TETRA TECH

Measuring the Trajectory of Biological Uplift in Space and Time

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Tetra Tech

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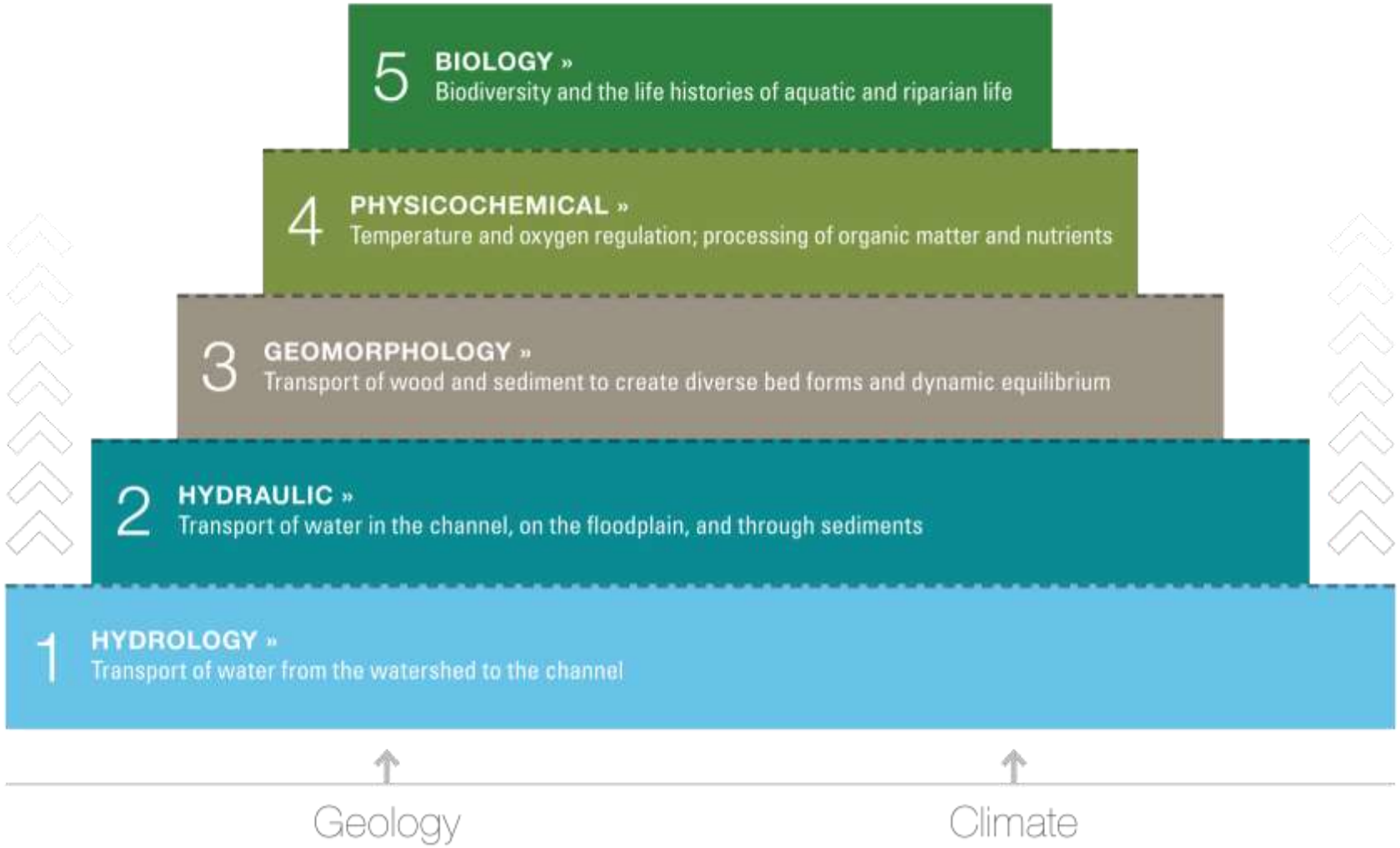
Evidence from Maryland Studies

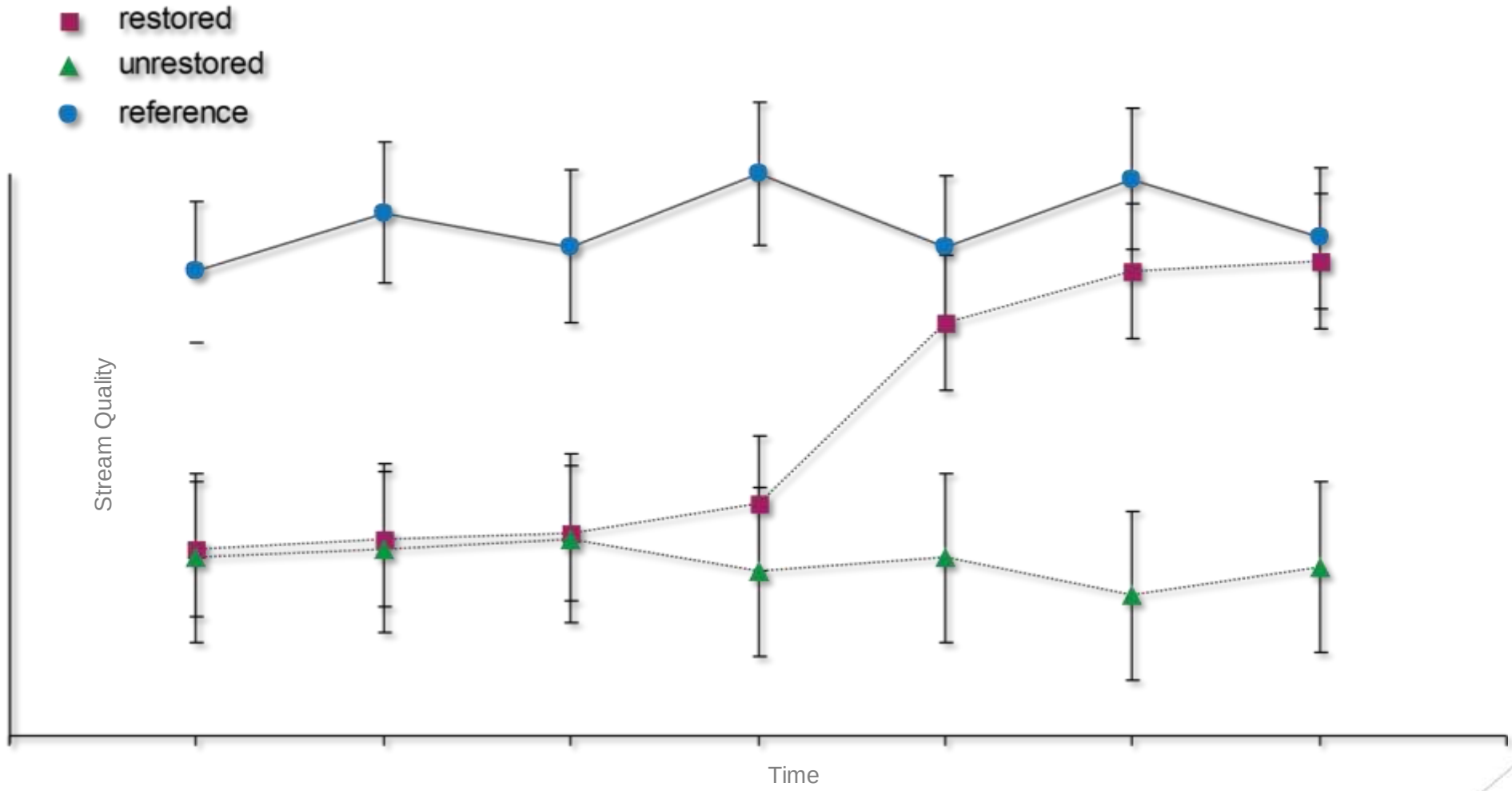
- Quandary of Poor Biological Uplift
- Factors Limiting Uplift
- Effect of Time to Mature
- Effect of Source Populations
- Lessons for Restoration Success and Monitoring

