



Forest Ecosystem Monitoring Cooperative Conference: 10/20/2025

Restoring Degraded Riparian Forested Buffers into Multi-Functional Habitats for Socio-Ecological Resilience

Restoration Ecologist, Educator
Jess Rubin, UVM ALE Department,
MycoEvolve

On Unceded Abenaki Territory

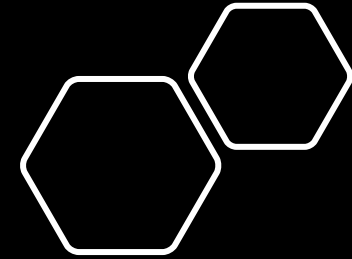


Mycoremediation for Watershed Restoration

IN THESE BINS GROWS THE MYCELIUM OF *Stropharia rugosoannulata* a.k.a "wine caps," "garden giants," or "King/Queen Stropharia." Ecological restoration business Mycoevolve and UVM, in a project funded by EPSCoR, are growing "mycofilters." Dairy effluent containing *E. coli* will be added to these bins and the outflow from the bins' spigots will be tested to evaluate the mycelium's efficacy as a water filter. Mycofiltration systems can be installed in swales, wetlands, riparian buffers, and rain gardens by farmers and other land managers to improve watershed health.


The Mycelium is the Message!

Questions?
Jess Rubin, yepeth@gmail.com
Dr. Josef Görres, jgorres@uvm.edu
Mycoevolve.net



- Objectives
- Context
- Pilot
- Methodology
- Findings
- Implications



A photograph of a forest with many bare trees and a few red flags on the ground. The text is overlaid on the top left of the image.

Multi-functional riparian forest buffers offer a holistic approach to address socio-environmental problems.

Riparian Buffer Issues in VT

Chemical Non-Native Species Removal

- Current large-scale removal involves glyphosate use

Water quality function uncertainty

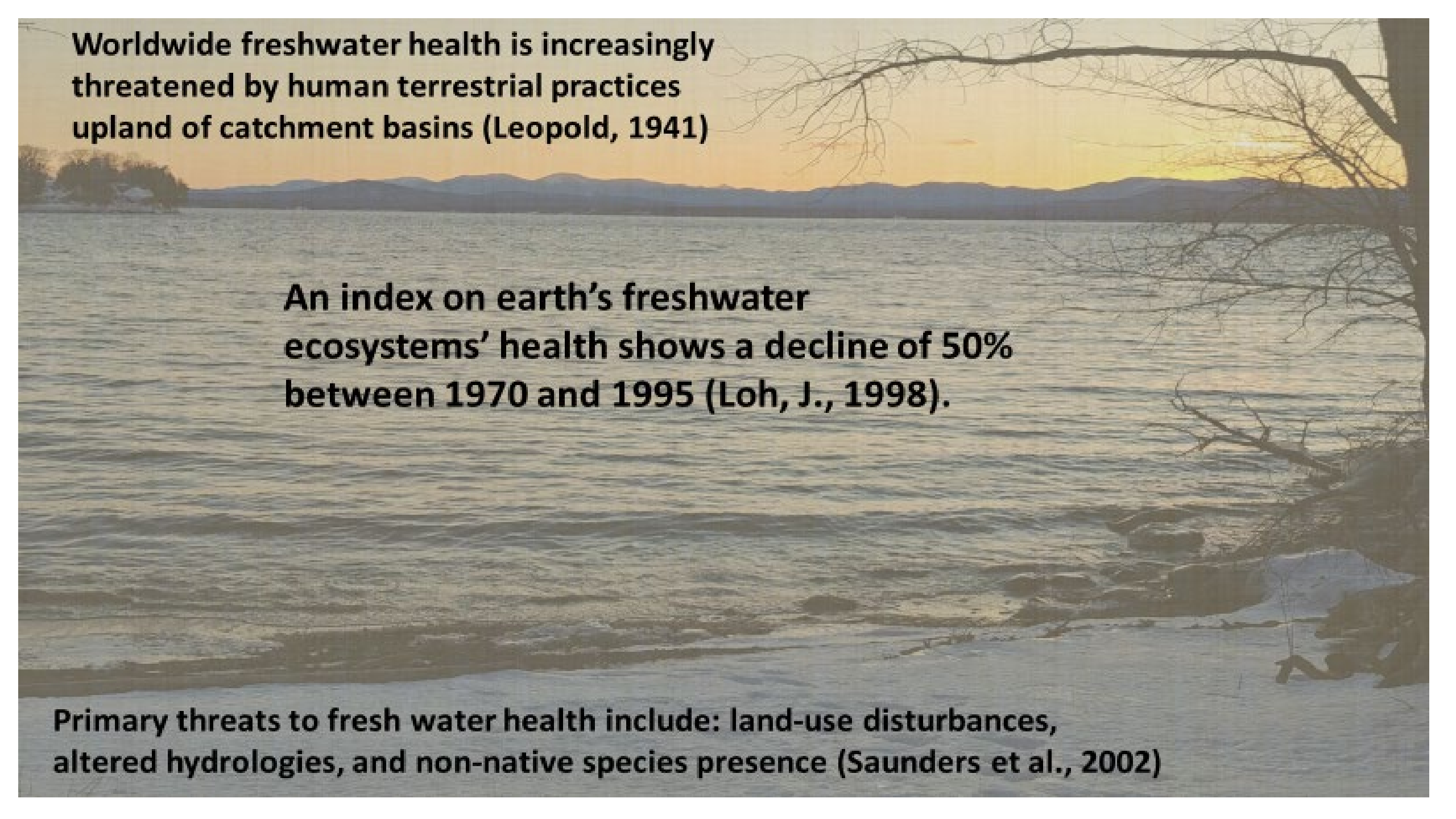
- Riparian buffers saturate with phosphorus (P)
 - Transition from P sinks to sources
- Minimal monitoring (data gathering)
- Minimal maintenance (harvesting)

Limited Pollinator habitat aims

- Lack of available palettes for ecosystems and soil types
- Palettes often include limited, deer resistant species
- Long-term data gathering is needed to track succession

No Abenaki orientation

- Most projects do not collaborate with nor offer access



Worldwide freshwater health is increasingly threatened by human terrestrial practices upland of catchment basins (Leopold, 1941)

An index on earth's freshwater ecosystems' health shows a decline of 50% between 1970 and 1995 (Loh, J., 1998).

Primary threats to fresh water health include: land-use disturbances, altered hydrologies, and non-native species presence (Saunders et al., 2002)

Phosphorus (P) in the Watershed

Agriculture, the largest cause of nonpoint source pollution (Zaring, 1996; USEPA 1992), accounts for an estimated 38-41% of base P loading for the VT portion of Lake Champlain (Lake Champlain Basin Program 2024).



Cyanobacterial bloom development is correlated with increased presence of soluble reactive phosphorus (SRP) (Cao et al., 2016; Wang and Wang, 2009)



6th Great Extinction

Insect pollinators, providing ecosystem services to > 80% of earth's flowering plants, are in serious (20–40%) population decline; an alarming situation for global biodiversity. (Nath et al. 2023)



Homegrown National Parks (Tallamy 2020)



Unceded Wabanaki Territory

Rematriation

supports Indigenous inhabitants to creatively stay in place. As we gather, we acknowledge this research occurs on unceded territory of the original inhabitants of N'Dakinna, the Abenaki. The people of the Dawnland are the traditional stewards and caregivers of the land. Our relationship to the land calls each person to be better caregivers of the land. We pay our respects to the ancestors who were here for all time, our elders, and our relations, past, present and emerging. We honor with gratitude this land and all it gives.

(Barger et al. 2025)



Eco-Literacy



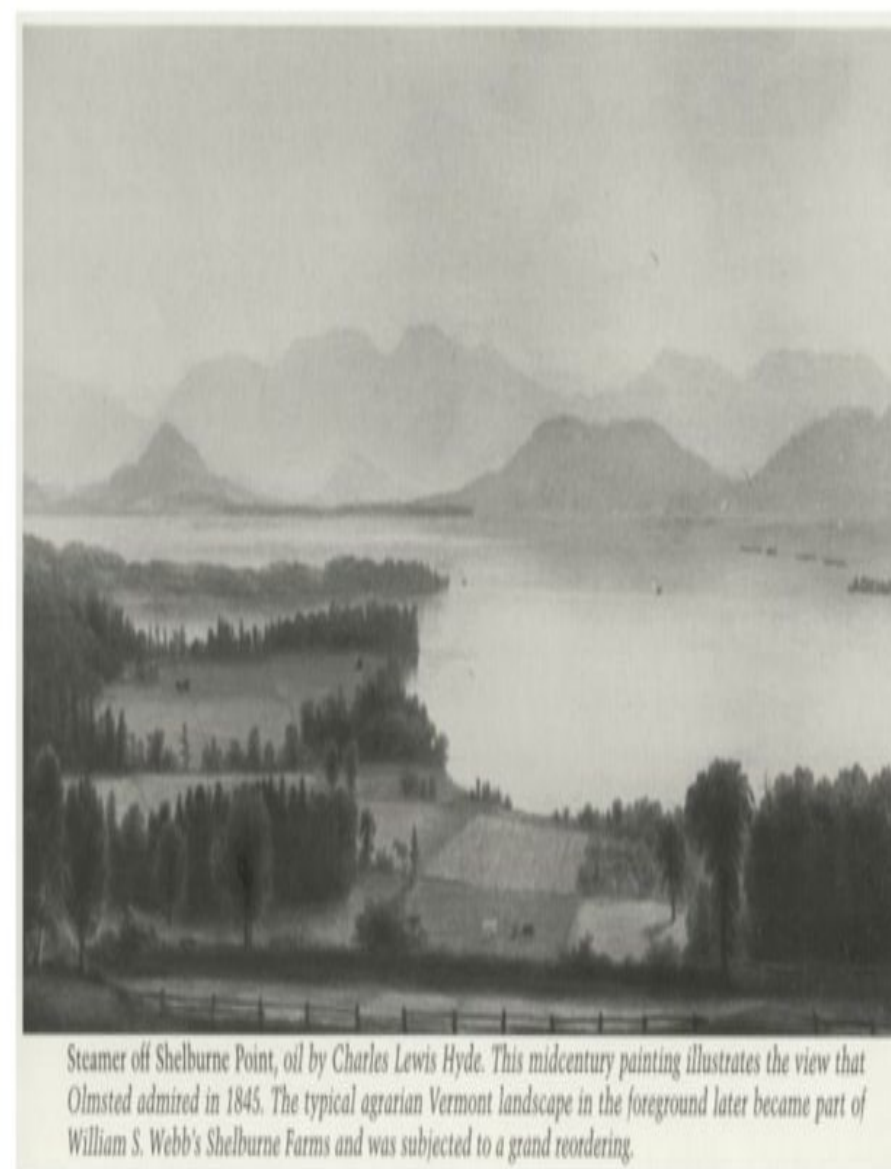
Crucial time to train next generation

“A significant need for practical, place-based educational activities to **cultivate both ecological literacy and responsibility**...help students connect their learning to the specific environmental **challenges faced by their community**.” (Fitriani et al. 2025)

Study Site History

Colonial time period

- Early 17th century: 90% Wabanaki were killed
- 18th century: colonizer land practices replaced those of Wabanaki
- 1840s colonially named 'Champlain Valley': VT's wool production center
- 1840-50's railroads increased sheep flock & dairy herd size
- Late 19th- 20th century: roads, ditches, installed without revegetating
- 1902 Shelburne Farms: "model farm" to experiment
- 1940s High soil P concentrations exacerbated by **superphosphate**
- Late 1950-60's Dutch elm disease
- Nonnative species grew
- 1972 Shelburne Farms became a nonprofit: Shelburne Farms Resources
- 1984 Public Agricultural and Environmental Education Center
- 2001 Shelburne Farms designated as National Historic Landmark





International Journal of
*Environmental Research
and Public Health*



Review

Potential for Mycorrhizae-Assisted Phytoremediation of Phosphorus for Improved Water Quality

Jessica A. Rubin ^{*} and Josef H. Görres

Plant and Soil Science, University of Vermont, Burlington, VT 05405, USA; jgorres@uvm.edu
^{*} Correspondence: Jessica.Rubin@uvm.edu; Tel.: +1-802-839-8286

Abstract: During this 6th Great Extinction, freshwater quality is imperiled by upland terrestrial practices. Phosphorus, a macronutrient critical for life, can be a concerning contaminant when excessively present in waterways due to its stimulation of algal and cyanobacterial blooms, with consequences for ecosystem functioning, water use, and human and animal health. Landscape patterns from residential, industrial and agricultural practices release phosphorus at alarming rates and concentrations threaten watershed communities. In an effort to reconcile the anthropogenic effects of phosphorus pollution, several strategies are available to land managers. These include source reduction, contamination event prevention and interception. A total of 80% of terrestrial plants host mycorrhizae which facilitate increased phosphorus uptake and thus removal from soil and water. This symbiotic relationship between fungi and plants facilitates a several-fold increase in phosphorus uptake. It is surprising how little this relationship has been encouraged to mitigate phosphorus for water quality improvement. This paper explores how facilitating this symbiosis in different landscape and land-use contexts can help reduce the application of fertility amendments, prevent non-point source leaching and erosion, and intercept remineralized phosphorus before it enters surface water ecosystems. This literature survey offers promising insights into how mycorrhizae can aid ecological restoration to reconcile humans' damage to Earth's freshwater. We also identify areas where research is needed.



