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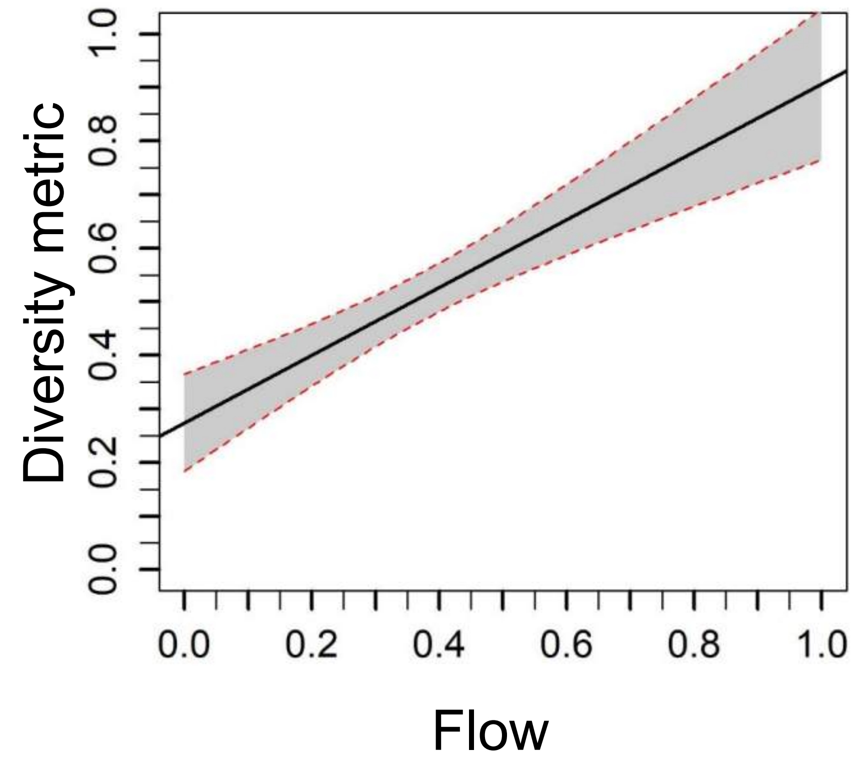
Quantifying flow–ecology relationships across flow regime class and ecoregions in South Carolina

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

- Provide a tool

Frame Work

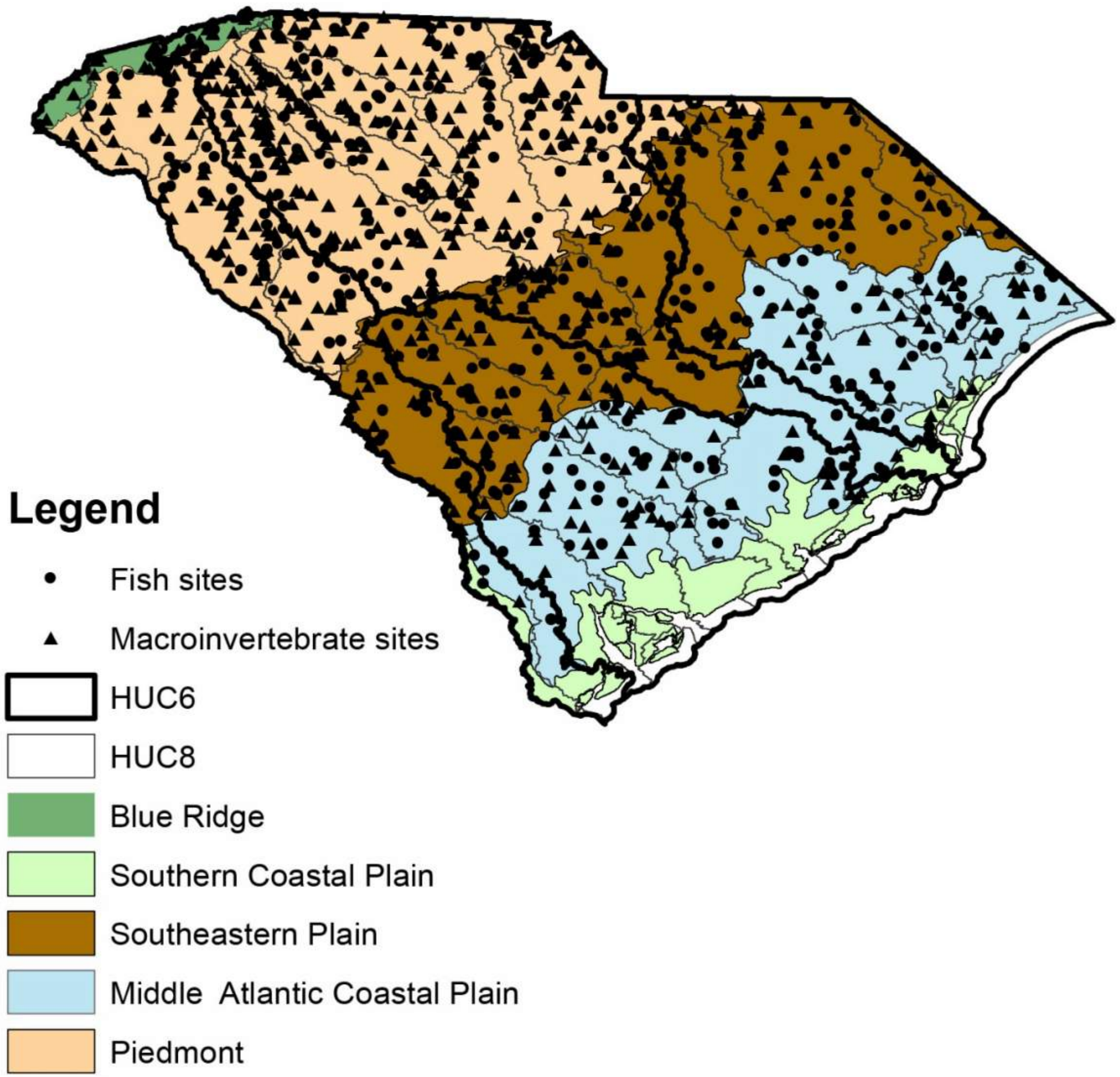
- The ecological limits of hydrologic alteration (ELOHA). Poff et al., 2010

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:

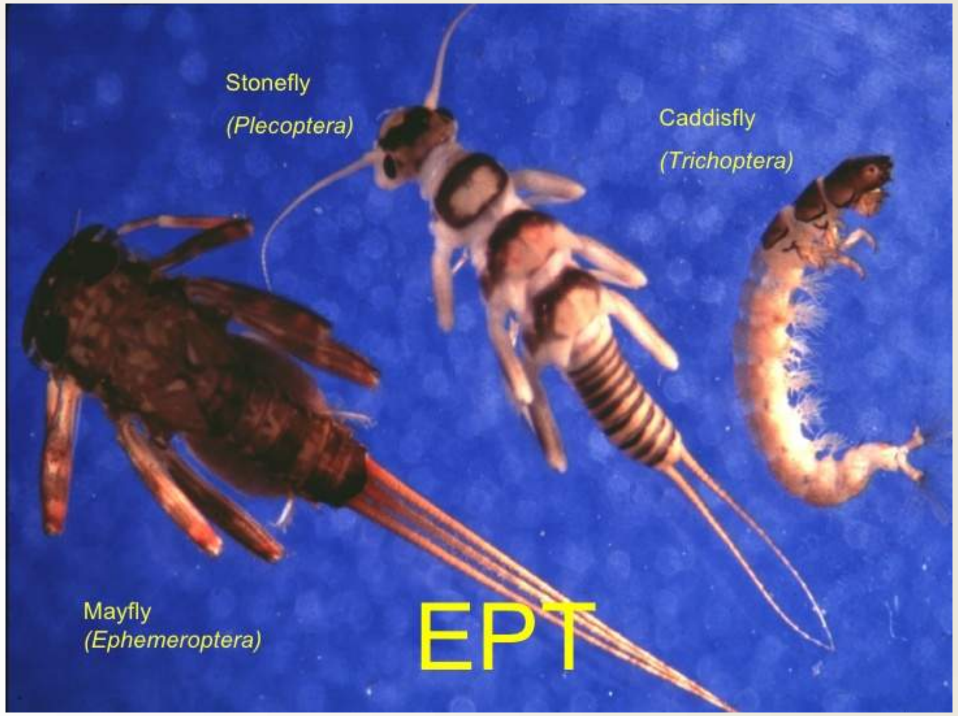
- 492 Fish sites (streams & rivers)
  - DNR
  - 8 biological response metrics
- 530 aquatic insects sites
  - DHEC
  - 6 biological response metrics