Quandary of Poor Biological Uplift

Stream Function Pyramid

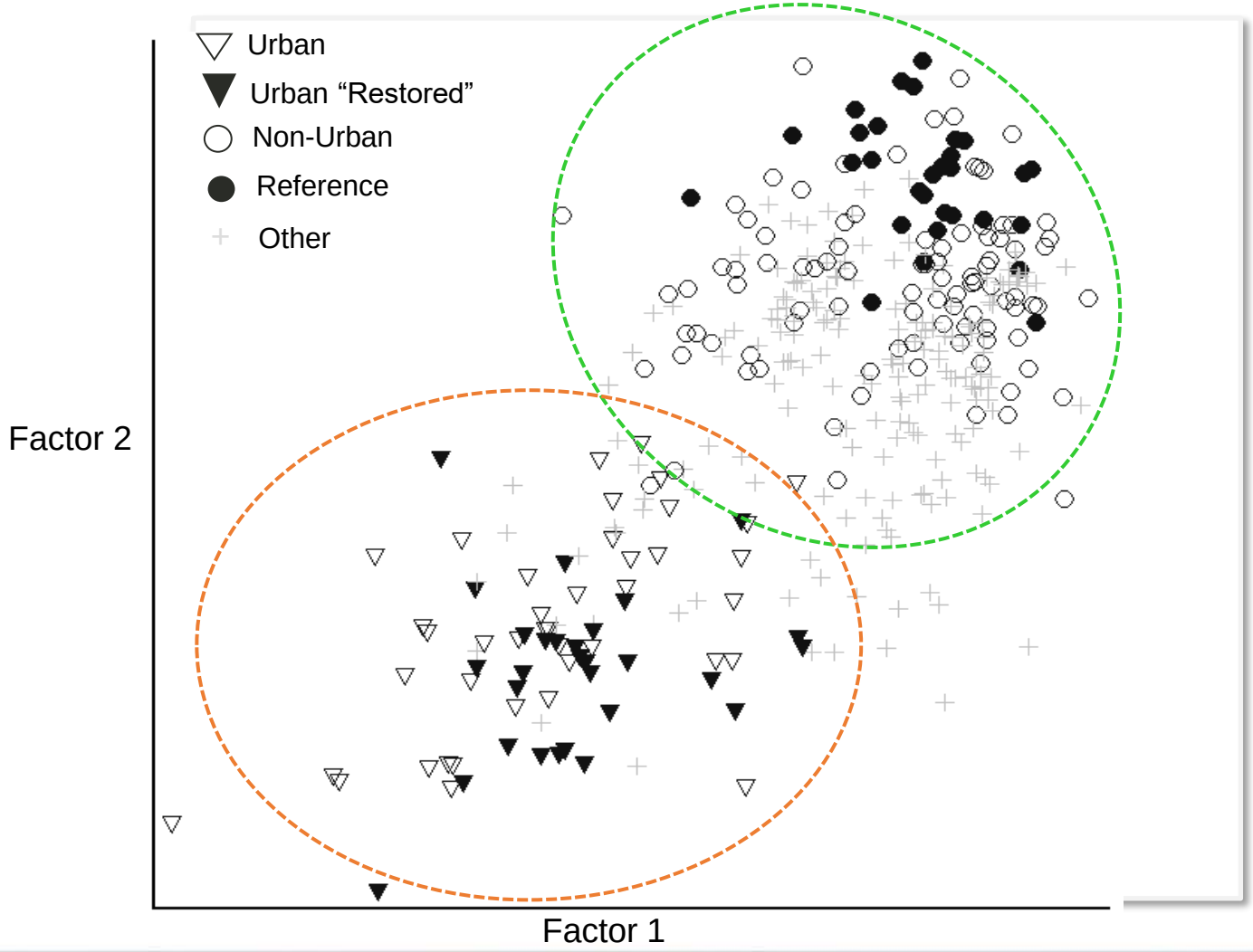


Goal of Restoration



Urban Restoration Sites Cluster with Urban Sites

Scott Stranko



Restoration Sites Do Not Match Reference Sites

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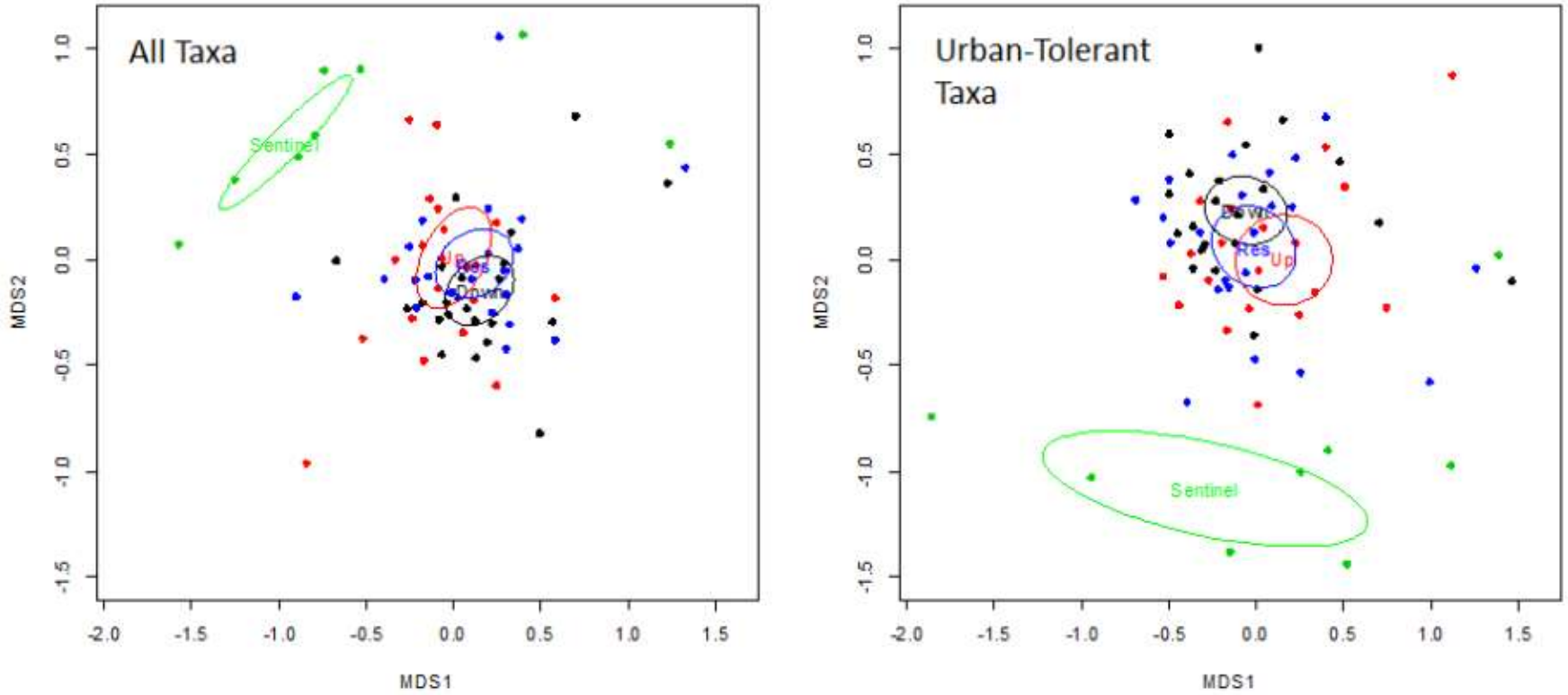
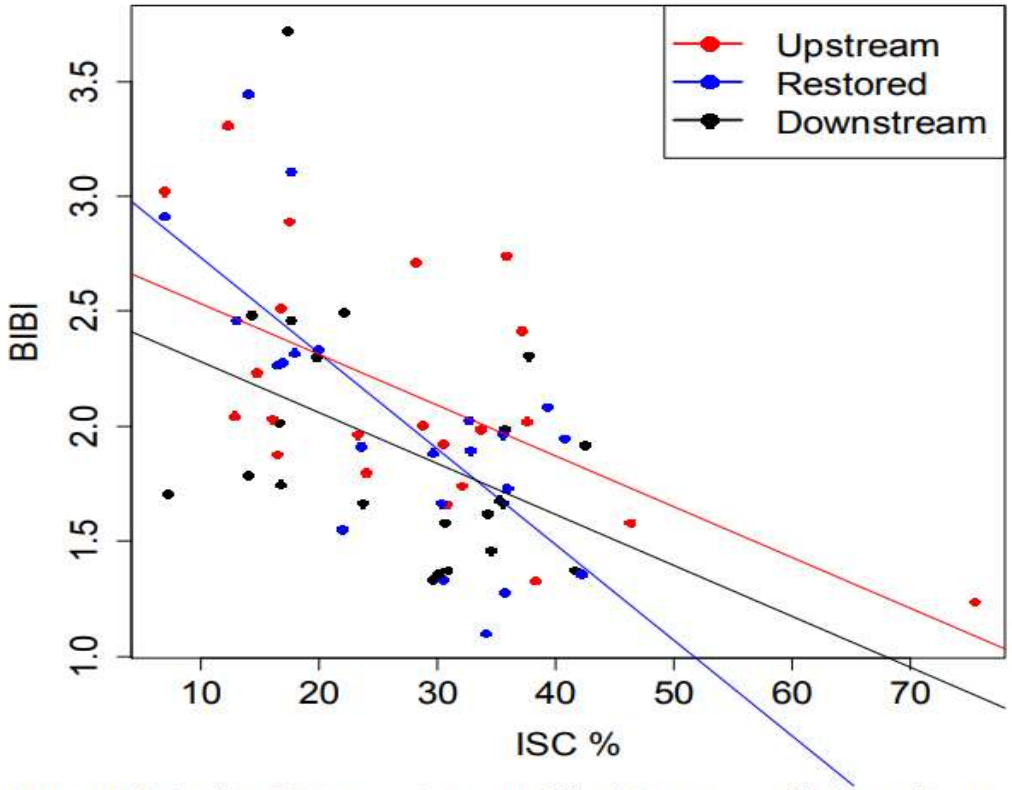


Figure 3. NMS ordination plot of benthic mcaronivertebrate community structure in Restored (blue), Upstream (red), and Downstream (black) sections compared with MBSS Sentinel Sites (green). Ellipses represent 95% CI around the centroid for each section.

Restoration Sites Do Not Outperform Upstream Sites



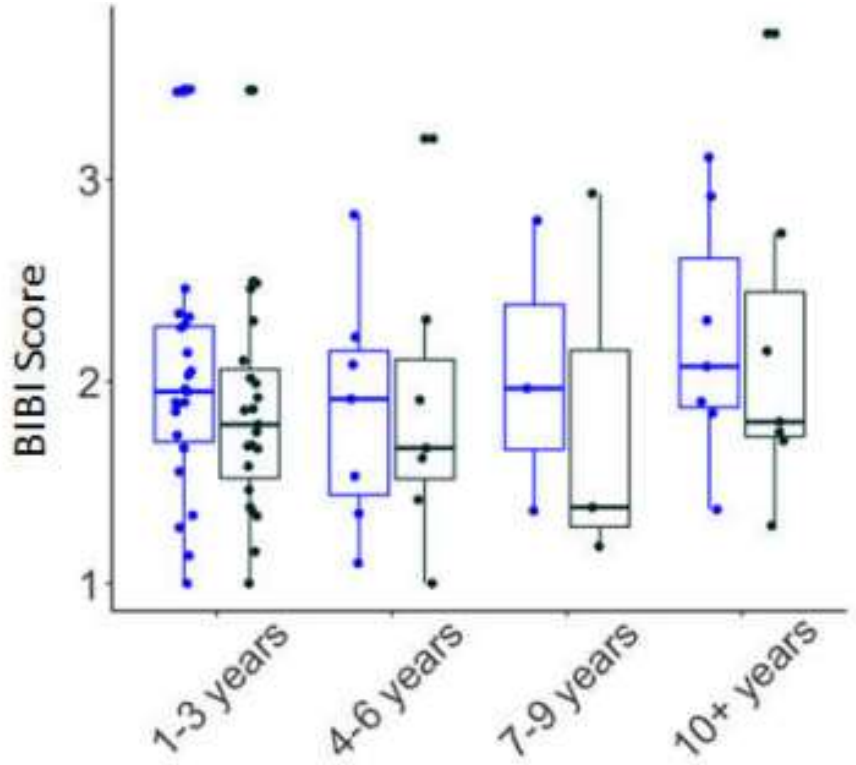


Figure 4. Relationship of BIBI scores in Restored (blue), Downstream (black), and Upstream (red) sections of Piedmont streams to %ISC in the watershed.

Physical Habitat Improved but Not IBI

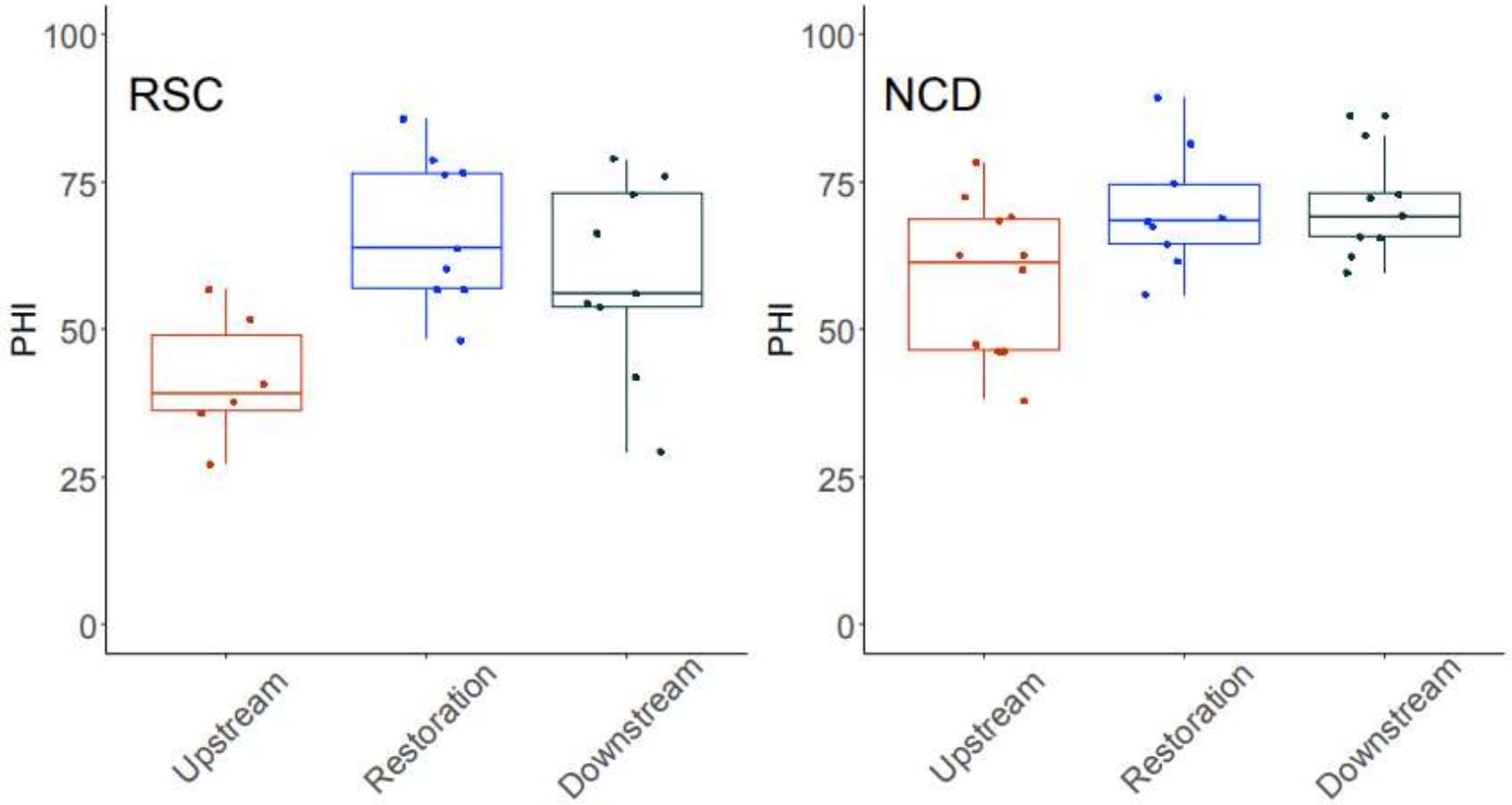


Figure 13. Physical Habitat Index scores for Upstream, Restored, and Downstream sections in Coastal Plain streams. Note that the figure does not incorporate the stream-specific effects that were modeled in the statistical analysis.

Vertebrate Community Trajectory in Regenerative Stream Conveyances

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What are RSCs?

- Regenerative stream conveyances (RSCs) typically
  - *transform* degraded, single-channel, lower-order streams (some with wetlands)
  - *into* stream-wetland complexes designed to provide more opportunity for sediment retention and nutrient removal
- RSCs result in channel widening and partial impoundments that
  - slow flow rates
  - typically reduce shading
  - create periodic anoxia
  - increase diel dissolved oxygen variation and ecosystem gross primary production (GPP)

What are RSCs?

Immediate post-construction

16 and 10 years post-construction

Wilelinor 2004 and 2020

North Cypress Branch 2010 and 2020

Conceptual Model

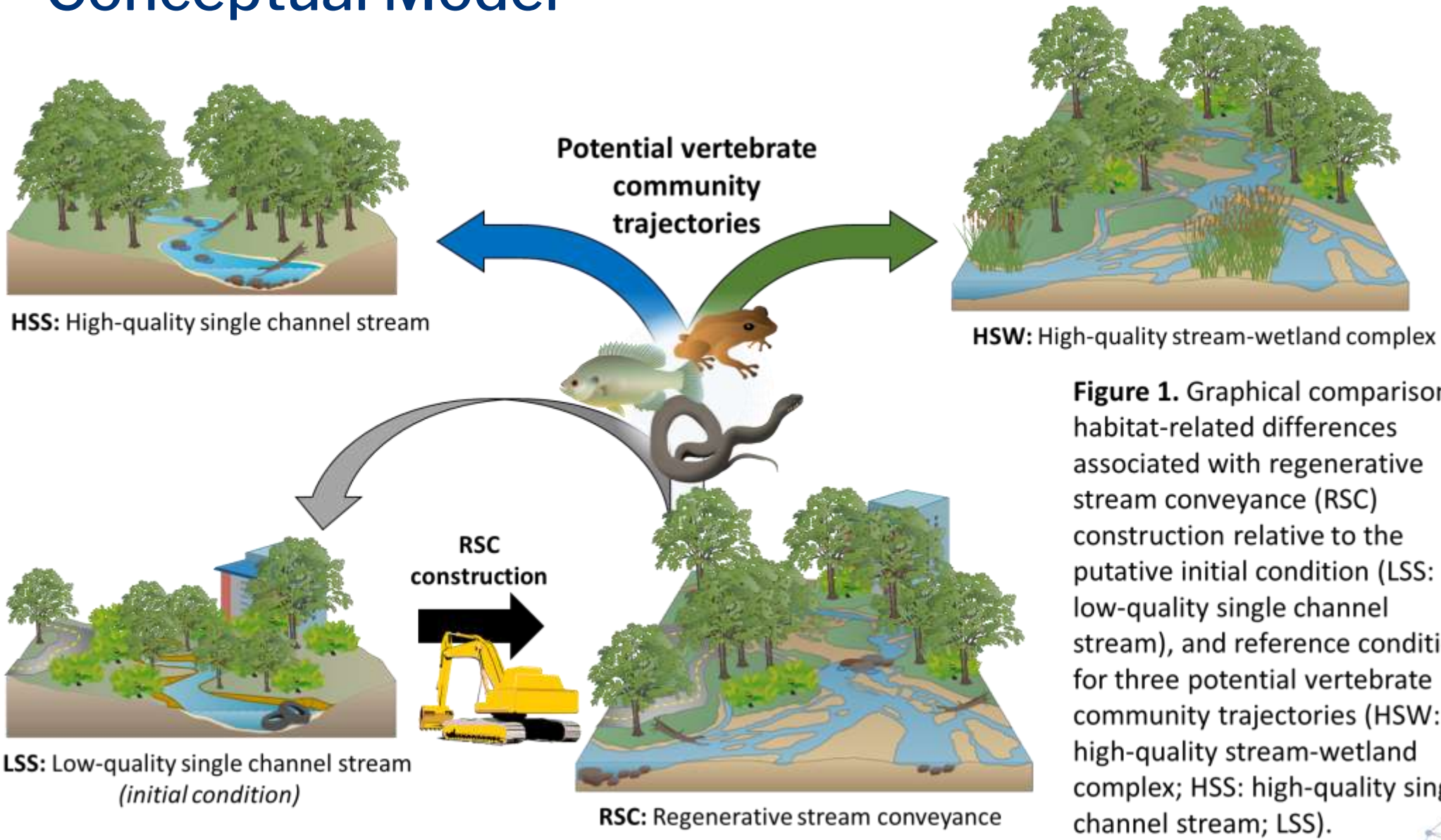


Figure 1. Graphical comparison of habitat-related differences associated with regenerative stream conveyance (RSC) construction relative to the putative initial condition (LSS: low-quality single channel stream), and reference conditions for three potential vertebrate community trajectories (HSW: high-quality stream-wetland complex; HSS: high-quality single channel stream; LSS).