Study Site Conditions

- Poorly drained, glaciolacustrine silty clay soils
- Highly erodible soils
- In pasture for decades
- Two drainage systems: tile network & series
- SRP concentrations > VT water quality x 18
- Categorized as fragmented



(Photo from Don Ross' students' report: Charlotte Adams, Lily Calabrese, Jon Liebherr, 2014)

(Rubin and Görres, 2022; Perrow et al. 2002; USDA 2006; USDA NRCS 2006I; VT ANR & DEC 2017)

Current site challenges

Abundant Common Buckthorn far beyond study area

- Current removal is miniscule in long-run
- Various vectors, (berries; birds, rodents, wind...)
- Long – term maintenance consistency

Compost pile (550 yd³) not able to be moved at this time

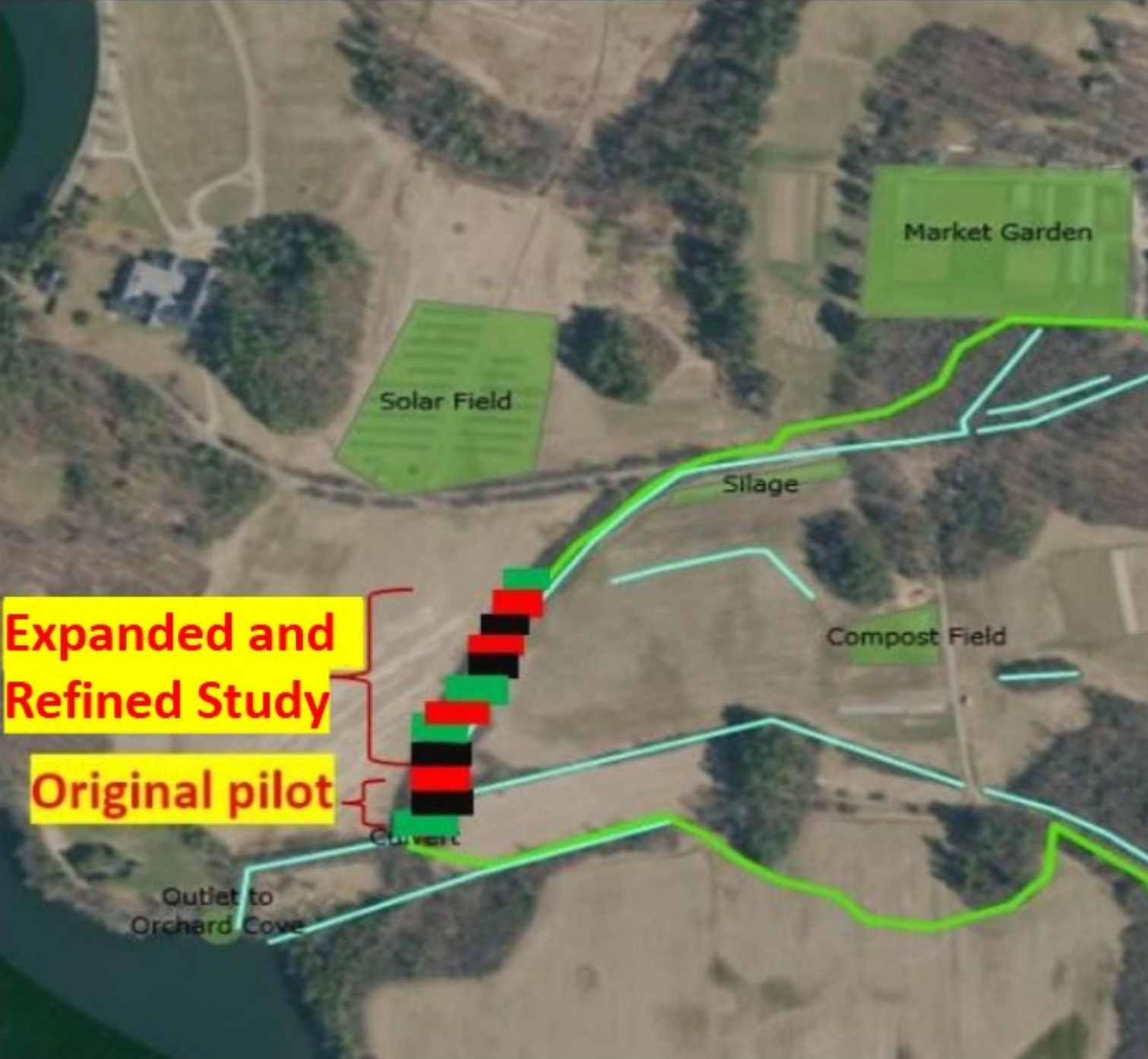
- Upslope surface & subsurface P inundations continue
- If removed yesterday, 6-9 decades before tangible results

Unmapped and broken tile drains going into the study sites

- Soil variability beyond normal for tracking P data
- Point sources of tile drain outlets impossible to locate

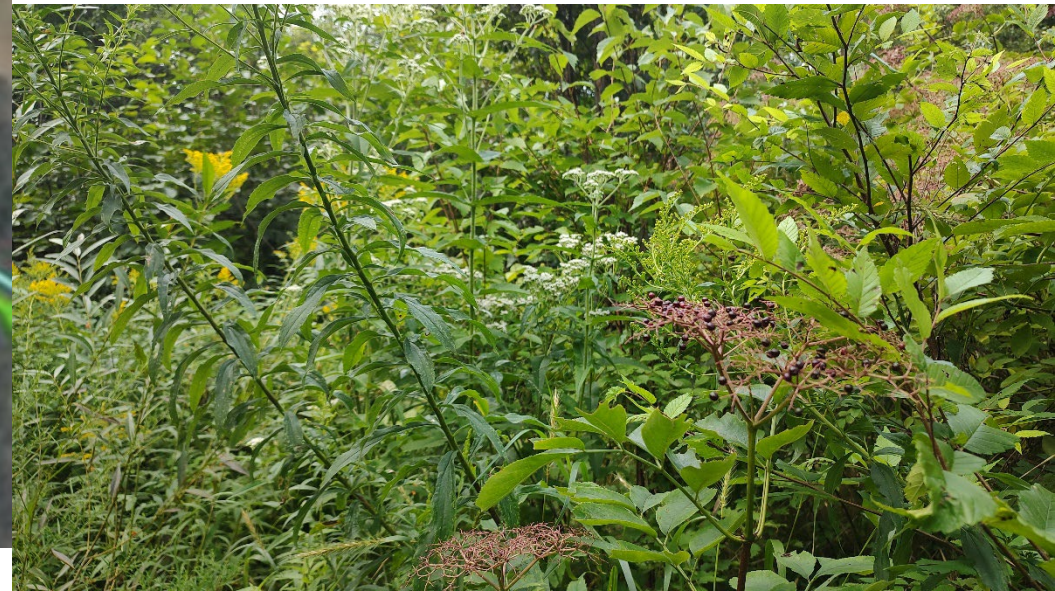


(Meals et al. 2010; Sharpley et al. 2013)

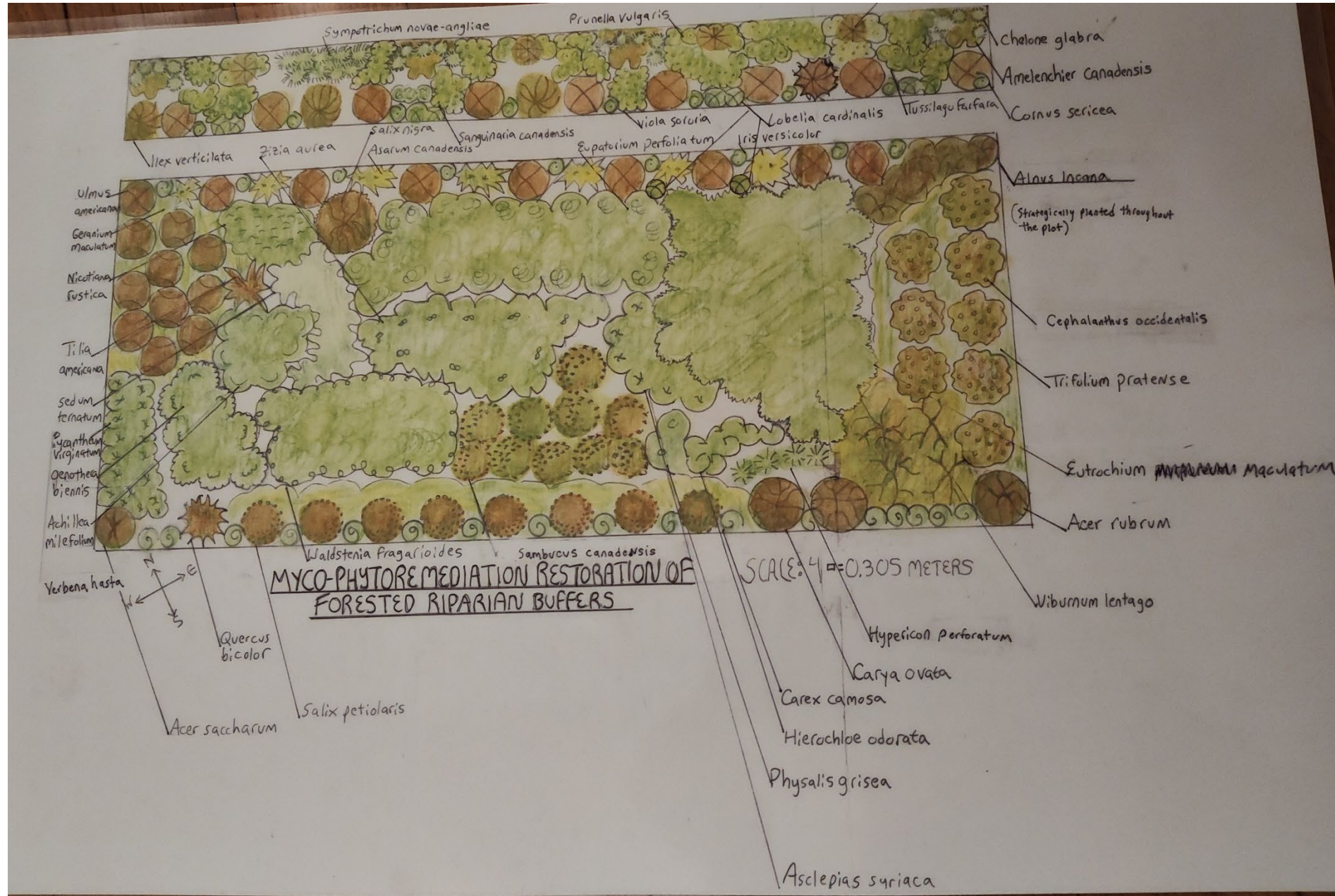


ckthorn with 3x in 2 season works
to reduce soluble reactive phosphorus (P)

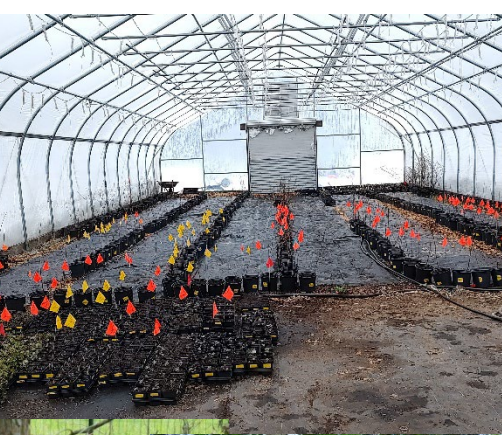
ality
uptake
between species but not treatment
ed than were planted
highest P concentrations (> 3000 mg/kg)
derestimates harvestable biomass P.
(a, b; Rubin et al. 2024)



Concept Map of Design



Site Preparation, Installation, Maintenance



Quantitative Data Collected

Phosphorus

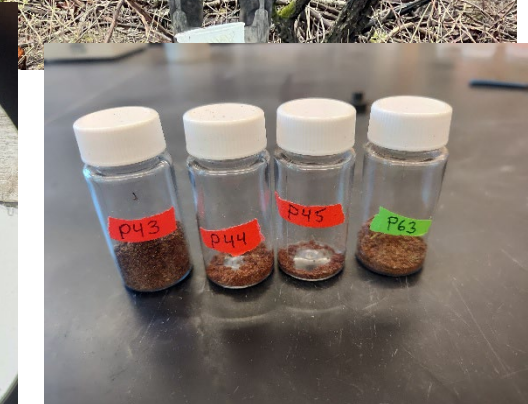
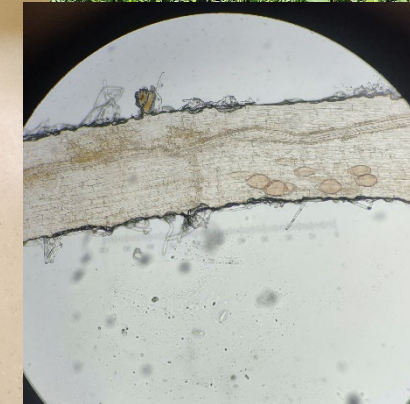
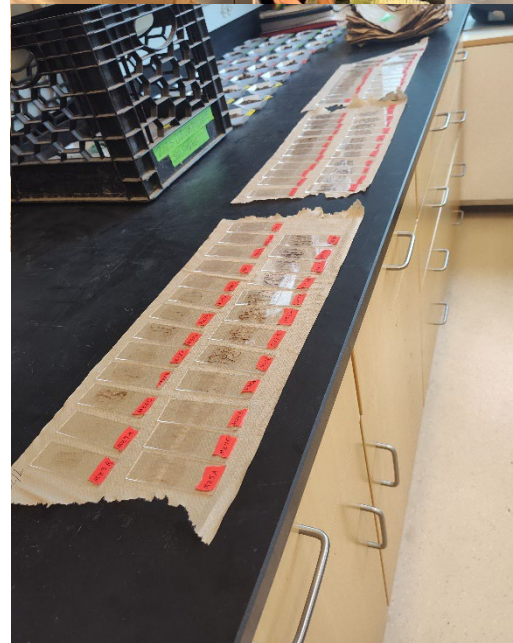
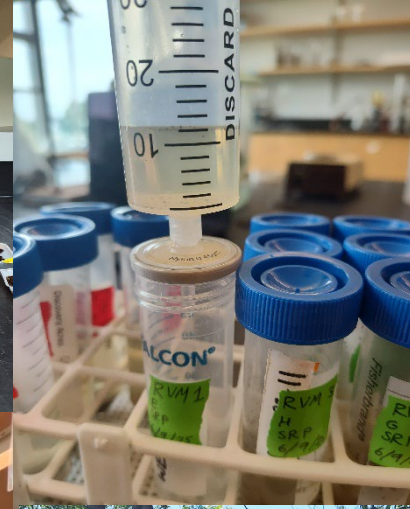
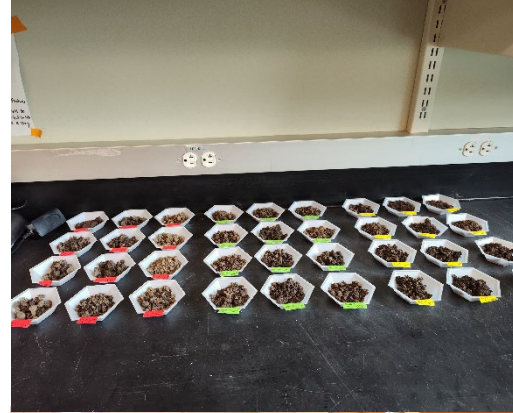
- Total P in soil
- Mehlich-3 P in soil
- SRP-WEP in soil water
- Plant P (Concentrations, Biomass)

