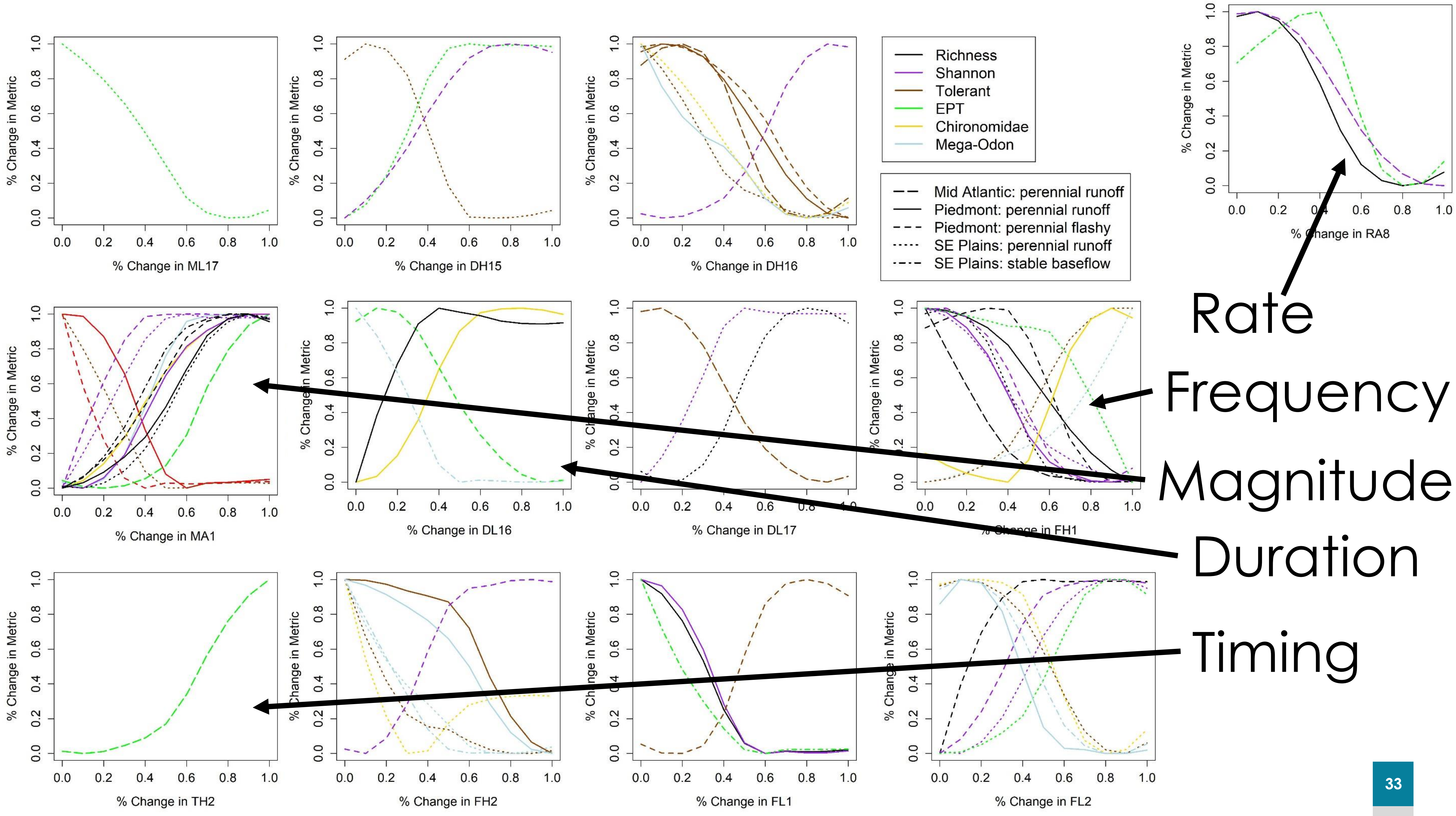




Major findings

All components of the flow regime are important

- Timing, magnitude, frequency, rate of change, and duration
- Not just minimum flows!



