Final Report:

Classification and Mapping of Riparian Forest along the White River in South Dakota

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Photograph of White River in the Badlands Ecoregion by Alex Cahlander-Mooers

Photographs of White River in the Pine Ridge/Pierre Shale Ecoregion near SD/NE border (top), lower River Breaks (middle) and Delta (bottom). Top two photographs by Alex Cahlander-Mooers, bottom photograph by Malia Volke.

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EXECUTIVE SUMMARY

Natural riparian woodlands provide important habitat for wildlife within the prairie landscape, supporting among the highest levels of avian and mammal diversity of any habitats in the Rocky Mountain and northern Great Plains regions. Riparian woodlands within the Great Plains Steppe Ecoregion contain a number of species of the greatest conservation concern in South Dakota [e.g., Bald Eagle (*Haliaeetus leucocephalus*), northern river otter (*Lontra canadensis*), and northern long-eared bat (*Myotis septentrionalis*)], as well as providing breeding and stop-over habitat for Neotropical migratory songbirds. Hence, mapping these habitats and characterizing their composition and quality is strategically important for landscape management and biodiversity conservation in South Dakota and across the upper Great Plains region.

The White River, in western South Dakota, is unregulated, with a largely intact, wooded riparian corridor and natural flow and sediment regimes. The delta forming at its confluence with the Missouri River at Lake Francis Case is one of the few areas on the Missouri where substantial natural recruitment of plains cottonwood is occurring. However, little is known about the vegetation and floodplain ecology of the White River, and the delta area itself is unstudied.

We conducted a two-year long project to map and classify riparian land cover and to sample and characterize plant communities within the White River floodplain along its entire length in South Dakota and in adjacent northwestern Nebraska. The project had the following four main components, which are separated into sections of the Results and Discussion:

- Part I: Classification and mapping of current (2010) land cover within the riparian corridor of the White River in South Dakota, plus portions of the river headwaters in Dawes County, Nebraska.
- Part II: Historical (1930s-2010) river channel dynamics and land cover change among the three upper segments of the White River.
- Part III: Vegetation patterns throughout the White River riparian corridor and by segment (ecoregion), including plant associations and community types.
- Part IV: A more in-depth analysis of forest vegetation and changes in historical land cover and river cross-section profiles within the delta and nearby transitional sections of the river (lower 29 km).

We divided the riparian corridor and river longitudinally into four segments, based in part on Level IV ecoregions: Pine Ridge/Pierre Shale, Badlands, River Breaks, and Delta. For Parts I, II, and a portion of Part IV, we mapped current (2010) or historical (1930s-present) land cover by interpreting and digitizing historical aerial photography in a Geographic Information System. For Part III, we sampled plant associations and broader community types found throughout the four segments in 2012 and 2013, using a modified Daubenmire plot-based methodology. Plant data were summarized by ecoregion and community type for species composition, richness, diversity, coefficients of conservatism, floristic quality, and wetland indicator scores. For woody vegetation types, tree densities, basal area, and canopy cover were also summarized. For Part IV, we quantified changes in space and time (1948-2012) in river cross-sectional profiles; extent, age, and distribution of riparian woodlands; and sampled woody plant species composition on the lower 29 km of the White River, including its delta with the Missouri River at Lake Francis Case.

Part I: Current (2010) Land Cover

Present-day land cover (based on 2010 NAIP imagery) across the riparian corridor of the White River is dominated grassland (40%), farmland (26%) and forest and other woody land cover types (23%, together "forestland"). Longitudinal variation in land cover and woody vegetation characteristics occurs among river segments. In the Pine Ridge/Pierre Shale segment, woody land cover composes 26% of the floodplain, with connected forests surrounding the narrow river and herbaceous cover types dominating the distal parts of the floodplain. In the Badlands the river increases in size, but forested patches are fewer, more open, and less connected than those upstream. Woody land cover (forestland) covers only 13% of the floodplain area. As the river continues into the River Breaks ecoregion it becomes larger, creating larger closed-canopy forested communities. Proportional area of woody land cover types reaches its peak in the Delta (57% of floodplain area) as does the area of marsh vegetation (11%). Within the Badlands and River Breaks segments, abandoned channels account for a small portion of the floodplain, but are the source of less common land cover types, such as marshes and wet meadows.

Part II: Historical (1930s-2010) Land Cover Change

The upper three segments of the White River (excluding the Delta) showed slight to moderate net change in land cover from the 1930s-2010. Channel was not measured in the Pine Ridge/Pierre Shale Ecoregion, but forestland (+4%) and herbaceous (-2%) land cover types showed only small net changes. Indeed, 83% of areas with forestland in the 1930s still had it in 2010 and 90% of herbaceous areas in the 1930s remained so in 2010. In both the Badlands (-29%) and River Breaks (-20%), channel area declined over time. Changes in herbaceous (+1%) and forestland (+8%) cover in the Badlands were slight to moderate. On the River Breaks, however, there was a moderate decline in herbaceous vegetation (-13%) but a steep increase in forestland (+58%), particularly closed canopy forest. The channel and floodplain in these two segments was dynamic, with only about a third of the area that was in river channel in the 1930s remaining so in 2010. One-third (33%) of the 1930s channel in the Badlands was forestland in 2010 and 48% of the 1930s channel in the River Breaks was forest in 2010. In the Badlands, about 50% of area that was forestland in the 1930s remained so in 2010, while for the River Breaks the percentage was 65%.

Connections between river flows or climate and trends in land cover change are unclear and have not yet been subjected to more formal analysis. Measures of river discharge, including base flows, numbers of zero-flow days, and high pulse flows, did vary among dates at stream gages (Oglala, Kadoka, and Oacoma gages) in each of these three segments, with generally lower base flows and/or a higher frequency of zero-flow days in the 1960s-1980s period.

Part III: Riparian Vegetation Patterns among Ecoregions and Community Types

Vegetation surveys at 299 sites throughout the floodplain identified 21 different existing plant associations (three of which, however, were missing from the South Dakota subset listing). Twelve additional associations were created, as plant community patterns did not match descriptions of existing associations. These new associations were often created to incorporate communities with dominant or subdominant non-native species, which are not included in existing association descriptions. For analysis, associations were grouped into broader community types based on dominant species.

Across all sites and study segments, the most common tree species, by far, were *Populus deltoides* and *Fraxinus pennsylvanica,* in both frequency and basal area. Overall, grass species were the most frequent species of plants found in the herbaceous layer throughout the floodplain. *Pascopyrum smithii* and *Bromus inermis* had the highest frequency and importance values, and other grass species were frequent with relatively high importance values. After *P. smithii* and *B. inermis*, some of the most common plant species sampled in the herbaceous layer were *Symphoricarpos occidentalis*, and *F. pennsylvanica* and *Salix interior* seedlings. The most common forbs were *Equisetum arvense, Solidago canadensis*, and *Apocynum cannabinum*. *Vitis riparia* was the most frequently found vine.

Plant community characteristics varied significantly among ecoregions. Sites in the Pine Ridge/Pierre Shale Ecoregion had consistently had lower values than the other ecoregions in terms of average species richness, species diversity, coefficients of conservatism, and floristic quality. Differences among the Badlands, River Breaks, and Delta ecoregions varied depending on the type of value, but all were typically greater than Pine Ridge/Pierre Shale. Species richness averaged highest in the River Breaks. Average wetland indicator scores showed the Pine Ridge/Pierre Shale floodplain had the lowest wetland affinity (more upland species) in its flora and the Delta had the highest wetland affinity (more wetland species), with the other two ecoregions intermediate.

Forestland structure and composition varied among ecoregions. Tree density was lowest in the Pine Ridge/Pierre Shale ecoregion and highest in the River Breaks. Although there was no significant difference, the Pine Ridge/Pierre Shale had fewer sites that contained small stems (younger trees), relative to the total number of wooded plots or large tree plots. Average DBH of cottonwoods and all trees were larger in the Pine Ridge/Pierre Shale than the other ecoregions, further suggesting that trees there averaged older. This larger tree, and particularly cottonwood, size is consistent with historical analyses, which suggest that this segment has been geomorphologically more static than other segments of the White River over the last 75 years.

Differences in plant community characteristics were weaker among community types than among ecoregions. Some community types had too few plots for statistically valid comparisons. In general, box elder communities had consistently lower values for richness, diversity, conservatism coefficients, and floristic quality than cottonwood, green ash, herbaceous, sandbar willow, and shrubland. Few other consistent trends were found among community types.

Few statistical differences in forest structure and density existed among community types, in part because of small sample sizes for some. Peachleaf willow communities had the highest overall woody stem density and large tree density, although these conclusions are based on only two peachleaf willow sites. For large tree density, green ash (*Fraxinus pennsylvanica*) communities, which represent a later successional stage, were denser than sandbar willow and cottonwood communities.

Part IV – Landscape Dynamics and Vegetation Patterns in the White River Delta

The lower White River near its confluence with the Missouri River at Lake Francis Case experienced high rates of channel and floodplain aggradation and associated geomorphic change during the post-dam era (1953/1954-2011). The total amount of thalweg aggradation ranged from 0.61 m at river-km 30.9 to nearly 12 m at river-km 3.1. Other post-dam changes to the channel and floodplain environment included narrowing and smoothing of the active channel, aggradation and leveling of the floodplain, and formation of prominent natural levees at some cross sections. Sedimentation during the post-dam period led to a flattening of the stream gradient within the delta, creating a "sediment wedge" within the lower 31 km of the White River, with stream gradient declining from 0.7 m/km in 1954 to 0.29 m/km in 2011. This sediment wedge was thickest in the lowermost 13 river-km of the White River where the gradient approached 0 cm/km.

The area of riparian forest within the White River delta increased by 49% during the post-dam period, increasing from 782 ha in 1948 (pre-dam) to 968 ha in 1983, and peaking at 1,230 ha in 2004, before declining to 1,164 ha in 2012. Riparian forest expansion occurred throughout most of the 29 km study reach where Lake Francis Case influenced stream flow and sediment regimes. Pre-dam woodland was mostly concentrated in narrow bands near the active channel, but during the post-dam era, woodland expanded landward. Although overall woodland area expanded between 1948 and 2012, it declined during intervals spanning high reservoir stages and Missouri River floods, including the years of 1997, 2010, and 2011. The majority of woodland losses throughout the study period were concentrated over river-km 0-10 where reservoir inundation was either permanent or was most variable and extreme, but losses also occurred further upstream where there was channel migration or woodland clearing by private landowners through the 1990s.

Age class proportions of the riparian forest summed for the study area changed markedly during the post-dam era. Pre-dam (1948) forest was dominated by the old age class (535 ha, 68%), post-dam forest at the midpoint of the study period (1983) was dominated by the young age class (445 ha, 46%), and post-dam forest at the end of the study period (2012) was dominated by the medium age class (539 ha, 46%). Medium age class forests dominated the lower half of the reach, while old age class forests dominated the upper half in 2012.

Cottonwood (*Populus deltoides*) was the dominant species across 34 stands sampled on the lower White River, occurring on all 25 tree-sized sites, composing 89% of tree stems and 93% of basal area. Unlike some of the other segments, peachleaf willow was the second most abundant tree species, rather than green ash (although green ash was more abundant in other sites sampled in Part III in the Delta). Within shrub-sized (predominantly younger) stands, cottonwood, peachleaf willow, and sandbar willow dominated the shrub layer; while in tree-sized stands, green ash was the dominant shrub/sapling species. Similarly, seedlings of peachleaf willow, cottonwood, and sandbar willow were abundant in the understory of shrub-sized stands; whereas green ash, sandbar willow, and riverbank grape were the most abundant species of woody seedlings in forest understories. High densities of cottonwood, sandbar willow, and peachleaf willow seedlings and saplings occurred on both the delta itself and on the adjacent lower White River, predominantly in stands <50 years old.

INTRODUCTION

Natural riparian woodlands provide important habitat for wildlife within the prairie landscape, supporting among the highest levels of avian and mammal diversity of any habitats in the Rocky Mountain and northern Great Plains regions (Finch and Ruggiero 1993). Riparian ecosystems along perennial and intermittent rivers in the Great Plains Steppe Ecoregion contain a number of species of the greatest conservation concern in South Dakota. Wooded habitats from riparian forests are of particular importance to the Bald Eagle (*Haliaeetus leucocephalus*), northern river otter (*Lontra canadensis*), and northern long-eared bat (*Myotis septentrionalis*) (SDGFP 2006). These riparian habitats also provide breeding and stop-over habitat for many Neotropical migratory songbirds (Dean 1999).

Throughout the American West, rivers and their riparian zones have been greatly modified by flow regulation by dams, water extraction for irrigation, alterations to sediment regimes, land use conversion, grazing and trampling by livestock, and spread of invasive species. These systems are also potentially sensitive to the effects of climatic change, as well as past and ongoing climatic variation. Within the northern Great Plains, large areas of riparian forests were lost due to land use conversion and permanent inundation by large Missouri River reservoirs during the last century, with new forest establishment (particularly of cottonwood) limited by regulated river flows (Johnson et al. 2012, Dixon et al. 2012). As riparian corridors are both valuable and threatened, mapping them and characterizing their composition and quality is strategically important for landscape management and biodiversity conservation in South Dakota (SDGFP 2006) and across the upper Great Plains region.

With the ubiquity of dams on most medium to large rivers in temperate North America (Graf 1999) and the Northern Hemisphere as a whole (Dynesius and Nilsson 1994, Nilsson et al. 2005), few unregulated systems exist that support natural river processes and ecosystem dynamics. The White River, in western South Dakota, is an unregulated system (Galat et al. 2005), with a largely intact riparian corridor and natural flow and sediment regimes. As such, the White supports important wooded riparian habitat in western South Dakota and may serve as a reference system for management and restoration of other rivers in the region. Given the historic, extensive loss of floodplain forest on the Missouri River (Dixon et al. 2012), the intact riparian corridor on the White may represent a significant proportion of the remaining riparian forests in the region. In addition, extensive areas of young cottonwood forest have formed on the lower White River and its delta with the Missouri River at Lake Francis Case. Such reservoir deltas constitute “novel habitats” in the regulated Missouri River system, potentially providing areas in which natural flow and sediment processes still drive riparian patch dynamics (Johnson 2002, Volke et al. in prep.).

Despite its status as a key, unregulated tributary to the Missouri and as a major wooded riparian corridor in western South Dakota, little is known about the vegetation and floodplain ecology of the White River (Galat et al. 2005), and the delta area itself is unstudied (Johnson 2002). Most of the recent ecological work conducted on the White was done for Fryda's thesis (2001), "A survey of the fishes and habitat of the White River, South Dakota." This research focused on fish and although riparian characteristics were assessed, they were not analyzed in detail. Other surveys are out of date or have included small portions of the White while focusing on broader areas (Reagan 1905, Von Loh et al. 1999, Stebler 1939). No studies have focused on the composition, structure, extent, and dynamics of vegetation along the entire riparian corridor of the White River.

The goals of our project are (1) to map and classify riparian vegetation along the entire length of the White River in South Dakota, including its delta with the Missouri River at Lake Francis Case; (2) to measure historical changes in land cover and channel dynamics; and (3) to quantify vegetation patterns and evaluate geographic differences in riparian habitat extent and composition along the river. This project helps address priority information needs within the South Dakota Wildlife Action Plan (SDGFP 2006), which takes a strategic, landscape approach to habitat conservation for all of the state's fish and wildlife species, and contributes to the long-term goal of SDGFP to develop a GIS database of woody riparian habitats in the state. Products from this study will aid SDGFP in conservation planning and implementation of on-the-ground management and restoration of riparian ecosystems, and may provide a resource for predicting the distribution of plants and animals of conservation need along the river. Techniques and products derived from this project may form the basis for similar work on other western South Dakota rivers and their riparian zones in the future.

The Results and Discussion sections of the report are divided into four parts, reflecting key themes in our work and addressing each project objective.

- Part I: Classification and mapping of current (2010) land cover within the riparian corridor of the White River in South Dakota, plus portions of the river headwaters in Dawes County, Nebraska.

- Part II: Historical (1930s-2010) river channel dynamics and land cover change among the three upper segments of the White River (excluding the last 17 km of delta-influenced habitat near the confluence with the Missouri River).

- Part III: Vegetation patterns throughout the White River riparian corridor and by segment (ecoregion), including plant associations and community types.

- Part IV: A more in-depth analysis of forest vegetation and changes in historical land cover and river cross-section profiles within the delta and nearby transitional sections of the river (lower 29 km).

Parts I-III of the study will be more fully documented through the MS thesis of Alex Cahlander-Mooers at the University of South Dakota, while Part IV forms a portion of the PhD dissertation work of Malia Volke at South Dakota State University.

STUDY AREA

River and Floodplain

The White River is a 6th order river that begins in northwestern Nebraska in Sioux County, west of Crawford, flows north into South Dakota and through the Pine Ridge Indian Reservation and South Dakota Badlands, and continues east until it flows into Lake Francis Case, a reservoir on the Missouri River, near Oacoma, SD (**Figure 1**). It drains a watershed of approximately 26,000 km^2 (10,200 mi^2), is one of the longest undammed rivers in the contiguous United States at 816 km (510 miles), and has a sinuous and geomorphically dynamic channel (Galat et al. 2005). 9.9 million metric tons of sediment are deposited annually by the White into Lake Francis Case, causing the formation of a large delta (Galat et al. 2005). The river has poor water quality because of its high sediment load due to badlands erosion of sands, clays, and volcanic ash, which gives it its milky white color and name. Suspended sediment jumps from 250 mg/L upstream to over 5000 mg/L after it passes through the Badlands. Because of the river's naturally high sediment load, it is excluded from the Federal Total Maximum Daily Load program, although it is listed as an impaired water body (Galat et al. 2005).

The ancestral White River dated back to the late Tertiary or Early Pleistocene, when it drained the southern Black Hills. The modern White River Basin's landscape was created slowly, throughout the Pleistocene, by wind and water erosion. The river shifted as, over time, some of its tributaries were captured by a relocating Cheyenne River. Further changes in the river's flow may have been caused by the uplifting of the Siouxana Arch and Chadron-Cambridge Arch systems, which caused the river to flow east, rather than south. The river was likely stable through the end of the Wisconsin glaciation (White 1982).

Changes to the White and its tributaries have continued since the end of the Pleistocene. The river's valley experienced alluviation during a period of aridity from 10,000 to 4,000 years ago, but since that time has experienced net erosion. Since the period of homesteading in the mid- to late 1800s, drainages and intermittent tributary streams have become V-shaped and gullied due to decreased prairie fire, causing increased grass cover and resulting in flows with reduced sediment (White 1982).

Presently, flow along the White River is strongly associated with snowmelt and precipitation events in the spring and early summer, the combination of which accounts for 80% of the annual precipitation. Because precipitation is localized, erratic, and unreliable, flow has been known to be intermittent, although it is typically perennial.

Tributaries are unreliable sources of water, with the exception being the Little White River, which flows from the Nebraska Sandhills. The Little White is also the primary source of winter discharge (Galat et al. 2005, Fryda 2001). During the dry season, ground water is below the river surface, but raises to it during wet periods (Ferrick et al. 1995).

The White River has a semi-arid continental climate, characterized by short, hot summers and long cold winters (Hogan 1995). There is extreme variation in seasonal and annual temperature and precipitation. The river basin has an annual temperature of 8.8 °C, with a range of up to 65.5 °C between annual low and high temperatures. Annual precipitation varies from 42 cm in the east and 52 cm in the west (Ruelle et al. 1993).

