Mycorrhizae Matters! ep 18

Wed, Apr 05, 2023 10:55AM 35:19

SUMMARY KEYWORDS

mycorrhizae, phosphorus, work, abenaki, plants, research, learned, soil, restoration, project, elderberries, field, concentrations, years, uptake, published, riparian buffers, plant, species, growing

SPEAKERS

Jess Rubin, Alison Adams, Cate Kreider

Cate Kreider 00:11

Welcome to Restoration Roundup, a monthly podcast that explores recent research on, new and emerging best practices for, and stories about riparian forest restoration. I'm Cate Kreider, a recent graduate of the University of Vermont, and the interim host and director of this podcast with the support of the UVM extension and Lake Champlain Sea Grant. On this show, we have covered a wide array of elements of the riparian biosphere, from the interactions between fish and birds to the impact of human presence such as nature trails and dams. But we've skirted over a major player in the ecosystem, especially as recent research is showing its value in restoration work, the mitigation of phosphorus pollution, and supporting native species. I'm talking about fungi. For this month's episode, I'm excited to welcome Jess Rubin, an alumni of the Gund Institute for the Environment and UVM's Plant and Soil Science Department. She's been working with one particular type of fungi, mycorrhizae as a Myco-phytoremediation research technician in UVM's Plant and Soil Science department, and through an ecological resilience service she runs called Myco-evolve. Mycorrhizae has the potential to be reintroduced in riparian buffers, and various ecotones to assist plants in phosphorous uptake among many other applications. Jess' work includes other aspects of phosphorus pollution mitigation strategies, such as native species selection and site management over time. Jess, thanks for coming in to talk about your research and findings. Welcome to the podcast.

Jess Rubin 01:50

Thanks, Cate. Good morning. Thanks for inviting us to share about our work.

Cate Kreider 01:55

Yeah, I'm excited to hear about it. I think it makes sense to start where you did. Can you talk about how you first became interested in and began working with mycorrhizae?

Jess Rubin 02:06

Jess Rubin 02:06

Sure, yeah, it's been a bit of a circuitous trail. Seven years ago, when serving as a public school science teacher, I realized too much of my energy was going towards teaching about problems rather than supporting and implementing solutions. Around that time, I was inoculated if you will, by being called in the forest to study fungi and upon meeting the radical mycology community, my proclivity towards attempting to restore ecosystems birthed my ecological resilience business Mycoevolve which offers earthworks education and research. Fellow Myco enthusiasts and I formed a collective lab where we grew saprophytic fungi, we then used in local remediation projects in unceded Abenaki territory. I paused teaching full time and worked for a UVM bio research lab as an assistant gathering data on non-native worms across the Northeast maple forests. After this project, its director soil scientist, Dr. Josef GÃ¶rres, mentored and collaborated with Mycoevolve in an EPSCoR three small business grant investigating microfiltration. We grew mycelial mats of King Stopharia, which folks may know is Wine Caps, stropharia rugosoannulata, and found that when dairy effluent full of E. coli was poured through these mycelial mats, or even was just in contact with Myco filter enzyme exudates, the E. coli liced. In other words: died. While, this was exciting to witness as it was mentioned by mycologist, such as Paul Stamets, it was concerning to learn about the potential harmful effects of nutrient cycling. Namely, microbes living around these micro filters were likely mineralizing phosphorus and releasing it into the water body. When I learned about this, I paused as it seemed akin to pollution swapping, which is when one contaminant is treated, in this case, E. coli, at the expense of another contaminant, the macro element phosphorus, being released. Mycoevolve began to get projects above my skill set and I realized I needed more training. Since I already had a master's in environmental science. I thought the only trail for me was through getting a PhD. After knocking on many doors, it became clear that this remediation field was new and though seen as intriguing, was primarily viewed as risky to most professors. I gratefully found a trail to receive more training through earning a second master's degree in the UVM plant soil science department and Dr. Josef GÃ¶rres's soil lab. I was keen to figure out ways to intercept phosphorus flowing into the lake. And when I learned about mycorrhizae's ability to expedite phosphorus into plants out of soil and soil water, something clicked. When I learned that more than 80% of terrestrial plants partner with mycorrhizae fungi, who appeared 400 million years ago, during the Devonian era supporting the migration of plants from aquatic to terrestrial habitats through their nutrient acquisition abilities, I felt dedicated to learning from and collaborating with these ecological ancestors and ecosystem engineers. When searching around and seeing no one applying this to protect waterways, I felt harnessed and committed to researching if in doing so we could protect our local watershed. The process unfolded pretty organically from here. In a UVM soil morphology, classification, and land use class researching a critical source area at Shelburne farms, where phosphorus was leaving the land entering water through a drainage way in a degraded riparian buffer, it became clear to me that this was a place mycorrhizae and their native plant partners could effectively facilitate green infrastructure to intercept phosphorus runoff. So I wrote grants and put the shovel in to get to work.

