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Biological Response to Stream Restoration

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The State of the Science and Practice of Stream Restoration in the Chesapeake: Lessons Learned to Inform Better Implementation, Assessment and Outcomes

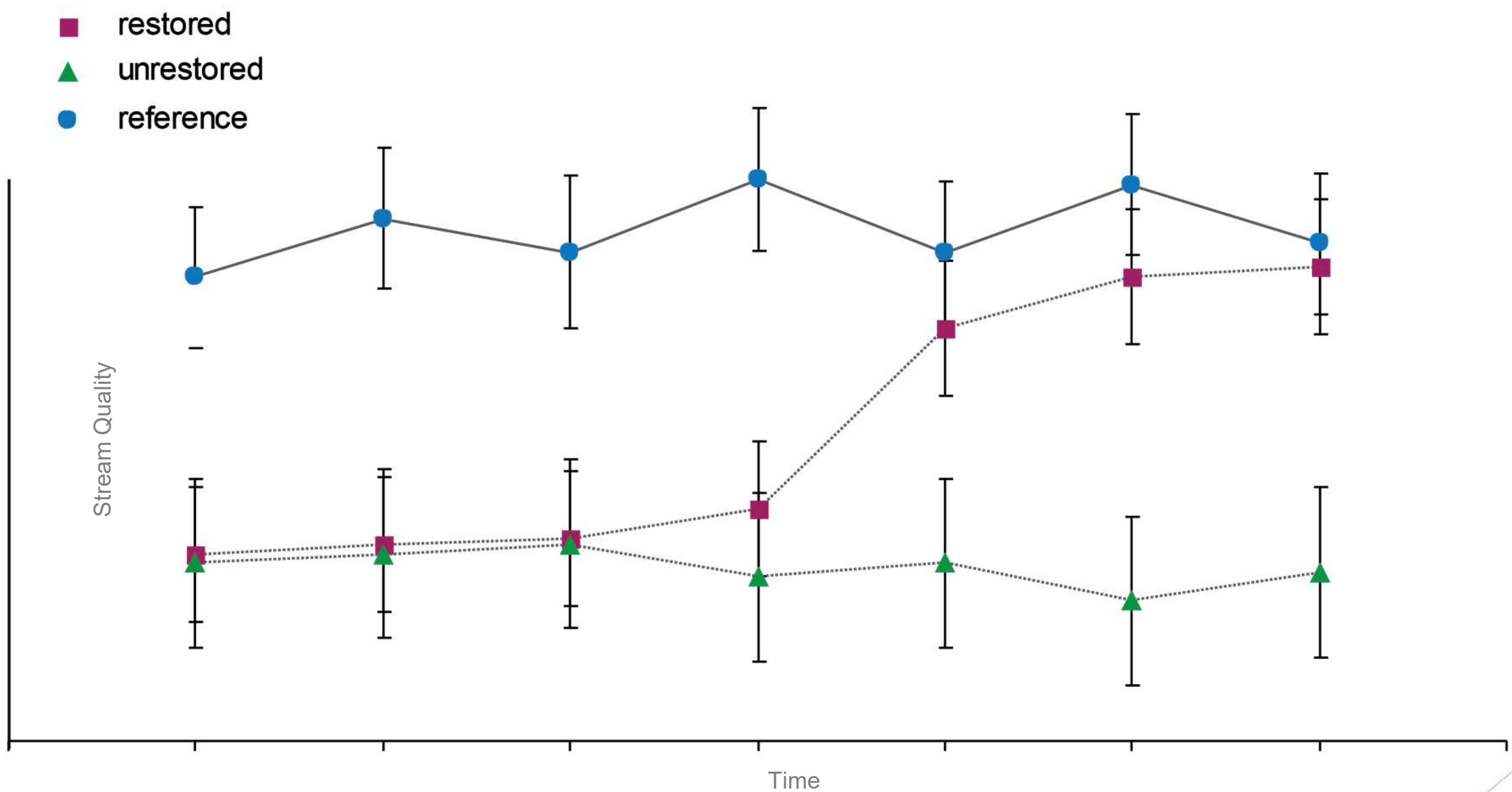
Scientific and Technical Advisory Committee

Chesapeake Bay Program
Science. Restoration. Partnership.

What's Up with Uplift

- Biological Uplift is Rare
- Limiting Factors are Many and Elusive
- Designs Should Address Limiting Factors
- Watersheds Determine Uplift Potential
- Threshold for Intervention Should be High

Goal of Biological Uplift from Restoration



Invertebrate Uplift is Rare

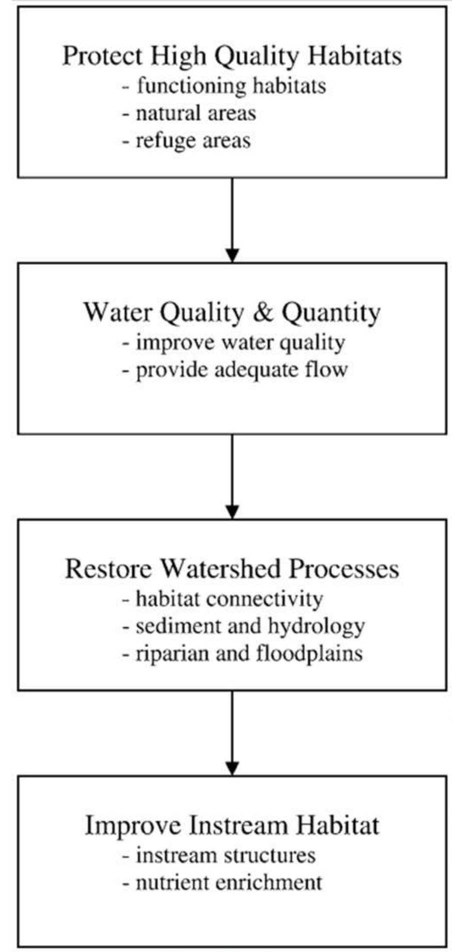
Palmer, M.A., H.L. Menninger, and E. Bernhardt. 2010. River restoration, habitat heterogeneity and biodiversity: a failure of theory or practice? *Freshwater Biology* 55: 205–222

- Only 2 of 78 stream or river restoration showed statistically significant increases invertebrate taxa richness data, though most projects enhanced physical habitat heterogeneity
- “Managers should critically diagnose the stressors impacting an impaired stream and invest resources first in repairing those problems most likely to limit restoration”

Fish Uplift is Rare

Roni, P, K. Hanson, and T. Beechie. 2008. Global Review of the Physical and Biological Effectiveness of Stream Habitat Rehabilitation Techniques. *North American Journal of Fisheries Management* 28:856-890

- 345 studies rarely demonstrated uplift, because of short duration and limited scope
- Reconnection of isolated habitats, floodplain rehabilitation, and instream habitat improvement sometimes increased local fish abundance
- Failure is attributable to inadequate assessment of historic conditions and factors limiting biota; poor understanding of watershed-scale processes; and monitoring at inappropriate spatial and temporal scales

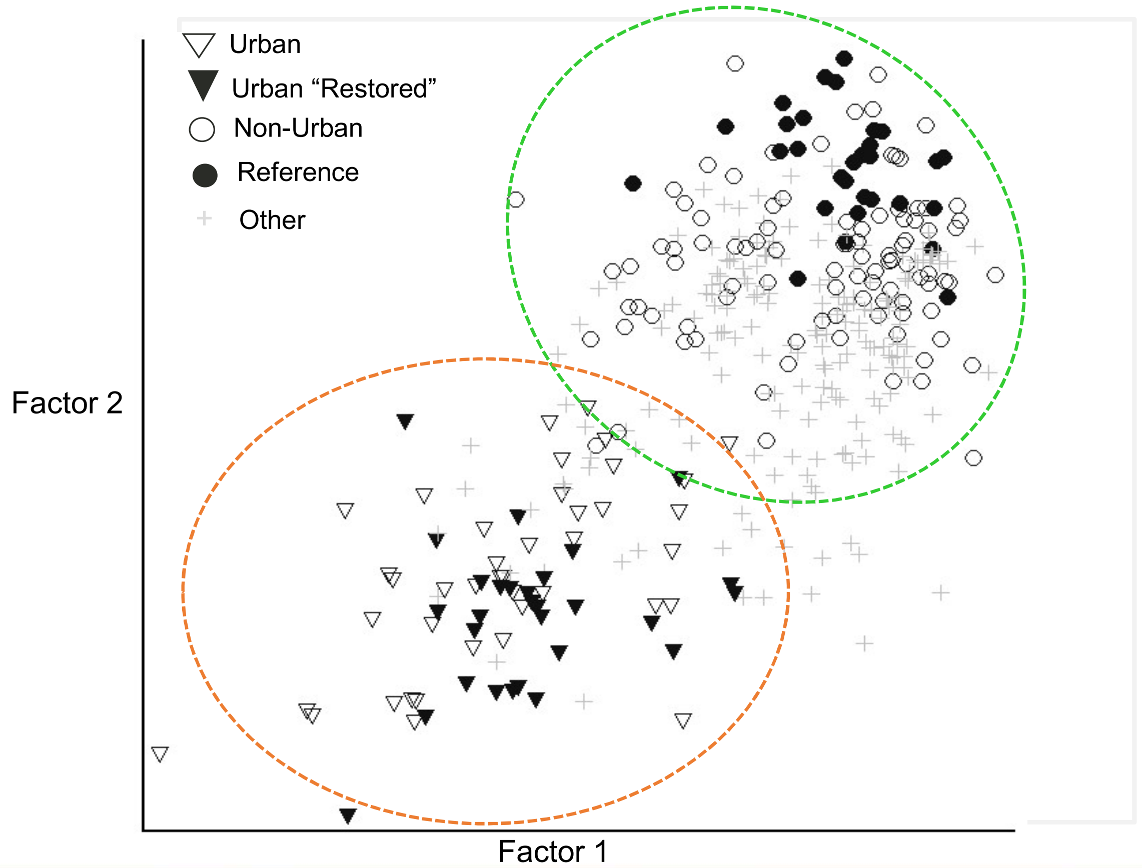


Biological Uplift in Chesapeake

- Stranko, S., R.H. Hilderbrand, and M.A. Palmer. 2012. Comparing the Fish and Benthic Macroinvertebrate Diversity of Restored Urban Streams to Reference Streams. *Restoration Ecology* 20:747–755
- Hilderbrand, R.H., J. Acord. 2017. Quantifying the ecological uplift and effectiveness of differing stream restoration approaches in Maryland. Chesapeake Bay Trust, Annapolis, MD
- Southerland, M. and C. Swan. 2017. Meta-Analysis of Biological Monitoring Data to Determine the Limits on Biological Uplift from Stream Restoration Imposed by the Proximity of Source Populations. Chesapeake Bay Trust, Annapolis, MD
- Southerland, M., B. Murphy, N. Roth, R. Woodland, and S. Filoso. 2021. Vertebrate Community Response to Regenerative Stream Conveyance (RSC) Restoration as a Resource Trade-Off. Chesapeake Bay Trust, Annapolis, MD

Urban Restoration Sites Cluster with Urban Sites

Scott Stranko



Restoration Sites Do Not Match Reference Sites

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CBTRUST
Chesapeake Bay Trust

