USING DIRECT ENVIRONMENTAL ORDINATION TO MATCH PLANT SPECIES TO FLUVIAL RIPARIAN SITES PART I: INTRODUCTION AND METHODS[1]

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Abstract. This investigation had two objectives: 1) to provide a scientific basis for revegetating a Superfund riparian area along Silver Bow Creek, Montana, and 2) to provide the Natural Resources and Conservation Service (NRCS) with detailed riparian vegetation information for the Silver Bow County Soil Survey. Substrates and vegetation along Silver Bow Creek were so drastically altered by historic floods and tailings depositions that the floodplain offered few clues for restoring native vegetation. The remedy entails removing contaminated materials in the floodplain and stream channel and reconfiguring the stream and floodplain using clean borrow material to achieve a stable stream gradient and associated floodplain. Rather than rely on guesswork to determine the placement of seedings and transplants, we investigated the abundance of naturally occurring riparian plant species on nearby clean substrates in relation to important soil properties. Sites, soils, and vegetation were sampled at 65 fluvial riparian sites. Soil texture and drainage classes (essentially depth to persistent wetness) are the primary factors controlling the distribution of riparian plant species. We identified four particle-size classes based on standard USDA criteria for classification at the family level, ranging from fine-loamy to sandy. Based upon USDA criteria for soils in Montana, six drainage classes from very poorly drained to well drained plus a ponded category covered the range of soil hydrology. These soil classes were used to ordinate the average relative cover of about 60 species that could be useful in revegetation. Results are applicable to revegetation because it entails careful mapping of the same soil properties. This is an adapted-species approach to revegetating within a scientific framework. Emphasis in this first of a two-part paper is on the criteria and methods used to partition soil environmental space as the basis for relating plants and their habitats.

Additional Key Words: particle-size classes, soil classification, drainage classes, plant habitats.

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Introduction

History

A long history of mining and smelting metal ores has left a legacy of environmental impacts in northern Silver Bow and Deer Lodge Counties in southwest Montana. Among the impacts was deposition of mine tailings along the entire length of Silver Bow Creek and the upper reaches of the Clark Fork River during several major flood events. As a result, the Silver Bow Creek floodplain has lain buried under a blanket of highly acidic, metal- and arsenic-laden tailings for nearly a century. The Silver Bow Creek floodplain is currently the site of Superfund remediation administered by the Montana Department of Environmental Quality. Reclamation strategy involves several steps: 1) removing tailings and contaminated soil from the creek bed and floodplain, 2) reconstructing a stream channel, 3) recontouring floodplain areas and adjacent side slopes, 4) covering disturbed areas with suitable soil borrow material, 5) seeding and planting predominantly native species adapted to local soil and site conditions, 6) monitoring reclamation results and adjusting the strategy as needed, 7) maintaining effective weed control.

What to Plant Where?

A number of standard factors are considered in making decisions about what to plant on a site requiring revegetation. Availability and cost of seed or planting stock certainly have an effect. Using species with desirable characteristics such as weed exclusion, winter hardiness, or effective site stabilization play important roles in revegetation decisions, as does understanding the establishment characteristics of desirable species. All of the above factors are generally well known. More difficult to obtain is information about the specific habitat requirements of riparian plant species under local climate, soil, and hydrologic conditions. Yet matching plants to habitat, which is at the core of successful revegetation, requires knowledge of the specific habitat requirements of numerous plant species in the local environment as well as how they respond to each other. This portion of the two-part paper describes the process and criteria used to develop information about riparian species habitat requirements for application to Silver Bow Creek.

Cooperation with the National Cooperative Soil Survey

The Silver Bow County Soil Survey, part of the USDA National Cooperative Soil Survey, was designed to provide a comprehensive inventory of soil, land, and vegetation resources. Significant changes were made from standard soil survey techniques to improve the scientific validity and usefulness of results. Through local input, riparian issues and management of contaminated and uncontaminated riparian areas were identified as some of the top natural resource concerns in the county. Providing high quality soils information along riparian corridors became a top priority for the soil survey.

