Spring 5-4-2024

Riparian Expansion Post-Restoration Efforts Along the Upper Clark Fork River

Makena Tanko

Riparian Expansion Post-Restoration Efforts
Along the Upper Clark Fork River

by

Makena Tanko

A thesis submitted in partial fulfillment of the
requirements for the degree of

Ecological Restoration, M.S.

Montana Tech
2024

Abstract

Floodplain restoration is an intricate process aimed at promoting water quality, biodiversity, and maintaining ecological balance. However, mapping vegetation patterns on a restored floodplain can be challenging due to different geomorphic locations across a river sections, including flooding regimes, sediment characteristics, elevation, and ground water availability. This study investigates the drivers of vegetation succession in floodplains post-restoration along the Upper Clark Fork River, encompassing Phases 1, 2, 3, and 5.

We analyzed key factors influencing vegetation response, including total canopy cover and woody vegetation health, in comparison to soil compaction, geomorphic location, distance from streambank, time post-restoration, and metal levels to determine which factor statistically had the most benefit at influencing vegetation expansion.

Time post-restoration showed the most significant factor in vegetation height and ground cover completing the requirements set by the Record of Decision for the Clark Fork River Operable Unit. The presence of bare ground facilitated woody seedling establishment and promoted woody vegetation growth. Soil compaction was not significant in vegetation expansion into the floodplain. Sandbar willows were found to be the most effective woody species in developing habitat for wildlife and higher shrub layer percentages. To prevent contamination into restored phases, restoration design should clean up phases in upstream to downstream sequential order. Understanding the drivers of vegetation succession enables river restoration practitioners to improve current restoration approaches and to formulate optimized restoration designs, thereby fostering superior ecological outcomes.

Keywords: floodplain restoration, geomorphic location, vegetation succession, X-Ray Fluorescence, total canopy cover

Dedication

I wish to dedicate this thesis to my family and many friends. To my Mother and Father, who gave me words of encouragement through the tough times and provided me with the ability to achieve my dreams. To my professors Dr. Gentry and Dr. Light who pushed me to attend graduate school and find my passion in life. Lastly, to Cassidy, Keith, Morgan M., Morgan S., and Nicholas who helped with field work and supported me throughout this process.

Acknowledgements

I would like to thank and acknowledge everyone who helped me throughout this thesis project. Everyone has helped me grow as a scientist and gave me extremely important knowledge to bring into the professional world.

First, I would like to express my deepest appreciation to my committee chair and research advisors:

Dr. Robert Pal, my committee chair, a special thank you for giving me guidance throughout this project. You have always been there by my side and gave such strong words of support even in hard times. I enjoyed spending time in the field with you and always cherished your advice. This project would not have been possible without you.

Joe Griffin, my research advisor, thank you for providing input and willing to join my committee midway through. Your experience and knowledge in restoration is invaluable and it really guided this project through to the end.

Dr. Dan Autenrieth, my research advisor, thank you for teaching me and guiding me through the world of statistics. Developing graphs with you really helped open my eyes to different ways you can look at data and gave me confidence that my data can tell a story.

I am also grateful to Alex Leone for being a huge help in developing the field method protocols and creating connections to make this project possible. You were an enormous help throughout this project, and I also cherished our time in the field together.

Thank you, Amy Sacry and Geum Environmental Consulting for giving me the opportunity to discuss my project with you and give advice on sampling techniques. Your advice helped me form a stronger dataset.

Thanks to undergraduate and graduate students who helped me with this project and gave me moral support: Taleigh Adrian, Keith Moore, Nicholas Rasschaert, and Morgan Schultz

This project was funded in part by the Clark Fork Coalition whose work has helped many people and protected the vital waters of the Clark Fork watershed. This project was also funded in part by Montana NSF EPSCoR, CREWS Commercialization Program, whose program helps promote sustainability and environmentally safe practices throughout Montana. Both organizations helped me develop lifelong relationships with agencies, private businesses, universities, and non-profit organizations.

Table of Contents

List of Tables

List of Figures

List of Equations

Glossary of Terms

Abbreviation	Term
ROD	Record of Decision
UCFR	Upper Clark Fork River
CFR	Clark Fork River
XRF	X-Ray Fluorescence
km	Kilometer
m	Meter
cm	Centimeter
As	Arsenic
Cd	Cadmium
Cu	Copper
Pb	Lead
Zn	Zinc
N	Number of Samples
PEL	Probable Effect Level

1. Introduction

Floodplain ecosystems and their relationship between biological and physical characteristics has received increasing attention since the 1980s. These systems are unique because of the extreme fluxes of material and energy that might occur from springtime snowmelt runoff or storm events and their adaptive vegetation patterns (Pautou, 1994). These patterns can be mapped out to identify floodplain vegetation characteristics in individual river basins to improve the restoration success of the floodplain ecosystem (Brinson, 1990; Roni et al., 2019). Many of these patterns are strongly influenced by the flooding regime of the river (Ortmann-Ajkai et al., 2018; Stammel et al., 2022). Within the floodplain, vegetation regeneration patterns have developed flexible strategies that have adapted to that component of the river (Dosskey et al., 2010). For example, the Sandbar willow (*Salix exigua*) has developed a regenerative pattern to quickly form thickets alongside the streambank in gravel or sand deposits (USDA, 2002).

Sedimentation production and erosion are created through channel movement and flooding patterns to produce different geomorphic locations on the surface of a floodplain (Hughes, 1997). Soils and sediment types have been shown to play an important role that influences vegetation distribution. Examples include Franceschi and Lewis (1979) on the Parana River of Argentina; Johnson et al., (1976) on the Missouri River of North Dakota; Morison et al., (1948) on the Bahr el Ghazal floodplain in the Sudan; Nanson and Beach (1977) on the Beatton River of British Columbia; Viereck (1970) on the Chena River floodplain in Alaska. Figure 1 shows vegetation expansion after flooding on a spatial scale.

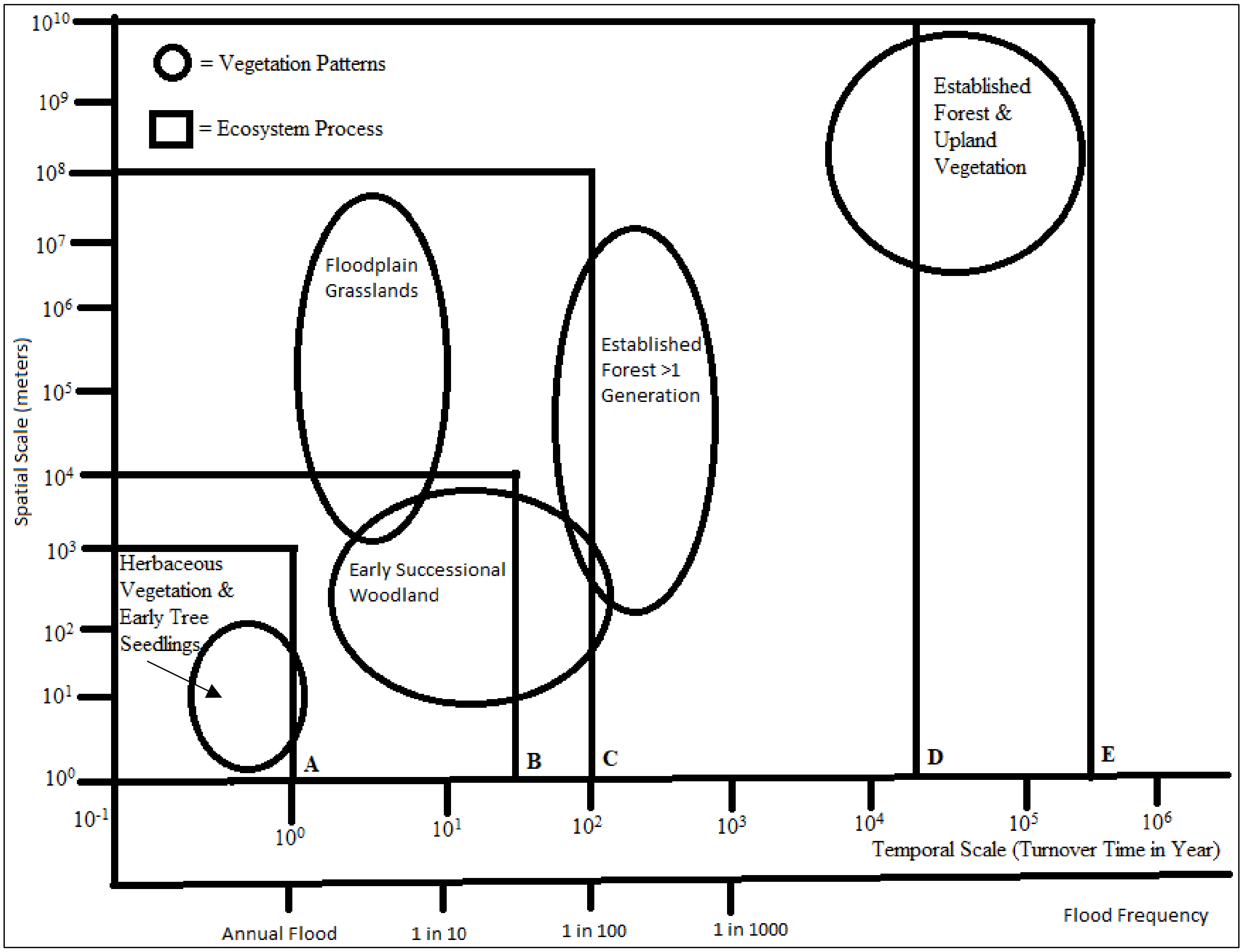

Figure 1: Floodplain Component in Reference to Flooding and Spatial Scale

Adapted from: Hughes (1997), Salo (1990), and Gosselink (1993)

A. Section A of Figure 1 illustrates the primary succession of wetland vegetation and woody species. Annual flooding occurs in this stage.
B. Medium frequency flooding of 10-year floods is associated with primary and secondary floodplain vegetation succession such as wetland indicators, grasslands, and shrublands.
C. Low-frequency flooding of 100-year floods is associated with long-term floodplain vegetation succession such as forests ranging around greater than one year old.

D. Long-term succession begins to occur on terraces and vegetation typing changes as species migration occurs further from the floodplain. Wetland indicators begin to disappear as the ecosystem changes to an upland. 1000-year flooding is associated with this spatial scale.
E. Ecosystem typing changes completely from a floodplain and biogeomorphic features and vegetation pattern are characteristically different than a floodplain.

Site disturbance in the form of flooding has been shown to promote shrub layer growth and tree seedling distribution. Huenneke and Sharitz (1986) describe the occurrence of flooding regimes on the Savannah River floodplain to be more influential than percent organic matter and pH of soil for tree seedling distribution. Frequency and duration of flooding were also shown to be most influential in seedling distribution and vegetation patterns in the floodplain of Passage Creek, Virginia (Hupp and Osterkamp, 1985). Soil types within the floodplain hold available moisture for vegetation due to the hydraulic conductivity. Soil moisture levels are more linked to rainfall than higher water tables as Klimo and Prax (1985) described in their 27-month study period on the Dyje River in Czechoslovakia. However, soil moisture does not directly influence vegetation distribution as wetland indicators can be found in different soil gradients and soil moisture levels (Hughes, 1997). Soil moisture does factor in the diversity of plants as the drier surface soils can affect survivability of most plants in the herb and shrub layers (Penka, 1991; Vasicek, 1991a, 1991b). To increase the survivability of plants in a restoration project, plants with higher drought tolerance need to be selected due to the unpredictable nature of flooding regimes and climate change.

Mining operations began in the late 19th century for gold, silver, and copper (Clark Fork Coalition, 2019). These operations brought significant wealth and attention towards Butte.