Mycorrhizae

- Root Colonization Counts
- DNA of fungi in soil

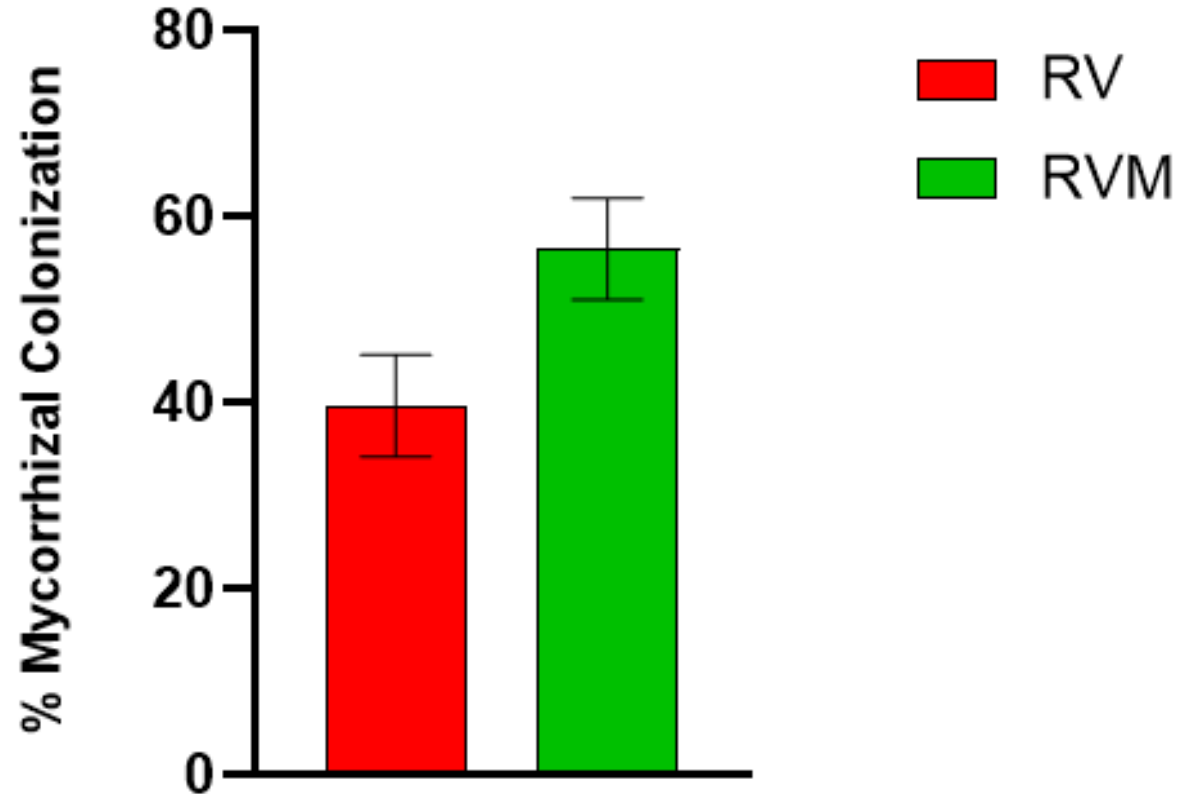
Pollinator Habitat

- Plant Species richness



Mycorrhizal Data; Checking Assumptions

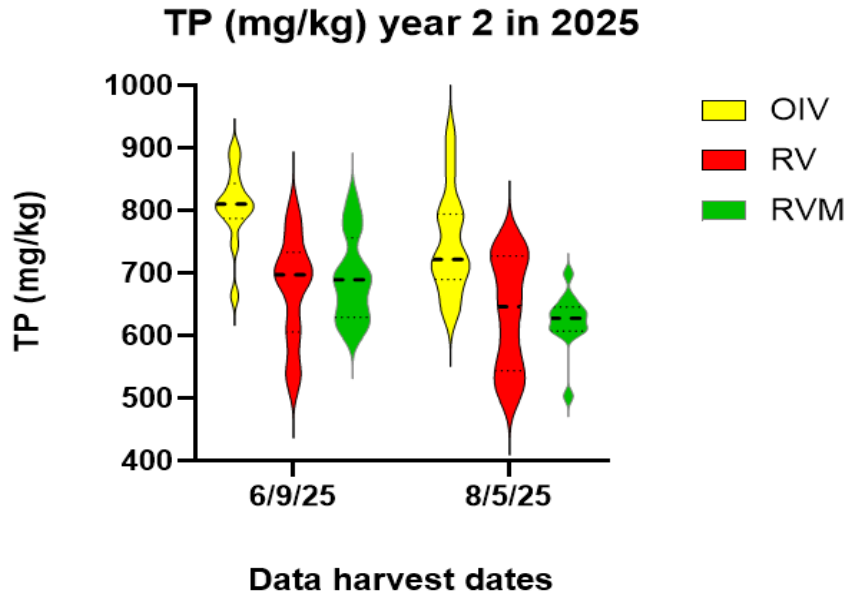
Mean % Mycorrhizal Colonization between Treatments



Statistically significant difference for:

- Treatment ($p < 0.001$) (RVM > RV)

Phosphorus in Soil & Soil Water Data



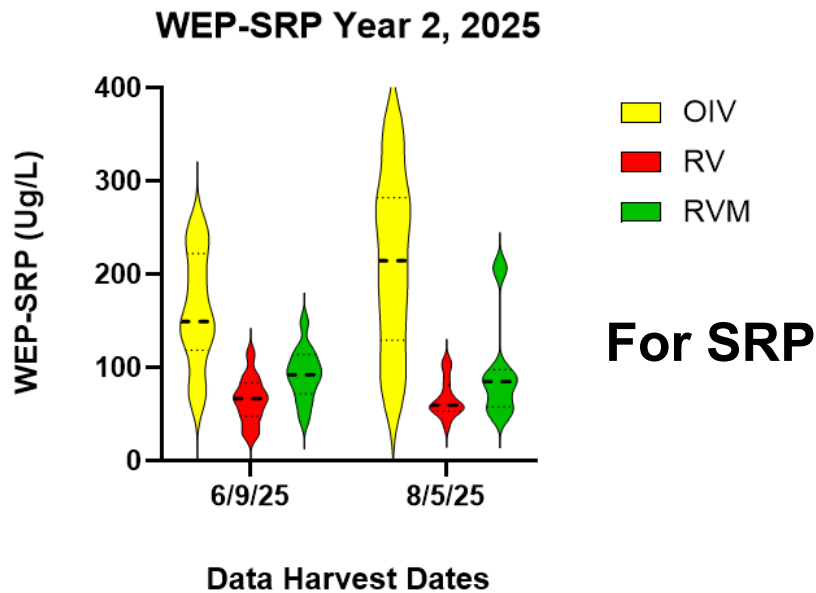
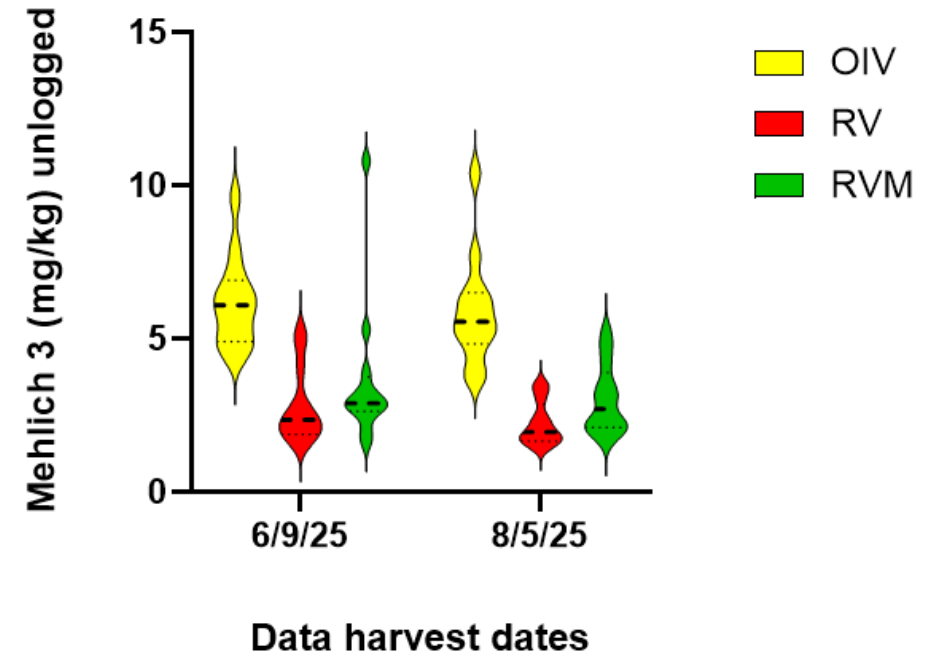
For all 3 P metrics, **Statistically significant difference for:**

- Treatment ($p < 0.001$) (OIV > RV & RVM)

For TP

For Mehlich 3

Mehlich 3 (mg/kg) year 2 in 2025



For SRP

Total Plant P Data

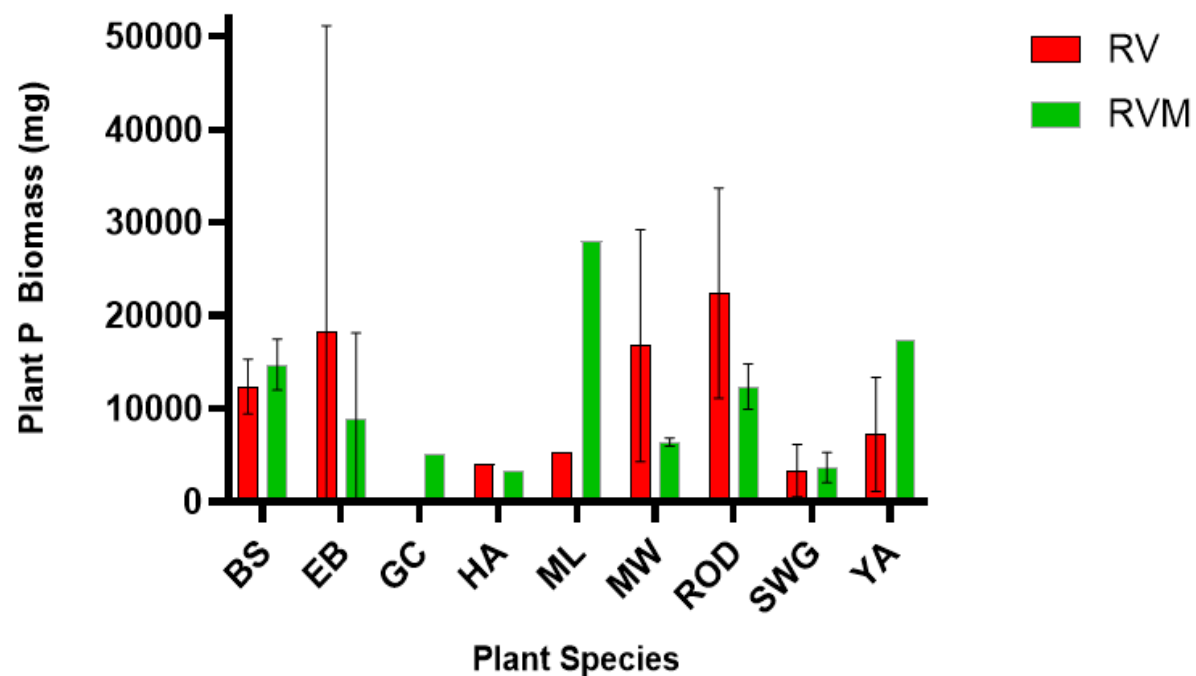
Plant P Biomass Statistically significant difference for:

- Category ($p < 0.001$) (Shrub > Fruit > Herbaceous)
- For Species ($p = 0.014$)

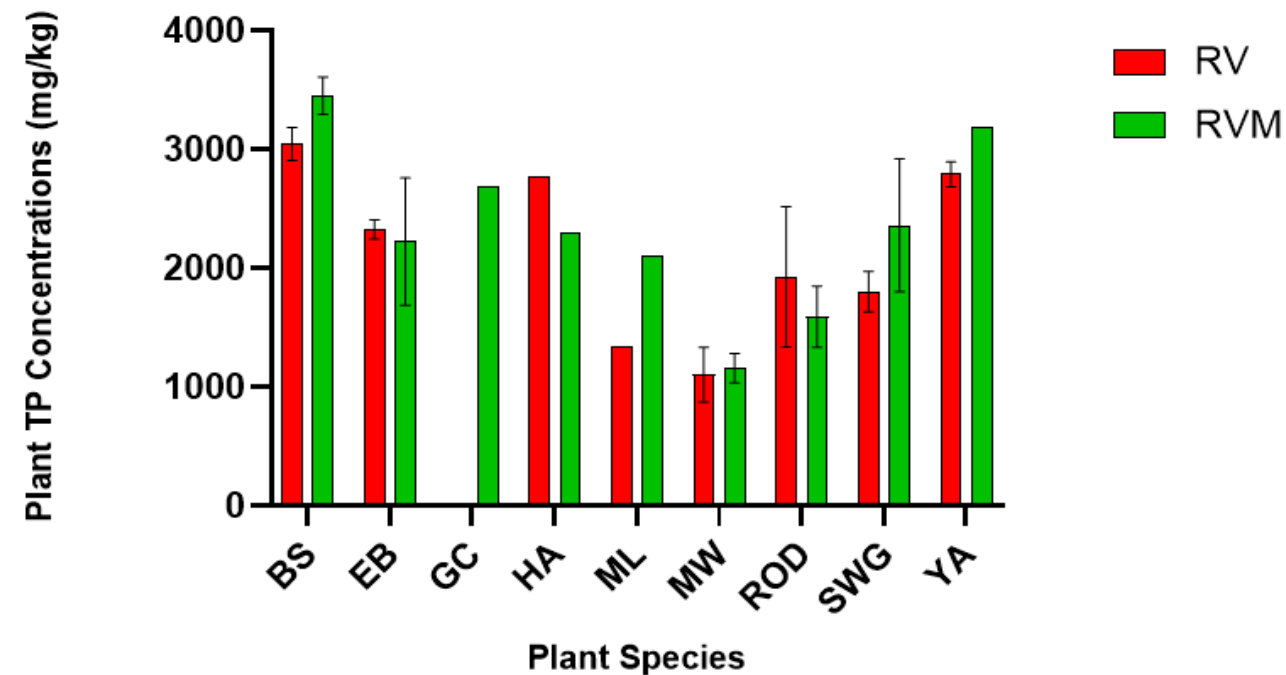
Plant P concentration Statistically significant difference for:

- Category ($p < 0.001$) (Herbaceous > Fruit > Shrub)

2025 Plant P Biomass Across Species



2025 P Plant Concentrations Across Treatments



Plant Species Richness (Counts)

Methodology:

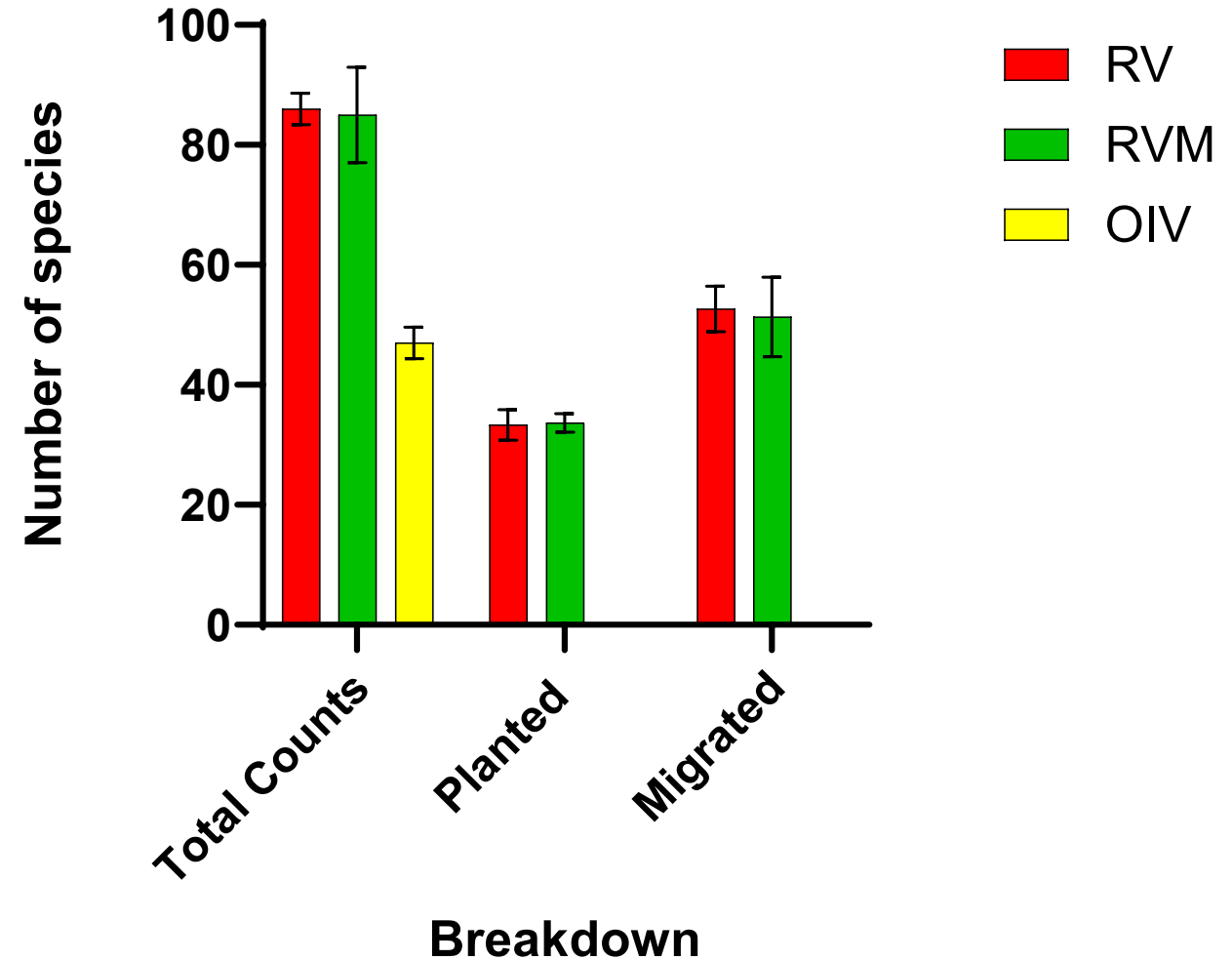
- 5 transects randomly generated each month
- Data pooled from May-August