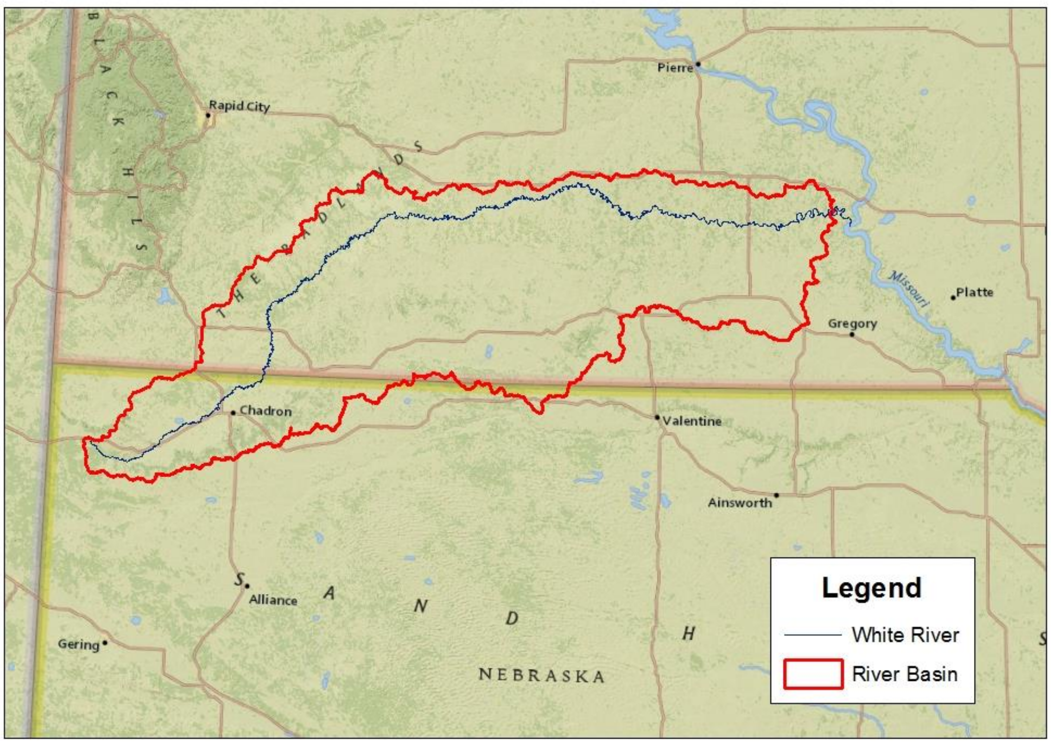

Figure 1. Regional map of the White River and its basin (National Geographic World Map (NGWM)).

Ecoregions and Study Segments

The White River passes through four Level IV ecoregions (Bryce et al. 1996): Pine Ridge Escarpment, Semiarid Pierre Shale Plains, White River Badlands, and River Breaks (**Figure 2**). Ecoregions denote ecosystems with similar type, quality, and quantity of environmental resources based on biotic and abiotic phenomena including geology, physiography, vegetation, climate, soils, land use, wildlife, and hydrology (Omernik 1987). They were designed to be used as a special framework for research, assessment, management, and monitoring of ecosystems and ecosystem components. Ecoregions begin at a broad, biome scale at Level I and become progressively more detailed down to Level IV ecoregions, which were delineated in order to provide state-level applications (Bryce et al. 1996). Because Level IV ecoregions were designed for assessing ecological phenomena at a state level, they may provide an appropriate classification for dividing and comparing the communities and flora along the White River. It should be noted, however, that a different system of primary ecoregion definition is used in the South Dakota Comprehensive Wildlife Conservation Plan, with the entire length of the White River in South Dakota (except for the delta, which may be in the Missouri River Ecoregion) classified as part of the Great Plains Steppe Ecoregion (SDGFP 2006).

For this project, the river has been divided into four main segments based on the four major (Level IV) ecoregions (**Figure 2**) plus the delta region adjacent to the river's confluence with Lake Francis Case. The Pine Ridge Escarpment and Semiarid Pierre Shale Plains were combined, as the river moves through both and serves as the boundary between the two in northwestern Nebraska and southwestern South Dakota. An additional segment was created for the delta area at the confluence of the White River with the Missouri at Lake Francis Case. No need for further segmentation of the river based on soil types, hydrology, or other factors was apparent. Arbitrary subdivisions of the segments were not done in order to keep the study focus on well-defined, meaningful geological and ecological units.

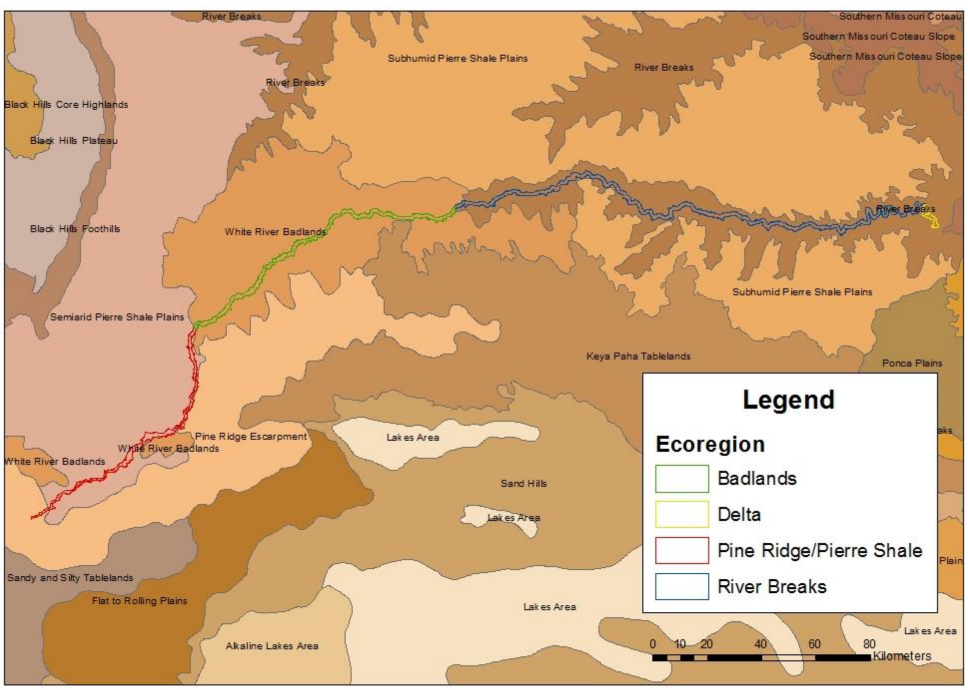

Figure 2. Floodplain study segments of the White River shown on the Level IV Ecoregion map.

The first study segment begins near the river's headwaters at the border between Sioux and Dawes County, Nebraska and flows for 177 km through a 175 km long floodplain (sinuosity = 1.01) bordered by the Semiarid Pierre Shale Plains and Pine Ridge Escarpment Ecoregions (Pine Ridge/Pierre Shale) until near the river's intersection with Pine Ridge Hwy 41 in South Dakota (**Figure 3**). This segment combines two ecoregions because the river meanders through both and often forms the border between them. The Pine Ridge Escarpment is found in the Western High Plains (Level III ecoregion) and is described as a mixed grass prairie with ponderosa pine (*Pinus ponderosa*) growing on north-facing ridges and outcrops. The soils found throughout the Pine Ridge Escarpment are primarily entisols and mollisols formed over Miocene sandstone. The Semiarid Pierre Shale Plains is found in the Northwestern Great Plains (Level III ecoregion) and is a mixed-grass prairie with a predominance of shortgrass species. There are a variety of soils found in the Semiarid Pierre Shale Plains including aridisols, mollisols, entisols, and inceptisols formed over Cretaceous Pierre Shale. There is also an outcrop of White River Badlands found in the floodplain before it reaches the main Badlands section (Bryce et al. 1996).

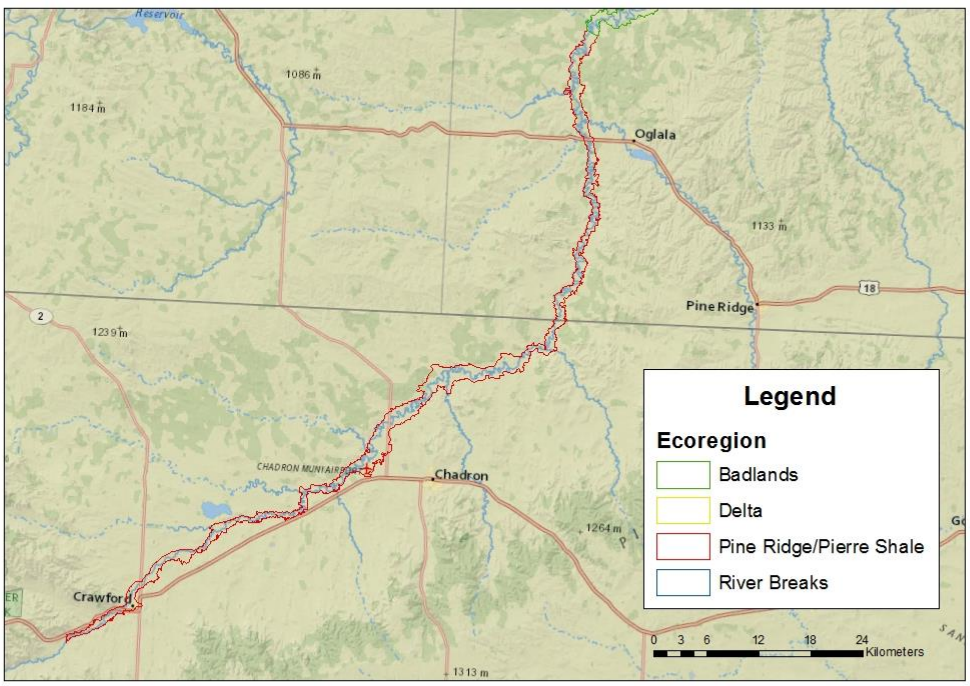

Figure 3. The Pine Ridge/Pierre Shale segment along the White River (NGWM).

The second segment begins near Pine Ridge Hwy 41 and continues for 240 km , flowing within a 150 km long floodplain (sinuosity = 1.60) through the White River Badlands Ecoregion (Badlands) until it reaches the River Breaks Ecoregion, near Kadoka, SD (**Figure 4**). The Badlands are found in the Level III Northwestern Great Plains Ecoregion, formed through erosion of clays and siltstones, and are described as a broken landscape with grass-covered sod tables. Soils found in the White River Badlands are aridisols, entisols, and inceptisols. The geology of the ecoregion has Oligocene Brule and Chadron claystone formed over Cretaceous Pierre Shale (Bryce et al. 1996).

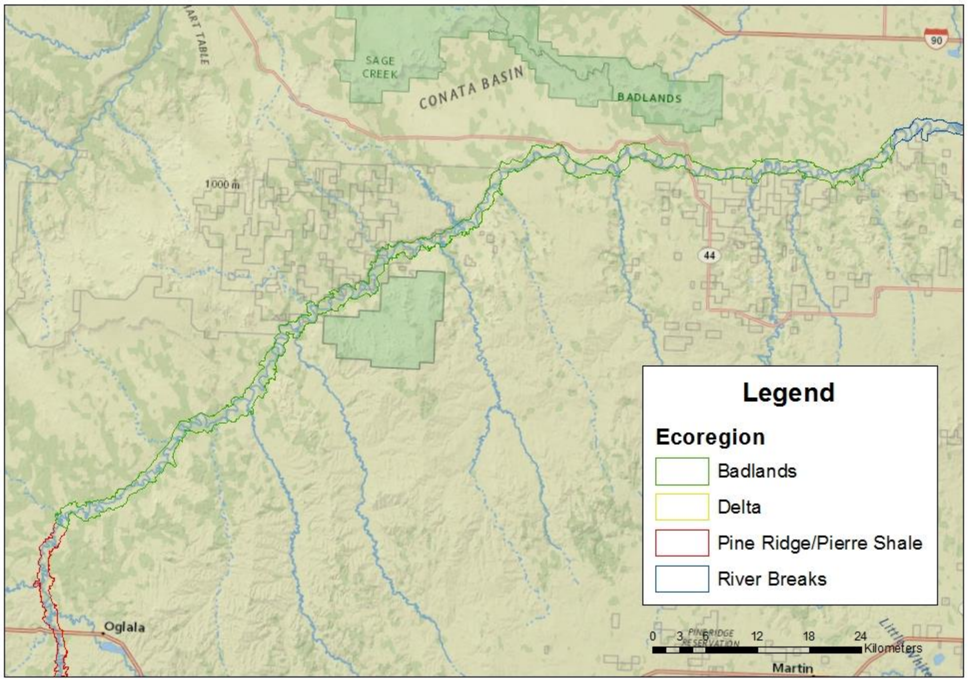

Figure 4. The Badlands segment along the White River (NGWM).

The third segment runs 382 km, within a 250 km long floodplain (sinuosity = 1.53), through the River Breaks Ecoregion near SD State Hwy 44 and State Hwy 73, south of Kadoka, SD (**Figure 5**). The River Breaks is found in the Northwestern Great Plains Level III Ecoregion and is formed from broken terraces and uplands of the Missouri River and its major tributaries. It has a dissected topography with wooded draws and uncultivated areas, with riparian forests dominated by cottonwood and green ash. A variety of soils occur through the River Breaks including mollisols, entisols, aridisols, vertisols, and inceptisols. The bedrock composition varies, but is composed of Cretaceous Pierre Shale in the White River area (Bryce et al. 1996). River Breaks is named for the steep bluffs, or breaks, that occur in the incised open valleys of the Missouri River and some of its tributaries (Ward 1927).

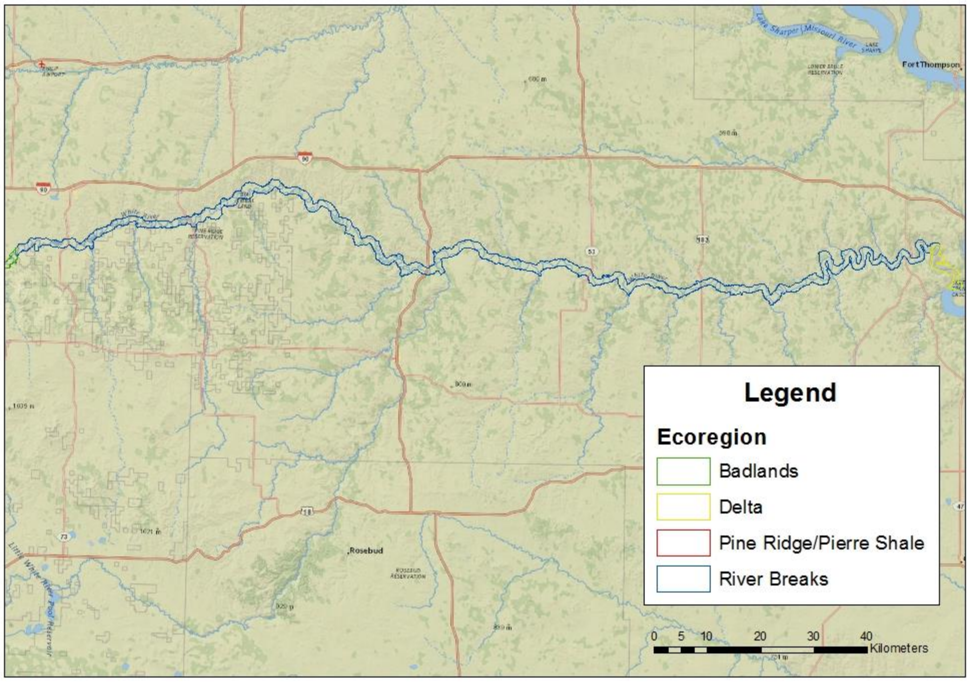

Figure 5. The River Breaks segment along the White River (NGWM).

The last segment (Delta) is defined as the last 17 km of the White River before its confluence with the Missouri River at Lake Francis Case (**Figures 6 and 7**). Here the White River becomes backed up and has formed a delta since the completion of the Fort Randall Dam in 1956 on the Missouri River. The extent of the delta was determined using historical aerial photography and flood maps to determine which forests had established before and after the reservoir. Work by Malia Volke (unpublished data) of South Dakota State University suggests that significant sedimentation has occurred both in the reservoir itself and in the channel and floodplain of the White River since the 1950s, from 12 m of aggradation at 3 km above the confluence and progressively declining upstream to 0.6 m at 31 km from the confluence (see Part IV). Hence, channel and floodplain sedimentation have strongly affecting the entire Delta segment as defined here (17 km), as well as having impacts on the lower 7-14 km of the River Breaks segment. Note that the boundary of the delta area is defined somewhat differently in Parts I-III than in Part IV of the Results and Discussion.

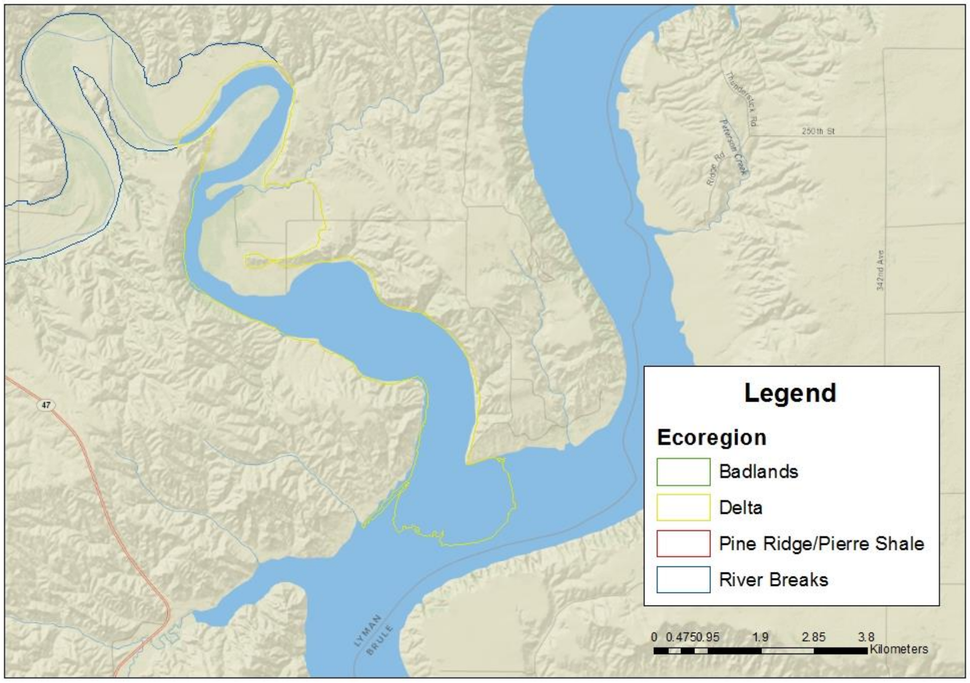

Figure 6. The Delta segment along the White River (NGWM).

