Determining the effects of legacy sediment removal and floodplain reconnection on ecosystem function and nutrient export

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Towson University

Co-authors: Patrick Baltzer, Patrick McMahon, Melinda Marsh, Kyle Bucher, Ryan Casey, Chris Salice

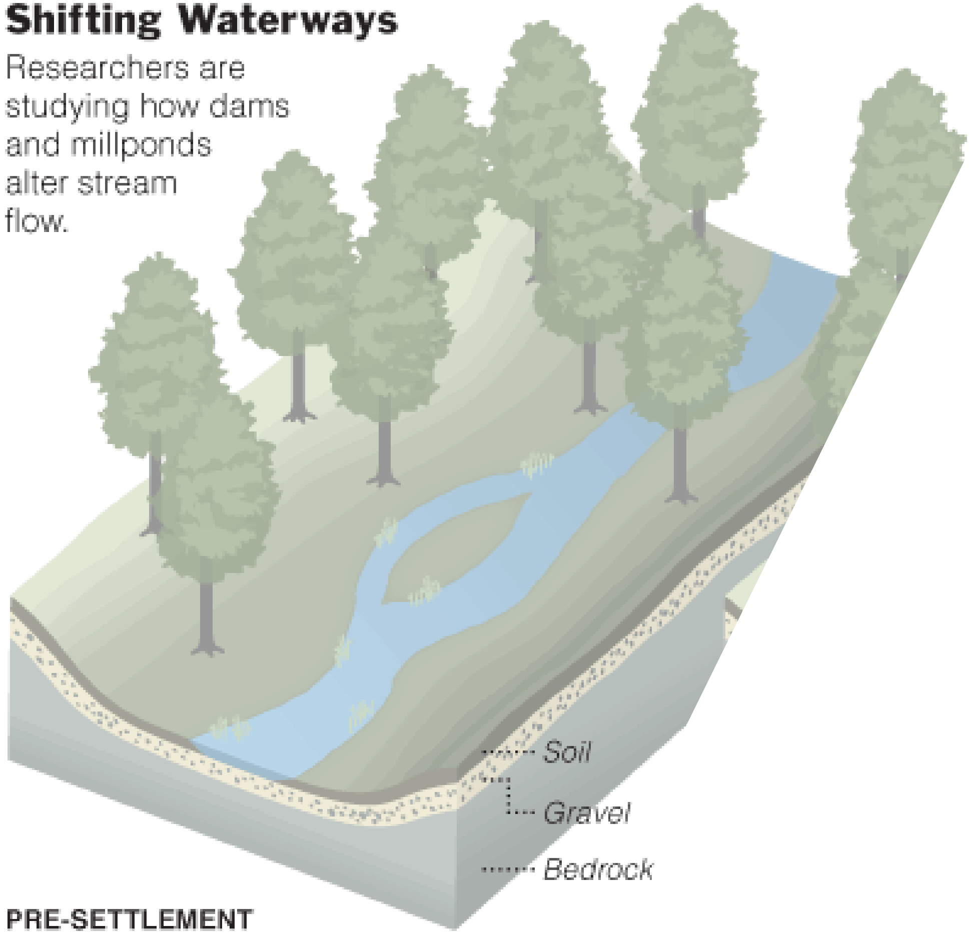
Acknowledgements

- Funding
  - Chesapeake Bay Trust (#13974), Towson University
- Logistical support – Ecotone, Inc.
- Landowners – Henry and David Pitts, Rigdon Family, Edwards Family, Harford County, City of Bel Air
- Students – Patrick McMahon, Patrick Baltzer, Ginny Jeppi

What are the goals and desired outcomes of restoration? What's the end point?

Shifting Waterways

Researchers are studying how dams and millponds alter stream flow.

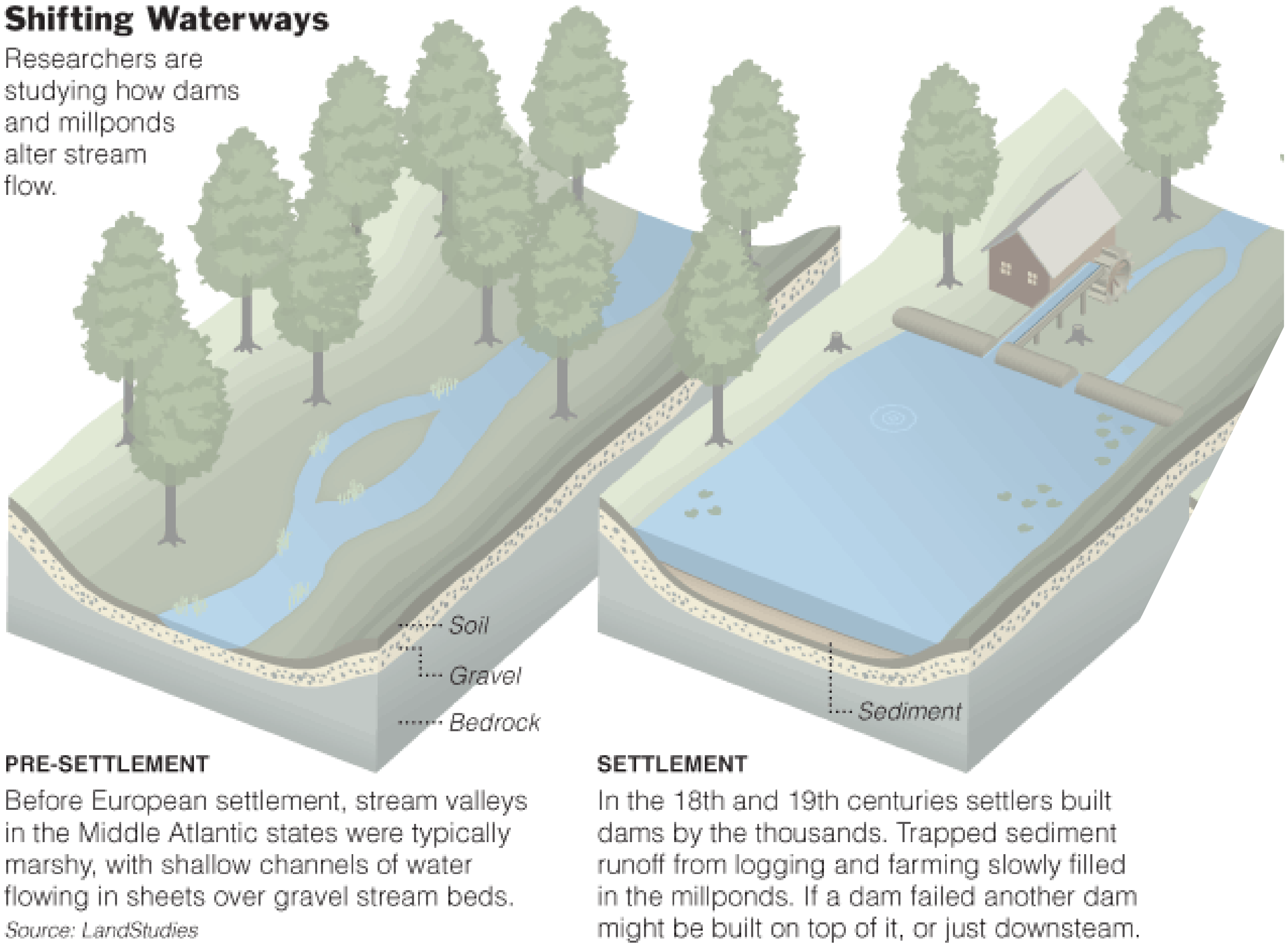


PRE-SETTLEMENT

Before European settlement, stream valleys in the Middle Atlantic states were typically marshy, with shallow channels of water flowing in sheets over gravel stream beds.

Source: LandStudies

What are the goals and desired outcomes of restoration? What's the end point?



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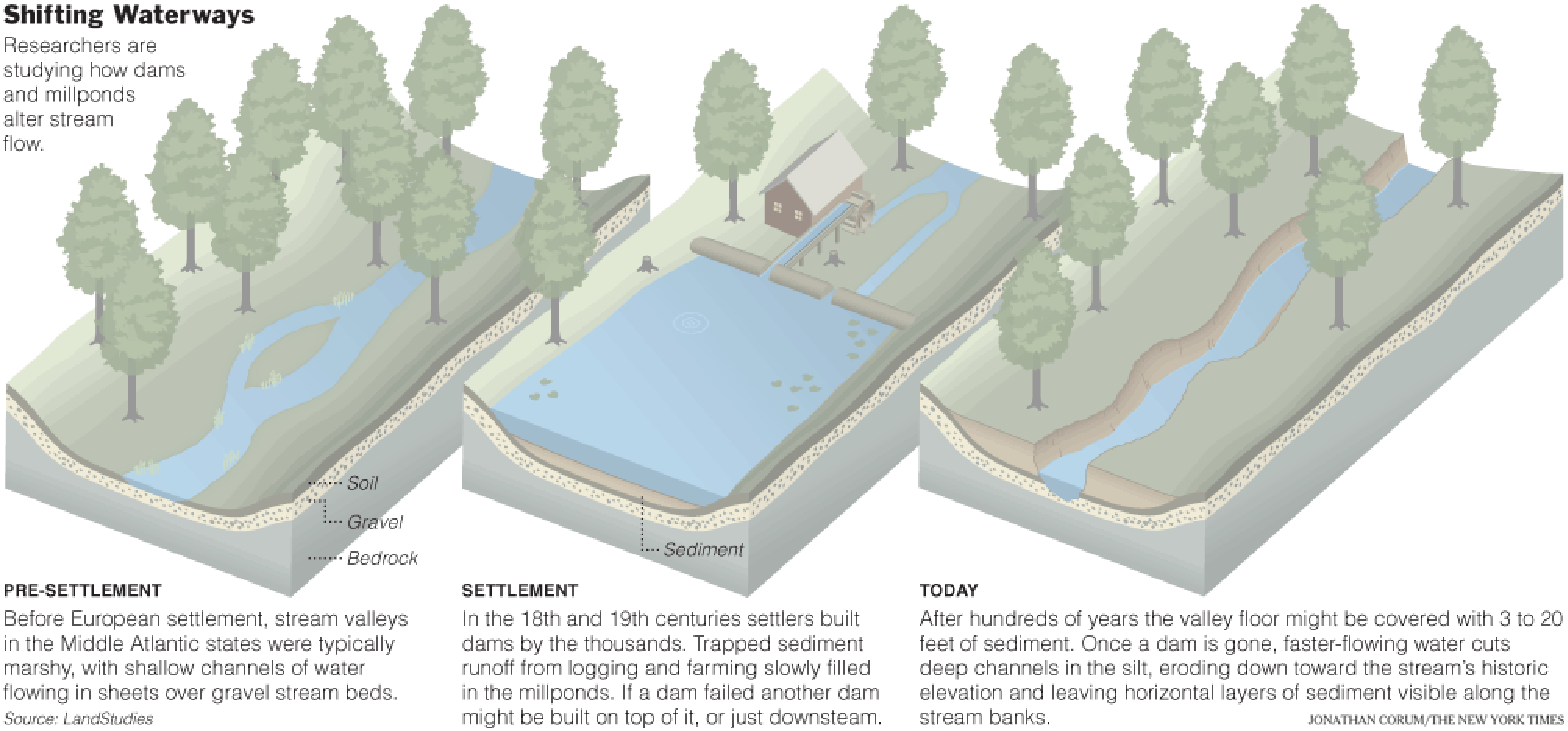


Original from nytimes.com


>5–10 mill dams / 10 km²
in north-central Maryland
Mill dam, Lancaster County, PA

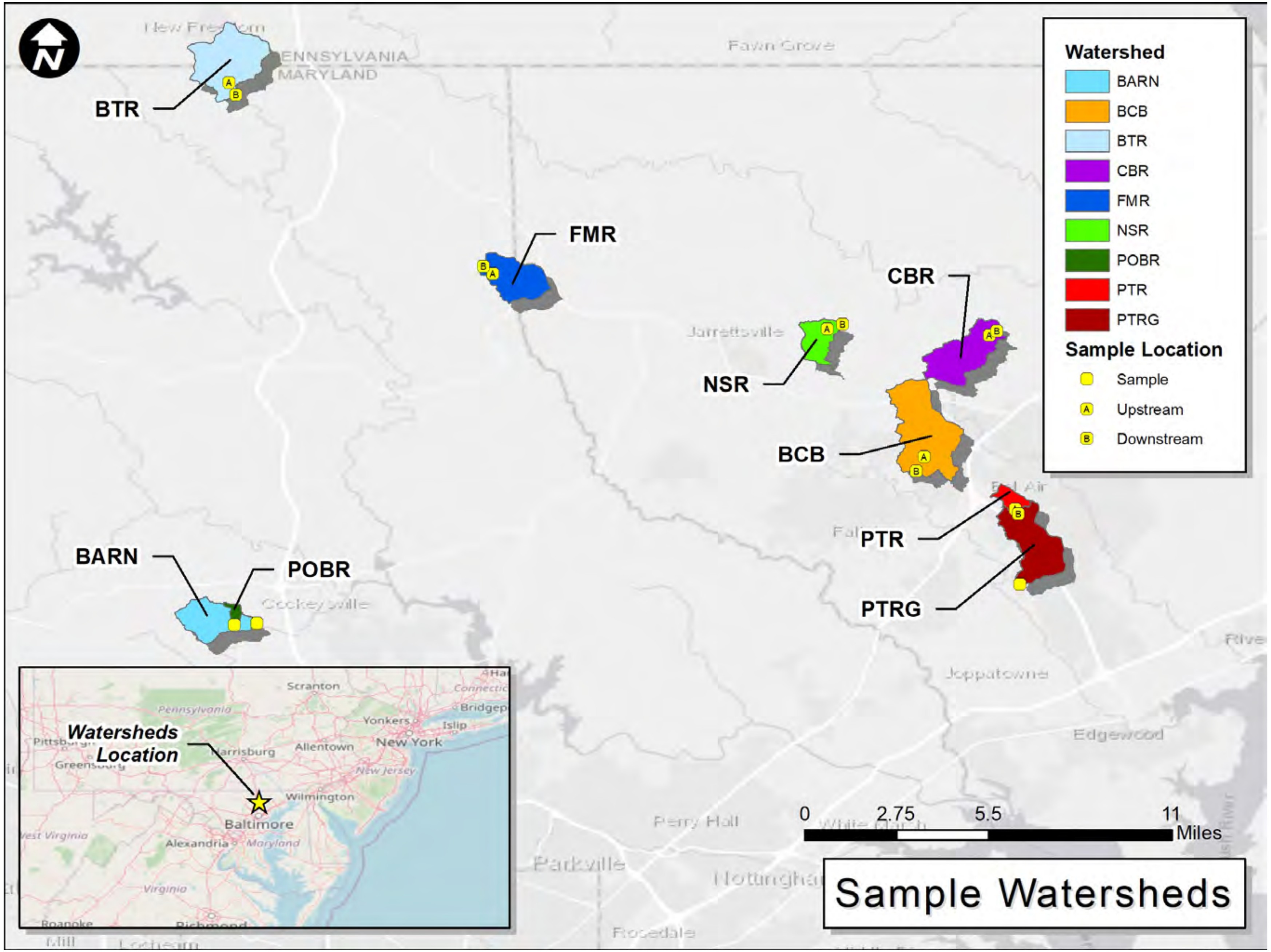
Likely outcomes & questions about Legacy Sediment Removal and Floodplain Reconnection

- Vegetation
  - Increased dominance of hydric vegetation
  - Change in community composition
  - Response to disturbance? Invasives?
- Water chemistry
  - Decrease in N, P and TSS due to increased overbank events and longer residence time
  - Relationship with drainage area? Impervious cover? Project length?

Study sites

6 restored watersheds, 3 others

- 4 agricultural watersheds
  - 3 row crop
- 2 (sub)urban watersheds
  - + 1 larger scale watershed
- 2 (mostly) forested watersheds



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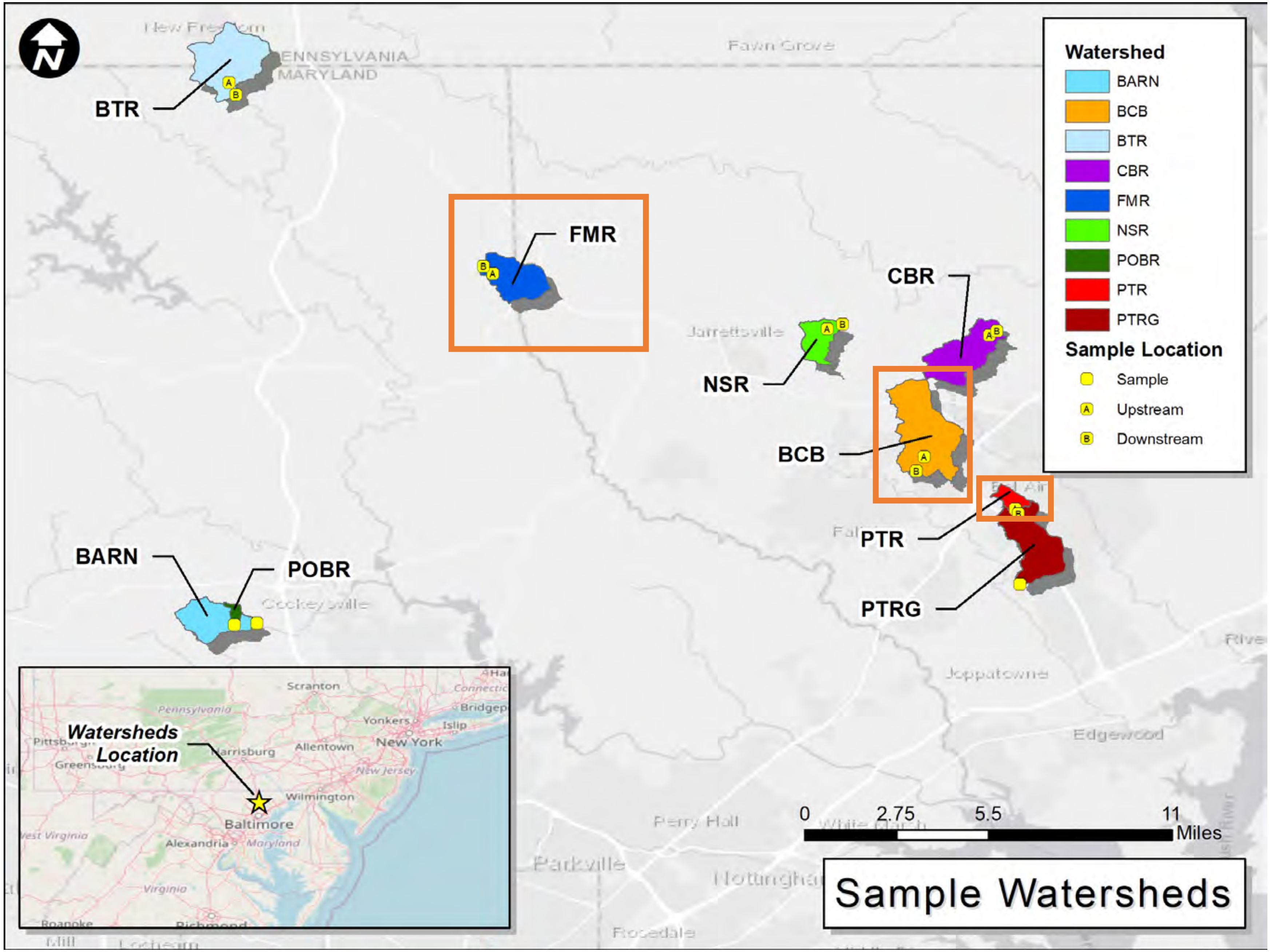
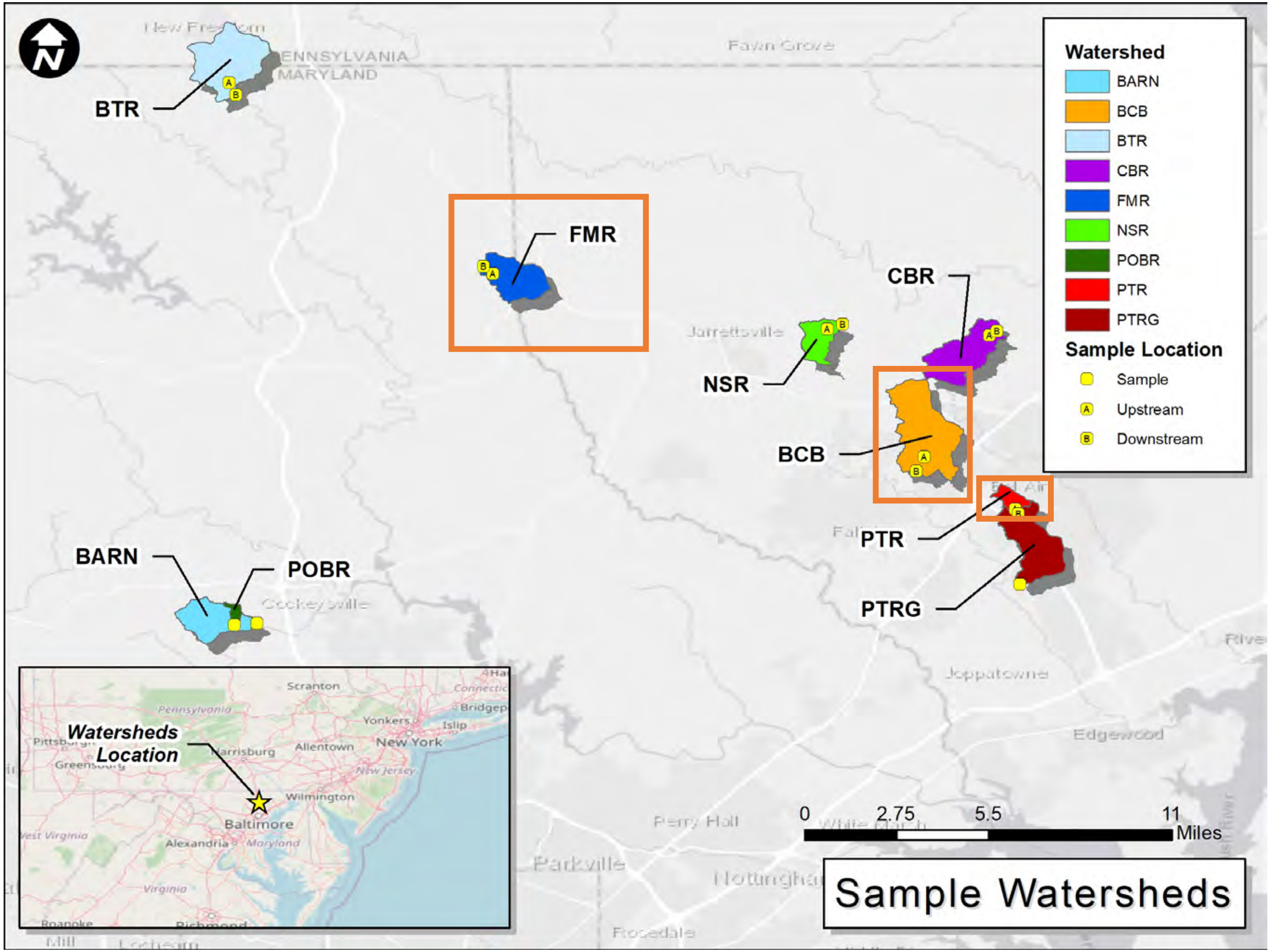


Study sites

6 restored watersheds, 3 others

- 4 agricultural watersheds
  - 3 row crop
- 2 (sub)urban watersheds
  - + 1 larger scale watershed
- 2 (mostly) forested watersheds
- All <8.2 km^2
- Agricultural: 0 – 73%
- Impervious: 0 – 56%
- Restored length: 1240 – 5230 ft
- Restoration age: 1 – 5 years

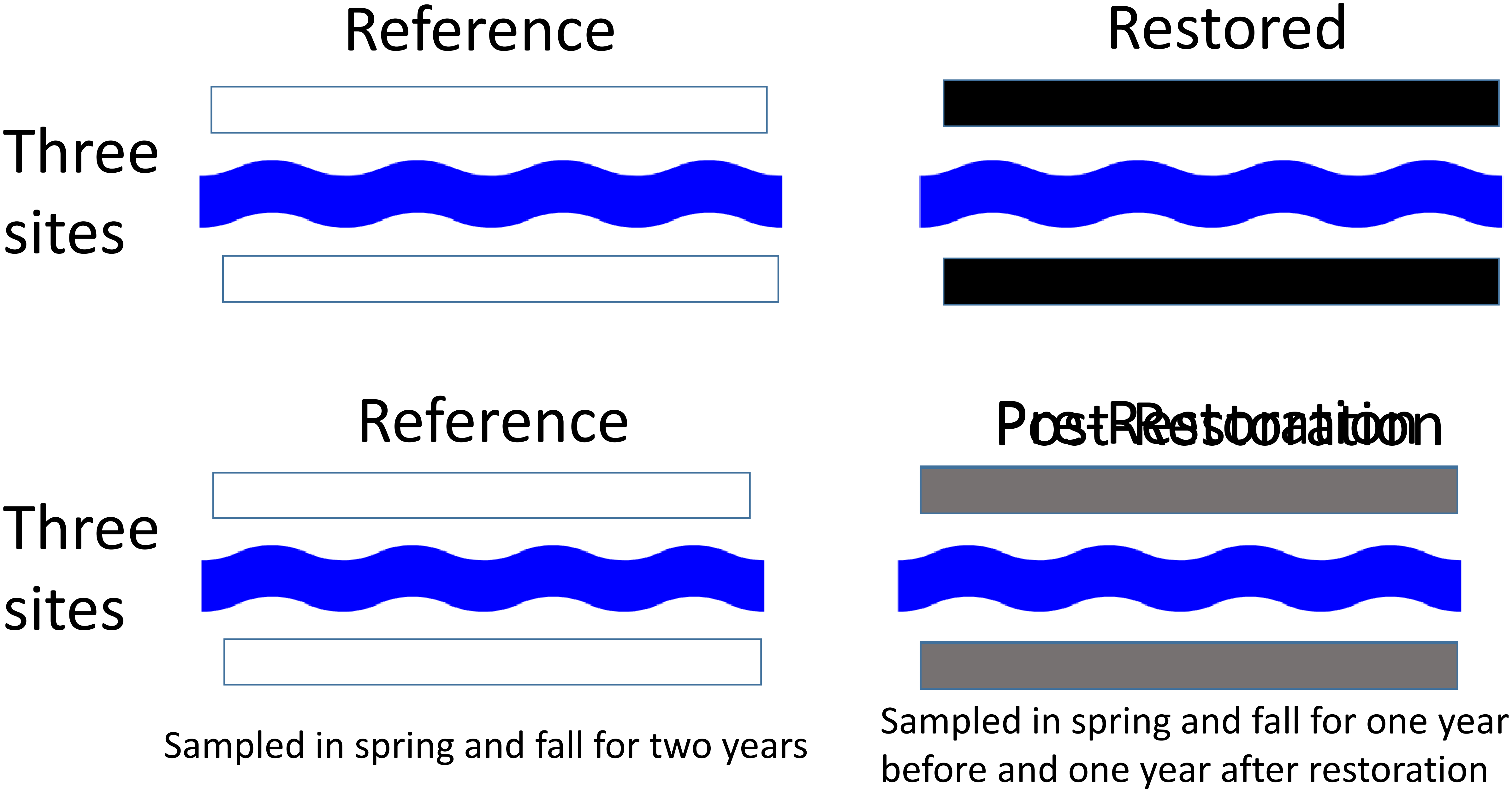



First Mine Branch

First Mine Branch

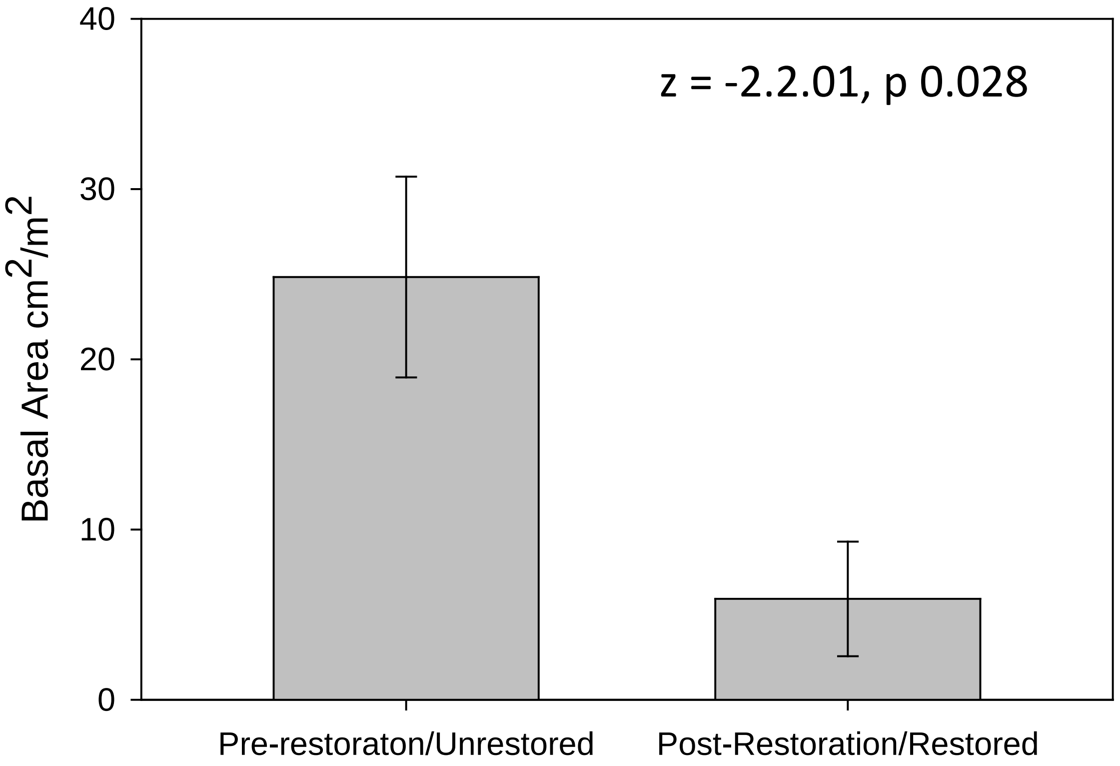
First Mine Branch

Vegetation: Sampled in spring and fall for two years



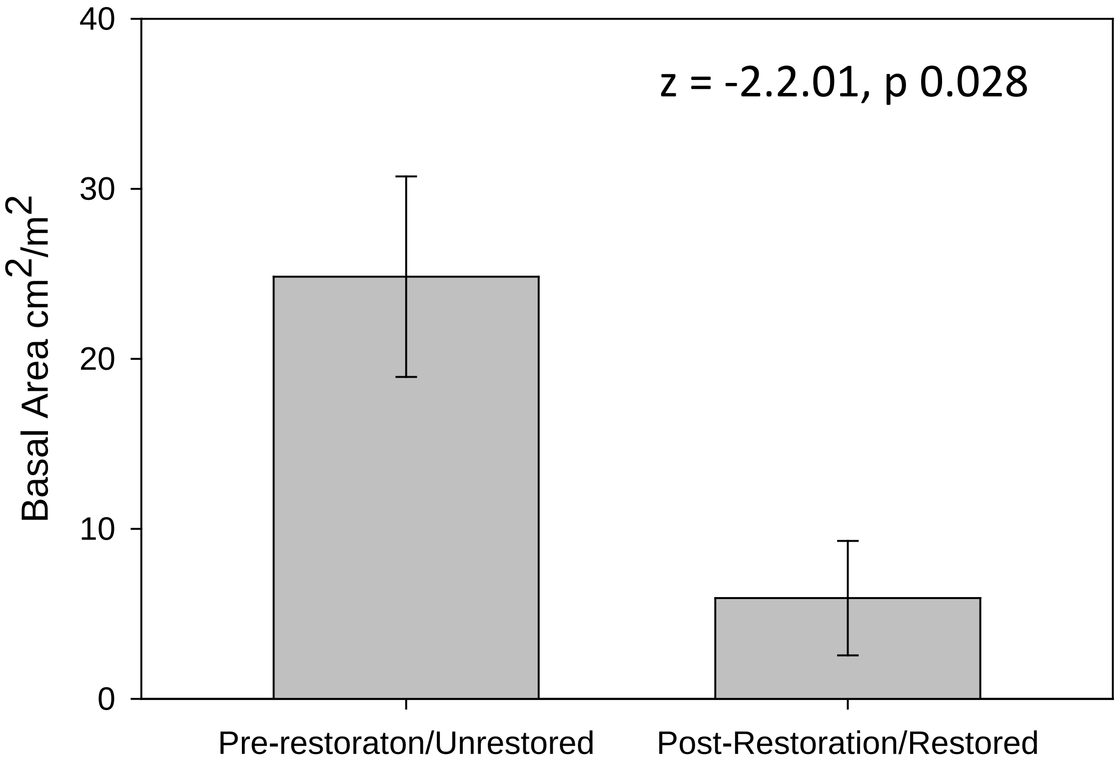
Woody vegetation: Decrease in area, mixed on diversity

- 81% decrease in basal area
- 20% decrease in species richness
- Areas *within* a site become more diverse
- But differences *between* sites decrease. Biotic homogenization?