Results:

- Significantly higher species richness in restored plots compared to control ($p < 0.001$)
- No statistical difference in species richness between RV & RVM ($p = 0.665$)



2025 Plant Richness (May-August)



Planted versus Migrated

Migrated:

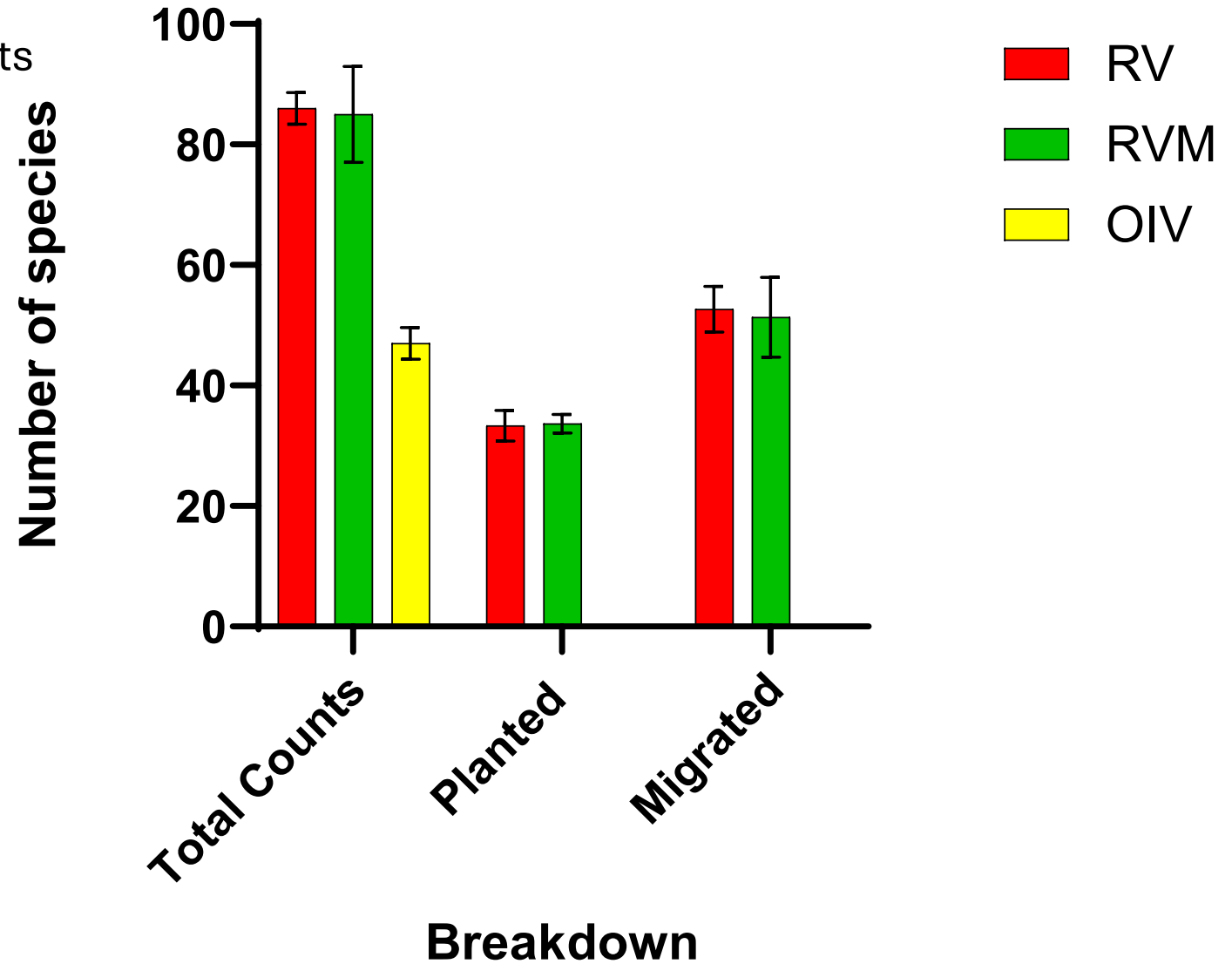
- Left in place, in seed bed, or from outside plots

Results:

- No difference between treatments in
 - planted or migrated species



2025 Plant Richness (May-August)



Findings and applications

1. Endemic mycorrhizae may not be necessary in riparian forested buffer restoration
2. Cyclical harvest & coppicing seems to facilitate P mitigation (& can be calculated)
3. Designing a native multi-synusial palette can increase pollinator habitat & allows for succession
4. Co-designing palette with the land's Original Peoples offers a model for reconciliation
5. Abundant eco literacy opportunities





Application of data

Inform Best Management Practice for RFBs

- Calculations that demonstrate P reduction is occurring
- Addition of phytoremediating maintenance (harvest)
- Benefits of multi-synusial design

Phosphorus (P) Pays Program

- Farmers get paid to reduce P

Harvest Assistance via Reclaiming the Commons

- While contributing to food & medicine security

Pollinator habitat enhancement

- Pollinator education to grow eco-literacy

Maintenance through service learning

- Train restoration workers in regenerative strategies

Educational Manual for the Farm

- To be shared with other research/education farms

Fact sheets

- For state agencies and practitioners

References

- Barger S, Maldonado J, Bunce Rodríguez KJ, et al (2025) Lessons from Place: Indigenous-Led Rematriation for Strengthening Climate Adaptation and Resilience. *J Geogr* 124:73–82. <https://doi.org/10.1080/00221341.2025.2512244>
- Borggaard OK, Gimsing AL (2008) Fate of glyphosate in soil and the possibility of leaching to ground and surface waters: a review. *Pest Manag Sci* 64:441–456. <https://doi.org/10.1002/ps.1512>
- Cao, X., Wang, Y., He, J., Luo, X., Zheng, Z., 2016. Phosphorus mobility among sediments, water and cyanobacteria enhanced by cyanobacteria blooms in eutrophic Lake Dianchi. *Environmental Pollution* 219, 580–587. doi:10.1016/j.envpol.2016.06.017
- Doherty, P., Geraldine Kochan & Peter A. Thomas, 1989. Archaeological Site Identification and Evaluation for Shelburne Business Park (Consulting Archaeology Program, Department of Anthropology No. 96). University of Vermont, Shelburne, VT.
- Donnis, Erica Huyler, 2000. *The History of Shelburne Farms; A Changing Landscape, an Evolving Vision*. The Vermont Historical Society, Shelburne, VT.
- Emmet, A., 1996. A Park and Garden in Vermont: Olmsted and the Webbs at Shelburne Farms. *Arnoldia* 56, 12–20.
- Fitriani S, Irdalisa I, Safi'i I, Mohamad H (2025) Growing Green Minds: Understanding Primary Students' Perspectives on Ecological Literacy. *Int J Soc Learn IJSL* 5:427–441. <https://doi.org/10.47134/ijsl.v5i2.398>
- Frink, D.S.& M.H., 1994. Shelburne South Commercial Park Town of Shelburne Chittenden County, Vermont, Phase I Archaeological Site Identification Study. Archaeology Consulting Team, Essex Junction, VT..
- Haviland, W.A., Power, M.W., 1994. *The Original Vermonters: Native Inhabitants, Past and Present*. UPNE, Hanover, NH.
- Hébert M-P, Fugère V, Gonzalez A (2019) The overlooked impact of rising glyphosate use on phosphorus loading in agricultural watersheds. *Front Ecol Environ* 17:48–56. <https://doi.org/10.1002/fee.1985>
- Henry R (2023) Natural Buckthorn Control. In: North. Gard. <https://northerngardener.org/natural-buckthorn-control/>. Accessed 17 Sep 2025
- Kolba, L.; Rubin, J.; Görres, J. *Growing Local Mycorrhizal Inoculum, A Guide and Insights from a Field Trial*; NESARE: Burlington VT, 2022; p. 14.
- Lake Champlain Basin Program (2024) Phosphorus Sources. In: Lake Champlain Basin Program. <https://www.lcbp.org/our-goals/clean-water/nutrients-and-cyanobacteria/phosphorus-sources/>. Accessed 15 Oct 2024
- Leopold, A., 1941. Lakes in relation to terrestrial life patterns, in: *A Symposium on Hydrobiology*. University of Wisconsin Press North Carolina, pp. 17–22.
- Lima IB, Boëchat IG, Fernandes MD, et al (2023) Glyphosate pollution of surface runoff, stream water, and drinking water resources in Southeast Brazil. *Environ Sci Pollut Res* 30:27030–27040. <https://doi.org/10.1007/s11356-022-24167-2>
- Loh, J., J. Randers, A. MacGillivray, V. Kapos, M. Jenkins, B. Groombridge, and N.Cox., 1998. Living Planet Report, Overconsumption is Driving the Rapid Decline of the World's Natural Environments. World Wildlife Fund, Switzerland
- Lozano VL& HNP (2024) Glyphosate lessons: is biodegradation of pesticides a harmless process for biodiversity? *J. Environmental Sci Eur* 36:. <https://doi.org/10.1186/s12302-024-00884-y>
- Nath R, Singh H, Mukherjee S (2023) Insect pollinators decline: an emerging concern of Anthropocene epoch. *J Apic Res* 62:23–38. <https://doi.org/10.1080/00218839.2022.2088931>
- Perrow, M.R. et al. *Handbook of Ecological Restoration*; Cambridge University Press: NY, 2002; Vol. 1 Principles of Restoration; ISBN 978-0-521-04983-2.

References

- Rigden J (2023) Eliminating Buckthorn Without the Use of Herbicide | Prairie Enthusiasts. <https://theprairieenthusiasts.org/eliminating-buckthorn-without-the-use-of-herbicide/>. Accessed 17 Sep 2025
- Robinson IV, F.W., 2007. *Powerful History: The Archaeology of Native People in the Champlain Lowlands*. UVM Consulting Archaeology Program & University of MA Amherst
- Rubin J, McGranaghan C, Kolba L, Görres J (2024) Restoring a Degraded Riparian Forested Buffer While Balancing Phosphorus Remediation, Biodiversity, and Indigenous Land Access. *Sustainability* 16:3366. <https://doi.org/10.3390/su16083366>
- Rubin JA, Görres JH (2022a) The effects of mycorrhizae on phosphorus mitigation and pollinator habitat restoration within riparian buffers on unceded land. *Restor Ecol* 31:e13671. <https://doi.org/10.1111/rec.13671>
- Rubin JA, Görres JH (2022b) Effects of mycorrhizae, plants, and soils on phosphorus leaching and plant uptake: Lessons learned from a mesocosm study. *PLANTS PEOPLE PLANET* 4:403–415. <https://doi.org/10.1002/ppp3.10263>
- Saunders DL, Meeuwig JJ, Vincent ACJ (2002) Freshwater Protected Areas: Strategies for Conservation. *Conserv Biol* 16:30–41. <https://doi.org/10.1046/j.1523-1739.2002.99562.x>
- Wiseman, F.M., 2001. *The Voice of the Dawn; An Autohistory of the Abenaki Nation*. University Press of New England, Lebanon, NH.
- Wiseman, F.M., 2018. *Seven Sisters; Ancient Seeds and Food Systems of The Wabanaki People and the Chesapeake Region*. Earth Haven Learning Center Inc., Thomasbury, Ontario Canada.
- Wiseman, F.M., 2005. *Reclaiming the Ancestors; Decolonizing a Take Prehistory of the Far Northeast*. University Press of New England, Lebanon, NH.
- Strullu-Derrien, C., Wawrzyniak, Z., Goral, T., Kenrick, P., 2015. Fungal colonization of the rooting system of the early land plant *Asteroxylon mackiei* from the 407-Myr-old Rhynie Chert (Scotland, UK). *Botanical Journal of the Linnean Society* 179, 201–213. doi:10.1111/boj.12307
- Strullu-Derrien, C., Selosse, M.-A., Kenrick, P., Martin, F.M., 2018. The origin and evolution of mycorrhizal symbioses: from palaeomycology to phylogenomics. *New Phytologist* 220, 1012–1030. doi:10.1111/nph.15076
- Su· J YuPing Su,· Yuxin weng^{2,3} · Gohar Ayub^{2,3} · Chenxing She, Yumei Xiao (2025) Insights Into Proliferation Effects of Low-Dose Glyphosate on Phytoplankton Communities | *Microbial Ecology*. *Microb Ecol* 88:.. <https://doi.org/10.1007/s00248-025-02581-6>
- Sun M, Li H, Jaisi DP (2019) Degradation of glyphosate and bioavailability of phosphorus derived from glyphosate in a soil-water system. *Water Res* 163:114840. <https://doi.org/10.1016/j.watres.2019.07.007>
- Tallamy DW (2020) *Nature’s Best Hope: A New Approach to Conservation That Starts in Your Yard*. Timber Press
- USDA NRCS *Farmland Classification Systems for Vermont Soils*; 2006; pp. 32–33;
- VT ANR & DEC *Vermont Water Quality Standards Environmental Protection Rule Chapter 29A*; Montpelier, VT, 2017; pp. 19–20;..
- Wang, Haijun, Wang, Hongzhu, 2009. Mitigation of lake eutrophication: Loosen nitrogen control and focus on phosphorus abatement. *Progress in Natural Science* 19, 1445–1451. doi:10.1016/j.pnsc.2009.03.009
- Zaring, D., 1996. Agriculture, Nonpoint Source Pollution, and Regulatory Control: The Clean Water Act’s Bleak Present and Future. *Harvard Environmental Law Review* 20, 515.