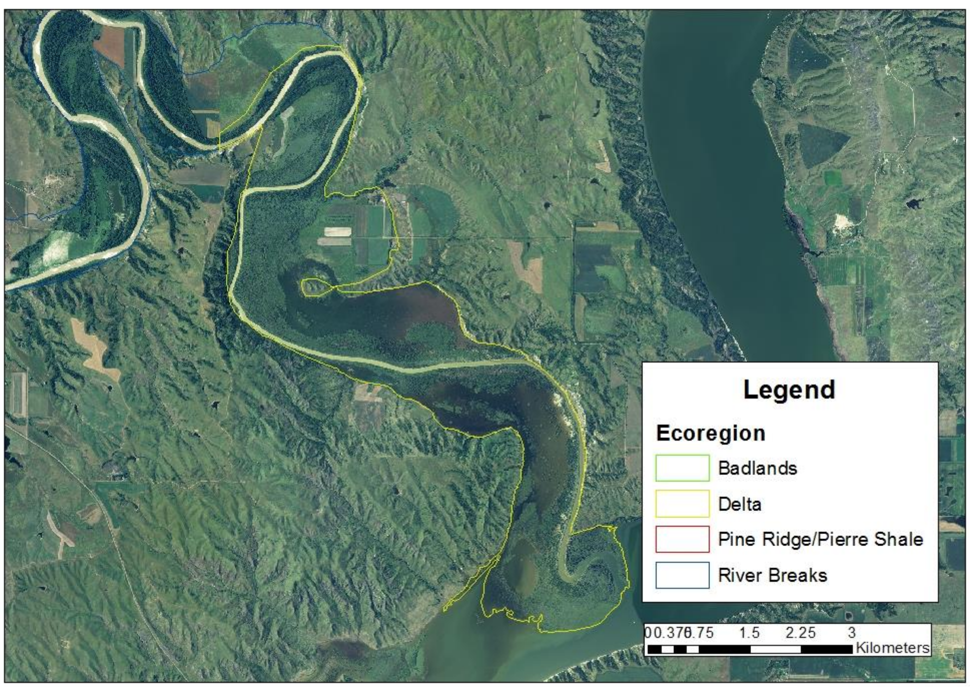

Figure 7. 2010 NAIP map of the Delta segment along the White River.

METHODS

Part I – Mapping Current (2010) Land Cover

Land Cover Mapping

Recent (2010) land cover was mapped along the entire floodplain of the White River from Fort Robinson State Park near Crawford, NE at the border of Sioux and Dawes County, to Lake Francis Case, near Oacoma, SD. Areas farther upstream in the river's headwaters in Sioux County were excluded because of the small size of the riparian zone and the difficulty in differentiating between the main channel of the White River and similarly sized tributaries. Mapping was completed using 2010 true color orthophotography (county mosaics) from the National Agriculture Imagery Program (NAIP), obtained from the USDA NRCS Geospatial Data Gateway (http://datagateway.nrcs.usda.gov/). Interpretation and delineation of land cover was done using an on-screen ("heads-up" digitizing) approach in ArcGIS 10.0, digitizing directly off of the NAIP aerial imagery.

Determining and delineating the precise extent of a riparian zone can be a difficult task because of the variation in metrics used to define the riparian zone (Naiman and Décamps 1997). For this study, the extent of the river's floodplain was used to define the riparian zone. A polygon of the river floodplain was created based on topographic maps and aerial photography to delineate the extent of the riparian corridor, allowing communities to be easily identified and differentiated as floodplain vs. outside of floodplain. In the vast majority of areas the floodplain was clear and easy to delineate. All areas mapped outside of the floodplain were excluded from the study and results.

Land cover polygons were classified and clipped to the floodplain boundary. Mapping was done at a 1:5000 scale with a minimum mapping unit of 0.25 hectares. Vegetation types were classified into broad community types based on structure (physiognomy) that was detectable from the aerial photography (**Table 1**). Polygons were at least 0.25 ha before they were clipped to the floodplain and the small fragments (<0.25 ha) created when clipped were left as is. Polygons greater than 0.25 ha after floodplain clipping were summarized and examined by size and number, in order to better characterize land cover patterns. Average patch sizes of the forestland cover types were compared among ecoregions to examine differences and trends in forests.

Table 1. Community cover types and broad cover categories for GIS mapping.

Cover Type	Community	Description
Water	Main channel	White River channel, including unvegetated sandbars
	Tributary channel	Channel of tributary river
	Lake	Lakes, ponds, reservoirs, oxbows, or other standing bodies of water
Herbaceous	Grassland	Grasses or other herbaceous cover, not tilled or mowed
	Wet meadow	Grasses or other herbaceous cover with evident hydric conditions
	Farmland	Agricultural fields, typically mowed grasses or alfalfa, and including row crops
	Marsh	*Typha* or similar herbaceous marshy wetlands
	Wet meadow/ willow mix	Sandbar willow and wet meadow mix
Forestland	Forest	Closed (>50% closed) canopy forest
	Woodland	Open (50%-10% closed) canopy forest
	Shrubland	Shrubs and small trees (>50% cover)
Developed	City/town	Cities and towns
	Farm complex	Farm buildings and lots

Isolated or small groups of trees (patch sizes below 0.25 ha) were not classified in forested communities but were lumped with the larger community in which they were found. Polygons of the channel were not created for portions of the river in the Pine Ridge/Pierre Shale ecoregion (segment 1) as the river is too small, narrow, and obscured by overhanging vegetation to accurately map its area. Sandbars without vegetation were lumped with the river channel because they were often indistinguishable from the color of the river and because their area depended on flow levels at the time of photography. Sandbar willow (*Salix interior*) and wet meadow communities along the river were mapped together as they were often indistinguishable on aerial photos and in field visits.

A line shapefile was created for the river channel centerline along the entire length of the White River within the study area. The length of the floodplain, for the entire study area and for the study segments, was determined by dividing the floodplain polygon perimeter by two. River length divided by floodplain length provided an estimate of river channel sinuosity overall and by study segment. An average width of the floodplain was determined by dividing the area of the floodplain by the length of the river segment running through it.

Originally, an attempt was made to classify and map communities to specific plant associations (Faber-Langendoen 2001) based on ground-truthed vegetation composition and structure; however, even when mapping at a scale finer than 1:5000 it was not possible to distinguish many of the communities with sufficient confidence to the plant association level. Hence, final mapping was not done to the association level.

Polygons of channel cutoffs were created for the Badlands and River Breaks segments in order to determine the proportions of different kinds of land cover that were established within abandoned channels. Cutoff polygons were not created for the Delta, as it did not have any. Cutoffs were also not delineated for the Pine Ridge/Pierre Shale section because the narrow channel made it difficult to determine previous channel locations and the connected nature of the forest made it difficult to differentiate stands that originated on cutoffs vs. those growing on other landforms. Overall, there was likely a bias towards mapping cutoffs that occurred in forested areas, as these were often the only areas that could be definitively determined to occur in a former channel cutoff.

CropScape Data

Agricultural land cover, in the form of Cropland Data Layer maps, was gathered from the National Agriculture Statistical Service for the entire floodplain and study segments (USDA 2010). The Cropland Data Program uses satellite imagery to provide crop-specific georeferenced cover estimates, as well as other cover, such as forests (NAAS 2014). Estimates of river segment-level cropland data were generated by intersecting the shapefile for each study segment with the CropScape layer, which generated a summary table of CropScape land cover types by study segment for 2010. CropScape land cover areas were compared with those derived by aerial photograph interpretation in the study area, in order to provide greater detail and accuracy in delineating the kinds of agricultural land use in the study area and for assessing the accuracy of CropScape data for quantifying floodplain and forest cover. Cover from the Cropland Data Layer was categorized into different land cover types for analysis.

Part II – Mapping Historical Land Cover Dynamics

Historical Land Cover Mapping

Historical land cover was mapped along 12 sections (4 in Pine Ridge/Pierre Shale, 3 in Badlands, 5 in River Breaks) of the White River floodplain throughout three ecoregion study segments (**Figure 8**). Cumulatively, these sections covered 24% of the floodplain area within the upper three ecoregion segments. Coverage was proportionally similar to this in the River Breaks (25%) and Badlands (26%) ecoregions, but proportional coverage was lower in the Pine Ridge/Pierre Shale segment (16%). Mapping was based on aerial photography from the late 1930s, early 1960s, early 1980s, early 1990s, 2004, and 2010 (**Table 2**). Images from the 1930s, 1960s, and 1980s were scanned and georectified in ArcGIS 10.0; images from the 1990s and 2000s were orthophotography that had already been rectified. 1930s imagery was obtained from National Archives, 1960s imagery from the Missouri River Institute and USDA Aerial Photography Field Office, 1980s imagery from the USDA Aerial Photography Field Office, and 1990s and 2000s imagery from the USDA Geospatial Data Gateway. These dates were chosen because aerial photos were available during these periods and were somewhat evenly spaced temporally.

Digitizing methods and land cover types were the same as those described for the 2010 land cover. Historical changes in the White River Delta were mapped separately (see Part IV), using similar, but slightly different methods.

Land cover changes were calculated in ArcMap® and Microsoft Excel®. The UNION tool in ArcMap was used for combining the mapping from two historical periods. Patch areas from these data were then analyzed in Excel and summarized using pivot tables to show how much of each cover type remained or was converted to a different cover type between the two periods.

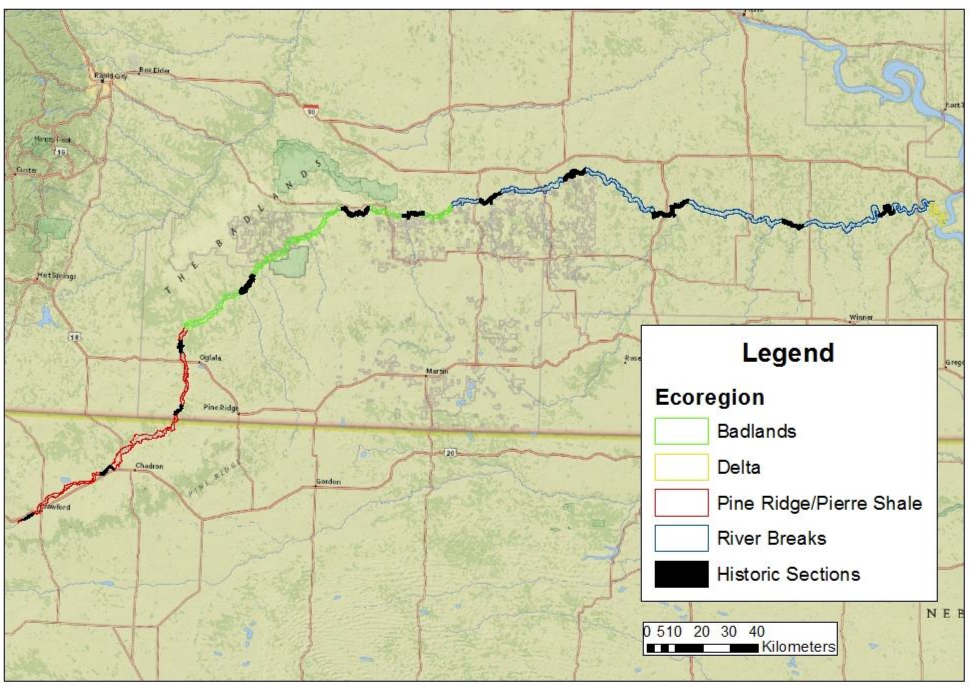

Figure 8. Study sections for historical change mapping (National Geographic World Map).

Table 2. Aerial photography information for historical periods. Year used was the year chosen for comparison when photography was taken over a number of years. For the 1930s-80s it is the median year, for the early 1990s it is 1991 because that is the year when most of the photographs were taken.

Period	**Photo Dates**	**Color**	**Year Used**	**Source**	**Scale**
Late 1930s	1937-39	B/W	1938	Agricultural Adjustment Administration	1:20,000
Early 1960s	1961-63	B/W	1962	Farm Service Agency	1:20,000
Early 1980s	1980-84	CIR	1982	National High Altitude Photography	1:58,000
Early 1990s	1991-94	B/W	1991	USDA Digital Orthoquads	1:40,000
2004	2004	Color	2004	National Agriculture Imagery Program (NAIP)	1:40,000
2010	2010	Color	2010	National Agriculture Imagery Program (NAIP)	1:40,000

Some community types were consolidated into broader cover categories (**Table 3**) for land cover change analysis. Because the areas of non-main channel water and developed lands were very low, they were combined into a single "other" category and not analyzed further. The willow mix community was treated independently, rather than lumped with herbaceous, because it is an early successional community type that plays a role in forest development.

Table 3. Cover types for each mapped community cover grouped for conversion analysis.

Cover Type	**Community**
Main Channel	White River Channel
Herbaceous	Grassland
	Wet meadow
	Farmland
	Marsh
Willow Mix	Willow Mix
Forestland	Forest
	Woodland
	Shrubland
Other	Tributary Channel
	Lake
	City/town
	Farm complex

Cover conversions were summarized by percent change between the historical periods and normalized by the number of years per period (% change per year). Regression analyses were run to examine temporal trends in annual land conversion rates between main channel, herbaceous, willow mix, and forestland for the entire floodplain, and for the Badlands and River Breaks reaches. The Pine Ridge/Pierre Shale Ecoregion was excluded from these calculations because its channel was not mapped as a polygon.

Discharge Data

Stream flow data were collected from three USGS stream gages along the river (**Table 4**). Each stream gage was located at the downstream end of the respective segment / ecoregion, so flow data could be compared and correlated with changes in historical land cover on that ecoregion. Analyses were done using the hydrological year, October 1 - September 30. For some metrics, separate analyses were run using just the high flow months of the year, March through July.

Historical flow data from 1944-2010 were imported and analyzed using the analysis software Indicators of Hydrological Alteration (IHA). IHA is used to quantify ecologically relevant changes in discharge over time by calculating 67 different statistical parameters. These parameters include streamflow magnitude, duration, and frequency, as well as measures of low and high flows and flood pulses (Richter et al. 1996). Analysis of variance (ANOVA) was used to examine differences among historical periods in these flow parameters. Periodic minima and maxima were calculated by the software using moving averages for every possible period within the water year. Low and high flood pulses were days that were more than 25 percent of the median flow.

Table 4. Names, USGS gage number, dates of stream sites. All sites are located on the White River. Only data from 1944-2010 were used in analyses.

Stream Gage	USGS Number	Collection Years	Segment
Near Oglala, SD	06446000	1943-present	Pine Ridge/Pierre Shale
Near Kadoka, SD	06447000	1942-present	Badlands
Near Oacoma, SD	06452000	1928-present	River Breaks

Part III – Quantifying Vegetation Patterns

Vegetation Sampling

Vegetation was surveyed along the White River from Fort Robinson State Park (at the border of Sioux and Dawes Counties), Nebraska to the river's confluence with the Missouri River at Lake Francis Case, south of Oacoma, South Dakota. Areas within the mapped floodplain were surveyed; including locations associated with the main channel and abandoned channels. Typically, main channel sites were areas of prairie, marsh, forest, etc. associated with the progressively migrating bends of the river, but occasionally were located along straight stretches of the river or farther away from the river. Abandoned channel sites were also prairies, marshes, and forests in the floodplain; however, they were established on abandoned channels or oxbows. Sites were chosen opportunistically based on access from private landowners and available public land. An attempt was made to spread site locations equally throughout the floodplain and among ecoregions. Forest sites that were selected had an unmanaged overstory with shrub and herbaceous layers with little to no grazing or clearing. Prairie sites were not mowed or heavily grazed for the season at the time of surveying. Minor disturbances were noted, but did not exclude an area from being surveyed. Mowed, heavily grazed, or largely disturbed areas were not used for surveys.

Reconnaissance (ground-truthing) of communities at the site occurred before vegetation sampling began to confirm the communities at the site, and to see if additional communities were present that were not evident on the aerial photographs used in the land cover mapping. Plot locations were then chosen arbitrarily at the site within the community types present by choosing locations that seemed representative. Sampling each type of community within a site was a priority and was done before large or abundant community types were resampled. Plant association type (Faber-Langendoen 2001a,b) was assessed and preliminarily assigned in the field.

Vegetation surveys occurred on White River floodplain sites throughout each of the four ecoregions. Plant communities at each site were surveyed using an altered Daubenmire (1968) method, using system of nested microplots within a macroplot. This method was chosen because it is commonly used, has been cited in hundreds of studies, and is recommended by the U.S. Forest Service for rangeland studies, including riparian sites (Stohlgren 2007). Stohlgren et al. (1998) showed the Daubenmire method to be the most accurate of common Great Plains survey methods without a time-consuming intensive species search. This method is ideal for this project as it works with the range of community types encountered during the surveys, including forests, shrublands, and prairies.

The macroplot was 5x25 m with the long axis running perpendicular to the river, as communities typically form bands from the river with the communities becoming more mature as they continue upland. If a community was narrower than 25 m, but greater than 20 m, the macroplot was shortened to the width of the community. If the communities were less than 20 m wide, then the macroplot was divided in two and the community surveyed with two half-macroplots (arranged parallel to the river). Woody plants (both trees and shrubs) greater than 1.5m tall were recorded and DBH (diameter at breast height, around 1.3 m) values were measured within the macroplot to determine population structure. 3 cm was the minimum DBH to be recorded; smaller individuals were only counted (**Figure 9**).

Modifications were made to the Daubenmire (1968) method to increase the precision in cover estimates without greatly increasing the amount of effort (time) for surveying. Rather than using forty 20 x 50 cm microplots, eleven 0.5 x 1 m microplots were used, stratified spatially across the entire macroplot (**Figure 10**). Microplots were evenly spaced, with eight running along the sides of the macroplot and three running down the center. This increased the area of herbaceous data per community from 4 m^2 to 5.5 m^2 and spread the distribution of the microplots in the macroplot. The increased size of the microplots increases cover accuracy from the Daubenmire protocol, which groups cover into categories rather than recording the actual cover. Because actual cover was estimated here, use of 0.5 x 1 m plots also reduced estimate error compared to the commonly used 1 x 1 m microplot (Clapham 1932). Small trees (taller than 1.3m, but less than 3 cm DBH) were counted throughout the macroplot (**Figure 9**), rather than on separate transects as it required no extra effort and was done while recording other woody data.

Large Trees	Small Trees	Sapling	Seedling
DBH > 3 cm DBH recorded	DBH < 3cm Height > 1.5m Macroplot Count	Woody Height < 1.5m Microplot Count	Herbaceous Microplot Cover

Figure 9. Designation of woody plants and their corresponding data collection method.

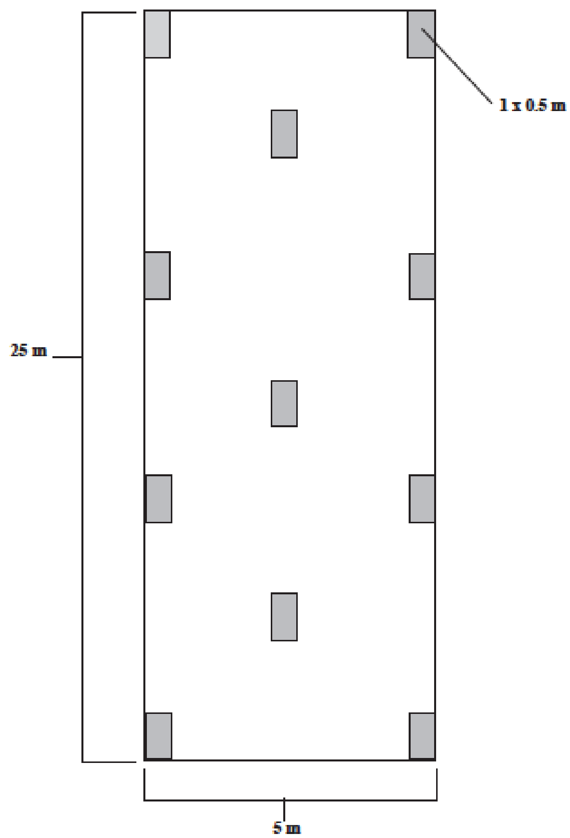

Figure 10. 5 x 25 m macroplot and locations of eleven 0.5 x 1m microplots.

Percent cover of the foliage area was visually estimated for herbaceous species and woody seedlings (woody species which have yet to develop wood) to the nearest 1%. Because of this, total cover across species may exceed 100%. Saplings (woody species with wood that are less than 1.5 m tall) were counted in each microplot. Shrub species that could be easily determined as individuals were treated as saplings and counted in microplots. Shrub species that were sprawling, acaulescent, or difficult to determine individuals, such as *Symphoricarpos occidentalis* or *Rosa* spp., had their cover recorded with herbaceous species. All vines were treated as herbaceous. Canopy cover was estimated in four directions perpendicular to the plot at each microplot on 24 points of a densiometer. Incidental species (observed in the community, but not recorded in plots) were also noted for the different communities at each site. This was done passively while surveying plots and moving through communities.

