Land Use and Era of Development Effects on PCB Contamination of Soils and Stormwater Sediments in the Chesapeake Bay Watershed




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Polychlorinated biphenyls: An environmental Legacy

1865

1970s

E.P.A. Bans Discharge of PCB's Directly Into the Nation's Waters

By BAYARD WEBSTER

The Environmental Protection Agency yesterday ordered the ban of the direct discharge of PCB's, a highly toxic industrial chemical, into United States waters.

The chemical, a close relative of DDT, has been found in scientific studies to cause deformities in fetuses, changes in liver function, nervous disorders and cancers in animals. Widespread in the environment, it is found in almost all major bodies of water in the world. Significant amounts have also been monitored in the air.

The ban follows results of recent studies that show that its levels in water and fish exceed by several factors those standards set by the E.P.A. and the Food and Drug Administration.

The only plants covered by the ban are some 20 factories that manufacture electrical transformers and capacitors and discharge their PCB's, used in electrical insulation, into bodies of water.

The E.P.A. noted in announcing the ban late yesterday that "past widespread use of the chemicals in the production of lubricant additives, hydraulic and compressor fluid, carbonless copy paper, plasticizers, paints and other products has resulted in PCB's being present throughout the environment.

"Although most of these uses have now been substantially curtailed, PCB's which have entered the environment cannot in most cases be recovered and will require many years to degrade. The public will be alerted to potential hazards by careful long-term monitoring of PCB levels in food."

One of the most prominent PCB contamination cases involved the General Electric Company, which had been dumping its PCB wastes into the Hudson River, causing fish to accumulate many times the permissible level of the chemical. A negotiated settlement between the company and the State Department of Environmental Conservation resulted in G.E.'s agreeing to cease its dumping and to pay $3 million toward cleansing the river and $1 million for research toward ending the problem.

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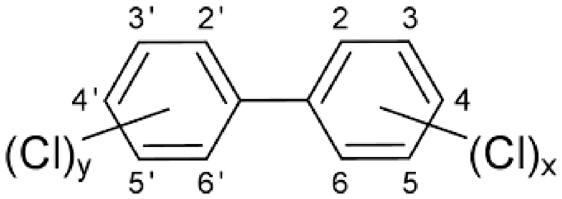
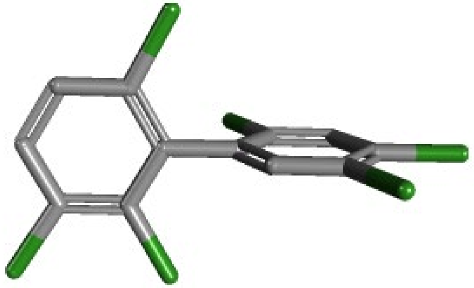
The ruling, which in effect calls for the zero discharge of PCB's into main bodies of water, follows the recent studies that indicated that the recently proposed permissible standard of one part per billion of PCB's in transformer plant waste waters could not be met.

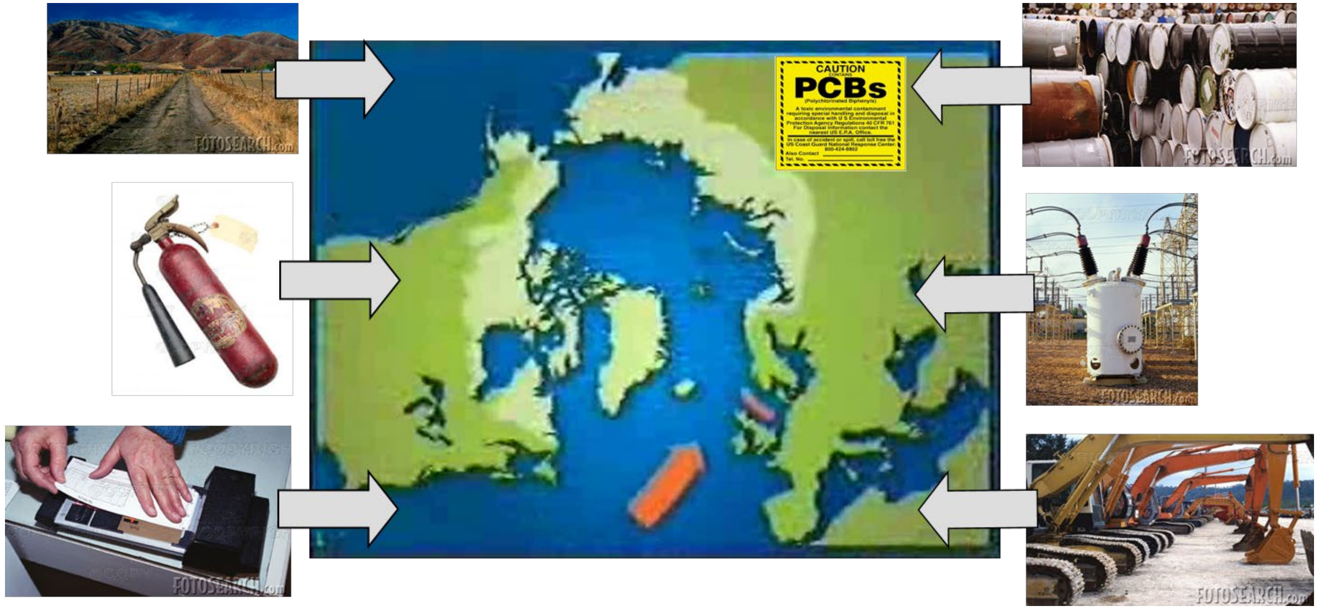
"The present problem of PCB contamination in the environment is so severe that in many waters throughout the United States PCB loads are already in excess of the criteria," E.P.A. Administrator Russell E. Train said in announcing the ban. His action came on the final day under the law for a decision in the PCB case, which had been argued most prominently by the Environmental Defense Fund, a Washington-based environmental law firm principally responsible for the banning of DDT in 1972.

The industrial chemical is widely used for insulating electrical equipment, in the recycling of wastepaper and in metal casting plants. Because of its widespread distribution in the environment, its resistance to biological degradation with a half-life of more than 25 years, PCB's are considered one of the most serious of the many environmental contamination problems prevalent today.

Monsanto Industrial Chemicals Company, the only American maker of the chemical, announced several months ago that it would quit production of the substance by October 31 of this year. There are no restrictions on the importation of PCB's. The Food and Drug Administration has already banned use of the chemical in the processing of food and feed, where it was sometimes used as cloth and paper insulation in containers and cartons.







Estimate: 0.6-1.2 billion kg worldwide

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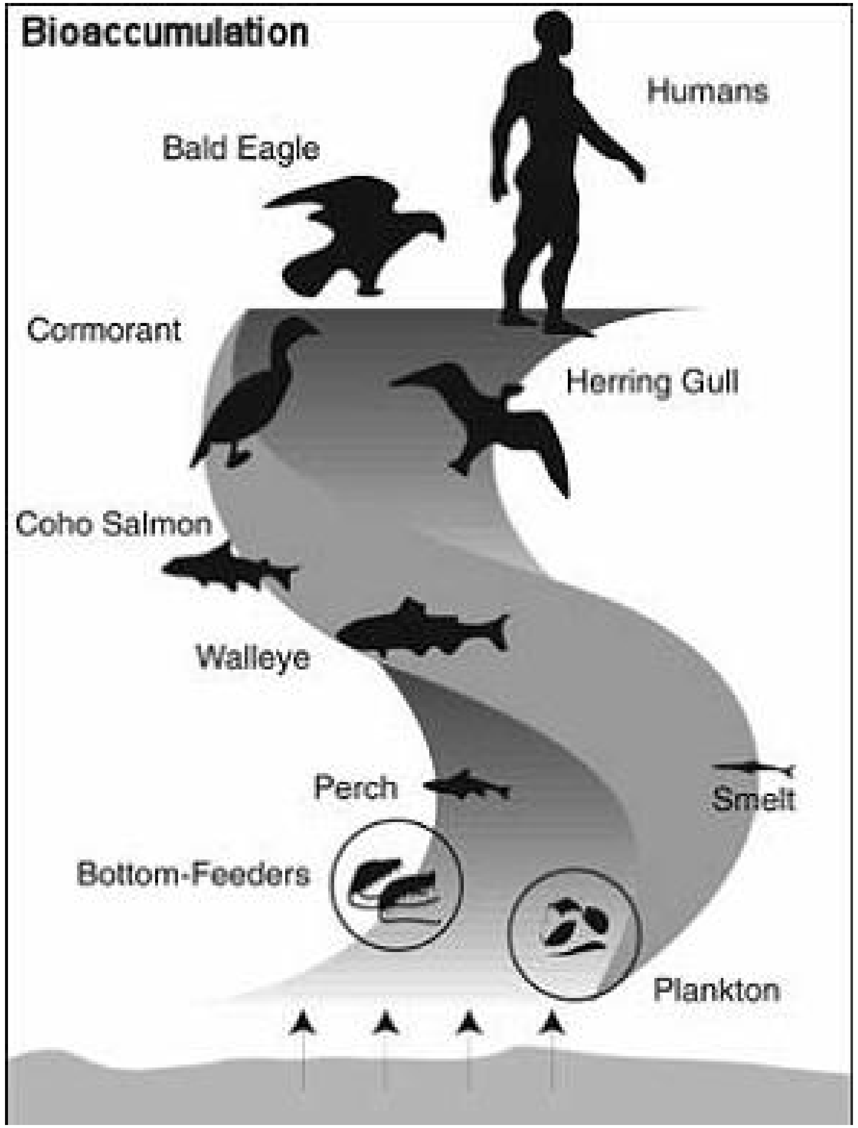
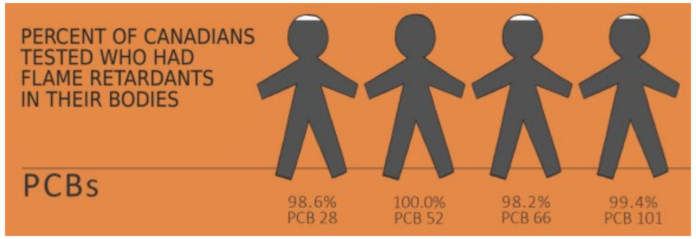
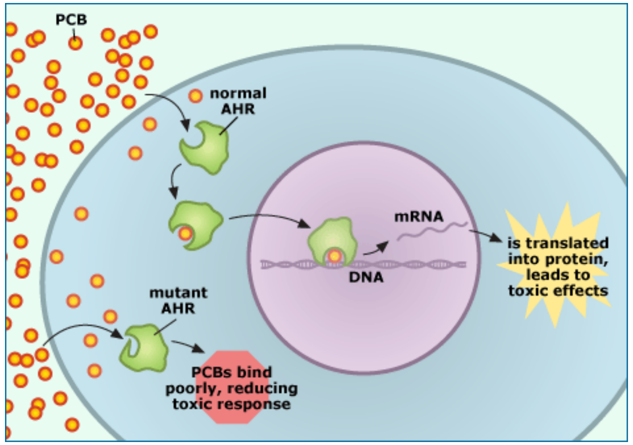
Why are PCBs of concern?



- Bioaccumulates and biomagnifies in the food chain
- Sediments/soils = **global sinks**
- Toxicological effects: Cancer, problems with endocrine and reproductive organs as well as immunological issues
- Humans: Source - ingestion (sea food, meat, poultry etc.)





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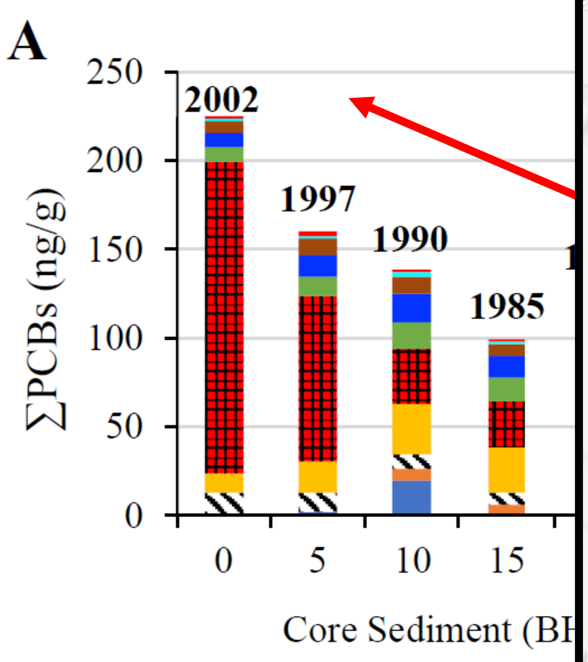
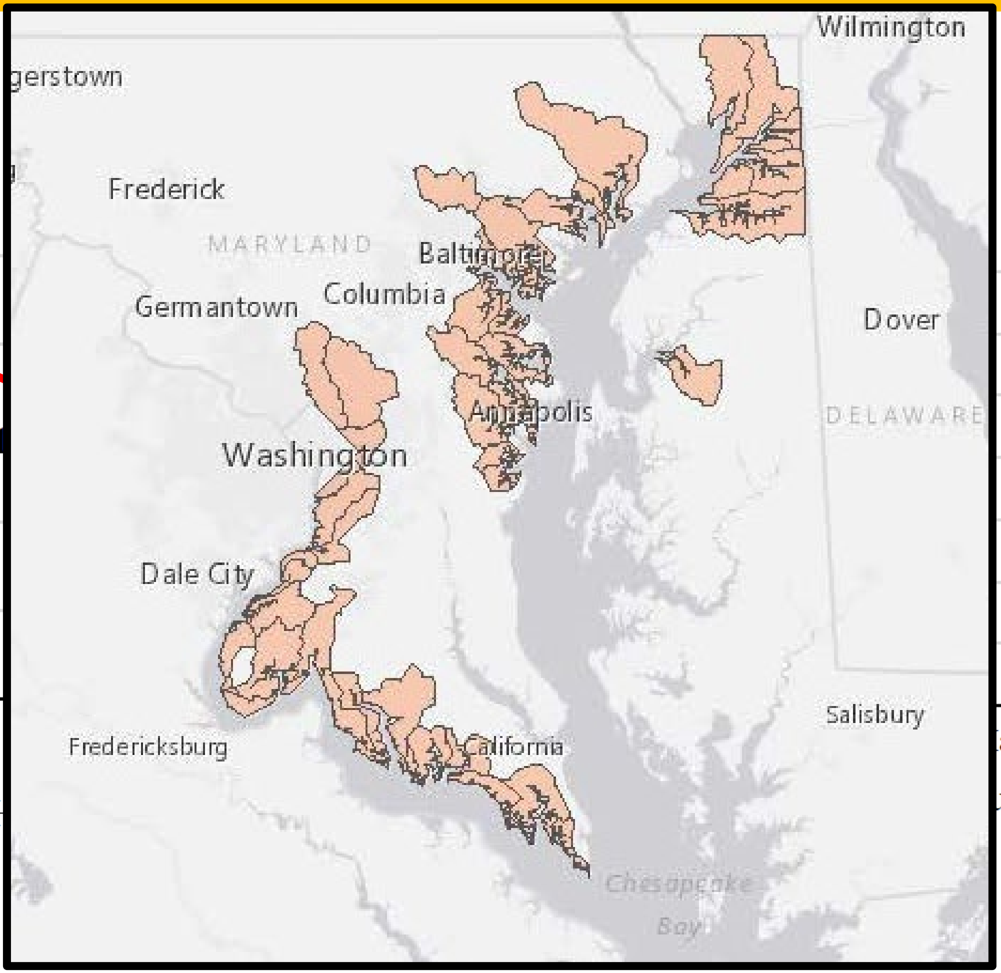
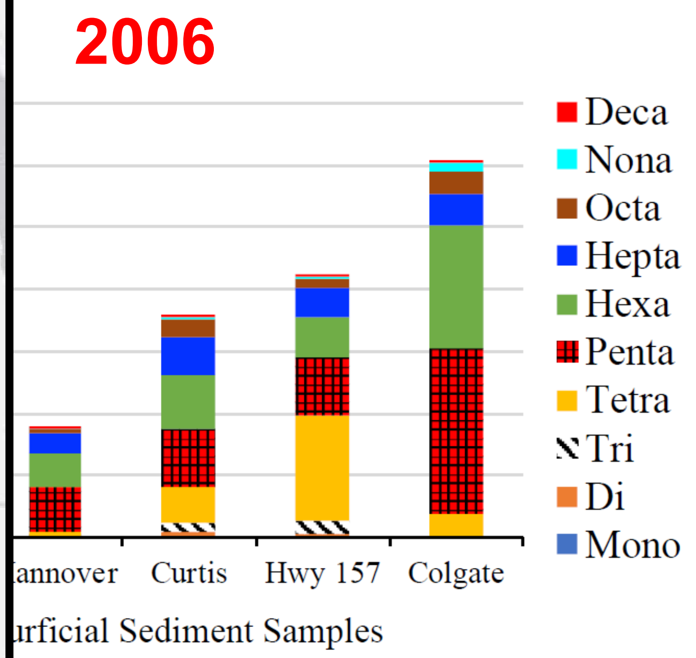
Legacy contamination or current sources?

Kaya et al (2019), STOTEN







Conclusion:

Not only legacy PCBs (Example of Baltimore Harbor)

⇒ **Current sources** are increasing the contamination level

⇒ **TMDLs in place** for watersheds in the Chesapeake Bay

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Impact of land development on PCB contamination

- Land-use categories
  - Residential
  - Commercial
  - Institutions
  - Industrial areas (light vs heavy)
  - Energy sites
  - Green spaces

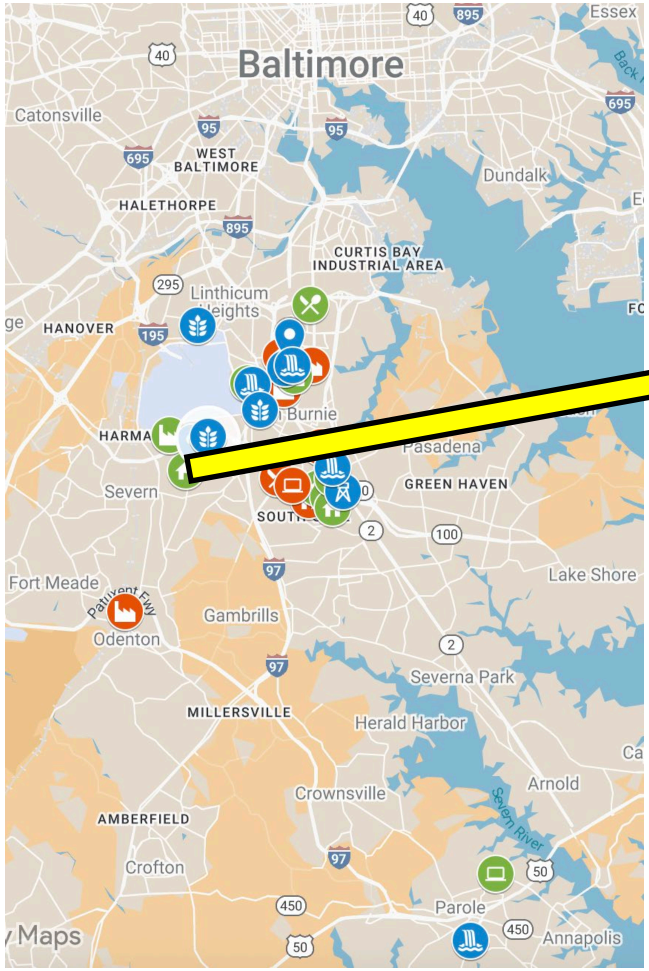




Objectives:

- Assess the **land use** and **time of development** impact on the presence of PCBs in soils and stormwater sediments
- Identify the **potential sources** of stormwater PCBs
- Provide information and **guidance** on PCBs presence (and removal) in stormwater

Map of the sampling sites



Abbreviation	Meaning
Res	Residential Area: Neighborhood
ID	Industry Area: Metal scrap yard, Automotive sales industry
Com	Commercial Area: Retail Shop
IN	Institutional area: Hospital
GS	Greenspace: Park
Pre70	Developed before 1970s (before PCB banned)
Po70	Developed after 1970s (after PCB banned)

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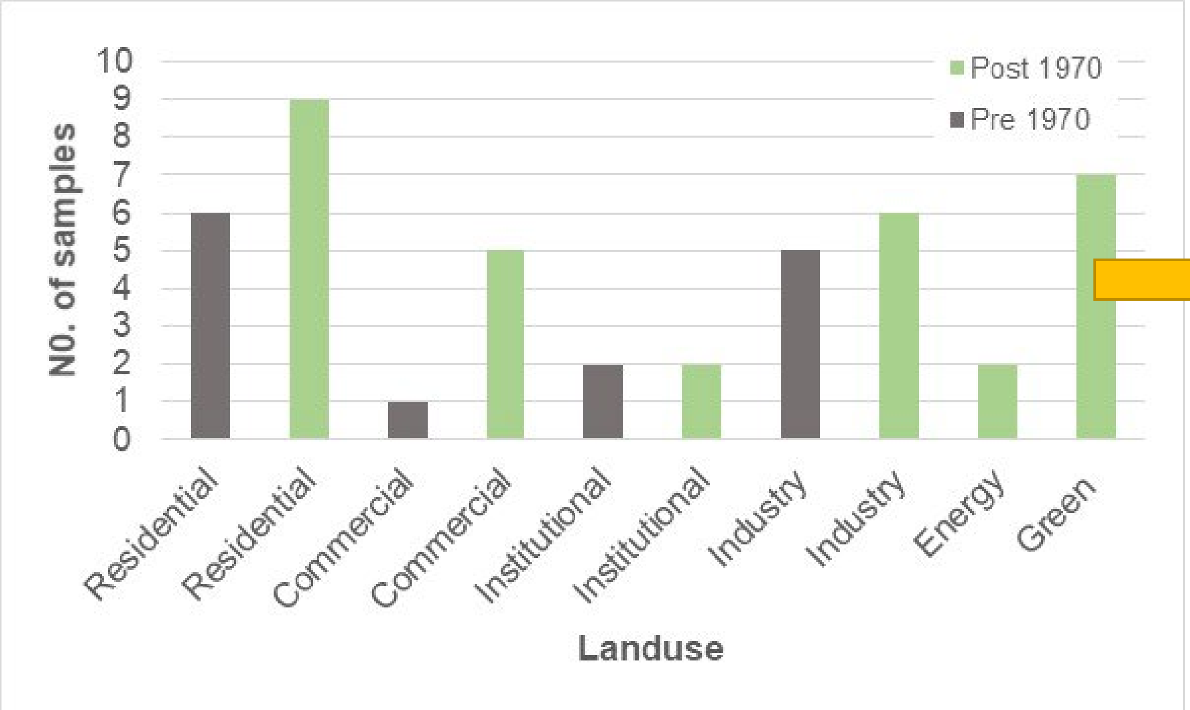
Number of collected samples



Greenspaces – 'control' areas

Summary:

- 82 samples were collected over 2 years (4 dry ponds included)
- 6 different land-uses
- 2 time eras
- Analyzed in triplicate

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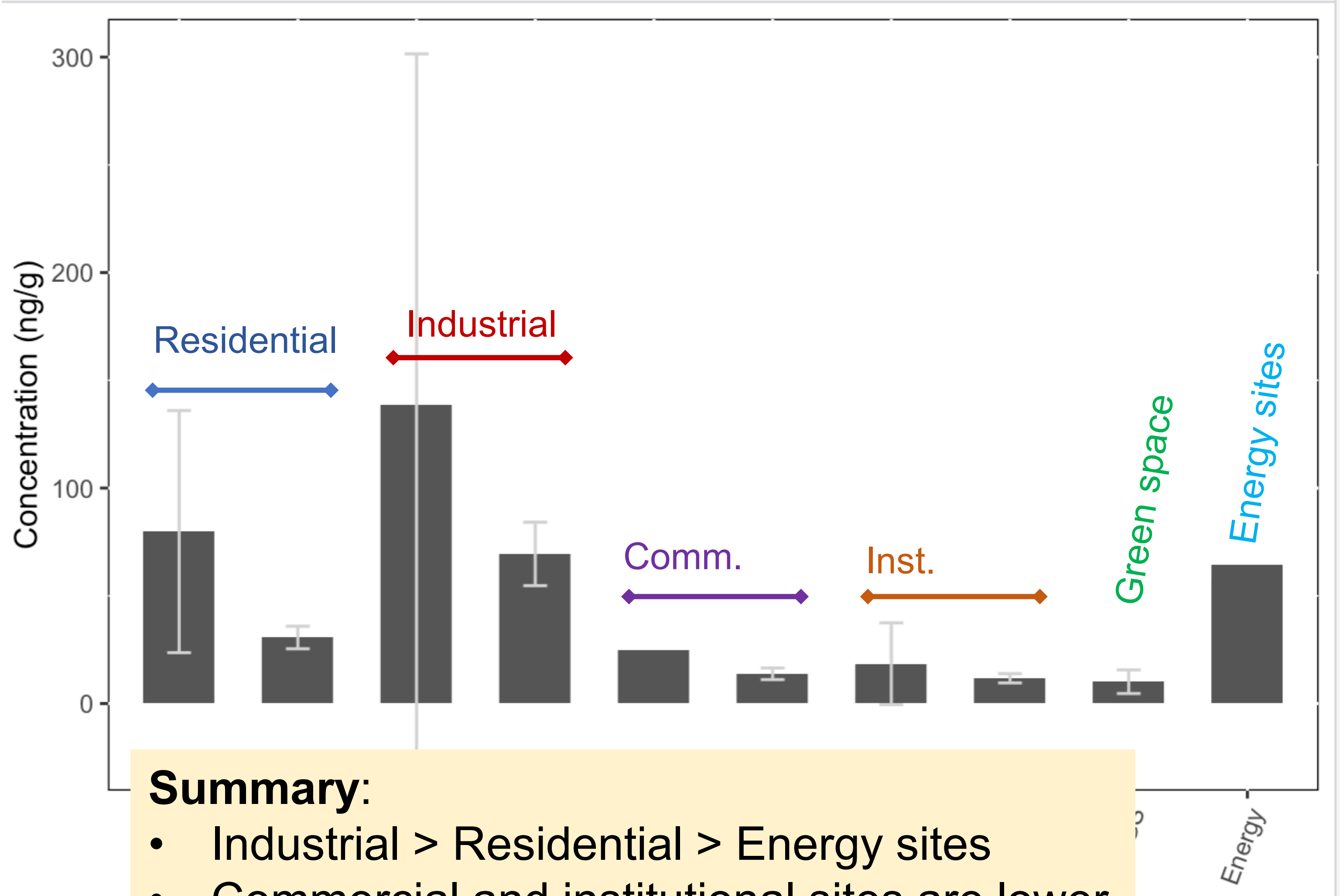
Landuse Type - Total PCB concentration



Category	Range (ng/g)	Average (ng/g)
Residential (Pre)	17.4-157	79.8
Residential (Post)	24.1-37.4	30.6
Industrial (Pre)	31.7-381.3	140
Industrial (Post)	59.0-79.8	69.4
Commercial (Pre)	24.9	24.9
Commercial (Post)	12.1-24.9	13.8
Institutional (Pre)	5.05-31.9	18.5
Institutional (Post)	10.2-12.3	11.7
Green Space	1.27-13.0	10.1
Energy sites	64.4	64.4

Summary:

- Industrial > Residential > Energy sites
- Commercial and institutional sites are lower
- Green spaces are the lowest of all
- Large range of concentrations

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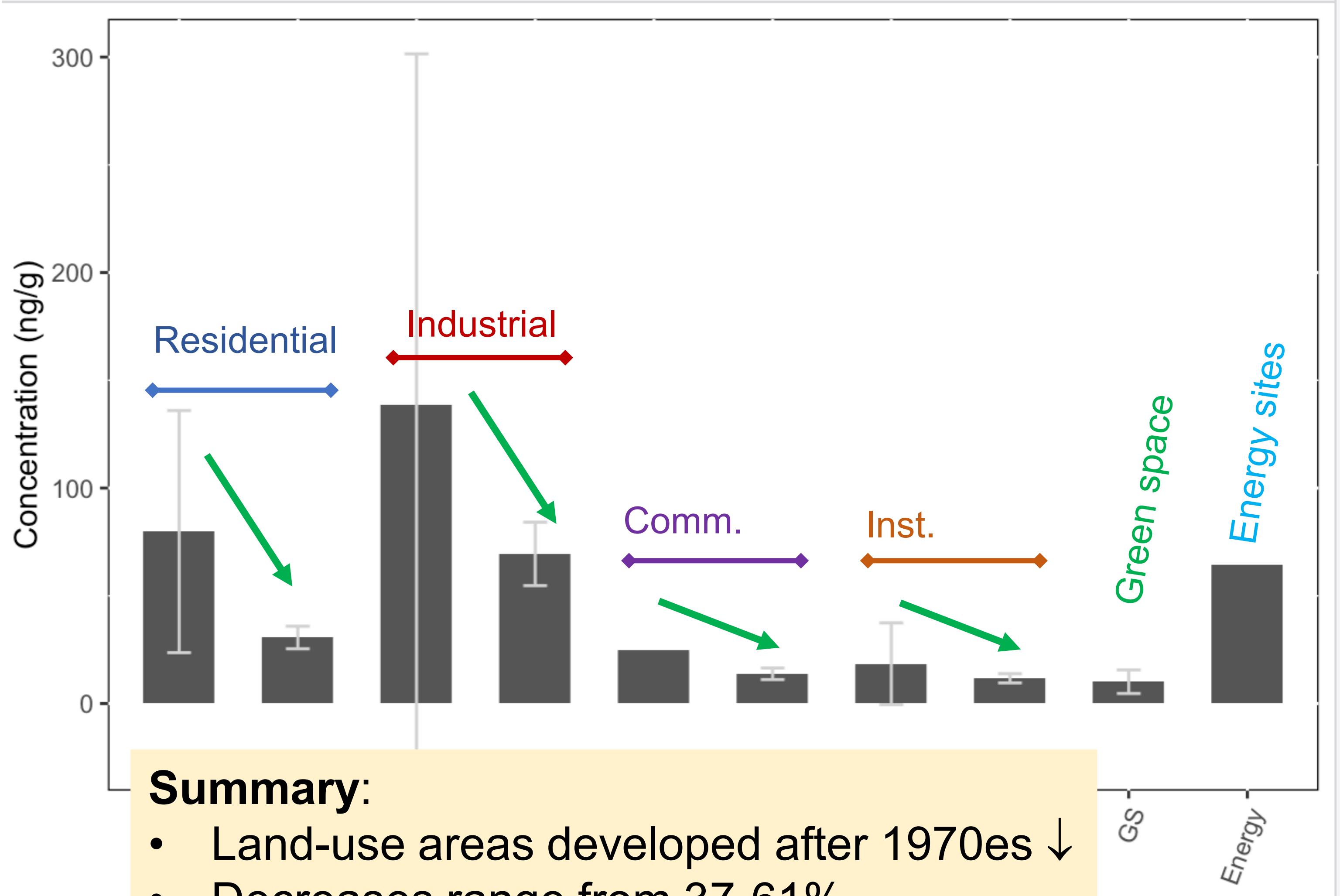
Development time - Total PCB concentration



Category	Average (ng/g)	Reduction
Residential (Pre)	79.8	61%
Residential (Post)	30.6	
Industrial (Pre)	140	50%
Industrial (Post)	69.4	
Commercial (Pre)	24.9	44%
Commercial (Post)	13.8	
Institutional (Pre)	18.5	37%
Institutional (Post)	11.7	
Green Space	10.1	-----
Energy sites	64.4	-----

Summary:
- Land-use areas developed after 1970es ↓
- Decreases range from 37-61%
- Largest decrease for Residential areas
- Difficult to determine re-development time

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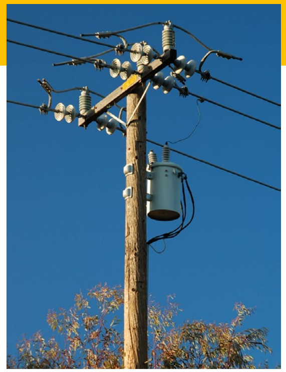
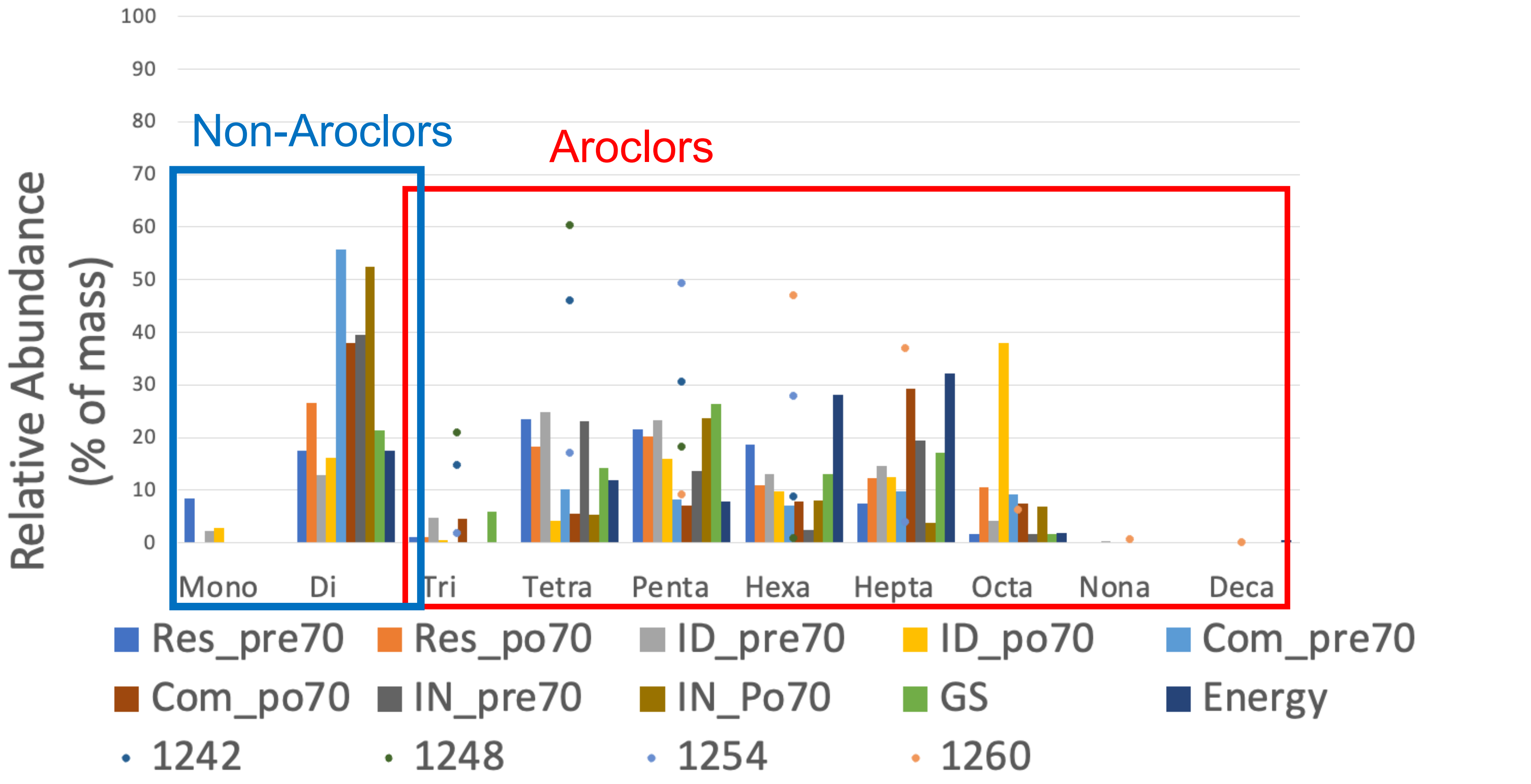
Known sources of PCBs



- Industrial products: Aroclors, A1242, A1248, A1254, A1260
  - ❖ Last two digits indicate chlorine % by weight
  - ❖ EX: Aroclor 1254 contains approximately 54% chlorine
  - ❖ Found in: Electrical transformers, capacitors, heat transfer fluids
- Building materials (recycled material)
  - ❖ Found in: Sealants, caulks, paints
- Other products
- Road paints


PCB sources – landuse category

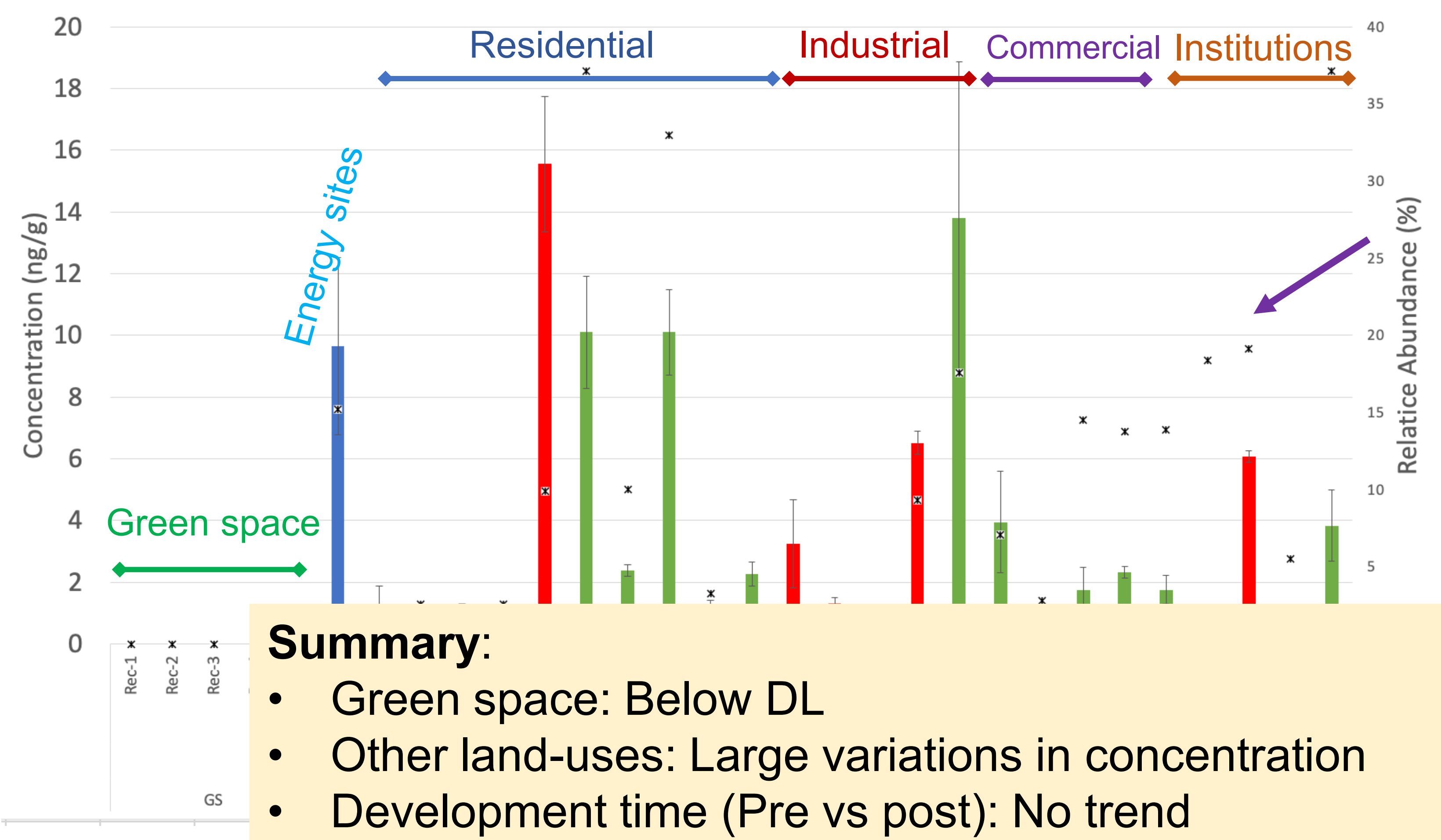


Summary:

- Samples are not originating from Aroclors (dots are not matching samples)
- Large presence of di-chlorinated PCB homologs
- Other sources for PCBs should be considered

PCB-11 in the collected samples (this study)

PCB-11 Concentration and relative abundance (% of total PCB mass)



PCB-11 is non-Aroclor

Summary:

- Green space: Below DL
- Other land-uses: Large variations in concentration
- Development time (Pre vs post): No trend
- Total PCB mass: Ranges from 0-36%
- Removal of road yellow road paints can reduce the PCB-11 level

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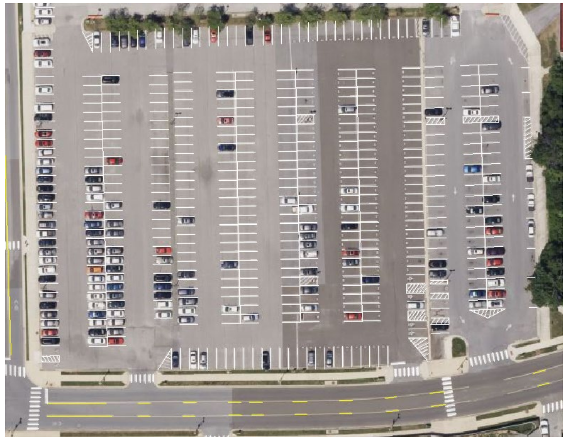
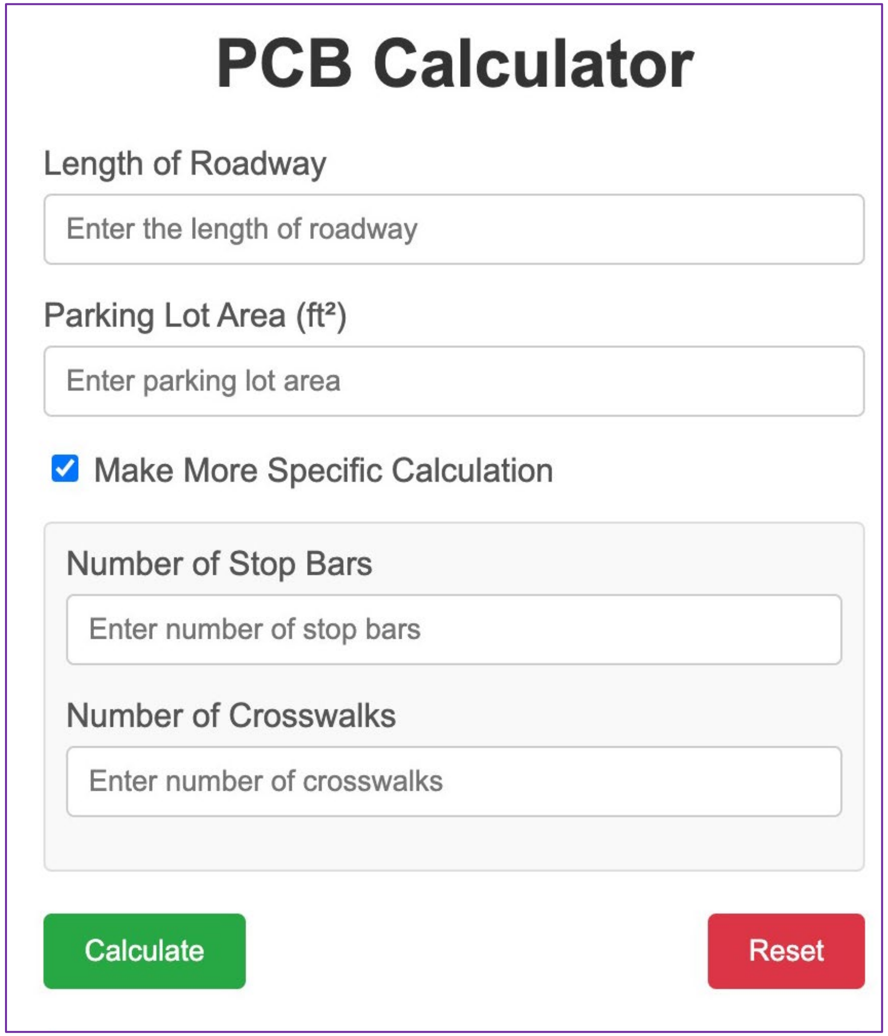
Road paint calculator (Capstone Project)

Estimate the area of road paint in a watershed:





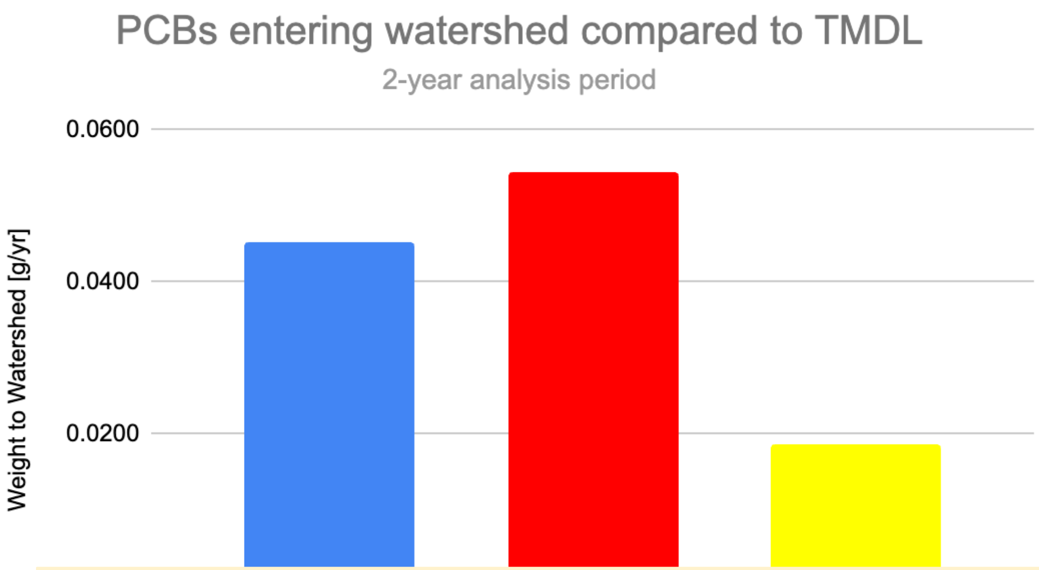
Color	White	Yellow
Length (ft)	184120.91	34486.91
Total Polylines	9426	298
+/- Error	6880.98	217.54
Area (sqft)	85260.68	28477.47
Volume (Cubic ft)	106.57585	35.5968375

Summary of College Park Drafting Data

Road paint calculator (Capstone Project)

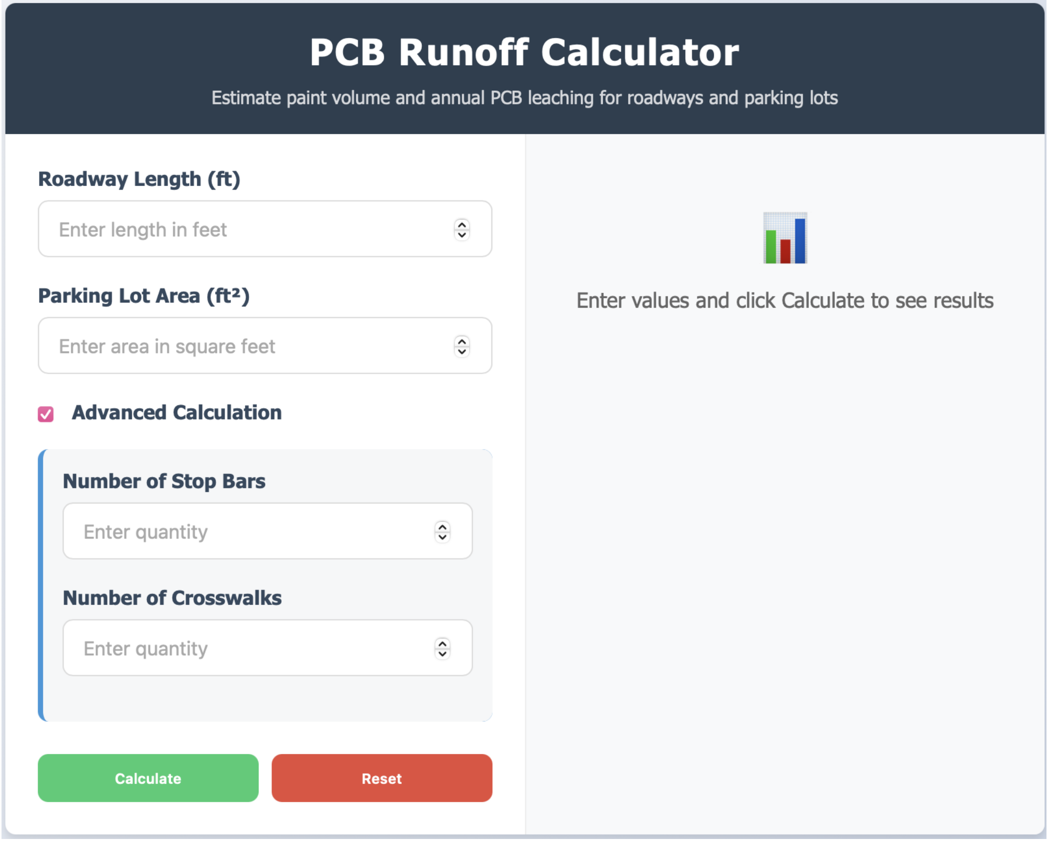
PCB Concentration	Low (g/ft^3)	High (g/ft^3)	Average (g/ft^3)
Yellow	0.0000727	0.001771	0.0011730
White	0.0000514	0.000074	0.0000584

PCB Calculator Concentrations



Summary:

- Estimate road paint areas (each color)
- Determine PCB concentration in paints
- Mass of PCBs from road paint in a watershed



PCB Calculator User Interface

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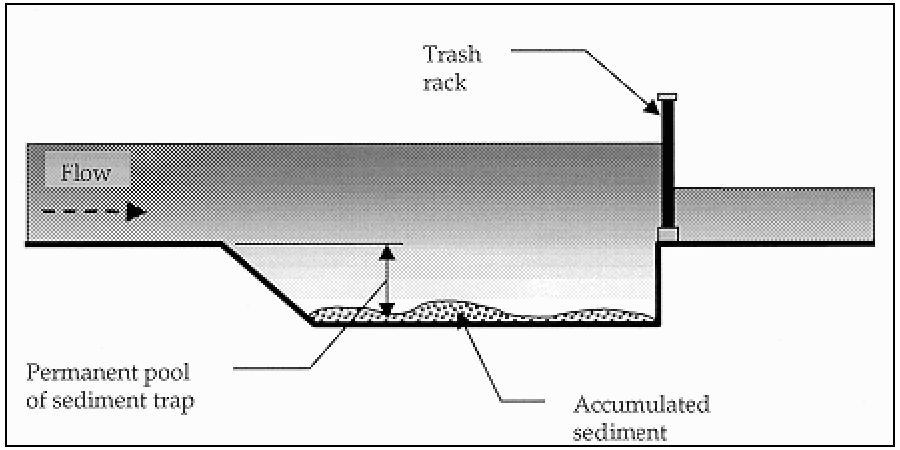
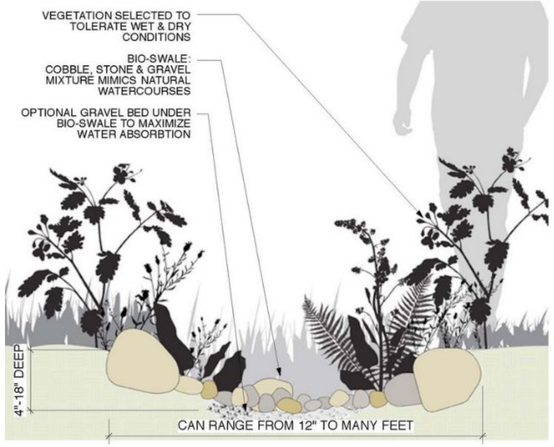
Stormwater treatment options

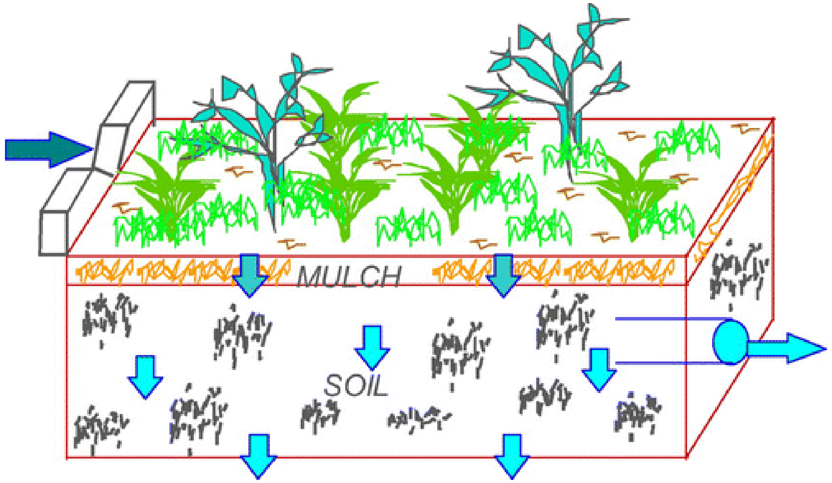
Sediment trap



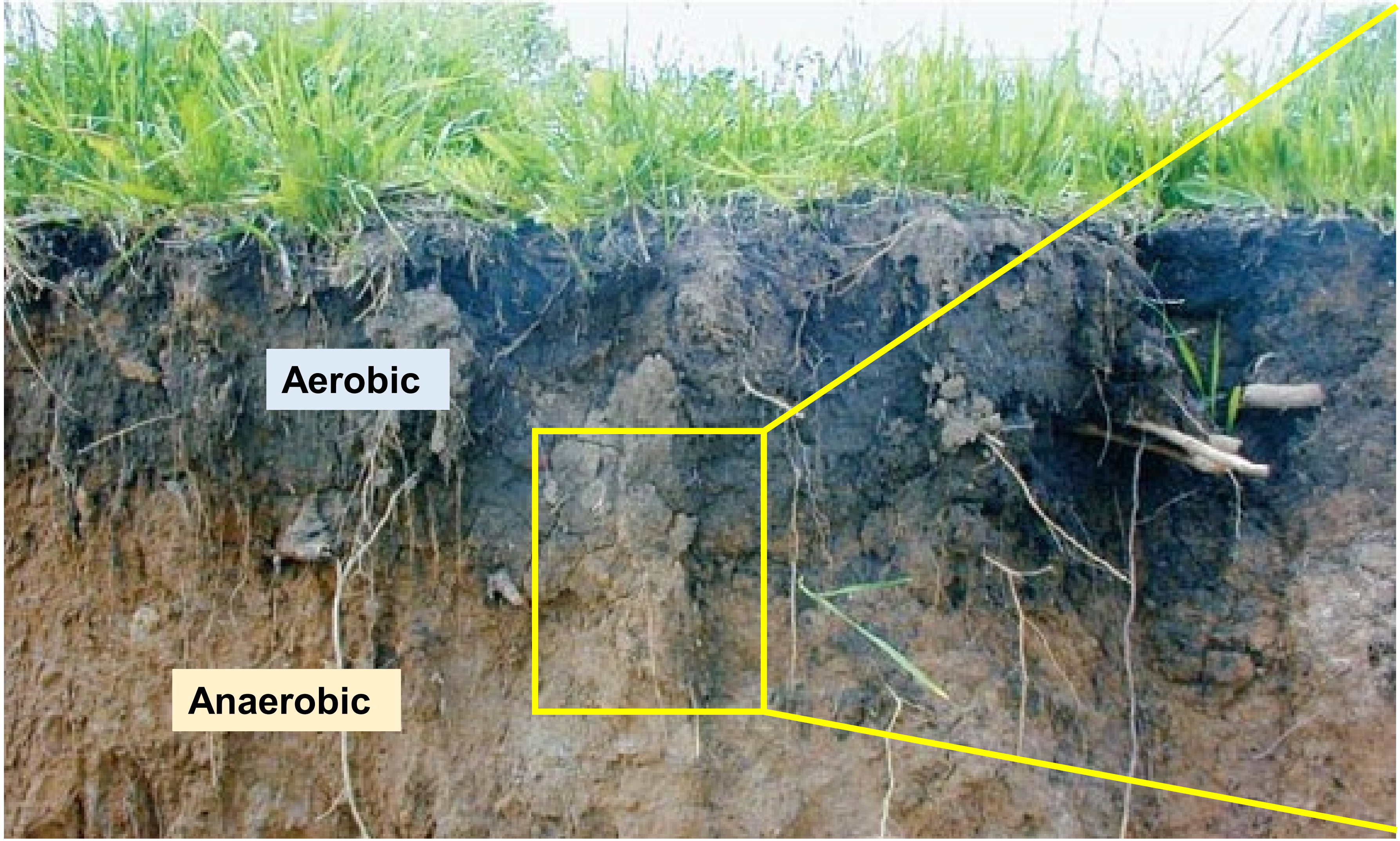
Swales



Bioretention cells

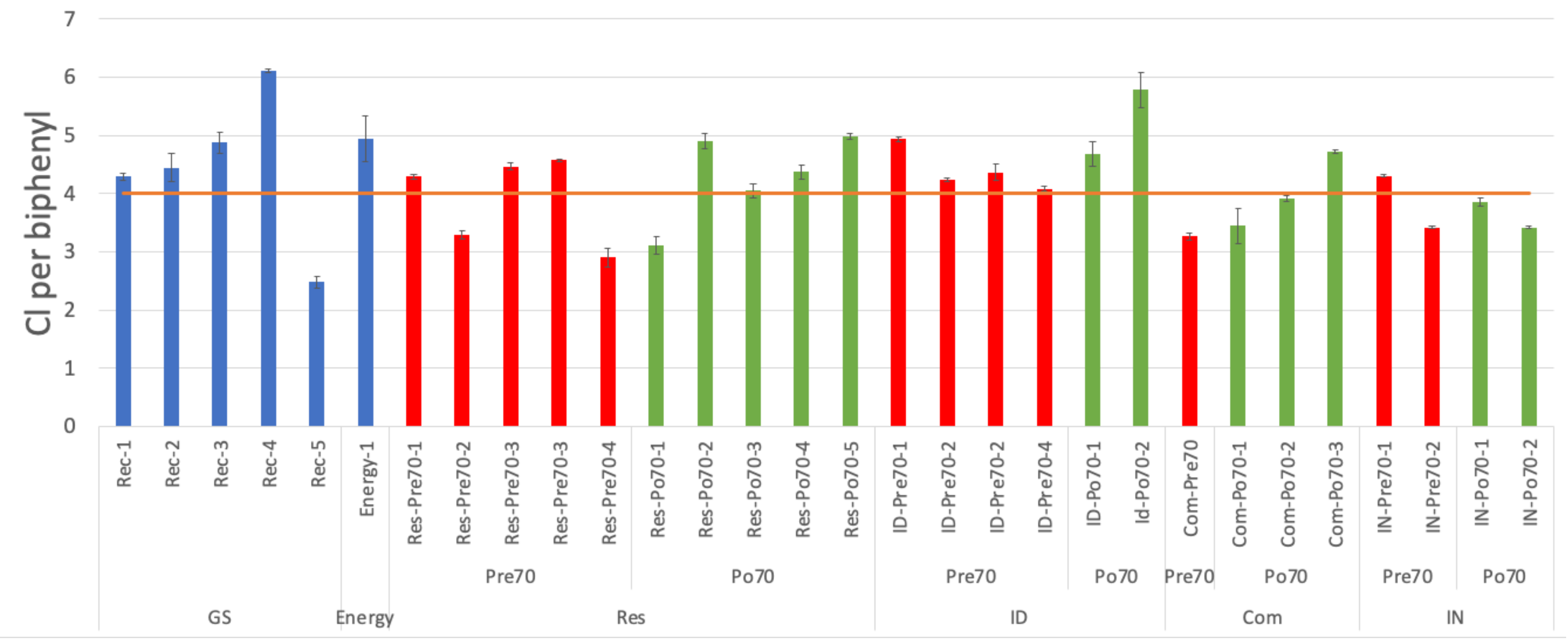


The Microbial Fate of PCBs in soil biofilm

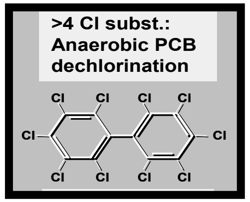


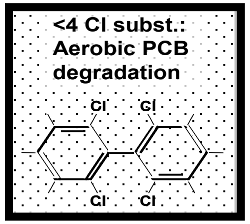
Signs of PCB biodegradation?

No. of chlorines per biphenyl at each site



Anaerobic conditions required





Aerobic conditions required

Summary:

- 66% of samples have >4 chlorines – anaerobic conditions are required
- 33% of samples have <4 chlorines – aerobic conditions are required
- Mass from samples <4 chlorines can be removed 'easily'

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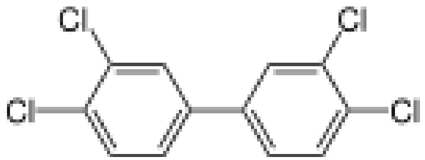
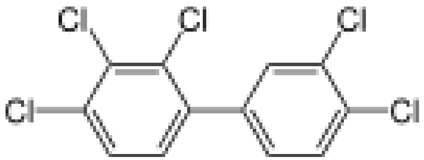
PCB Toxicity

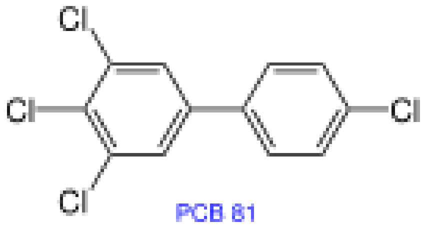
- 12 PCB congeners (of total 209) are VERY toxic
- "Dioxin-like PCBs" – due to chemical structure
- Can be reduced by bacterial degradation in soil biofilms



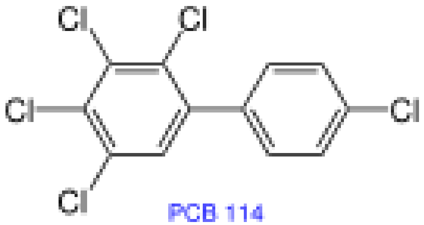
PCB 77



PCB 105



PCB 81



PCB 114

Toxicity Equivalency Factors

PCB congener	IUPAC No.	Mammals	Fish	Birds
Non-*ortho* PCBs				
3,4,4′,5-	81	0.0001[a,b,c,e]	0.0005	0.1[e]
3,3′,4,4′-	77	0.0001	0.0001	0.05
3,3′,4,4′,5-	126	0.1	0.005	0.1
3,3′,4,4′,5,5′-	169	0.01	0.00005	0.001

Toxicity Equivalency Factors

Dioxin-like PCB	TEF
77	0.0001
81	0.0003
126	0.1
169	0.03
105	0.00003
114	0.00003
118	0.00003
123	0.00003
156	0.00003
157	0.00003
167	0.00003
189	0.00003

TEQ_{PCB} **Safe sediment Value = 20 pg TEQ/g** (Eljarrat et al., 2001)

Date from this study:

Land Use	Development	Sample information	TEQ-PVB
Residential	Pre-1970s	Res-Pre70-3	26.3 ± 36.9
Industrial	Pre-1970s	ID-Pre70-1	41.2 ± 2.0
Industrial	Pre-1970s	ID-Pre70-4	20.9 ± 0.8

Summary:
- Samples which TEQ exceed the safe sediment value are listed
- 3 of 45 samples **exceeded** the Safe Sediment Value
- These 3 samples were from **Pre-1970s**: **Residential** and **Industrial**
- All other samples are below the safe limit or <MDL

Effect of Street Sweeping?

Estimated removal of PCBs based on collected data in this study

- Street sweeping FY24: Collection of **234 tons** of debris
- Using ‘typical’ street sweeping calculations:
  234 tons (assume US & wet) x 0.7 = 164 US dry tons = **148,750 kg** street sediment/solids
- Using PCB conc. of ~ 50 ng/g = 50 ug/kg [Low-mid range of our data]

= ~ 7.4 g of PCBs collected

Street sweeping in this area:
- Targeted areas include
- "Arterial Roads, Industrial/Business districts, and NPDES Priority Areas."
- Sweeps are performed twice per month

→ Can Street Sweeping become more targeted?

Summary & Conclusions

- 82 samples were collected over 2 years, 6 different land-uses, 2 time eras (Pre and Post PCB ban in 1970s)
- Highest total PCB concentrations in Pre-1970s Residential and Industrial areas
- Reductions in total PCB concentrations from 37-61% were observed Post-1970s
- Sources of PCBs are not ‘clean’ Aroclors, but are mixed
- PCB-11 (non-Aroclor) from yellow road paint contributes from 0-33% of the total PCB mass
- PCB toxicity exceeded guidelines from 3/45 samples (Pre-1970s Residential and Industrial areas)
- Stormwater is an important carrier of PCBs
- Street sweeping and biodegradation in BMPs can reduce PCB mass

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Acknowledgements

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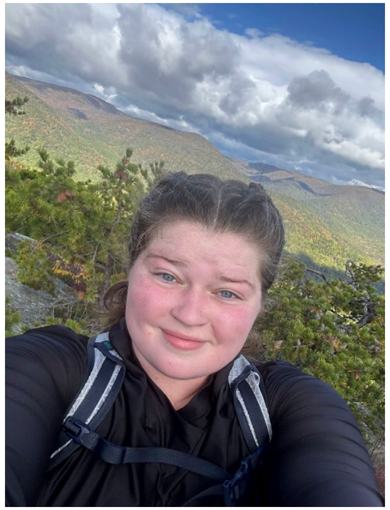

Catherine Elliott

Allen P. Davis

UMD, Civil and Environmental Engineering
Capstone Group: Genevieve Sullivan, Geoffrey Dochat, Graham Simon, and Brett Strauss

[Project ideas are appreciated. Please reach out if you are interested]

Translation Slides

What are the take home points?
What does this mean for me?

