Restoring a First Order Stream and Adjacent Riparian Wetlands In West Virginia: Integrating Lessons from Science and Practice

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Visual Abstract. Panel 1 (left; Pre-Restoration): A degraded wetland as a cattle pasture featuring song sparrows (*Melospiza melodia*), earthworms (*Oligochaeta*), and multiflora rose (*Rosa multiflora*). Panel 2 (Active Restoration): Streambank grading, seeding, coir mesh installation, live-staking, rock vanes, wood vanes, and woody vegetation planting. Panel 3 (Post-Restoration); Early restoration habitat, featuring meadow jumping mice (*Zapus hudsonius*), yellow flatsedge (*Cyperus flavescens*), flat-headed mayflies (*Eperous* sp.). Panel 4 (Future Outlook); Projected outlook of our restoration featuring tree swallows (*Tachycineta bicolor*), common buttonbush (*Cephalanthus occidentalis*), and narrow-winged damselflies (*Enallagma* sp.). (Scientific Illustration by J. Spahr Science Visuals; permission to use granted.)

ABSTRACT

Stream and wetland mitigation knowledge and understanding are rapidly evolving. However, the objectives of mitigation are wide-ranging. In 2021, a branch of Deckers Creek (Preston Co., West Virginia, USA) was restored by bank recontouring, reconnecting the incised channel to the constructed bankfull bench floodplain, creating small wetlands, and planting native riparian vegetation. Our research objectives were to 1) provide annual biodiversity and abundance data before, during, and after mitigation efforts and 2) assess woody-vegetation growth (height and diameter) and survivorship of a 10% biochar and 90% compost mixture. The complexity of mitigation warrants discussing challenges before, during, and after mitigation occurs. During restoration efforts, we encountered several challenges that were overcome through perseverance and collaboration. We incorporated ideas and practices from academia and the private sector to provide a detailed list of challenges encountered during our mitigation efforts, the solutions enacted, and future management implications to streamline mitigation planning.

INTRODUCTION

Mitigation is praised as significant progress for counteracting wetland and stream losses compared to the previous on-site, in-kind creation activities to satisfy permitting conditions. Instead of parcels spread out like postage stamps matching disturbances across the landscape, mitigation banking allows for bundling smaller impacts in a watershed, economy of scale, and projects protected in perpetuity. However, aquatic mitigation assessment is inherently complex because of wetland and stream managers' wide-ranging objectives and goals, which often differ from researchers and mitigation practitioners (bankers) (Strager et al. 2011). Because of the complex aquatic and wetland mitigation needs, researchers must communicate practices and findings to the mitigation practitioners and wetland managers through peer-reviewed literature, conversations, and other outlets. The importance and complexity of mitigation warrant the need to share success stories and failures (Selego et al. 2012; Petty et al. 2013; Gingerich et al. 2014) so that managers and practitioners can improve and expand mitigation efforts (Paul et al. 2022). Wetland researchers can contribute by sharing their knowledge of the ecological responses observed within mitigated wetlands (Balcombe et al. 2005; Gingerich and Anderson 2011; Gingerich et al. 2015; Noe et al. 2022), but ultimately these responses must be linked to success criteria to be meaningful. Sharing this knowledge increases management effectiveness for other wetland professionals (Paul et al. 2022). With these examples in mind, we share our lessons merging field research (i.e., science) and mitigation implementation (i.e., practice) from a combined restoration and research effort of a north-central West Virginia first-order stream and adjacent riparian wetlands.

In 2017, a headwater dam of Deckers Creek in Preston County, West Virginia, USA, was renovated to increase water capacity in the impoundment (Becker et al. 2022). Increasing water capacity was necessary to meet the need for improved water supply in residential areas (Becker et al. 2022). The increased water capacity led to a loss of palustrine wetlands and a small riverine system (Becker

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et al. 2022) through conversion to an open-water system created by the impoundment. The West Virginia Conservation Agency (WVCA) implemented a mitigation project on the Ruby Run tributary to offset these impacts as part of the permitting process.