Mining, smelting, and milling operations were unregulated at the time which led to the disposal of smelting waste and tailings into Silver Bow Creek and the Clark Fork River (CFR hereinafter). The various waste contained elevated levels of metals such as cadmium (Cd), copper (Cu), lead (Pb), zinc (Zn), metalloid arsenic (As) and acid producing rock (US EPA, 2007). The finer sediments were hydraulically transported downstream towards the Milltown Dam in Missoula. In 1908 a flooding event occurred which dispersed mine waste into the floodplain of the CFR and left more than five billion liters of mine waste behind the Milltown Dam (National Weather Service, 2018).

The Upper Clark Fork River (UCFR hereinafter) from Warm Springs to Missoula is part of one of the largest Superfund complexes in the US. The section from Warm Spring to Garrison is known as Reach A and considered to be the most contaminated portion (US EPA, 2004). The State of Montana is focusing its cleanup efforts in Reach A to remediate and restore the CFR. Cleanup efforts began in 2013 and to date, 19 kilometers (km) have been remediated (Reach A is approximately 80 km of streambank) (Stone, 2023). Full completion is anticipated in 2038. The 2004 Record of Decision (ROD) stated cleanup activities will mainly focus on the first 69 km in Reach A between Warm Springs Ponds to upstream of Garrison (US EPA, 2004). Currently, seven of the twenty-two phases have been completed (Stone, 2023). Phase 1 was completed first in 2014 and the most recent Phase 3 was completed in 2023. The use of restoration techniques has varied throughout the project’s timeline across phases. The ROD requires a 10-year review for each phase after completion (US EPA, 2004). The main goal of the CFR restoration project is to improve water quality, restore a vital and diverse fishery, and healthy riparian corridors to the river and its tributaries (Clark Fork Coalition, 2016).

The purpose of this project was to analyze the factors that are driving succession in the floodplain of the CFR after remediation and restoration activities have occurred. There are many factors that drive succession such as sediment type or the type of vegetation planted in a restoration project. Vegetation dynamics and river morphology are intricately linked because of interactions between sediment transport, flow, and aquatic and terrestrial ecosystems (Simon et al., 1999). River restoration research has primarily focused on the physical dimension of streams morphology dynamics. There is less research about the factors driving the rate of biogeomorphic succession. Biogeomorphic succession describes the feedback between fluvial processes and vegetation succession that led to a transition from bare river deposited sediment to fully developed riparian plant communities (Schindler et al., 2016; Simon and Collison, 2002).

This project aims to discover what factors are allowing vegetation to expand in the floodplain after a completed phase in the CFR restoration project. The selection of phases to be sampled were determined by their completion date. The data will create a better understanding of how natural succession progresses in the floodplain. The use of this data could provide river restoration practitioners with information about factors that drive vegetation expansion for future restoration projects. The data also will provide monitoring information on the current status of the CFR restoration and determine if it is going to meet the ROD expected outcomes.

2. Methods

2.1. Research Site Characterization

The CFR flows from its headwaters at Warm Springs, Montana, to Missoula, Montana for 193 km. The study area is located in the UCFR basin which is in southwest Montana, USA near the city of Butte (Figure 2). The CFR watershed ends when it flows into Lake Pend Oreille stretching more than 500 km (U.S. National Park Service, 2021). From the Continental Divide near Butte, Montana, the CFR accumulated water from 45,000 km of streams and creeks (Clark Fork Coalition, 2019). On average 621 m^3/s is discharged into Lake Pend Oreille making it the largest river by volume in Montana (US EPA, 2024). The mean annual precipitation for the CFR watershed is 635 mm and has a mean annual temperature of about 5.1 degrees Celsius in the river (US Geological Survey, 2024; US National Cooperative Soil Survey, 2016). Habitat classification for the CFR watershed is intermountain grasslands, sagebrush steppes, riparian woodland and scrubland, and mixed conifer forest (CDM, 2010). The geographic landforms in the UCFR watershed are stream terraces and fan remnants with slopes ranging from zero to 25 percent (US National Cooperative Soil Survey, 2016). The typical pedon classification for the CFR watershed is very cobbly sandy loam derived mainly from granite (US National Cooperative Soil Survey, 2016).

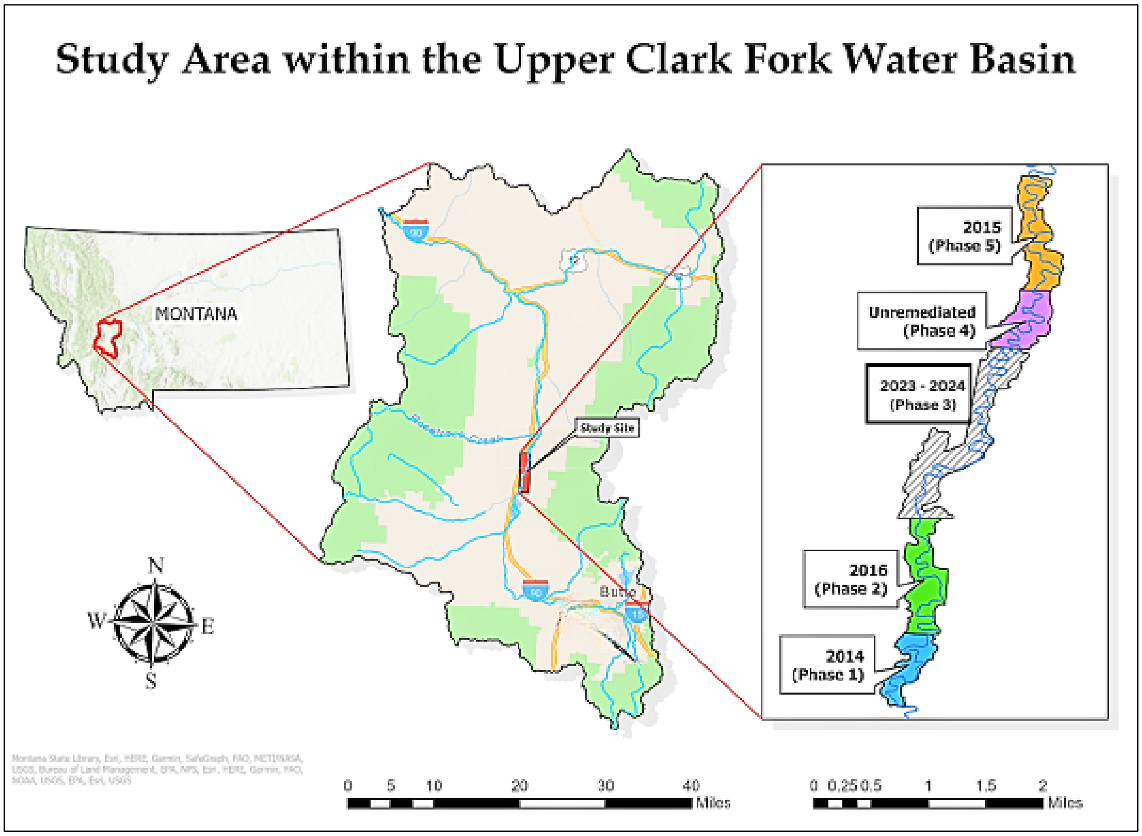

Figure 2: Map of the Study Site

Adapted from: Stapley (2023)

2.2. General Transect Parameters

The phases selected for monitoring are Phases 1, 2, 3, and 5. These phases have been completed from several months to nine years ago (Stone, 2023). The older phases should be more advanced in floodplain succession. The geomorphic locations that were selected for sampling include point bars, counter-point bars, and upstream and downstream preferential flow paths. A total of three point bars, three counter-point bars, and three preferential flow paths were sampled in each phase. The geomorphic locations were selected at random using a geographic information system. The sampling locations for these phases are displayed in Appendix A. The vegetation on these sites have had time to establish themselves and grow as listed per the expected outcomes in the ROD (US EPA, 2004). Table I presents the total transects and plots for each phase. The data collected in the vegetation plots is in Table II.

Table I: Sampling Location and Sampling Design

Phase Number	Phase Length	Total Plots	Total Piezometers	Phase Completion Year
Phase 1	~ 1,000 Meters	120 Sample Plots	24 Piezometers	2014
Phase 2	~ 1,600 Meters	120 Sample Plots	24 Piezometers	2016
Phase 3	~ 2,500 Meters	120 Sample Plots	24 Piezometers	2022
Phase 5	~ 1600 Meters	120 Sample Plots	24 Piezometers	2015
Total: 4 Phases	~ 6,700 Meters Total	480 Total Sample Plots	96 Piezometers	

2.3. Establish Transects and Plots: Point Bars, Counter-Point Bar and Preferential Flow Paths

2.3.1. Point Bars

Point bars are low-lying geomorphic features which constantly accumulate sediment deposition and experience higher rates of flooding (Stromberg, 2001). Sediment and vegetation litter is deposited on point bars making them nutrient rich areas. However, the vegetation in this geomorphic location is challenged by prolonged periods of inundation. Pioneer plant species are well adapted to growing in these conditions. The point bars were selected for this study due to their unique feature in building up sediment and the restoration planting was kept to a minimum. The restoration work involved constructing the shape, elevation, and specific grade material for point bars (Natural Resource Damage Program and Geum Environmental Consulting, Inc., 2020; US EPA, 2004). Because there is no active revegetation work performed on the point bars, vegetation succession is primarily occurring naturally through suckering or seed dispersal (Bourgeois et al., 2016). The transect line should show the expansion or shrinkage of vegetation into the floodplain. Bankfull vegetation indicators form over an exceptionally long time. The constructed phases did not have consistent bankfull indicators (Lichvar et al., 2012). The edge of vegetation closest to the water was used as the starting point for sampling.

To determine the position of the transect line, the transect extended perpendicular from the apex of the curve. This allowed for as close to an equal distance from the upstream bank and downstream bank of the point bar. The transect line started at the vegetation edge and ran along a bearing that is perpendicular to the meander curve. The transect line extended 20 m from the edge of the vegetation at the streambank into the floodplain. The vegetation might be submerged along the streambank. The submerged vegetation was included in the data collection. Wooden stakes were used to denote the starting and ending points of the transect lines.

Measurements for the data were collected on the transect line using a 1 × 1-meter vegetation monitoring plot.

Figure 3: Edge of Vegetation Approach and Point Bar Transect

The vegetation monitoring plots are placed closer together at the beginning of the streambank. The first plot is placed at the edge of the transect line where the vegetation begins at the streambank. Figure 3 shows the placement of the vegetation monitoring plot beginning at the streambank edge and the point bar transect approach. The first measurement was taken from meter zero to one. To collect the second sample the plot was flipped over the transect line and the measurement was taken from meter one to two. For the first five samples this was repeated to collect the first five meters from the edge of the vegetation. After the fifth sample the spatial pattern between vegetation plots on the transect line increased to every three meters. For example, sample five was collected from meter four to five and sample six was collected meter seven to eight. A total of 10 vegetation monitoring plots were collected for each point bar site.

2.3.2. Counter-Point Bar

Counter-point bars are located opposite of the point bar. The streams velocity flows at a faster rate in these locations striking the streambank before it is deflected in another direction (Stromberg, 2001). If the streambank is not stable, erosion could occur at a much faster rate.

Figure 4: Counter-Point Bar with Coir Log Restoration Approach

To prevent this from occurring, the correct vegetation and restoration techniques need to be applied (Hubbard et al., 2003). Figure 4 depicts a counter-point bar two in Phase 1 with the coir log restoration approach encouraging bank stability. The floodplain beyond the bankfull is higher in elevation than point bars. By placing the transect line opposite of the point bar transect, succession can be compared between the two to determine the factors that are driving vegetation expansion. The floodplain elevation and vegetation structure between point bars and counter-point bars could show the disconnect between vegetation and groundwater levels.

The start of the transect line began at the edge of the vegetation, similar to the point bar transects. The transect line extended opposite of the point bar transect line. The transect line was 20 meters in length. A wooden stake was hammered into the ground at the end of the transect line.