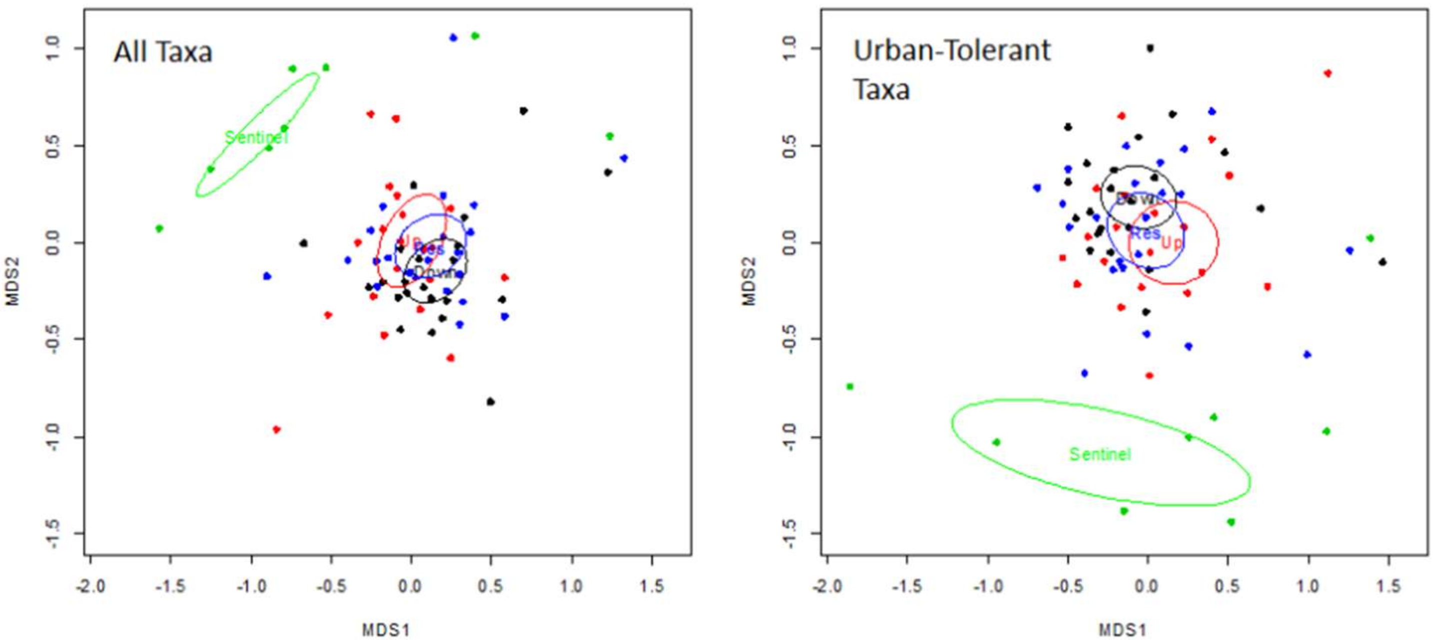


Figure 3. NMS ordination plot of benthic mcaronivertebrate community structure in Restored (blue), Upstream (red), and Downstream (black) sections compared with MBSS Sentinel Sites (green). Ellipses represent 95% CI around the centroid for each section.

Physical Habitat Improved but Not IBI

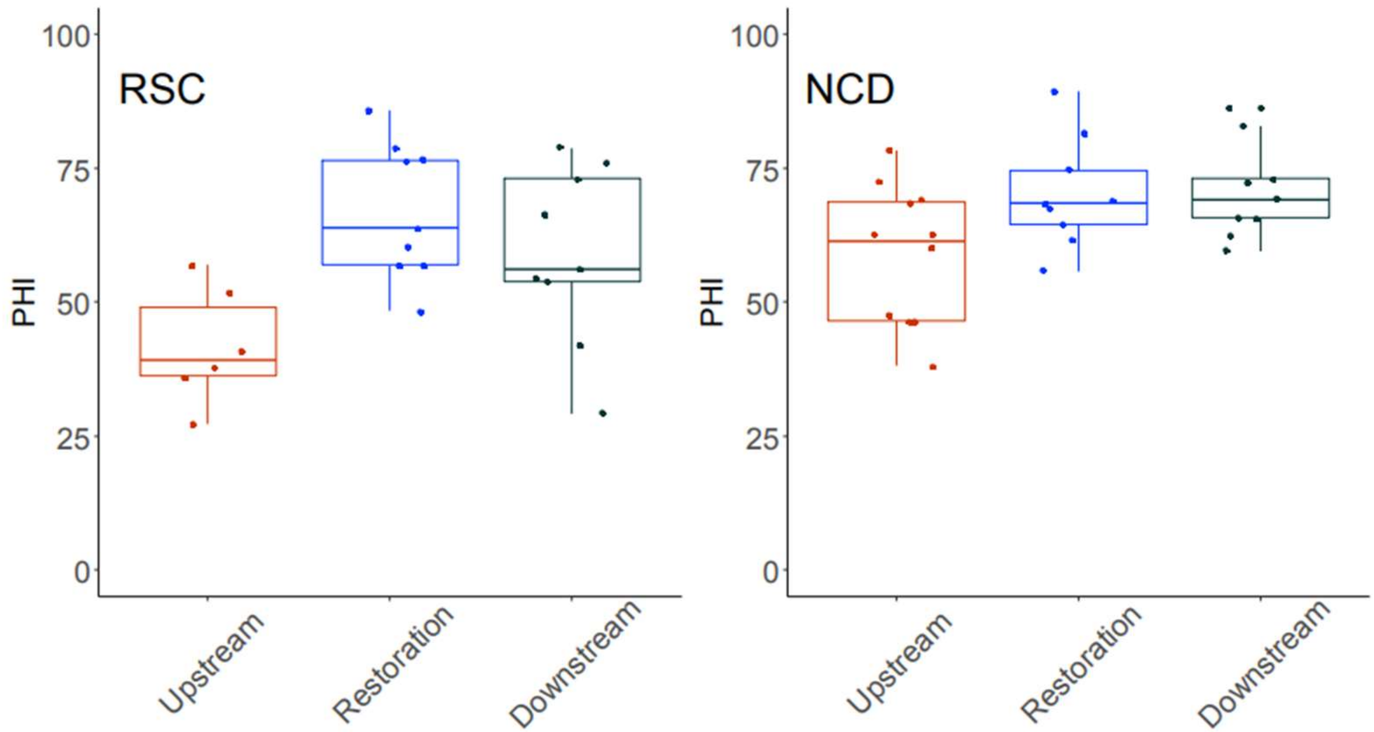
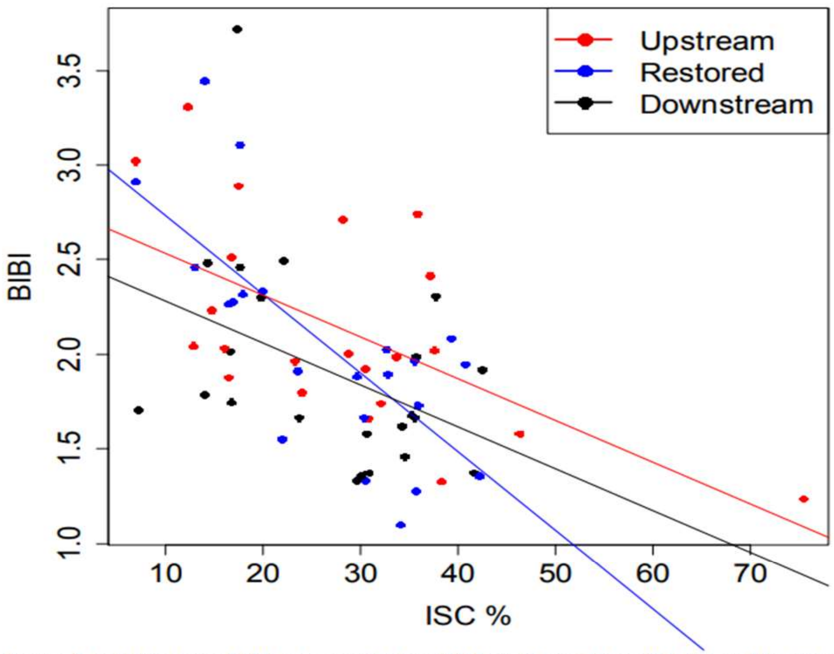


Figure 13. Physical Habitat Index scores for Upstream, Restored, and Downstream sections in Coastal Plain streams. Note that the figure does not incorporate the stream-specific effects that were modeled in the statistical analysis.

Restoration Sites Do Not Outperform Upstream Sites



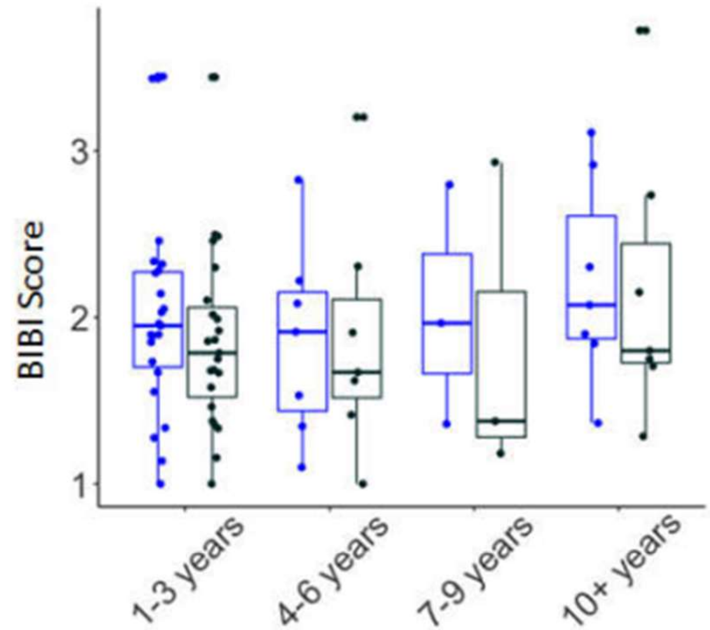


Figure 4. Relationship of BIBI scores in Restored (blue), Downstream (black), and Upstream (red) sections of Piedmont streams to %ISC in the watershed.

Vertebrate Community Trajectory in Regenerative Stream Conveyances

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Conceptual Model of Vertebrates in RSCs

