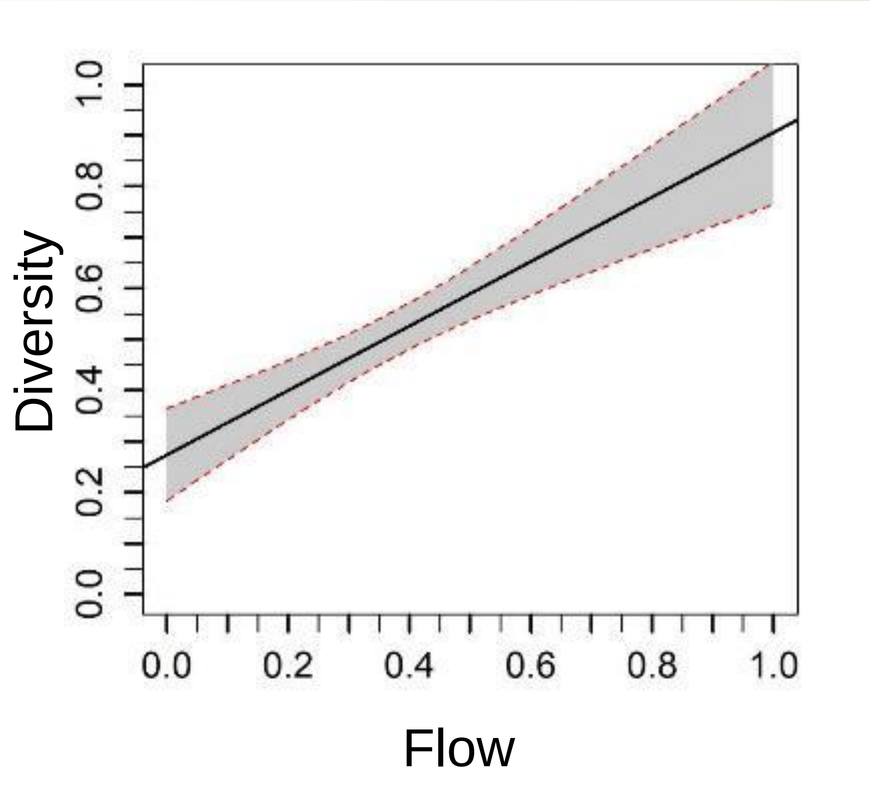
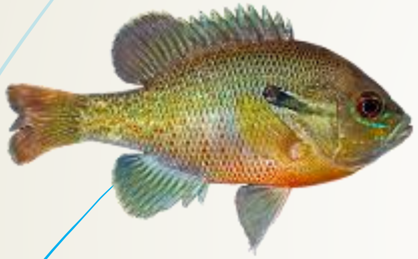
Objective

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



Frame Work

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



Build a hydrologic foundation of streamflow 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

1. Build a hydrologic foundation of streamflow data

- Matching data
- 171 flow metrics for each stream segment
  - 24 metrics minimally redundant and ecologically relevant
  - Timing, magnitude, frequency, rate of change, and duration

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

Frame Work

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

1. Build a hydrologic foundation of streamflow data

Classify natural river types

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

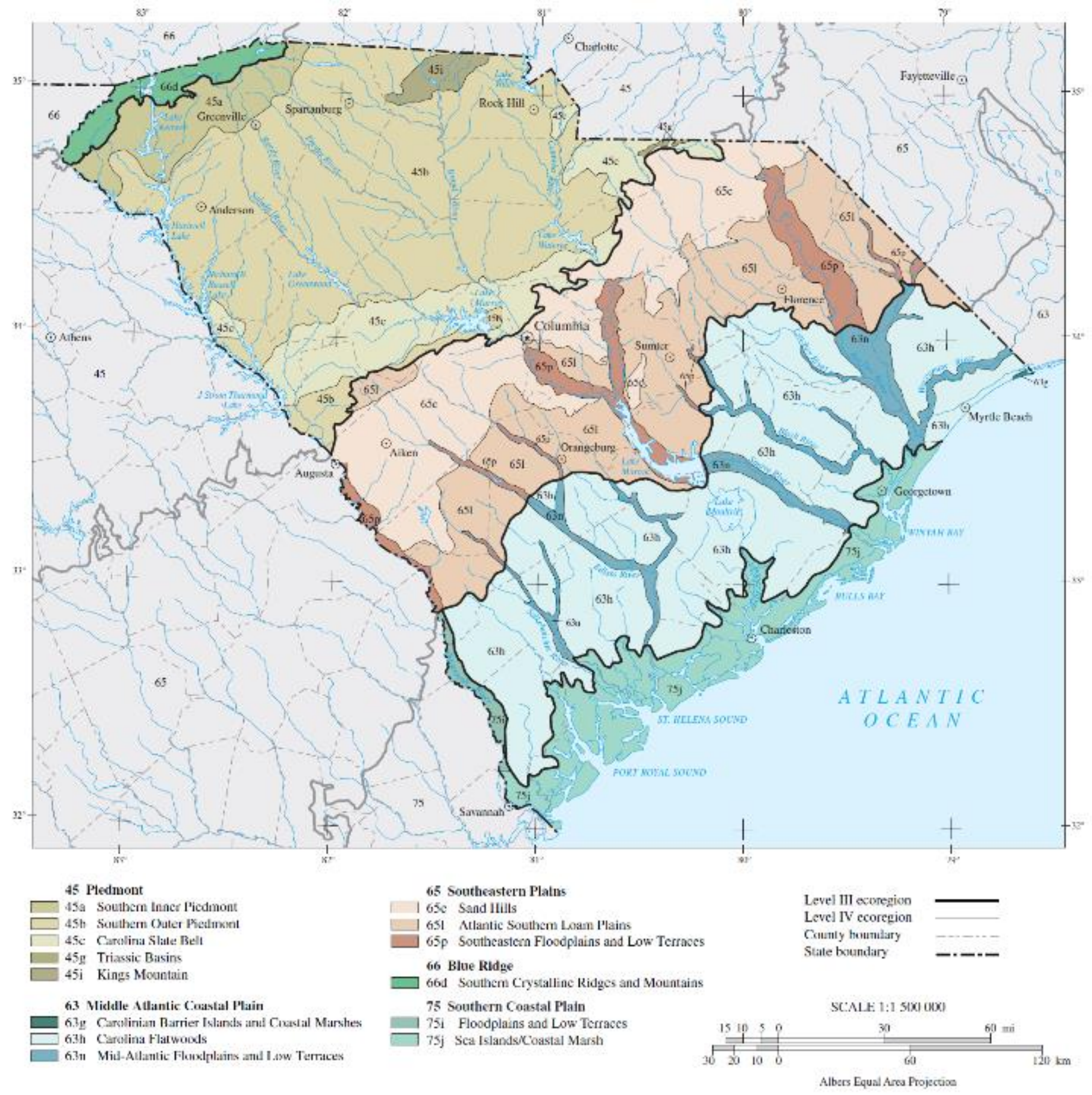
4. Recommend water flow standards to achieve river condition goals

2. Classify natural river types

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

B. Relationship holds for these un-sampled streams

C. Guide future monitoring and management efforts



Ecoregions

- Organisms differ among ecoregions
- Piedmont
- Southeastern Plains
- Middle Atlantic Plains

Frame Work

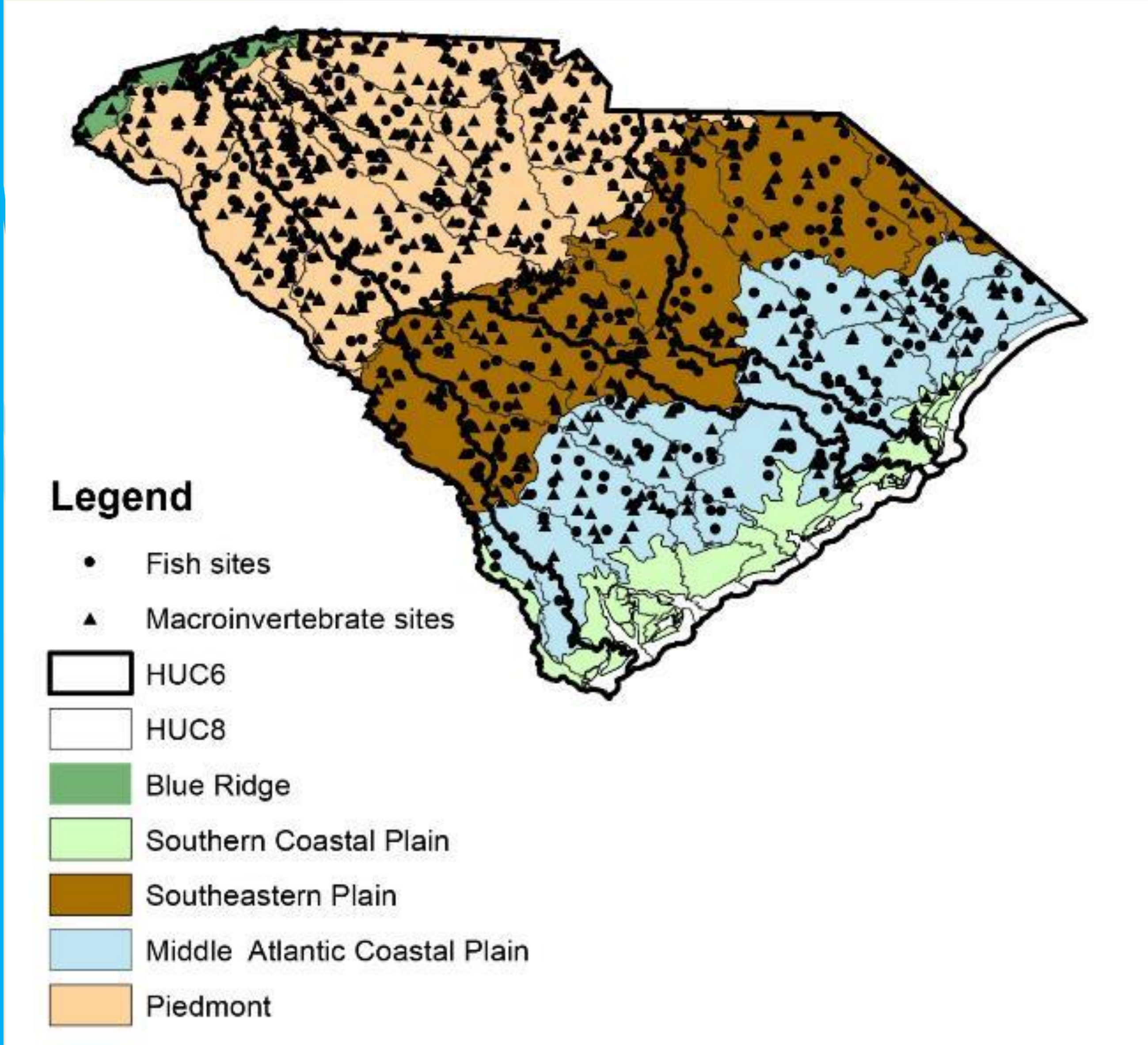
- The ecological limits of hydrologic alteration (ELOHA). Poff et al., 2010

1. Build a hydrologic foundation of streamflow data

2. Classify natural river types

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**
- **Shannon's** diversity index
- Proportional representation of individuals in the genus ***Lepomis***
- Proportional representation of **tolerant** individuals
- Proportional representation of **lotic** individuals
- Proportional representation of individuals belonging to a **breeding strategy**
  - Open substrate spawning, brood hiding, and nest spawning species

