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Manuscript Accepted for *Environmental Research Letters*

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ISSN: 1748-9326

Soil Health Metrics for Assessment of Floodplain Restorations

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Should be online anytime now….

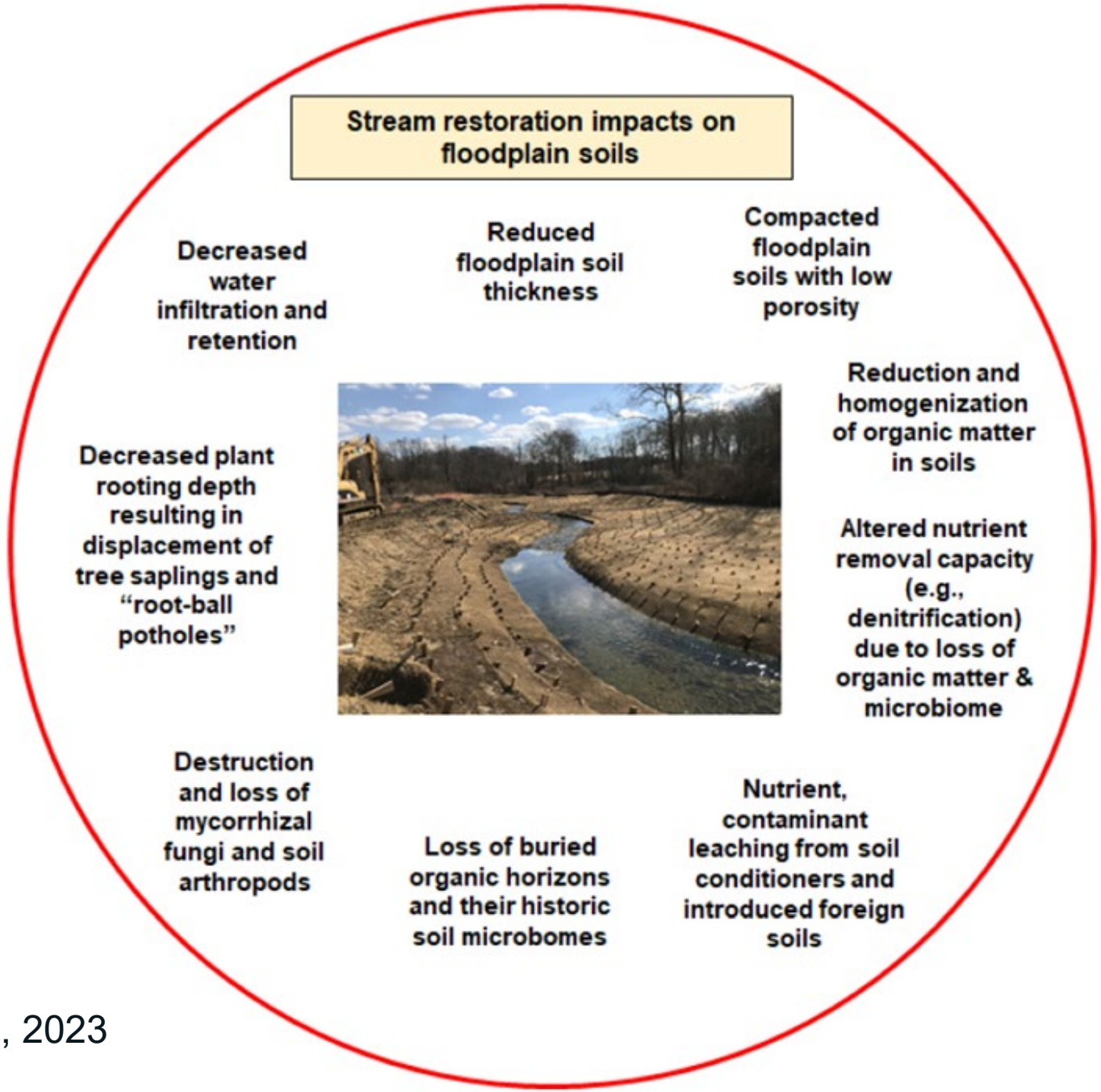
Stream Restoration – Water Quality & Ecological Uplift

- 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?