The vegetation monitoring plot started at the beginning of the vegetation on the streambank. After the first sample, additional plots were surveyed along the transect line to collect five consecutive plots worth of data. After sample five, the distance between vegetation monitoring plots increased to every three meters. There was a total of 10 vegetation monitoring plots collected along each transect line.

2.3.3. Preferential Flow Paths

Preferential flow paths refer to the paths or channels within a river system that water tends to follow during overbank flow (Stromberg, 2001). These flow paths are determined by various factors, including the river's topography, sediment deposition and erosion patterns, vegetation, and previous flow history.

The preferential flow path had two transect lines. The first transect line extended from the upstream streambank at the vegetations edge. The second transect line extended from the downstream streambank at the edge of the vegetation. The transect lines extended 20 meters in length. Preferential flow path Phase 1 transect two was smaller in distance and the transect lines did overlap. The transect lines almost form a connected straight line from upstream and downstream of each streambank. At the end of each transect line a wooden stake was hammered into the ground.

The vegetation monitoring plot placement on the transect line followed the 'counter-point bar' layout. The first five meters were sampled consecutively and then the spatial pattern increased to every three meters distance between vegetation monitoring plots. A total of 10 samples were collected for each transect line.

2.4. Vegetation and Soil Data Collection

2.4.1. Vegetation Cover Collection

Vegetation cover was analyzed using the total canopy cover method. The total canopy cover is comprised of the tree, shrub, and herb layers (Coulloudon et al., 1999; Daubenmire, 1959). The grasses, forbs, shrubs and cryptogamic crust represent the herb layer. Shrubs that are below 130 centimeters are included in the herb layer percentage (Wilson, 2011). The percent vegetation cover of all these components was recorded separately. Additionally, the coverage of sedges and rushes was also recorded for this layer as they indicate wetlands (Lichvar et al., 2012). Bare ground areas are an important category because they are more susceptible to invasive weed species and are high priority to restore and fill in with natives (Monteiro et al., 2016). The second layer consists of the shrub layer, composed of branching woody vegetation, while the third layer comprises the tree layer, consisting of tall, single-stemmed woody vegetation (Coulloudon et al., 1999; McDonald et al., 1991). To be categorized in the shrub layer, vegetation must be above 130 cm (Wilson, 2011). The percentage of each vegetation cover layer should not exceed 100 percent. The three layers can be 300% when comprised together. The analysis of each layer was then done to analyze succession in the floodplain and determine the complexity of the vegetation structure. Vegetation health targets were set by the ROD and were used to analyze the status of the floodplain. The minimum vegetation performance standards that are required by the ROD are listed in Table II below.

Table II: Minimum Vegetation Performance Standards

Minimum Vegetation Performance Standards			
After Year Number	Percent Planted Woody Species Survival	Percent Preferred Woody Species Canopy Cover	Percent Total Canopy Cover of Non-Weed Perennial Vegetation
1	90	N/A	90-98
2	90	N/A	95-98
4	X	N/A	98
5	X	50	98
7	X	60	98
10	N/A	80	98

Source: US EPA (2004)

2.4.2. Woody Vegetation Sampling

The primary vegetation for establishing streambank stability and expansion is woody vegetation. The tensile strength provided by the woody vegetation's roots stabilizes the soil and enhances the soil strength (Thorne, 1990). Vegetation increases bank stability in the case of a storm event, by intercepting rainfall that would have entered the streambank increasing surcharge, by reducing positive pore-water pressure through soil moisture absorption (Simon and Collison, 2002). The primary woody vegetation observed in the field was Sandbar and Booth's willows. Table III contains the preferred woody species to be planted according to the ROD and was expected in the floodplain of the CFR.

Table III: Preferred Woody Species According to ROD

Preferred Woody Species

Common Name	Scientific Name
All Native Willow Species	*Salix* spp.
Water Birch	*Betula occidentalis*
Red-Osier Dogwood	*Cornus sericea*
Common Chokecherry	*Prunus virginiana*
Western Serviceberry	*Amelanchier alnifolia*
Mountain Alder	*Alnus incana*
Cottonwood	*Populus trichocarpa*

Source: US EPA (2004)

In each vegetation monitoring plot, the vegetation height of the five tallest woody species was recorded. The vegetation height could help determine the age class of willows growing in that area. Tree seedling density counts were collected to show succession is initiated. The max seedling height is five cm. Tree cover for the plot was recorded for the third layer of total canopy cover. Native willows are not recorded under tree cover as they are a shrub species. The woody vegetation cover was split into two categories. The first category was the percentage of Sandbar willows. The second category was the percentage of any other woody vegetation. To be considered tree cover, the minimum height must be 400 cm. Willow growth is primarily found in wetland and moist soils which will show the succession of wetland vegetation into the floodplain. The dominant woody species for the plot were also recorded as Sandbar, Booth's willows, or other. Determining the dominant woody species provides insight for future projects on what species is thriving the best under the current conditions.

2.4.3. Soil Data Collection

To determine the depth to the water table, a piezometer was installed in the center of the first and last monitoring plot in each transect line of each phase that is being analyzed (Bätz et al., 2016). The piezometers are placed at meter one and meter 20. A total of two piezometers were installed at each transect. A drive post was used to drive the perforated PVC pipe into the ground to the groundwater level. All the perforated PVC pipes were 1.2 meters in length. E-tape was used to collect the groundwater level distance from the surface. The groundwater levels were all collected on September 18th, 2023, to ensure there is no variation due to a storm event or barometric pressure change. If there were any copper salts or contamination present that was recorded. Soil compaction was collected in plots 1, 3, 5, 10 and 20 using a FieldScout soil compaction meter. The last soil measurement collected was a soil sample. The soil sample was collected near the center of plots 1, 3, 5, 10 and 20. From the surface of the soil to 12 cm down is the depth of the soil collection.

A Niton XL5 plus portable X-ray Fluorescence (XRF) was used to determine the chemical composition and metals concentration. The metals analyzed were As, Cd, Cu, Pb, and Zn. The XRF and sample cup setup is shown in Figure 5. The XRF was assessed using a quality control sample five times to ensure the XRF was calibrated. The sigma value was 1.5 for the XRF sampling. The XRF faces limitations in measuring lighter elements, improper sample preparation, and insufficient measurement time. These limitations were controlled by following a strict sample preparation regime. To prepare the soil to be analyzed by the XRF, the soil was dried in a Thermo Scientific drying oven for 48 hours. The soil was then sieved through a 250-micrometer opening film to achieve a fine aggregate. The fine aggregate was then poured into XRF sample cups. The XRF sample cups were scanned for 90 seconds, and the five metals of concern were recorded.

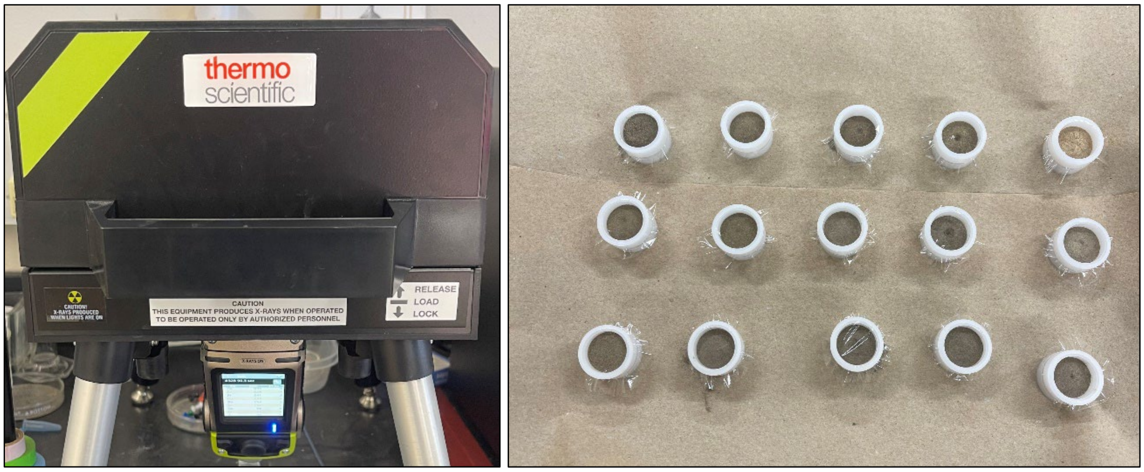

Figure 5: XRF Analyzer Setup and XRF Sample Cups

Imported backfill material is required to meet the design criteria specified in the ROD (EPA, 2004, Section 13.8.2.1 and are presented in Table IV).

Table IV: Cover Soil for Excavated Area Design Criteria

Cover Soil for Excavated Area Guidelines	
Depth	The entire depth of contamination is to be removed from slickens areas. The goal of cover soil is to facilitate hospitable rootzone of at least 45 centimeters of non-toxic rooting media.
Coarse Fragment Contents	Particles greater than 0.2 centimeters will constitute less than 45 percent. Maximum rock size is 15 centimeters
Texture	Sandy loam or finer
pH	Between 6.5 and 8.5 for entire depth of cover soil
Metal Concentration	Arsenic < 30 ppm, Cadmium < 4 ppm, Copper < 100 ppm, Lead < 100 ppm, and Zinc < 250 ppm
Organic Matter	> 1.5 percent of composted organic matter in upper 15 centimeters for upland areas. Riparian areas must have approximately five to seven percent organic matter levels

Source: US EPA (2004)

2.5. Statistical Analysis

The software used to perform all statistical analyses was in Minitab® Statistical Software V21.4. A P-value of less than 0.05 is accepted as statistically significant. For a comparison of different factors, Welch's ANOVA was used to determine the difference of means between groups. Welch's ANOVA was selected because the data groups have unequal variances. The Spearman correlation test was used to analyze the heavy metal levels for correlation between one another. Games-Howell test was used for post-hoc analysis to determine statistical difference and provide grouping.

Interval plots were used with a 95% confidence interval from the mean. The sample size is 480 samples. Woody vegetation height statistical analysis used the average vegetation height of the five tallest woody vegetation in each plot. Total sample size of woody vegetation samples is 2,400 including plots with zero woody vegetation present. Response and explanatory variables are listed in Table V below.

Table V: Tested Variables

Response Variable	Explanatory Variable
Ground Cover Percentage	Time Post-Restoration
Shrub Percentage	Distance from Streambank
Woody Vegetation Height	Geomorphic Location
Woody Seedling Count	Soil Compaction
Willow Percentage	Metal Levels

3. Results

3.1. Study Site Assessments

Across all phases and geomorphic locations, meter one had a ground cover mean of 58%, as shown in Figure 6. Further into the floodplain at 20 meters the ground cover mean was 76%. Ground cover includes litter, biocrust, grass, sedge, forbs, and shrubs. '100-BG' is calculated by taking the bare percentage subtracted from the litter, biocrust, grass, sedge, forbs, and shrub percentage. Ground cover percentage is not statistically significant extending from the streambank into the floodplain. The analysis of variance showed an F-value of 1.67 and a P-value of 0.098. However, Figure 6 does show a trend with increasing groundcover moving from meter one to meter 20. Figure 6 includes all geomorphic locations and phases.