STUDY AREA

Ruby Run, a branch of Deckers Creek, flows through the JW Ruby Research, Education, and Outreach Center (REOC) in Preston County, West Virginia, USA. Ruby Run is a first-order headwater stream of Deckers Creek (Figure 1a). The stream has a contributing drainage area of 2.2 km2 and is 1.62 km long. The stream flows under a road through a culvert. The upstream 35% is on private property, while the downstream end (65%) flows through the REOC, including the wetland easement boundary, as a narrow (mean ± SE width: 2.44 ± 0.32 m) and shallow (mean ± SE depth: 25.37 ± 4.23 cm) 1st order stream (Becker et al. 2022). While the upstream channel has many riffles, large rocks, and cobble, as the stream continues downstream and loses grade, the water depth increases, and the substrate becomes finer and the water murkier.

The portion of the stream that flows through the easement area had 679 m of fencing installed in 2010, adding a 22–91 m buffer on either side of the stream to prevent degradation by livestock from adjacent pastures (Becker et al. 2022). However, management does not always follow intention, and cattle periodically accessed the stream from 2010 until 2021 for forage and water. In addition, mowing occurred within the easement area to maintain and repair the fence. While this grazing and mowing did not dramatically cause a further decline in wildlife habitat quality (Becker et al. 2022), this fence was removed in June 2021 to allow for expanded restoration activities, including bank recontouring, to reconnect the incised channel to the constructed bankfull bench floodplain (Figure 1b). The cows did not have access to the easement area during this time as they were moved to other grazing lands, and the fence was replaced in July 2021, extending the easement area 15–20 m wide.

RESTORATION TIMELINE

In June 2021, the WVCA and contractors started restoring the degraded Ruby Run. The stream was heavily incised, resulting in head cuts and eroding banks that were unstable and contributed pulses of sediment during rain or disturbance events. The restoration design plan called for creating a bankfull bench to act as a floodplain with occasional pocket wetlands at the toe of the slope (Figure 2).

Before the restoration efforts at Ruby Run, biological surveys were conducted from February 2017–May 2021 (Becker et al. 2022). Pre-restoration data were collected on abundance and diversity data for anurans, birds, fish,

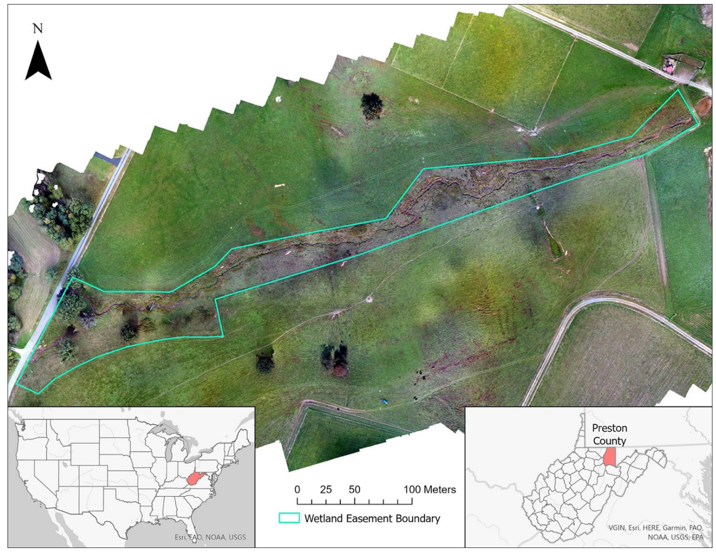

Figure 1a. Ruby Run and adjacent wetland easement boundary pre-restoration, Preston County, West Virginia, USA.