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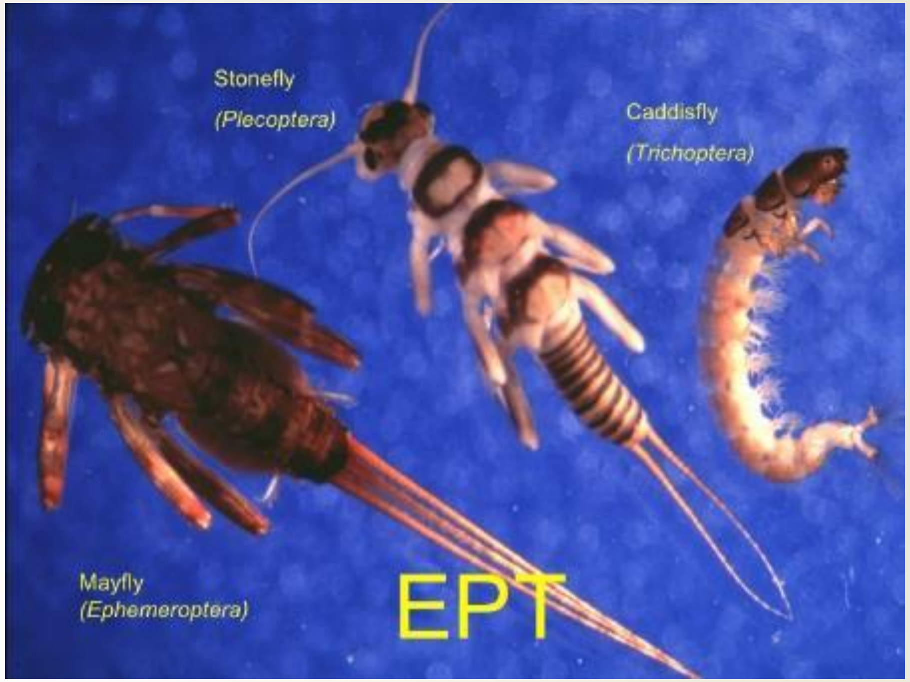
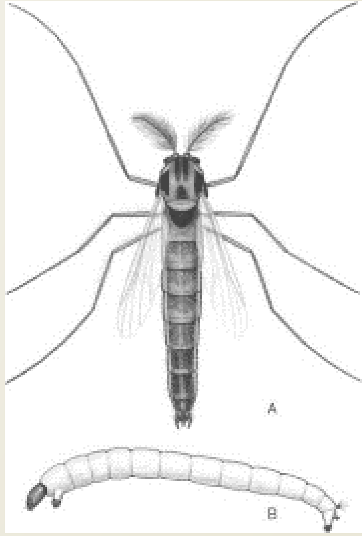
Slideshare.com



Aquatic insects

- **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



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

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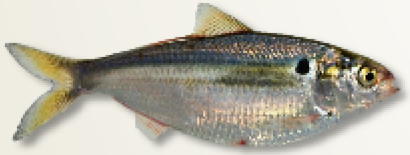
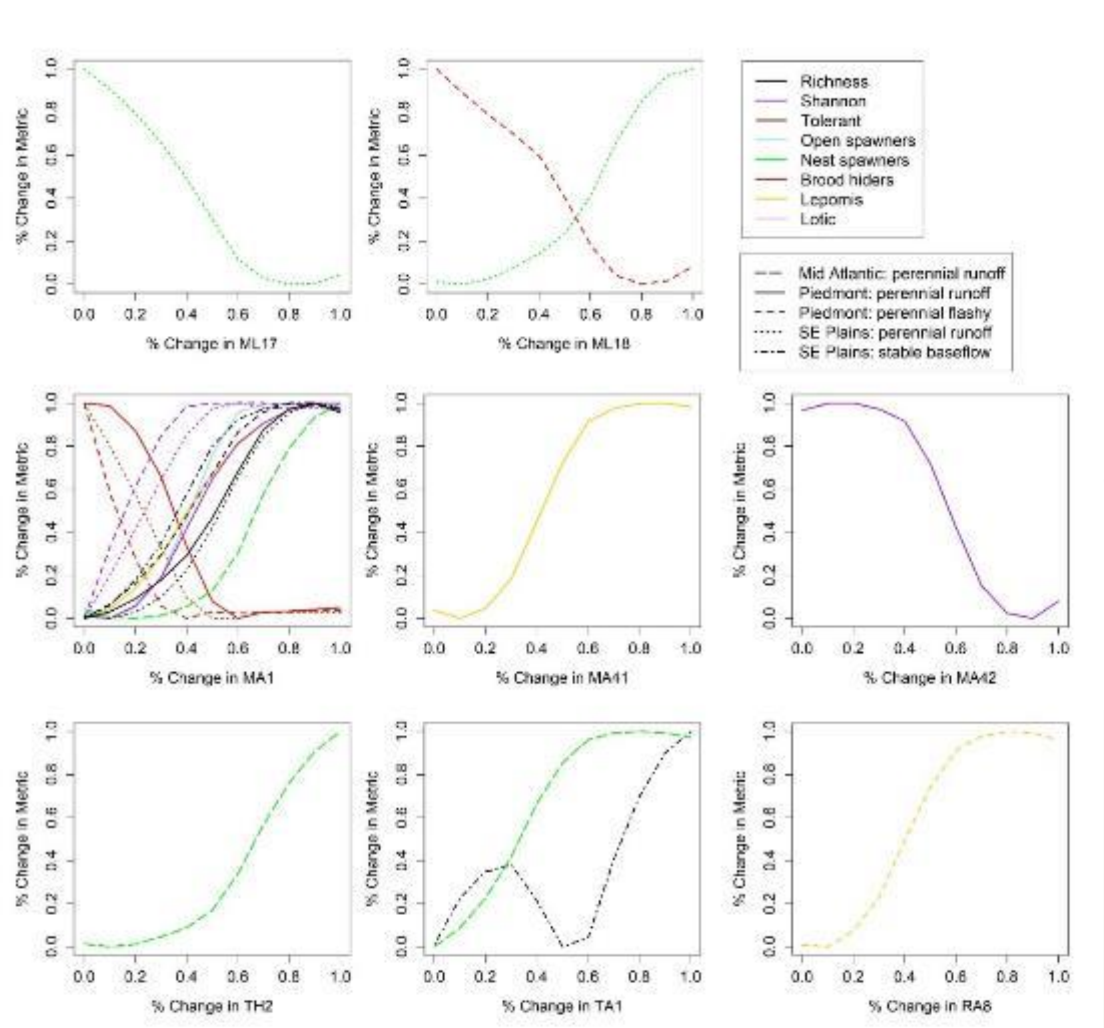
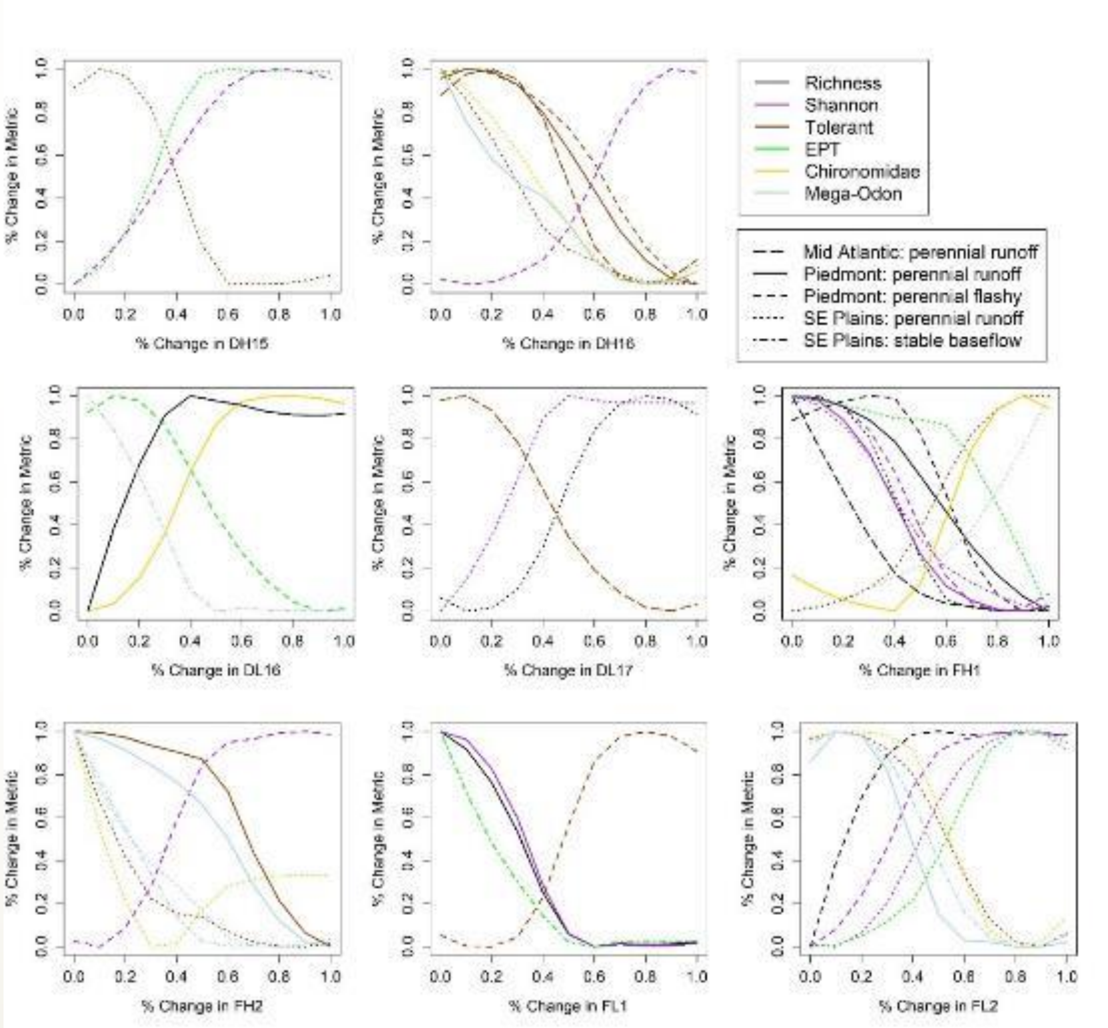


Recommend water flow standards to achieve river condition goals
  - Major finding
  - Focus on results relevant to the Edisto Basin and recommendations