Site Selection for Field Study

- Natural factors were similar among stream types, except for larger catchment sizes that are inherent to HSWs

- 8 HSS *High-quality Single Streams* = 453–664 acre catchments
- 8 HSW *High-quality Stream Wetlands* = 552–52,936 acres
- 8 LSS *Low-quality Single Streams* = 134–669 acres
- 11 RSC *Regenerative Stream Conveyances* = 30–4550 acres

- Total of 35 sites sampled during August-September 2020

HSS-10

HSW-17

LSS-4

RSC-2

RSCs with Age and Catchment Areas

	RSC Site Name	Date constructed	Age (years)	Catchment (acres)
RSC-1	Bacon Ridge	2018	2	1757
RSC-2	N Branch Cypress Creek	2010	10	461
RSC-3	Crofton Tributary	2011	9	211
RSC-4	Dividing Creek	2016	4	220
RSC-5	Howard's Branch	2003	17	237
RSC-6	Cabin Branch Saltworks Creek	2013	7	121
RSC-8	Wilelinor	2004	16	262
RSC-9	Church Creek at Allen Apartments	2017	3	30
RSC-10	Cowhide Branch to Weems Creek	2013	7	4550
RSC-11	Church Creek at Bywater	2015	5	67
RSC-12	Church Creek at Annapolis Harbour Center	2014	6	151

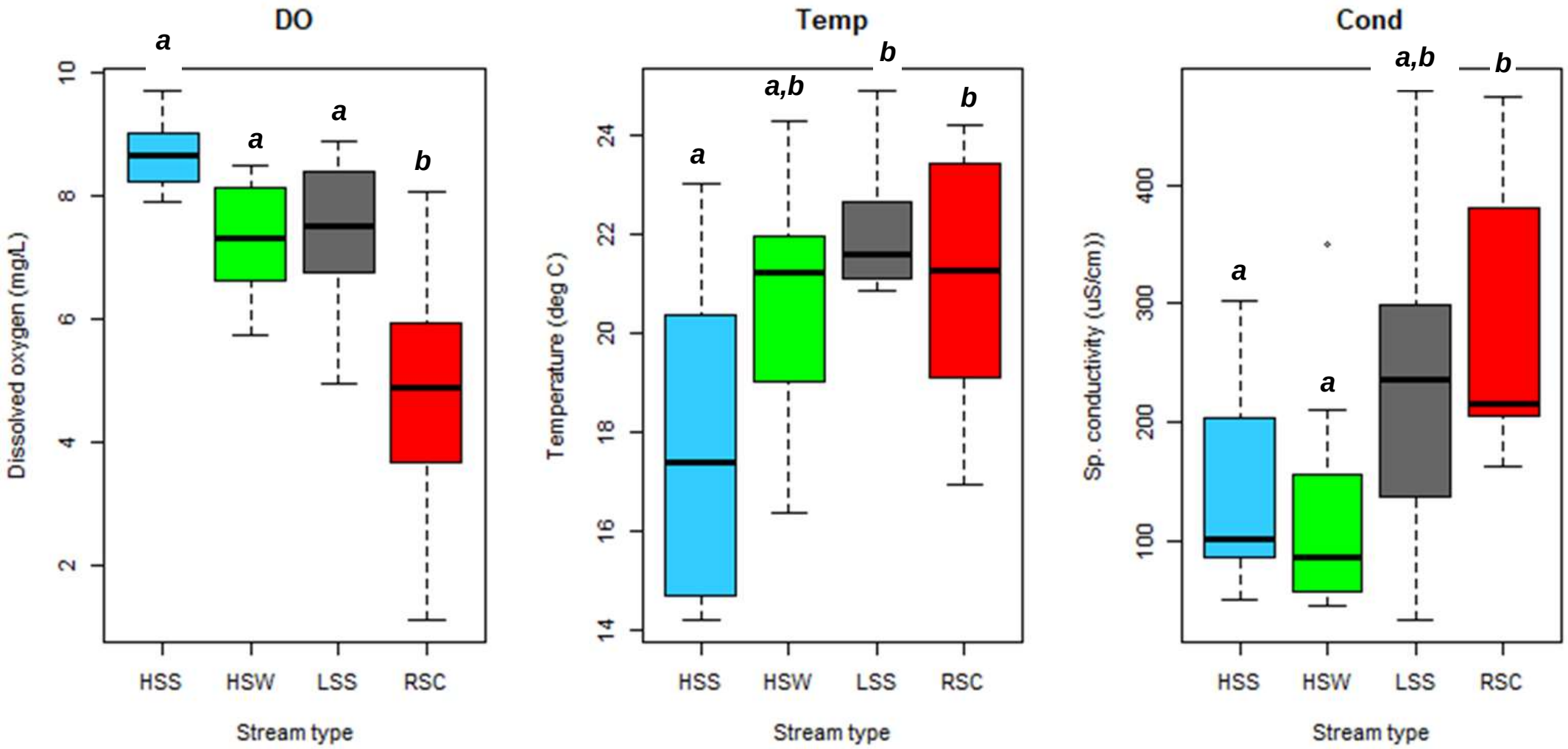
Field Sampling Methods

Sampling Protocols

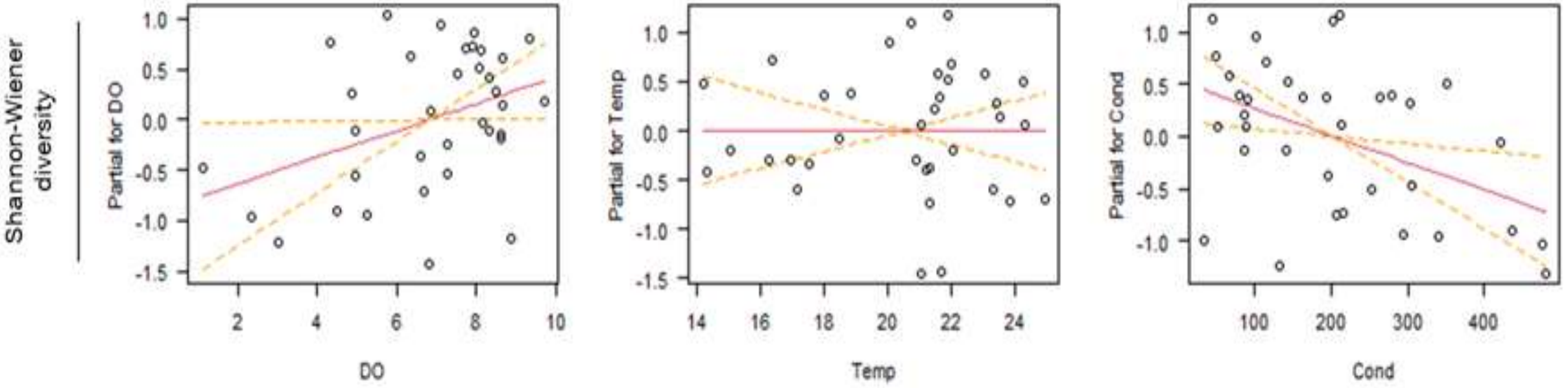
- MBSS for Fish, Herps, Habitat
- Basic Water Quality of Dissolved Oxygen, Temperature, Conductivity
- Stream Metabolism

- High flow days after rain were not sampled
- All sites were sampled in August-September 2020 with sampling of each stream type spread across the calendar

Water Quality is Different in RSCs

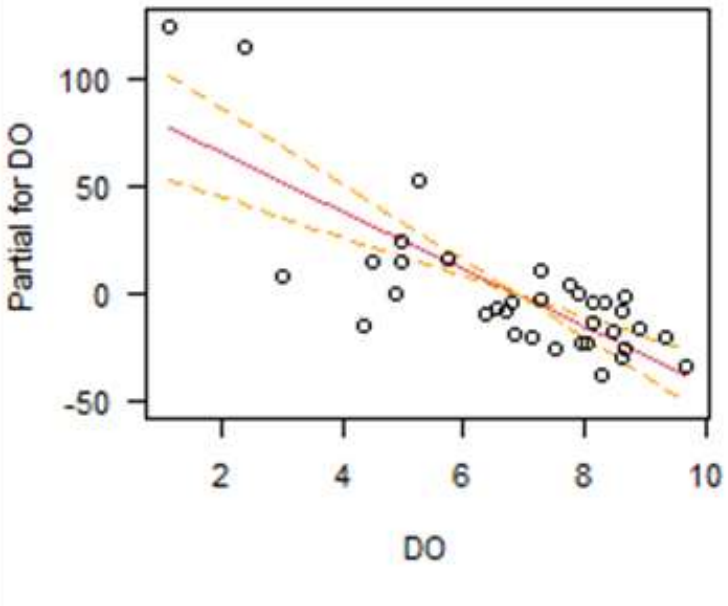


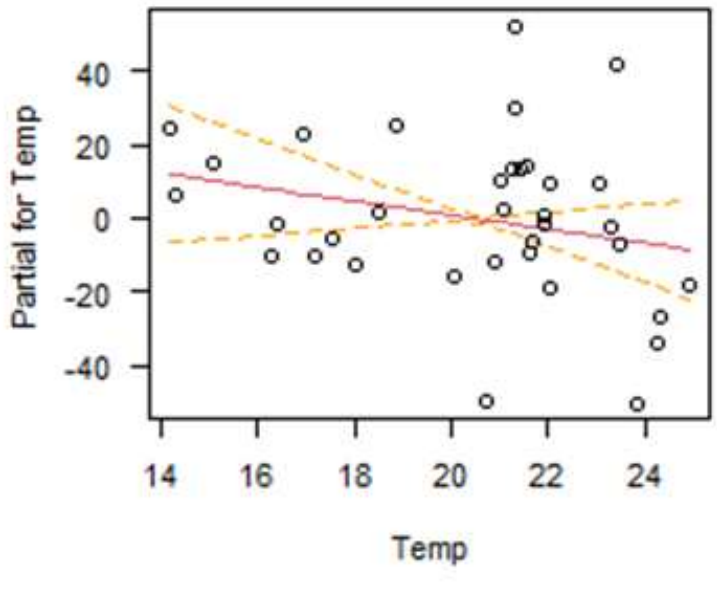
Fish Diversity Increases with DO and Decreases with Conductivity