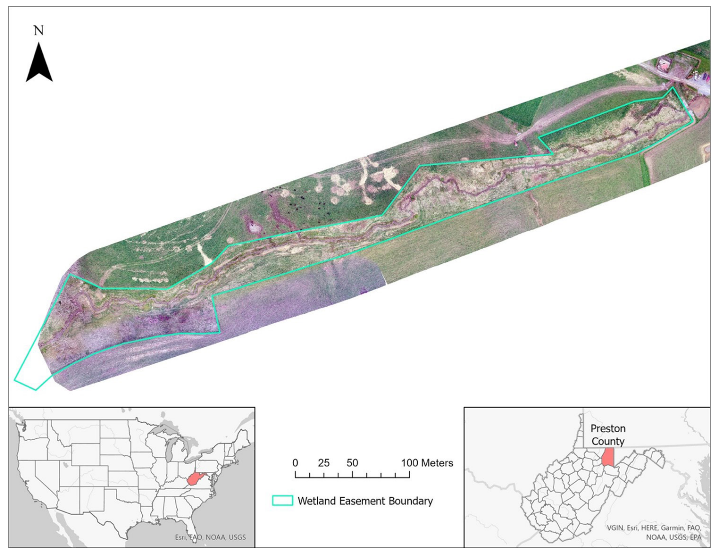

Figure 1b. Ruby Run and adjacent wetland easement boundary post-restoration, Preston County, West Virginia, USA.

macroinvertebrates, turtles, small mammals, and vegetation using standardized techniques (Anderson et al. 2013; Edalgo and Anderson 2007; Gulette et al. 2019; Selego et al. 2012; Veselka et al. 2010a,b). Between 2017–2020 235 species (six anurans, six small mammals, 13 fish, 58 birds, and 154 plants) were documented within or along Ruby Run, 78% being native to West Virginia (Becker et al. 2022). Due to the small size of the wetland and lack of open water, Ruby Run did not provide habitat for several wetland-dependent birds (Becker et al. 2022). Additionally, anuran diversity declined annually for unknown reasons (Becker et al. 2022). Thus, the lack of species richness indicated that Ruby Run was an excellent candidate for wetland restoration (Becker et al. 2022). These restoration surveys have been continued since the restoration efforts and will continue during post-restoration monitoring. Biological surveys will document the Ruby Run study site's taxonomic abundance and diversity changes.

Figure 2. The streambank grading of Ruby Run and the adjacent wetlands, Preston County, West Virginia, USA. (Note: All photos taken by Andrew MacKenzie)

The stream design called for a 3:1 slope to create a 6-foot (1.8 m) wide bankfull bench on each side of Ruby Run. Using an excavator, the stream banks were graded from the upstream property line, 420 m downstream. Topsoil was staged and respread after excess debris and soil were removed from the easement area. Log vanes, rock vanes, and point bars were placed on the outside edges of highly erodible bends (Figure 3), requiring one extraneous load of rocks that resembles a riprap bed needed to armor the confluence of a wet-weather seep and the stream at the beginning of a turn (Figure 4).

Figure 3. Wet-weather seep before being armored with rocks resembling riprap along Ruby Run's streambank in Preston County, West Virginia, USA.

In addition to stabilizing the banks, multiple instream structures (coarse woody habitat, rock j-hooks, and root wads) were added to reduce channel velocity and provide cover for aquatic organisms (Rosgen 1996). These structures include a cobble bed to stimulate and promote riffle habitat and two root wad features sticking out of the floodplain.

Within a week of the last active construction (July

Figure 4. Log vanes, rocks vanes, point bar, and rocks resembling riprap along Ruby Run's streambank, Preston County, West Virginia, USA.

Figure 5. Vegetation sprouting underneath coir mesh. (Scientific Illustration by J. Spahr Science Visuals, permission to use granted.)

2021), the WVCA seeded the exposed bank with native perennial vegetation (Ernst Conservation Seeds Eastern Native Habitat & Conservation Reserve Enhancement Program (CREP) Mix; Table 1) along the slopes and a native floodplain cover crop (Ernst Conservation Seeds Floodplain Mix; Table 2) for the bankfull bench. After seeding, mesh coir mats were installed to reduce erosion or the loss of seeds through wind or water erosion (Figures 5 and 6).