Three major findings

1. We found many relationships

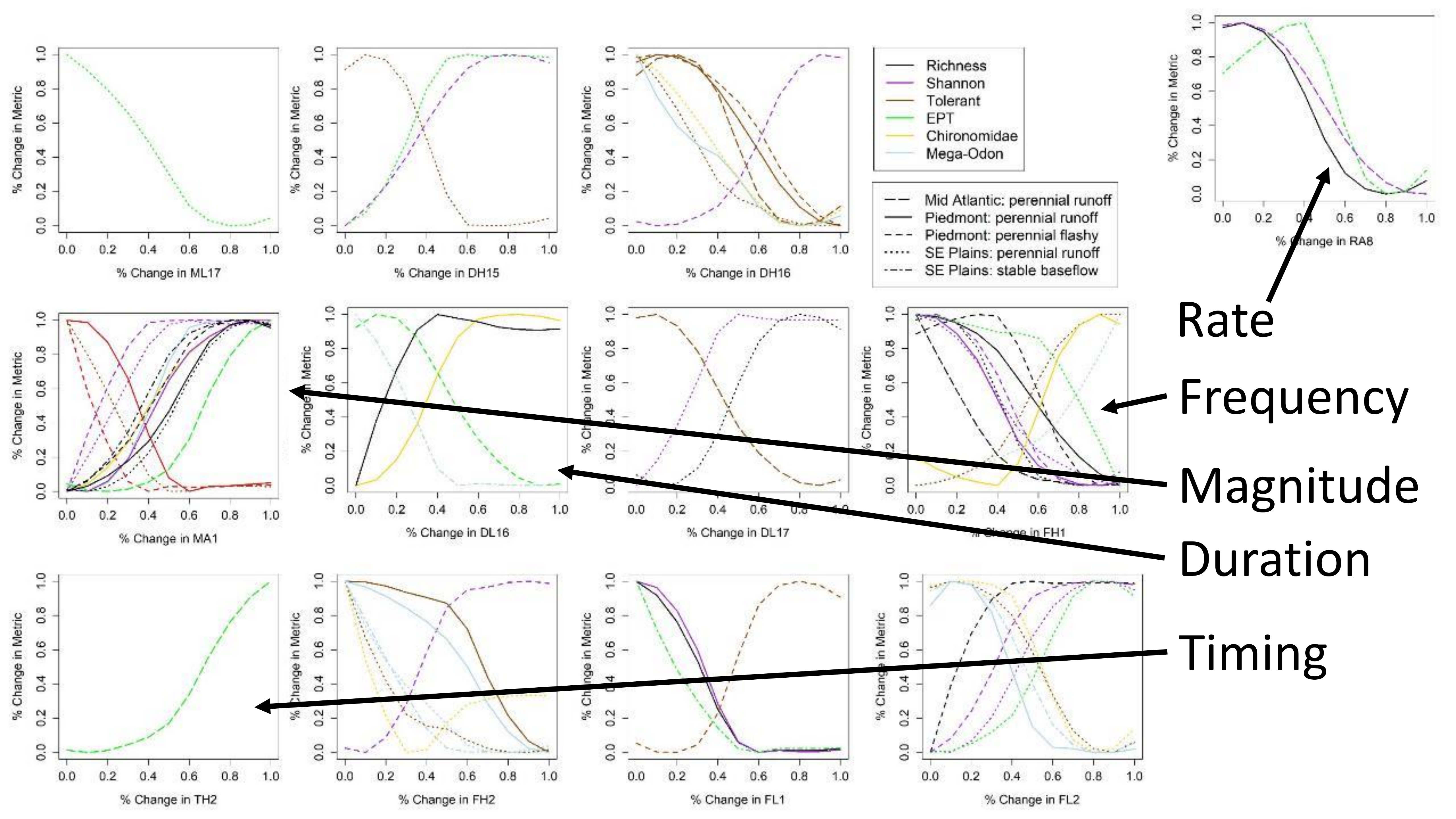




Three major findings

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!



% 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
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
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

- [illegible] (tim[illegible]g of low flow events)
  - [illegible]o habitats
  - [illegible]n of life-cycle cues (spawning, egg hatching, migration) and [illegible]ses in recruitment
  - Invasion o[illegible]

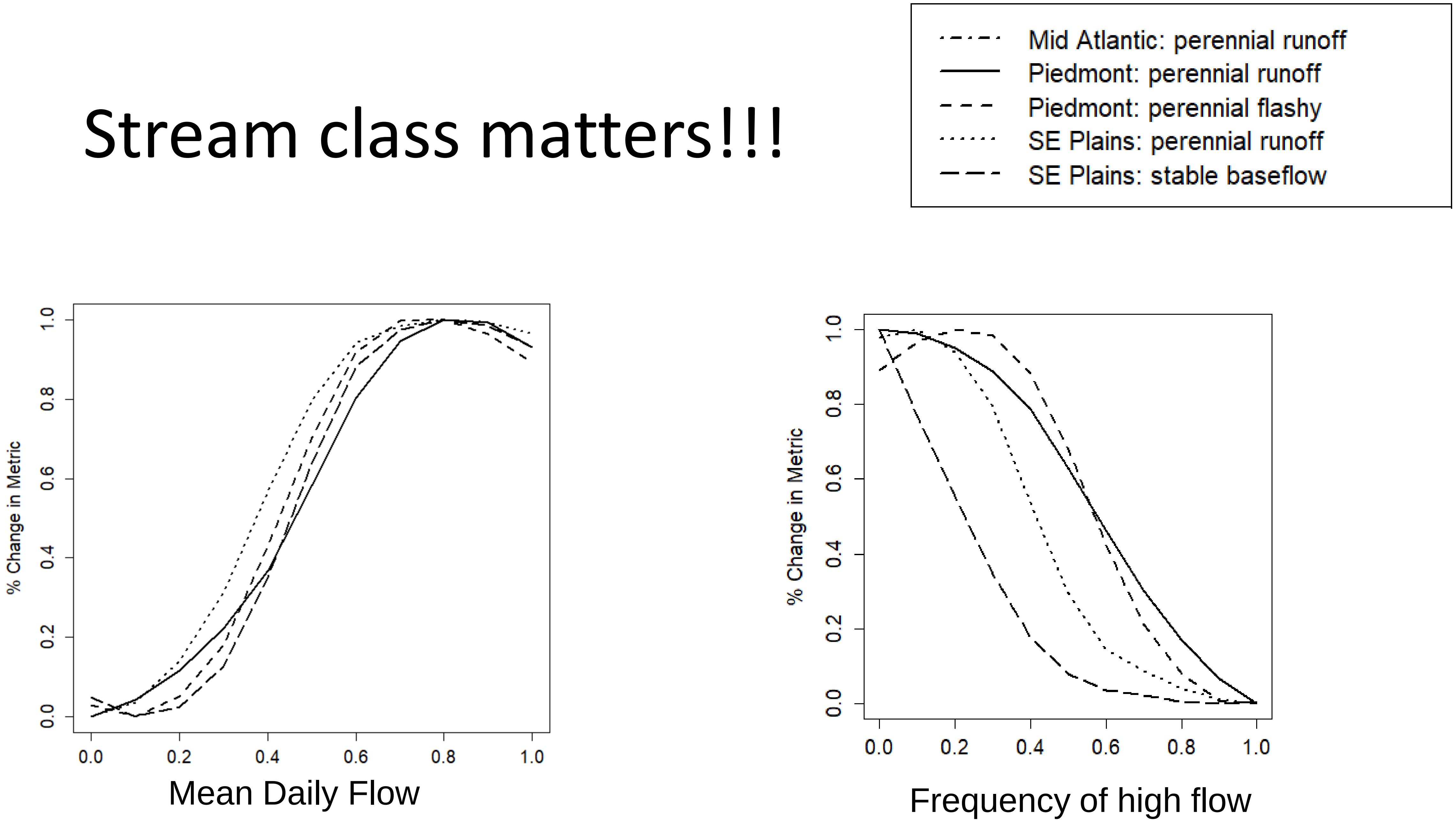
Three major findings

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!!!



Edisto Basin

1. We found many relationship
   – Prioritize metrics

2. These relationships differ between stream classes

3. All components of the flow regime are important

ID relevant stream classes

Strongest relationships
and
Flow regime components

Biological and SWAM relevance

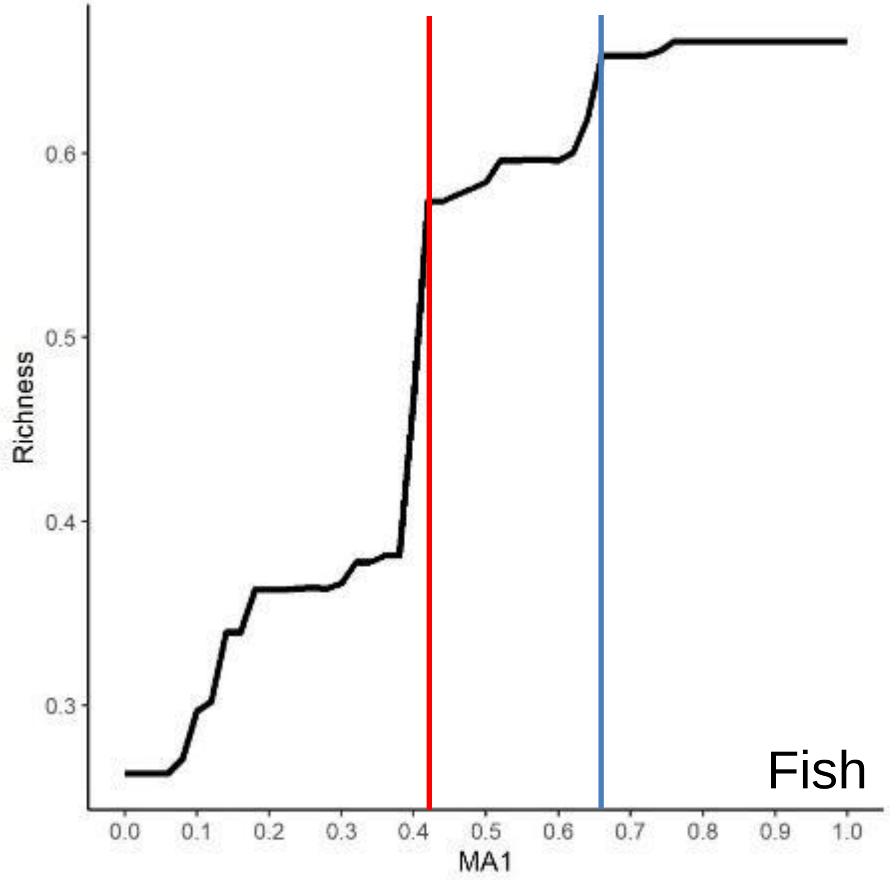
How can we use these relationships?

- Defining biological response limits
  - zones low, medium, and high change in the biological condition of streams along flow gradients
  - Searching for area 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?

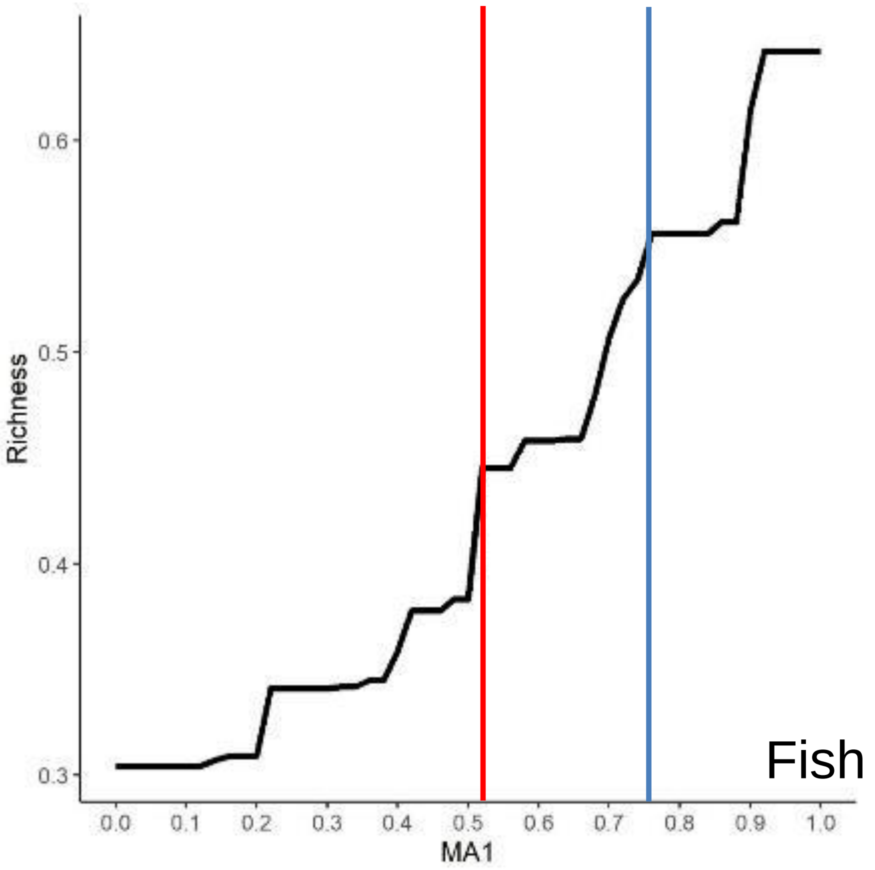
Mean daily flow (MA1): biological response limits