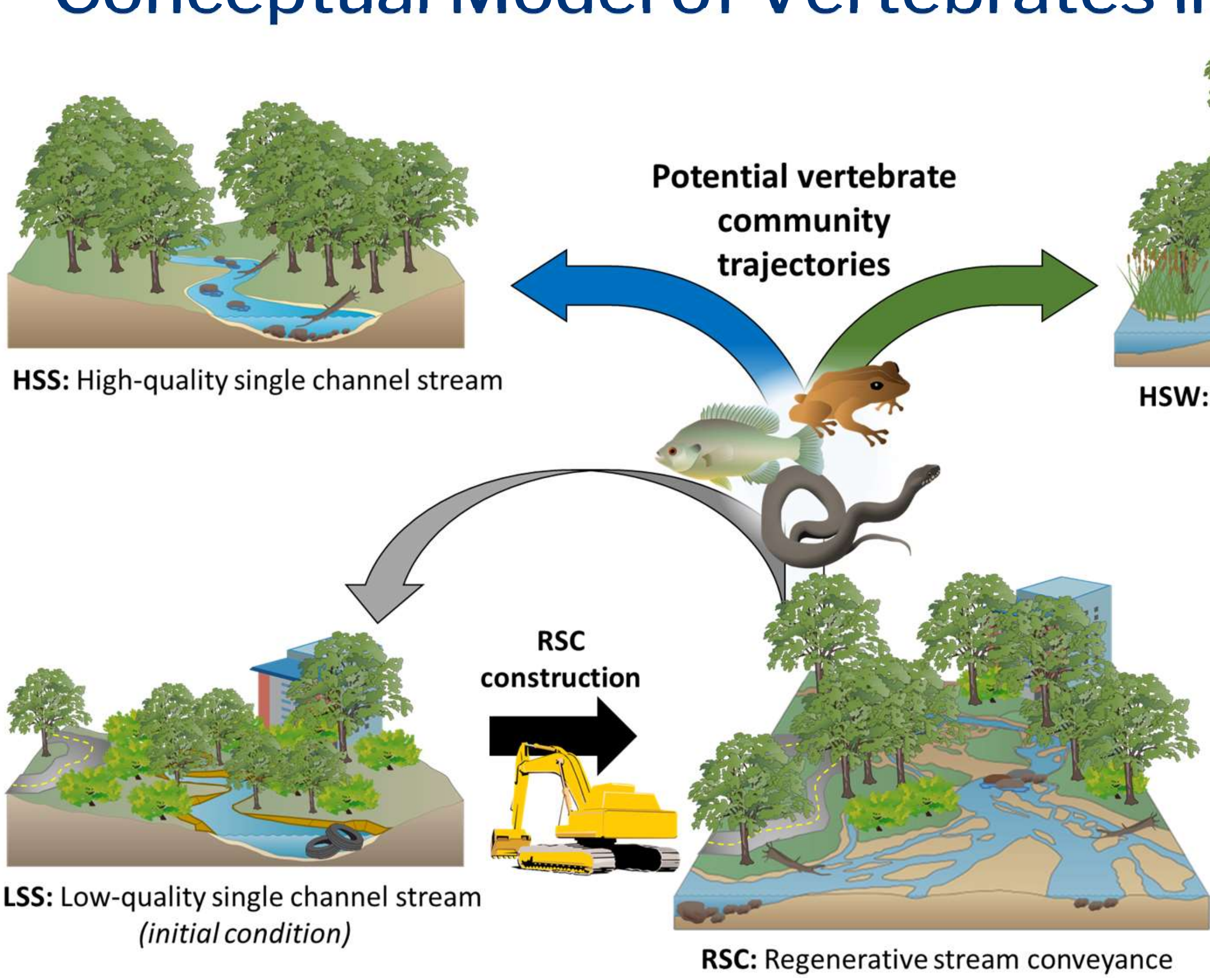
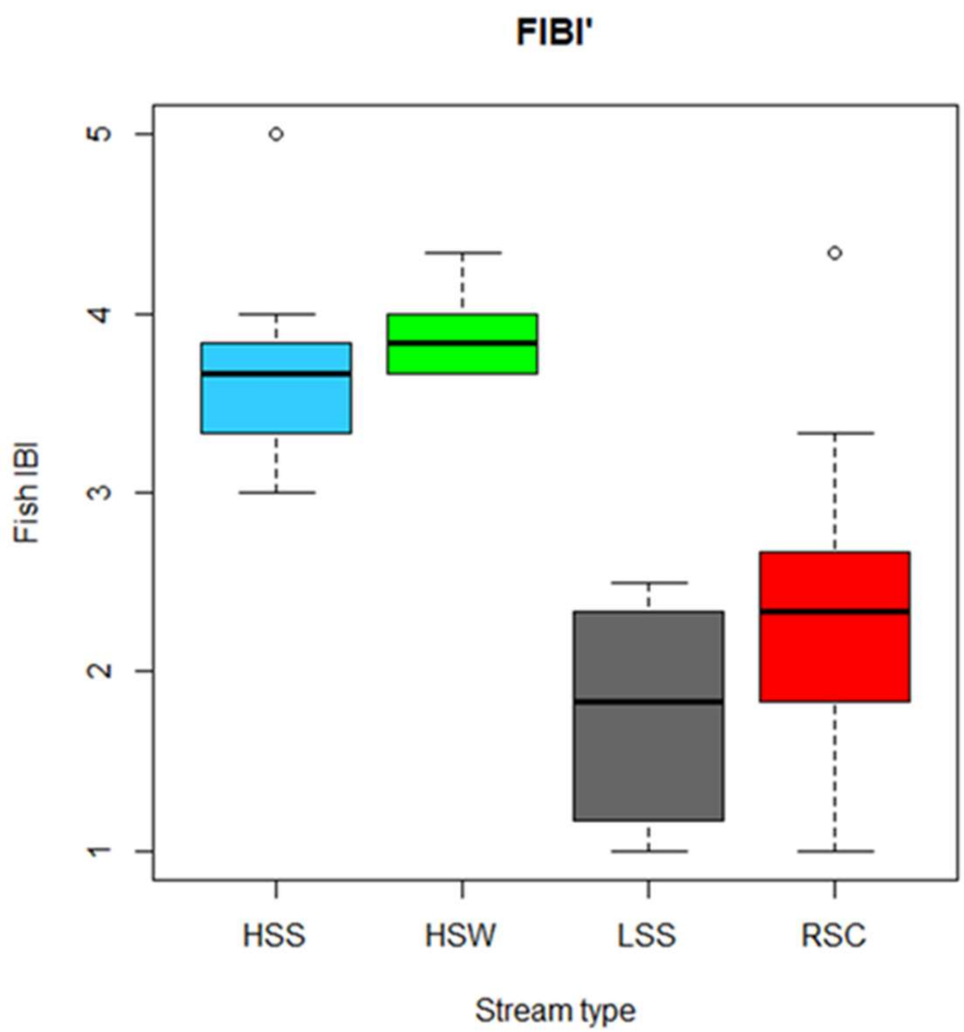


Figure 1. Graphical comparison of habitat-related differences associated with regenerative stream conveyance (RSC) construction relative to the putative initial condition (LSS: low-quality single channel stream), and reference conditions for three potential vertebrate community trajectories (HSW: high-quality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

RSC FIBI is Low



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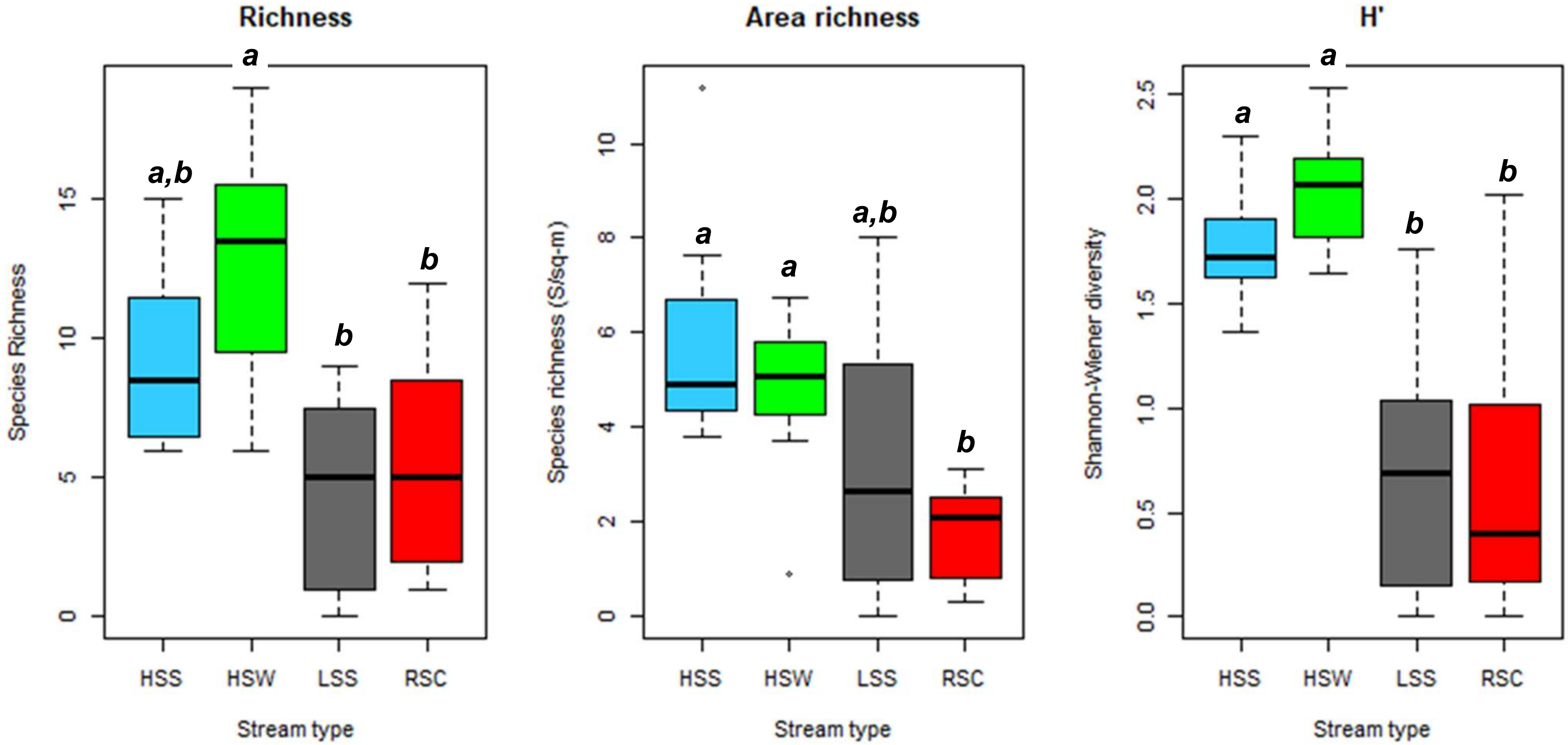
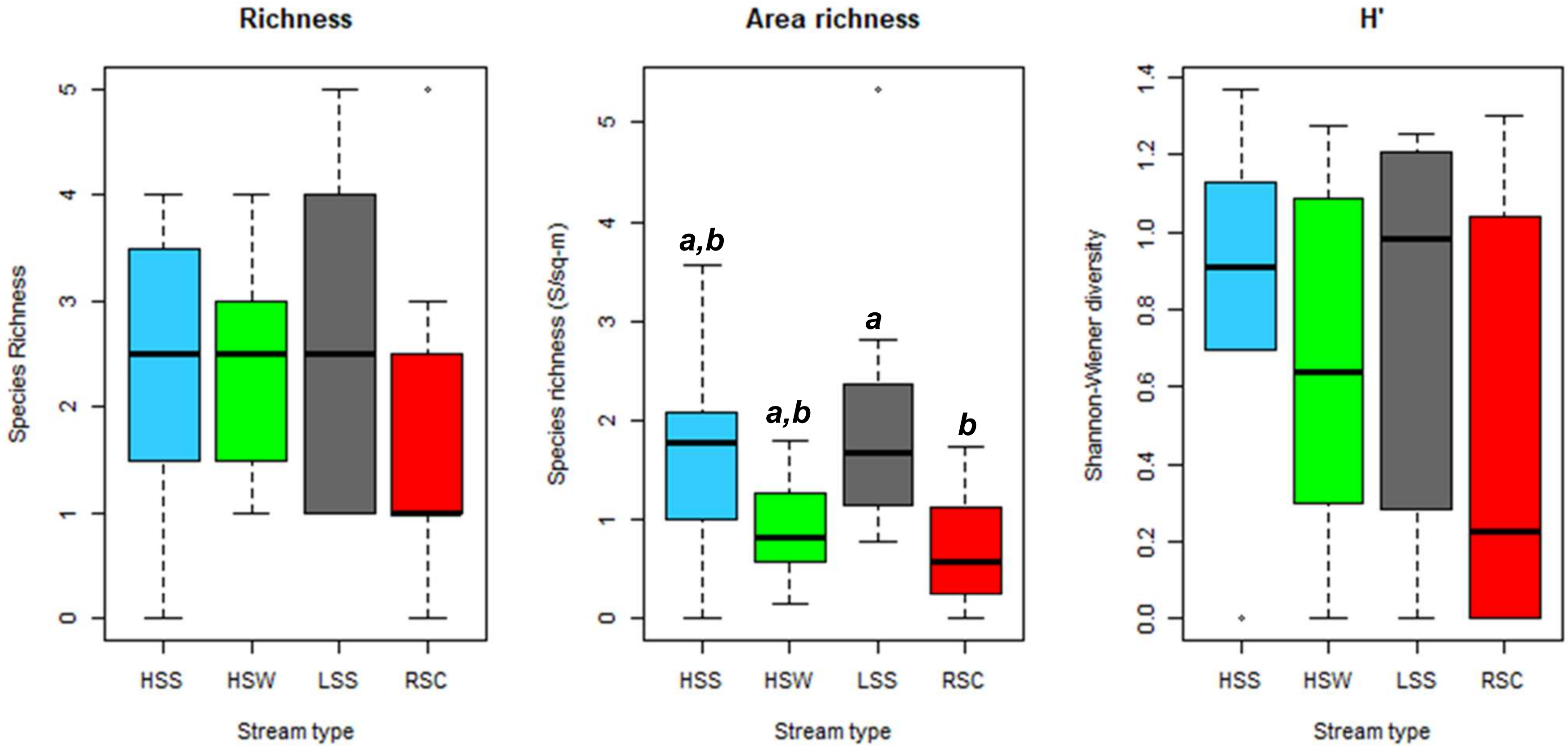
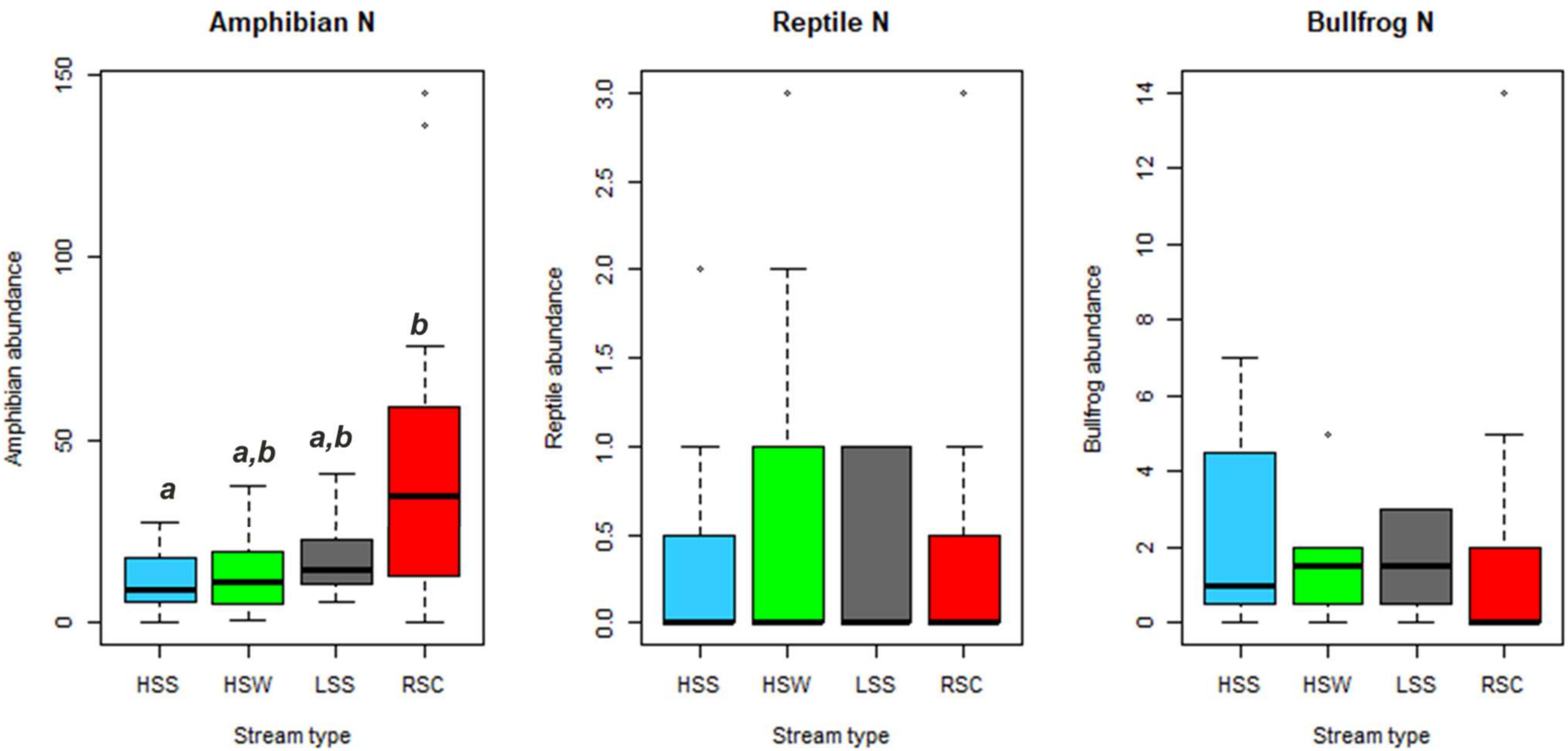
RSC Fish Diversity is Low