Cate Kreider 05:41

So this work at Shelburne farms, and all of the research that went into the second master's degree is what I'd love to hear more about today. Can you summarize what your experiments and research were and what the goals were?

Jess Rubin 05:54

J Jess Rubin 05:54

Sure, yeah, I'm gonna talk about two projects. So I'll start with the Shelburne farms project. So I began gathering baseline data at the Shelburne farms site, and also researching every application of mycorrhize to water quality protection that I could find and field and mesocosm studies. And this resulted in a literature review, published in 2021 in the International Journal of Environmental Research and Public Health in a special issue of pollution and remediation management. And that article is titled "Potential for Mycorrhizae: Assisted Phytoremediation of Phosphorus for Improved Water Quality". And that robust literature review helped us establish that this association of mycorrhizae and plants through myco-phytoremediation for water quality protection was indeed possible and worth researching and applying to landscapes. So then our task was to see how it can work and with funding from Lintilhac and Northeast SARE, if folks aren't familiar with SARE it's a USDA program in partnership with University of Maryland that support Sustainable Agriculture Research and Education, offering farmer driven grassroots grants and education programs. So we did a series of greenhouse mesocosm experiments to understand phosphorus cycling in the plants working with buckthorn and willow. Buckthorn, because this was the main species growing in the degraded buffers that we were aiming to restore, and willow, because it was one of the many native species we planted in the restoration plots. We learned a lot from this mesocosm study, most notably that phosphorus is uptaken into the plant in the summer. When harvesting plants in late winter, which is what coppicing recommendations suggest, for example, when people prune their apple trees, no phosphorus will be removed because at that time, it's all in the roots. Basically, when angiosperms go into senescence in early fall, phosphorus moves into the roots. So we learned that the time to harvest plants to maximize phosphorus removal is late summer before senescence. And if you do this cyclically and carefully plants still have time to harden off before the frost. Then we began field trials at Shelburne farms, restoring the degraded riparian buffer. This involved three treatments: Control, which was the buckthorn monoculture, and two restored plots, in which the buckthorn was removed and replaced by native polycultures, one of which was inoculated with mycorrhizae. This involved extensive site preparation. I was mentored by Mike Bald of Got Weeds in removing buckthorn in this case, it was common buckthorn, rhamnus cathartica, mechanically with no chemicals. So we removed a lot of buckthorn. We meanwhile, pasteurized low phosphorus compost soil, inoculating half the soil with a commercial mycorrhizal mix, potting up the native plant palette, putting up fences, then planting and gathering data. Now it's worth noting that a huge amount of labor of this process was due to the grassroots community during COVID. Basically all research at UVM shut down. So we continued it through Mycoevolve. And we are really grateful to a huge network of friends, community members and volunteers, and in this sense, see it as a community project. The three objectives were to decrease phosphorus concentrations in soil and soil water to increase pollinator habitat and to facilitate Abenaki rematriation. We gathered a lot of data involving soil phosphorus, soil-water phosphorus, plant phosphorus, mycorrhizal populations and plant species diversity and began to work with the Abenaki. We discovered that 88% of our plant palette was edible, medicinal and utilitarian to them. So from this we published an article in a peer reviewed journal, Restoration Ecology in 2022, titled "The effects of mycorrhizae on phosphorus mitigation and pollinator habitat restoration within riparian buffers on unceded land", and that summarizes two years of our data. We currently have a another article on three years of our data under review by the journal ecological applications. But the brass tacks of our findings are that there were statistically significant lower numbers of soil phosphorus and soil water phosphorus concentrations in the inoculated restored plots. And the metrics we use to measure phosphorus involve total phosphorus, Mehlich three extractable phosphorus, and water extractable soluble phosphorus. We also found from the highest to the lowest in terms of plant uptake of phosphorus was elderberry, sambucus canadensis, meadow willow, salix petiolaris, red osier dogwood, cornus sericea, arrowwood, viburnum dentatum, and common buckthorn had the lowest phosphorous uptake rhamnus cathartica. There wasn't a significant difference between the inoculated and uninoculated plots in terms of plant phosphorus uptake, however. We also learned that the biodiversity was high in the