Soils are difficult to study because most important characteristics are hidden from view. Even the most intensive countywide soil survey will sample but a tiny fraction of the total landmass in the county. Available soils data must be interpolated over large areas to produce soils maps. Understanding the relationships of soils in local areas to observable landscape features such as geologic parent material, landform, climate, and plant community characteristics becomes essential to creating accurate soils maps. Studying relationships of specific riparian plant communities to local soil and hydrologic conditions was a critical part of the Silver Bow County Soil Survey to provide quality soils information about fluvial riparian areas in the county. Thus, the needs of reclamation planning along Silver Bow Creek and the needs of the Silver Bow County Soil Survey merged in this study of local riparian areas.

Floodplain and Riparian Soils

Most riparian soils in Silver Bow County occur on floodplains. As a group, floodplain soils have a number of common characteristics. They form in the deep unconsolidated alluvium of sediment deposited during flood events and channel deposits exposed by lateral migration of the stream or river. As a result, the most floodplain soils are very deep, lack significant subsoil horizon development, and characteristically have stratified soil textures. Differences in soil texture among strata may be insignificant or abrupt and prominent. Buried A-horizons or organic layers are common, as are the near-surface accumulation of soil organic matter and variable depths to groundwater.

Riparian Soils in Northern Silver Bow County

Plant communities, as well as individual plant species, respond to a wide range of soil physical and chemical properties that can vary from site to site. Within a local environment, however, many soil properties may reasonably be considered constant or at least have differences which are not significant to the plant communities growing there, although such assumptions cannot be made over large geographic areas in the intermountain west. For example: local climate and parent material conditions in northern Silver Bow County limit the significance of salinity or sodicity in soils. Soil textures in floodplains there are highly variable, although they tend toward the coarse end of the spectrum due the predominance of granite, rhyolite, and coarse-grained Tertiary valley fill parent materials. A wide range of soil drainage classes exists in local riparian soils, associated with variable depths to groundwater.

Objectives

Objectives of this study were to relate the occurrence of important riparian plant species to specific soil and hydrologic conditions in the local environment, and to use that information to successfully establish select commercially available species to revegetate the Silver Bow Creek floodplain following remediation.

Methods and Materials

Field Sampling: Soil and Site Data

Between 1997 and 2002, 65 sample sites were selected based on the occurrence of target species in semi-natural plant communities. Sites had to be large enough so that a transect at least 10 meters long could be run through the site while staying within a specified plant community type. A soil pit was excavated, generally down to 152 cm (60 inches), at a representative location within each study site. Soil pits were hand dug 76 to 102 cm (30 to 40 inches) deep by approximately 61 cm (24 inches) wide to provide a good view of the strata. A hand bucket auger was used to sample deeper horizons down to 152 cm with samples laid out by auger increments of about 30 cm (one foot). In instances where channel deposits of very cobbly or very gravelly sand were encountered, deep sampling with the bucket auger was not feasible. The minimum sampling depth in those instances was 102 cm (40 inches).

An experienced soil scientist described soil profiles at each sample site according to current National Cooperative Soil Survey standards (Soil Survey Staff, 1996). Diagnostic horizons and other diagnostic features in soil profiles were identified and soils classified to the family level of the US Soil Classification system (Soil Survey Staff, 1999). Soil horizons were analyzed for texture, color, pH, rock fragments, and calcium carbonate. All soil analyses were completed in the field to the extent possible. Samples were passed through a 2-mm sieve to measure gravel content and to improve accuracy of hand texture estimates. Volume of rock fragments larger than gravel was estimated visually. Soil pH was measured using a series of pH dyes covering the full range of pHs found in soils. Selected soil samples were brought back to the lab for hydrometer analysis to check field texture results or for drying and sieving in some instances.

Site data collected at each sample location included drainage class determinations, slope steepness, aspect, surface stoniness, slope shape, depth to groundwater, parent material, landform, flooding frequency, impact class, root distribution, and groundwater oxygen levels. Geographic coordinates were obtained with a hand-held global positioning system (GPS) receiver.