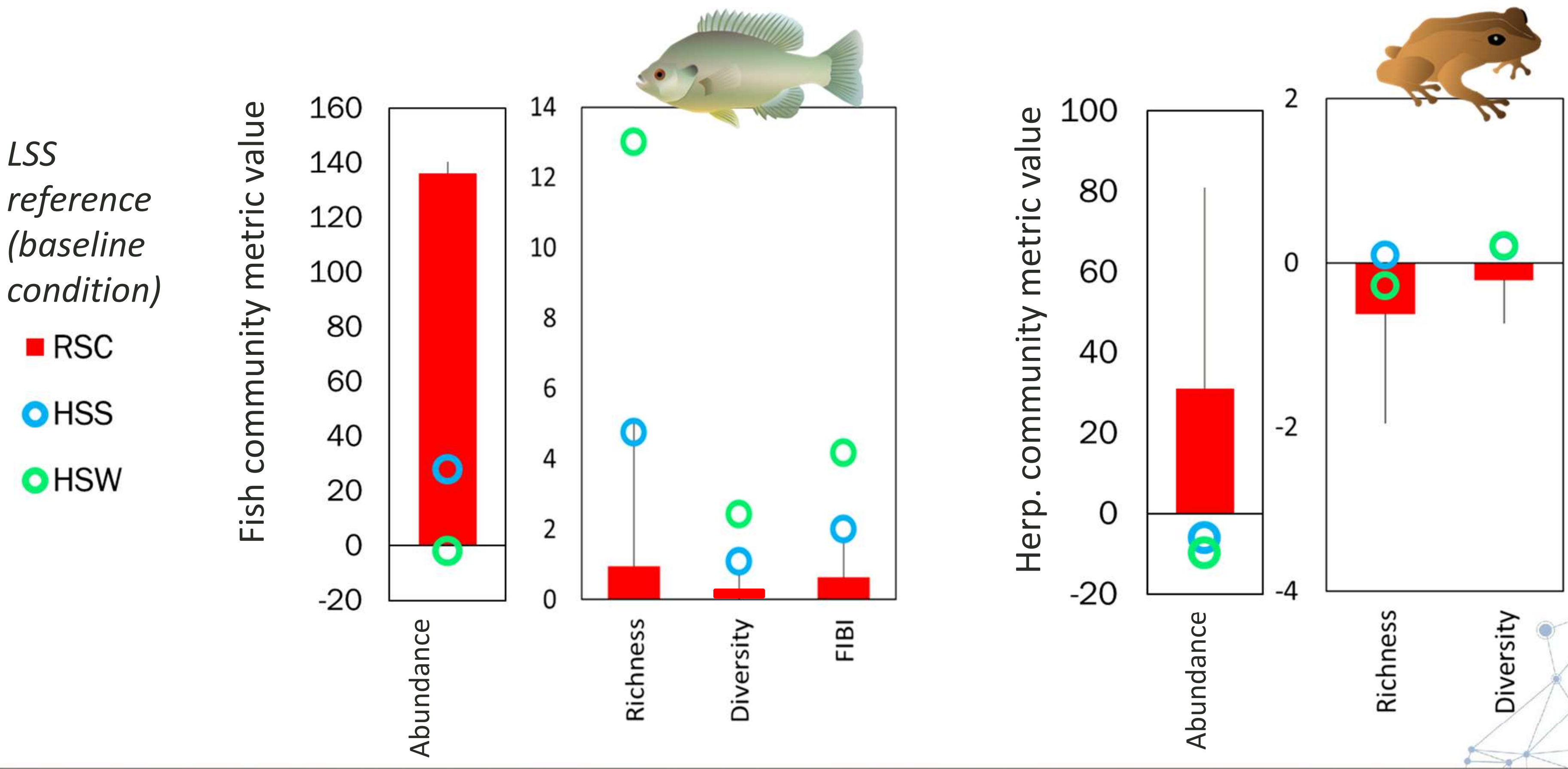
Herpetofauna Diversity is Similar



Frog Abundance in High in RSCs



RSC Vertebrate Abundance Increased



Biological Uplift – Limits of Study Designs

- Only a small proportion of projects are monitored
- Most are only monitored after construction, so must use reference sites that may
  - Be less degraded than site
  - Don’t have same history as site
  - Create variability that masks the signal
- Before-After-Control-Impact (BACI) study designs are preferable but very rare

Biological Uplift – Positive Examples

Dave Penrose on Invertebrates

- Foster’s Creek, NC
- Carolina Bison, NC
- Dodson Branch, NC

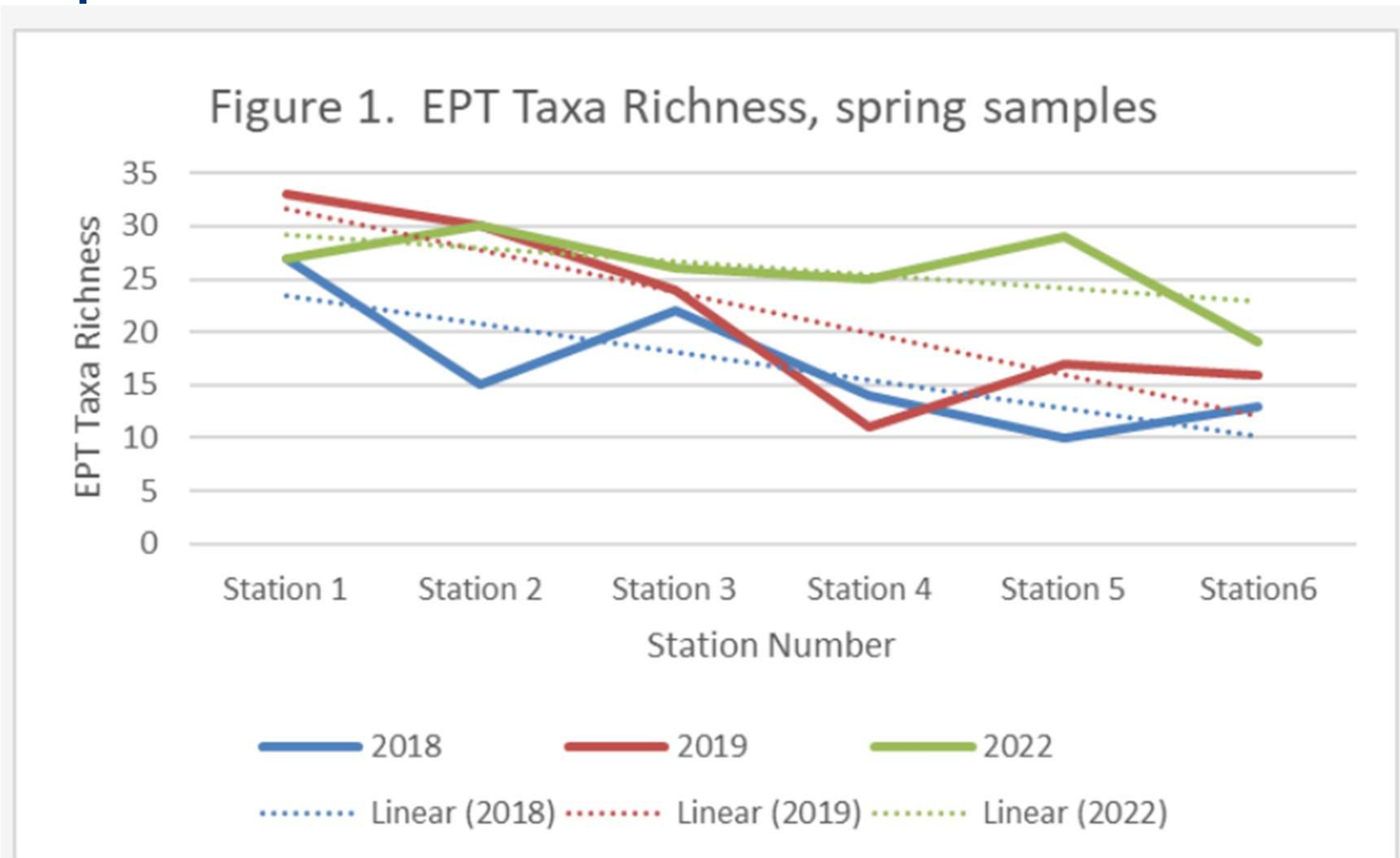
Bob Siegfried on Fish

- Timsbury Creek, VA
- Little Westham Creek, VA
- Protor’s Creek, VA

Amy Braccia on Stream-Wetland Complex

- Licking River Drainage, KY

EPT Uplift at Foster's Creek NC



Riparian Vegetation at Dotson Branch NC

	Dotson Branch Station #4			
	14-Apr-16	13-Apr-18	2-Apr-19	14-Apr-20
Total Taxa Richness	22	27	22	41
EPT Taxa Richness	4	9	8	16
Seasonal Correction	4	9	8	15
EPT Abundance	17	40	28	77
Biotic Index	5.74	5.11	5.62	4.65
Seasonal Correction	6.24	5.61	6.12	4.70
# Taxa ≤ 2.5	1	4	3	7
Bioclassification*	Fair	Good/Fair	Fair	Good