Douglas Griffith (Anne Arundel County Bureau of Watershed Protection & Restoration)

Breck Sullivan (Chesapeake Bay Program)

Take-Home Messages

- Not all PCBs are created equal
  - 12 (of 209) congeners are identified as toxic
- Development era (pre- or post- 1979 ban) and land use are important factors in source assessment & ID.
  - PCB contribution from pre-ban residential and industrial sites much higher than contribution from post-ban counterparts.
  - Different congeners b/t industrial and residential sites
- Potential for PCB remediation in BMPs – IF designed to do so.

What does this mean for me?

Anne Arundel County

- **Regulatory:** TMDLs could be revised to focus on Aroclors or toxic congeners only, instead of *total* PCBs by weight
  - **Example:** Road paint – PCB11 may be a large contributor to overall SW loads, but is less toxic
- **Targeting:** Land use and development can inform focus areas and BMP type for best “bang-for-buck”
  - **Example:** Concentrating street sweeping in pre-ban era residential and industrial eras
- **Degradation:** PCB type in SW load can inform the type of BMP necessary to achieve full degradation
  - **Example:** Require anaerobic soil conditions, therefore wet ponds are not idea for PCB remediation

QUESTIONS?

Contact: bvk@umd.edu




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EXTRA SLIDES

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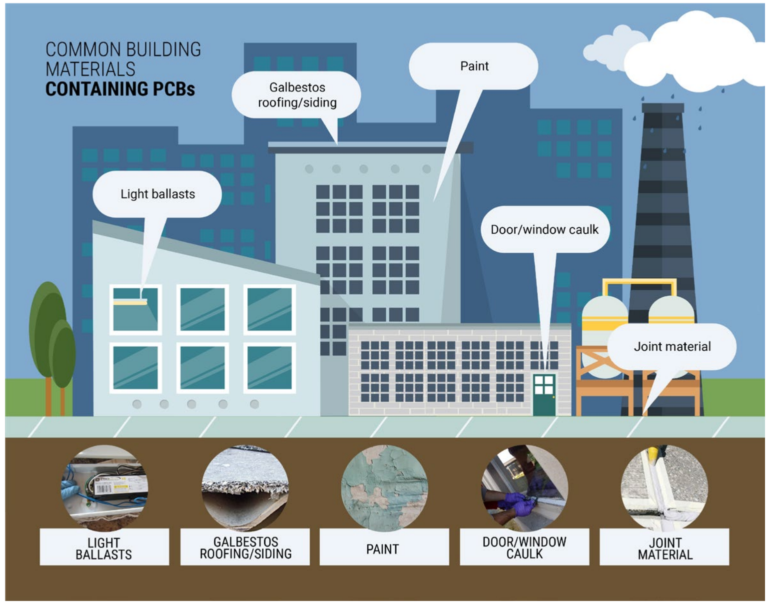
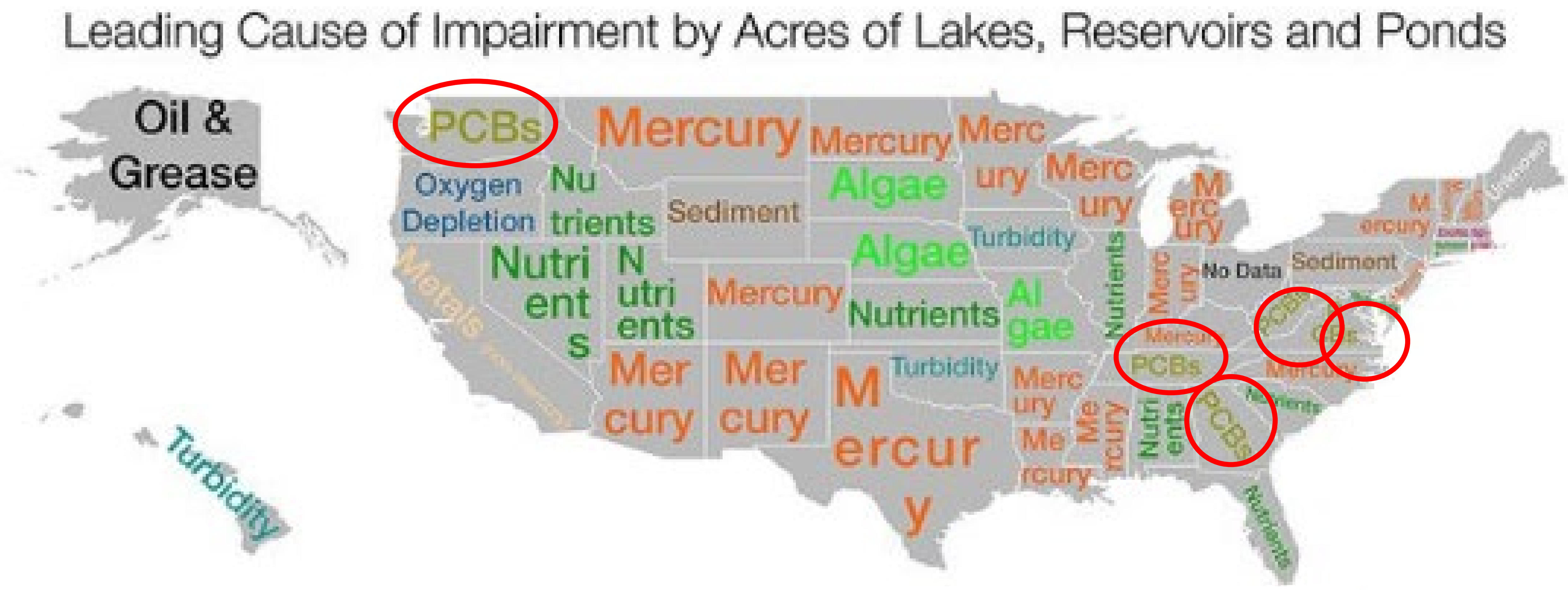
Land Use and Era of Development Effects on PCB Contamination of Soils and Stormwater Sediments in the Chesapeake Bay Watershed

Next steps

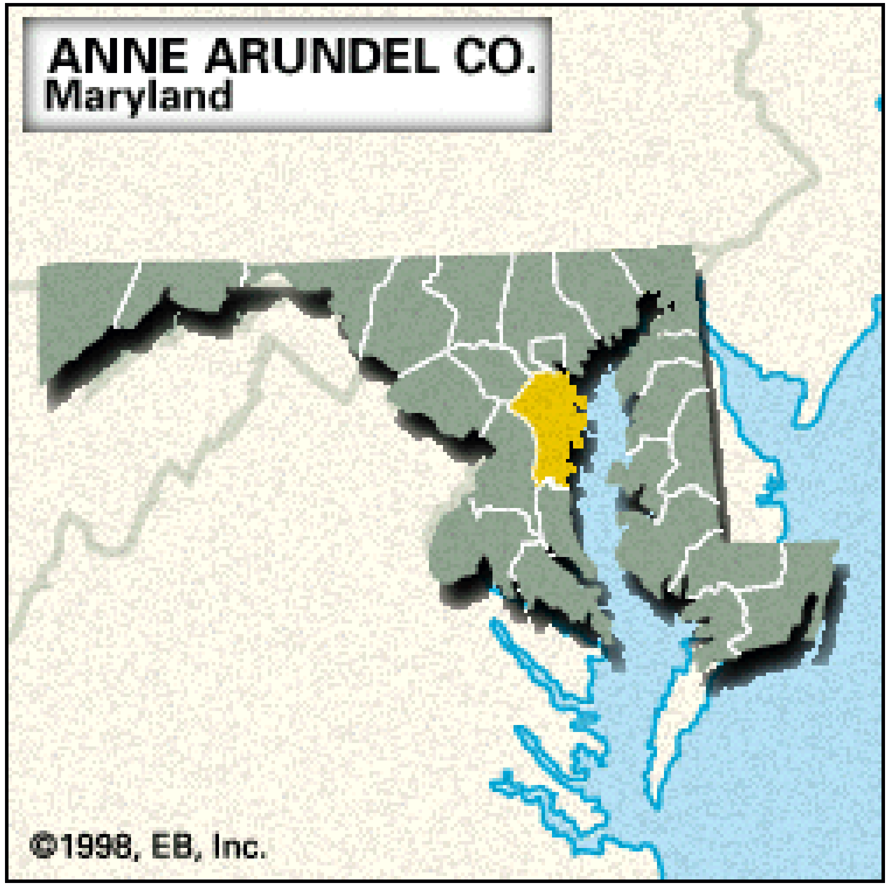
- Assess the impact of soil and particle types
- Expand the road pain study to include other paint colors
- Assess presence of other PCB sources and their contributions
- Investigate if stormwater BMPs can be designed to remove PCBs simultaneously with other contaminants (N, P) via biodegradation, bioaugmentation?



Causes of water impairment in the US



Sampling locations



Objectives

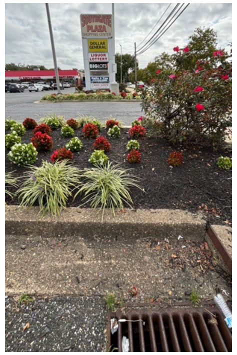
- Assess the **land use** and **time of development** impact on the presence of PCBs in soils and stormwater sediments
- Identify the **potential sources** of stormwater PCBs
- Provide information and **guidance** on PCBs presence (and removal) in stormwater

Residential neighborhoods

Before 1970es

After 1970es

Light commercial areas



Before 1970es

After 1970es

Energy site

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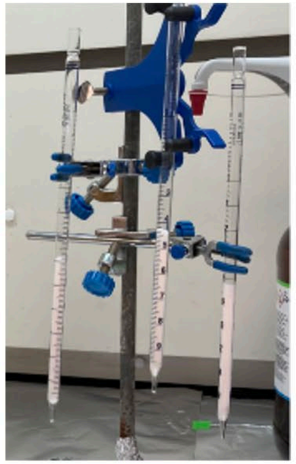
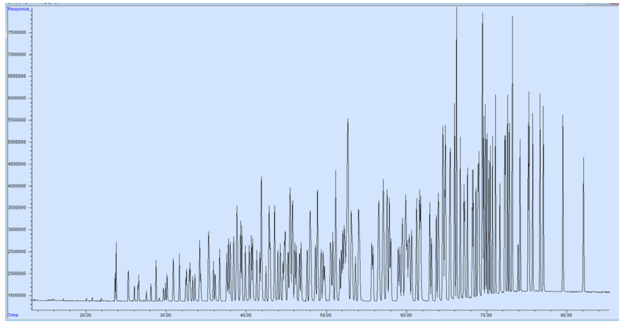
Experimental process



Sample Collection → Microwave Extraction → Clean up → Gas Chromatograph (ECD) analysis → Data Analysis

Detection Limit vs Below Quantifiable Limit

- Not all 209 PCB congeners are quantifiable in each sample
- How can we determine the **Total PCB concentration**?
  - Define BQL = 0 → Underestimation
  - Define BQL = ½ QL → Overestimation
- **Kaplan-Meier** ranking assessment
  - Statistical method using a value between 0 and ½ QL
- Provides **more accurate** estimate of data BQL for use in total pollutant measurements

Summary:

- Detection Limit (DL): 0.0420-2.85 ug/mL
- Methods Detection Limit (MDL): 0.00841-0.570 ng/g

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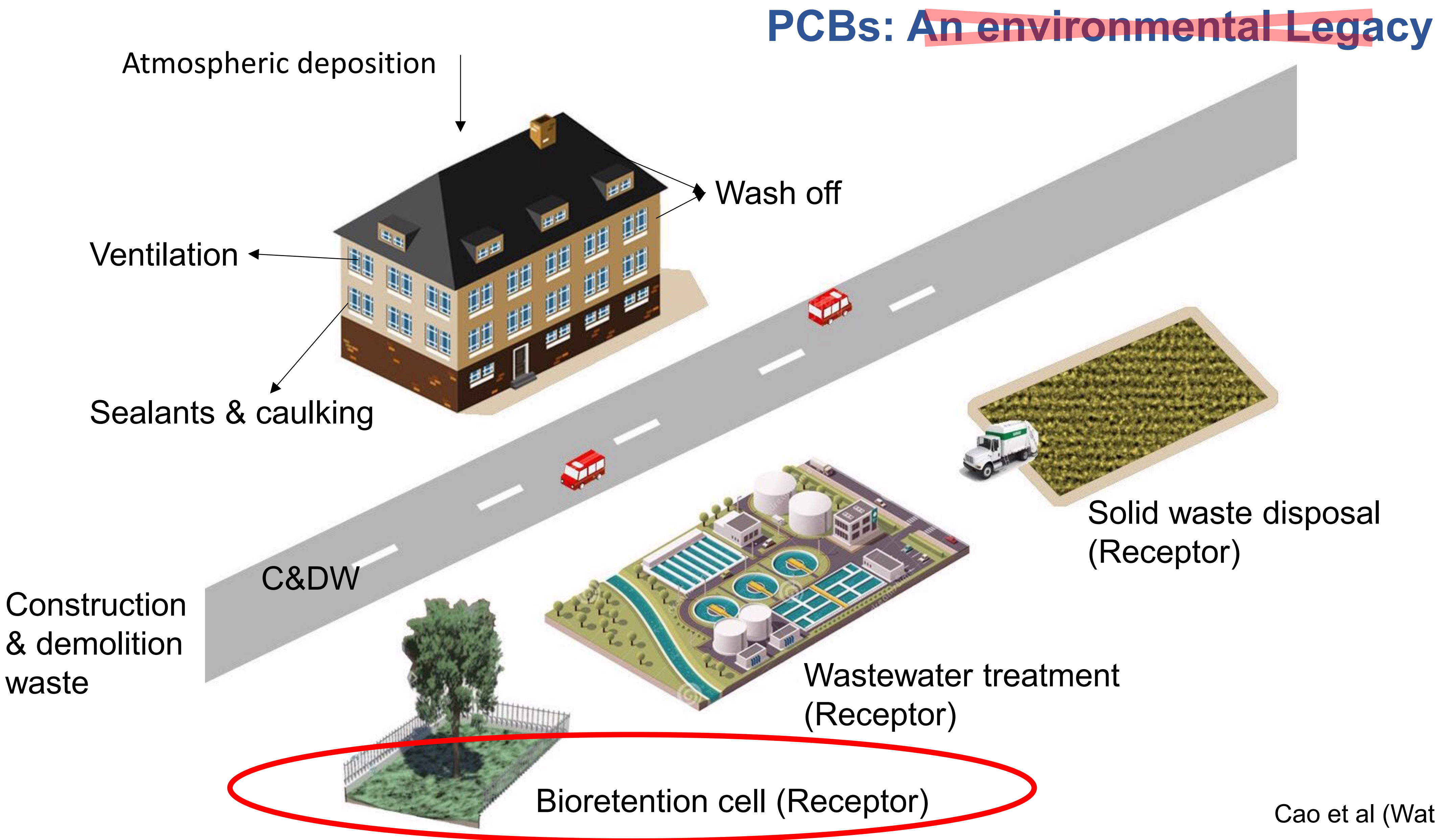
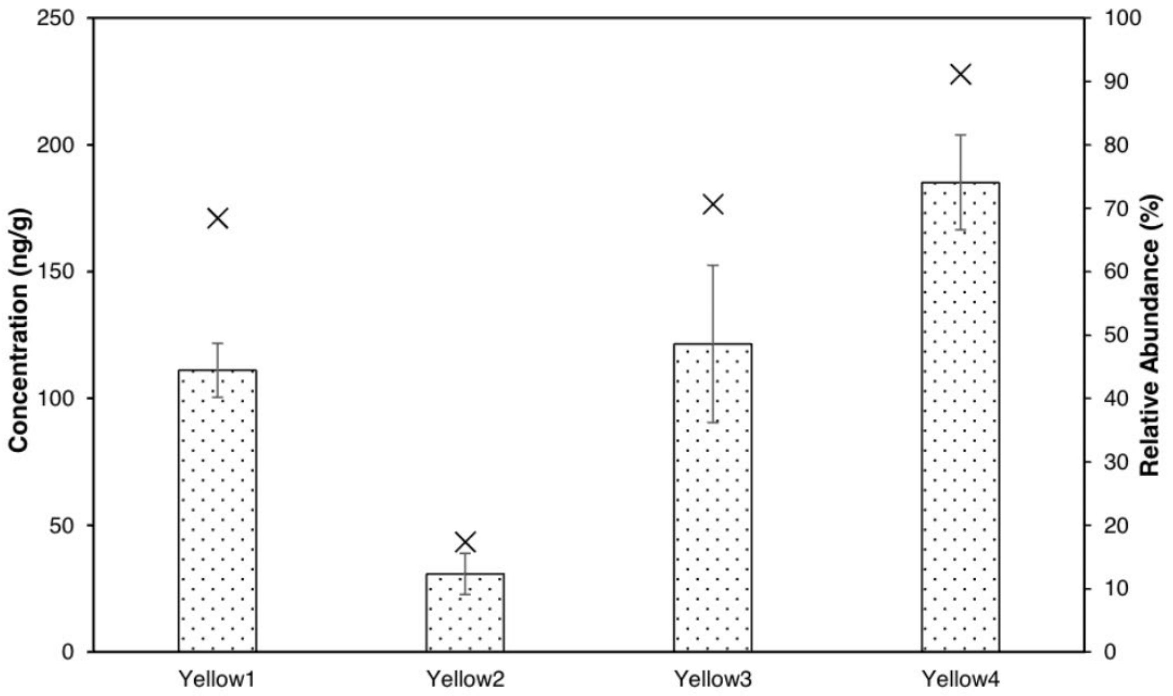
Current sources and receptors of PCBs

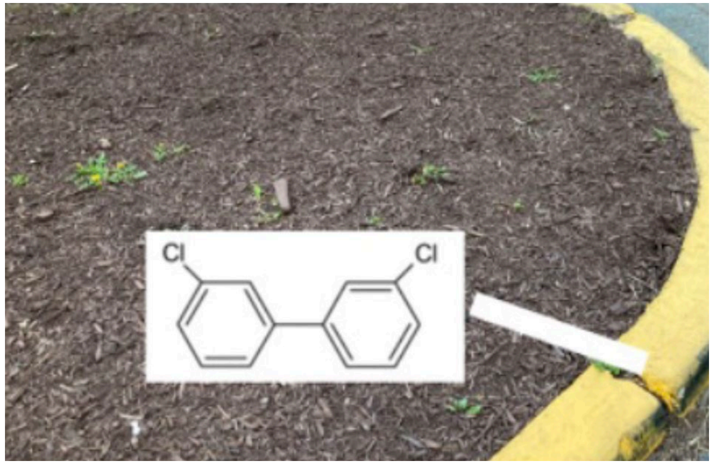


Cao et al (Wat Res), 2019

Earlier study of yellow road paint

PCB 11 in yellow road paints





- The relative abundance of PCB 11 ranged from 17% to 91% of total PCB concentrations in yellow roadway paints
- Road paint flake exist in the soil/sediment sample might impact the concentration of samples.

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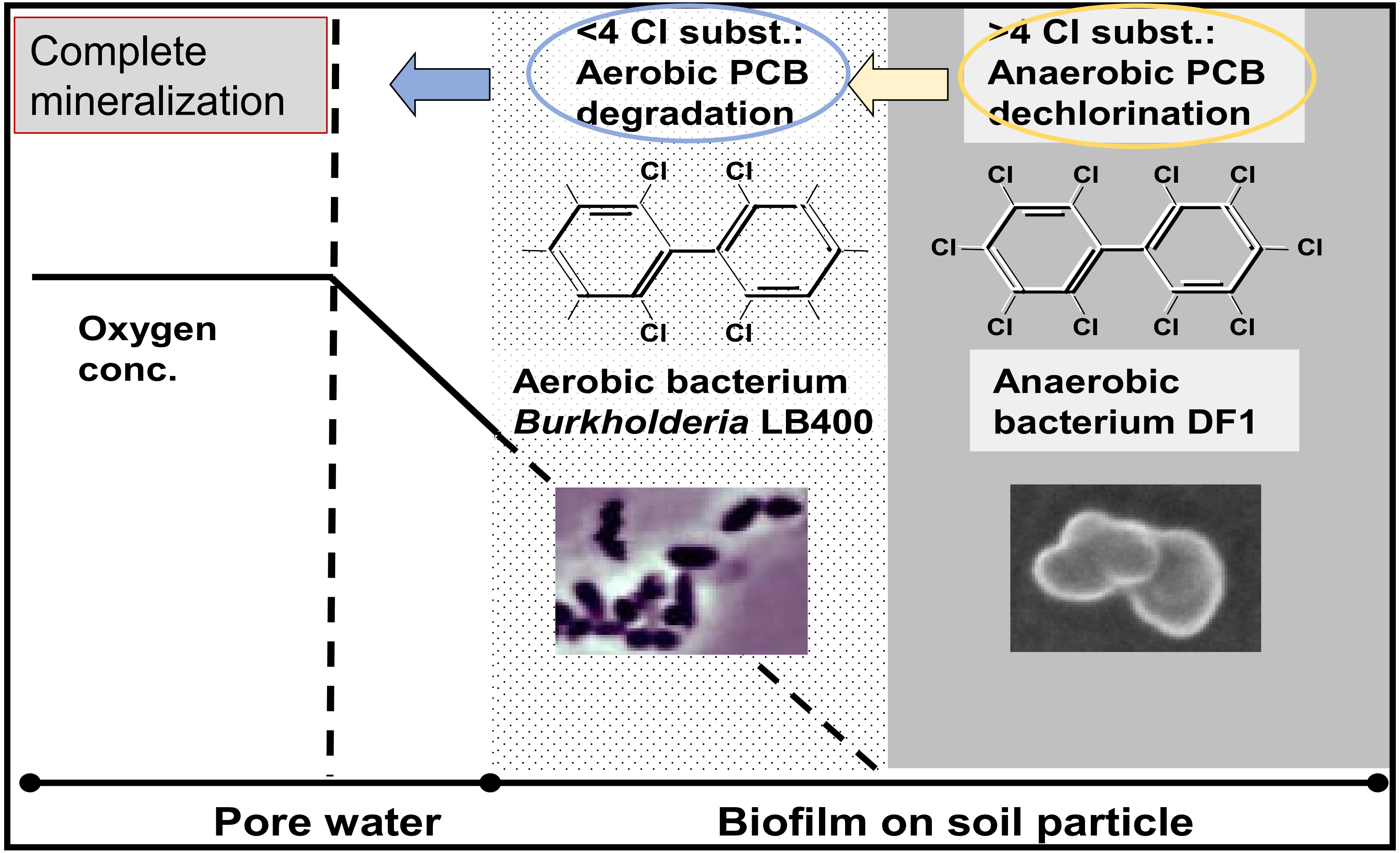
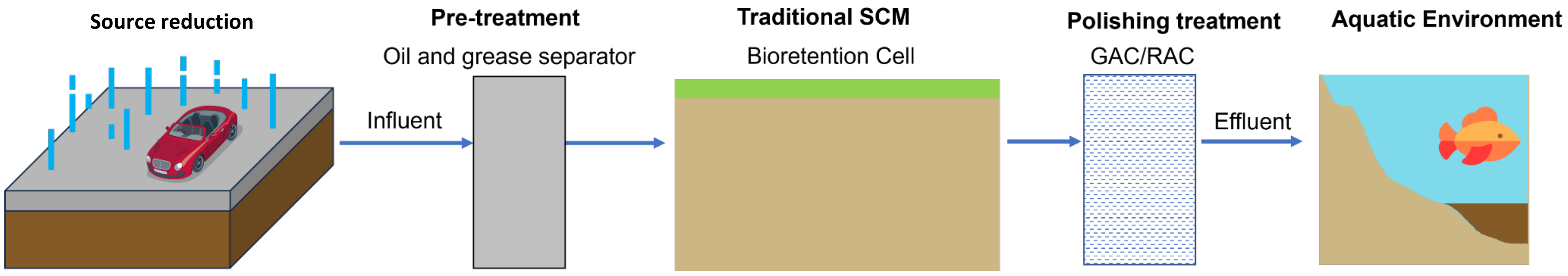
The Microbial Fate of PCBs in soil



Stormwater Treatment Train System

Results from completed SERDP-DOD project:



Literature review & preliminary results:
- Stormwater composition
- Street sweeping

Field study Joint Base Lewis McCord
- Effect of storage
- PAH removal

Field & laboratory studies: PAHs, PCBs, Cu, Zn

Laboratory studies: PAHs, PCBs, Cu, Zn

Not included in this project

Outcome: Demonstrated effect of the treatment train by use of project data for Mass Balance Estimation for each process step

Effect of Street Sweeping?

POLLUTANT LOADING			SOURCE REDUCTION (STREET SWEEPING)[2]			PRE-TREATMENT (OIL GRIT SEPARATOR)[3]			STORMWATER BMP[3]			POLISHING TREATMENT (BIOCHAR)[4]		
Pollutant	Concentration (mg/L)[1]	Annual Load (lbs)	% Reduction	Load Reduction (lbs)	Reduced Load (lbs)	% Reduction	Load Reduction (lbs)	Reduced Load (lbs)	% Reduction	Load Reduction (lbs)	Reduced Load (lbs)	% Reduction	Load Reduction (lbs)	Reduced Load (lbs)
Total Cu	0.013	0.120	31	0.037	0.083	10	0.008	0.075	23.5	0.018	0.057	77	0.044	0.013
Diss Cu	0.0065	0.060	10	0.006	0.054	0	0.000	0.054	0	0.000	0.054	77	0.042	0.012
Total Zn	0.0757	0.700	75	0.525	0.175	10	0.017	0.157	71.7	0.113	0.045	37	0.016	0.028
Diss Zn	0.029	0.268	10	0.027	0.241	0	0.000	0.241	0	0.000	0.241	37	0.089	0.152
PAHs (sum of reported PAHs)	0.00141	0.013	unk	0.000	0.013	unk	0.013	0.013	unk	0.000	0.013	90	0.012	0.001
1: Source: Chapter 6 **Site Assumptions** Drainage Area: 1ac Impervious Cover: 80% Annual Rainfall: 59" Runoff Coefficient: 0.77 Annual Runoff: 40.9"			2: Source: Chapter 11; assumes regenerative air sweepers with monthly sweeping; portional reduction in efficiency made for diss metals to acount for reduced efficiency; note this does not account for accumulation that may occur between sweeping events			3: Based on oil grit separators which are known poor pollutant removal performers			3: Source: Chapter 3; no significant difference reported between dissolved metals influent and effluent so assumed 0% reuduction			4: Source: Chapters 7 and 8; assumed eff for biochar (vs GAC); applied dissolved metals eff to total metals		

Conclusion:

- Pollutant removal efficiencies > 70% may be achievable across contaminants
- A treatment train can:
  - Improve performance for a broad range of COCs
  - Reduce maintenance burden
  - Extend the life of the structural BMP

Acknowledgment Slide

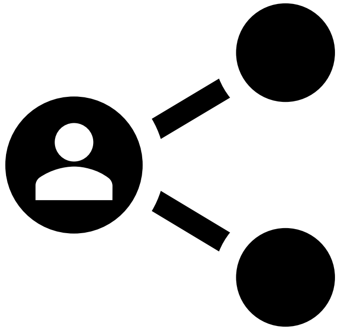
- Acknowledge the funding partners for this program which include the following partners and especially acknowledge those that funded your project, if known
- Err on acknowledging too many partners vs too few

Here are all the funding partners in the program as of 5/6/24:

What does this mean for me?

Chesapeake Bay Program

Advance CBP Outcome



Share across Jurisdictions

Inform Policy

Target resources and data

Use of molecular sewage indicator methods to reduce uncertainty in watershed remediation efforts and water contact recreation

CBT Pooled Monitoring Workshop

Maryland Department of the Environment
Baltimore, MD 21230
June 18, 2025

University of Maryland
CENTER FOR ENVIRONMENTAL SCIENCE
INSTITUTE OF MARINE & ENVIRONMENTAL TECHNOLOGY

Institute of Marine and Environmental Technology

Eric J. Schott
University of MD Center for Environmental Science, IMET

Zooquatic, Baltimore DPW, Blue Water Baltimore, Healthy Harbor Initiative

Research Question and Hypotheses

- Question 5a: “Restoration at project scale”: Pollutants of emerging concern, Bacteria.
- *Original Hypotheses*
- **H1**) Combining MST and FIB methods will allow a qualitative assignment of the relative proportion of human versus non-human FIB in a given water sample.
- **H2**) Daily testing, using both standard FIB culture and PCR methods to detect human vs non-human fecal bacteria, will show that high FIB counts do not always correspond to high human MST (Bacteroides) signals.
- **H3**) Daily testing of water quality will provide knowledge about the duration and drivers of sewage-derived bacteria and other FIB in tidal water that could not be achieved with weekly testing.

Swimmable Harbor Goals

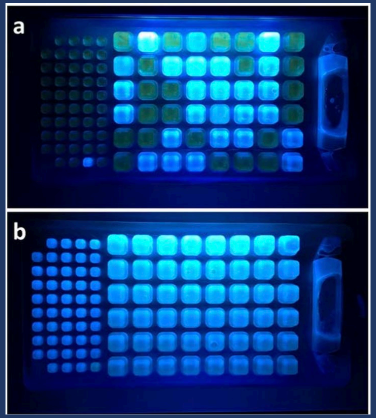
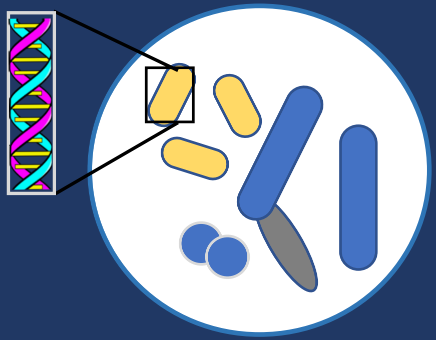
- Goal set in 2010 by the Waterfront Partnership
- Baltimore under EPA, DOJ sewage consent decree
- “Swimmable” = Fecal Indicator Bacteria below EPA threshold

The reimagined Middle Branch

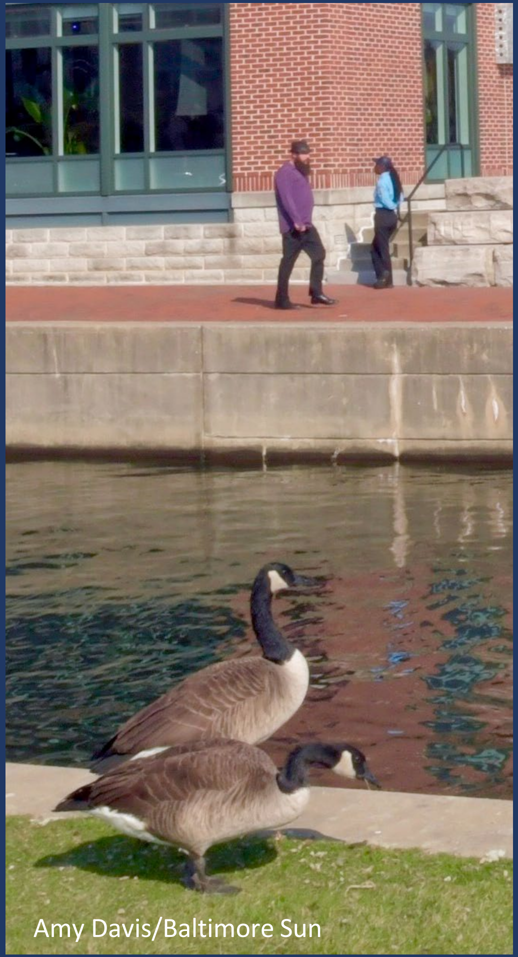
Baltimore Blue Way

Fecal Indicator Bacteria (FIB) can be measured many ways

e.g., Enterococcus

	M-entero agar	IDEXX	Species-specific qPCR
			
Minimum process time	24 hours	24 hours	6 hours
What is measured	Colony growth	Metabolic activity	Bacteria genomic DNA
Data output	CFU	MPN	Genome copy

FIB have various possible origins

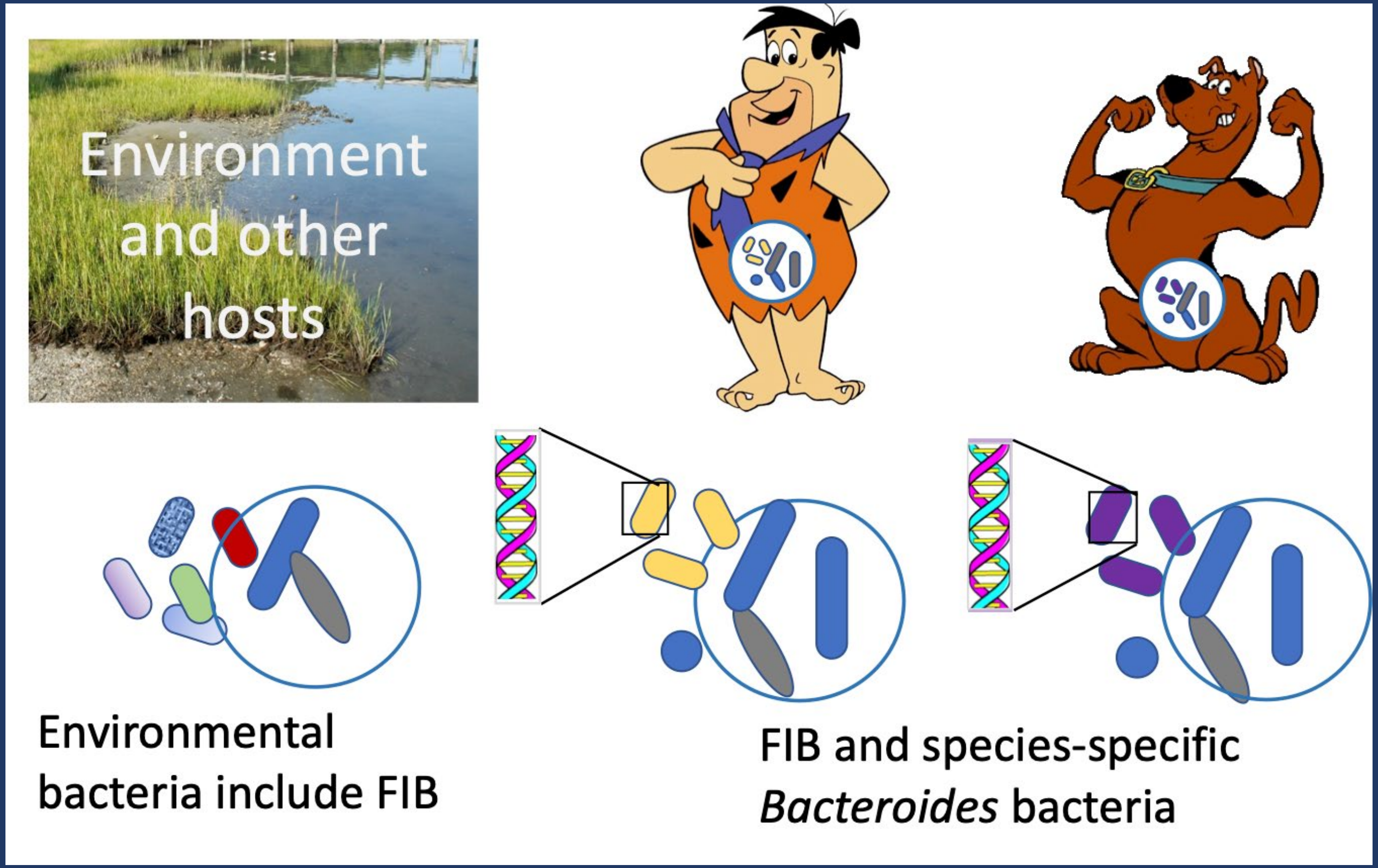


Amy Davis/Baltimore Sun

(Upper photo: Cladophora in Baltimore:
https://eyesonthebay.dnr.maryland.gov/hab/news_062404.cfm)

Some fecal indicator species are more host-specific than others

E. coli
Enterococcus



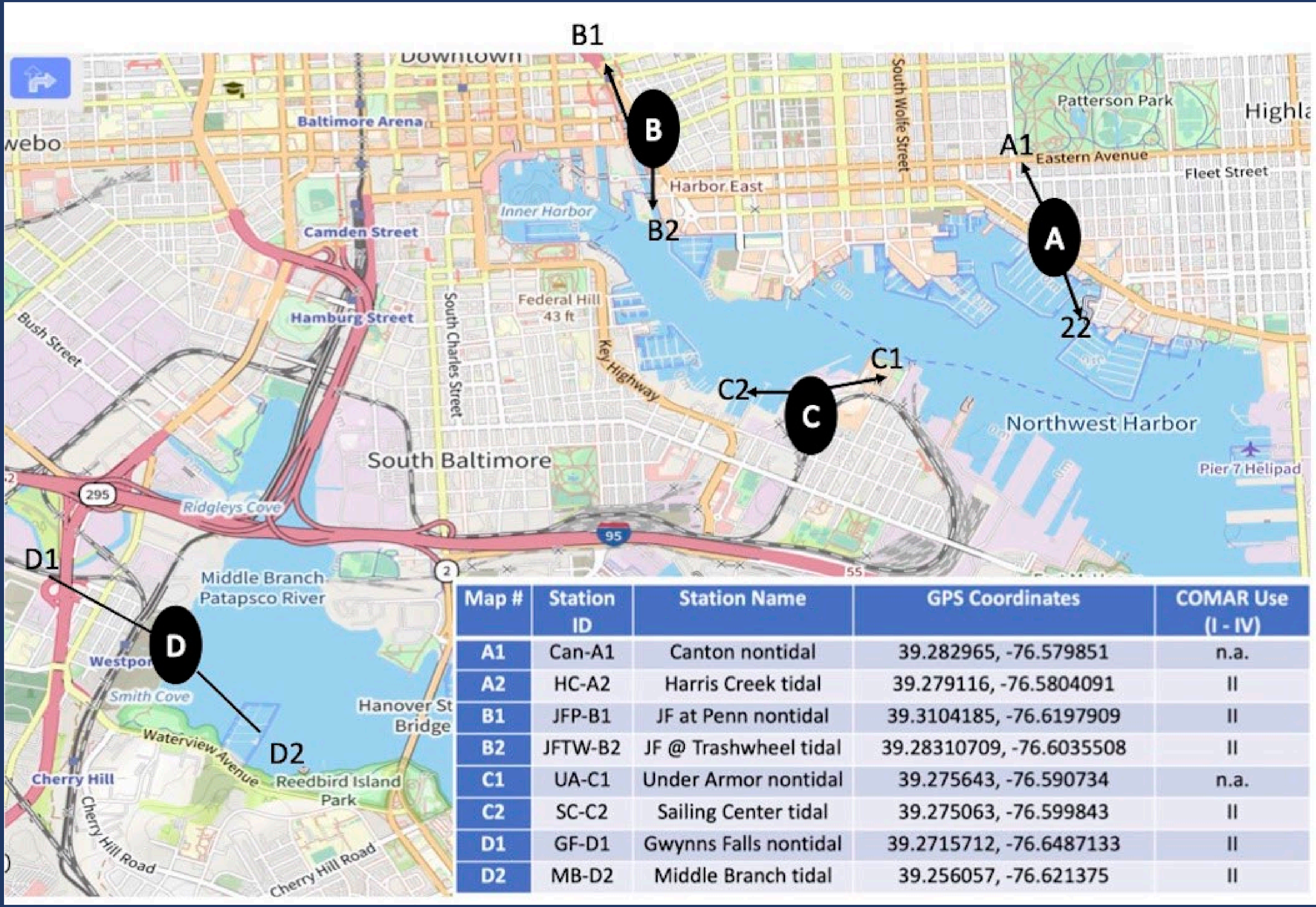
Lachnospiracae, humans
Others species for other hosts

Study design

Paired tidal and nontidal sites, four locations

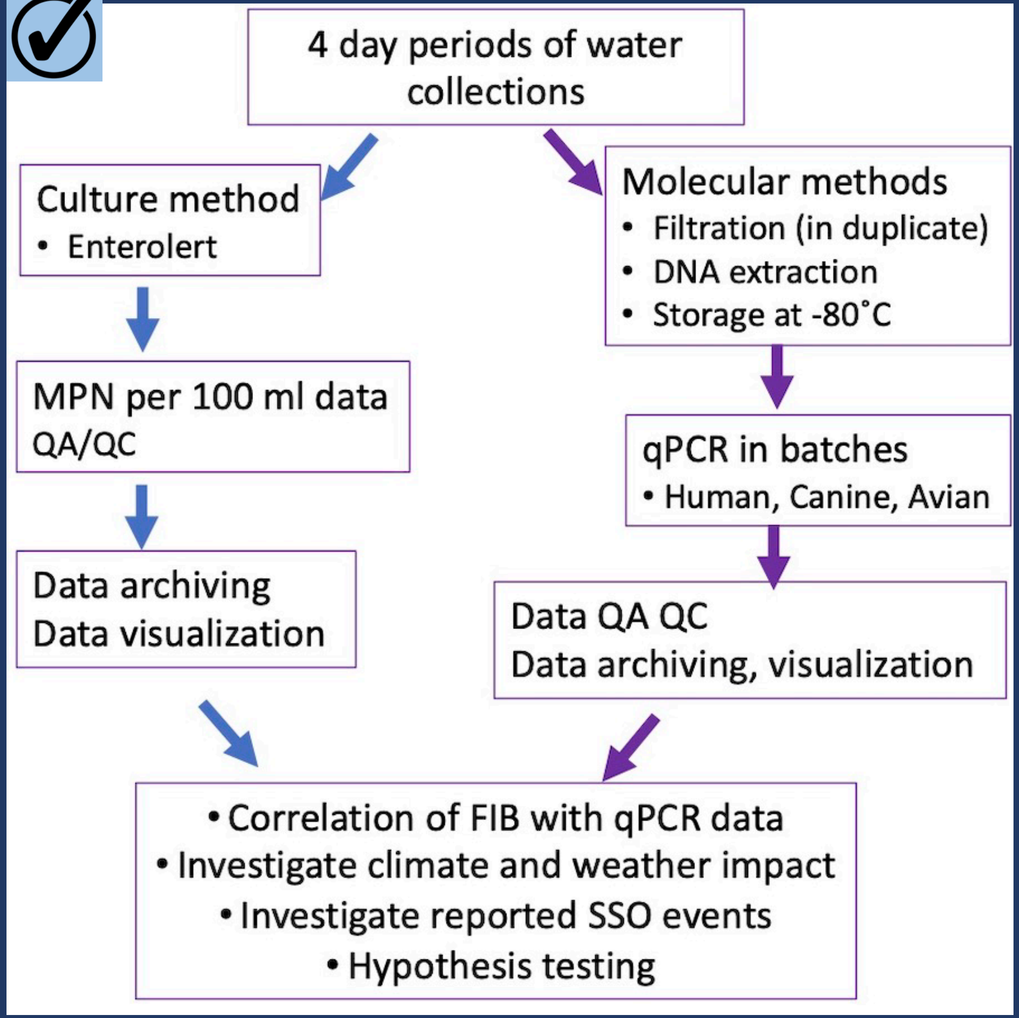
Four-day repeated samples at each location
-morning collection by 9 am

Three months in the recreational season
-July, Aug, Sept.



Map #	Station ID	Station Name	GPS Coordinates	COMAR Use (I - IV)
A1	Can-A1	Canton nontidal	39.282965, -76.579851	n.a.
A2	HC-A2	Harris Creek tidal	39.279116, -76.5804091	II
B1	JFP-B1	JF at Penn nontidal	39.3104185, -76.6197909	II
B2	JFTW-B2	JF @ Trashwheel tidal	39.28310709, -76.6035508	II
C1	UA-C1	Under Armor nontidal	39.275643, -76.590734	n.a.
C2	SC-C2	Sailing Center tidal	39.275063, -76.599843	II
D1	GF-D1	Gwynns Falls nontidal	39.2715712, -76.6487133	II
D2	MB-D2	Middle Branch tidal	39.256057, -76.621375	II

Study Design



Human, canine

QA/QC

Anticipated findings

Rivers and major outfalls will behave like point sources to the estuary

→ MPN and human MST will be higher in the river than in the receiving tidal water

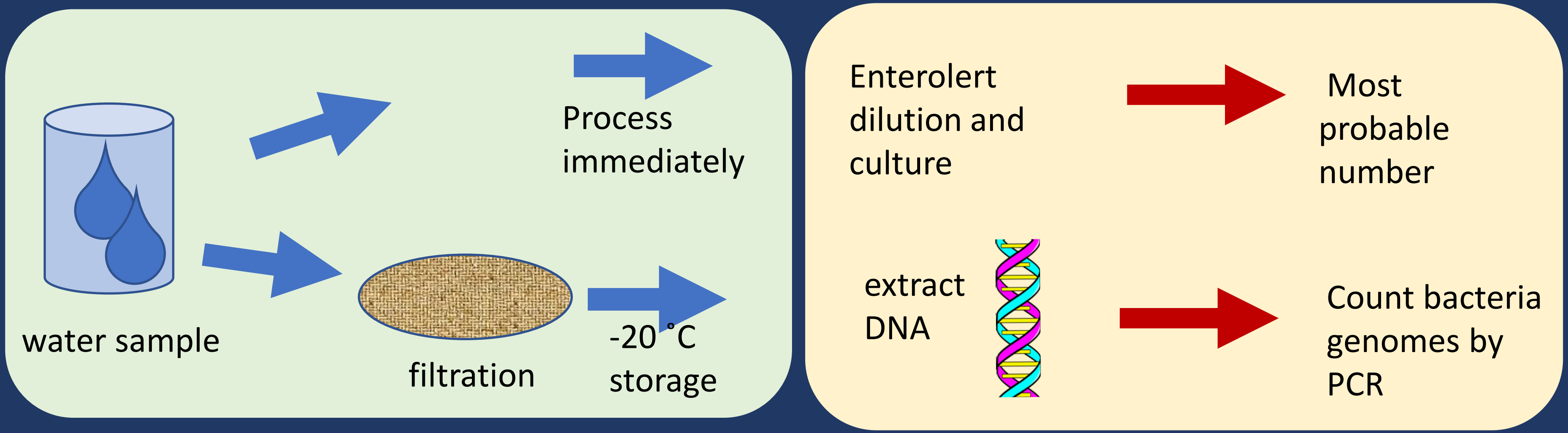
Tidal versus nontidal locations

→ Rainfall will be a driver of high MPN and MST signal

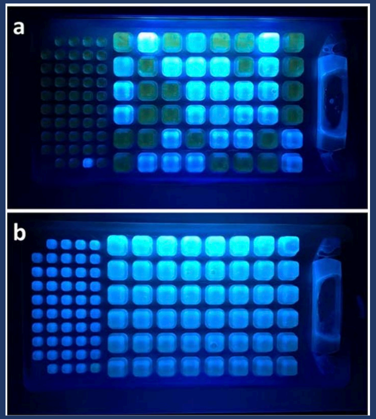
In the absence of rain, if there are non-human sources of enterococcus in the tidal water, then the upstream MST will be higher than in the tidal water, but Enterolert may be higher in the estuary.

Canine MST is hard to predict. Will not necessarily correlate with human MST or with Enterolert. Based on prior data, there may be high levels in direct harbor runoff.

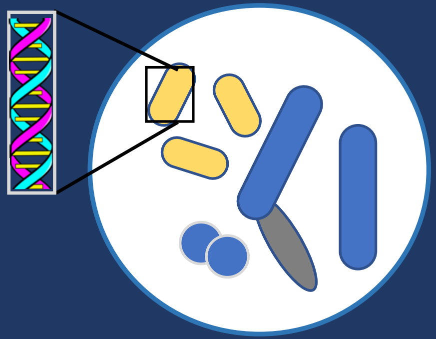
Analytical approaches



Enterolert



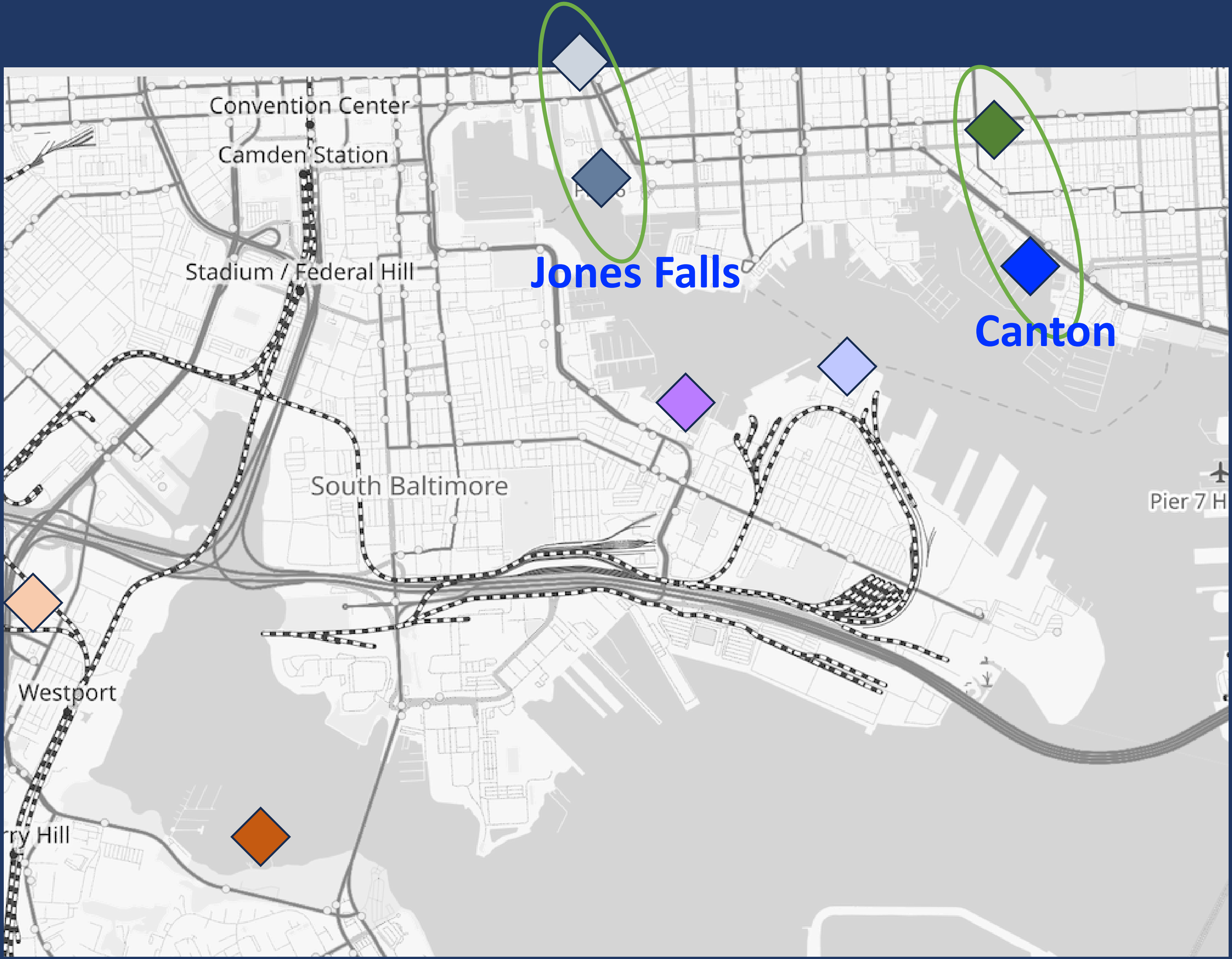
Human and Canine PCR



Visualization and inspection of results

- Compare paired locations: Tidal / Nontidal
- Compare qualitative trends of Enterolert vs qPCR
- Human and canine
- Rainfall effects

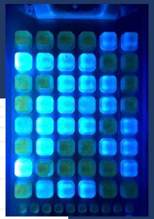
Jones Falls and Canton

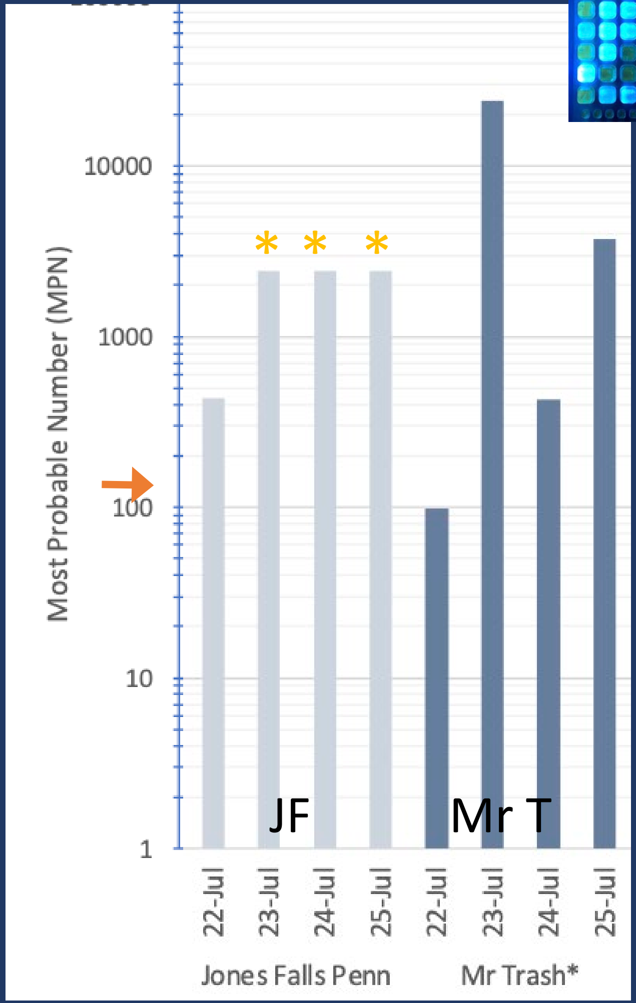


Jones Falls / Mr. Trash Wheel

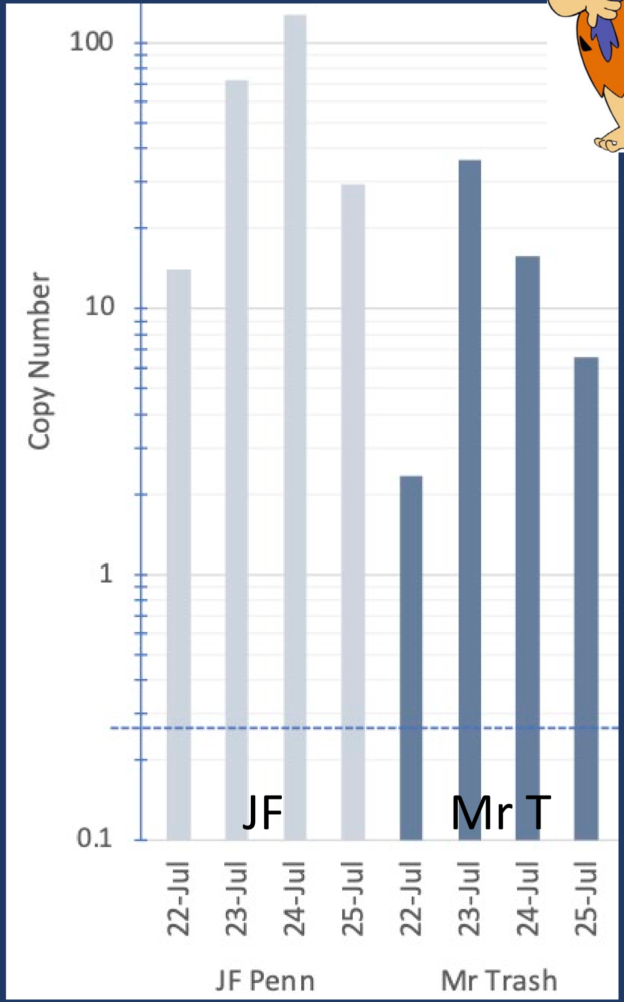
July

Enterolert

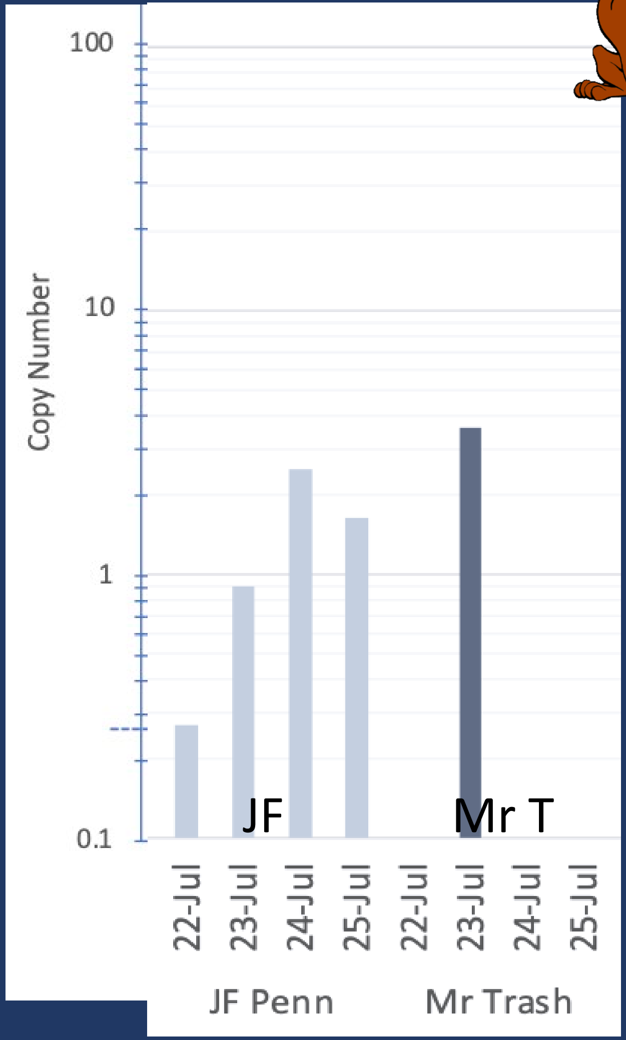




Human MST



Canine MST



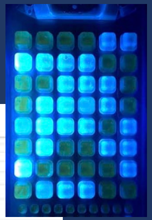
* Upper limit of Enterolert assay

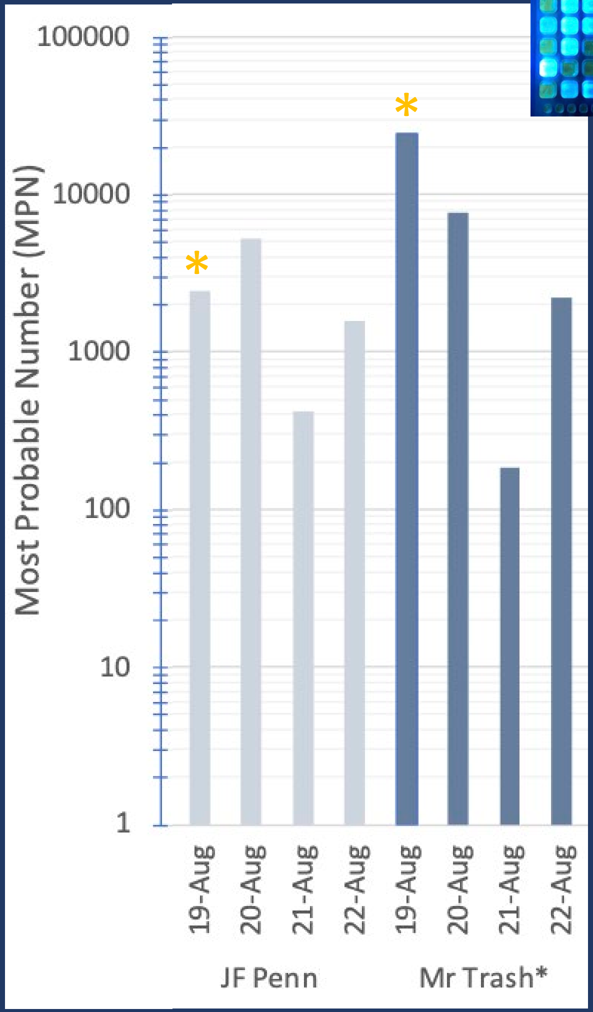
0.3 " rain 2 pm on July 22, trace at 11 pm July 23

Jones Falls / Mr. Trash Wheel

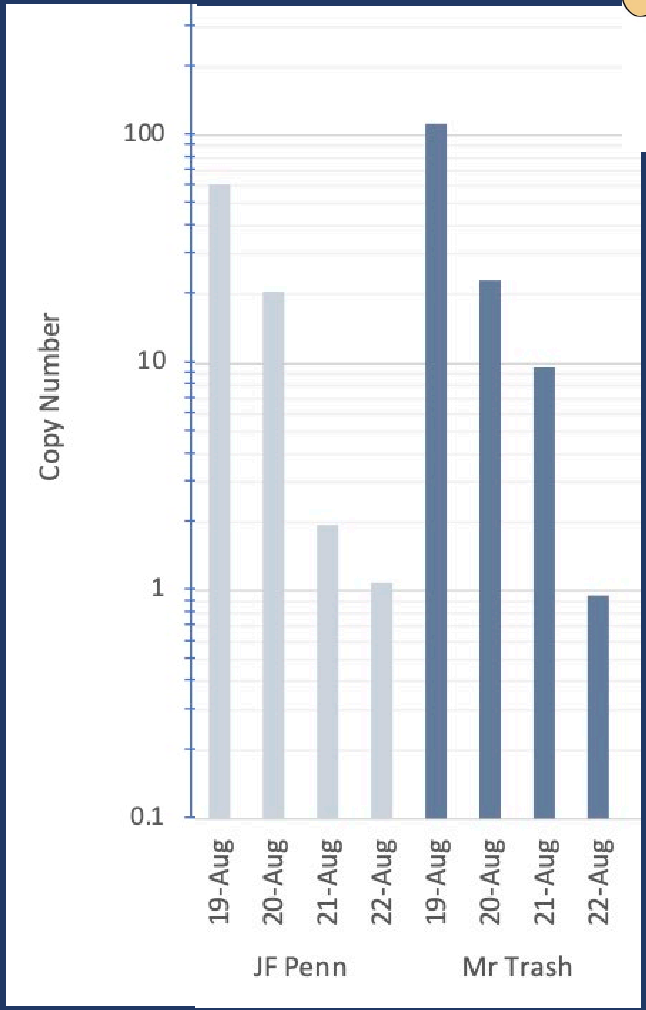
August

Enterolert

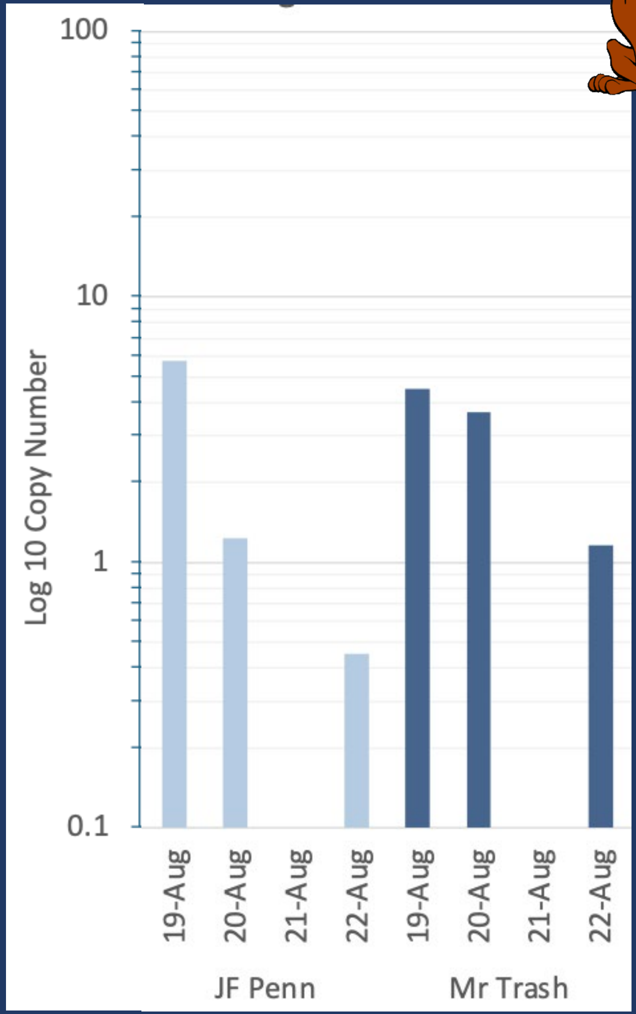




Human MST



Canine MST

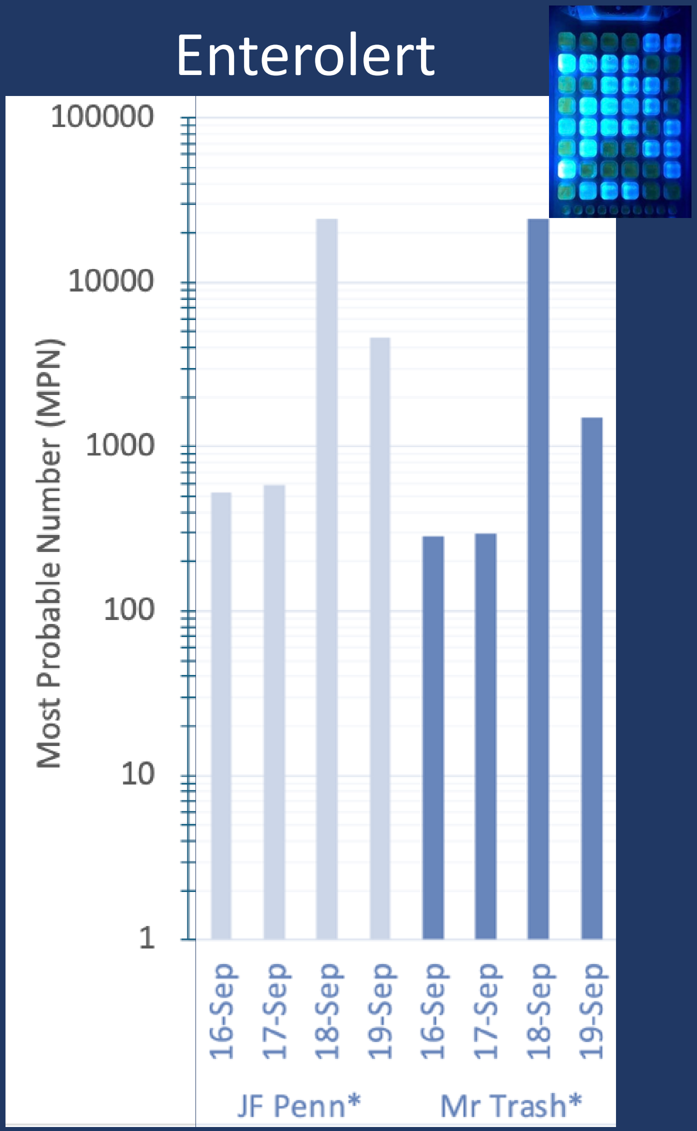


* Upper limit of enterolert assay

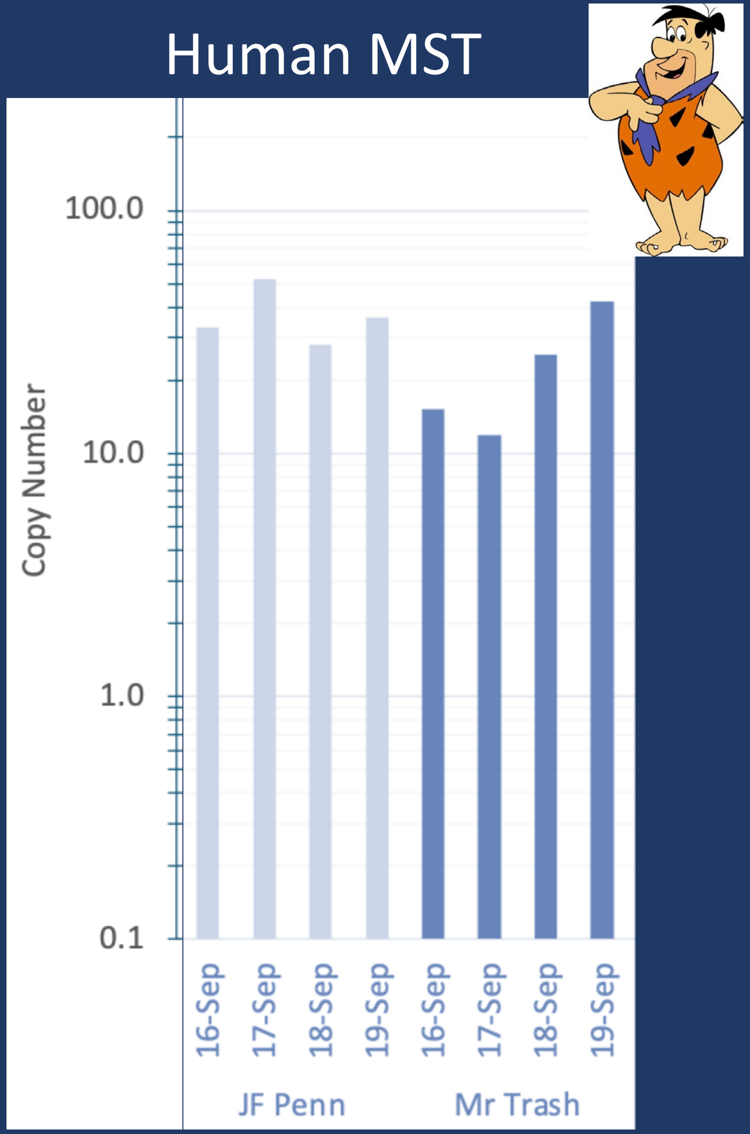
1.0 - 2.7 inches late on Aug. 18.