Sandbar willow (*Salix interior*) community plots were surveyed differently as they were often quite dense and the typical protocol would have been too time-consuming. Sandbar willow stems were always treated as saplings and seedlings because the DBH was rarely greater than 3 cm and stems grew too dense to be counted individually across the entire macroplot like regular trees. Microplots were completed normally for herbaceous cover and stem counts, but an additional 11 microplots were added to

create a more accurate estimate of woody stem density. Canopy cover was not collected for sandbar willow communities as their height was often near the height of the densiometer and could not have been recorded consistently or accurately.
Some herbaceous communities, typically marshy communities, adjacent to the river that were less than 5m wide were surveyed without a macroplot and with the 11 microplots placed arbitrarily throughout the community.

A small number of sites (five) within the Badlands National Park section of Pine Ridge Reservation were only surveyed for species present and tree DBH. This was because there was limited access to the section of Badlands National Park found within Pine Ridge Reservation and fieldwork was limited to species identification and woody data. Some of these data were excluded from some of the analyses.

Unidentified species were either recorded as an "indeterminable" species or recorded as a specific unknown species. Indeterminable individuals were those that were too immature or senesced to be confidently identified and were recorded to the most specific taxon as possible (e.g. indeterminable grass, indeterminable forb, indeterminable chenopod). Species that could not be determined in the field, but that had characteristics that could lead to future identification to genus or species, were assigned numbers and were consistently labeled under the specific unknown ID. After all of the field data were recorded unknown species were either identified or labeled to the most specific taxon possible using collections, photos, and/or descriptions.

All *Juniperus* species were categorized as *Juniperus virginiana* (eastern red cedar) because there was difficulty determining species with certainty. It is quite possible that many of the junipers found along the White River are hybrids between *J. virginiana* and *J. scopulorum*. Fassett (1944) found numerous patches of *Juniperus* in what is now Badlands National Park and on a bluff of the White River outside Interior, SD, in which the individuals could not be classified as either species.

Flora and Associations

In the field, species were typically identified with *Flora of Nebraska* (Kaul et al. 2011) and/or *The Vascular Plants of South Dakota* (Van Bruggen 1985), but the Latin name from the USDA Plant Database (http://plants.usda.gov) was used for the final species name. Common names, family, identification code, growth duration, growth habit, and native status according to the USDA Plant Database were also recorded. Great Plains Region wetland indicator status was recorded for each species according to the 2012 National Wetland Plant List (Lichvar et al. 2012). Species were also checked on the South Dakota and Nebraska noxious and threatened/endangered species lists, although no species found were classified as threatened or endangered. Species' coefficients of conservatism were recorded from the *Coefficients of Conservatism for the Vascular Flora of the Dakotas and Adjacent Grasslands* report (NGPFQAP 2001).

Plant associations were determined following site visits from *Plant Communities of the Midwest* (Faber-Langendoen 2001a). Plant associations that were found in the field, but missing from the South Dakota Subset were noted (Faber-Langendoen 2001b). Some new plant association types were created for this study because existing associations did not match community patterns in the field. It was determined that ecological group was too broad of a category, as most sites fell into only two groups: Northern and Central Great Plains Wooded Riparian Vegetation, and Great Plains Mixedgrass Prairies. Because associations were too specific and ecological groups were too broad, some associations were lumped into "community types" based on dominant trees (**Table 5**). Sandbar willow shrublands was treated separately from shrublands because the willow groups were clearly unique from the rest of the Shrubland associations.

Table 5. Created community type classifications for associations and their descriptions.

Community Type	**Description**
Box Elder Forest	Forests dominated by box elder, lacking cottonwood
Cottonwood Forest	Includes all of the cottonwood forests
Green Ash Forest	Forests dominated by green ash, lacking cottonwood
Herbaceous Vegetation	Includes all herbaceous dominated associations
Peachleaf Willow	Forests dominated by peachleaf willow
Red Cedar Woodland	Forests or woodlands dominated by red cedar
Russian Olive Woodland	Forests dominated by Russian olive
Sandbar Willow	Shrublands dominated by sandbar (coyote) willow
Shrubland	Shrublands not dominated by sandbar willow

Analysis of Plant Community Patterns

Species data for each community type and association were summarized. Woody cover was summarized by absolute and relative frequency, and absolute and relative basal area. Herbaceous species were summarized by absolute and relative frequency, mean and relative cover, and importance value. The importance value was calculated from the sum of the relative frequency and relative cover. Importance values were not calculated for woody species because there were few species and the importance of a species could be easily assessed based on frequency and basal area alone.

A number of different methods were used to quantify, compare and analyze floristic quality at the site level, including species richness, Shannon-Weiner Diversity Index, mean Coefficient of Conservatism, weighted Coefficient of Conservatism, and Floristic Quality Index. Ideally, these comparisons would be weighted proportionally to the relative area of each community type within each site, but this was not possible to do based on the inability to consistently create accurate maps to community or association level.

Species richness was determined for all sites in two different ways, one by including incidental species (total richness), and another by only including species found within the plots (plot richness). Richness calculations included all plant taxa present, including those not identified to species level.

Shannon-Weiner Diversity Index (H) was calculated because it takes into account both species richness and evenness to better define diversity of a plot. It was calculated by taking the negative sum of the relative cover (P_i) of each species at a plot multiplied by the natural log of its relative cover:

$$H = -\sum P_i(\ln P_i)$$

Coefficients of Conservatism ($\bar{C}$) data were calculated from the average of the C-values of all species found at each site (Wilhelm 1977). The coefficients of conservatism are values (0-10) assigned to native plant species based on their likelihood of being encountered in disturbed or natural areas. The lowest values correspond to Grime's (1974) ruderal, or weedy, species and have values of 0-1. Species with the highest values, 7-10, are less tolerant of stresses and require habitats further along in succession (Taft et al. 1997). Values are determined at the state level by local experts, so they can vary greatly among states (Rothrock and Homoya 2005, Bouraghs et al. 2006). For this project all values were taken from the South Dakota list, as the majority of the study area was in South Dakota and the sites in Nebraska were near the border.

Coefficient of Conservatism data were analyzed a number of ways; including or excluding non-native species (because non-native species are not assigned values), and using total (including incidentals) or plot richness, for a total of four calculations. Only plants identified to species level were used for these calculations. Mean, unweighted Coefficients of Conservatism were calculated by:

$$\bar{C} = \frac{\sum C}{N}$$

Weighted Coefficients of Conservatism ($w\bar{C}$) were calculated by multiplying the C-value of a species with its relative abundance at each plot and summing these values across all species. Because this required relative abundance, this was only done for herbaceous species and excluded incidental species. This is calculated by:

$$w\bar{C} = \Sigma\, p * C$$

Floristic Quality Index (FQI) incorporates species richness with Coefficient of Conservatism. This is calculated by taking the mean Coefficient of Conservatism and multiplying it by the square root of the number of species with Coefficient of Conservatism values found at the plot:

$$\text{FQI} = \bar{C}\sqrt{N}$$

Species were assigned numerical values based on their Wetland Indicator Status designations (**Table 6**). Some species lacked Wetland Indicator Status designations so calculations were performed twice, once with the missing species excluded, and once with the missing species assigned a value of 5, the upland value.

Table 6. Wetland Indicator Status and their assigned numerical value used for calculations

Wetland Indicator Status	**Numerical Value**
OBL	1
FACW	2
FAC	3
FACU	4
UPL	5
None	5 (or not calculated)

Wetland Indicator Status data were summarized by calculating the Wetland Prevalence Index, using the average numerical value of the Wetland Indicator Status or by summing the weighted indicator status with the relative percent cover (Wentworth et al. 1988). The first method includes all species and was performed twice, with and without incidental species. The second method only includes herbaceous species and requires cover estimates. Hence, incidentals were not included.

Woody data were calculated and compared a number of different ways among ecoregions and community types. Stem density was compared for all stems, large stems, and small stems at each site. Basal area was compared for all species, only cottonwoods, and non-cottonwood species at each site.

All values were compared using ANOVA among ecoregions and community types, with multiple comparisons using Tukey's post-hoc comparison of means. Statistical significance was defined at $p \leq 0.05$ and results were considered nearly or marginally significant for $0.05 < p < 0.10$.

Part IV – Landscape Dynamics and Vegetation Patterns in the White River Delta

Measuring the Formation of the White River Delta

Historic stream cross sections from the U.S. Army Corps of Engineers (USACE) were used to investigate geomorphic changes that occurred along the lower White River and along the Missouri River (Lake Francis Case) near the White River-Missouri River confluence during the post-dam era. USACE surveyed repeat cross sections every few kilometers downstream of river-km 42.3 on the White River since 1954, and near the White River-Missouri River confluence at Missouri River km 1608.4 since 1953. Nine cross sections ranging from White River km 3.1 to 30.9 were surveyed every 3 to 15 years between 1954 and 2011 (the cross section at river-km 16.0 was not established until 1986). The cross section located at river-km 1608.4 on the Missouri River was surveyed several times between 1953 and 2011. The 1953/1954 cross section surveys were completed 1-2 years following closure of Fort Randall Dam, which forms Lake Francis Case, and were considered representative of the pre-dam channel and floodplain environment for this investigation.

All available cross sections from the lower White River and its confluence with the Missouri River were initially inspected to identify cross sections that exhibited a net increase in thalweg elevation (maximum depth of the channel, or minimum elevation of the cross section) during the post-dam era. After determining that all cross sections located downstream of White River km 31 exhibited a net increase in thalweg elevation over the study period, a subset of cross sections from this group was then selected for further investigation. Five cross sections from the White River and one cross section from Lake Francis Case near the confluence were used to construct graphs illustrating geomorphic change over time. Cross section width was plotted against elevation using SigmaPlot 12.0 to identify changes in river channel and floodplain morphology between measurement periods spanning 1953/1954-1973, 1973-1996, and 1996-2011. The net change in thalweg elevation at each cross section during each measurement interval was calculated by determining the minimum elevation of each cross section and subtracting it from the minimum elevation of the cross section for the next year of measurement. The rate of change in thalweg elevation was calculated by dividing the net change by the number of years between measurements. The net change in thalweg elevation and the rate of change in thalweg elevation for each cross section at each measurement interval were compared graphically. The gradient of the lower 31 km of the White River in 1954 (2 years post-dam) and in 2011 (59 years post-dam) was constructed from thalweg elevations at each of nine cross sections within the study reach and determined by calculating the slope of a linear regression line running through the thalweg elevation at all nine cross sections using SigmaPlot 12.0.

Measuring Changes in Riparian Woodland Area over Time

Changes in the area and age classes of riparian woodland within the lower White River during the post-dam era were quantified using historic aerial photos and GIS-based mapping. The only pre-dam image available was from 1948, taken 4 years prior to complete closure of Fort Randall Dam in 1952. Post-dam aerial photos were for years 1983, 1991, 1998, 2004, 2010, and 2012. Imagery from 1948-1998 was obtained from the USDA Aerial Photography Field Office (http://www.apfo.usda.gov/); imagery from 2004-2012 was obtained from the USDA NRCS Geospatial Data Gateway (http://datagateway.nrcs.usda.gov/) (**Table 7**).

Table 7. Description of historical aerial photography used for measuring historical changes in riparian woodland area in the White River delta.

Date(s)	Source	Description	Scale	Pixel Resolution
1948	United States Department of Agriculture (USDA)	black-and-white	1:20,000	0.5-0.6 m
1983	National High Altitude Photography (NHAP)	color-infrared	1:60,000	1.3 m
1991, 1998	National Aerial Photography Program (NAPP)	black-and-white	1:40,000	0.5 m
2004	National Agricultural Imagery Project (NAIP)	county mosaic orthophotography, natural color	1:40,000	1 m
2010, 2012	National Agricultural Imagery Project (NAIP)	county mosaic orthophotography, natural color	n/a	1 m

Aerial photos older than 2004 lacked geospatial information, hence were geo-rectified using ArcGIS 10.0 and the 2010 NAIP orthophotography as a base map. At least three points linking features (e.g., road intersections, buildings) common to both images were selected as control points to reference the historic image to the base map. The default projection for the NAIP orthophotography was NAD 1983 UTM Zone 14N, which was utilized for all other images and subsequent shapefiles.

The study area encompassed a 29 km reach of the lower White River and its floodplain which included both the White River delta (Delta) as defined previously and the river-delta transition zone (lower 12 km of the River Breaks section), as the exact boundary of long-term reservoir influence and deltaic processes is uncertain. The lateral boundary was determined from a Digital Elevation Model (3 m pixel size) contour that marked the transition from the low relief of the valley floor to the steep valley wall. Adjustments were made to align this boundary with the 2010 NAIP orthophotography to exclude non-floodplain features such as intersecting upland watersheds from the study area. A total of 2,699 ha of floodplain and reservoir area was contained within the delta study area as defined.

Digitizing methods followed those of Dixon et al. (2012) , though a different land cover classification system was used for this study. Land cover was broadly classified as either riparian woodland (≥50% woodland canopy cover) or other land cover (e.g., <50% woodland canopy cover, herbaceous vegetation, river channel, and reservoir). Hence, the definition used here for riparian "woodland" is congruent with the definition of forest (≥50% canopy cover) used in Parts I-III. Riparian woodland included cottonwood/willow forest, willow shrubland, tree saplings, and tree seedlings. The area of riparian woodland was calculated for each time period and compared between years.

Overlays of classified images from select years (1948/2012, 1991/1998, and 2010/2012) were produced to compare changes in the area and location of riparian woodland over time. Classifications were improved by field reconnaissance (ground-truthing), which included sampling of woodland composition and structure in selected stands and visual inspection by walking through the study reach.

To assess flood damage and mortality associated with the 2011 Missouri River flood, the highest stage on record for Lake Francis Case, two additional woodland categories were added to the 2012 classified image: (1) complete mortality of riparian woodland and (2) flood damaged riparian woodland. Complete mortality was assigned to woodland patches that were present in 2010 but no longer appeared as green woody vegetation in the 2012 image. Flood damaged woodland was defined as woodland patches that were present in both 2010 and 2012, but showed reduced canopy cover (<50%) in 2012. Dead canopy cover was measured by both the proportion of leafless trees and the presence of bare soil or woody debris within the 2010 woodland polygon. The 2010 and 2012 classified images were overlaid to determine the location and areal extent of flood related damage and mortality.

Riparian woodland age classes were delineated and mapped from three aerial photos representing the pre-dam (1948), post-dam midpoint (1983), and post-dam endpoint (2012) of the study period. On each image, the riparian woodland cover class was broadly divided into young, medium, and old age classes. The young age class was defined as woody vegetation less than tree size (<10 cm dbh), including sandbars colonized by woody seedlings and/or saplings and shrubland typically dominated by willows. The medium age class was defined as young forest (trees ~10-20 cm dbh), typically composed of dense cottonwood trees of uniform size. The old age class was applied to later successional forest, typically with larger, more widely spaced cottonwood trees and a diverse mid-story. The area of riparian woodland age classes was compared numerically and graphically between years. To detect any longitudinal pattern of riparian age classes, the study reach was evenly divided into six, 4.8-km (3 mile) long segments. The percent of riparian woodland area in the young, medium, and old age classes was calculated in each segment.

Woody Vegetation and Cottonwood Recruitment Patterns in the Delta

Stands were divided into two main size categories related to age. These included a tree size category (stands in which the majority of cottonwood trees were $\geq$10 cm dbh) and a shrub size category (stands containing only shrubs and saplings <10 cm dbh and $\geq$1 m tall). Species specific data on densities of each were obtained through field sampling and are presented in the Results and Discussion. Sampling was conducted using the point-centered quarter method for trees (Cottam and Curtis 1956) and a line-strip method for shrubs (Lindsey 1955) as in the work by Dixon et al. (2010) on the Missouri River. These methods were used for sampling the 34 stands being studied in the doctoral research of Malia Volke. Methods and sites summarized in Parts I-III differ from these and represent work by Alex Cahlander-Mooers as part of his MS thesis.

RESULTS AND DISCUSSION

Part I – Current (2010) Land Cover for the Entire Corridor and by Ecoregion

The total area of the mapped riparian corridor along the White River within our study area was 60,188 hectares (**Table 8**). Although the River Breaks ecoregion held half of the floodplain area, it only contained 42% of the total channel length. The Pine Ridge/Pierre Shale Ecoregion contained 20% of the total floodplain area, but about a third of the channel length. The Badlands floodplain area (28% of total) to river length (26% of total) was proportionate. The Delta represented only 3% of the entire study area and 2% of the river length. The greatest among of elevation change and highest river and floodplain gradients occurred in the Pine Ridge/Pierre Shale Ecoregion, with the gradient progressively flattening through the Badlands, River Breaks, and the Delta.

Table 8. Total floodplain area, length, average width, and river length among ecoregions for the entire White River floodplain. Percent of total for study area is in parentheses.

Ecoregion	Pine Ridge / Pierre Shale	Badlands	River Breaks	Delta	Total
Floodplain Area (ha)	12,143 (20%)	16,635 (28%)	29,801 (50%)	1,609 (3%)	60,188
Floodplain Length (km)	156.6	159.3	256.5	17.6	590.1
Average Floodplain Width (km)	0.577	0.671	0.672	1.057	0.651
River Length (km)	271.3 (30%)	237.3 (26%)	381.8 (42%)	16.6 (2%)	907.1
Elevation Change (m)	306	198	254	10	768
Floodplain Slope (m/km)	1.95	1.24	0.99	0.57	1.30
River Slope (m/km)	1.13	0.83	0.67	0.60	0.85

Across the whole study area, herbaceous cover types dominated the floodplain, comprising about two thirds of the total area; of which 40% was grasslands and 26% farmland (**Table 9, Figure 11**). Grasslands may have been overestimated relative to other less abundant herbaceous cover types like wet meadows and marshes because of the difficulty differentiating these cover types from the more generic grasslands cover type. Forestland covered 23% of the total floodplain area, most of which (18%) was closed canopy forests. Area of shrublands was likely underestimated, as they were difficult to distinguish from other forestland and some grassland cover types. Area of water was 7% of the total study area, mostly from the river's main channel.