Rate

Frequency

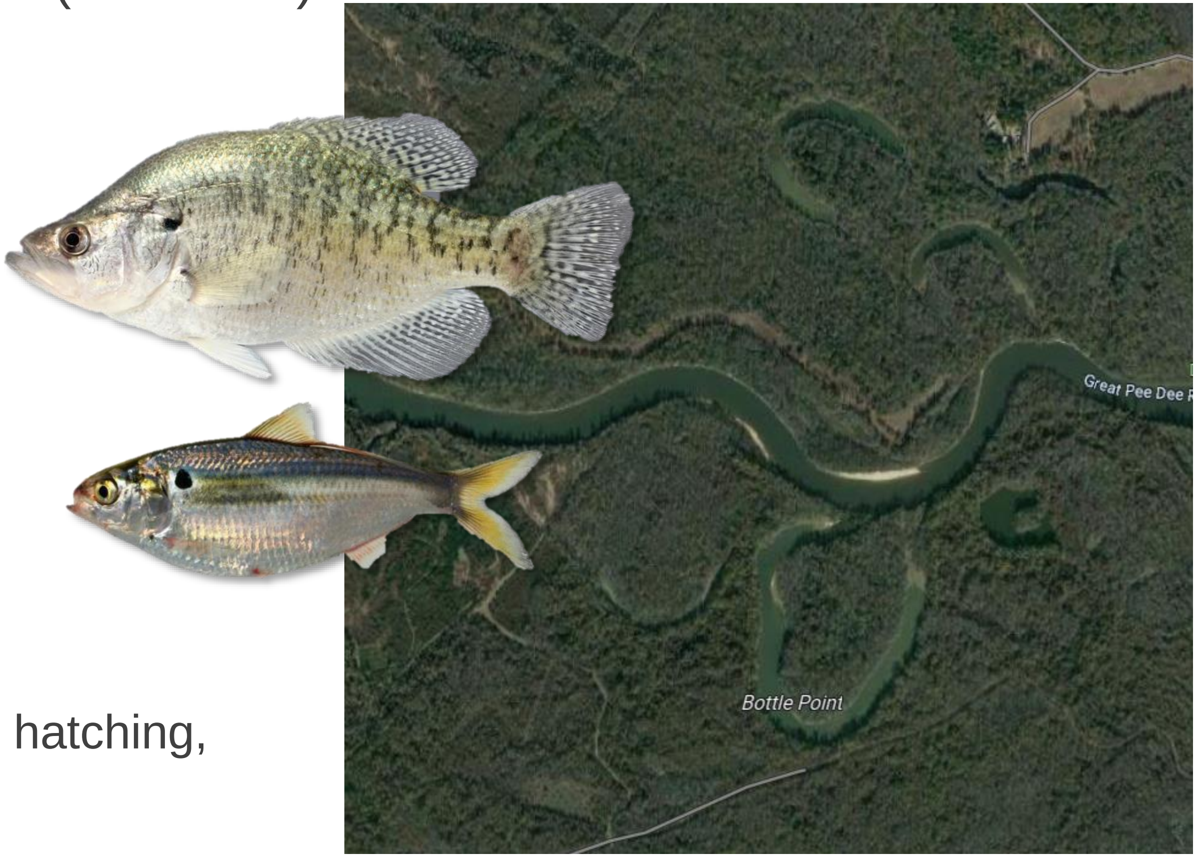
Magnitude

Duration

Timing

Relevance of flow regime components

- Magnitude: MA1 (mean daily flow) and ML17 (base flow)
  - Alteration of habitat
  - Reduced water quality and higher mortality
- Duration: DL16 (duration of low flow)
  - Alteration of connectivity
  - Increased duration of low water quality
- Timing: TL1 (timing of low flow events)
  - Loss of access to habitats
  - Disruption of life-cycle cues (spawning, egg hatching, migration) and decreases in recruitment
  - Invasion of exotics