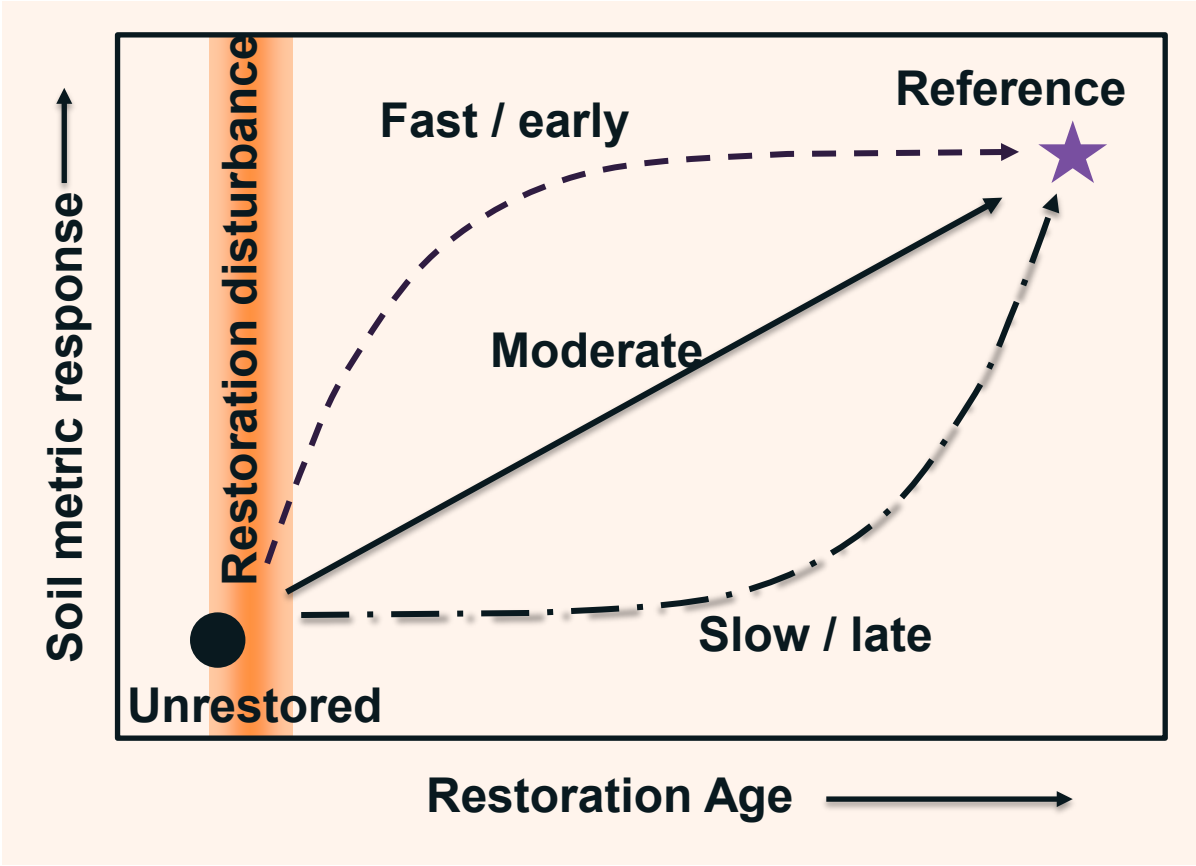
- Lack of knowledge on soil health and its important consequences
- Absence of specific design & implementation "best practices"
- **Unavailability of specific soil metrics & tests**
- **Unknown "Desired" or "reference" soil conditions**
- Lack of regulatory credits or benefits for restoration agencies