- Reductions in MA1 would negatively impact the number of species

SE Plains: Perennial runoff



SE Plains: Stable baseflow

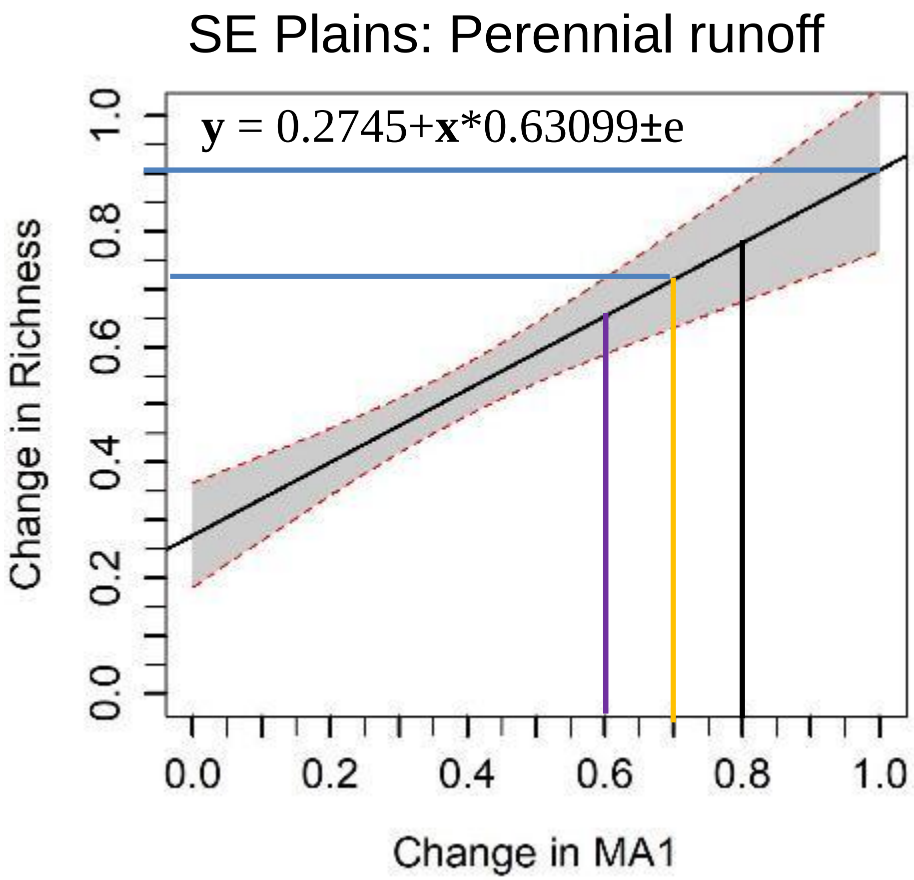


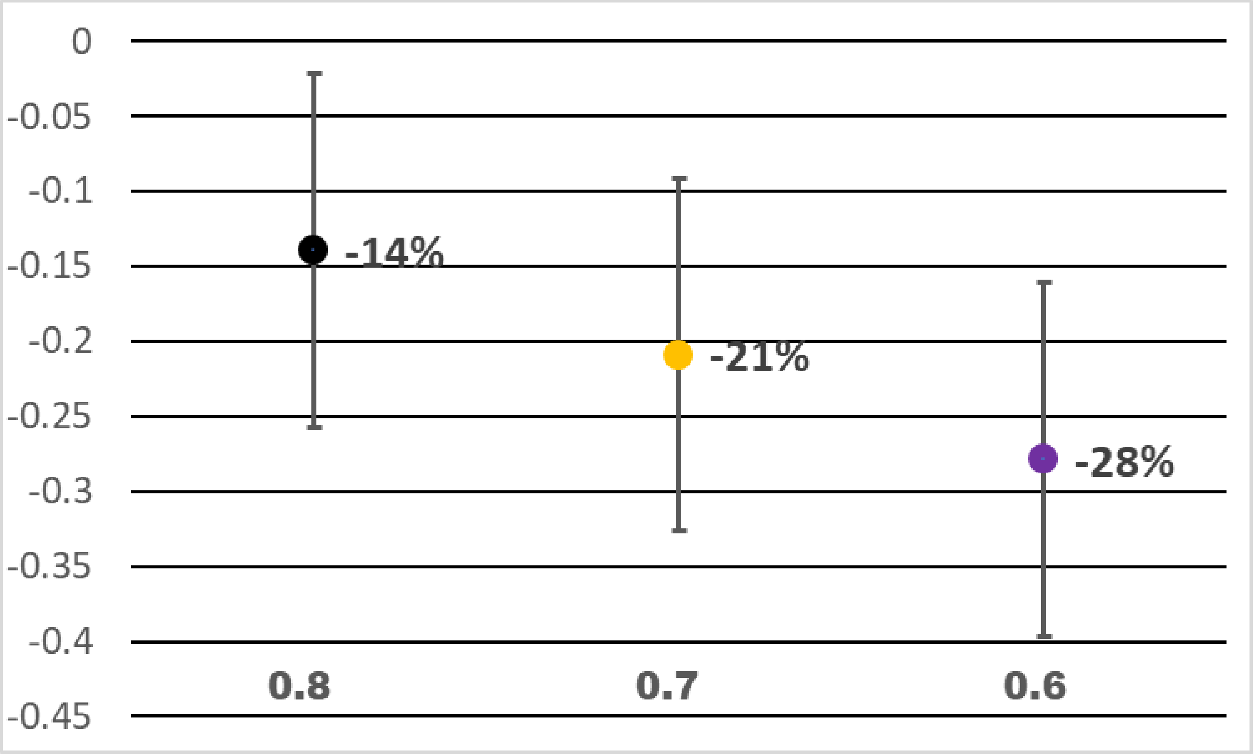
How can we use these relationships?

- 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

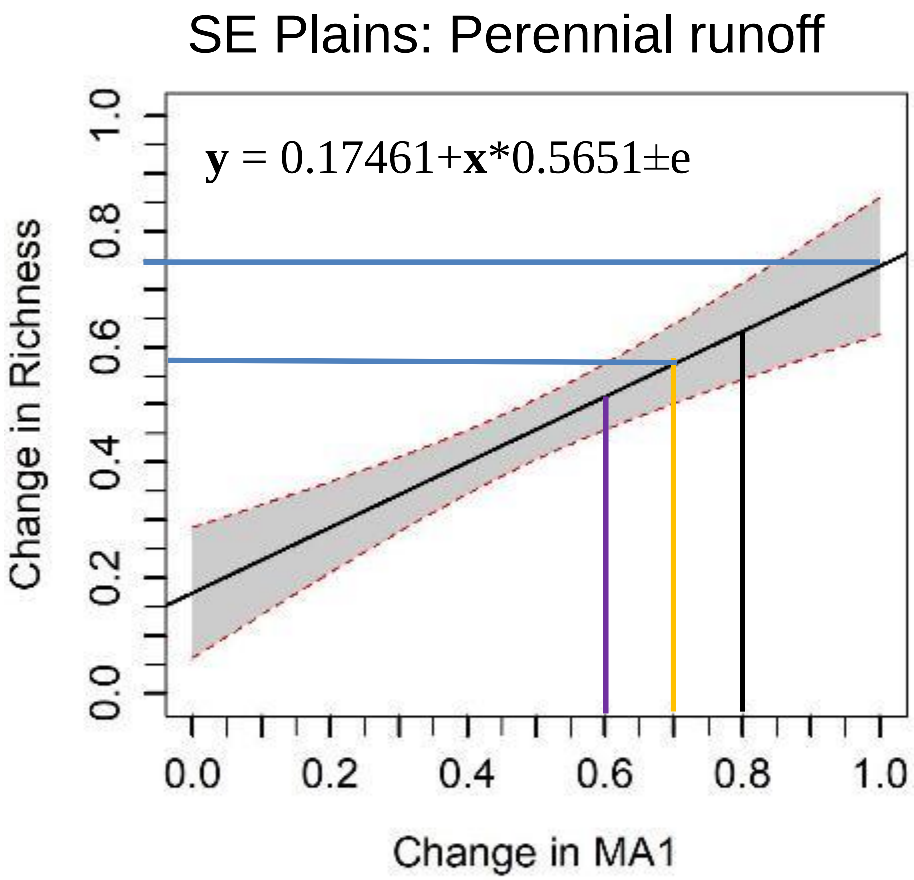
- Predicting responses
  - If we alter flow by X amount what will be the biological response?