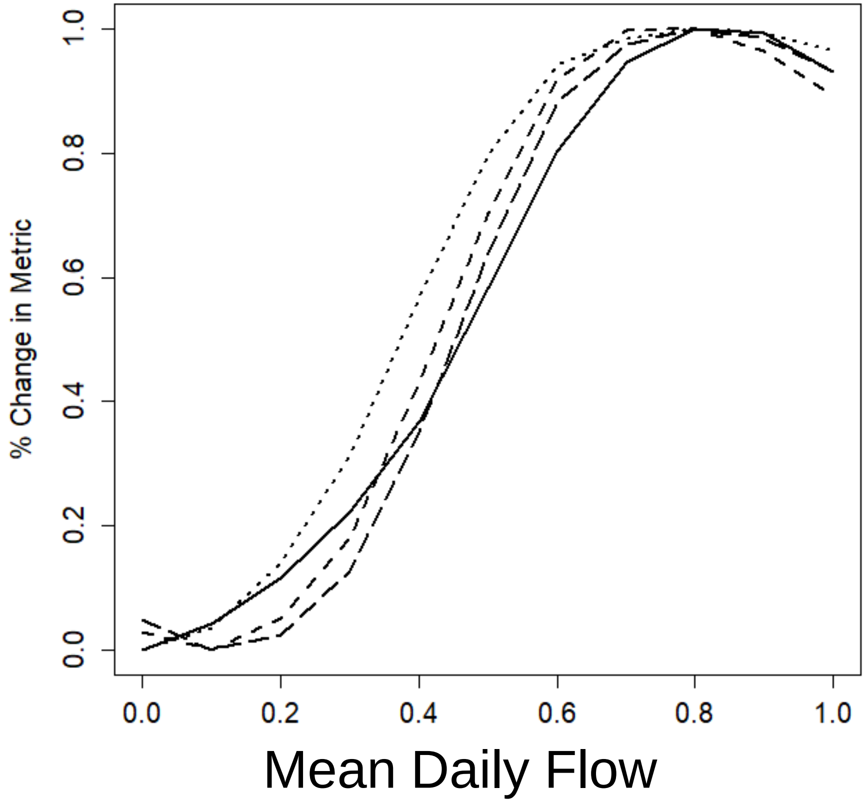
Major findings

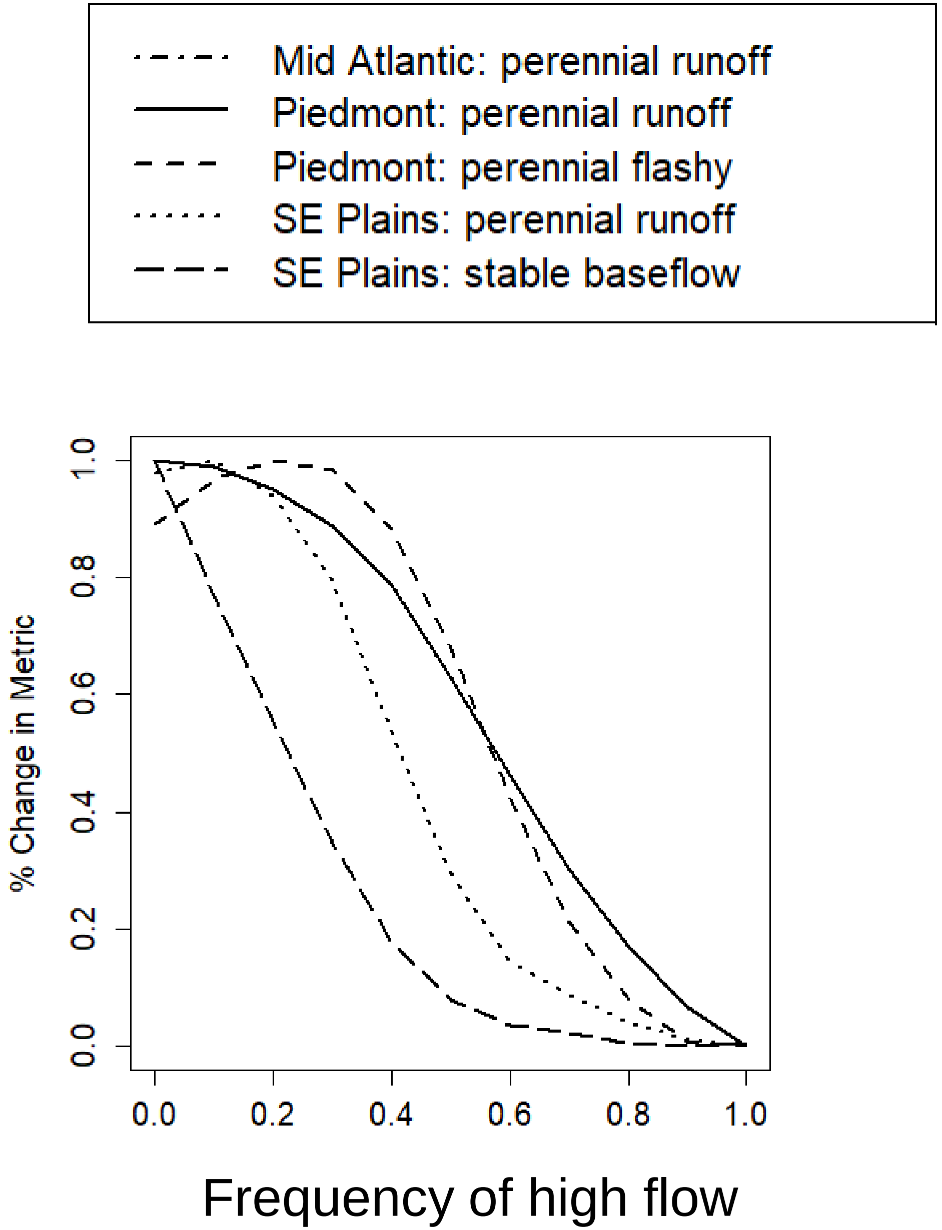
All components of the flow regime are important

These relationships differ between stream classes

- A single flow standard for the whole state will be inadequate

Stream class matters!!!



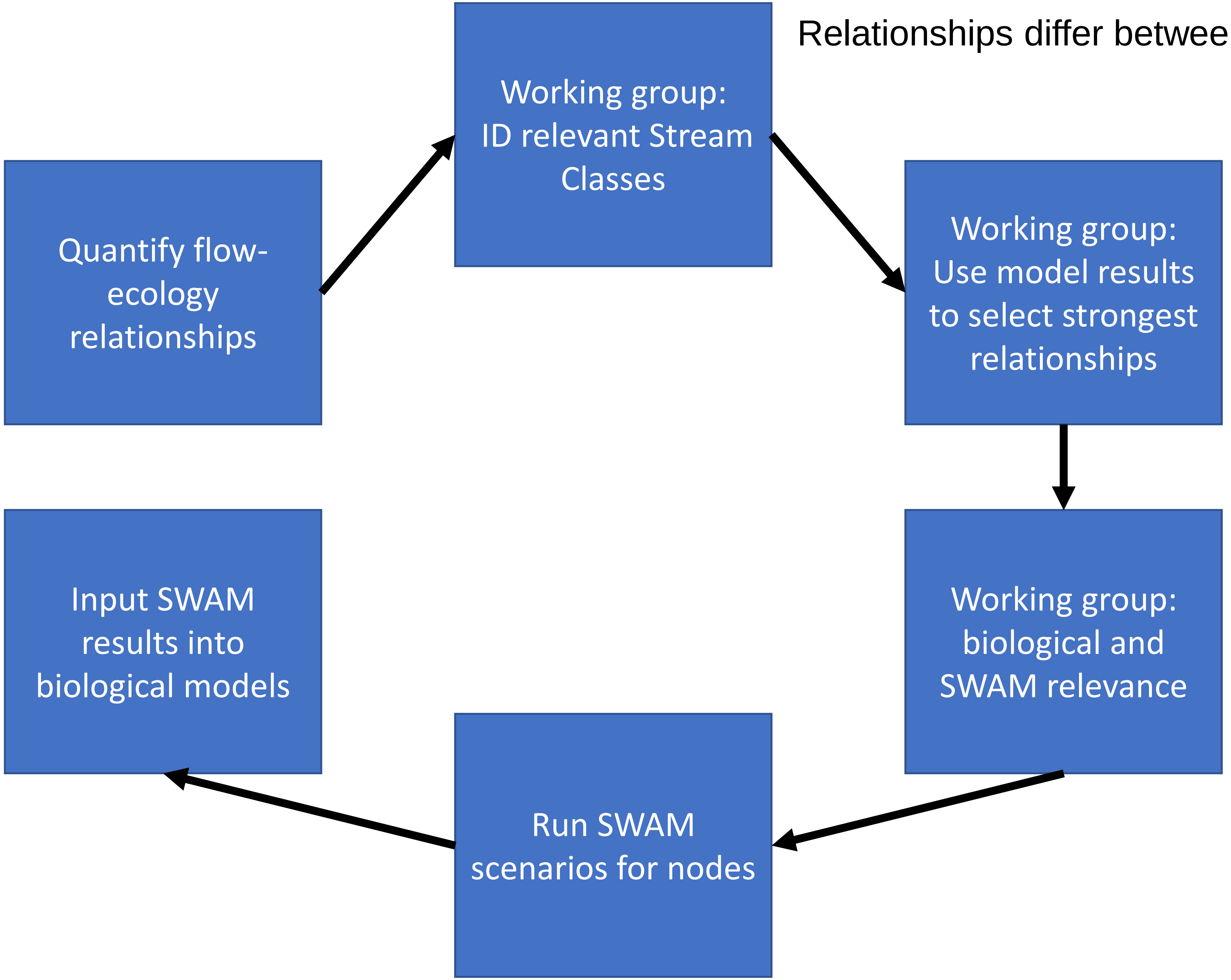


Frame Work

- The ecological limits of hydrologic alteration (ELOHA). Poff et al., 2010

    1. Build a hydrologic foundation of streamflow data
    2. Classify natural river types
    3. Determine flow-ecology relationships associated within each river type