restored plots. In fact, 50 genera of unplanted species appeared in the restored plots, and our DNA analysis highlighted abundance of phosphorus solubilizing bacteria. So the other project I'll briefly discuss that was part of my master's research and is continuing today is at a collective farm in the intervale, in Burlington on unceded Abenaki territory called Digger's mirth. With funding from a different NE SARE partnership project we did a large random block design mesocosm experiment researching if mycorrhizae could be effective in high versus low phosphorus soils working with two native shrubs salix niger, black willow and cornus sericea, red osier dogwood. The idea was to inform fieldwork we were planning on conducting that summer. And findings from this study were published in May 22 in a peer reviewed journal called People Plants Planet titled "Effects of Mycorrhizae Plants and Soil on Phosphorus Leaching and Plant Uptake: Lessons Learned from a Mesocosm Study". And we did this because it's a well known concept that not all symbiosis are mutual beneficial, there can be parasitic symbiosis. A paper was written in 1997 by scientists, Johnson, Graham and Smith titled "Functioning of Mycorrhizal Associations Along the Mutualism to Parasitism Continuum Spectrum". And in it they describe how the symbiotic relationship between mycorrhizae plants can range from being mutually symbiotic to being parasitically symbiotic. So for example, in certain soils with high phosphorus concentrations, mycorrhizae can be more like a parasite in the sense that it can take carbon from the plant, but not necessarily offer phosphorus because in such high phosphorus abundance plants can acquire it through diffusion. Findings from that mesocosm research were namely that more phosphorus was uptaken in the black willow than the red osier dogwood and this may be due to root morphology, rather than mycorrhizae. There was not really a significant effect of the mycorrhizae and likely researching mycorrhizae in mesocosms of only one plant species does not reflect their multiple partner nutrient cycling strategies. It was neat to see presence of mycorrhizal propagules even in the mesocosms with no plants taken from soils which indicated potential to incorporate mycorrhizae in edge of field areas. Even though tilling can disturb mycorrhizal networks, there are some surviving propogules and hence ways to incorporate mycorrhizae on organic farms. Last summer, we began field work on this project looking at mycorrhizal banks, basically strips of vegetation that can host mycorrhizae, serving as sources of mycorrhizae for cultivated fields. And you can read about our first year findings in the NE SARE website. It's under Project 121-391 titled "Mycorrhizae Banks to Enhance Vegetable Yield and Reduce Water Quality Impairment by Mitigating Excessive Soil Phosphorus". We are in our second year of this two year project, we installed mycorrhizal banks of polyculture cover crops instead of the shrubs that we'd research in the mesocosm studies because it turned out that they were too cumbersome for the farm to navigate with equipment and the shade that they cast on the field. So the polyculture cover crops involved vetch, oats and clover and we separated the treatments with radish strips because radish in the brassicaceae family are non mycorrhizal. Some sections of the banks were inoculated and some were not and parsley was planted in all of them. So it's also worth noting that the strategy of inoculation we used was haphazard in that it just involved taking soil from a wild buffer adjacent to the field. So we investigated the difference in soil phosphorus, soil water phosphorus and plant phosphorus concentrations and the mycorrhizal populations and we found some notable things. First, we wrote and published a manual on growing local mycorrhizal inoculum, which we simultaneously were doing in the greenhouse, and just want to offer a shout out to our stellar intern Luca Kolba, who headed that up, and when we grew that endemic mycorrhizae in the greenhouse and pot cultures, it was from wild buffers adjacent to the field. Additionally, secondly, we confirm that that haphazard technique of inoculation, just taking soil from a wild buffer and inoculating a field bed with it was ineffective due to the low propogule count. So none of our data metrics, the soil phosphorus, the soil water phosphorus, the mycorrhizal counts, the parsley phosphorus uptake, were significant when we were looking at the haphazard inoculated banks versus the control banks. Third, we found that the lowest concentration of soil phosphorus and soil water phosphorus was in the wild buffers, followed by the field banks and the highest phosphorus concentrations for all phosphorus metrics were found in the field. So this demonstrates how farming practices really do affect phosphorus concentrations, and how the least disturbed areas with the most robust underground networks tend to have the lowest concentrations of phosphorus. This was already in the literature, but it was super neat to see that reflected in our data.