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

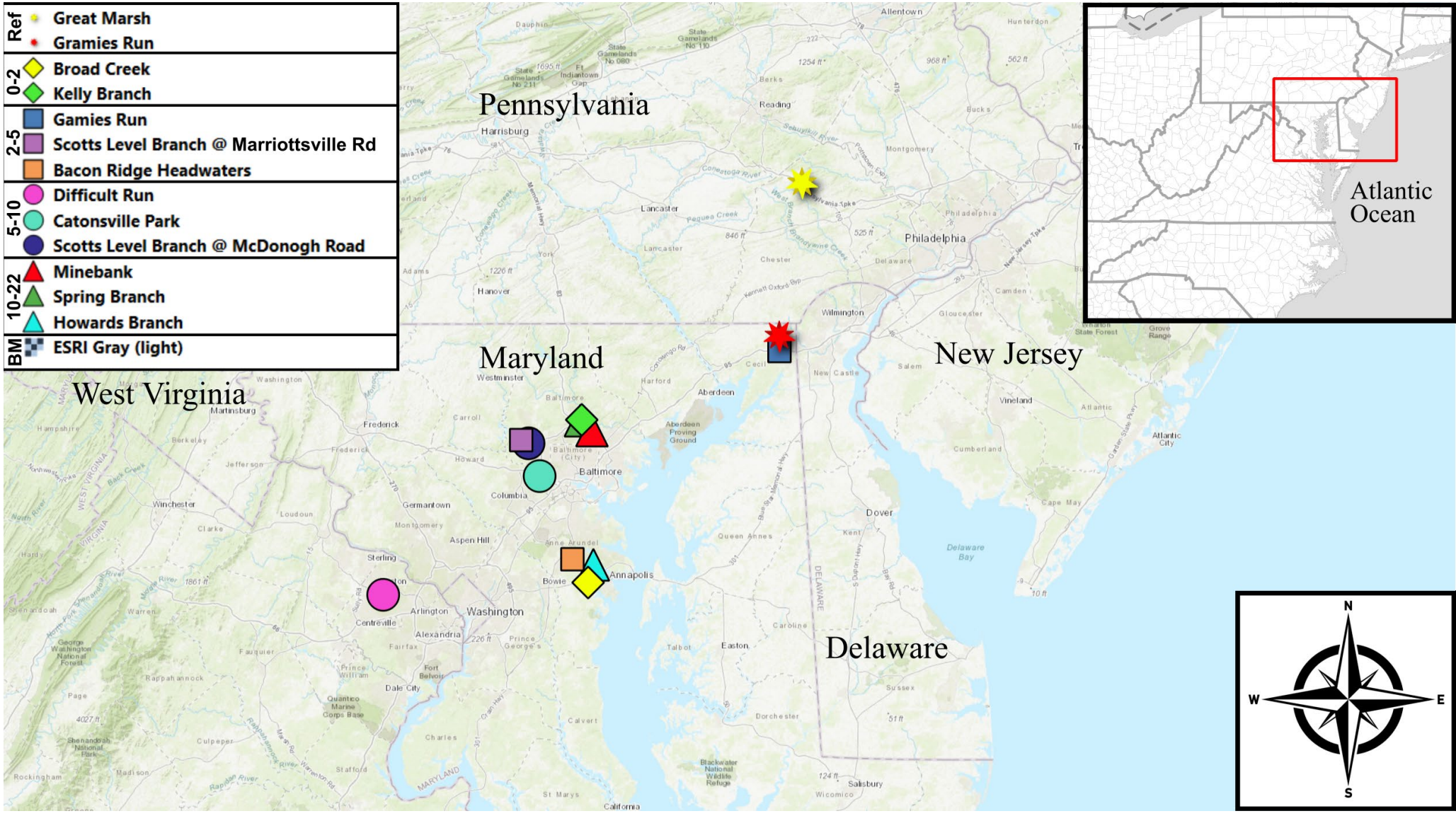
Gramies Run floodplain wetland, MD –

proximal to Gramies Run restoration

Great Marsh, PA –

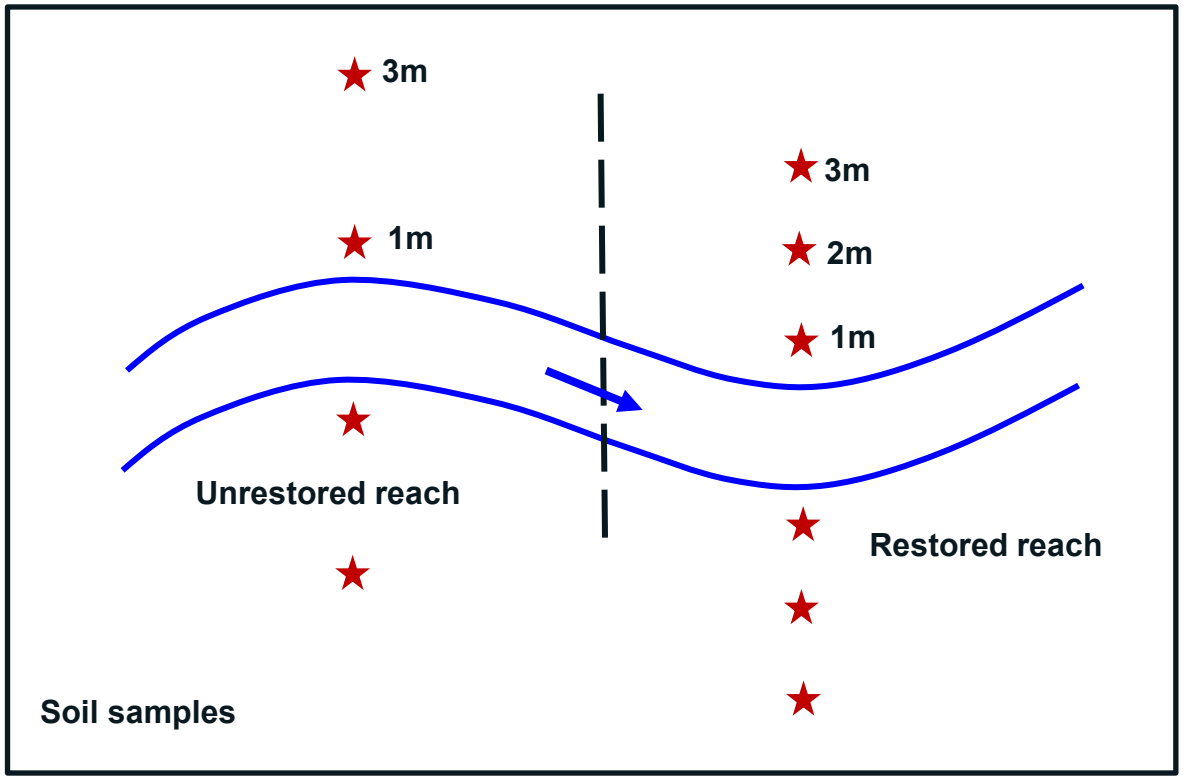
Undisturbed early Holocene freshwater marsh

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

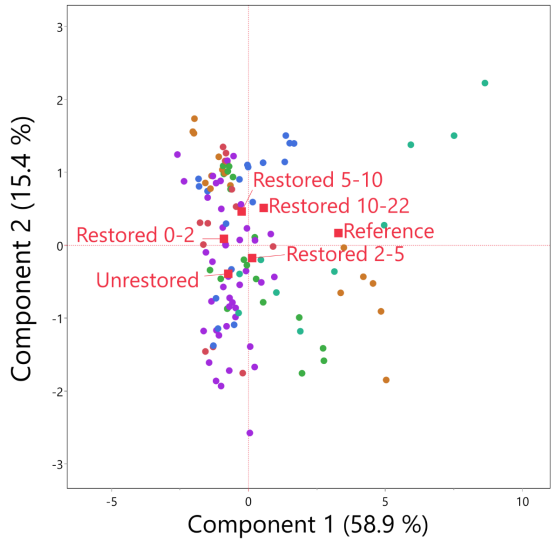
- Achieved Restoration (AR) towards reference conditions

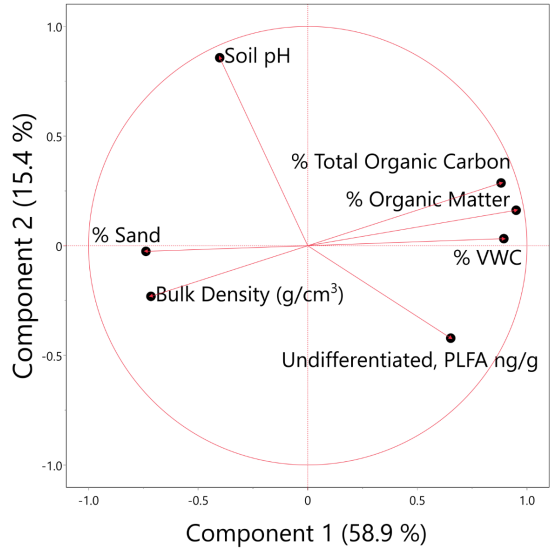
- **Years to recovery to reference sites**