Acknowledgements

UVM & Associated Community

Dr. Josef Görres, Dan Needham of AETL, Statistician Dr. Maria Sckolnick, Data Visualization Specialist Kristin Florian, Crops & Soil Lab, Horticulture Farm, Former mentees Luca Kolba, Kat O'Neil, Abby Meunier, Bri Arnold, Intern Ruth Stumpfoll, Marlie Hunt, Amrita Shore, Dr. Joe Edwards

Abenaki Community

Abenaki Clan Mothers, Alnobaiwi, Carol McGranaghan of Missisquoi Abenaki Nation

Agricultural Community

Dana Bishop Shelburne Farms Land Manager
Mike Bald of Got Weeds?
Community volunteers, esp. Gene Sweetser, Thomas Sutton, Christian Yarrow Perry

Project Advisory Committee

Dr. Joshua Faulkner. Dr. Josef Gorres, Alex De Pillis, Tre McCarney, Carol McGranaghan

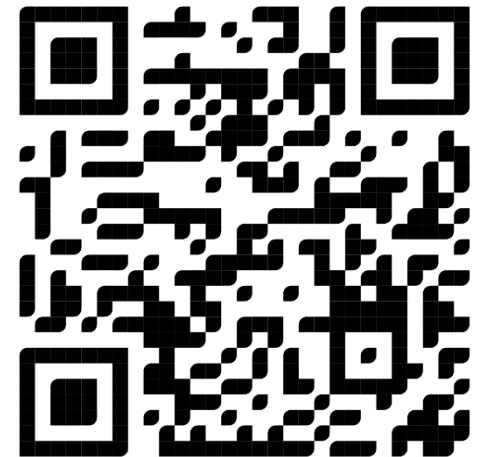
Funders & collaborators



University of Vermont
College of Agriculture and Life Sciences
Department of Agriculture, Landscape, and Environment



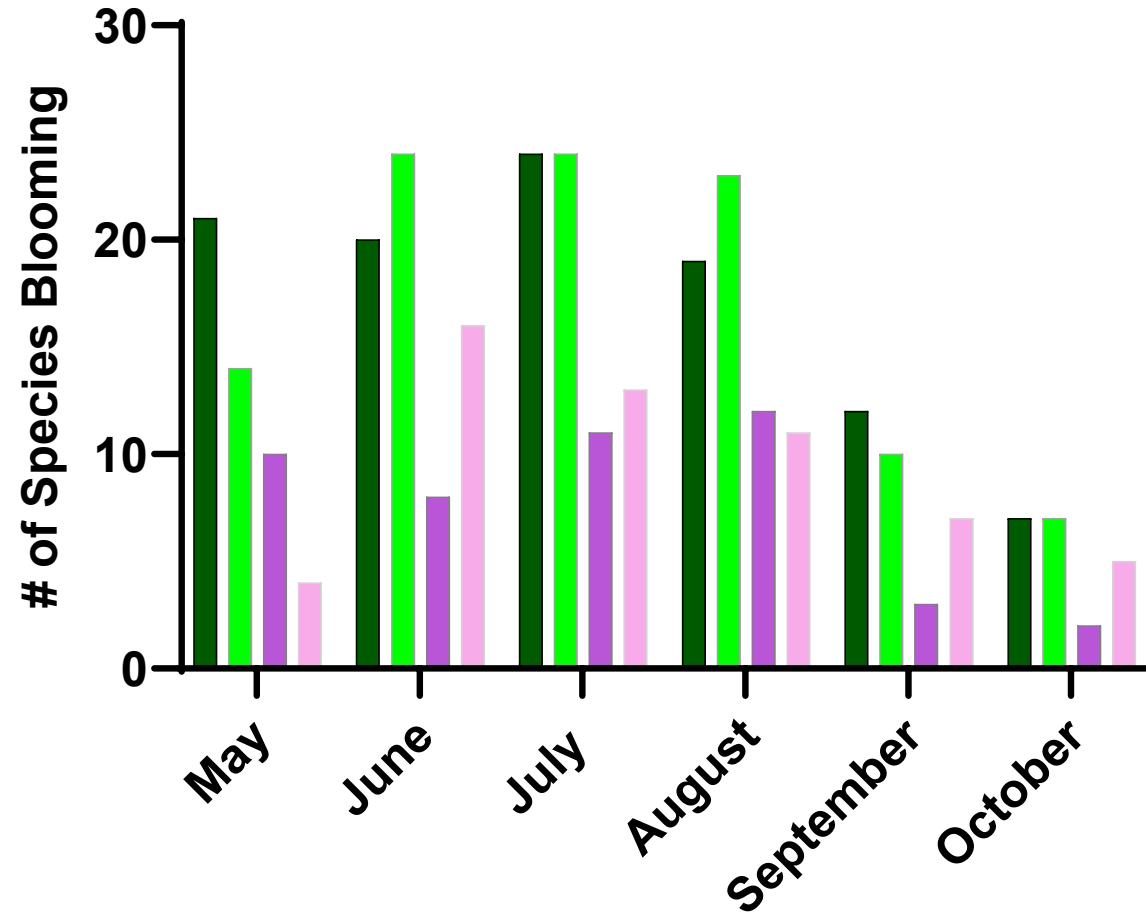
Questions, Insights..



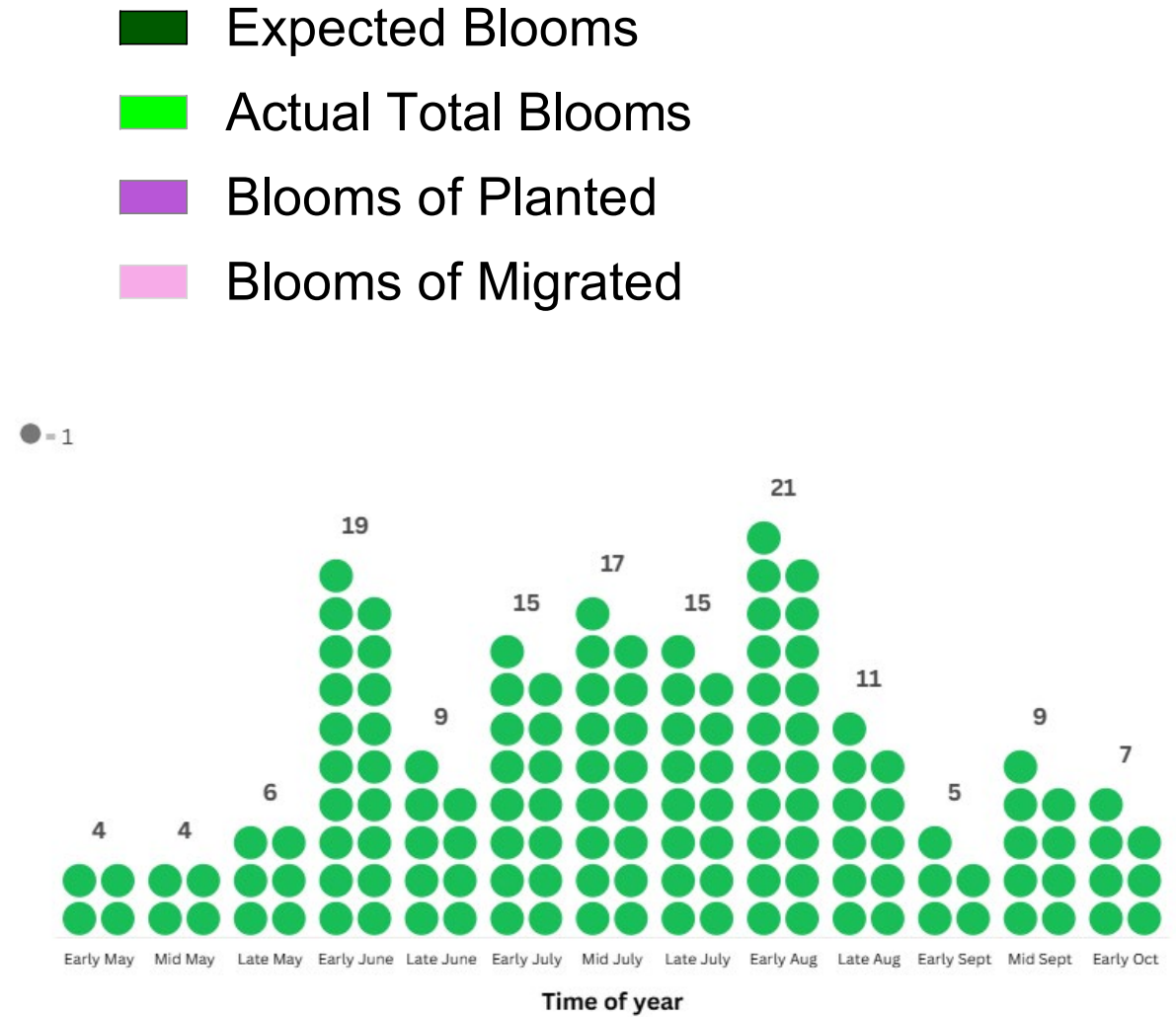
www.mycoevolve.net

Jessica.Rubin@uvm.edu

Comparing 2025 Blooming Times

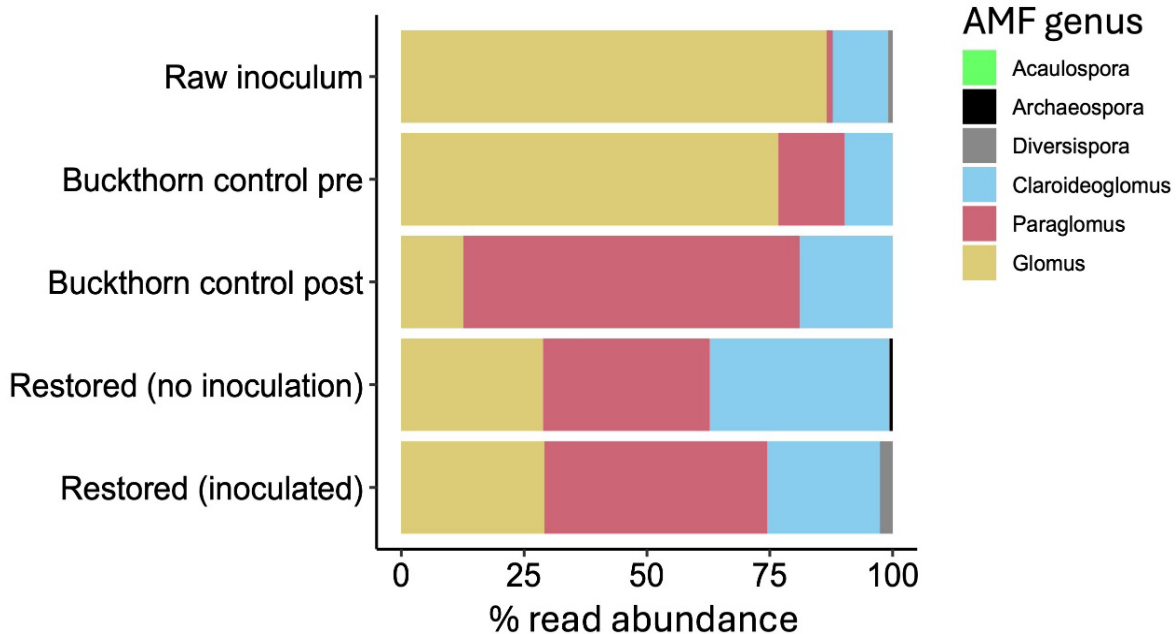
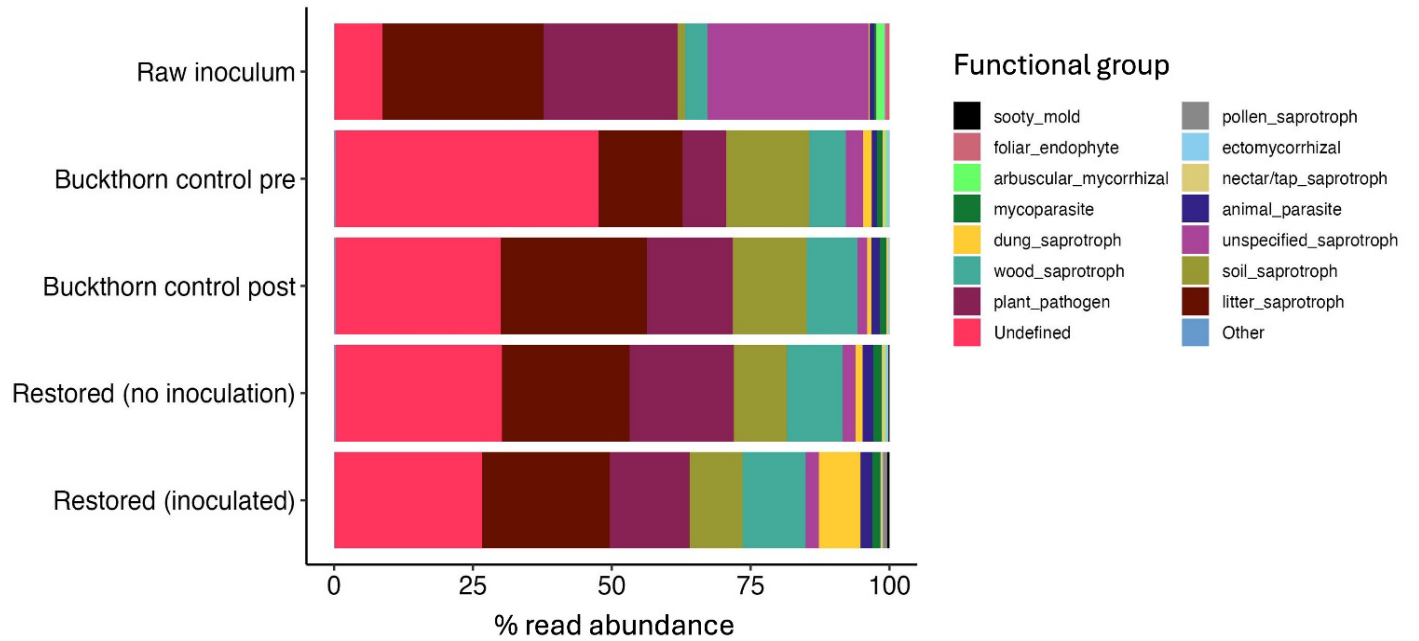


Blooms for Pollinators



- Ground Truth Palettes as not always accurate
- Native and migrated plants are crucial for pollinators