Recommend water flow standards to achieve river condition goals



Working group:
ID relevant Stream Classes

Relationships differ between stream classes

Quantify flow-ecology relationships

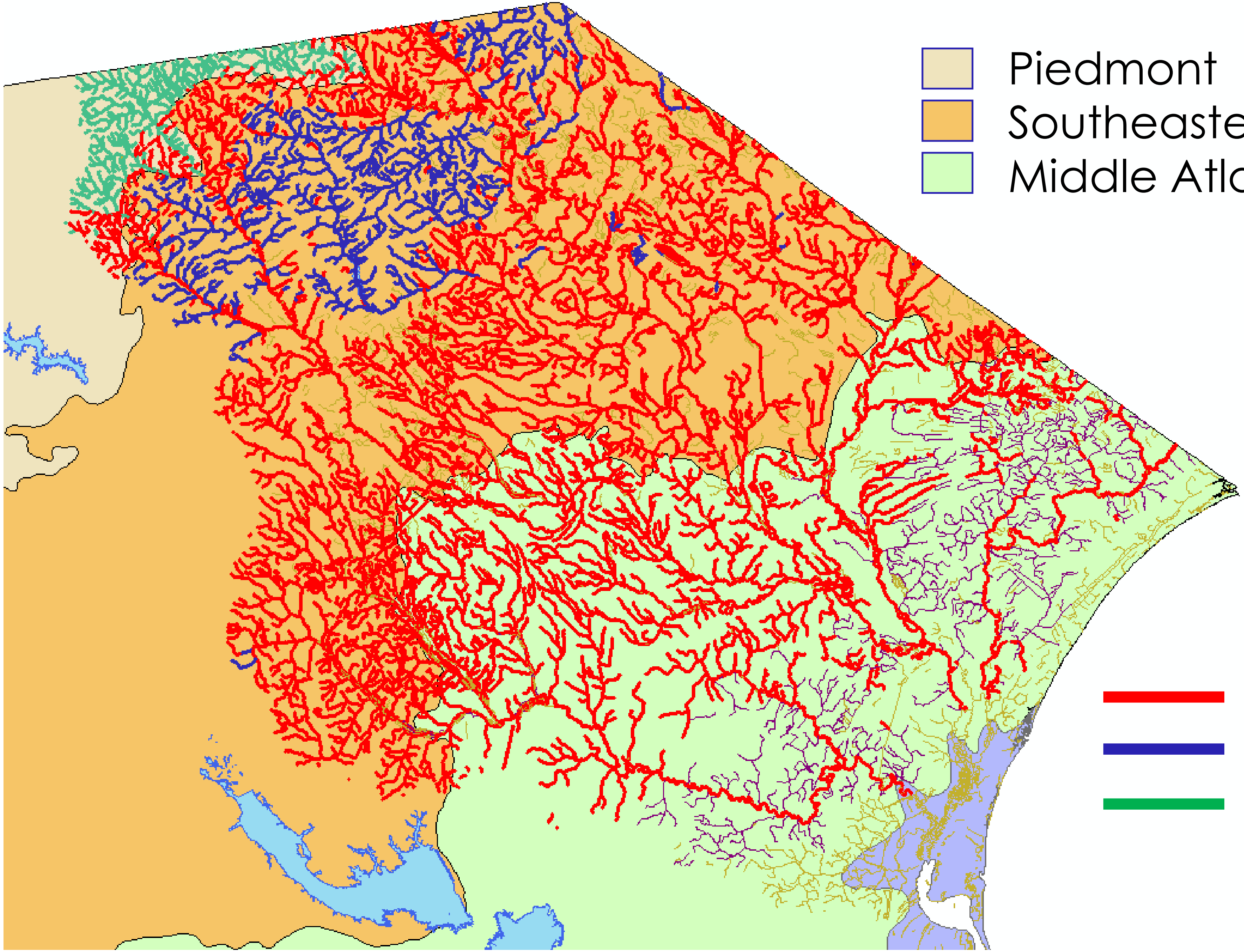
Working group:
Use model results to select strongest relationships

Many relationships to work with

Working group:
biological and SWAM relevance

Run SWAM scenarios for nodes

Input SWAM results into biological models



🟫 Piedmont
🟧 Southeastern Plains
🟩 Middle Atlantic Coastal Plain

🟥 1: perennial runoff
🟦 3: stable baseflow
🟩 4: perennial flashy

Stream classes

🟥

- Perennial runoff streams, characterized by moderately stabile flow and distinct seasonal extremes (Class 1, 615 stream segments)

🟦

- Stable baseflow streams: characterized by high precipitation, sustained high baseflows, and moderately high run-off (Class 3, 183 stream segments)

🟩

- Perennial flashy; characterized by moderately stabile flow with high flow variability (coefficient of variation in daily flows) (Class 4, 138 stream segments)