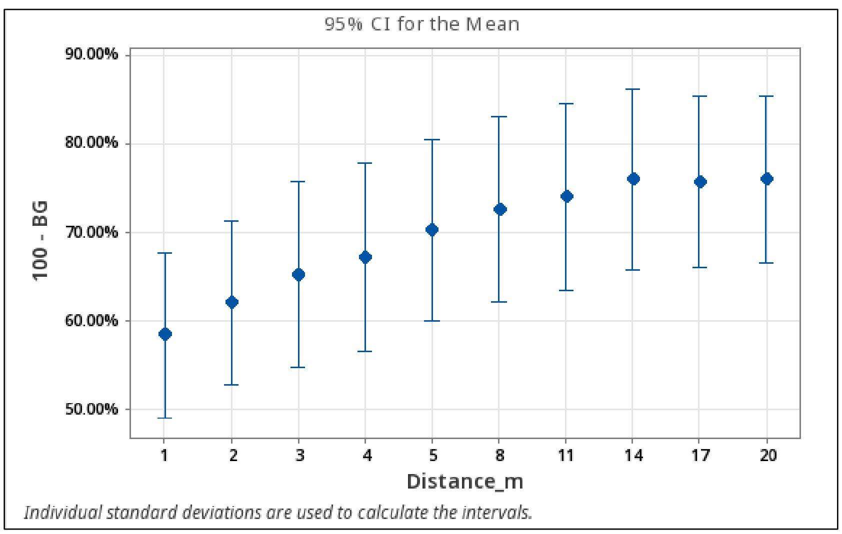

Figure 6: Relationship Between Total Ground Cover and Distance from River Across All Transects

Due to Phase 3 being recently completed, ground cover was significantly less dense and grouped statistically different, as shown in Table VI. Figure 7 shows across Phases 1, 2, and 5 the ground cover is being met to the ROD's standards on geomorphic locations counter-point bar, preferential flow paths upstream, and preferential flow path downstream. The red dashed line is the expected 90% groundcover to be met by the ROD.

Table VI: Games-Howell Test of Ground Cover and Phase Number

GamesHowell	Grouping	Mean	N
Phase 1	A	0.86	120
Phase 2	A	0.85	120
Phase 3	B	0.25	120
Phase 5	A	0.83	120
Difference of Levels (Phase)	T-Value	Adjusted P-Value	
2-1	0.0	1.000	
3-1	-20.8	0.001	
5-1	-0.7	0.893	
3-2	-19.7	0.002	
5-2	-0.7	0.900	
5-3	21.3	0.001	

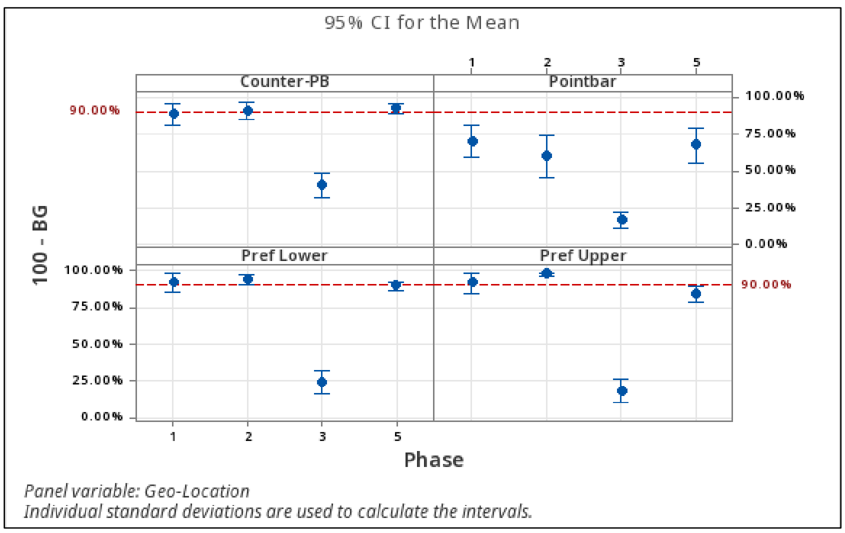

Figure 7: Ground Cover Displaying Phase and Geomorphic Location

Woody vegetation average height across all the phases and geomorphic locations shows a decline in height after five meters as shown in Figure 8. The average height of woody vegetation for the first five meters is 70 cm. From meter eight to meter 20 the average height of woody vegetation is 47 cm. ANOVA showed an F-value of 1.64 and a P-value of 0.107. The data is not statistically different from each other.

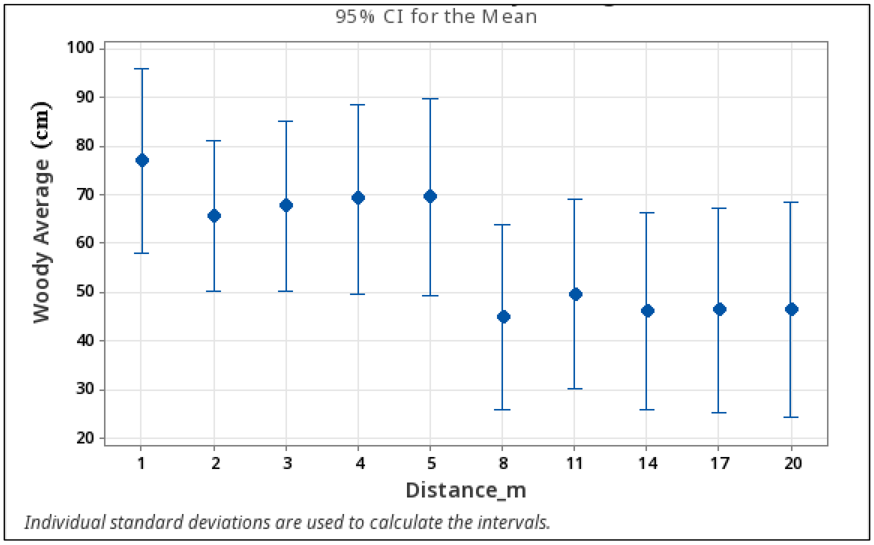

Figure 8: Average Woody Vegetation Height (cm) Across All Transects in Relation to Distance (m)

Figure 9, shows woody vegetation height in Phase 1 was the highest with an average of 96 cm. Phase 1 was completed in 2014 and has the longest time to recover after restoration. However, Phase 2 had the second highest average woody vegetation height with a mean of 70 cm. Phase 2 was completed in 2016. Phase 5 was completed in 2015 and had an average of 50 cm. One-way ANOVA of woody average versus phase showed an F-value of 49.98 and a P-value of less than 0.001. Games-Howell test results are displayed in Table VII.

Table VII: Games-Howell Test of Phase and Woody Vegetation Height

GamesHowell	Grouping	Mean	N
Phase 1	A	96	120
Phase 2	B	70	120
Phase 3	C	17	120
Phase 5	B	50	120
Difference of Levels (Phase)	T-Value	Adjusted P-Value	

2-1	-2.8	0.025
3-1	-10.1	0.002
5-1	-5.1	0.002
3-2	-7.9	0.001
5-2	-2.4	0.073
5-3	5.4	0.001

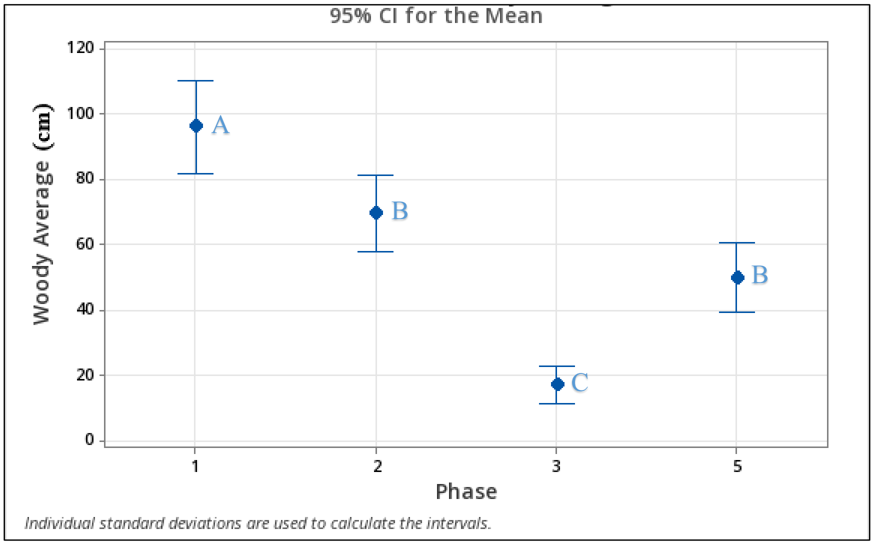

Figure 9: Average Woody Vegetation Height (cm) Separated by Phase

Average Sandbar willow percentage of woody vegetation present in each plot is labeled as 'Sanbar%' as seen in Figure 10. In relation to Figure 9, Figure 10 showed Phases 1 and 2 had the highest Sandbar willow percentage for all the transects. Phase 1 had the highest mean of 70% and Phase 2 had a mean of 69%. Phase 5 had a significantly lower mean of 34%. Analysis of variance using one-way ANOVA showed an F-value of 22.11 and a P-value of less than 0.001. The alternative hypothesis is Sandbar willow percentage is statistically different in Phases 1 and 2 from Phases 3 and 5. Games-Howell test results grouped Phase 1 and 2 in grouping A and Phase 3 and 5 in grouping B as shown in Table VIII.

Table VIII: Games-Howell Test of Phase and Sandbar Percentage

Games-Howell	Grouping	Mean	N

Phase 1	A	70%	120
Phase 2	A	69%	120
Phase 3	B	42%	120
Phase 5	B	34%	120
Difference of Levels (Phase)	T-Value	Adjusted P-Value	
2-1	-0.2	0.997	
3-1	-6.6	0.001	
5-1	-5.1	0.003	
3-2	-6.2	0.002	
5-2	-4.7	0.002	
5-3	1.4	0.481	

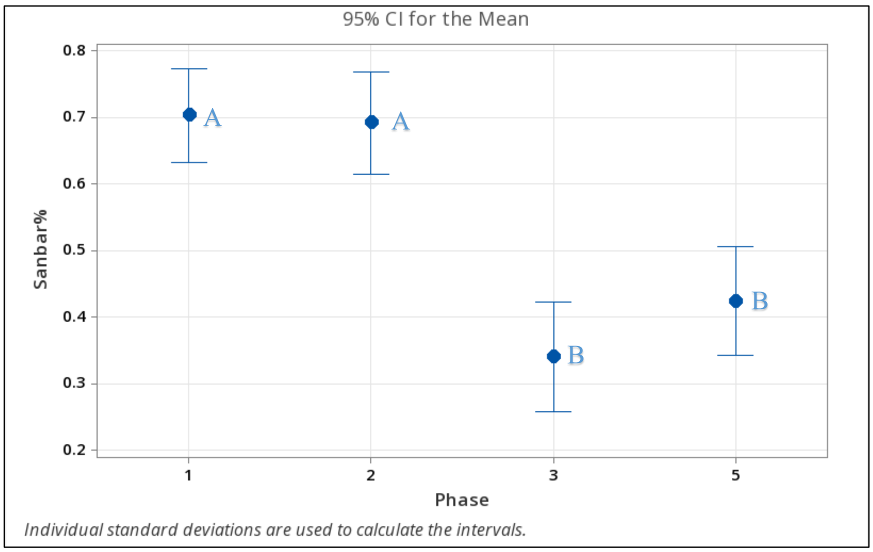

Figure 10: Average Sandbar Percentage of Woody Vegetation in Each Plot Separated by Phase

Woody vegetation seedling count showed a constant decline further into the floodplain from the streambank in all phases and geomorphic locations in Figure 11. Woody seedling counts are labeled as 'Woody seedl' as seen in Figure 11 and Figure 12. Woody seedling counts were highest at meter one with a mean of seven and lowest at meter 17 with a mean of 0.8. An F-value of 8.69 and a P-value of less than 0.001 was shown in the analysis of variance. The accepted hypothesis is the alternative hypothesis. The alternative hypothesis is woody seedling counts decrease going further from the streambank into the floodplain. Table IX displays the grouping according to Games-Howell test results.