Fish Metrics

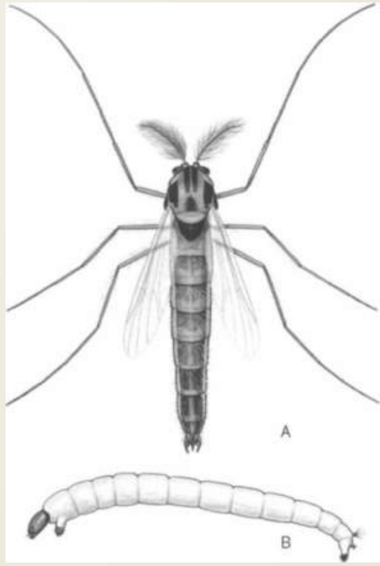
- **Richness:** number of species
- **Shannon's** diversity index: weights richness by abundance
- Proportional representation of **sunfish**
- Proportional representation of **tolerant** individuals
- Proportional representation of **flow specialists**
- Proportional representation of individuals belonging to a **breeding strategy**
  - Open substrate spawning, brood hiding, and nest spawning species

Aquatic insects

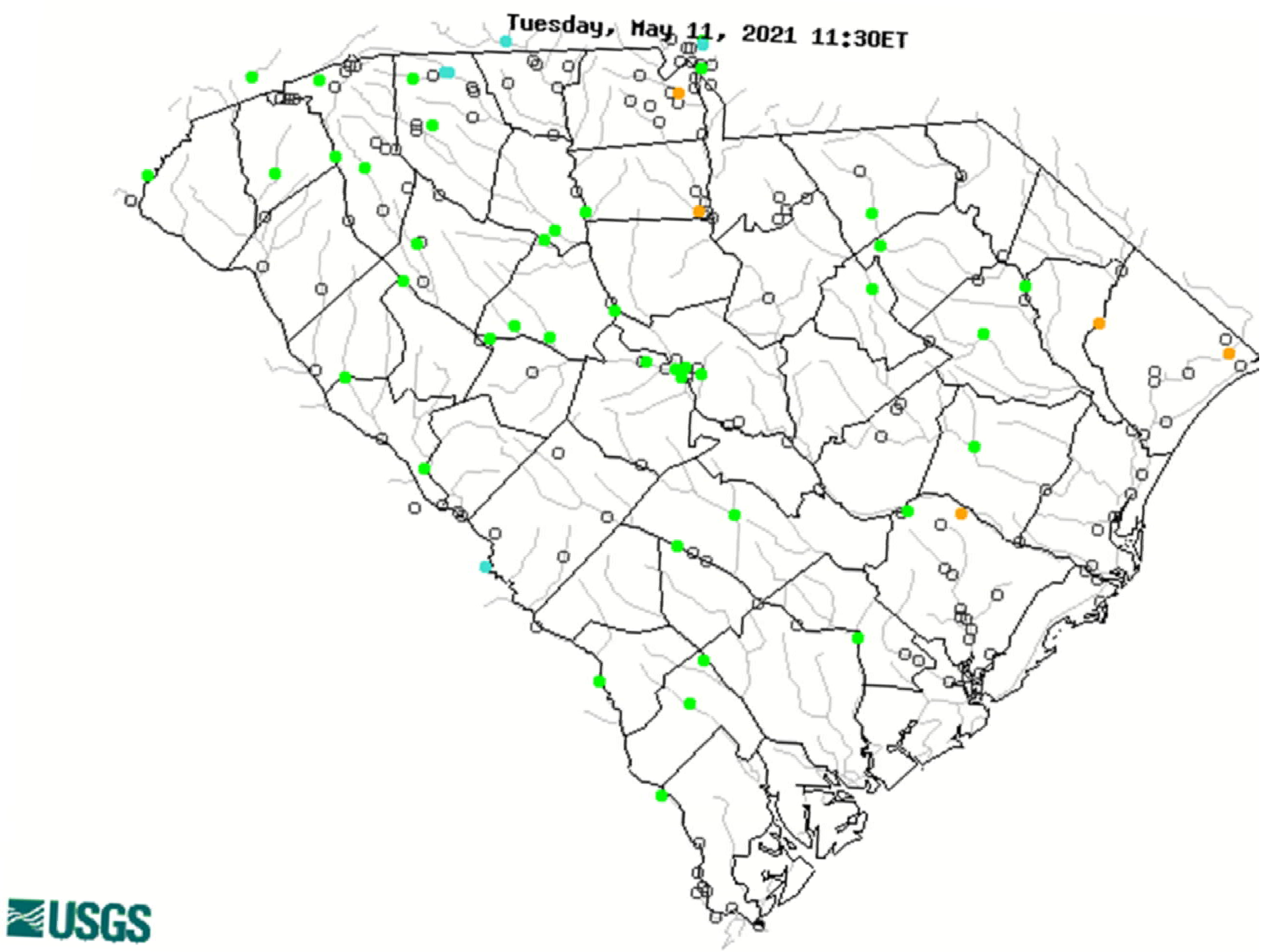
Slideshare.com

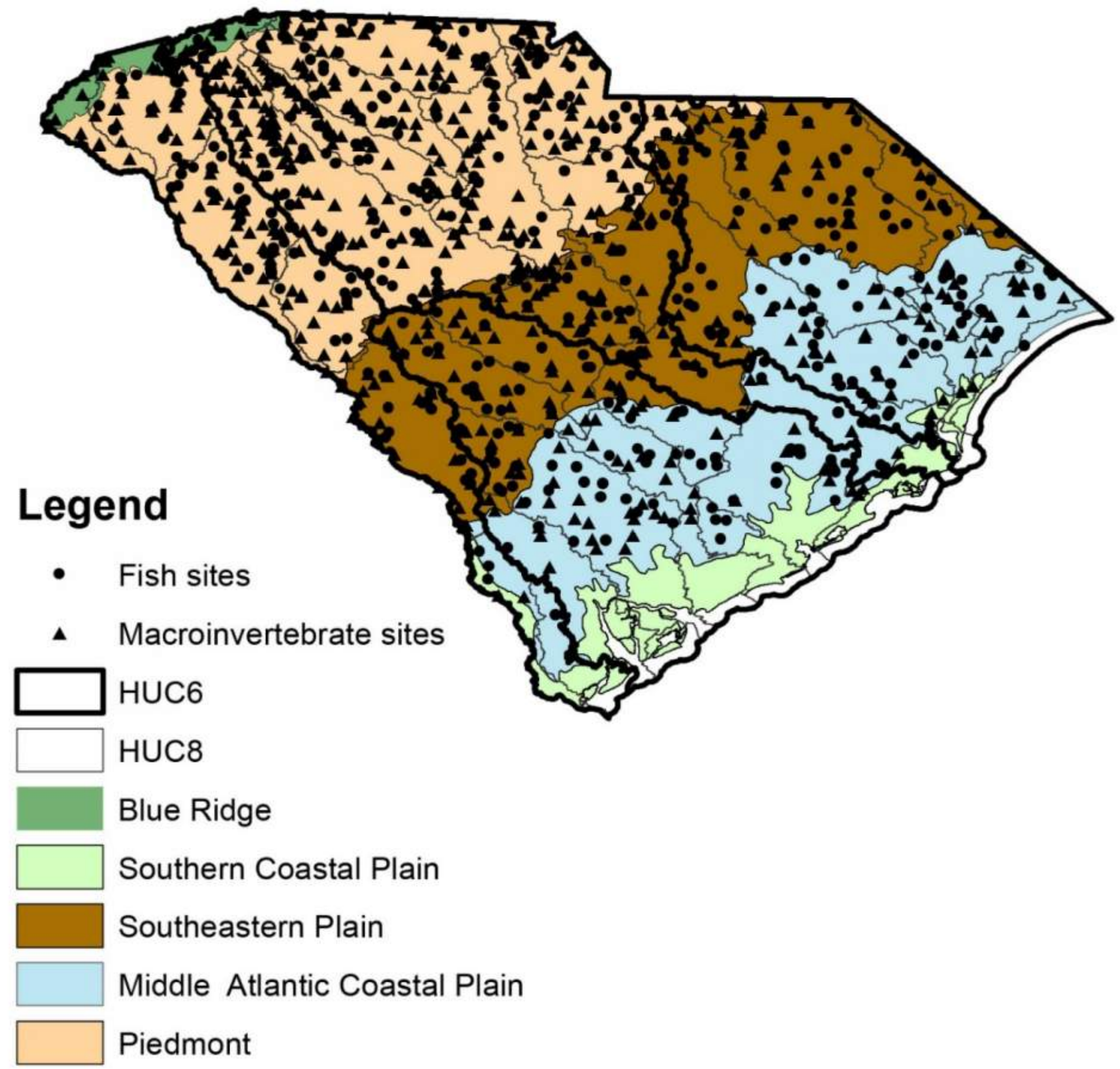


- **Richness**
- **Shannon's** diversity index
- Proportional representation of individuals within the Orders **EPT**
- Proportional representation of individuals within the family **Chironomidae**
- The **Megaloptera-Odonata** index
- **Tolerance** index