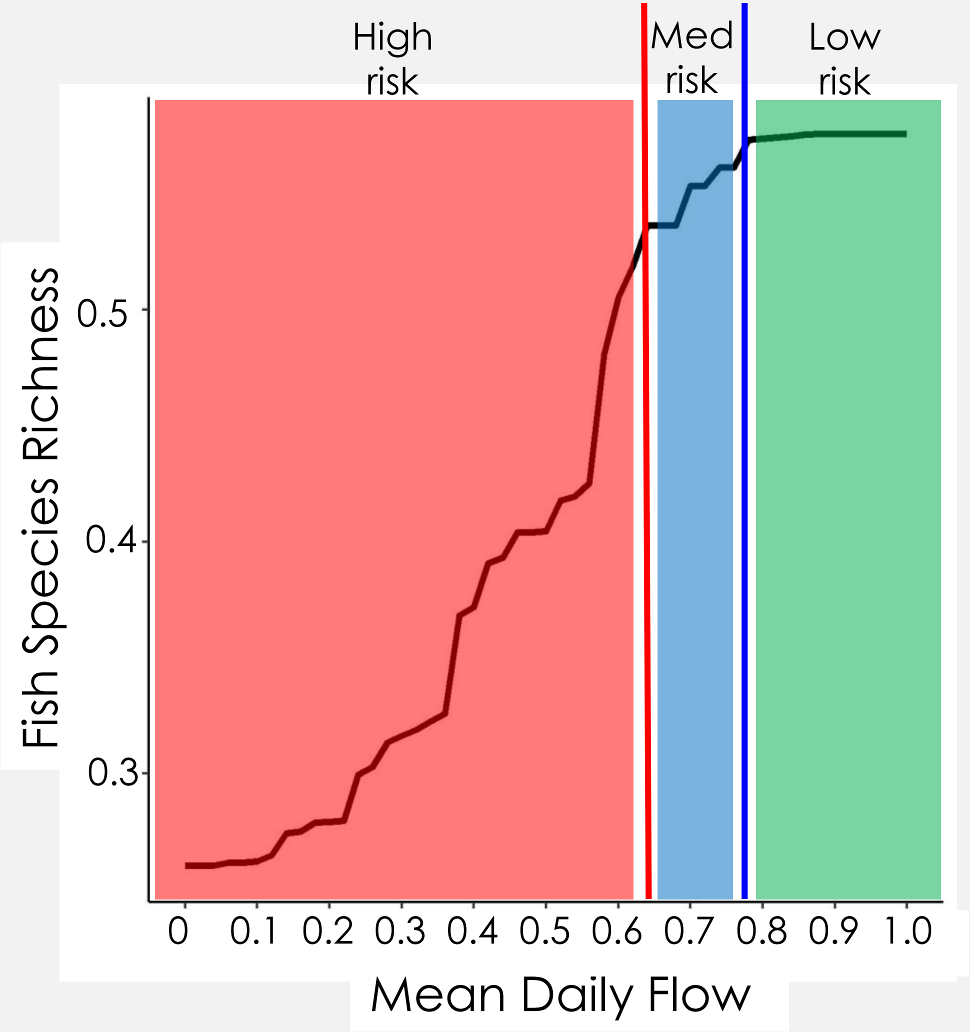
How can we use these relationships?

- Defining biological response limits
  - Searching for points along flow gradients that induce changes in the biological metric
  - Zones low, medium, and high change in the biological condition of streams along flow gradients
- Predicting responses
  - If we alter flow by X amount what will be the biological response?

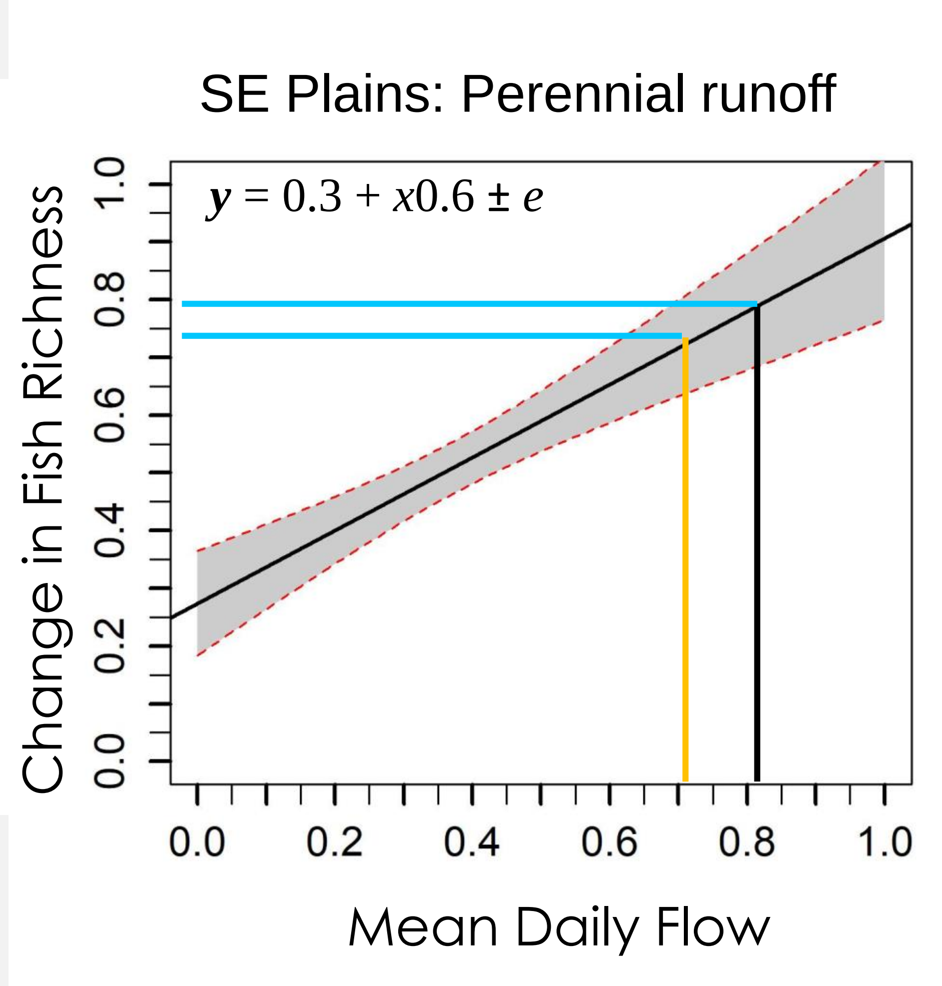
Mean daily flow (MA1): biological response limits