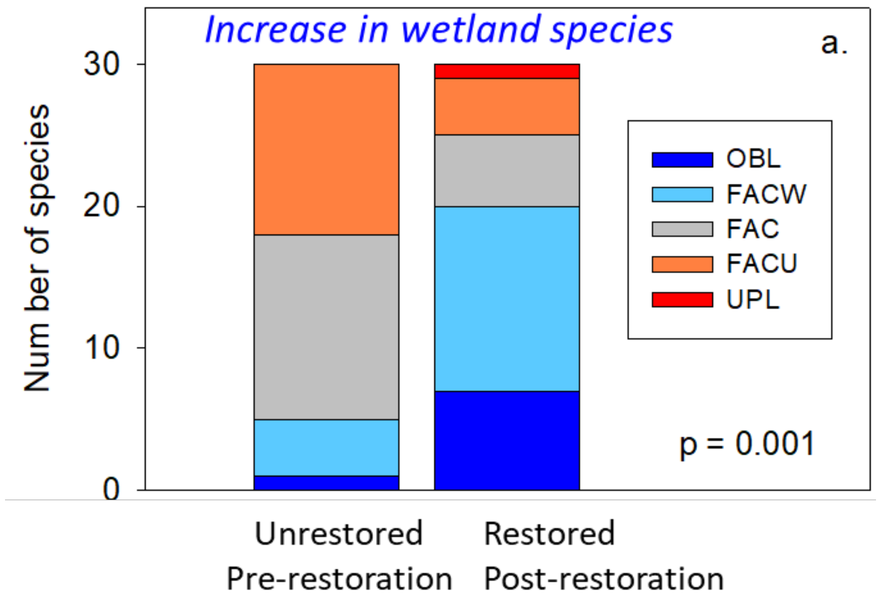
Woody vegetation: Decrease in area, mixed on diversity

- 81% decrease in basal area
- 20% decrease in species richness
- Areas *within* a site become more diverse
- But differences *between* sites decrease. Biotic homogenization?
- Similar species composition in unrestored and restored reaches
- No significant indicator species changed in importance due to planting



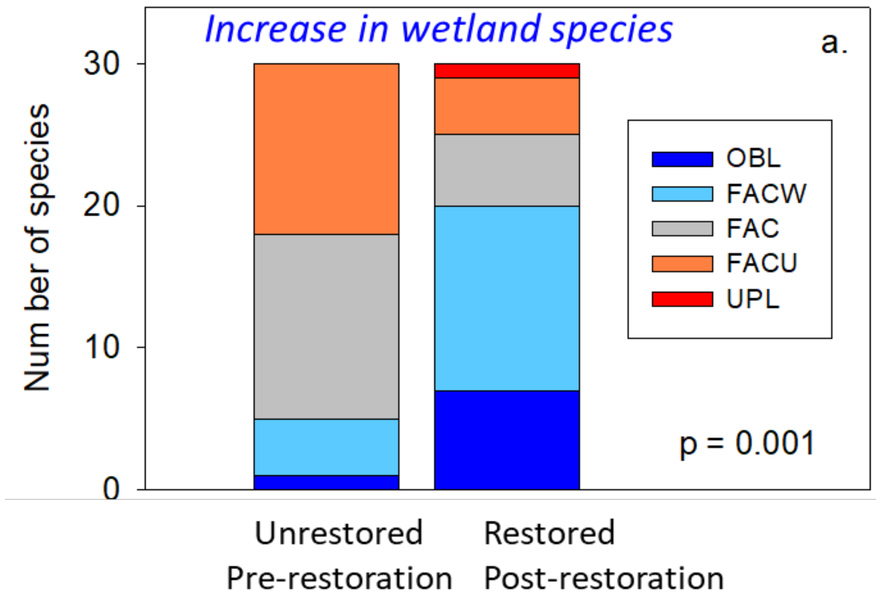
Herbaceous vegetation: More hydrophytic, other improvements

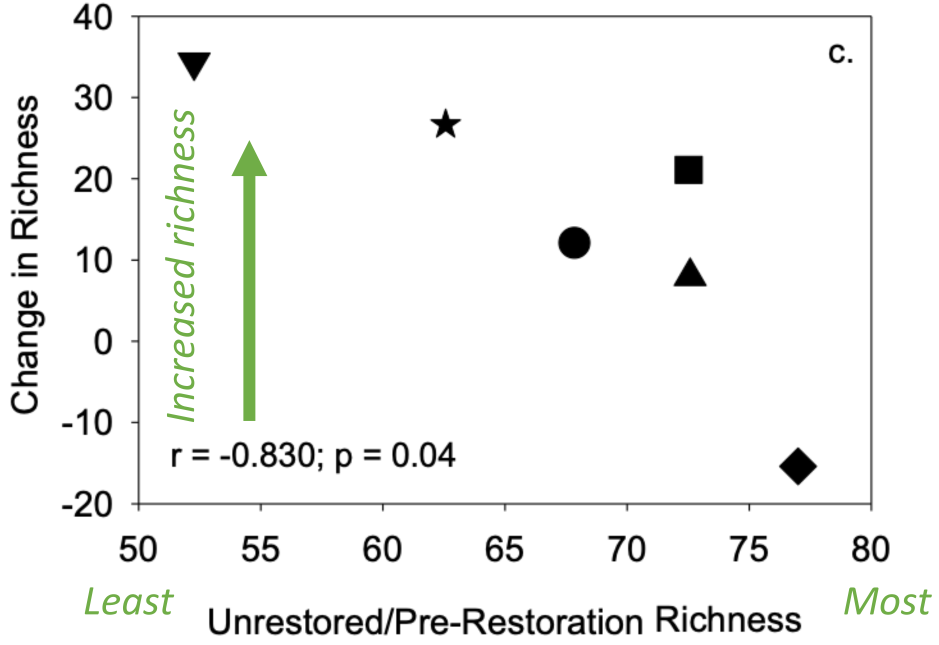
- Post-restoration is more hydrophytic (decrease in Wetland Indicator Score)
- Sites become more different from each other (upstream/seedbank contribution?)



Herbaceous vegetation: More hydrophytic, other improvements

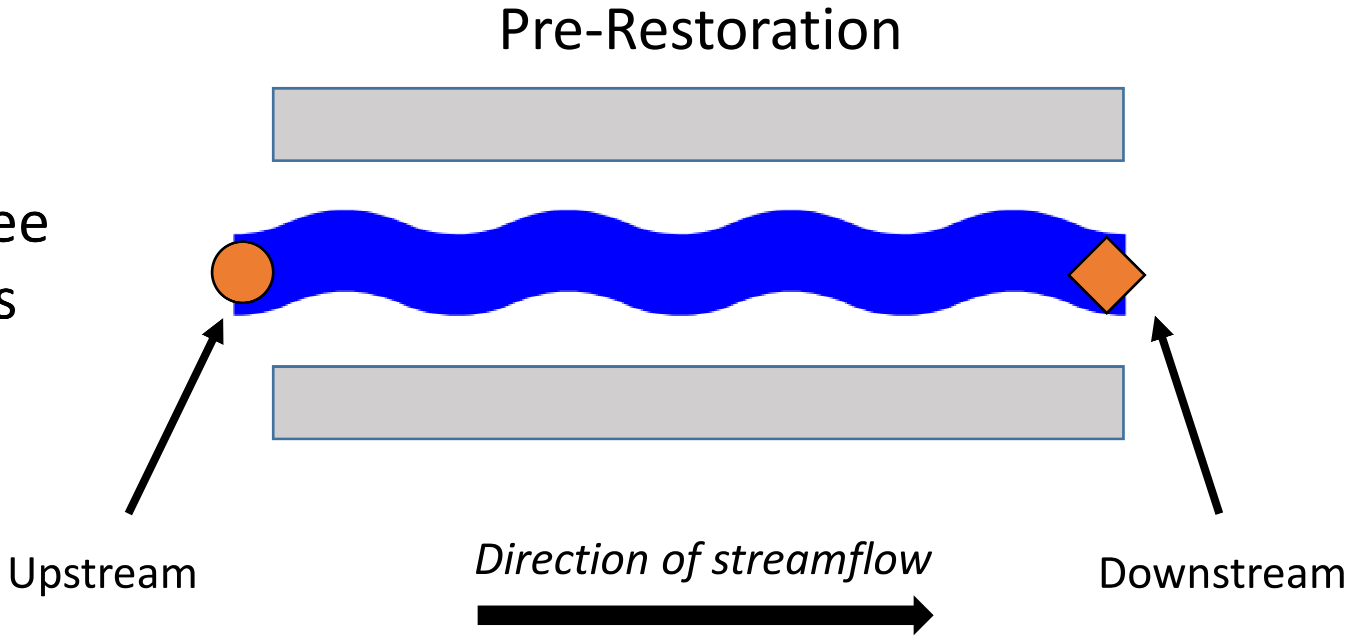
- Post-restoration is more hydrophytic (decrease in Wetland Indicator Score)
- Sites become more different from each other (upstream/seedbank contribution?)
- Slight increases overall in quality, richness, & diversity
- Sites that start with low quality vegetation improve, but sites with high quality vegetation decrease in quality
- 74% loss of skunk cabbage – slow regeneration?





Sampling approach

Three sites

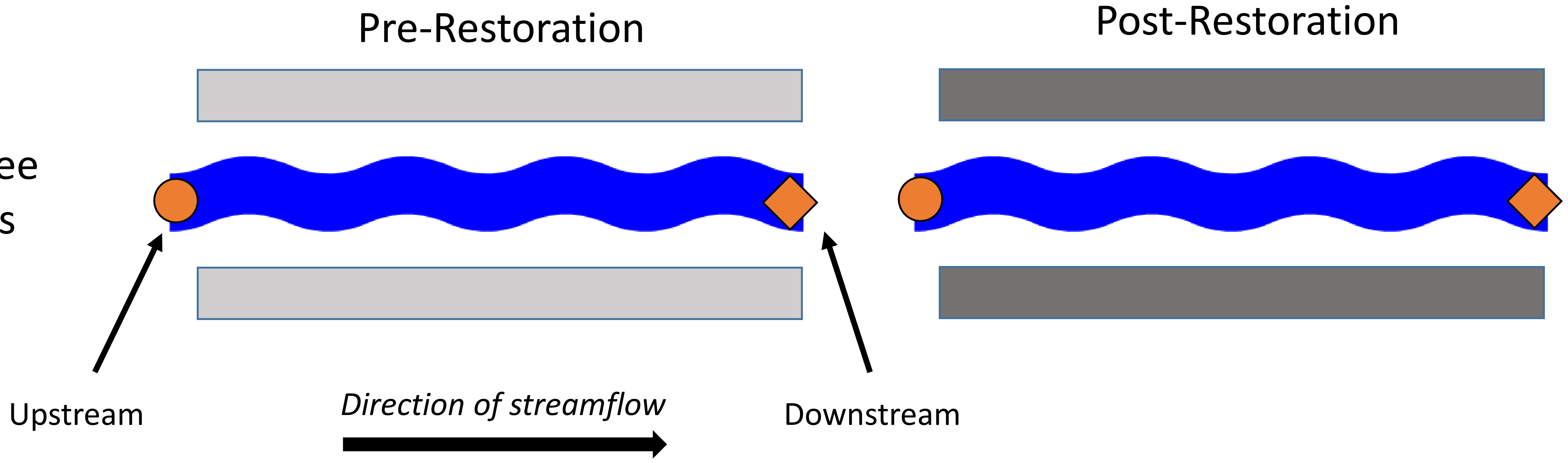


Flux/load =

Downstream – Upstream

Sampling approach

Three sites



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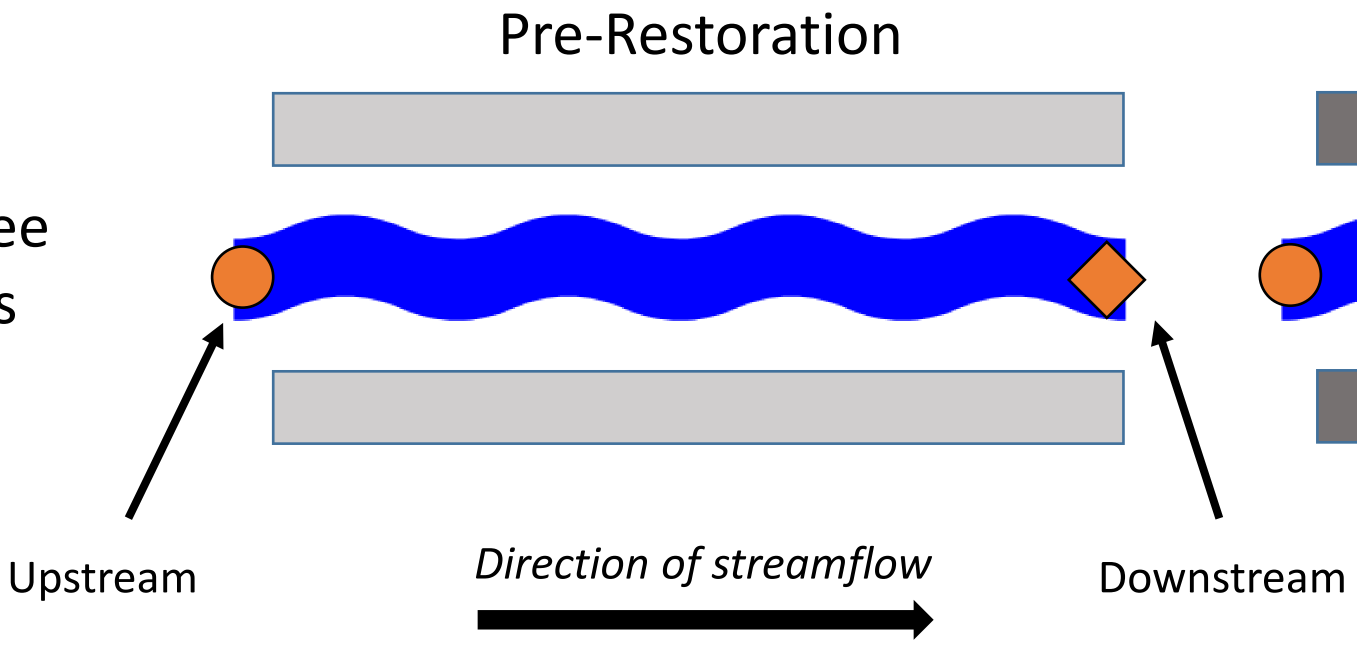

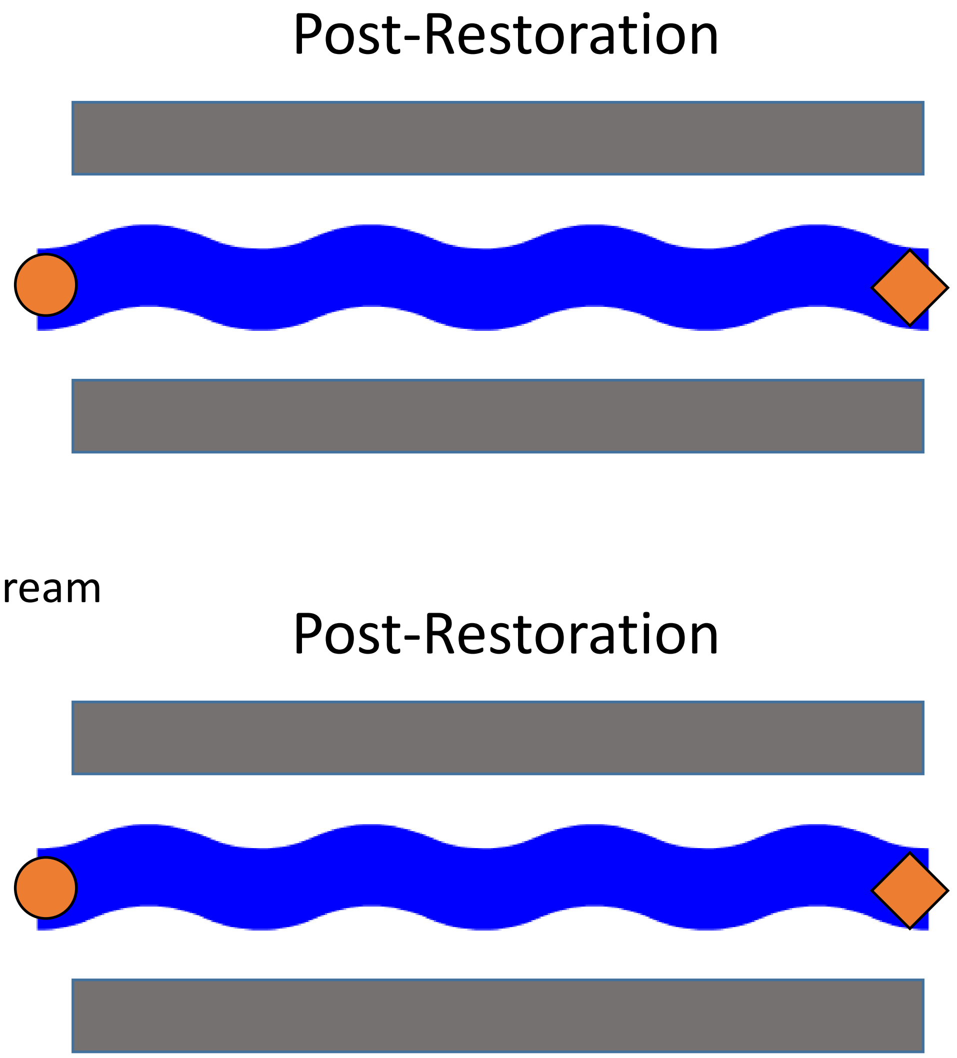

Three sites

Three sites

Flux/load =

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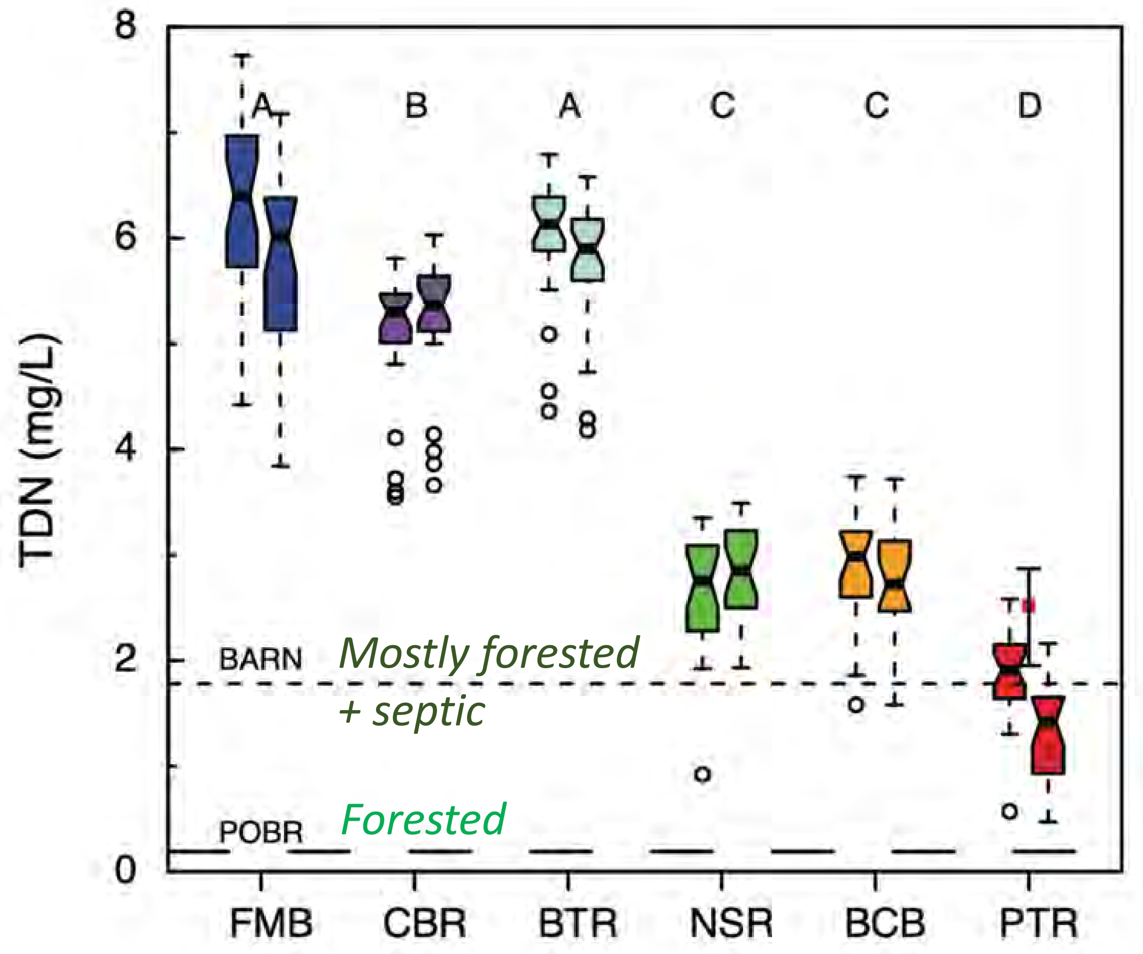
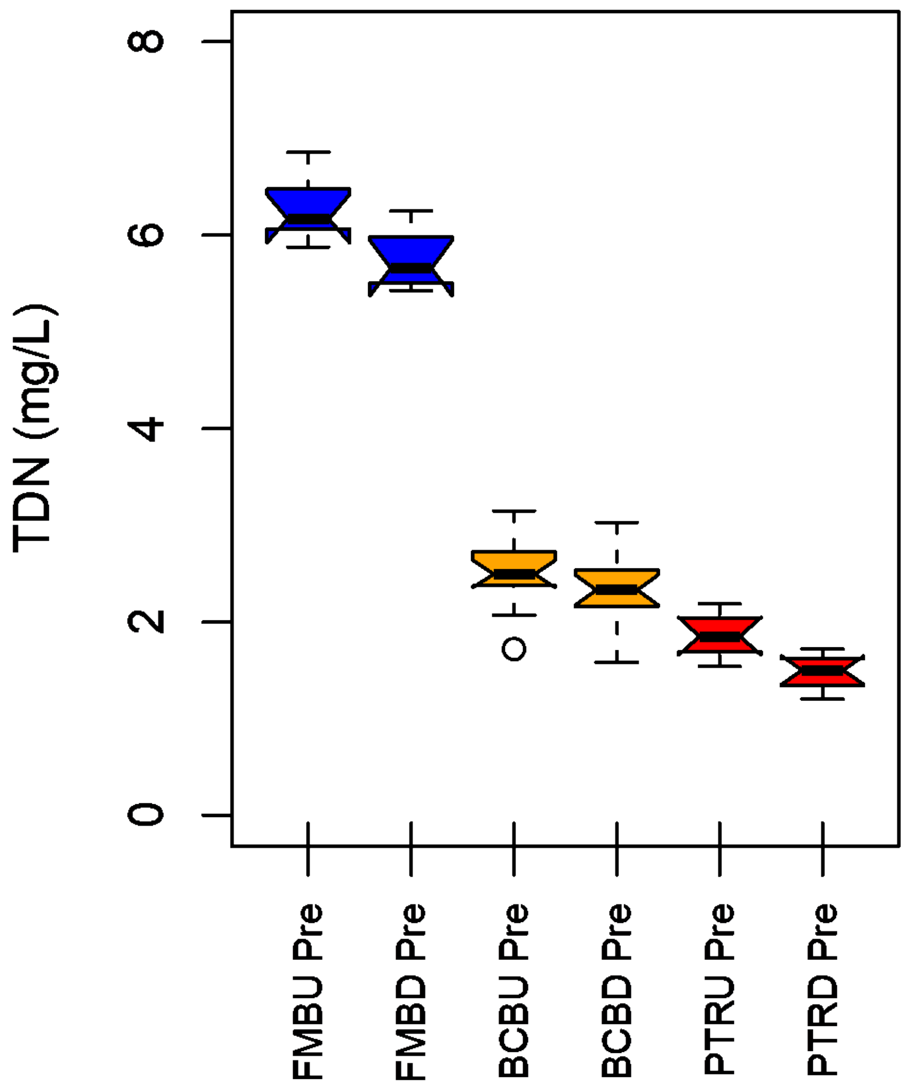
Biggest control for baseflow N: land use



Most active agriculture → Most urban

McMahon et al. (2021) *Environmental Research Letters*
https://iopscience.iop.org/article/10.1088/1748-9326/abe007

Pre-restoration baseflow N differences across reaches



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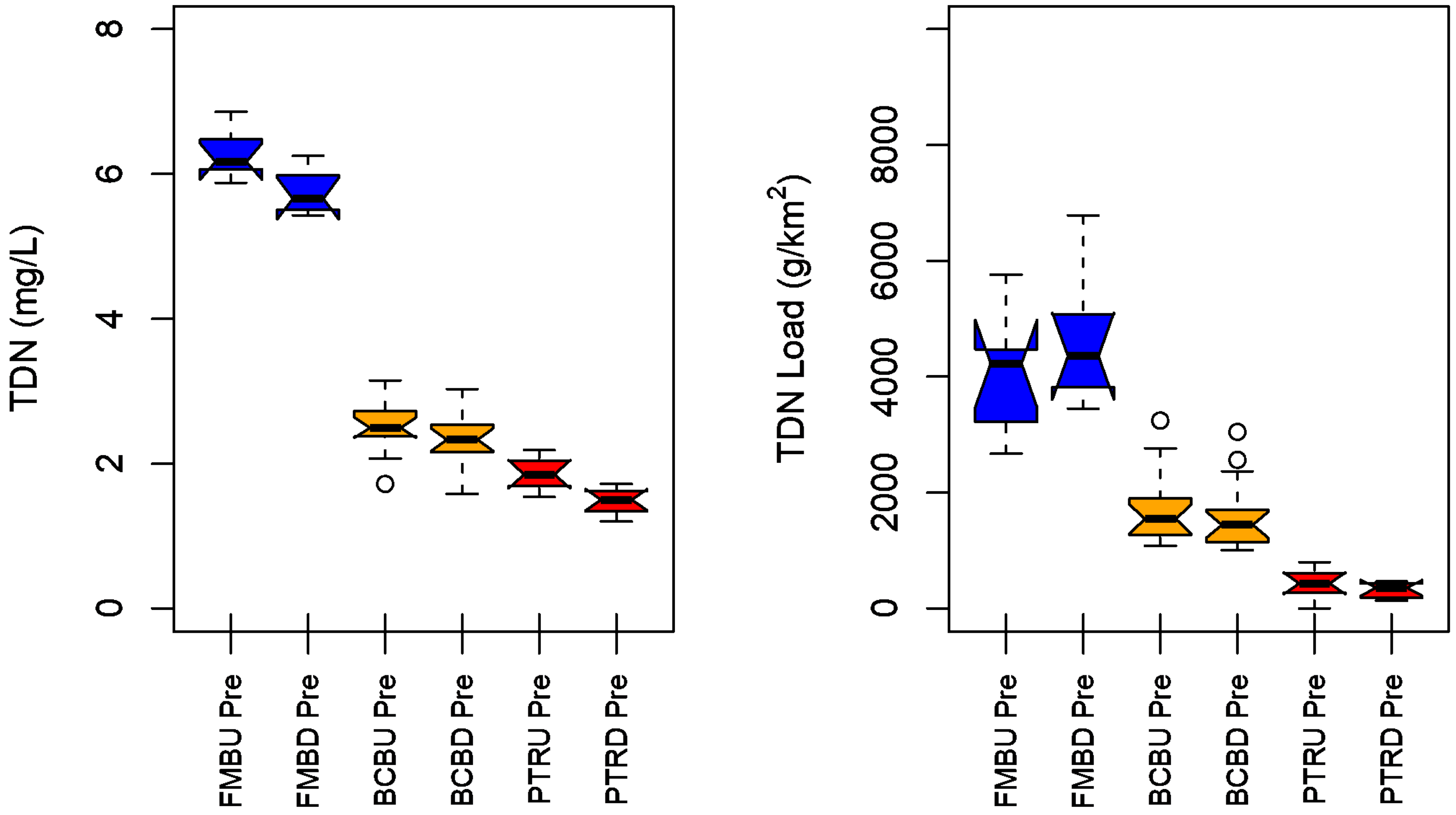
Pre-restoration baseflow N differences across reaches