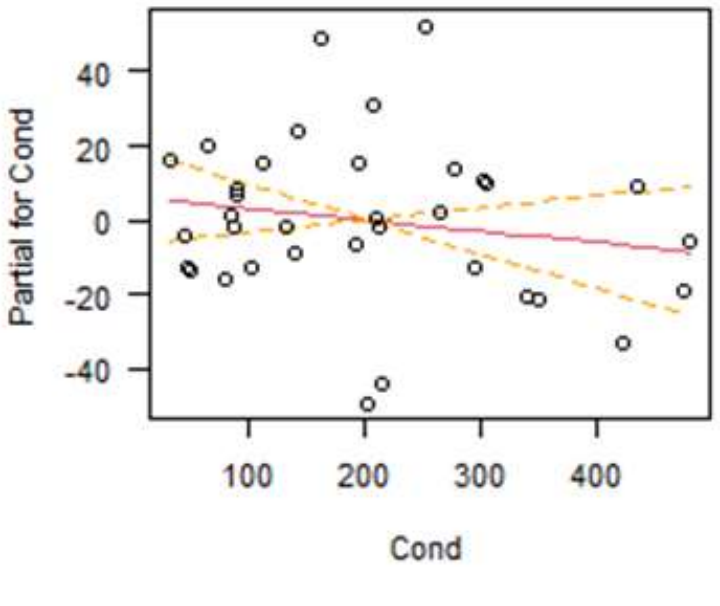


Herpetofauna is Not Reduced by Water Quality

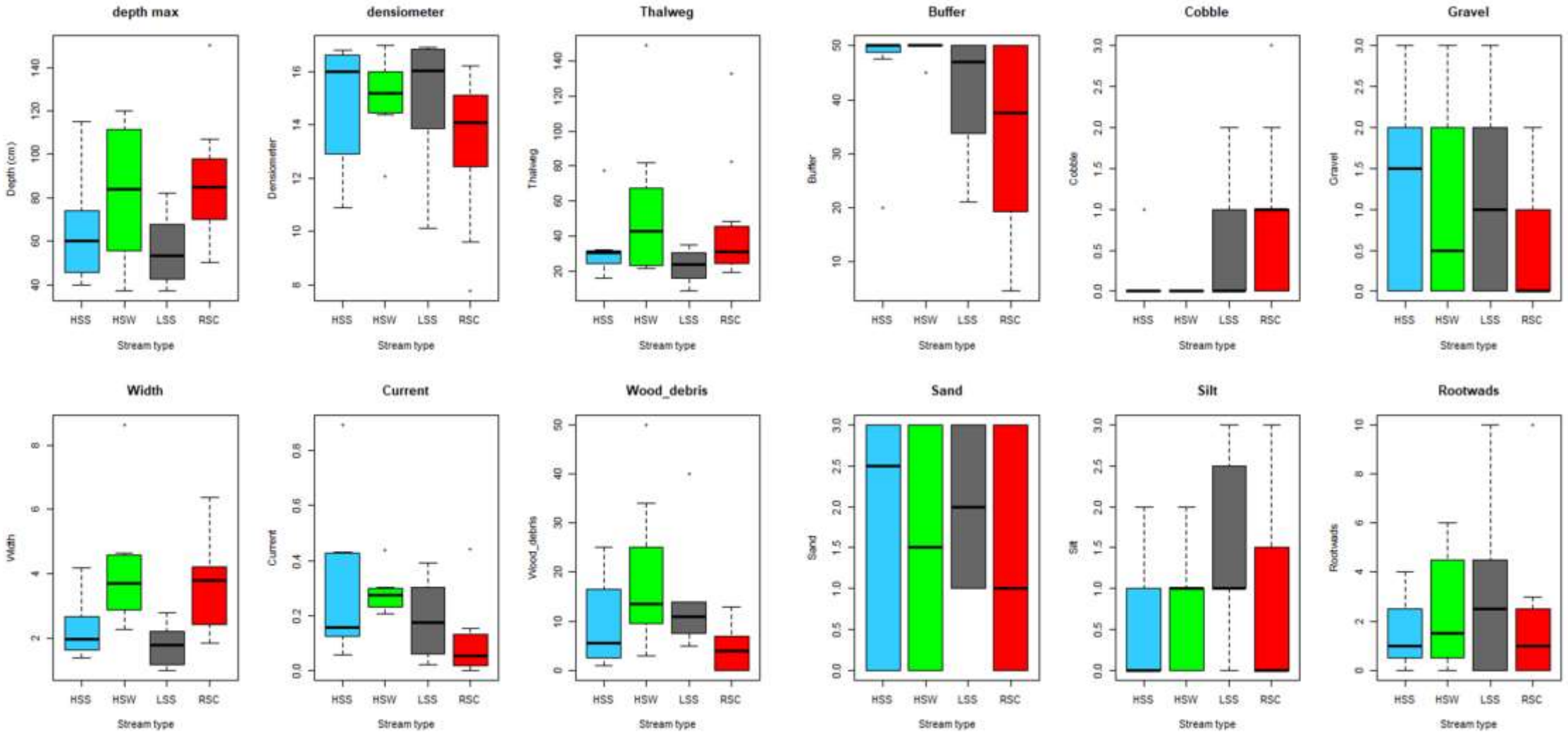
Amphibian abundance



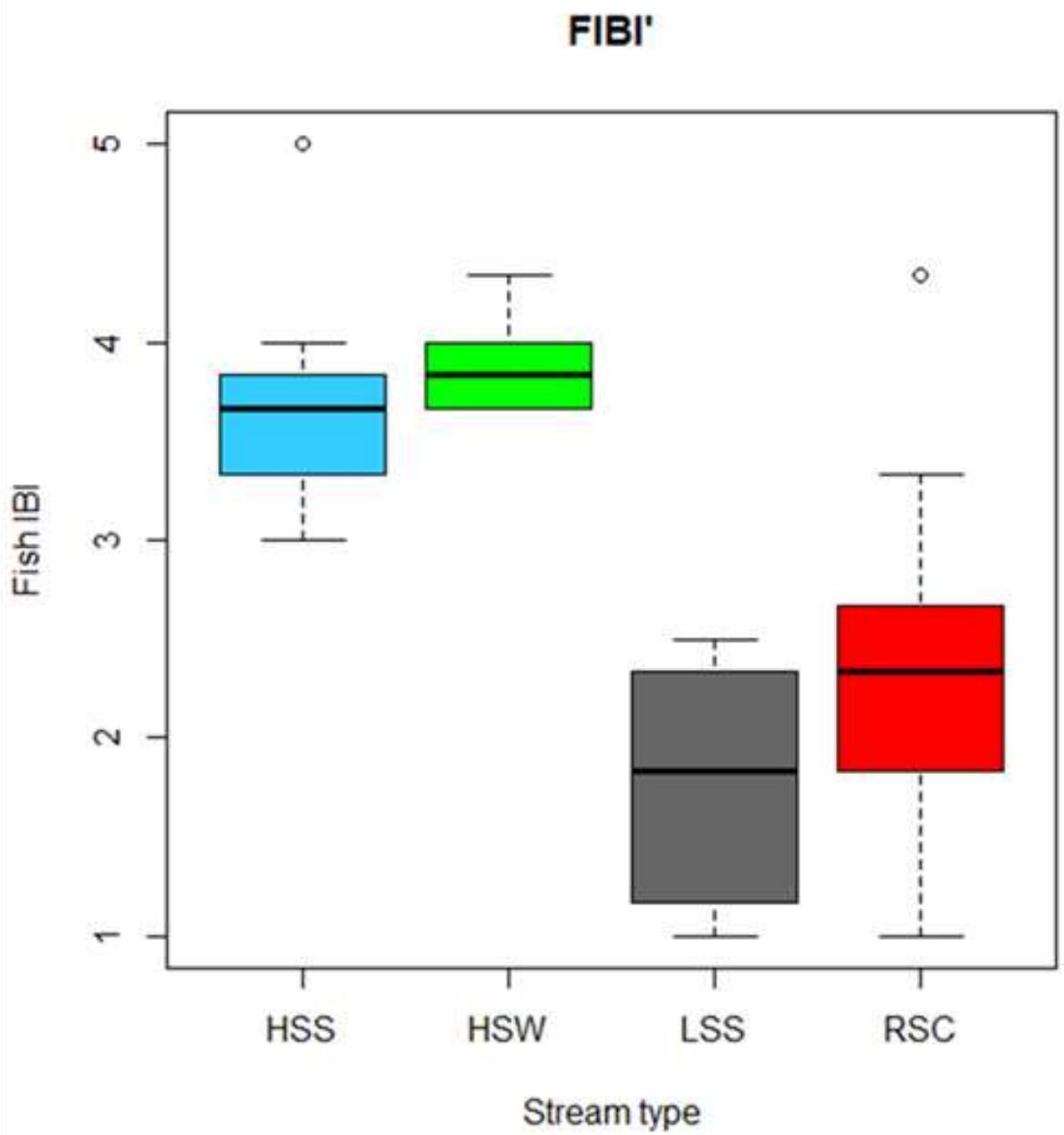




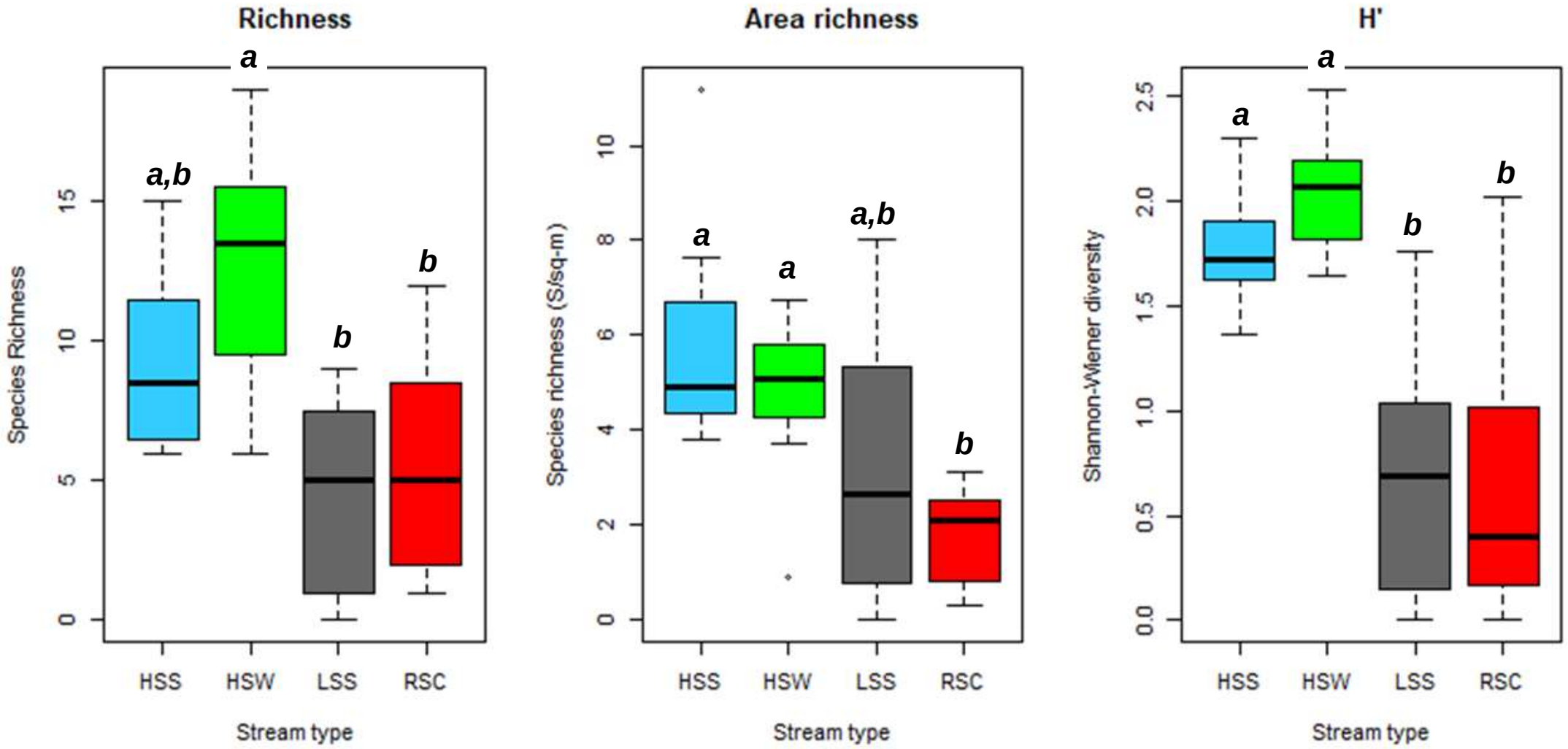
Habitat is Similar in RSCs (except for Buffers and Cobble)