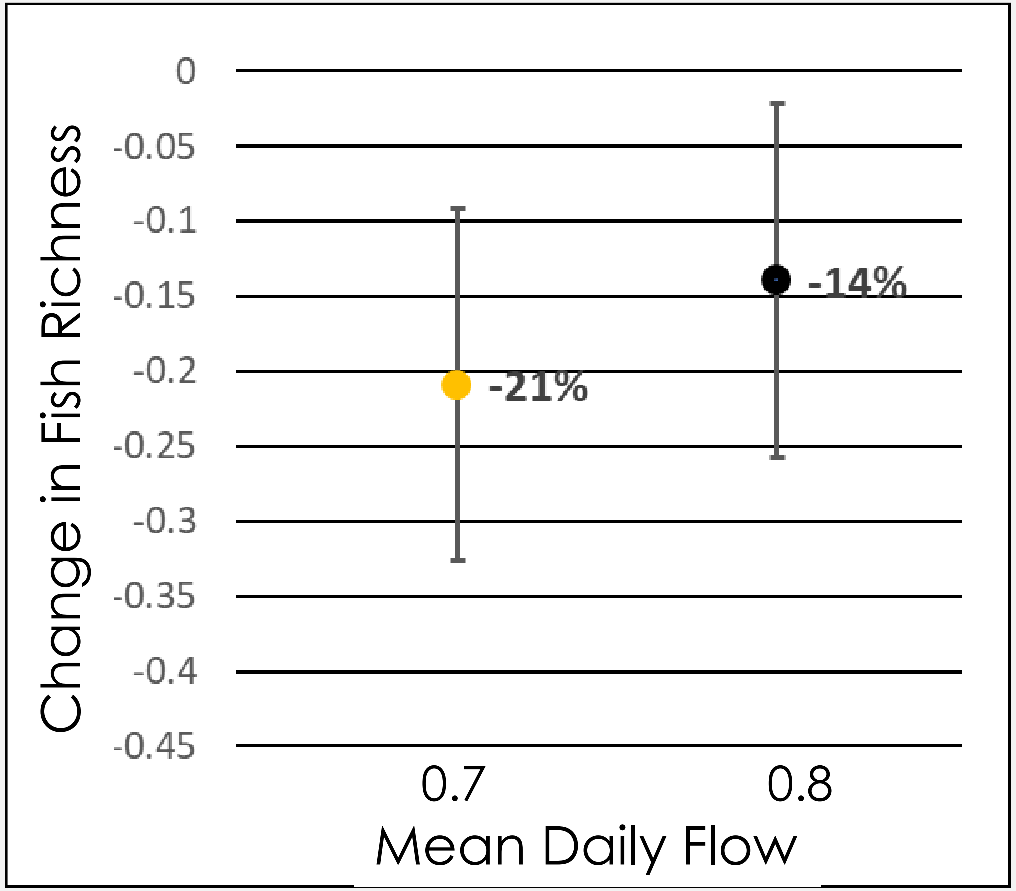
- Lines defined by working group

- Performance measure



Mean daily flow (MA1): predictions





Key to Understanding the Results of the Surface Water Modeling Scenarios:

Standard Error

Mean daily flow (MA1): N. Pacolet near Fingerville

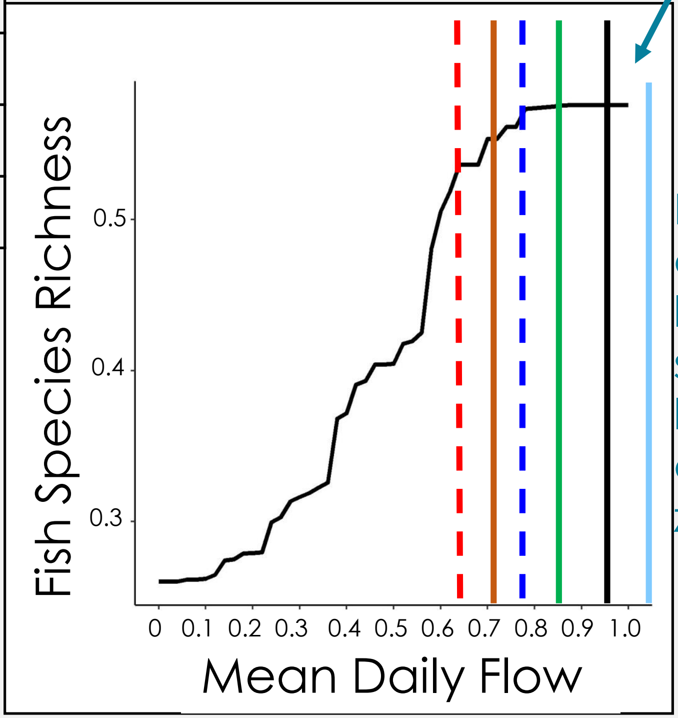
Scenario	Current	Predicted	% change	Bio Metric	Change in Bio	SE
UIF	320	368.91	15.4%	Richness	12.7%	7
HD 2070	320	257.78	-19.4%	Richness	-15.9%	7
Full	320	227.65	-28.8%	Richness	-23.6%	7
MD 2070	320	283.39	-11.3%	Richness	-9.3%	7