No substantial change post-restoration



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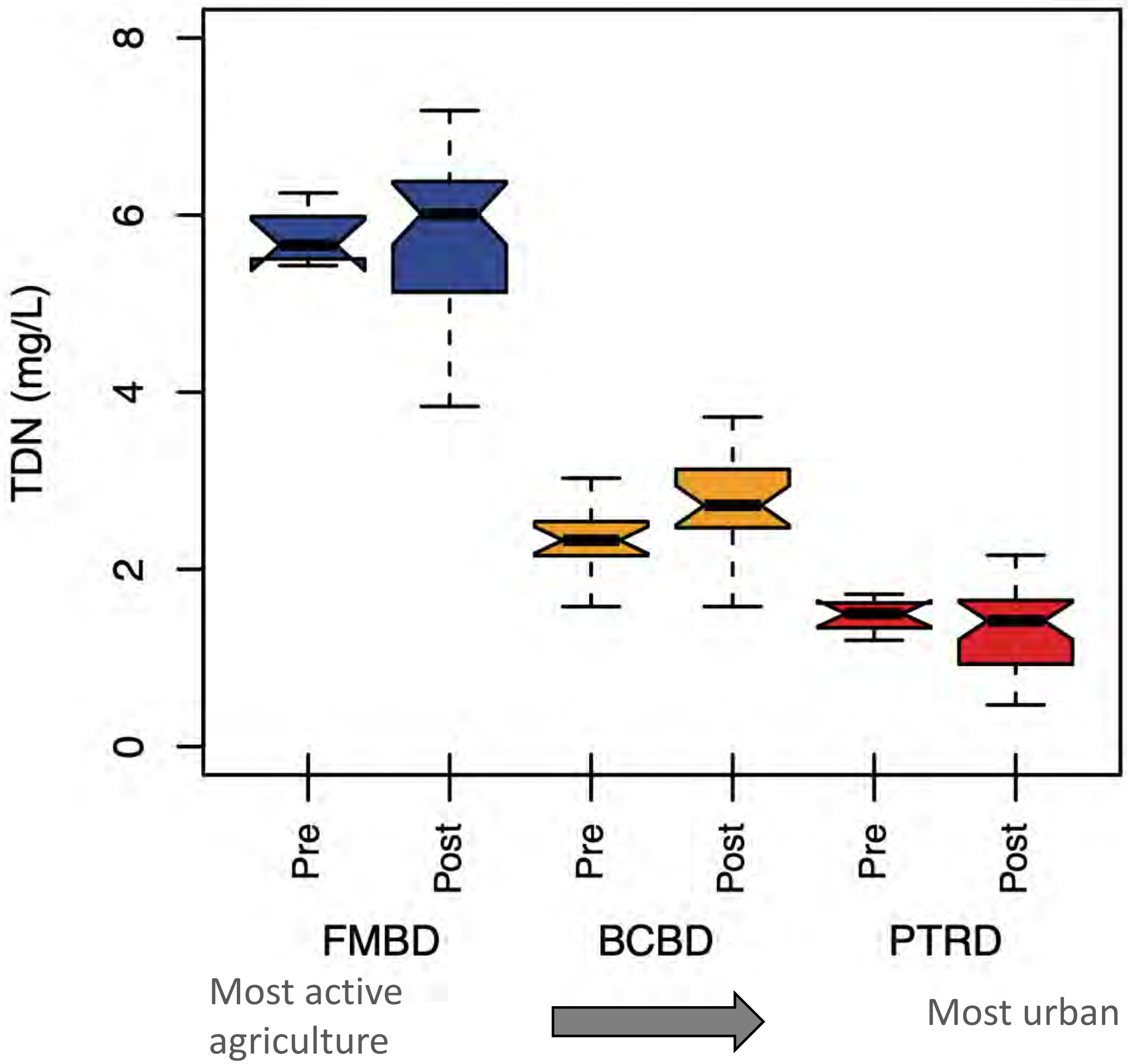
Baseflow N concentrations quite similar after restoration



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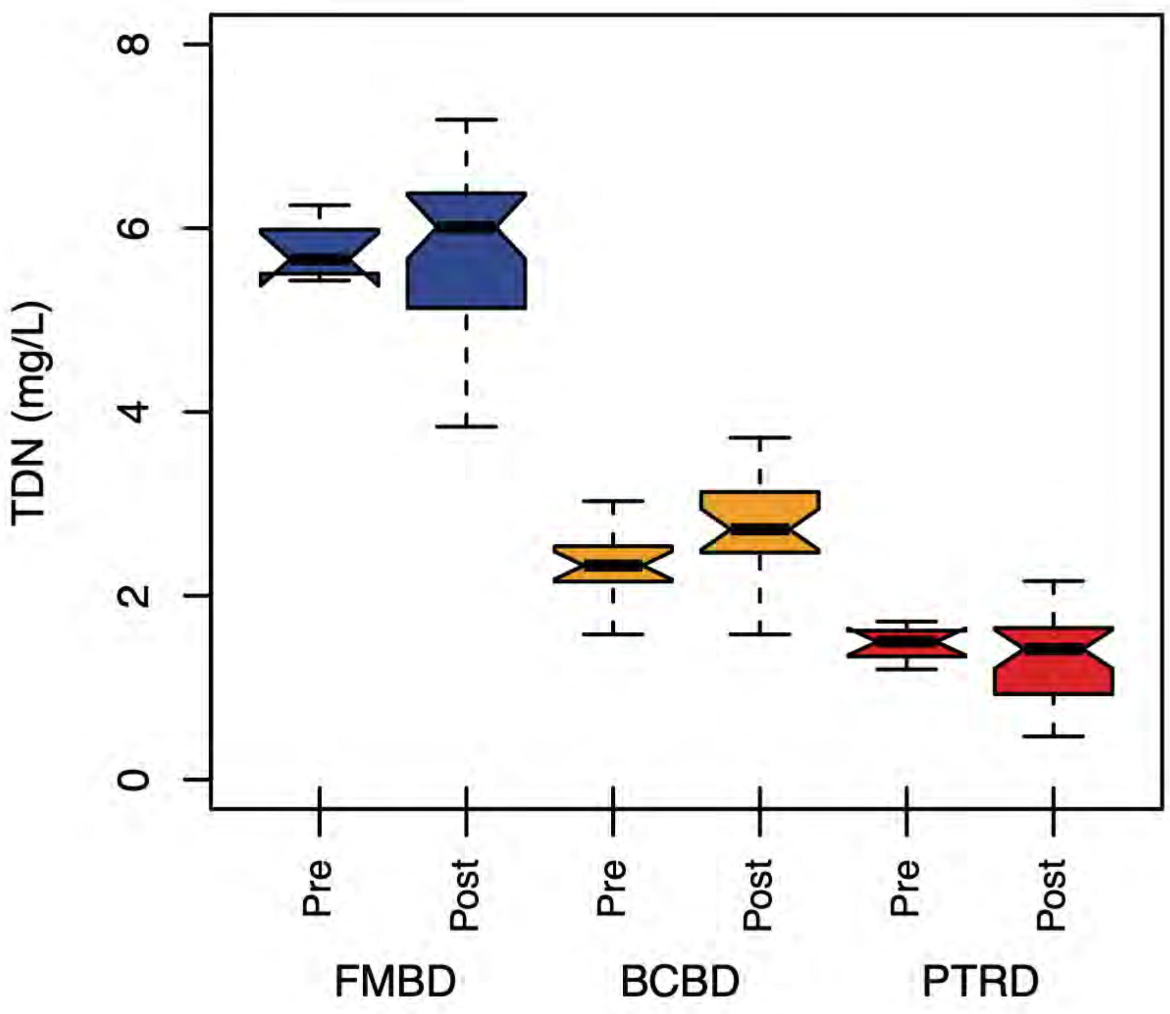
Baseflow N concentrations quite similar after restoration, fluxes higher



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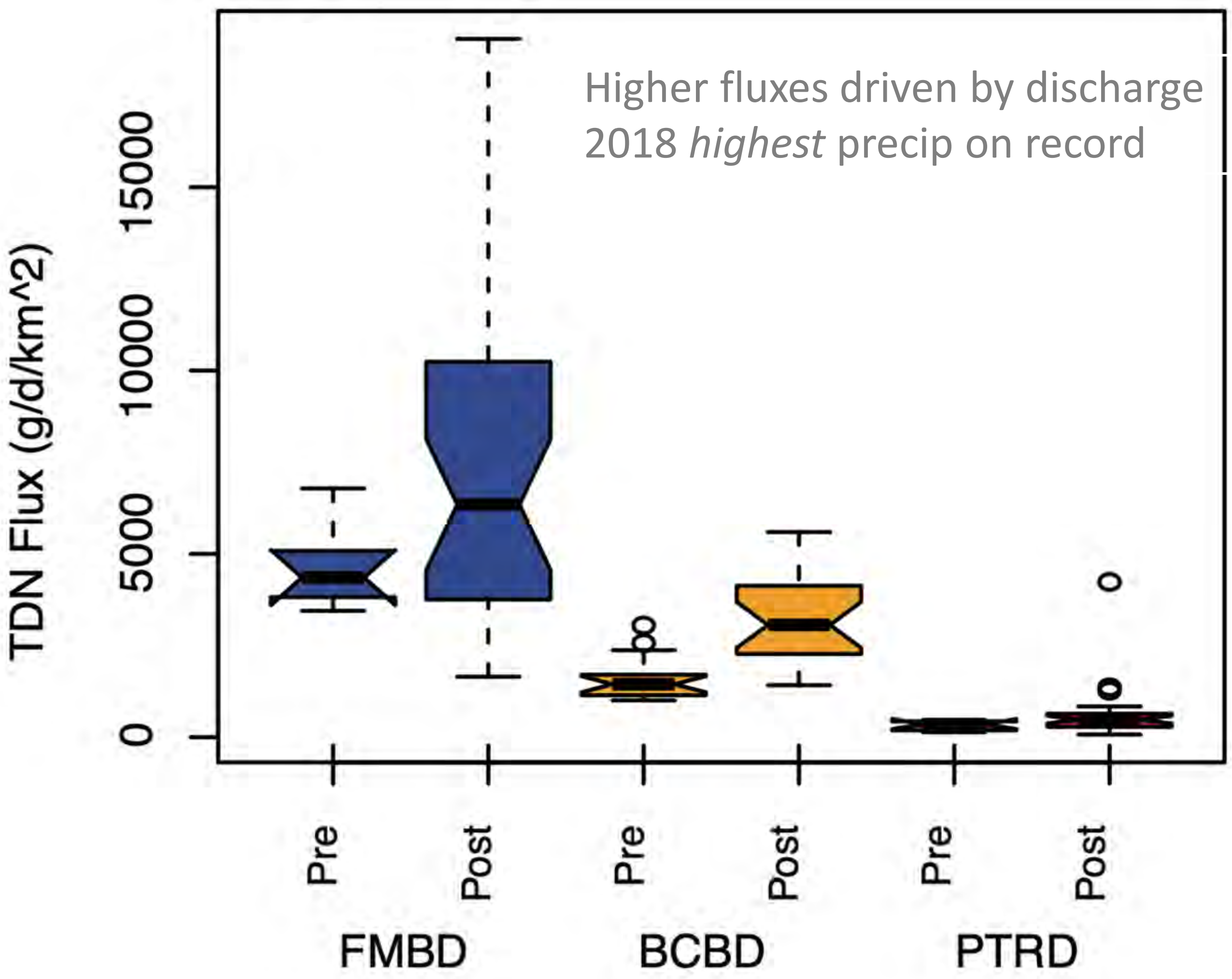

Higher fluxes driven by discharge
2018 *highest* precip on record

McMahon et al. (2021) *Environmental Research Letters*
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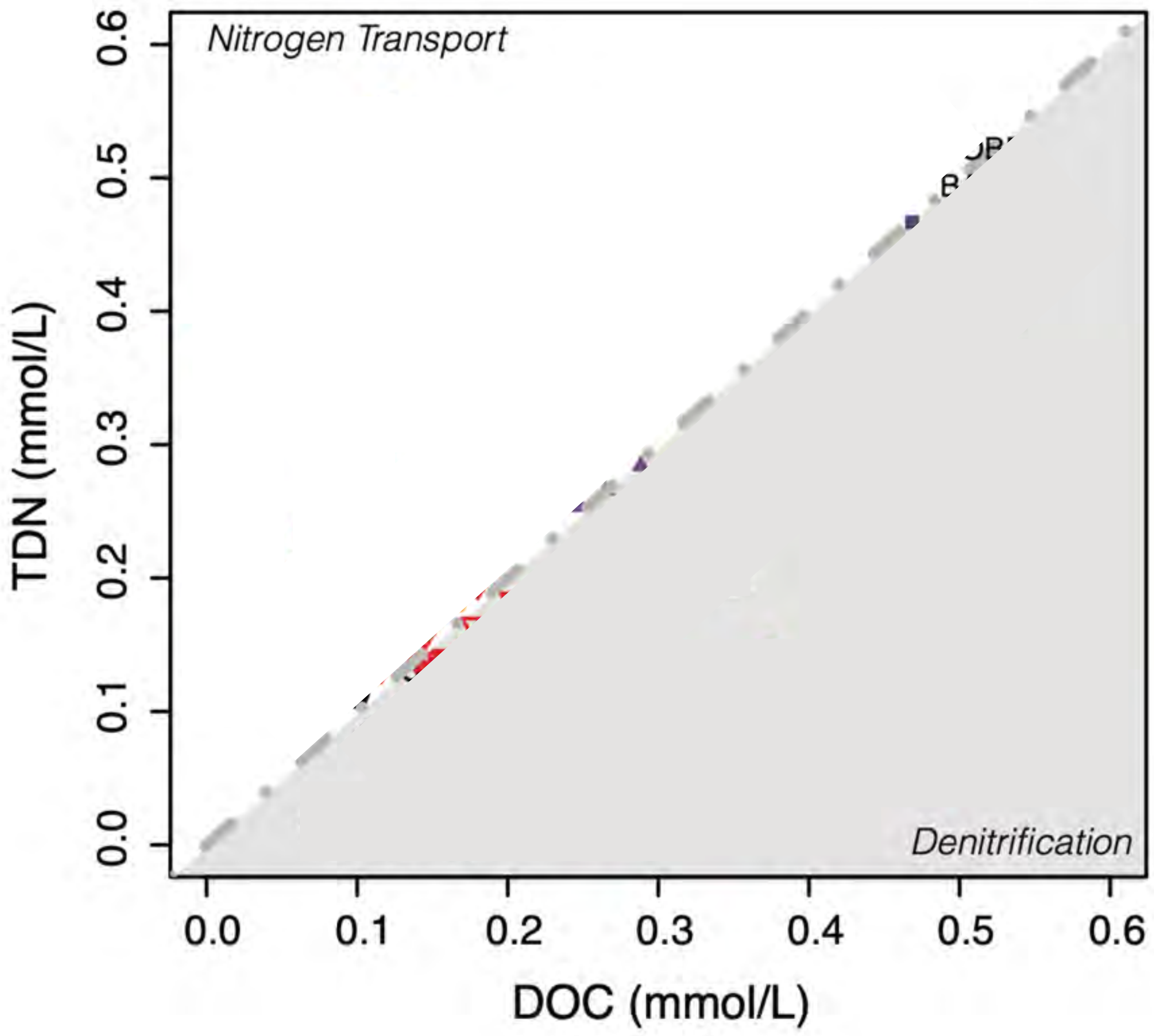
Carbon availability appears to be limiting denitrification



Similar dissolved organic carbon concentrations pre- & post-restoration

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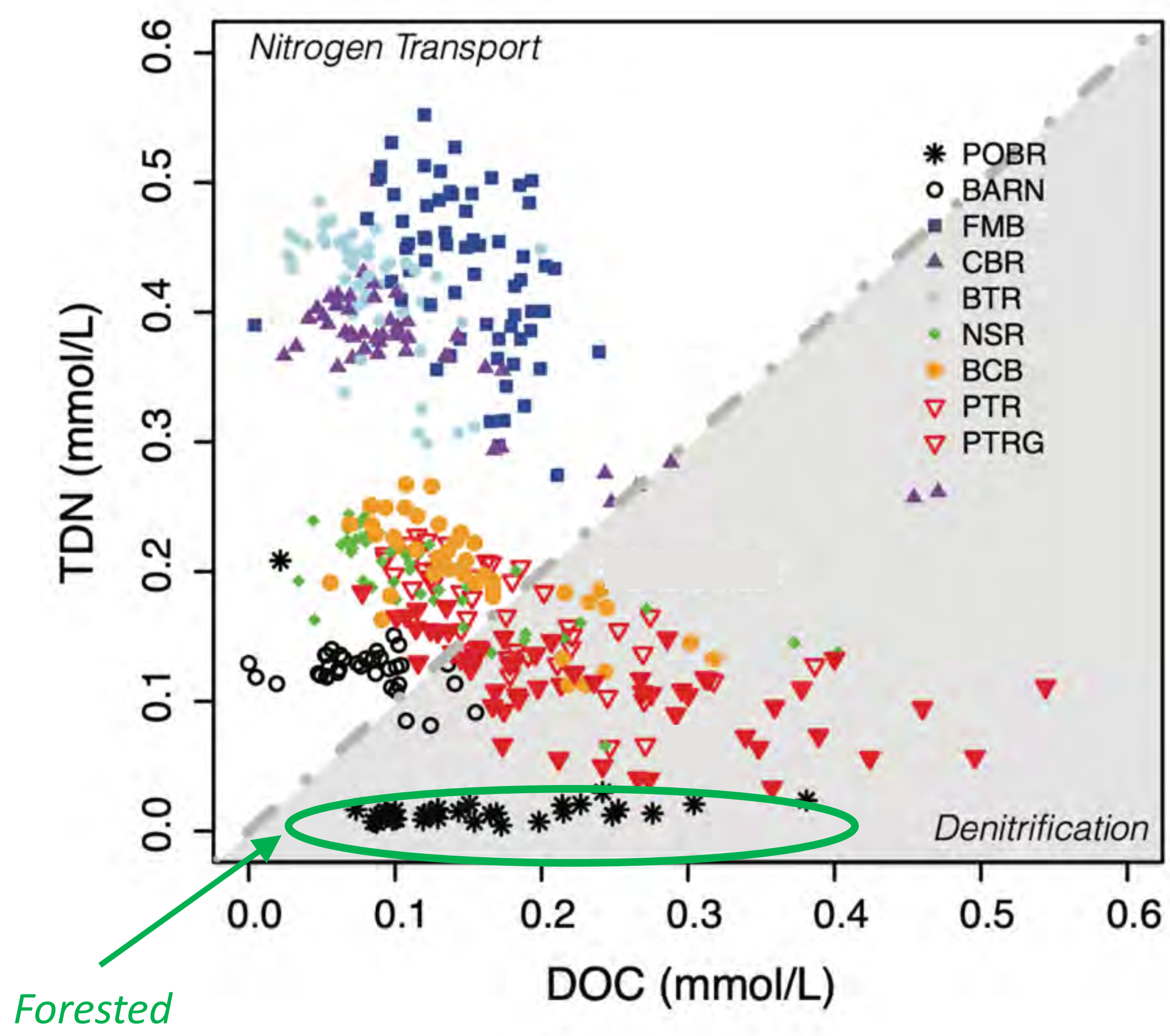

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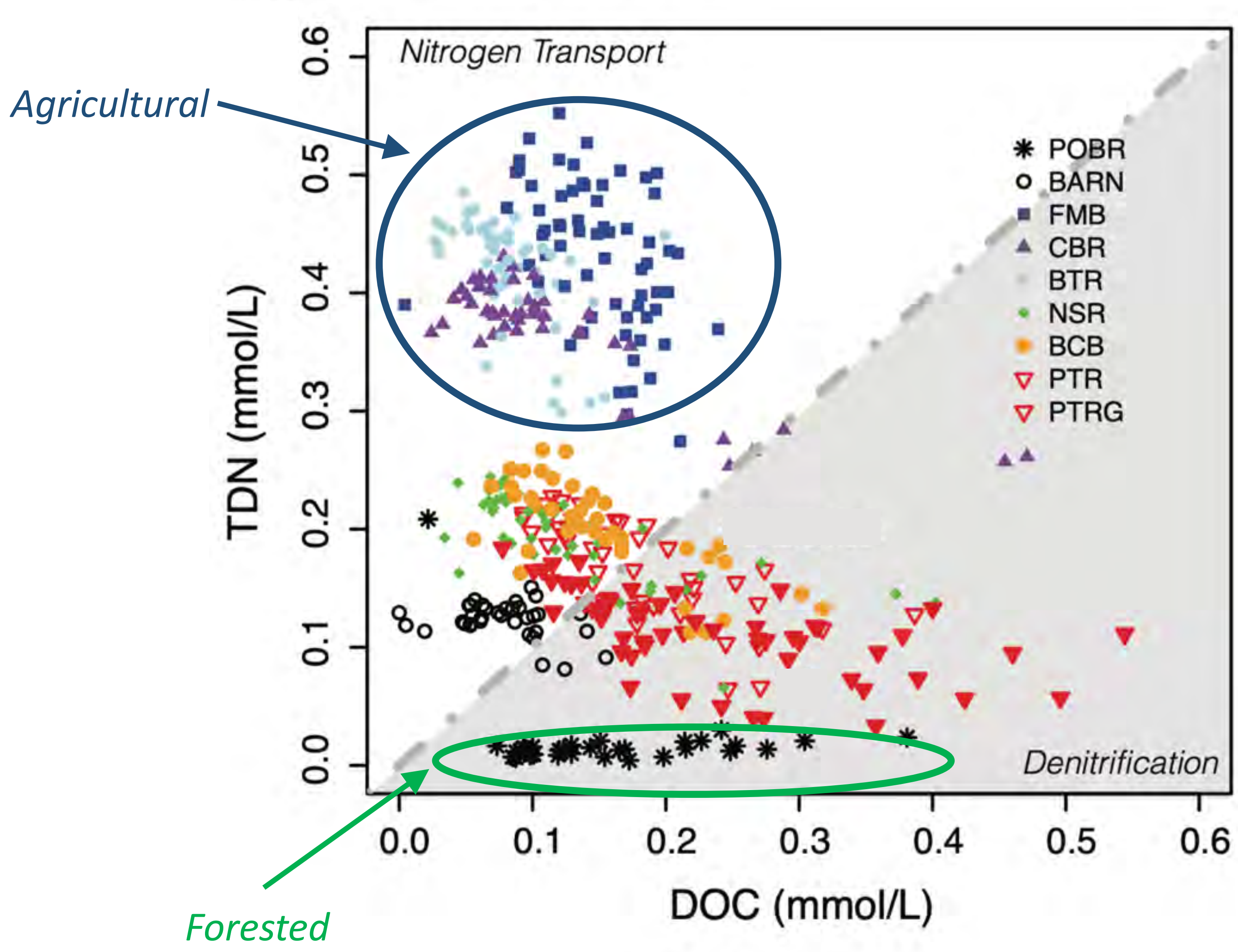

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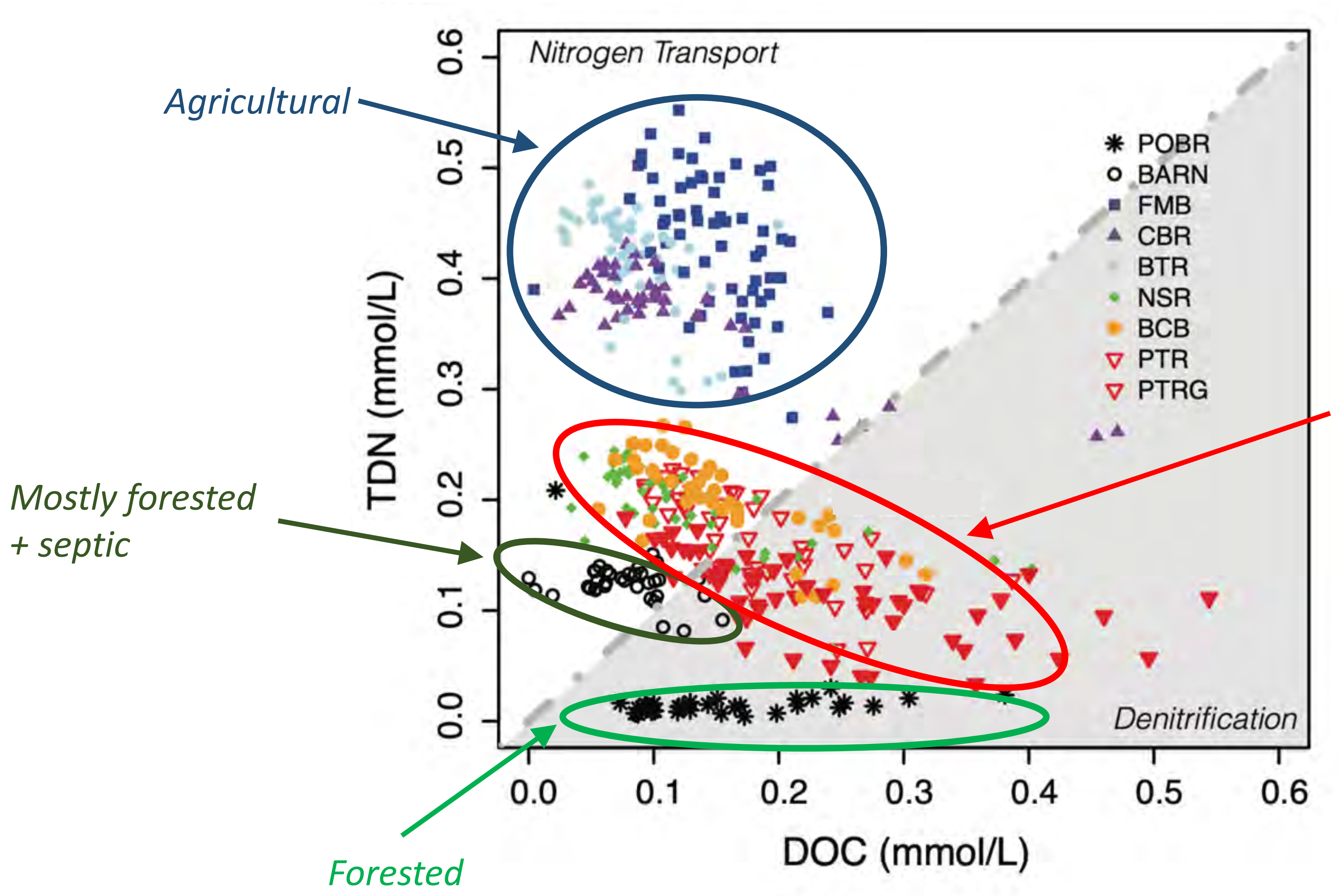

Similar dissolved organic carbon concentrations pre- & post-restoration

At Big Spring Run in PA, denitrification was not observed in groundwater (not even stream) until 5–6 years after restoration

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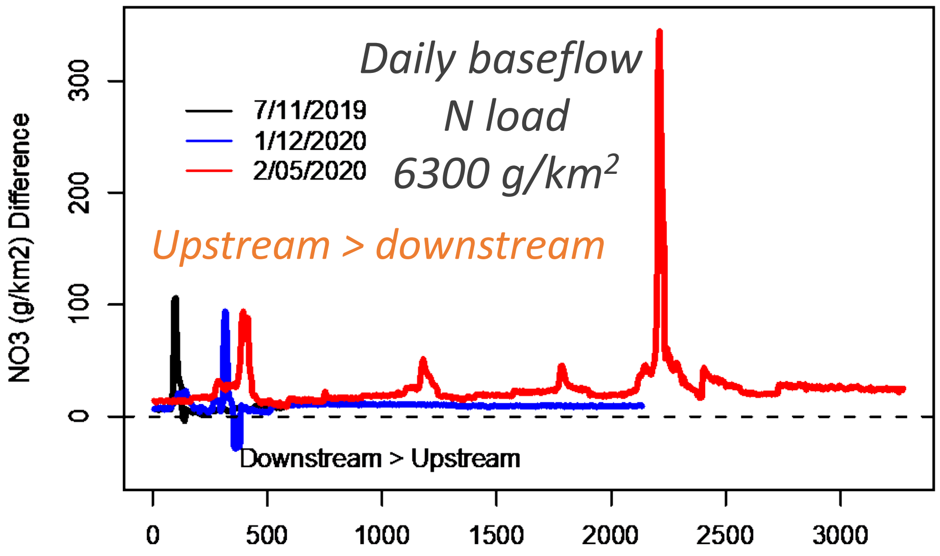
Hints of downstream mitigation based on difference in event loads

FMB: Most ag site



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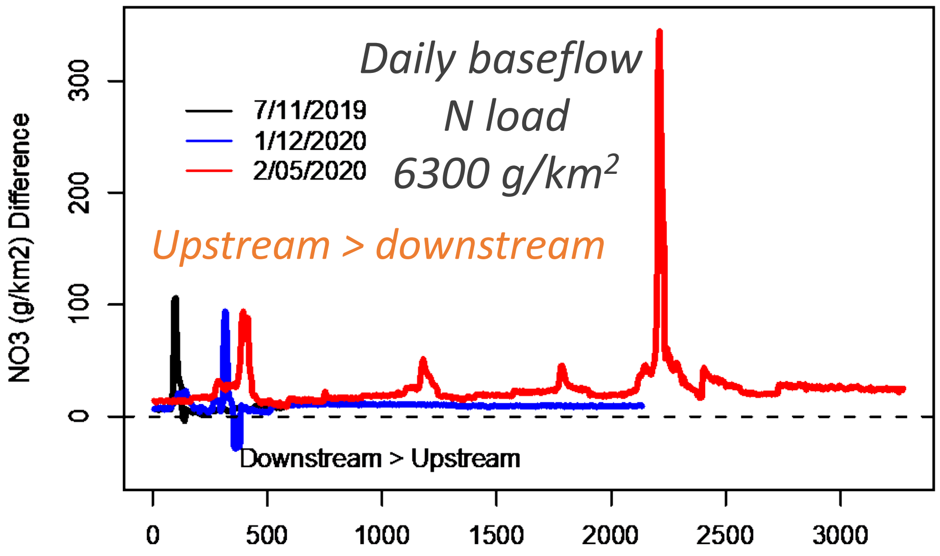