Riparian Wetland at Carolina Bison NC

	Carolina Bison #1		Carolina Bison #2	
Collection Date	Apr 2019	Apr 2022	Apr 2019	Apr 2022
Total Taxa Richness	11	33	19	31
EPT Taxa Richness	3	17	5	10
EPT Abundance	5	75	16	59
No. Intolerant Taxa	1	6	3	4
Dominant in Common	**12.5%**	**36.8%**	25.0%	26.0%

Blockage Removed

Timsbury Creek Results

	2017- Pre-constru	Post-constru	2019	2020
American Eel	X	X	X	X
Bluegill	X	X	X	X
Bluehead Chub	X	X	X	X
Creek Chub	X	X	X	X
Creek Chubsucker	X	X	X	X
Largemouth Bass	X	X	X	X
Red Breast Sunfish	X	X	X	X
Tesselated Darter	X	X	X	X
Yellow Bullhead	X	X	X	X
Chain Pickerel	X			X
Eastern mudminnow	X		X	
Pirate perch	X		X	X
Green Sunfish		X	X	X
Black Crappie		X		
Warmouth		X		
Mosquito fish			X	X
Smallmouth Bass				X
Brown Bullhead				X
Pumpkinseed Sunfish				X
Total individuals captured				
	114	91	203	153

Increased Riffle Habitat

Little Westham Creek Results

Little Westham Creek Fish Species Caught By Year - Restorations Reach

	2017- Pre-constructi	2019	2020	2021
Bluegill	X	X	X	X
Largemouth Bass	X	X	X	X
Eastern mosquitofish	X	X	X	X
Green Sunfish	X		X	X
Tessellated darter	X		X	X
Pumpkinseed	X		X	
Pirate perch	X			X
Yellow Bullhead	X			X
Warmouth	X			
American eel	X			
Central Stoneroller		X	X	X
Spotfin Shiner		X	X	X
Bluntnose Minnow		X	X	
Creek chub				X
Channel Catfish			X	
Gizzard Shad			X	
Red Breast Sunfish			X	
Total species captured				
	10	*6*	12	10
Total individuals captured				
	233	*205*	60	57

Increased Riffle Habitat to 50% of Channel

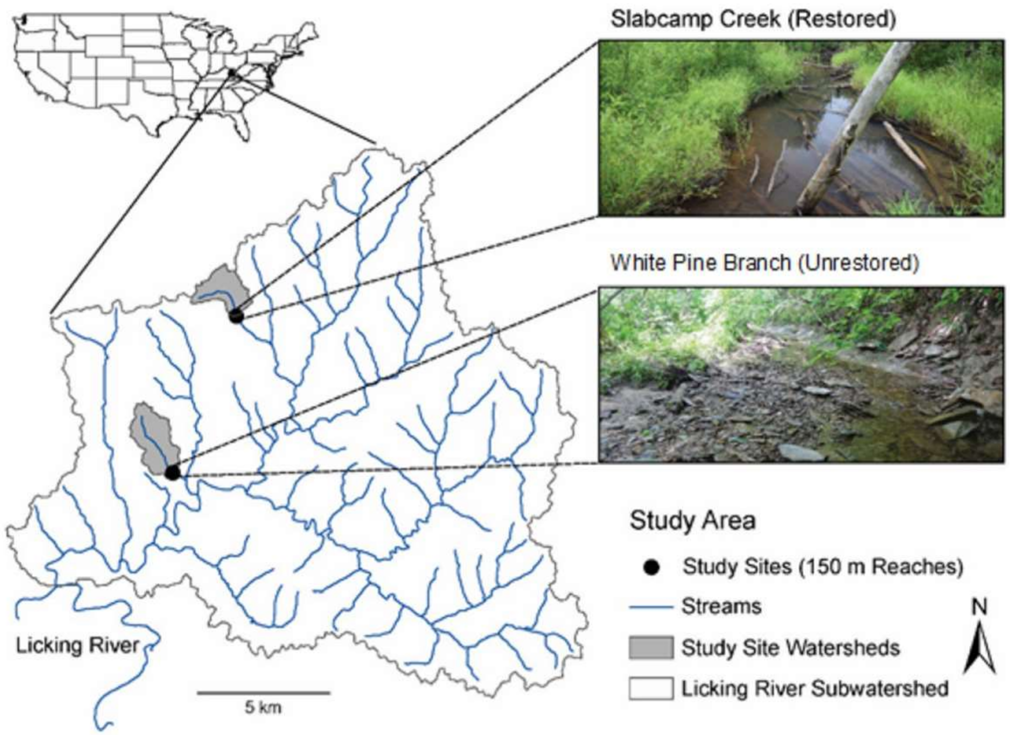
Buried Acid Soils

Proctors Creek Results

Proctors Fish Species Caught By Year - Restoration Reach 3	
2018 - Pre-construction	**2021- Post-construction**
Pirate Perch	Pirate Perch
Chain Pickerel	Chain Pickerel
Largemouth Bass	Largemouth Bass
American Eel	American Eel
	Bluehead Chub
	Mud minnow
	Creek chub
	Red Breast Sunfish
	Yellow Bulllhead
	Golden Redhorse
	Bluegill
	Mosquito fish
Total Individuals Captured	
9	37

Macroinvertebrate Uplift in Stream-Wetland Complex KY

Braccia, A., J. Lau, J. Robinson, M. Croasdaile, J. Park, and A. Parola. 2023. Macroinvertebrate assemblages from a stream-wetland complex: a case study with implications for assessing restored hydrologic functions. Environmental Monitoring and Assessment 195:394



- Macroinvertebrate density and biomass were consistently higher with EPT biomass from restored pools was 3-4x greater
- Importance of habitat-specific sampling designs that report the absolute abundance of potential biological indicators

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Biological Uplift of Hyporheic Taxa

Robertson, A.L., D.M. Perkins, J. England, and T. Johns. 2021. Invertebrate Responses to Restoration across Benthic and Hyporheic Stream Compartments. *Water* 13:996

Erica Gies. 2022. To Revive a River, Restore Its Liver: Radical reconstruction in Seattle is bringing nearly dead urban streams back to productive life. *Scientific American* April 1.

Hilderbrand, R.H., T. Bambakidis, and B.C. Crump. 2023. The Roles of Microbes in Stream Restorations. *Microbial Ecology*.

Biological Uplift of Hyporheic Taxa

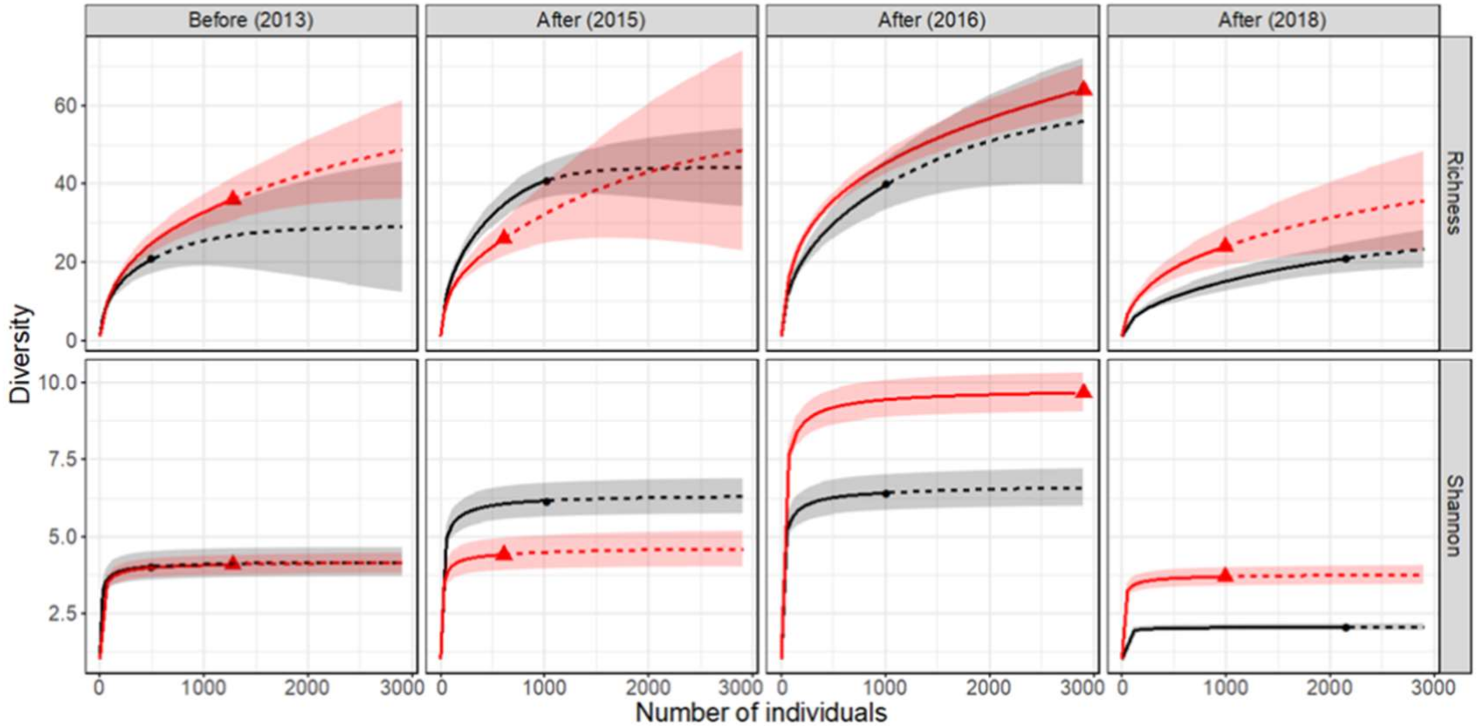

Figure 4. Sample-size based rarefaction (solid line segment) and extrapolation (dotted line segments) diversity curves for hyporheic assemblages in control (black) and impact (red) reaches of the River Lambourn pre and post restoration. The shaded areas represent 95% confidence intervals.