C

Cate Kreider 16:17

So you've been working with this material and these questions for a long time. And I really appreciate you laying that all out. We will have links to your website, Mycoevolve in the blog post that accompanies this episode, so anyone interested can find them easily and read the research more in depth. So thanks for giving that overview. But I'm really curious about what is coming up next. What are you working on right now? And where are you hoping to go next with it?

J

Jess Rubin 16:47

Thanks. Yeah, so we are actually continuing both those projects. I'll start with Shelburne farms. So this coming growing season, we are gathering a fourth year of data on our original proof of concept thanks to funding from the Lake Champlain Basin program. And the metrics will involve soil phosphorus, soil water phosphorus, plant phosphorus concentrations, mycorrhizal colonization, and plant diversity. That's also thanks to lintilhac funding. We are currently growing endemic mycorrhizae using the manual we just published from the most wild forested area of that farm. We are working closely with the Abenaki grandmother Carol McGranahan, amending the plant palette to include even more species that are culturally relevant and useful to the Abenaki. We're actively growing relationships with various Abenaki members and learning how we can set these research plots up in ways that can become Abenaki harvest ways for them to access and from where they can teach their youth about their traditional plants and uses. We are growing a bio regional network for eco literacy with four-H, a partnership with CBU and Shelburne farms called Field and Forest and creating curriculum for schools such as Hunt Middle School, pending funding for transportation. So, these research sites can become a living laboratory to support eco literacy where students learn about the application of science to restore ecosystems. Finally, we're gearing up to triple the size of the restoration area. Next spring, funding pending, there will be three of each treatment instead of using a commercial mycorrhizae as we did in the proof of concept study, we will use endemic mycorrhizae that we're currently growing, we are amending the plant palette with even more plants relevant to the Abenaki such as sweet grass, and we will be training and employing Vermont YouthBuild and Vermont Youth Conservation Corps in site preparation and installation next spring. This of course depends on the many grants we've recently and are in process of writing and submitting. And I will note that the least savory part of my job, supporting this work, is writing a ton of grants and it is challenging to get this research funded. Sometimes we are only able to get small grants and when our work requires say $300,000 to fund our whole team and gather enough data it is a incredibly time consuming and humbling endeavor. Our work at diggers mirth the second year of this two year project we are going to be gifting the farm viable endemic mycorrhizae in a few weeks grown from wild buffers adjacent to their field.