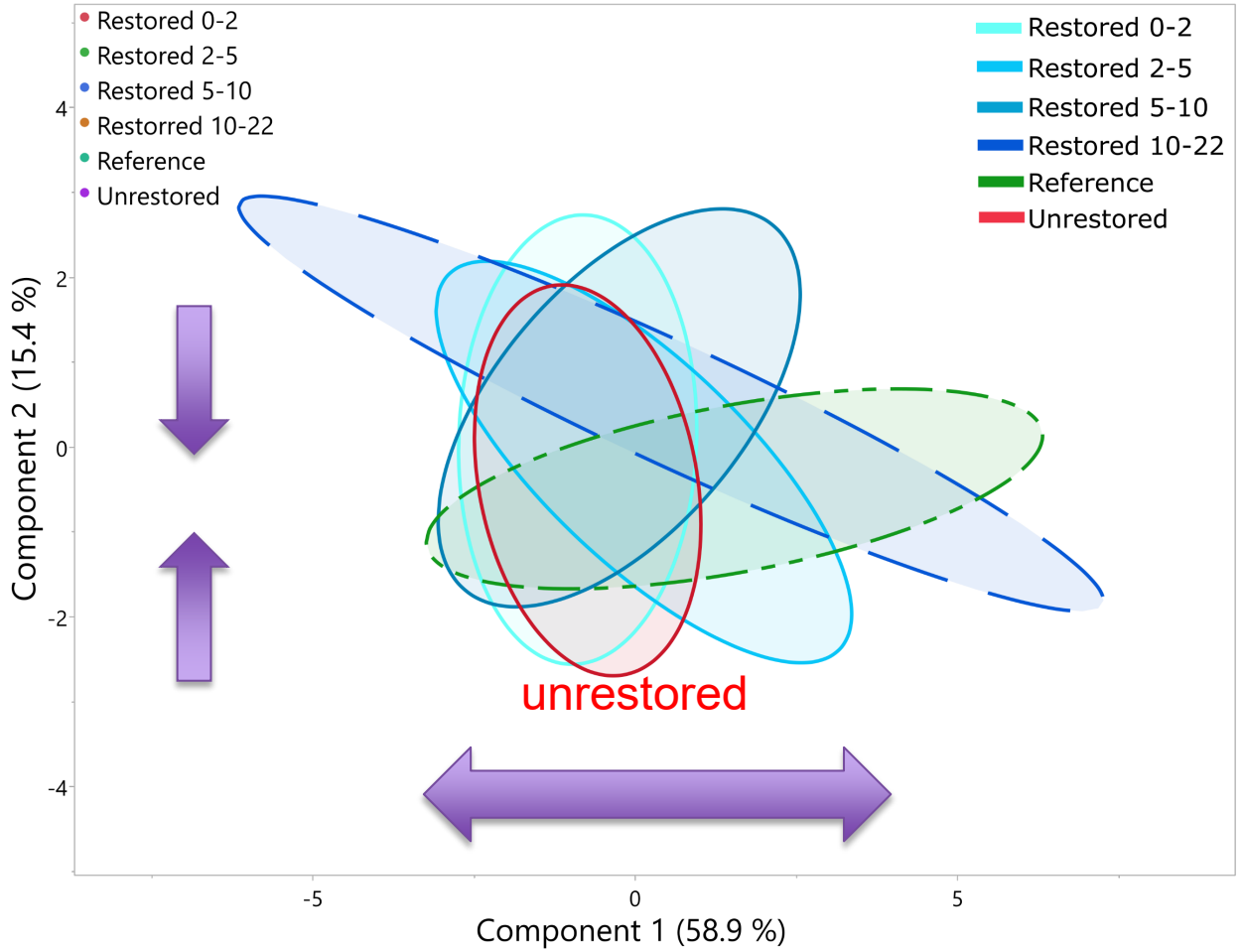
Results

PCA Reveals Distinct Clusters & Evolution of Restored Sites

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