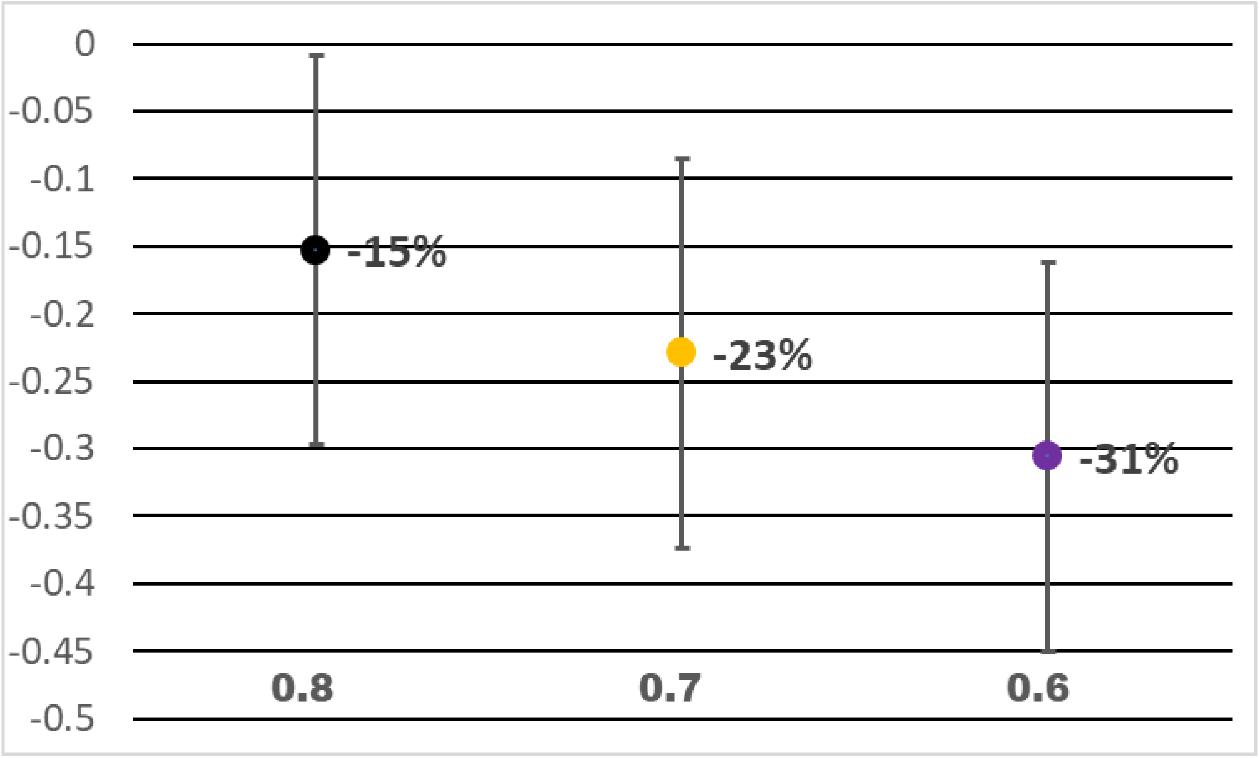
Mean daily flow (MA1): predictions





Mean daily flow (MA1): predictions

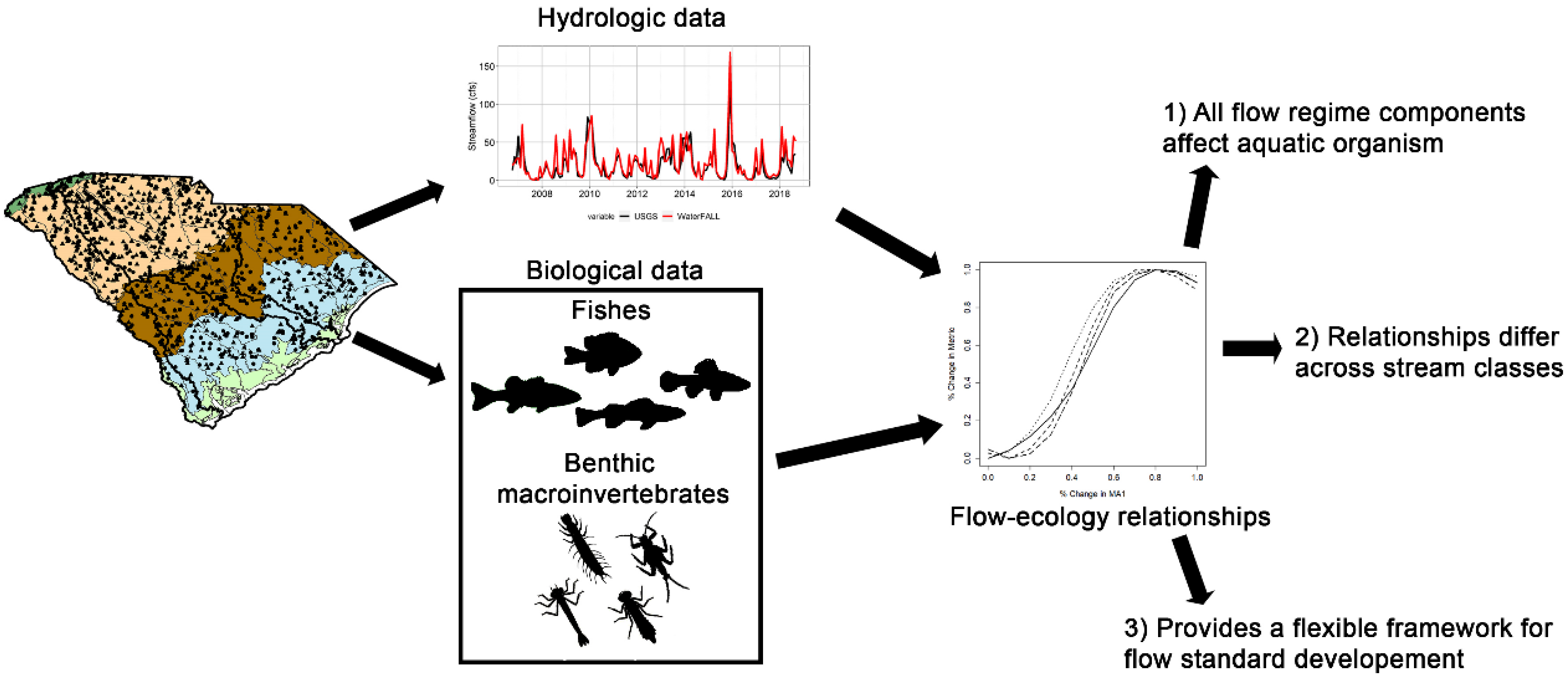




Summary

- 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



Hydrologic data
Streamflow (cfs)
2008
2010
2012
2014
2016
2018
variable USGS WaterFALL
Biological data
Fishes
Benthic macroinvertebrates
% Change in Metric
% 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

Proposal

- Incorporate 4 flow-ecology metrics as performance measures of Edisto River water use scenarios. They are:
  - Mean Daily Flow (MA1)
  - Base Flow Index (ML17)
  - Duration of Low Flow (DL16)
  - Timing of Low Flow (TL1)

- These were chosen based on:
  - Relevance to water withdrawal and drought management
  - Strength of relationship
  - Distribution: All stream classes and basin area represented
  - Readily calculable in SWAM

Proposal

- **Why?** This enables you to evaluate the actual impact on the basin's health *and* compare multiple scenarios quickly

- **How** to use them? There are multiple possibilities. We recommend:
  - Evaluate the performance of water use scenarios on stream and river health
    - Strategic nodes, stream reaches of interest, and selected tributaries.
  - Use them in a risk management context: high, medium, low risk (we have an example)

Proposal: Low-Med-High Risk Ranges

	Instream Flow Performance Recommendations and Risk Ranges								
Stream Type:	**Southeastern Plains 1 (SE1)**			**Southeastern Plains 3 (SE3)**			**Mid-Atlantic 1 (M-A-1)**		
	Risk Ranges								
	Low	**Med**	**High**	**Low**	**Med**	**High**	**Low**	**Med**	**High**
Flow Metric									
Mean Daily Flow (FR)	>0.66	0.42-0.66	<0.42	>0.75	0.52-0.75	<0.52			
Base Flow (MR)							>0.68	0.25-0.68	<0.25
Base Flow (MT)							>0.60	0.36-0.60	<0.36
Low Flow Duration (FR)				<0.13	0.13-0.40	>0.40			
Low Flow Duration (FT)							<0.20	0.20-0.60	>0.60
Calendar Day of Lowest Flow (MO)				>280	262-280	<262			
Calendar Day of Lowest Flow (FT)							>250	232-250	<232

Proposal: Mock SWAM Output with Measures

Hydrology:												
	EDO03 SOUTH FORK EDISTO RIVER NR MONTMORE NCI, S. C. Flow (CFS)	**EDO14 SOUTH FORK EDISTO RIVER ABOVE SPRINGFIELD, SC Flow (CFS)**	**HUC402 Outlet Flow (CFS)**	**EDO05 SOUTH FORK EDISTO RIVER NEAR DENMARK, SC Flow (CFS)**	**EDO06 SOUTH FORK EDISTO RIVER NEAR COPE, SC Flow (CFS)**	**EDO07 SOUTH FORK EDISTO RIVER NEAR BAMBERG, SC Flow (CFS)**	**EDO11 EDISTO RIVER NEAR BRANCHVILLE, SC Flow (CFS)**	**HUC601 Outlet Flow (CFS)**	**EDO13 EDISTO RIVER NR GIVHANS, SC Flow (CFS)**	**EDO01 MCTIER CREEK (RD 209) NEAR MONETTA, SC Flow (CFS)**	**EDO02 MCTIER CREEK NEAR NEW HOLLAND, SC Flow (CFS)**	**Shaw Outlet Flow (CFS)**
mean flow (CFS)	185	367	451	714	774	949	1890	2021	2593	24	49	132
median flow (CFS)	168	329	402	631	654	801	1452	1468	1751	18	37	116
25th percentile flow (CFS)	122	237	276	428	435	472	979	899	994	12	26	83
10th percentile flow (CFS)	95	180	206	317	322	339	725	642	658	8	17	59
5th percentile flow (CFS)	78	145	166	252	256	270	614	521	520	6	13	48
Mean Daily Flow % / Fish richness (MA1)	0.81	0.88	0.71	0.92	0.83	0.92				0.69	0.70	0.78
Base Flow Index / Macroinvertebrate richness (ML17)							0.78	0.51	0.88			
Base Flow Index / Macroinvertebrate tolerance (ML17)							0.88	0.44	0.79			
Low Flow Duration % / Fish richness (DL16)	0.16	0.21	0.11	0.24	0.18	0.12						
Low Flow Duration % / Tolerant fish (DL16)							0.14	0.33	0.13			
Calendar day of lowest flow / MO index (TL1)	291	299	281	291	289	288						
Calendar day of lowest flow / Tolerant fish (TL1)							277	237	269			
Stream Class (SE1, SE3, M-A-1)	SE3	SE3	SE3	SE3	SE3	SE3	M-A-1	M-A-1	M-A-1	SE1	SE1	SE1

Acknowledgements

- **Clemson**:
  - ***Luke Bower***
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  - Lorianne Riggin
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  - David Eargle
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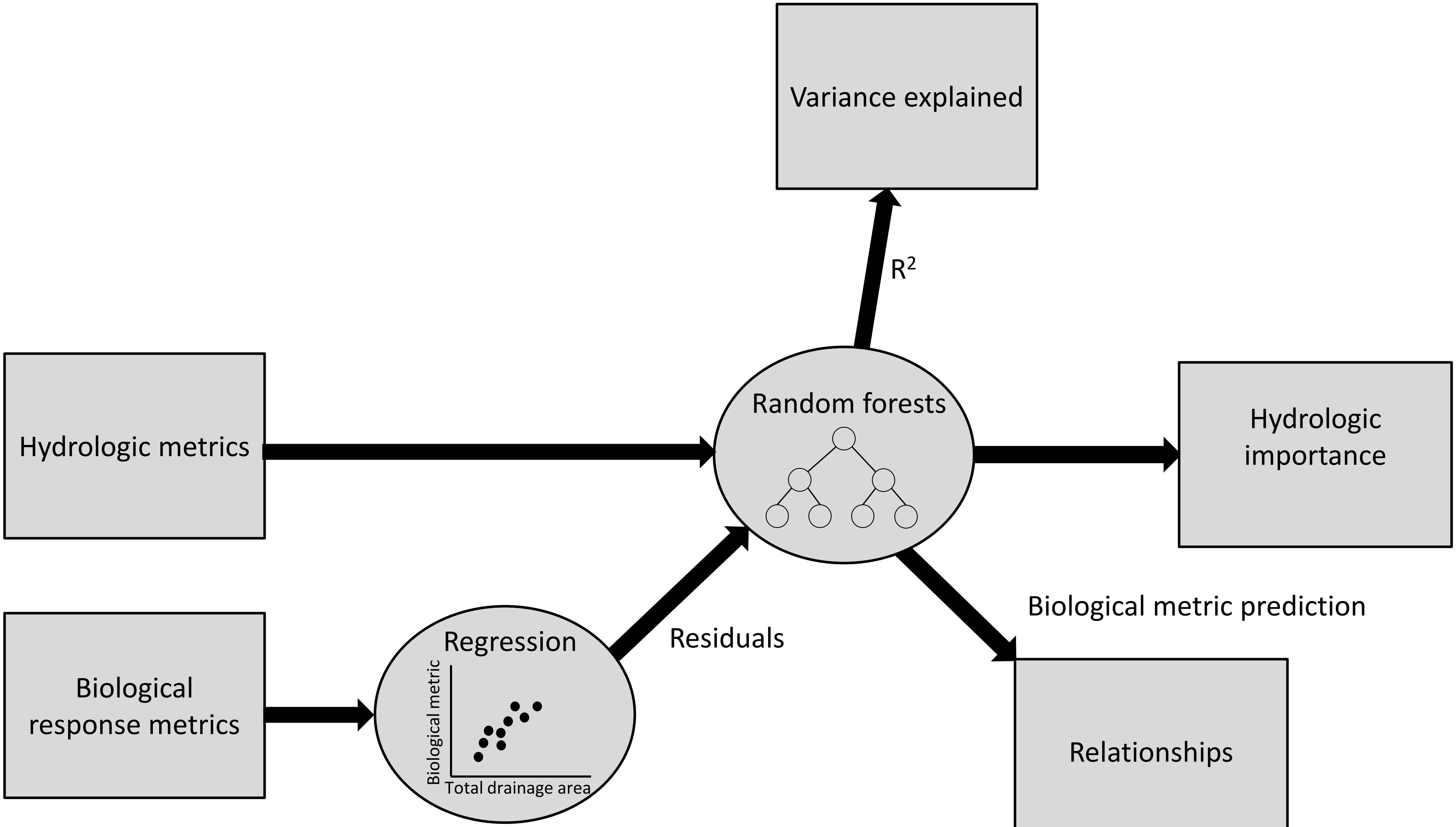
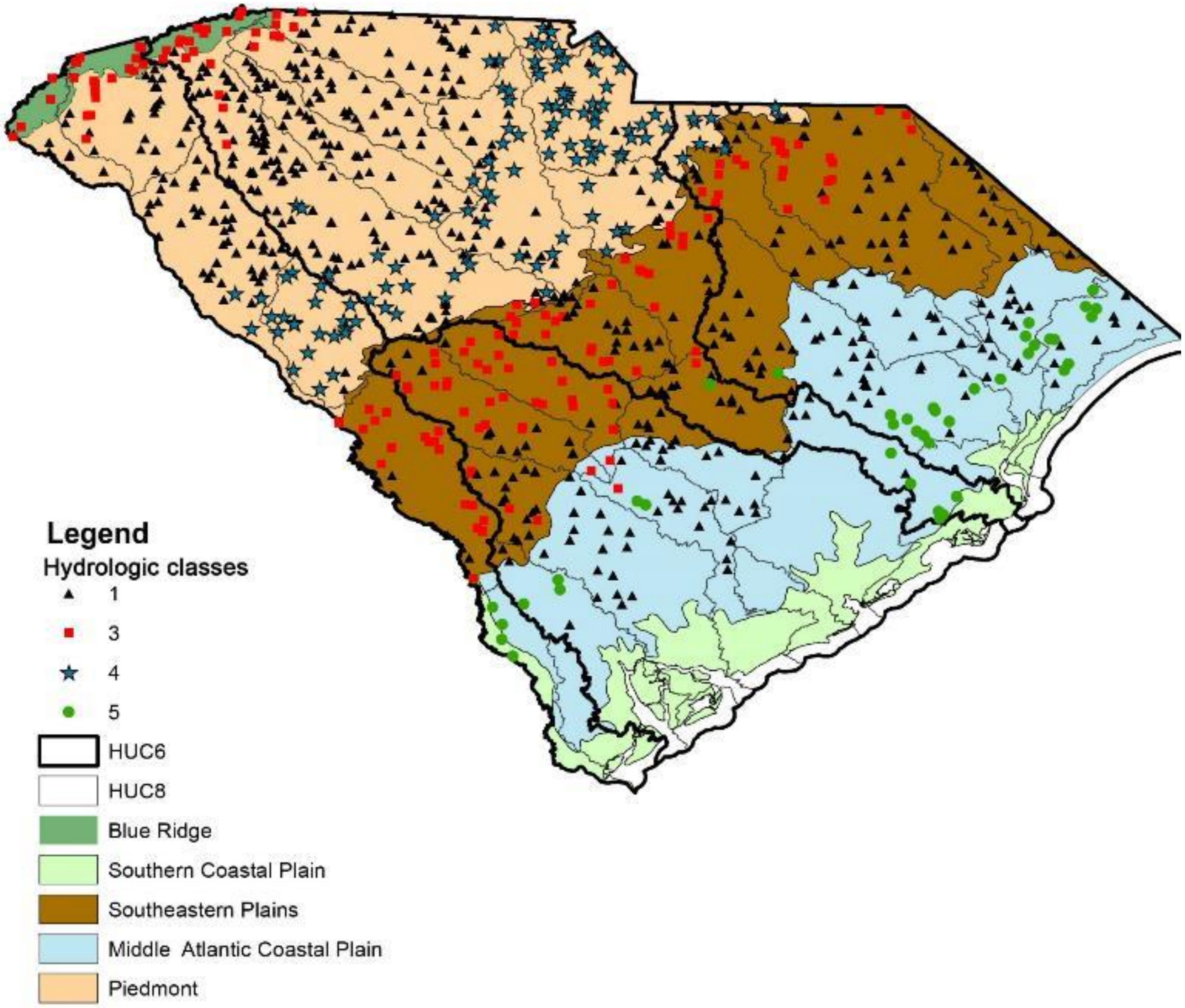
  - Leigh Monroe
  - Heather Preston
- **RTI**:
  - ***Michele Eddy***
  - Benjamin Lord
- **The Nature Conservancy**
  - ***Eric Krueger***
- **Funding**: The Nature Conservancy and South Carolina Water Resources Center