We will be installing a random block design study comparing the wild endemic mycorrhizae we grew versus commercial mycorrhizae versus no inoculum on parsley phosphorus, soil phosphorus and soil water phosphorus concentrations and look at the mycorrhizal colonization. That final report will be submitted the end of August so stay tuned for that.

C Cate Kreider 19:44

I know I'm gonna stay tuned with that. That sounds like a lot of things to be looking forward to with this project. I think a lot of our listeners will be able to sympathize with the struggle of finding the funding to do this work, but people will also find it really useful and helpful going forward. I think we both hope. So I would really like to hear about how this work, which is aimed at buffer maintenance in agricultural settings is applicable to restoration work across the state. I noticed that some of the methods you were talking about, for example, one of your recommendations is coppicing shrubs to maximize phosphorous uptake, and that certain species had much higher phosphorus uptake and more success with that coppicing strategy. So, talking about those strategies and how they relate to site maintenance in restoration is something really interesting to me. And I think to many of our listeners.

J Jess Rubin 20:38

Yeah, well, we really do believe and hope that our work is applicable to restoration work across the state. And while we are doing this on a farm, we think not only can it be applied to a lot of areas on farms, where there's riparian buffers, but throughout the bio-region where there's riparian buffers or any form of ecotone between water and land, and that some of these strategies over time can reduce phosphorus concentrations entering the water. In terms of coppicing, there really is a tremendous value of returning to sites and coppicing. This is part of maintenance and facilitating annual phosphorus removal. I'm not sure how many of you are familiar with a recent book that colleague Mark Krawczyk published on coppice agroforestry. But in it Mark highlights how coppicing has been an ancient practice for a long time in human history. He dates it back to the late Mesolithic period, which is around 5000 years ago, and that's in Europe. So I'm not actually sure on this continent or elsewhere in the world, but likely as long or maybe even longer. So both in harvesting the fruits and I'll add nuts and coppicing woodies we are able to learn about some of the nuances involved in phosphorus uptake in plants. So elderberries, we found had the largest phosphorus concentrations, around 3000 milligrams per kilogram, of woodies, so far, willow has the most phosphorus uptake. Next year, we're going to research herbaceous species such as sweet grass. But it's worth noting that even with all of this phosphorus uptake and annual removal of some of these species, that's still a very small amount in comparison to what's in the soil from 400 years of colonial land practices, and phosphorus is a very slow moving cycle. However, if it is understood that it will take more than two decades before tangible effects in the actual soil phosphorus concentrations become visible, which is what the literature says. In the interim, we could talk about some of the more short term social and economic benefits of coppicing, which, as Mark's book highlights, was once a practice that was shared as ways to tend common lands. So focusing on elderberries for a moment, I learned from a UVM Extension staff member recently that this excellent elderberry guide that was published in 2016 by Rose Wilson and a robust team of professionals. It was, uh, "Growing Elderberries: A Production Manual and Enterprise Viability Guide for Vermont and the Northeast" did not take off the way folks thought it was going to in the East Coast. Even though a friend in California recently told me that elderberry planting is really taking off out there. The reason given was because the labor required in harvesting was beyond the capacity of the farmers as well as the low price of elderberries in Europe. But other projects I've been working on remind me of the ability and need we have to facilitate reclaiming the commons. So less managed riparian restoration projects could be cyclically harvested by Abenaki, as it is their ancestral land. Similarly, like gleaning, other marginalized folks can harvest from these buffers as part of a bio regional effort to create more local food security. It would be a super double function strategy of marginalized populations removing phosphorus from the landscape in other words, offering maintenance, and in turn receiving food, medicine and craft supplies. The species we're coppicing, willow, dogwood, and arrowwood are useful to the Abenaki for medicine and crafts as well as valuable to pollinators. These shrubs coppice well, the Abenaki we work with only harvest a quarter annually, so each plant will have three years to recover and the remaining three quarters can offer habitats to invertebrates and early and late migrating birds. A needed area of the research is to determine how much phosphorus each plant species uptakes because there's a lot more species we planted that we have not yet tested. And I'm actually particularly curious about how much phosphorus can be removed from shagbark hickory nuts and swamp white oak acorns.