Table IX: Games-Howell Test of Distance (m) and Woody Seedling Counts

GamesHowell	Grouping	Mean	N
Distance (m)			
1	A	7.0	48
2	A, B	5.6	48
3	A, B, C	3.9	48
4	A, B, C, D	3.1	48
5	B, C, D	2.4	48
8	B, C, D	2.0	48
11	D	0.94	48
14	D	0.88	48
17	D	0.77	48
20	C, D	1.3	48

Difference of Levels (Distance)	T-Value	Adjusted P-Value
2-1	-0.9	0.995
3-1	-2.4	0.371
4-1	-3.1	0.082
5-1	-3.7	0.015
8-1	-4.0	0.006
11-1	-5.4	0.004
14-1	-5.6	0.001
17-1	-5.6	0.003
20-1	-4.8	0.007
3-2	-1.4	0.931
4-2	-2.1	0.529
5-2	-2.7	0.176
8-2	-3.0	0.090
11-2	-4.5	0.001
14-2	-4.7	0.001
17-2	-4.7	0.001
20-2	-3.9	0.009
4-3	-0.8	0.998
5-3	-1.6	0.866
8-3	-1.9	0.667

11-3	-3.7	0.015
14-3	-3.9	0.009
17-3	-4.0	0.007
20-3	-2.9	0.127
5-4	-0.8	0.999
8-4	-1.1	0.980
11-4	-3.0	0.110
14-4	-3.2	0.073
17-4	-3.2	0.057
20-4	-2.1	0.518
8-5	-0.4	1.000
11-5	-2.1	0.553
14-5	-2.2	0.445
17-5	-2.4	0.375
20-5	-1.3	0.948
11-8	-1.6	0.841
14-8	-1.8	0.759
17-8	-1.9	0.684
20-8	-0.9	1.000
14-11	-0.2	1.000
17-11	-0.5	1.000
20-11	0.7	1.000
17-14	-0.3	0.998
20-14	0.8	0.993
20-17	1.0	0.99

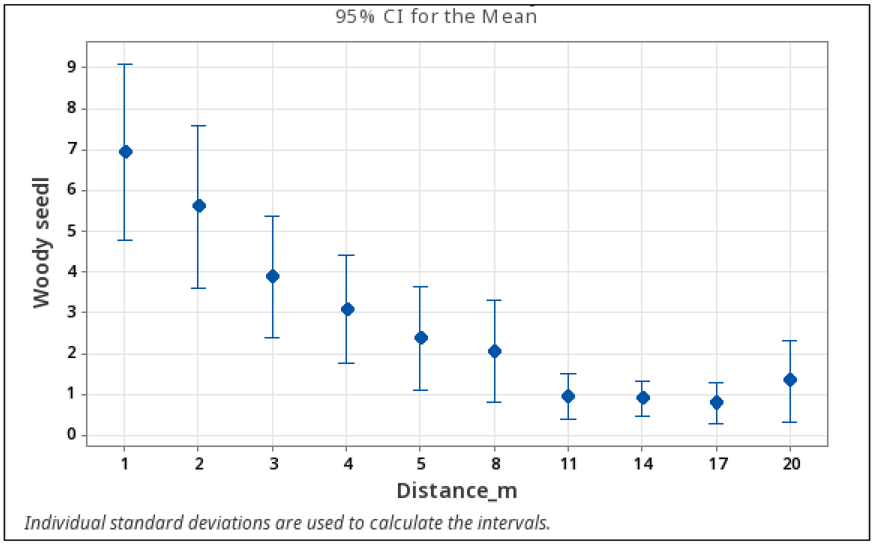

Figure 11: Relationship Between Woody Vegetation Seedling Count and Distance from Streambank Across All Transects

Figure 12 displays the woody seedling count and groundcover side by side. There is a trend that as there is more bare ground, there is a higher probability of more woody seedlings being present. At meter one the mean of woody seedlings count is 7.0 and ground cover is 58%. At meter 20 the mean of woody seedlings count is 1.3 and ground cover is 76%.

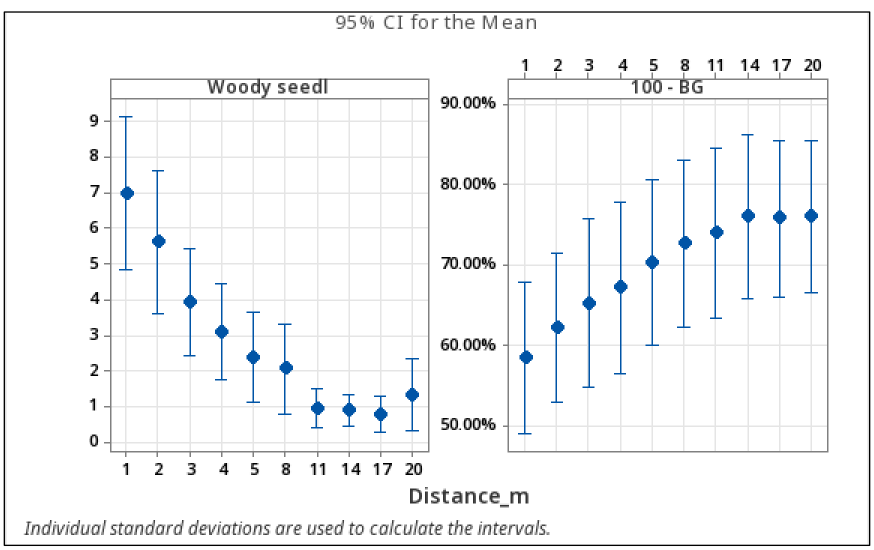

Figure 12: Woody Vegetation Count Next to Ground Cover Percentage Across All Transects

The shrub percentage in Figure 13 follows a similar pattern to the willow heights and seedling counts. The shrub percentage decreases when going further into the floodplain. At meter one the mean was 19% and at meter 20 the mean was 7%. Analysis of variance showed an F-value of 5.1 and a P-value of less than 0.002. Games-Howell test calculation is displayed in Table X.

Table X: Games-Howell Test of Shrub Percentage and Distance (m)

GamesHowell	Grouping	Mean	N
Distance (m)			
1	A	19%	48
2	A, B, C	14%	48
3	A, B	14%	48
4	A, B, C	13%	48
5	A, B, C	12%	48
8	C	7%	48
11	B, C	8%	48
14	B, C	7%	48
17	B, C	8%	48
20	C	7%	48

Difference of Levels (Distance)	T-Value	Adjusted P-Value
2-1	-1.9	0.677
3-1	-1.5	0.870
4-1	-2.1	0.510
5-1	-2.6	0.241
8-1	-4.4	0.001
11-1	-3.9	0.008
14-1	-4.3	0.002
17-1	-3.9	0.008
20-1	-4.4	0.001
3-2	0.3	1.000
4-2	-0.4	1.000
5-2	-0.9	0.997
8-2	-3.2	0.055
11-2	-2.5	0.279
14-2	-3.0	0.092
17-2	-2.5	0.268
20-2	-3.2	0.052

4-3	-0.7	1.000
5-3	-1.1	0.980
8-3	-3.3	0.045
11-3	-2.6	0.214
14-3	-3.1	0.071
17-3	-2.7	0.204
20-3	-3.3	0.042
5-4	-0.5	1.000
8-4	-2.7	0.196
11-4	-2.0	0.581
14-4	-2.5	0.261
17-4	-2.1	0.536
20-4	-2.7	0.185
8-5	-2.3	0.398
11-5	-1.6	0.834
14-5	-2.2	0.484
17-5	-1.7	0.783
20-5	-2.3	0.378
11-8	0.6	1.000
14-8	-0.01	1.000
17-8	0.3	1.000
20-8	-0.1	1.000
14-11	-0.6	1.000
17-11	-0.2	1.000
20-11	-0.7	0.999
17-14	0.4	1.000
20-14	0.0	1.000
20-17	-0.4	1.000

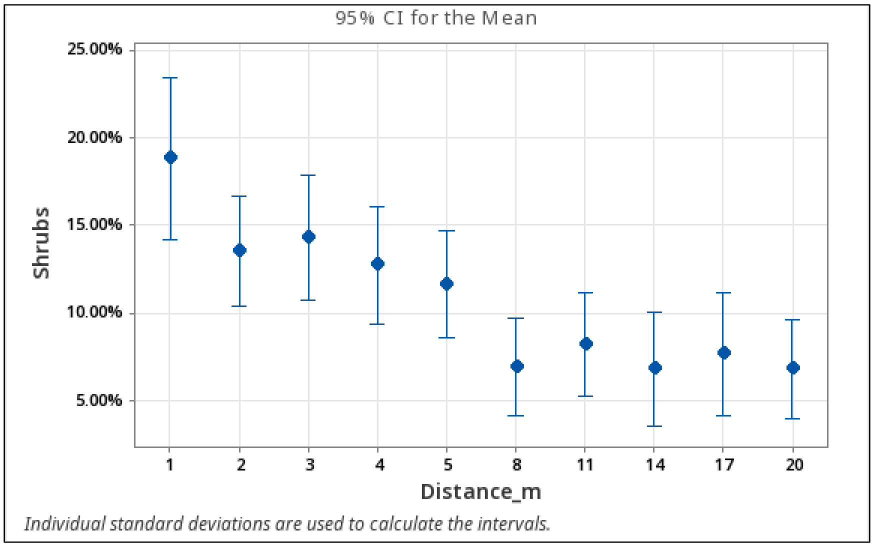

Figure 13: Shrub Percentage in the Herb Layer Across All Transects

3.2. Metal Analysis

The measured metal concentration (XRF analysis) was compared to the ROD criteria for clean backfill, and a compliance ratio for each metal of concern and arsenic was calculated based on the formula:

Equation 1: Compliance Ratio Equation

Metal Standard Level = (([Sample Level] As / 30 As Target) + ([Sample Level] Cu / 100 Cu Target) + ([Sample Level] Pb / 100 Pb Target) + ([Sample Level] Zn / 250 Zn Target)) / 4

Cadmium concentrations were below the instrument detection level.

If the compliance ratio is over one, the metal concentrations exceed the criteria specified in the ROD. If the metal compliance ratio is equal to or less than one, the metal concentrations comply with the ROD requirement. The compliance ratio is labeled as 'Metal Level Standard' in Figure 14, Figure 15, Figure 16, and Figure 18.

Figure 14 presents the composite number for the compliance ratio of all metals in each phase and geomorphic locations. The red dashed line denotes the line of compliance. Phase 3 was the most recently restored phase (2023) and recorded the lowest metal levels. Phase 3 is upstream from the unremediated phases and reflects soils and sediment that have not been contaminated by groundwater or sediment deposition from upstream.

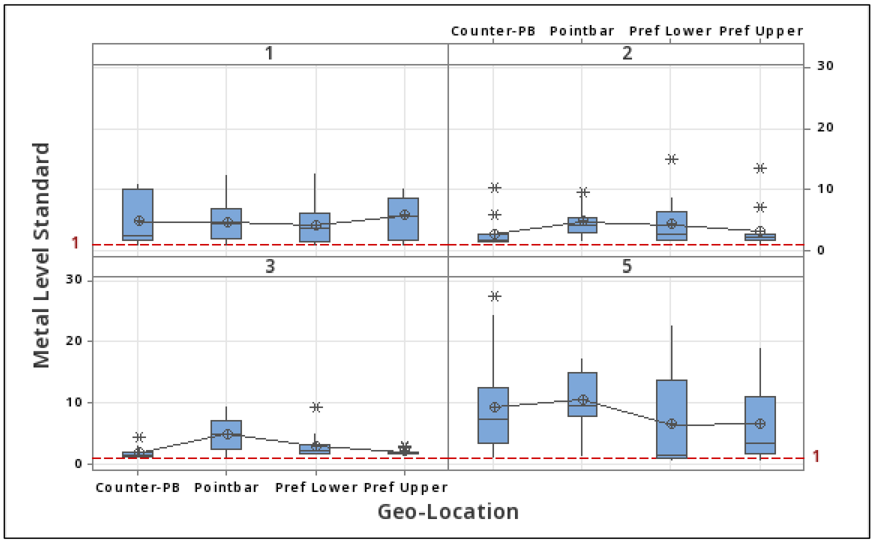

Figure 14: Box Plot of Compliance Ratio According to ROD Cleanup

The clean backfill criteria were excerpted from a consensus-based sediment quality guidelines for freshwater ecosystems (MacDonald et al., 2000) that was specifically derived by the Probable Effect Level (PEL hereinafter) for *Hyalella azteca*, 28-day test (PEL-HA28). PEL means when that level is being exceeded, environmental factors will begin to experience adverse effects. This guideline does not reflect the metal level vegetation would be phytotoxic. The guideline was used as guidance to protect aquatic organisms from the eventual entrainment of backfill into the active river system.