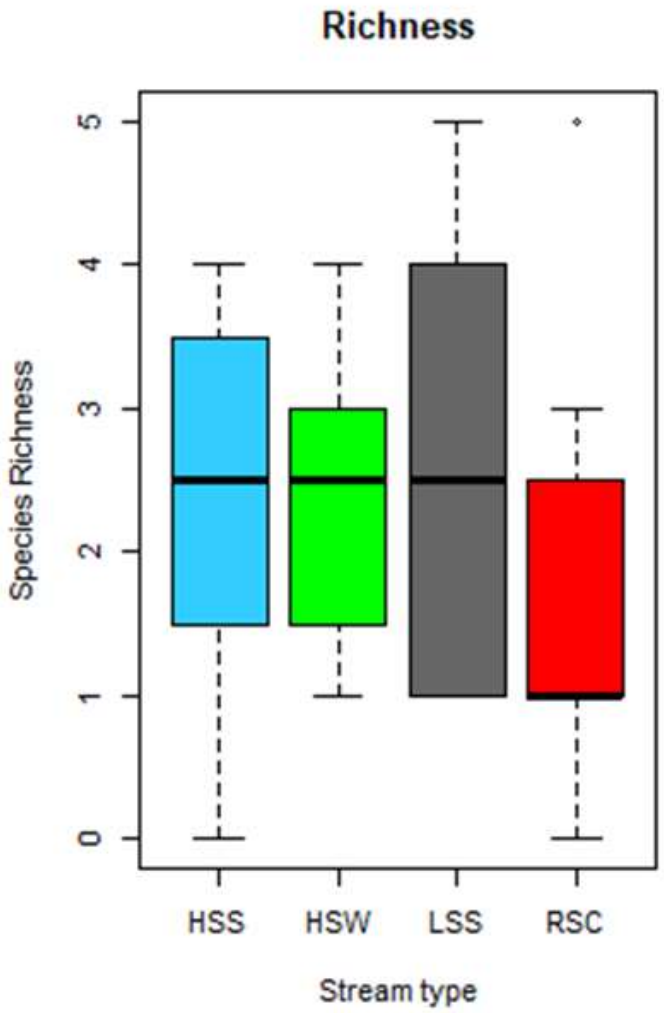
RSC FIBI is Low

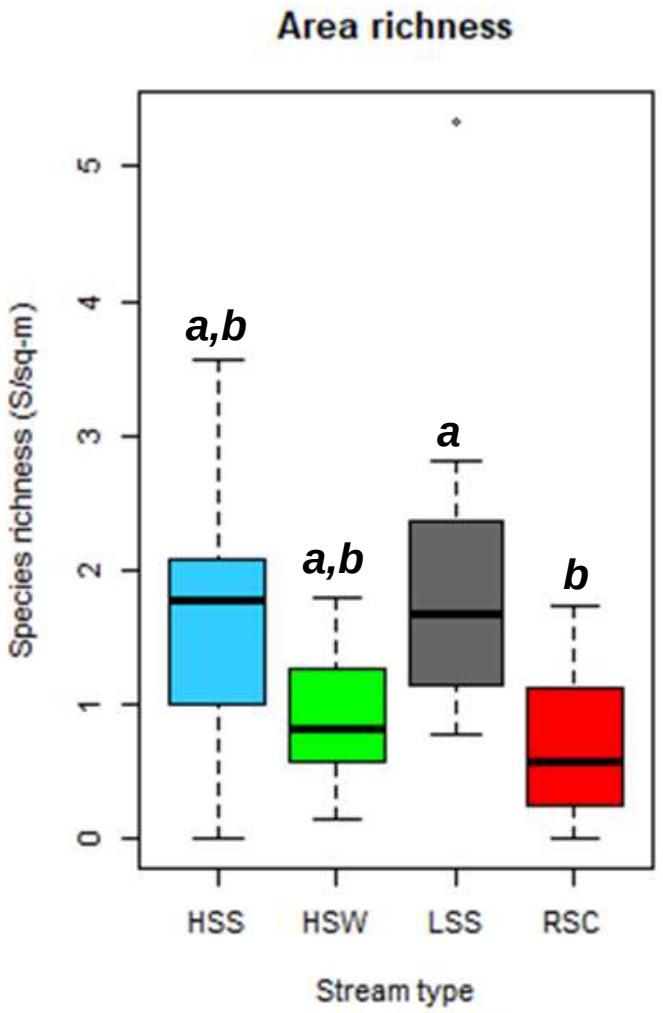


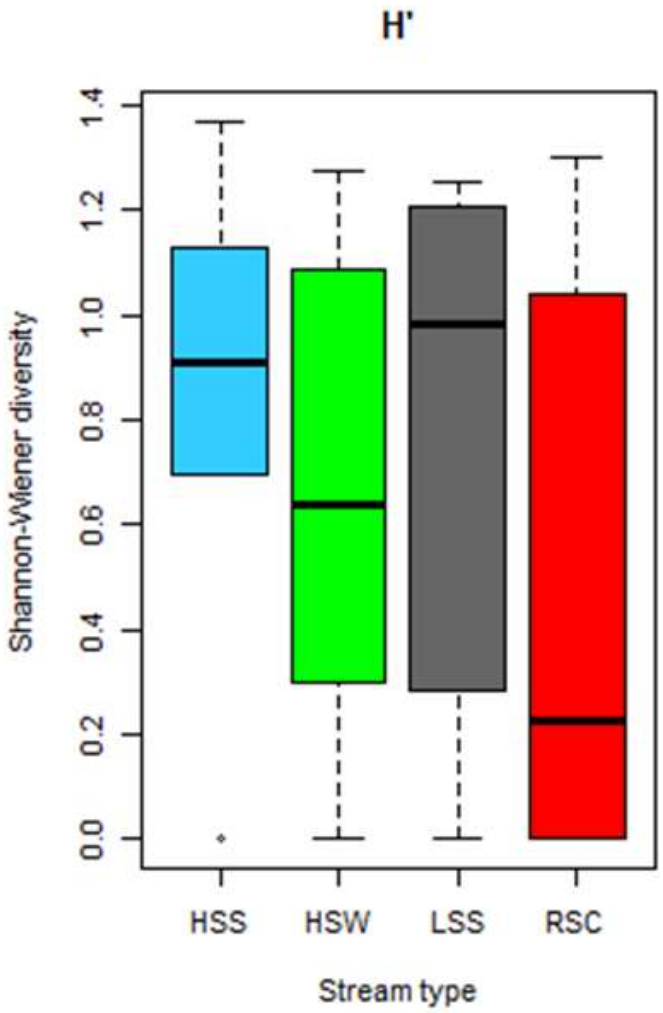
RSC Fish Diversity is Low



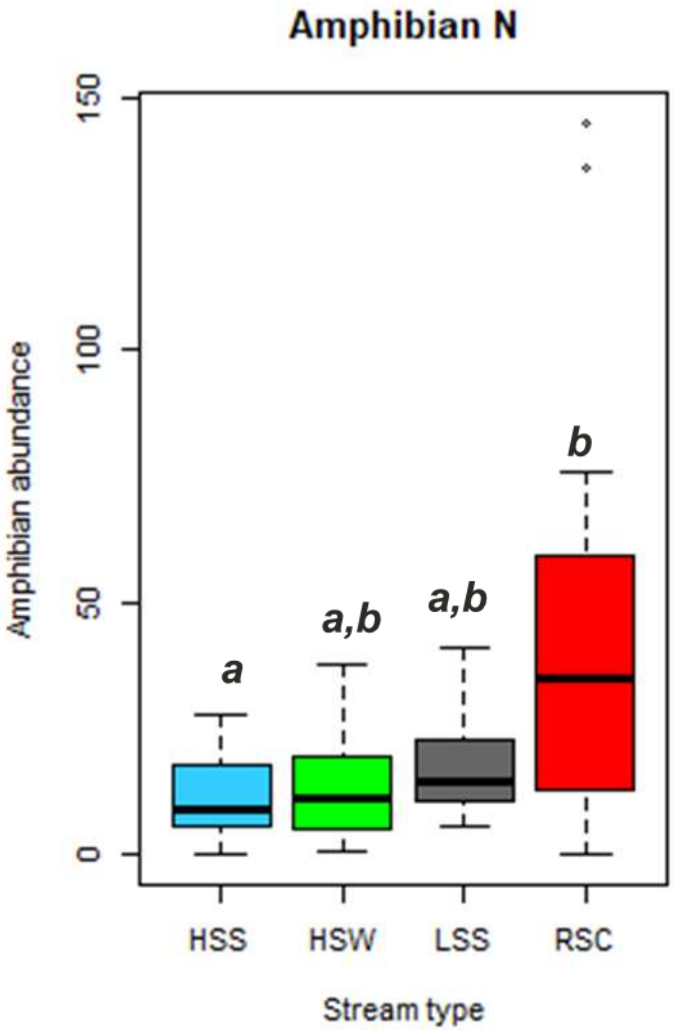
Herpetofauna Diversity is Similar

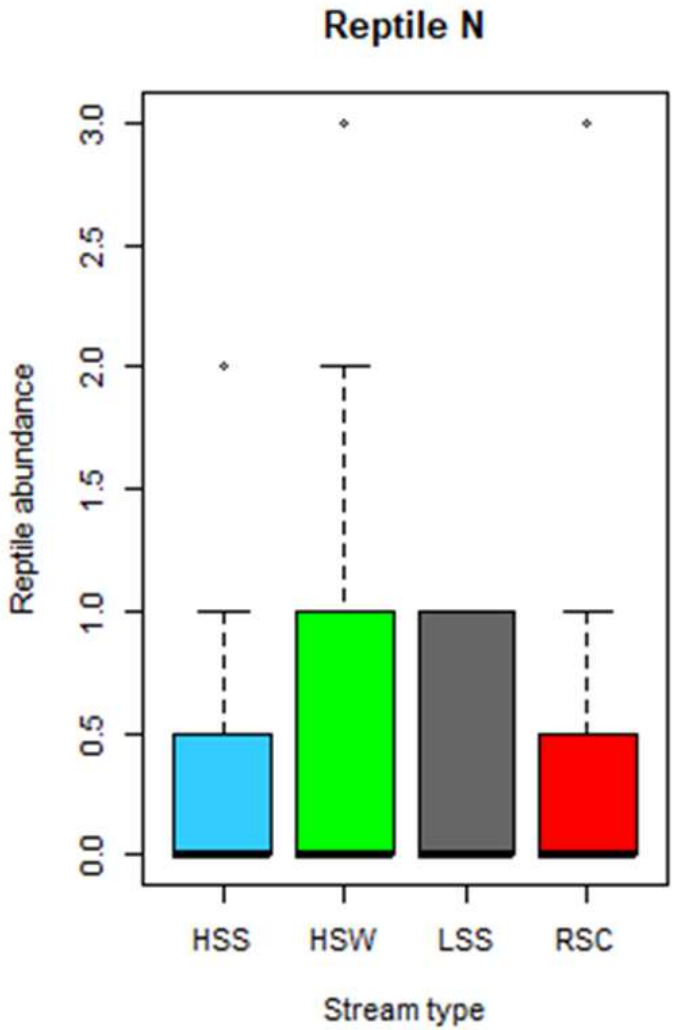


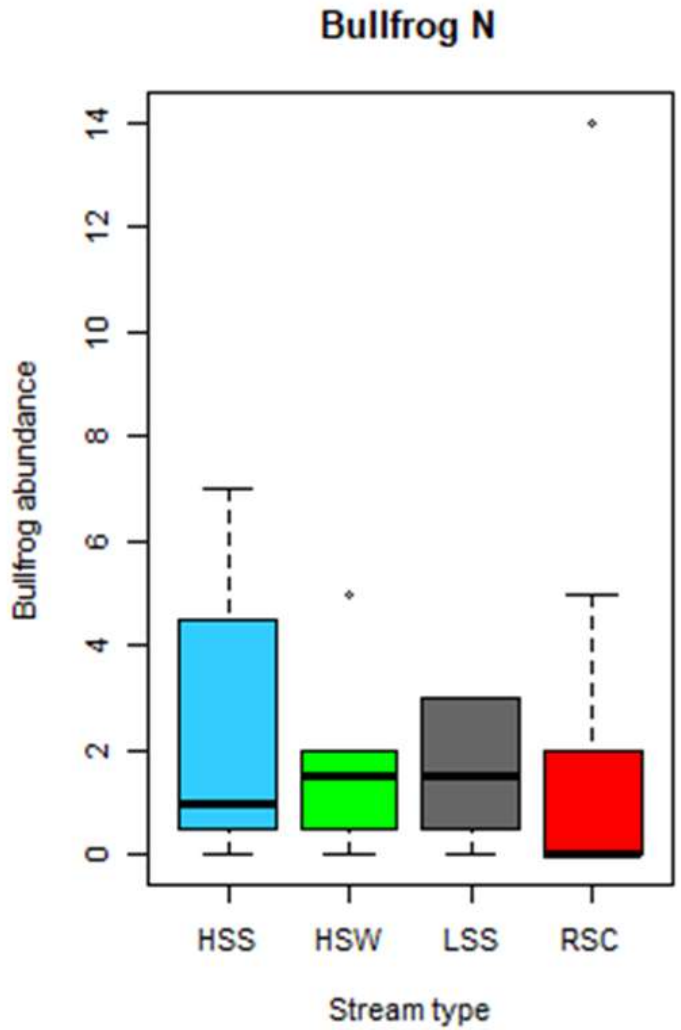




Frog Abundance in High in RSCs



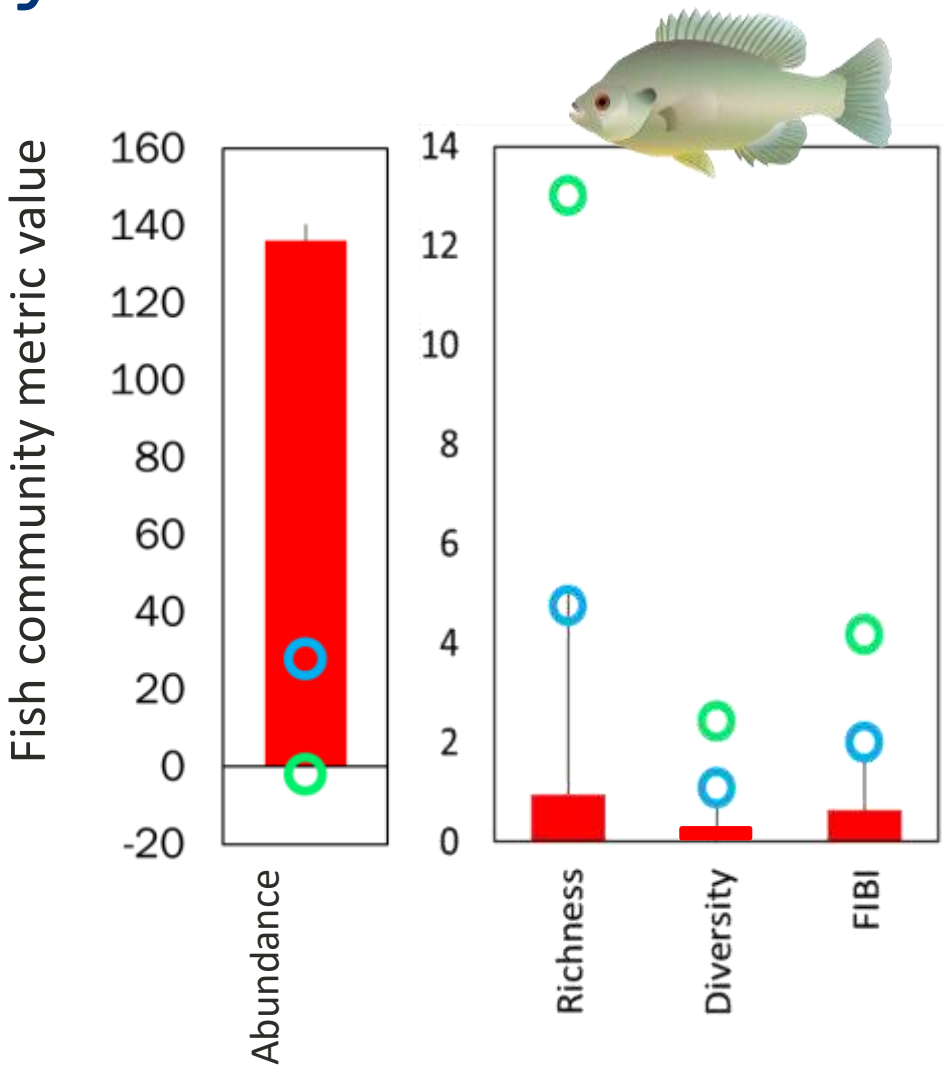


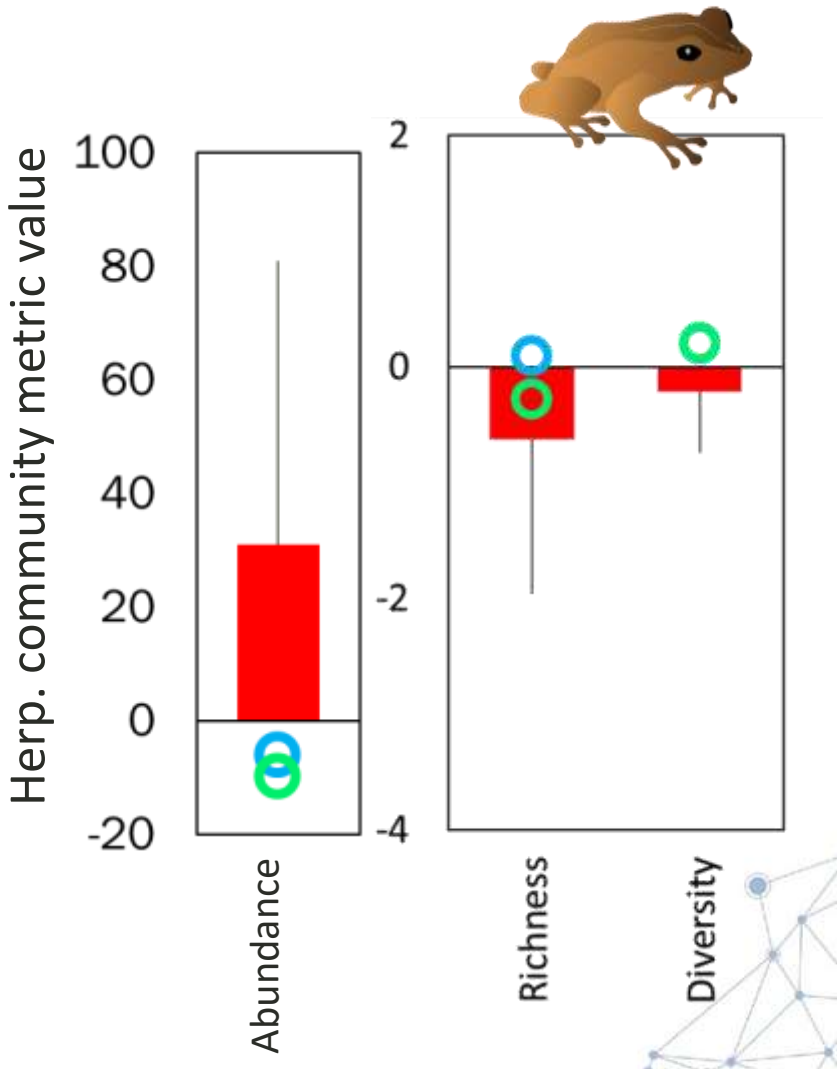


RSC Fish Communities Only Partially Approach High Quality

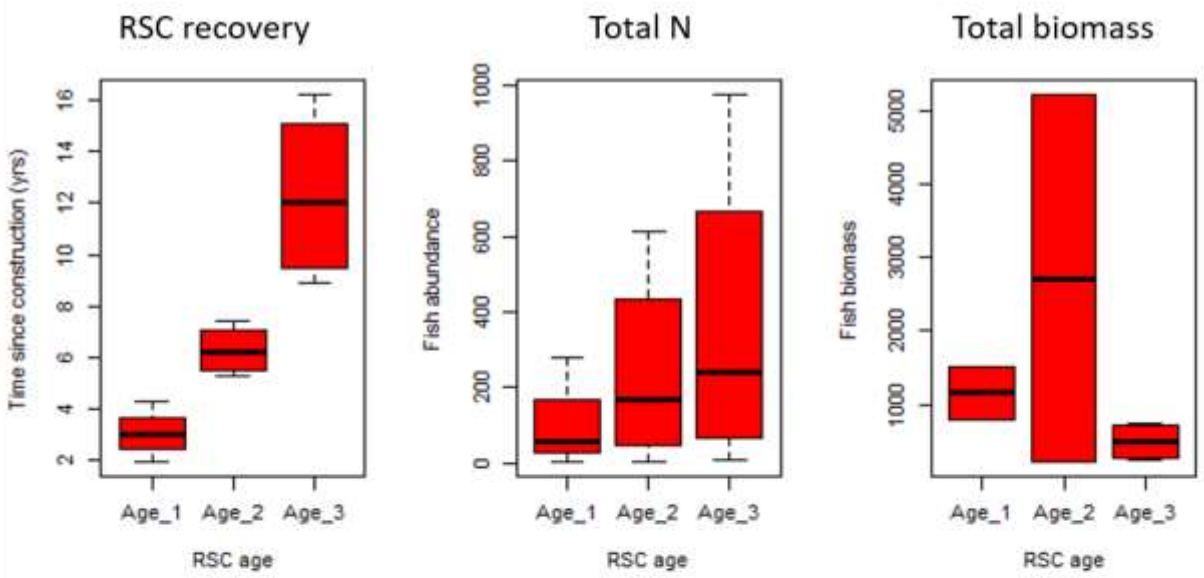