C

Cate Kreider 24:58

Yeah, so there's a lot of things to consider that other restoration workers can can take into their work, I hope. And I also noticed that you talked about mycorrhizae having applications in wetlands and stormwater runoff infrastructure. This was in your literature review, I believe. So could you explain how that usage differs from including it in riparian buffers?

J

Jess Rubin 25:23

Yeah, that's a, that's a neat question and definitely one that merits a lot more research. Each site has its particular conditions, starting with the parent material, the soil type, the texture, the land use history and the current use. I'd say that mycorrhizae can be applied in various contexts, but they're certainly not a silver bullet, nor are they working alone. A huge part of their efficacy is due to their symbiotic relationships with microbes and plants. The tricky part about wetlands and stormwater runoff areas is the high volume of water that inundates these sites. Often this amount of water and lack of oxygen will prohibit terrestrial mycorrhizal activity. However, this is a vast arena for research as we advance in DNA sequencing to be able to start to discern which genera and species of mycorrhizae fungi can endure which particular conditions. So, you know, I imagine in our lifetime, this will be mapped out and we'll be able to guide practitioners to begin to carefully apply mycorrhizae in these more aquatic areas.

C

Cate Kreider 26:33

And, to swing back to the original goal of this work, which was agricultural contexts with the understanding that it does work in riparian contexts as well: how do you hope to make this research available for reference and use by Vermont farmers? You've already taken steps to make your research methods and resources accessible to them. But what else is there?

J

Jess Rubin 26:55

Well, we recently shared some of our Diggers Mirth research at the Vermont NOFA winter conference, which also included sharing a guide for farmers that we published on how to grow mycorrhizae and that can be accessed through the NorthEast SARE website, 121-391. For our research at Shelburne farms, we aim to publish a guide for farmers and restoration practitioners on riparian buffer restoration after our large impending installation in 2024. We will likely offer on site workshops as well once the restoration is established. We think sharing this with both farmers, riparian restoration practitioners and land managers in general, can help support amending some of the bio-regional best practices to support nutrient mitigation, pollinator habitat and, with abenaki harvesting, facilitate rematriation throughout the watershed. And I'm not sure how many farmers are going to be attending the Eagle Hill Northeast Natural History conference the weekend of April 20th through 22nd. But on that Friday, nine to noon, we will be offering a tour of our site with an informational packet, noting that it's still quite early in the blooming season, but if any farmers attend that it's another avenue to share.

C Cate Kreider 28:10

Yeah, thank you. I think that you're putting a lot of work into making sure that this research in all of its forms is accessible to the people that you're really hoping are able to use it in impactful ways. So, I think that's super commendable and important to the community. Thank you.

J Jess Rubin 28:30

Thanks.

C Cate Kreider 28:31

But I... I also think it brings up another value that you've used throughout your work: inclusion and collaboration with Abenaki people is a part of your experimental design and results. Can you speak on that decision and the impacts it had on your work?