Native woody vegetation was planted between March and May 2022 (Figure 7). The wettest areas along the bankfull bench were planted with common buttonbush (Cephalanthus occidentalis), eastern ninebark (Physocarpus opulifolius), pin oak (Quercus palustris), and river birch (Betula nigra). The top of the bank and drier reaches of the floodplain were planted with American plum (Prunus americana), eastern cottonwood (Populus deltoides), eastern redbud (Cercis canadensis), swamp white oak (Quercus bicolor), and river birch (Betula nigra). All woody vegetation was tagged with numbered aluminum tags (Racetrack, UNSPSC: 55121500) attached with zip ties (Figure 8a and

Figure 6. Vegetation growth six months (12/15/2021) after coir mesh installation along Ruby Run, Preston County, West Virginia, USA.

Figure 7. Woody Vegetation Installed along Ruby Run and within the adjacent wetlands, Preston County, West Virginia, USA.

8b). Woody vegetation in the floodplain was planted with tree tubes (Max Grow, A.M. Leonard, SKU: MG60) held up by wooden oak stakes (Figure 8c and 8d). After the woody vegetation planting occurred, we added coconut fiber weed guards (44 cm. diameter; A.M. Leonard, SKU: CD44A) as weed control. In addition to weed control, we actively manage and remove invasive woody vegetation as it is observed.

ADAPTIVE MANAGEMENT IN THE FIELD

Adaptive management is an approach to natural resource management, emphasizing learning through management when knowledge is incomplete or uncertain (Walters 1986; Allen and Garmestani 2015). In terms of mitigation, uncertainty must be addressed to meet the success criteria necessary for releasing mitigation credits or permitting liability. Despite the uncertainty, scientists, managers, and policymakers must act to counter unforeseen constraints and limitations that stymie restoration success (Allen and Garmestani 2015). These unforeseen circumstances were documented at our site, and below we describe the challenges faced and the adaptive management steps we took to correct the events.

Fencing

The Ruby Run stream and adjacent wetland were fenced in 2010 (Becker et al. 2022). From 2010–2017, cows were allowed in the wetland, and mowing still occurred. The cows were allowed limited access to drinking water, and periodic mowing ceased in 2020. Although the fence was installed well before the planned wetland restoration, this was an opportunity to conduct pre-restoration biological surveys for anurans, birds, fish, macroinvertebrates, small mammals, turtles, and vegetation.

During the restoration efforts, the fencing was extended in June 2021 to include a larger wetland buffer. However, some wetland areas were still not included in the conservation easement, partly due to the grazing and hay-making requirements needed to maintain a working farm. Pocket peninsular-shaped wetlands extending from the easement area do not generate enough economic return to justify preservation compared to haying in straight lines and along contours. These wetlands outside the easement area have

Figure 8a. Creating a hole for woody vegetation, Preston County, West Virginia, USA.

Figure 8b. Installing woody vegetation and closing the hole, Preston County, West Virginia, USA.

Figure 8c. Installing wooden stake and tree tube, Preston County, West Virginia, USA.

Figure 8d. Zip-tying tree tube and zip-tie to a wooden stake, Preston County, West Virginia, USA.

not been intensively monitored and represent a research gap. Nor did they represent any ecological credit or permitting requirement. Herein lies the challenge in mitigation fencing design, finding a monetary compromise between the landowner's current and future planned land use with the loss of convenience or any future revenues associated with that land.