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**
- Accounts for withdrawals, discharges, and reservoirs within the river network
- Calibration against 59 USGS gages
  - 12 year calibration
  - 8 year validation

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)	Approximatel y 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

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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]

Frame Work

- 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

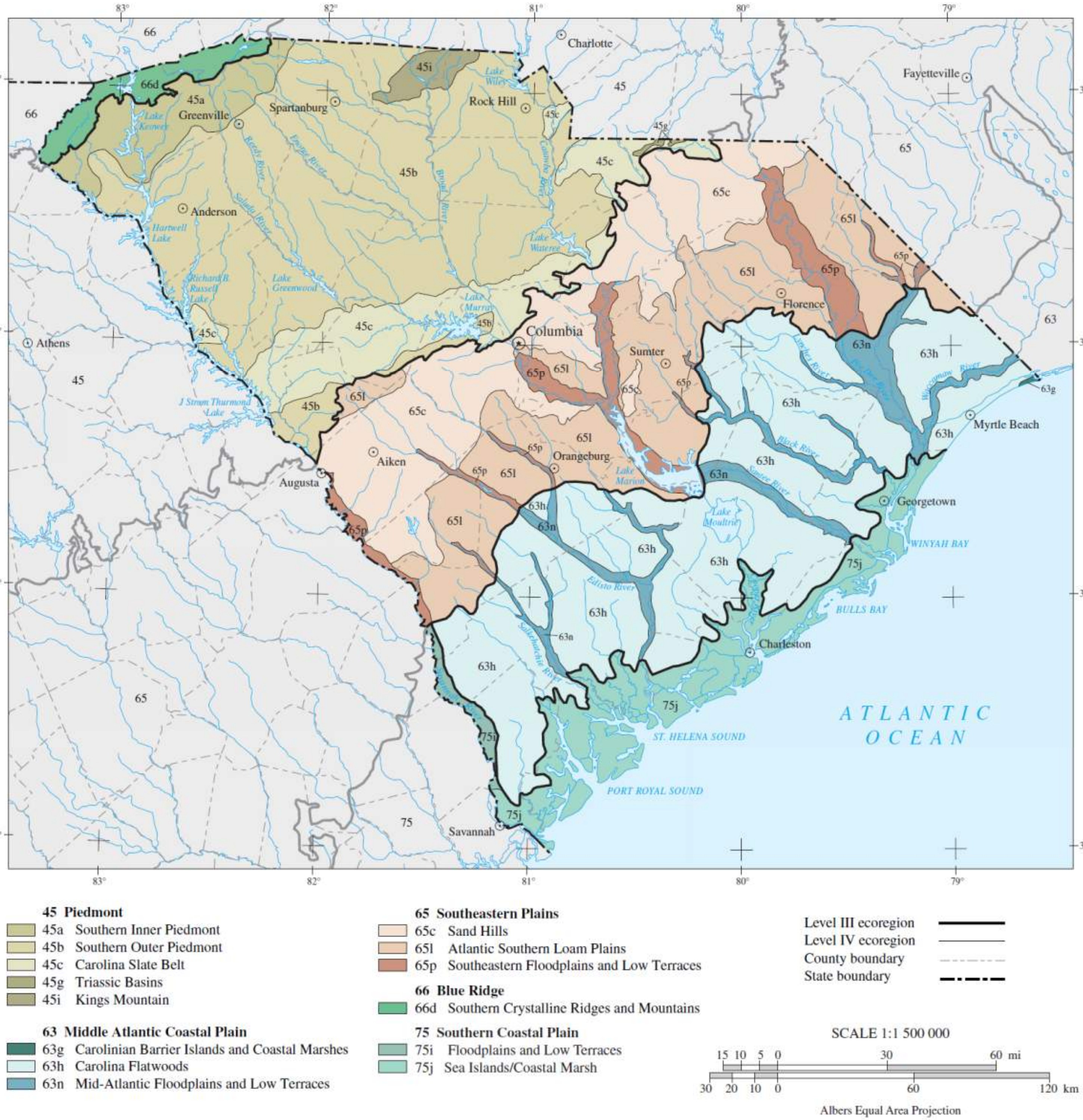
3. Determine flow-ecology relationships associated within each river type

4. Recommend water flow standards to achieve river condition goals

2. Classify natural river types

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

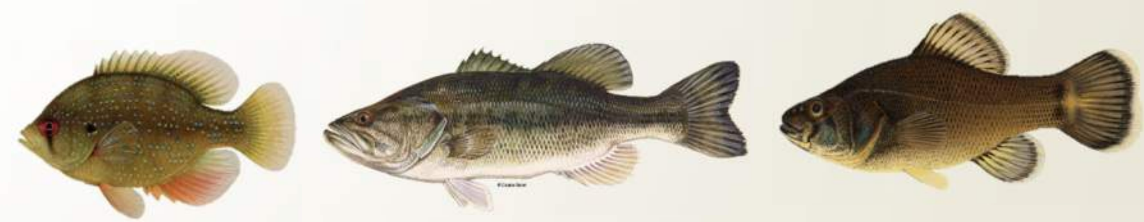
B. Relationship holds for these un-sampled streams