LSS reference (baseline condition)

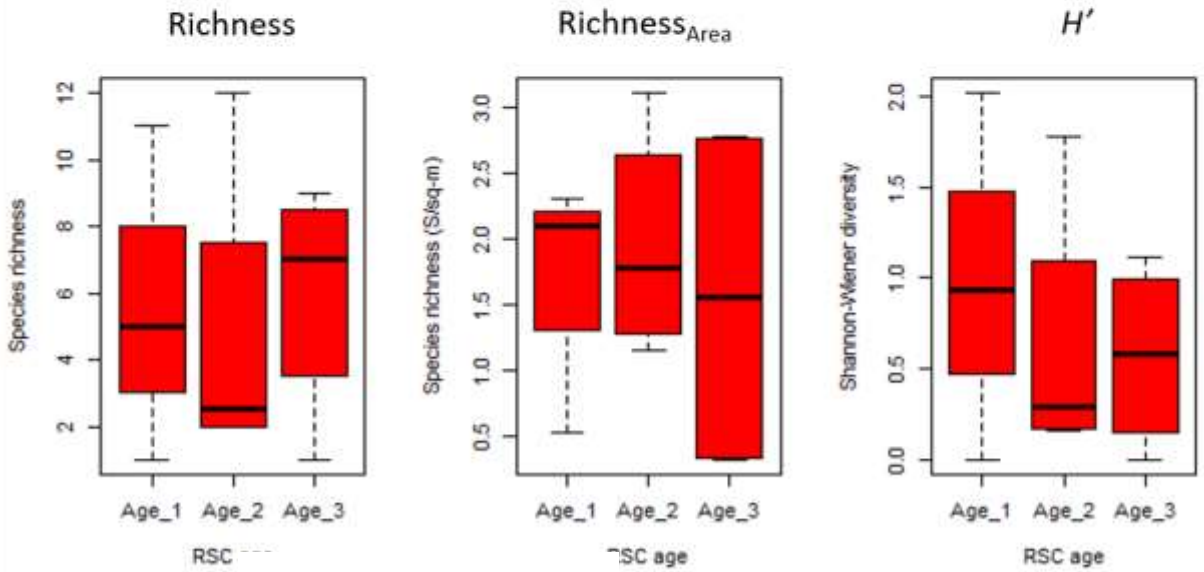
- RSC
- HSS
- HSW





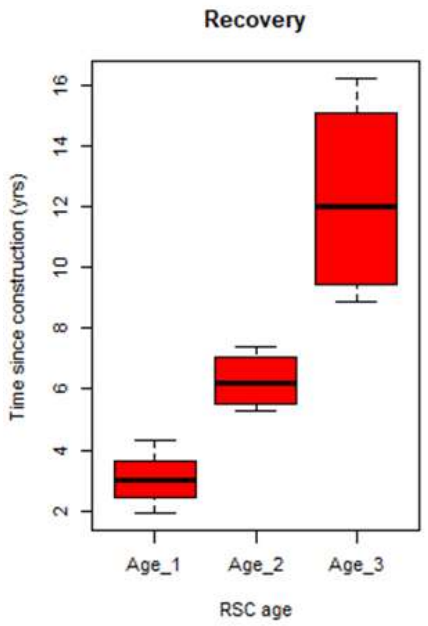
Fish Abundance but not Diversity Increases with Time since RSC Construction

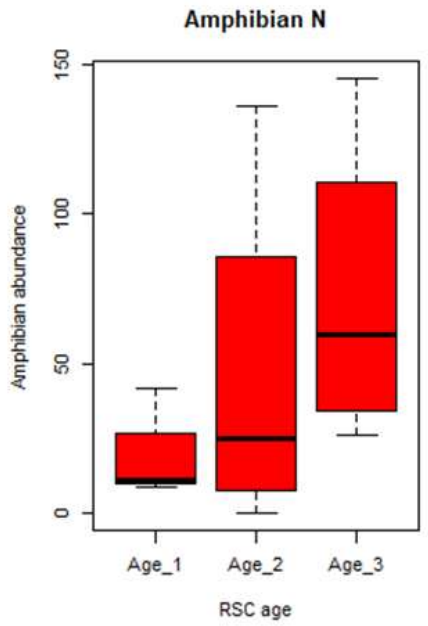


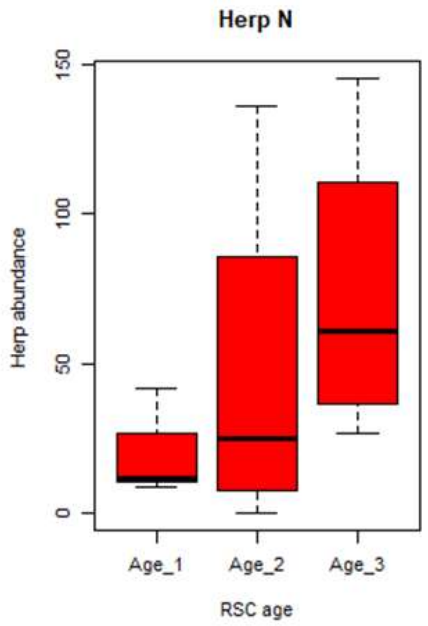


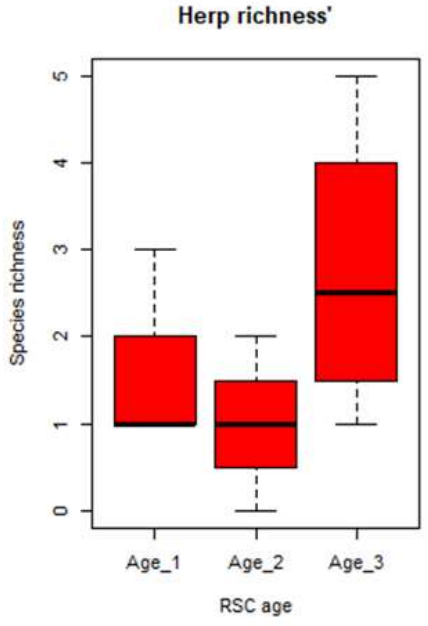
Age_1 = 1.9–4.3 yrs
Age_2 = 5.3–7.4 yrs
Age_3 = 8.9–16.2 y

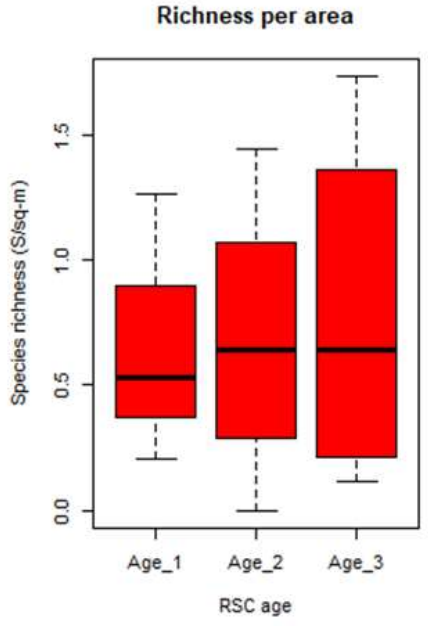
Herp Abundance and Diversity Increases with Time since RSC construction