Administration v. Practical

After physically restoring the wetland and seeding, tree planting was the last restoration aspect planned to occur during the fall of 2021. However, the restoration contract, maintained through the WVCA, was divided into separate scopes of work (i.e., contracts). Due to administrative handling, the tree planting bids were offered in early spring 2022. Herein lies another challenge, the administrative side of restoration versus the practical. The contract was separated based on the expectation of cost savings: 1) construction companies with heavy equipment were hired to do the restoration with oversight, and 2) it was thought a specialty planting company would be able to be most cost-effective with planting pricing. Unfortunately, this only sometimes happens, and the bids were returned over the allocated funding. While we cannot know if offering one contract may have resulted in savings, we do know that two contracts require two companies to mobilize and demobilize at a site: potentially negating any savings.

Although initial bids were too expensive, WVU faculty and staff could work with the WVCA to "sponsor" the riparian education opportunities with labor provided by student volunteer organizations. Student groups were recruited and earned fundraising dollars for their organizations, resulting in a prolonged planting effort over 27 calendar days: March 25–April 22, 2022. Our effort resulted in over 30 volunteers from nine student organizations, including but not limited to a diverse group that included The Wildlife Society, Men's Volleyball Club, Society of Automotive Engineers, Women in Natural Resources, and the Graduate Student Association. The bare-root saplings were planted in bunches, while the plants remained dormant in cold storage in a freezer at the West Virginia University greenhouse. In the field, saplings were placed in 5-gallon buckets of water and covered loosely with a tarp to ensure the roots did not dry out.

Research Design

Another challenge of tree planting was implementing a study design required to conduct research as part of the lead author's thesis. The research question - what the magnitude of the effects of biochar additions on riparian tree growth and survival is - is inconsequential to permit conditions. Biochar composition is like charcoal and is made by burning agricultural and forestry organic material. However, pyrolysis produces biochar to increase carbon storage and reduce contamination (Lehmann 2007).

During restoration, we used 10% hardwood biochar:90% compost as a soil amendment during the planting. One-half of the woody vegetation, by species, received a treatment of 0.25 L of 10% hardwood biochar:90% compost mixture, and the others received no biochar (control). We used a 10% hardwood biochar: 90% compost mixture because of our restoration permitting requirements. We knew the mixture's effects were unknown, and we did not want our woody vegetation to perish. We will monitor growth (height and diameter at ground level) and survivorship.

Fine Tuning in the Field

Despite planting getting a late start in the spring, after the WVCA realized it needed more funds for a contractor, our team could mobilize and complete the required planting. Our final challenge was to accomplish this task with volunteers. We tried several methods and techniques in-house with research staff before inviting student groups to help plant woody vegetation to ensure that we maximized the woody vegetation planted.

In the first attempt, we: 1) dug the holes for woody vegetation, 2) walked back to the starting point and planted the woody vegetation with or without the treatment, and 3) walked back to the starting point, then tagged and flagged woody vegetation. We encountered three challenges with this method. First, we were unable to locate several holes that were previously created. Second, walking back to our starting point two times was highly inefficient. Third, only one person was responsible for installing the woody vegetation, treatment, flagging tape, and metal tags, leading to a significant time sink.

We adjusted our methods in the second attempt: 1) one individual dug holes for woody vegetation while another followed behind and planted the woody vegetation and soil amendment, and 2) we returned to the starting point, and both individuals would tag and flag the woody vegetation. This method was more efficient. However, there were two additional challenges that we discovered. First, the individual digging holes worked far faster than the individual with the woody vegetation and soil amendment. Second, flagging and tagging the trees took a significant amount of time.

We adjusted our methods once more. This time, we had one individual dig holes with a dibble bar while a second individual followed behind and placed one wooden stake into each hole until all holes for a plot were established. A third individual would carry a 5-gallon bucket of biochar, premade identification tags, and flagging tape. If applicable, this individual would place the biochar in the hole and attach a tag to the wooden stake. The fourth individual would place the woody vegetation into the hole and close the hole shut. If we were attaching tree tubes, we would have the first and second individuals return to the starting point and fasten the tree tubes until all woody vegetation in a plot was planted.