Limiting Factors are Many and Elusive

Habitat

Time to Mature

Flow

Water Quality

Proximity to Sources

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Vertebrate Community Trajectory in Regenerative Stream Conveyances

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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

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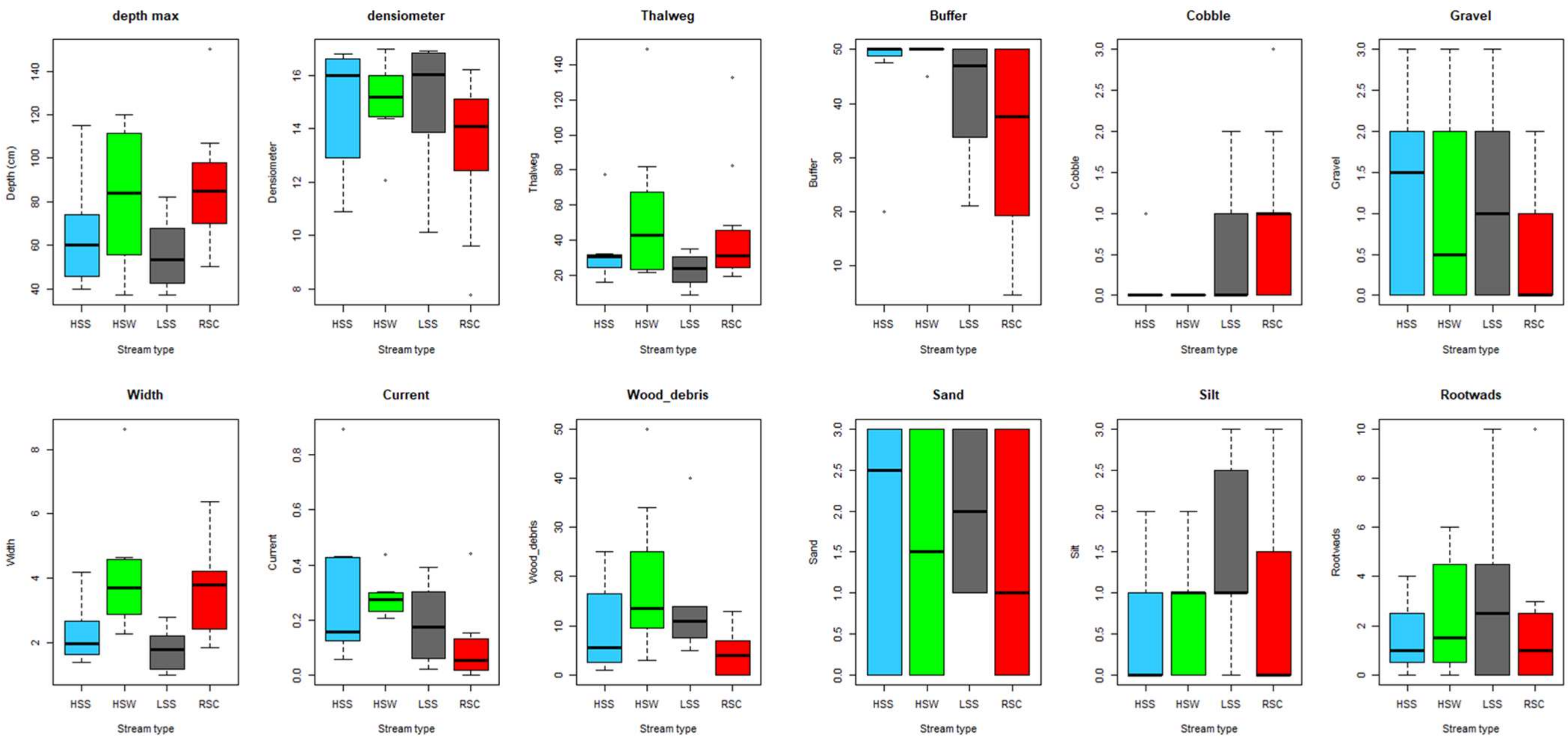
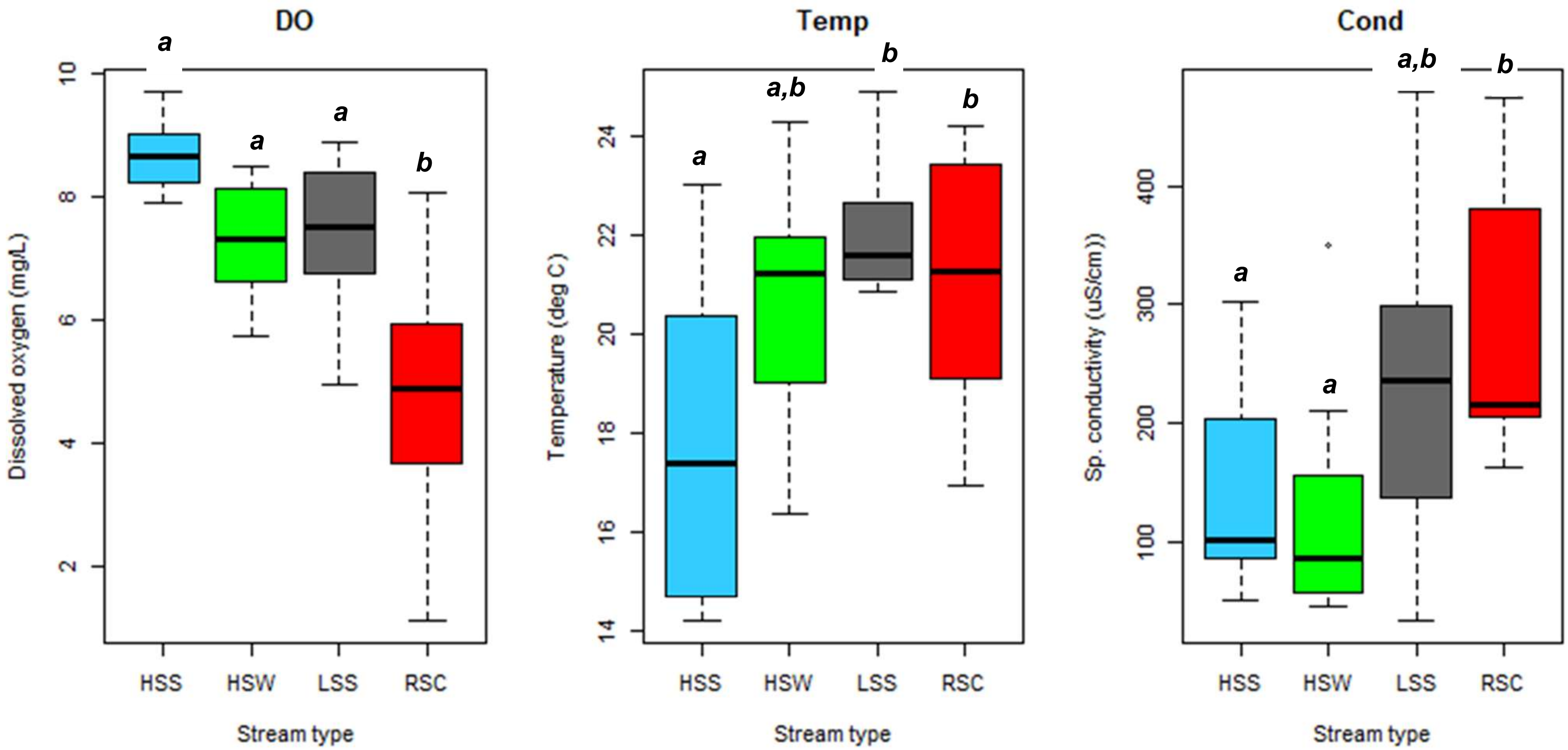
Habitat is Similar in RSCs (except for Buffers and Cobble)



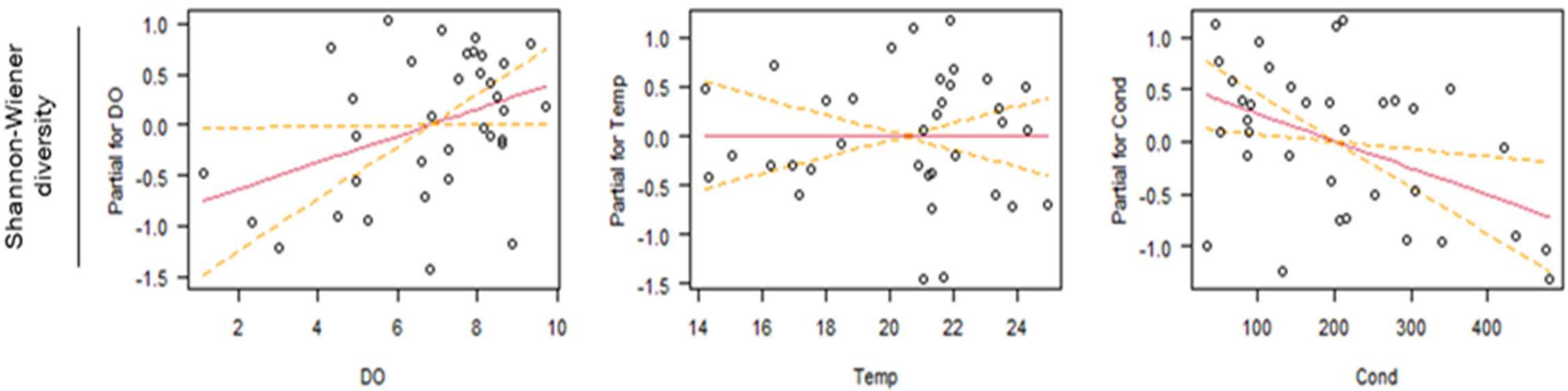
Flow and Water Quality Remain Limiting

- 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
- High temperatures and sunlight can cause trophic cascade of epiphytic algae (Fairfax County, VA)

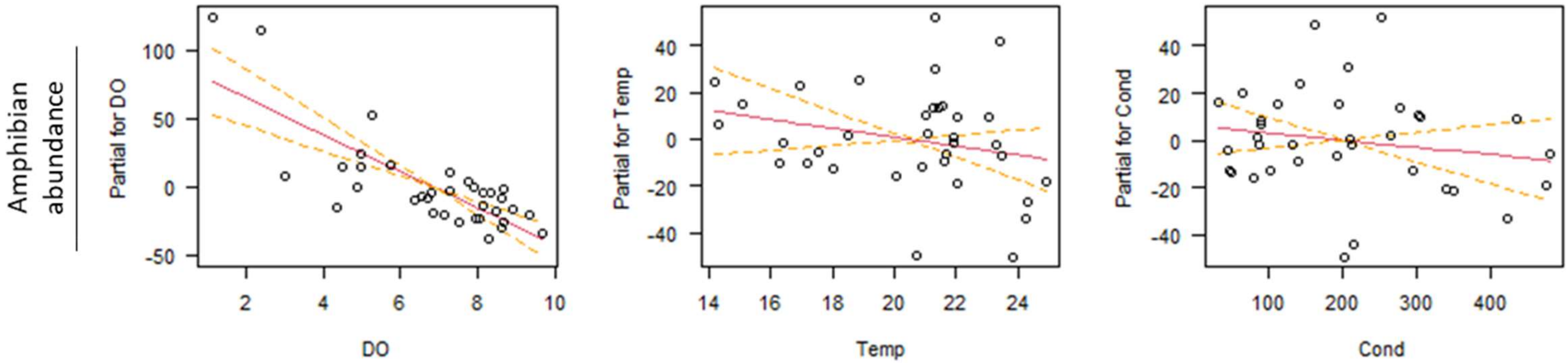
Water Quality is Different in RSCs



Fish Diversity Increases with DO and Decreases with Conductivity



Herpetofauna is Not Reduced by Water Quality



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Uplift May Improve 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