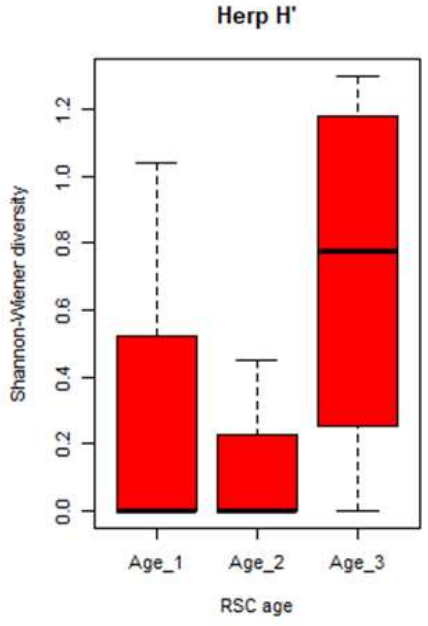




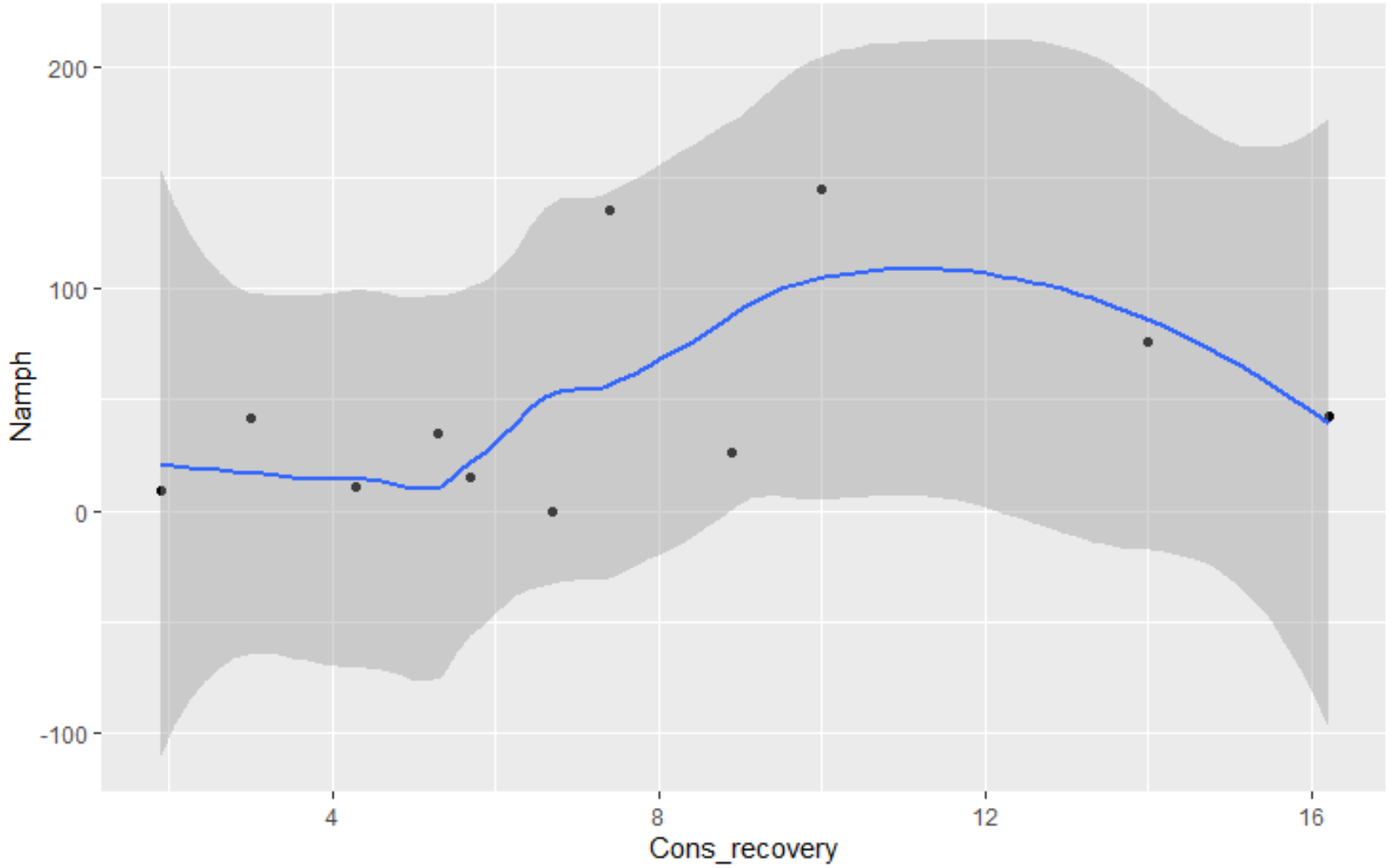








Herp Abundance takes 8 years to Increase after RSC construction



Limits on Biological Uplift from Proximity of Source Populations

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Biological Data

- Benthic Index of Biotic Integrity (BIBI) converted to single 1-5 scale
- MBSS or comparable Montgomery County sampling methods in Central Maryland
- 625 reference sites with distance to restoration sites calculated along stream network
- Reference defined as BIBI of 2.75 (comparable to non-impaired)

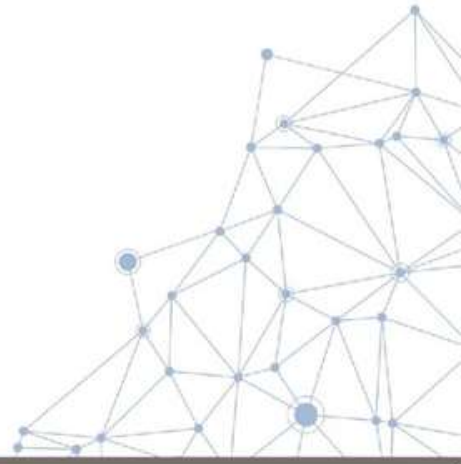
Restoration Site Data

- 30 restoration sites with biological data
  - Anne Arundel
  - Baltimore County
  - Carroll County
  - Frederick County
  - Harford County
  - Howard County
  - Montgomery County
- 18 sites with post-construction data
- 12 sites with sampling ≥ 2 years post construction and ≥ 3 references sites

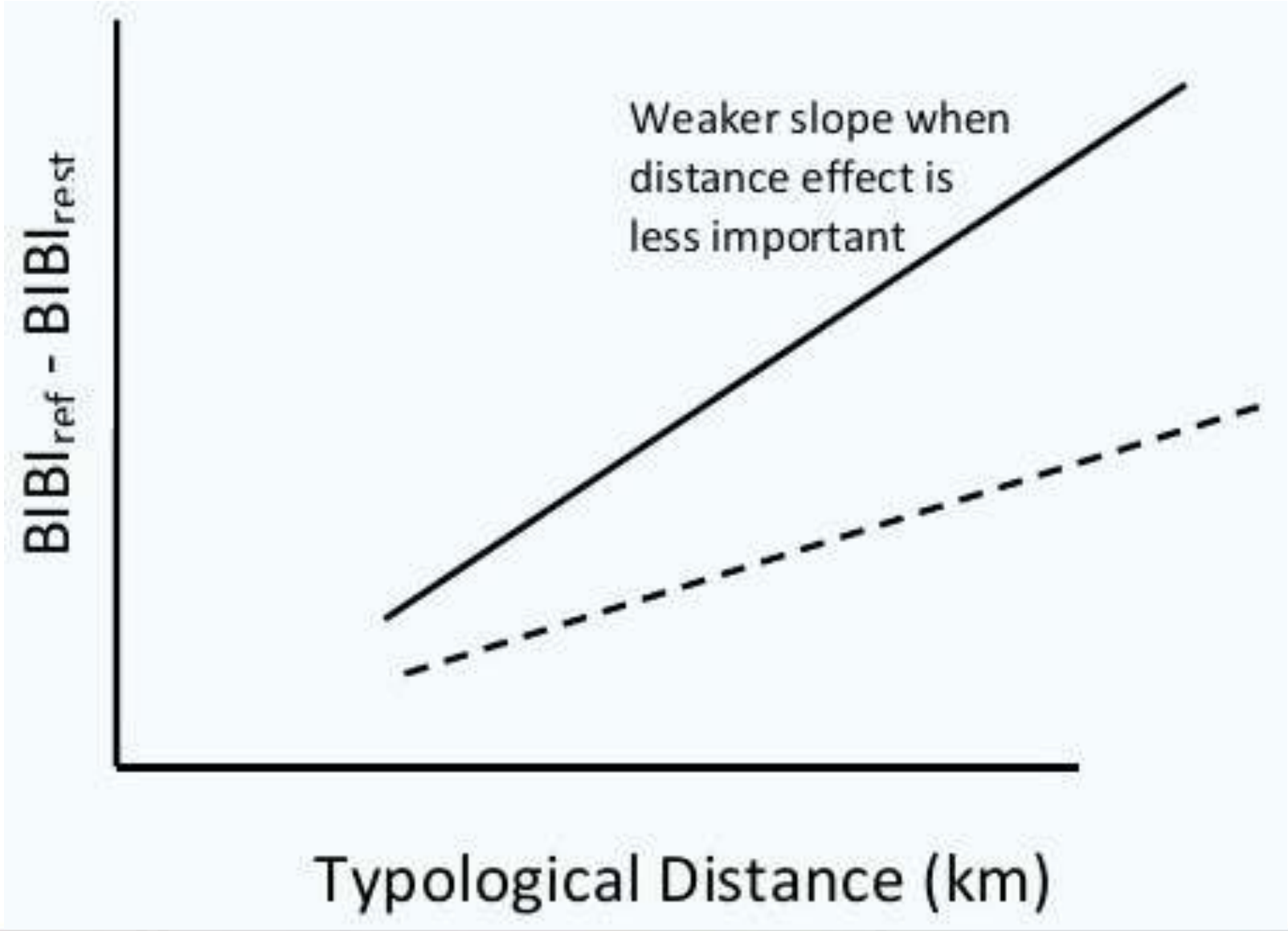
Thanks to all our partners

Methods

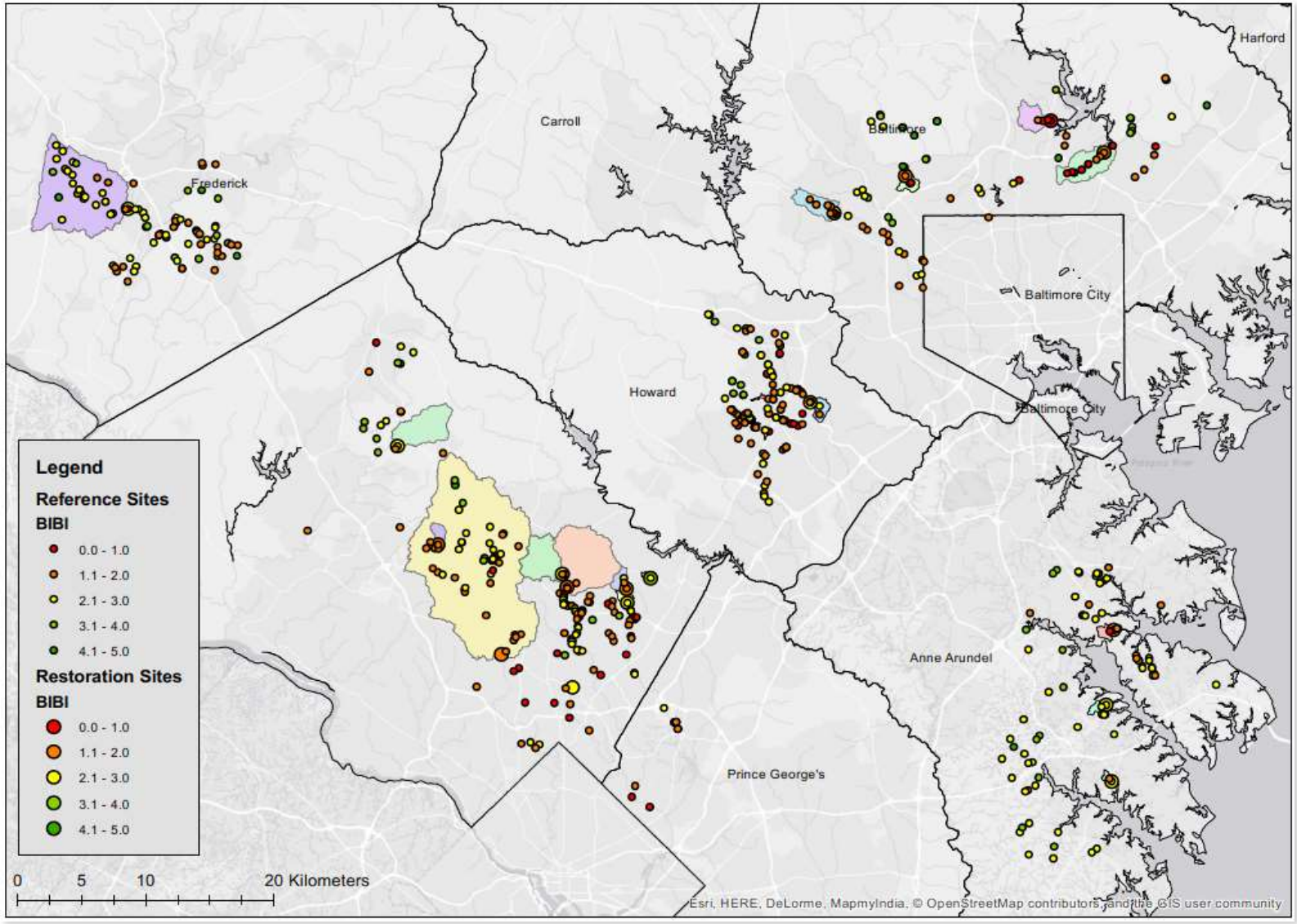
- Distance between restorations and reference sites within a 15-km radius of the restoration site (Sunderman et al. 2011)
- Calculated shortest along-stream-network (typological) distance between the restoration site and each reference site
- Calculated the difference in BIBI scores (BIBIref – BIBIrest)
- Regressed the degree of difference in BIBI scores against typological distance
- Multiple regression accounting for
  - Distance between reference and restoration sites
  - Times sampled at reference and restoration sites
  - Drainage area of reference site