Jones Falls / Mr. Trash Wheel
September

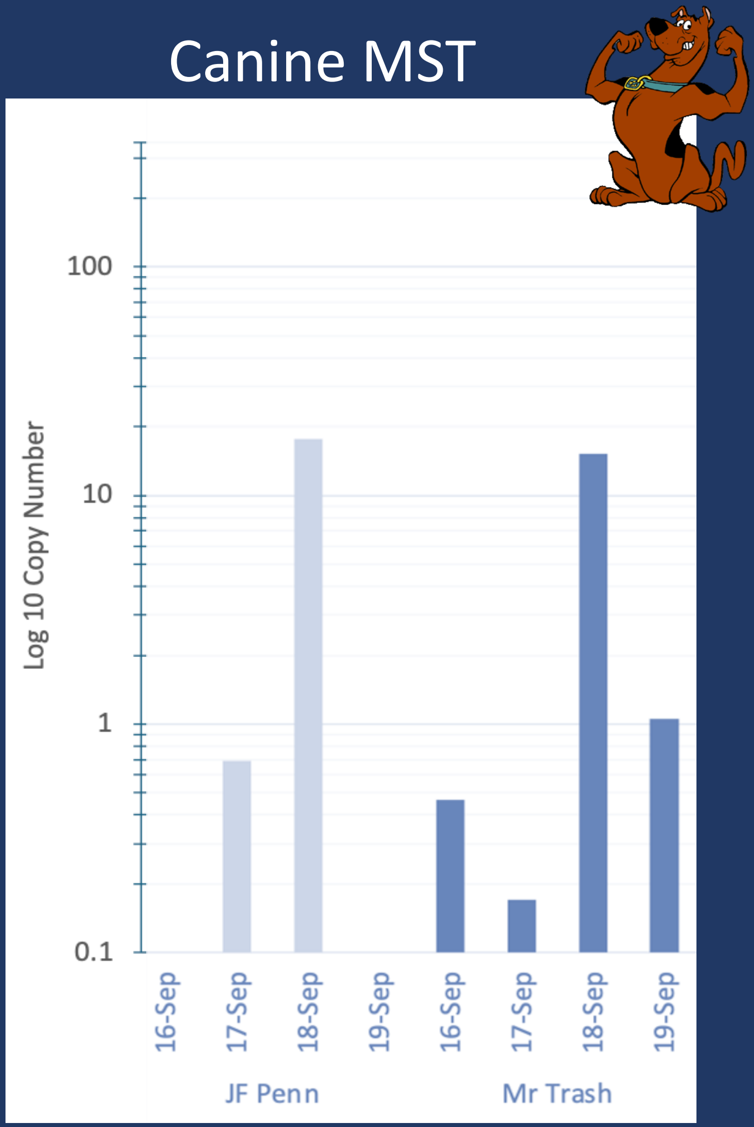
Enterolert



Human MST



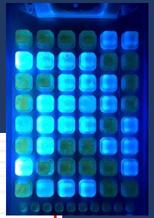
Canine MST

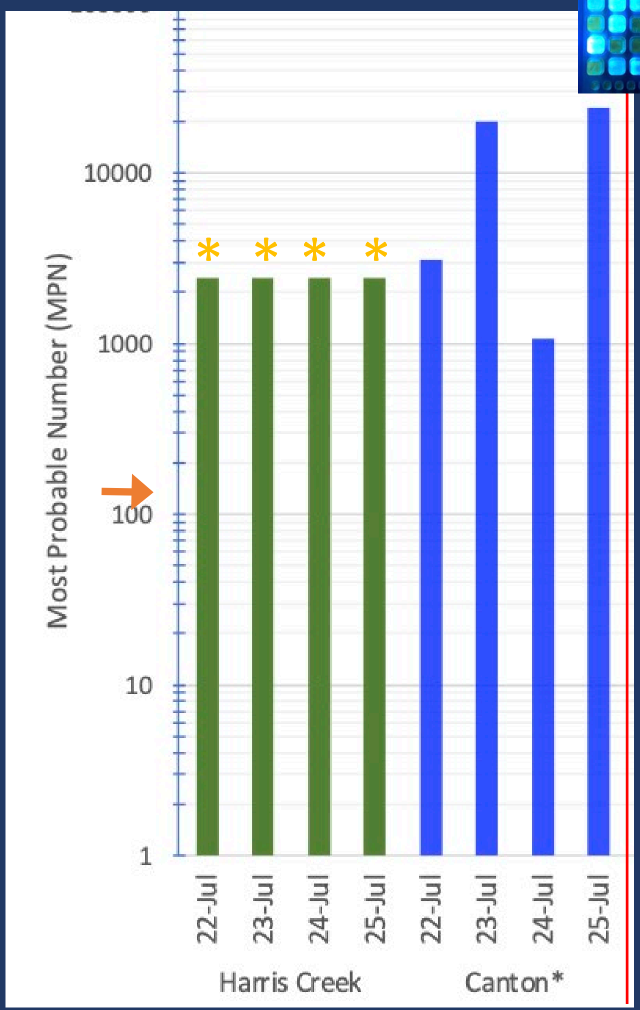


0.5" rain 4 am - 8 am Sept 18

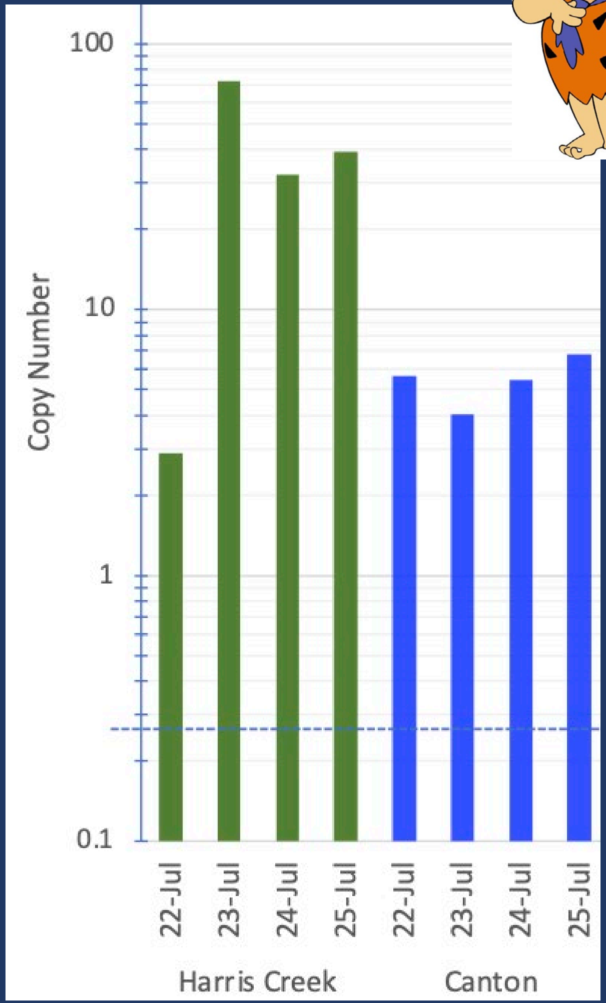
Harris Creek / Canton
July

Enterolert

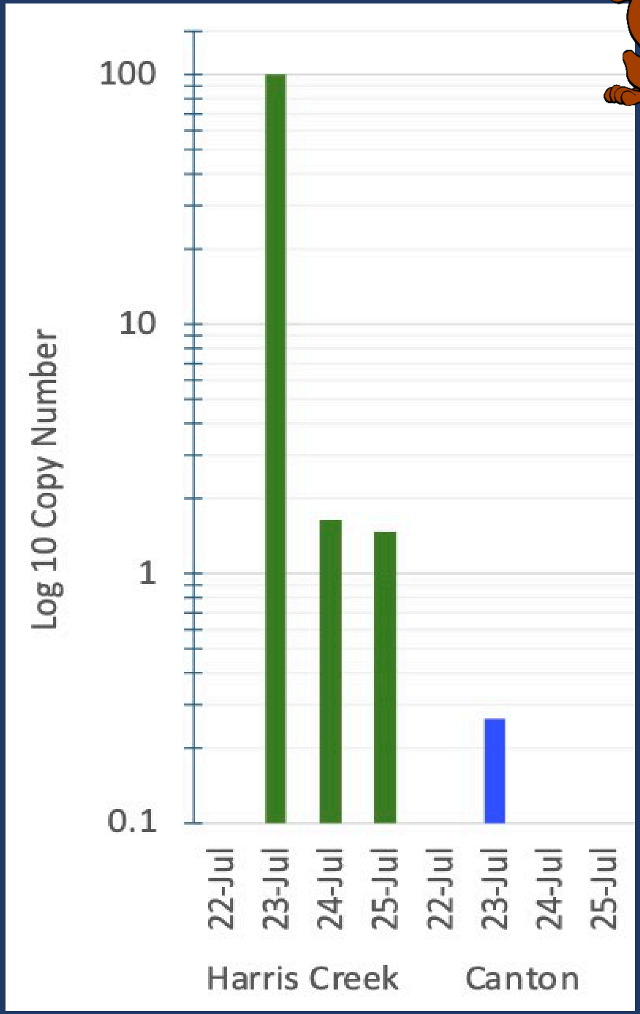




Human MST



Canine MST

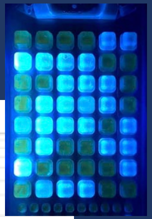


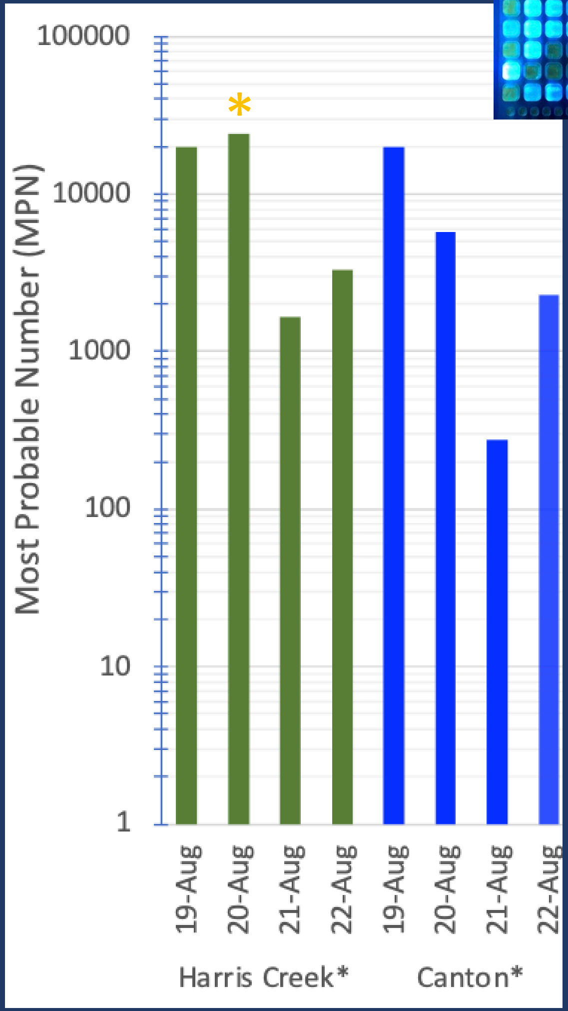
* Upper limit of Enterolert assay

0.4 “ rain late on July 22

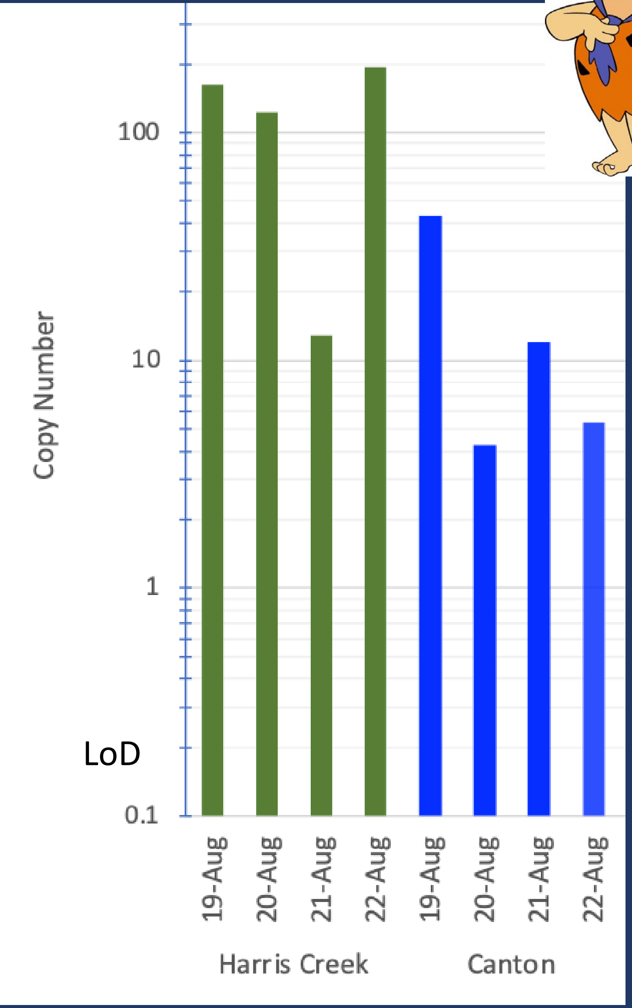
Harris Creek / Canton
August

Enterolert

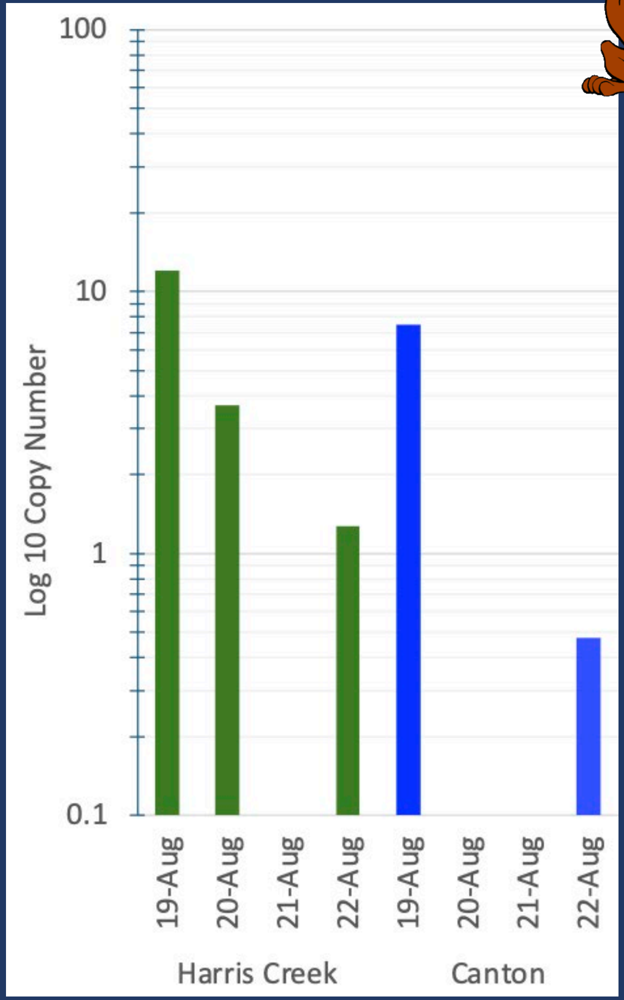




Human MST



Canine MST

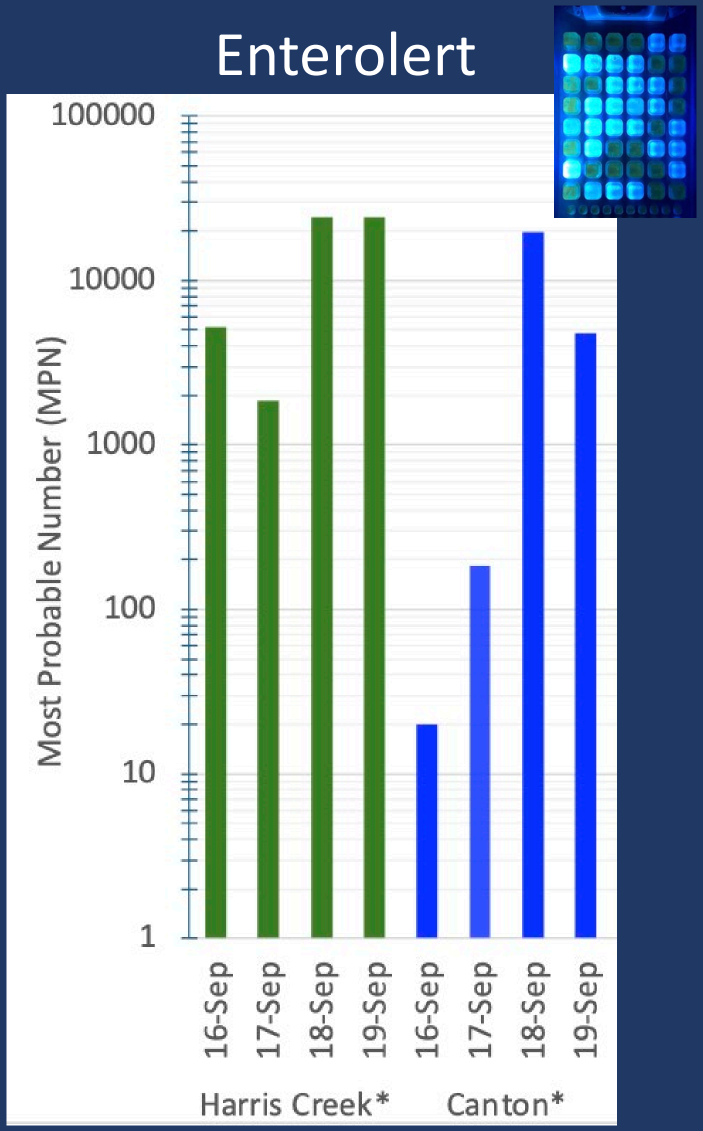


* Upper limit of enterolert assay

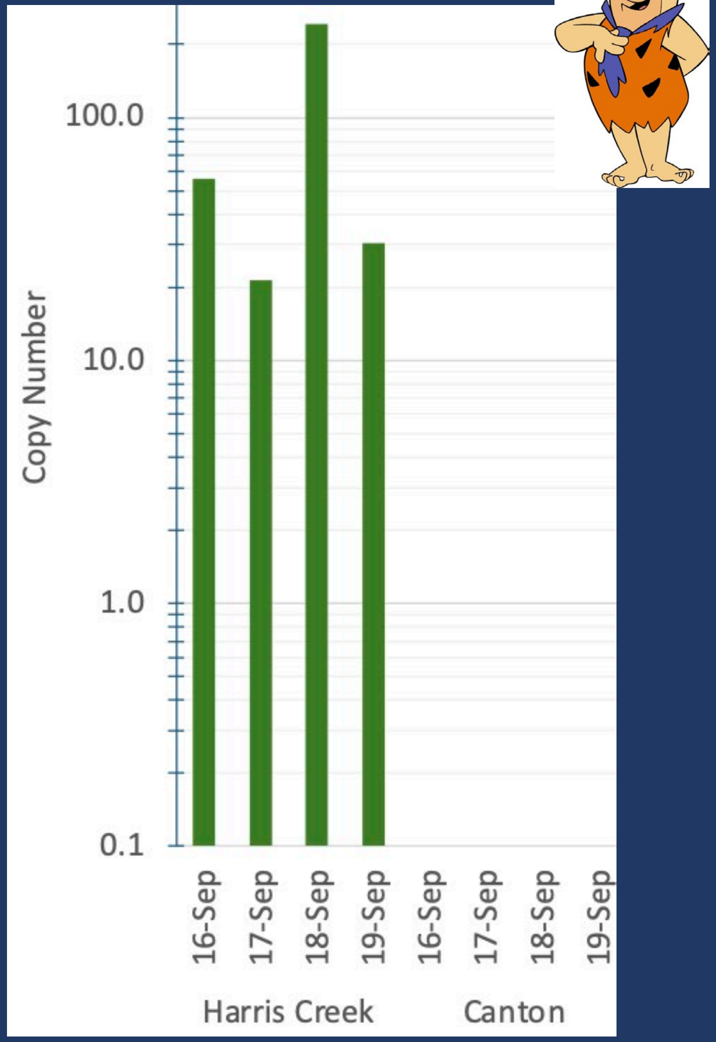
Rain late on Aug. 18.

Harris Creek / Canton
September

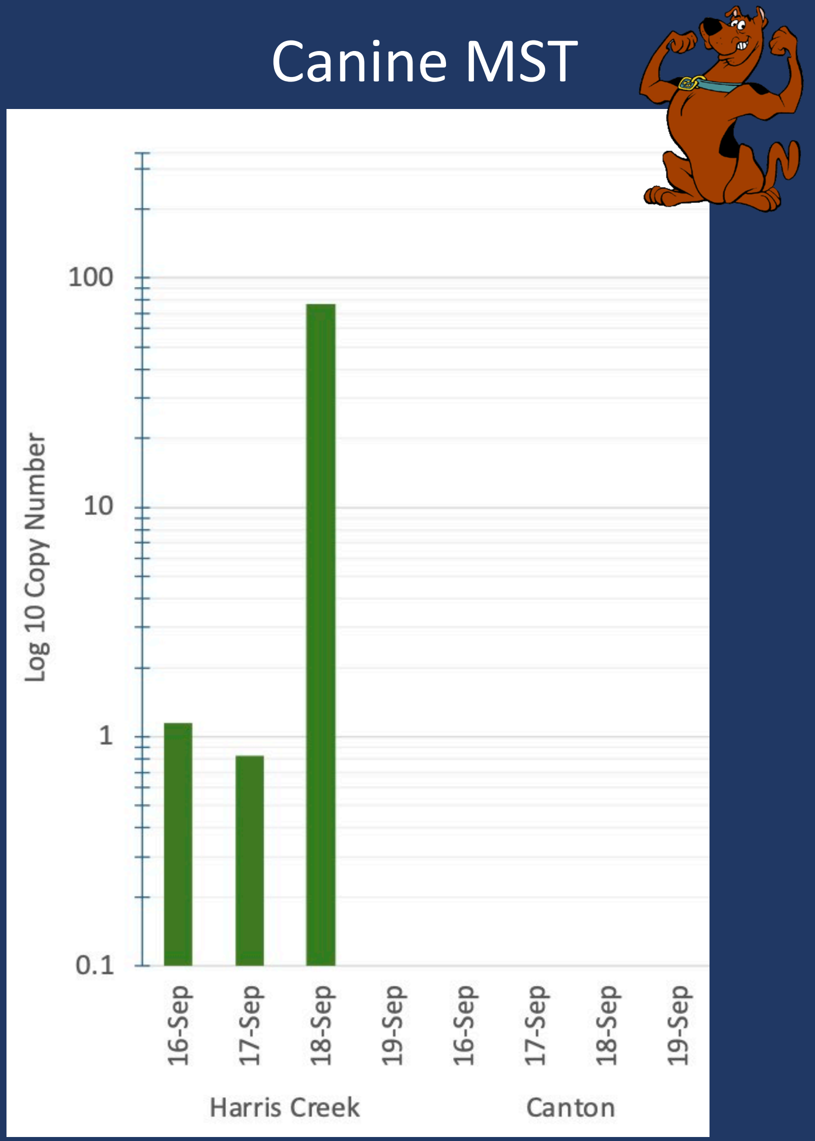
Enterolert



Human MST

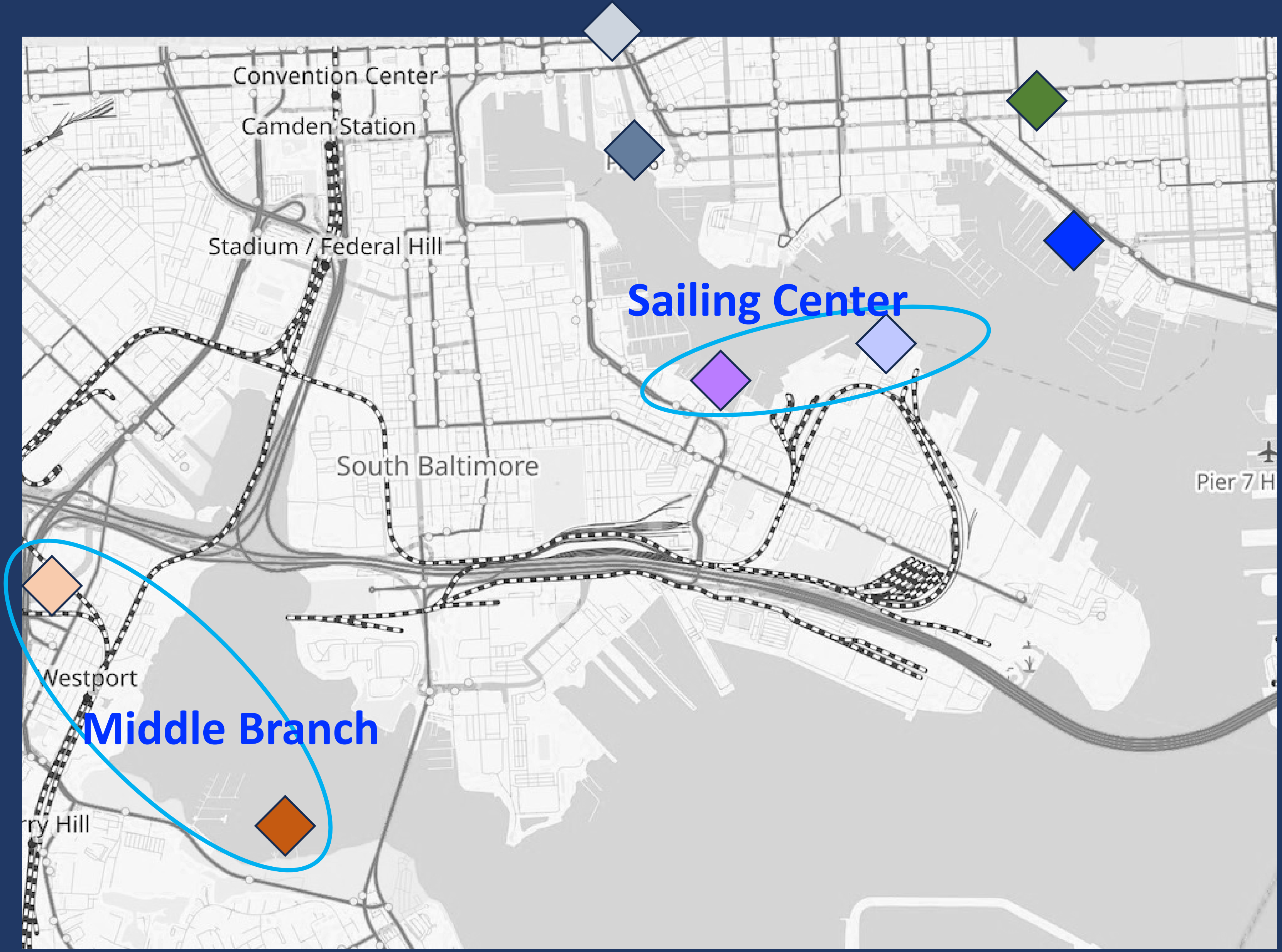


Canine MST

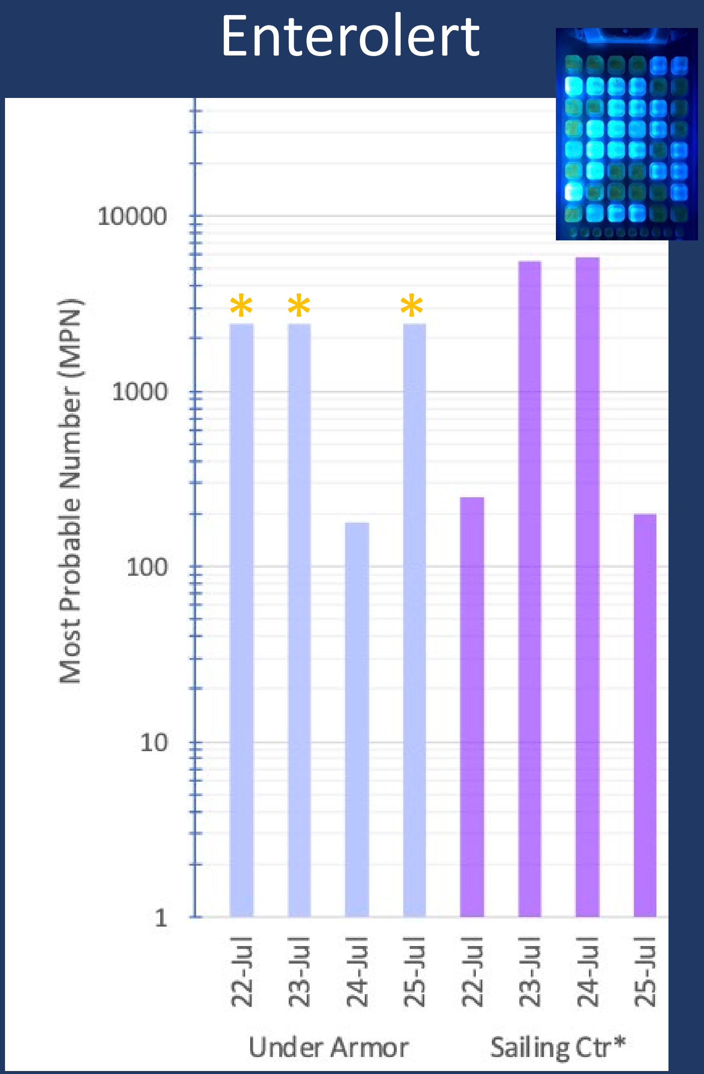


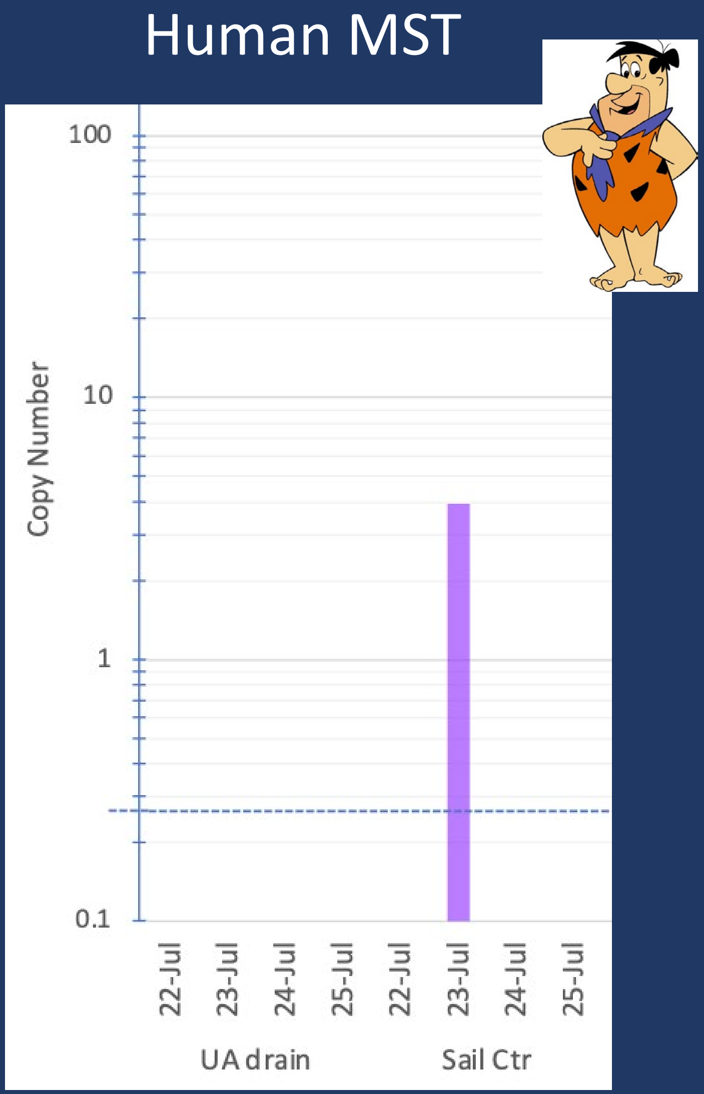
0.5“ rain 4 am - 8 am Sept 18

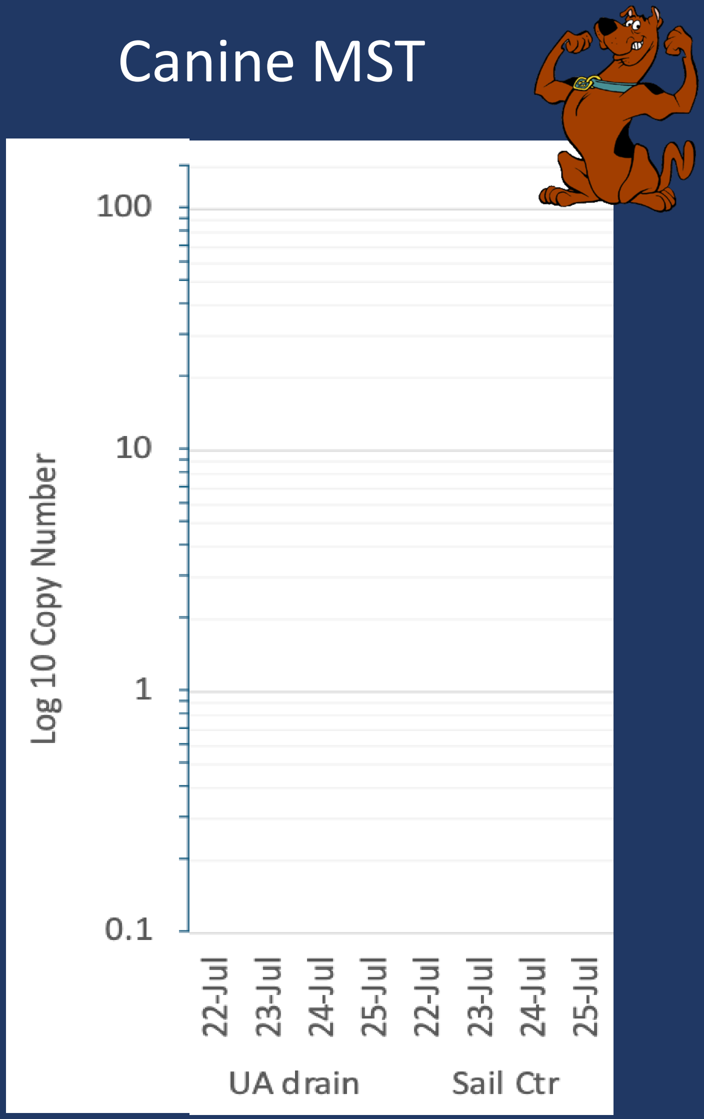
South shore of Inner Harbor and the Middle Branch



UA Drain / Sailing Center
July



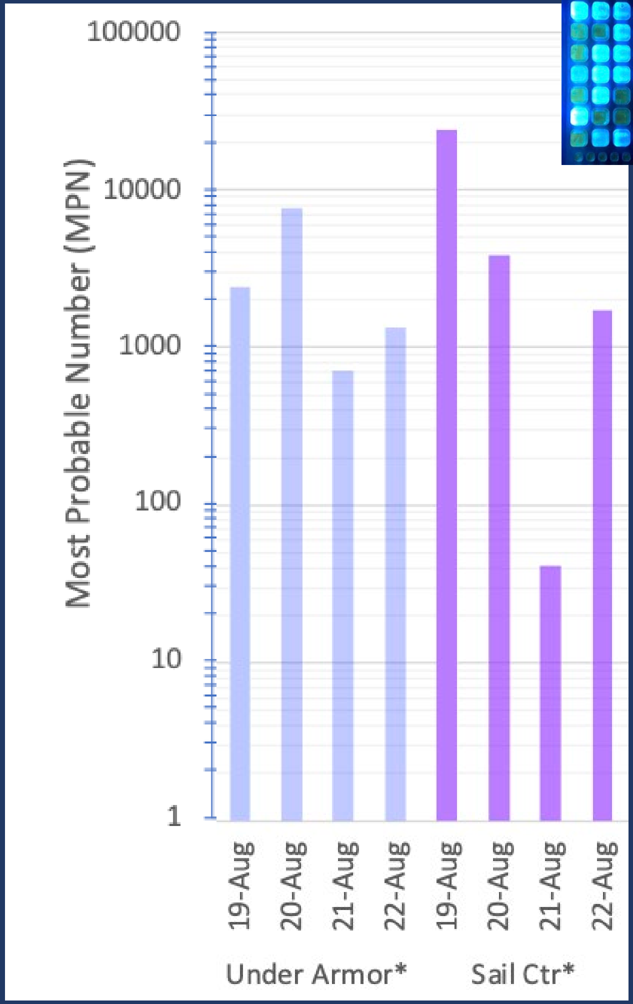


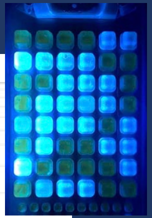


0.4 “ rain late on July 22

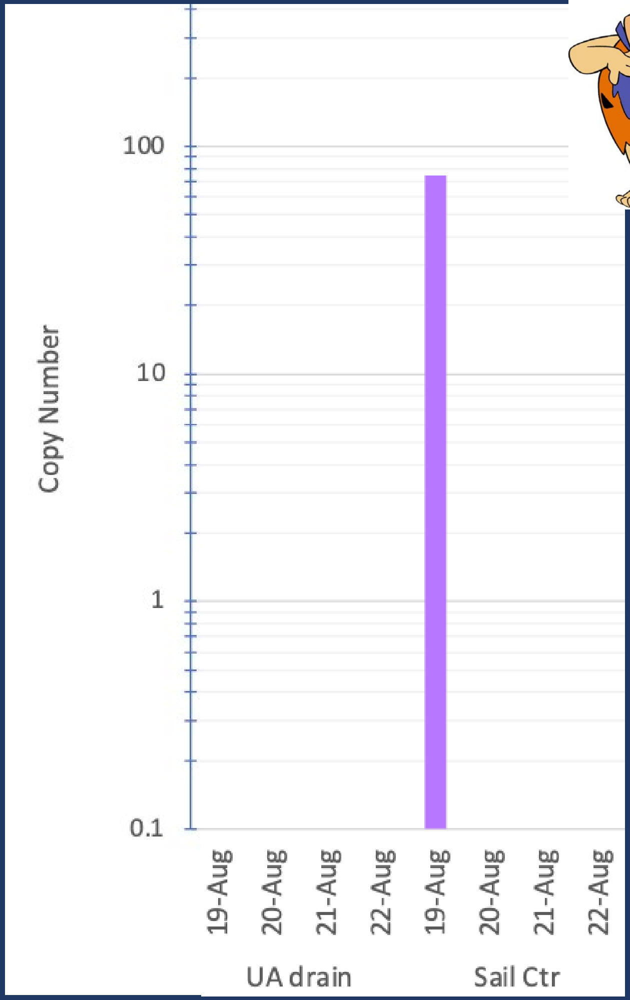
UA Drain / Sailing Center
August

Enterolert

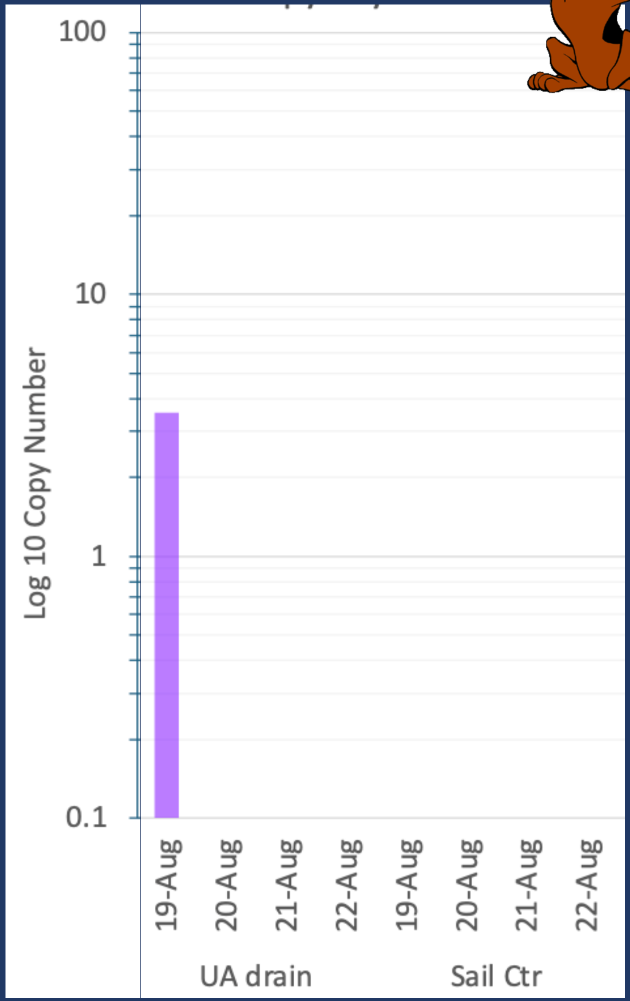




Human MST



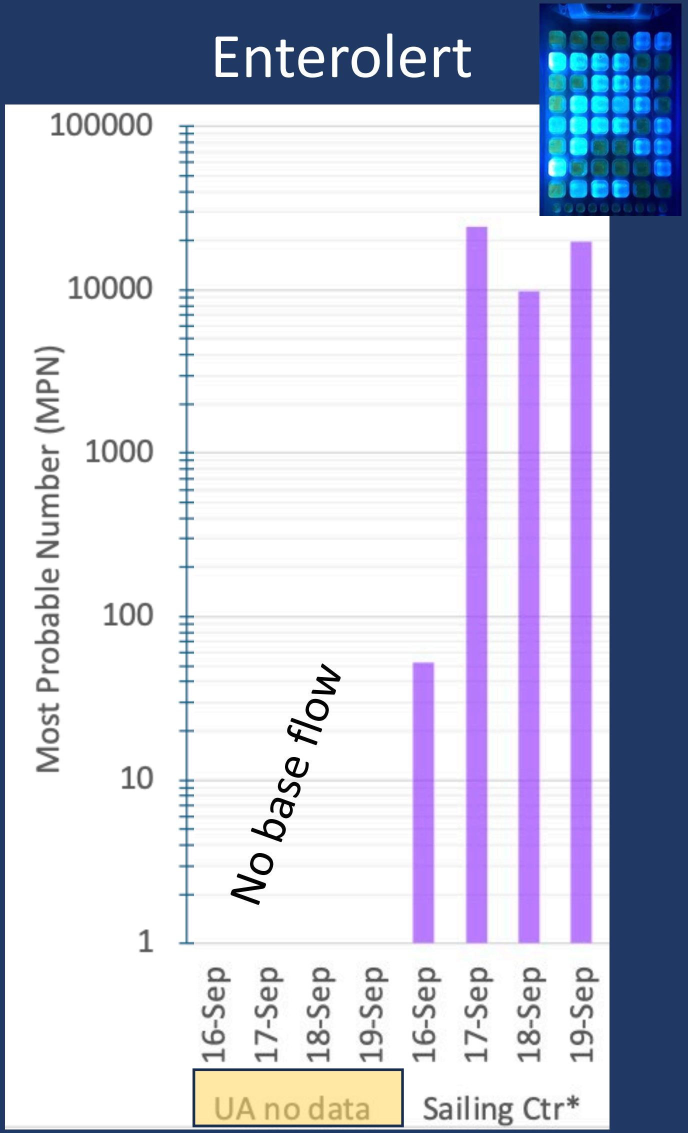
Canine MST



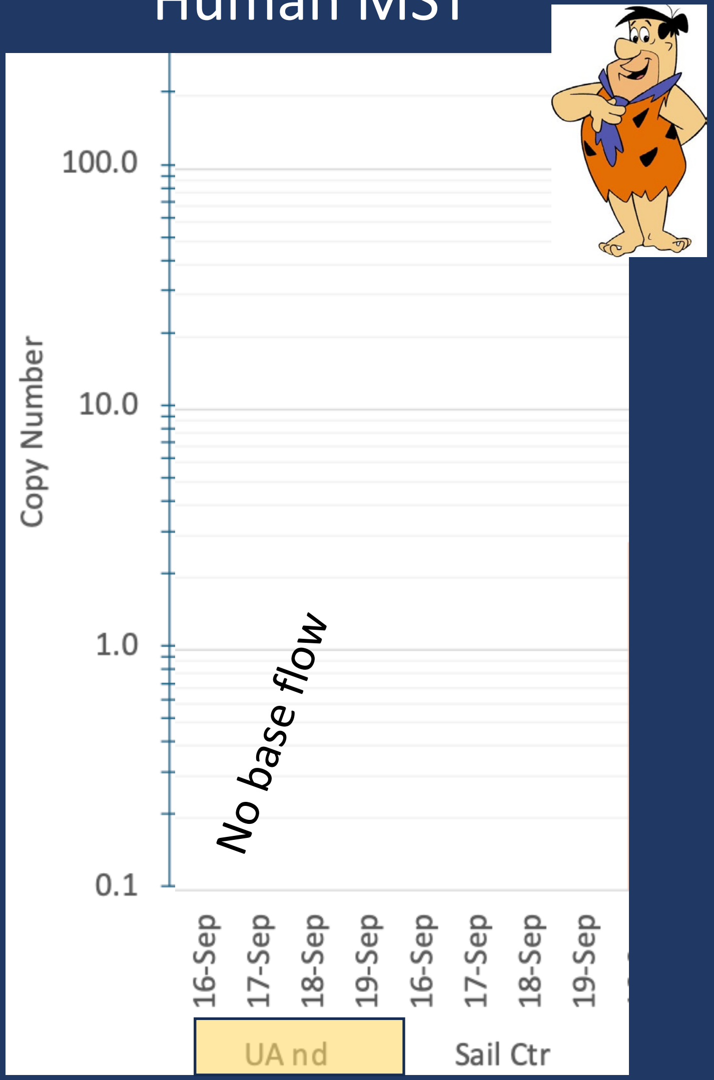
Rain late on Aug. 18

UA Drain / Sailing Center
September

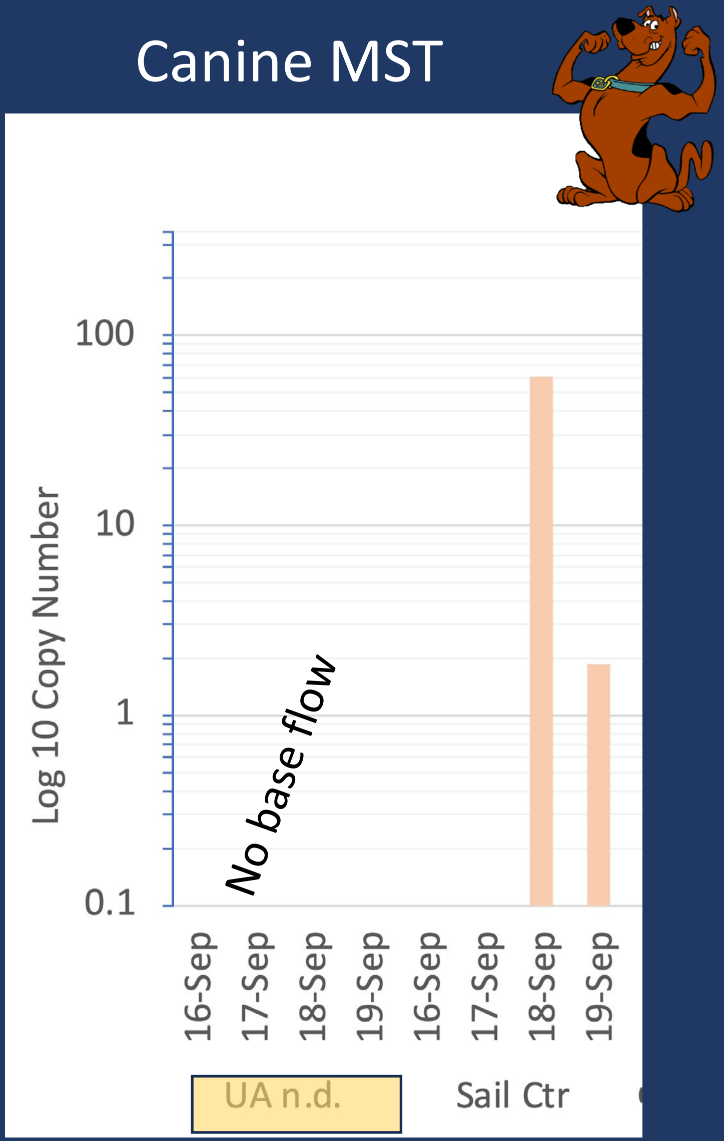
Enterolert



Human MST



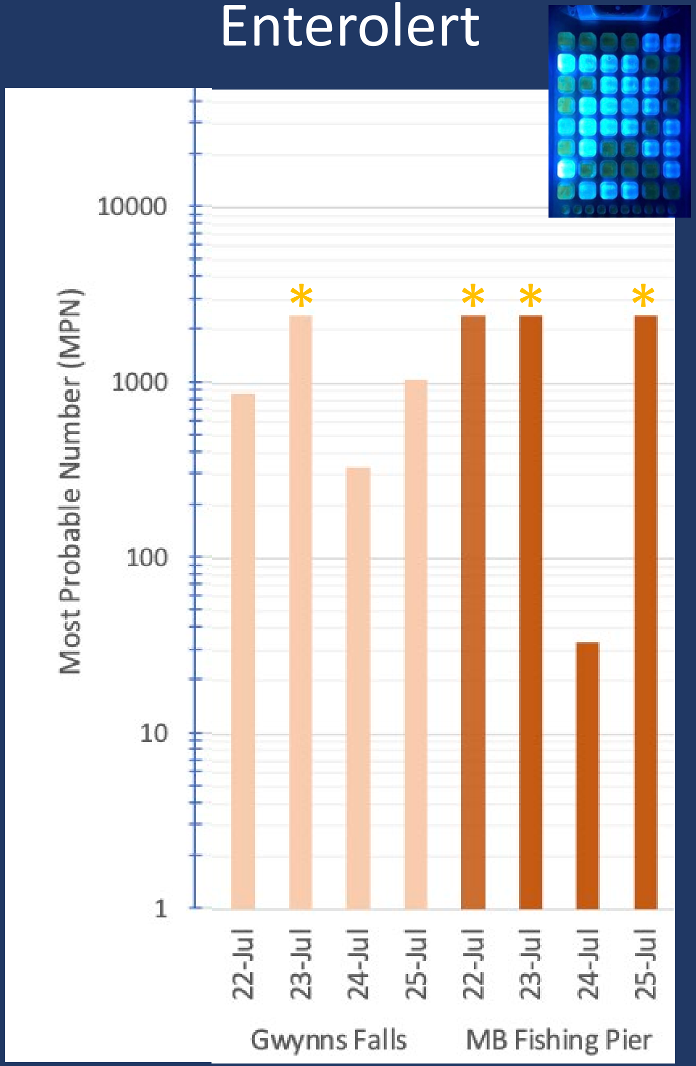
Canine MST



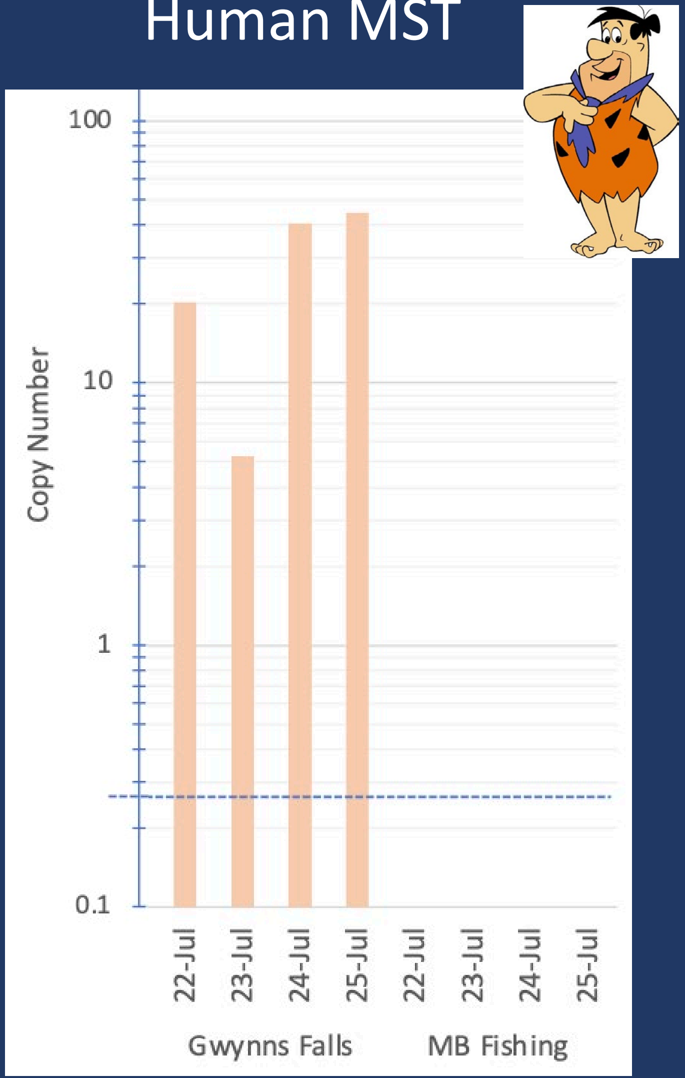
0.5“ rain 4 am - 8 am Sept 18

Gwynns / Fishing Pier
July

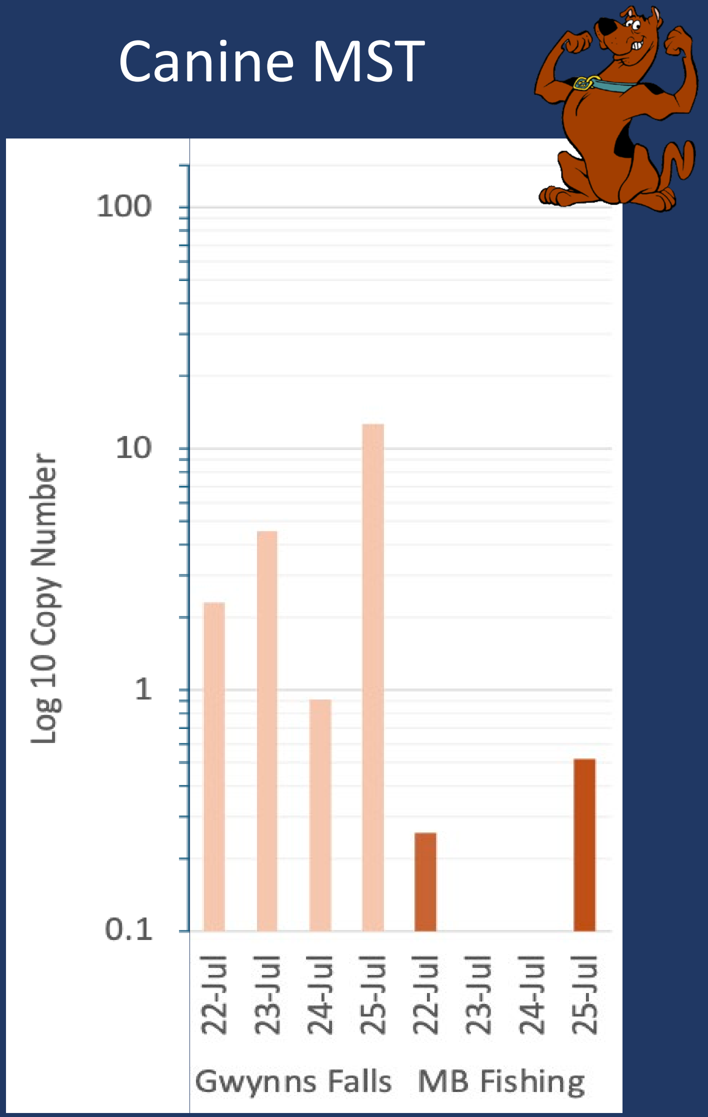
Enterolert



Human MST



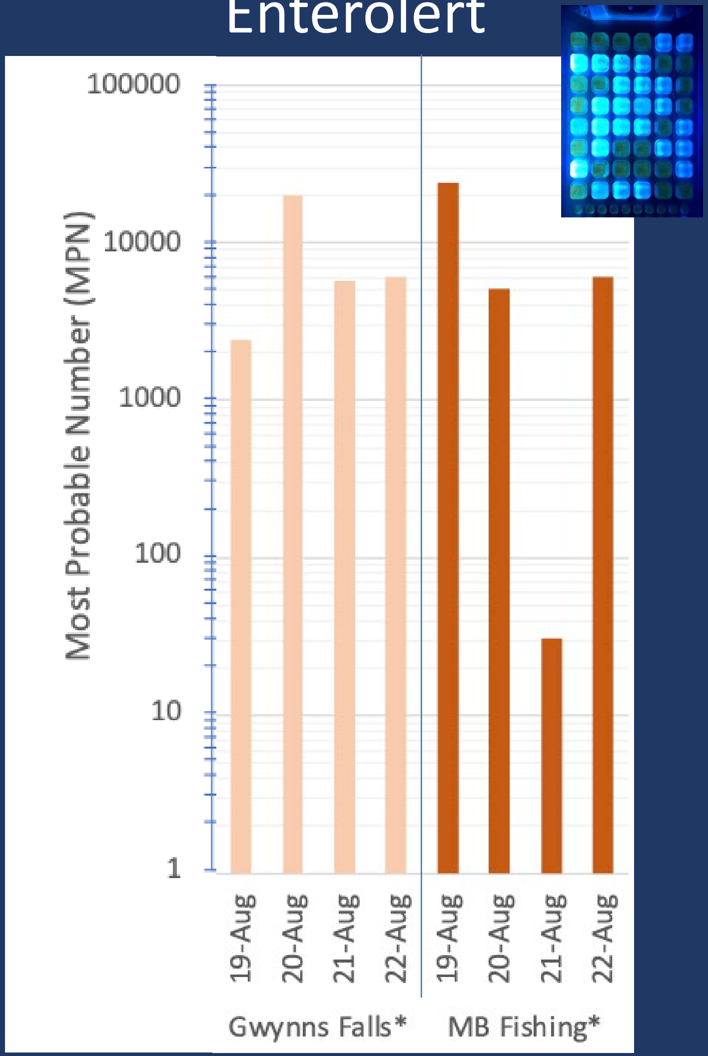
Canine MST



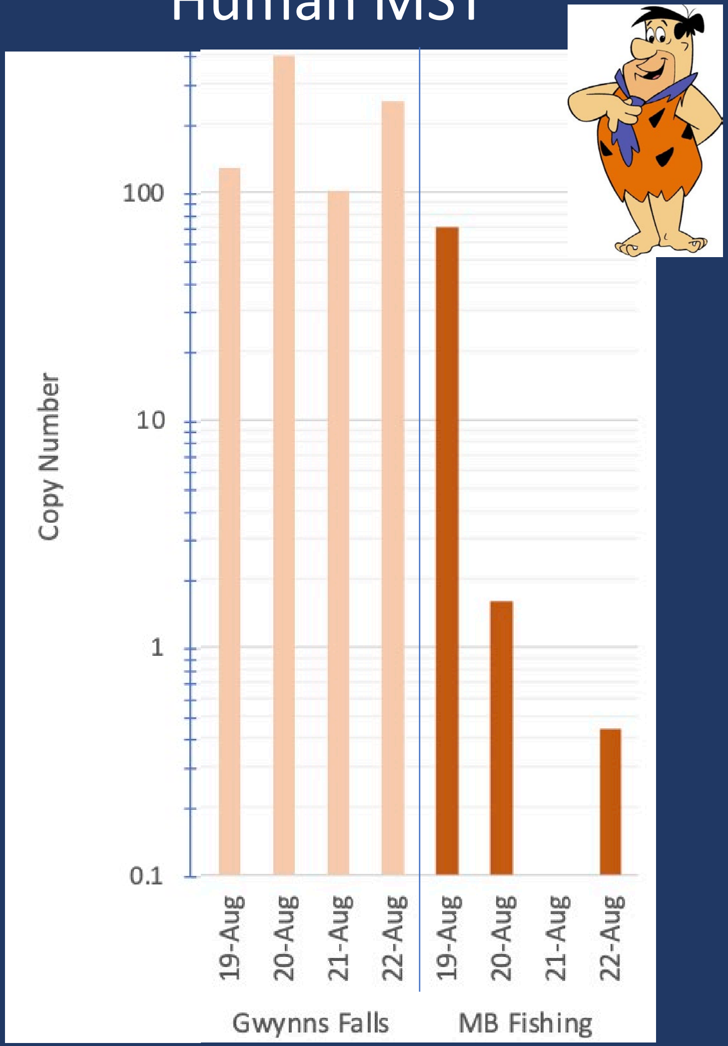
0.4 “ rain late on July 22

Gwynns / Fishing Pier
August

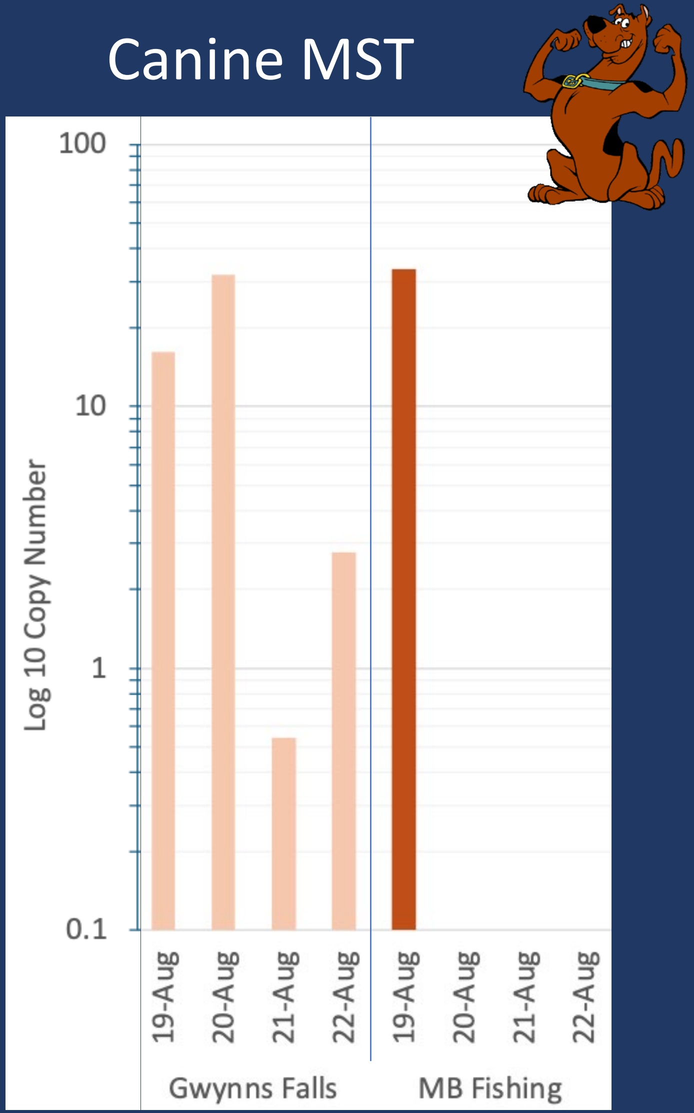
Enterolert



Human MST



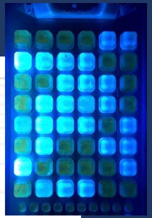
Canine MST

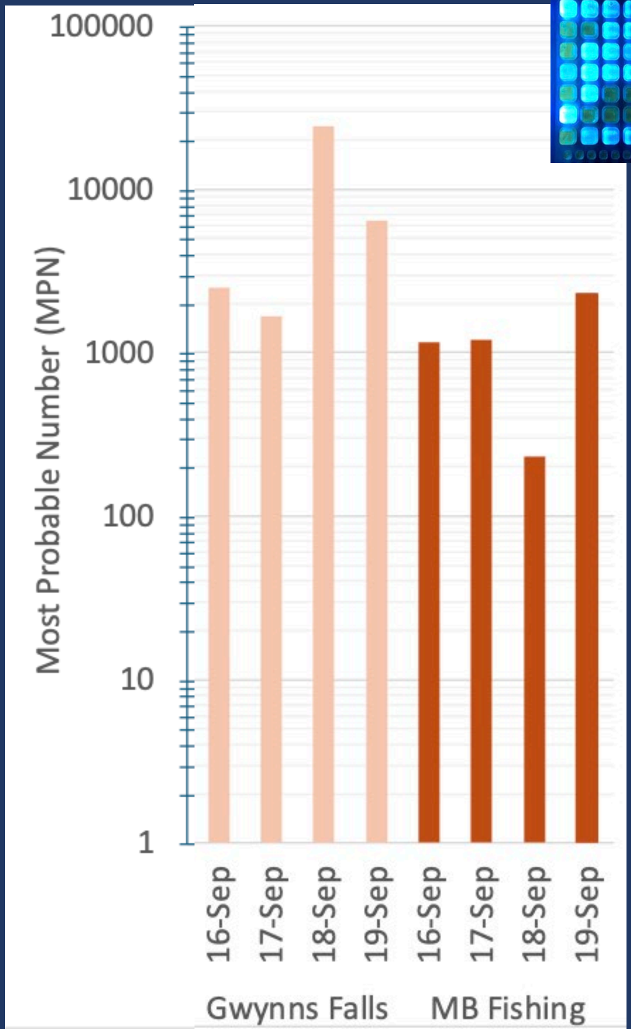


Rain late on Aug. 18

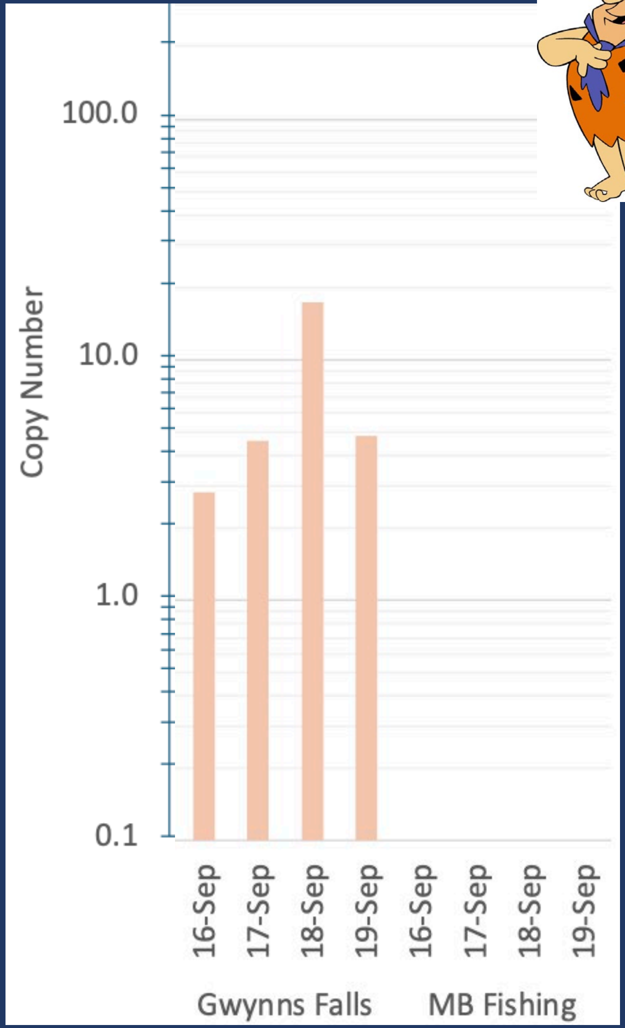
Gwynns / Fishing Pier
September

Enterolert

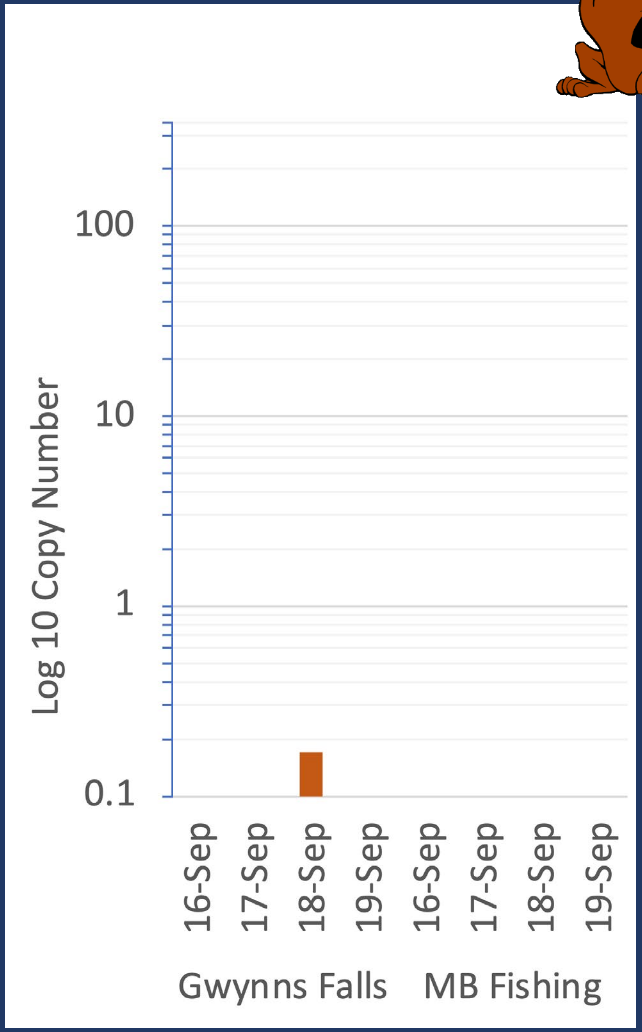




Human MST



Canine MST



0.5“ rain 4 am - 8 am Sept 18

Back to the hypotheses

- **H1**) Combining MST and FIB methods will allow a qualitative assignment of the relative proportion of human versus non-human FIB in a given water sample.