Current Use Scenario Mean Daily Flow

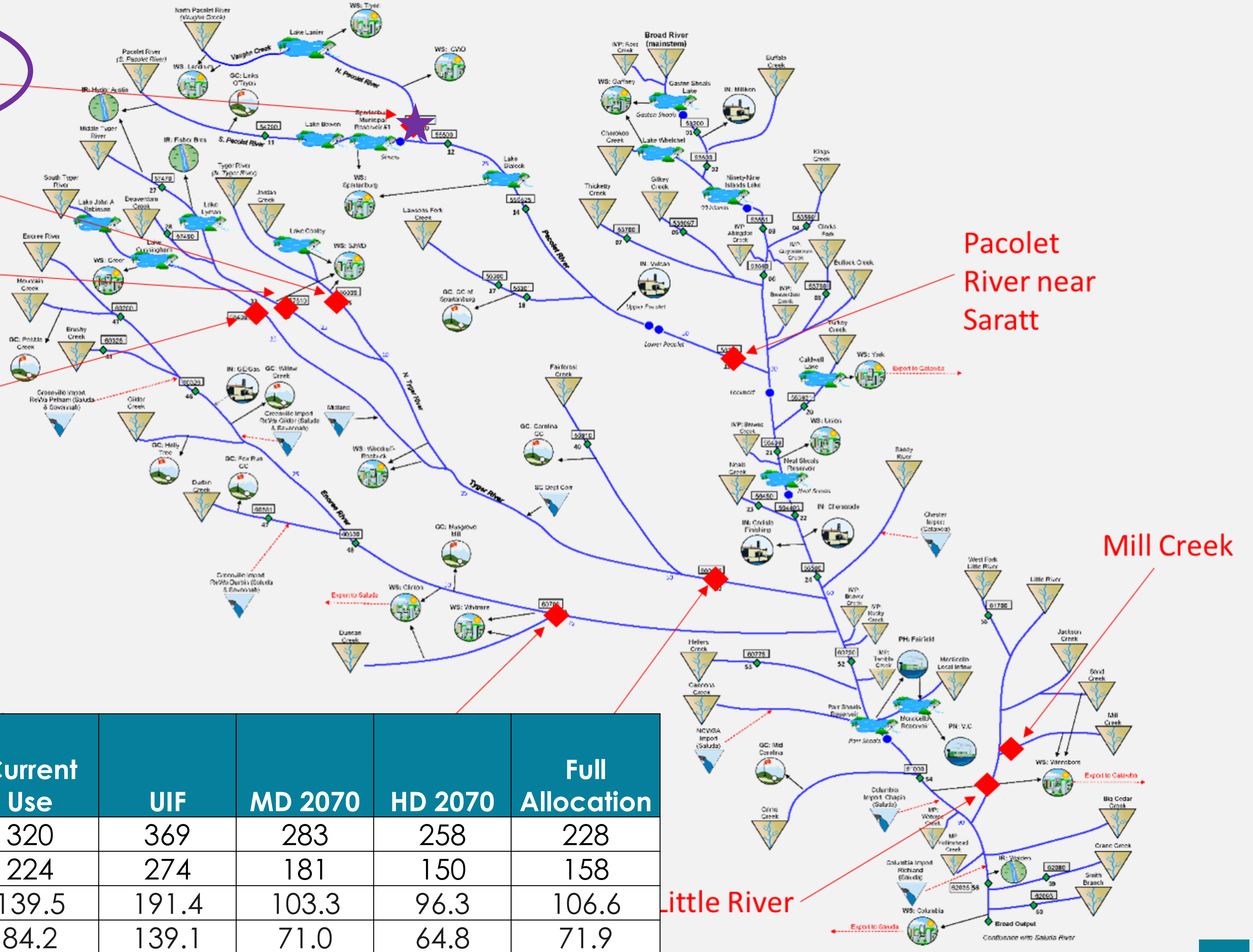
Scenario Mean Daily Flows

% Changes for each scenario are relative to the Current Use Scenario

Colored lines correspond to scenario results shown in the table



Dashed red and blue lines separate the low medium and high risk zones



N. Pacolet near Fingerville

N. Tyger below Wellford

Middle Tyger near Lyman

S. Tyger below Duncan

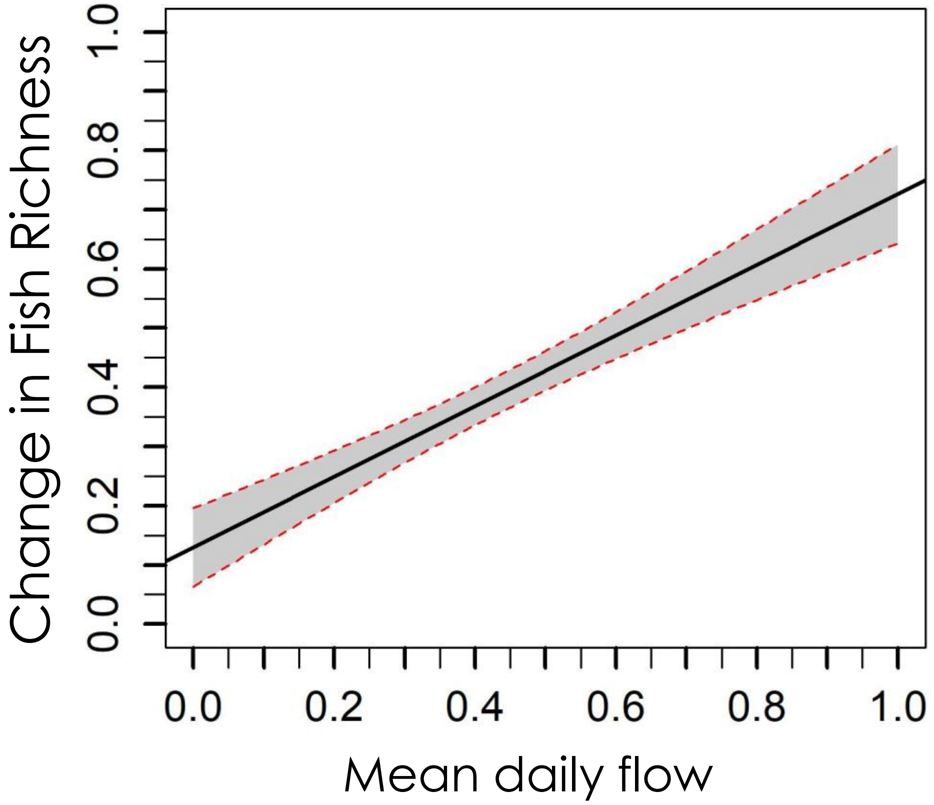
Pacolet River near Saratt

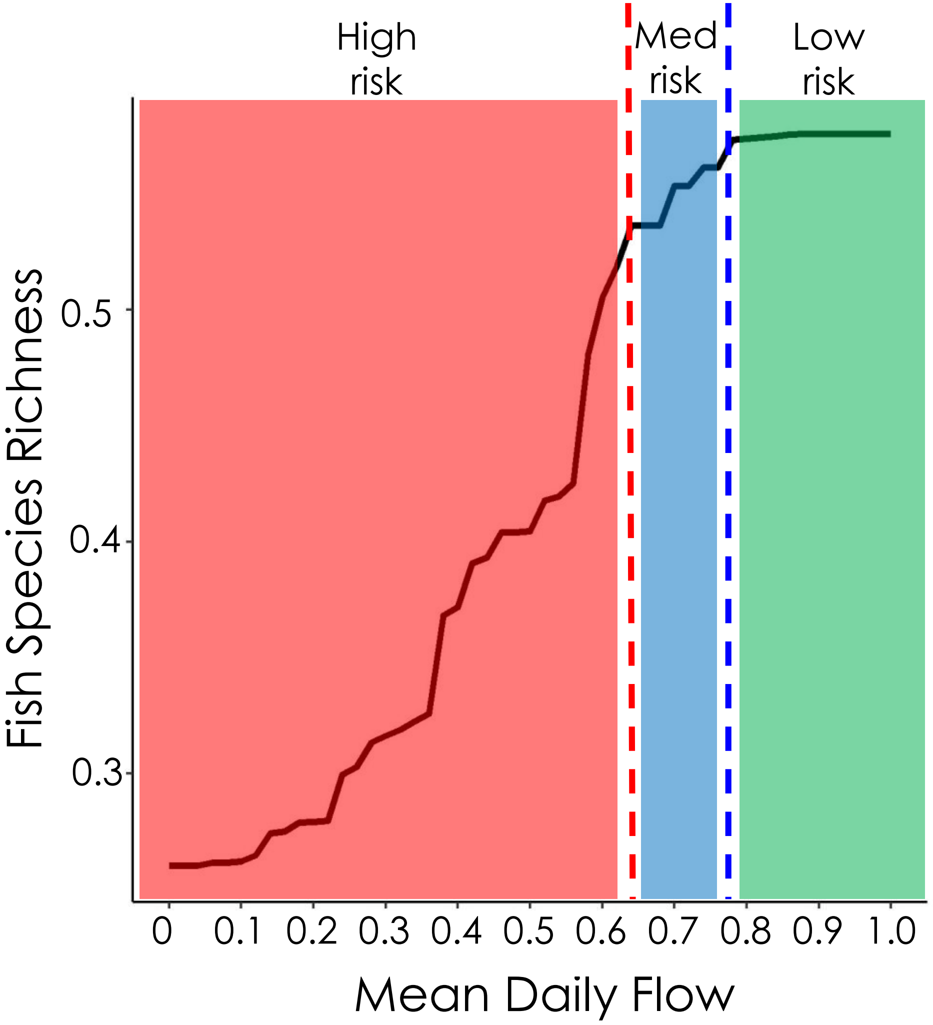
Mill Creek

Little River

BRD12: N. Pacolet River near Fingerville	Current Use	UIF	MD 2070	HD 2070	Full Allocation