Figure 15 displays compliance ratio with the variable of distance into the floodplain which showed a decrease from the streambank at meter one to meter 20 in the floodplain. The mean at meter one was six and the mean at meter 20 was three showing an increase of two times in metal levels at the streambank as to 20 meters into the floodplain. The P-value was 0.001 with an F-value of 4.89. Table XI lists the grouping of data according to Games-Howell results.

Table XI: Games-Howell Test of Compliance Ratio and Distance (m)

GamesHowell	Grouping	Mean	N
Distance (m)			
1	A	6.0	48
3	A	6.1	48
5	A, B	5.1	48
11	B	3.4	48
20	B	3.4	48

Difference of Levels (Distance)	T-Value	Adjusted P-Value
3-1	0.1	1.000
5-1	-1.0	0.873
11-1	-3.3	0.011
20-1	-3.2	0.017
5-3	-1.0	0.878
11-3	-2.9	0.033
20-3	-2.9	0.042
11-5	-1.8	0.364
20-5	-1.8	0.394
20-11	-0.0	1.000

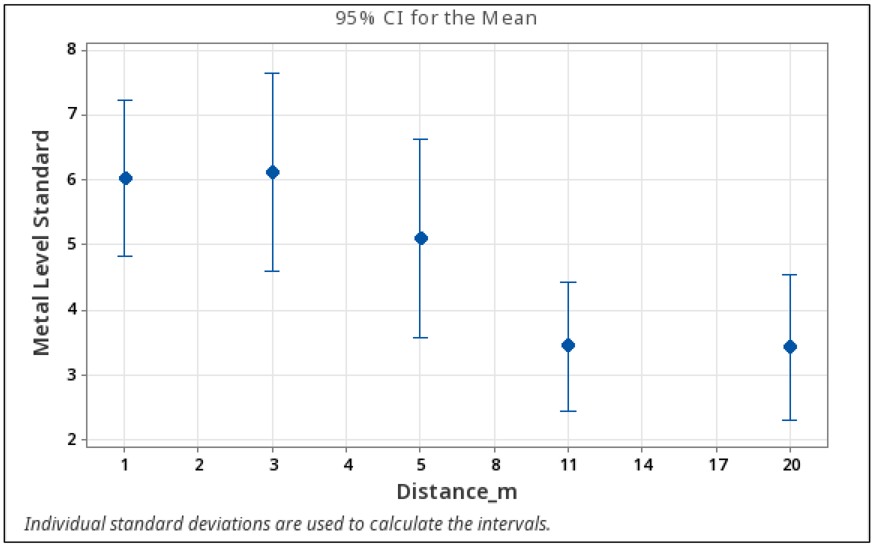

Figure 15: Compliance Ratio with Distance Variable Across All Transects

Compliance ratio was the highest in Phase 5 with a mean of eight as shown in Figure 16. Phase 5 had around an increase of two times the compliance ratio compared to Phase 1 and Phase 2. The analysis of variance for compliance ratio in each phase showed an F-value of 14.53 and a P-value of less than 0.001. The alternative hypothesis for Figure 16 is compliance ratio is statistically higher in Phase 5 as opposed to Phases 1, 2, and 3. Games-Howell test results grouped Phase 5 separately from Phases 1, 2, and 3 shown in Table XII.

Table XII: Games-Howell Test of Compliance Ratio and Phase

GamesHowell	Grouping	Mean	N
Phase 1	B	5	60
Phase 2	B	4	60
Phase 3	B	3	60
Phase 5	A	8	60
Difference of Levels (Phase)	**T-Value**	**Adjusted P-Value**	
2-1	-1.9	0.237	
3-1	-3.8	0.002	
5-1	3.6	0.003	
3-2	-1.7	0.306	
5-2	4.8	0.001	
5-3	6.0	0.001	

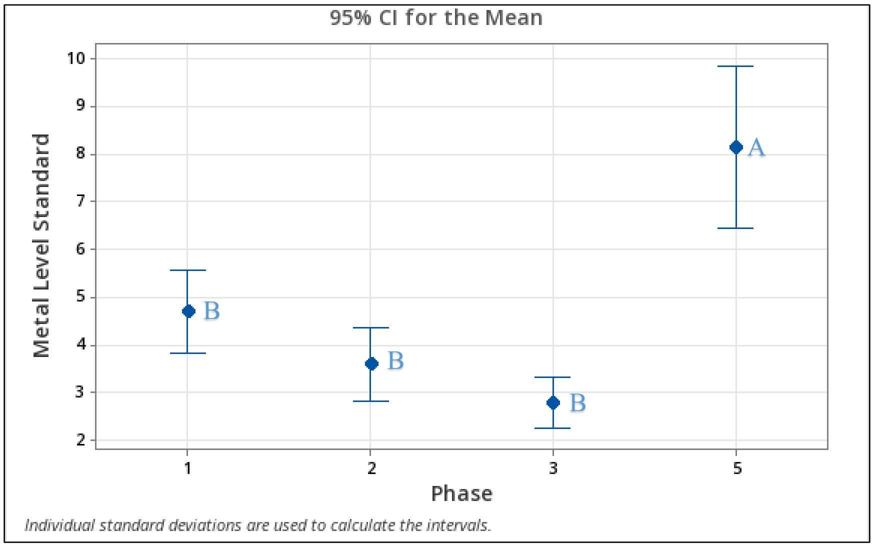

Figure 16: Compliance Ratio for each Phase

Using Spearman Correlation, all the metals were in correlation with one another. Table XIII below displays the R^2-value of correlation between the metals. A correlation R^2-value between 0.7 and 0.9 is accepted which indicated the metals are highly correlated (Schober et al., 2018).

Table XIII: Metal Level Correlation

Spearman Correlation			
	As	Pb	Cu
Pb	0.8		
Cu	0.8	0.9	
Zn	0.8	0.9	0.9

Cu, Pb, and Zn showed the highest correlation with a R^2-value of 0.9 (See Table XIII and Figure 17).

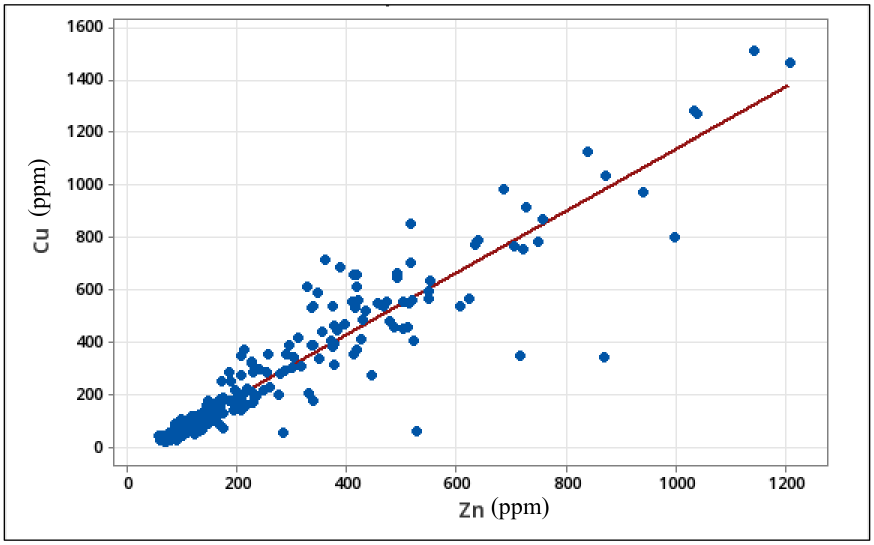

Figure 17: Copper and Zinc Concentrations (mg/Kg) Scatterplot Correlation

The contour plot indicated compliance ratio decreases when ground cover increases moving further away from the streambank in Figure 18. Compliance ratio was lowest between meters 17 and 20. Figure 18 is for Phase 1 and geomorphic location counter-point bar. All the contour plots created followed this same pattern.

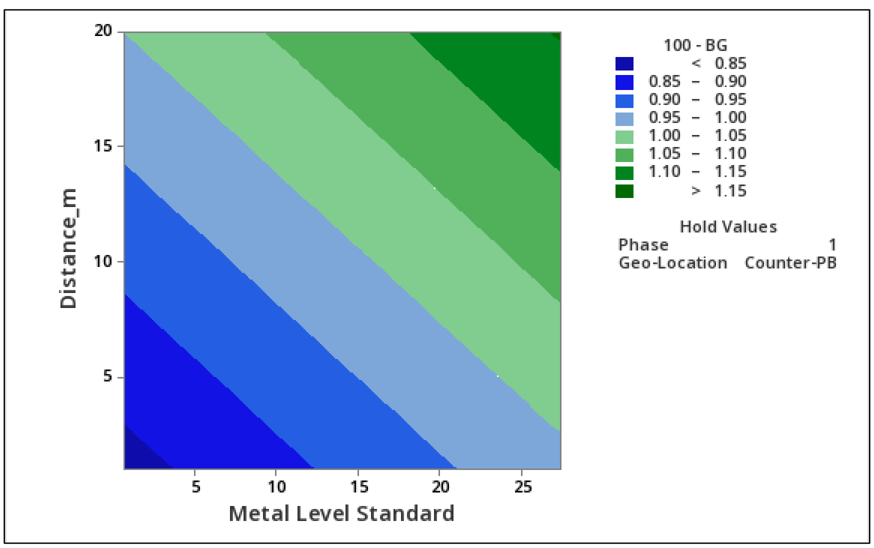

Figure 18: Metal Compliance Ratio Contour Plot for All Transects

4. Discussion

Restoration activities at the UCFR are using adaptive management to develop the most efficient restoration techniques to achieve remedial action objectives according to the ROD. There is still an additional 14 years of restoration activities anticipated to clean up the UCFR from mining damages that occurred in the 19th century. The data in this project aims to provide consultants and government agencies with information on what factors are driving vegetation succession in a restored floodplain. The data also gives insight into what restoration techniques performed most effective in:

- Establishing a permanent native vegetative cover
- Providing geomorphic stability to streambanks to withstand 10-year flood event
- Minimizing transport of contaminants of concern through surface water erosion or wind erosion
- Development of different age classes of key woody plant species
- Achieving soil As concentrations in top five cm to be less than human health action level
- Restoring the floodplain back to its historic setting.

The purpose of establishing a permanent vegetative cover has many benefits such as increasing infiltration of flood waters, establishing habitat for wildlife, nutrient cycling, and carbon sequestration (Moreno-Mateos et al., 2012; Serra-Llobet et al., 2022). Figure 6 showed that ground cover increased the further into the floodplain from the streambank. The ground cover guideline of achieving 90% ground cover was being met in counter-point bars, upstream preferential flow paths, and downstream preferential flow paths for Phases 1, 2, and 5. This was illustrated in Figure 7. In all the phases, ground cover was not being met at the point bars. Point bars receive higher rates of flooding, and the vegetation could be inundated for longer periods of time which indicates bare ground percentage should be higher at these geomorphic locations (Stromberg, 2001). Achieving 90% ground cover on point bars is unachievable due to the nature of the rivers flooding patterns. Phase 3 was most recently restored in 2022. Allowing vegetation to establish and recover after a restoration project is a significant factor in determining the success of a restoration project. Vegetation and wetland indicators can take upwards of 10 years to establish (Hughes, 1997). Figure 7 shows that Phase 3 after being restored, bare ground cover is significantly lower with a mean ground cover of 25% showing time being a factor driving vegetation succession into a restored floodplain.