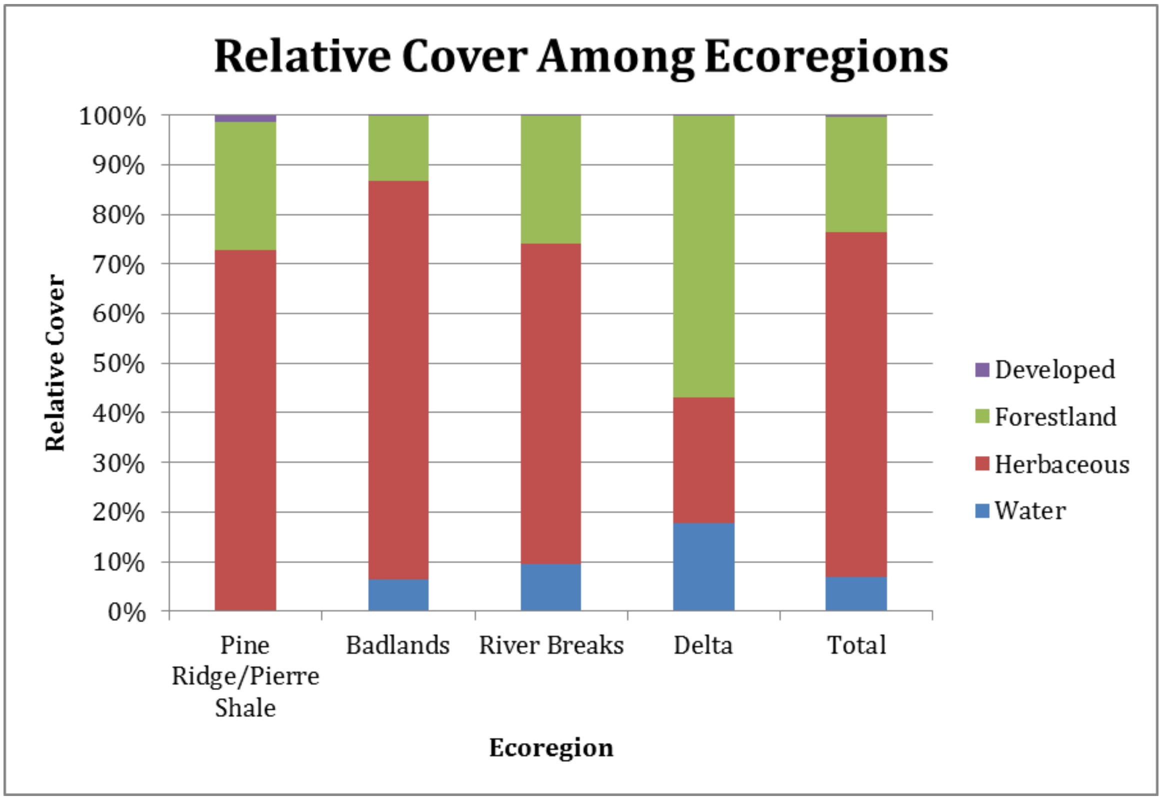

Figure 11. 2010 relative area of major land cover types, by ecoregion, within the floodplain of the White River.

Table 9. Land cover areas and % by specific and broader categories within each ecoregion segment and across the entire White River riparian corridor, based on 2010 NAIP imagery.

Land Cover	**Pine Ridge/ Pierre Shale**	**Badlands**	**River Breaks**	**Delta**	**Total**
Main Channel	0 (0%)	1,023 (6.2%)	2,803 (9.4%)	100 (6.2%)	3,926 (6.5%)
Tributary Channel	0 (0%)	14.1 (0.08%)	45.4 (0.2%)	0 (0%)	59.5 (0.1%)
Lake	24.7 (0.2%)	20.1 (0.12%)	21.4 (0.07%	187 (11.6%)	253.2 (0.4%)
Total Water	**24.7 (0.2%)**	**1,057.2 (6.4%)**	**2,870 (9.7%)**	**287 (17.8%)**	**4,239 (7%)**
Grassland	4,616 (38%)	11,030 (66.3%)	8,502 (28.5%)	81.6 (5.1%)	24,230 (40.3%)
Wet Meadow	0.87 (0.01%)	23.4 (0.14%)	49.1 (0.2%)	4.2 (0.3%)	77.6 (0.1%)
Farmed Field	4,199 (34.6%)	2,007 (12%)	9,409 (31.6%)	129.3 (8%)	15,743 (26.2%)
Marsh	7.9 (0.07%)	16.6 (0.1%)	132.3 (0.4%	171 (10.6%)	327.8 (0.5%)
Wet Meadow/ Willow Mix	3.6 (0.03%)	276.8 (1.7%)	1,099 (3.7%)	20.9 (1.3%)	1,400 (2.3%)
Total Herbaceous	**8,827 (72.7%)**	**13,354 (80.2%)**	**19,191 (64.4%)**	**407 (25.3%)**	**41,778 (69.4)**
Forest	2,365 (19.5%)	1,310 (7.9)	6,186 (20.8%)	851 (53%)	10,711 (17.8%)
Woodland	571 (4.7%)	728 (4.4%)	1,346 (4.5%)	57.6 (3.6%)	2,702 (4.5%)
Shrubland	202 (1.7%)	172.5 (1%)	172.7 (0.6%)	4.6 (0.3%)	551.9 (0.9%)
Total Forestland	**3,138 (25.8%)**	**2,210.5 (13.3%)**	**7,704 (25.9%)**	**913.2 (56.9%)**	**13,965 (23.2%)**
City/Town	114.8 (1%)	6.8 (0.04%)	1.5 (0.01%)	0 (0%)	123.1 (0.2%)
Farm Complex	38.4 (0.3%)	8.1 (0.05%)	34.7 (0.12%)	1.3 (0.08%)	82.4 (0.1%)
Total Developed	**153.2 (1.3%)**	**14.9 (0.1%)**	**36.2 (0.1%)**	**1.3 (0.08%)**	**205.5 (0.3%)**
Total	**12,143**	**16,636**	**29,801**	**1,609**	**60,188**

The riparian corridor in the Pine Ridge/Pierre Shale Ecoregion was dominated by herbaceous cover (73%), which was split almost evenly between grasslands (38%) and farmland (35%) (**Table 9**, **Figure 11**). Area of the willow mix community was very low because patches were often smaller than the 0.25 ha minimum mapping unit and hence were lumped with the surrounding land cover types. Willow mix communities may also have been smaller on this segment because the channel was incised and disconnected from the greater floodplain in some areas (**Figure 12**). 26% of the corridor area in this ecoregion was forestland, most of which was closed canopy forests (19%). Crawford, NE (city/town land cover) accounted for about 1% of the ecoregion and there was little other developed land. There was very little cover from water because the channel was too narrow and obscured by overhanging vegetation to be accurately mapped through the Pine Ridge/Pierre Shale Ecoregion segment.

Figure 12. Incision of the White River in the Pine Ridge/Pierre Shale Ecoregion at Fort Robinson State Park, NE.

Cover in the Badlands Ecoregion was dominated by herbaceous communities (79%) (**Table 9**, **Figure 11**). Unlike in the Pine Ridge/Pierre Shale Ecoregion, this was mostly grasslands (66%) with a smaller proportion of farmland (12%). Forestland made up 13% of the area, about half of its relative cover in the Pine Ridge/Pierre Shale. Relative area of woodlands and shrublands was similar to that of the Pine Ridge/Pierre Shale, but relative area of forest was greatly reduced. The White River channel made up about 6% of the total area in the riparian corridor in the Badlands Ecoregion. Because there are no cities or towns in the Badlands floodplain, there was very little area of development. The change in floodplain cover, particularly the decline in riparian forest, from the Pine Ridge/Pierre Shale to Badlands Ecoregion can be seen dramatically in an aerial photograph of the ecoregion boundary (**Figure 13**).

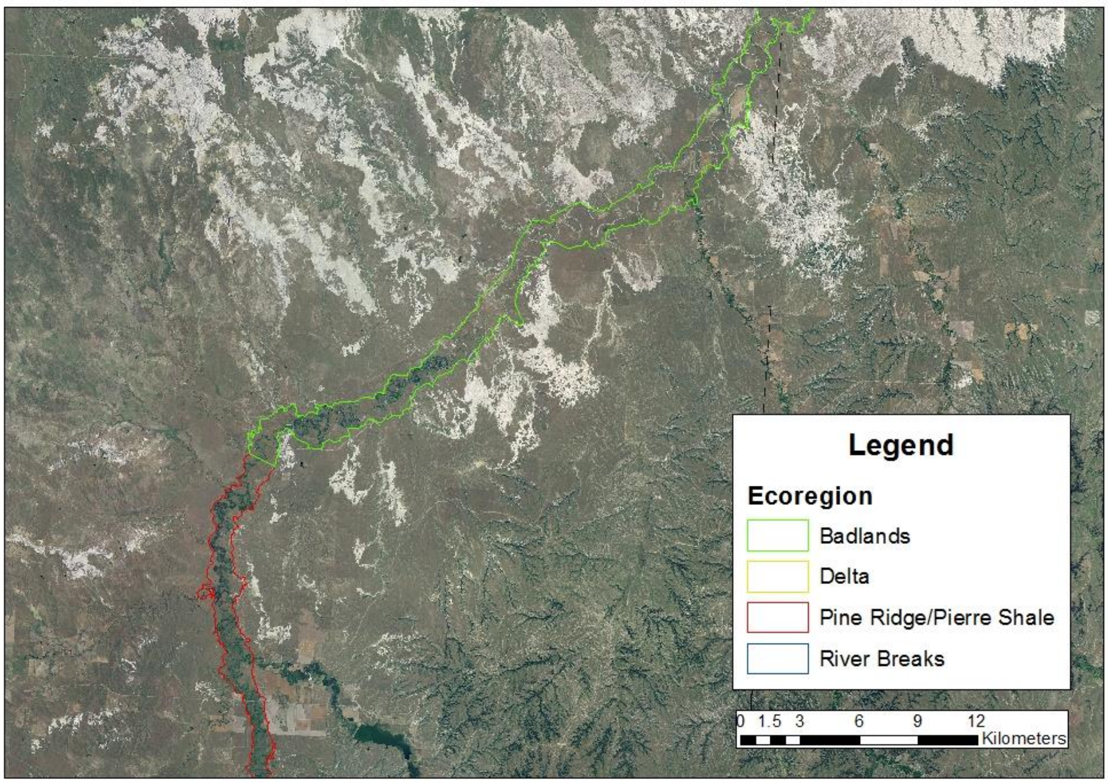

Figure 13. 2010 aerial imagery along the White River at the border with the Pine Ridge / Pierre Shale and Badlands Ecoregions in Shannon County, SD. Note the change from a more forested floodplain to a more herbaceous floodplain shortly downstream (northeast) of the border.

The majority of the floodplain within the River Breaks Ecoregion was herbaceous (61%). Like the Pine Ridge/Pierre Shale, this was split between grasslands (29%) and farmland (32%) (**Table 9, Figure 11**). Herbaceous/willow mix communities comprised nearly 4% of the floodplain, which was much higher than in the other ecoregions. Forestlands made up 26% of the segment, most of which (21%) was forest. Woodlands and shrublands comprised 5% and 0.6%, respectively, similar to their coverage on the other ecoregions. Channel was about 9% of the total area. Like the Badlands, the floodplain had very little development. The stark change in cover that was seen between the Pine Ridge/Pierre Shale and Badlands Ecoregions was not seen between the Badlands and River Breaks (**Figure 14**) as the forest size increases gradually, rather than abruptly.

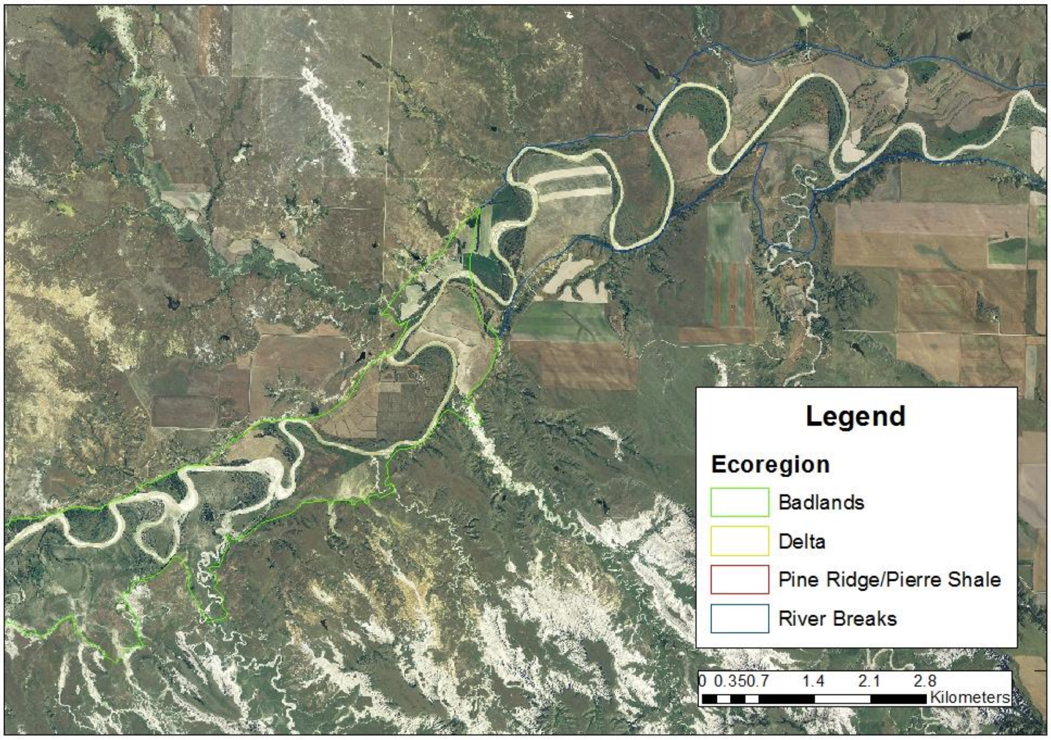

Figure 14. 2010 aerial imagery along the White River at the border with the Badlands and River Breaks Ecoregions in Jackson County, SD. Note that it is the land cover outside the floodplain that is the most obvious change between the ecoregions.

Unlike the other segments, the Delta was dominated by forestland (57%), nearly all of which (90% of forestland area) was forest (**Table 9, Figures 11 and 15**). Woodlands occurred in similar proportions as the other segments, but the Delta had the lowest relative area of shrubland of any of the ecoregion segments. Relative area of herbaceous cover types was greatly reduced compared to the other segments, covering only 24% of the total area in the Delta. Unlike the other segments, much of the herbaceous cover was marshes (11% of total area). The Delta also had a greater proportion of water cover (18%), which was split between the river channel (6%) and lakes (12%). The lake coverage in the delta was formed from flooded areas near, but not connected to, Lake Francis Case. Relative areas of herbaceous land cover and water likely vary greatly from year to year based on differences in the Missouri River flow regime and the timing of aerial imagery.

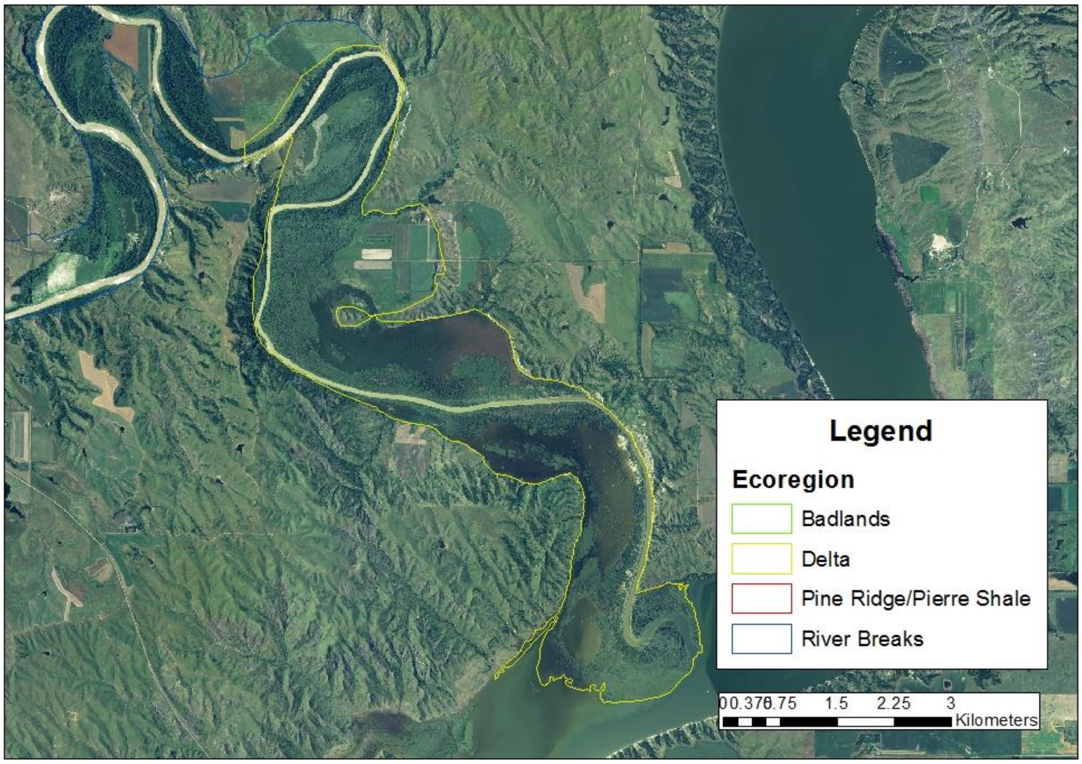

Figure 15. 2010 NAIP imagery of the delta of the White River with the Missouri River at Lake Francis Case.

Analysis of Variance (ANOVA) was used to compare the average patch sizes of woody land cover (forestland) across study segments. The smallest average patch sizes of forestland cover types were found in the Badlands, whereas the Delta had significantly larger patches than any other segment. When comparing closed canopy forest patches alone, the results were similar, with the Delta having the largest and Badlands the smallest average patch sizes. Density (# patches per km^2) of forestland cover types followed a similar pattern to average patch area, with the Badlands having the highest number of forestland polygons per km^2, and the Delta having the least, with the Pine Ridge/Pierre Shale and River Breaks intermediate.

Although Pine Ridge/Pierre Shale and River Breaks did not differ significantly from each other in their mean patch areas for forests and forestland areas, their densities differed, with the River Breaks having about 50% more forest patches per km^2 than the Pine Ridge/Pierre Shale. The general nature of the forestland types varied between these two ecoregions, with the Pine Ridge/Pierre Shale forestland being generally connected and contiguous across the floodplain (**Figure 16**) or strictly following the river (**Figure 17**), while the forestland of the River Breaks was generally confined to point bars or abandoned channels (**Figure 18**).

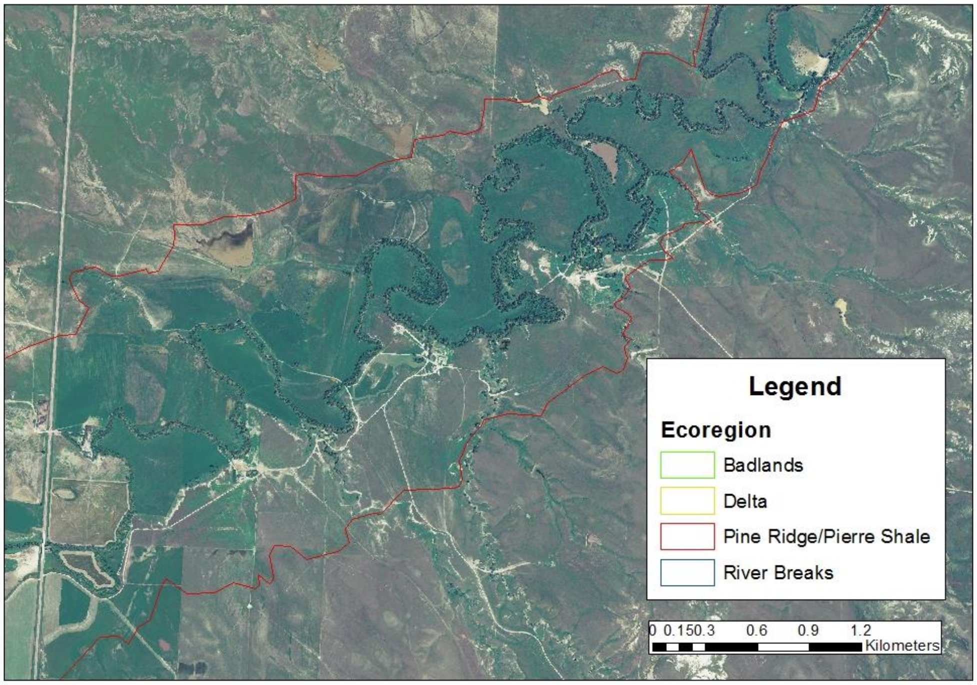

Figure 16. Connected forests of the White River covering and following the river in the Pine Ridge/Pierre Shale Ecoregion near Chadron, NE.