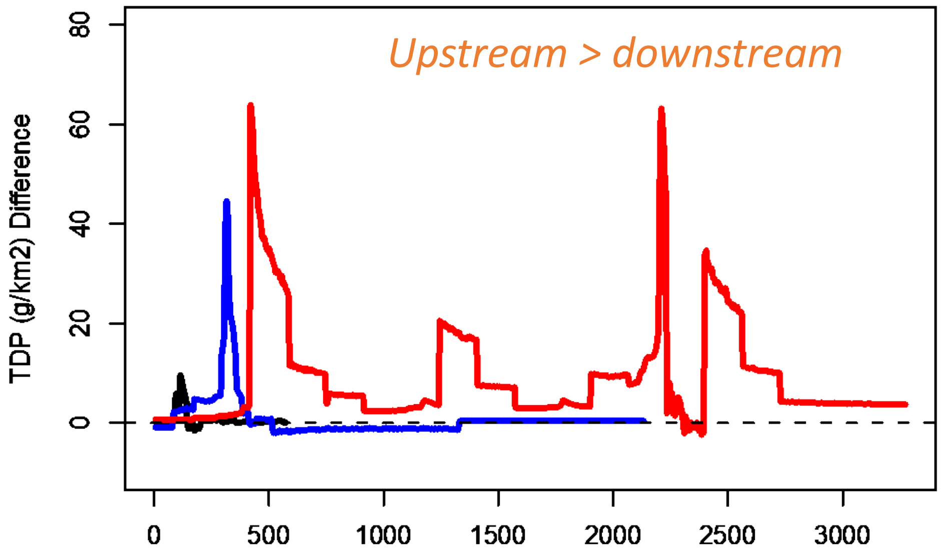

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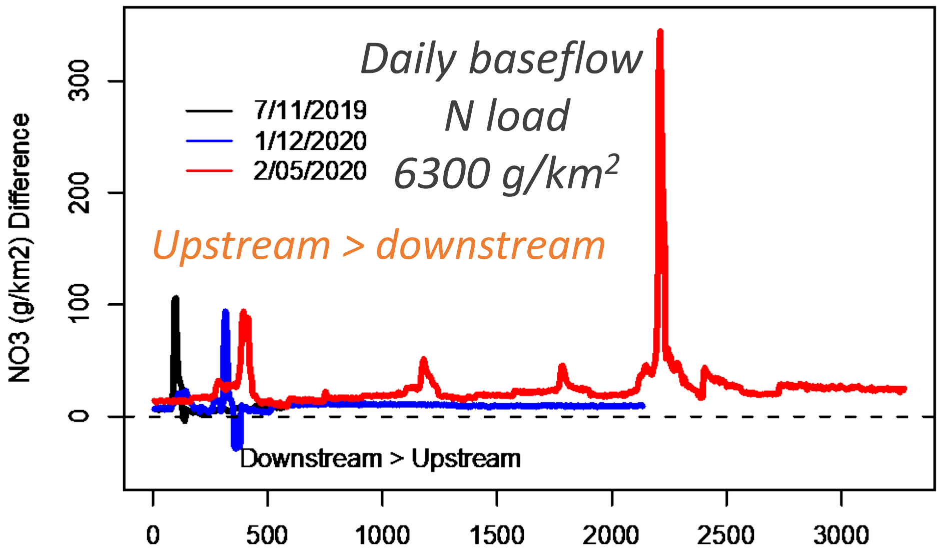

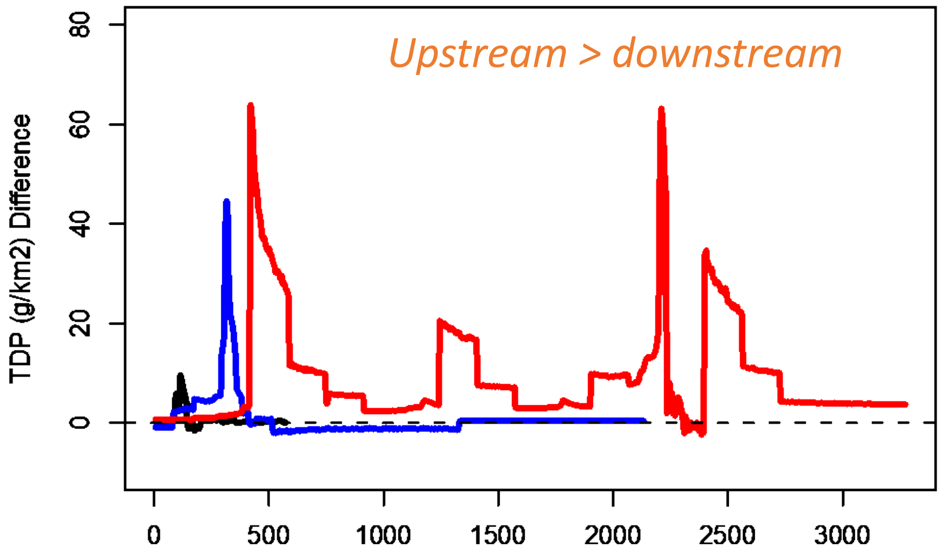

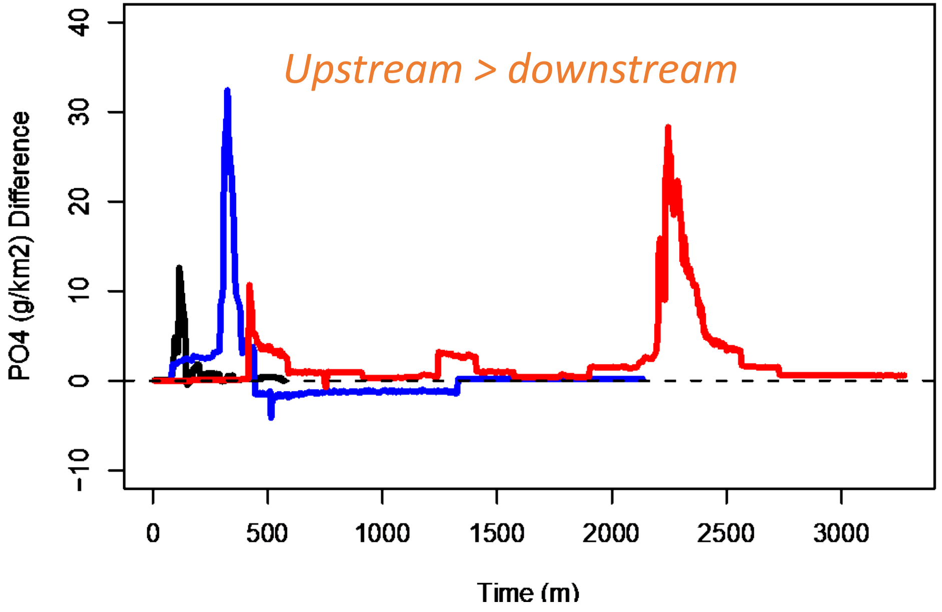

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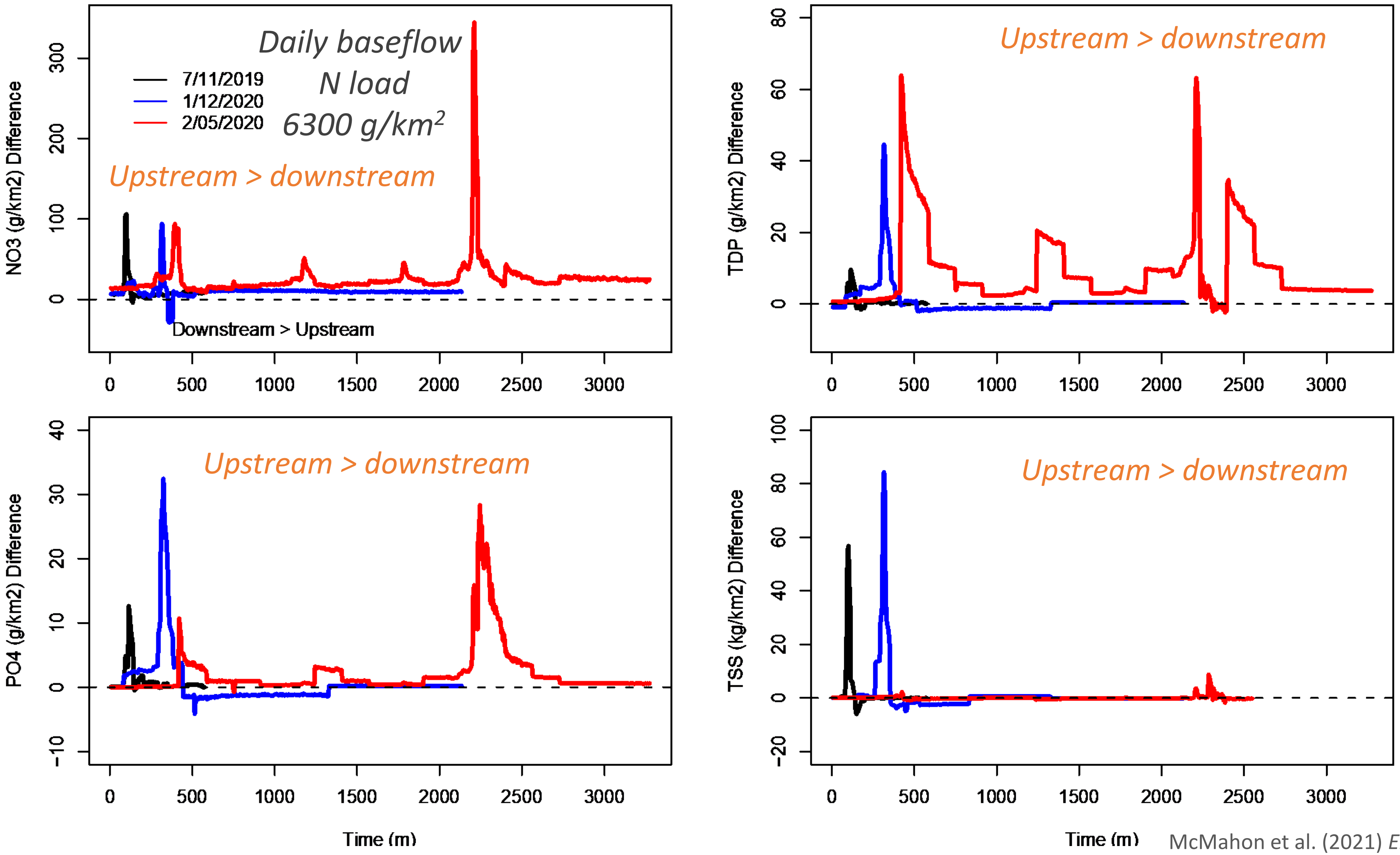


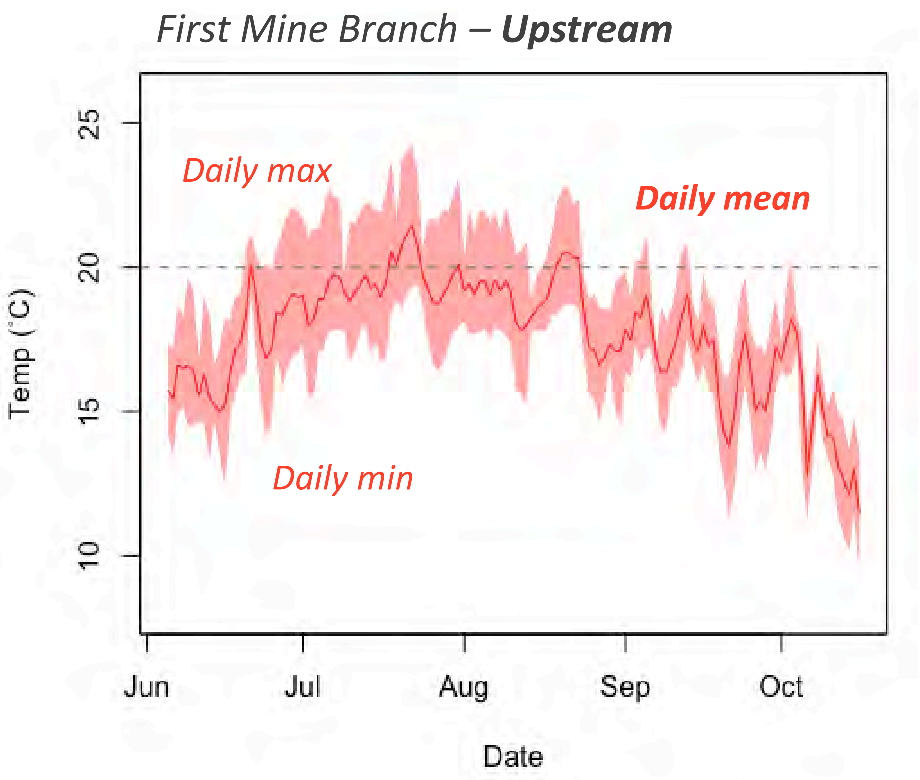
For all parameters

Peak reductions: 5–19%

Integrated reductions: 10–37%

McMahon et al. (2021) *Environmental Research Letters*
https://iopscience.iop.org/article/10.1088/1748-9326/abe007

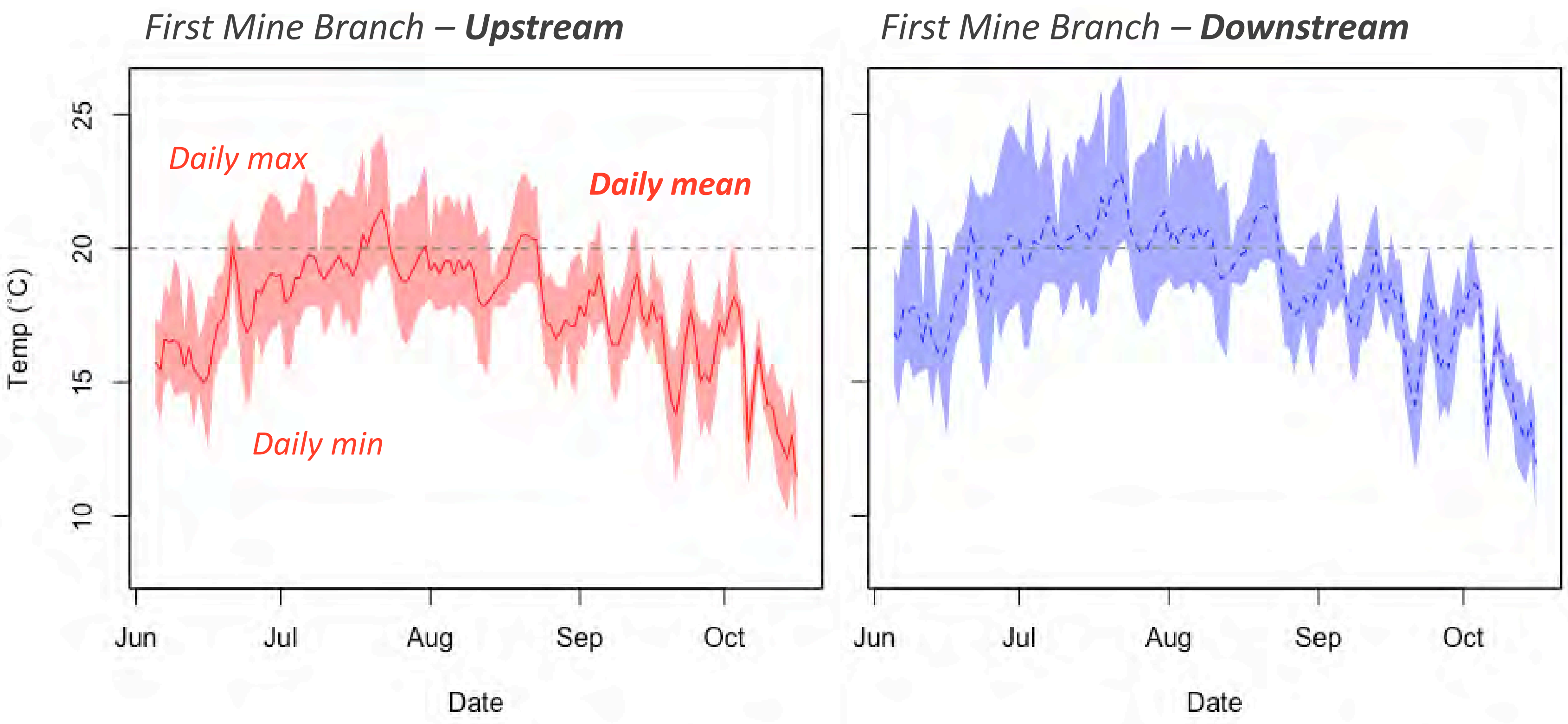
Preview on temperature: First Mine Branch (most ag site)



June – Aug.
Time <20˚C

76%

Preview on temperature: First Mine Branch (most ag site)



June – Aug.
Time <20˚C

76%

59%

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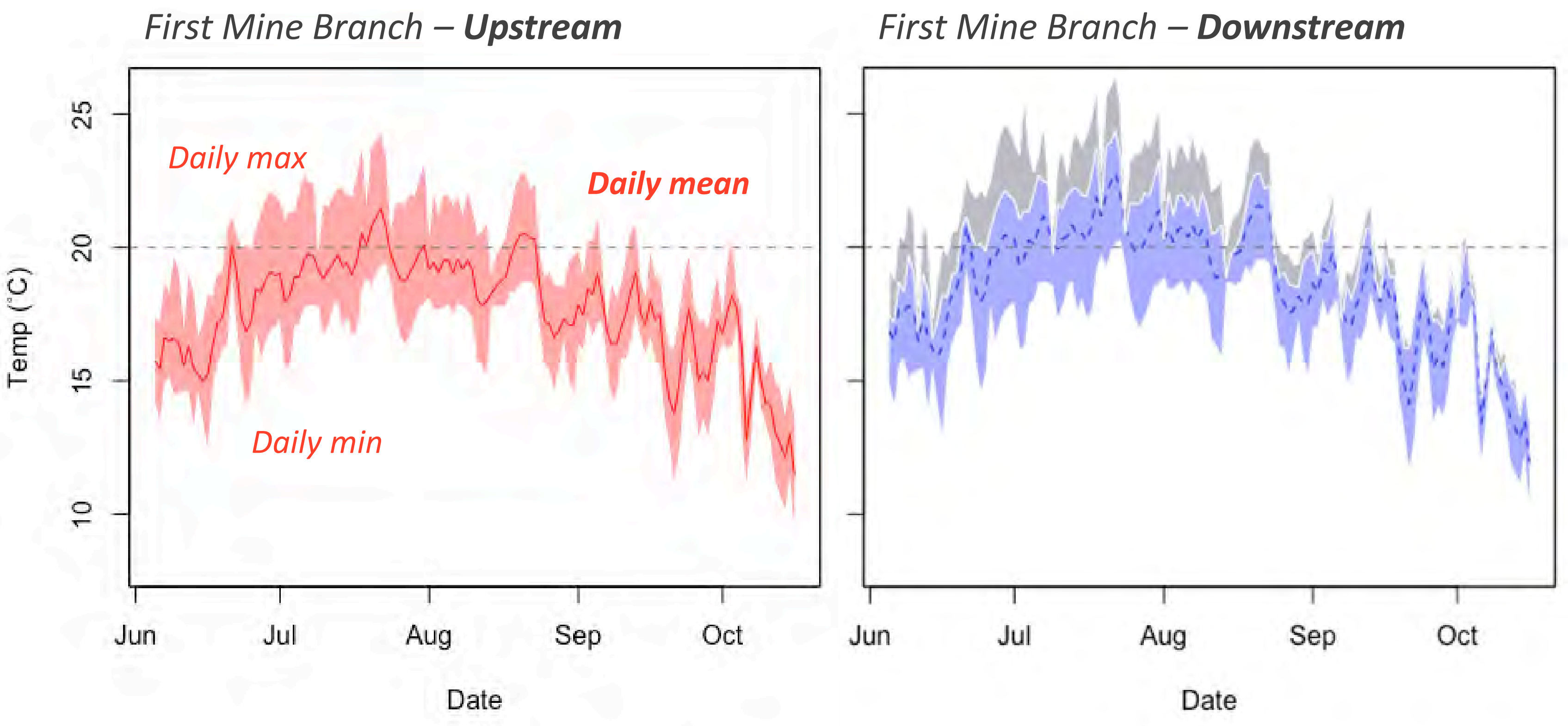

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Time <20˚C

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59%

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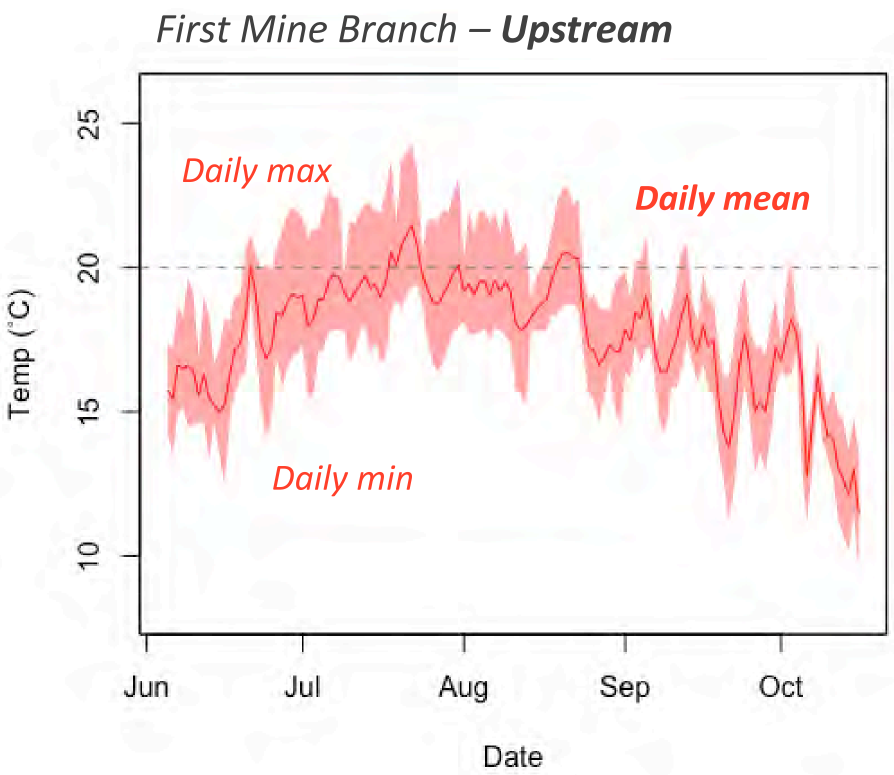
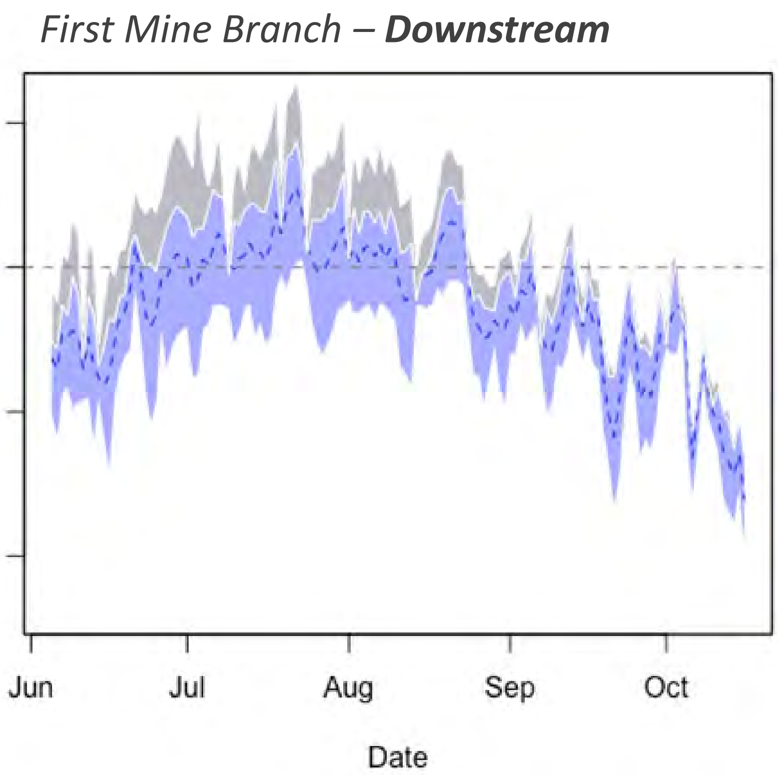
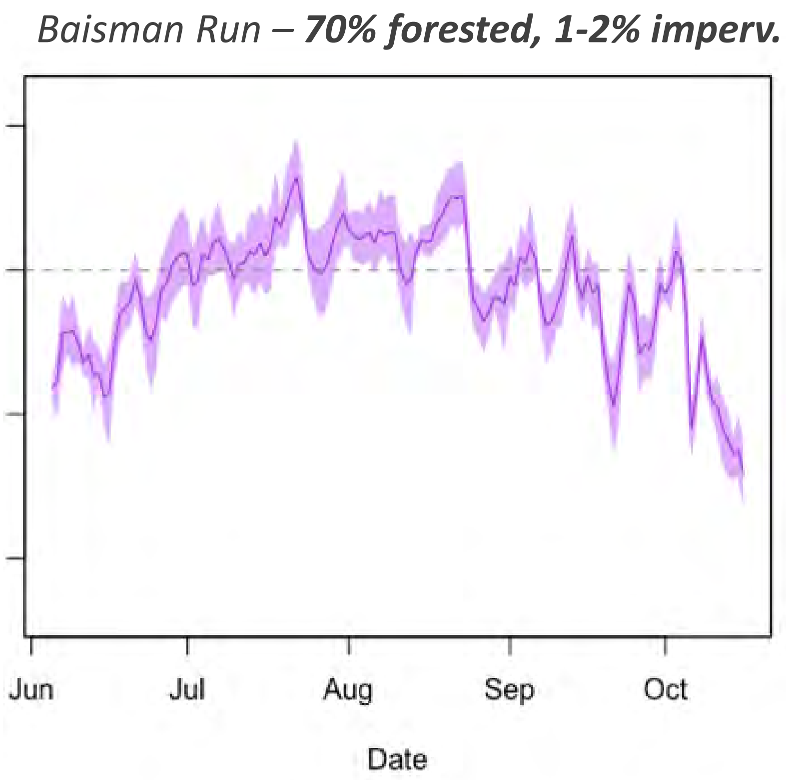






June – Aug. Time <20˚C	76%	59%	47%

Summary - Water

- Weather (2018) made the study “interesting”
- Agricultural land use is the biggest driver of N concentrations
- Denitrification appears to be limited by carbon
- No significant difference in N after restoration
- During stormflow
  - Hints of slightly lower fluxes on downstream end
  - Of interest: storm N shifts with more ammonia & dissolved organic N (or NO_3^- decreases more than total dissolved N)

Vanessa B. Beauchamp and Joel Moore Towson University

Translation Slides by Scott Lowe

What does this mean for me?

- The wet year of 2018 obscured some results in research
  - Nutrients, Sediment, and Temperature inconclusive
  - Why no dilution in higher discharges?
- Land Use of Watershed has dominant impacts
  - Are urban loads correlating with Bay Model?
- Legacy Sediment Removal increases hydrophytic vegetation establishment and decreases invasives at these sites – at least initially
- Majority of herbaceous vegetation established was not planted, majority of woody vegetation was planted

What does this mean for me?

What do I take from this if I am a practitioner:

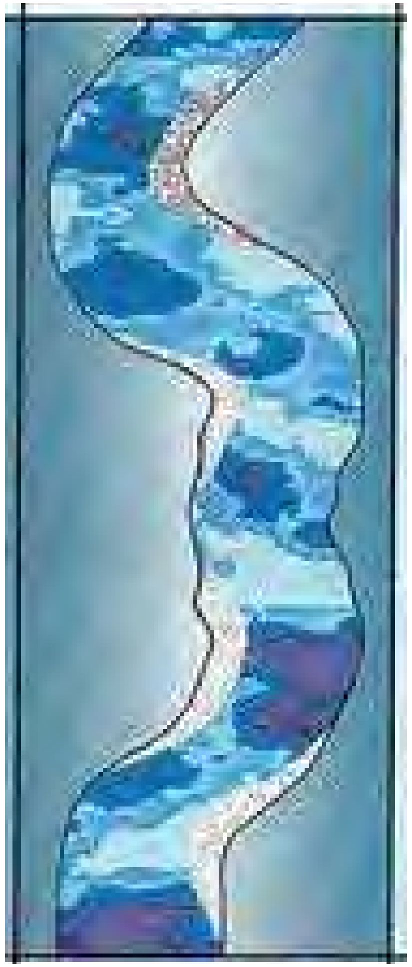
- What is optimal selection of floodplain access elevation? Significance of baseflow versus flood flow nutrient and sediment fluxes?
- Siting of projects relative to land use
- Planting plan strategies
- Look for ways to create more storage or increase retention time for storm flows

What do I take from this if I am a regulator:

- Temperature fluctuations may be negligible but additional data in normal year needed
- Lower risk of invasives – at least initially
- Higher likelihood of self mitigating wetland impacts with hydrophytic vegetation quickly established?

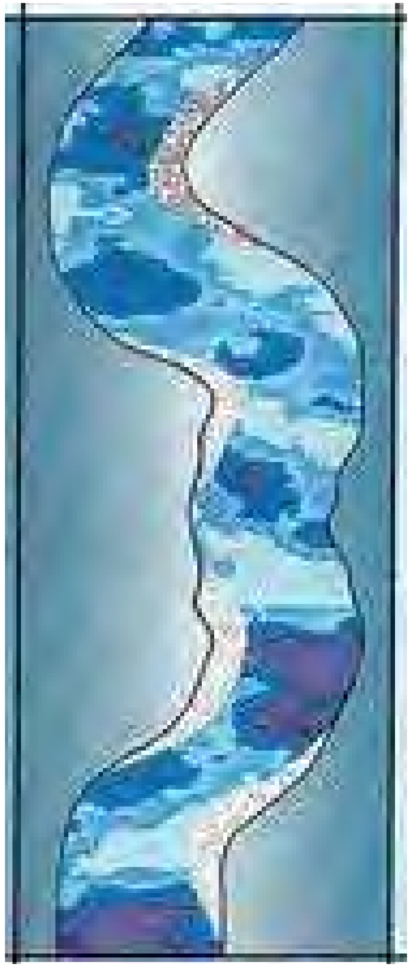
Extra background slides

What are the goals and desired outcomes of restoration?