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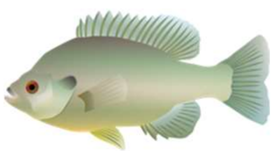
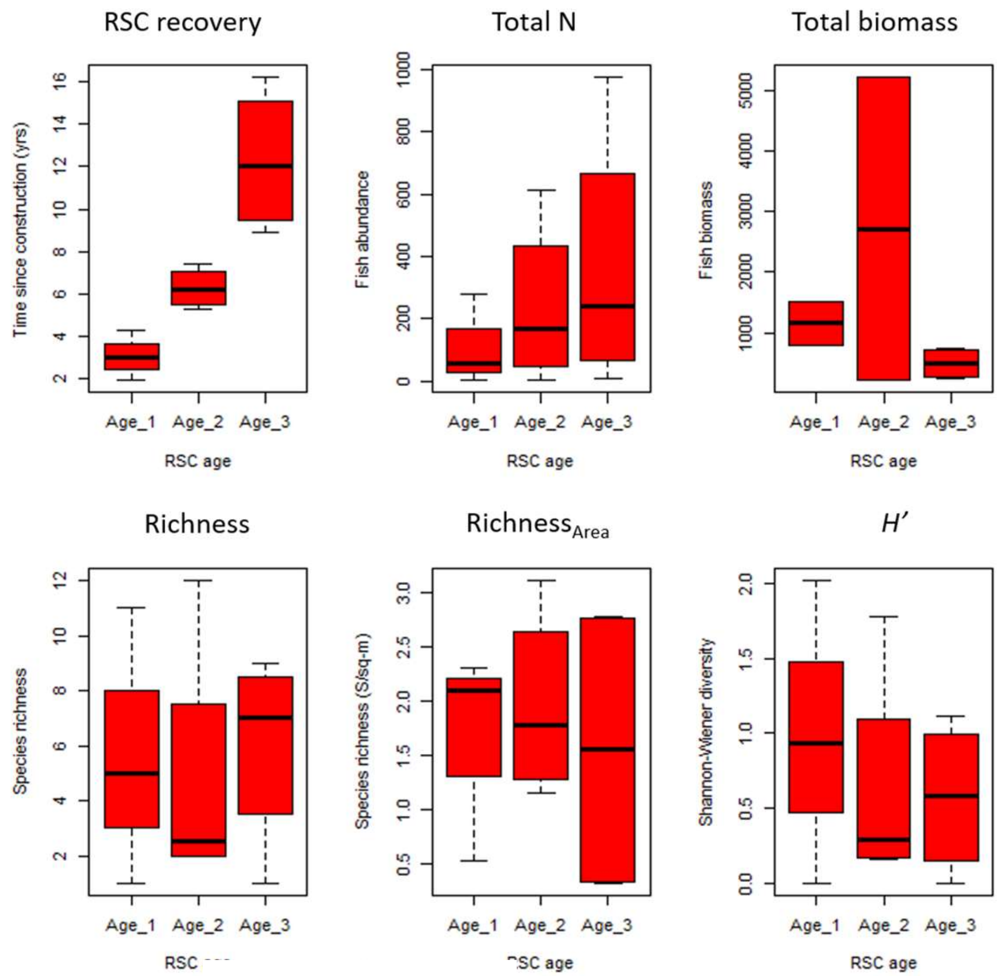
Restoration Site Sampling

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*

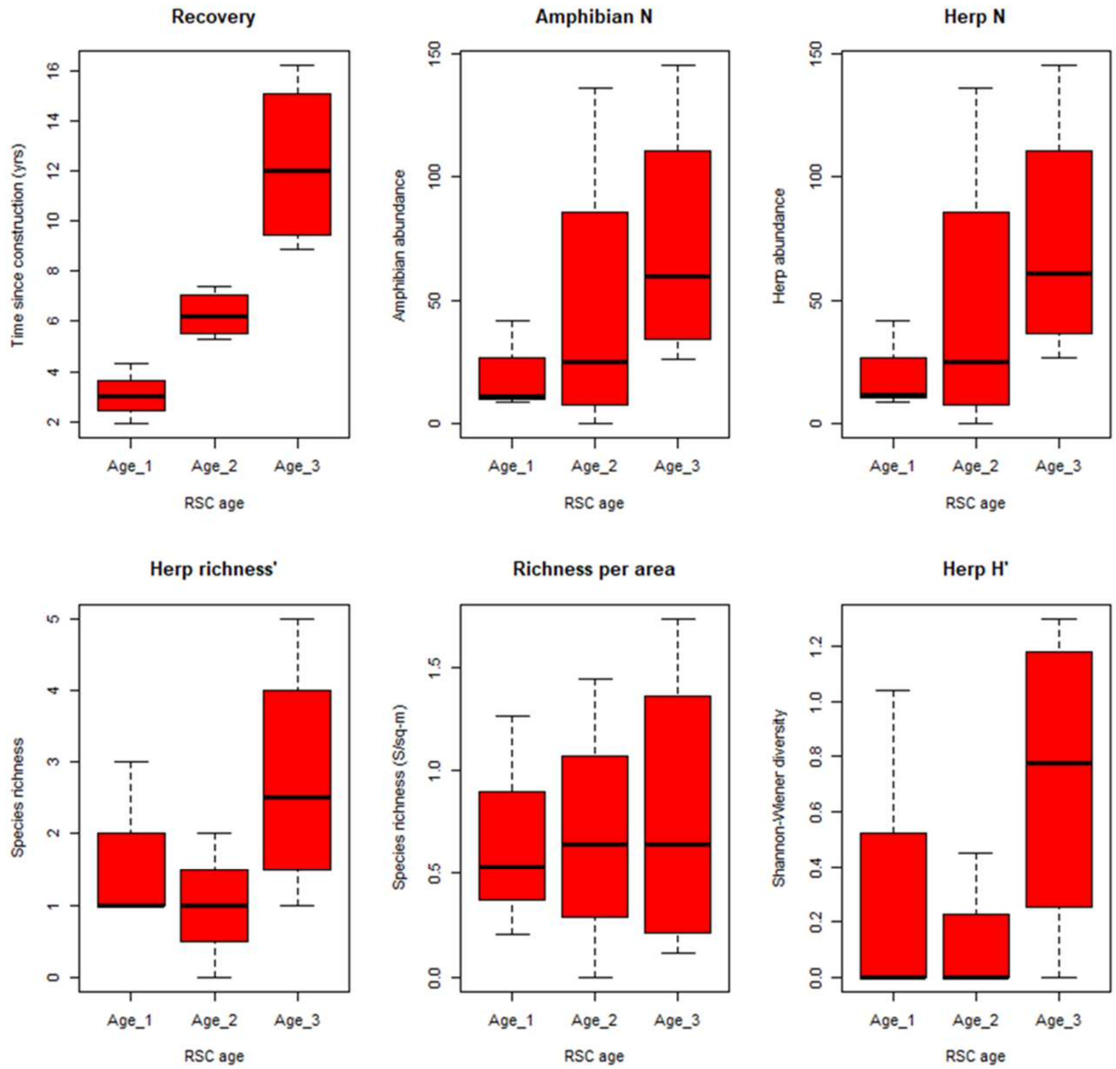
Fish Abundance but not Diversity Increases with Time since RSC Construction



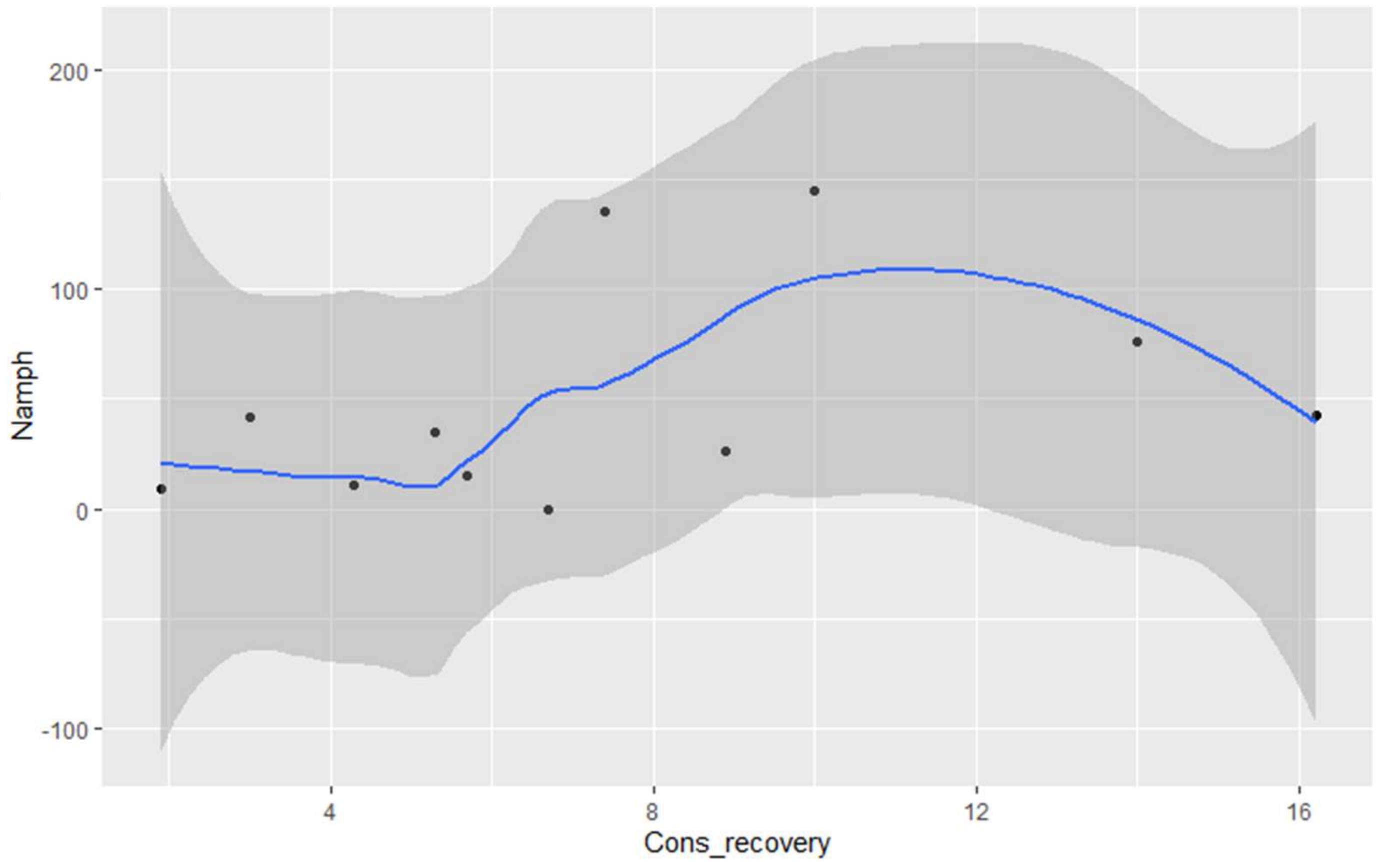


Age_1 = 1.9–4.3 yrs
Age_2 = 5.3–7.4 yrs
Age_3 = 8.9–16.2 y

Herp Abundance and Diversity Increases with Time since RSC construction



Herp Abundance takes 8 years to Increase after RSC construction



Movement Barriers May Limit Uplift

- Proximity of source populations and connectivity are needed for movement, drift, or aerial dispersal
- Headwaters and other streams may lack upstream populations
- Physical barriers limit fish movement
- Water quality can be a barrier too
- Poor dispersers will take longer/if ever to repopulate

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Limits on Biological Uplift from Proximity of Source Populations

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Proximity to Sources Significant Over Time

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.