  Human MST marker did not always track with Enterolert

- **H2**) Daily testing, using both FIB culture and PCR methods to detect human vs non-human fecal bacteria, will show that high FIB counts do not always correspond to high human MST (Bacteroides) signals.

  This is true especially at the Sailing Center and Middle Branch

- **H3**) Daily testing of water quality will provide knowledge about the duration and drivers of sewage-derived bacteria and other FIB in tidal water that could not be achieved with weekly testing.

  The decay rate of MPN and MST signals can be seen to differ in August at the Sailing Center and Middle Branch

NEXT

Further study of archived samples

DNA-based methods allow archiving of water, filters or DNA

Re-investigation with the same targets

Re-investigation for new targets
- Total enterococcus
- Birds, other hosts
- Rats?

PCR methods have a wide range of assay quantification. 1 copy to 1 million.

Build local capacity

Engaged working group
- Non-profits
- Academia
- Municipal

Private lab

Technician training

Shared/pooled resources

Collections
Contract lab
Training and expertise

IMET
Institute of Marine & Environmental Technology

Thanks to many

CBTRUST
Chesapeake Bay Trust

Institute of Marine and Environmental Technology

Mariah Mckenzie
Interns

BALTIMORE CITY
DPW
DEPARTMENT OF PUBLIC WORKS

Van Sturdevant, Joan White, Kim Grove

ZQ

Brent Whitaker
Morgan Shapiro

BLUE WATER BALTIMORE

Alice Volpitta, Sarah Holter, others

WATERFRONT PARTNERSHIP OF BALTIMORE

Allison Blood
Adam Lindquist

Translation: Use of Molecular Sewage Indicators

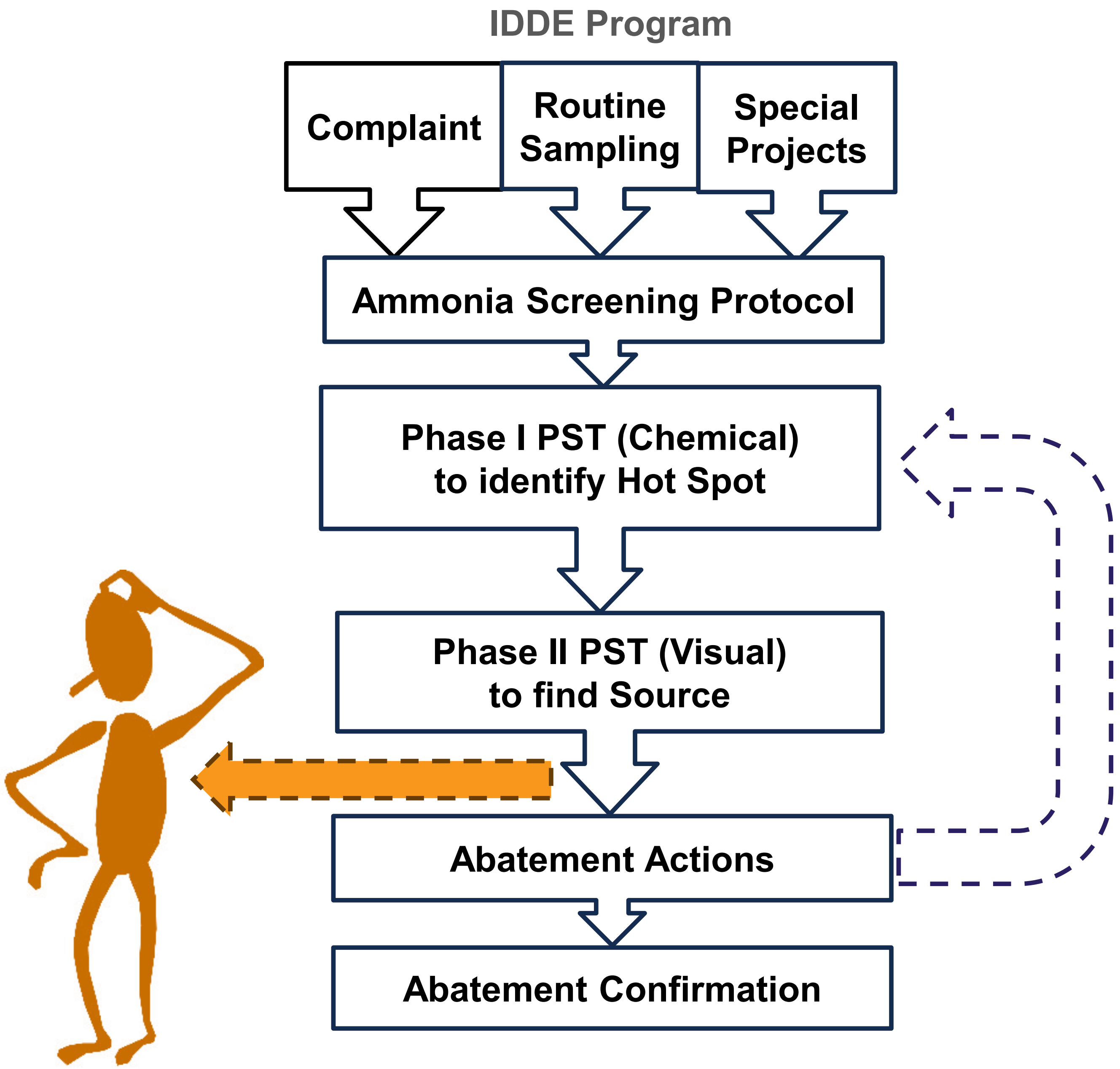
Chesapeake Bay Trust
Pooled Monitoring Program
2025 Annual Meeting

BALTIMORE CITY DEPARTMENT OF PUBLIC WORKS

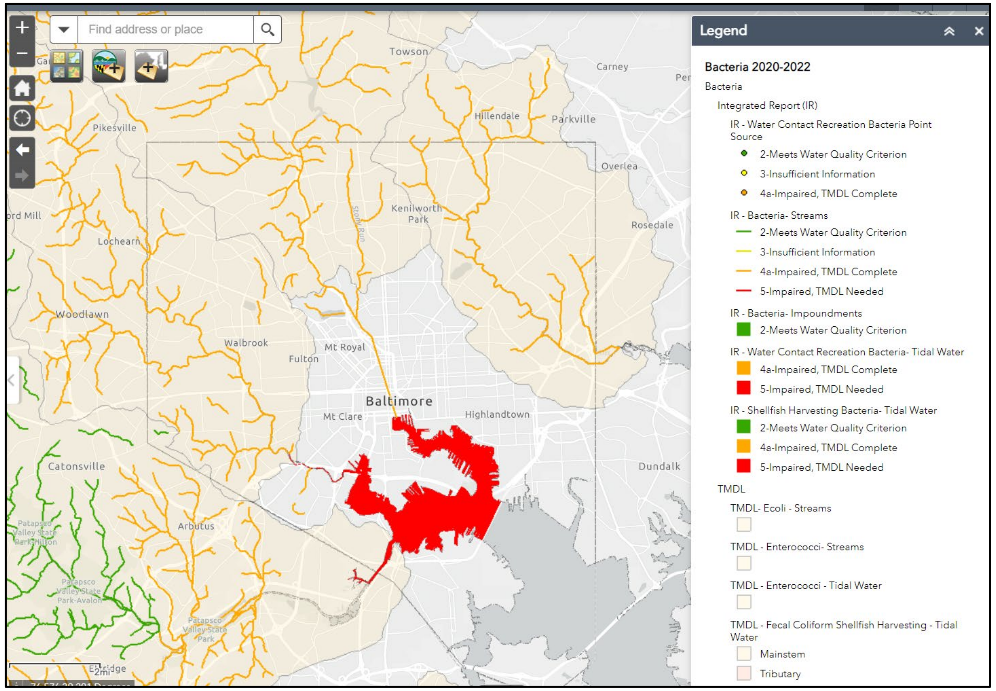
\
June 18, 2025

MST: Past Use

- Used when other investigation techniques have been exhausted.
- Human markers < 1%, discontinue investigation.
- FY 17 to 19: 14 of 20 PST investigations allowed to be discontinued.



Ultimate Goal: Swimmable Waters

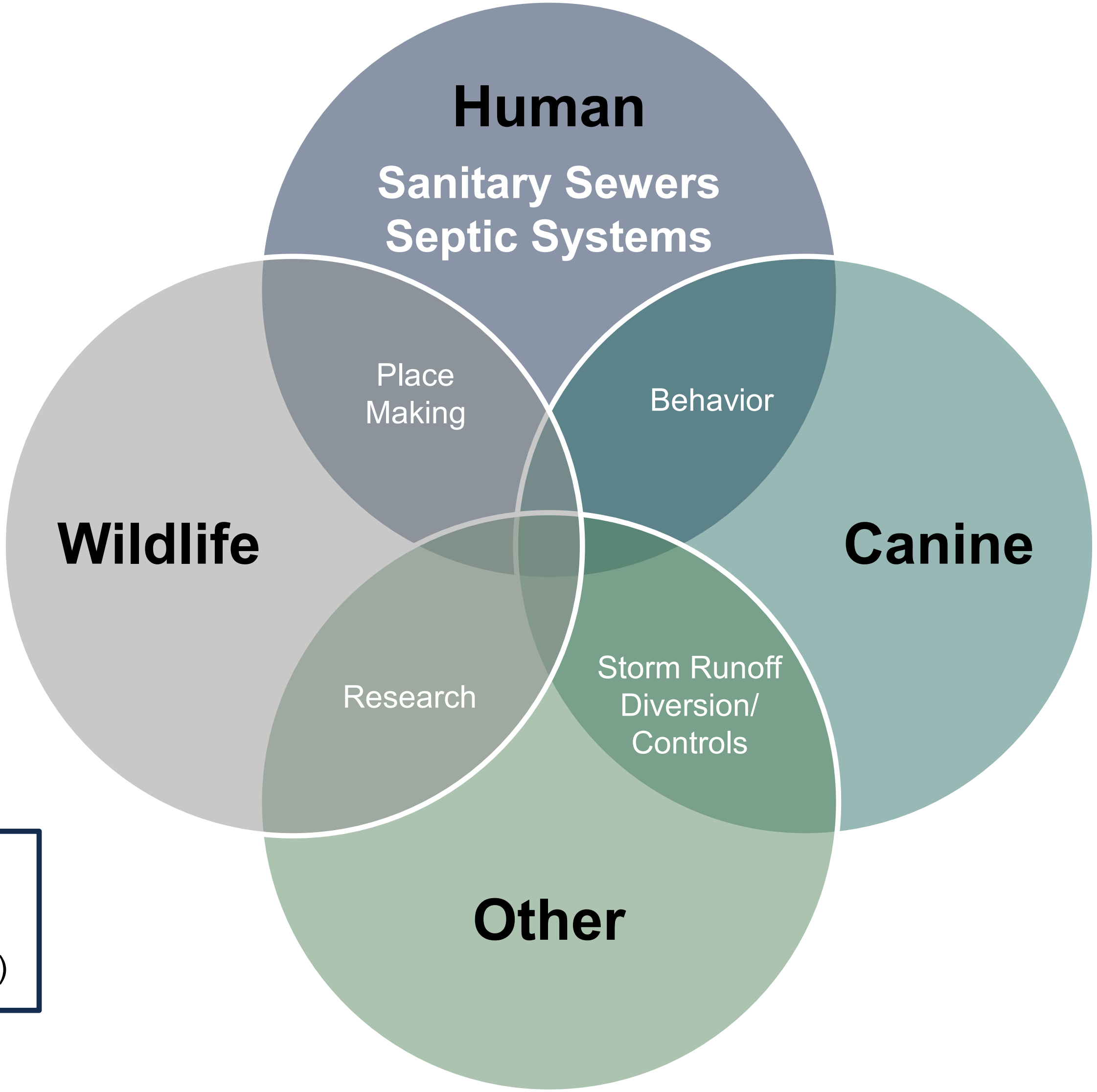


Source: Water Quality Assessments (IR) and TMDLs (state.md.us)

Enterococcus Criteria

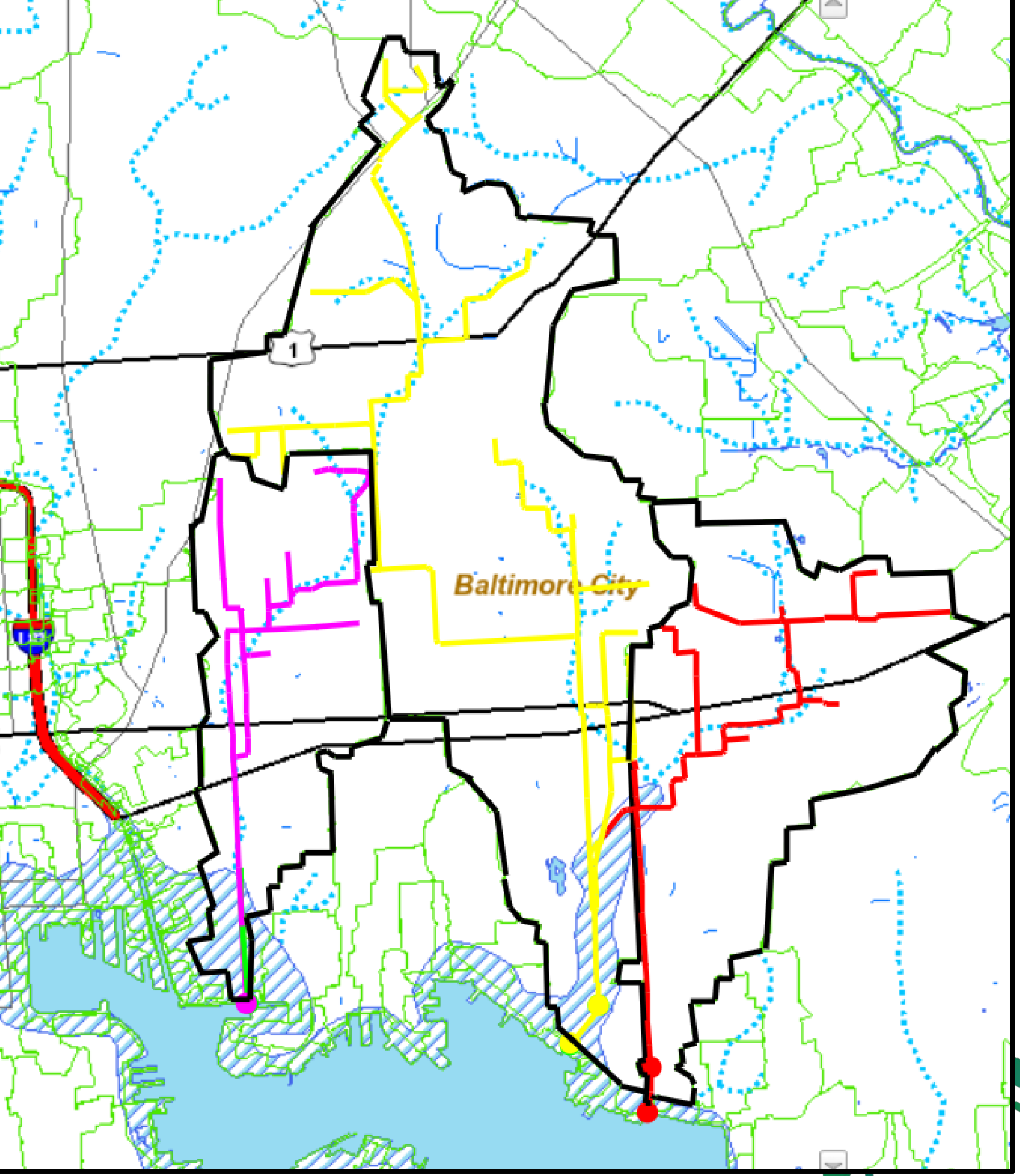
Geometric mean (GM) for 90+ days < **35** MPN / 100 ml

Less than 10% of single sample results > **130** MPN / 100 ml (STV)



Observations from this research

- Swimmable waters will not be achieved solely by fixing the sanitary sewer system.
- Canine sources are primarily conveyed by stormwater runoff.
- Human markers demonstrate a more complex fate-transport pathway.
- The other bacteria sources need to be identified.

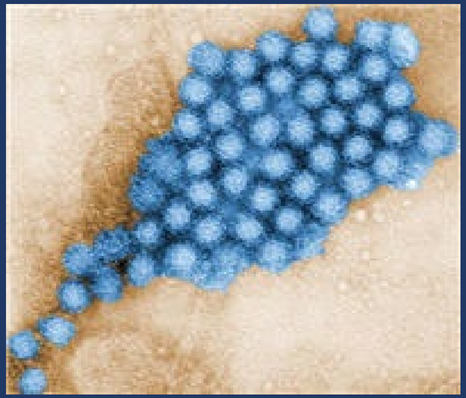


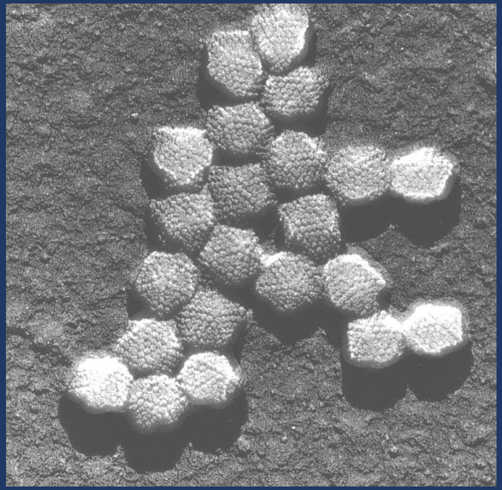
MST: Future

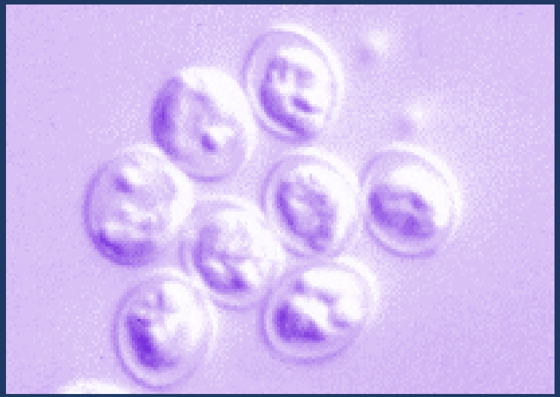
Historic stream conveyance

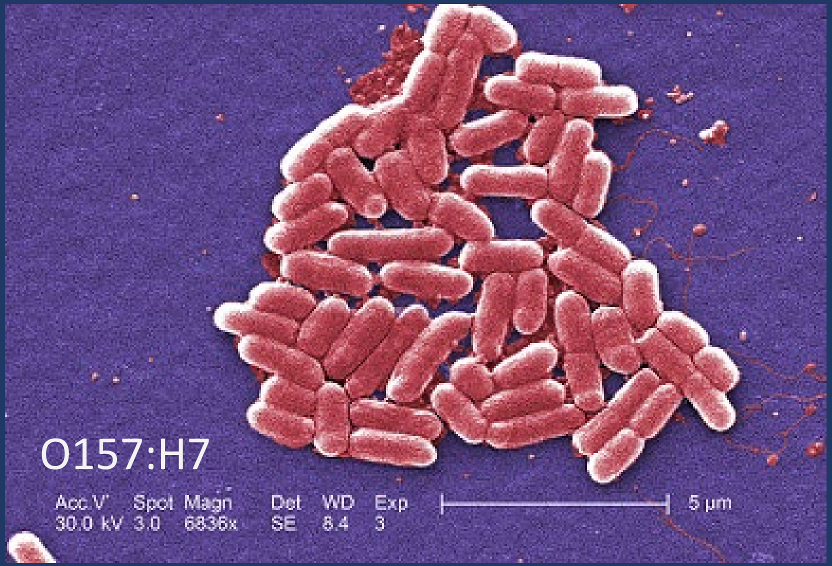
1. Same-day sampling of buried stream to determine spatial source trends.
2. Use more markers (birds, rats, deer).

Human pathogens common in sewage


Norovirus


Adenovirus

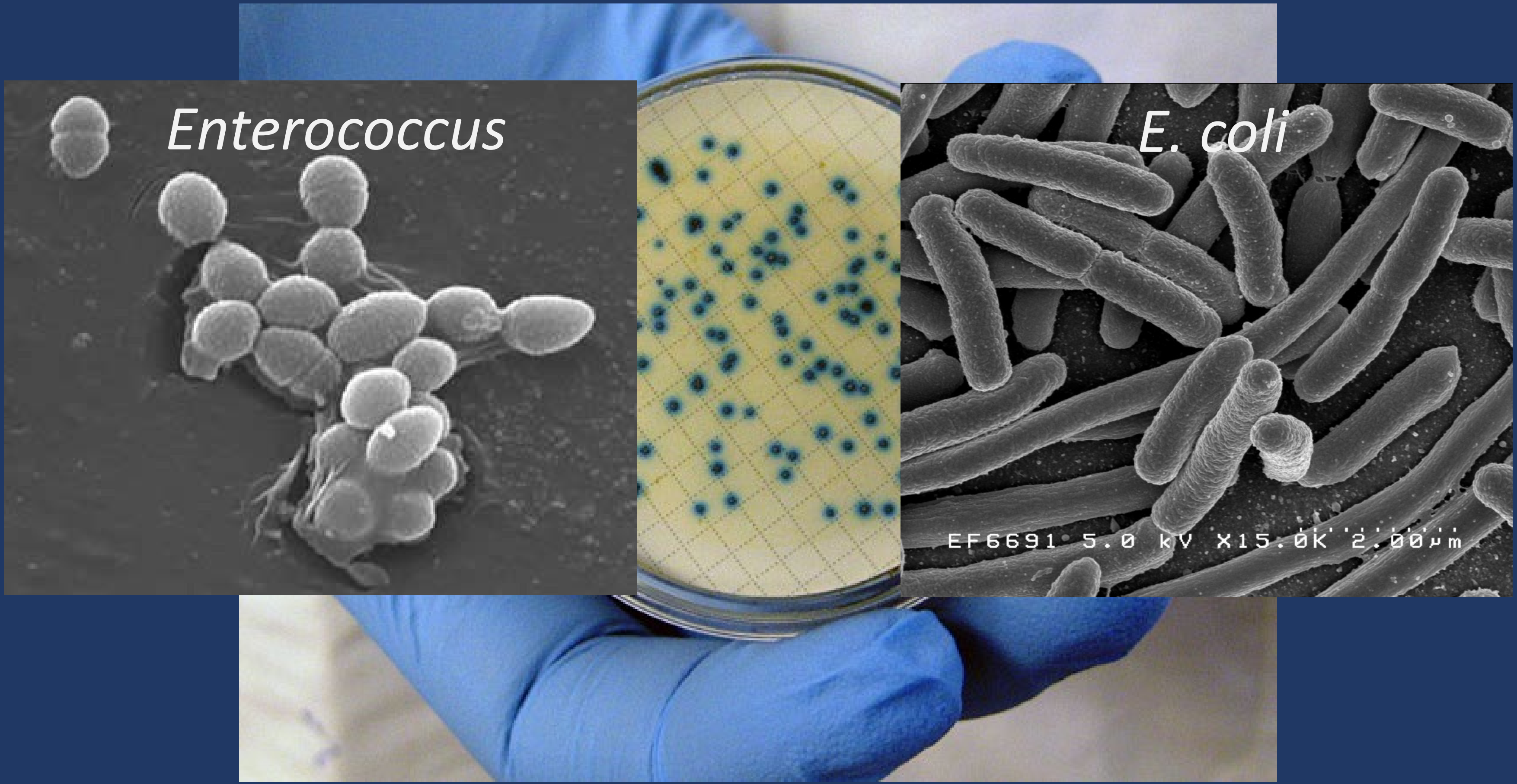

Cryptosporidium



Enteropathogenic *E. coli*

Markers for sewage presence

- FIB = fecal indicator bacteria
- Semi-selective culture methods
- Facultative anaerobes
- Not pathogenic



Basic conclusions from Enterolert data

1. We should have diluted 1/10 from the start (July)
2. High entero correlates with rain
3. Upstream usually higher than downstream

    This needs statistical tests

Basic conclusions from Human MST data

1. Upstream usually higher than downstream
2. High Human MST correlates with rain
3. Sci Ctr on Aug 19?
4. Large % of not detected is unexpected. More QC needed.

Basic conclusions from Canine MST data

1. Upstream higher than downstream
2. High Canine MST correlates with rain
3. Mr Trash and Harris Creek often positive

ASSESSING THE FEASIBILITY OF ASSISTED MACROINVERTEBRATE TRANSLOCATION IN ACHIEVING ECOLOGICAL UPLIFT IN RESTORED STREAMS

Fagbohun, I.R. (Ph.D. Student, Pennsylvania State University, irf5076@psu.edu)

Allen, D.C. (Associate Professor of Aquatic Ecology, Pennsylvania State University)

Sweetman, J.N. (Assistant Research Professor of Aquatic Science, Pennsylvania State University)

Hildebrand, R.H. (Associate Professor, University of Maryland Center for Environmental Science)

Key Research Question

Can assisted migration of benthic macroinvertebrates from reference streams be used to facilitate biodiversity recovery in restored streams?

Stream Restoration does not always achieve its goal of biodiversity uplift

Polluted Stream

Restoration

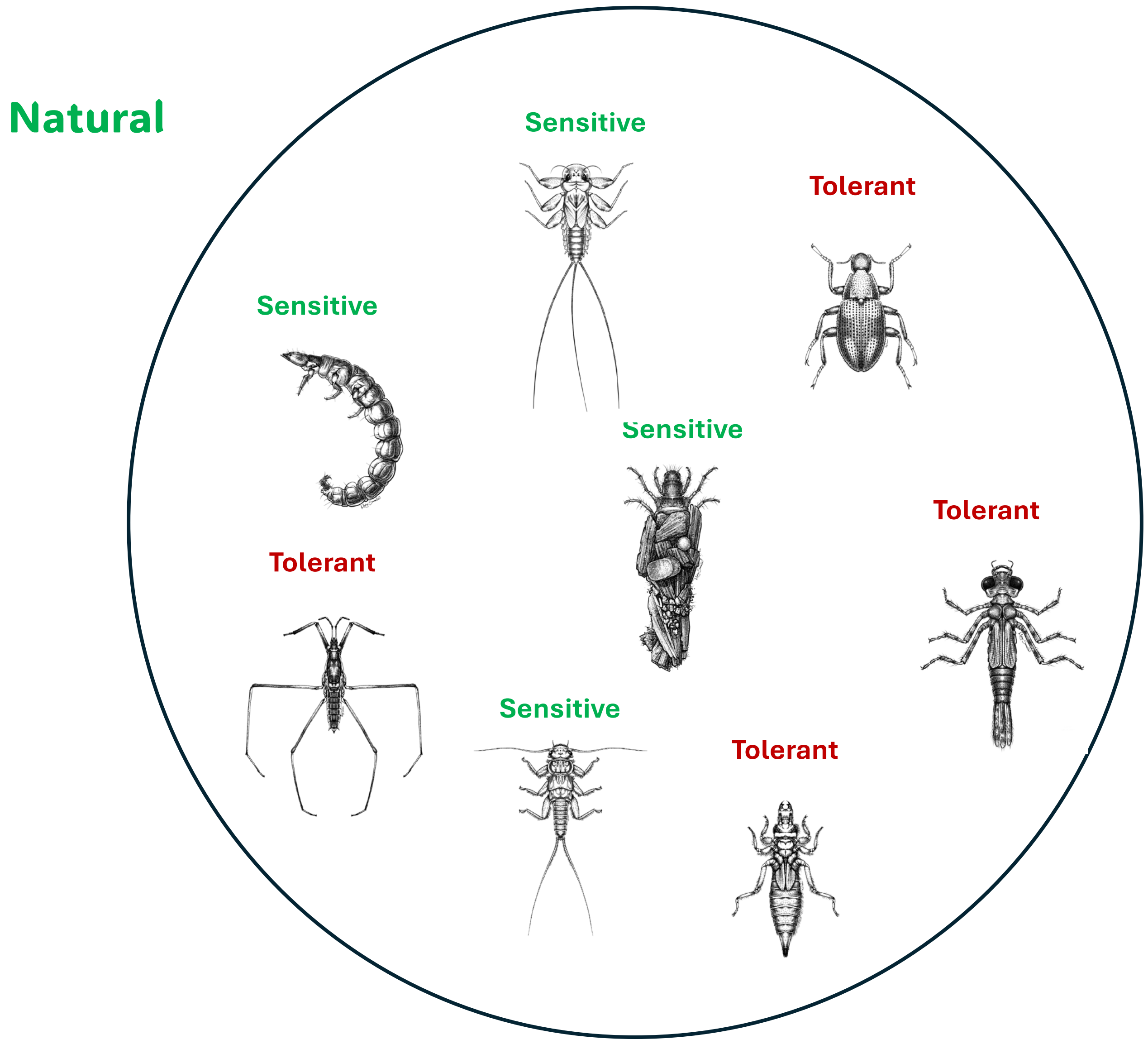
Restored Stream

Improved Water Quality ✓

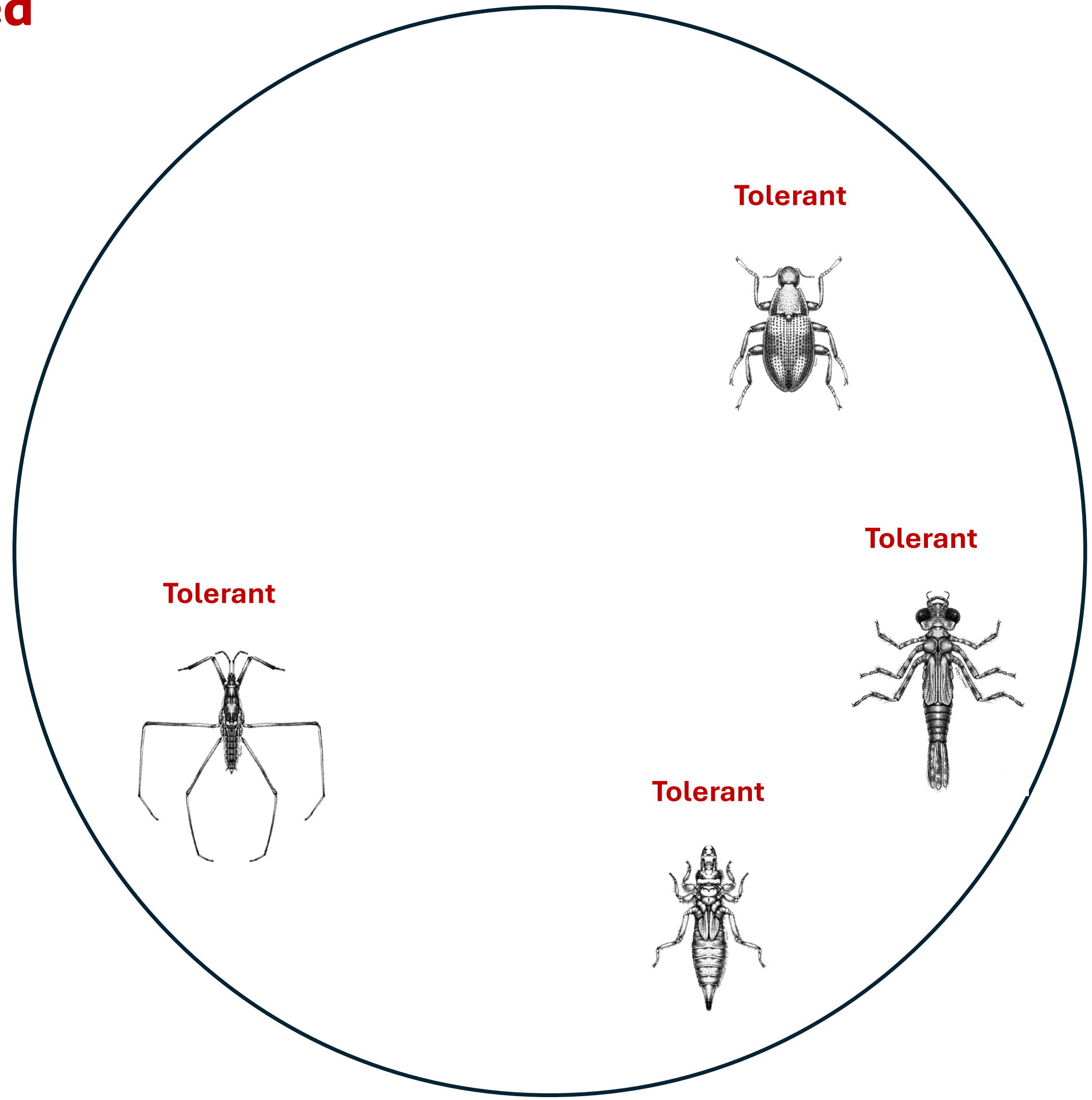
Improved Geomorphological Features ✓

Improved Biodiversity ✗

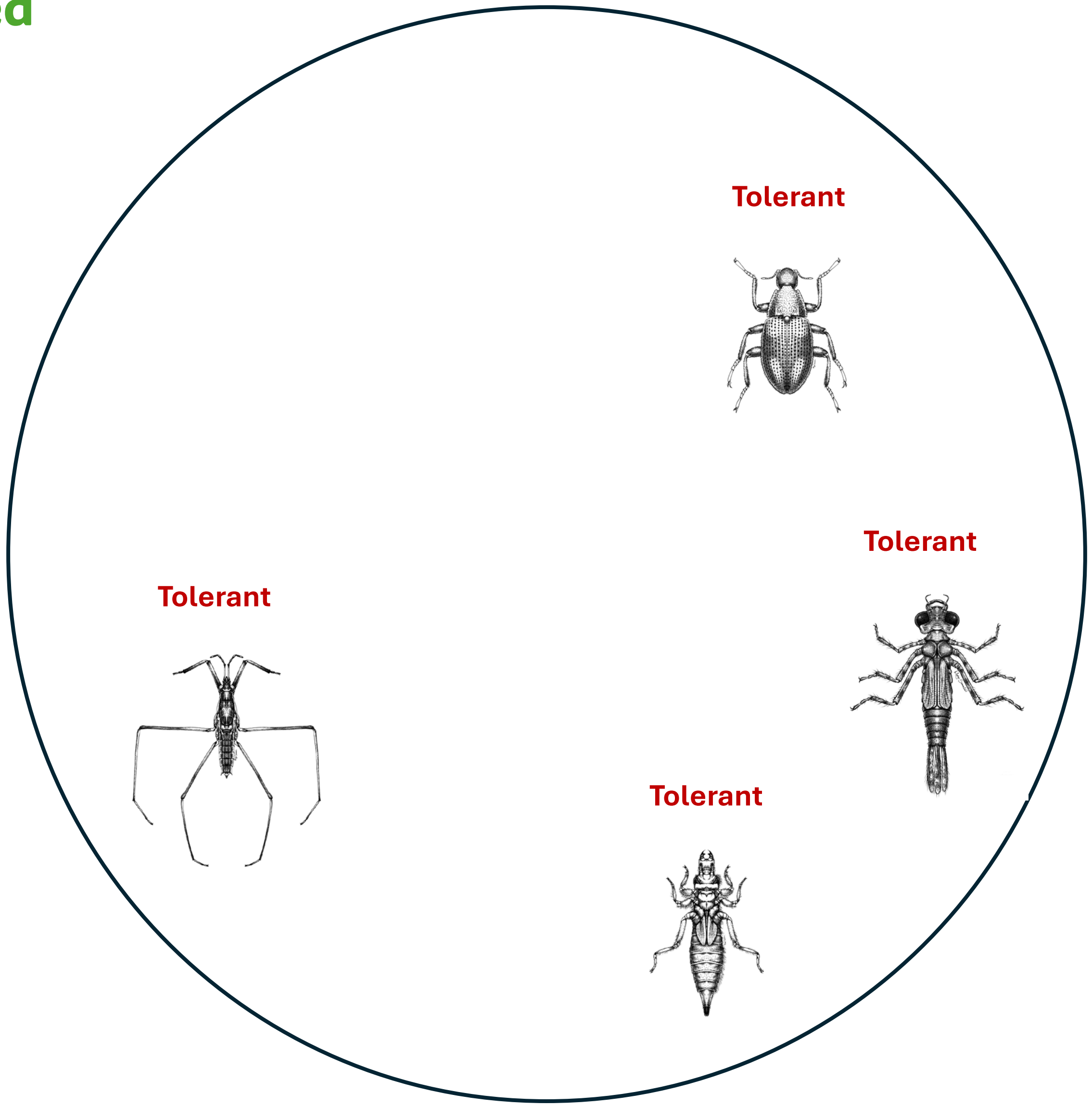
Sensitive Macroinvertebrate Taxa Fail to Recolonize Restored Reaches following Stream Restoration



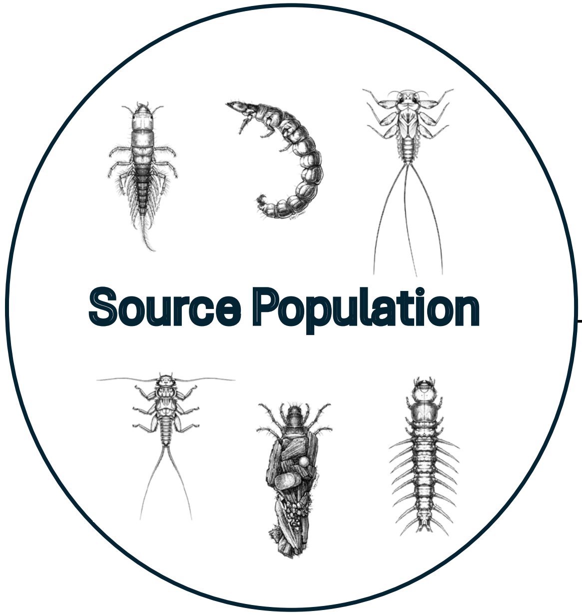
Polluted



Restored



Why are Sensitive Macroinvertebrates unable to Colonize Restored Reaches?

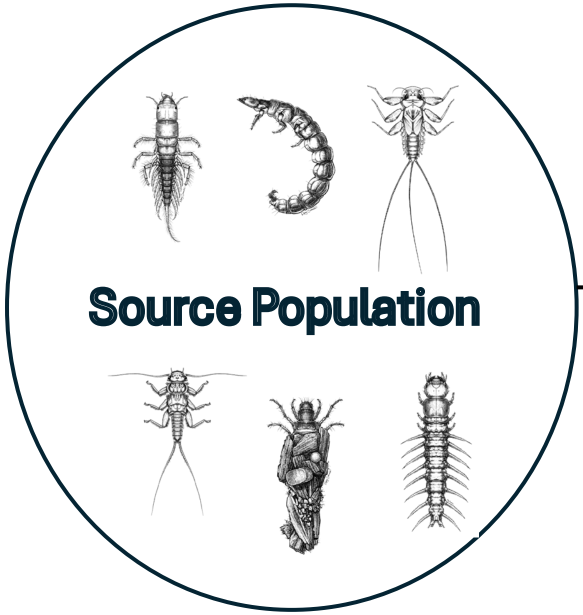


>5km

Restored Stream

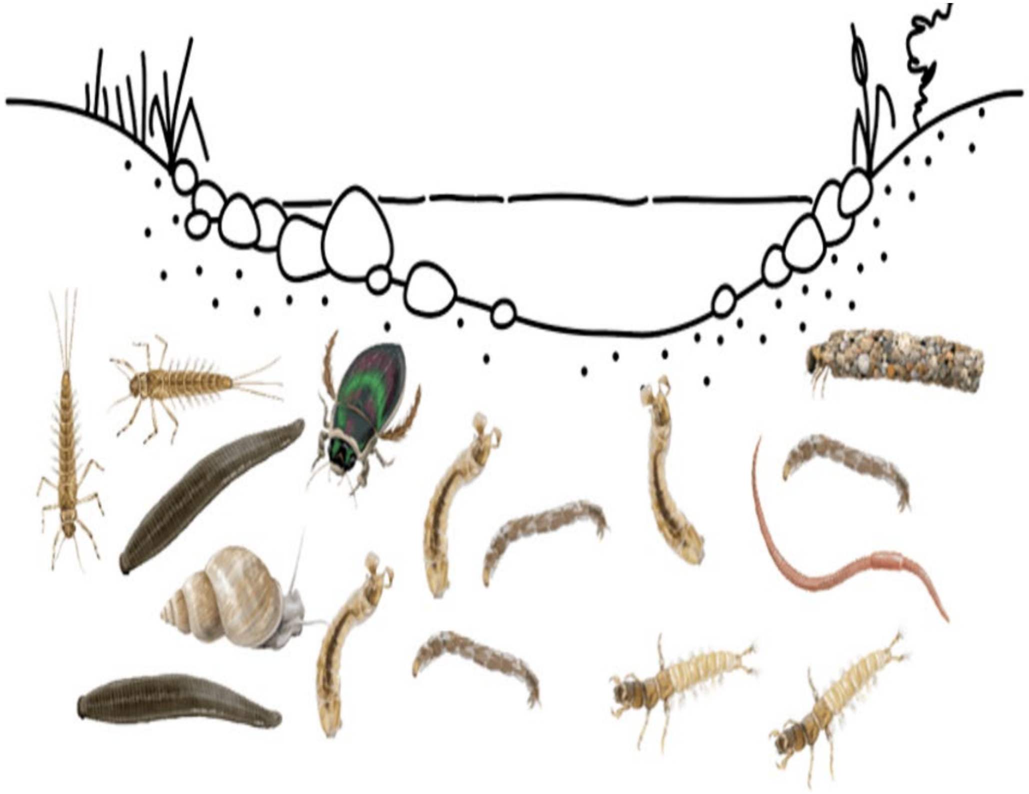
H_1: By translocating macroinvertebrate from reference streams to restored streams, we can facilitate biodiversity recovery in restored streams.

Reference/Natural/Sentinel/Donor Stream



Human assisted Migration

Restored/Recipient Stream

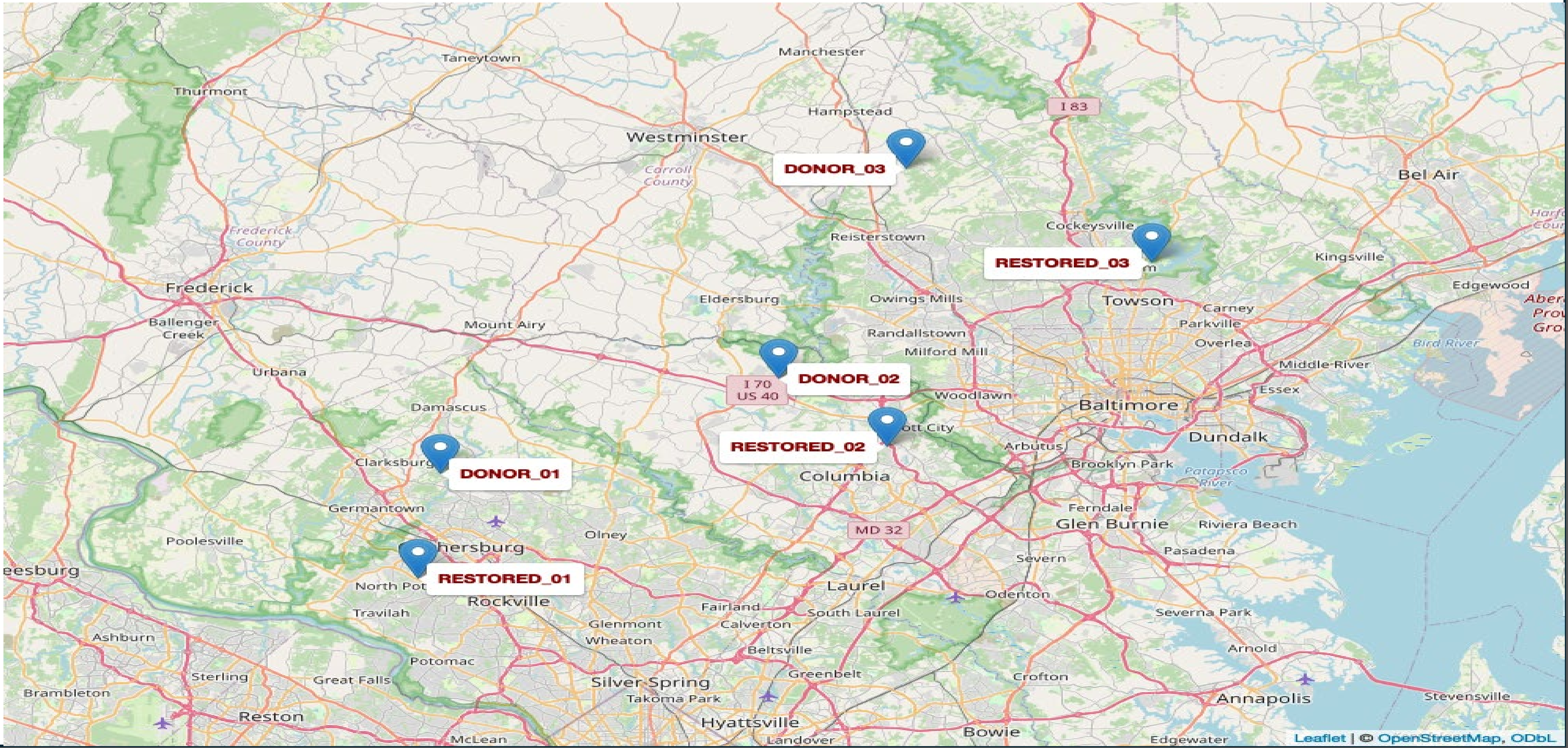


Q1: Which natural substrate is best to accumulate and transplant benthic macroinvertebrates?

Q2: Will sensitive macroinvertebrate taxa from reference streams survive in restored reaches?

Q3: How will seasonal changes influence transplant and survival of macroinvertebrates?

We selected THREE REFERENCE STREAMS and paired each of them with A RESTORED STREAM within the SAME SUB-DRAINAGE.

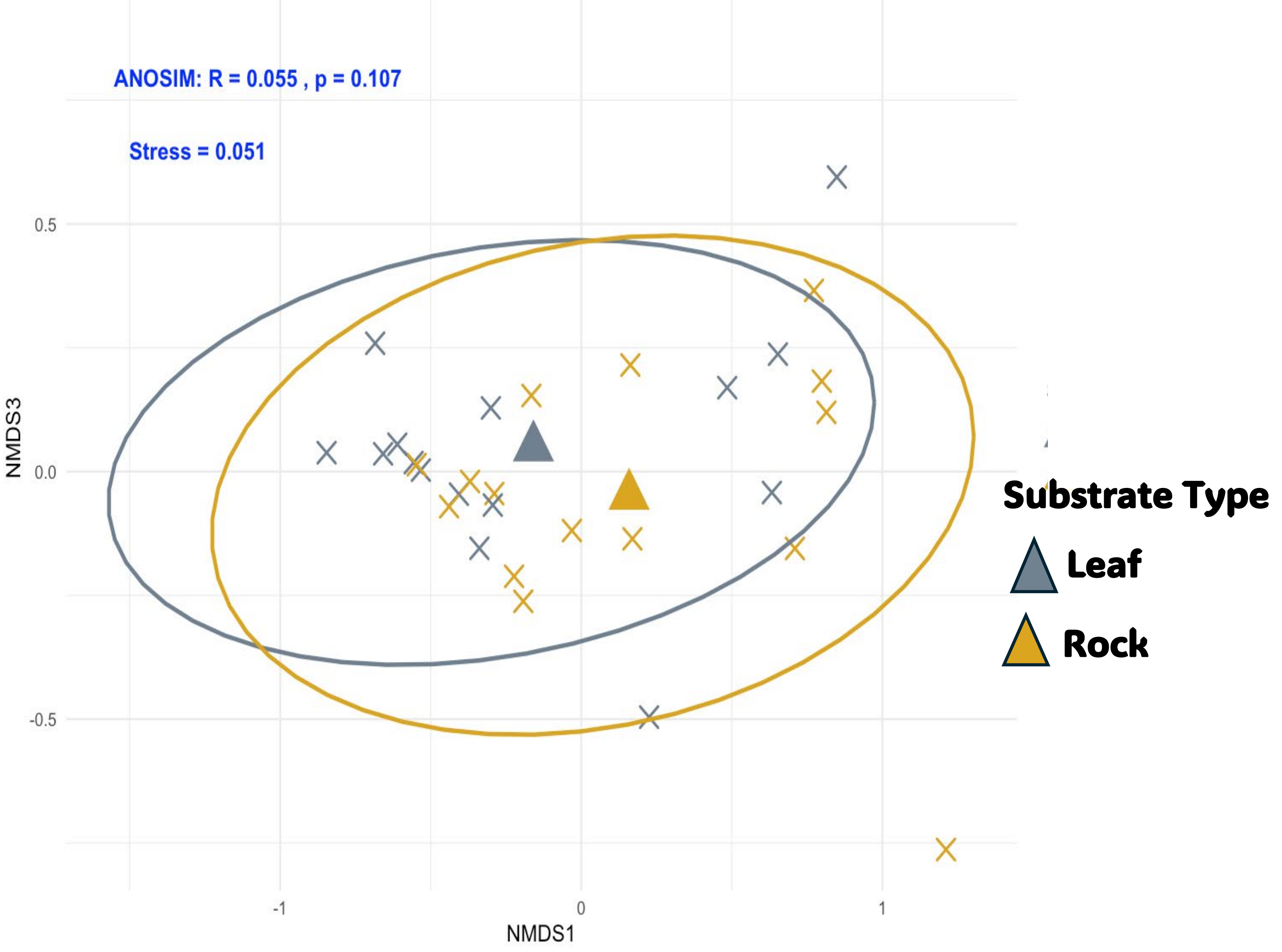


We incubated 60 macroinvertebrate cages containing leaf or rock substrates in the reference streams for FOUR WEEKS for macroinvertebrate COLONIZATION.

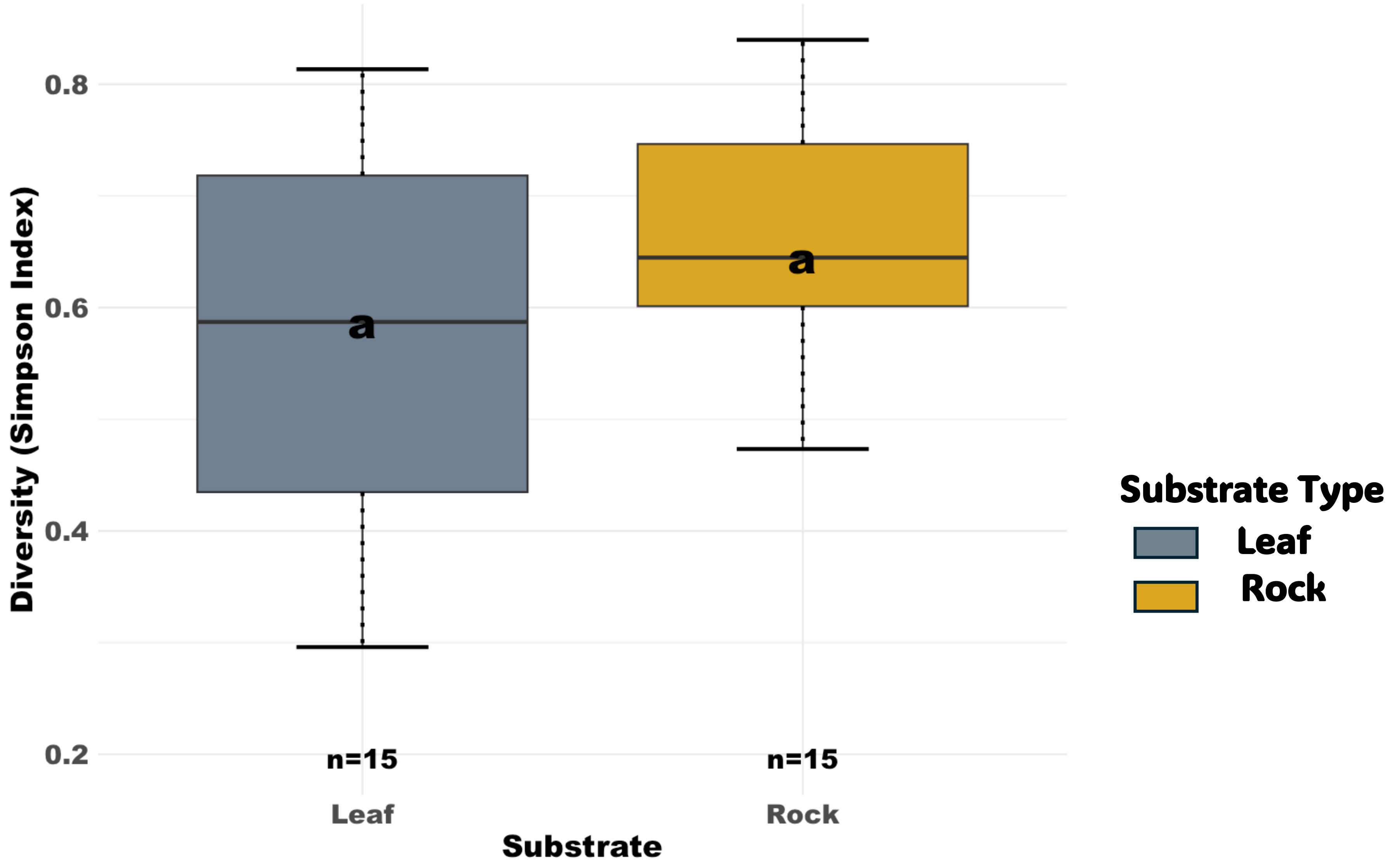
After four weeks, 30 macroinvertebrate cages were randomly selected for SAMPLING and 30 were randomly selected for TRANSPLANT

We transplanted 30 macroinvertebrate cages covered with ultrafine meshes to restored streams and left them for FOUR WEEKS to estimate survivability.