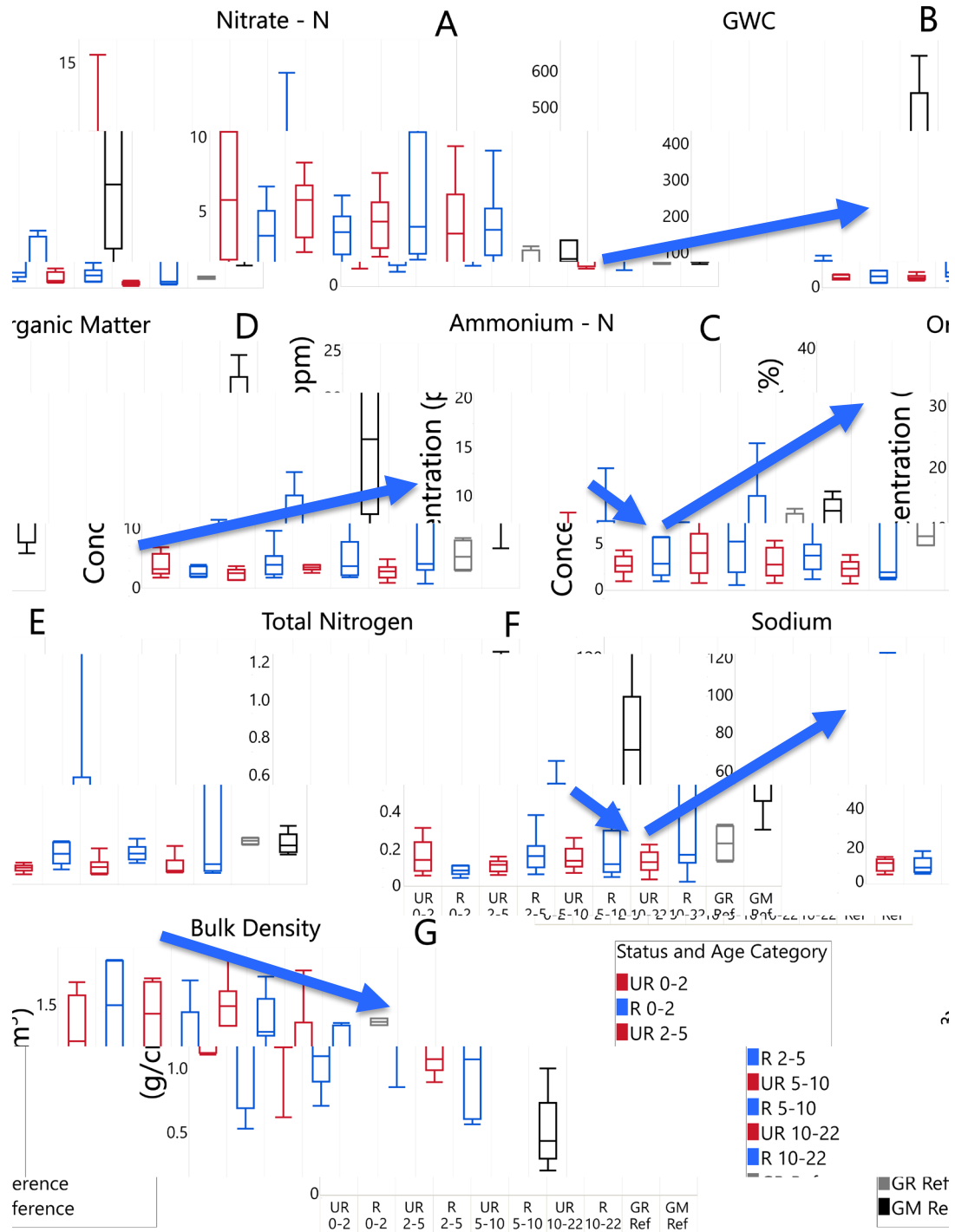






Soil Health Metric Recovery Post-Restoration

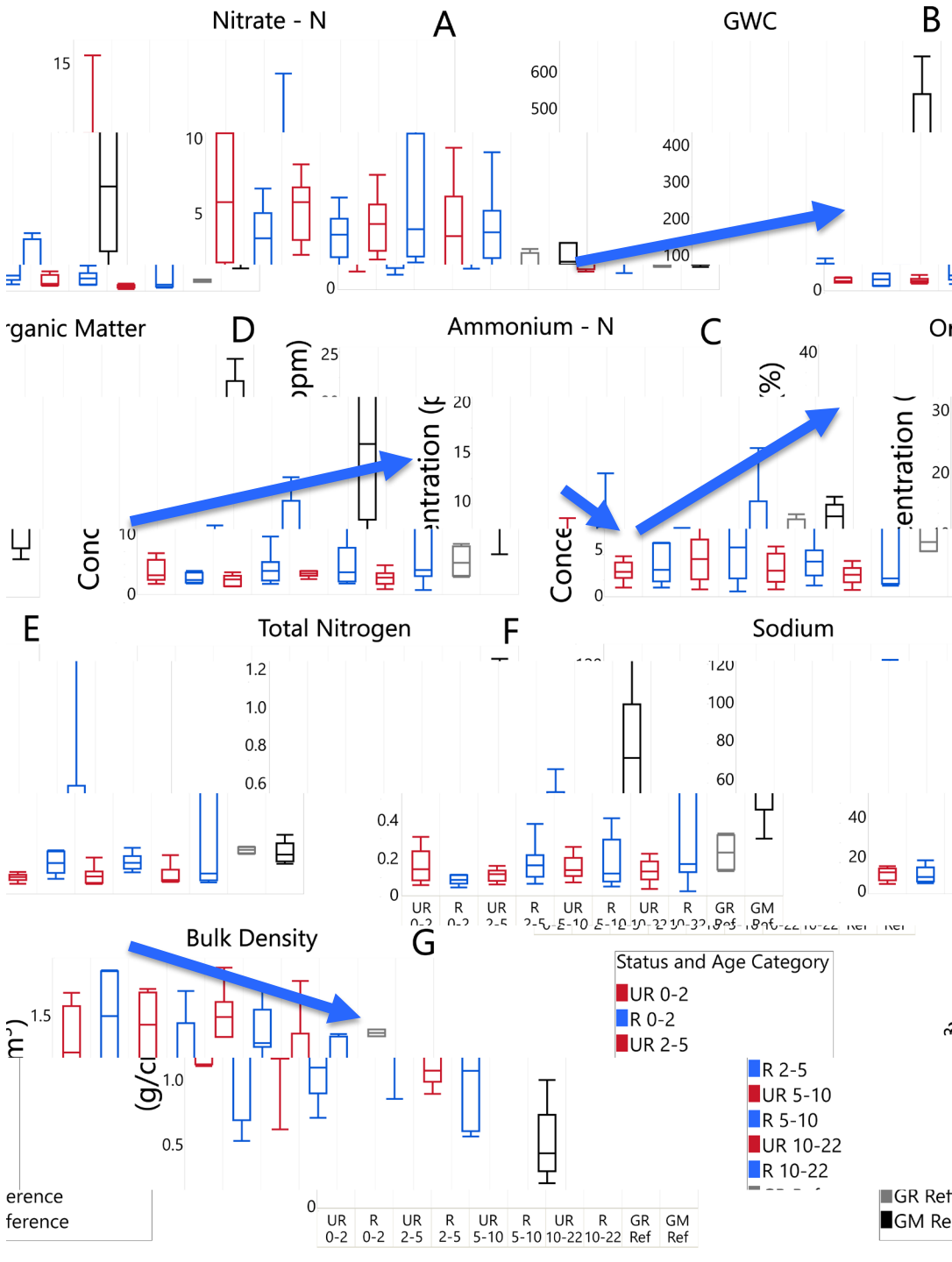
Red – unrestored; **blue** - restored; **black** - reference