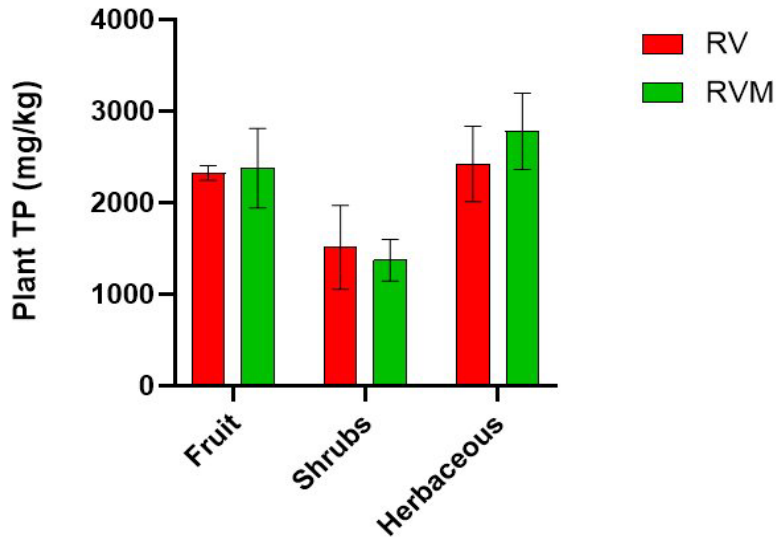
Glimpse into soil 2024 DNA



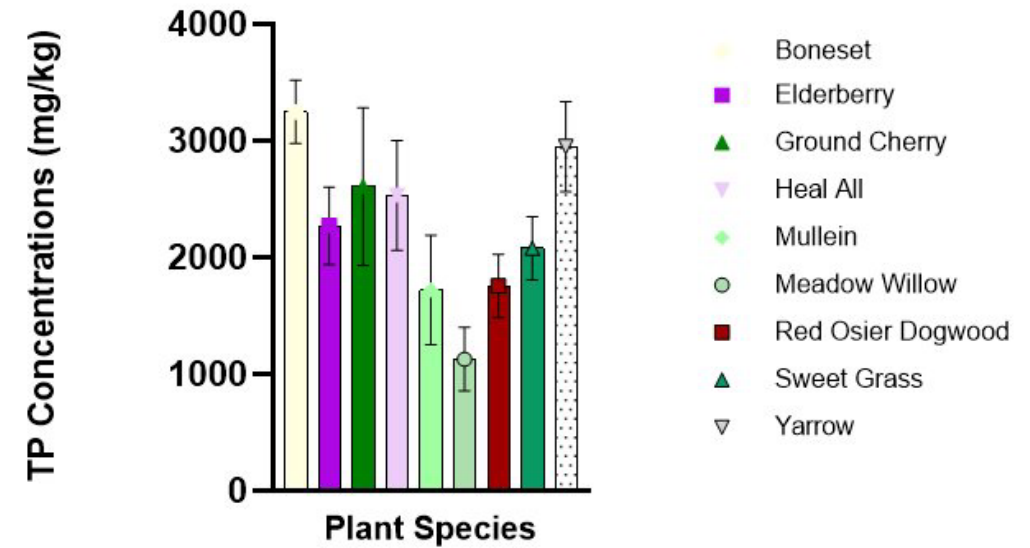
- Endemic mycorrhizae complex
- Fungal communities arise seasonally
- Not a direct transfer of fungi via inoculation
- Dung saprotrophs in restored inoculated
- Current endemic growing strategies may encourage generalists

More details on Plant P Uptake

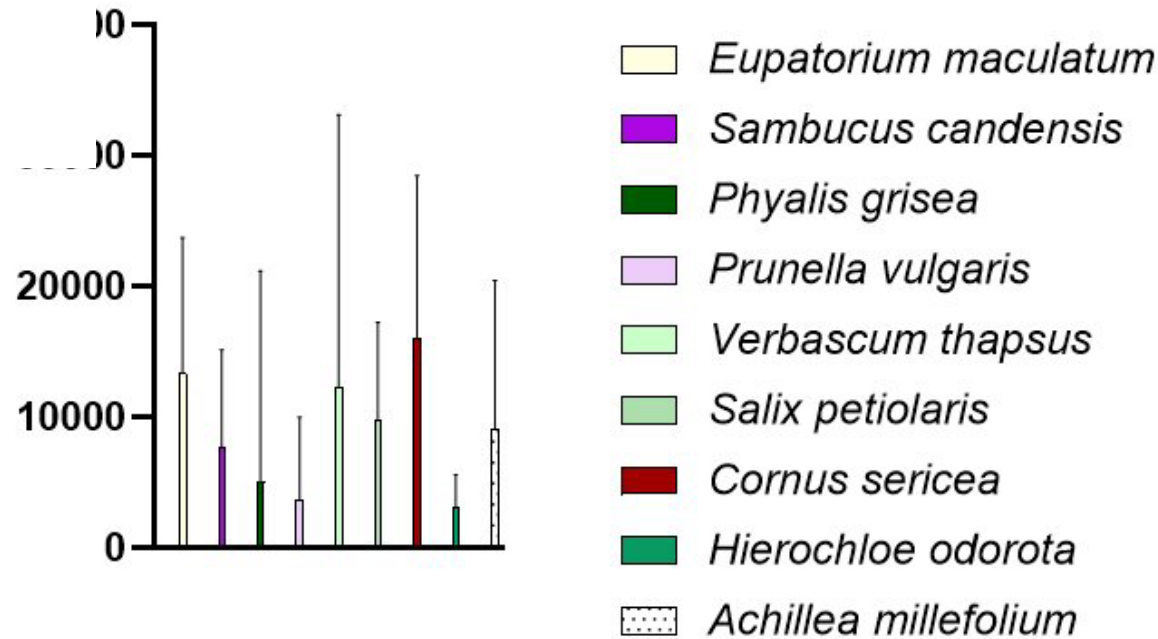
2025 Plant P Concentrations Category & Treatment



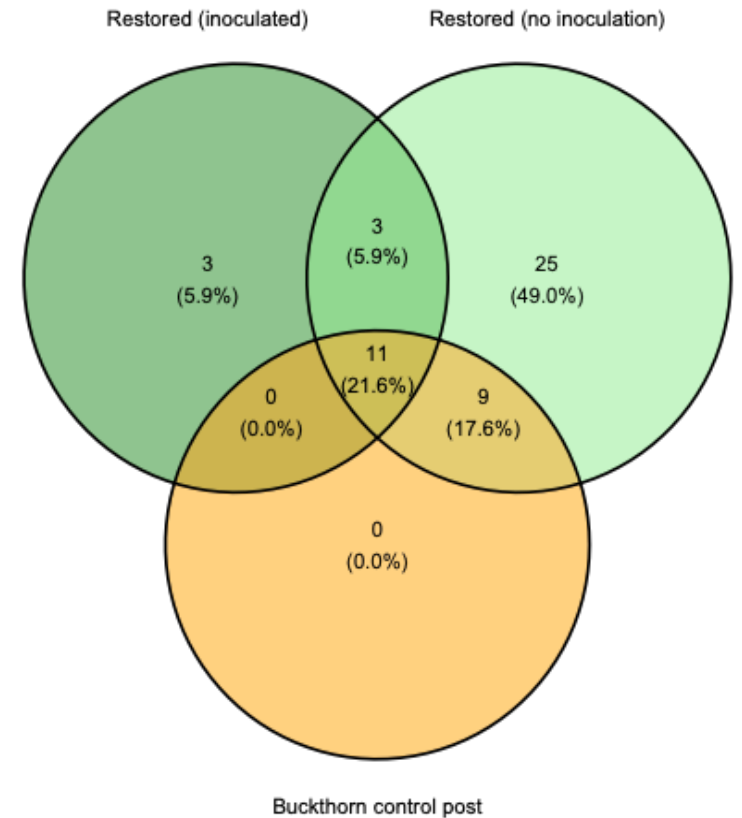
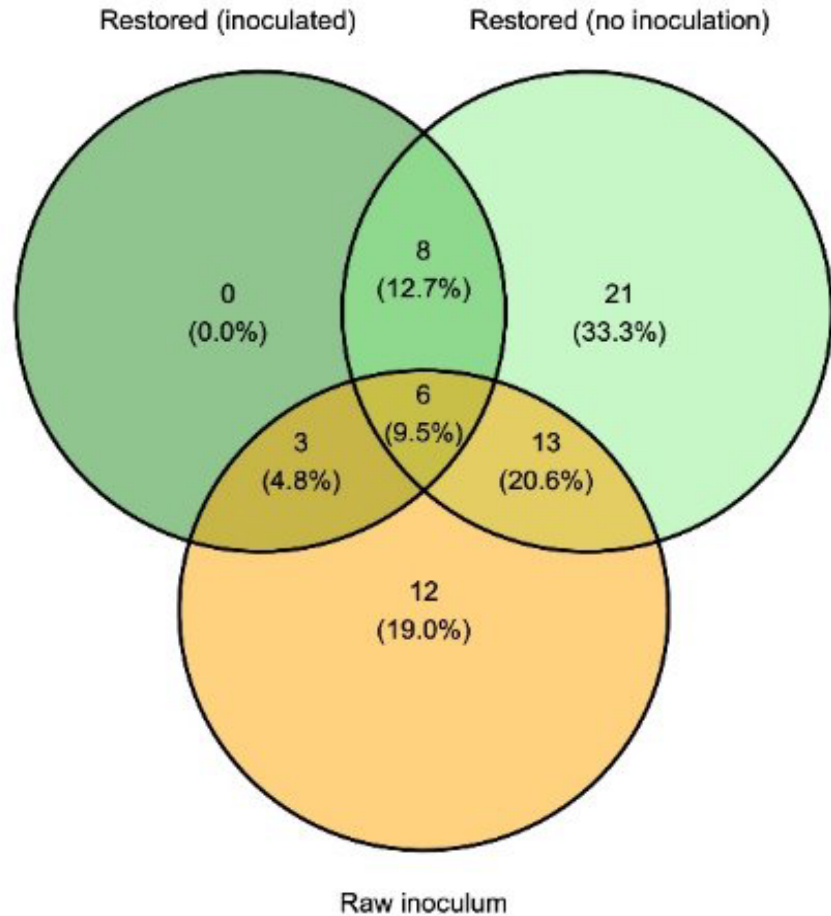
2025 Plant TP Concentrations



2025 Plant P Biomass

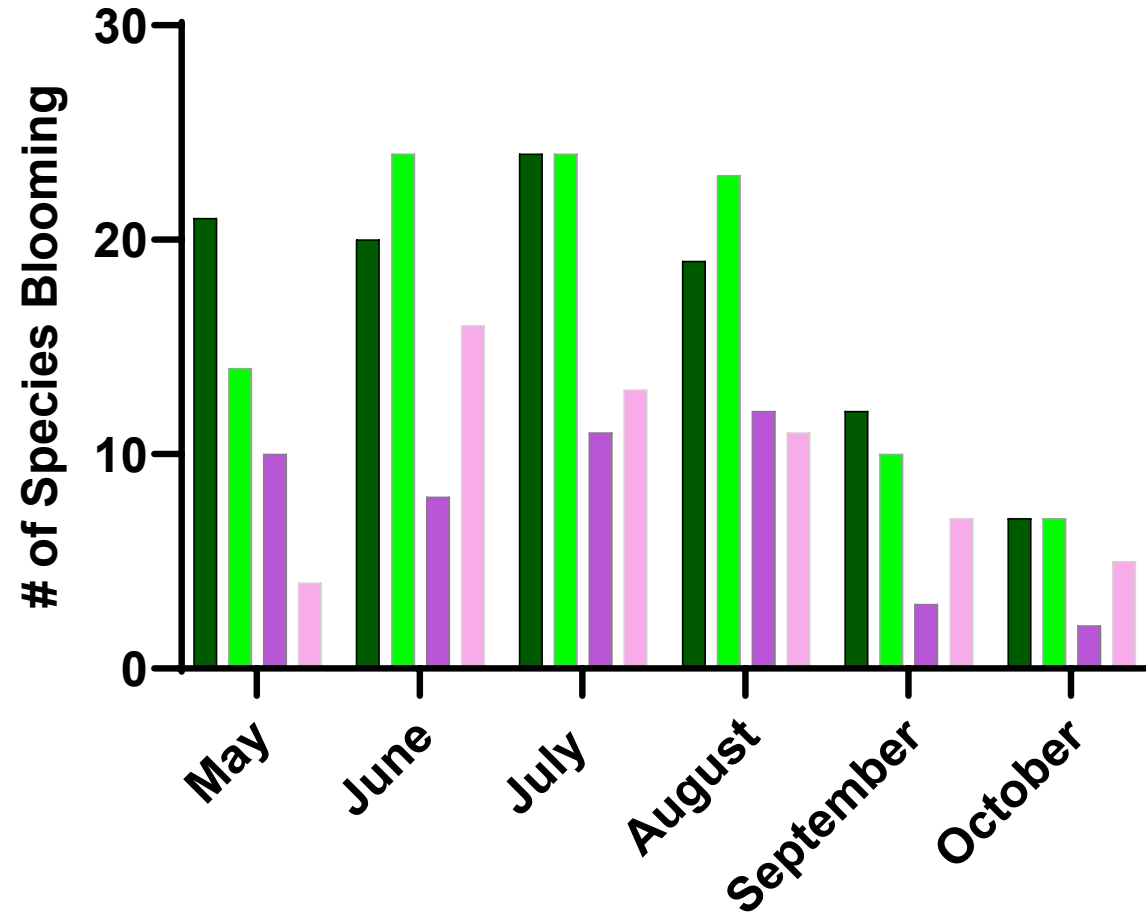


More on 2024 Soil DNA

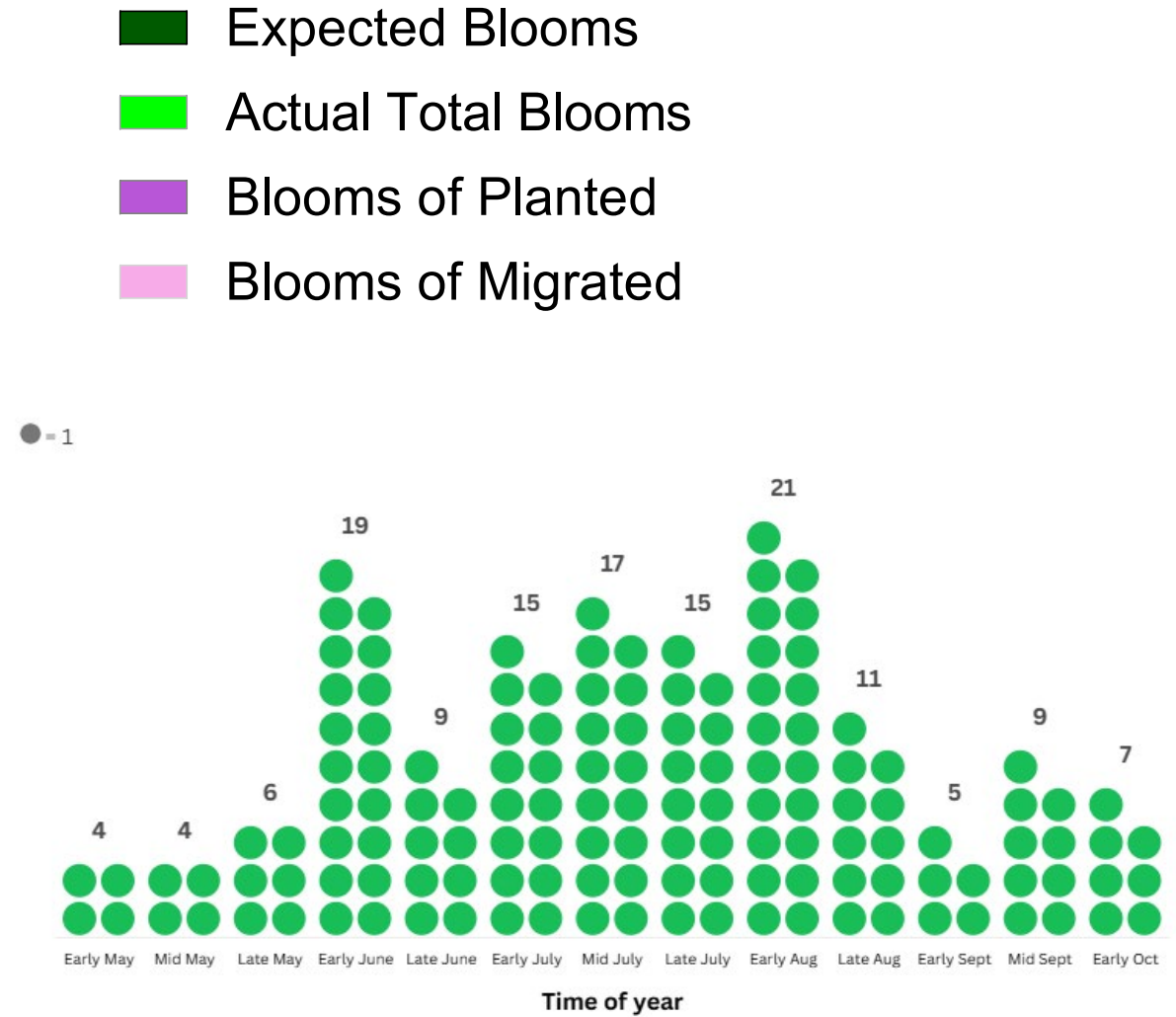


We used high-throughput amplicon sequencing with general fungal and AMF-specific primers because the general fungal primers (ITS) do not work well for AM fungi. We used the dada2 bioinformatics pipeline to process raw sequences and clustered at 97% OTUs (operational taxonomic units). Taxonomy was assigned by blasting representative sequences against the UNITE database to identify general fungi and the MaarjAM database to identify AM fungi. Analysis was done based on the relative read abundance or presence/ absence of general fungal OTUs and AM fungal taxa.