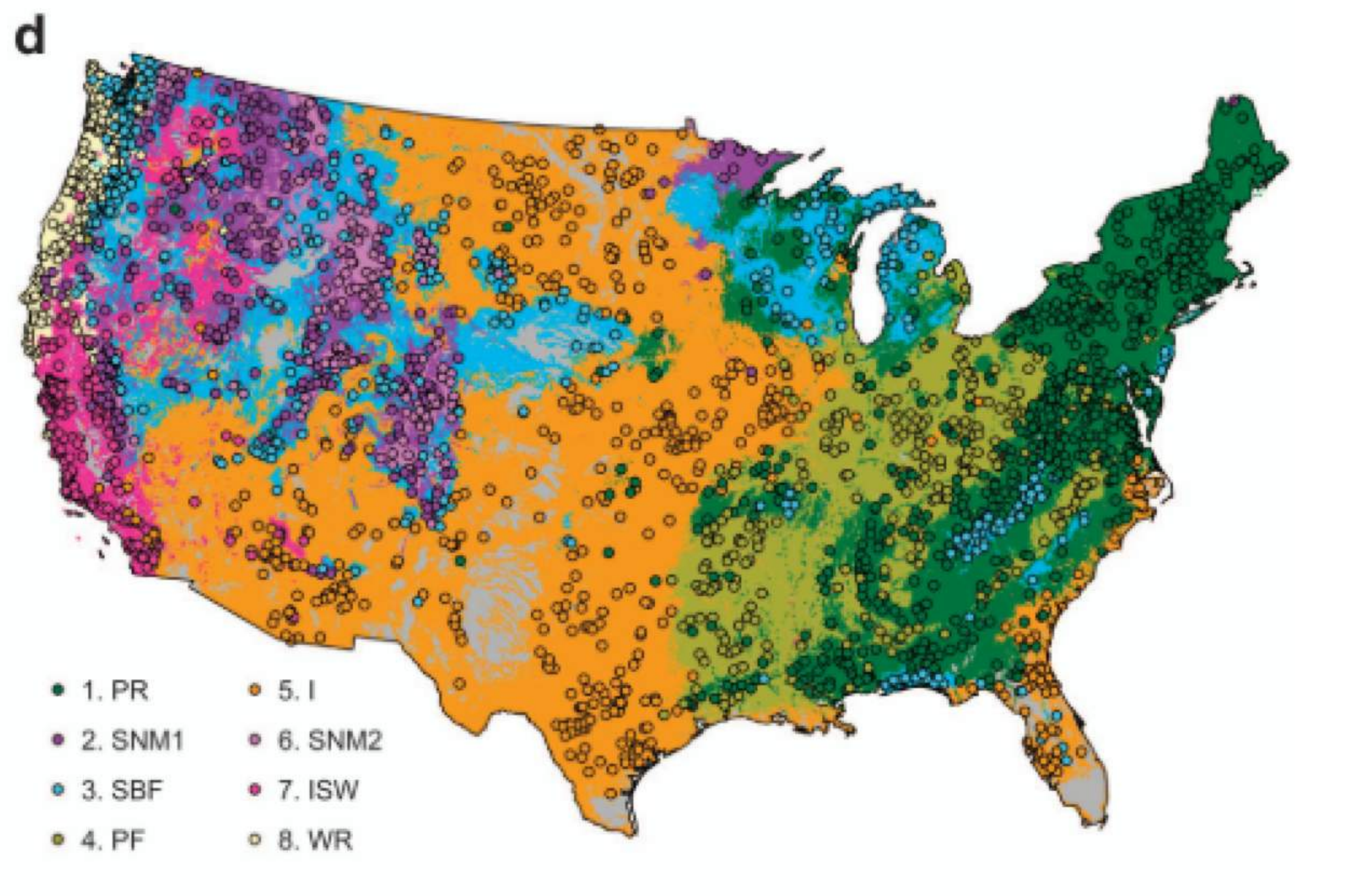
Ecoregions

- Organisms differ among ecoregions
- Piedmont

- Southeastern Plains



Existing classification framework



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

SE plains:
-Perennial runoff
-Stable baseflow

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)
- Intermittent streams, classified by intermittent periods of no flow punctuated by flooding events (Class 5, 45 stream segments)

Frame Work

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1. Build a hydrologic foundation of streamflow and biological data

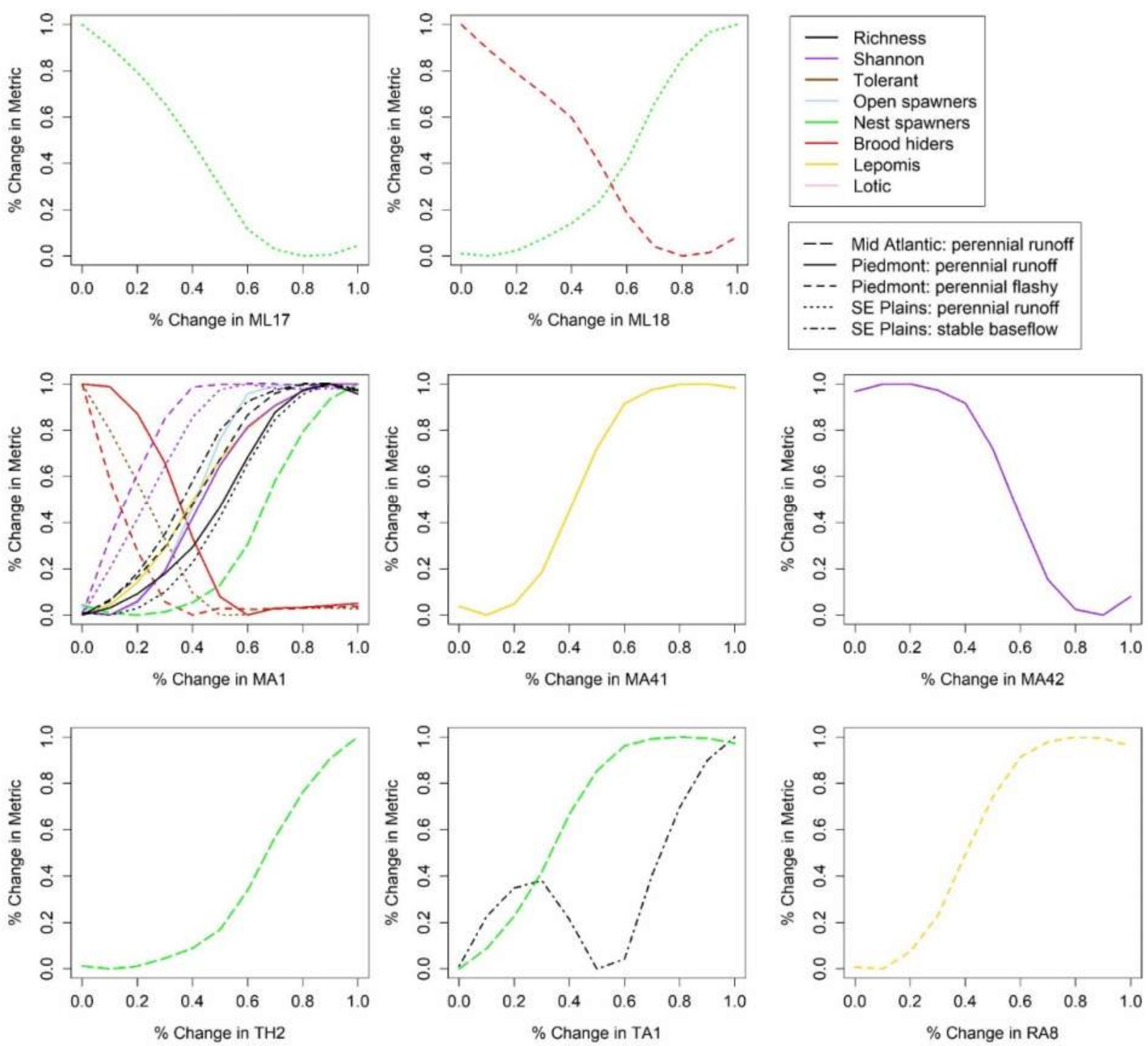
2. Classify natural river types

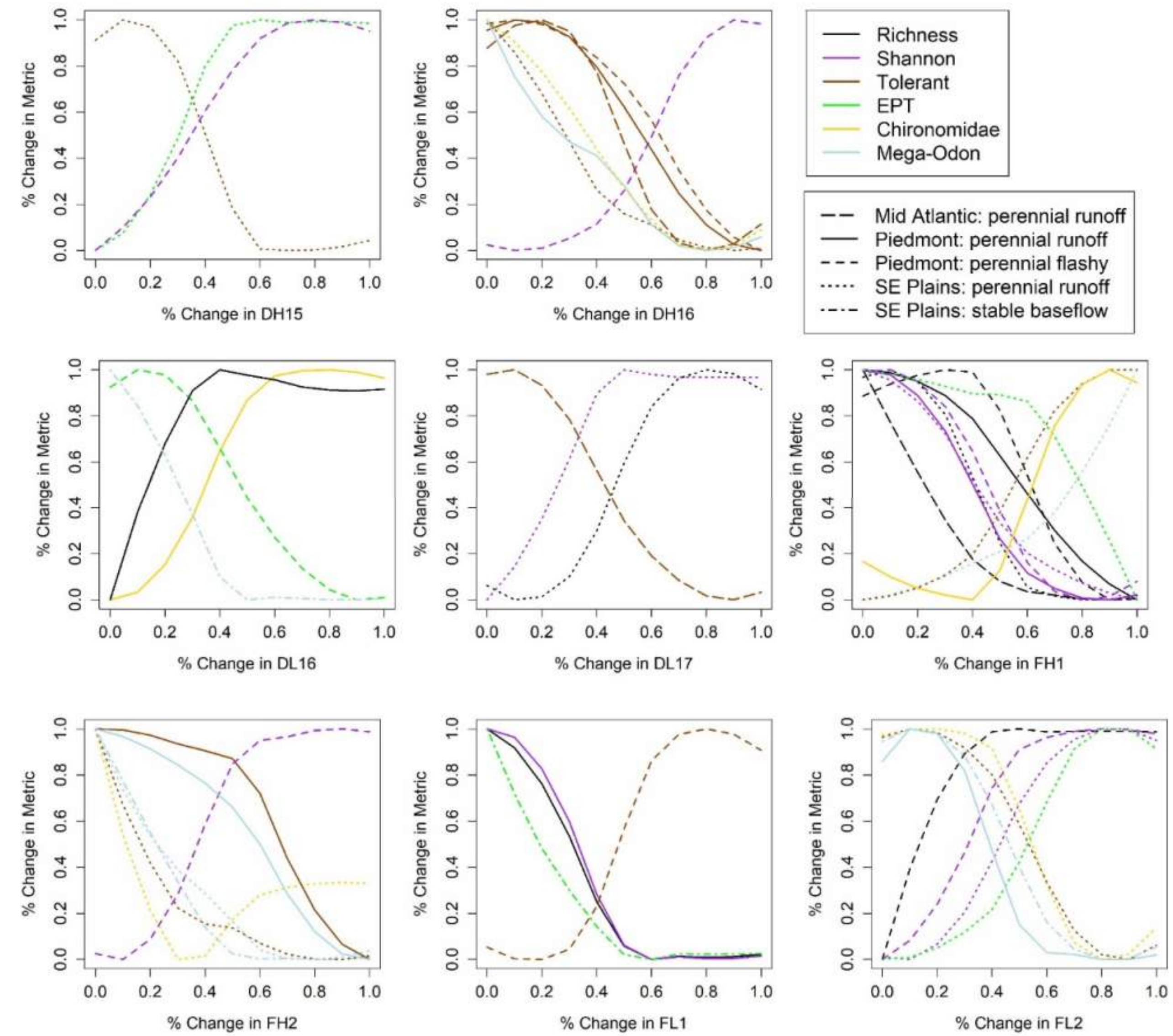
Determine flow-ecology relationships associated within each river type