Clearing bare ground for native vegetation to establish in a restoration project is effective at promoting woody seedling growth. As seen in Figure 12, there is a correlation between lower bare ground cover percentage and higher woody seedling count. Woody vegetation is a key factor in providing streambank stability and habitat for wildlife (Serra-Llobet et al., 2022). To encourage woody seedling numbers, bare ground needs to be established so the seedlings are not out competed and shaded by grasses or forbs.

This study also showed that using Sandbar willows in a restoration project they had higher woody vegetation growth than other willow species such as Booth's willows. Sandbar willows grow to an average height of six meters and Booth's willows grow to an average height of seven meters (USDA, 2002; USDA, 2024). Selecting the most effective vegetation could lead to greater success in a restoration project. Figure 10 shows Phases 1 and 2 with higher Sandbar willow percentages than Phases 3 and 5. Figure 9 shows Phase 2 had a mean woody vegetation height of 70 cm and Phase 5 had a mean woody vegetation height of 50 cm. This is significant because Phase 2 was completed in 2016, a year after Phase 5 was completed in 2015. Figure 9 and Figure 10 indicate that using Sandbar willows in a restoration project, woody vegetation height will be higher and create more habitat for wildlife.

The primary goal of the CFR Operable Unit is aimed to clean up contaminants of concern and restore the watershed to its pre-mining nature. A reason the metal levels were significantly higher in Phase 5 as opposed to Phases 1, 2, and 3 could be that contaminated sediments from unrestored Phase 4 are being transported downstream to Phase 5. To prevent this from occurring, restoring phases in upstream to downstream sequential order would prevent leaching of contaminants into restored phases. Heavy metal contaminants are most likely transported through the river as Figure 15 shows metal levels were highest closer to the streambank and decrease the further into the floodplain. There is still an expectation that groundwater contamination is also causing recontamination in restored phases. The most recently restored section, Phase 3, showed the lowest compliance ratio level with a mean of three (Figure 16). After restoration, the metal levels are expected to rise again slightly as shown in Phases 1 and 2 in Figure 16.

This study showed the factors driving succession in a restored floodplain are time to grow, proper vegetation (e.g., Sandbar willows), exposed bare ground for woody sapling dispersal, and lower metal levels for higher vegetation growth. The data also provides insight on the status of the restored phases on the UCFR. There are still many factors that were not analyzed such as groundwater metal contamination and effectiveness of borrow soil used for the CFR restoration. By focusing on the most crucial factors that drive vegetation expansion, it will create a more effective restoration project and lead to a successful outcome.

4.1. Implications for Practice

The practice of ecological restoration aims to reestablish the historical environmental structure and accelerate the recovery of an ecosystem. Determining the most effective restoration techniques requires monitoring and implementation of adaptive management. Roni et al. determined using traditional sampling methods of transects and monitoring plots are still appropriate for evaluating the effectiveness of restoration in a floodplain (Roni et al., 2019). However, remote sensing and drone imagery have been gaining increasing attention and are more likely to be more cost-effective and efficient in monitoring restoration projects on a larger scale. Monitoring post-restoration is an essential part of a project's success and helps advance the scientific field of restoration. Implementing techniques that have been monitored are most reliable in providing the most effective methods to accelerate the recovery of an ecosystem. Restoring phases or sections of a river in upstream to downstream sequential order could prevent unremediated sections upstream from contaminating restored phases downstream. The ideal method for designing vegetation would be to use native drought tolerant species (e.g., Sandbar willows) to enhance vegetation growth and succession into a floodplain. Using plants that provide root tensile strength will create reinforced root-soil composite to prevent erosion on susceptible streambanks in a restoration project. Through the use of traditional and new monitoring techniques, the most effective methods used in a restoration project can be determined to advance the field of restoration and applied to future projects for an accelerated recovery of floodplain ecosystems.

5. Bibliography

Bätz, N., Colombini, P., Cherubini, P., & Lane, S.N. (2016). Groundwater controls on biogeomorphic succession and river channel morphodynamics. *Journal Geophysical Resources Earth Surface, 121*, 1763– 1785.

Bourgeois, B., Vanasse, A., González, E., Andersen, R. & Poulin, M. (2016). Threshold dynamics in plant succession after tree planting in agricultural riparian zones. *Journal Applied Ecology*, *53*: 1704-1713.

Brinson, M.M. (1990). Riverine forests. In Lugo, A., Brinson, M.M., & Brown, S. (Eds.). *Forested wetlands*, *87*-141. New York: Elsevier.

CDM. (2010, April). *Clark Fork River Operable Unit Milltown Reservoir/Clark Fork River NPL Site Powell, Deer Lodge, and Granite Counties, Montana Part2: Geomorphic, Hydrologic, and Hydraulic Investigation for Phase 1 Remedial Design/Remedial Action.* Montana Department of Environmental Quality.

Clark Fork Coalition. (2016). *Upper Clark Fork Aquatic Restoration Strategy II*. Clark Fork Coalition.

Clark Fork Coalition. (2019, February 21) *Clark Fork River Watershed Restoration*. Clark Fork Coalition.

Coulloudon, B., Eshelman, K., Gianola, J., Habich, N., Hughes, L., Johnson, C., Pellant, M., Podborny, P., Rasmussen, A., Robles, B., Shaver, P., Spehar, J., Willoughby, J. (1996, revised 1999). *TR 1734-04 Sampling Veg Attributes, BLM*. US Bureau of Land Management.

Daubenmire, R. (1959). A Canopy-coverage method of vegetational analysis. *Northwest Science, 33:43-64*.

Dosskey, M.G., Vidon, P., Gurwick, N.P., Allan, C.J., Duval, T.P. & Lowrance, R. (2010). The Role of Riparian Vegetation in Protecting and Improving Chemical Water Quality in Streams. *JAWRA Journal of the American Water Resources Association*, *46*: 261-277.

Duiker, S.W. (2005, March 8). *Effects of Soil Compaction.* Penn State Extension.

Franceschi, E.A., & Lewis, J.P. (1979). Notas sobre la vegetacion del valle Santafesino del Rio Parana (Republica Argentina). *Ecosur 6,* 55-82.

Gosselink, J.G., Brinson, M.M., Lee, L.C., & Auble, G.T. (1990): Human activities and ecological processes in bottomland hardwood ecosystems: the report of the ecosystem work group. In Gosselink, J.G., Lee, L.C., & Muir, T.A. (Eds.). *Ecological processes, and cumulative impacts: illustrated by bottomland hardwood wetland ecosystems, Chelsea*, *549*-98. MI: Lewis Publishers.

Hubbard, L.C., Biedenharn, D.S., & Ashby, S.L. (2003). Assessment of environmental and economic benefits associated with streambank stabilization and phosphorus retention. *Water Quality Research Program Technical Notes Collection (ERDC WQTN-AM-14).* U.S. Army Engineer Research and Development Center, Vicksburg, MS.

Huenneke, L.F., & Sharitz, R.R. (1986). Microsite abundance and distribution of woody seedlings in a South Carolina cypress-tupelo swamp. *American Midland Naturalist, 115*, 328-35.

Hughes, F.M. (1997). Floodplain biogeomorphology. *Progress in physical geography*, *21*(4), 501-529.

Hupp, C.R., & Osterkamp, W.R. (1985). Bottomland vegetation distribution along Passage Creek, Virginia, in relation to fluvial landforms. *Ecology, 66*, 670-81.

Johnson, W.C., Burgess, R.L., & Keammerer, W.R. (1976). Forest overstorey vegetation and environment on the Missouri River floodplain in North Dakota. *Ecological Monographs, 46*, 59-84.

Klimo, E., & Prax, A. (1985). Soil conditions. Floodplain forest ecosystem. In Penka, M., Vyskot, M., Klimo, E. & Vasicek, F. (Eds.). *Before water management measures*, *61*-79. Amsterdam, Elsevier.

Lichvar, R.W., Melvin, N.C., Butterwick, M.L., & Kirchner, W.N., (2012). *National Wetland Plant List Indicator Rating Definitions*. US Army Corps of Engineers.

MacDonald, D.D., Ingersoll, C.G., Berger, T.A. (2000, January 13). *Development and Evaluation of Consensus-Based Sediment Quality Guidelines for Freshwater Ecosystems*. US EPA.

McDonald, L.H., A.W. Smart, & R.C. Wissmar. (1991). Monitoring guidelines to evaluate effects of forestry activities on streams in the Pacific Northwest and Alaska. US Environmental Protection Agency. EPA 910/9-91-001. *Center for Streamside Studies in Forestry, Fisheries and Wildlife*. University of Washington, Seattle, Washington.

Minitab, LLC. (21.4). (2023).

Monteiro, J.A.F., Kamali, B., Srinivasan, R., Abbaspour, K., & Gücker, B. (2016) Modelling the effect of riparian vegetation restoration on sediment transport in a human -impacted Brazilian catchment. *Ecohydrol*ogy, *9*: 1289– 1303.

Moreno-Mateos D., Power M.E., Comin F.A., & Yockteng R. (2012). Structural and functional loss in restored wetland ecosystems. *PLoS Biology, 10*:1–8.

Morison, C.G.T., Hoyle, A.C., & Hope-Simpson, J.F. (1948). Tropical soil-vegetation catenas and mosaics. *Journal of Ecology*, *36*, 1-84.

Nanson, G.C., & Beach, H.F. (1977). Forest succession and sedimentation on a meandering river floodplain, northeast British Columbia, Canada. *Journal of Biogeography, 4*, 229-51.

National Park Service. (2021, March 23). *The Clark Fork River (U.S. National Park Service)*. National Park Service.

National Weather Service. (2018, March 12). *Flooding in Montana National Weather Service, NOAA's*. National Weather Service.

Natural Resource Damage Program & Geum Environmental Consulting, Inc. (2020, December). *Revised Restoration Plan For The Clark Fork River Aquatic And Riparian Resources: UCFRRestorationPlanUpdate2020*. Natural Resource Damage Program & Geum Environmental Consulting, Inc.

Ortmann-Ajkai, A., Csicsek, G., Hollós, R., Magyaros, V., Wágner, L., & Dénes, L. (2018). Twenty-Years' Changes of Wetland Vegetation: Effects of Floodplain-Level Threats. *Wetlands*, *38*, 591 - 604.

Pautou, G., & Arens, M.F. (1994). Theoretical habitat templets, species traits and species richness: floodplain vegetation in the Upper Rhône River. *Freshwater Biology*, *31*, 507-22.

Penka, M. (1991). The water relations of the herb, shrub, and tree layers of the floodplain forest. In Penka, M., Vyskot, M., Klimo, E., & Vasicek, F. (Eds.). *Floodplain forest ecosystem. II. After water management measures*, *419*-47. Amsterdam, Elsevier.

Roni P, Hall JE, Drenner SM, Arterburn D. (2019). Monitoring the effectiveness of floodplain habitat restoration: A review of methods and recommendations for future monitoring. *WIREs Water;6*: e1355.

Salo, J. (1990). External processes influencing origin and maintenance of inland water - land ecotones. In Naiman, R.J., Decamps, H. (Eds.). *The ecology, and management of aquatic-terrestrial ecotones*. *UNESCO/MAB Series, 4*, *37*-64. New Jersey: Parthenon.

Schindler S., O'Neill F.H., Biró M., Damm C., Gasso V., Kanka R., van der Sluis T., Krug A., Lauwaars S., Sebesvari Z., Pusch M., Baranovsky B., Ehlert T., Neukirchen B., Martin J.R., Euller K., Mauerhofer V., & Wrbka T. (2016). Multifunctional floodplain management and biodiversity effects: a knowledge synthesis for six European countries. *Biodiversity and Conservation*, *25*:1349–1382.

Schober, P., Boer, C., & Schwarte, L. (2018, May). Correlation Coefficients: Appropriate Use and Interpretation. *Anesthesia & Analgesia, 126*(5): p 1763-1768.