Comparing 2025 Blooming Times



Blooms for Pollinators



- Ground Truth Palettes as not always accurate
- Native and migrated plants are crucial for pollinators

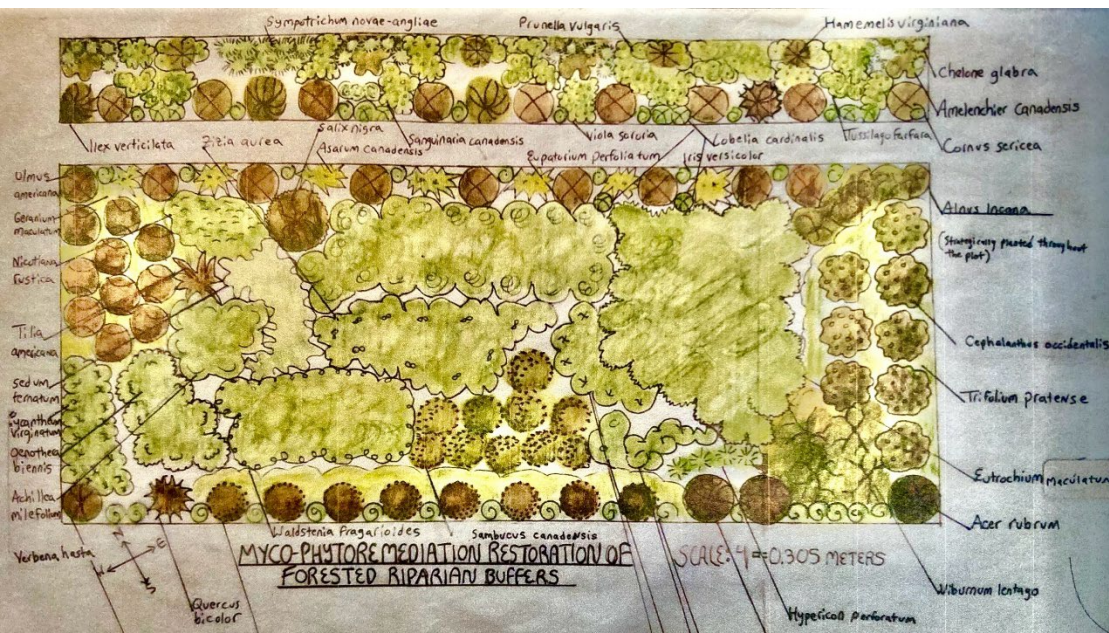
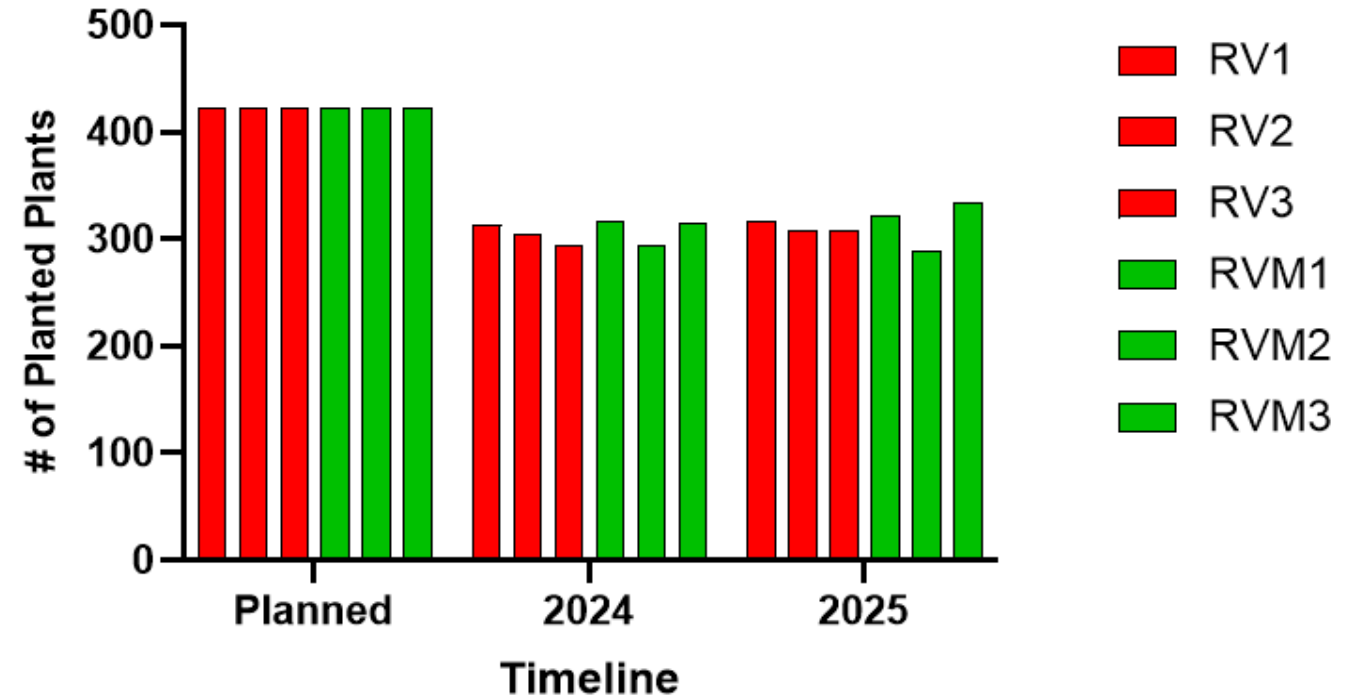
Survivability Data

- Not all survived in the nursery
- Not all survived once planted
- Some reproduced

Results:

- No statistical difference in plantings' survival between treatments ($p = 0.823$)
- Species had statistical significance ($p < 0.001$) for survival

Plant Survival across Treatments



No need for Glyphosate

- 3 x in 2 seasons cut back = 90% death rate, rest is easy to strip
 - habitat for overwintering invertebrates, fungi, early migrants...

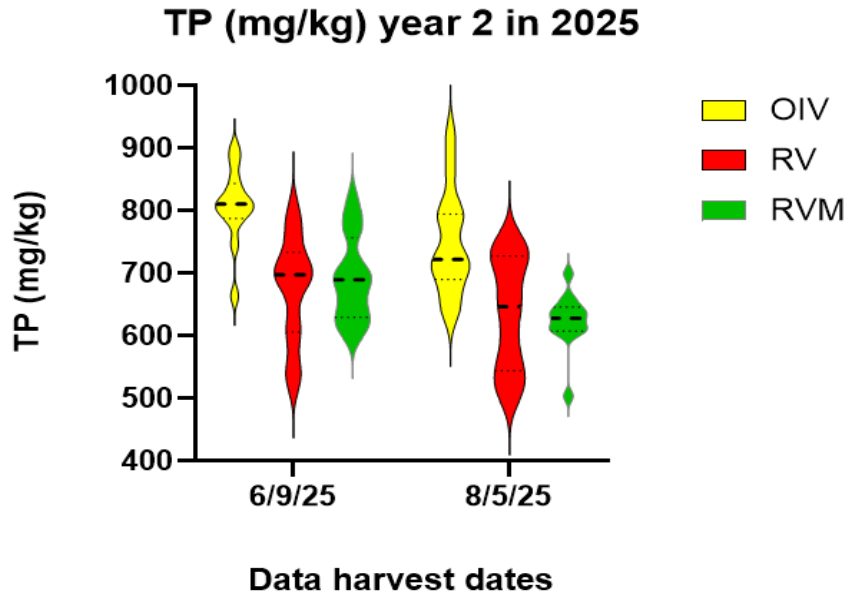
Research indicates glyphosate can

- increase P cycling in soil & water while contributing complex compounds that harm terrestrial & aquatic ecosystems.
- contribute to P saturation in soils and decrease soil capacity to absorb and retain phosphate; adding to water quality impairment.



(Borggaard and Gimsing 2008; Hébert et al. 2019; Lima et al. 2023; Lozano 2024; Su-2025; Sun et al. 2019; Henry 2023; Rigden 2023; Rubin et al. 2024)

Phosphorus in Soil & Soil Water Data

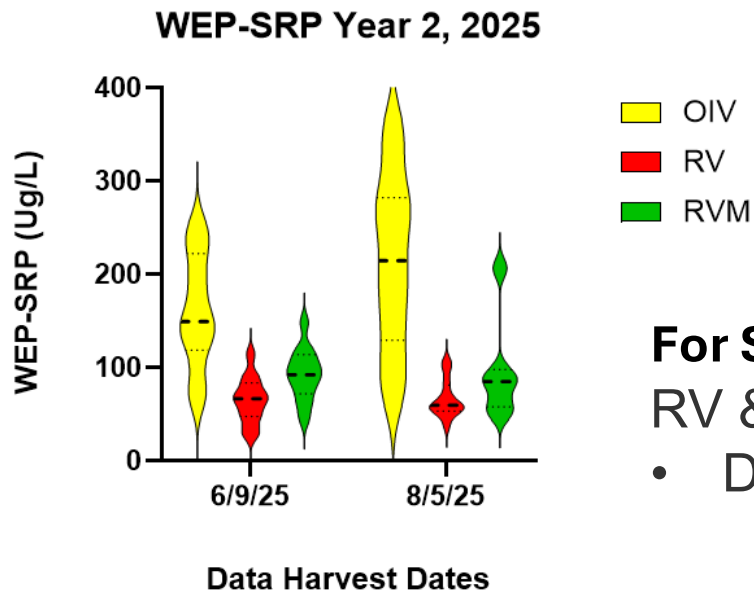


For all 3 P metrics, **Statistically significant difference for:**

- Treatment ($p < 0.001$) (OIV > RV & RVM)

For TP:

- Date ($p < 0.001$) (6/9/25 > 8/9/25)
- Not between RV & RVM ($p = 0.997$)

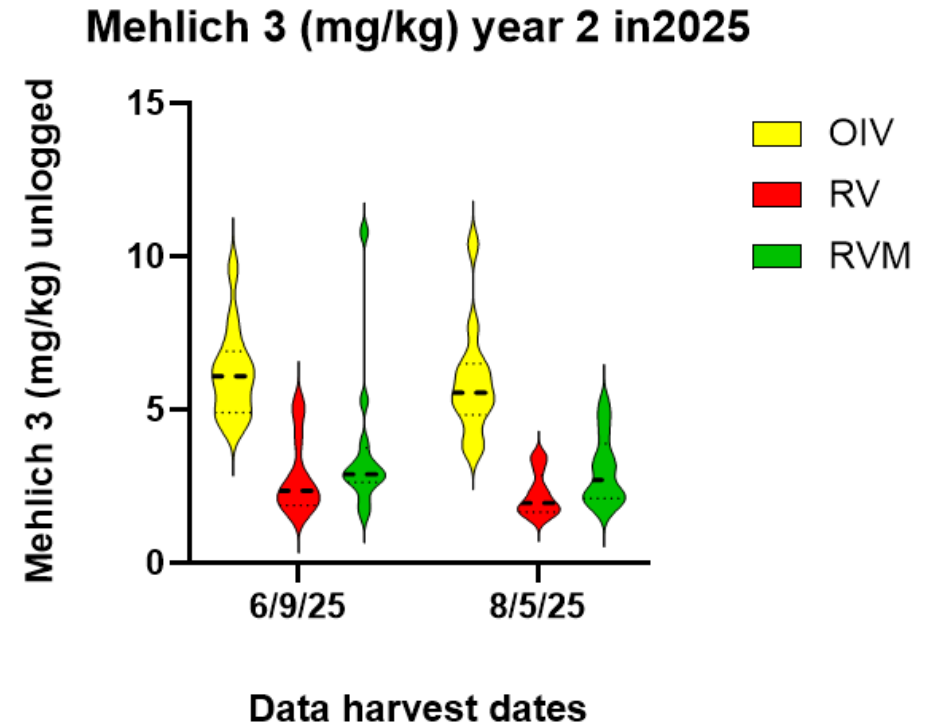


For Mehlich 3 not:

- RV & RVM: ($p = 0.132$)
- Date: ($p = 0.055$)

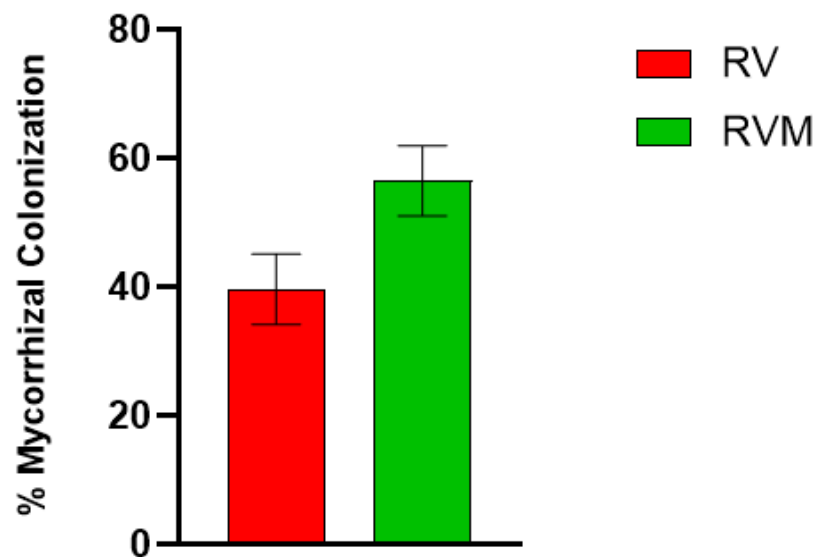
For SRP not for:

- RV & RVM: ($p = 0.064$)
- Date: ($p = 0.064$)