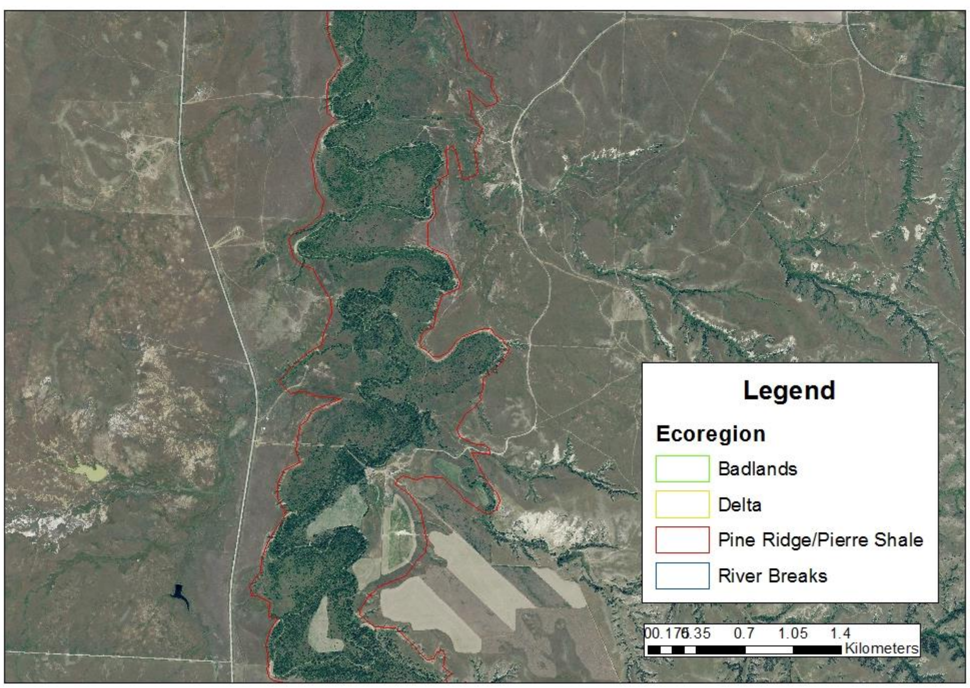

Figure 17. Connected forests of the White River covering much of the floodplain in the Pine Ridge/Pierre Shale Ecoregion within the Pine Ridge Indian Reservation, Shannon County, SD.

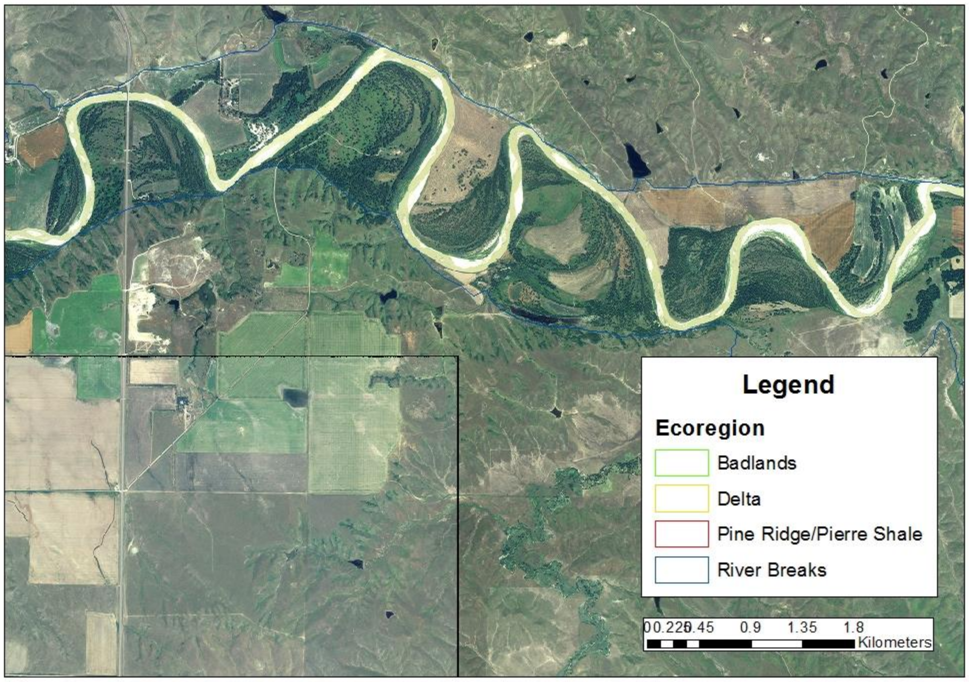

Figure 18. Forest of the White River separated by the river and isolated to point bars and abandoned channels on the border of Lyman and Tripp Counties, SD in the River Breaks Ecoregion.

Land Cover Estimates from Cropland Data Layer (CropScape)

Land cover area estimates gathered from the National Agriculture Statistical Service via CropScape differed slightly from those determined from aerial photography interpretation and digitizing in this project and these differences varied greatly among the ecoregions (**Tables 10 and 11**, **Figure 19**). Overall, water cover was similar throughout both mapping types, with Cropland Data Layer cover underestimating (relative to the mapping in this project) it in the Pine Ridge/Pierre Shale and Badlands Ecoregions. In general, the Cropland Data Layer mapped 10-15% more herbaceous (includes farmland) land cover. Within herbaceous cover, our mapping delineated more land as cropland and less as other herbaceous covers, relative to the Cropland Data Layer (**Table 11**). Estimates of forestland area were lower in the Cropland Data Layer in all of the ecoregions. The greatest difference in the two mapping methods was in the Badlands, with four times as much forest mapped using our methods than was delineated in CropScape. Across the entire study area, this project mapped around twice as much forest area as CropScape. Details on areas for more specific land cover categories within CropScape are provided in the Appendix in **Table A1**.

Table 10. 2010 Cropland Data Layer cover in hectares in the White River floodplain among ecoregions and consolidated into cover types. Percent cover for each cover type within each ecoregion is in parentheses.

Cover Type	Pine Ridge/ Pierre Shale	Badlands	River Breaks	Delta	Total
Water	**9.9 (0.1%)**	**649.9 (3.9%)**	**3165.3 (10.6%)**	**280.9 (17.4%)**	**4106.0 (6.8%)**
Herbaceous	7337.7 (60.6%)	14034.6 (84.4%)	14700.8 (49.3%)	295.1 (18.3%)	36368.1 (60.5%)
Crop (Farmland)	2471.5 (20.4%)	1278.0 (7.7%)	7539.7 (25.3%)	249.6 (15.5%)	11538.9 (19.2%)
Total Herbaceous	**9809.2 (81.0%)**	**15312.5 (92.1%)**	**22240.5 (74.6%)**	**544.7 (33.8)**	**47907.0 (79.6%)**
Forestland	**1767.9 (14.6%)**	**467.4 (2.8%)**	**3747.4 (12.6%)**	**767.9 (47.7%)**	**6750.6 (11.2%)**
Developed	**529.7 (4.4%)**	**189.1 (1.1%)**	**660.2 (2.2%)**	**16.5 (1.0%)**	**1395.4 (2.3%)**
Total	**12116.6**	**16618.8**	**29813.5**	**1610.0**	**60159.0**

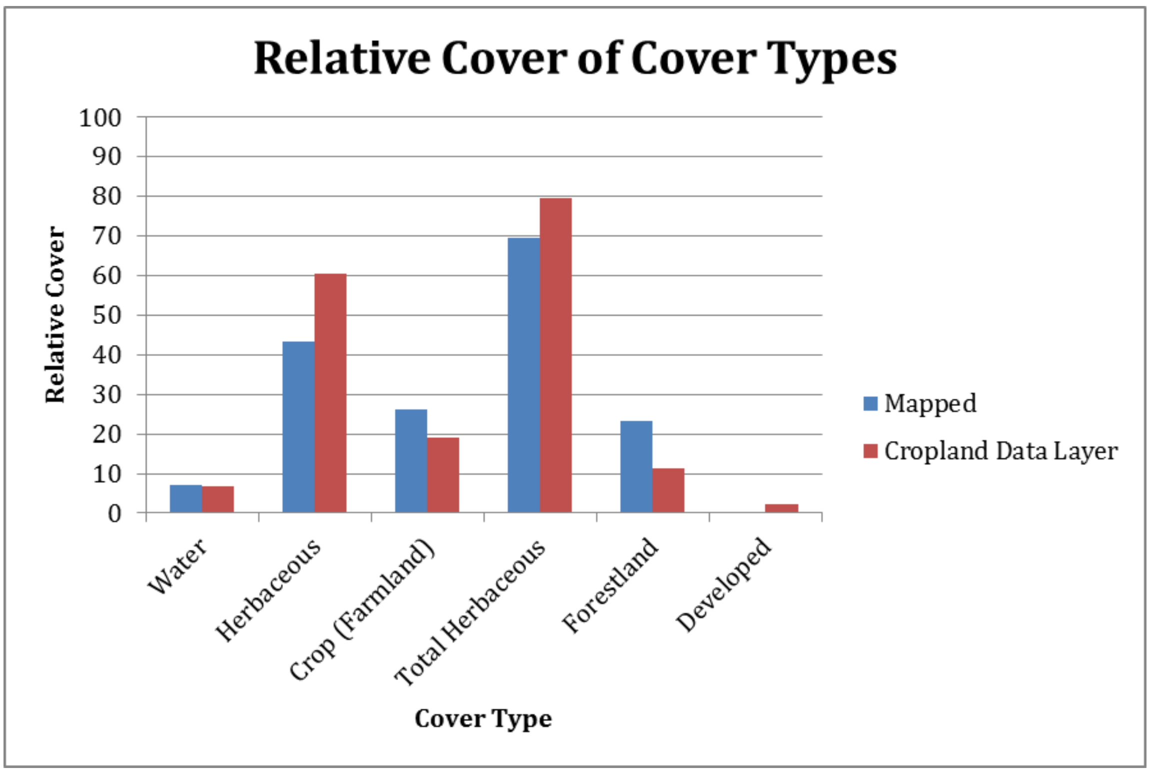

Figure 19. 2010 relative cover of cover types for the entire White River floodplain as mapped for this project versus Cropland Data Layer cover.

Table 11. Percent difference between 2010 mapped cover and Cropland Data Layer cover among ecoregions.

Cover Type	**Pine Ridge/ Pierre Shale**	**Badlands**	**River Breaks**	**Delta**	**Total**
Water	**-144.4%**	**-62.4%**	**9.3%**	**-2.3%**	**-3.1%**
Herbaceous	37.1%	19.2%	33.5%	5.6%	28.5%
Crop (Farmland)	-69.6%	-56.1%	-25.0%	48.4%	-36.6%
Total Herbaceous	**10.2%**	**12.9%**	**13.7%**	**25.2%**	**12.8%**
Forestland	**-77.1%**	**-372.2%**	**-105.7%**	**-19.0%**	**-106.8%**
Developed	**71.2%**	**92.1%**	**94.6%**	**92.2%**	**85.3%**

2010 Land Cover within Former Channel Cutoffs

As noted in the Methods section, land cover within former channel cutoff sites (abandoned channels) was assessed for the Badlands and River Breaks Ecoregion segments. These were not assessed within the Pine Ridge / Pierre Shale segment because of the narrow nature of the river channel and hence difficulty in delineating abandoned channel areas. No cutoffs were noted in the Delta segment.

Abandoned channels made up a small proportion of the total floodplain area in the Badlands and River Breaks ecoregions; 1.3% (213.6 ha) of Badlands and 2.5% (731.4 ha) of the River Breaks. Abandoned channels were likely underestimated in both segments; however, particularly in the Badlands, because the predominant herbaceous cover made it more difficult to identify former channel locations there than in the more wooded River Breaks. In contrast to forests, abandoned channels that have developed herbaceous vegetation may be indistinguishable from adjacent grasslands on aerial imagery because the distinctive horseshoe look of an abandoned channel does not appear.

The land cover found in identified abandoned channel sites was similar for the Badlands and River Breaks Ecoregions (**Table 12**). Forestland accounted for 40% and 45% of the Badlands and River Breaks cutoff area, respectively. Herbaceous cover types accounted for 54% and 51% of the cutoff area for the Badlands and River Breaks, respectively. The amount of developed land found in cutoffs was negligible.

Table 12. 2010 land cover areas (ha) within abandoned channel sites along the White River for the Badlands and River Breaks study segments. Percent cover in parentheses.

Land Cover	Badlands	River Breaks
Water	**11.6 (5.4%)**	**28.3 (3.9%)**
Grassland	72.4 (33.9%)	224.1 (30.6%)
Wet meadow	11.4 (5.3%)	25.5 (3.5%)
Farmland	11.9 (5.6%)	42.0 (5.7%)
Marsh	13.0 (6.1%)	62.4 (8.5%)
Willow/herbaceous mix	7.0 (3.3%)	19.4 (2.7%)
Total herbaceous	**115.7 (54.2%)**	**373.4 (51.1%)**
Forest area	67.2 (31.4%)	273.7 (37.4%)
Woodland	12.0 (5.6%)	37.2 (5.1%)
Shrubland	7.1 (3.3%)	18.8 (2.6%)
Total forestland	**86.4 (40.4%)**	**329.7 (45.1%)**
Total	**213.6**	**731.4**

The proportion of the total forestland area within each segment that occurred in abandoned channels was relatively low, at around 4% for both the Badlands and River Breaks (**Table 13**). The biggest difference between the segments was that nearly 11% of the shrublands in the River Breaks occurred on abandoned channel sites vs. only 4% in the Badlands. Only a small proportion of the grassland, farmland, and herbaceous/ willow mix in both segments occurred in channel cutoff areas. Although the total area of wet meadows was not large in cutoff areas, it accounted for about half of wet meadow area in both ecoregions. Former cutoffs provided a high proportion of the marshland area in each segment, at 79% in the Badlands and 47% in the River Breaks.

Table 13. Area (ha) and % of total floodplain land cover, by land cover type, that occurred in abandoned channels in the Badlands and River Breaks Ecoregions.

Cutoff Cover	Badlands	River Breaks
Forest	67.2 (5.1%)	273.7 (4.4%)
Woodland	12.0 (1.7%)	37.2 (2.8%)
Shrubland	7.2 (4.1%)	18.8 (10.9%)
Forestland	**86.4 (3.9%)**	**329.7 (4.3%)**
Grassland	72.4 (0.7%)	224.1 (2.6%)
Wet Meadow	11.4 (48.6%)	25.5 (51.9%)
Farmland	11.9 (0.6%)	42.0 (0.5%)
Marsh	13.0 (78.6%)	62.4 (47.1%)
Wet Meadow/Willow Mix	7.0 (2.5%)	19.4 (1.8%)
Herbaceous	**115.7 (0.9%)**	**373.4 (1.9%)**

Discussion

Channel conditions varied longitudinally across ecoregions. Where the river begins it is covered by the forest canopy and is rather incised and disconnected from most of the floodplain. The river eventually becomes a 6^{th} order stream, but throughout the Pine Ridge/Pierre Shale it has characteristics of a headwater stream (1^{st}-3^{rd} order) covered by a canopy from the surrounding vegetation (Vannote et al. 1980). As the river continues through this segment it grows in width and discharge and becomes less incised, but continues to be covered by canopy. White stated that some of the drainages flowing into the White River have become more gullied in the periods after homesteading due to decreased sediment flow from a changing landscape (1980). It may be that the small river near the headwaters experienced the same phenomenon, causing it to be more incised than downstream. In the Badlands the river begins to have characteristics like a mid-sized river, with its increased size and no longer is covered by a forest canopy (Vannote et al. 1980). The channel area increases even more in the River Breaks Ecoregion, which creates more potential area for community establishment. Although Vannote's river continuum concept is commonly used for describing channels and their ecology, the White River does not fit well into this concept, primarily because after it flows through the Badlands it gains sediment that inhibits autotrophic productivity (Galat et al. 2005) that is typically gained with growing channel size (Vannote 1980).

Forestland cover varied greatly across ecoregions. In the Pine Ridge/Pierre Shale Ecoregion, forests are closed canopy and connected, bordering the river on each side, with little open-canopy woodlands or shrublands. In the Badlands, the proportion of forestlands is only half of what is found in the Pine Ridge/Pierre Shale and River Breaks. Badlands riparian forests do not border the river on both sides, but are separated and isolated to point bars and cutoffs. Woody cover types tended to be more open in the Badlands as well, with a higher proportion of woodlands to forests and similar proportional area of shrubland as in the Pine Ridge/Pierre Shale and River Breaks ecoregions. The River Breaks had similar proportions of forests and woodlands as the Pine Ridge/Pierre Shale, but rather than being connected, the forests were separated and mostly located on point bars and abandoned channels. River Breaks had the least proportional area of shrubland cover of the three natural segments. The majority of the Delta was dominated by closed-canopy forests, with little woodland or shrubland.

The amount of land cover that was formed from evident channel abandonment in the Badlands and River Breaks was only a small fraction of the total area in each segment's floodplain. River Breaks had twice the relative area of abandoned channels as Badlands. Oxbow lakes were not very prevalent along the river, although channel cutoffs were evident. This suggests that when channel abandonment occurs, the formed oxbow rapidly fills and is colonized by vegetation, rather than remaining a lake. Water levels on the White are not fully sustained throughout a summer, which gives vegetation opportunities to become established in oxbow lakebeds.

The vast majority of the Badlands' marshes occurred in cutoff area, along with nearly half of its wet meadows. In the River Breaks, about half of both wet meadows and marshes were formed in abandoned channels. Hence, although abandoned channels represent only a small proportion of the floodplain, they appear to be important in the formation of less abundant herbaceous land cover types.

Forestland cover was proportionately greater in both segments' abandoned channels than it was in the rest of the floodplain. In the Badlands, percent forest cover was three times higher in abandoned channels than in the rest of the floodplain, whereas woodland cover occurred nearly equally in both. The hydrological conditions in cutoffs likely create opportunities for forests to grow to be denser, with more closed canopies, than in non-cutoff areas for a variety of reasons. They occupy a lower elevation in the floodplain, contain residual water, and likely were created in a single event, causing the stands to be the same age. The River Breaks had similar patterns, with greater proportions of forests and similar proportions of woodlands in abandoned channels compared to the rest of the floodplain. Shrublands were more common in abandoned channels in both segments, showing that channel abandonment is important to establishing those community types.

These results differ considerably from Stella et al. (2011), who found that 50% of cottonwood forests along the Sacramento River, compared to about 5% on the White, were formed at abandoned channels. These results are more congruent with the research performed by Naiman et al. (2010), who consider abandoned channels as minor pathways for riparian community establishment. Richter and Richter (2000) also found that channel abandonment on the Yampa River in Colorado only accounted for a small portion of the floodplain, effecting only 0.2% of the cover change per year.

Part II – Historical Land Cover Dynamics

The area of the channel (-23%) and herbaceous cover (-6.4%) decreased from the 1930s to 2010 across the floodplain within the upper three study segments. Woody vegetation (forestland) increased 34%, with most of this expansion in forests (**Table 14**, **Figure 20**). Net declines in channel and herbaceous, and the net increase in forest would have been stronger had it not been for an increase in channel area and herbaceous land cover and a decrease in forest area between 2004 and 2010. Most of the net increase in forest occurred between the 1930s and 1980s, with relatively little change thereafter.