LESSONS LEARNED (WITH POTENTIAL TIPS FOR INCREASED SUCCESS)

Most challenges were overcome through collaboration and perseverance. Below, we've outlined critical information we learned during the restoration process to provide guidance and solutions to future wetland restoration projects. In addition, we had spoken to several wetland restoration specialists in the private sector. We incorporated ideas from the private sector during our research and included other recommended practices but not utilized in this restoration.

Fencing

Establishing a fence around a conservation easement is a wetland restoration technique often used to prevent unwanted outcomes within an easement area. At the Ruby Run tributary, the main objective of our fence was to prevent cattle degradation. Cattle often congregate in riparian wetlands because of the accessibility to water, favorable terrain, and abundant supply of lush vegetation (Kovalchik and Elmore 1992).

In 2010, fencing was installed along 679 m of Ruby Run protecting 2.22 ha of palustrine emergent wetlands and riparian buffers ranging from 22 to 91 m on either side of the stream (Becker et al. 2022). However, this fence was removed during active construction, and following restoration, a new fence was erected. Efforts should be made to truncate the timing to coordinate restoration activities to minimize resource waste. Fencing should be done upon completion of heavy equipment restoration activities, based on the completed project footprint and with a compromise to appease ecological permit conditions and the landowners.

Equipment and Materials

Ultimately, as we learned during and post-pandemic, despite planning, material and supplies are subject to price fluctuations, and materials don't generally become more affordable once a new price point is settled. Time is of the essence when estimating the cost of equipment and labor to do a job. Delays, whether administrative or from weather, are costly. However, permit conditions dictate what qualifies for a successful restoration regardless of cost. This project divided construction and planting into two separate jobs to save money. However, this backfired, especially as many restoration companies are becoming vertically integrated and completing tasks from design to build-out to maximize economic return. This can be handled in two ways from a contracting and managerial perspective. If the WVCA wanted to select one contractor to complete the job promptly, the contract could and should include a clause for liquidated damages or fees for not meeting timelines or build requirements.

Alternatively, and in the case of Ruby Run, money can be saved but not without coordination. Deliberate effort should dictate the sources of seeds and plants to optimize success. For example, wetland and riparian seed mixes were selected from Ernst Conservation Seeds, a provider of ecoregion-specific, commercially available native seed mixes. The tree species were chosen based on the availability of state nurseries, which are almost always the most cost-effective but do not always carry the broadest selection of species. However, careful examination of tree life histories will often result in the ability to choose species that tolerate the hydroperiod at the site and, or have a proclivity to thrive in the climate. Of note, though, to be cost-effective, we did not choose American sycamore (Plantanus occidentalis) or red maple (Acer rubrum) because of their ability to establish on their own as pioneer species (Larsen 1953; Steele et al. 2020).

If one finds themselves in a restoration project manager position, putting together a species list and supplies, there are other challenges to consider. Tree orders from different vendors will arrive staggered, and tree form and root structures are not uniform across species, which required a variable effort to ensure holes were large enough not to "J-hook" roots. Additionally, creating additional labels when stock arrives can be essential, as sometimes they fall off. Moreover, we recommend ordering and installing weed control concurrent with planting, as there is significant herbaceous competition early in the growing season.

Tree Planting (without tree tubes and wooden stakes)
Organizing and coordinating tree planting labor is best left to professional contractors. While successful restoration through volunteer labor is possible, adapting a system based on the number of people that show up on a volunteer workday is cumbersome and not always the most efficient. To counter, create a planting system that can be modified based on participants to optimize efficiency. This document outlines several methods and techniques before inviting groups to help plant woody vegetation (see Adaptive Management in the Field) to ensure that volunteer labor and time were maximized.