4. Recommend water flow standards to achieve river condition goals

Three major findings

1. We found many relationships

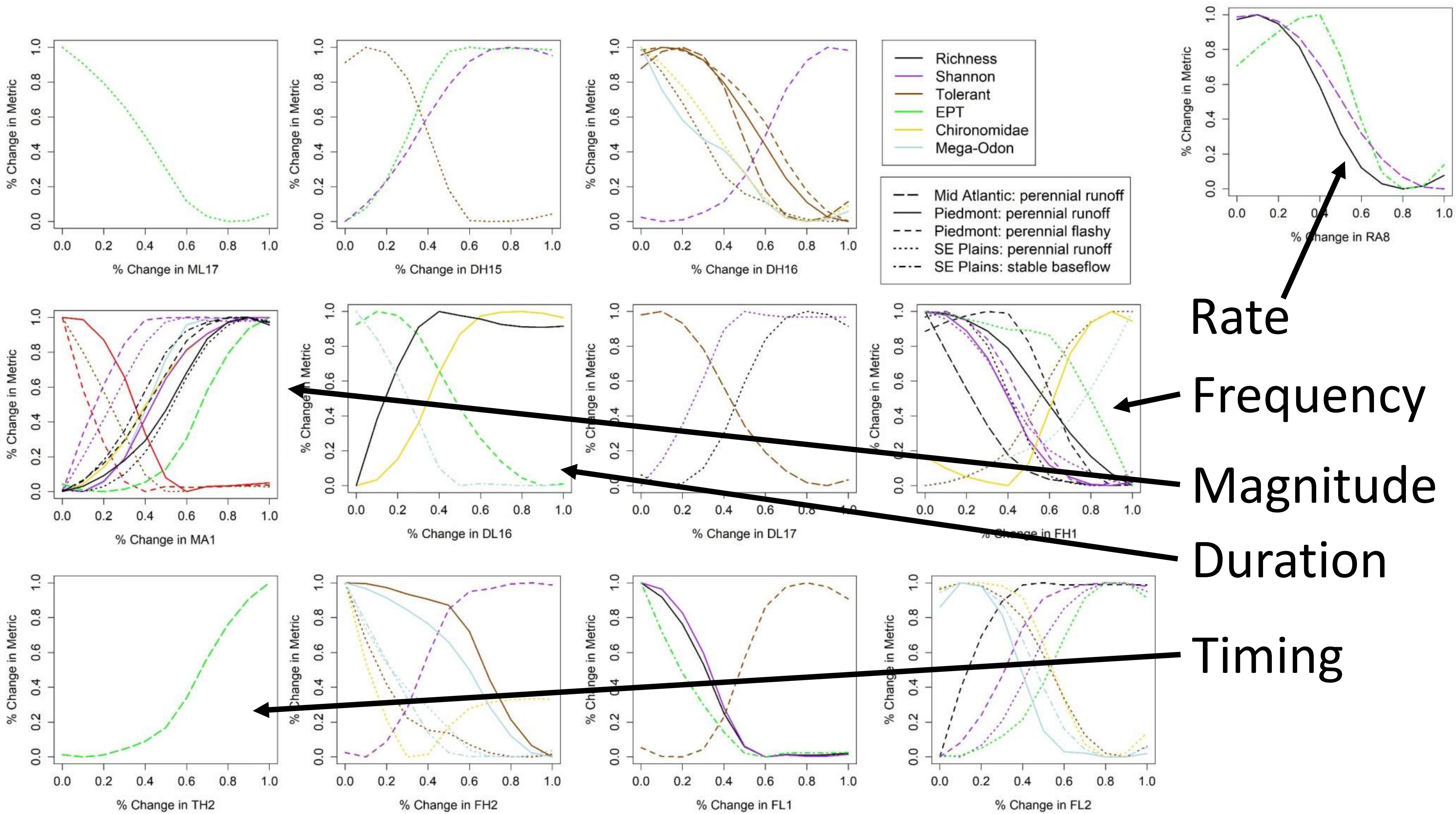




Three major findings

1. We found many relationships

2. All components of the flow regime are important
   - Timing, magnitude, frequency, rate of change, and duration
   - Not just minimum flows!


Richness
Shannon
Tolerant
EPT
Chironomidae
Mega-Odon
Mid Atlantic: perennial runoff
Piedmont: perennial runoff
Piedmont: perennial flashy
SE Plains: perennial runoff
SE Plains: stable baseflow
% Change in Metric
% Change in ML17
% Change in DH15
% Change in DH16
% Change in RA8
% Change in MA1
% Change in DL16
% Change in DL17
% Change in FH1
% Change in TH2
% Change in FH2
% Change in FL1
% Change in FL2
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
- (tim g of low flow events)
  - o habitats
  - of life-cycle cues (spawning, egg hatching, migration) and ses in recruitment
  - Invasion of

Three major findings

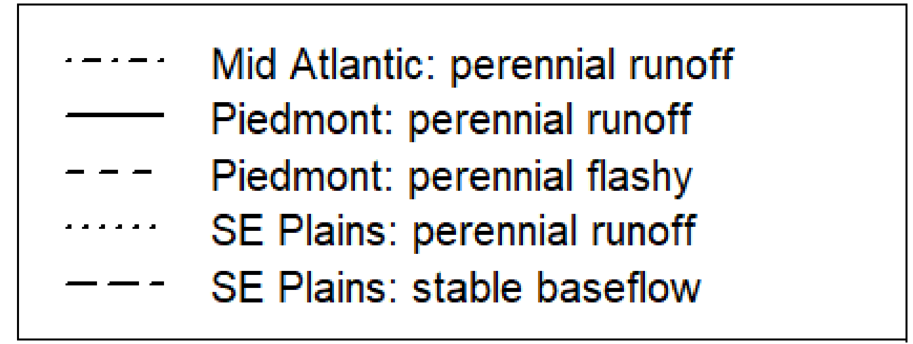
1. We found many relationships

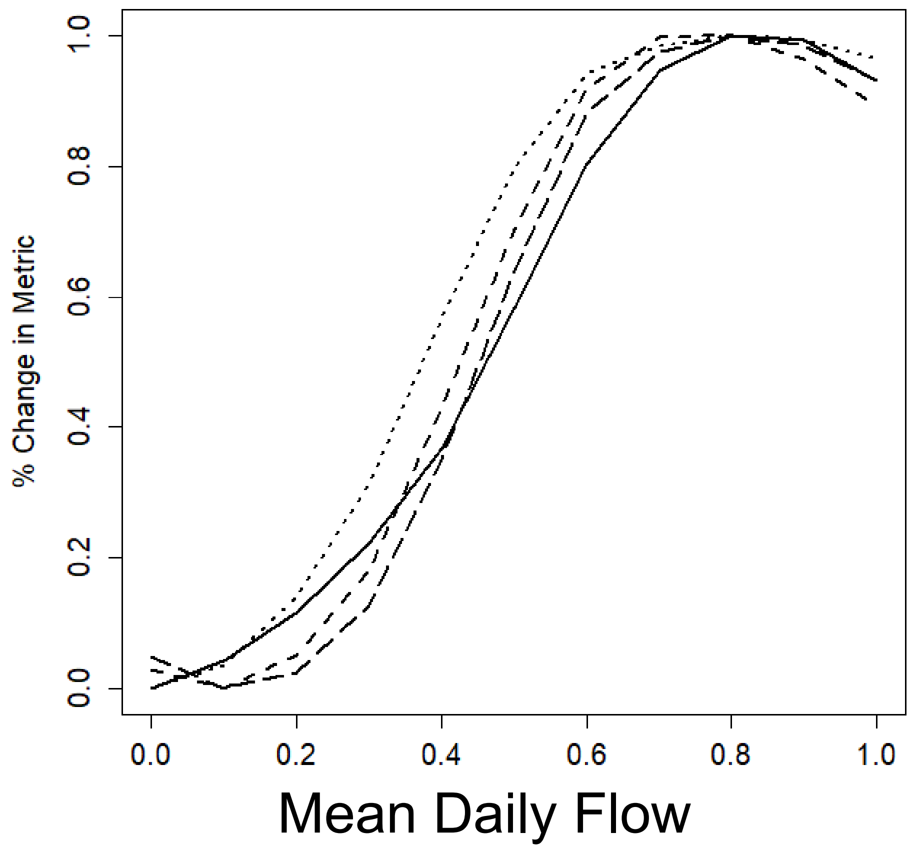
2. All components of the flow regime are important