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Designs Should Address Limiting Factors

Best Candidates Have Single or Few Stressors

- Point sources such as Acid Mine Drainage (improvement in remediated Youghiogheny River)
- Agricultural settings where riparian vegetation can increase instream wood and reduce temperatures (increased number and size of trout in Upper Beaver Creek watershed)
- Upstream gullies with little or no water and habitat (not only effective at reducing sediment and nutrients loadings, but any biota added is positive)

TETRA TECH

Instream Habitat Sometimes Creates Uplift

- Habitat is necessary but not sufficient for uplift
  - Increase vegetation/roots at margin
  - Increase wood in the channel
  - Increase stability of the substrate
- Best response from habitat specialists with water quality tolerance, e.g., sunfish and frogs

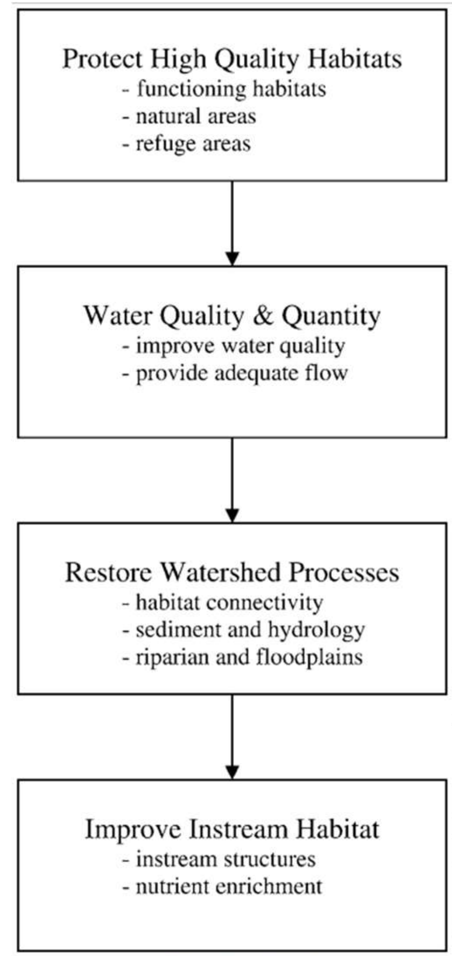
Hydrology Sometimes Creates Uplift

Palmer, M.A. and J.B. Ruhl. 2015. Aligning restoration science and the law to sustain ecological infrastructure for the future. *Frontiers in Ecology and the Environment* 13: 512–519.

- "Evidence suggests that restoring particular facets of a flow regime can produce desirable conservation outcomes, but context is paramount."
- Going beyond discrete flow events and enhancing or redirecting subsurface flow may be critical to future climates

Water Quality Solutions are Paramount

- Stream restoration can reduce nutrients and sediment, but usually not all water quality stressors at a site and may have unintended consequences like low DO
- Phil Roni has a hierarchy of steps where addressing water quality precedes hydrology and instream habitat

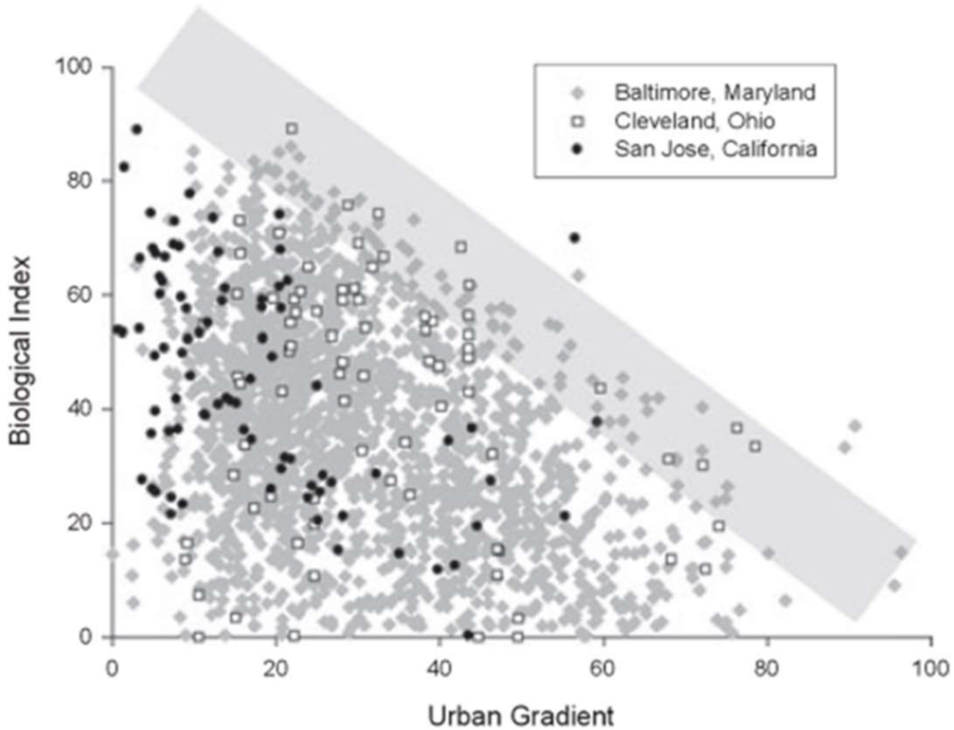


Watersheds Determine Uplift Potential

- All watersheds are modified from historical conditions
- Best remaining streams may trap species/communities in vulnerable "islands"
- Impervious surfaces limit uplift potential, even in stream-wetland complexes
- Watersheds pose uncontrollable and unknown stressors
- Potential can be estimated by (Bob Siegfried):
  - What is already there?
  - What can live there (in the watershed)?
  - What can get there?
- Redefine goals as Observed/Expected (O/E)

Urbanization Determines Uplift Potential

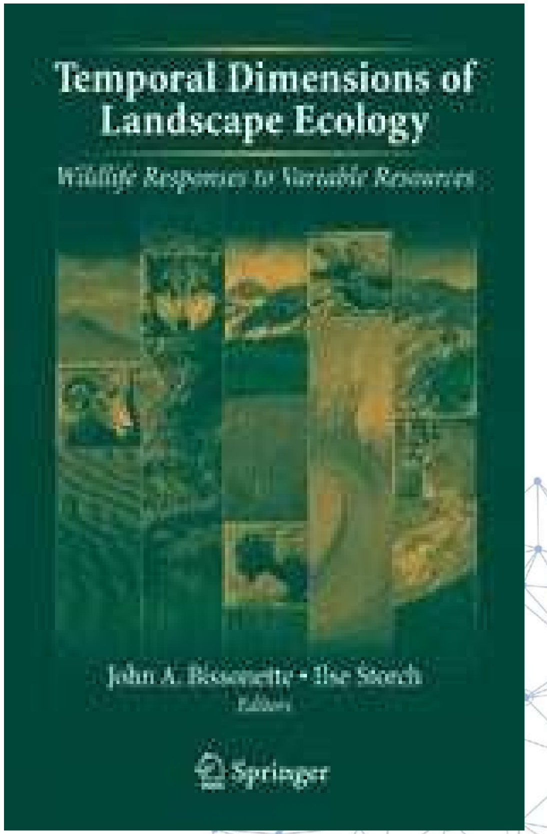
Paul, M.J., D.W. Bressler, A.H. Purcell, M.T. Barbour, E.T. Rankin, and V.H. Resh. 2009. Assessment tools for urban catchments: defining observable biological potential. *Journal of the American Water Resources Association* 45(2): 320-330



Plot of macroinvertebrate index response to an urban gradient in 3 biomes across the US. From Paul et al. 2009.

Threshold for Intervention Should be High

- We rarely really know what is limiting, that's why it's called "Urban Syndrome"
- Often unaware of "Ghost of Land Use Past"
- There may be "Unexpected Consequences"



Unexpected Consequences

Wood, D., T. Schueler, and B. Stack. 2021. A Unified Guide for Crediting Stream and Floodplain Restoration Projects in the Chesapeake Bay Watershed. Master Stream Restoration Crediting Guide, Chesapeake Bay TDML

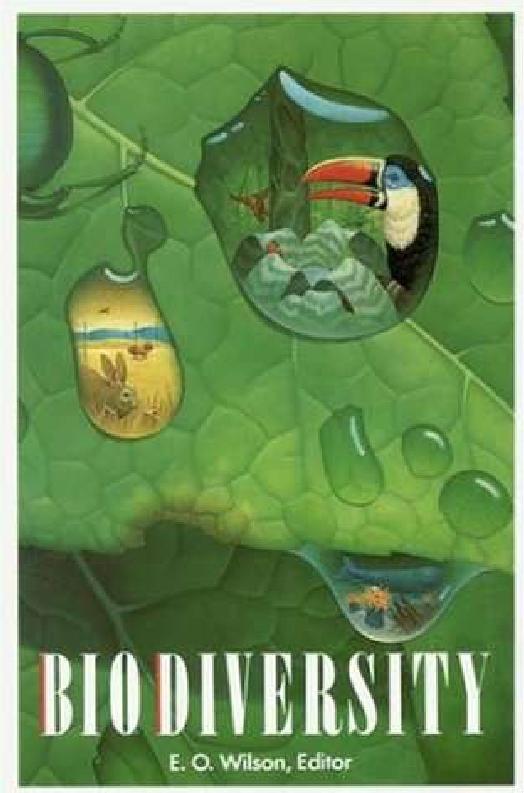
Table 19. Review of Potential Unintended Impacts Associated w/ Stream and Floodplain Restoration Projects

Impact [1]	*Project Stream Channel*
Depleted DO	Associated with stagnant surface waters and high dissolved organic carbon. Often observed as seasonal.
Iron Flocculation	Observed in both restored and unrestored streams. Associated with high dissolved organic carbon, anoxic conditions and the use/presence of ironstone.
Warmer Stream Temps	Associated with loss of tree canopy in the riparian corridor. Stream and floodplain connection to groundwater in the hyporheic aquifer can mitigate increased temperatures.
More Acidic Water	Associated with disturbance of channel and floodplain soils during construction.
More Stream Primary Production	Associated with loss of canopy cover in the riparian corridor.
Benthic IBI Decline	Associated with construction disturbance, with recovery to pre-project levels in some cases.
Construction Turbidity	Sediment erosion during construction, especially when storm flows overwhelm instream ESC practices
Floodplain/Valley Bottom/Downstream Ecosystems	
Project Tree Removal	Riparian/floodplain forest losses are common due to clearing for design and construction access.
Post-Project Tree Loss	Field and lab studies show that long-term soil inundation results in mortality and morphological changes in tree species.
Invasive Plant Species	Construction disturbance and frequent inundation of the floodplain can serve as vectors for invasive species along restored and unrestored streams.
Change in Wetland Type or Function	Changes in vascular plant communities as a result of floodplain inundation are expected and may be desirable or undesirable depending on the habitat outcome.
Downstream Benthic Decline	Associated with changes in habitat conditions, and construction disturbance. Changes may be temporary.
Blockage of Fish Passage	Incision, large drops or structure failures can impede passage. More study needed

[1] Impacts are defined in relation to the stressors measured in a comparable unrestored urban stream/floodplain system.

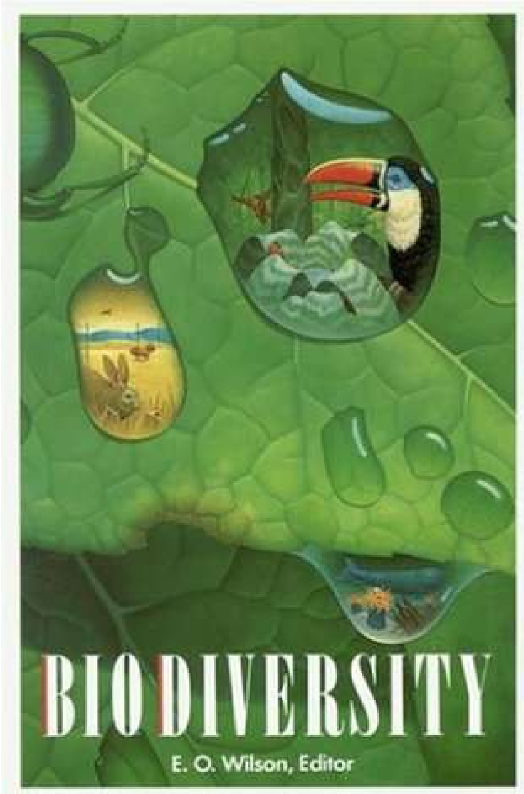
Rules for Intervention

- Avoid restoration where sensitive species/communities exist
- Use least invasive approach first
- Don't assume erosion needs to fixed in every situation (may be natural dynamics)
- Don't assume all streams should look alike (biodiversity requires and historically we had many stream types)



Finding that 10% Improvement

- Find streams with few limiting stressors
- Look outside urban settings
- Fill degraded gaps in good landscapes
- Remove physical barriers
- Add missing or diverse habitats
- Give it a decade



Questions

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