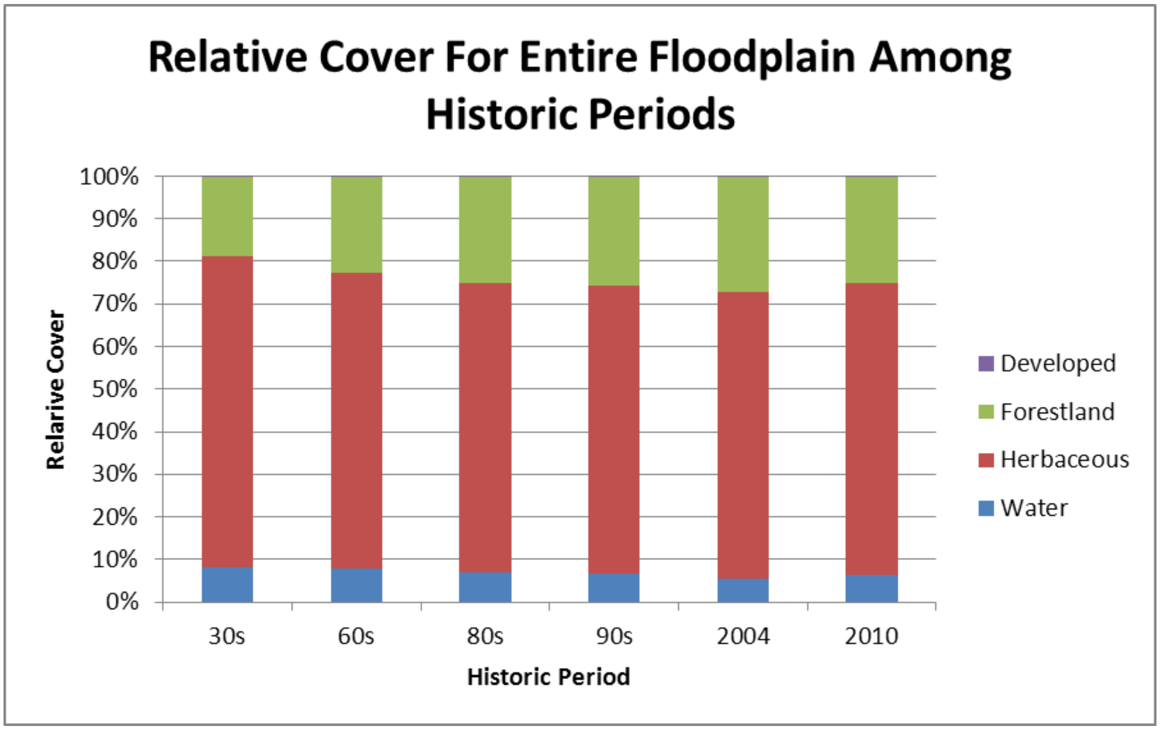

Figure 20. Historical changes in total relative cover by land cover type within the White River floodplain on the upper three White River study segments (Delta excluded).

Table 14. Historical land cover (ha) of the White River within mapped sections of the upper three study segments (Delta excluded). Percentage of area in parentheses.

Land Cover	**1930s**	**1960s**	**1980s**	**1990s**	**2004**	**2010**
Main Channel	1112.0 (8.0%)	1045.0 (7.5%)	958.3 (6.9%)	884.6 (6.4%)	758.7 (5.5%)	856.3 (6.2%)
Tributary Channel	14.1 (0.1%)	14.7 (0.1%)	14.5 (0.1%)	13.5 (0.1%)	13.6 (0.1%)	25.3 (0.2%)
Lake	0.6 (0.0%)	15.6 (0.1%)	9.3 (0.1%)	8.7 (0.1%)	0.0 (0.0%)	1.6 (0.0%)
Water Total	**1126.7 (8.1%)**	**1075.2 (7.7%)**	**982.0 (7.1%)**	**906.7 (6.5%)**	**772.3 (5.6%)**	**883.2 (6.3%)**
Grassland	2945.8 (21.2%)	4428.7 (31.8%	3920.7 (28.2%)	4114.6 (29.6%)	4967.7 (35.7%)	5357.7 (38.5%)
Wet Meadow	0.7 (0.0%)	70.6 (0.5%)	28.1 (0.2%)	8.1 (0.1%)	11.4 (0.1%)	39.5 (0.3%)
Farmland	6886.9 (49.5%)	4899.7 (35.2%)	5165.2 (37.1%)	4989.8 (35.9%)	4056.7 (29.2%)	3761.8 (27.0%)
Marsh	0.6 (0.0%)	8.8 (0.1%)	20.2 (0.1%)	22.4 (0.2%)	0.0 (0.0%)	41.3 (0.3%)
Willow Mix	342.8 (2.5%)	283.0 (2.0%)	288.4 (2.1%)	299.0 (2.1%)	323.2 (2.3%)	321.8 (2.3%)
Herbaceous Total	**10176.7 (73.1%)**	**9690.7 (69.7%)**	**9422.6 (67.7%)**	**9434.0 (67.8%)**	**9359.0 (67.3%)**	**9522.1 (68.4%)**
Forest	2041.0 (14.7%)	2470.4 (17.8%)	2775.6 (19.9%)	3005.9 (21.6%)	3044.7 (21.9%)	2729.2 (19.6%)
Woodland	489.0 (3.5%)	503.9 (3.6%)	651.3 (4.7%)	478.0 (3.4%)	593.9 (4.3%)	597.4 (4.3%)
Shrubland	66.8 (0.5%)	166.1 (1.2%)	67.7 (0.5%)	70.7 (0.5%)	121.9 (0.9%)	156.3 (1.1%)
Forestland Total	**2596.9 (18.7%)**	**3140.4 (22.6%)**	**3494.6 (25.1%)**	**3554.6 (25.5%)**	**3760.5 (27.0%)**	**3482.9 (25.0%)**
City/Town	6.3 (0.0%)	5.3 (0.0%)	7.0 (0.1%)	13.7 (0.1%)	11.8 (0.1%)	12.4 (0.1%)
Farm Complex	6.8 (0.0%)	1.7 (0.0%)	7.3 (0.1%)	4.5 (0.0%)	9.9 (0.1%)	12.8 (0.1%)
Developed Total	**13.1**	**7.1 (0.1%)**	**14.3 (0.1%)**	**18.1 (0.1%)**	**21.7 (0.2%)**	**25.2 (0.2%)**
Total	**13913.4**	**13913.4**	**13913.4**	**13913.4**	**13913.4**	**13913.4**

The Pine Ridge/Pierre Shale Ecoregion land cover remained relatively consistent over the historical periods, although there was some variation period to period with herbaceous cover decreasing by 2% and forestland cover increasing by 4% over 1930s-2010 (**Figure 21**, **Table 15**). The amount of herbaceous land mapped as farmland decreased over time and the grassland portions increased, particularly from the 1960s to 1980s, when mapped farmland area dropped by 47% and grassland area more than doubled. Woodland area showed a sharp increase (44%) during the same period and increased 71% overall, while forest area remained fairly stable. It was difficult to separate grassland from farmland and different photo types (black and white, color infrared, color) may have caused some of the differences in what was delineated in farmland versus grassland in different time periods. Some differences may have also been caused by the time of year the photograph was taken (for haying), or photograph year (fallow fields). Most land conversion in the Pine Ridge/Pierre Shale Ecoregion occurred from the 1930s-80s, after which there was less land conversion. There was no mapped channel area (because of the narrow channel and overhanging vegetation) in this area, and the channel here is likely less dynamic than on the other segments, eroding less old habitat and creating less new riparian habitat.

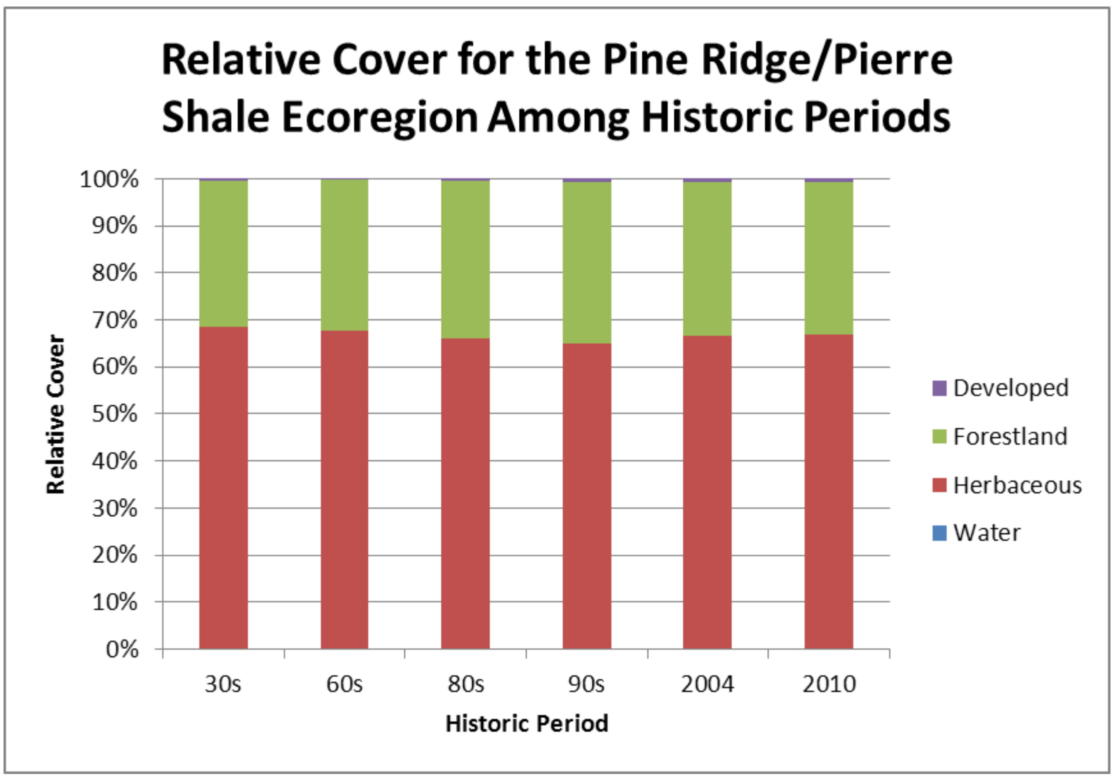

Figure 21. Historical changes in total relative cover by land cover type within the White River floodplain in the Pine Ridge/Pierre Shale Ecoregion.

Table 15. Historical land cover (ha) of the White River floodplain within mapped sections of the Pine Ridge/Pierre Shale Ecoregion. Percentage of area in parentheses.

Community Type	1930s	1960s	1980s	1990s	2004	2010
Lake	0.6 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	1.3 (0.1%)
Water Total	**0.6 (0.0%)**	**0.0 (0.0%)**	**0.0 (0.0%)**	**0.0 (0.0%)**	**0.0 (0.0%)**	**1.3 (0.1%)**
Grassland	254.3 (13.2%)	325.6 (16.9%)	755.3 (39.2%)	822.9 (42.7%)	954.8 (49.6%)	758.3 (39.4%)
Wet Meadow	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.9 (0.0%)
Farmland	1054.2 (54.8%)	978.4 (50.8%)	517.9 (26.9%)	428.6 (22.3%)	326.6 (17.0%)	524.6 (27.2%)
Marsh	0.6 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.4 (0.0%)	0.0 (0.0%)	0.5 (0.0%)
Willow Mix	8.0 (0.4%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)
Herbaceous Total	**1317.1 (68.4%)**	**1304.0 (67.7%)**	**1273.2 (66.1%)**	**1251.9 (65.0%)**	**1281.4 (66.6%)**	**1284.2 (66.7%)**
Forest	518.7 (26.9%)	544.6 (28.3%)	535.0 (27.8%)	568.8 (29.5%)	524.5 (27.2%)	481.8 (25.0%)
Woodland	74.2 (3.9%)	71.4 (3.7%)	102.6 (5.3%)	90.6 (4.7%)	92.8 (4.8%)	127.0 (6.6%)
Shrubland	7.3 (0.4%)	0.0 (0.0%)	6.0 (0.3%)	0.3 (0.0%)	10.6 (0.6%)	16.6 (0.9%)
Forestland Total	**600.2 (31.2%)**	**616.0 (32.0%)**	**643.7 (33.4%)**	**659.8 (34.2%)**	**628.0 (32.6%)**	**625.4 (32.5%)**
City/Town	6.3 (0.3%)	5.3 (0.3%)	7.0 (0.4%)	13.7 (0.7%)	11.8 (0.6%)	12.4 (0.6%)
Farm Complex	1.1 (0.1%)	0.0 (0.0%)	1.4 (0.1%)	0.0 (0.0%)	4.0 (0.2%)	2.0 (0.1%)
Developed Total	**7.4 (0.4%)**	**5.3 (0.3%)**	**8.4 (0.4%)**	**13.7 (0.7%)**	**15.9 (0.8%)**	**14.4 (0.7%)**
Total	**1925.3**	**1925.3**	**1925.3**	**1925.3**	**1925.3**	**1925.3**

The Badlands Ecoregion saw strong decreases in the area of the main channel over time (29%), which would have been even greater, had channel area not increased between 2004 and 2010 (**Table 16**, **Figure 22**). Like the Pine Ridge/Pierre Shale, herbaceous cover remained steady (albeit with variation back and forth between grassland and farmland) with a net change of only 1% increase. There was a moderate net increase (8%) in the area of woody land cover (forestlands), largely because of a steep increase in shrubland (vs. a decline in woodland) in 2004-2010. Actual area of closed canopy forest remained fairly stable over time. The decline in the area of the river channel appears to be a controlling factor in the increase in forests in the Badlands, and contributed to the minor increases in herbaceous cover area. Changes in cover occurred gradually over time, unlike the sharp changes observed before the 1980s on the Pine Ridge/Pierre Shale Ecoregion.

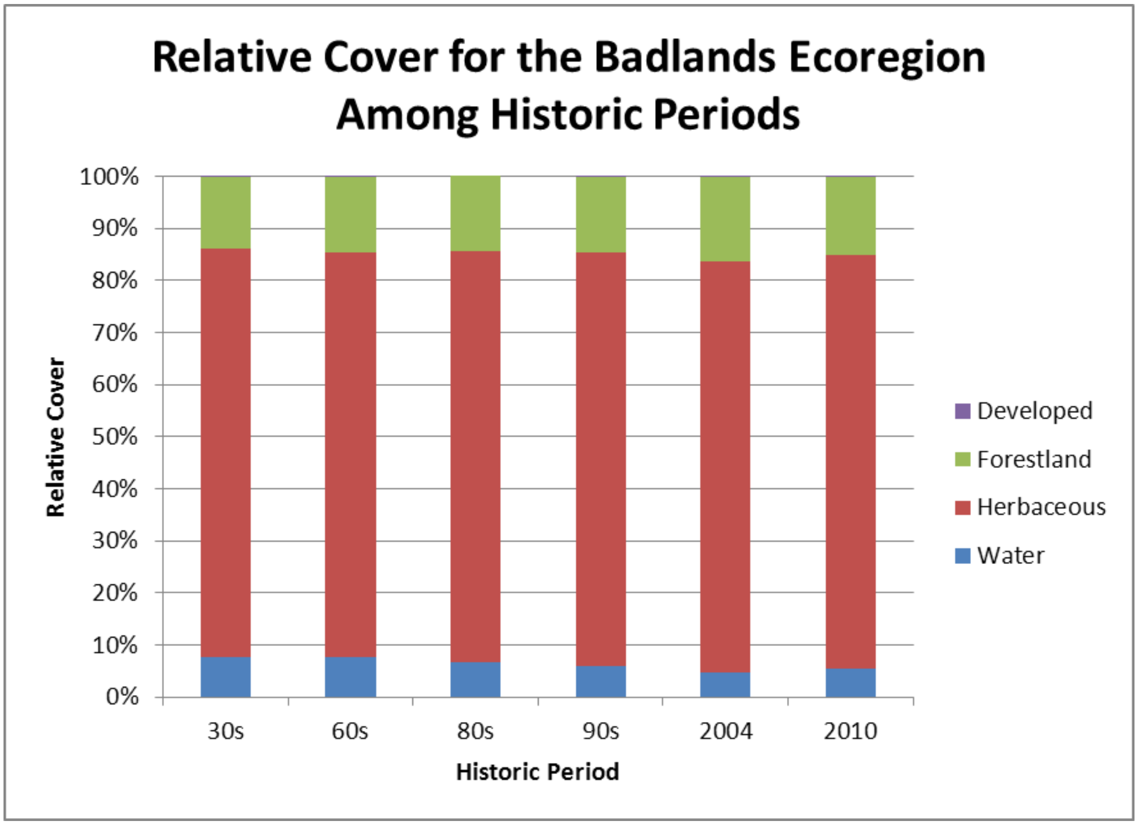

Figure 22. Historical changes in total relative cover by land cover type within the White River floodplain in the Badlands Ecoregion.

Table 16. Historical land cover (ha) of the White River floodplain within mapped sections of the Badlands Ecoregion. Percentage of area in parentheses.

Community Type	1930s	1960s	1980s	1990s	2004	2010
Main Channel	334.2 (7.6%)	327.4 (7.4%)	286.8 (6.5%)	246.4 (5.6%)	210.2 (4.8%)	237.4 (5.4%)
Lake	0.0 (0.0%)	13.0 (0.3%)	6.3 (0.1%)	8.7 (0.2%)	0.0 (0.0%)	0.3 (0.0%)
Water Total	**334.2 (7.6%)**	**340.4 (7.7%)**	**293.1 (6.7%)**	**255.0 (5.8%)**	**210.2 (4.8%)**	**237.7 (5.4%)**
Grassland	1720.4 (39.1%)	2270.9 (51.7%)	1599.8 (36.4%)	1681.8 (38.3%)	2270.6 (51.6%)	2287.1 (52.0%)
Wet Meadow	0.7 (0.0%)	4.1 (0.1%)	7.0 (0.2%)	2.5 (0.1%)	0.0 (0.0%)	15.9 (0.4%)
Farmland	1642.0 (37.3%)	1073.4 (24.4%)	1769.2 (40.2%)	1708.7 (38.9%)	1111.9 (25.3%)	1097.6 (25.0%)
Marsh	0.0 (0.0%)	3.7 (0.1%)	0.0 (0.0%)	3.9 (0.1%)	0.0 (0.0%)	5.4 (0.1%)
Willow Mix	91.0 (2.1%)	55.3 (1.3%)	94.6 (2.2%)	98.6 (2.2%)	81.0 (1.8%)	91.4 (2.1%)
Herbaceous Total	**3454.0 (78.6%)**	**3407.5 (77.5%)**	**3470.5 (78.9%)**	**3495.7 (79.5%)**	**3463.4 (78.8%)**	**3497.3 (79.5%)**
Forest	403.4 (9.2%)	404.9 (9.2%)	379.9 (8.6%)	499.8 (11.4%)	466.7 (10.6%)	424.3 (9.7%)
Woodland	193.5 (4.4%)	164.4 (3.7%)	236.0 (5.4%)	114.7 (2.6%)	227.9 (5.2%)	144.1 (3.3%)
Shrubland	8.2 (0.2%)	78.4 (1.8%)	16.9 (0.4%)	26.8 (0.6%)	23.7 (0.5%)	87.3 (2.0%)
Forestland Total	**605.0 (13.8%)**	**647.7 (14.7%)**	**632.8 (14.4%)**	**641.3 (14.6%)**	**718.3 (16.3%)**	**655.7 (14.9%)**
Farm Complex	3.2 (0.1%)	0.8 (0.0%)	0.0 (0.0%)	4.5 (0.1%)	4.5 (0.1%)	5.8 (0.1%)
Developed Total	**3.2 (0.1%)**	**0.8 (0.0%)**	**0.0 (0.0%)**	**4.5 (0.1%)**	**4.5 (0.1%)**	**5.8 (0.1%)**
Total	**4396.4**	**4396.4**	**4396.4**	**4396.4**	**4396.4**	**4396.4**

Similarly to the Badlands Ecoregion, the area of the main channel in the River Breaks decreased over time (**Table 17**, **Figure 23**), but only by 20%, compared to the Badlands' 29%. As with the Badlands, however, channel area decline would have been much greater (29%), had it not been for apparent channel widening that occurred during 2004-2010. Among the three ecoregions, the River Breaks saw the greatest reduction in herbaceous cover (12%) and the greatest increases in forestland cover (58%). Most of this increase in forestland cover was due a 63% increase in forest area, with closed canopy forest composing 83% of the woody (forestland) land cover within this ecoregion. In addition, most of this directional change (in both woody and herbaceous vegetation) occurred between the 1930s and 1980s, with little change thereafter. Whereas the Badlands forestland likely developed in conjunction with channel narrowing, the increase in woody vegetation on the River Breaks was much larger than the decrease in channel area, suggesting that new forests colonized former herbaceous areas or formed through channel migration that affected all types of land cover.