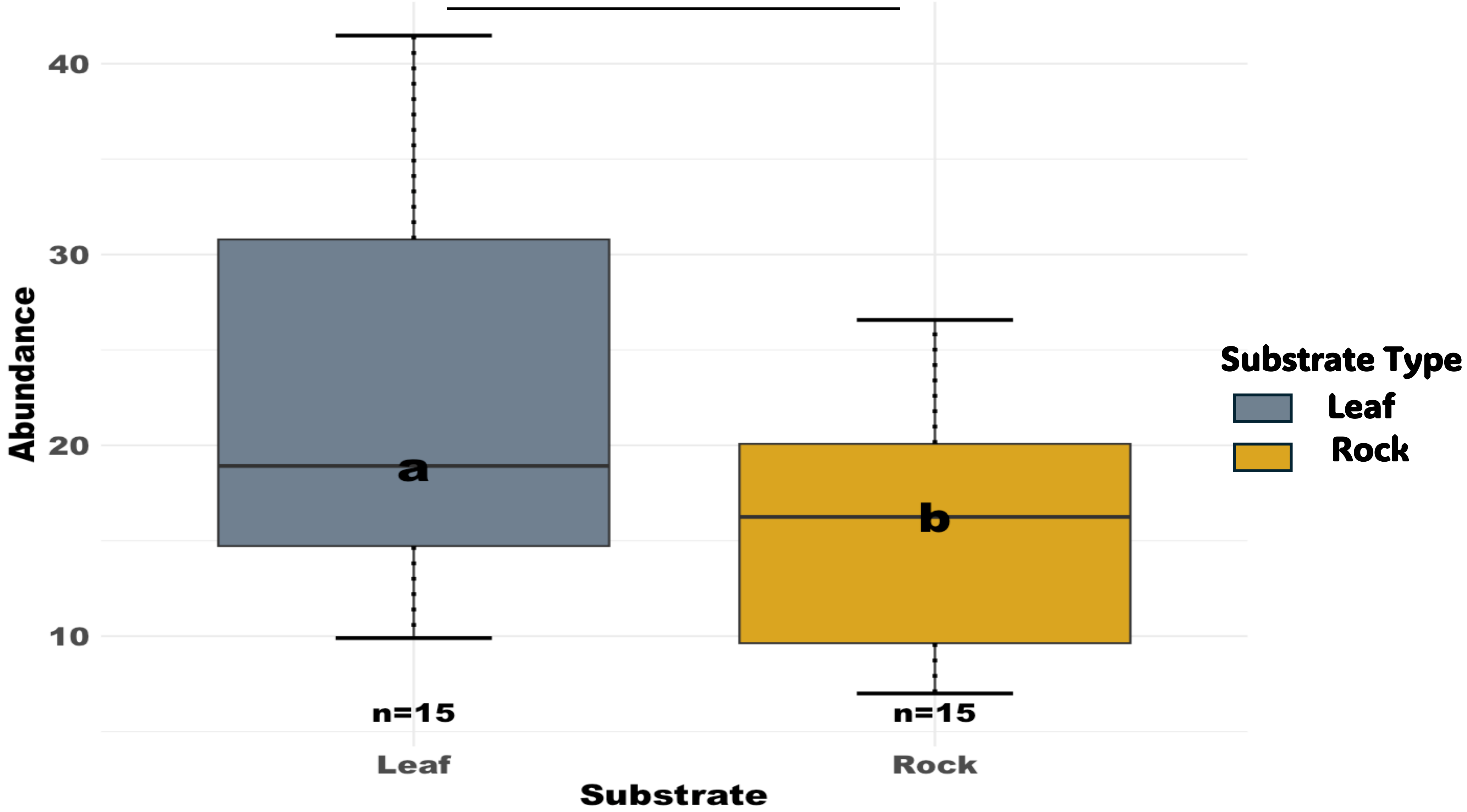
Similar Communities of Macroinvertebrate accumulated on the Leaf and Rock Substrates



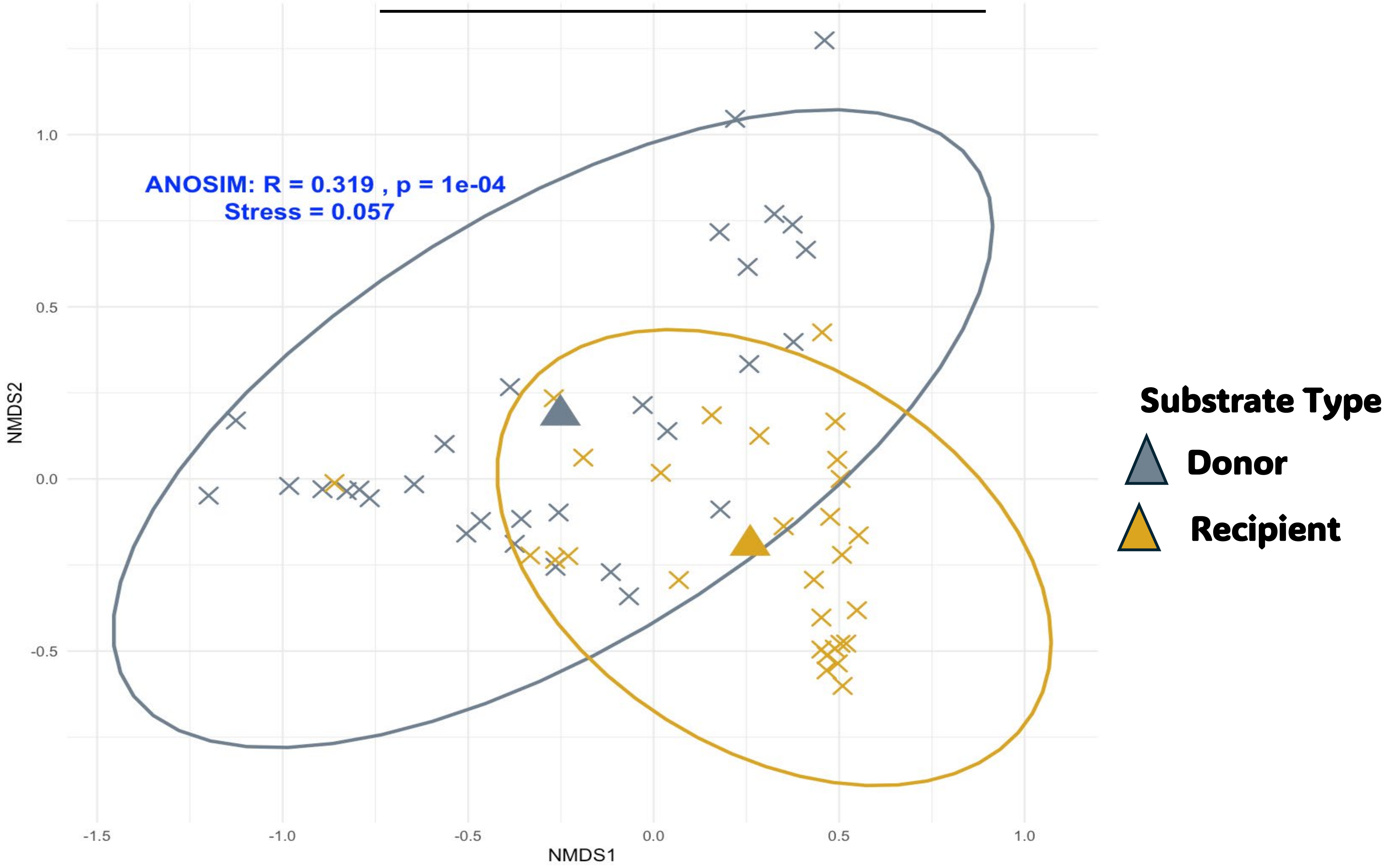
Both Rock and Leaf Substrates showed similar macroinvertebrate Diversity.



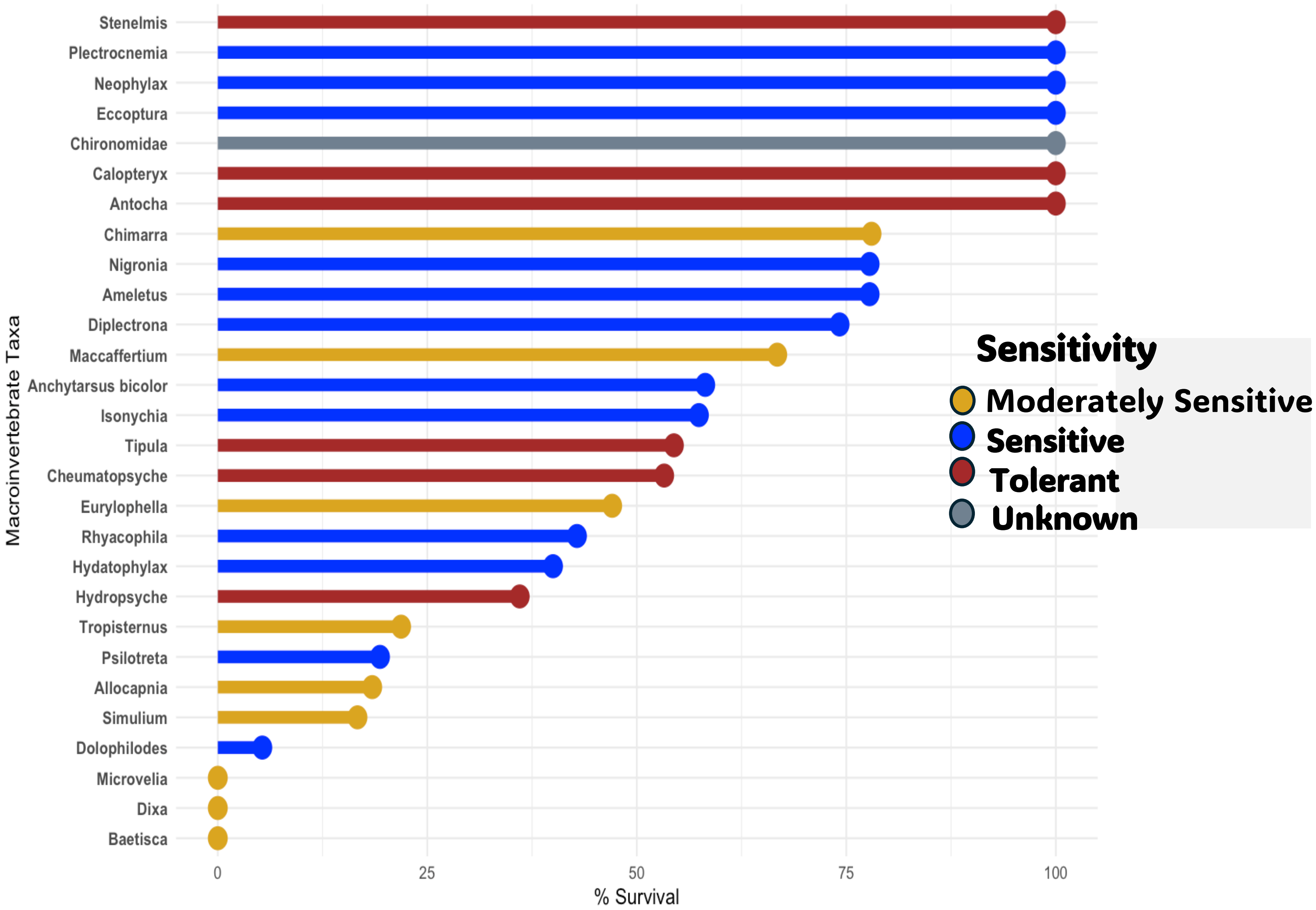
Individual Abundance of Macroinvertebrates was significantly higher on leaf substrates.



Macroinvertebrate community composition differ before and after transplant.



Several Sensitive macroinvertebrate taxa showed a high rate of survivability in the restored reaches



Argia
Baetis
Boyeria
Dubiraphia
Glossosoma
Isoperla
Lepidostoma
Leptophlebia
Molanna
Neureclipsis
Nyctiophylax
Probezzia
Ptilostomis
Rhagovelia

Excluded from the analysis because abundance in the Donor Site was < 5

Q3: How will seasonality influence macroinvertebrate transplant and survivability?

Still In the works

- Completed Data Collection on the 9th of May 2025
- Samples currently under processing
- Expected to be completed by the end of summer.

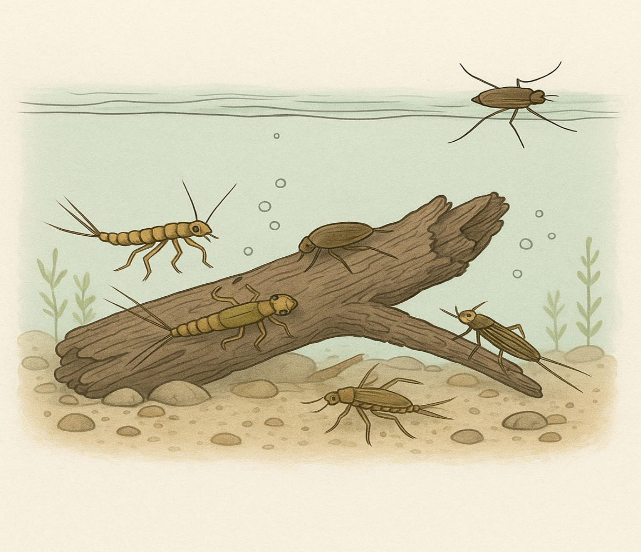
What are we expecting to see?

- If macroinvertebrate community assemblages differ significantly across seasons?
- Which season will be best for a larger translocation effort?

Final Thoughts: Assisted migration of macroinvertebrates can be used to facilitate biodiversity recovery in restored reaches

Leaf substrate is suitable for benthic macroinvertebrate accumulation and transplant.

Sensitive macroinvertebrate taxa can survive in restored reaches.



THE ALLEN LAB at
The Pennsylvania
State University

CBTRUST
Chesapeake Bay Trust

Sweetman Lab
Aquatic Ecology & Environmental Change

Thank You

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MARYLAND
DEPARTMENT OF NATURAL RESOURCES

MDOT
MARYLAND DEPARTMENT OF TRANSPORTATION
STATE HIGHWAY ADMINISTRATION

Translation Slides

Translation Slides
by
Scott Lowe, McCormick Taylor

What does this mean for me?

- Recolonization of macroinvertebrates has been difficult for restored stream reaches, efforts to accelerate recolonization are desirable and unclear to date

- The study indicates survivability of sensitive species in restored streams - suggesting that the absence of macroinvertebrates is due to poor source populations upstream of the restoration sites and not due to the restoration activity.

What do I take from this if I am a Practitioner?

- **Design to match habitats of donor streams (mimic physical structures, energy inputs, and H&H characteristics)**

- **Determine optimal locations and densities of transfer cages, long-term recolonization trends, and approved locations of donor streams**

What do I take from this if I am a Regulator?

- Is species relocation an activity managed by an applicant or an agency?
- What are comparable water quality, drainage area, and land use parameters between donor and restoration reaches?
- What are upstream source populations?

Using eDNA methods to extend biological sampling and identify candidate restorations for species reintroductions

Key Research Question: The effectiveness of biological community restoration at the project scale

Bob Hilderbrand, Rodney Richardson, Regina Trott
UMCES Appalachian Lab, Frostburg, MD

Louis Plough UMCES Horn Point Lab, Cambridge, MD

Clay Raines
USGS Eastern Ecological Science Center, Leetown, WV

Thanks to the many funders and partners

CBTRUST
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Howard County Maryland

Anne Arundel County Maryland

Montgomery County Maryland 1776 Gardez Bien

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Empowering people. Restoring nature.

Chesapeake Bay Program
A Watershed Partnership

Maryland Department of Natural Resources

United States Environmental Protection Agency

National Fish and Wildlife Foundation
NFWF

Baltimore City DPW
Department of Public Works

MDOT
Maryland Department of Transportation
State Highway Administration

Key idea(s): Stream restorations are effective, but the biota cannot be detected / become established

H1: Ecological recovery is limited by the stream's ability to support the desired taxa.

H2: Ecological recovery is possible, but is limited by our inability to detect organisms present at such low abundances as to be undetectable using current sampling methods.

H3: Ecological recovery is limited by a failure of fish and/or benthic macroinvertebrates to recolonize the stream. Follows from rejecting H1 and failing to reject H2

All three hypotheses use DNA sequencing methods

Microbes: Stream sediment microbial communities have successfully predicted stream condition

Fish and Benthos: eDNA metabarcoding is used for identifying the fish and benthic invertebrates in the stream. Data are geographically filtered to include only those taxa found in the 20+ years of MBSS sampling.

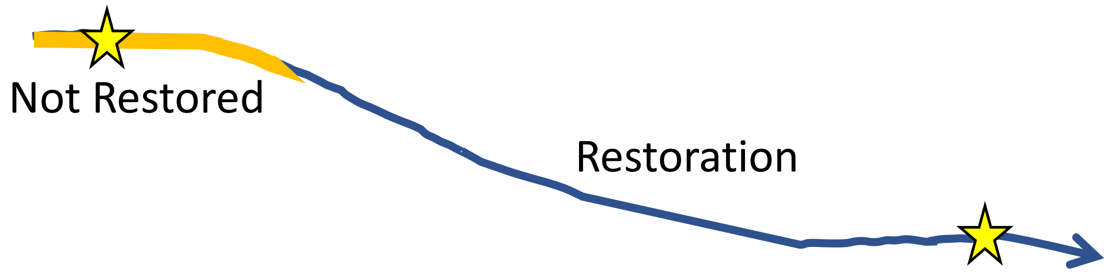
26 restorations examined using water samples and sediments collected ~100m above the project and at the bottom of the restoration project

Single eDNA sample collected in spring

Across the urban gradient

RSC-ish and NCD-ish restorations

Various times since restored



1. Compare taxa in restored vs above.
2. Compare taxa in eDNA vs physical collections

We should expect to see more taxa and more ‘desirable’ or sensitive taxa in restored sections.

Results preview – evidence for restoration success

Microbial communities did not provide enough resolution for confidence in the predictions.

Combined eDNA and physical sampling found **more fish and benthic macroinvertebrate taxa** in RESTORED sections compared to the upstream controls

Combined eDNA and physical sampling found **more sensitive fish and sensitive benthic macroinvertebrate taxa** in RESTORED sections compared to the upstream controls

eDNA identified **more benthic macroinvertebrate taxa** AND **more sensitive benthic macroinvertebrate taxa** than physical sampling. Not the case for fish.

Microbial communities did not provide much resolution on predicting stream condition: disappointing resolution

Microbial communities predicted the BIBI +/- 0.5 with 30% accuracy. Better than guessing (8 prediction categories), but not good enough

Increased to 60% accuracy at BIBI +/- 0.75

Low variability in predictions. Nearly every site was predicted to be BIBI=3.0.

No directional bias in over- or under-predicting the BIBI. It just didn't work well.

Precludes rigorous assessment of H1: We cannot independently assess if streams can harbor desired fish or benthics

Ecological recovery is somewhat limited by our inability to detect organisms. eDNA improves this for benthics.

Restored sections had significantly more benthic macroinvertebrate taxa

AND

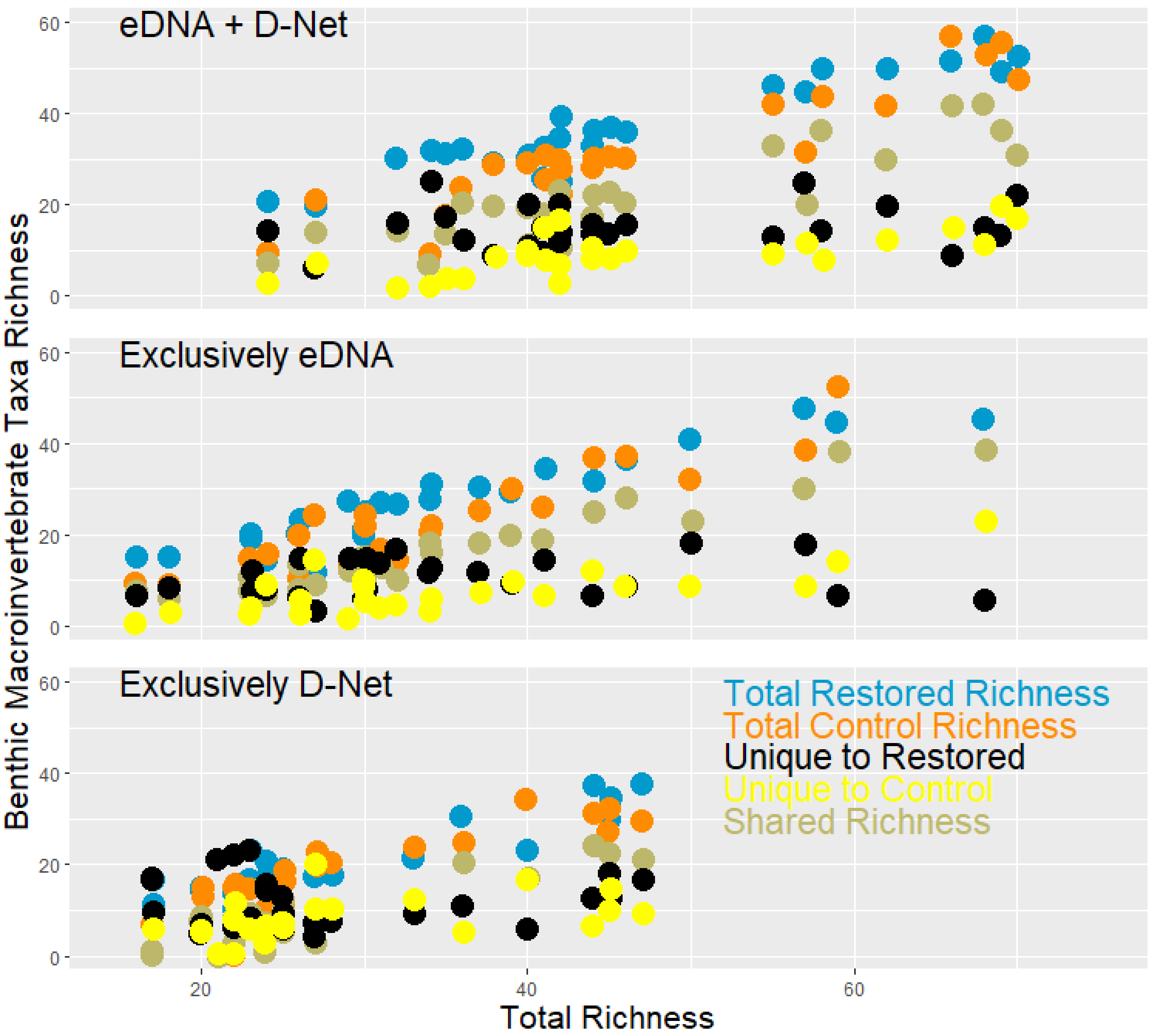
eDNA identified additional taxa present in restored sections, but not found upstream of the restoration

***This includes additional sensitive taxa eDNA identified additional taxa for benthic macroinvertebrates and provides additional sensitivity when combined with D-Net sampling

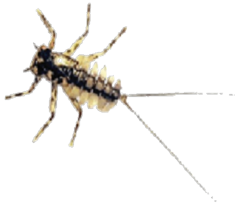
eDNA+DNet: RESTORED sections tend to have more benthic taxa

eDNA-only: RESTORED sections tend to have more benthic taxa

D-net only: No differences



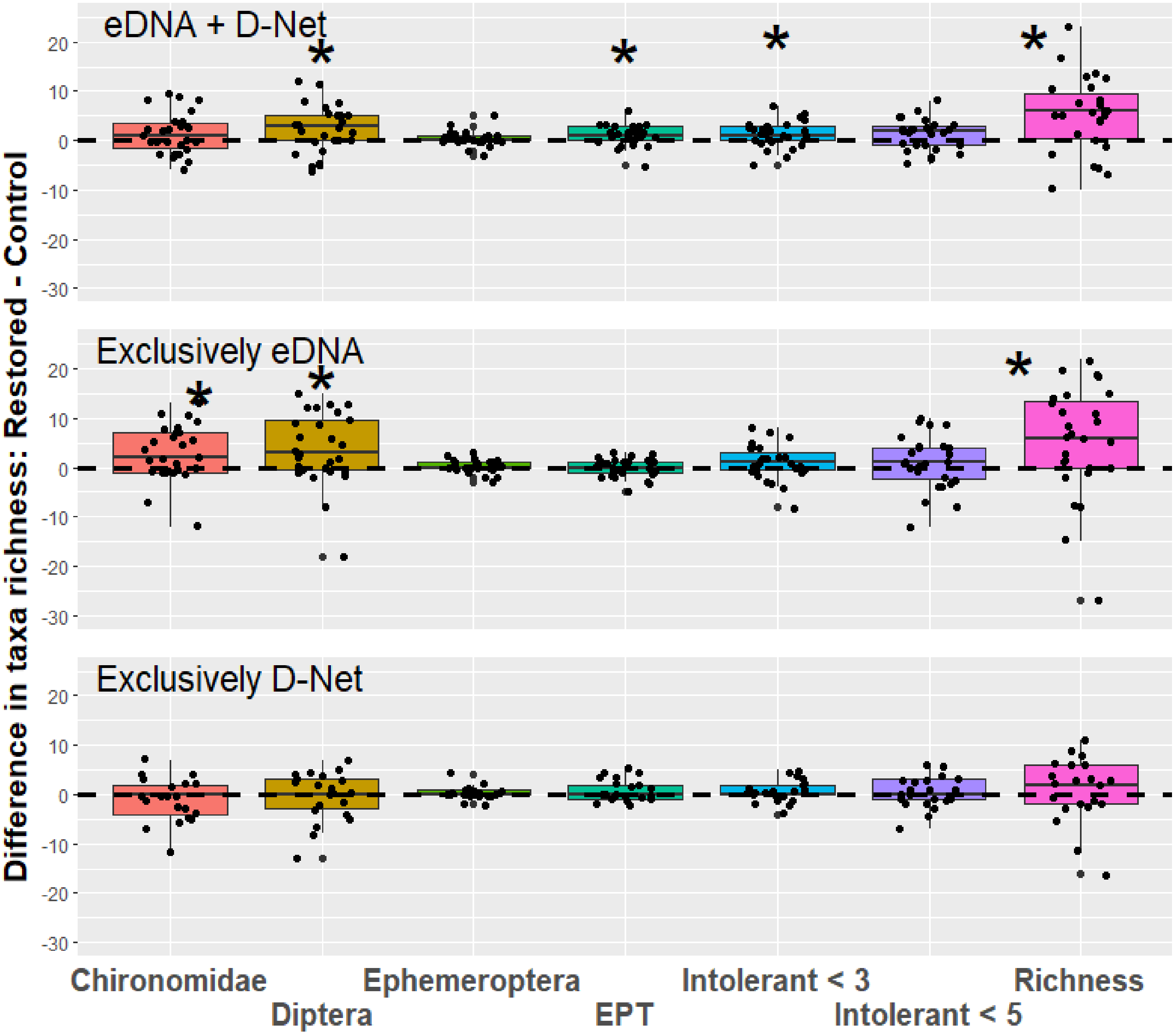
Benthics



eDNA+DNet suggests RESTORED sections tend towards higher richness, more Dipterans, EPT, & sensitive taxa

eDNA-ONLY: suggests RESTORED sections tend towards higher richness, more Chironomidae, Dipterans & sensitive taxa

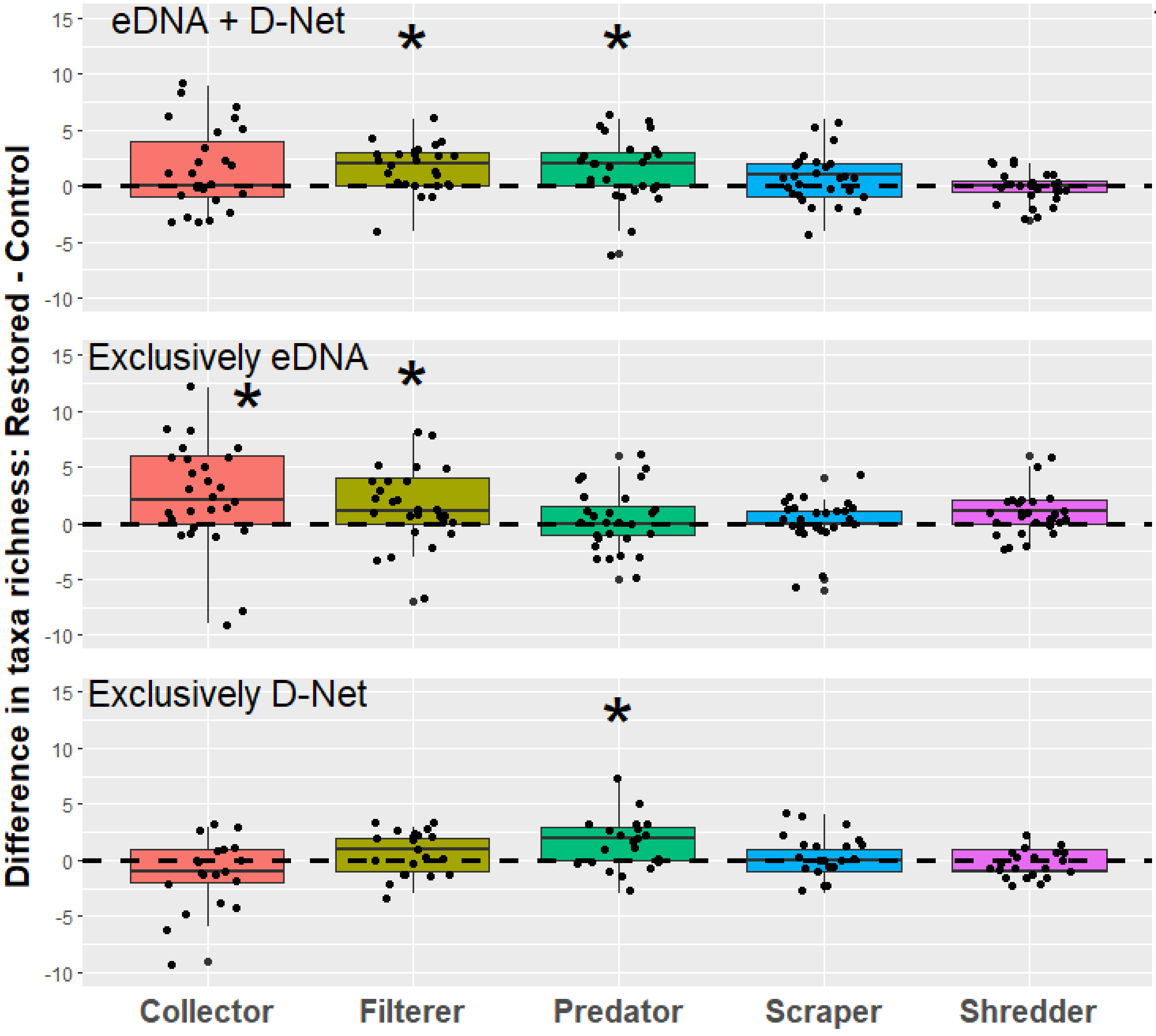
D-Net ONLY: No differences found between Restored and CONTROL sections



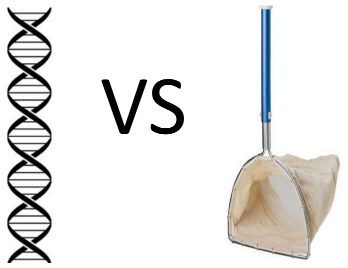
Benthics

eDNA+DNet suggests restored sections tend towards higher richness of Filterer and Predator functional groups

eDNA-ONLY suggests restored sections tend towards higher richness of Collector and Filterer functional groups

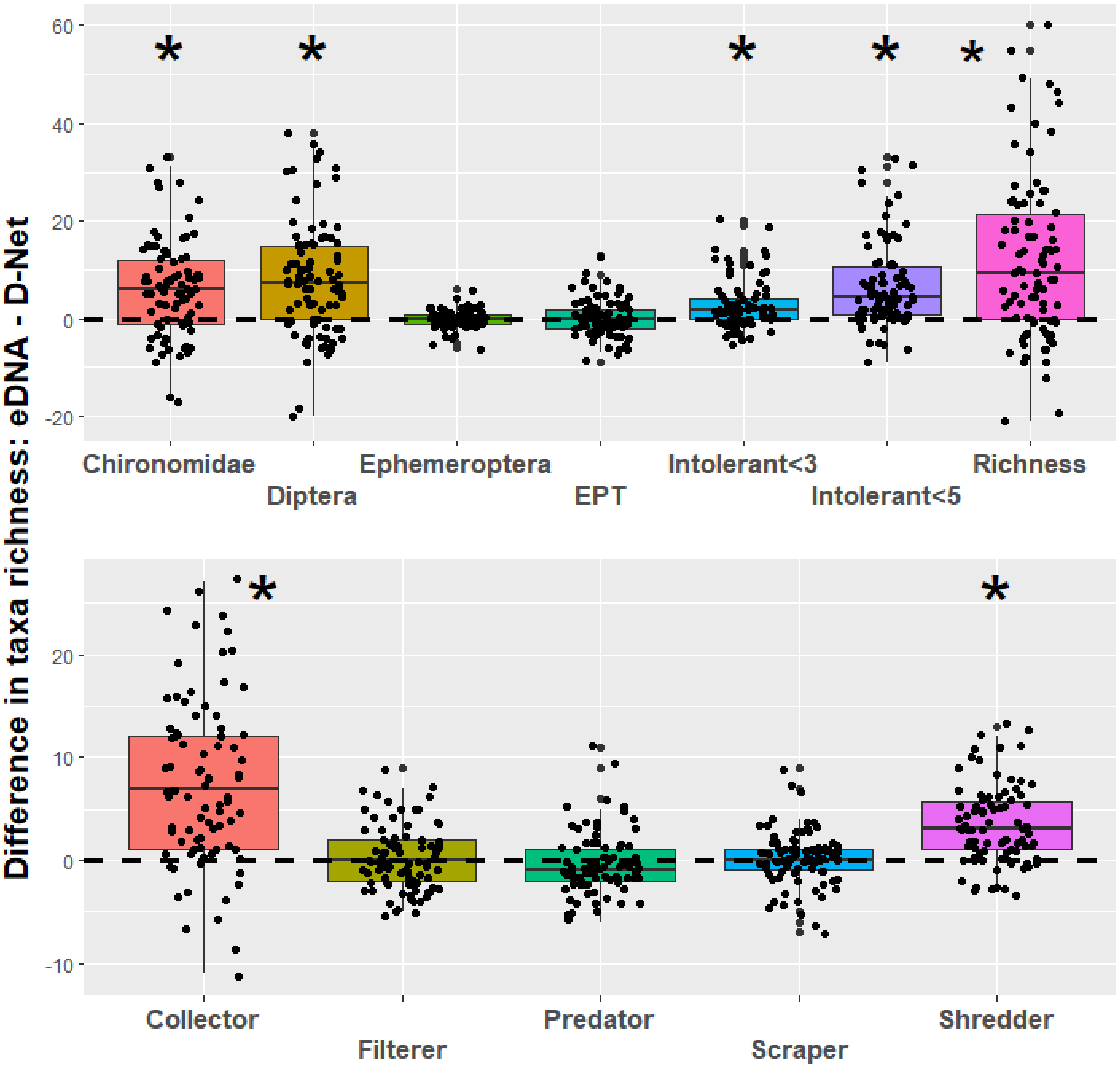


eDNA vs D-Net sampling

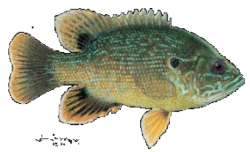


eDNA+DNet suggests restored sections tend towards higher richness of Filterer and Predator functional groups

eDNA-ONLY suggests restored sections tend towards higher richness of Collector and Filterer functional groups

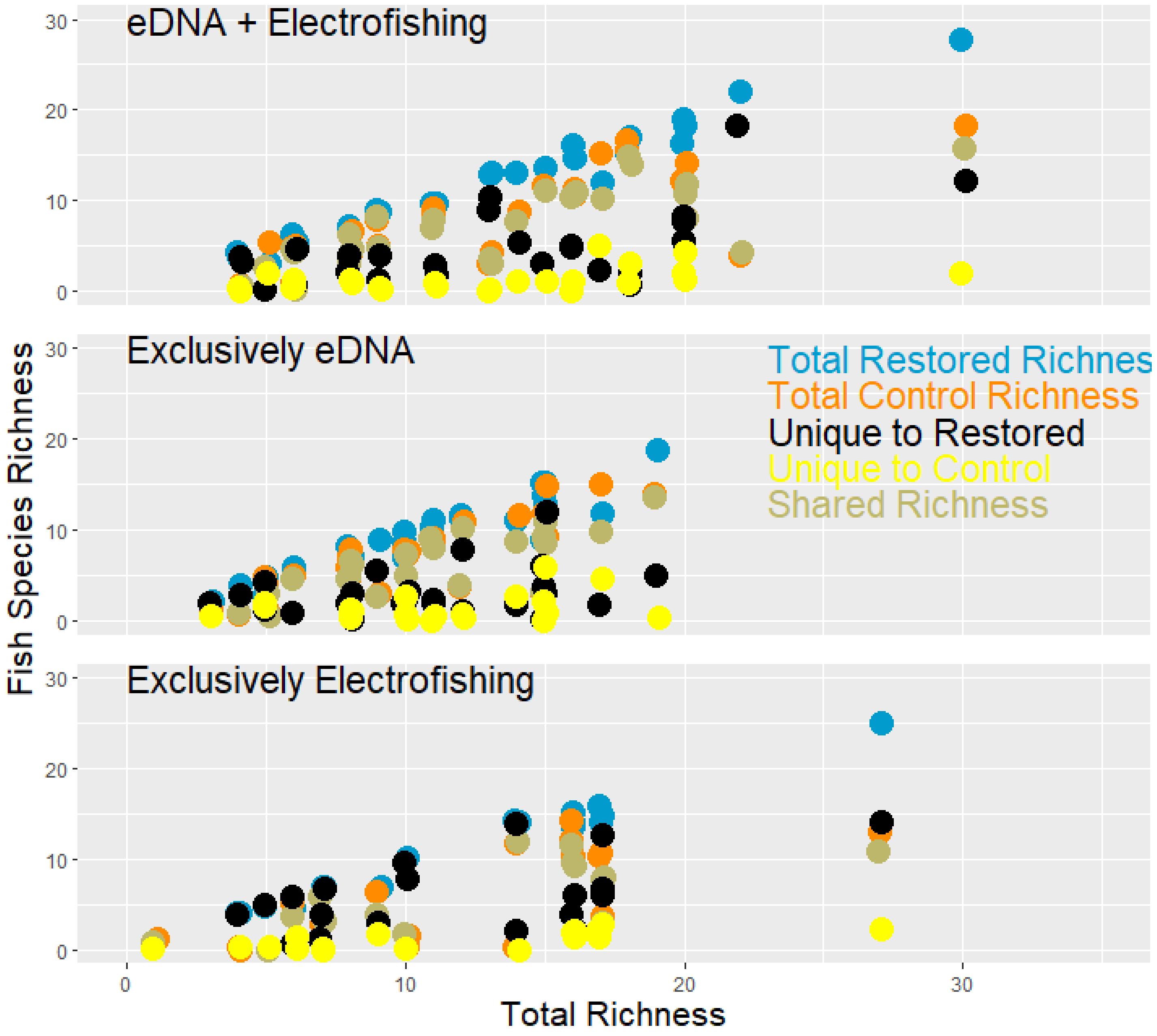


Fish

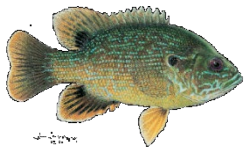


More fish species were found in RESTORED sections compared to the CONTROL sections for all collection methods analyzed.

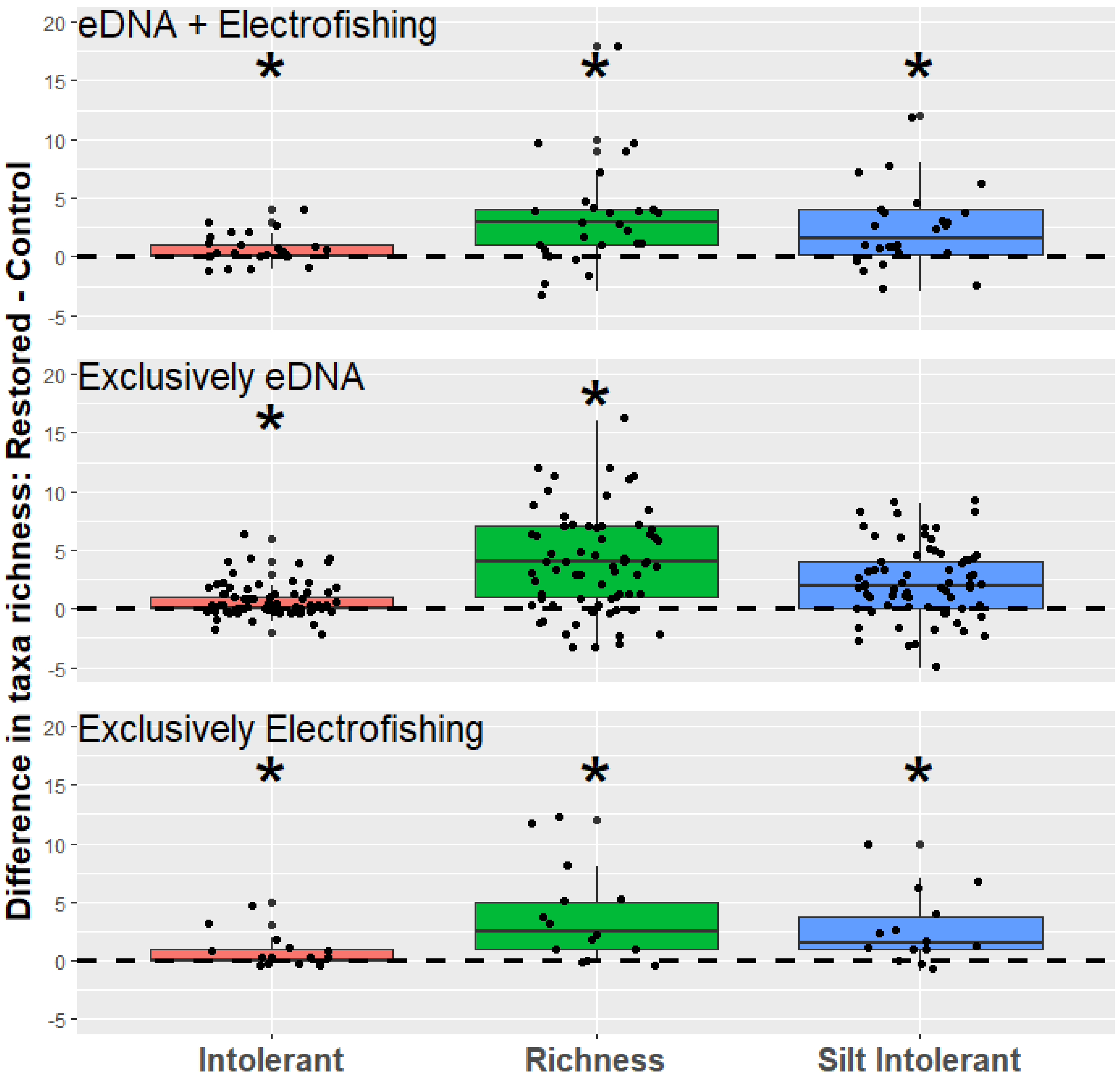
Including eDNA with the electrofishing data tended to improve the number of species found at a site.



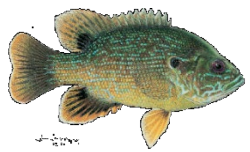
Fish



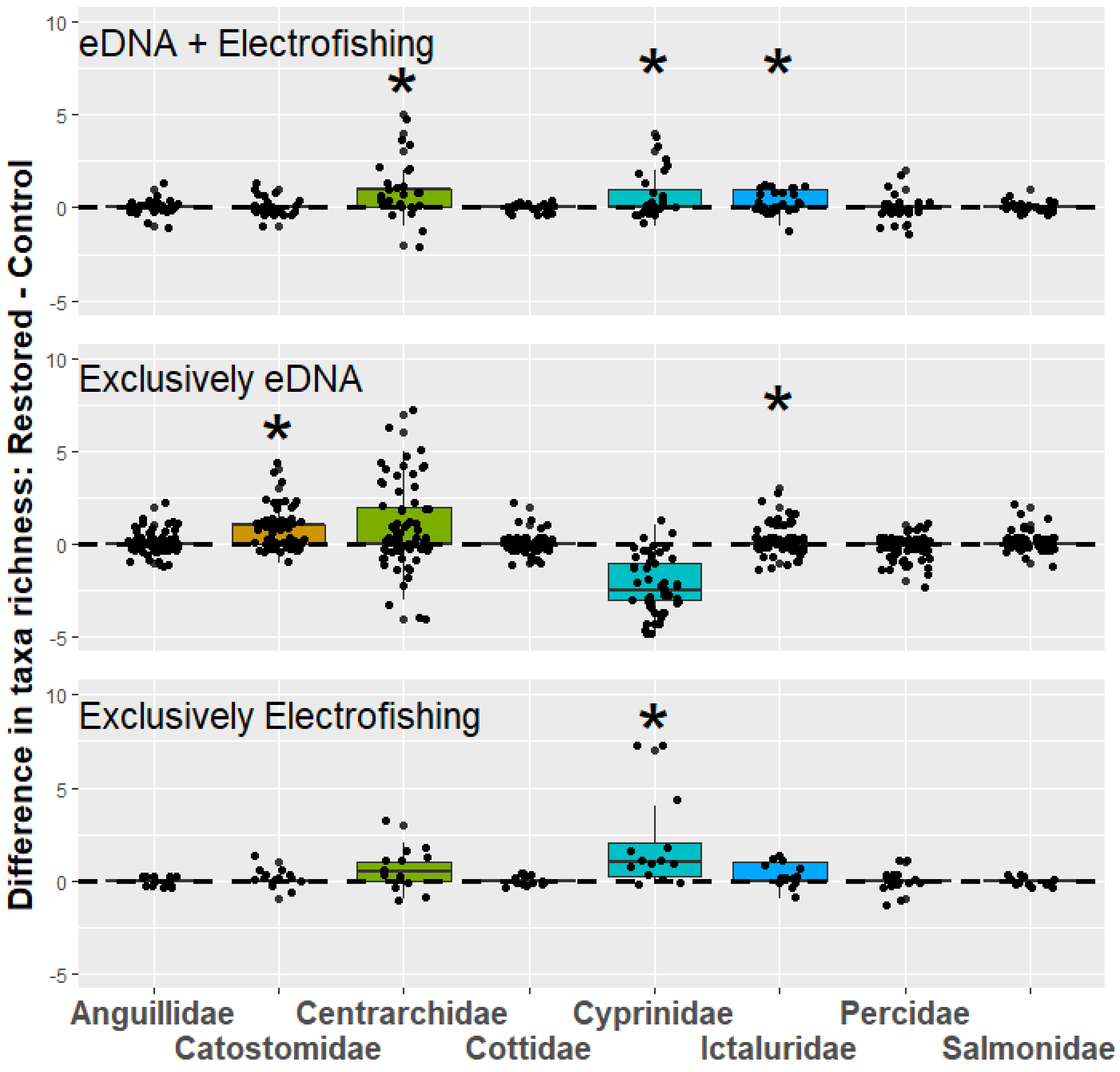
Across all aspects shown, RESTORED sections had significantly more fish species than CONTROL sections.



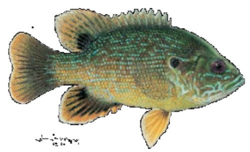
Fish



Including eDNA with electrofishing data tended to increase the sensitivity of the findings.



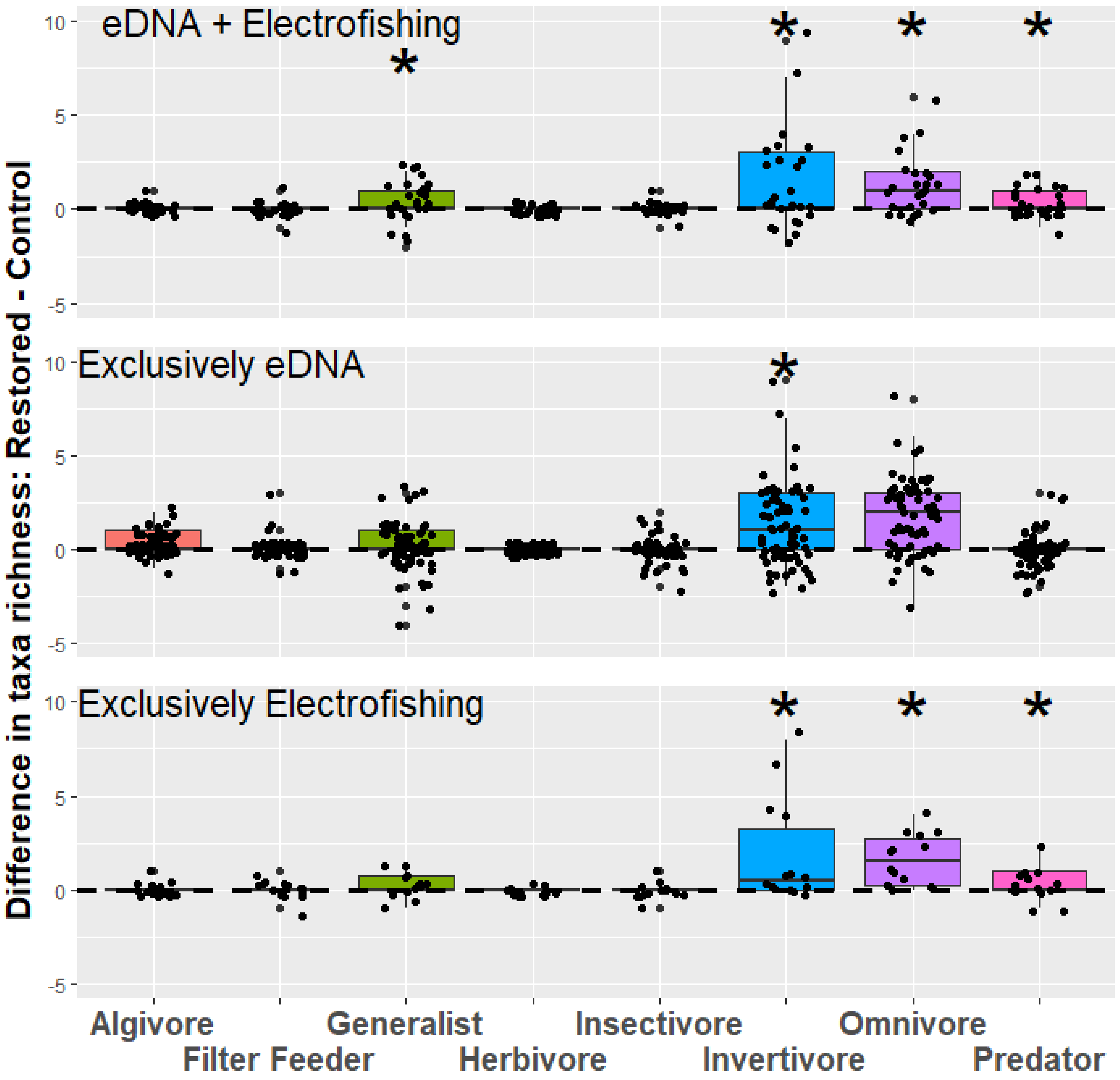
Fish



RESTORED sections had significantly more species in several trophic groups compared to CONTROL sections

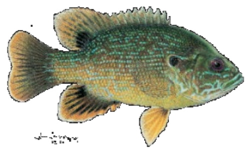
Including eDNA with electrofishing data tended to increase the sensitivity of the findings.

eDNA alone was not as good as electrofishing in identifying differences between RESTORED and CONTROL sections



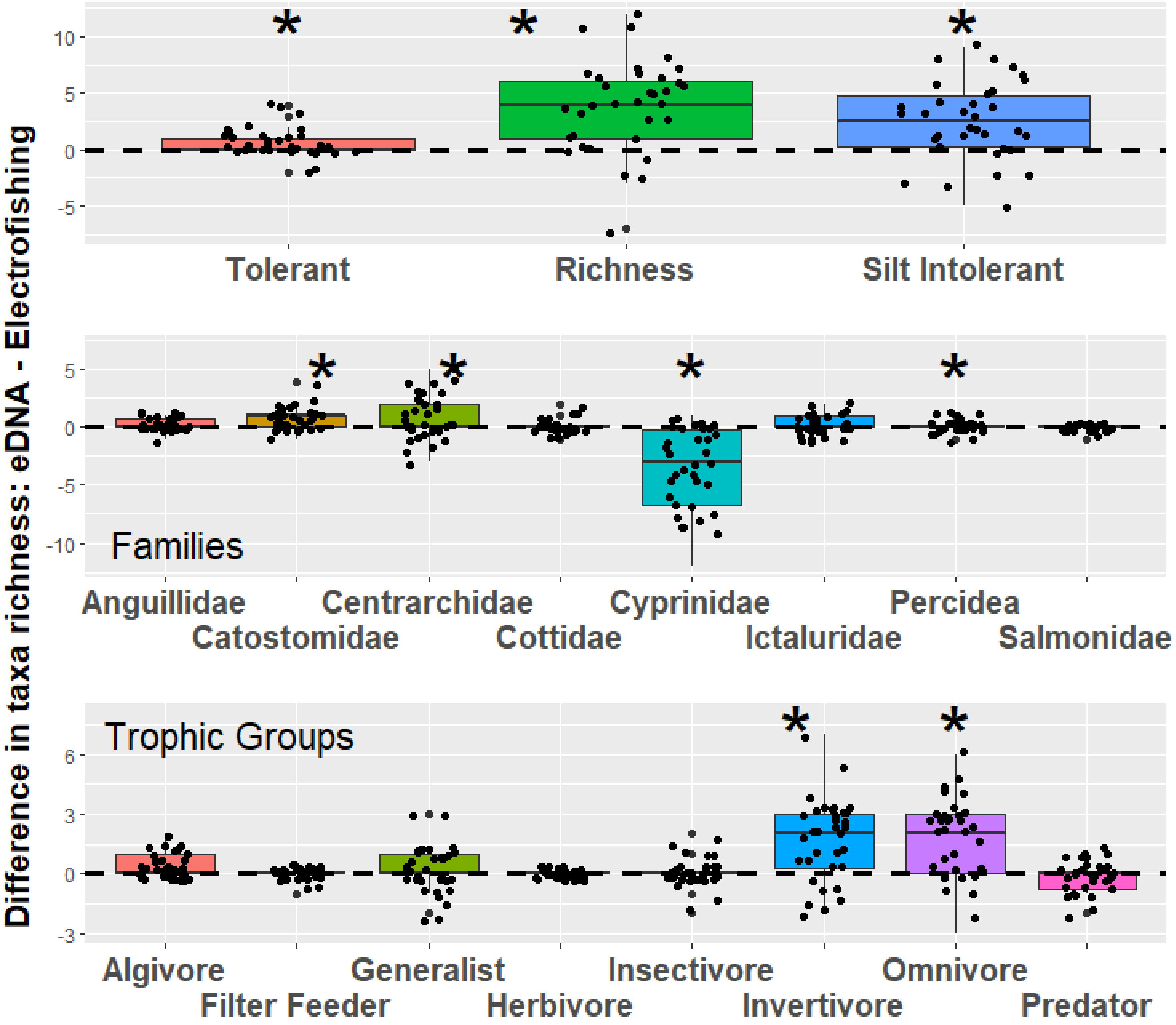
eDNA vs Electrofishing

VS



Compared to electrofishing, eDNA identified significantly more species, more sensitive species, and across different taxonomic and trophic groups.

The minnows (Cyprinidae) were the only group where electrofishing was superior to eDNA in finding more species.



Summary - eDNA is worth the effort

Increased sensitivity of eDNA showed differences between RESTORED and CONTROL sections that traditional D-Net sampling did not find for the benthics

eDNA consistently identified more taxa for both fish and benthics, and more sensitive taxa than traditional monitoring

Combined eDNA and physical sampling found **more sensitive fish and benthic macroinvertebrate taxa** in RESTORED sections compared to the upstream controls

Microbial communities did not provide enough resolution to provide confidence in the predictions

*Adding eDNA information did not appreciably change IBI scores for fish or benthics

Final Thoughts

Restorations are still missing most of the indicator taxa & adding eDNA data did NOT change the IBI scores. There are still limitations in terms of the restorations themselves and in how we evaluate them.

My white whale – An eDNA IBI not part of this project. A story and a caution with AI

Results were better than guessing a stream’s FIBI or BIBI, but not by much and is unreliable based on my attempts – Random Forest, Ordinal Logistic Regression

eDNA is not a replacement for physical sampling, but it substantially adds to the knowledge at each site, even for the fish

Microbial communities are not reliable predictors of condition using my methods

Translation Slides

What are the take home points?
What does this mean for me?

Translation Slides by

Jay Killian, MD DNR, MBSS

Take-home messages from this research

- eDNA detects higher richness in benthic and fish communities not detected using traditional methods (e.g., D-net, electrofishing). This is likely due to:
    1) eDNA samples "all" habitats (e.g., not just 20 ft^2 of best available habitat)
    2) traditional rapid assessment methods do not provide a complete census of all taxa living in a stream.

- eDNA detected subtle biological changes (e.g., addition of taxa) associated with restoration
    - "New" intolerant taxa found downstream, but no changes observed in EPT and other important indicators that would change an IBI

What does this mean for me?

- eDNA used in tandem with traditional methods may provide a more complete picture of the biological changes resulting from restoration

- eDNA is a promising technique for stream bioassessments, however much research is still needed to:
  - Reliably compare results from eDNA and traditional sampling methods
  - Correlate abundance of eDNA with the abundance of actual taxa
  - Determine the best time of year to sample using eDNA
  - Evaluate eDNA performance over habitat types (e.g., blackwater), land use gradients, and biodiversity gradients.
  - How long is eDNA detectable before degrading into something not useful in monitoring?
  - Can eDNA be developed into its own new assessment tool?

ECOSYSTEM SERVICES

ECOSYSTEM PLANNING & RESTORATION

CENTER FOR WATERSHED PROTECTION

Work in the Wet Versus Work in the Dry for Stream Restoration: A Comparison of Downstream Turbidity and Sediment Loads

Carol Wong, CWP; Kip Mumaw, ES
Bryan Seipp, Rich Starr EPR

Pooled Monitoring Forum: Restoration Research to Make Science and Regulatory Connections

Project Hypothesis

H1. The turbidity resulting from Wet Construction will be higher during active construction, but turbidity will not be completely eliminated during Dry Construction, with an expected spike in turbidity when the stream flow is released for the night and elevated levels of turbidity expected for both cases after construction ends for the day.

- H1A. The observed average Turbidity (Average NTU) will be higher during the Wet Construction Period.
- H1B: The estimated hours exceeding Maryland’s turbidity standards for Wet Construction are less than 50% greater than the exceedance time for Dry Construction.

H2. The suspended sediment load associated with Dry Construction will not be meaningfully different than the load associated with Wet Construction, such that absolute difference between total suspended solids loads (lbs.) is less than 25% of the average suspended sediment load between the two methods.

H3. The sediment load associated with the Construction in the Wet or Construction in the Dry will be significantly less than the sediment load associated with the 1.25-year storm for the watershed.

Site Selection

Criteria

Construction within Study Timeframe

Minimum project length

Use of Natural Channel Design

Reliable baseflow for consistent data collection

Confirmed funding

Administrative feasibility and stakeholder cooperation

Process and Selection

Developed a site evaluation form to screen potential projects

Applied Structure ranking system to ensure alignment with research objectives.