Soil Health Metric Recovery Post-Restoration

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

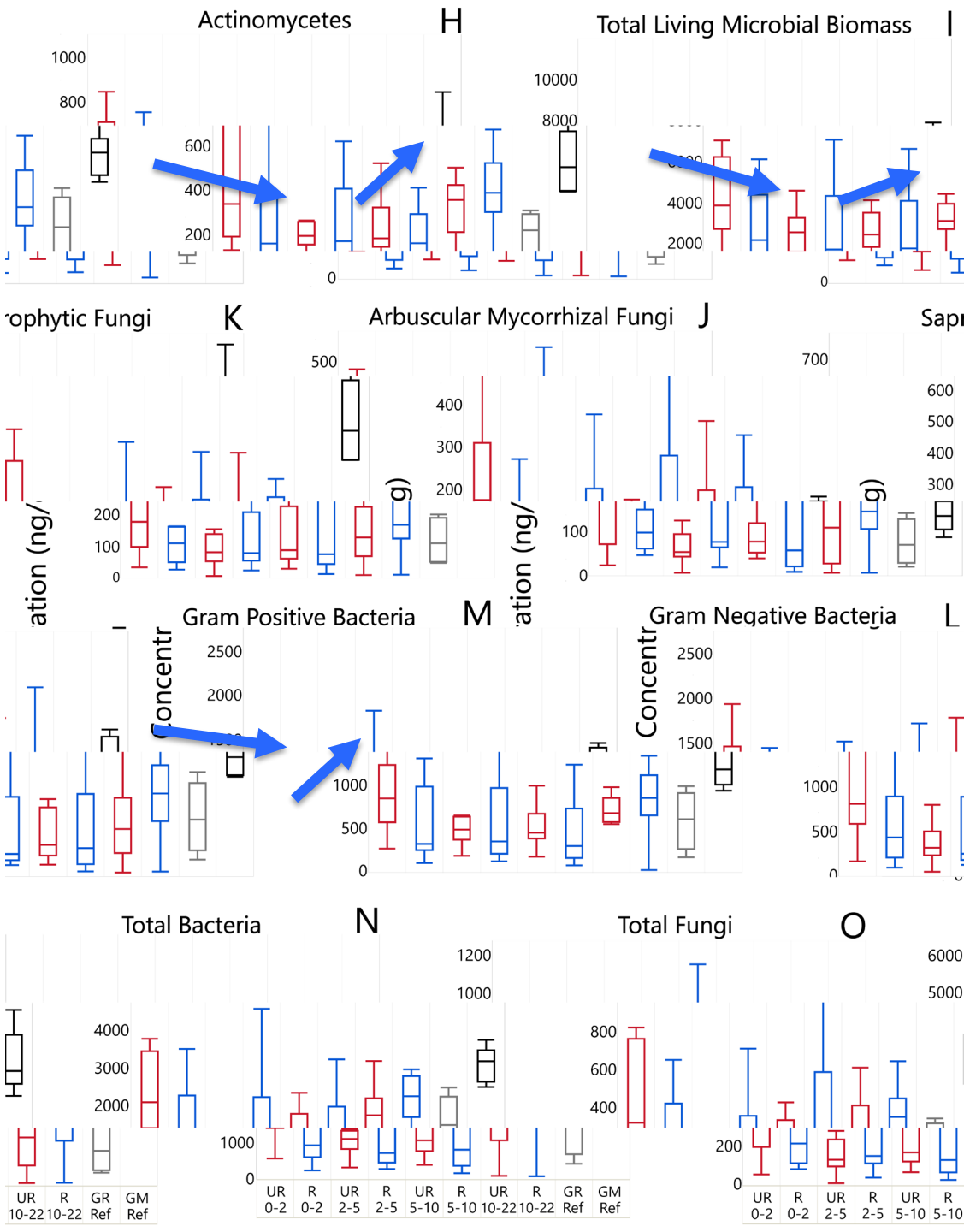
- GWC, organic matter, ammonium, and total nitrogen <u>increased with time</u> after restoration
- Nitrate and bulk density <u>decreased with time</u> after restoration
- **Soil health metrics trended towards** measured **reference condition with time**