Analytical Approach



Restoration and Nearby Reference Sites



Restoration Site Sampling

Site	Year Restored	Eco Region	County	DA (ac)	IA (%)	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Wilelinor	2006	Coastal Plain	Anne Arundel	151.40	30.04								2.14	1.57	1.86	3.00	1.86	2.14	2.14	2.71	2.14	
Howards Branch	2000	Coastal Plain	Anne Arundel	247.38	1.05								1.86	2.43	2.14	2.71	2.71	2.71	2.43	2.71	3.00	
Dividing	2015	Coastal Plain	Anne Arundel	257.70	18.46											2.71	2.14	2.43	2.14	1.86		
Cypress	2013	Coastal Plain	Anne Arundel	275.70	38.80										1.57	1.57	1.57	1.86	2.14		1.57	
Muddy Branch	2016	Coastal Plain	Anne Arundel	364.17	1.39															3.86	3.86	1.29
Woodvalley	2005	Piedmont	Baltimore	392.49	10.64											2.00	1.67	1.67				
Spring Branch	2008	Piedmont	Baltimore	1006.08	14.73											1.67	1.67	1.00	1.00			
Scott's Level	2014	Piedmont	Baltimore	1150.06	22.18												1.33	1.00	1.00		3.00	
Minebank Run	2014	Piedmont	Baltimore	2121.17	15.08											1.33	1.33	2.33	1.00	1.00		
Piney Run	2016	Piedmont	Carroll	9483.48	16.47															2.67	2.33	2.33
Little Tuscorora	2016	Piedmont	Fredrick	3575.69	4.72														3.00	3.00	3.00	3.00
Ballenger Creek	2007	Piedmont	Fredrick	9731.18	6.79				2.00	2.50	2.75	2.50	2.25	2.75	3.25	3.00	2.50	2.50		2.50		
Wheel Creek	2016	Piedmont	Harford	432.09	23.66							1.00			2.67	3.00	2.33	1.33	2.00	1.00	2.70	2.70
Red Hill Branch Lpax	2012	Piedmont	Howard	52.55	12.74											2.67	1.67	1.67	2.00	2.00	2.33	
Dorsey Hall Lpax	2015	Piedmont	Howard	3701.69	19.30															2.67	3.00	
Batchellors Run East	2013	Piedmont	Montgomery	568.46	3.15					4.00					3.00							
Breewood Tributary	2015	Piedmont	Montgomery	51.80	31.79											1.75	2.25	1.75	2.00	1.00		2.50
Bryants Nursery Run	2013	Piedmont	Montgomery	315.14	5.05					2.25					3.50							
Goshen Branch	2013	Piedmont	Montgomery	2494.13	1.29						2.67	2.67			2.67	3.00					2.33	
Gum Springs Trib	2013	Piedmont	Montgomery	232.47	8.10						1.67	2.67			2.00		2.67				2.33	
Hollywood Branch	2015	Piedmont	Montgomery	388.54	16.47											1.50		1.50				
Left Fork Paint Branch	2013	Piedmont	Montgomery	81.79	9.71								2.67			4.00					3.67	
Lower Donnybrook	2015	Piedmont	Montgomery	221.63	36.85												1.25	1.00	2.25			
Mill Creek and Tribs	2013	Piedmont	Montgomery	329.43	17.64						2.00	1.00				1.00	1.67				1.33	
Northwest Branch	2013	Piedmont	Montgomery	7104.02	5.19										2.33					2.00	2.67	
Northwest Branch - Batchellors Run I & II	2013	Piedmont	Montgomery	2136.67	3.82					2.50					2.25					2.00		
Sherwood Forest	2014	Piedmont	Montgomery	552.88	9.94					2.00					1.25							
Turkey Branch - Rock Creek NW Branch	2007	Piedmont	Montgomery	26129.05	14.64			1.50				1.50			1.00		2.00	1.25				
Upper Northwest Branch	2013	Piedmont	Montgomery	3310.82	6.51		3.25			1.75					3.00							
Upper Right Fork Paint Branch	2013	Piedmont	Montgomery	473.25	6.68						3.33	1.33			1.00	1.67					2.00	

Pre-restoration *Restoration Year* *Post-restoration*

Statistical Analysis

Two Analyses:

- Mixed-effects model regression of differences in BIBI scores (BIBIref – BIBIrest) considering the effects of (1) site alone, (2) typological distance between restoration and reference sites, (3) differences in year of sampling between sites, (4) size of drainages to sites, and (5) all interaction terms
- Simple linear regressions of difference between reference streams (BIBI ≥ 2.75) and the BIBI of the monitoring sites

Distance to Good Sites is Significant

SOV	Estimate	Standard Error	t	P
(Intercept)	**5.42E-01**	**1.64E-01**	**3.307**	**0.001231**
Site-Cypress	**8.61E-01**	**1.52E-01**	**5.673**	**9.11E-08**
Site-Goshen Branch	3.49E-01	1.79E-01	1.946	0.053923
Site-Gum Springs Trib	1.02E-01	2.98E-01	0.341	0.733395
Site-Howards Branch	-4.32E-01	2.37E-01	-1.822	0.070759
Site-Left Fork Paint Branch	**-1.21E+00**	**3.59E-01**	**-3.375**	**0.000983**
Site-Mill Creek and Tribs	**1.45E+00**	**1.77E-01**	**8.181**	**2.62E-13**
Site-Northwest Branch	-9.16E-02	2.18E-01	-0.42	0.674883
Site-Red Hill Branch Lpax	**4.72E-01**	**1.54E-01**	**3.068**	**0.002639**
Site-Spring Branch	**1.76E+00**	**2.03E-01**	**8.644**	**2.09E-14**
Site-Turkey Branch-Rock Creek NW	**1.06E+00**	**2.08E-01**	**5.086**	**1.29E-06**
Site-Upper R Fork Paint Branch	4.69E-01	3.59E-01	1.306	0.19401
Site-Wilelinor	**3.64E-01**	**1.80E-01**	**2.026**	**0.044836**
Site-Woodvalley	**1.89E+00**	**1.79E-01**	**10.543**	**< 2e-16**
Distance	**3.16E-05**	**1.38E-05**	**2.296**	**0.023345**
Drainage	-6.35E-06	1.39E-05	-0.457	0.648374
Years	-5.25E-03	9.48E-03	-0.553	0.581087

Mixed-effects model regression of differences in B-IBI scores (BIBIref – BIBIrest) against sites, typological distance between restoration and reference sites, differences in year of sampling between sites, and size of drainages to sites. Multiple $r^2 = 0.71$.

Distance to Good Sites is Significant

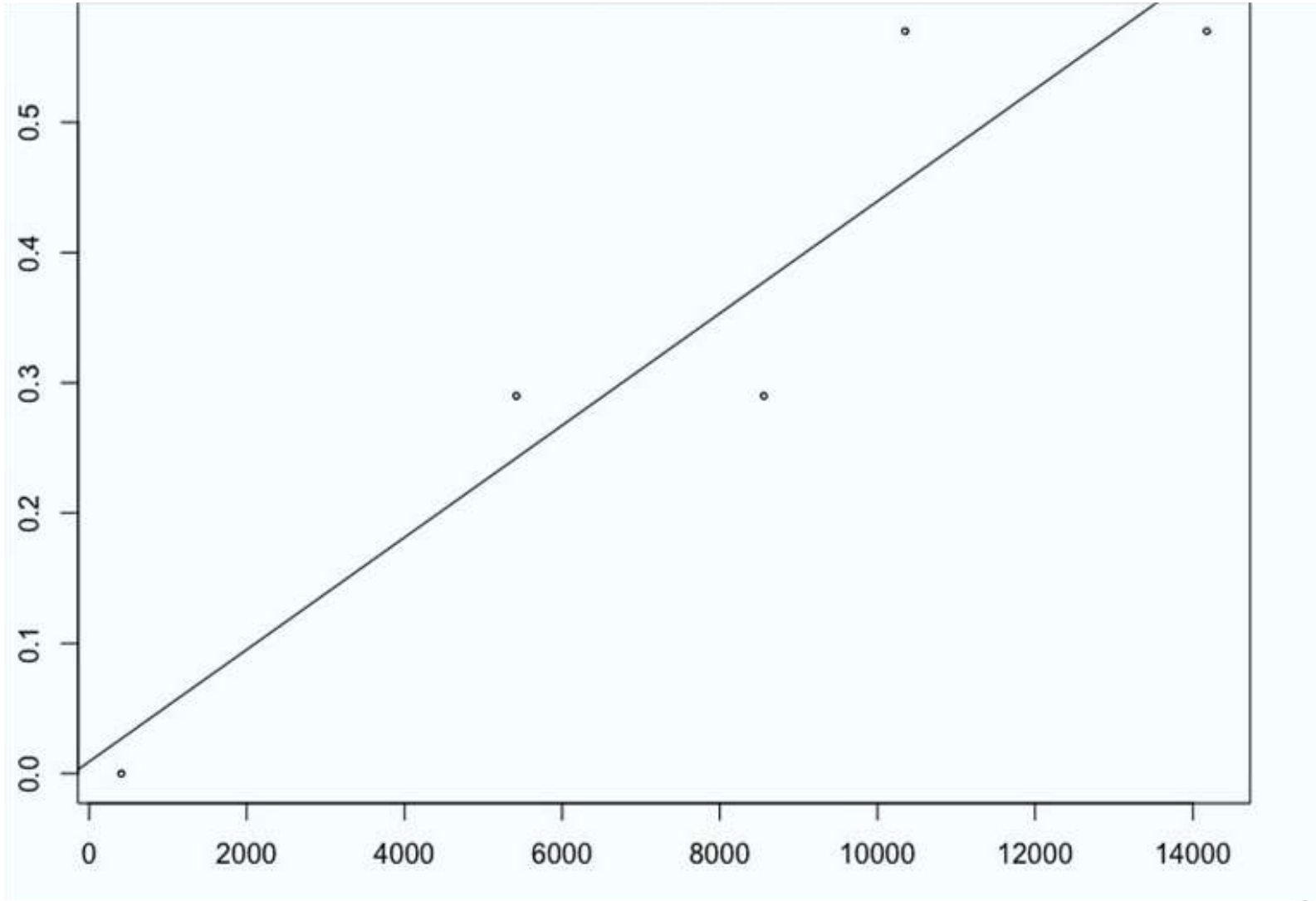
- Significant site effects
- Significant effect of distance to reference site at p=0.023
- Year difference with reference site, catchment size, and interactions were not significant, so were removed for parsimonious model (multiple r^2=0.71)

Only 4 of 12 Sites Show Uplift

Site	Intercept	Slope	p	r^2
Ballenger Creek	0.22	6.00E-05	0.012	0.17
Cypress	0.88	8.40E-05	0.09	0.2
Goshen Branch	1.1	-1.75E-06	0.96	0.0003
Gum Springs Trib	0.84	-1.10E-05	0.77	0.13
Howards Branch	0.009	4.30E-05	0.02	0.88
Mill Creek and Tribs	1.9	3.36E-05	0.59	0.03
Northwest Branch	0.94	-4.20E-05	0.71	0.04
Red Hill Branch	0.21	1.00E-04	0.01	0.38
Spring Branch	3.6	-1.10E-04	0.05	0.55
Turkey Branch	3.9	1.00E-04	0.43	0.12
Wilelinor	0.02	1.03E-04	0.26	0.15
Woodvalley	2.8	-5.40E-05	0.41	0.06

Best Example of Biological Uplift

Howards Branch
>1 year post Restoration



Significant Proximity Effect with More Years Post Construction

- 4 sites with significant effect of proximity of good streams were sampled 3, 5, 7, and 15 years post construction
- 8 sites with non-significant proximity effect were sampled 6, 5, 5, 2, 2, 2, 2, 2 years post construction
- In general, the longer the site was sampled post-construction, the more likely was a significant proximity result

Conclusions

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Poor Biological Uplift

- Benthic macroinvertebrate diversity was lower in NCDs and RSCs than upstream references
- Fish IBI was lower in RSCs than high-quality streams, with RSCs non-significantly higher than low-quality streams
- Fish and frog abundance in RSCs are higher than both low- and high-quality streams

Factors Affecting Biological Uplift

Habitat

Flow

Water Quality

Time to Mature

Proximity to Sources

Habitat is Not Limiting

- Physical Habitat Index (PHI) exceeds upstream references in both NCD and RSCs
- RSCs are similar to regional references in 10 of 12 habitat features (except cobbles and buffers)
- RSCs recreate stream-wetland structure (such as width and depth) typical of high-order streams in reaches that are low-order

Flow and Water Quality Remain Limiting

- Vertebrate uplift in RSCs appears constrained by continuing poor water quality
- RSCs do not attain reference DO and conductivity
- Reference flow levels may or may not be obtained

Uplift Improves with Time

- Benthic macroinvertebrate IBI slight but non-significant increase after 7 years
- Fish abundance but not diversity increases with time since RSC construction
- Herp abundance and diversity increase with time since RSC construction
- Number of frogs in RSCs increases over 8 years and then plateaus

Source Populations Improve Uplift

- Benthic macroinvertebrate IBIs in stream restorations were variable. but significantly higher in restorations closer to other healthy streams
- Proximity to source effect become significant between 3-7 years post construction
- Potential for biological uplift from restoration is limited by proximity of source populations—i.e., “if you build it, they may not come”

Lessons for Restoration Success

- Biological uplift requires uplift in other stream functions, i.e., ecological uplift
- Need to consider all potentially limiting factors—habitat, flow, water quality, time, and source populations
- Consider guidelines for restoration that incorporate good streams as "stepping stones" to facilitate dispersal from more remote species pools to recolonize restorations
- Temper expectations for biological uplift from stream restoration projects, especially in urban settings with poor water quality
- Refinements to stream restoration design may improve biological trajectories, but our understanding of ecological states may also limit uplift

Lessons for Monitoring

- Both benthic macroinvertebrate and fish communities (and others if possible) should be monitored, because responses may differ
- Potential limiting factors should also be monitored (habitat, flow, water quality, time, source populations) to inform planning and design
- Site-specific improvement is best demonstrated with Before-After-Control-Impact (BACI) study design with 2 years monitoring prior to construction
- Independent monitoring may be warranted to ensure results are fully (and perceived as) objective

Questions

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