Initial pool = 40 sites/ 7 sites met key study requirements/ 3 met study and schedule requirements

Natural Channel Design

Natural Channel Design Priority 2 Restoration

Stream is relocated to a new, stable meandering alignment at the existing floodplain (bankfull) elevation

Constructed within the incised valley, without major regrading of the floodplain

Re-establishes natural stream functions, including:

Floodplain connection during high flows

Sediment transport continuity

Aquatic and riparian habitat enhancement

Structures Used in this Study

Riffle Grade Control

Cascade Structures & Log Cascades

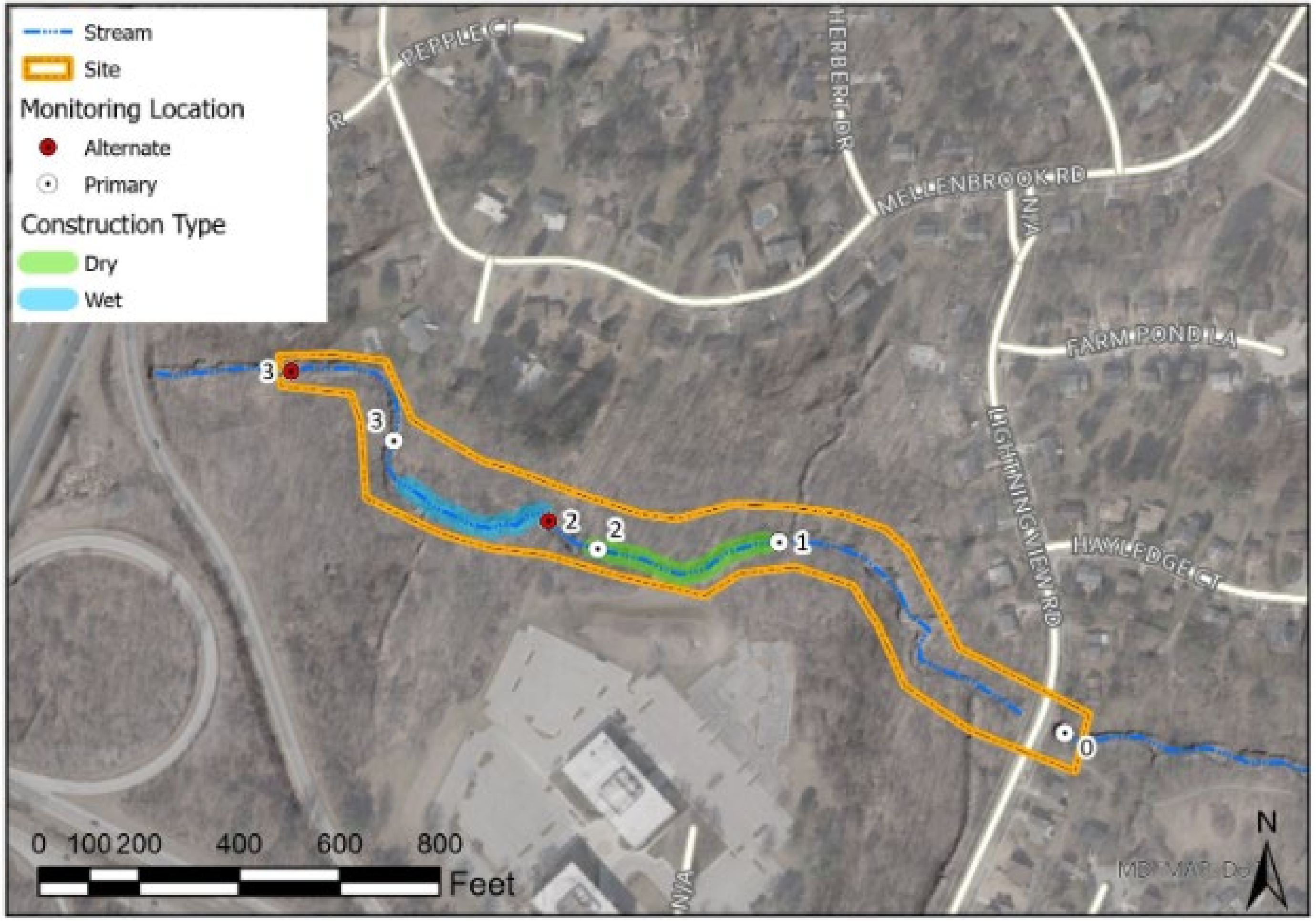
Rock Toe & Boulder Toe

Log Toe & Wood Toe

Pool Enhancements

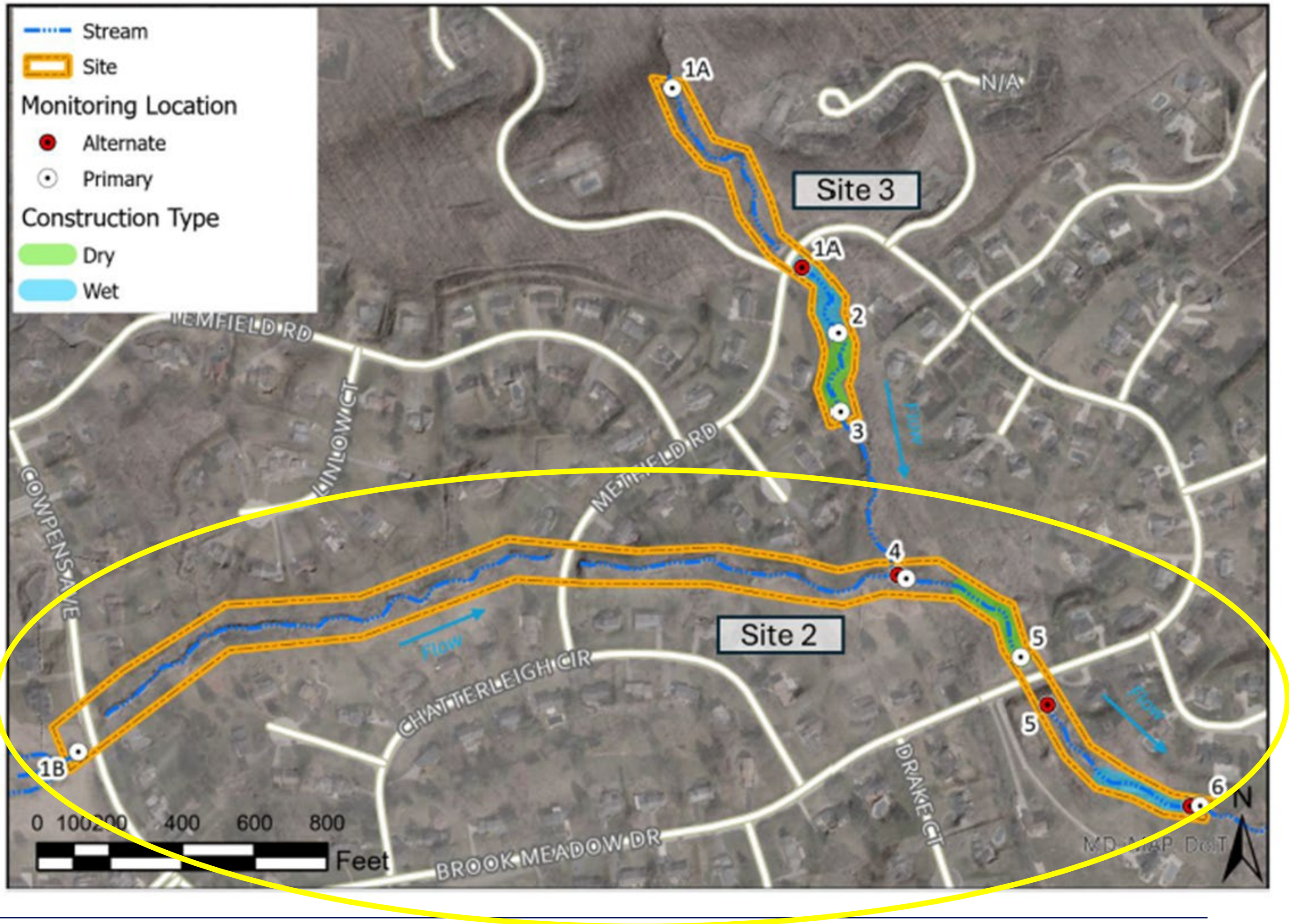
Site 1: Mellen Court

- **Project length= 3022 ft**
- **Study reach = 500 ft**
- **Channel width= 14 ft**
- **Stream Order= 3rd Order**
- **Drainage Area= 0.8 sq. Mi.**
- **Stream Bed Material = Gravel Cobble**
- **NCD Priority 2 Design**



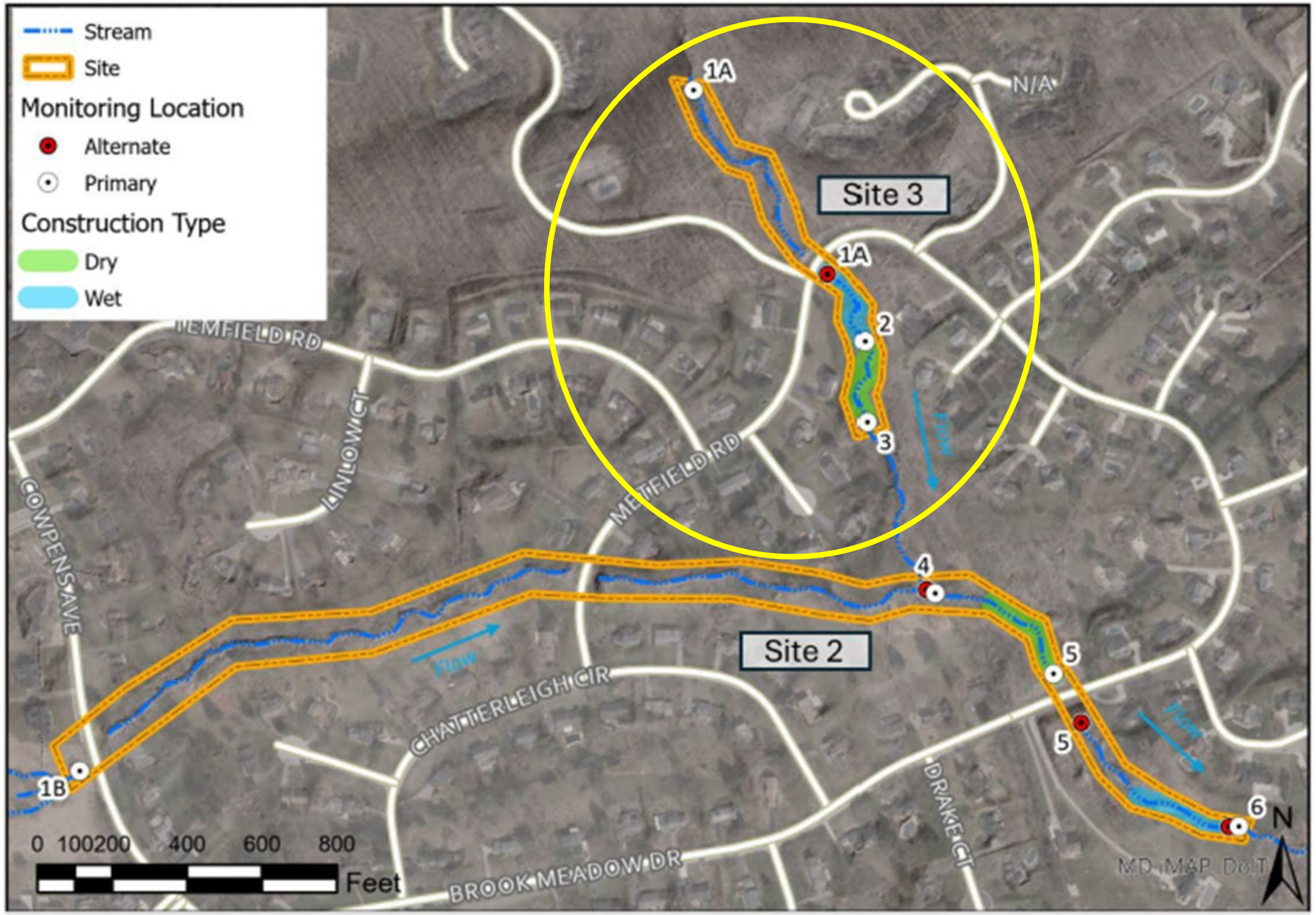
Site 2: Minebank Run At Metfield - Beeches Lower (Minebank Upstream)

- Project length= 4719 ft
- Study reach = 370 ft
- Channel width= 20 ft
- Stream Order= 2nd Order
- Drainage Area= 0.53 sq. Mi.
- Stream Bed Material = Gravel Cobble
- NCD Priority 2 Design

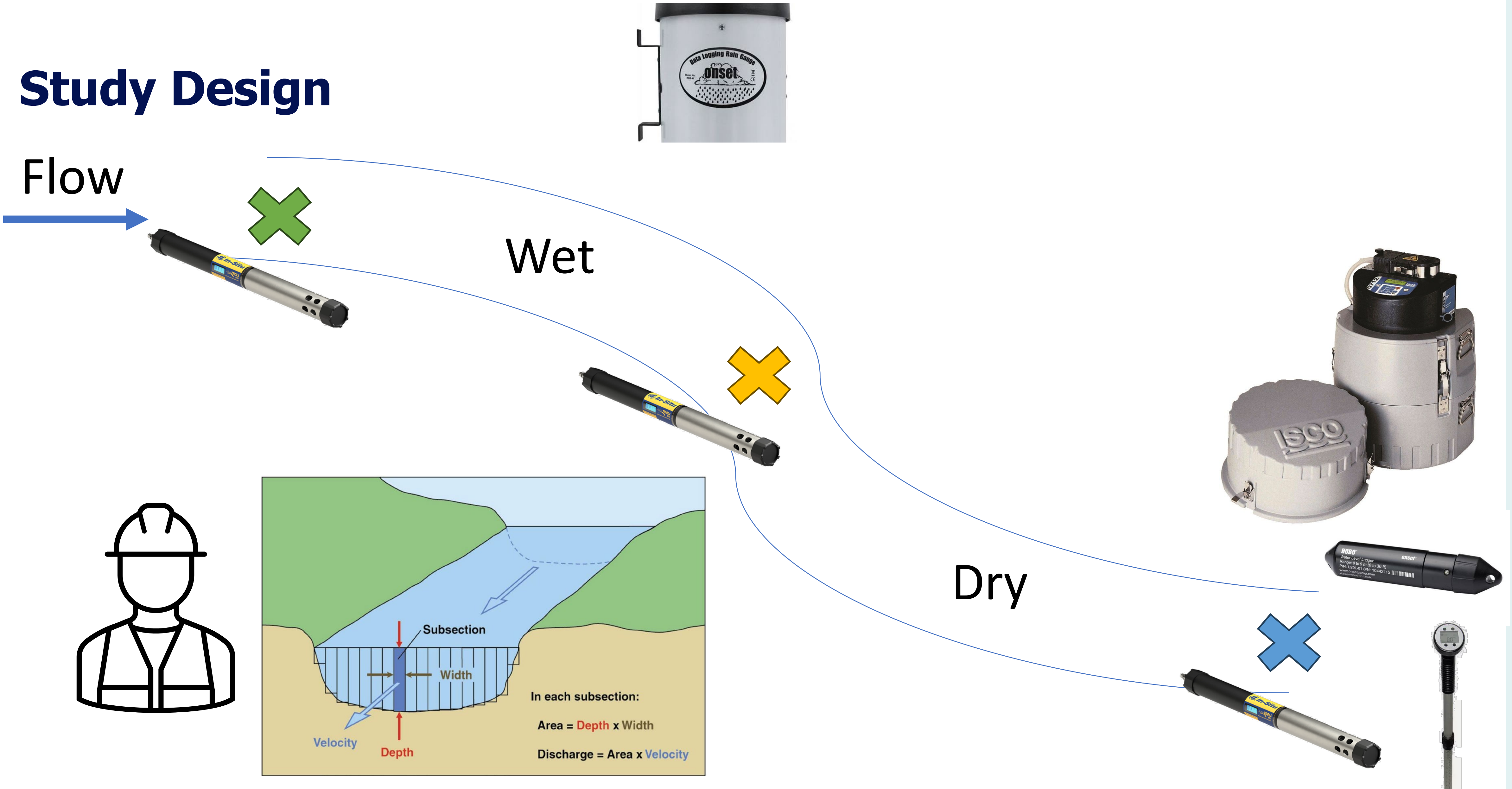


Site 3: Minebank Run At Metfield- Cowpens Lower (Minebank Downstream

- Project length= 1396 ft
- Study reach = 430 ft
- Channel width= 9 ft
- Stream Order= 1st Order
- Drainage Area= 0.13 sq. Mi.
- Stream Bed Material = Gravel Cobble
- NCD Priority 2 Design

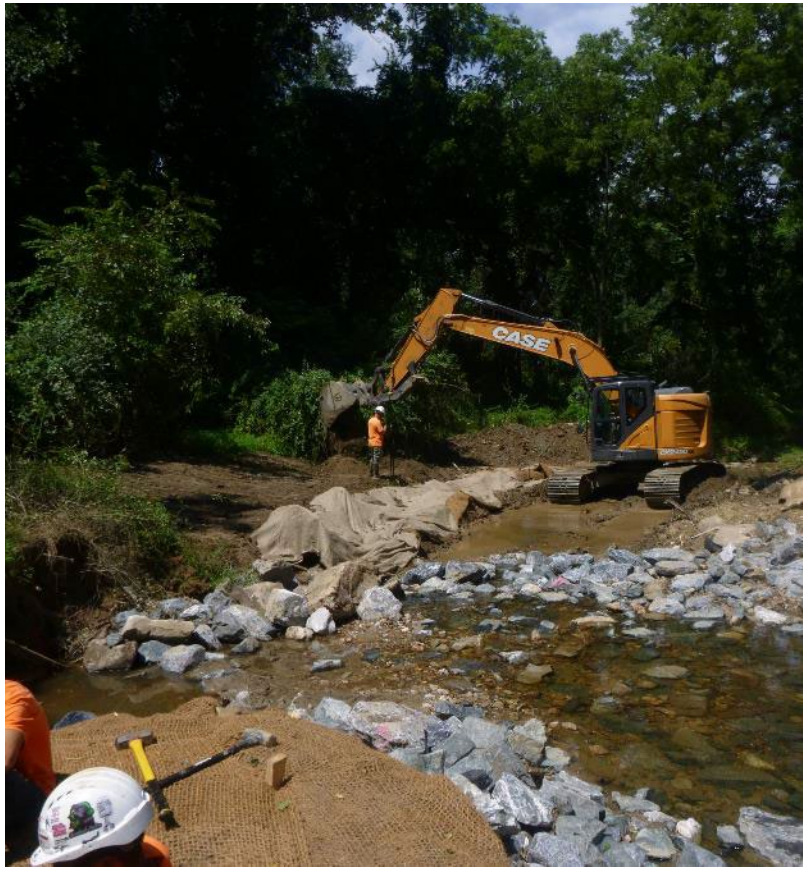


Study Design



Site 1: Mellen Ct. Setup

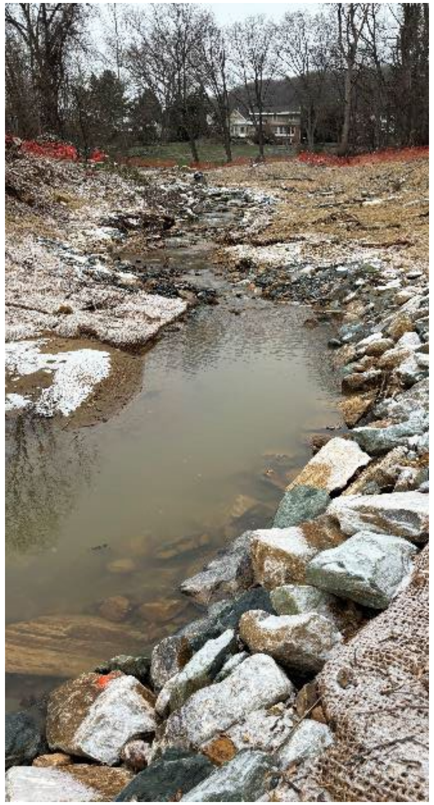
Site 1: Mellen Ct. Work in the Dry



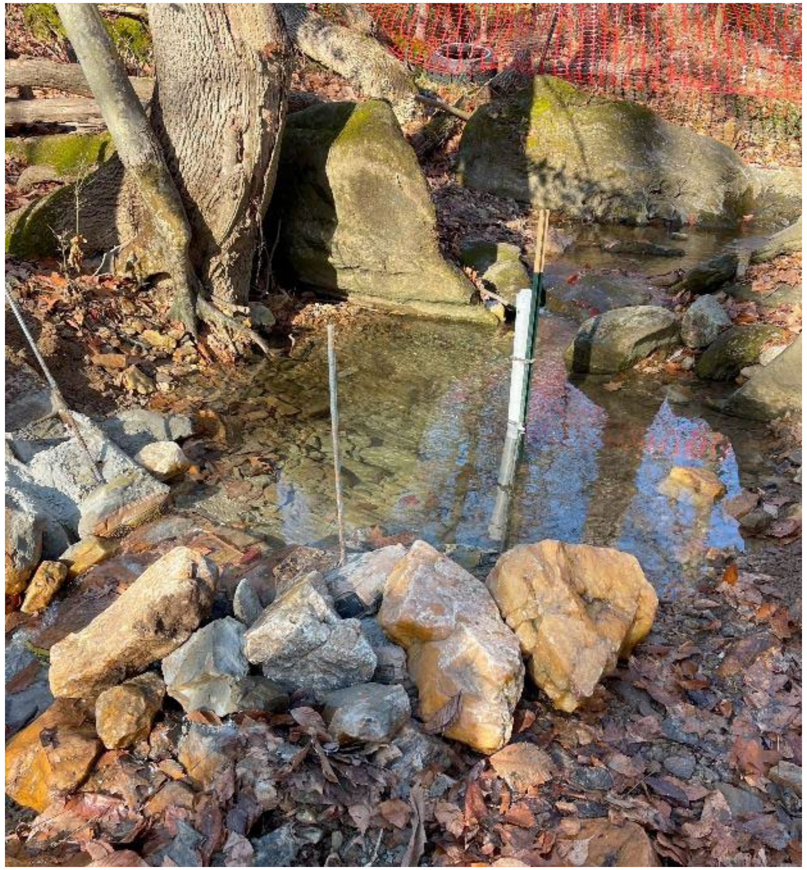
Site 1: Mellen Court Work in the Wet

Site 2: Minebank (Downstream) Setup

Site 2: Minebank (Downstream) Work in Wet



Site 2: Minebank (Downstream) Work in Dry

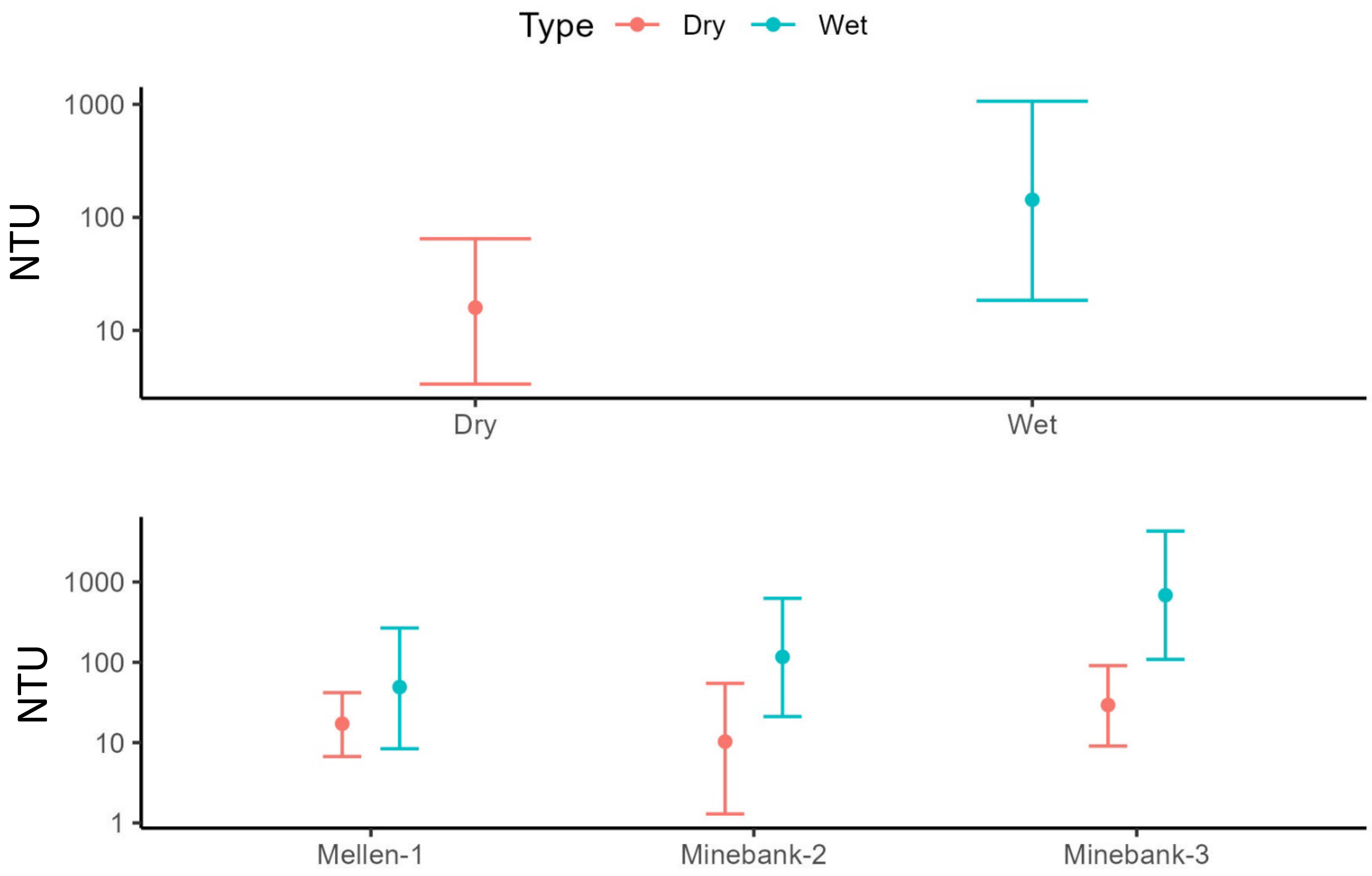


Site 3: Minebank (Upstream) Setup




Site 3: Minebank (Upstream) Work in Wet

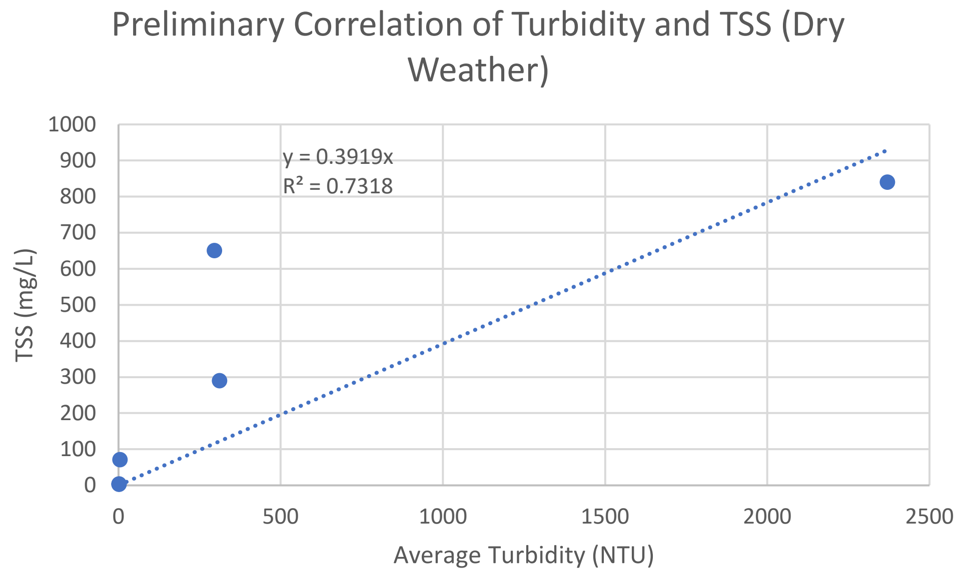
Average Turbidity (Hourly)

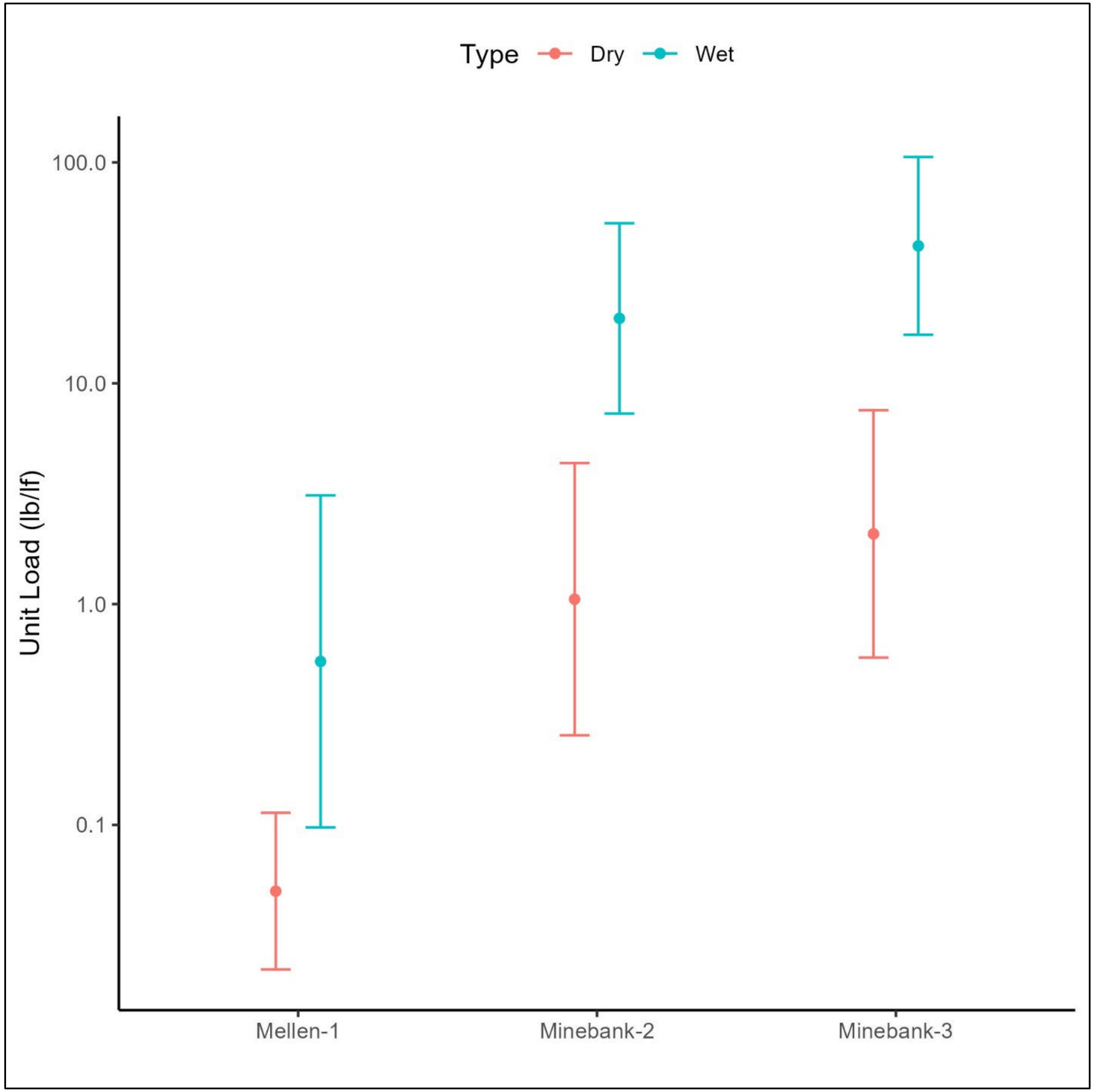


With all sites combined, graph to the left shows average hourly turbidity during construction in the wet and the dry. Note: the y-axis is in log scale.

The same information as above and broken down by site. Red is construction in dry stream and blue is construction in a wet stream. Note: the y-axis is in log scale.

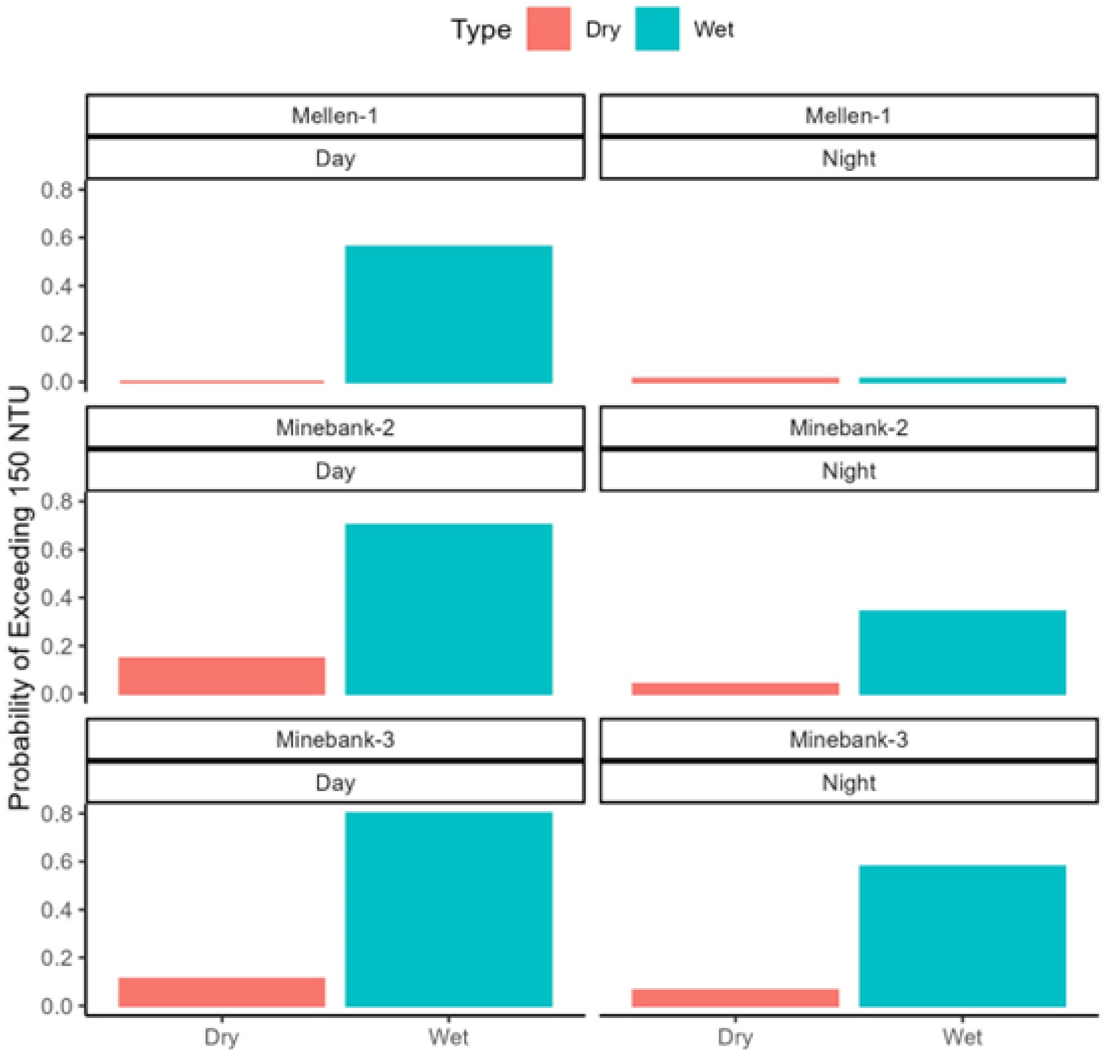
Total Sediment Load (lb)





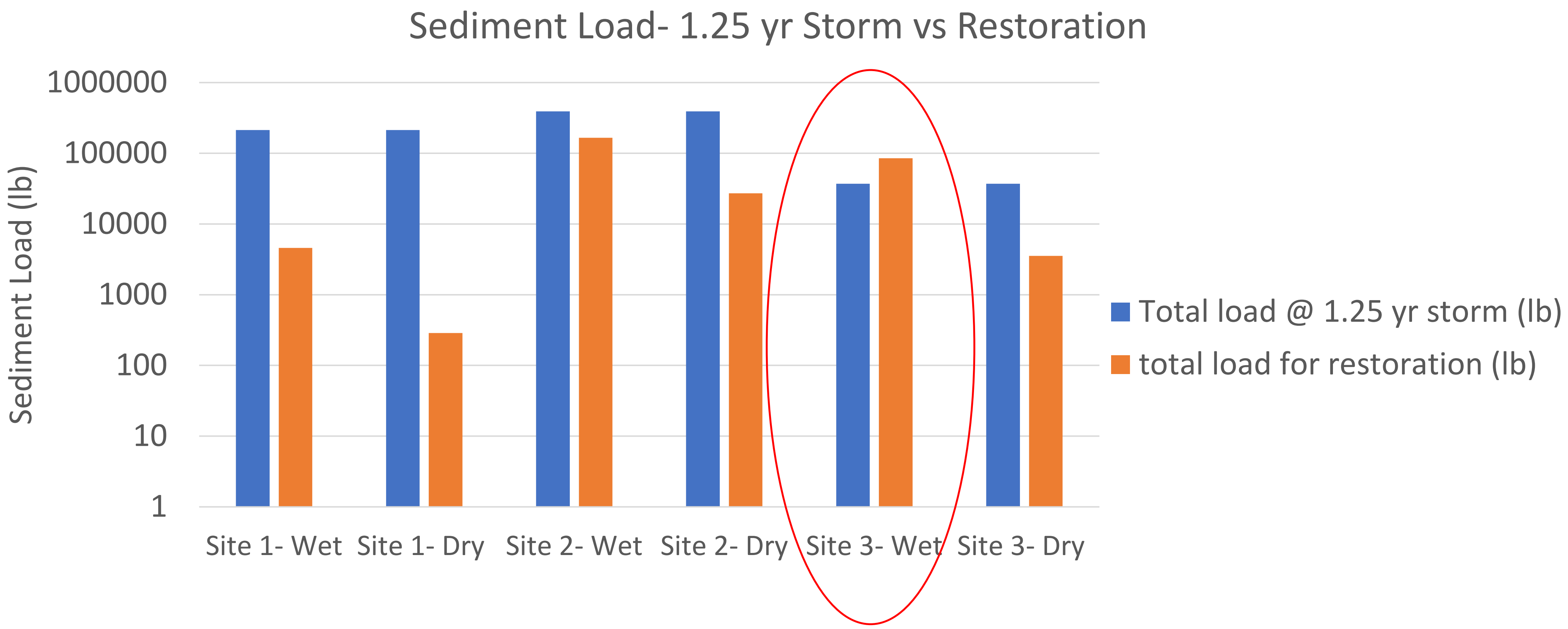
The graph to the right is comparing the total sediment per linear foot at each site, separated by dry construction and wet construction. Total load was calculated used the turbidity data, the correlation curve (above) and flow

Percent Exceedance of 150 NTU for Dry and Wet Construction



The probability of exceeding the benchmark of 150 NTU at each site, divided by type of construction (dry or wet) and time of day (day or note).

Sediment Load- 1.25 year storm



Take Home Summary

- **Hypothesis 1A – Turbidity Levels:**
  Wet construction significantly increases turbidity downstream compared to dry construction (avg. 5.7x higher; $p < 0.001$).
- **Hypothesis 1B – Regulatory Exceedance:**
  Probability of exceeding Maryland's 150 NTU turbidity standard is ~16.6x higher during wet construction ($p < 0.001$).
- **Hypothesis 2 – Suspended Sediment Load:**
  Suspended sediment load from wet construction is ~16x higher than from dry construction ($p < 0.001$), far exceeding the 25% difference threshold.
- **Hypothesis 3 – Comparison to 1.25-Year Storm:**
  At two of three sites, construction (wet or dry) contributed less sediment than the 1.25-year storm. Site 3 is an outlier—wet construction exceeded storm load, cautioning against broad generalizations.

Construction pace differences between wet and dry methods ranged from 9% to 15% across sites. Sites 1 and 3 were completed more quickly using dry methods, while Site 2 was faster with wet construction.

Thoughts and Lessons Learned

- **Monitoring location**
  - Turbidity changes based on distance from construction
  - Incomplete mixing during monitoring in 1st order steams due to low flow
- **Construction efficiency**
  - Difficult to capture differences between different work crews which can impact the efficiency or general pace of a project
  - Difficult to gage crew efficiency due to smaller streams and short reaches
- **Construction sequence**
  - Sediment storage capacity at new reaches and sediment travel
- **Study methodology**
  - Equipment maintenance and inspection frequency
  - Weir design needs careful consideration to allow for proper mixing
  - Standardized, detailed construction log during monitoring
  - Limit relocation of monitoring equipment

Acknowledgments

Ecosystem Planning & Restoration (EPR)

Center for Watershed Protection

Ecosystem Services

Baltimore County Maryland

MLS

Chesapeake Bay Trust

Maryland Department of Natural Resources

Anne Arundel County Maryland

Montgomery County Maryland

McCormick Taylor

United States Environmental Protection Agency

Chesapeake Bay Program
A Watershed Partnership

National Fish and Wildlife Foundation
NFWF

Baltimore City DPW
Department of Public Works

MDOT
Maryland Department of Transportation
State Highway Administration

Howard County Maryland

KCI

Maryland Department of the Environment

Charles County Watershed Protection & Restoration

Harford County Maryland

Frederick County, Maryland 1748

Prince George's County Maryland

SMC

THANK YOU!

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Translation

Ben Green; Frederick County (MD)

- Stream restoration projects are complex.
  - **Only 8% of potential sites were available for this study.**
- There is a process in place that can be utilized in future research to expand this dataset.
  - **Incentives for future participation?**
- Regarding varying subwatershed characteristics: Greater understanding of these research questions could add another tool to the toolbox.
  - **Provide more opportunities for implementing our projects and better serving our communities.**

Soil Health Metrics for Assessment of Stream and Floodplain Restorations

Shreeram P. Inamdar, Joseph Galella, Md. Moklesur Rahman, Eric Moore, Marc Peipoch, Jinjun Kan, Alexis Yaculak, Matthew Sena, Bisesh Joshi, and Sujay Kaushal

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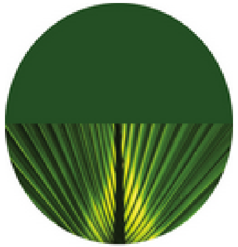

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Soil Health Metrics for Assessment of Floodplain Restorations

Joseph George Galella[1], Md. Moklesur Rahman[1], Eric Moore[1] Marc Peipoch[2], Jinjun Kan[2], Alexis M Yaculak[3], Matthew Sena[4], Bisesh Joshi[3], Sujay S Kaushal[5], and Shreeram Inamdar[1*]

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Should be online anytime now….

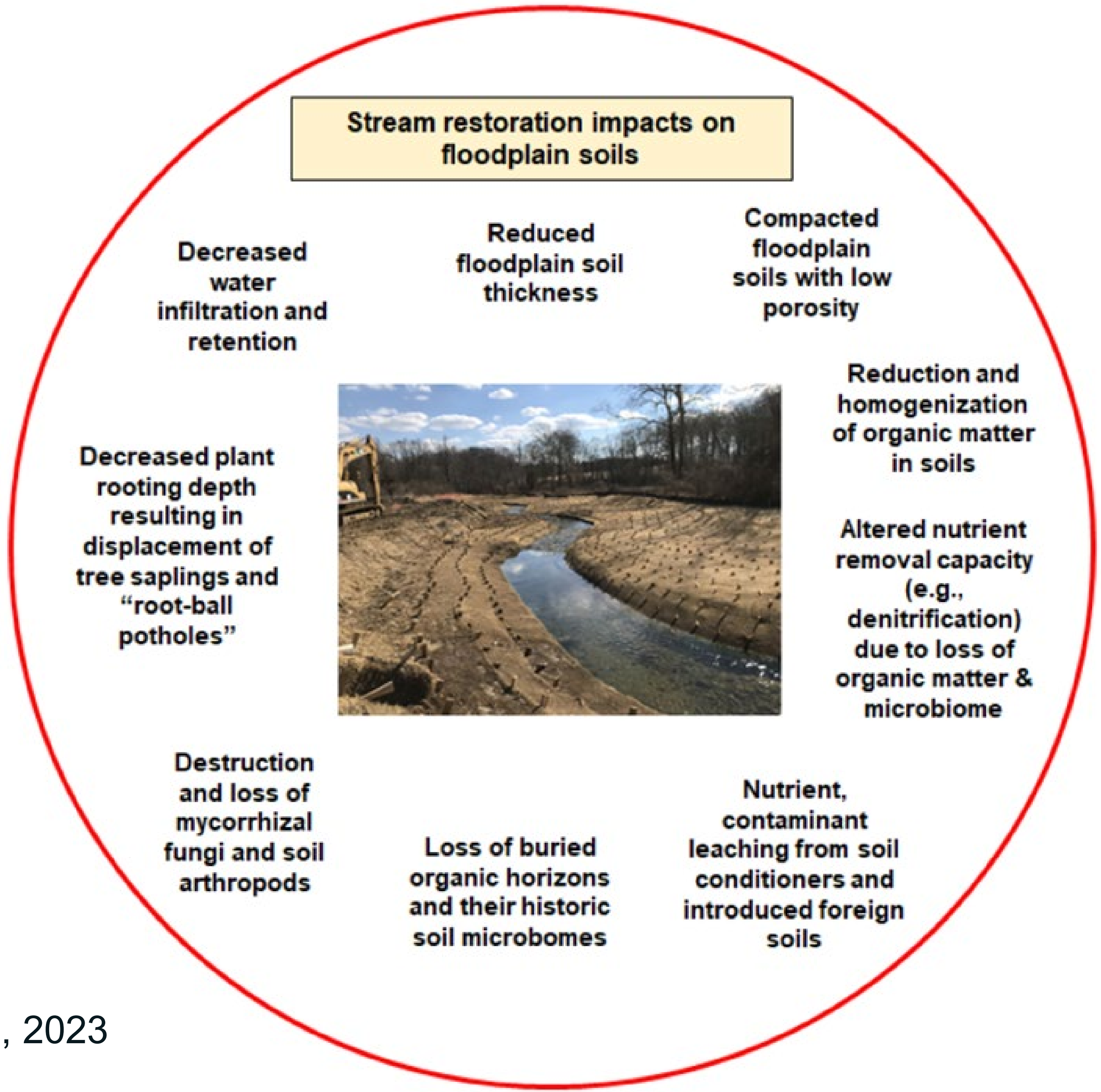
Stream Restoration – Water Quality & Ecological Uplift

- Key tool to mitigate nutrient pollution and meet regulatory TMDL goals
- **Provided important gains in erosion control & water quality improvement**
- **But some challenges remain with ecological uplift**

Soil Health – a key missing component

- **Lack of soil health contributing to some of the unattained ecological uplift?**

- **What is Soil health?** – **soil physical, chemical & biological properties** that **enhance ecosystem services** – infiltration, erosion control, nutrient removal & cycling (e.g., denitrification), plant growth & resilience, microbial and insect habitat, etc.



Inamdar et al., 2023

Why isn't Soil Health considered in restorations?

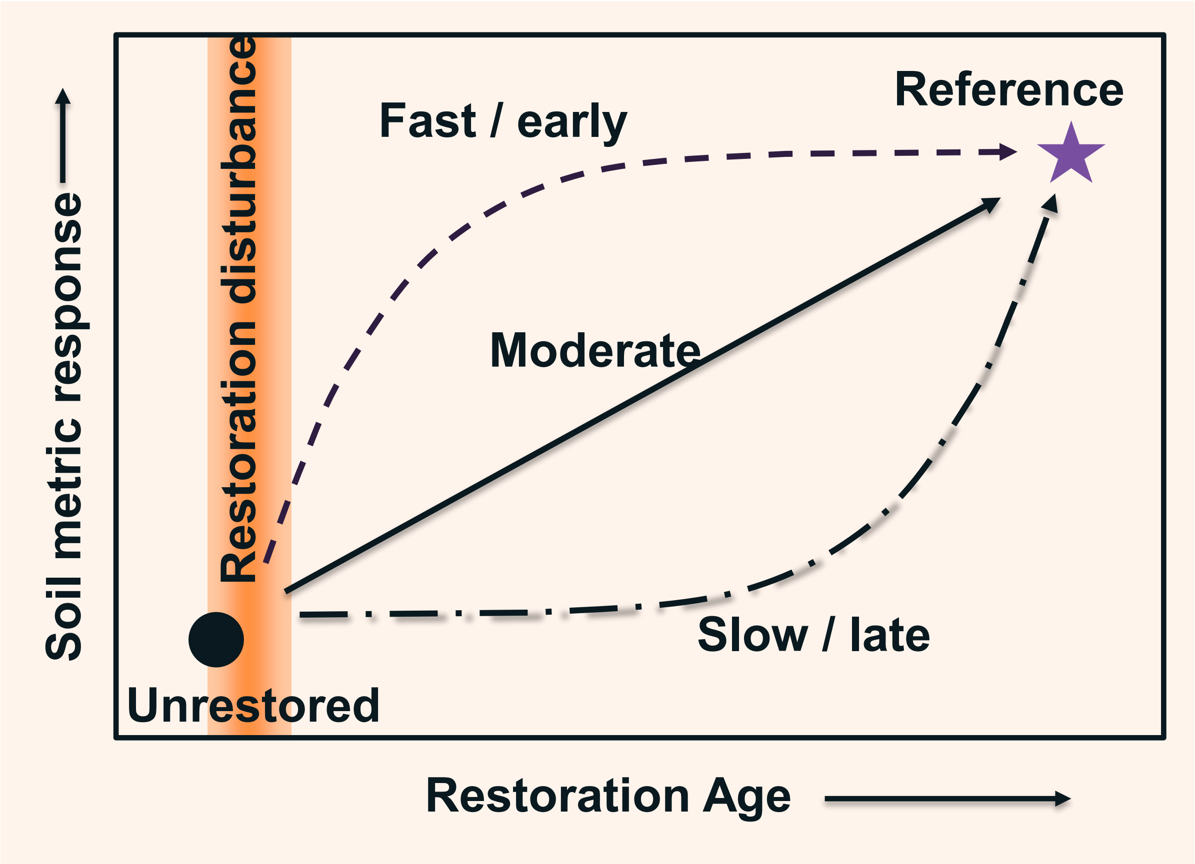
- Lack of knowledge on soil health and its important consequences
- Absence of specific design & implementation "best practices"
- **Unavailability of specific soil metrics & tests**
- **Unknown "Desired" or "reference" soil conditions**
- Lack of regulatory credits or benefits for restoration agencies

Main Research Questions

- **How does soil health change following restoration?**
- **Which soil health metrics are sensitive and show consistent change?**
- **How do the restored soil health metrics compare against those for "*reference*" floodplains?**

….answers for researchers & restoration practitioners

Hypothesis: different rates of change in soil metrics



Some soil health metrics will recover quickly others may take time

Site Selection

- **11** restoration sites
  - across various post restoration age categories
- **2** minimally disturbed "reference" sites
- All restorations were NCD in design, with additional floodplain reconnection and RSC elements in design

Age Category (yrs)	Sites Sampled
0 - 2	2
2 - 5	3
5 - 10	3
10 - 22	3
Reference	2

Reference Sites

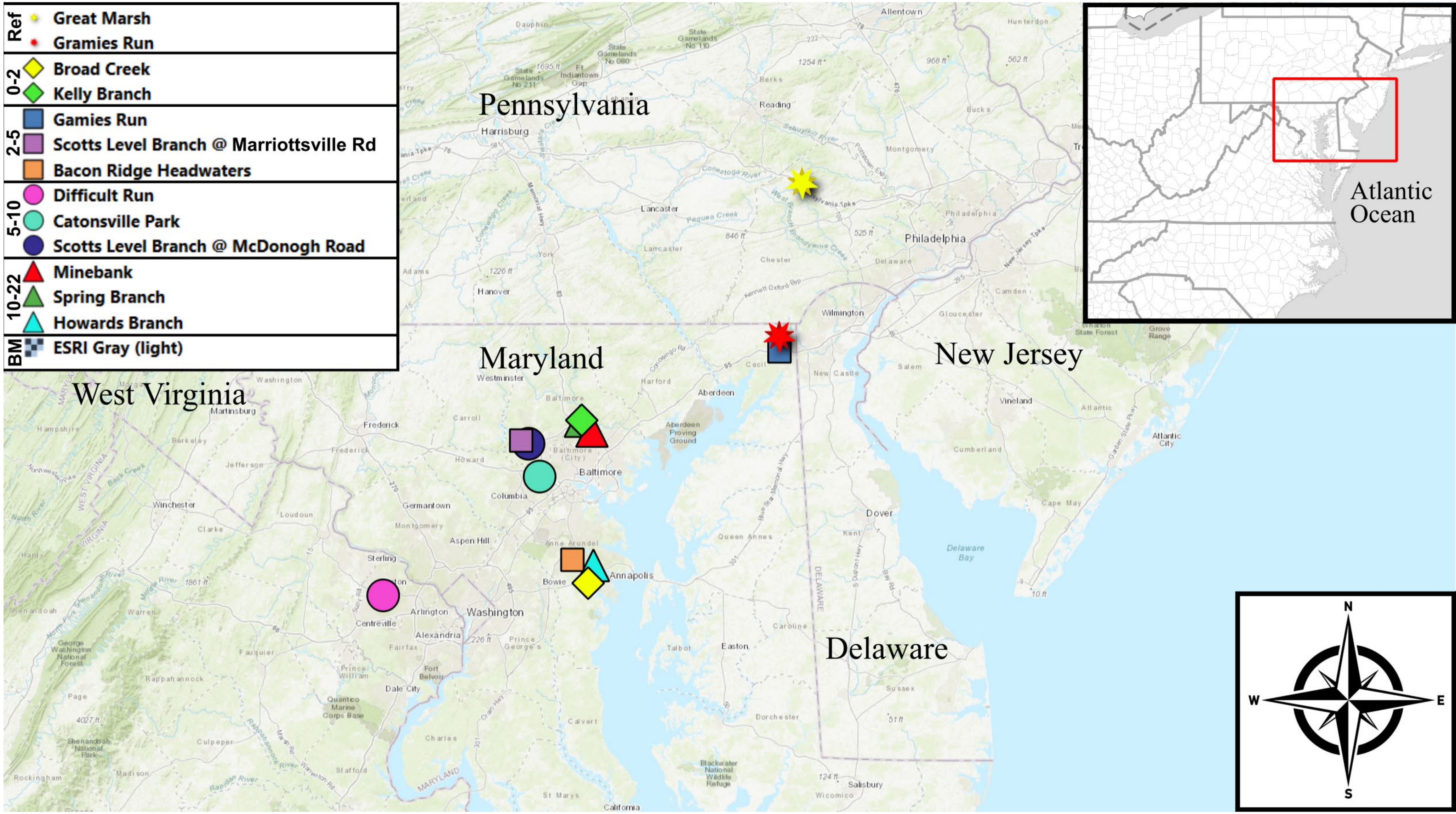
Gramies Run floodplain wetland, MD –

proximal to Gramies Run restoration

Great Marsh, PA –

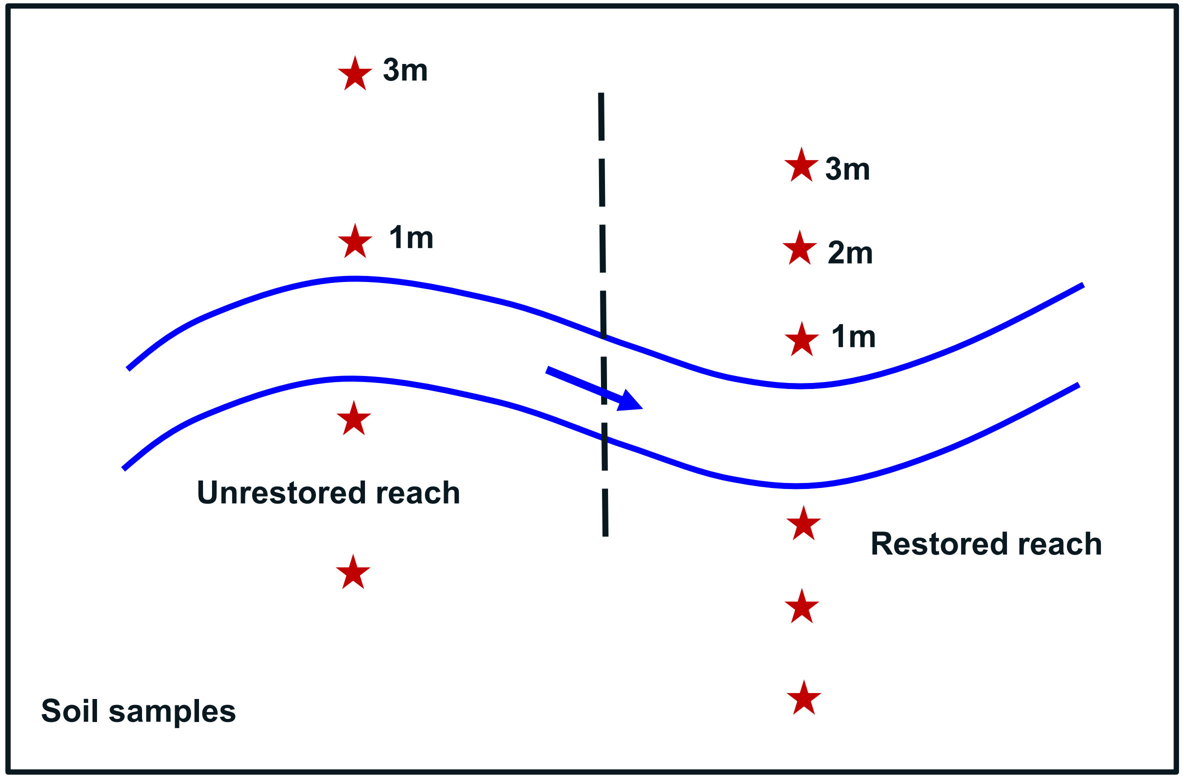
Undisturbed early Holocene freshwater marsh

Samples Collected in Mid-Atlantic



Samples Collected in Mid-Atlantic

Top 6-8 inches composite sample



10 samples per site – 6 restored; 4 unrestored

5 random samples at each reference

Variety of Soil Health Metrics Measured

Physical	Chemical	Biological
Bulk Density (g/cm^3)	Ammonium (ppm), Nitrate (ppm)	Actinomycetes (ng/g)
Gravimetric Water Content (%)	Total Nitrogen (%), Phosphorus (ppm)	Arbuscular Mycorrhizal Fungi (ng/g)
Volumetric Water Content (%)	Calcium (ppm), Magnesium (ppm)	Functional Group Diversity Index
Macroaggragates (% >0.25mm)	Potassium (ppm), Sodium (ppm)	Gram Negative Bacteria (ng/g)
Microaggragates (% <0.25mm)	Base Saturation (%), CEC (meq/100g)	Gram Positive (ng/g)
Sand (%)	Organic Carbon (%), Organic Matter (%)	Saprophytic Fungi (ng/g)
Silt (%)	Soil pH,	Total Bacteria (ng/g)
Clay (%)	Boron (ppm), Cobalt (ppm),	Total Fungi (ng/g)
	Copper (ppm), Iron (ppm),	Total Living Microbial Biomass (ng/g)
	Manganese (ppm), Zinc (ppm)	Undifferentiated (ng/g)

Most metrics are easily accessible for practitioners but differ in cost

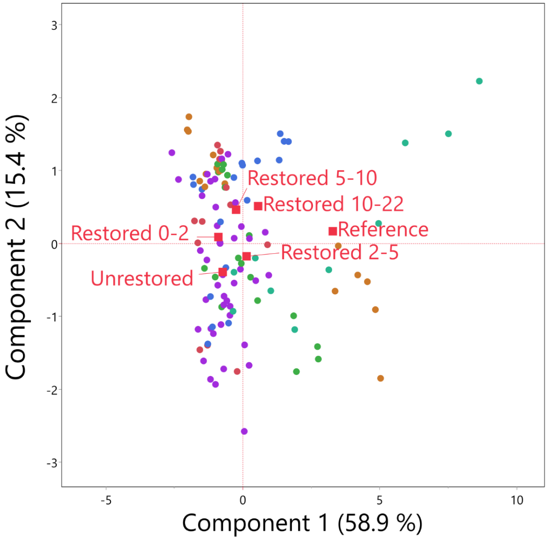
Data Analysis & Evaluation

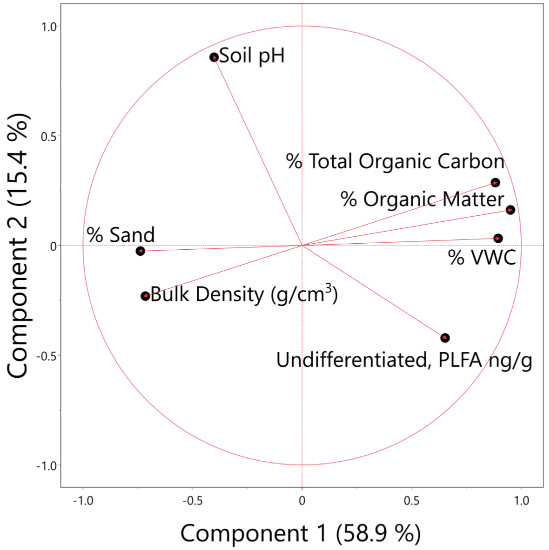
- **Comparisons: unrestored - restored - reference;**
  - **restored for age categories**
- **Principal component analysis** (PCA)
- **Box plot comparisons**
- % Change
- Achieved Restoration (AR) towards reference conditions
- **Years to recovery to reference sites**

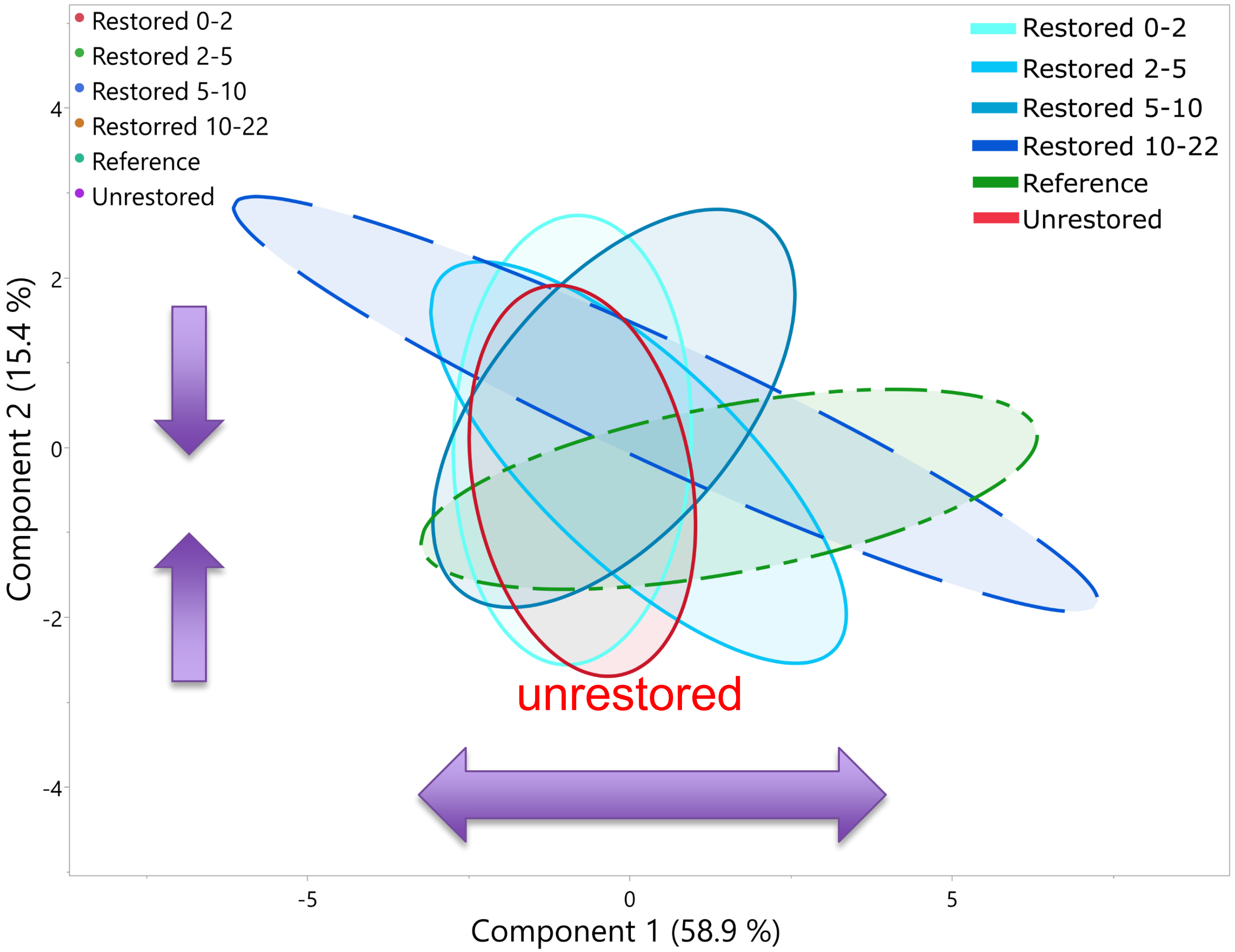
Results

PCA Reveals Distinct Clusters & Evolution of Restored Sites

- Restored and unrestored sites differed
- Restored sites evolved in a distinct manner

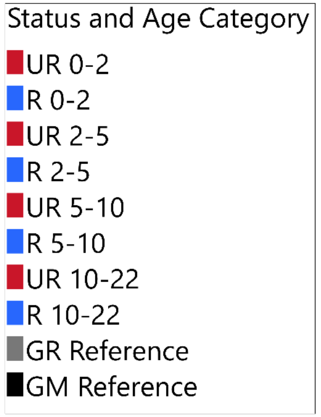


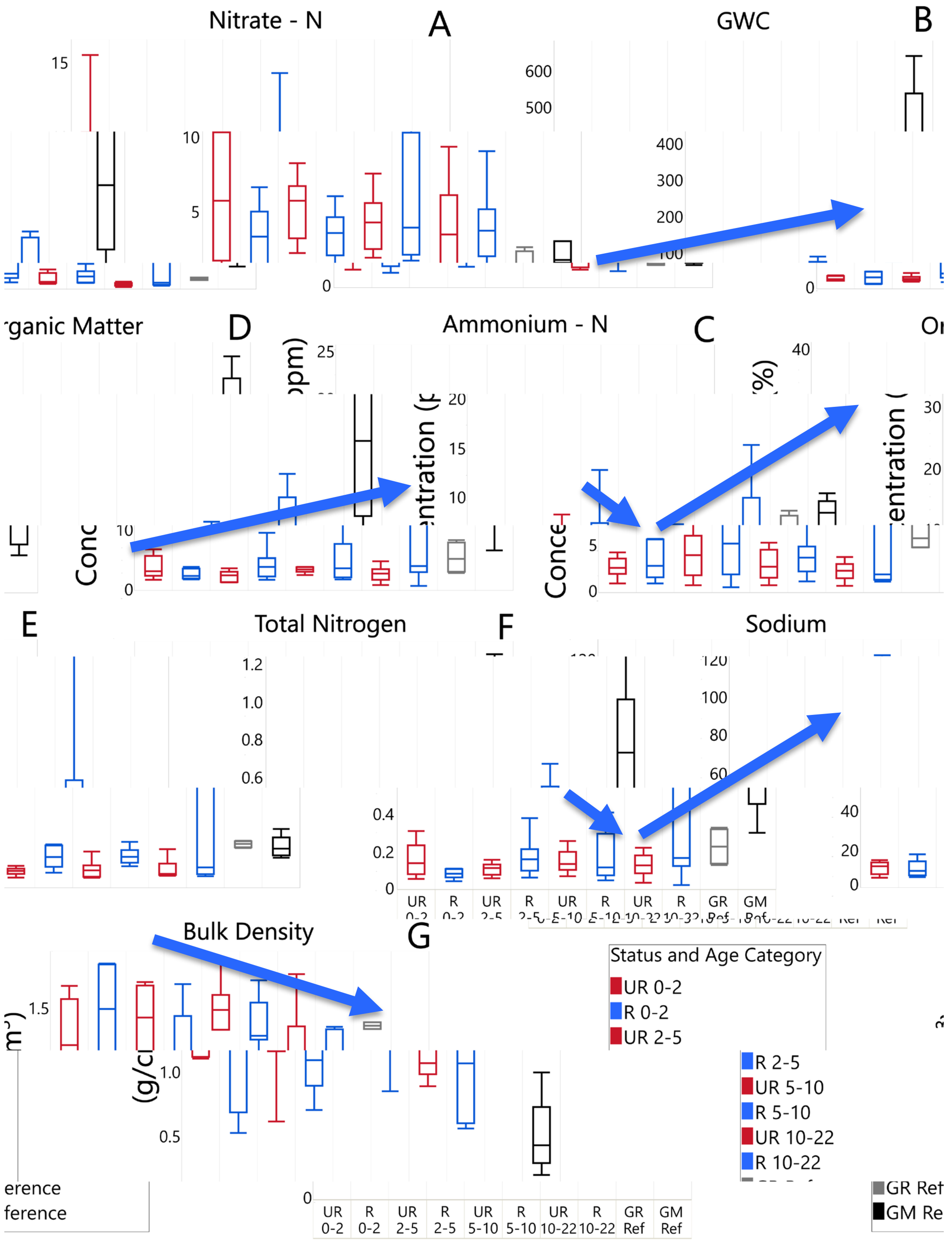




Soil Health Metric Recovery Post-Restoration

Red – unrestored; **blue** - restored; **black** - reference

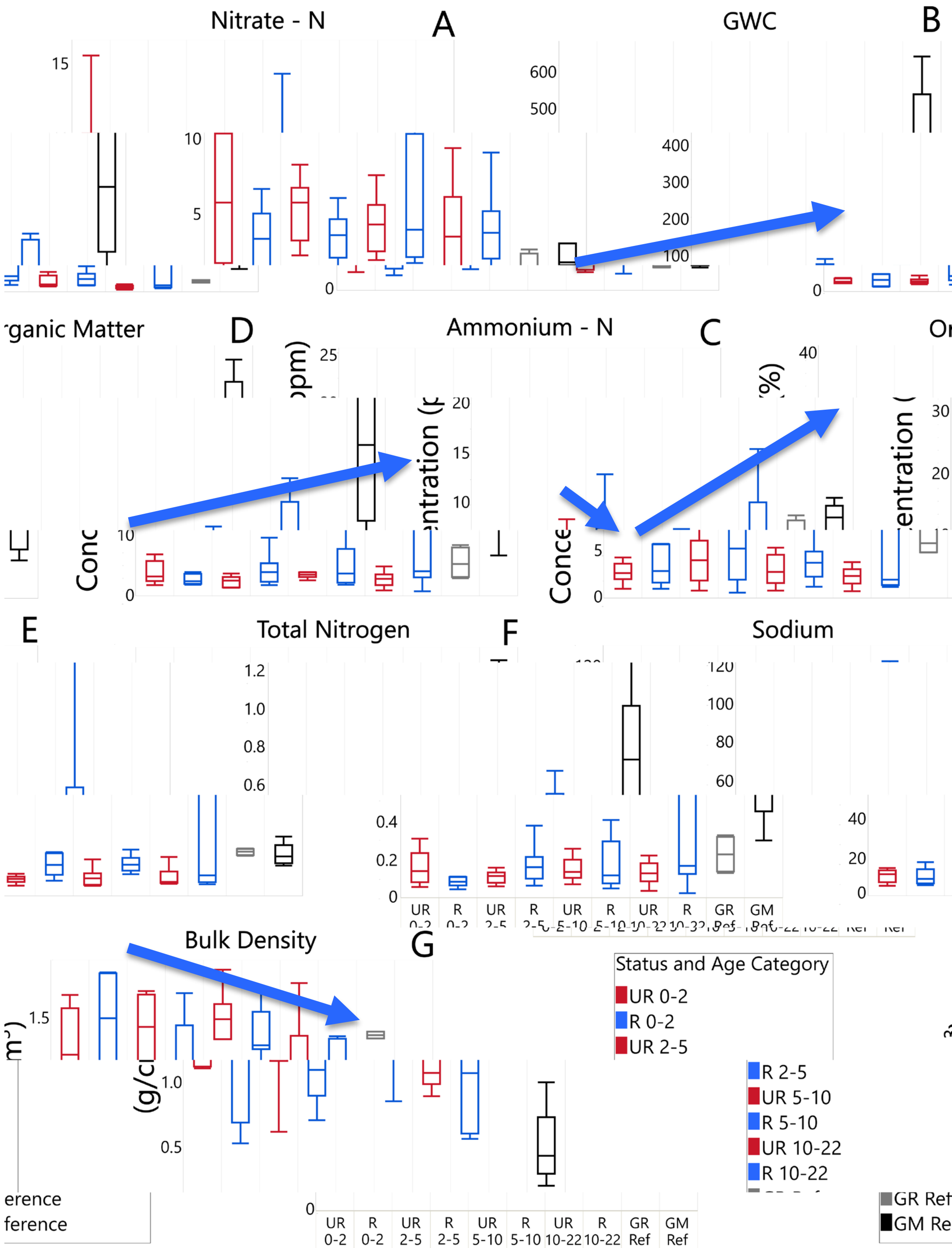




Soil Health Metric Recovery Post-Restoration

Red – unrestored; **blue** - restored; **black** - reference

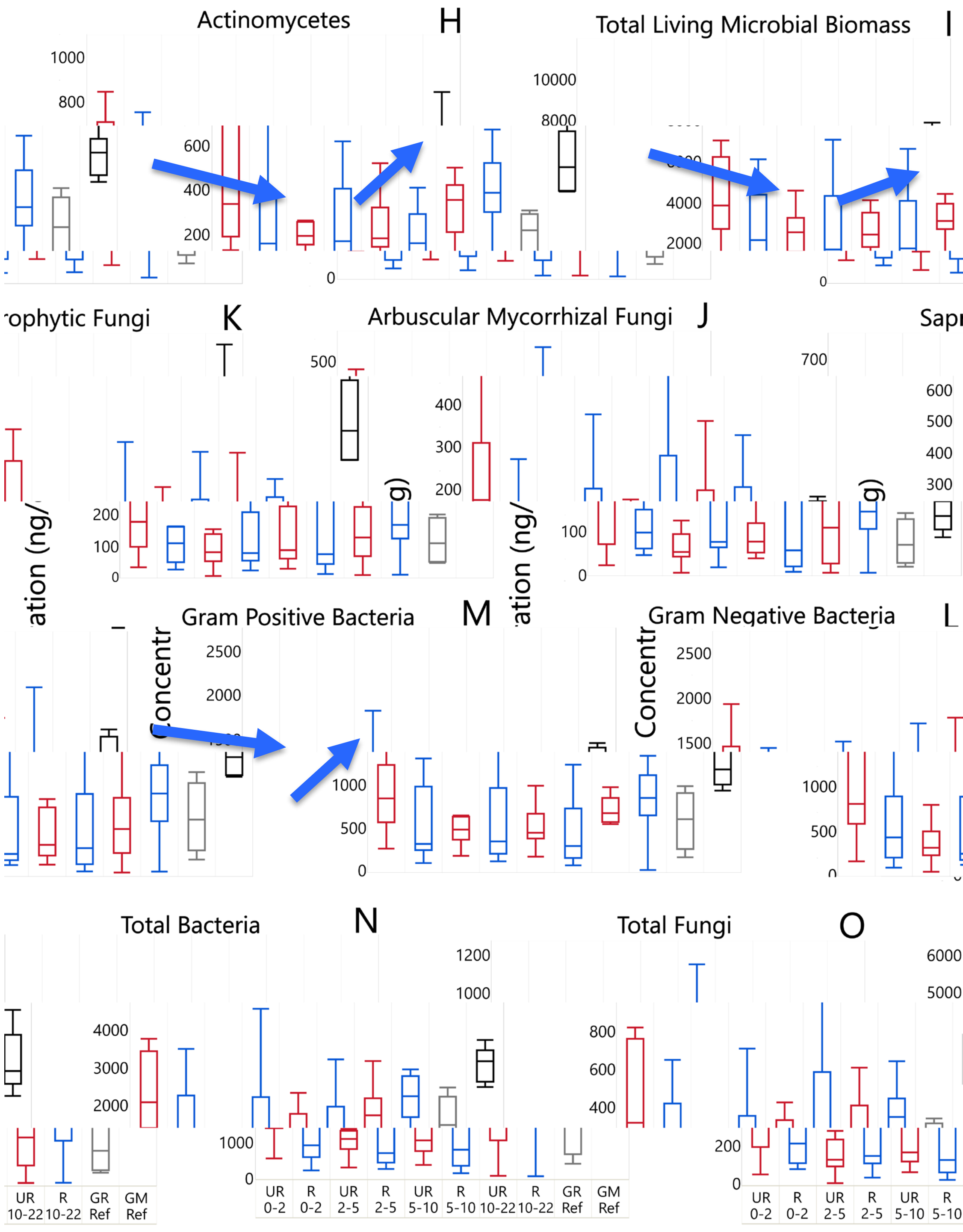
- GWC, organic matter, ammonium, and total nitrogen <u>increased with time</u> after restoration
- Nitrate and bulk density <u>decreased with time</u> after restoration
- **Soil health metrics trended towards** measured **reference condition with time**