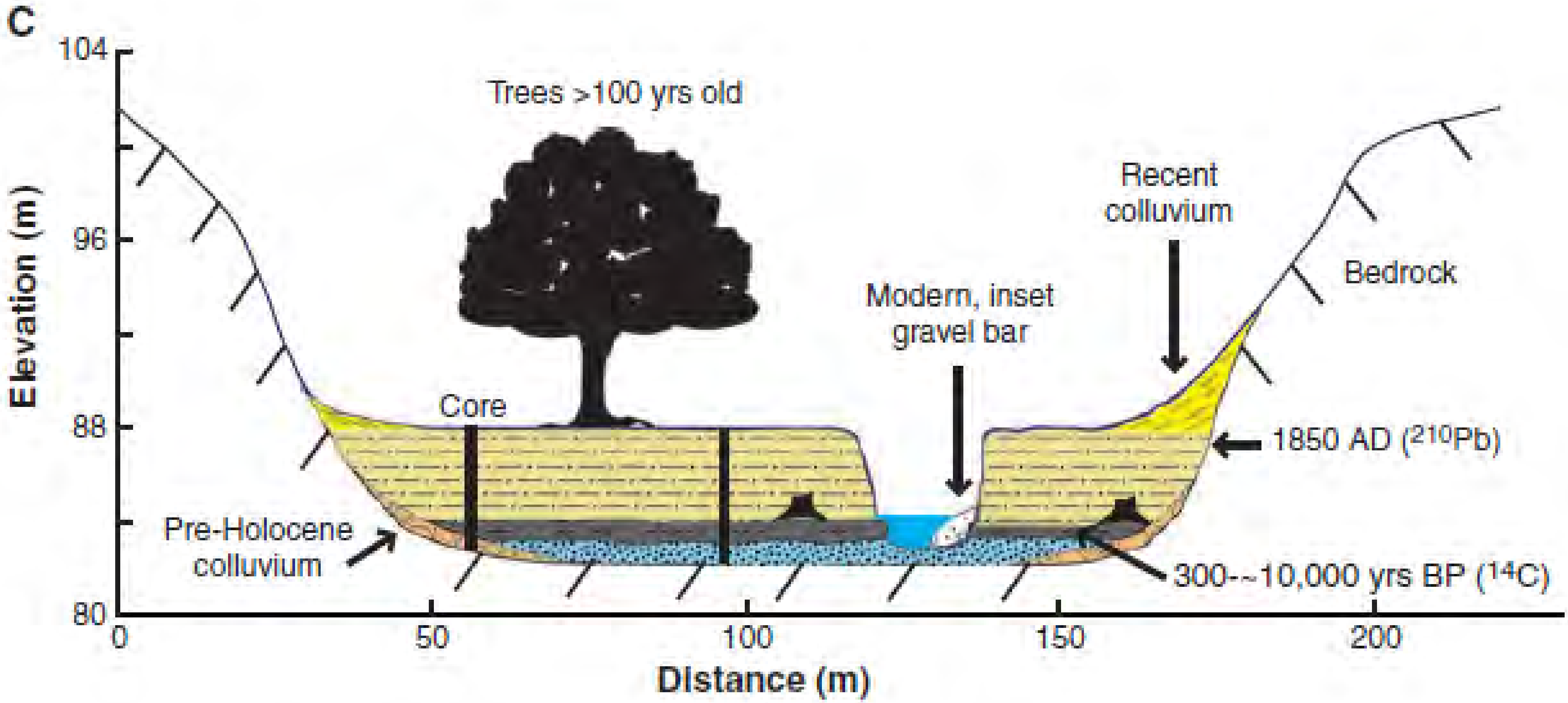
Meandering

What are the goals and desired outcomes of restoration?



Meandering

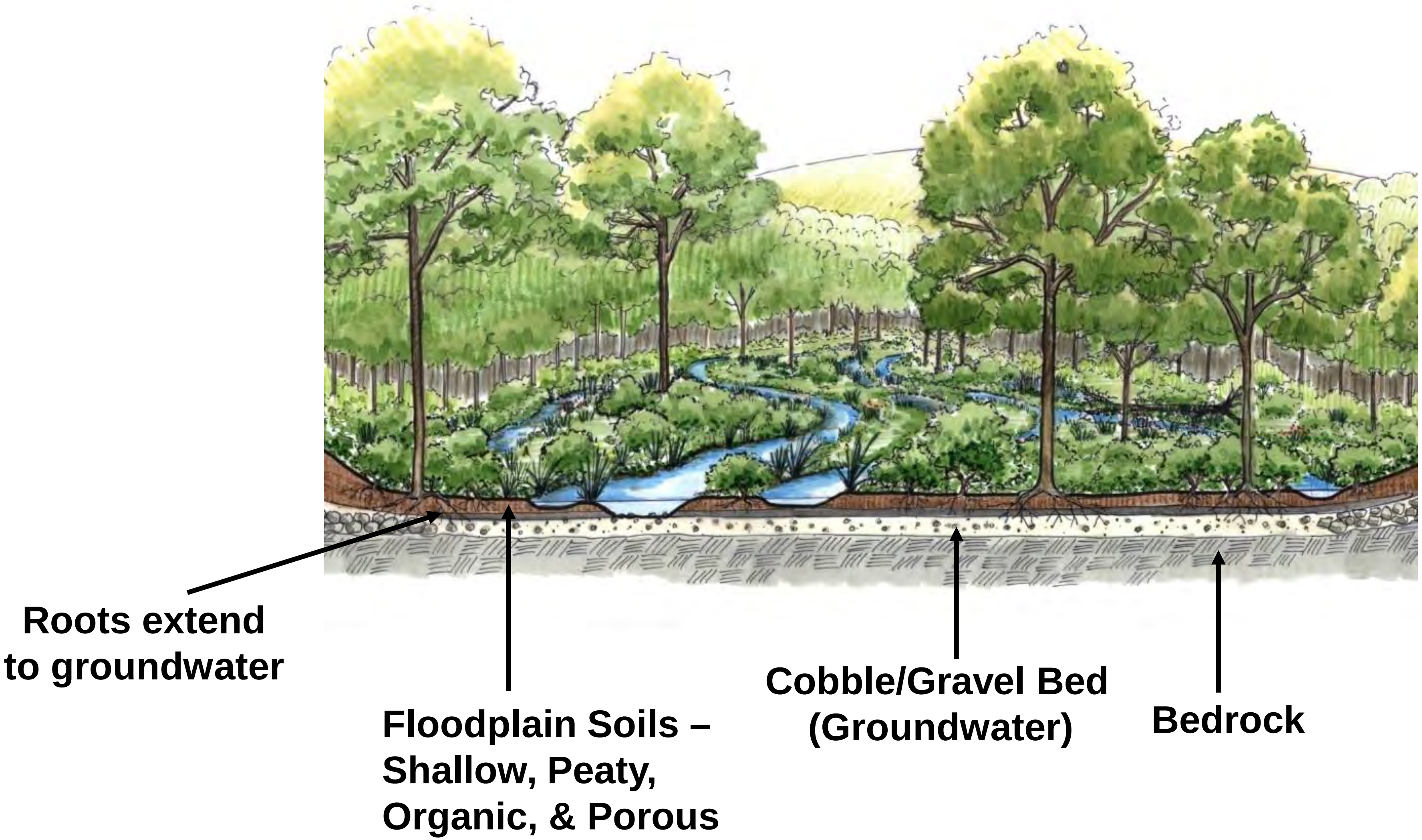
Anastomosing

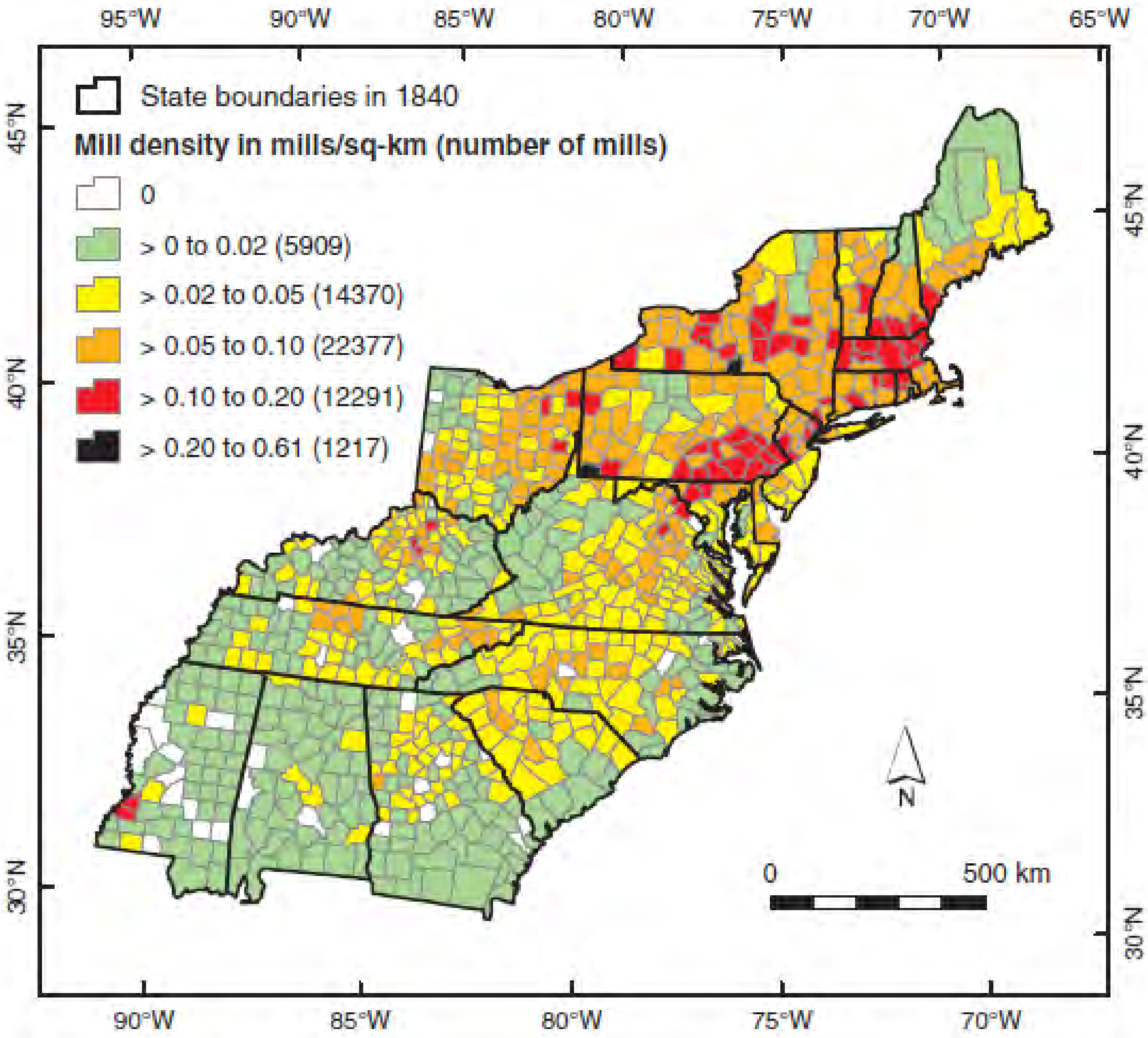


C
Trees >100 yrs old
Recent colluvium
Bedrock
Modern, inset gravel bar
Core
1850 AD (^{210}Pb)
Pre-Holocene colluvium
300--~10,000 yrs BP (^{14}C)
Elevation (m)
104
96
88
80
0
50
100
150
200
Distance (m)

Natural Piedmont Stream Valley

Connectivity between rooting zone, groundwater, and stream flow





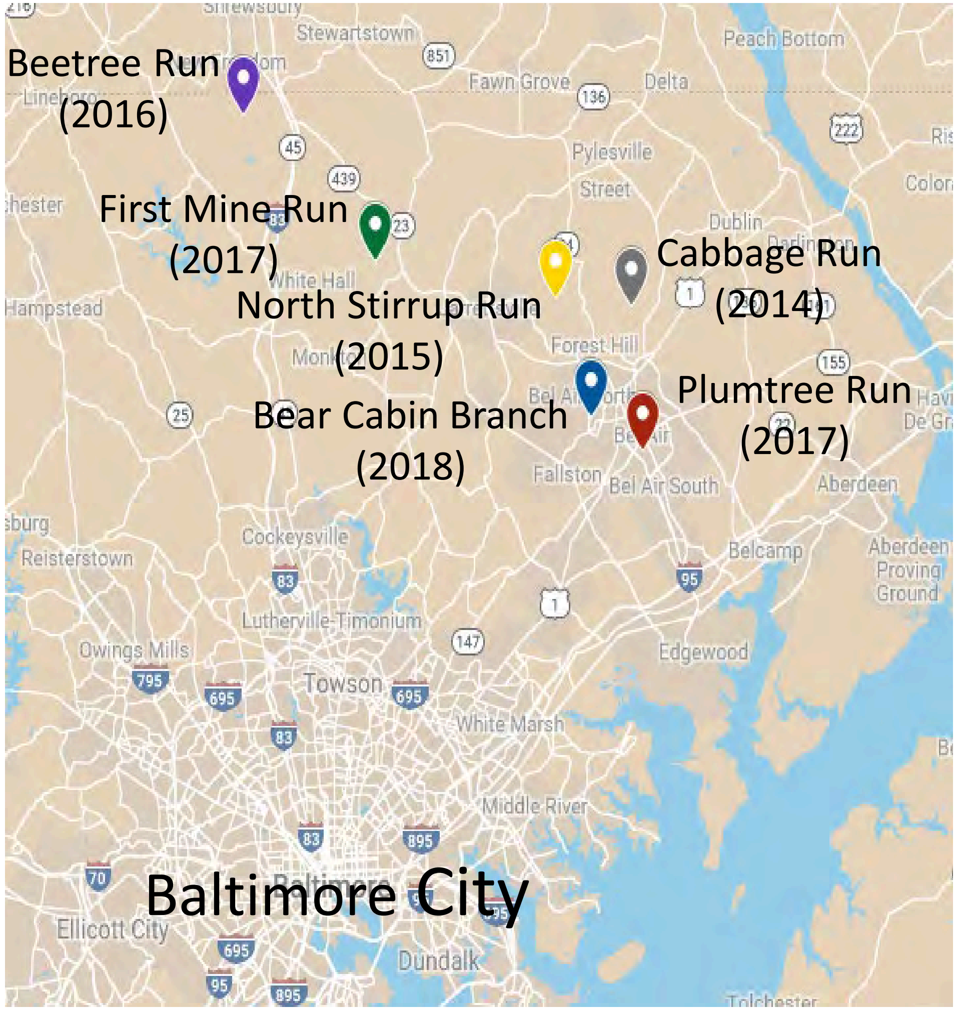
95°W
90°W
85°W
80°W
75°W
70°W
65°W
45°N
40°N
35°N
30°N
State boundaries in 1840
Mill density in mills/sq-km (number of mills)
0
> 0 to 0.02 (5909)
> 0.02 to 0.05 (14370)
> 0.05 to 0.10 (22377)
> 0.10 to 0.20 (12291)
> 0.20 to 0.61 (1217)
N
0
500 km

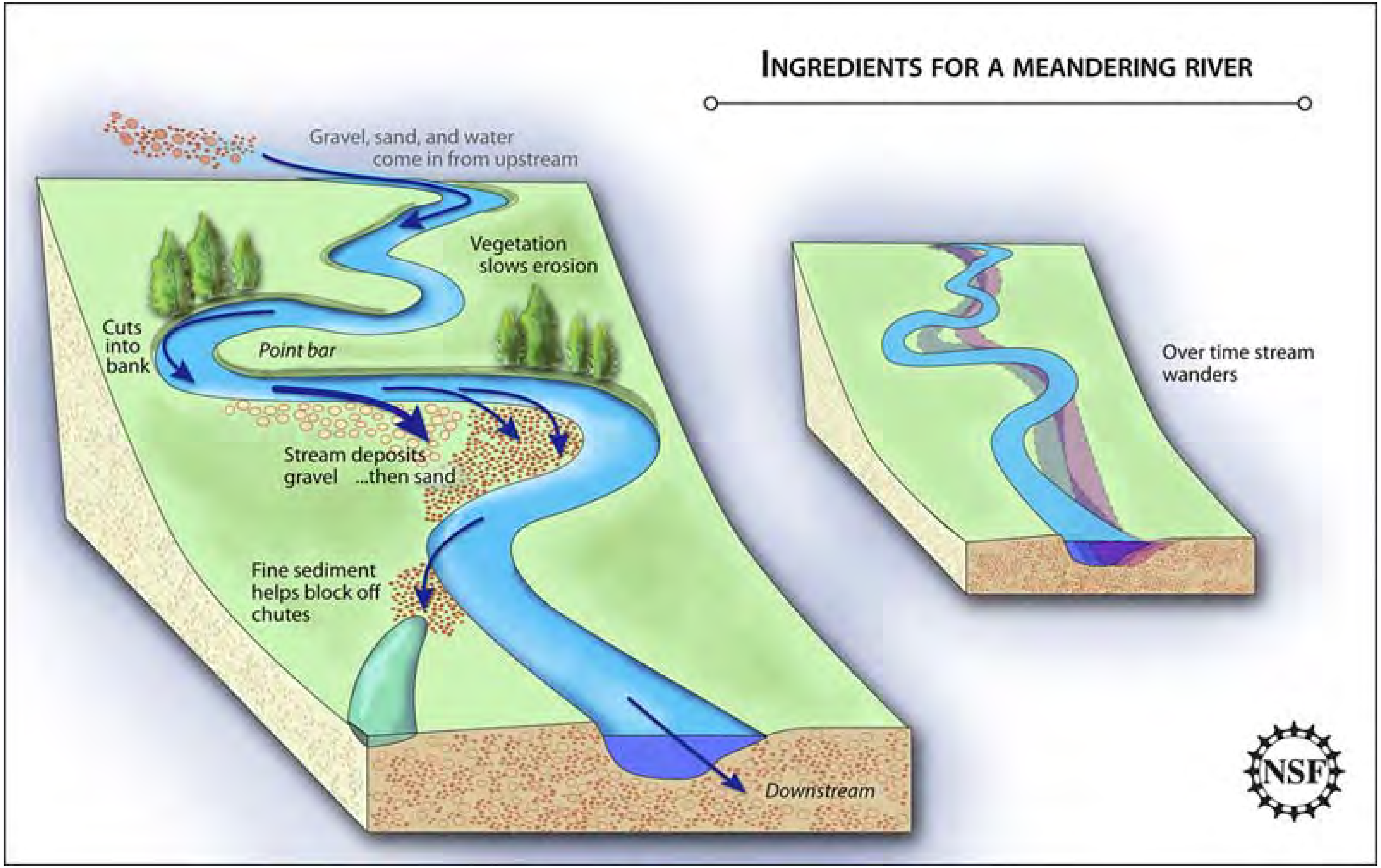
Summary - Vegetation

- Decrease in woody vegetation
  - Removal of trees
  - Near-complete elimination of vines
  - Community similarity among sites increases
- Increase in hydrophytic, native vegetation
  - Loss of species (like skunk cabbage) that don’t disperse/regenerate well from seed
  - Loss of forest understory species
  - Increase in graminoid species (grasses, rushes, sedges)
    - Response to hydrology and light

Study sites – *for questions*

Site	Drainage Area (km^2)	Forest (%)	Impervious surface cover (%)	Restoration length (linear ft)	Usage
BTRD	6.55	14.5	1.26	5320	Reforesting / Retired Agricult-ural
BTRU	6.03	13.3	1.03		
FMRD	3.88	26.4	1.26	2400	Row crop with (former) forested buffer
FMRU	2.93	22.5	1.68		
NSRD	2.25	37.7	6.14	2600	Pasture / Active cattle farm
NSRU	1.83	43.8	7.51		
CABD	4.97	7.92	13.7	1340	Row Crop & Retired pasture
CABU	4.40	10.7	14.6		
BCBD	8.18	21.6	21.6	3675	Suburban / Retired Agricultural
BCBU	7.07	21.9	21.9		
PTRD	0.96	5.01	56.4	1240	Dense urban
PTRU	0.88	3.29	54.9		

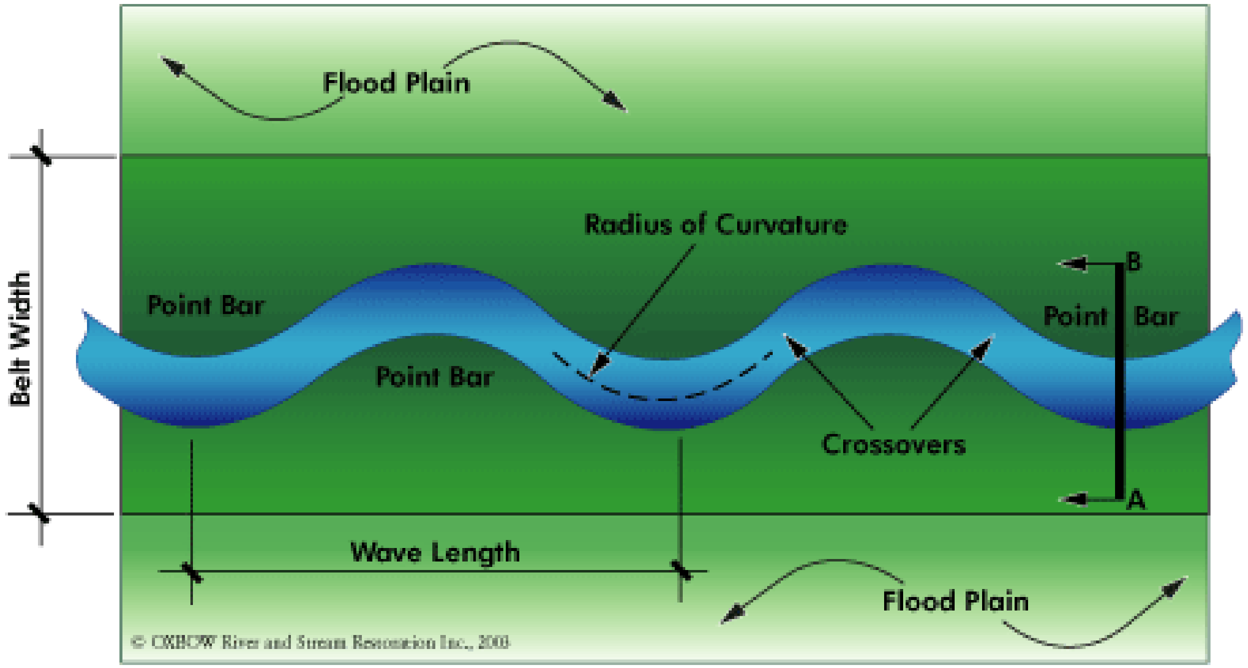




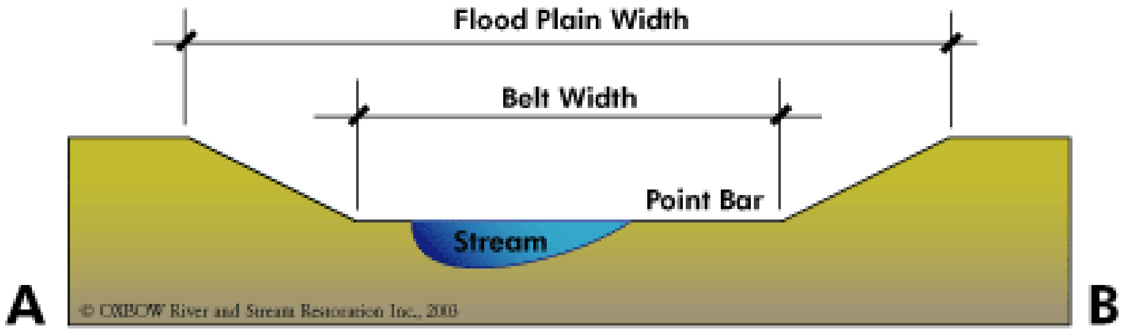
http://www.berkeley.edu/news/media/releases/2009/10/images/invitro1_h.jpg