Field Sampling - Vegetation

After a typifying spot was selected and a soil pit dug, nearby vegetation was sampled by estimating canopy coverage (Daubenmire, 1959). Frame size was 1.0 x 0.5 meters. The frame was marked to indicate 1%, 5%, 10%, 15%, 25%, and 50% areas. For each species, canopy coverage was estimated to the nearest percent insofar as possible. A value of 0.5% cover was used in data analysis where the average coverage of a species was less than 1%.

Ten or 20 frames were sampled at each sample location. If woody plants did not interfere with tape and plot placements, frames were sampled along a single transect at one-meter intervals on each side of the soil pit. If that was impractical (e.g., due to dense woody plants), plots were located in a circle around the soil pit. Despite limitations associated with visual estimates, summary cover values were calculated to 0.1% to minimize rounding errors. Data summaries include average canopy coverage, relative cover, and frequency. The latter is the percentage of sample frames in which a species occurred. In each frame, ground cover was estimated as bare soil, coarse fragments (>2mm), and plant litter. Ground cover plus basal area of all plants equals 100% of the sampled area.

Methods - Ordinations

The principal investigators independently concluded that two factors appear to dominate environmental control over the distribution of riparian plant species in northern Silver Bow County: soil texture and drainage class. A direct ordination approach was used correlate the relative abundance of about 60 plant species with riparian soil and hydrologic conditions. Since revegetation is planned on a map indicating soils and hydrologic classes, our direct ordinations were applicable to riparian revegetation in a way that indirect ordinations (environmental axes inferred from species endpoint choices) never could be.

Total canopy coverage in a plant community can be less than 50% in a well-drained or moderately well-drained site, or about 200% in a layered community in poorly drained or somewhat poorly drained sites. We used relative cover as an index of importance for the Z-axis of ordinations, just as relative cover is used when calculating proportional abundance indices.

One problem with our approach is that a species present in small quantity can pull the average relative cover down for a site class, whereas if it is absent, it will have no effect. Therefore, if a species is typically well represented (i.e., >5% relative cover) on a site type and one sample had a trace amount (i.e., <1% relative cover), we did not include that sample point in the calculation of average canopy coverage for the class. This was necessary just six times. If the species was present only in a single sample of a site class, we included the data irrespective of amount.

Particle-Size Classes

Particle-size classes, used as family *differentiae* in the U.S. Soil Classification System, provide an integrated measure of the effects of both soil texture and rock fragments in the soil. They were used as the basis for differentiating soil profiles of variable textures into four distinct groups based on particle-size distribution. Particle-size classes differ from texture classes in several respects. First, they include rock fragments in the classification. Texture classes are based solely on the fine-earth (<2.0 mm) fraction of the soil.

A second distinction between family particle-size classes and texture classes is that texture classes can be applied to any horizon or soil sample irrespective of position in a soil profile. At the family level of soil classification, particle-size criteria apply only to a specific portion of the soil profile called the control section. The control section of a soil will vary depending on other characteristics of the profile. In deep floodplain soils with limited subsoil horizon development, however, the particle-size control section will always be 25 to 100 cm (10 to 40 inches). Family classes are based on the weighted averages of percent clay, sand, silt, and rock fragments in the control section. Thus, difficulties associated with assigning a specific texture classes to highly stratified floodplain soils are avoided.

The basic particle-size classes for family level classification of soils in the U.S. Soil Classification System that were used in this study (Soil Survey Staff, 1999) are as follows:

Fine-loamy: 18 to 35% clay (by weight) in the fine-earth fraction and less than 35% rock fragments.

Coarse-loamy: less than 18% clay (by weight) in the fine-earth fraction, do not have a texture of sand or loamy sand and less than 35% rock fragments.

Sandy: sandy or loamy sand textures and less than 35% rock fragments.

Loamy-skeletal: 35% or less clay (by weight), do not have a texture sand or loamy sand and have 35% or more (by volume) rock fragments.

Sandy-skeletal: sandy or loamy sand textures and have 35% or more (by volume) rock fragments.