J Jess Rubin 28:47

Thanks. Yeah, this decision arose pretty early on when it became clear that it would just be another Neo-colonial project if it did not also attempt to address the social devastation that accompanied the ecological devastation of the landscape through colonial settlement and agriculture. Three years ago, Mycoevolve wrote a grant to New England Grassroots Environmental Fund, which funded a local Abenaki group, AlnÃ´baiwi, to offer a rematriation ceremony at the site the first summer after the installation. And in that process, we became really clear that it's part of our responsibility to do all we can to facilitate the reconciliation of the broken relationships to the land. With the original peoples of this land and with their sacred relationships to the land. Abenaki clan mothers led the ceremony and we are learning to follow their ancestral guidance. We aim to facilitate the passing on of their plant and land tending knowledge to Abenaki youth. The impact it's had on our work is of humility. We've done our best to be accomplices and allies in supporting Abenaki rematriation, which really involves the women in particular. We've made many mistakes and the colonial framework from which we operate sometimes can be oppressive to the process. Even for those of us on our team who've been attempting anti-colonial work within and beyond ourselves for more than a decade. Grants, deadlines, deliverables; so much of the framework is outside of the slow reciprocal cycles in nature and amidst those who tend and then in turn are tended by the land. We continually interface with these edges and do our best to listen and follow Abenaki wisdom where we are able, and I would say it continues to be a steep learning curve. In working with Abenaki I've become aware of how many ways I have been colonized despite my personal rewilding ancestral practices, and how much anti-colonial work I need to continually do on my thinking, approach and communication while operating the system I am in to do this reconciliation work. And I'm discovering that when I orient from my ancestral tradition center, it's easier to bridge the frameworks.

C

Cate Kreider 31:08

Again, some really valuable partnerships and efforts being made. I think a lot of people are familiar with, as you say, the colonial frameworks that our academic field is just inundated with, and so... much respect to the efforts being made to part from that and create space for other cultures and ways of thinking. So thank you for that and good luck moving forward to increase their involvement and the value of your research to that community. I think we need to start wrapping up. So let's finish off with one more general question. What do you think is the most valuable takeaway from your work?

J

Jess Rubin 31:49

Yeah, I'd say two things. So one of them is about checking all assumptions. When I was working on my second masters, my committee had cut out several of my original objectives, because, as they rightly pointed out, much of what I was trying to investigate was too ambitious to do all at once. However, there was one data parameter I was not willing to let go of, and I'm so glad I didn't. That was the tedious work of quantifying mycorrhizal presence in the plots. We had formerly assumed that buckthorn did not have a very robust mycorrhizal presence. But it turns out, while they only partner with six or seven plants, they are very, very limited in the understory where they grow, they do actually have quite developed mycorrhizal networks. So, checking assumptions when you can, and if budgetary personnel or time restraints don't allow you to check for assumptions, then at least identify assumptions and hold them lightly. I'd say the second takeaway is patience and humility. Research indicates that it will take at least four to ten decades for tangible differences and phosphorus soil concentrations to be evident after mitigation strategies are applied. This is due to the very slow moving phosphorus cycle. Ultimately, this makes sense and is a relatively quick turnaround considering this legacy phosphorus is from 400 years of colonial land practices. Yet still, it's a long time and a challenge to advocate for because funders want deliverables. And so it's humbling and relieving at the same time to realize this is the work of multiple generations. Hence, we need to find funding for this long term research in which these slow trends can be tracked over the next few, or more than few, decades. And we're just beginning this work. Our task is to learn as much as we can, move the work forward conscientiously, train the next generation, support long term maintenance and monitoring, and research while working as diligently as we can. And this requires patience and humility, knowing and trusting that through slow deliberate change, reconciliation can occur.

C

Cate Kreider 34:07

Yeah, Jess, thank you so much for coming to speak with me and thank you for researching the application of mycorrhizae and other phosphorus pollution mitigation methods in riparian buffers. I know many of our listeners will be excited to see you progress in the coming years and that you have a lot of fascinating work ahead of you. Best of luck to you.

J

Jess Rubin 34:26

Thanks so much, Cate for allowing us the opportunity to share about our work and thanks to all of you out there for offering time to listen.

C

Cate Kreider 34:45

Today's episode featured the call of the Wood Thrush. It was recorded by Christopher McPherson in Hillsborough County, New Hampshire on May 20 of 2021.

A

Alison Adams 34:54

For more information about today's topic and other topics related to riparian forest restoration visit the Restoration Roundup Podcast tab of Lake Champlain Sea Grant's Watershed Forestry Partnership website. This project has been funded wholly or in part by the United States Environmental Protection Agency under an assistance agreement to NEIWPCC in partnership with the Lake Champlain Basin program.