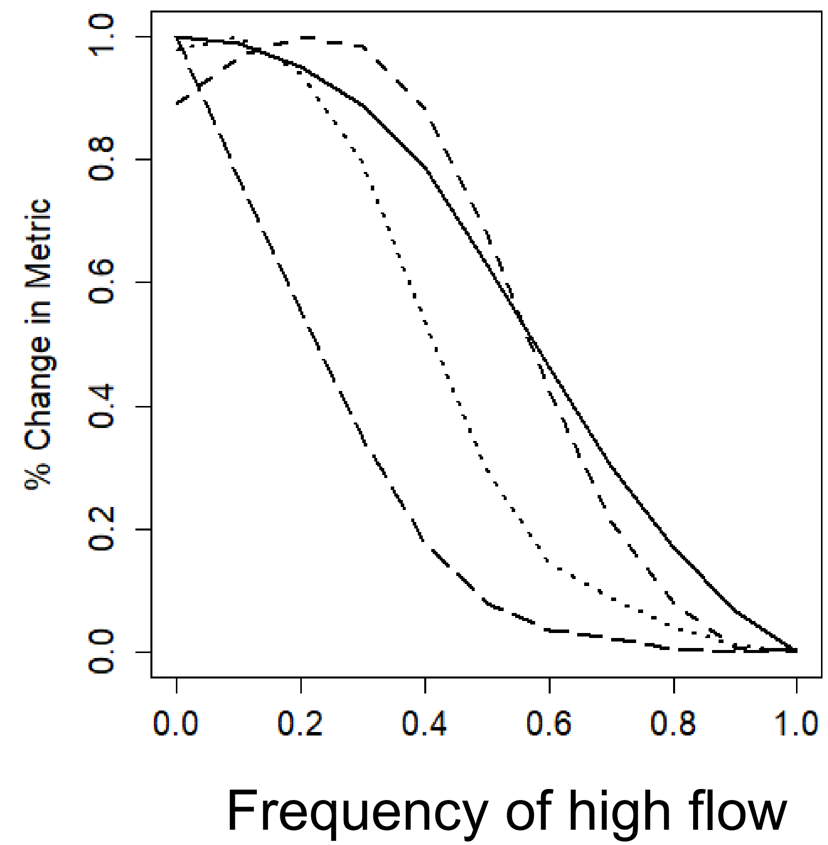
3. These relationships differ between stream classes

   - 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

Broad Basin

1. These relationships differ between stream classes

2. We found many relationship
   – Prioritize metrics by working group

3. All components of the flow regime are important

ID relevant stream classes

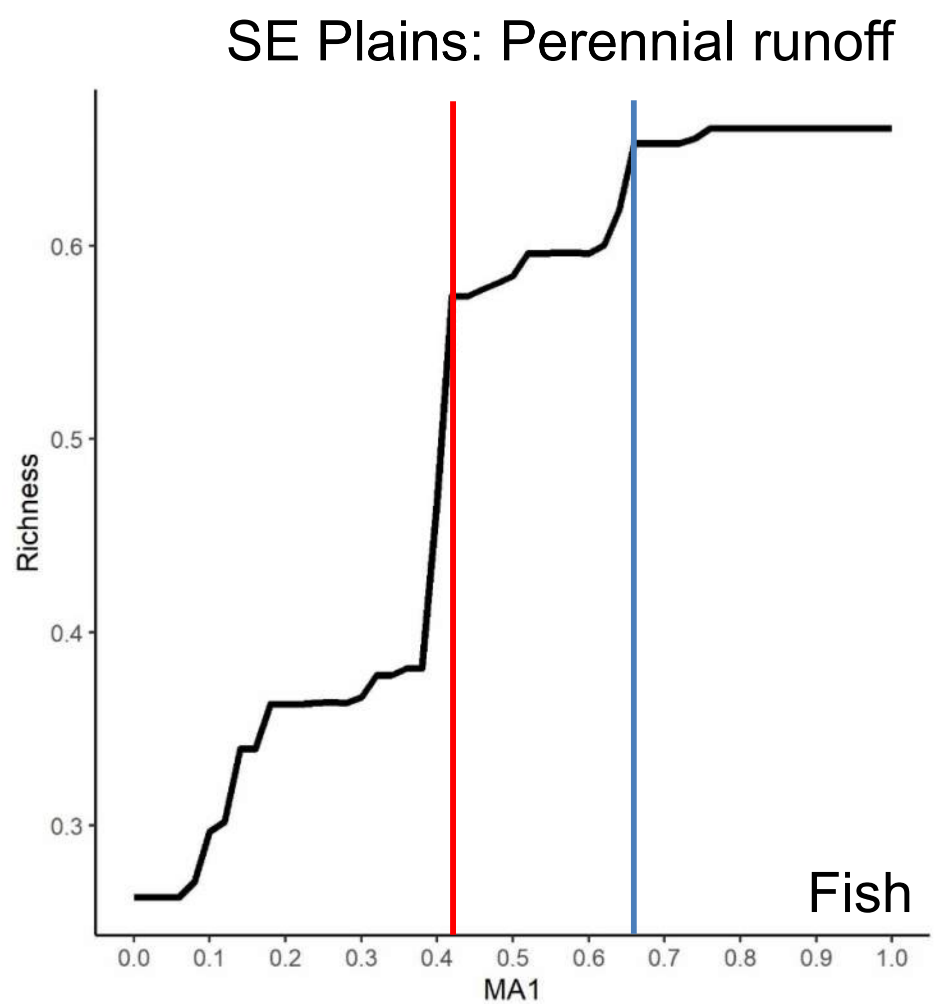
Strongest relationships
and
Flow regime components

Biological and SWAM relevance

How can we use these relationships?

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

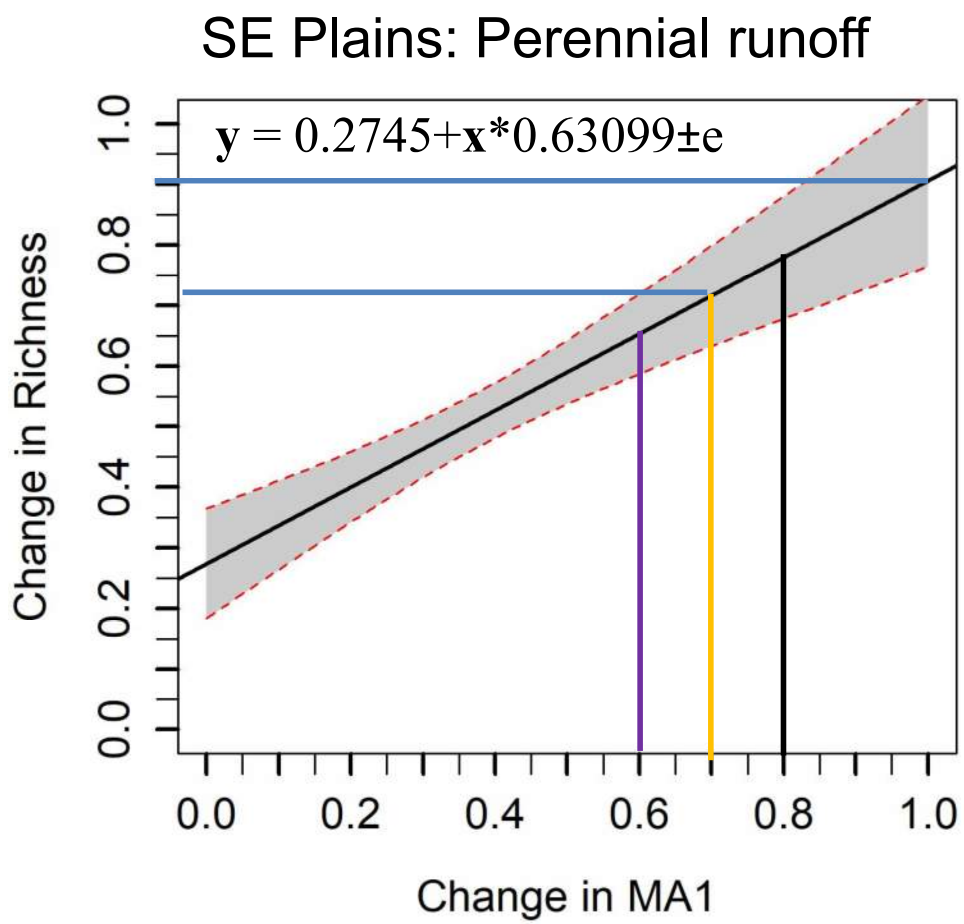
Mean daily flow (MA1): biological response limits