These standard classes were modified slightly to obtain greater resolution of particle-size classes among the largely coarse-textured floodplain soils of Silver Bow County and to provide a more discriminating basis for ordinations. None of the floodplain soils sampled had enough clay to qualify for the fine family (>35% clay). Classes used in the study were:

Fine-loamy: fine-loamy particle-size family; primarily stratified loams, silt loams and light clay loams or fine-loamy over sandy-skeletal with a minimum of 50 cm (20 inches) of fine-loamy material above the sandy-skeletal substratum.

Coarse-loamy - loamy strata: coarse-loamy particle-size family; primarily stratified sandy loams, fine sandy loams, and loams.

Coarse-loamy - sandy strata: coarse-loamy particle-size family; primarily stratified sandy loams, fine sandy loams, loamy sands and sands.

Sandy or Sandy-skeletal: sandy or sandy-skeletal particle-size families.

Each of the soil profiles sampled was placed into one of the four particle-size classes based on the weighted averages of all strata within the 25 to 100 cm (10 to 40 inch) control section. Additional quantitative criteria were added to these classes to ensure consistent assignment of highly stratified soil profiles to the ordination classes, specifically when contrasting particle sizes were encountered. The goal was to partition the full range of soil texture/particle size distributions found in riparian soils of northern Silver Bow County into four ordination classes from the heaviest textures (fine-loamy) to the coarsest textures (sandy or sandy-skeletal).

Soil Drainage Classes

Soil drainage classes describe the capacity of a soil to transmit free water down through the profile. More importantly for this project, they also describe the relative oxidation-reduction conditions in a soil. Saturated soils exhibit anaerobic or reducing conditions while well-drained soils provide a more oxidizing environment. At the wet end, soil drainage classes are directly related to the presence of a persistent high water table and are based on direct morphological evidence in the soil profile indicating the depth at which persistent wetness occurs. Persistent in this context refers to a water table that remains in the soil long enough to create reducing conditions. Soil drainage class criteria as applied in Montana are as follows:

Very poorly drained:	0 to 30 cm (0 to 12 inches) to a persistent high water table.
Poorly drained:	30 to 61 cm (12 to 24 inches) to a persistent high water table.
Somewhat poorly drained:	61 to 107 cm (24 to 42 inches) to a persistent high water table.
Moderately well drained:	107 to 203 cm (42 to 80 inches) to a persistent high water table or evidence in the soil of restricted internal drainage without a persistent high water table.
Well drained:	the normal condition for soils without restricted internal drainage.

Persistent or fluctuating water tables under natural conditions can be identified in soils by distinctive redoximorphic features present in the soil. Thus, depth to a persistent water table can be measured long after the groundwater has receded. Restricted drainage in the absence of a persistent high water can similarly be identified based on redoximorphic features.

Soils that have been saturated for a sufficiently long period of time to create reducing condition become gleyed, exhibiting gray, bluish gray or greenish gray colors similar to those found in plugged drainpipes of a house. A soil with direct evidence of gleying at 25 cm and below would be considered very poorly drained even if no current water table were found in the soil, especially if landscape position supports this designation. Iron in soils that have fluctuating wet and dry periods rusts just like the steel on fenders on an old car. This "rust" leaves distinctive orange, red, or yellow mottles or redox concentrations in the soil. A soil that exhibits common or abundant redox concentrations at the 70 cm to 90 cm depth with no gleying in the profile would be considered moderately well drained, especially if there were a distinct change in soil texture immediately above or below this layer. Care must be taken, however, not to mistakenly interpret features inherited from the original parent material as redox features. Often, there will be auxiliary clues such as landscape features or changes in the plant community to support observations of redox features in the soil. Other diagnostic features, such as manganese concretions, can be of value in assessing high groundwater conditions but are not commonly found in soils of northern Silver Bow County.

Frequently updated Keys to Soil Taxonomy (Soil Survey Staff, 1998) attempt to define gleyed features and redox concentrations in soils to identify poorly, very poorly, and somewhat poorly drained soils for soil classification. Unfortunately, establishing criteria that will identify these features under the full range of conditions found in soils remains elusive. Soils in Montana with obvious gleying often do not meet the specific color criteria provided in Keys to Soil Taxonomy. Redoximorphic features should be viewed as a change from the normal well-drained condition. This requires the observer to be familiar with normal conditions. Often, a sample taken under reduced soil conditions that does not meet color requirements when moist will exhibit a distinct bleaching of color upon drying. This change in color from a wet to dry state can be diagnostic of reducing conditions in the soil.