https://lternet.edu/research/keyfindings/river-corridors

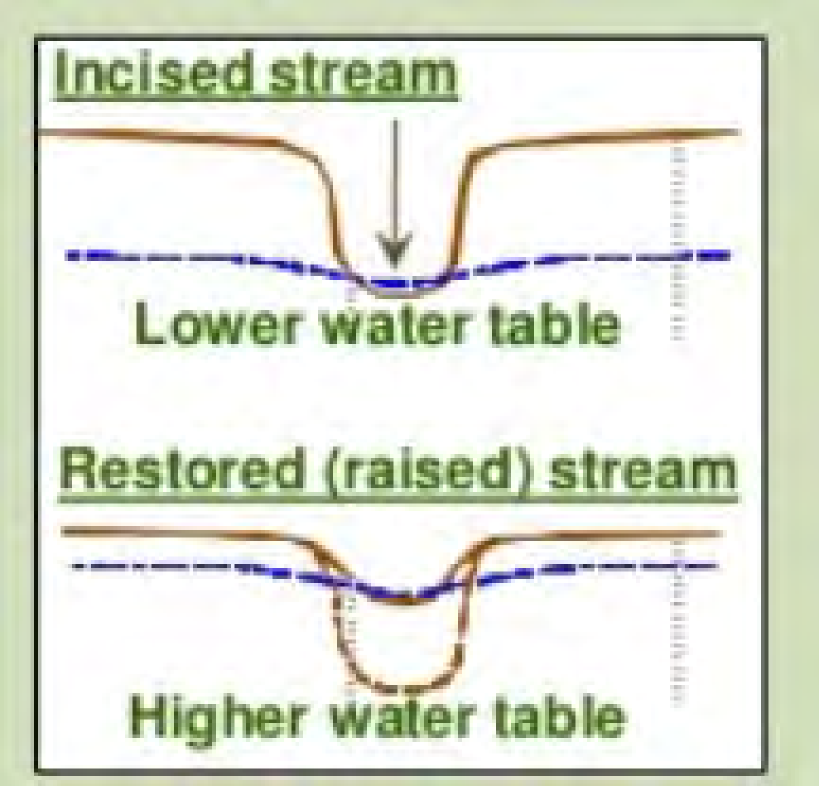
MEANDER GEOMETRY



MEANDER CROSS SECTION AB



http://www.oxbowriver.com/Web_Pages/Services_Pages/Services_NCD/NCD_Meander.html



https://www.montgomerycountymd.gov/water/restoration/streams.html

Extra site description slides

Bear Cabin Branch

Bear Cabin Branch

Plum Tree Run


Plum Tree Run

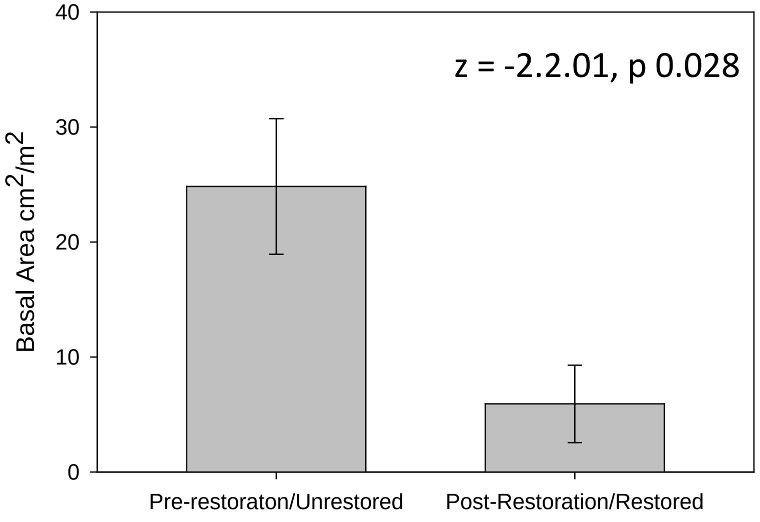
Plum Tree Run

Plum Tree Run

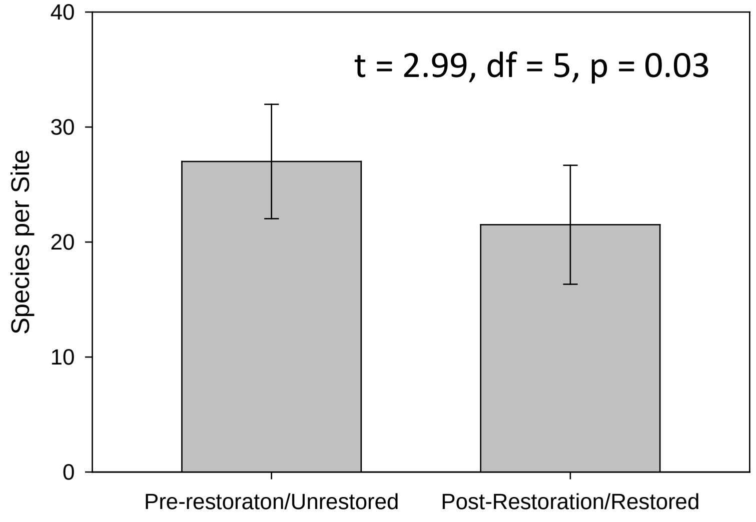
Extra riparian vegetation slides

Average 81% DECREASE in basal area and 20% decrease in woody species richness

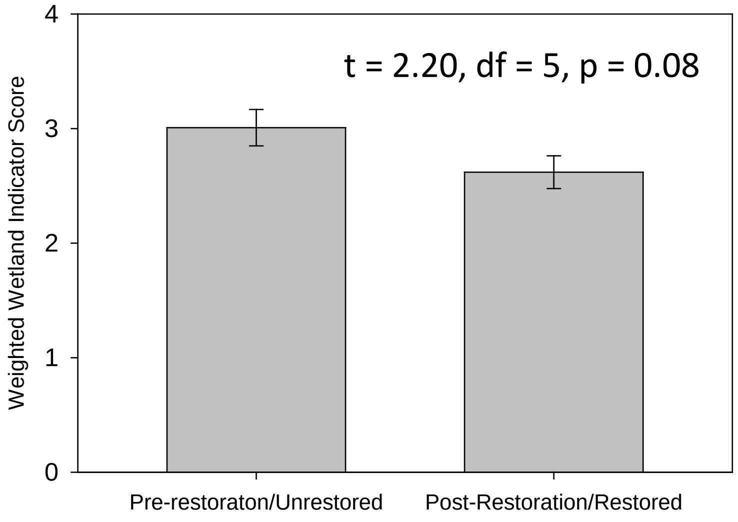
Basal area



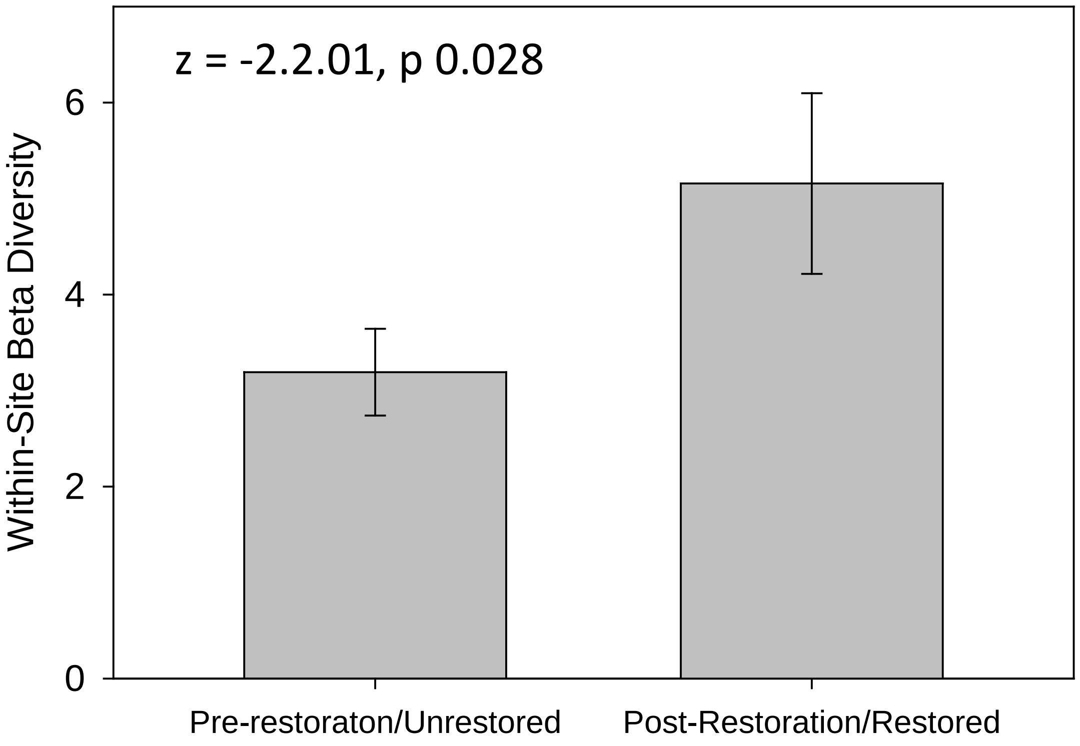
Species Richness

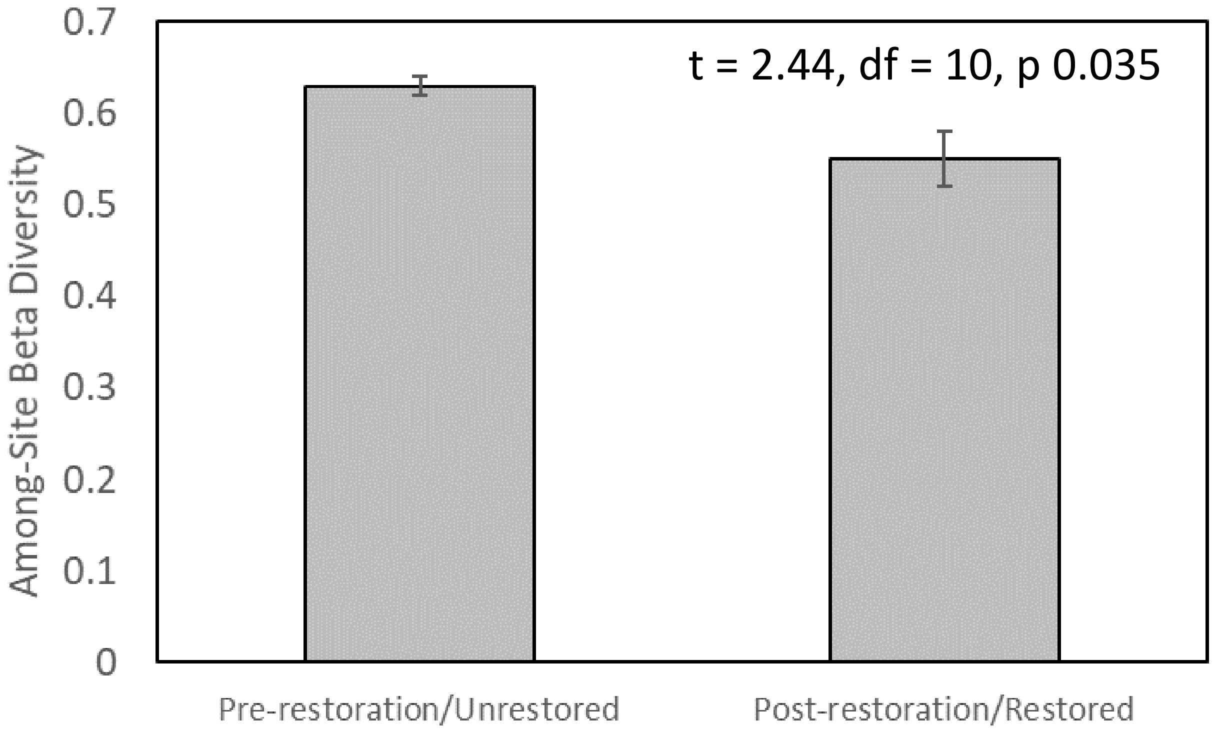


Weighted Wetland Indicator Score

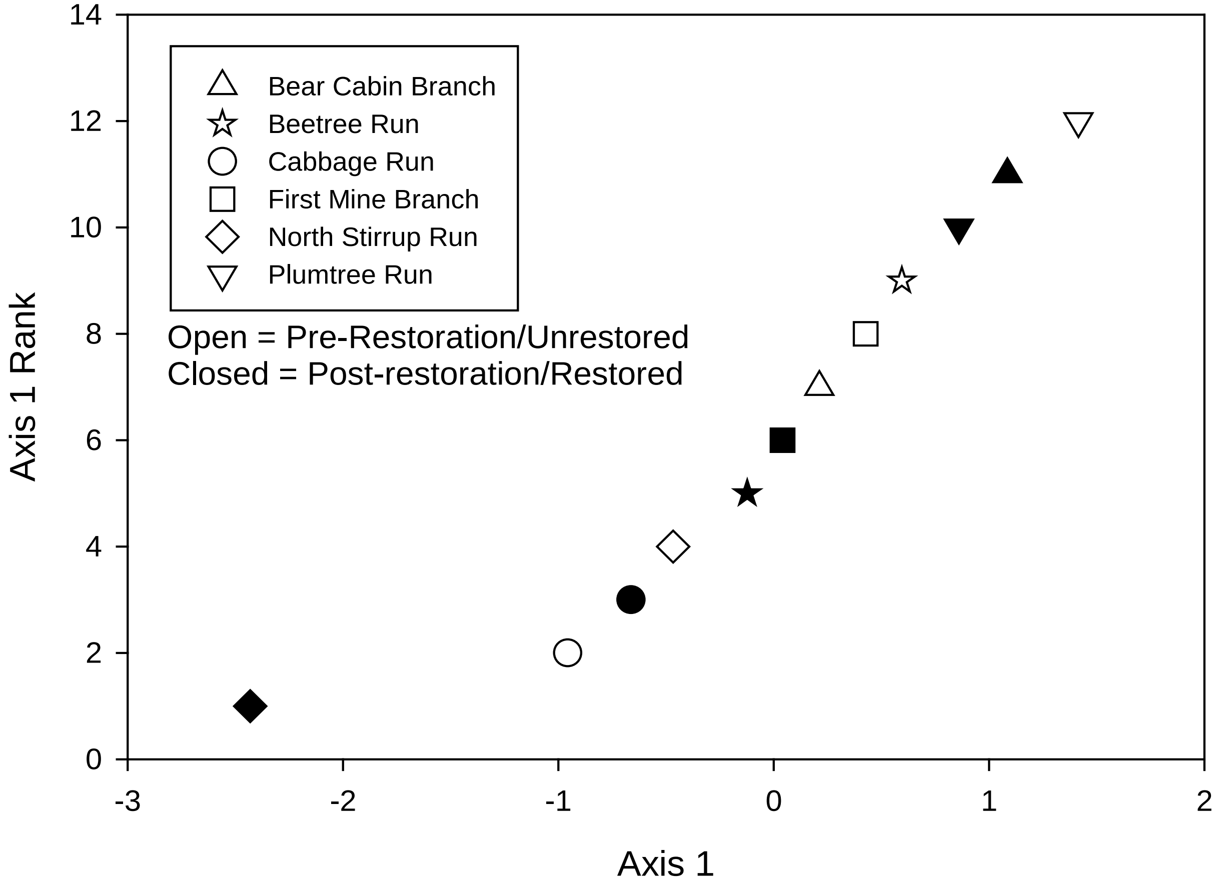


Woody Layer Beta Diversity

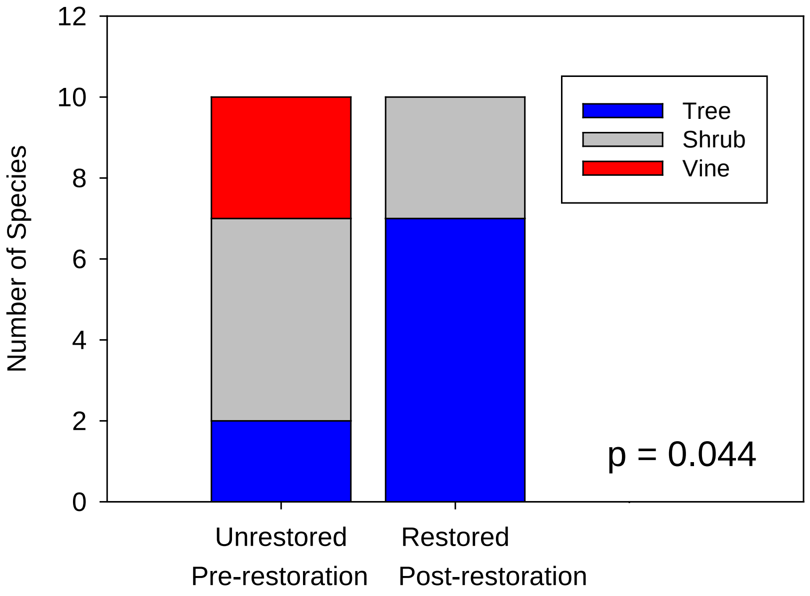


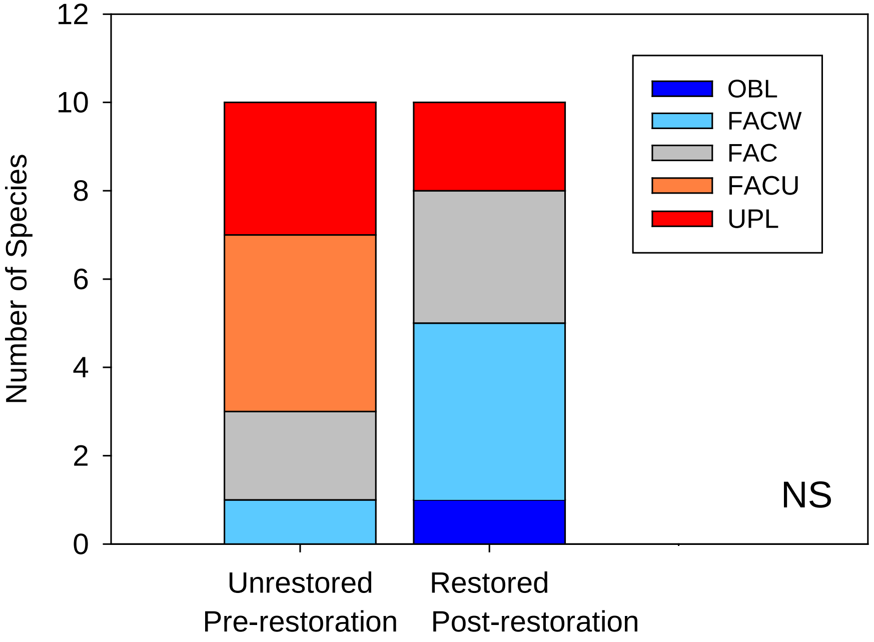


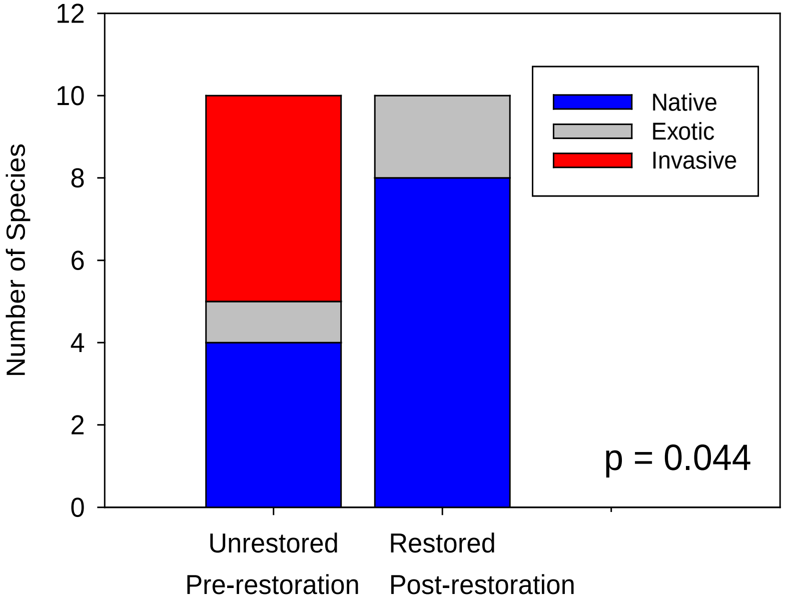
Woody Vegetation NMDS



Change in composition of important species (high indicator values)







Change in Indicator Value

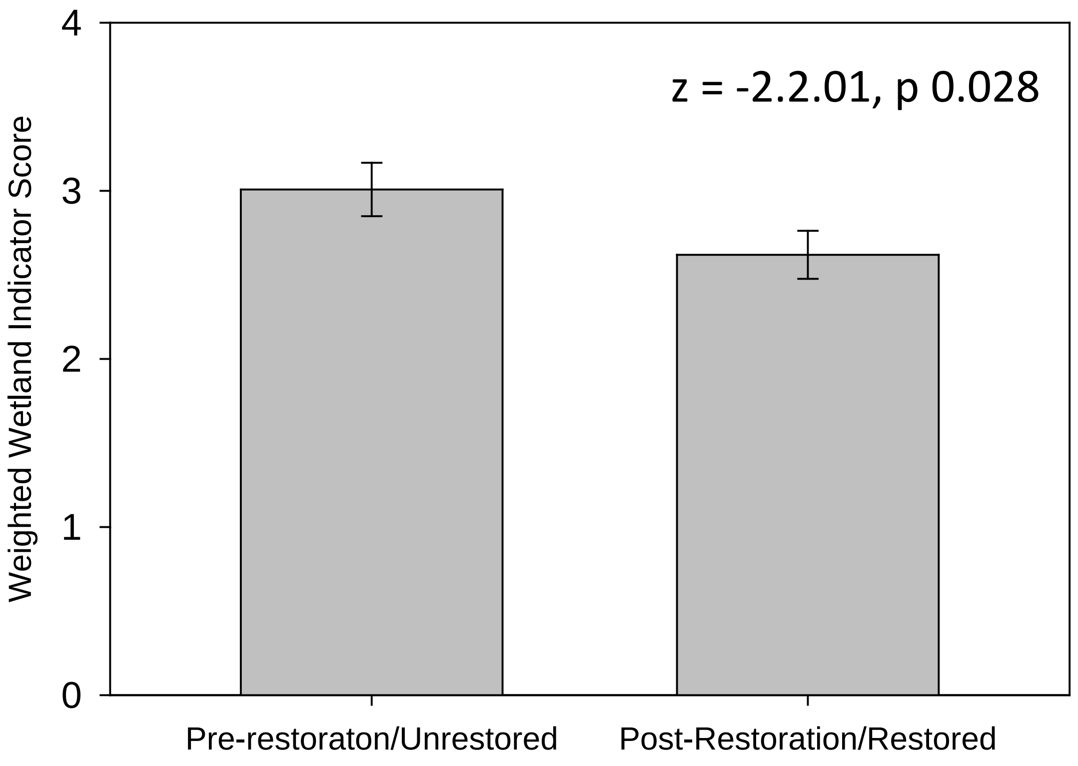
Species	Common name	Un/Pre Restored IV	Restored IV	Change	Planted Sites
Salix purpurea	purpleosier willow	0	67	67	3
Viburnum prunifolium	blackhaw	19	60	41	2
Aronia arbutifolia	red chokeberry	4	37	33	1
Salix nigra	black willow	31	63	32	5
Quercus velutina	black oak	2	29	27	0
Acer platanoides	Norway maple	46	1	-45	0
Lonicera japonica	Japanese honeysuckle	50	0	-50	0
Celastrus orbiculatus	oriental bittersweet	71	14	-57	0
Rubus occidentalis	black raspberry	60	2	-58	0
Rubus phoenicolasius	wineberry	63	1	-62	0

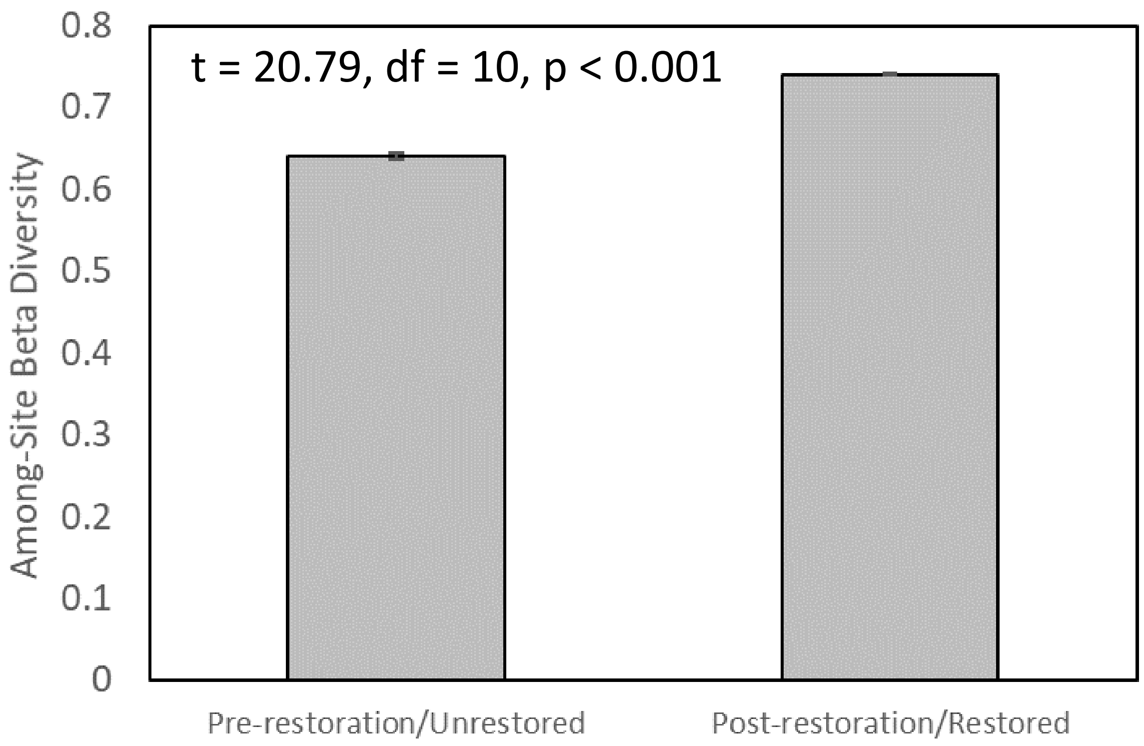
Woody Vegetation

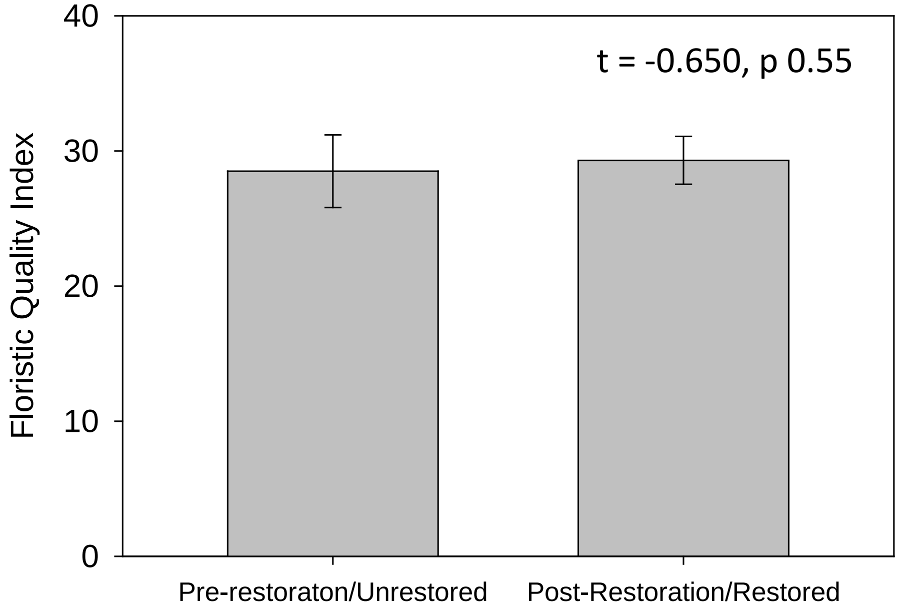
- Large decrease in basal area and species richness
- Areas within a site become more diverse, but differences between sites decrease. Biotic homogenization?
- Similar species composition in unrestored and restored reaches
- No significant indicator species – *Salix purpurea* (purple osier or basket willow) importance increases due to planting

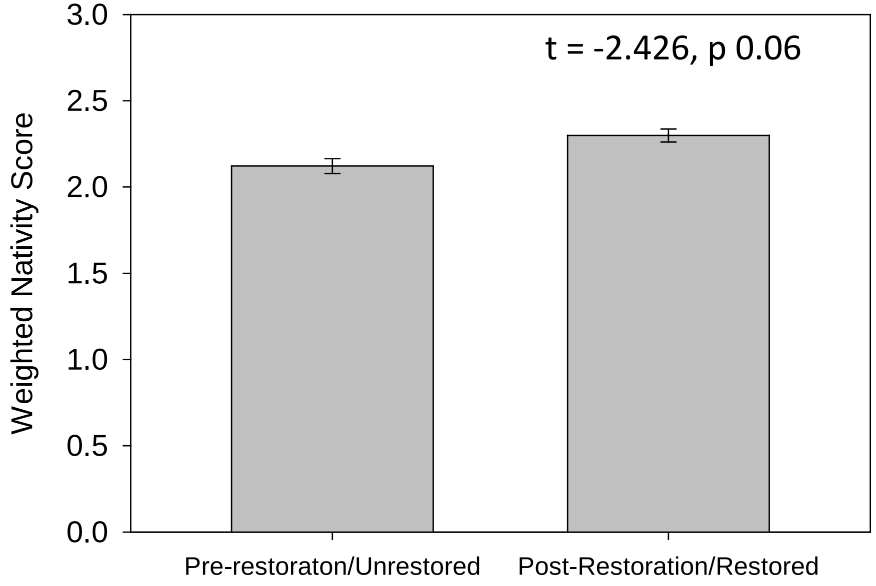
https://www.willowsvermont.com/purbl.html

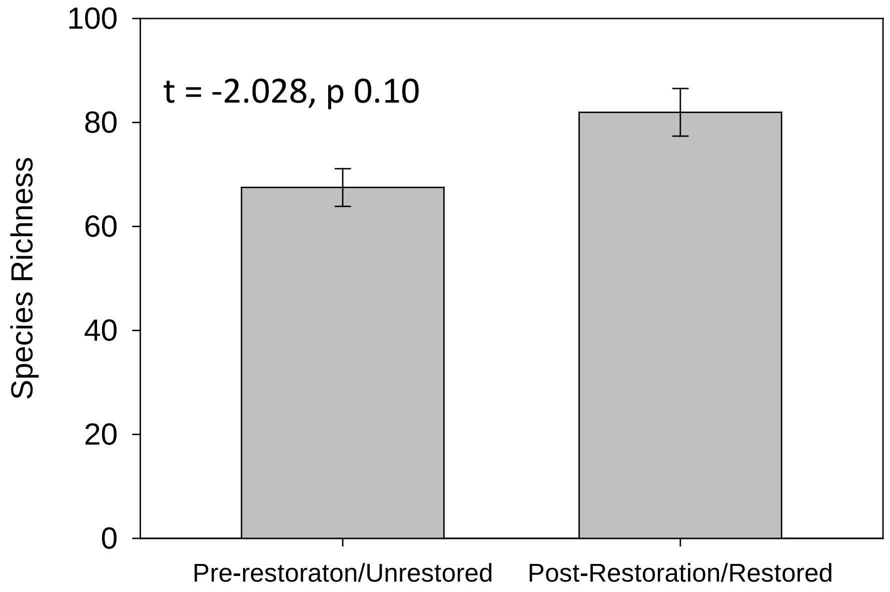
Herbaceous Layer Vegetation

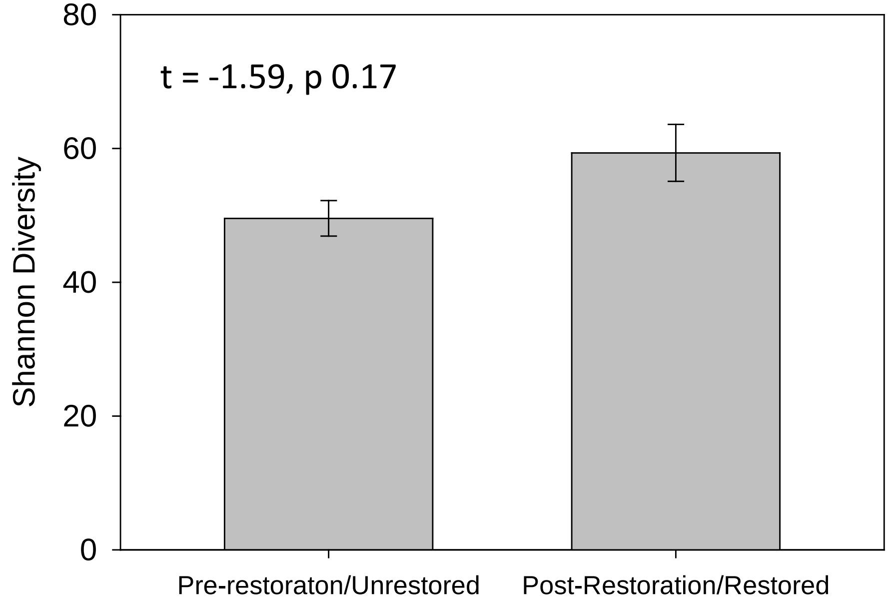


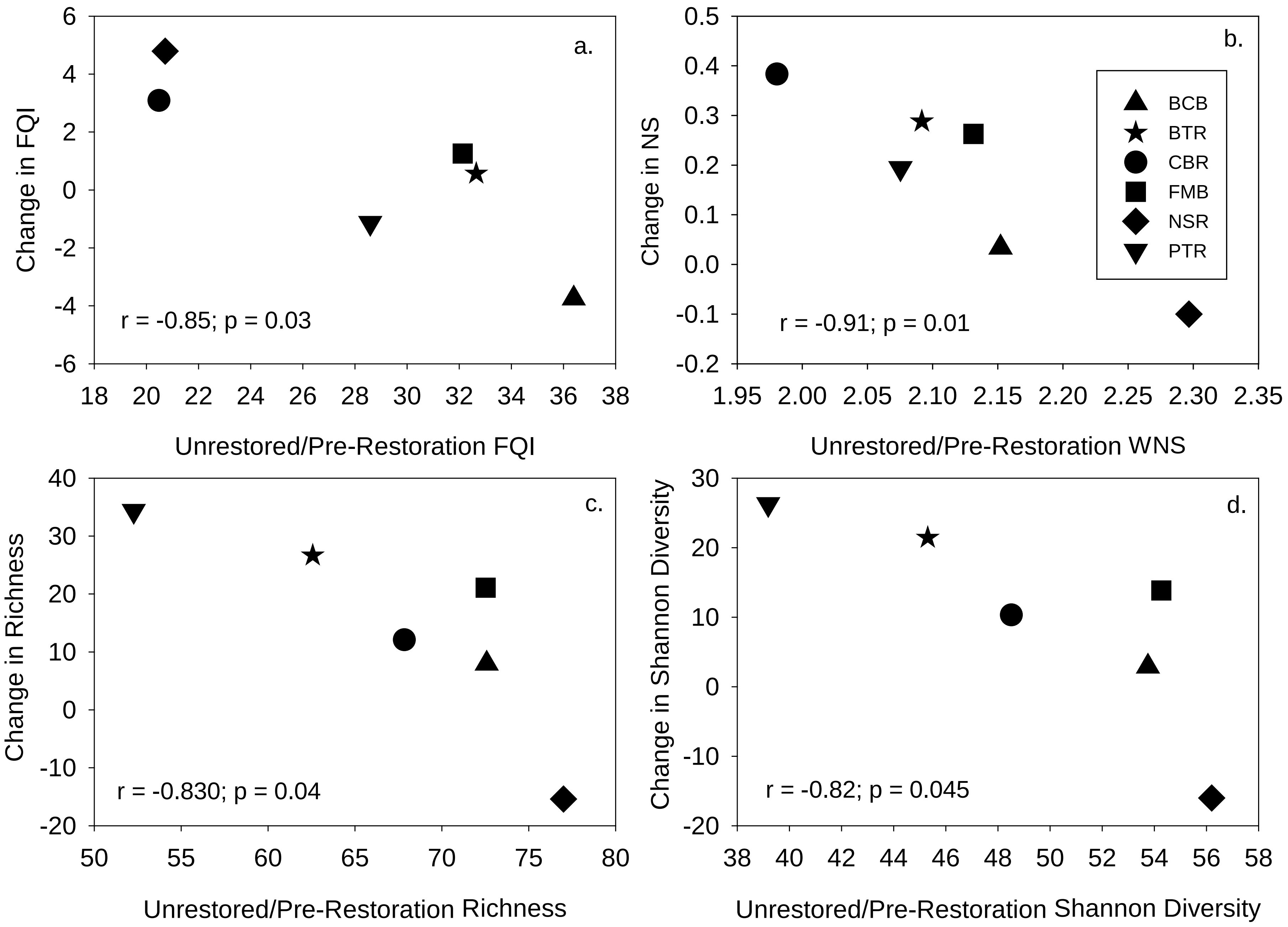



t = -0.650, p 0.55
Floristic Quality Index
40
30
20
10
0
Pre-restoraton/Unrestored
Post-Restoration/Restored


t = -2.426, p 0.06
Weighted Nativity Score
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Pre-restoraton/Unrestored
Post-Restoration/Restored