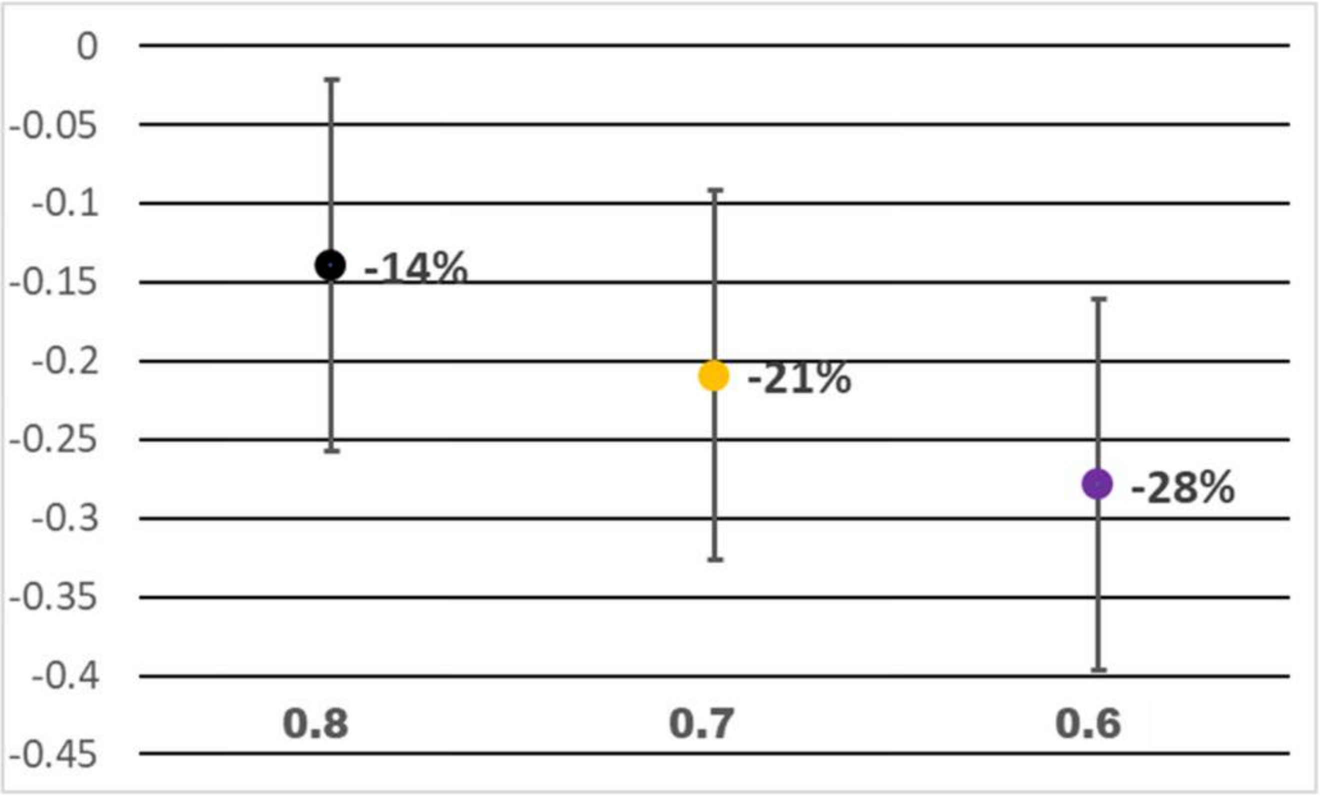


How can we use these relationships?