Serra-Llobet A., Jähnig S.C., Geist J., Kondolf G.M., Damm C., Scholz M., Lund J., Opperman J.J., Yarnell S. M., Pawley A., Shader E., Cain J., Zingraff-Hamed A., Grantham T.E., Eisenstein W., & Schmitt R. (2022). Restoring Rivers and Floodplains for Habitat and Flood Risk Reduction: Experiences in Multi-Benefit Floodplain Management From California and Germany. *Frontiers in Environmental Science, 9*:778568.

Simon, A., Curini, A., Darby, S., & Langendoen, E. (1999). Stream-bank mechanics and the role of bank and near-bank processes in incised channels. In Darby S., Simon A. (Eds.). *In Incised River Channels*, *123*–152. Wiley: New York.

Simon A., & Collison A. J. C. (2002). Quantifying the mechanical and hydrologic effects of riparian vegetation on streambank stability. *Earth Surface Processes and Landforms, 27*: 527–546.

Stammel, B., Stäps, J., Schwab, A., & Kiehl, K. (2022). Are natural floods accelerators for streambank vegetation development in floodplain restoration? *International Review of Hydrobiology, 107*, 76–87.

Stapley, D. (2023, May). Microbiome Recovery of the Upper Clark Fork River Restoration Site. Montana Technological University.

Stone, K. (2023, March 22). *State of Montana Clark Fork River Operable Unit Strategic Plan*. Montana Department of Environmental Quality.

Stromberg J. C. (2001). Restoration of riparian vegetation in the south-western United States: importance of flow regimes and fluvial dynamism. *Journal of Arid Environments*, *Volume 49*, Issue 1, Pages 17-34, ISSN 0140-1963.

Thorne C. R. (1990). Effects of vegetation on riverbank erosion and stability. In John Wiley & Sons, Inc. (Eds.). *In Vegetation and Erosion: Processes and Environments, 125*–144. England, Chichester.

USDA. (2002, February 5). *Sandbar Willow Plant, USDA*. United State Department of Agriculture.

USDA. (2024, February 28). *USDA Plants Database.* United States Department of Agriculture.

US EPA. (2004). *Clark Fork River Operable Unit. Record of Decision. Part 2: Decision Summary.* US EPA.

US EPA. (2007). *Method 3051A: Microwave Assisted Acid Digestion of Sediments, Sludges, Soils, and Oils.* US EPA.

US EPA. (2024, March 15). *Clark Fork River Discharge. USGS Water Data for the Nation*. US EPA.

US Geological Survey. (2016, March 26). *Clark Fork at Deer Lodge MT. USGS Water Data for the Nation*. US Geological Survey.

US National Cooperative Soil Survey. (2016, February). *Official Series Description - CLARK FORK RIVER Series*. US National Cooperative Soil Survey.

Vasicek, F. (1991). Changes in the structure and biomass of the herb layer under the conditions of a medium moisture gradient. In Penka, M., Vyskot, M., Klimo, E., & Vasicek, F. (Eds.). *Floodplain forest ecosystem. II. After water management measures*, *201*-27. Amsterdam, Elsevier.

Vasicek, F. (1991). The reactions of the shrub layer. In Penka, M., Vyskot, M., Klimo, E., & Vasicek, F. (Eds.). *Floodplain forest ecosystem. II. After water management measures*, *229*-42. Amsterdam, Elsevier.

Viereck, L. A. (1970). Forest succession and soil development adjacent to the Chena River in interior Alaska. *Arctic and Alpine Research,* 2,1-26.

Wilson, J. B. (2011). Cover plus: ways of measuring plant canopies and the terms used for them. *Journal of Vegetation Science*, *22*(2), 197–206.

6. Appendix A: Sampling Locations

Figure 19: Phase 1 Sampling Locations

Figure 20: Phase 2 Sampling Locations

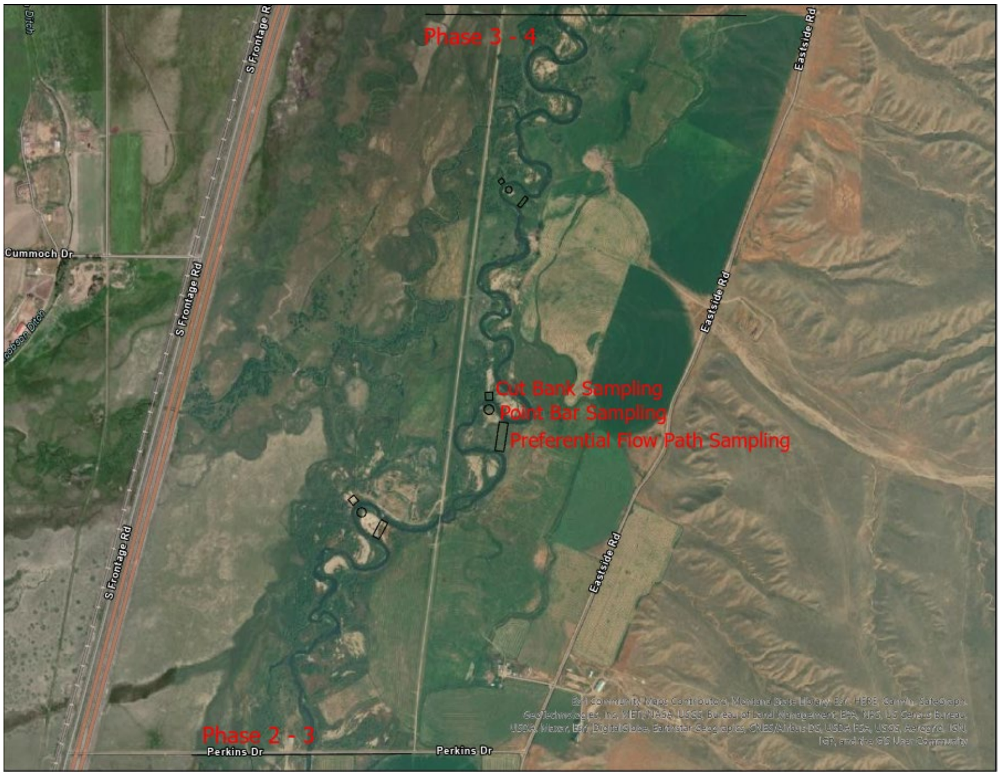

Figure 21: Phase 3 Sampling Locations

Figure 22: Phase 5 Sampling Locations

Figure 23: Transect Line (20 m) Monitoring Plot Spatial Pattern

7. Appendix B: Invasive Species & Vegetation Performance Attributes

Table XIV: Invasive Species According to ROD

Invasive Species	
Common Name	Scientific Name
Canada Thistle	*Cirsium arvense*
Common Tansy	*Tanacetum vulgare*
Dalmatian Toadflax	*Linaria dalmatica*
Houndstongue	*Cynoglossum officinale*
Kochia	*Kochia scoparia*
Leafy Spurge	*Euphorbia esula*
Perennial Pepperweed	*Lepidium latifolium*
Russian Olive	*Elaeagnus angustifolia*
Russian Thistle	*Salsola iberica*
Spotted Knapweed	*Centaurea maculosa*
Yellow Toadflax	*Linaria vulgaris*
Whitetop	*Cardaria draba*

Source: US EPA (2004)

Table XV: Vegetation Performance Attributes According to ROD

Vegetation Performance Attributes
Woody Browse Levels
Completeness of the canopy within the streambank buffer
Vegetation cover
Production
Species richness
Structural diversity
Maturation periods
Plant reproduction
Evidence of successional processes

Source: US EPA (2004)

8. Appendix C: Compaction Depth Factor

Root growth begins to decrease linearly when penetration resistance is at 100 psi and completely stops at 300 psi (Duiker, 2005). Compaction depth was determined when it reached above 220 psi. Compaction psi was determined 220 due to the variation in compaction levels ranging from 220 – 290 psi. Compaction depth did not have any correlation to ground cover percentage, woody seedling counts, or distance (m) from streambank. Figure 24 shows the variation in compact depth in relation to distance (m) from streambank and does not match any other graphs. The F-value is 1.06 and the P-value is 0.378 for Figure 24.

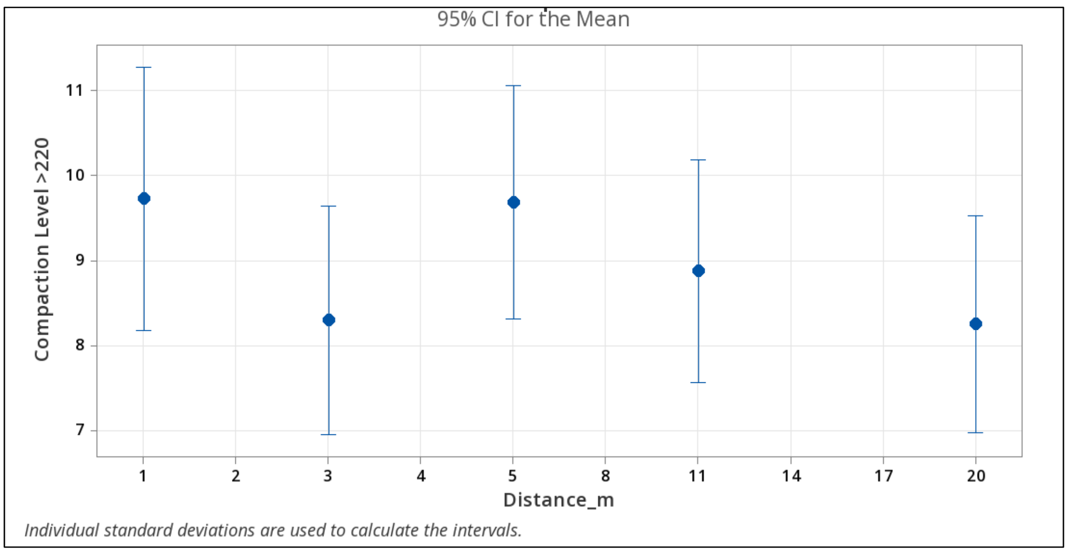

Figure 24: Compaction Depth at >220 psi in Relation to Distance (m)

Compaction depth might be a factor in compliance ratio as shown in Figure 25. Compaction depth is closely related to Figure 16. However, this might be occurring because Phase 4 has not been restored and metals could be leaching into Phase 5 through surface water or groundwater.

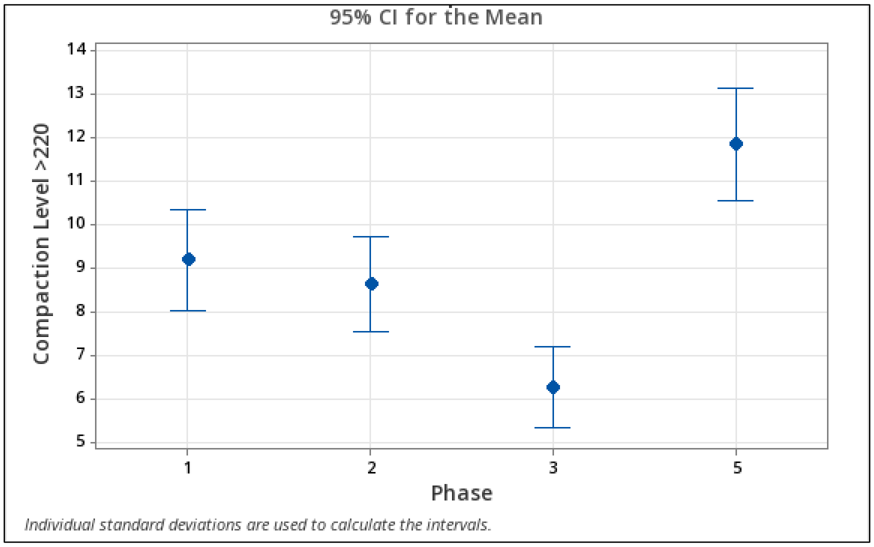

Figure 25: Compaction Depth at >220 psi for each Phase