Biological (PLFA) Recovery Post-Restoration

- **All microbial groups were negatively affected by restoration for the first decade** after completion

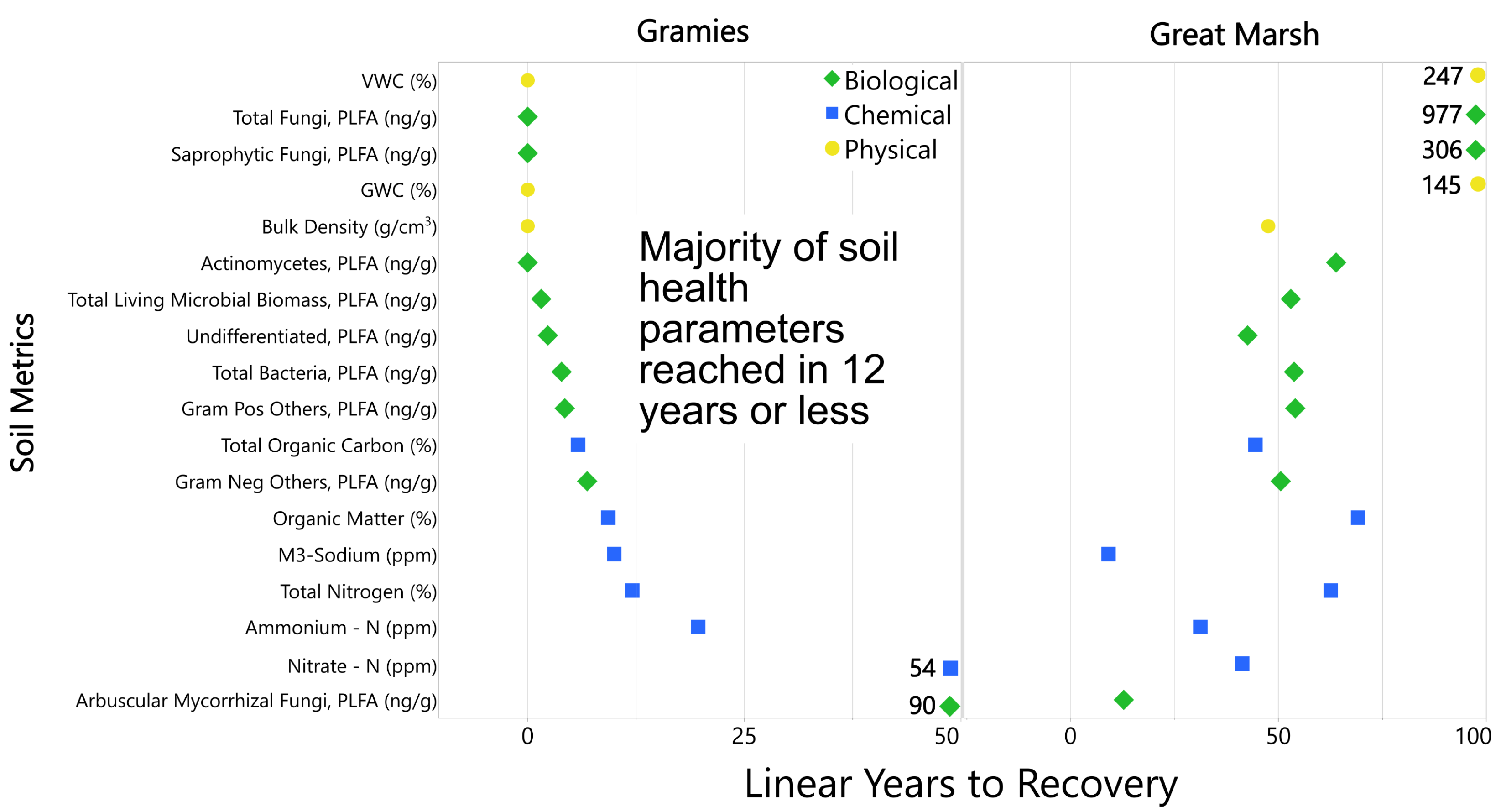
- Slowly recovered



Percent Change

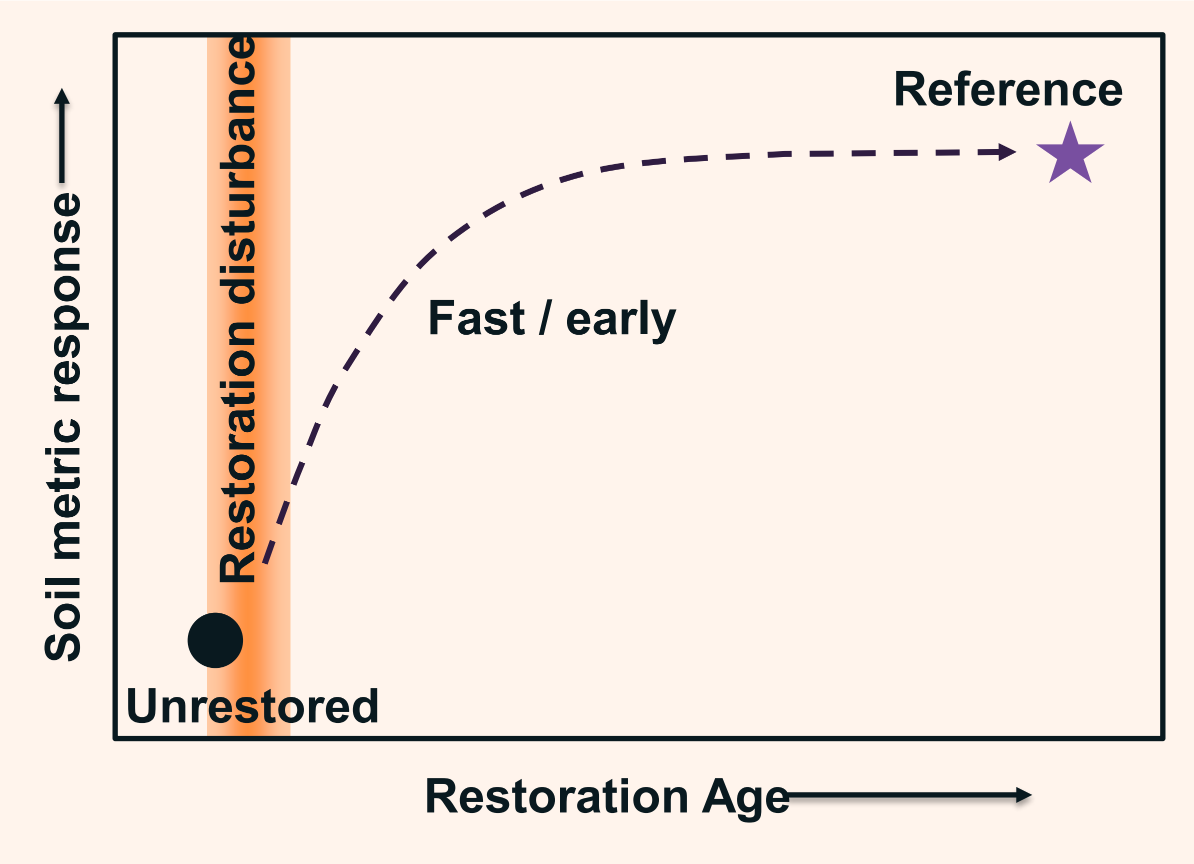
Soil Metrics	% Change 0-2	% Change 2-5	% Change 5-10	% Change 10-22	% Change Overall
Bulk Density (g/cm^3)	3.06	-11.70	-8.70	-16.23	-9.86
GWC (%)	10.15	64.62	31.93	360.68	87.49
VWC (%)	-4.18	32.75	20.22	170.78	39.75
SOM (%)	-16.62	81.73	34.16	182.58	69.65
NO_3^- - N (ppm)	-47.28	-26.23	41.32	-0.28	-9.96
Na (ppm)	-2.79	115.11	88.24	227.05	117.28
SOC (%)	-25.63	92.03	70.80	121.94	74.30
NH_4^+ - N (ppm)	66.89	28.92	29.00	156.87	62.13
Total Nitrogen (%)	-35.88	64.50	18.66	120.89	44.51
Total Living Microbial Biomass PLFA (ng/g)	-36.17	19.89	-14.91	35.25	2.67
Total Bacteria PLFA (ng/g)	-41.86	34.83	-12.10	33.33	4.03
Gram Pos Others PLFA (ng/g)	-38.81	18.09	-24.68	30.53	-1.50
Actinomycetes PLFA (ng/g)	-41.16	21.20	-24.37	22.34	-3.87
Gram Neg Others PLFA (ng/g)	-44.81	68.65	7.36	41.42	13.77
Total Fungi PLFA (ng/g)	-34.13	86.48	10.56	13.18	10.80
Arbuscular Mycorrhizal Fungi PLFA (ng/g)	-35.02	99.55	35.66	0.03	12.96
Saprophytic Fungi PLFA (ng/g)	-33.36	76.98	-6.54	26.38	9.00

Years to Recovery with respect to Reference Sites



- **Years to recovery differed with choice of reference sites**
- Gramies – floodplain wetland - more achievable in a realistic time frame
- Great Marsh – freshwater emergent marsh - at the higher end?
- **Selection of reference sites important - type, restoration goals**

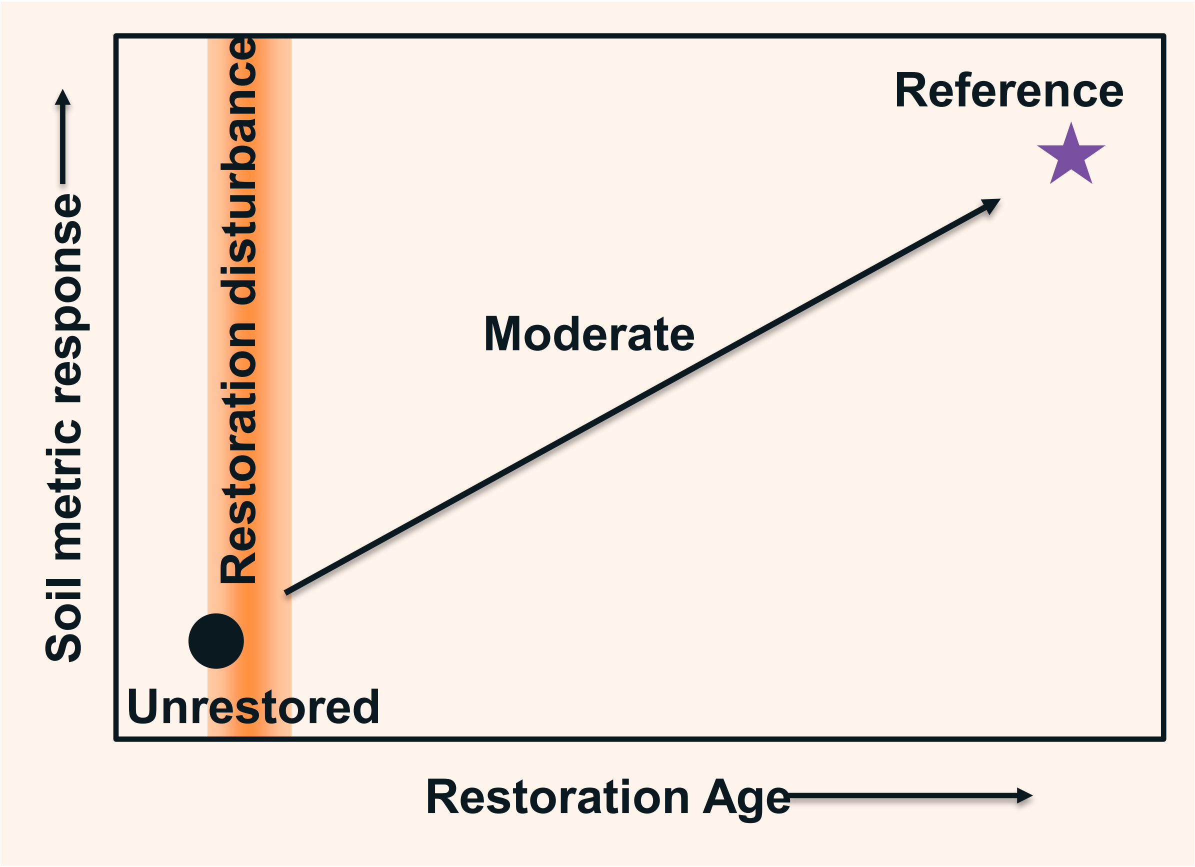
Soil metrics – fast / early - 0-2 yrs



- **Gravimetric Water Content ↑**
  - Regrading and reconnection of floodplain
- **Nitrate - N ↓**
  - Increased Denitrification
- **Ammonium - N ↑**
  - Increased Mineralization

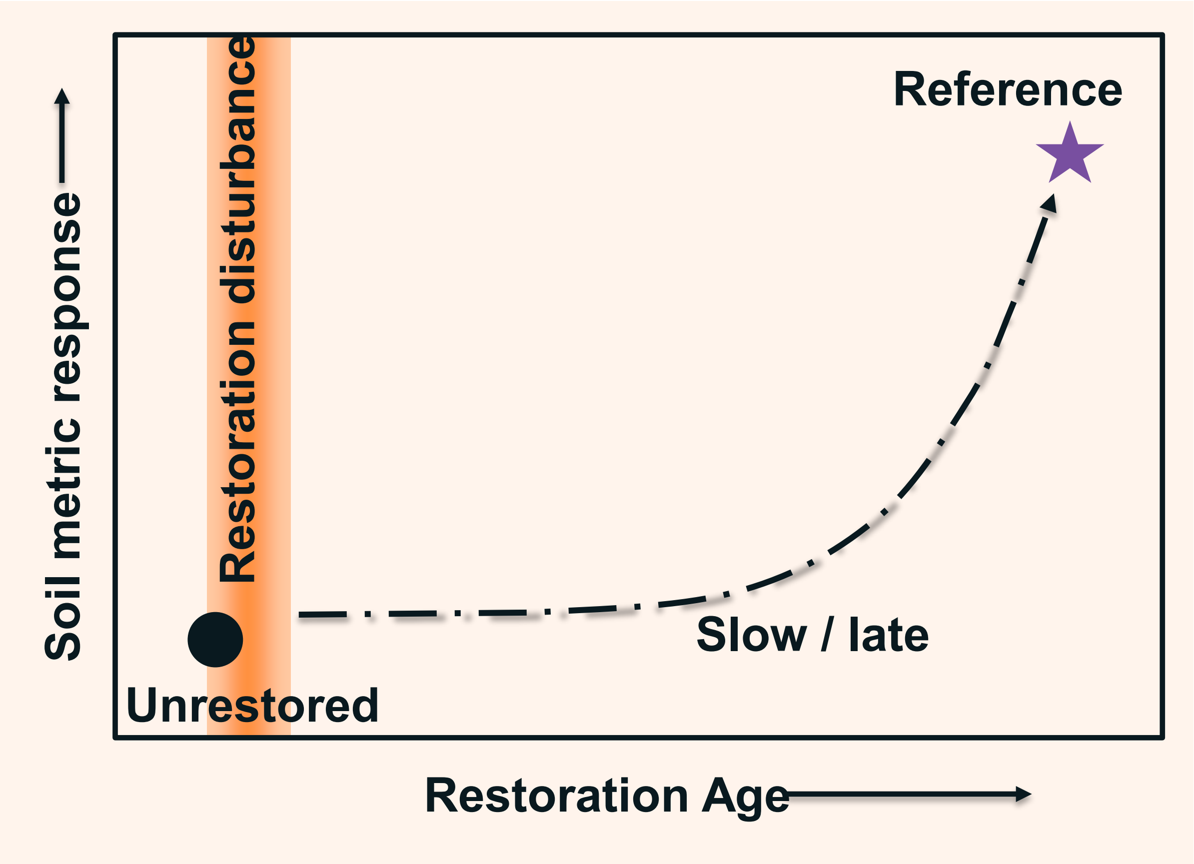
Soil metrics – moderate – 2-10 yrs

- **Bulk Density ↓**
  - Recovers after compaction from heavy machinery
- **Total Nitrogen ↑**
  - Increased biomass in nitrogen cycle
- **Organic Matter ↑**
  - Increased vegetation



Soil metrics – slow > 10 yrs

- **All microbial metrics**
  - Total Living Microbial Biomass
  - Total Bacteria
  - Total Fungi
  - Actinomycetes
  - Arbuscular Mycorrhizal Fungi
  - Saprophytic Fungi
  - Gram Negative Bacteria
  - Gram Positive Bacteria



Conclusions

- Our study identified soil health metrics that were sensitive and changed consistently with restoration
- Soil metrics recovered at different rates post restoration
- Future restorations should incorporate a mix of these soil health parameters in their post-restoration monitoring
- Selection of reference sites is critical for realistic recovery metrics and timeframes

Identifying restoration practices and landscape variables that increase native plant establishment and mitigate plant invasion

Gabrielle N. Ripa[1], J. Leighton Reid[1],
Theresa M. Wynn-Thompson[2]
and Jacob N. Barney[1]

[1]Virginia Tech School of Plant and Environmental Sciences
[2]Virginia Tech Department of Biological Systems Engineering

Invasive species are a global threat to biodiversity

Global econ. cost: **$423B**

60% of extinctions driven solely or partly by invasive species

Interfere with restoration goals

IPBES 2023

Can stream restoration encourage invasion?

Disturbance creates establishment opportunities

Increase in “free space”

Soil disturbance

Research Questions

- Determine restoration techniques and environmental factors of existing stream restoration projects that limit invasion of non-native plant species and facilitate native plant establishment.
  - Compare the vegetation community of restored with un-restored stream reaches.
  - Provide recommendations on stream restoration techniques and planting practices that facilitate native plant establishment and minimize colonization of invasive plants.

Research Questions

- Determine restoration techniques and environmental factors of existing stream restoration projects that limit invasion of non-native plant species and facilitate native plant establishment.

  - Compare the vegetation community of restored with un-restored stream reaches.

  - Provide recommendations on stream restoration techniques and planting practices that facilitate native plant establishment and minimize colonization of invasive plants.

Hypotheses

Invasive plant colonization will be correlated with increased resource availability and increased disturbance.

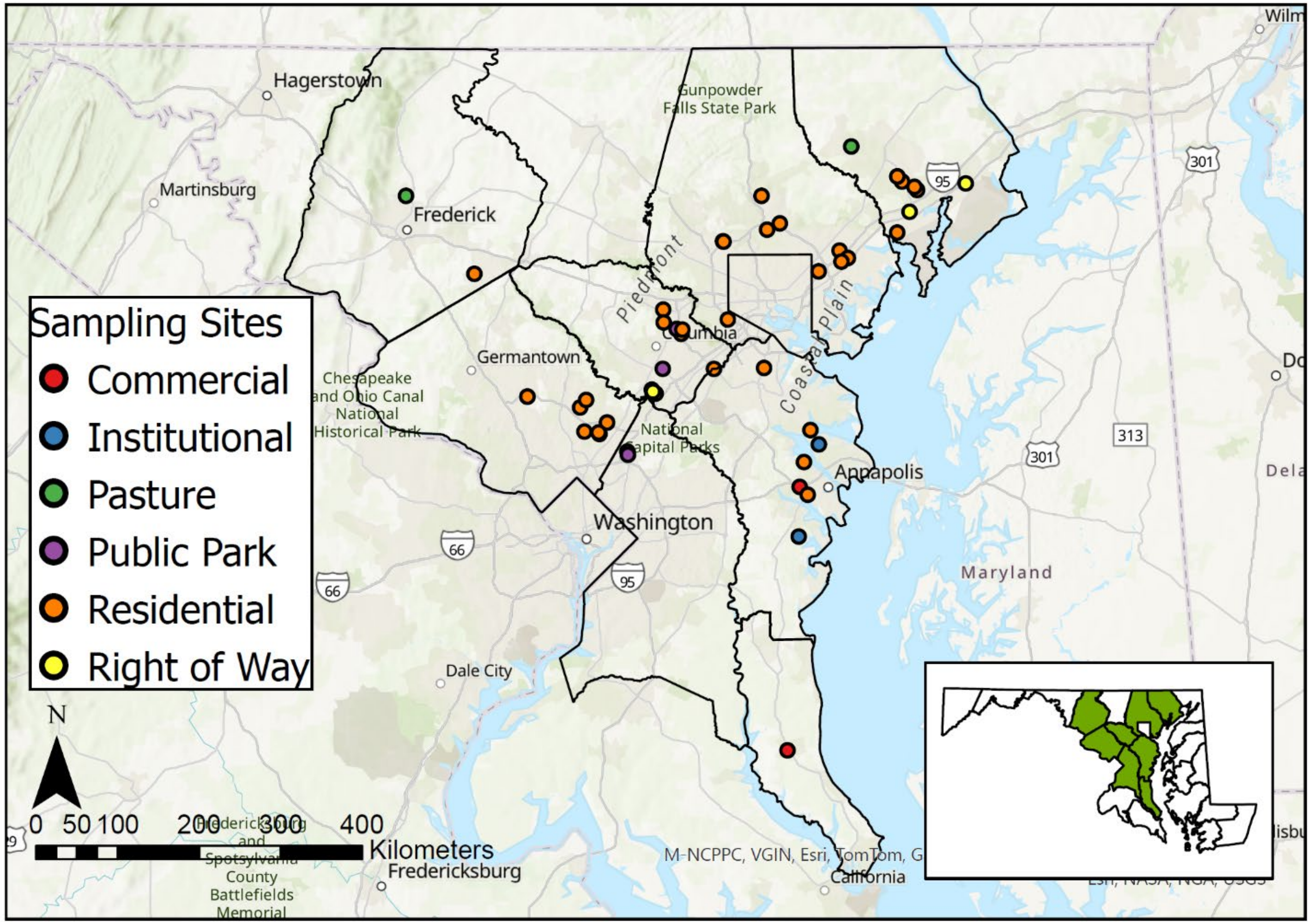
Restored reaches will have greater invasive plant cover than unrestored reaches.

Study Design

46 paired sampling streams (n=92)

- Restored reach
- Unrestored reach

6 sampling points/stream along 100 m reach (n=600)



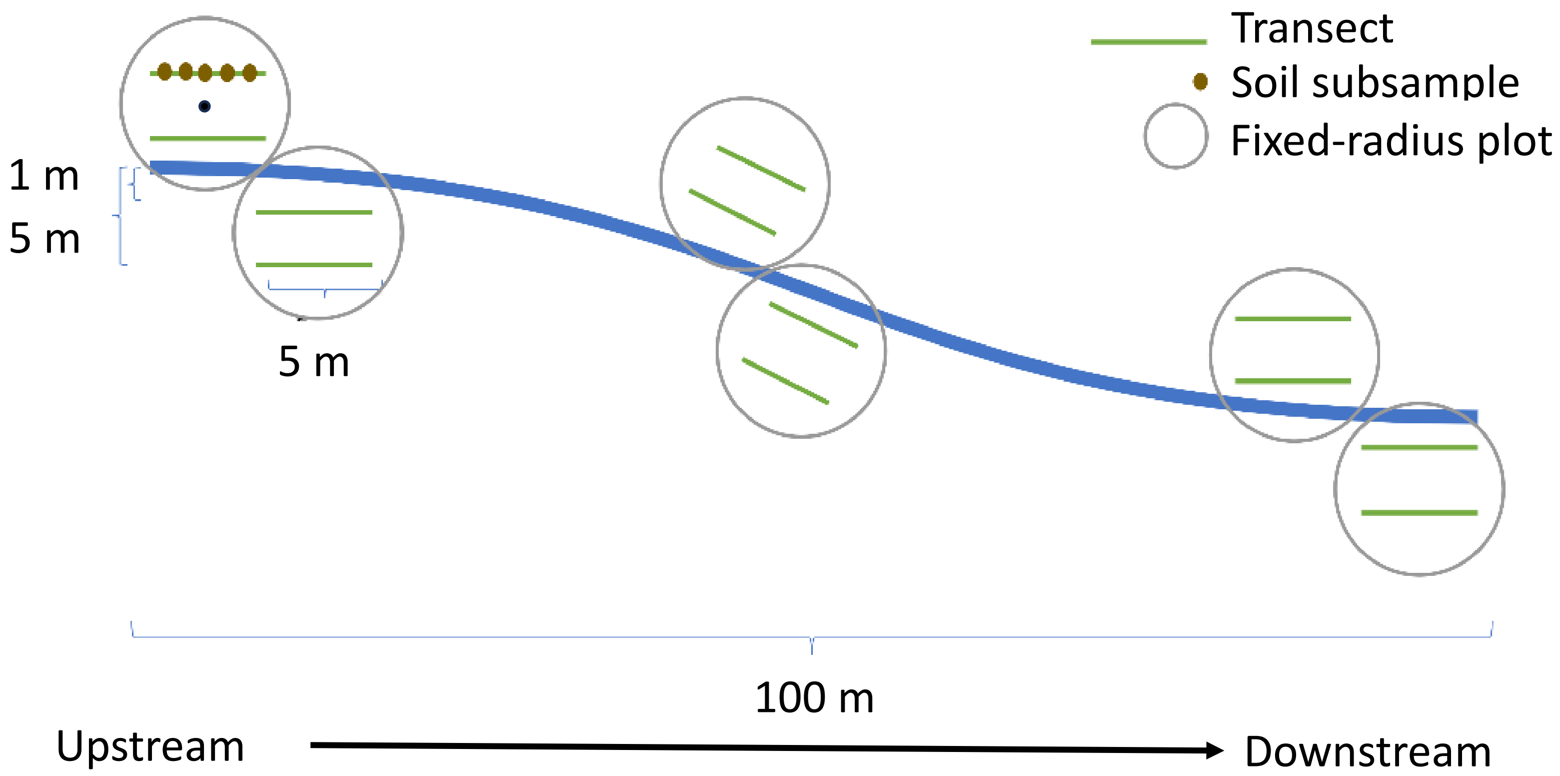
Study Design

46 paired sampling streams (n=92)

- Restored reach
- Unrestored reach

6 sampling points/stream along 100 m reach (n=600)

Vegetation and Soil Sampling



2 transects/point
(n=12/stream)

5 soil samples/transect
(n=60/stream)

1 fixed-radius plot/point
(n=6/stream)

Species Indices

- Using non-native* and native species

- $$Nonnative\ \ Species\ Index = \frac{\left(\frac{nonnative\ species\ richness}{overall\ species\ richness}\right) + \left(\frac{nonnative\ species\ cover}{total\ cover}\right)}{2}$$

- NNSI = Non-native species index (USDA PLANTS)
- NSI = Native species index (USDA PLANTS)

*93% of non-native species observed are also considered invasive by US-RIIS

Utilizing paired design to reduce noise

Unrestored

0.33

-0.67

Restored

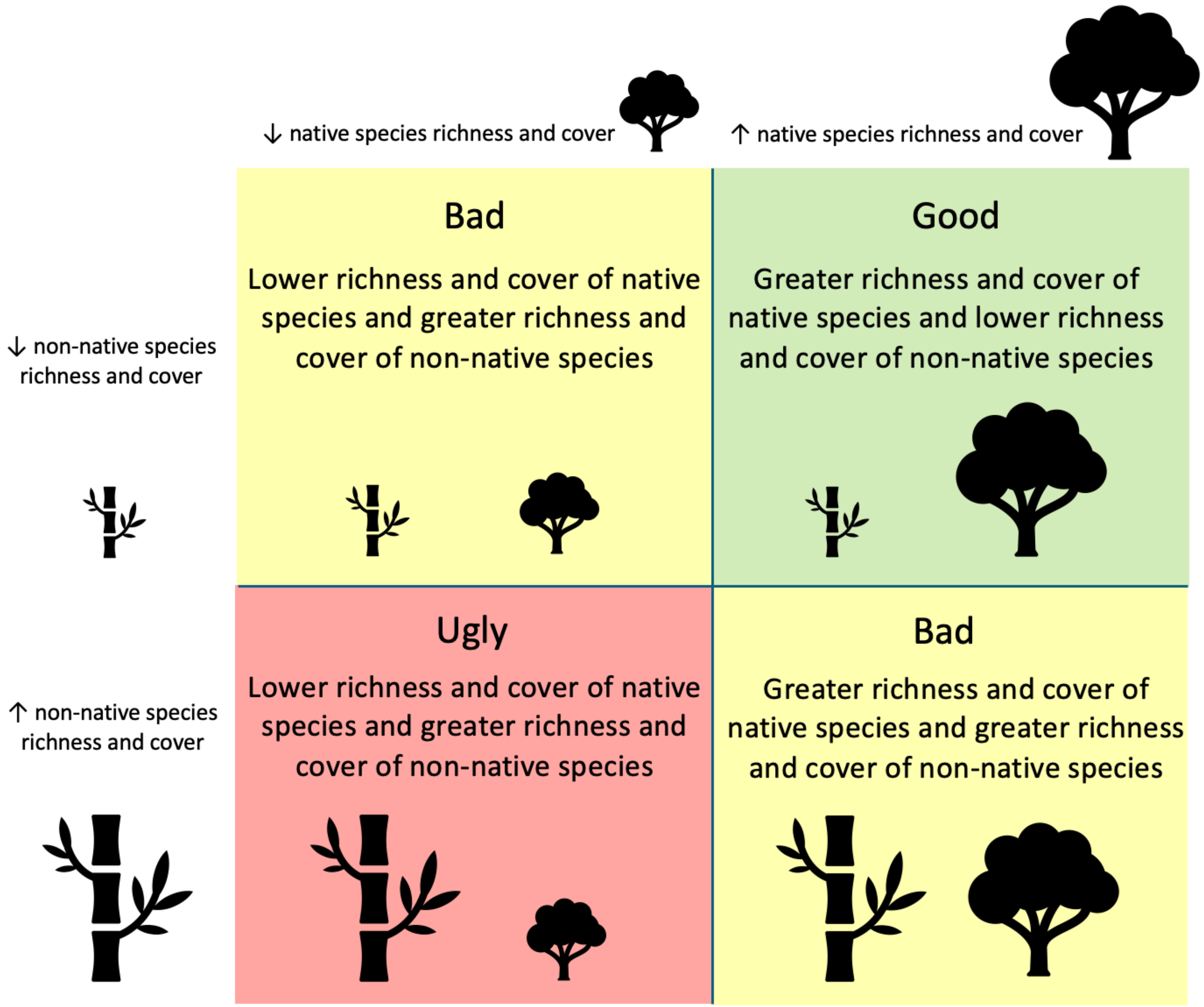
0.52

-0.32

$NNSI_{U-R}$ -0.19

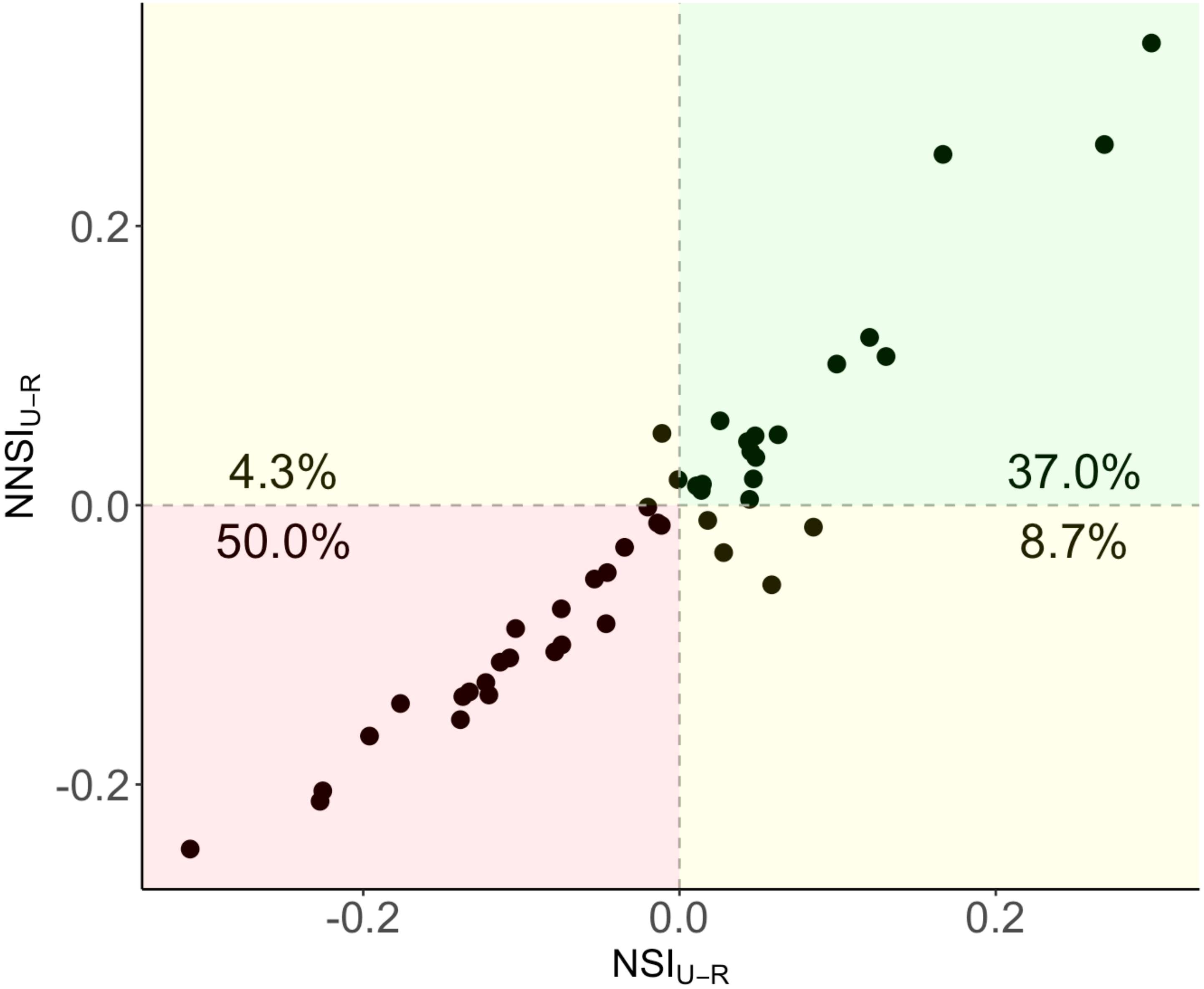
NSI_{U-R} -0.35

Potential Revegetation Outcomes

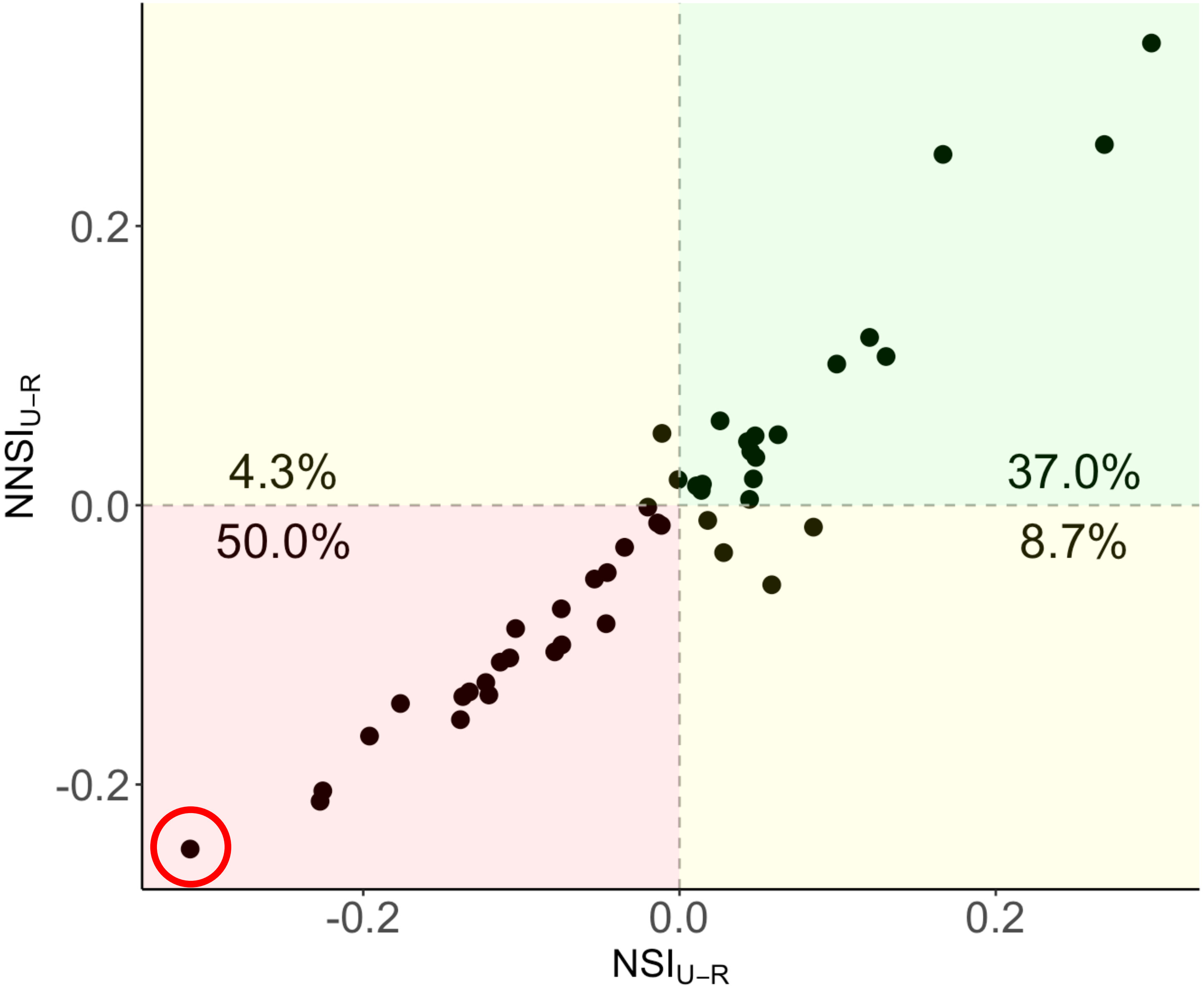


Results

Stream restoration worsens plant invasion in most cases



Example: poor outcome



Species coverage of a poor outcome

Restored: 27 native species, 15 non-native species

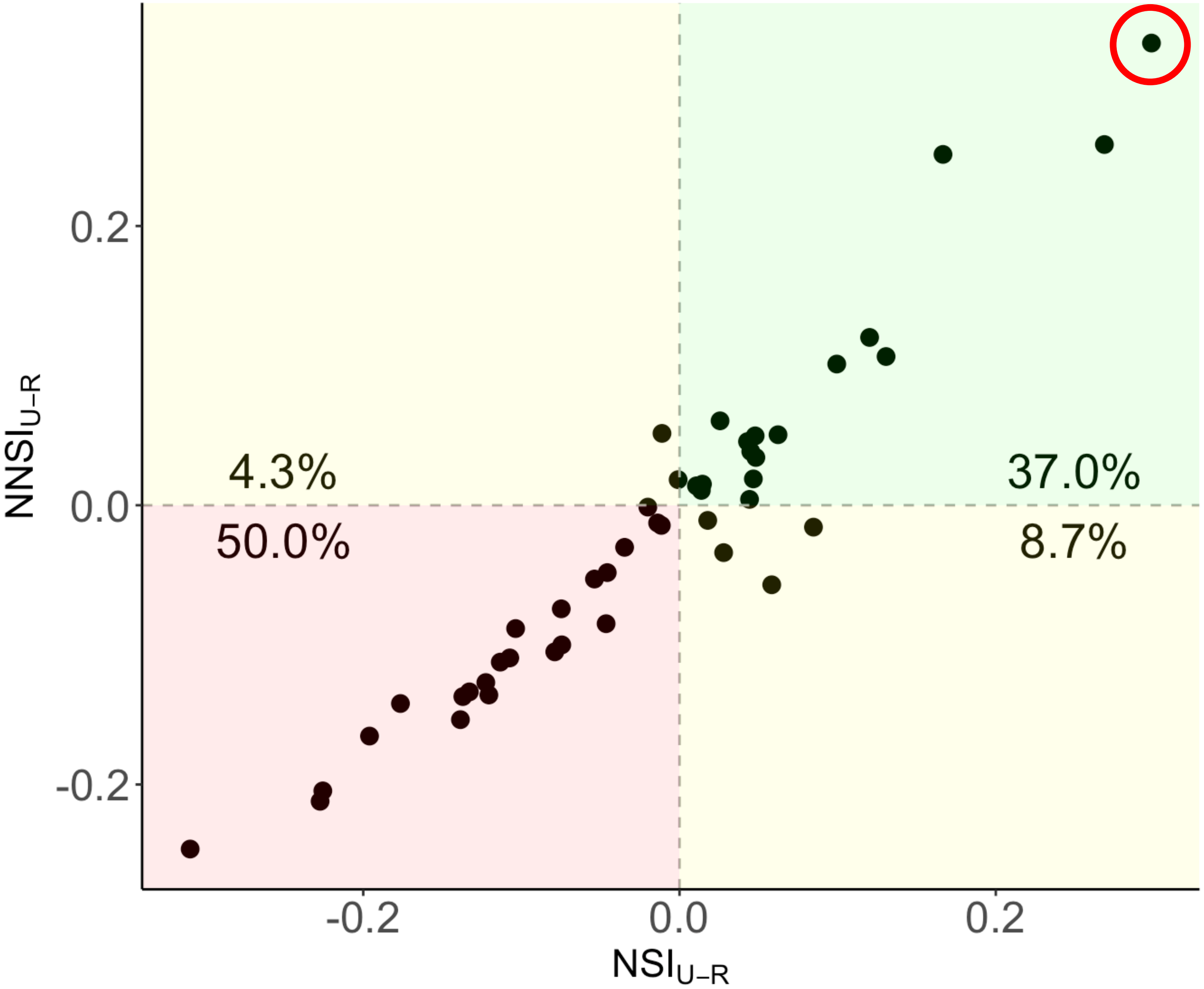
Species	% Coverage
Japanese stiltgrass*	24.3
Red maple	14.1
Redtop*	8.5
American elm	6.3
Sugar maple	5.7
Ground ivy*	3.7
Ostrich fern	3.1
Multiflora rose*	3.1
Violet spp.* (maybe)	2.7
Skunk cabbage	2.3

Unrestored: 28 native species, 8 non-native species

Species	% Coverage
Tulip poplar	24.5
American hornbeam	20.9
New York fern	19.1
Red maple	6.8
Ground ivy*	4.9
Blackgum	4.0
White oak	3.3
Red oak	3.3
Japanese barberry*	1.8
Pignut hickory	1.6

*non-native

Example: desired outcome



Species coverage of a desired outcome

Restored: 22 native species, 10 non-native species

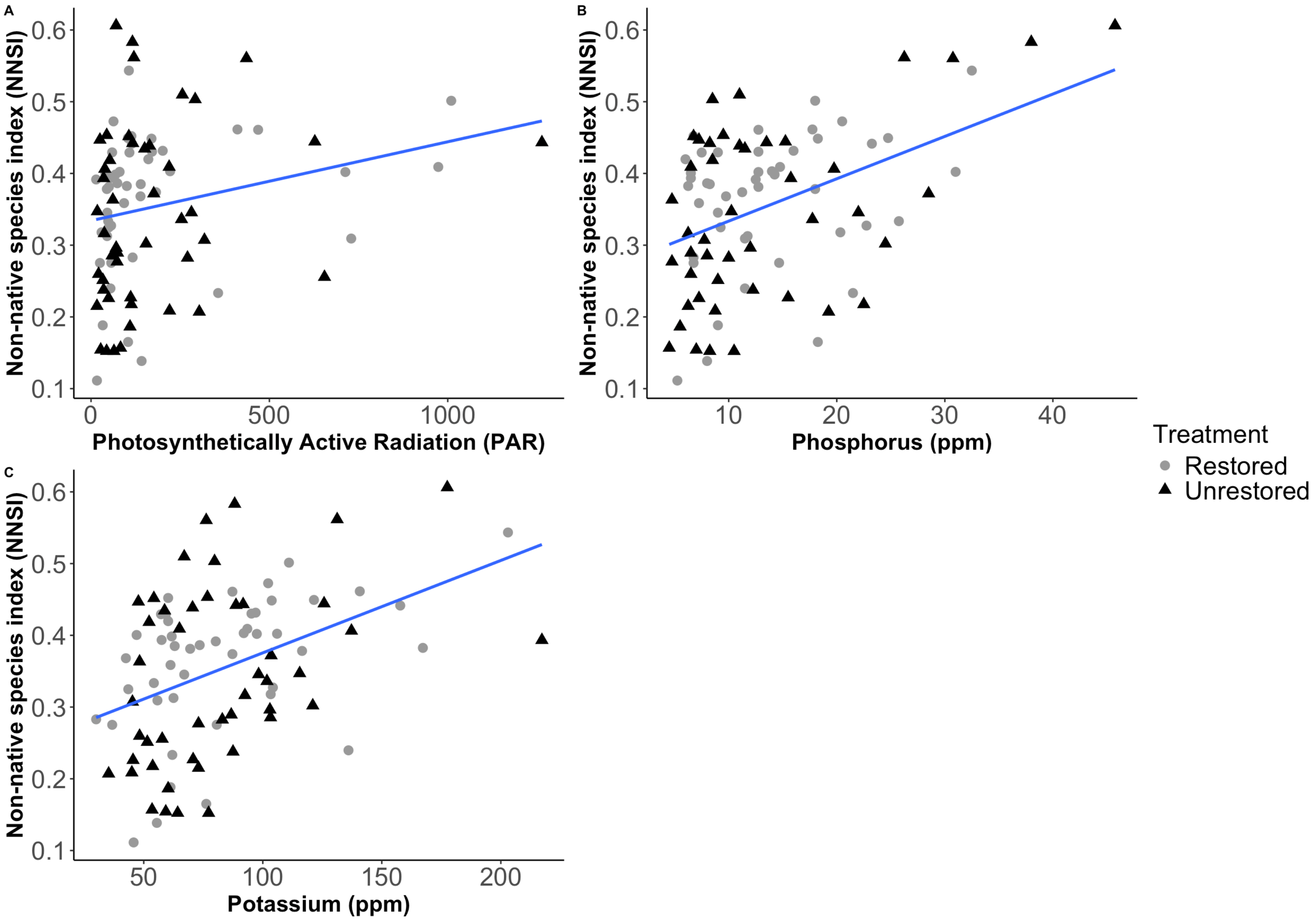
Species	% Coverage
Tulip poplar	20.7
English ivy*	13.4
Sycamore	12.9
Sweetgum	9.7
Red maple	7.3
White ash	4.4
Japanese honeysuckle*	4.3
Scarlet oak	3.9
Poison ivy	3.7
White oak	3.7

Unrestored: 15 native species, 15 non-native species

Species	% Coverage
English ivy	23.0
Boxelder	7.8
Tree-of-heaven*	7.6
Porcelainberry*	6.7
Japanese knotweed*	6.3
American elm	5.8
Chinese wisteria*	5.5
Sweet autumn clematis*	4.2
Amur honeysuckle*	3.8
Tulip poplar	3.2

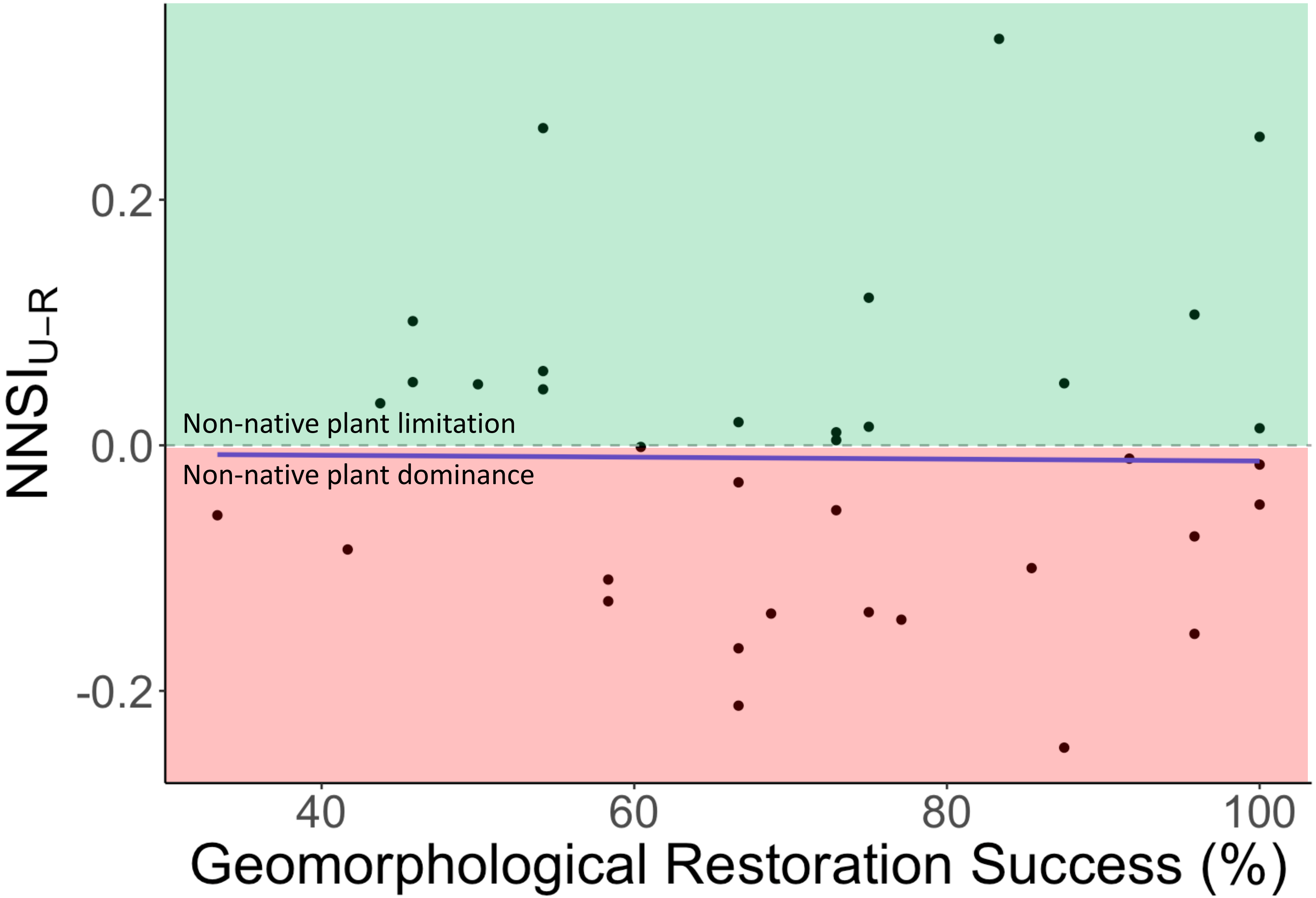
*non-native

Resources impacted invasion overall BUT did not differ between restored and unrestored sites



Time since restoration did not impact invasion

Invasion is unrelated to geomorphological outcomes




In most cases, restoration has worsened invasion…
but the outcomes are unrelated to geomorphology or resource availability

Disturbance

Tree removal

- Increase in space and light availability

Soil disturbance

- Increase in space and nutrients
- Stimulates the seedbank

https://www.jmu.edu/news/facmgt/2015/09/09-heroic-stream-restoration.shtml

Urban context

Most restoration sites studied are in urban areas

Invasive plant material readily available in urban areas

Will look more into influence of landscape context in next analyses

No relationship between geomorphology and vegetation outcomes

Monitoring geomorphology offers no insight into the vegetation community

Possible to improve geomorphology without also improving the vegetation

Research Questions

- Determine restoration techniques and environmental factors of existing stream restoration projects that limit invasion of non-native plant species and facilitate native plant establishment.

  - Compare the vegetation community of restored with un-restored stream reaches.

  - Provide recommendations on stream restoration techniques and planting practices that facilitate native plant establishment and minimize colonization of invasive plants.

Hypotheses

Surrounding landscape context (e.g., area of watershed in urban/ag) will be a driver of invasion.

Projects that limit disturbance to the soil and leave mature trees will have lower invasion.

Restoration Project Attributes

Project construction length

Project goals

Design approach

Monitoring/management

Limits of disturbance

ConYear	Design Plans	Design Report	As-Built Plans	Monitoring Report	Design Firm	Project Goal
2007	☑	☐	☐	☐	CCJM, Ecosite, Brightwat	
2013	☑	☐	☐	☐	USACE Baltimore, MD	BS, EC, Habitat
2003	☑	☐	☐	☑	Greenhorne & O'Mara	BS
2012	☑	☑	☐	☑	KCI	BS
2016	☑	☐	☑	☑	Century Engineering	FC
2013	☑	☐	☑	☐	McCormick Taylor	
2012	☑	☐	☐	☑	JMT	Mitigation
1995	☐	☐	☑	☑	Brightwater	Mitigation
2015	☑	☑	☑	☐	KCI	MS4, WQ
2000	☐	☑	☑	☑	Greenman-Pedersen, Co	BS, EC, Habitat,
2004	☑	☐	☐	☑	Ecotone	Mitigation
2013	☑	☑	☑	☑	KCI	
2014	☐	☐	☑	☑	RK&K	MS4
2013	☑	☑	☑	☑	Parsons Brinckerhoff	BS, EC, Habitat
2012	☑	☐	☐	☑	Coastal Resources, PB	Mitigation, BS,
2012	☑	☐	☐	☑	Coastal Resources, PB	Mitigation, BS,
2010	☑	☑	☑	☑	PB Americas, Coastal Res	BS, WQ
2015	☑	☐	☐	☐	CPJ Associates	
2006	☐	☐	☑	☐	Underwood & Associates	
2009	☑	☐	☐	☑	KCI	BS, Habitat
1999	☑	☐	☐	☑	Environmental Systems /	BS, Habitat
2013	☑	☑	☑	☑	KCI	BS

Planting plans

- How many layers of vegetation were planted?
- Were mature trees left within LOD?
- Was vegetation selected by zone?
- For how many years was the project monitored?
- Was there an invasive species management plan?
- Was a reference model used?
- Does the planting list reflect the natural community type?
- What is the proportion of native/non-native/invasive stems planted?
- What was the stem/seed density planted?

Project status

Field sampling complete

Manuscript drafted for first objective

Finish analyses for second objective:

Landscape context

Project attributes

Planting plans

Thanks to...

Chesapeake Bay Trust

MARYLAND CB TRUST Protect the Chesapeake

Maryland Department of Natural Resources

Montgomery County Maryland

United States Environmental Protection Agency

Chesapeake Bay Program
Science. Restoration. Partnership.

National Fish and Wildlife Foundation
NFWF

Anne Arundel County Maryland

Invasive Species
COLLABORATIVE AT VIRGINIA TECH

FRALIN LIFE SCIENCES INSTITUTE
GLOBAL CHANGE CENTER
VIRGINIA TECH.

COLLEGE OF AGRICULTURE AND LIFE SCIENCES
SCHOOL OF PLANT AND ENVIRONMENTAL SCIENCES
VIRGINIA TECH.

What are the take home points? What does this mean for me?

Translation slides by Joe Berg

Restored sites studied had higher NNI species

- Since tree clearing allows more room and sunshine to stimulate plant growth, and soil disturbance stimulates seed establishment and releases nutrients, both apparently favoring NNI species over native species
- as a practitioner I want to minimize my projects LOD and tree removal
- as a regulator/reviewer, I want to minimize tree clearing and ground disturbance, and maybe extend the monitoring period for control of NNI species

- Next Steps
  - Evaluation of planting plan influence on plant community quality
  - How design approach influences plant community condition


Questions?
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Website: gabriellenripa.weebly.com

Evaluating Stream Restoration Tradeoffs in Water Quality across Watershed Scales

Sujay Kaushal, Sydney Shelton, Ashley Mon,
Ashley Bianca Dann, & Weston Slaughter
University of Maryland, Department of Geology

Translation: Ari Engelberg
Maryland Department of Natural Resources

Challenges in Detecting Effects of Restoration and Conservation – Why?

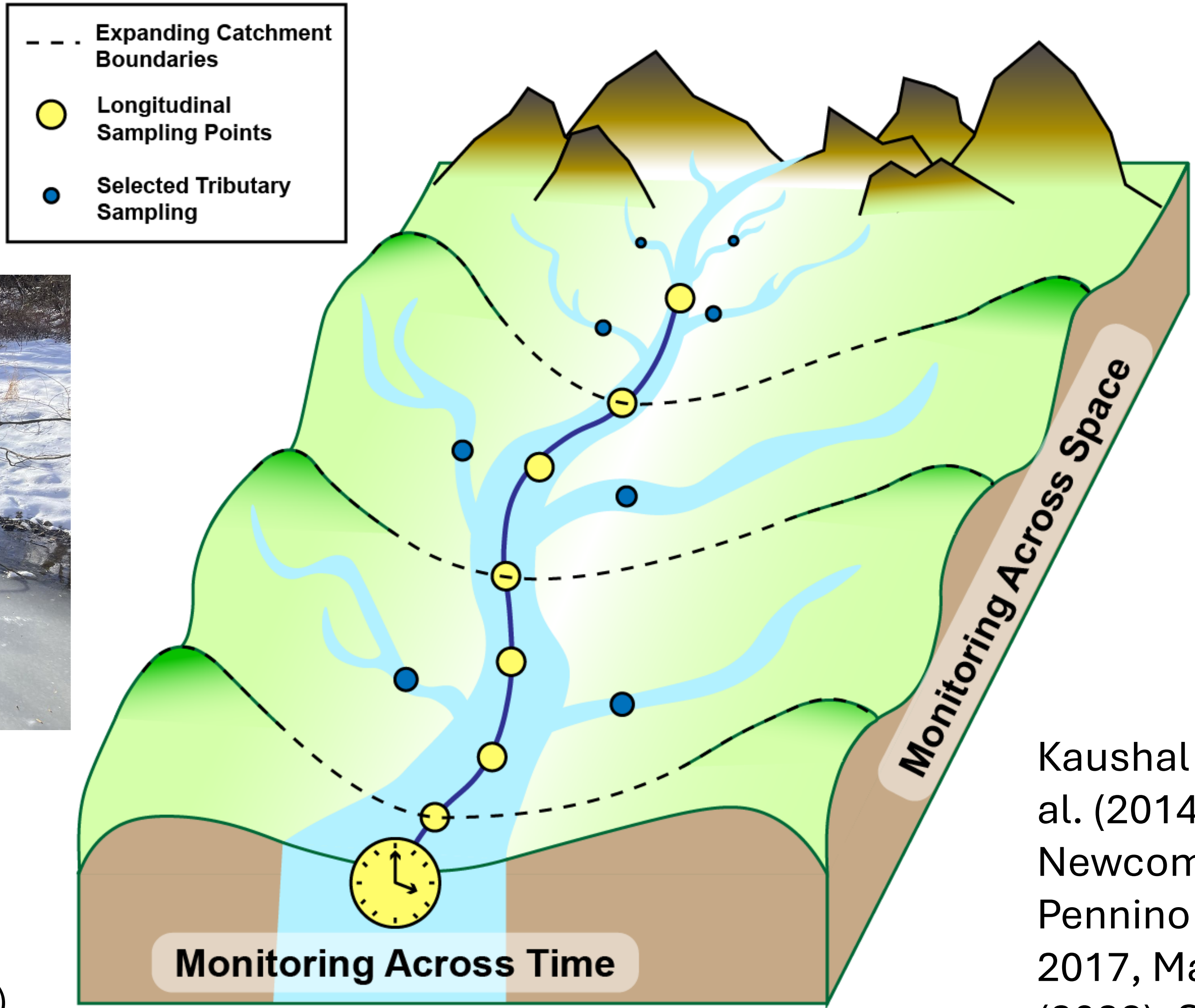
-Most monitoring efforts occur over time – what about space?

-We focus on one or a few metrics – a more holistic approach?

-What about connections along flowpaths to receiving waters?