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

Mean daily flow (MA1): predictions

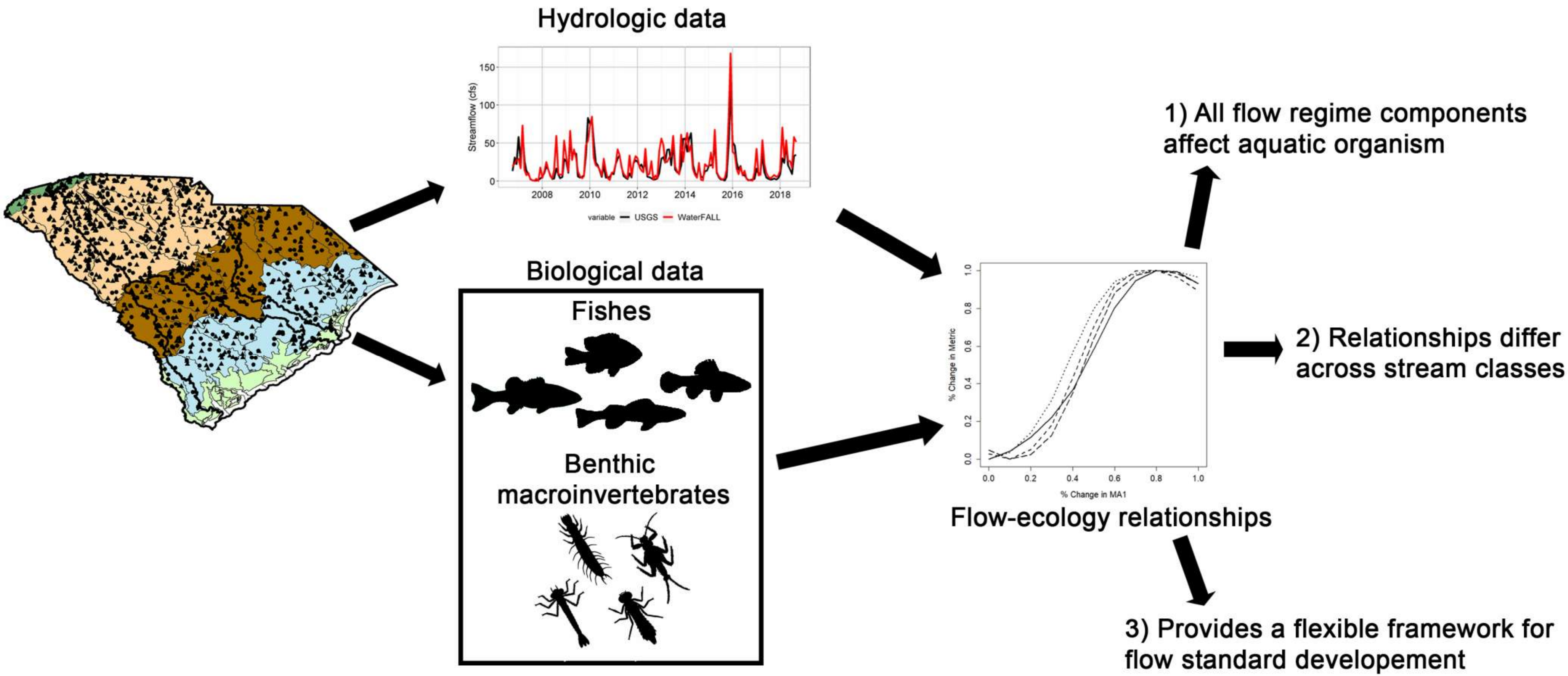


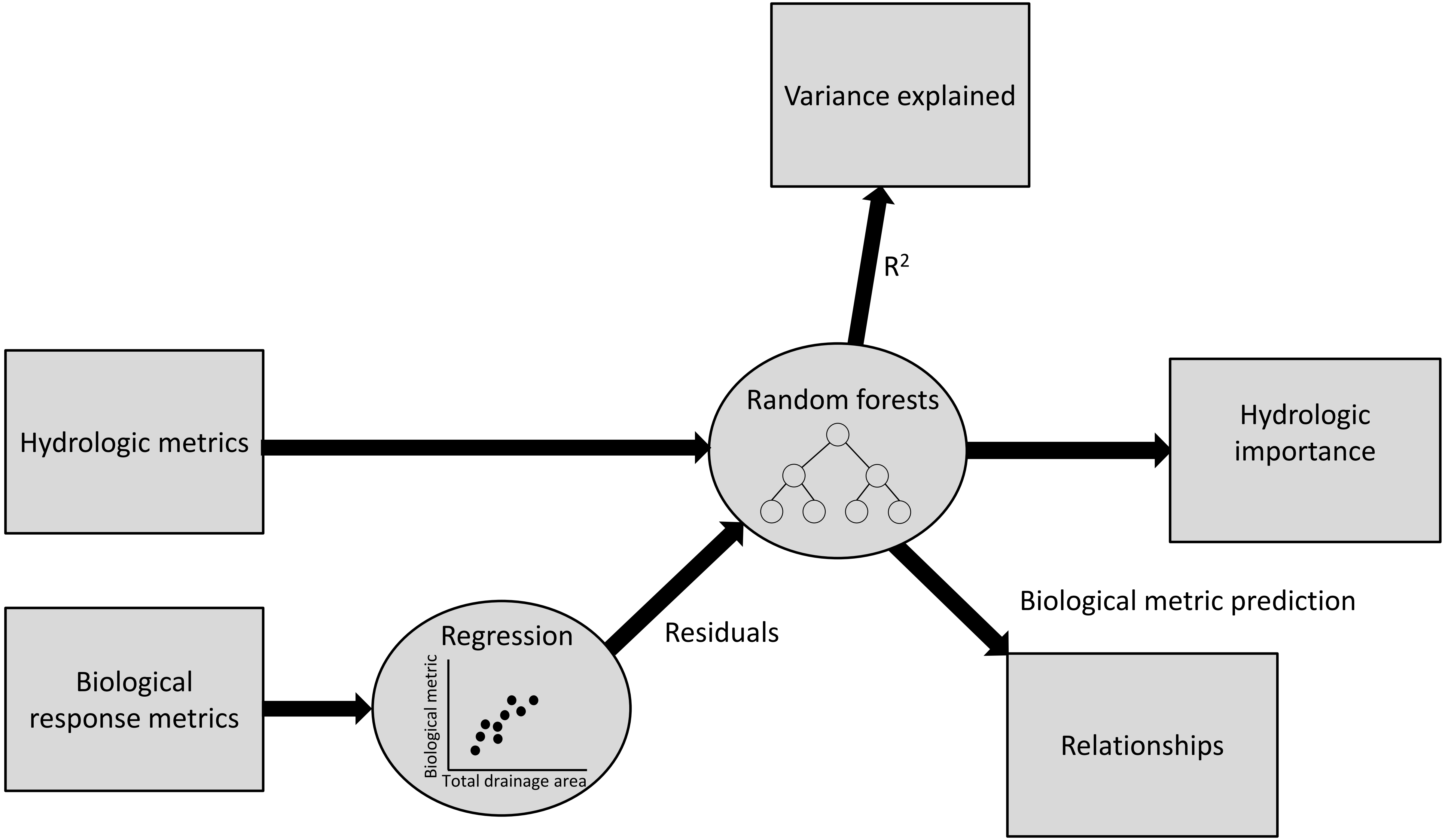


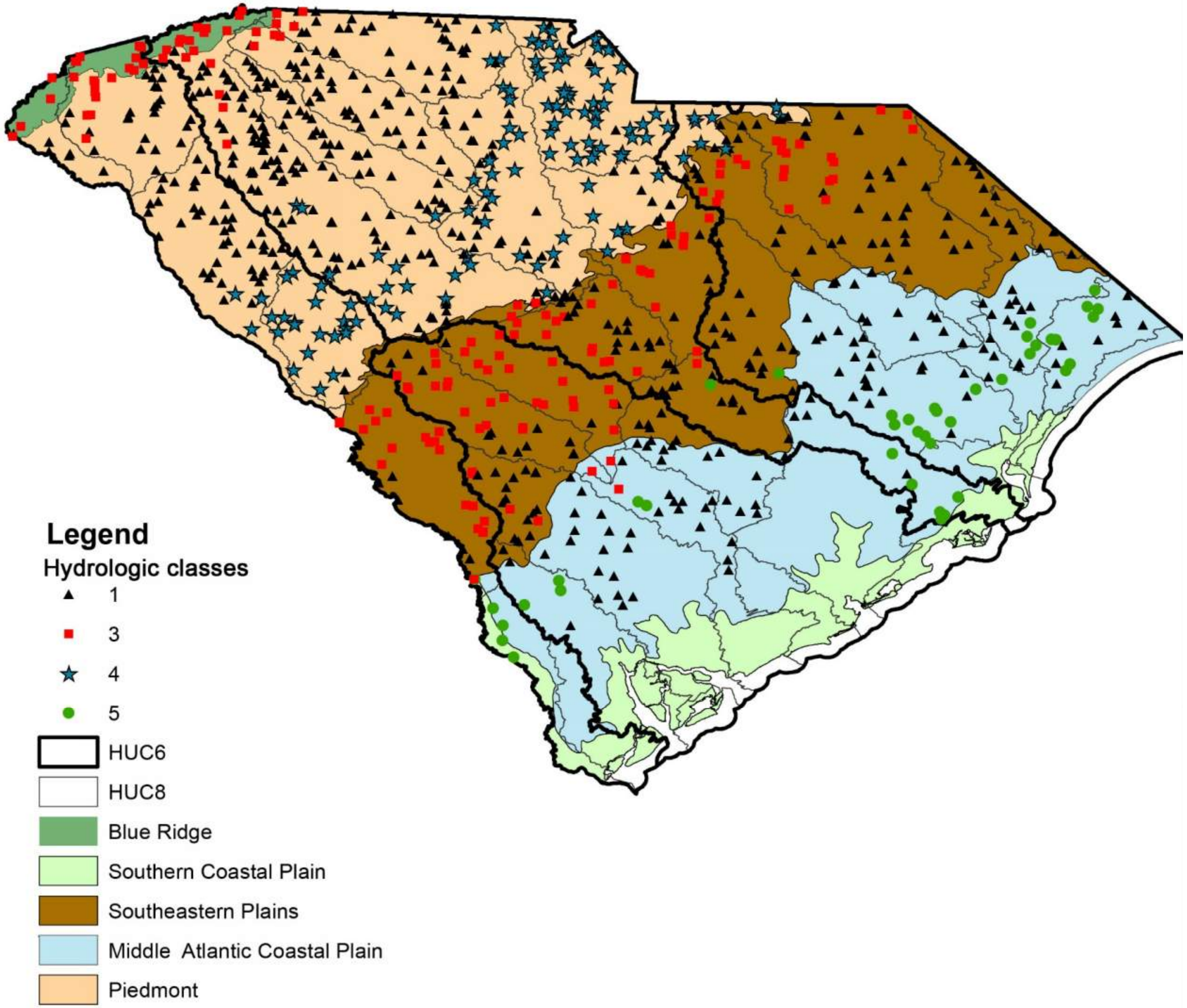
Summary

- Developed a flexible framework
  - Accounts for spatial variation
  - Impact on fishes and aquatic insects
  - Counts for all components of the flow regime (Timing, magnitude, frequency, rate of change, and duration)
  - Can be applied across SC and locally
- Inform the discussion on flow standards
  - Flexibility in use and water modeling approaches


Thank you!
Questions?


Hydrologic data
Streamflow (cfs)
150
100
50
0
2008
2010
2012
2014
2016
2018
variable USGS WaterFALL
Biological data
Fishes
Benthic macroinvertebrates
% Change in Metric
0.0
0.2
0.4
0.6
0.8
1.0
% Change in MA1
Flow-ecology relationships
1) All flow regime components affect aquatic organism
2) Relationships differ across stream classes
3) Provides a flexible framework for flow standard developement


Variance explained
R^2
Hydrologic metrics
Random forests
Hydrologic importance
Biological response metrics
Regression
Biological metric
Total drainage area
Residuals
Biological metric prediction
Relationships


Legend
Hydrologic classes
1
3
4
5
HUC6
HUC8
Blue Ridge
Southern Coastal Plain
Southeastern Plains
Middle Atlantic Coastal Plain
Piedmont