mean flow (cfs)	320	369	283	258	228
median flow (cfs)	224	274	181	150	158
25th percentile flow (cfs)	139.5	191.4	103.3	96.3	106.6
10th percentile flow (cfs)	84.2	139.1	71.0	64.8	71.9
5th percentile flow (cfs)	63.9	112.8	54.6	48.0	53.4

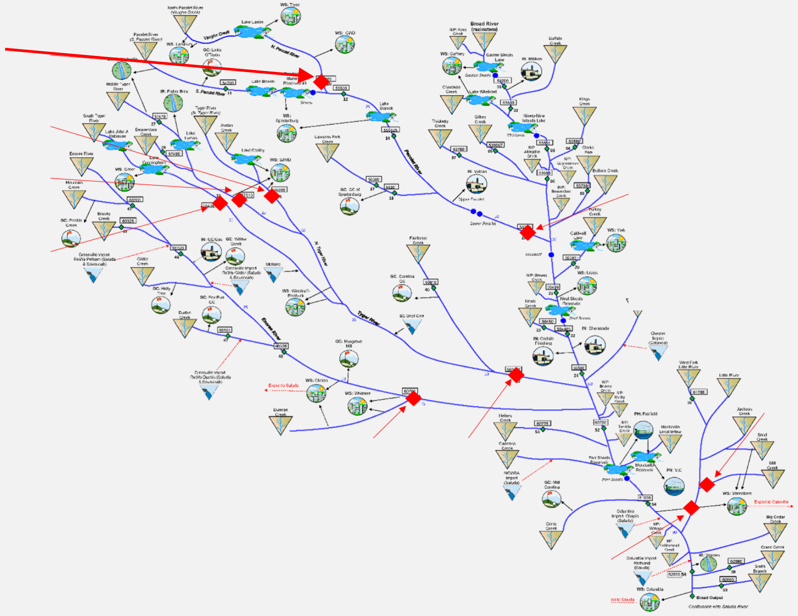
Example from the Broad River
Fish Richness-MA1: Piedmont: perennial runoff





Example from the Broad River

Scenario	Current	Predicted	% change	Bio Metric	Change in Bio	SE
UIF	320	368.91	15.4%	Richness	12.7%	7
HD 2070	320	257.78	-19.4%	Richness	-15.9%	7
Full	320	227.65	-28.8%	Richness	-23.6%	7
MD 2070	320	283.39	-11.3%	Richness	-9.3%	7



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