Biological (PLFA) Recovery Post-Restoration

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

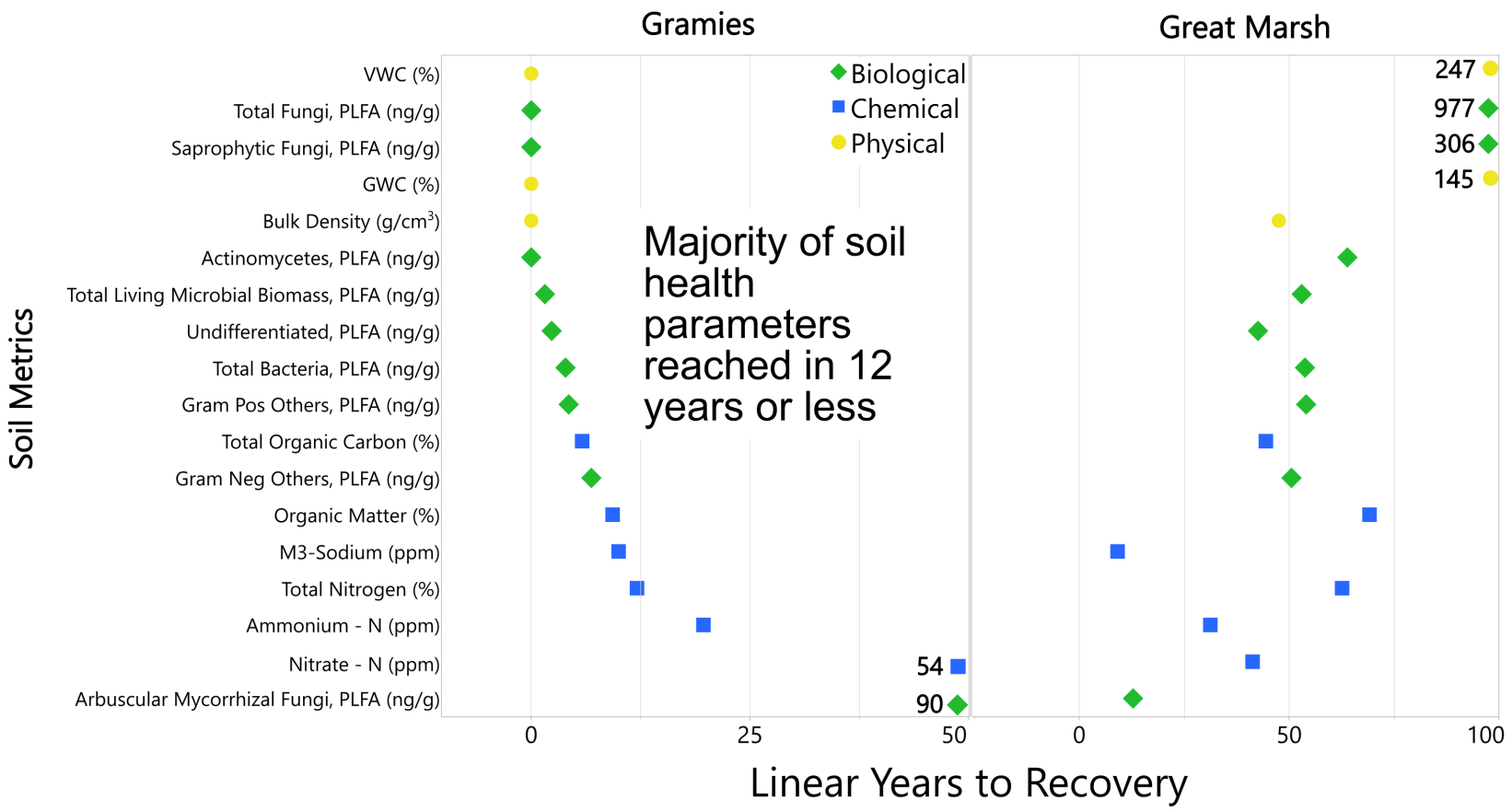
- Slowly recovered



Percent Change

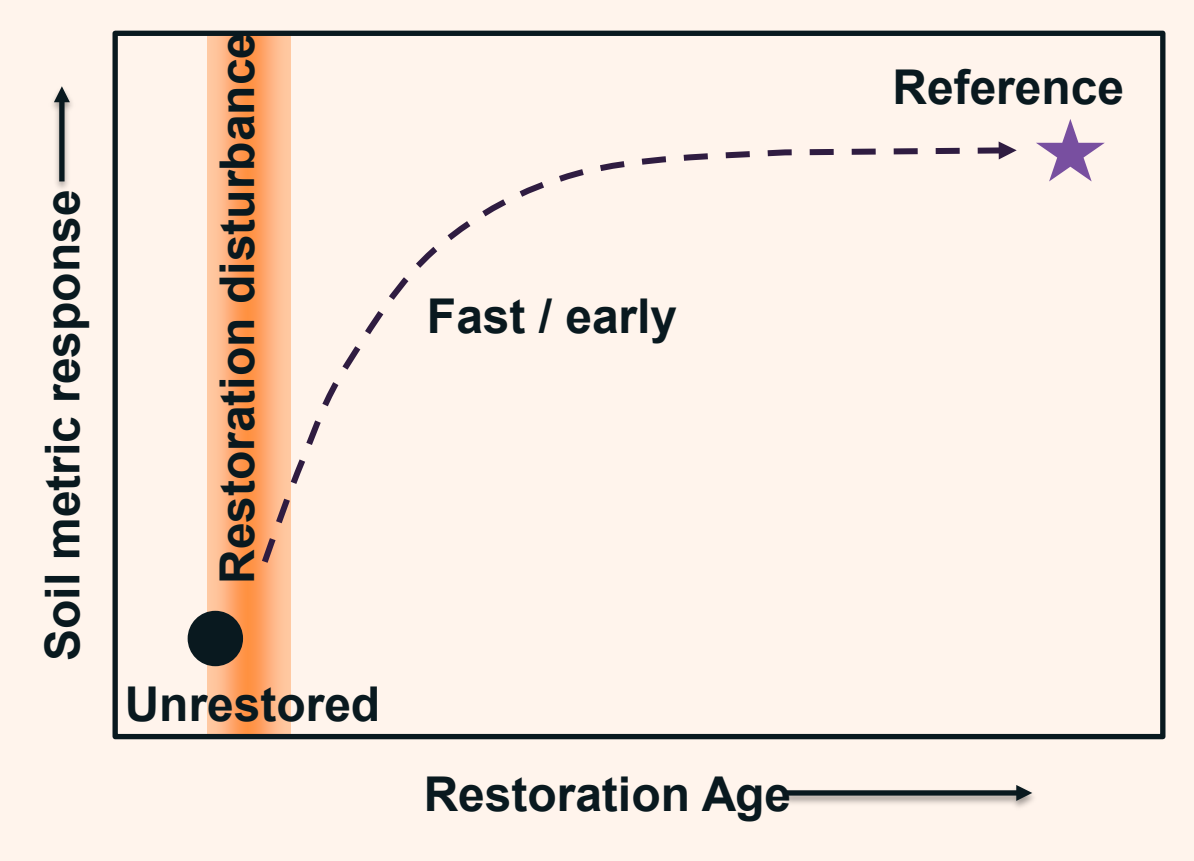
Soil Metrics	% Change 0-2	% Change 2-5	% Change 5-10	% Change 10-22	% Change Overall
Bulk Density (g/cm^3)	3.06	-11.70	-8.70	-16.23	-9.86
GWC (%)	10.15	64.62	31.93	360.68	87.49
VWC (%)	-4.18	32.75	20.22	170.78	39.75
SOM (%)	-16.62	81.73	34.16	182.58	69.65
NO_3^- - N (ppm)	-47.28	-26.23	41.32	-0.28	-9.96
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**