Ordinations and Local Riparian Environments

Six soil drainage classes from very poorly drained to well drained and an additional ponded category were used for the hydrologic component of ordinations. "Ponded" isn't technically a drainage class, but it refers to the presence of surface water. These are combined with the four particle-size classes in the ordination of two-dimensional environmental space for riparian species of northern Silver Bow County. Figure 1 shows the number of sites sampled for each possible combination of particle-size and drainage class. (In important respects, this is the plant's habitat.) The distribution of sample sites within the graph reflects local environmental conditions of riparian areas in northern Silver Bow County.

No attempt was made to sample each possible combination equally. Some combinations are much more prevalent than others under local conditions and some potential combinations do not exist at all in riparian areas of northern Silver Bow County. For example, if a sandy-skeletal soil of moderately well-drained hydrology occurred, it would have virtually no plants, it would be so droughty and infertile. With perhaps a few weeds, we would have no reason to sample the site.

Species distributions, examined in Part II of this paper, are displayed using the same format except the z-axis is relative canopy coverage of a species for each combination of particle-size and drainage classes where it occurred.

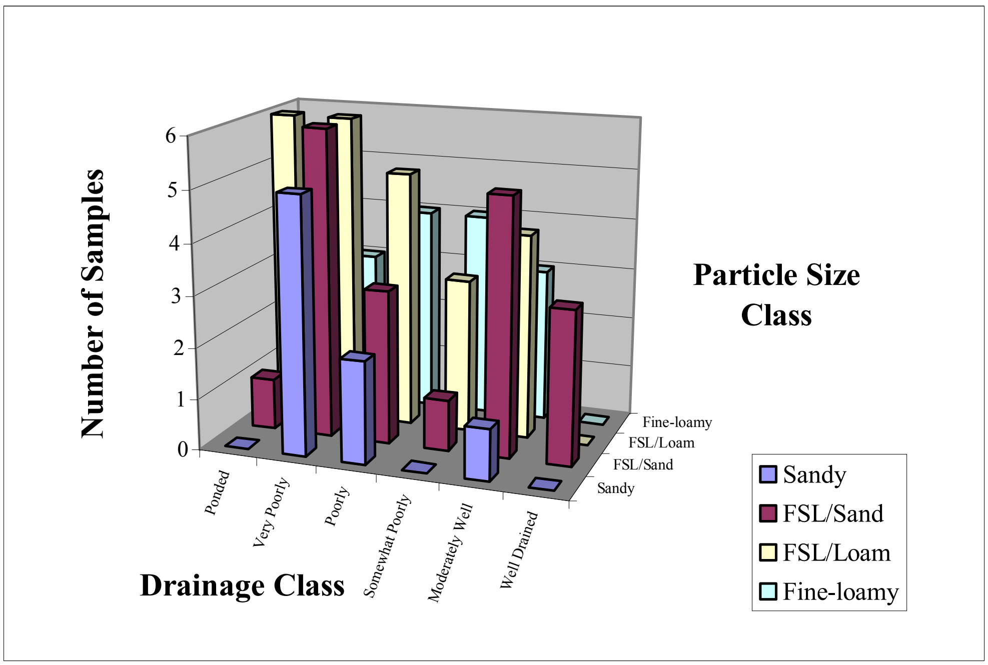

Figure 1. Number of samples in each combination of particle-size and drainage class.

The well-drained segment of the chart could be eliminated except for a few riparian species of wide ecological amplitude. Well-drained conditions generally do not exist in riparian areas of northern Silver Bow County. Riparian sites with strictly sandy or sandy-skeletal soils are rare for the area except along the margins of existing streams. Finally, soils with the most reducing conditions would be expected to occur in the back corner of the graph due to the combination of finer texture and the poorest drainage conditions. Here anaerobic conditions limit the occurrence of many plant species. Ordination results with respect to target riparian species and their importance for revegetation along Silver Bow Creek will be covered in Part II of this paper.

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