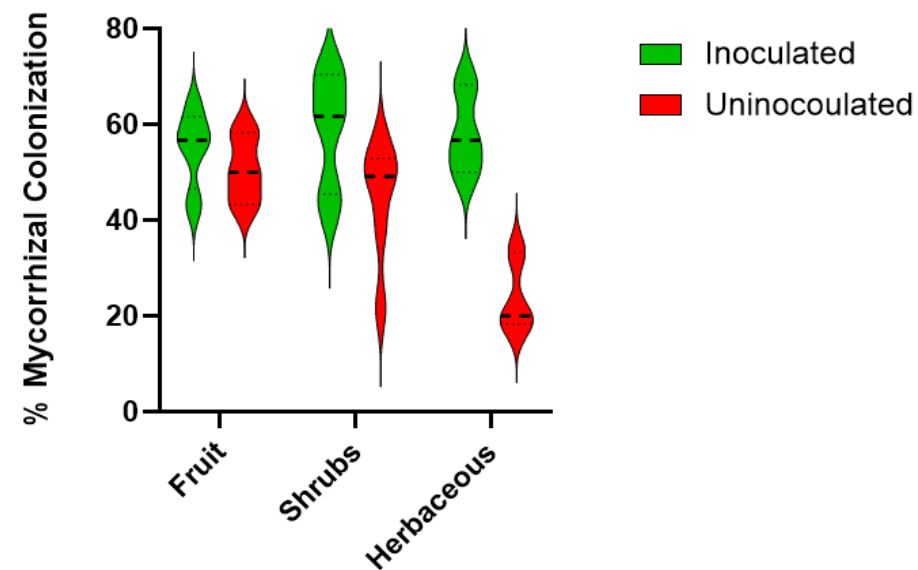


Mycorrhizal Data; Checking Assumptions

Mean % Mycorrhizal Colonization between Treatments



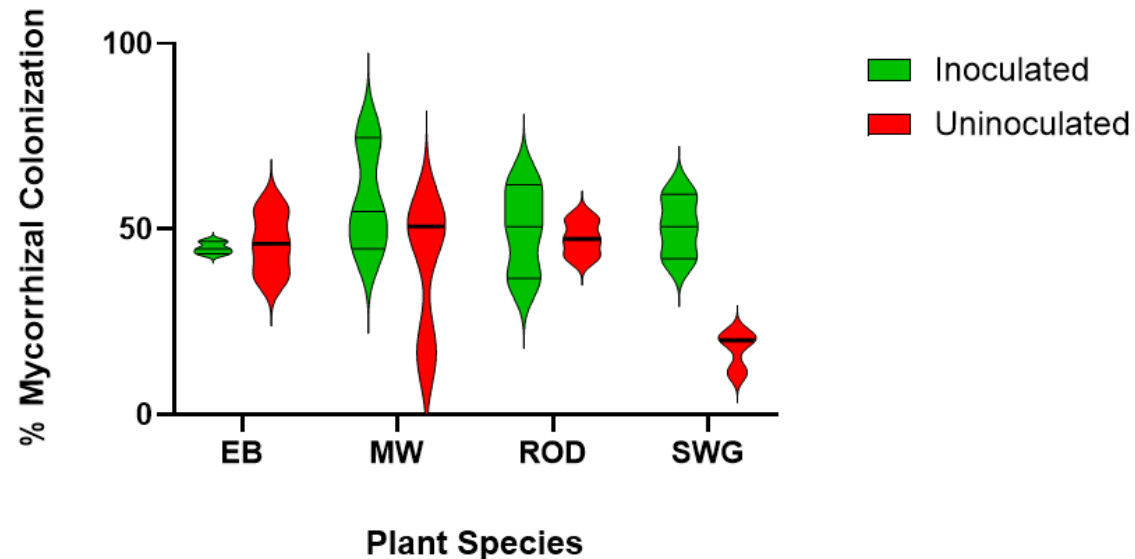
% Mycorrhizal Colonization 2025 Across Plant Category



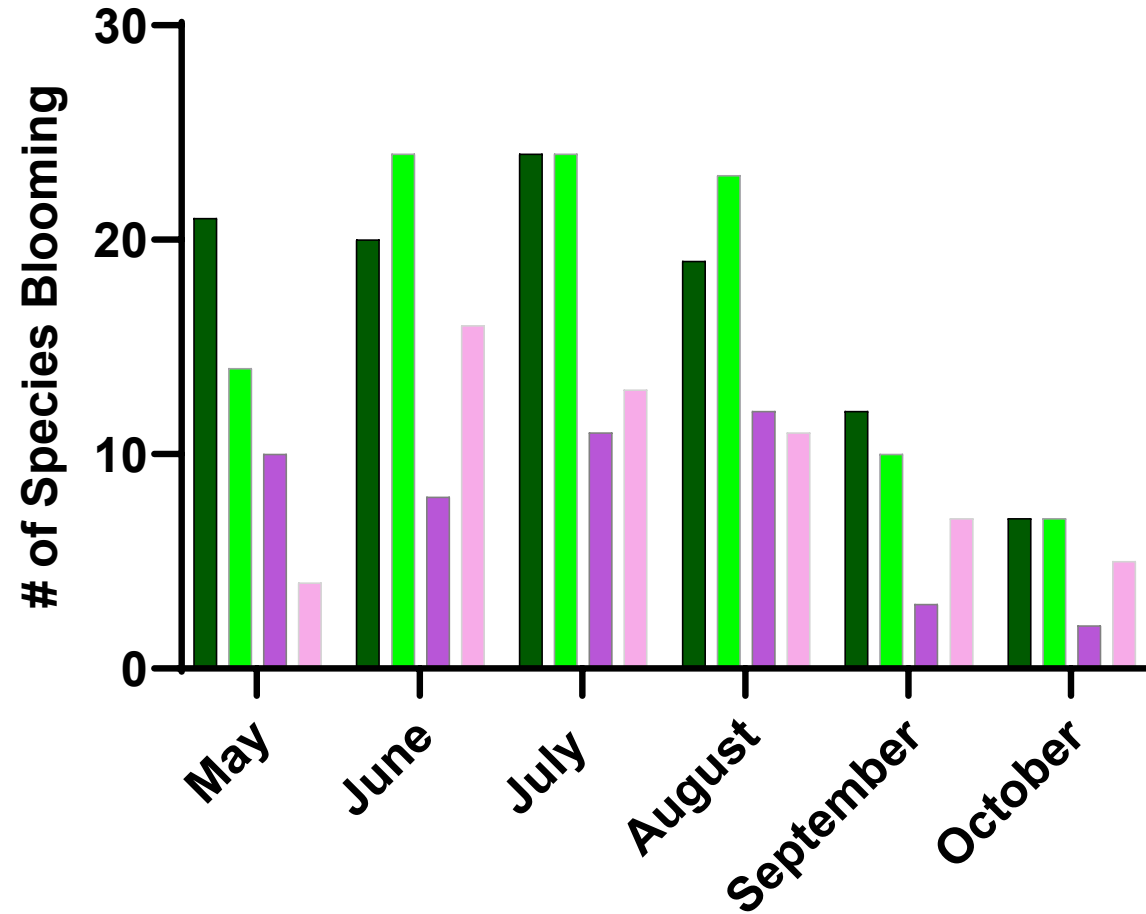
Statistically significant difference for:

- Treatment ($p < 0.001$) (RVM $>$ RV)
- Treatment with category ($p < 0.009$) Herbaceous
- Treatment with species ($p = 0.023$) SWG

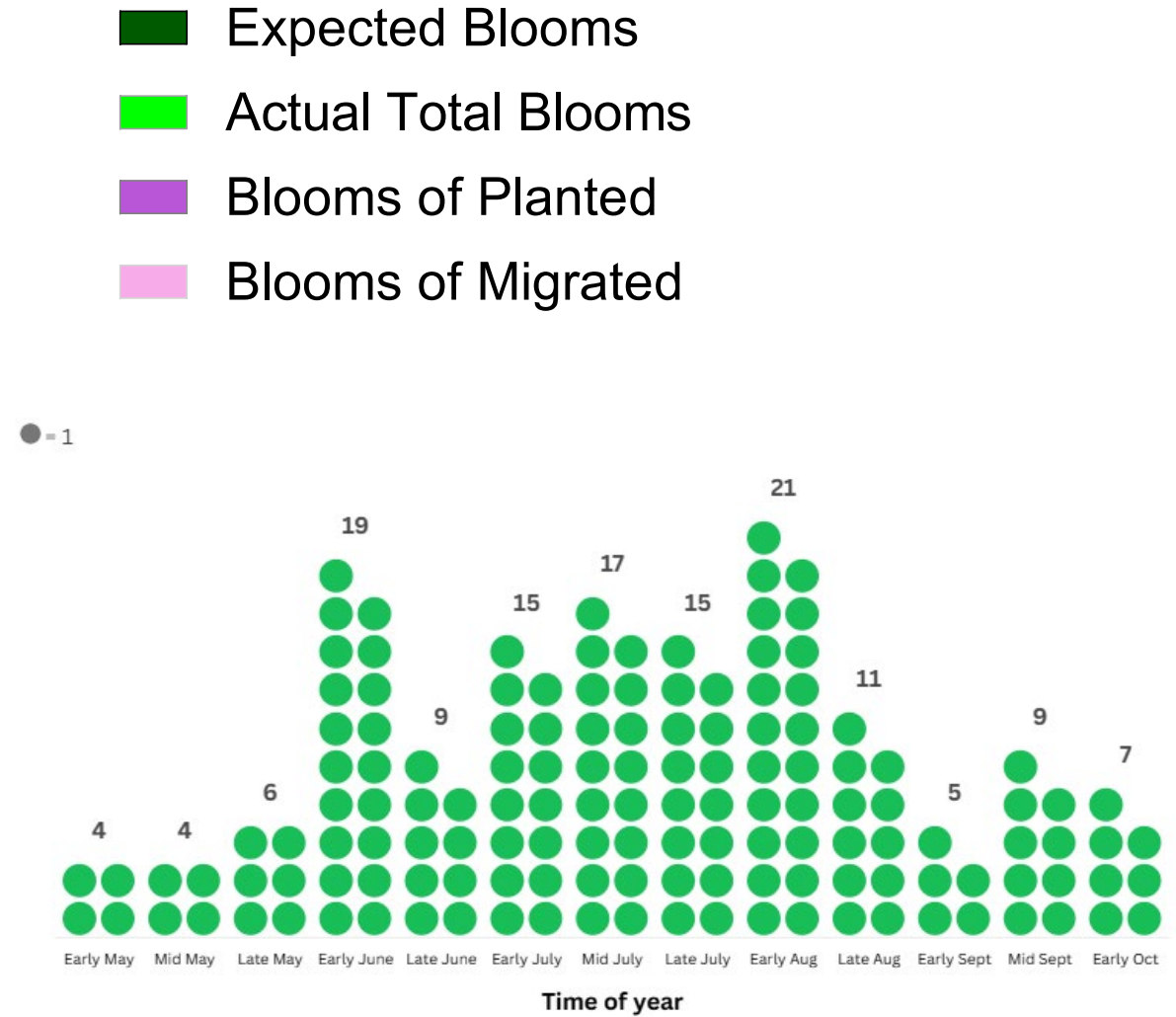
% Mycorrhizal Colonization 2025 Across Plant Species



Comparing 2025 Blooming Times



Blooms for Pollinators



- Ground Truth Palettes as not always accurate
- Native and migrated plants are crucial for pollinators

Current site challenges

Abundant Common Buckthorn far beyond study area

- Current removal is miniscule in long-run
- Various vectors, (berries; birds, rodents, wind...)
- Long – term maintenance consistency

Compost pile (550 yd³) not able to be moved at this time

- Upslope surface & subsurface P inundations continue
- If removed yesterday, 6-9 decades before tangible results

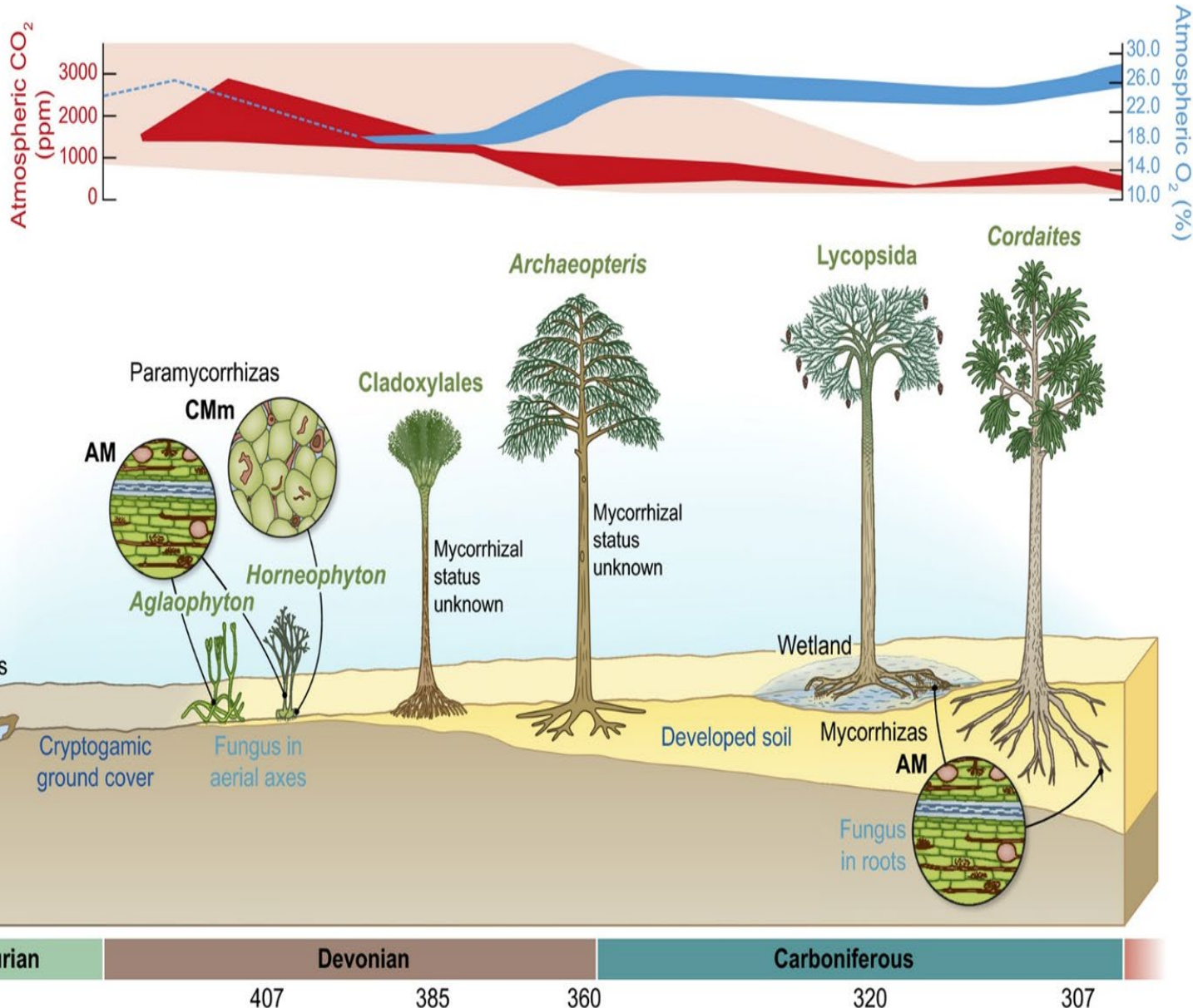
Unmapped and broken tile drains going into the study sites

- Soil variability beyond normal for tracking P data
- Point sources of tile drain outlets impossible to locate



(Meals et al. 2010; Sharpley et al. 2013)

Mycorrhizae arise



Mycorrhizal symbiosis at the dawn of land flora

Earliest fossil evidence for plant-fungal interactions found in 407-million-yr-old Rhynie chert