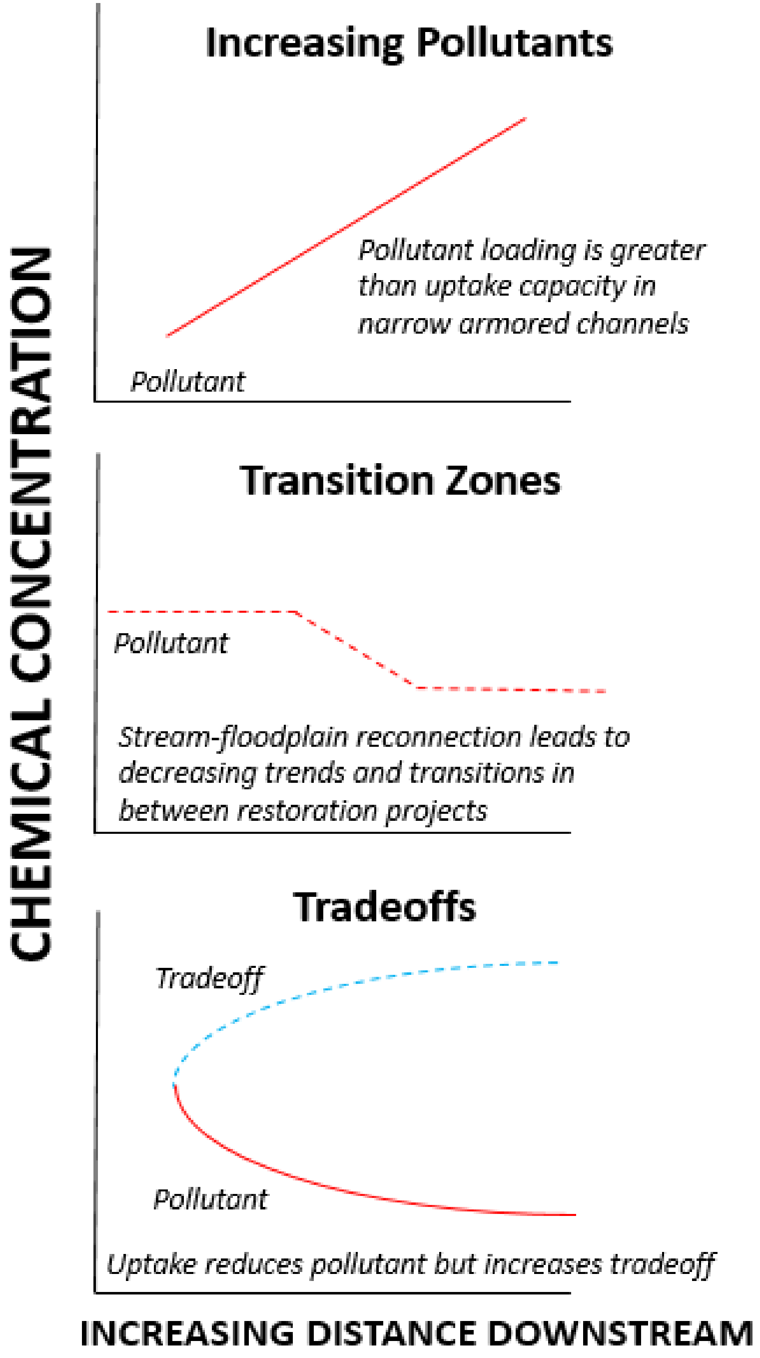
The Watershed Continuum Approach

Wes Saughter



Kaushal et al. (In Prep)

Kaushal and Belt (2012), Kaushal et al. (2014, 2023), Sivirchi et al. 2011, Newcomer-Johnson et al. (2014), Pennino et al. (2016), Smith et al. 2017, Maas et al. (2023), Malin et al. (2023), Shelton et al. (2023)



Adapted from Kaushal et al. (2023)

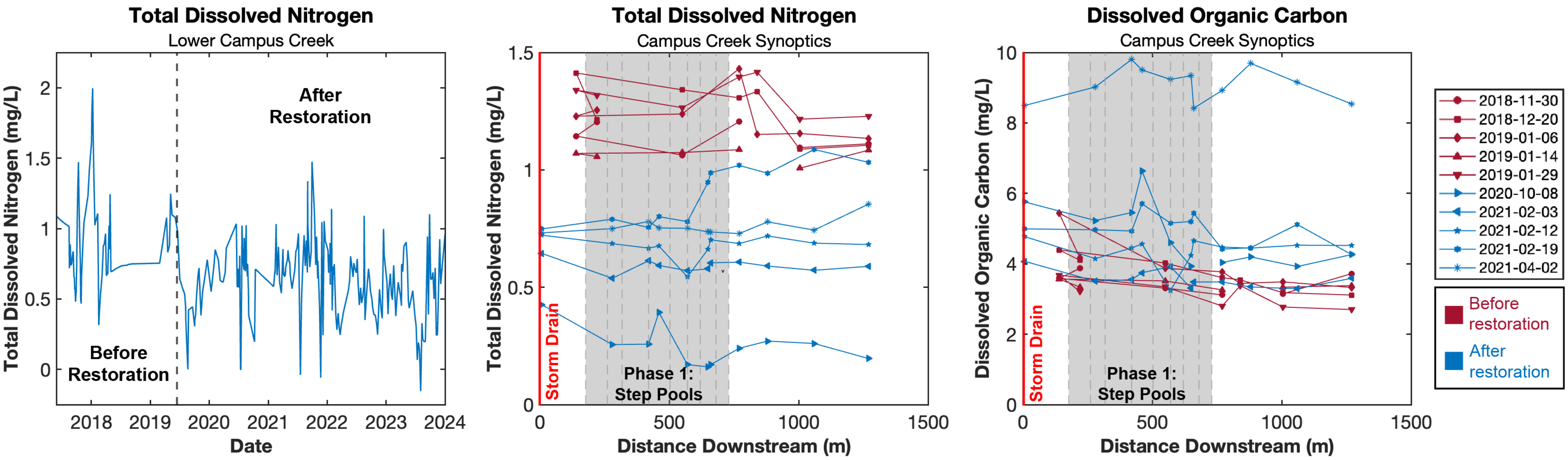
Hypotheses

-There will be decreasing trends in pollutants and increasing trends in water quality tradeoffs along restored stream flowpaths based on different types of stream-floodplain reconnection.

-Decreasing trends in pollutants along stream flowpaths will be related to increasing riparian buffer widths across watershed scales.

***There will be longitudinal trends in co-benefits of restoration and conservation!**

Stream Restoration Can Reduce Nitrogen across Space-Time

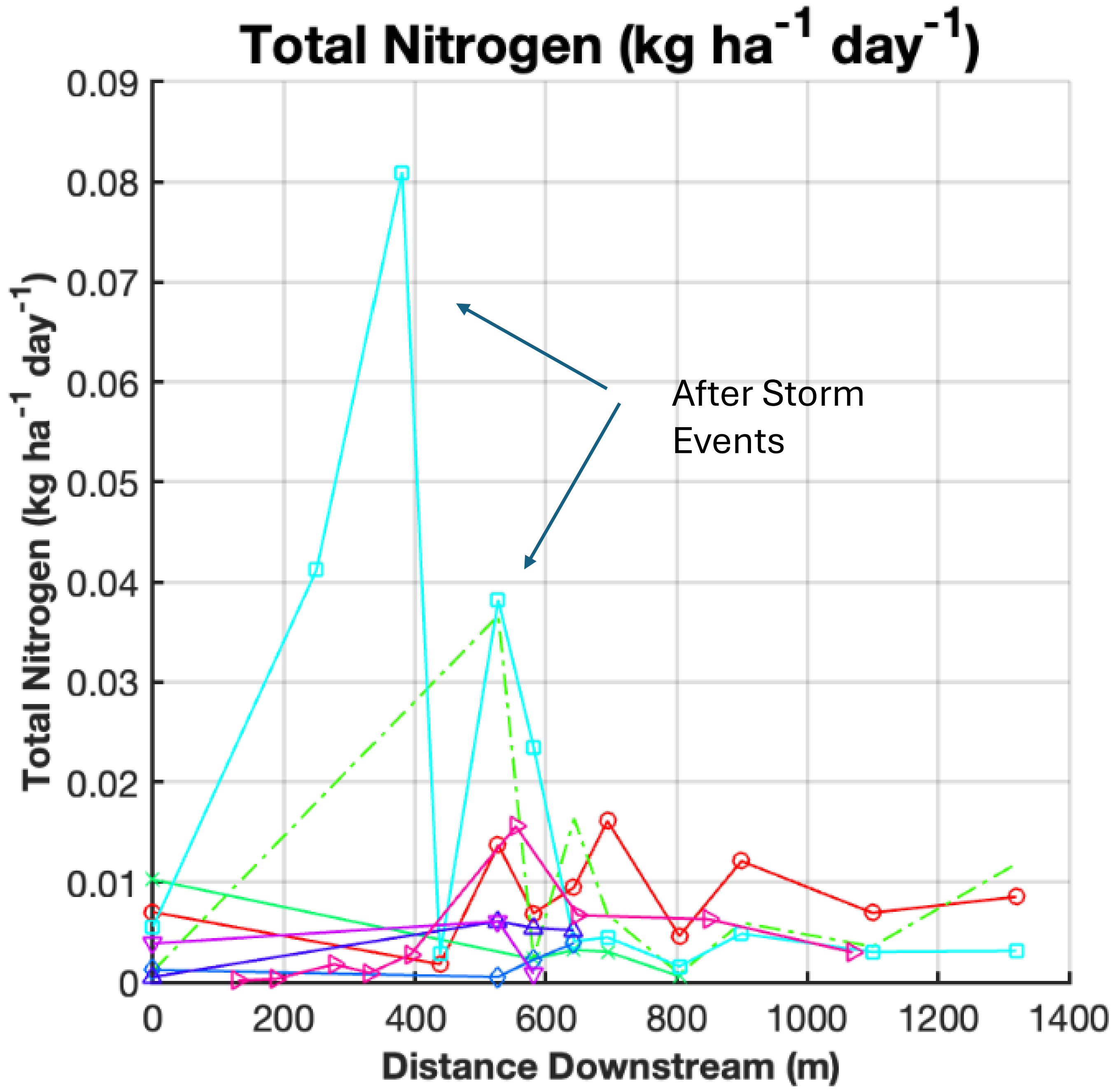


Kaushal et al. (In Prep)

Stream Restoration Can Increase Organic Carbon

Tradeoff or Benefit?

Nitrogen Export Reductions along Flowpath



What Are Tradeoffs?

Potential Water Quality Benefits	Potential Water Quality Costs
Decreased nutrients and sediments due to greater retention in floodplains and pools →	Increased hypoxic and anoxic periods of low dissolved O_2 (DO)
Decreased N and P along stream flowpaths due to greater biological uptake →	Increased production of algae and bacteria and biochemical oxygen demand (BOD)
Decreased concentrations of Na^+ and Cl^- from road salts through soil ion exchange →	Increased mobilization of N, P, and metals from soil ion exchange sites and Na dispersion of soils
Decreased sediment due to retention of particulates in RSC pools and floodplains →	Increased mobilization of dissolved P from soils due to desorption at low DO and high pH

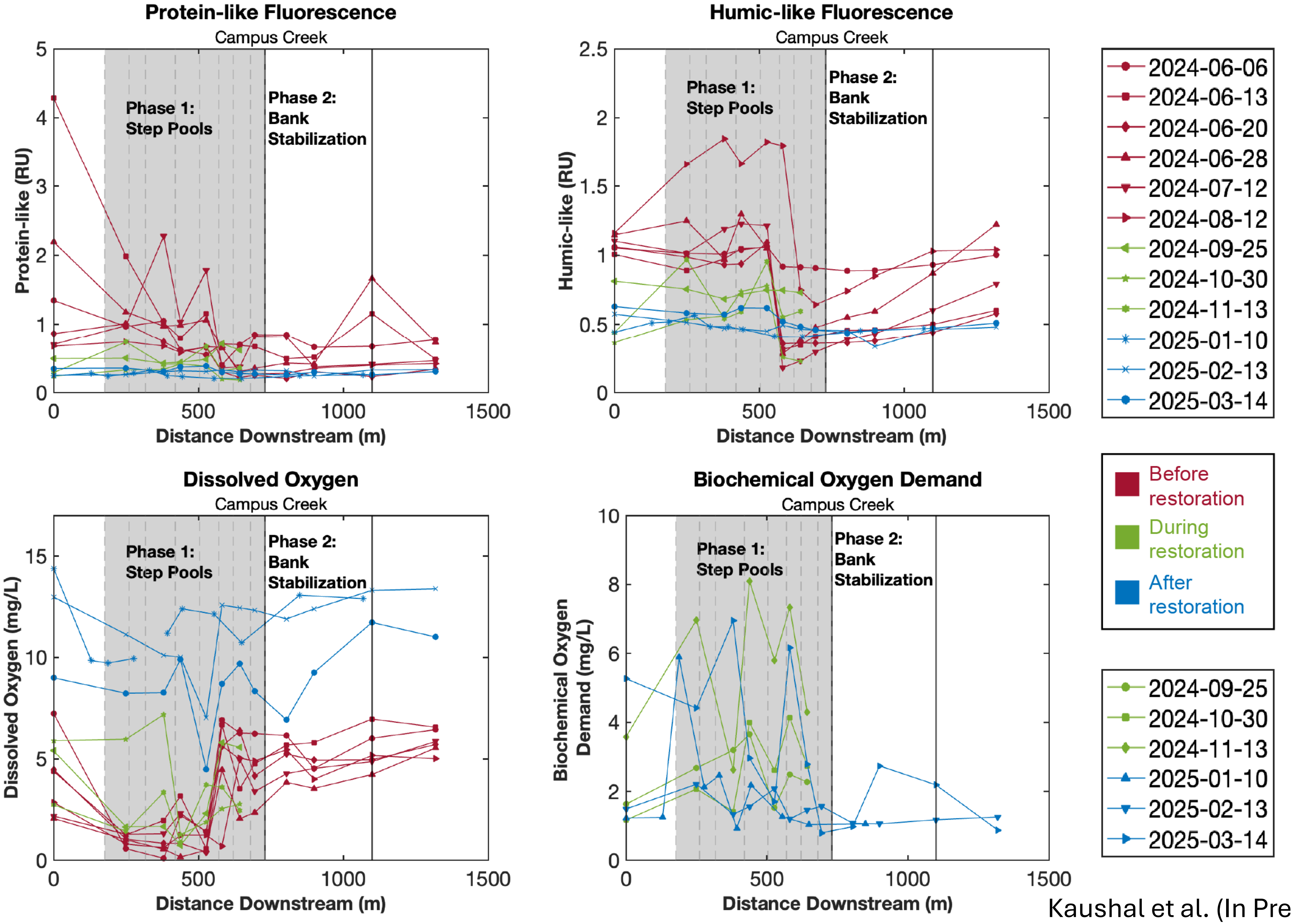
Kaushal et al. (In Prep)

***What Are Co-Benefits?** Attenuation of nutrients, salts, metals, and increases in hydrologic connectivity (Kaushal et al. 2023, Shelton et al. 2024, Malin et al. 2024)

Trading Nitrogen for Carbo

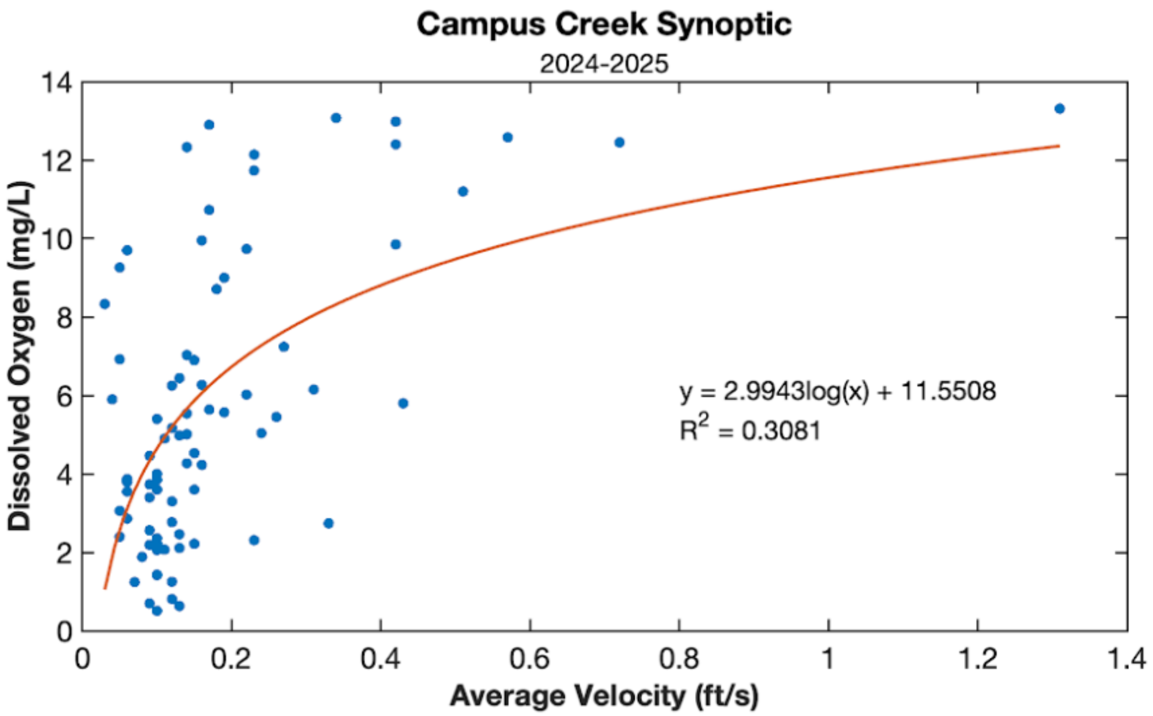
Nitrogen is reduced but reactive carbon is increased.

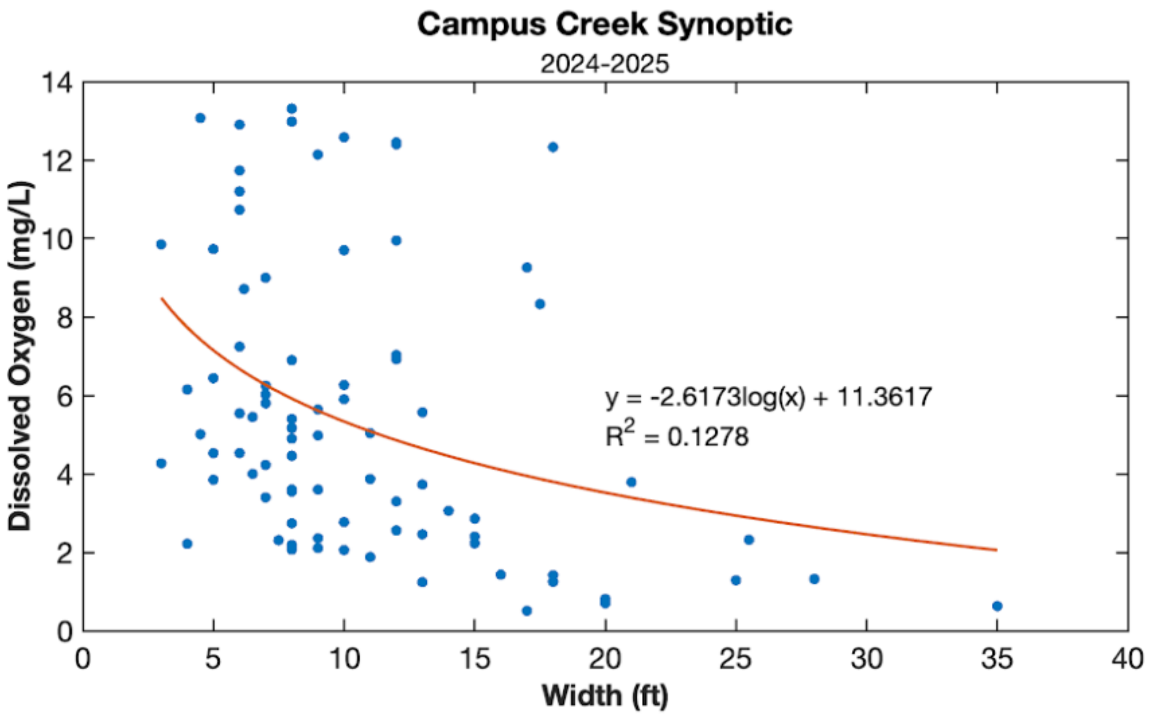
Tradeoff or Benefit?



Kaushal et al. (In Prep)

Dissolved Oxygen Is Related to Stream Width and Stream Velocity along Watershed Flowpaths





Kaushal et al. (In Prep)

Tradeoff: Trading Decreased Stream Velocity for Lower Oxygen?

Tradeoff or Benefit?

Restoration Realities: Comparing Hydrologic Connectivity

-*Channel Stabilization* (In-stream structures and water In the channel)

-*Floodplain Reconnection* (Designed to spill water out of the channel)

-*Step Pool* Conveyance (Designed to slow flow and pool water)

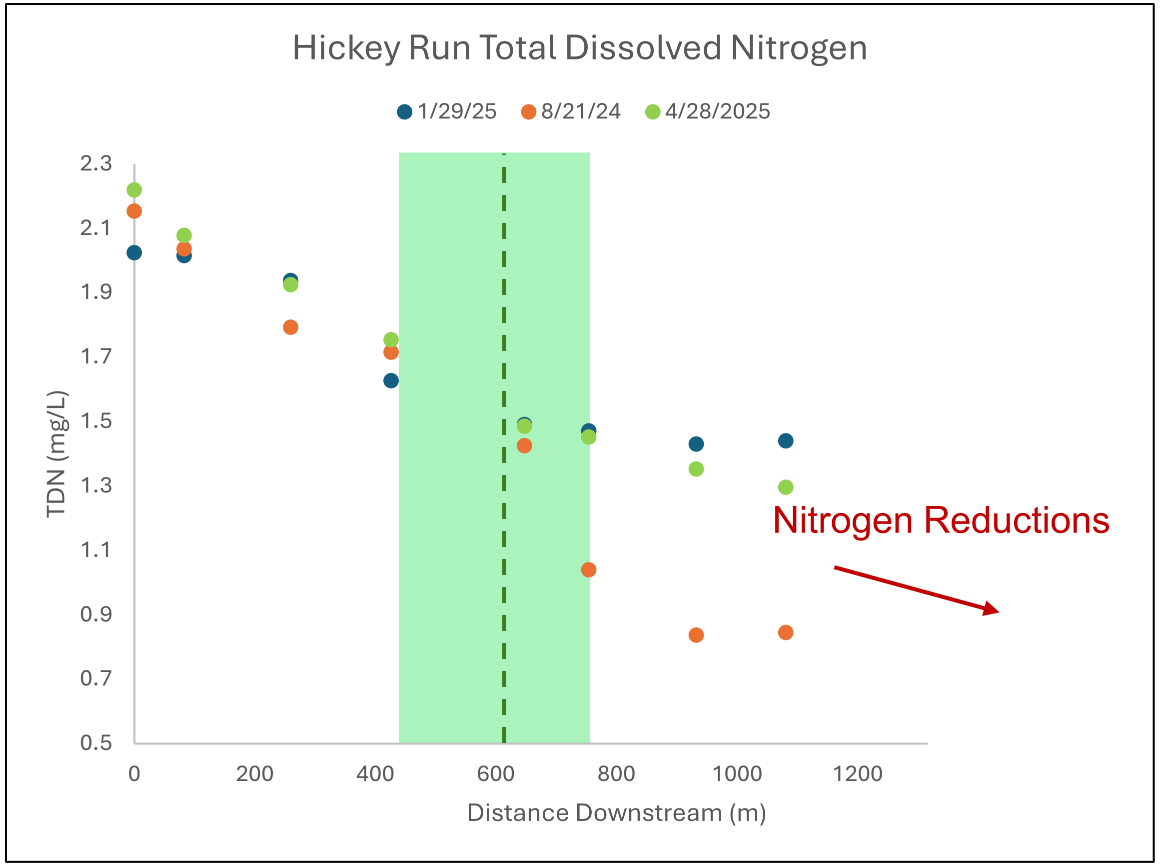
Photo Courtesy: Kelsey Wood

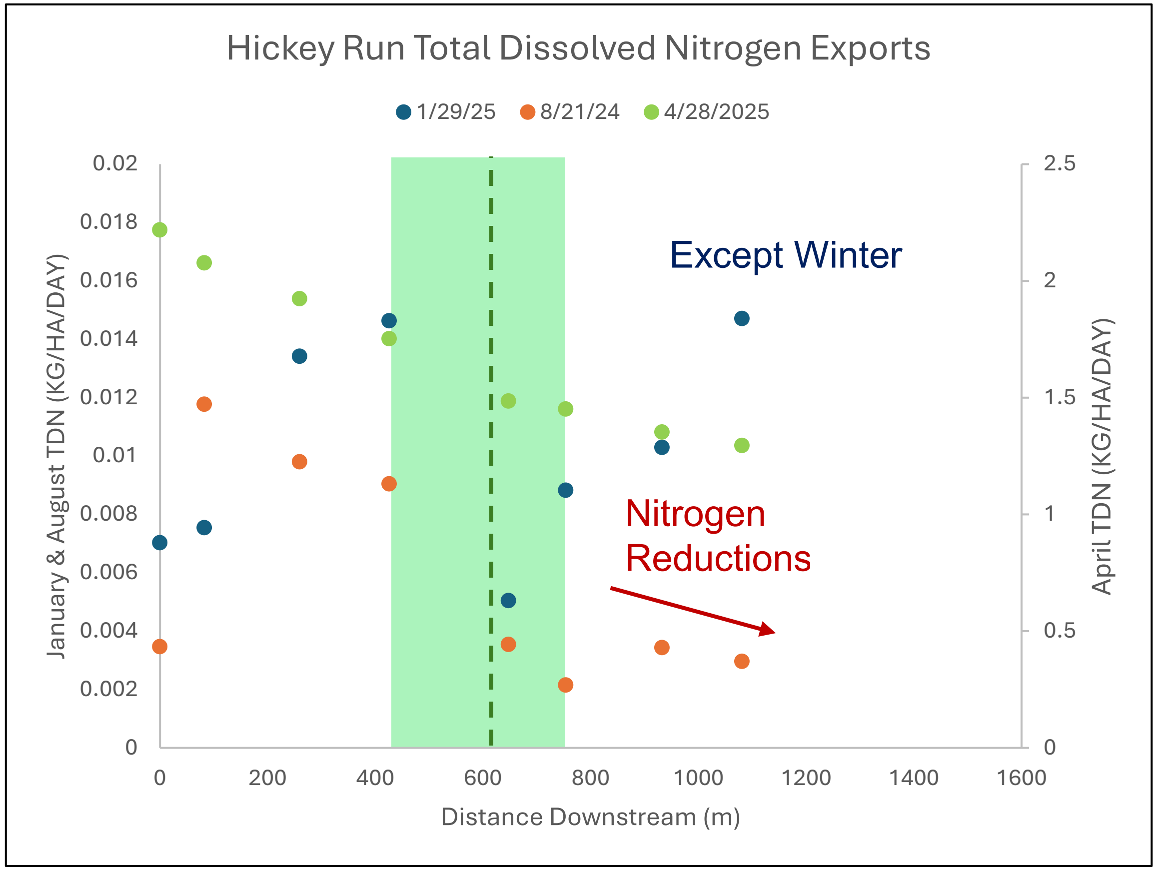
Hickey Run: Can Water Quality Improve?

Water quality improves as urban Hickey Run flows from storm drain, through and downstream of stream restoration projects, and through National Arboretum

Thanks to Ashley Dann

Hickey Run

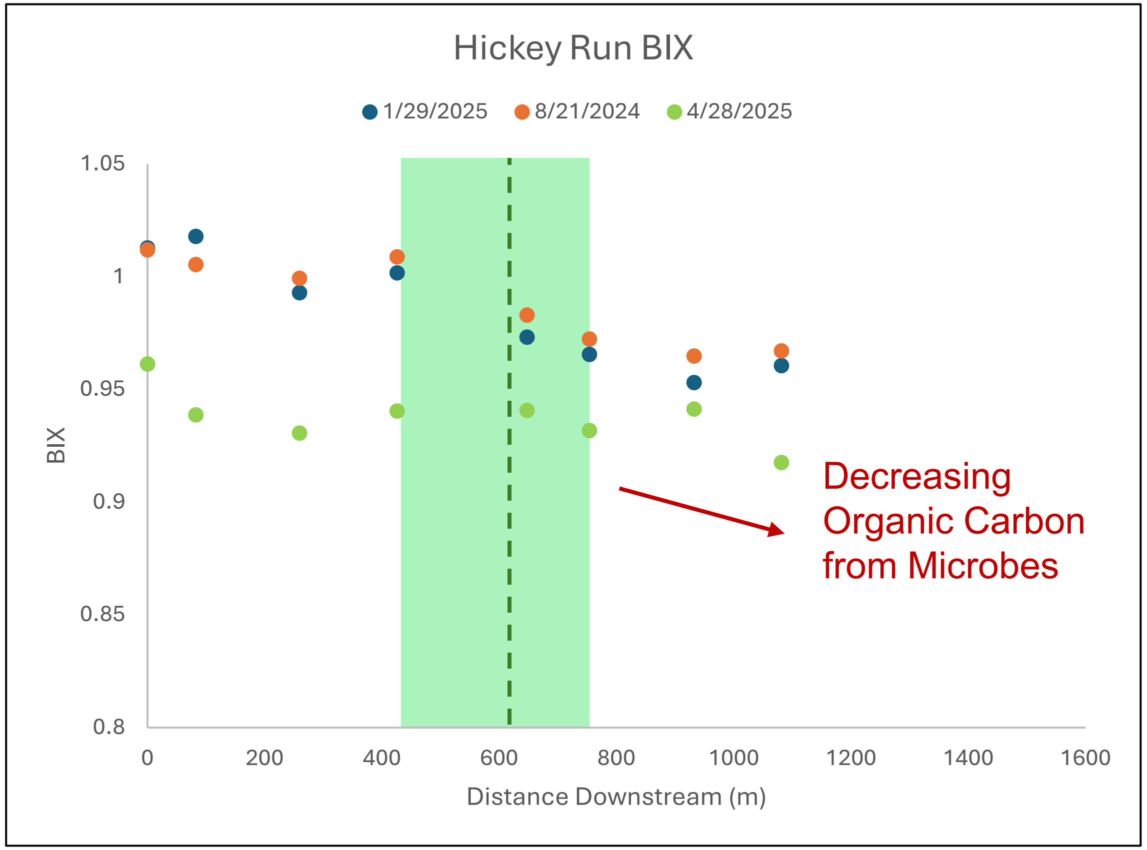


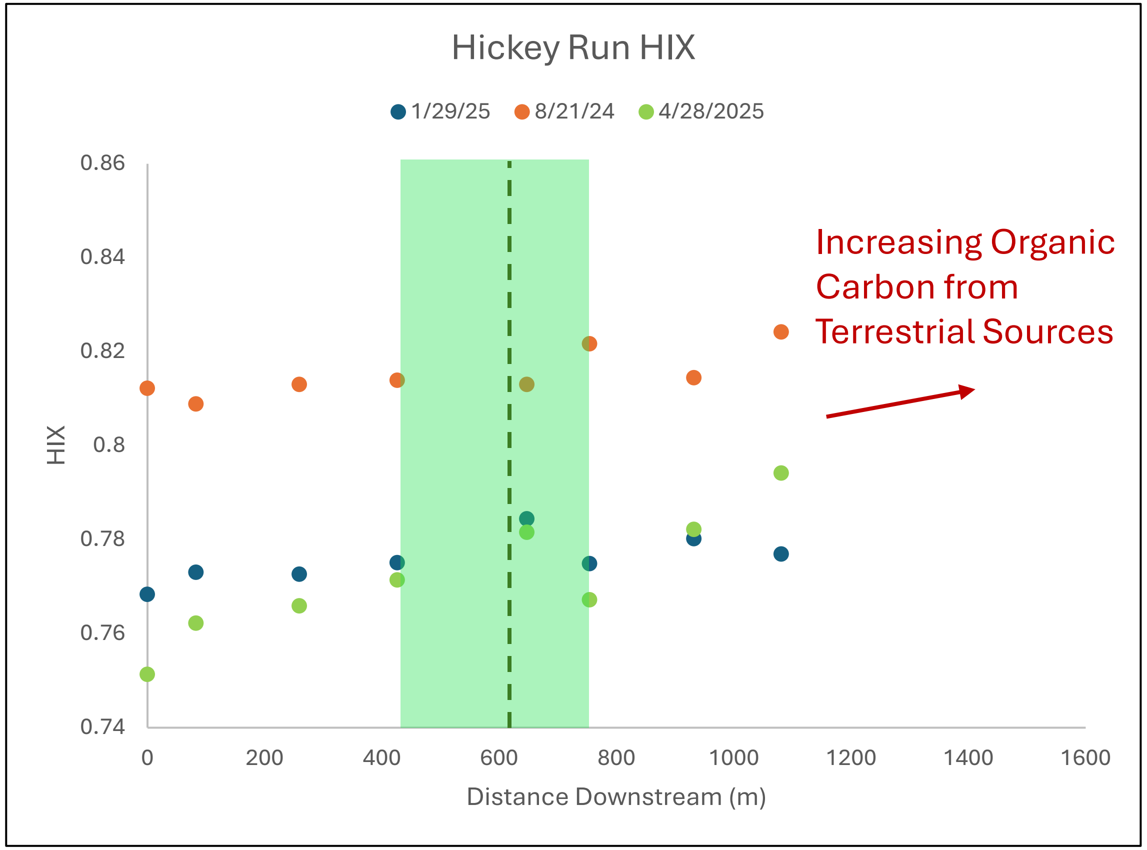


Longitudinal decline in N concentrations and watershed N exports as Hickey Run flows from storm drain through stream restoration project and National Arboretum

Thanks to Ashley Dann

Hickey Run

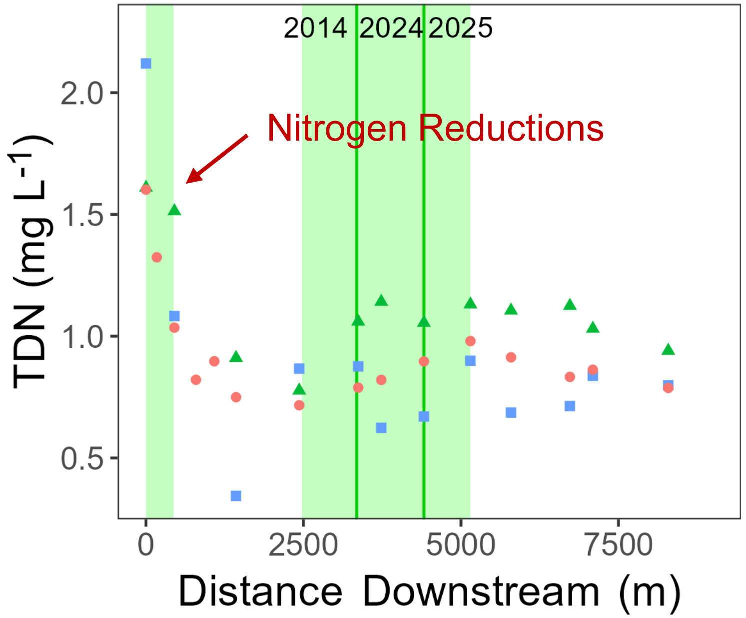


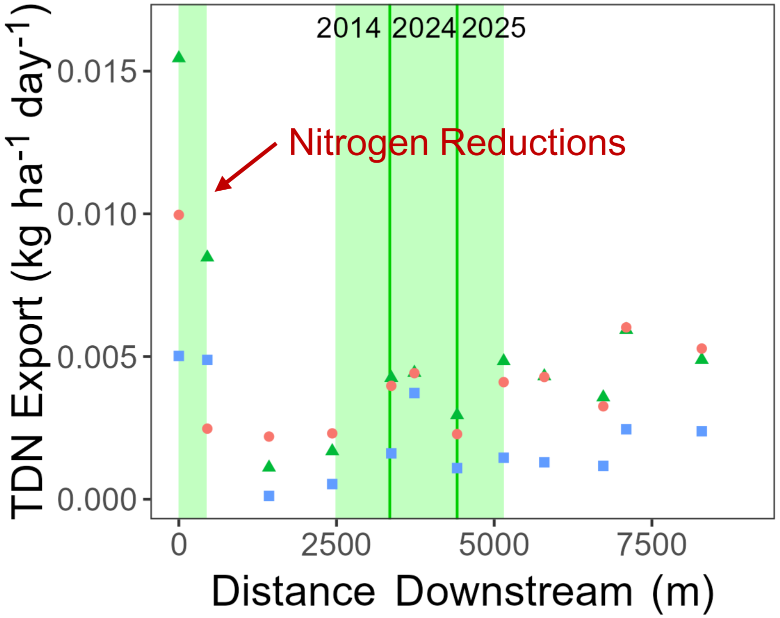


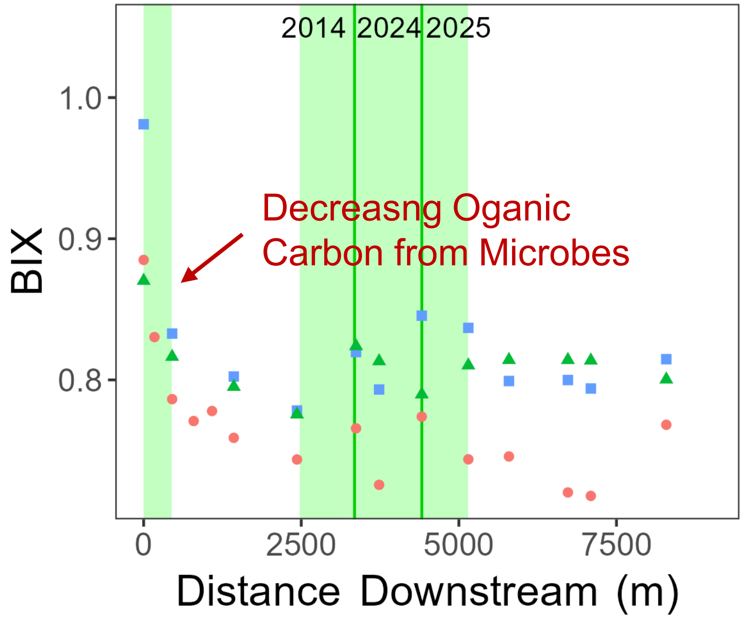
Longitudinal change in organic matter sources as Hickey Run flows from storm drain through stream restoration project and National Arboretum

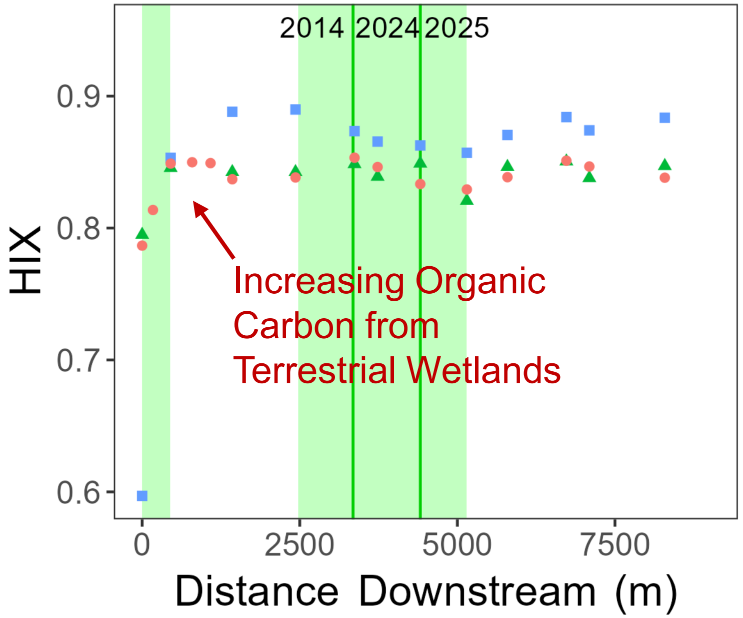
Thanks to Ashley Dann

Scotts Level Branch: Nitrogen Reductions









Restored

03/12/2025 Construction
01/15/2025 Construction
08/15/2024

Thanks to Sydney Shelton

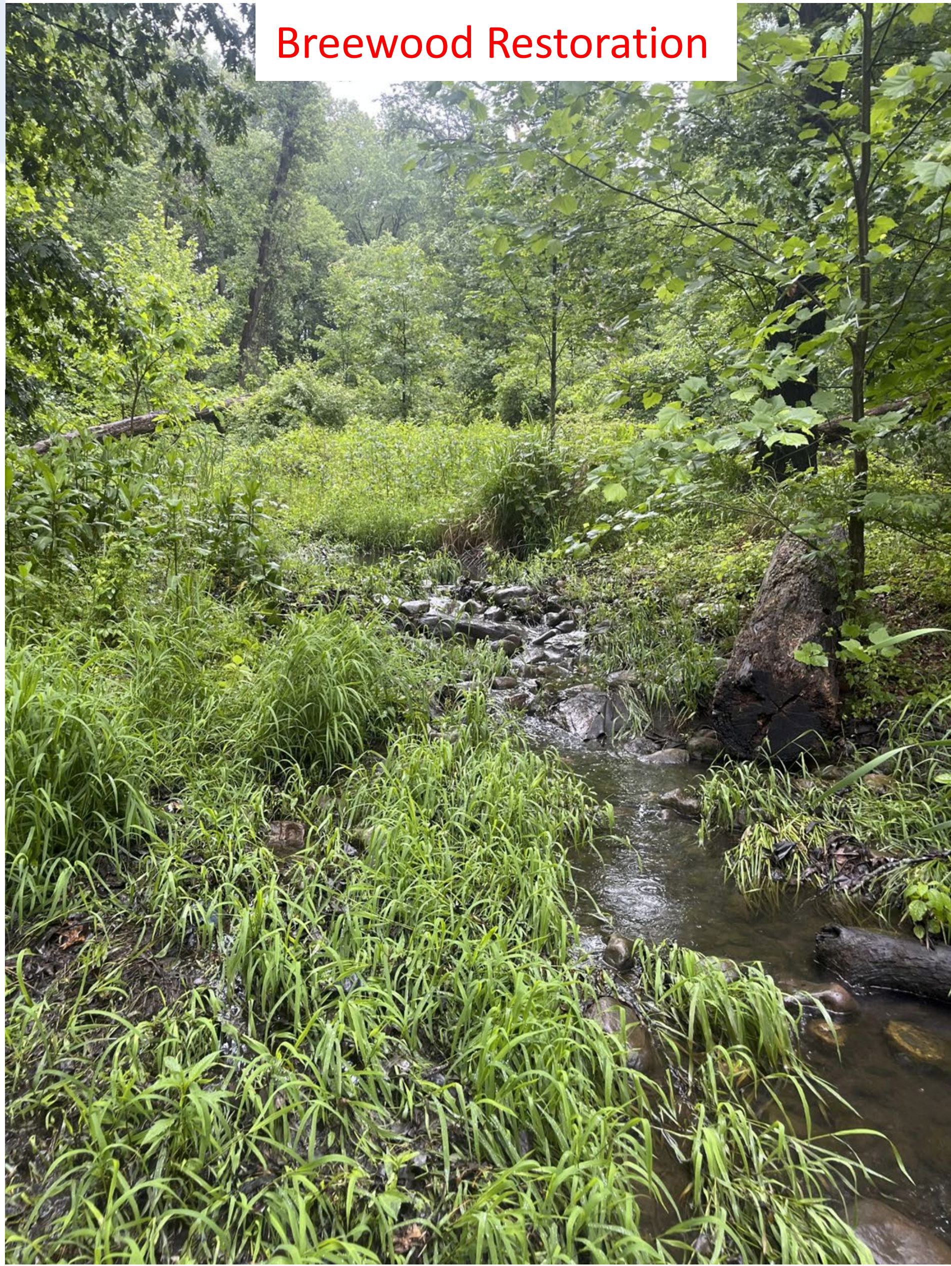
Section 319

NONPOINT SOURCE PROGRAM SUCCESS STORY

Maryland

Stream Restoration Reduces Peak Storm Flow and Improves Aquatic Life in Sligo Creek

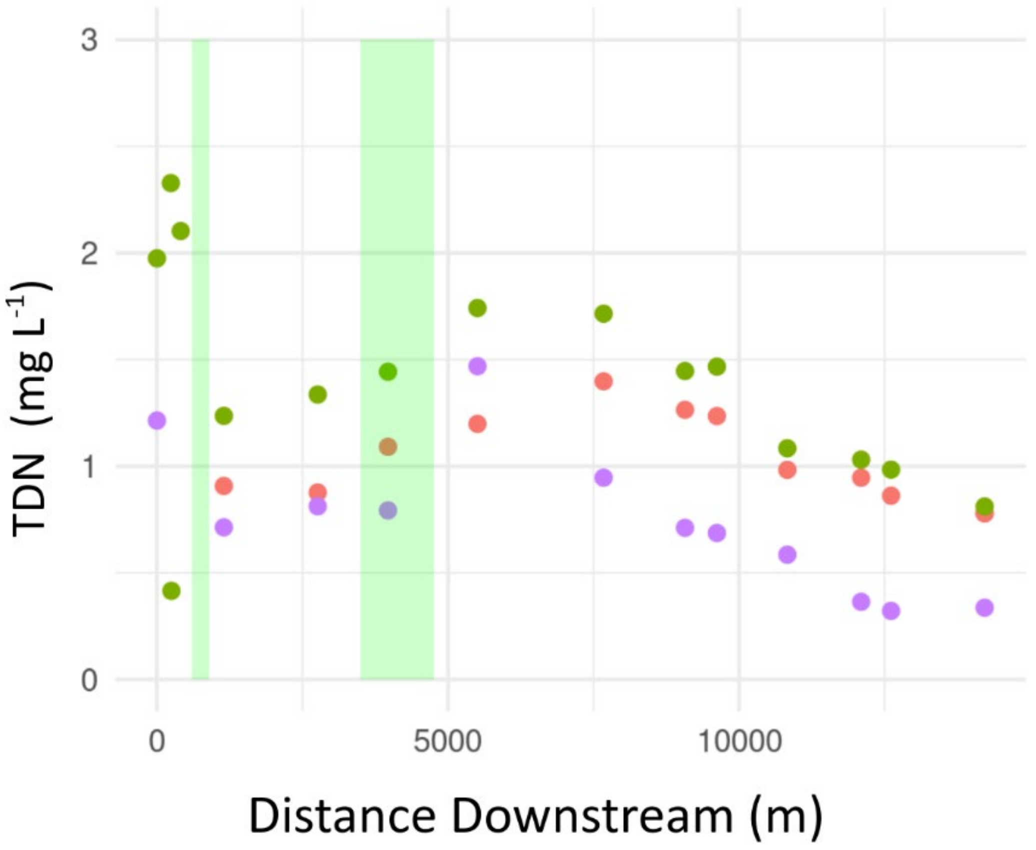
Retention Pond along Stream Synoptic

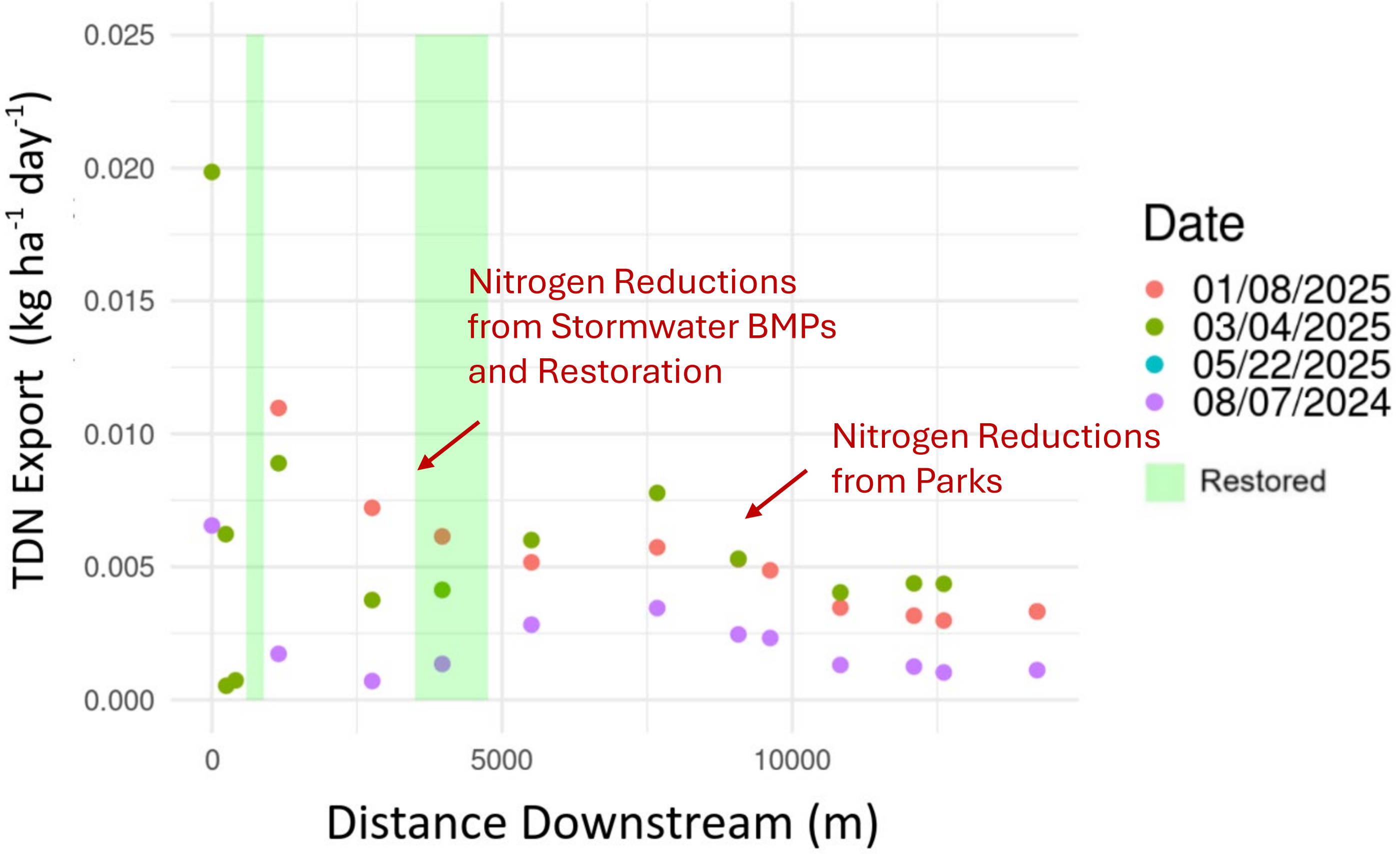


Breewood Restoration

Thanks to Wes Slaughter

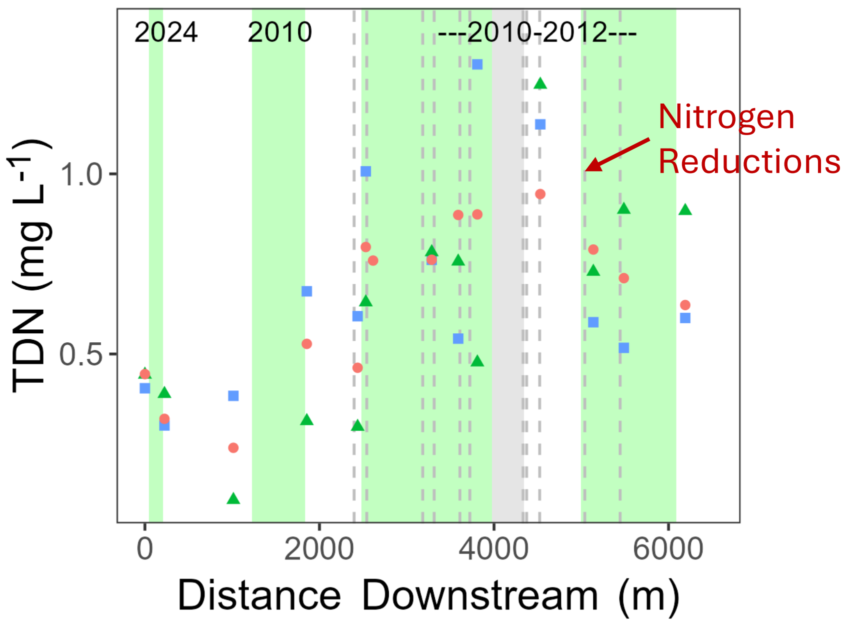
Nitrogen Reductions along Sligo Creek

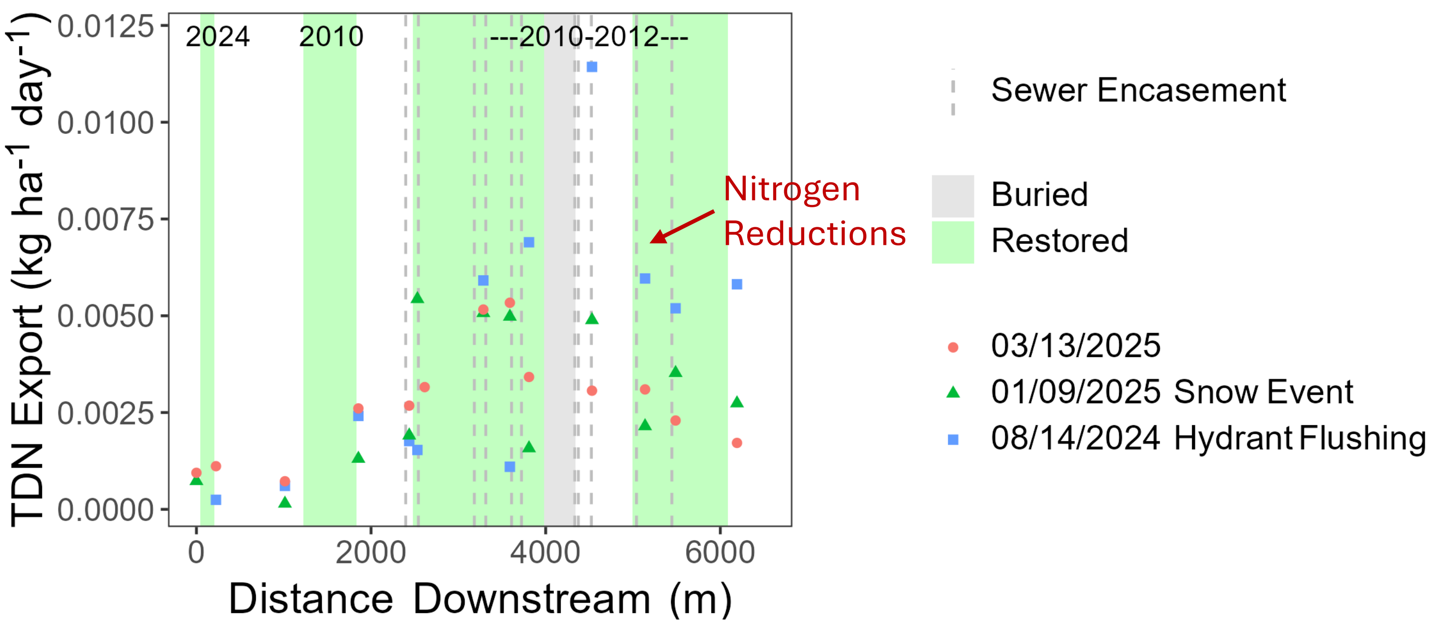


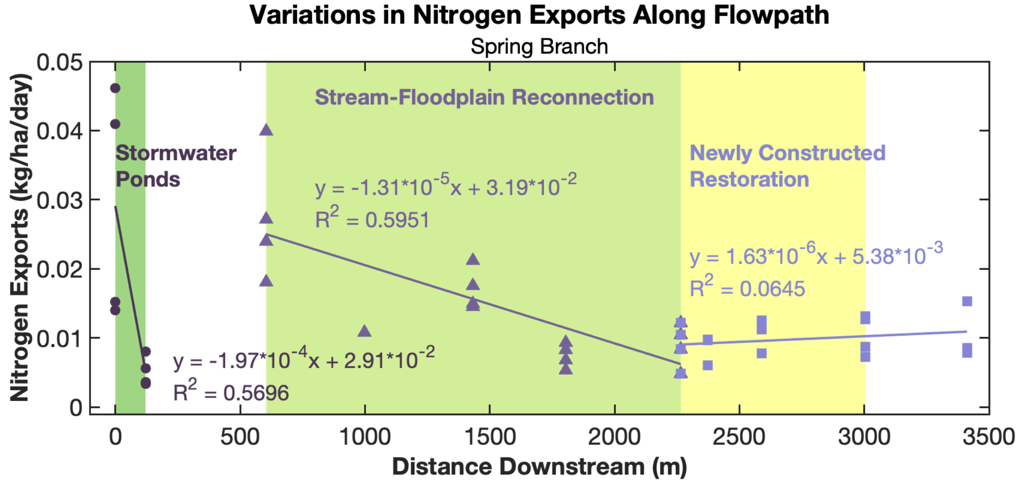


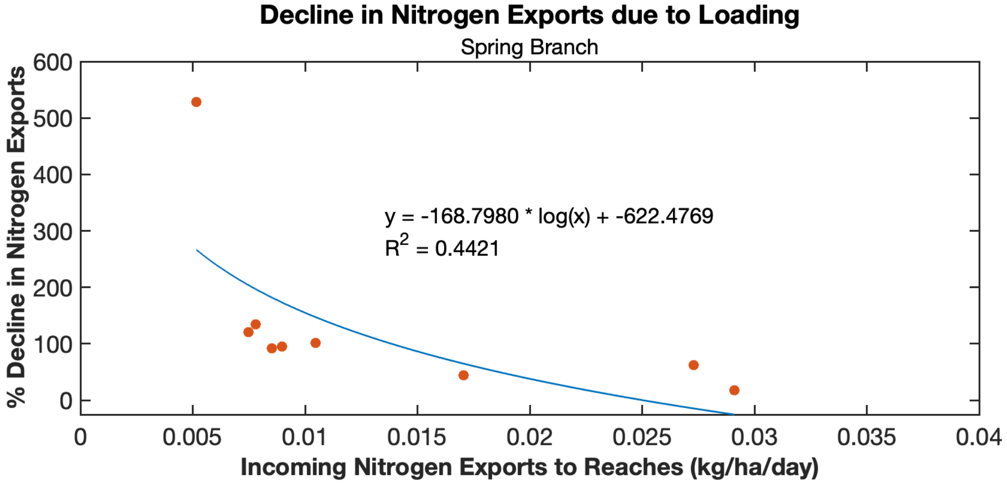
Thanks to Wes Slaughter

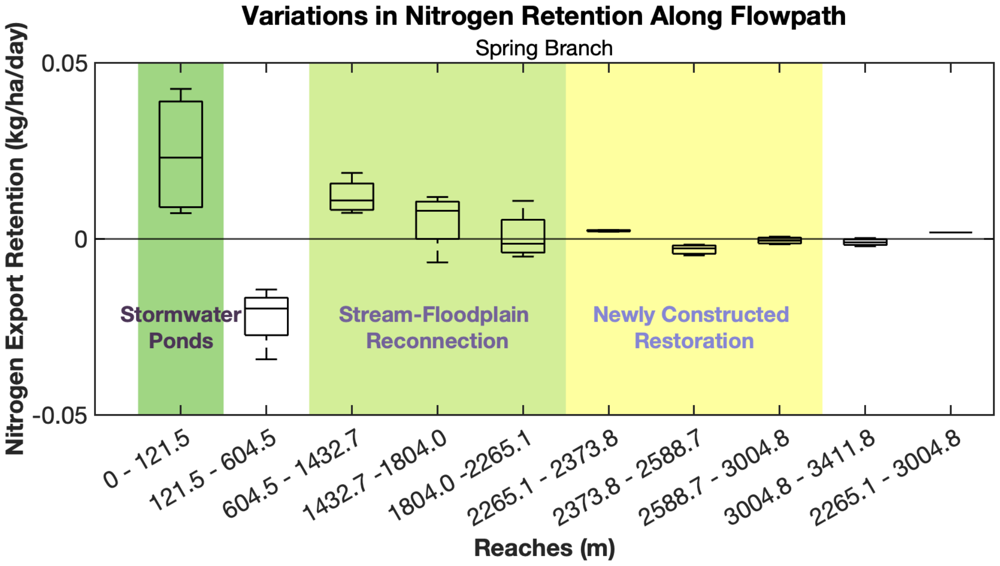
Watts Branch: Variations in Nitrogen Reductions





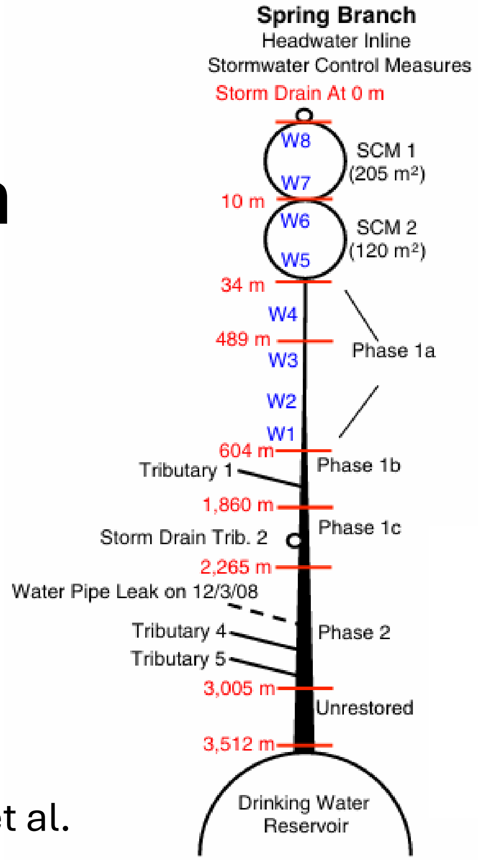






Variations in Nitrogen Retention Can Be Quantified Among Reaches

Sivirichi et al. (2011)



Kaushal et al. (In Prep) and *many thanks* to Ashley Mon!

Newcomer Johnson et al. (2014)

Conclusions for Year 1

-Stream-floodplain restoration can reduce nitrogen transport at watershed scales.

-There can be tradeoffs between nitrogen retention, carbon, and dissolved oxygen.

-Water quality hot spots and transition zones can be identified and guide restoration.

-The downstream distance that water quality can be restored can be quantified.

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- Thank you to Chris Ruck, Shannon McKenrick, and Carol Cain for suggestions.
- Thank you to all CBT partners.

Translation Slides

What are the take home points?
What does this mean for me?

Translation Slides by Ari Engelberg

What does this mean for me?

- These streams exhibited very dynamic patterns in nutrient levels as water flowed through the restorations. This likely reflects a combination of the effects of the restoration and local watershed conditions.
- Increasing levels of terrestrial carbon in some stream restorations was correlated to decreasing N levels as you moved from upstream-downstream (Scotts Level and Hickey Run).
- Potential trade offs between nutrient reduction and dissolved oxygen reduction in restorations that slowed stream flow (Campus Creek)
- Some potentially identifiable effects of stormwater management at the watershed scale resulted in decreased N loads (Sligo Creek) . Will need more work to tease apart what's causing this pattern.

What does this mean for me?

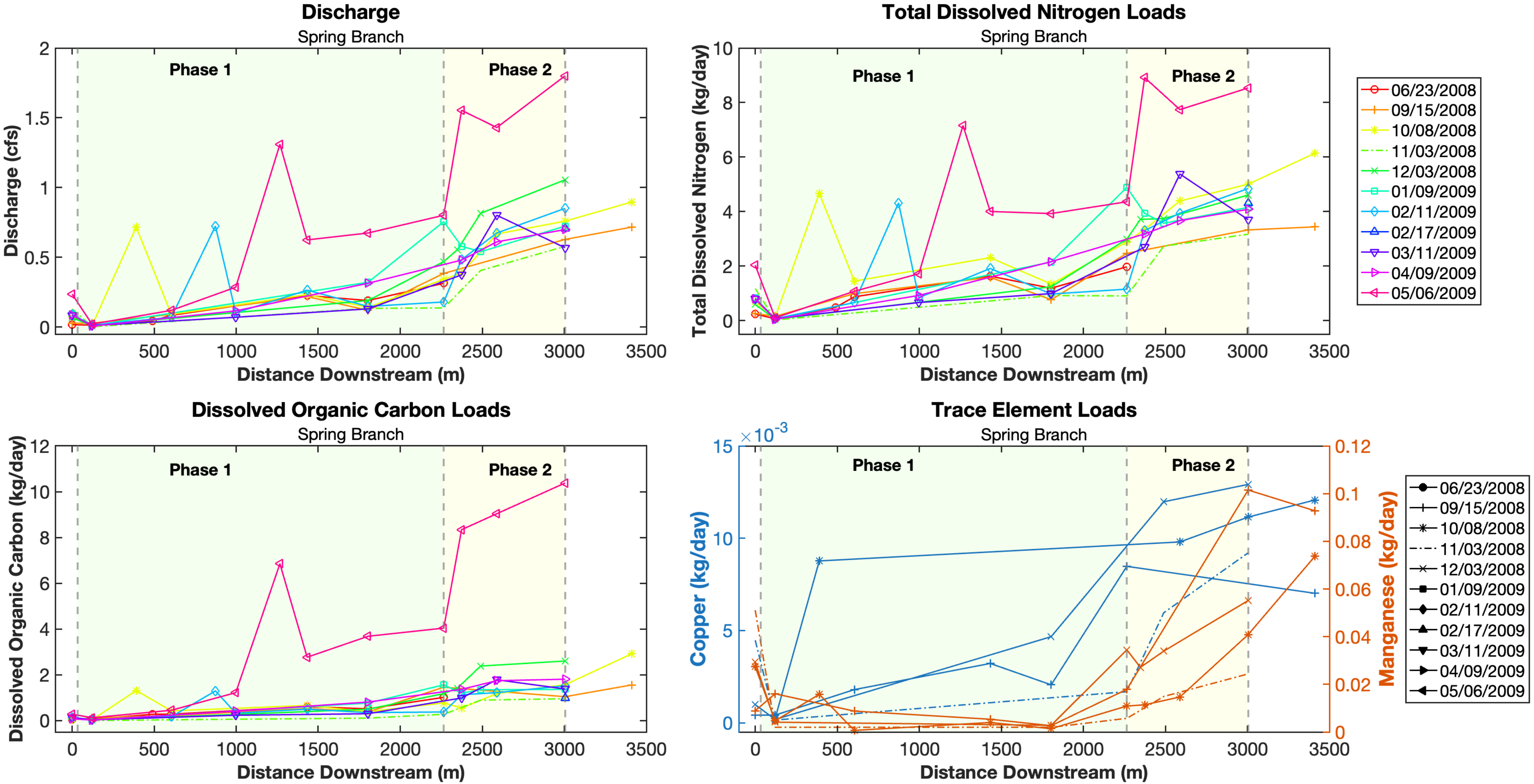
What do I take from this if I am a practitioner:

- Keep in mind potential trade offs from slowing down streamflow.
- Minimize limit of disturbances during construction and protect riparian buffers; mature forest provides a critical carbon source for the stream that may promote denitrification and nutrient cycling.

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

- Keep in mind the above when siting and reviewing stream restorations.
- Consider increasing post-restoration longitudinal sampling of funded or permitted projects. This may supplement traditional before/after sampling to reveal useful information on restoration performance.

Pollution “Hot Spots” Can Be Identified along Watersheds



Kaushal et al. (Submitted)

Future and Ongoing Work

-Continue longitudinal monitoring and analyze incoming results

-Statistical relationships between land use/land cover and pollutant concentrations and loads (*e.g.*, Kaushal et al. 2023, Maas et al. 2023)

-Analysis of statistical breakpoints to detect restoration and conservation signals and how far they persist downstream (*e.g.*, Shelton et al. 2024)

-Comparison of changes in concentrations and loads before and after stream restoration over time and space (*e.g.*, Mayer et al. 2022, Kaushal et al. 2023)

-Comparisons using 3 paired and nested watersheds (Scotts Level/trib, Hickey Run/Springhouse trib, Paint Branch/Campus Creek trib) .