Luke Bower: lmbower@clemson.edu


Thank you!
Questions?

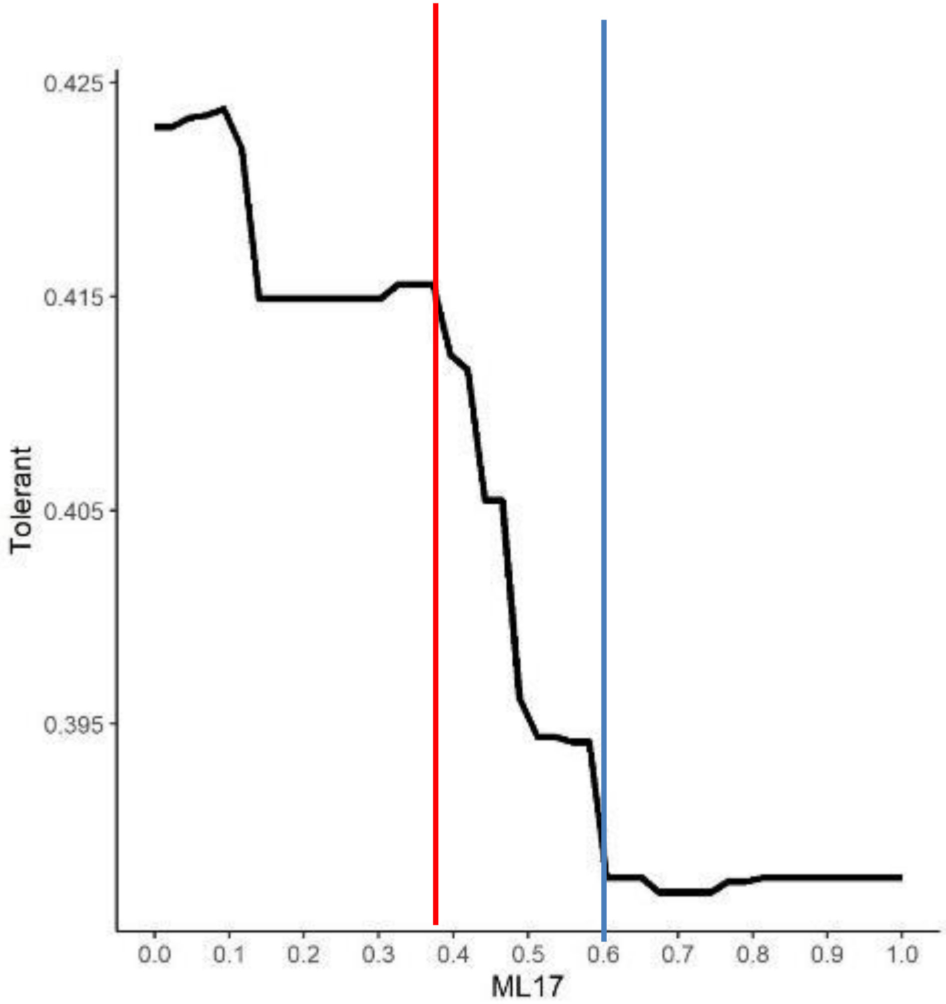


Variance explained
R^2
Hydrologic metrics
Random forests
Hydrologic importance
Biological response metrics
Regression
Biological metric
Total drainage area
Residuals
Biological metric prediction
Relationships

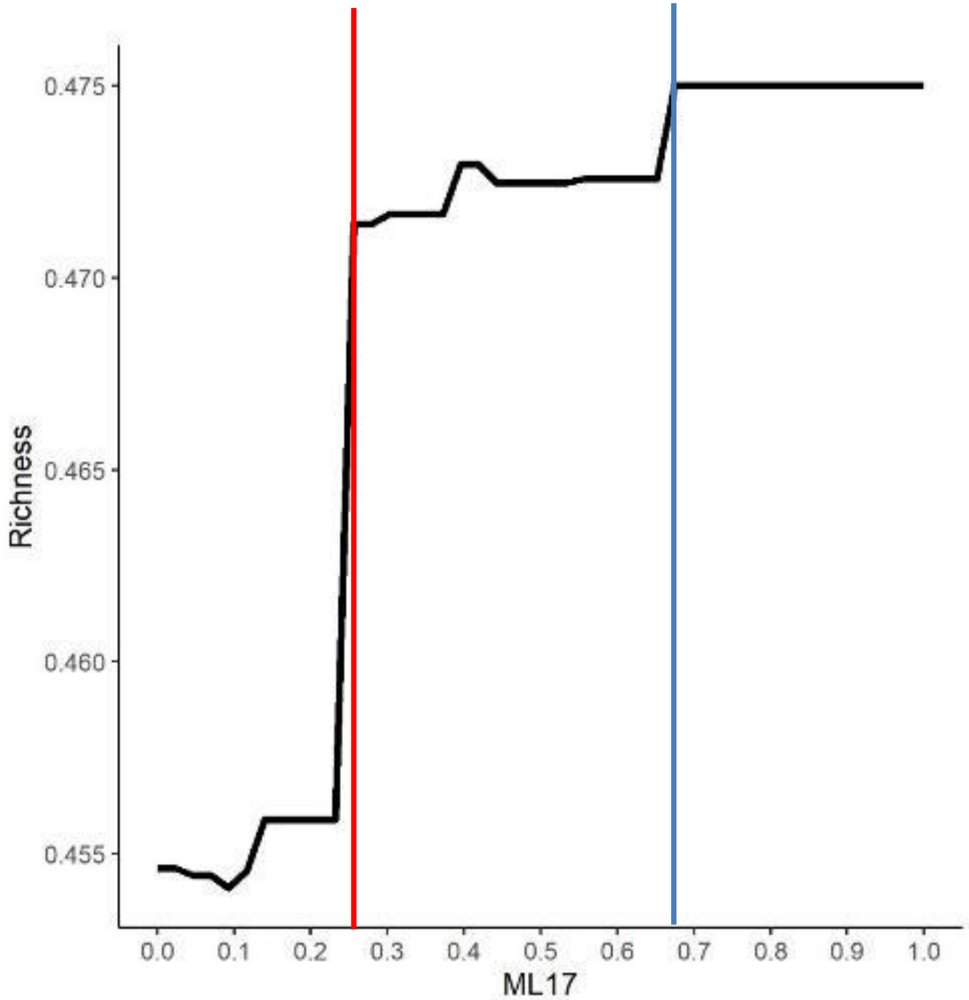

Legend
Hydrologic classes
1
3
4
5
HUC6
HUC8
Blue Ridge
Southern Coastal Plain
Southeastern Plains
Middle Atlantic Coastal Plain
Piedmont