Timing
To increase efficiency and effectiveness during wetland restoration, we should have a timeline and optimize our construction schedule to meet weather and sensitive species survey windows. For example, construction for stream systems is best in late summer during low water season but timed correctly so fall rains can stabilize slopes via the germination of annual and perennial herbaceous communities. However, depending on the potential presence of an endangered species, surveys may need to be conducted a year before garnering U.S. Fish and Wildlife Service Section 7 Endangered Species Act approval. A fall planting of woody vegetation is generally preferred to allow some root growth over winter. Still, a spring supplemental planting may be necessary to replace some trees that don't survive. Planting in late spring or mid-summer is not recommended or advised. Supplemental watering and moisture-holding media may be necessary to give the best chance of survival.

MANAGEMENT IMPLICATIONS

We hope this case study provides insight into challenges encountered during a wetland restoration project. We present the following summary for consideration before and during wetland restoration projects.

1) Plan out a timeline for construction events that maximize your restoration success. Allow room for contingency planning and understand that the plan will fail in some way and adjustments will be necessary.

2) Truncate the time allowed between bidding construction costs and opening day to minimize the chance of price changes and fluctuations hindering your design objectives.

3) Check in on the project after significant storm events and regularly look for indicators of failing to start adaptive management proactively. This can include fences in disrepair, structures that have been compromised due to high flows, or the proliferation of invasive species communities that will alter or limit succession.

4) Use a wetland mitigation planting tool to increase vegetation survivorship. DeBerry et al. (2021) released a wetland mitigation planting tool that projects ecological performance standards and planting costs of woody vegetation. This can be used to predict stem density and stem area at the groundline for woody vegetation.

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TABLES 1 AND 2 ON NEXT PAGE

Table 1. Species composition of Ernst Seeds Eastern Native Habitat & CREP Mix.

Species	Scientific Name	Proportion of Seed Mixture
Big Bluestem	*Andropogon gerardii*	0.4
Virginia Wildrye	*Elymus virginicus*	0.268
Switchgrass	*Panicum virgatum*	0.15
Partridge Pea	*Chamaecrista fasciculata*	0.06
Indiangrass	*Sorghastrum nutans*	0.05
Purple Coneflower	*Echinacea purpurea*	0.03
Blackeyed Susan	*Rudbeckia hirta*	0.03
Oxeye Sunflower	*Heliopsis helianthoides*	0.01
Common Milkweed	*Asclepias syriaca*	0.001
Wild Bergamot	*Monarda fistulosa*	0.001

Table 2. Species composition of Ernst Seeds Floodplain Mix.

Species	Scientific Name	Proportion of Seed Mixture
Indiangrass	*Sorghastrum nutans*	0.238
Virginia Wildrye	*Elymus virginicus*	0.2
Big Bluestem	*Andropogon gerardii*	0.155
Fox Sedge	*Carex vulpinoidea*	0.12
Lurid Sedge	*Carex lurida*	0.05
Blunt Broom Sedge	*Carex scoparia*	0.05
Hop Sedge	*Carex lupulina*	0.045
Blue Vervain	*Verbena hastata*	0.04
Oxeye Sunflower	*Heliopsis helianthoides*	0.02
Wild Bromegrass	*Bromus altissimus*	0.015
Swamp Milkweed	*Asclepias incarnata*	0.01
Soft Rush	*Juncus effusus*	0.01
Boneset	*Eupatorium perfoliatum*	0.005
Common Sneezeweed	*Helenium autumnale*	0.005
Golden Alexanders	*Zizia aurea*	0.005
New England Aster	*Aster novae-angliae*	0.004
Purplestem Aster	*Aster puniceus*	0.004
Flat Topped White Aster	*Aster umbellatus*	0.004
Wild Bergamot	*Monarda fistulosa*	0.004
Ditch Stonecrop	*Penthorum sedoides*	0.004
Narrowleaf Mountainmint	*Pycnanthemum tenuifolium*	0.004
Woolgrass	*Scirpus cyperinus*	0.004
Great Blue Lobelia	*Lobelia siphilitica*	0.003
Wrinkleleaf Goldenrod	*Solidago rugosa*	0.001