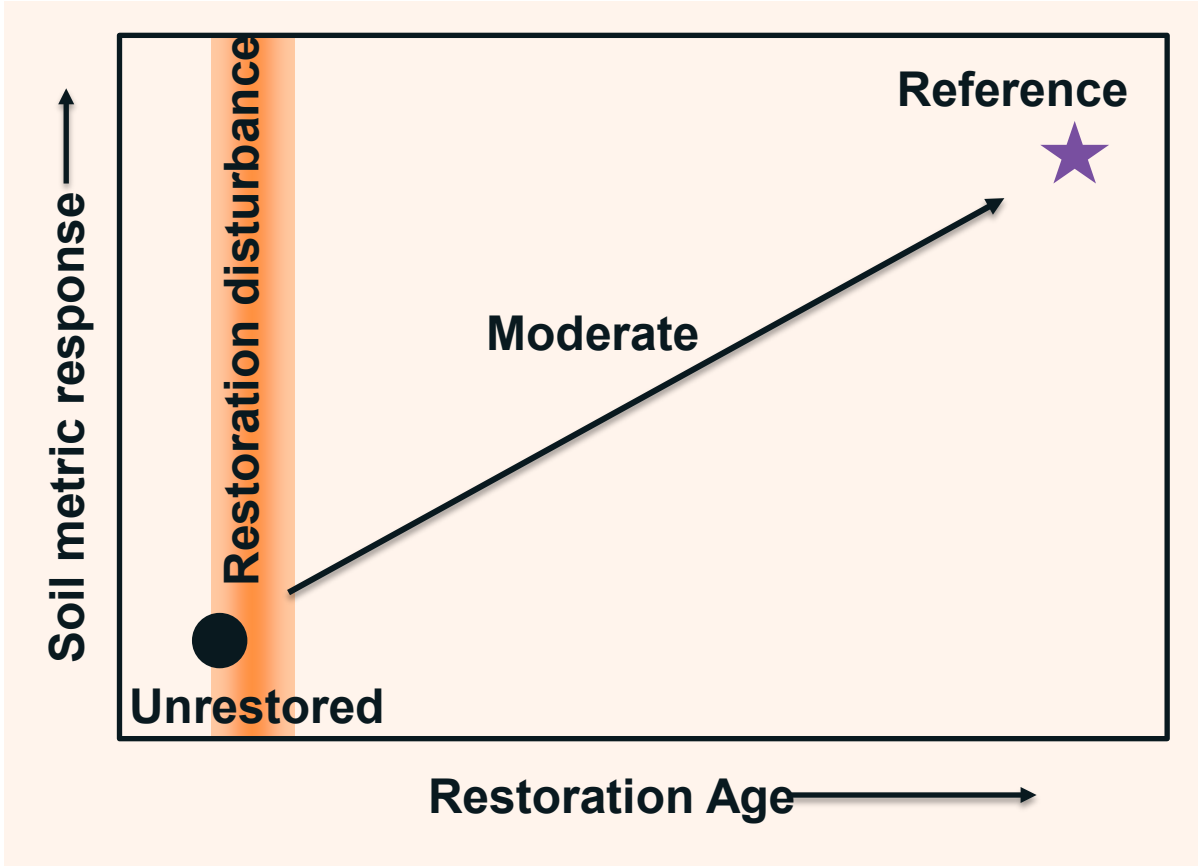
Soil metrics – fast / early - 0-2 yrs



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

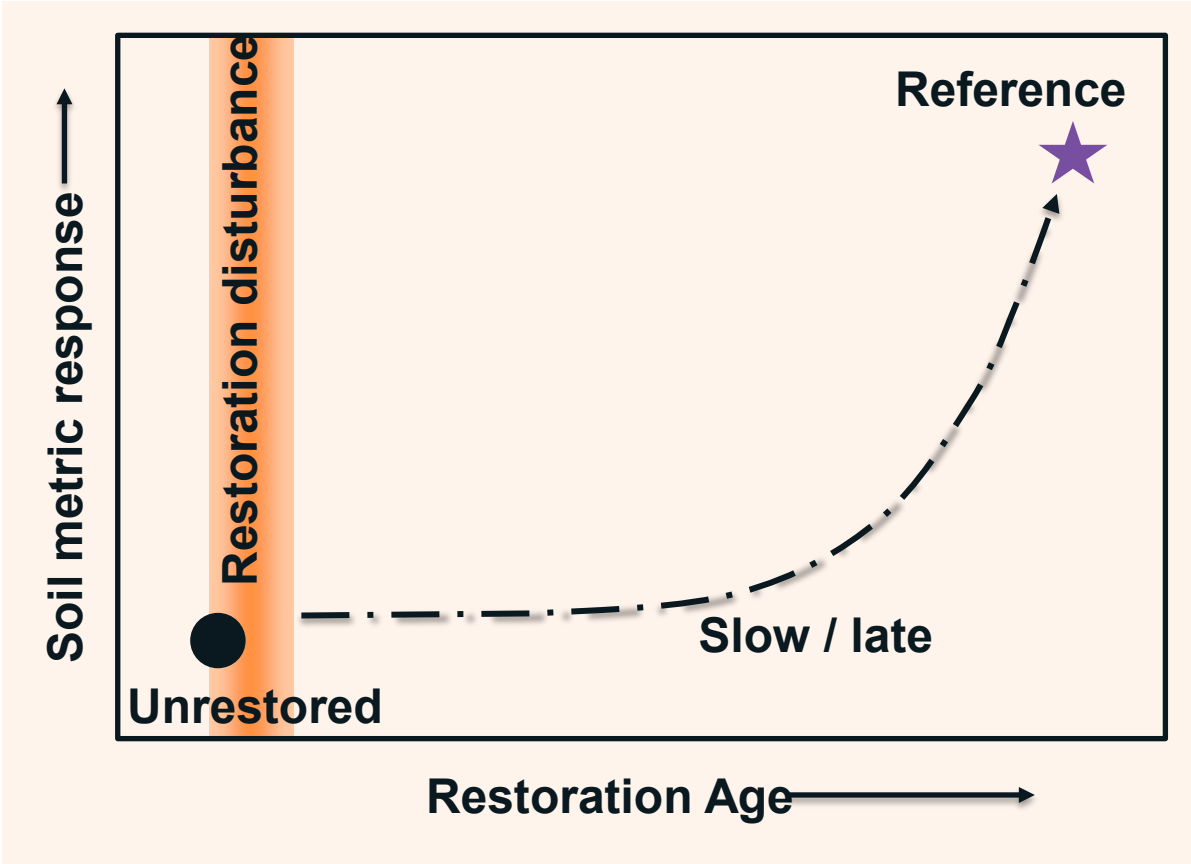
Soil metrics – moderate – 2-10 yrs

- **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