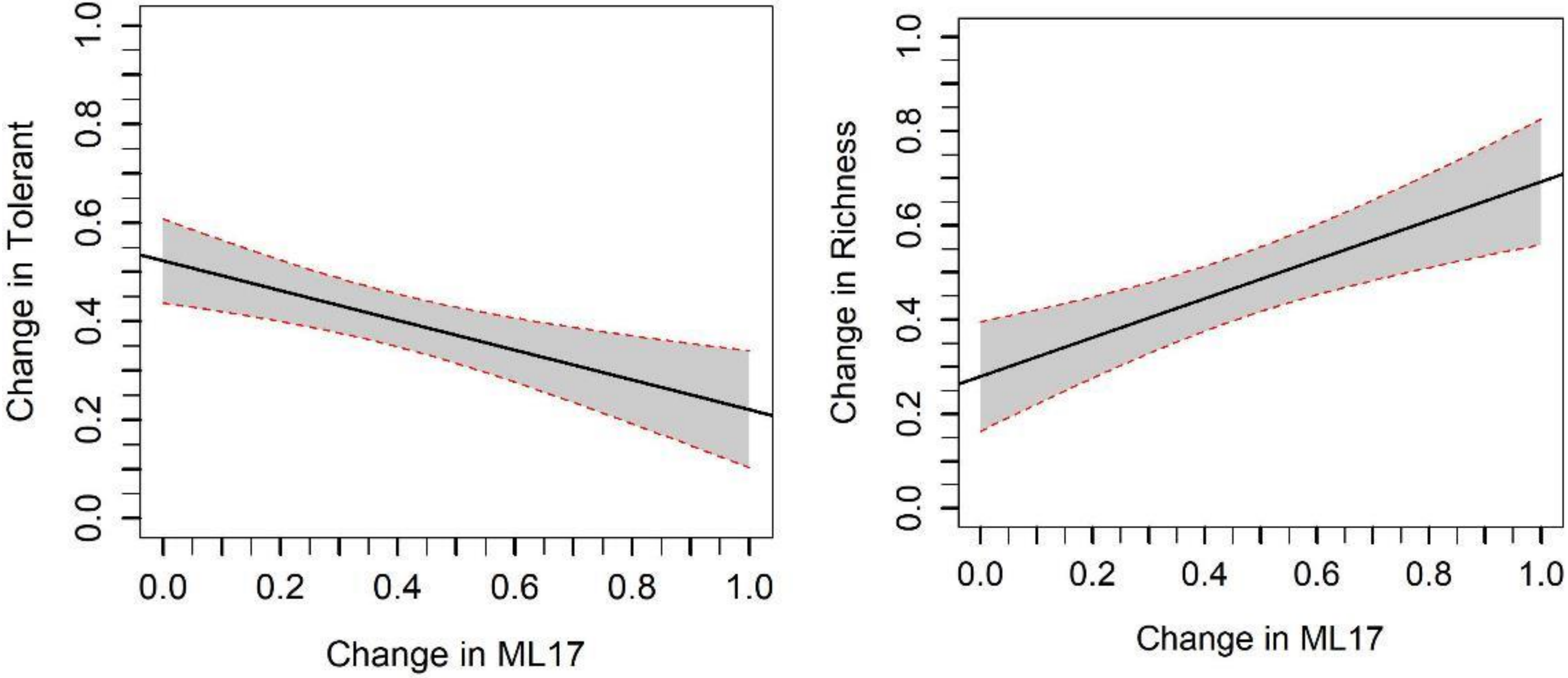
Base flow (ML17)

Mid Atlantic Plains: Perennial runoff



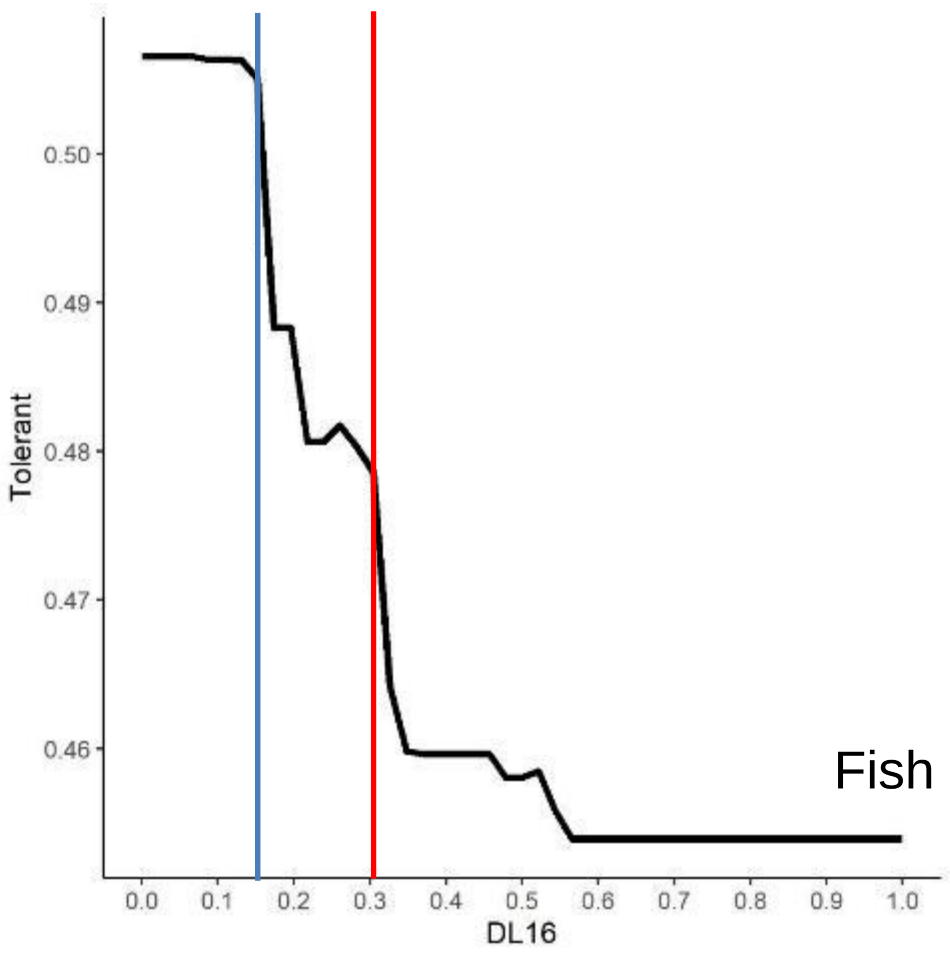
Mid Atlantic Plains: Perennial runoff



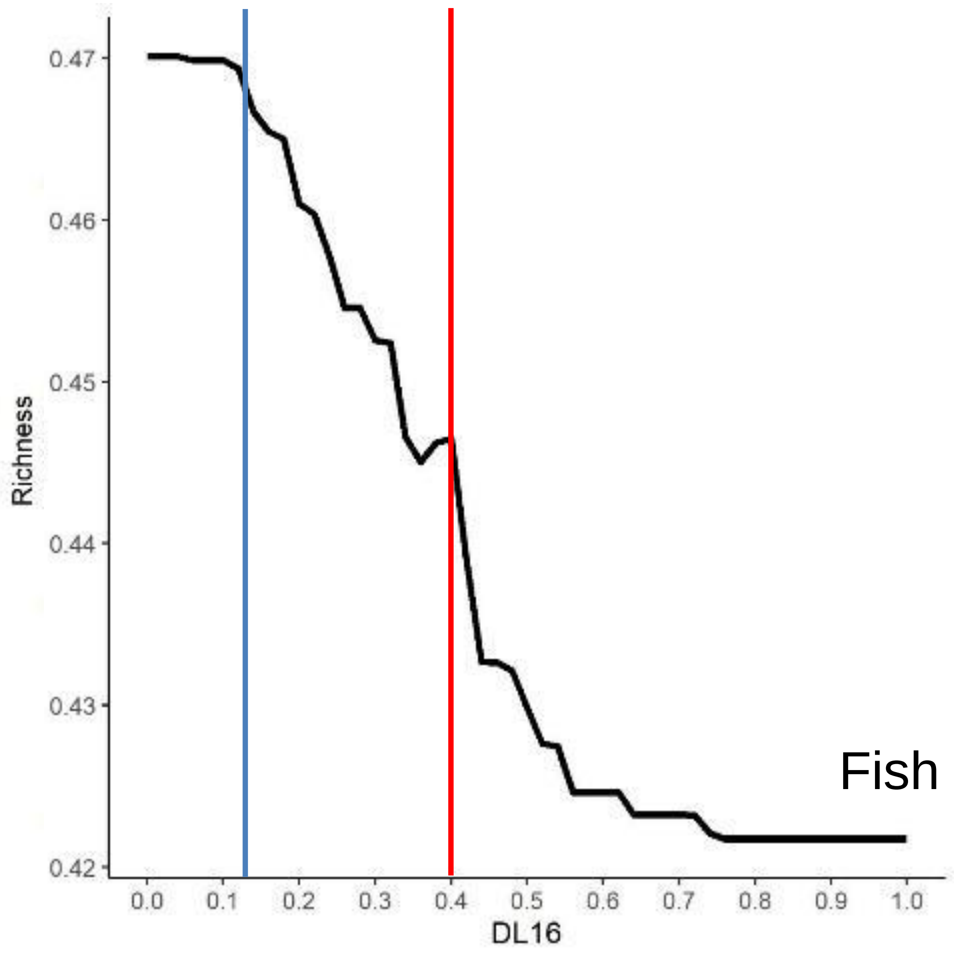

Change in Tolerant
0.0
0.2
0.4
0.6
0.8
1.0
Change in ML17
Change in Richness
0.0
0.2
0.4
0.6
0.8
1.0
Change in ML17

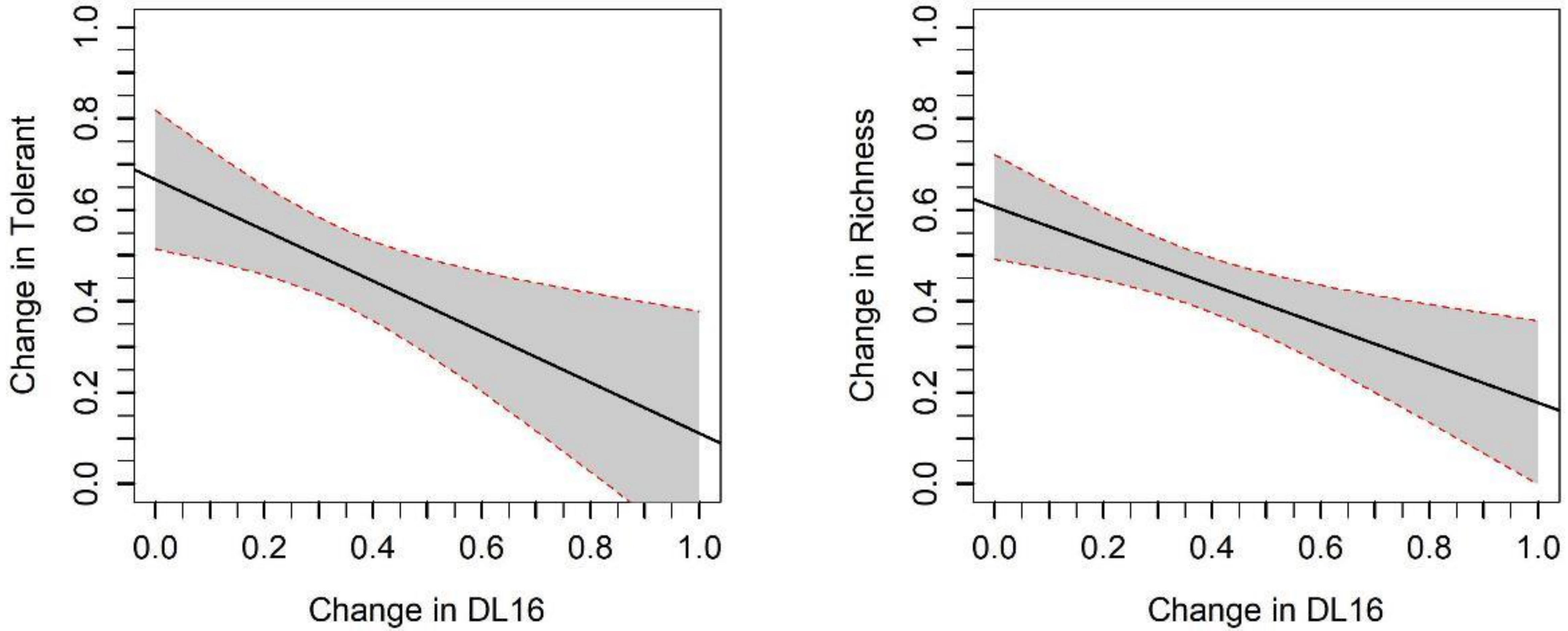
Duration of low flow (DL16)