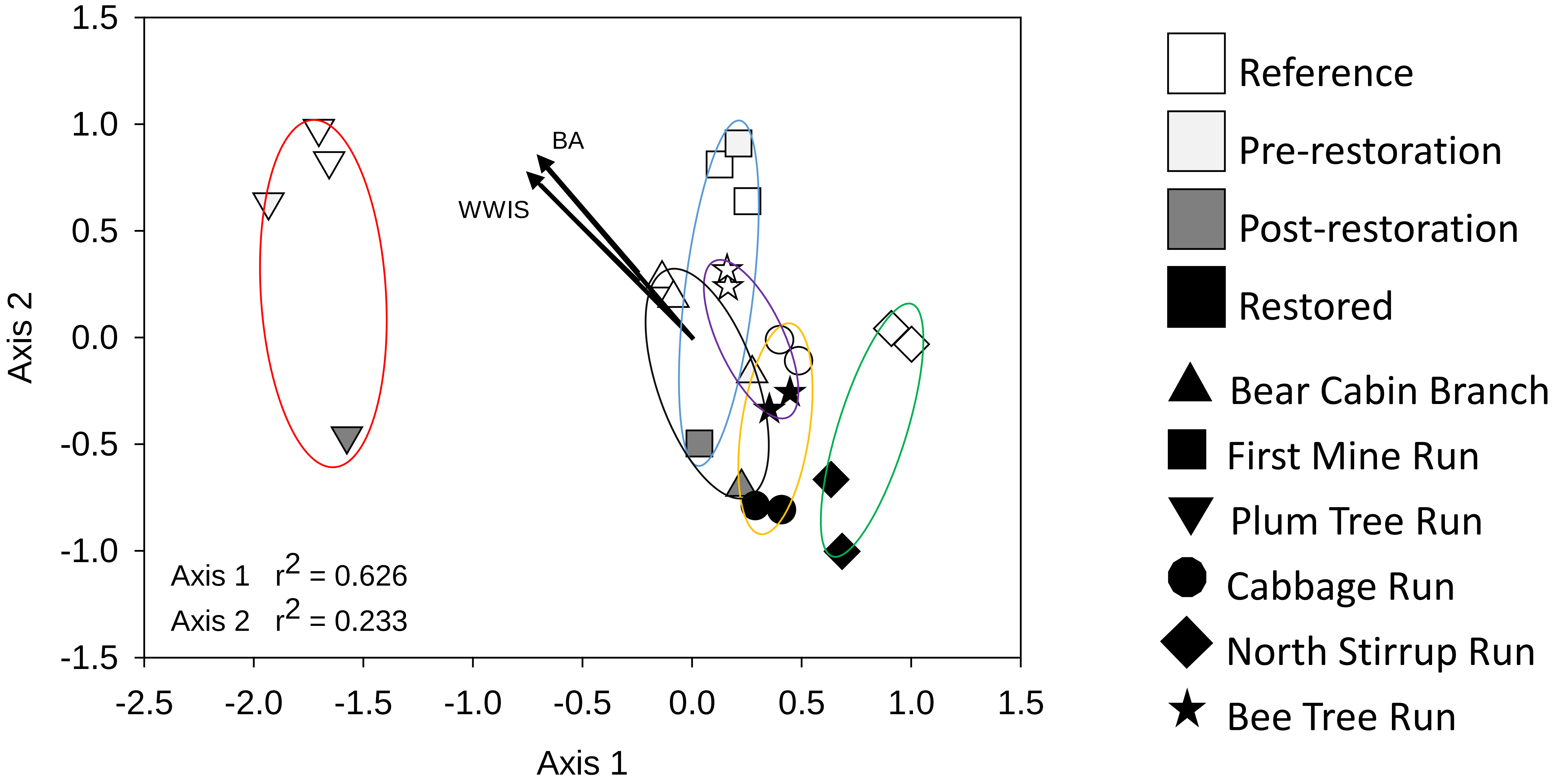

t = -2.028, p 0.10
Species Richness
100
80
60
40
20
0
Pre-restoraton/Unrestored
Post-Restoration/Restored

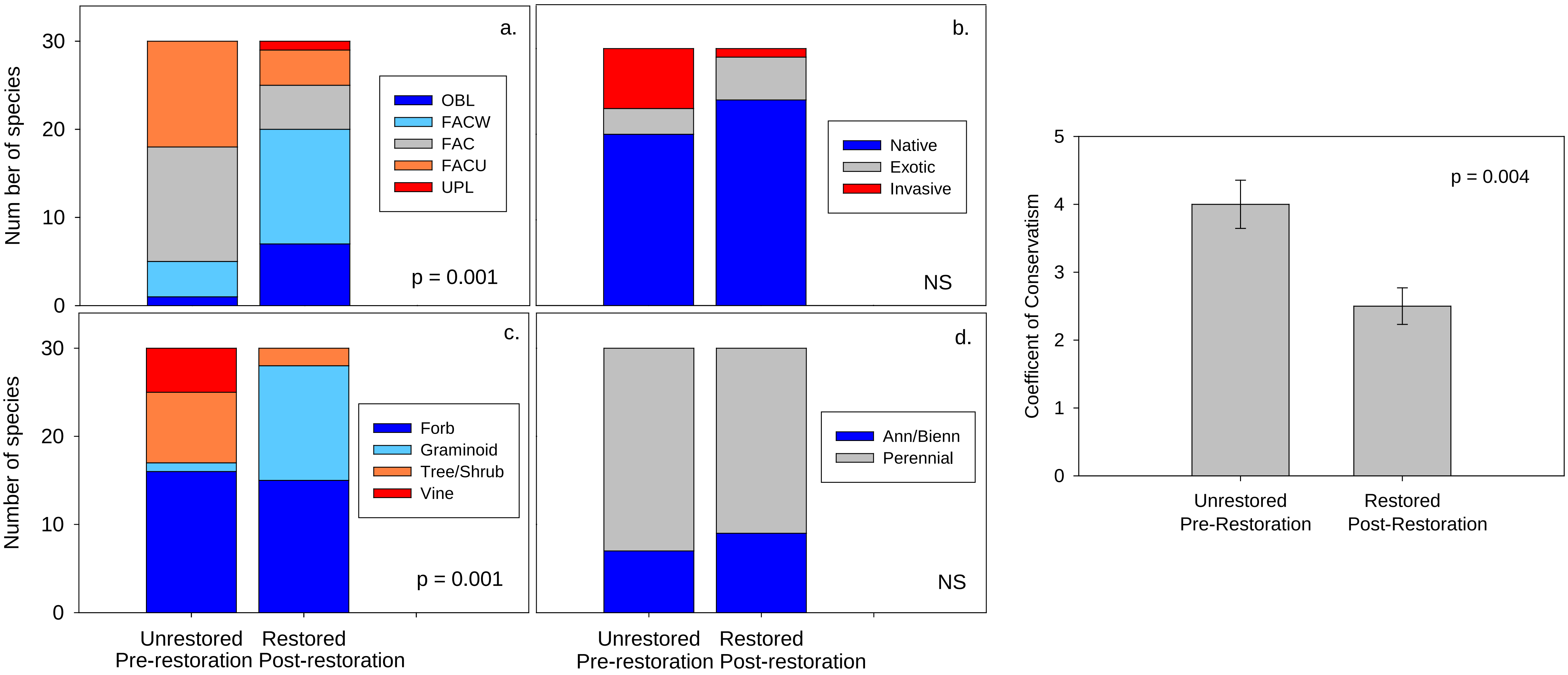

t = -1.59, p 0.17
Shannon Diversity
80
60
40
20
0
Pre-restoraton/Unrestored
Post-Restoration/Restored



a.
Change in FQI
r = -0.85; p = 0.03
Unrestored/Pre-Restoration FQI
b.
Change in NS
r = -0.91; p = 0.01
Unrestored/Pre-Restoration WNS
BCB
BTR
CBR
FMB
NSR
PTR
c.
Change in Richness
r = -0.830; p = 0.04
Unrestored/Pre-Restoration Richness
d.
Change in Shannon Diversity
r = -0.82; p = 0.045
Unrestored/Pre-Restoration Shannon Diversity

Herbaceous vegetation – Change in composition, sites maintain identity



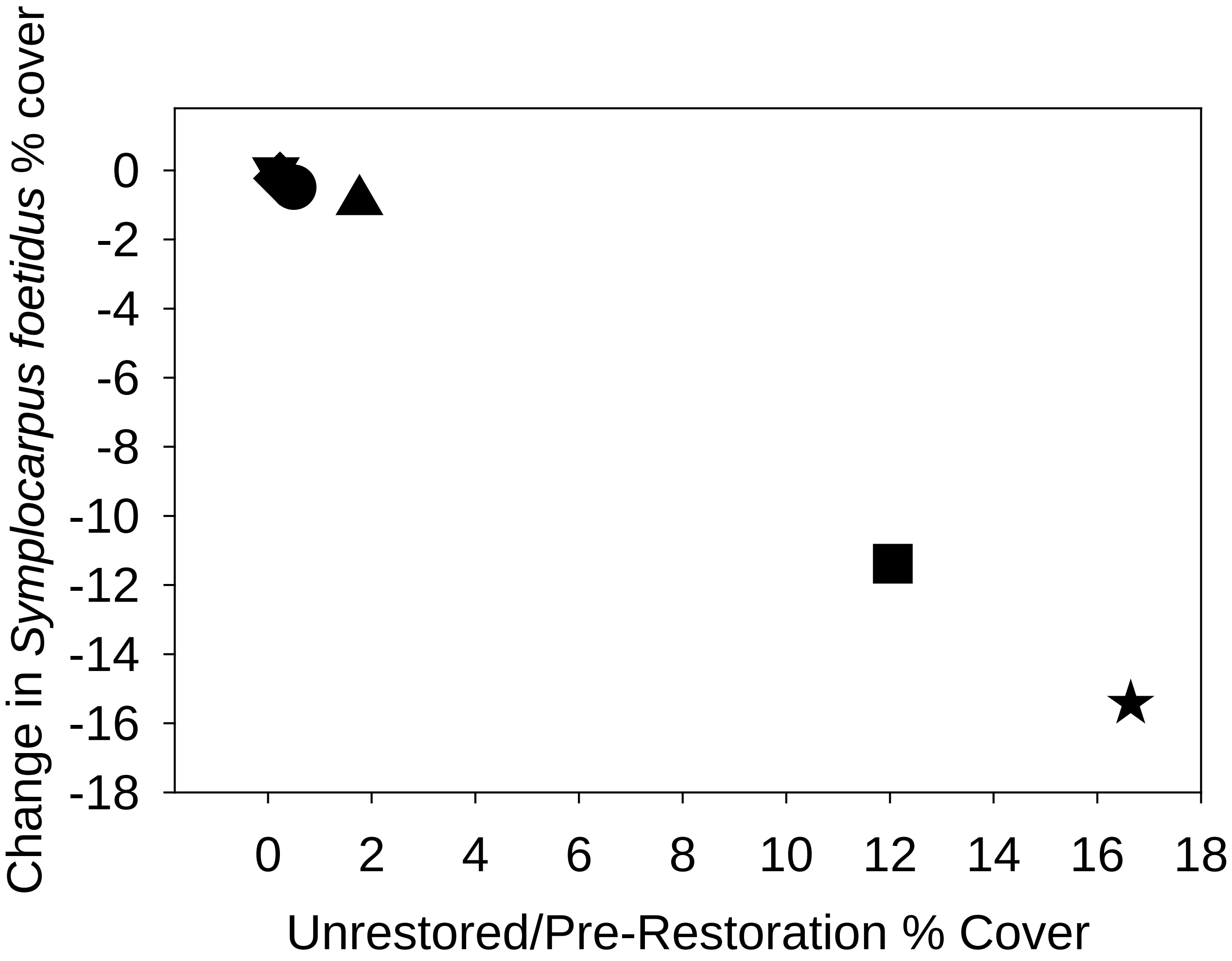


Num ber of species
30
20
10
0
a.
OBL
FACW
FAC
FACU
UPL
p = 0.001
b.
Native
Exotic
Invasive
NS
Number of species
30
20
10
0
c.
Forb
Graminoid
Tree/Shrub
Vine
p = 0.001
d.
Ann/Bienn
Perennial
NS
Unrestored
Pre-restoration
Restored
Post-restoration
Unrestored
Pre-restoration
Restored
Post-restoration
Coefficent of Conservatism
5
4
3
2
1
0
p = 0.004
Unrestored
Pre-Restoration
Restored
Post-Restoration

Indicators of unrestored reaches	
Alliaria petiolata	garlic mustard
Rosa multiflora	multiflora rose
Symplocarpus foetidus	skunk cabbage
Parathelypteris noveboracensis	New York fern
Polystichum acrostichoides	Christmas fern
Arisaema triphyllum	*Jack in the pulpit*
Circaea alpine	enchanters nightshade
Carpinus caroliniana	hop hornbeam
Persicaria virginiana	Virginia jumpseed
Clematis virginiana	virgin's bower
Geum canadense	white avens
Viola sororia	blue violet
Lindera benzoin	spice bush
Amphicarpaea bracteata	hog peanut

https://www.inaturalist.org/photos/1840324
https://www.illinoiswildflowers.info/grasses/plants/ny_fern.htm
https://www.prairiemoon.com/viola-sororia-common-blue-violet-prairie-moon-nursery.html

Average 74% DECREASE in skunk cabbage cover



https://www.nps.gov/miss/learn/nature/skunkcabbage.htm

https://urbanecologycenter.org/blog/native-plant-eastern-skunk-cabbage.html

Indicators of restored reaches

70 species identified

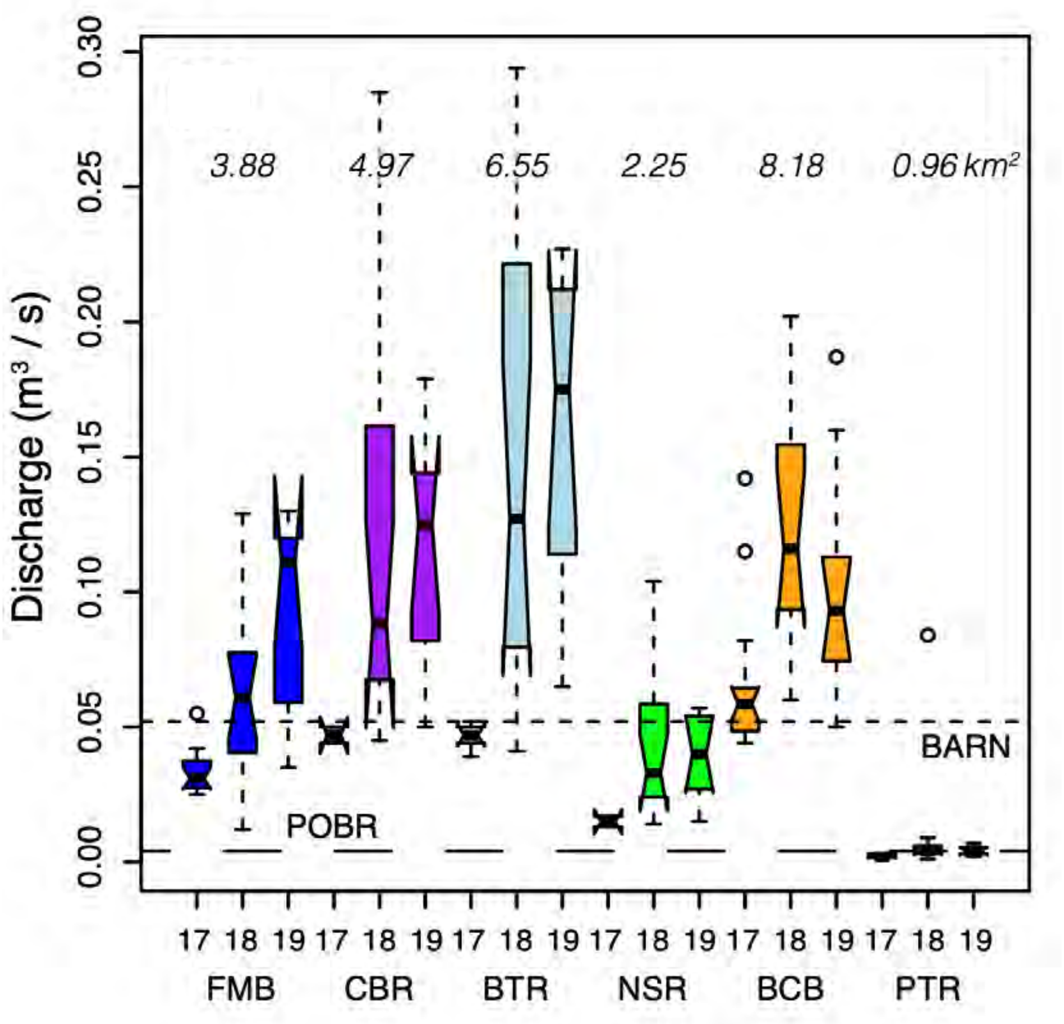
Herb/Graminoid = 96%
Obligate/FACW = 50%
Native = 70%
Planted = 13%

Majority of dominant/indicator species were NOT PLANTED

Evidence for seed bank or downstream dispersal?

Extra water quality slides

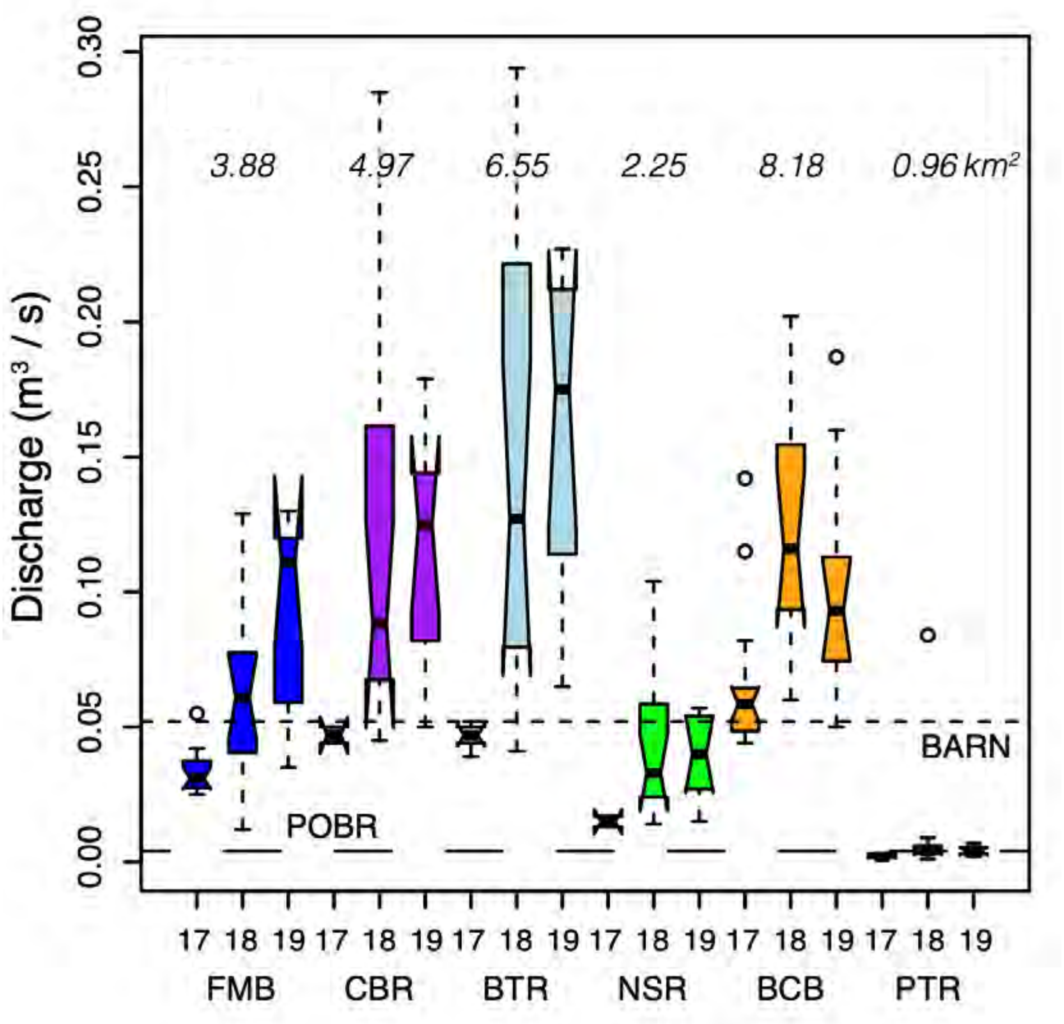
Elevated baseflow discharge (& fluxes) in 2018 & 2019

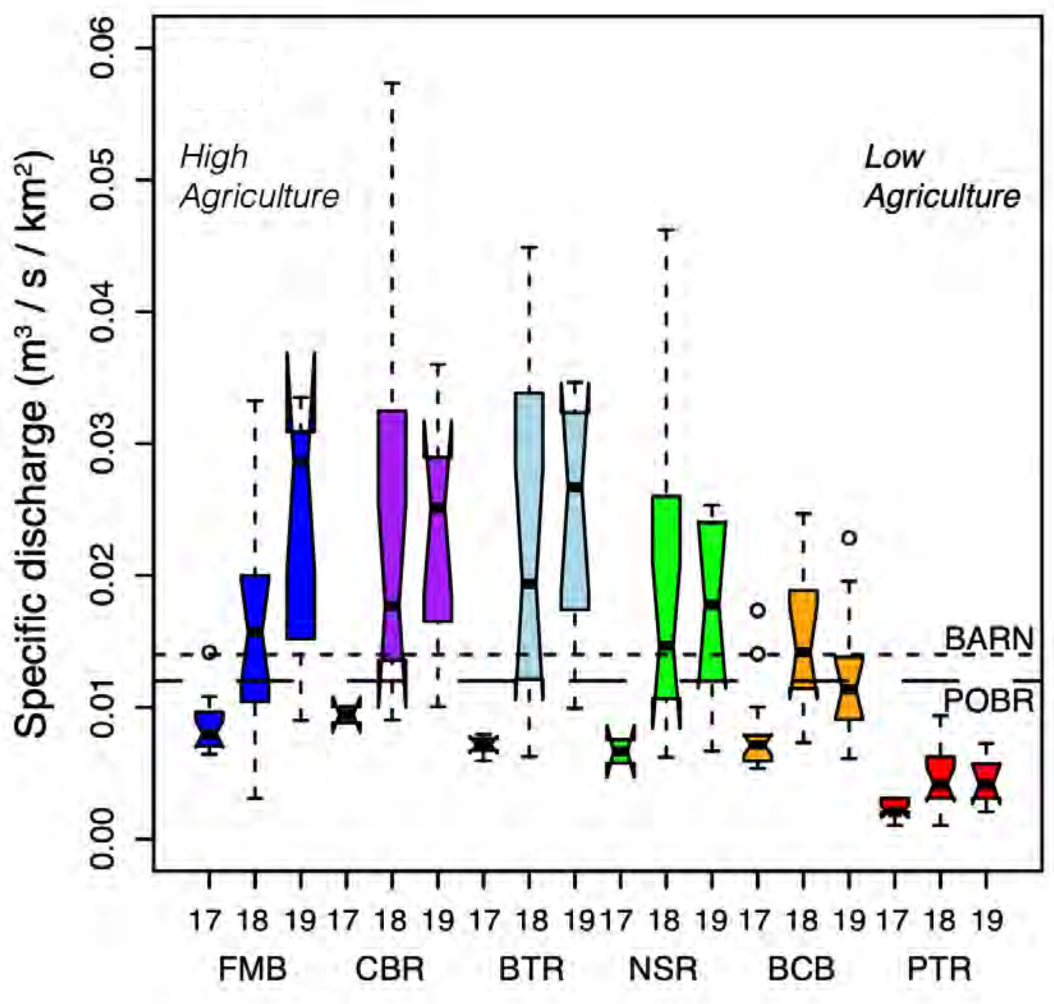


Most active agriculture

Most urban

Elevated baseflow discharge (& fluxes) in 2018 & 2019

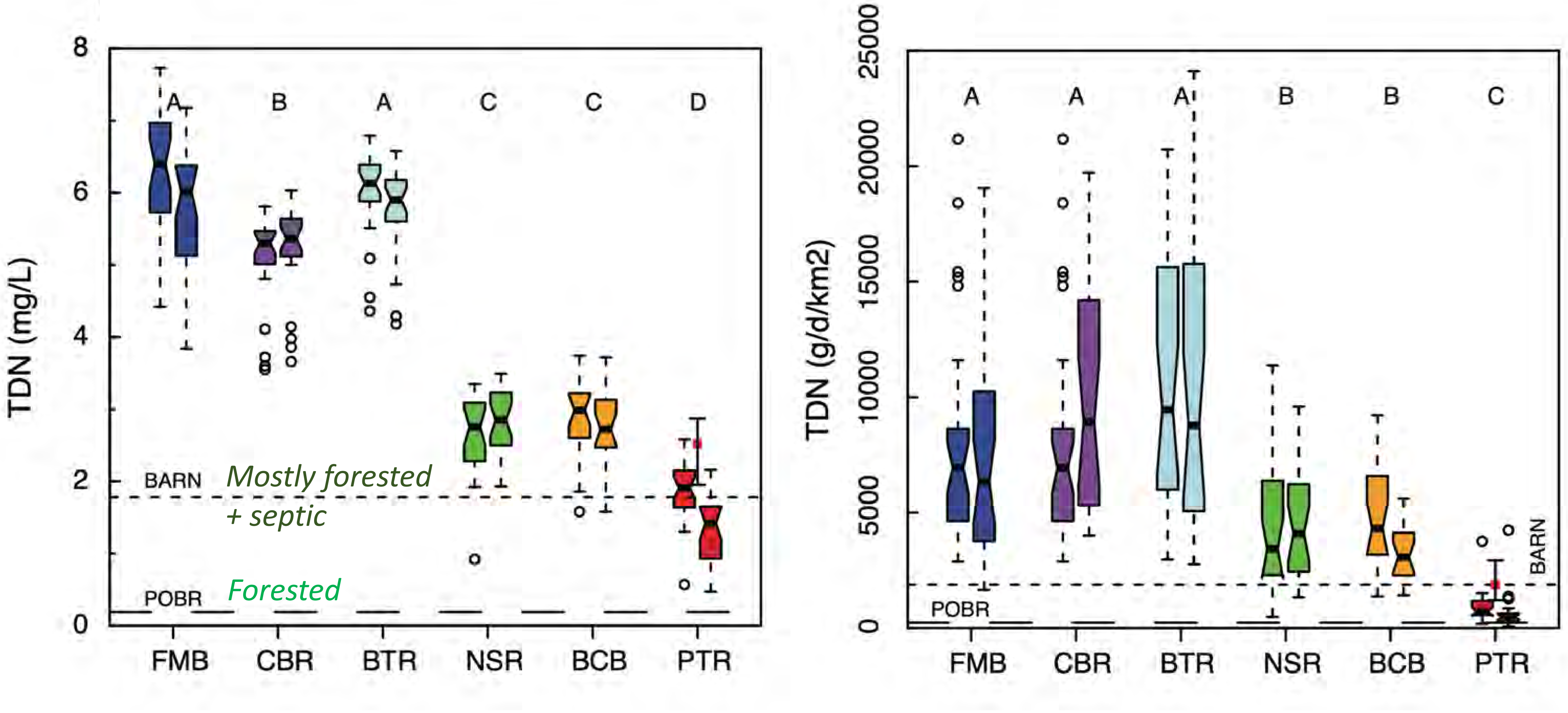




Most active agriculture

Most urban

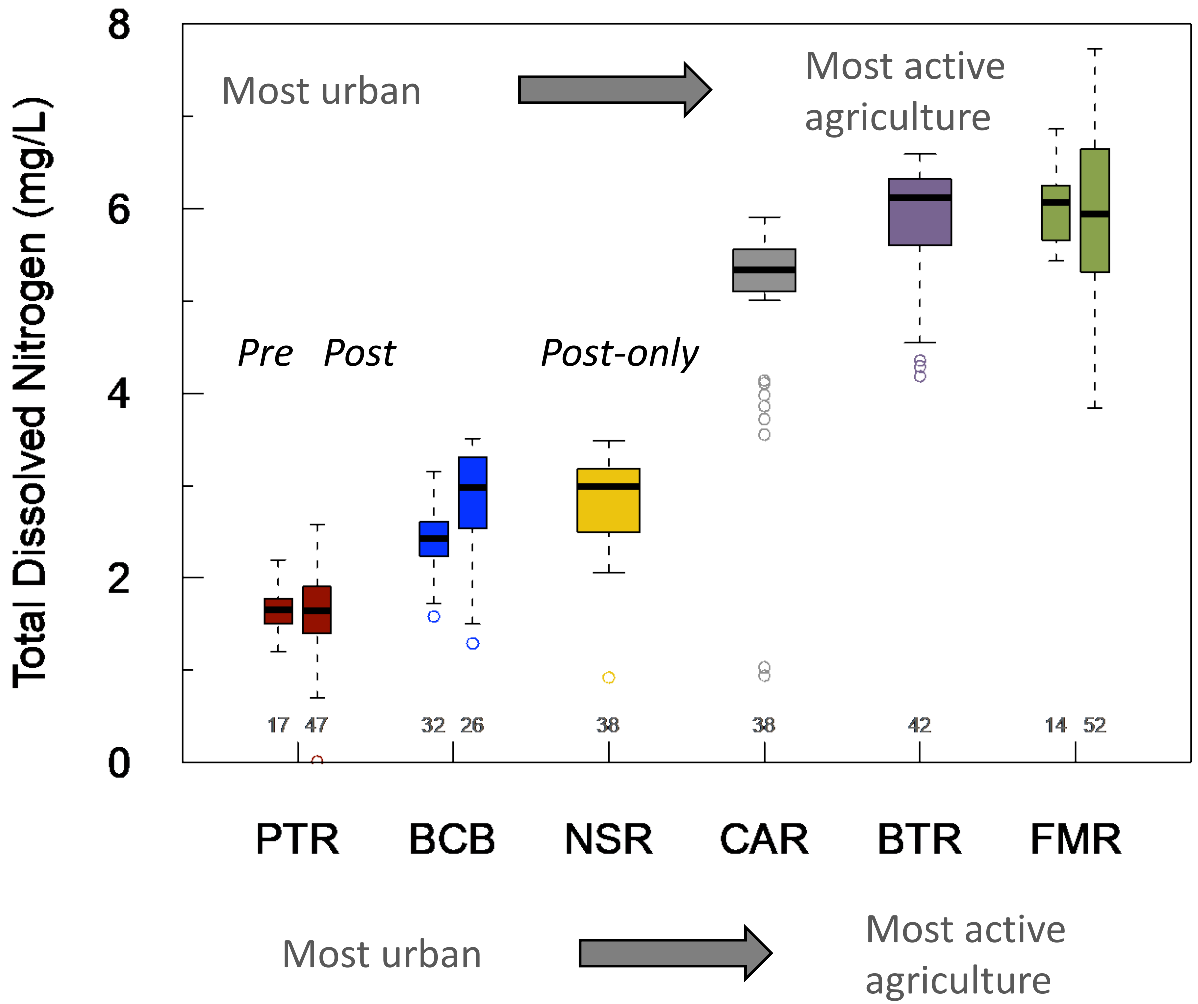
Biggest control for baseflow N: land use

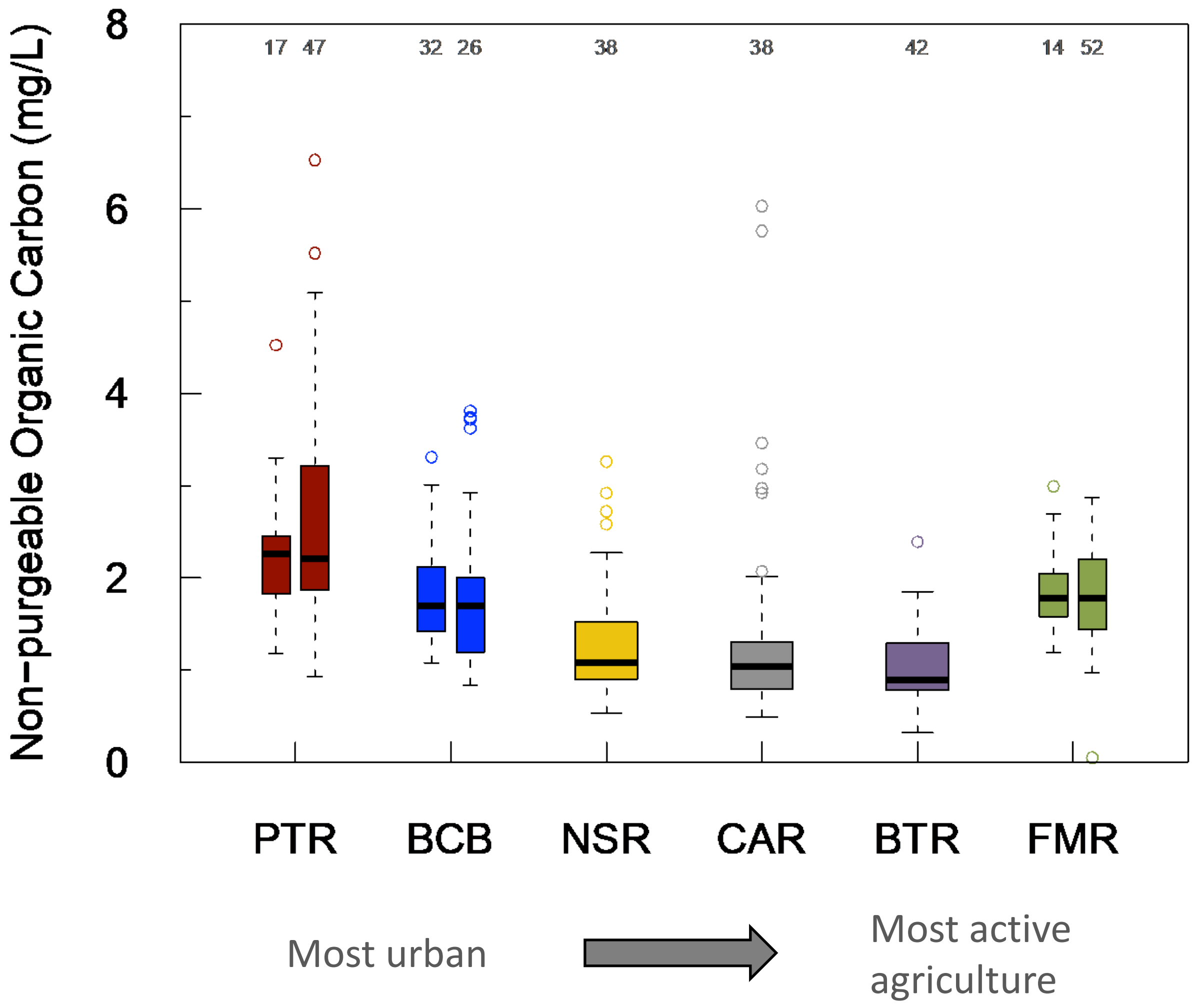


Most active agriculture

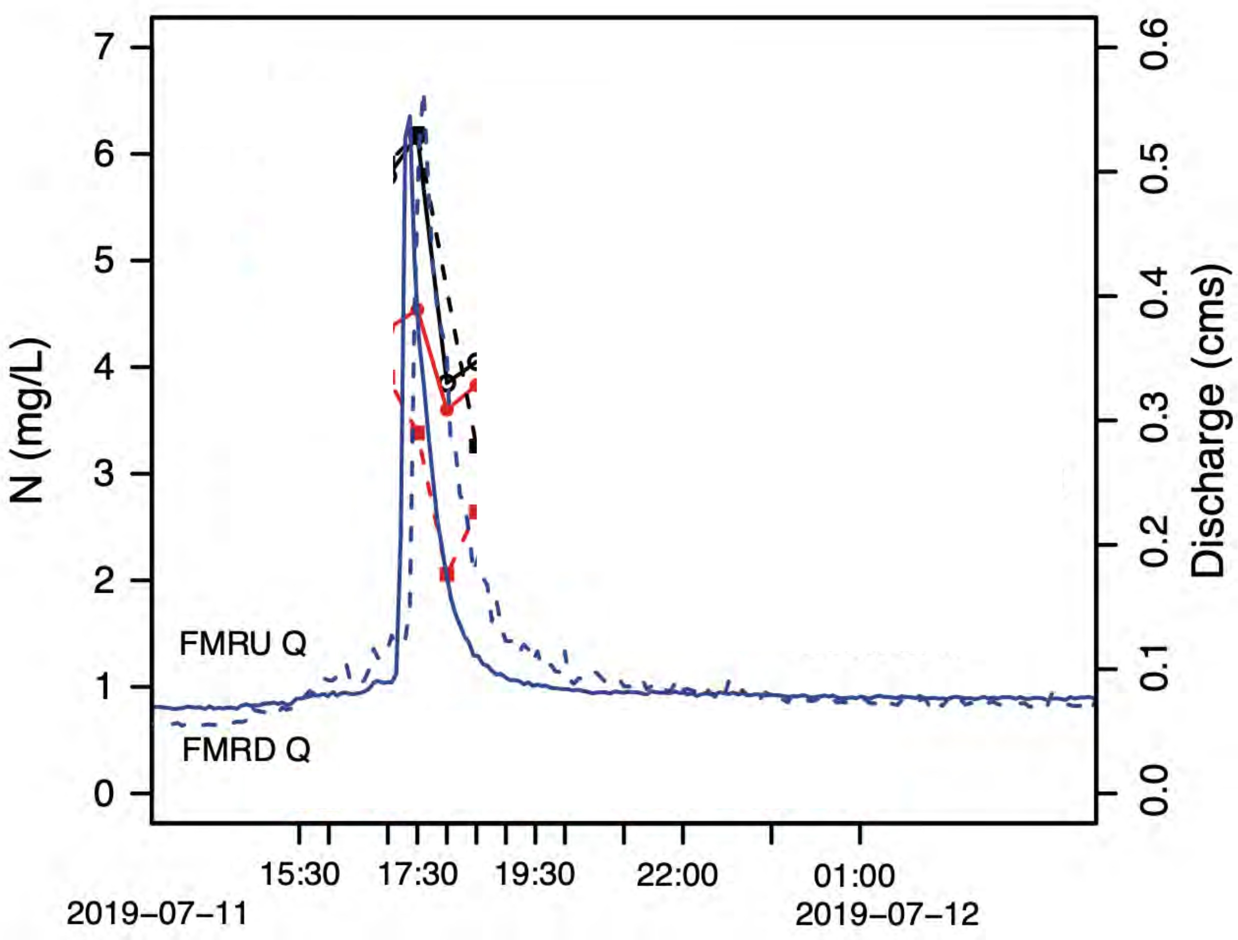
Most urban

Biggest control for N: land use – *C also but generally opposite*
Pre-/Post-restoration: no significant difference (yet)





Decrease in N, increased P & TSS during storm events at FMB *(most ag.)*



McMahon et al. (2021) *Environmental Research Letters*
https://iopscience.iop.org/article/10.1088/1748-9326/abe007

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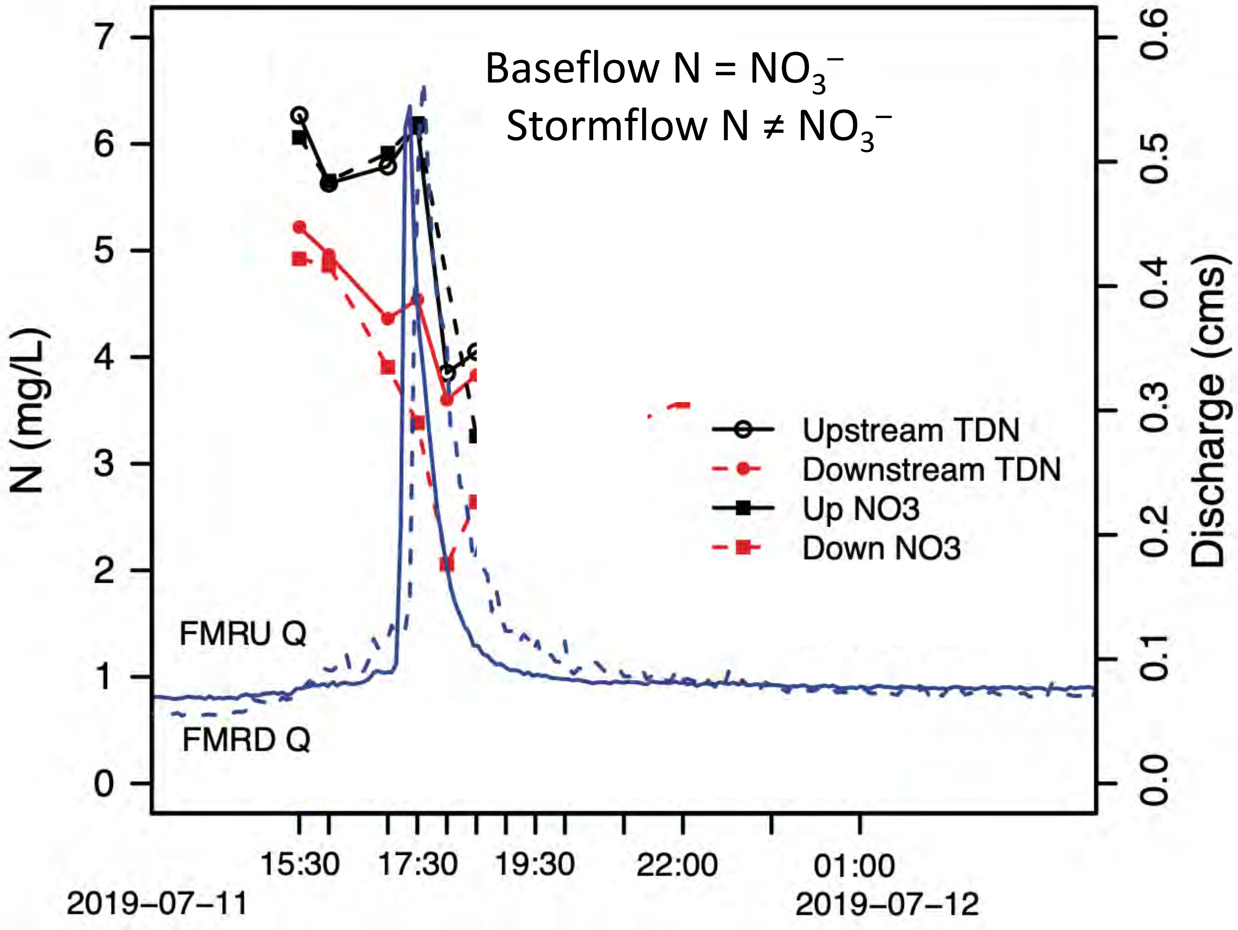

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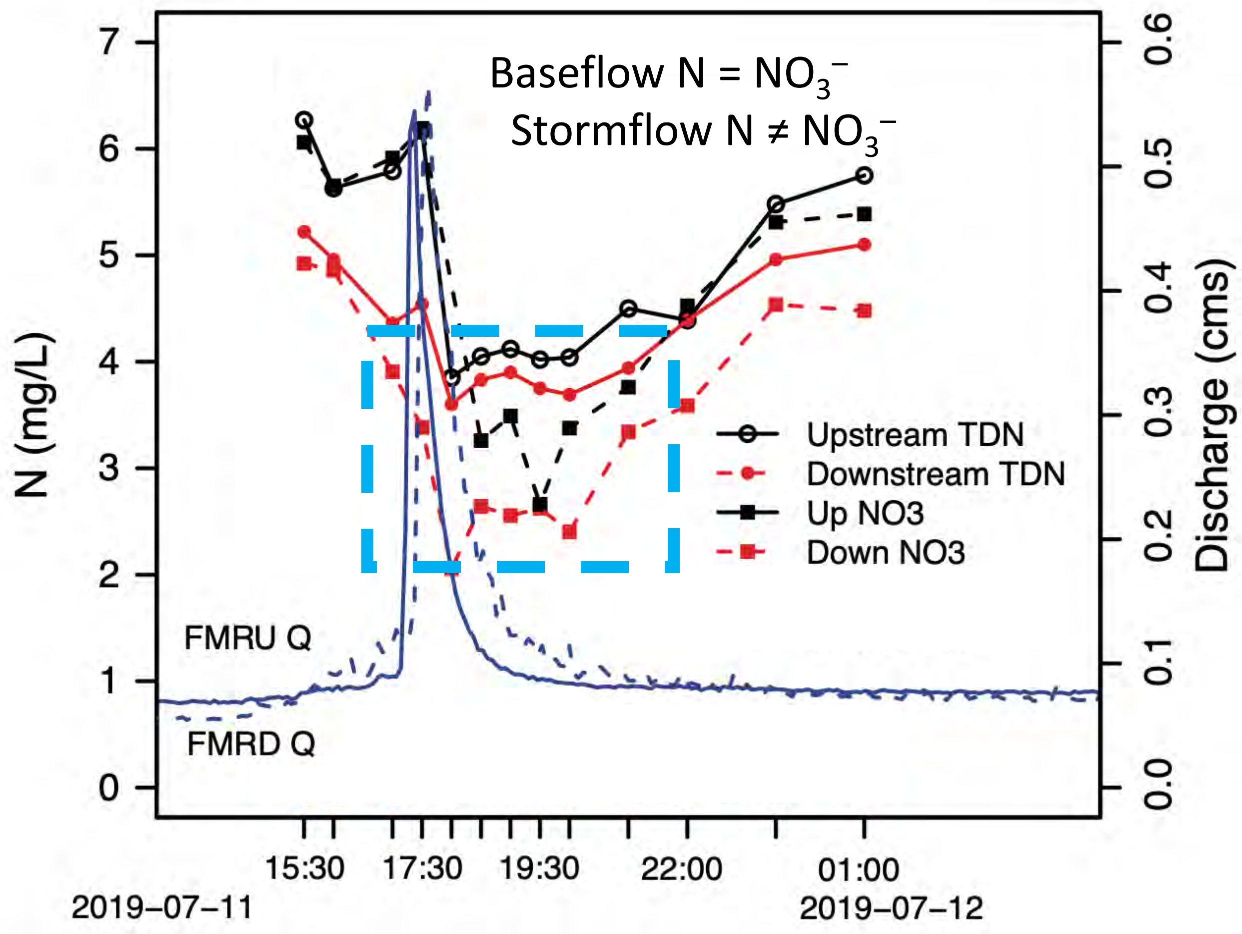

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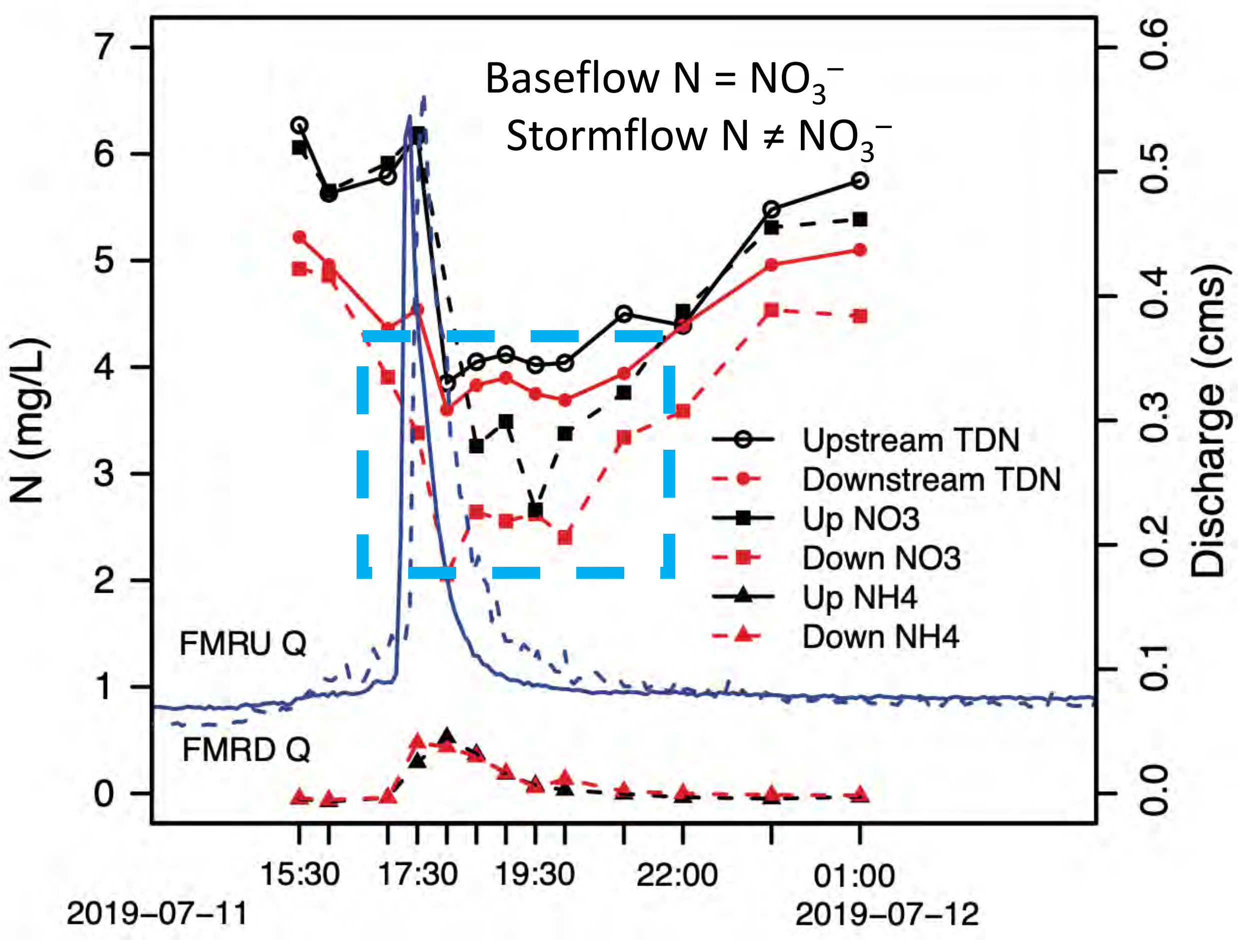

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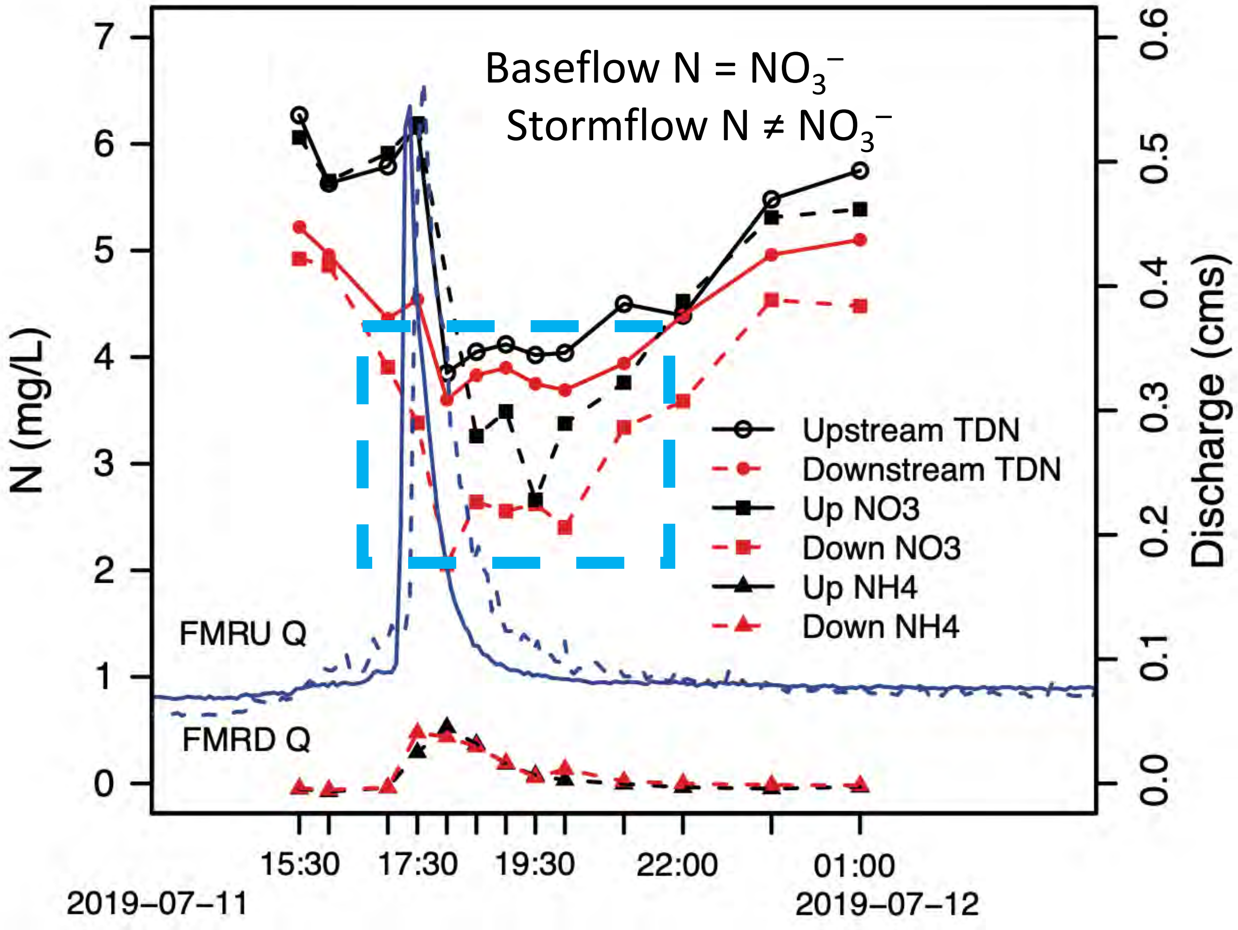

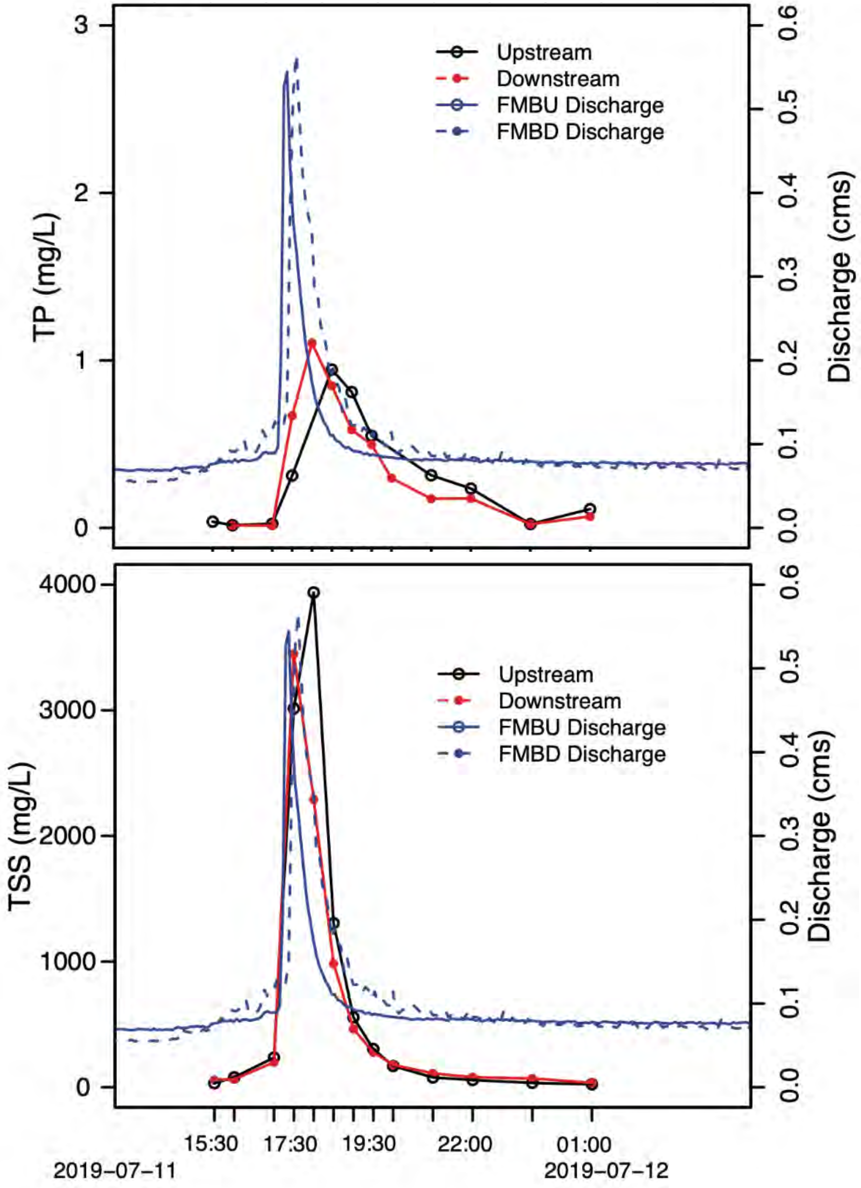

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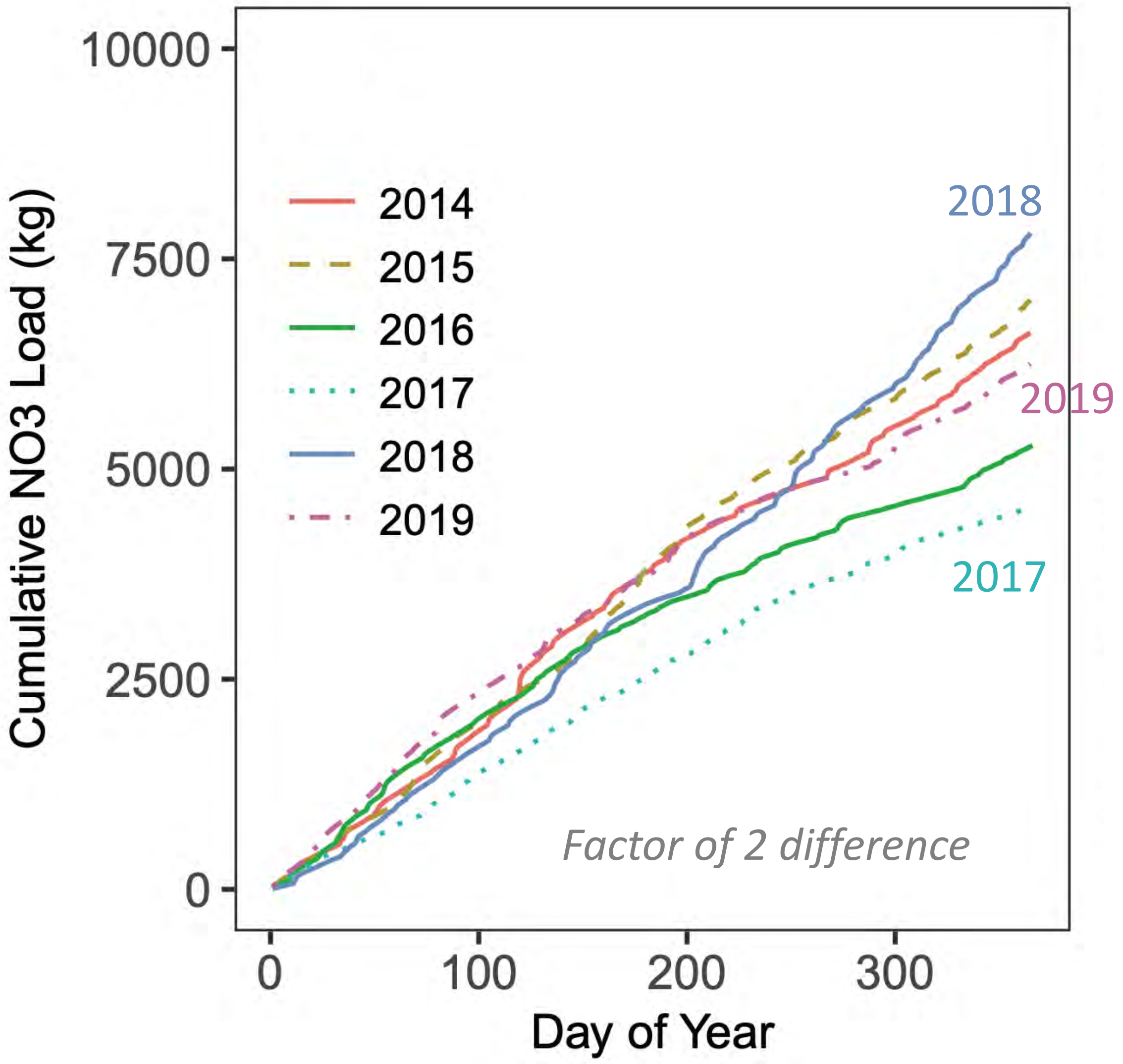
Restoration not detectable downstream (restoration 15% of watershed)

N via baseflow, TSS (&P) via stormflow *downstream of most urban site*



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