Mid Atlantic Plains: Perennial runoff

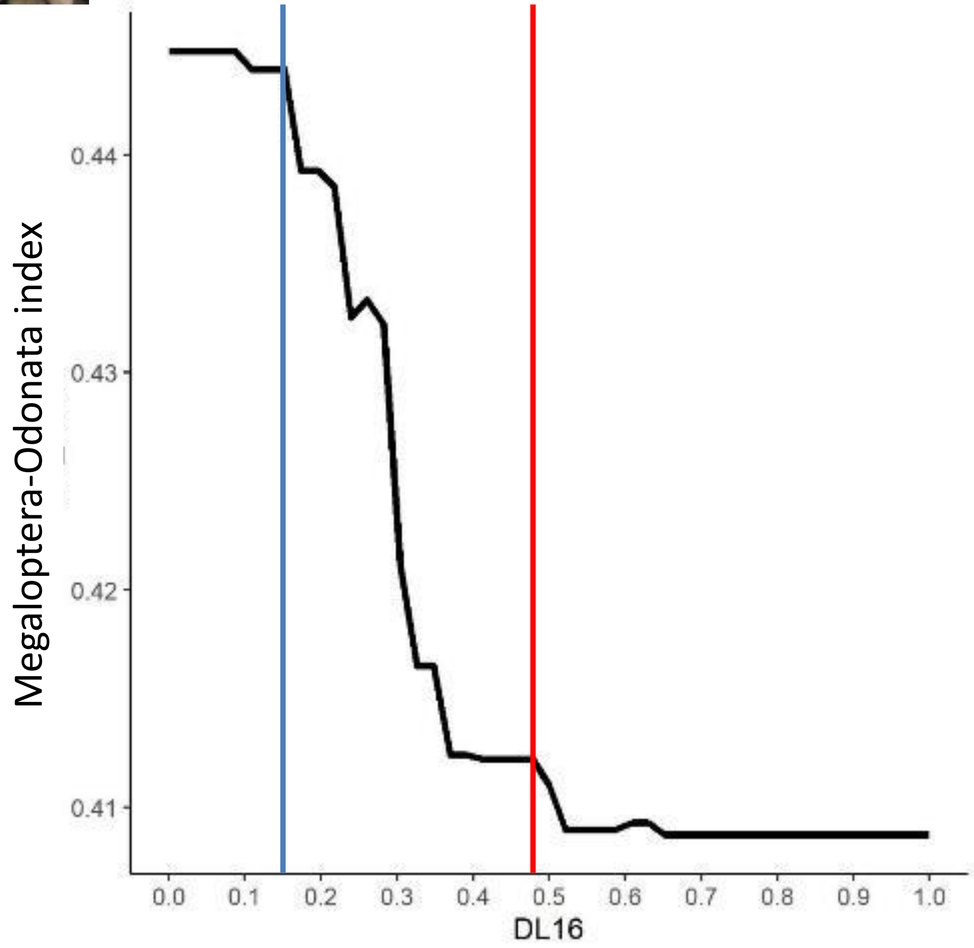


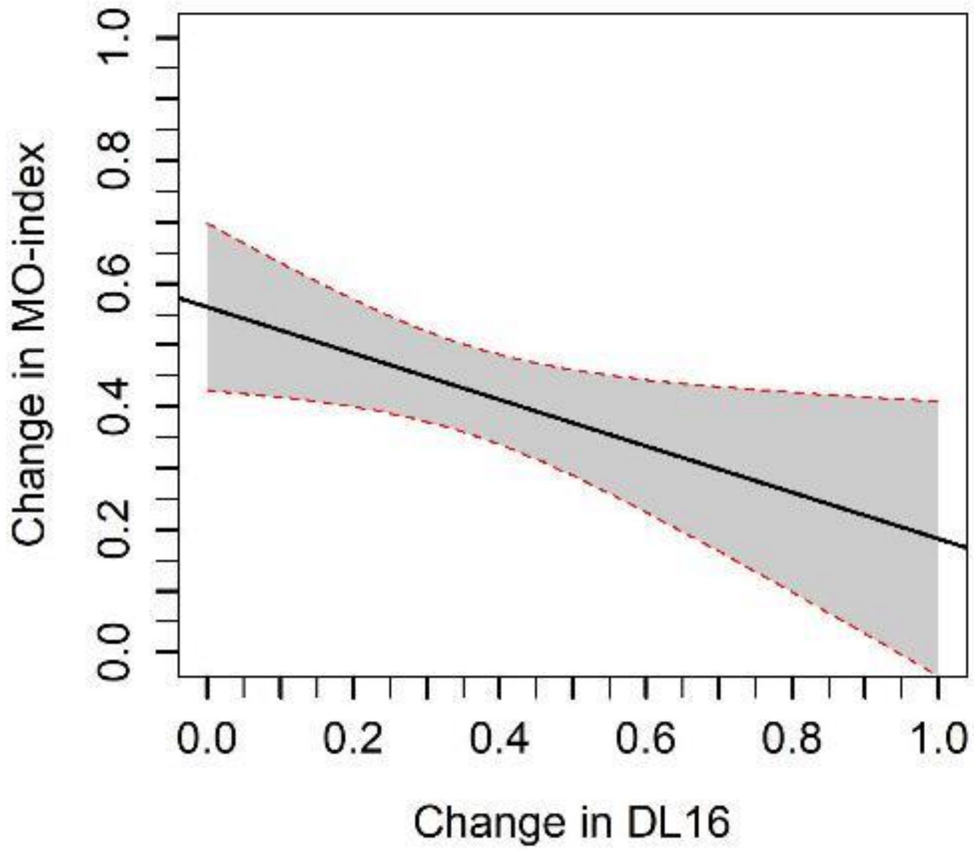
SE Plains: Stable baseflow




Change in Tolerant
0.0
0.2
0.4
0.6
0.8
1.0
Change in DL16
Change in Richness
0.0
0.2
0.4
0.6
0.8
1.0
Change in DL16

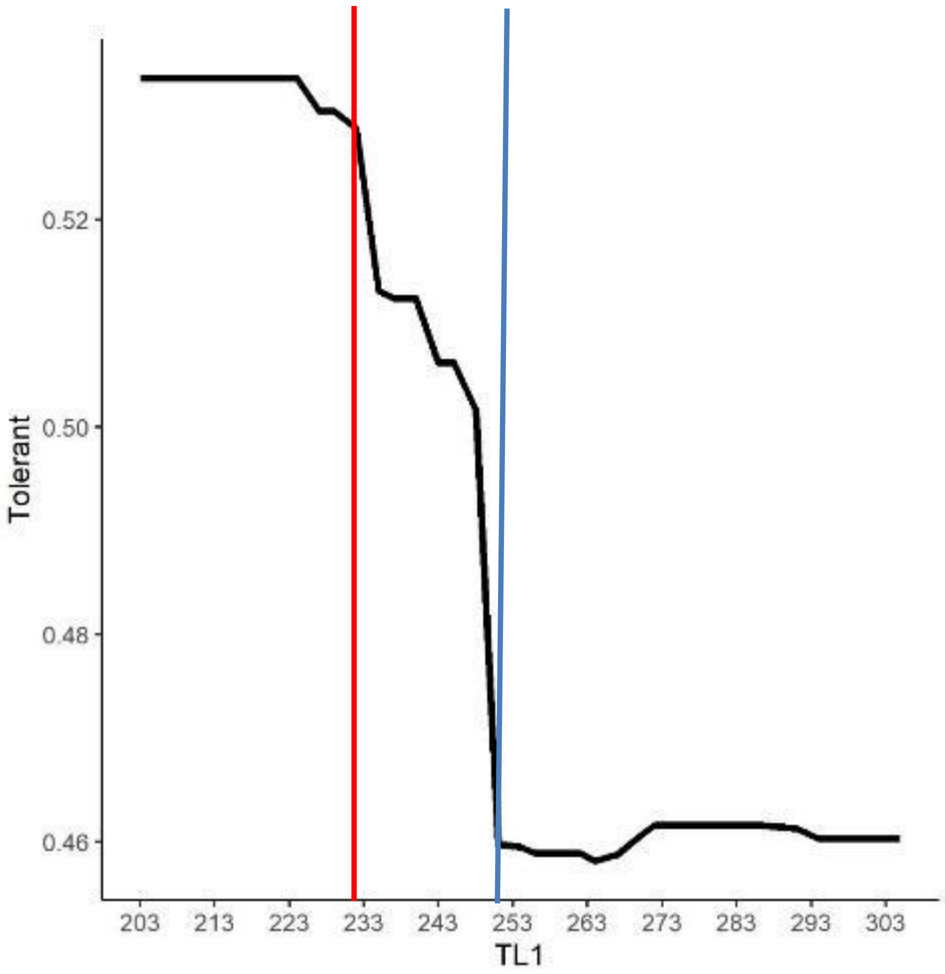
SE Plains: Stable baseflow



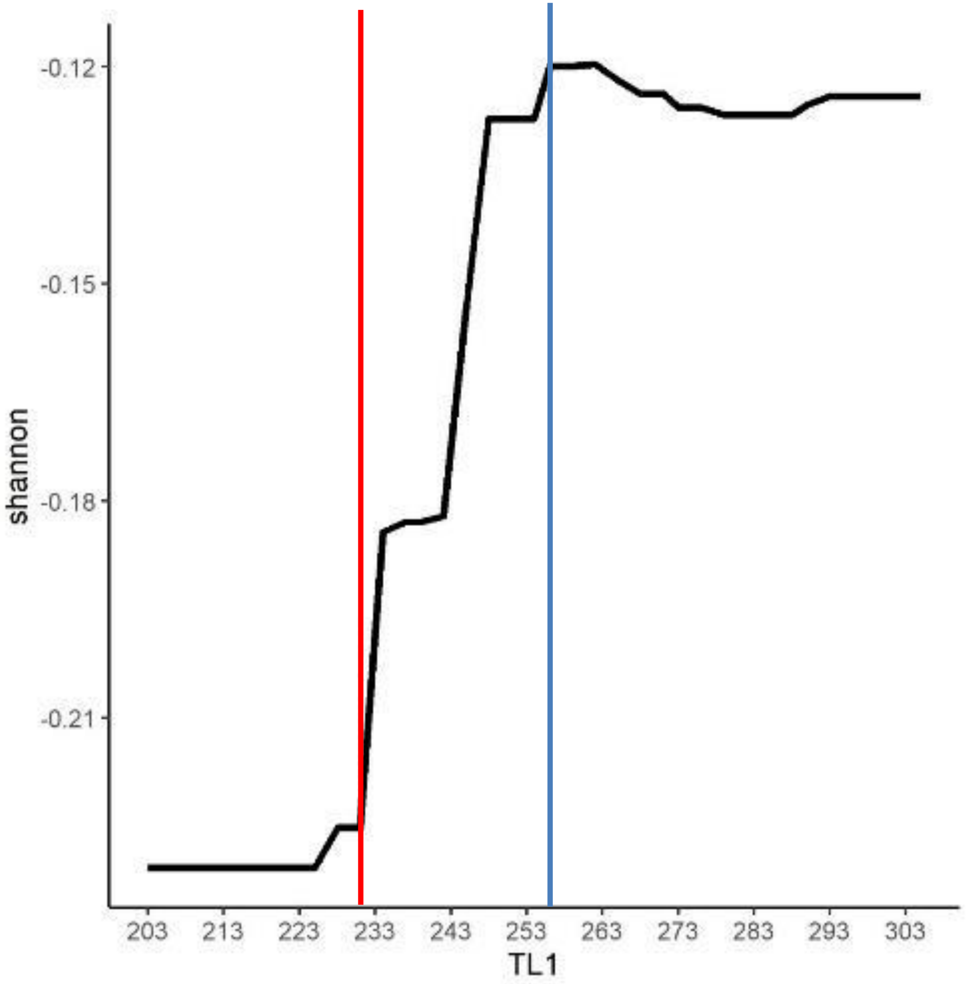


Timing of low flow (TL1)

Mid Atlantic Plains: Perennial runoff



SE Plains: Stable baseflow



(Timing of low flow events in Julian days)

Timing of low flow (TL1)