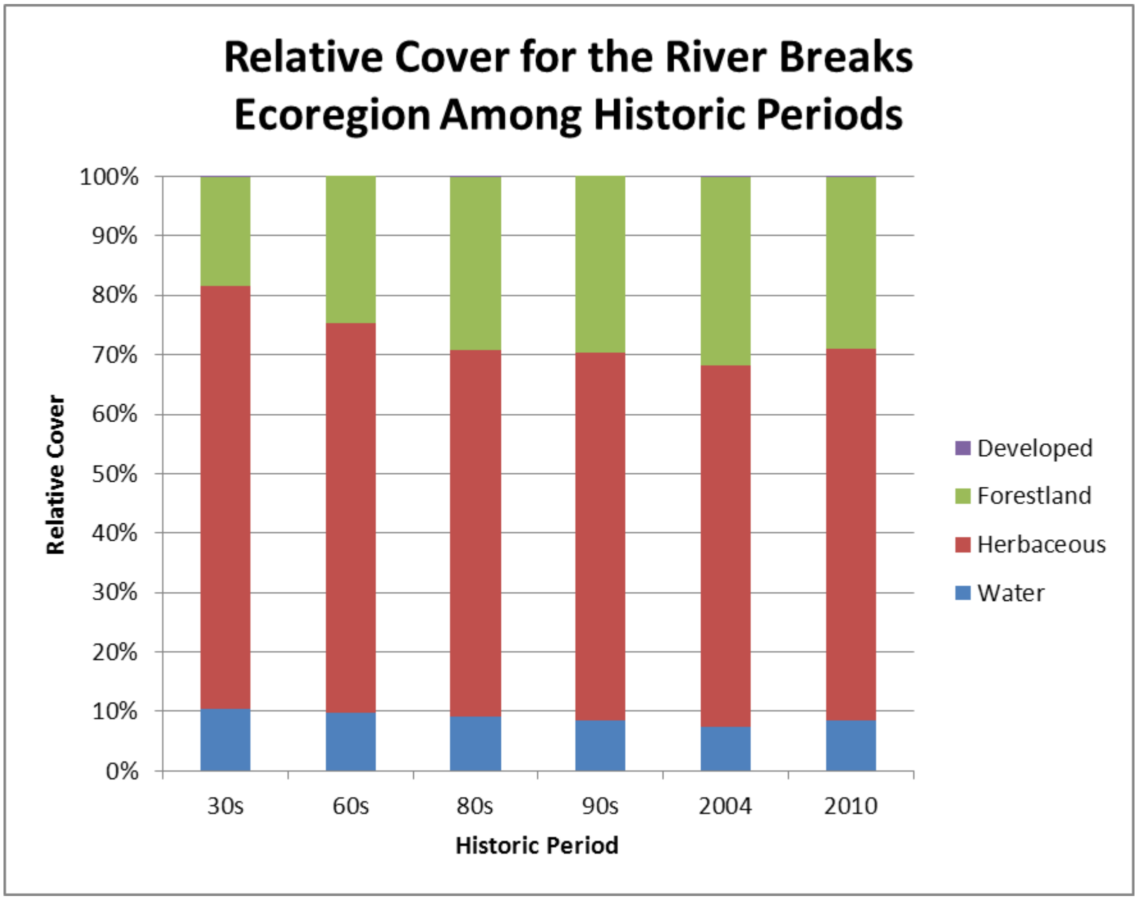

Figure 23. Historical changes in total relative cover by land cover type within the White River floodplain in the River Breaks Ecoregion.

Table 17. Historical land cover (ha) of the White River floodplain within mapped sections of the River Breaks Ecoregion. Percentage of area in parentheses.

Community Type	**1930s**	**1960s**	**1980s**	**1990s**	**2004**	**2010**
Main Channel	777.8 (10.2%)	717.6 (9.5%)	671.4 (8.8%)	638.2 (8.4%)	548.4 (7.2%)	618.9 (8.2%)
Tributary Channel	14.1 (0.2%)	14.7 (0.2%)	14.5 (0.2%)	13.5 (0.2%)	13.6 (0.2%)	25.3 (0.3%)
Lake	0.0 (0.0%)	2.6 (0.0%)	3.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)
Water Total	**791.9 (10.4%)**	**734.8 (9.7%)**	**688.9 (9.1%)**	**651.7 (8.6%)**	**562.1 (7.4%)**	**644.2 (8.5%)**
Grassland	971.1 (12.8%)	1832.2 (24.1%)	1565.7 (20.6%)	1609.8 (21.2%)	1742.3 (23.0%)	2312.3 (30.5%)
Wet Meadow	0.0 (0.0%)	66.5 (0.9%)	21.1 (0.3%)	5.6 (0.1%)	11.4 (0.2%)	22.8 (0.3%)
Farmland	4190.7 (55.2%)	2847.8 (37.5%)	2878.1 (37.9%)	2852.5 (37.6%)	2618.2 (34.5%)	2139.6 (28.2%)
Marsh	0.0 (0.0%)	5.1 (0.1%)	20.2 (0.3%)	18.1 (0.2%)	0.0 (0.0%)	35.5 (0.5%)
Willow Mix	243.9 (3.2%)	227.7 (3.0%)	193.8 (2.6%)	200.4 (2.6%)	242.2 (3.2%)	230.4 (3.0%)
Herbaceous Total	**5405.7 (71.2%)**	**4979.3 (65.6%)**	**4678.8 (61.6%)**	**4686.4 (61.7%)**	**4614.1 (60.8%)**	**4740.6 (62.4%)**
Forest	1119.0 (14.7%)	1520.9 (20.0%)	1860.6 (24.5%)	1937.3 (25.5%)	2053.5 (27.0%)	1823.1 (24.0%)
Woodland	221.4 (2.9%)	268.1 (3.5%)	312.7 (4.1%)	272.7 (3.6%)	273.1 (3.6%)	326.3 (4.3%)
Shrubland	51.4 (0.7%)	87.7 (1.2%)	44.8 (0.6%)	43.6 (0.6%)	87.6 (1.2%)	52.4 (0.7%)
Forestland Total	**1391.7 (18.3%)**	**1876.7 (24.7%)**	**2218.2 (29.2%)**	**2253.7 (29.7%)**	**2414.2 (31.8%)**	**2201.9 (29.0%)**
Farm Complex	2.5 (0.0%)	0.9 (0.0%)	5.9 (0.1%)	0.0 (0.0%)	1.3 (0.0%)	5.0 (0.1%)
Developed Total	**2.5 (0.0%)**	**0.9 (0.0%)**	**5.9 (0.1%)**	**0.0 (0.0%)**	**1.3 (0.0%)**	**5.0 (0.1%)**
Total	**7591.7**	**7591.7**	**7591.7**	**7591.7**	**7591.7**	**7591.7**

Historical trends in land cover (specifically, in riparian woodland and forest cover) for the Delta segment are covered in Part IV, along with other data on the delta.

Land Cover Conversion

As expected for an unregulated river, the land cover of the floodplain was dynamic, in some areas changing dramatically over time. Only a third of the area that was the main channel in both the Badlands and River Breaks during the late 1930s remained so through 2010 (**Tables 18-20**). In the Badlands (**Table 19**) this was mostly converted to forestland (33%), followed by herbaceous cover (24%), and willow mix (11%). The area of the channel was too small in the Pine Ridge/Pierre Shale to map with any accuracy, so conversion from channel area would have been very limited and could not be analyzed. Instead, conversion to and from forestland and herbaceous cover was analyzed. Land conversion in the Pine Ridge/Pierre Shale was much less than in the other areas with 90% of herbaceous areas and 83% of forestland remaining in the same land cover class after seven decades (**Table 21**). In the Badlands 90% of the 1930s herbaceous cover remained so through 2010, but only half of its 1930s forests remained (**Table 19**). 2010 forestland cover in the Badlands resulted mostly from areas that had been main channel (33%) and willow mix (50%) in the 1930s. River Breaks had a higher proportion of retained forests (65%) than the Badlands and lower sustained herbaceous cover (78%) than the other ecoregions (**Table 21**). More of the River Breaks' main channel in the 1930s was converted by 2010 to forestland (48%) and less into herbaceous cover (24%), compared with the Badlands. Annual % rates of conversion from channel (or for herbaceous and forestland, for Pine Ridge/Pierre Shale) to other land cover types for each historical time period are shown in **Figures 24-27**. Lower conversion rates to forestland in the later time periods (e.g., 2005-2010) may be in part because the intervals were too short for forestland to develop.

Table 18. Land cover conversions for the White River floodplain (Badlands and River Breaks ecoregions only) from the 1930s to 2010 time periods.

1930-2010	**Main Channel**	**Herbaceous**	**Willow Mix**	**Forestland**
Main Channel	30.63%	16.35%	9.10%	43.37%
Herbaceous	3.70%	83.72%	1.61%	10.75%
Willow Mix	10.12%	21.38%	4.26%	64.10%
Forestland	4.51%	27.19%	1.81%	66.25%

Table 19. Land cover conversions for the White River floodplain within the Badlands Ecoregion from the 1930s to 2010 time periods.

1930-2010	**Main Channel**	**Herbaceous**	**Willow Mix**	**Forestland**
Main Channel	31.75%	24.24%	10.80%	33.05%
Herbaceous	2.71%	90.61%	1.04%	5.50%
Willow Mix	8.98%	34.86%	6.05%	50.12%
Forestland	5.29%	40.28%	2.44%	51.92%

Table 20. Land cover conversions for the White River floodplain within the River Breaks Ecoregion from the 1930s to 2010 time periods.

1930-2010	**Main Channel**	**Herbaceous**	**Willow Mix**	**Forestland**
Main Channel	30.15%	12.95%	8.36%	47.81%
Herbaceous	5.28%	77.61%	2.39%	14.55%
Willow Mix	10.88%	16.14%	3.73%	69.05%
Forestland	6.11%	25.97%	2.32%	65.28%

Table 21. Land cover conversions for the White River floodplain within the Pine Ridge/Pierre Shale Ecoregion from the 1930s to 2010 time periods.

1930-2010	**Herbaceous**	**Forestland**
Herbaceous	90.16%	9.25%
Willow Mix	27.92%	72.08%
Forestland	16.83%	82.96%

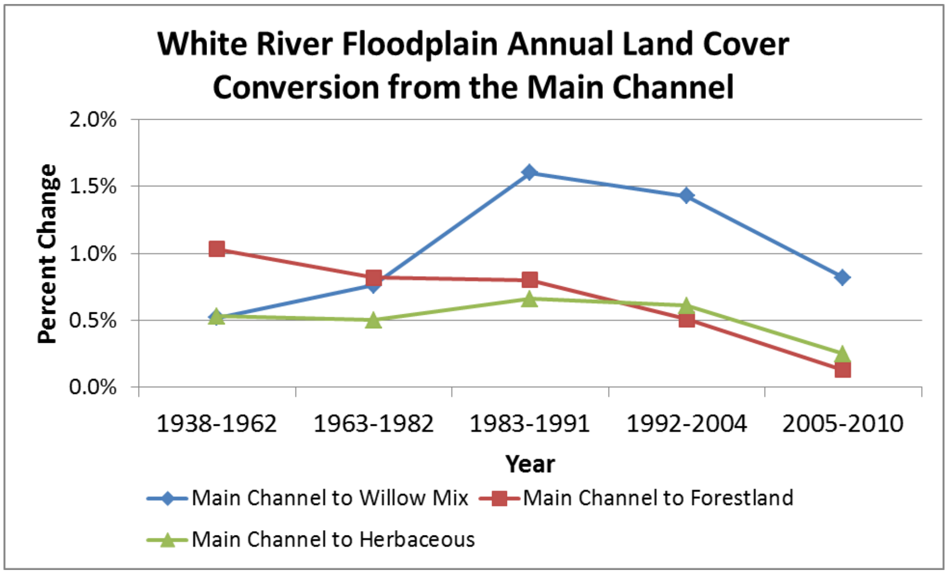

Figure 24. Annual % changes, by photograph interval, in land cover due to land cover transitions from main channel to other land cover types for the White River floodplain (Badlands and River Breaks ecoregions only).

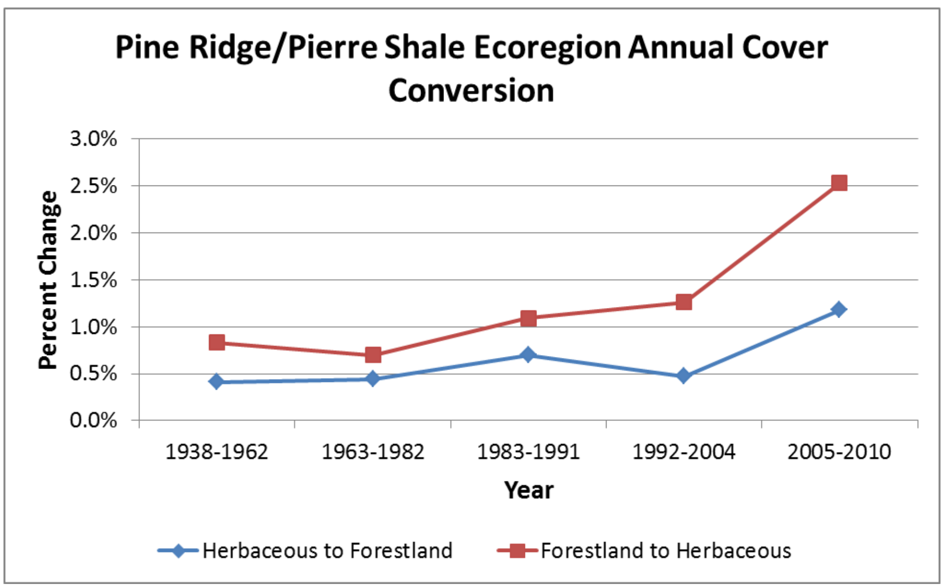

Figure 25. Annual % changes, by photograph interval, in land cover due to land cover transitions between herbaceous and forest for the White River floodplain in the Pine Ridge/Pierre Shale Ecoregion.

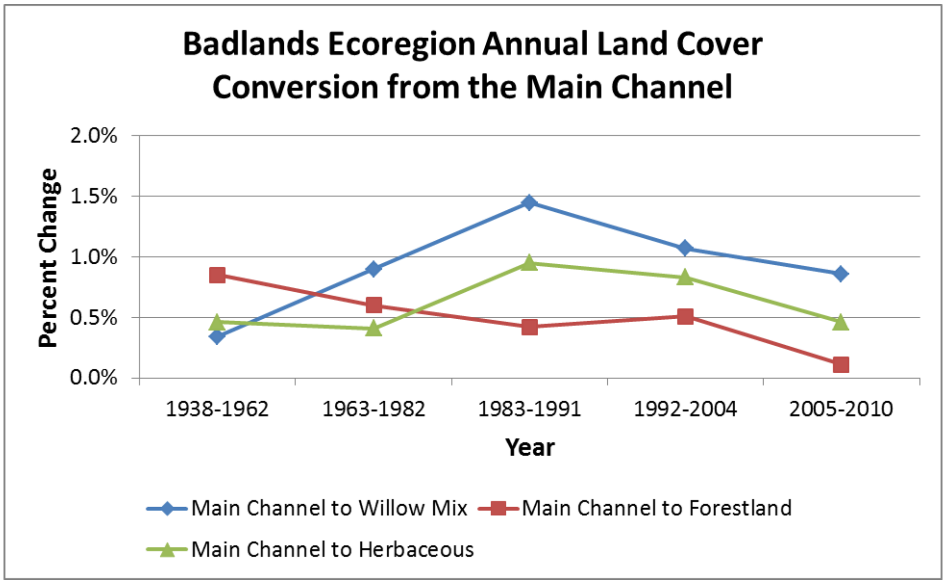

Figure 26. Annual % changes, by photograph interval, in land cover due to land cover transitions from main channel to other land cover types for the White River floodplain in the Badlands Ecoregion.

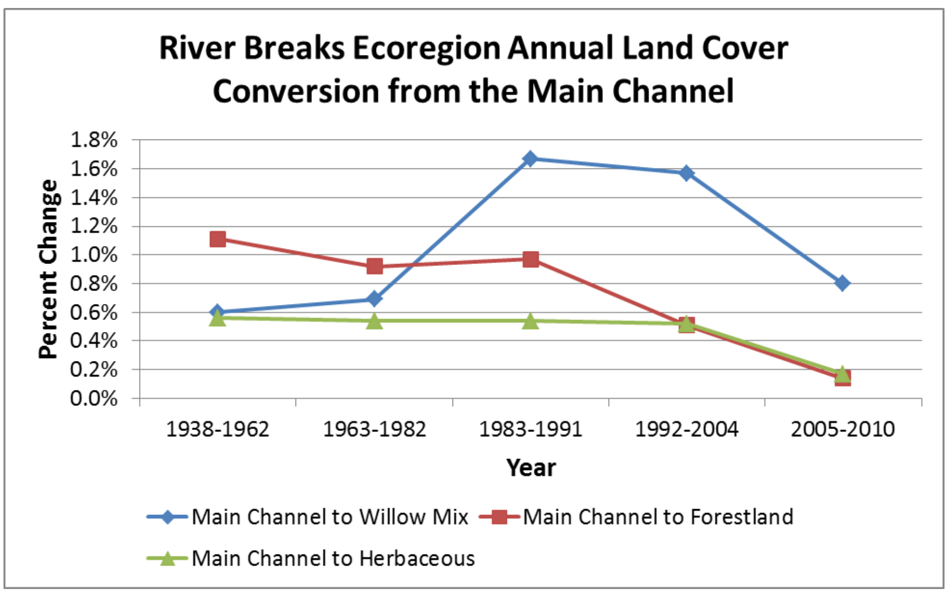

Figure 27. Annual % changes, by photograph interval, in land cover due to land cover transitions from main channel to other land cover types for the White River floodplain in the River Breaks Ecoregion.

Spatial and Historical Patterns in River Discharge

Mean discharge, peak flow, and stream power all varied significantly among the three gages (**Table 22**). In each metric Oglala (Pine Ridge/Pierre Shale Ecoregion) had the lowest values, Kadoka (Badlands Ecoregion) had intermediate values, and Oacoma (River Breaks Ecoregion) had the highest values. These are consistent with their longitudinal positions on the river. As expected, flow increased significantly from upstream to downstream in most quantitative metrics. Base flow was significantly lower in the Badlands than the other ecoregions. The River Breaks Ecoregion experienced significantly fewer zero flow days than the other ecoregions.

Table 22. ANOVAs comparing mean discharge, peak flow, and stream power among stream gages. Letters indicate significant ($p \leq 0.10$) differences among groups.

Measurement	**Oglala**	**Kadoka**	**Oacoma**	**p-value**
Mean Discharge	1.5^{a}	7.6^{b}	16.9^{c}	**<0.001**
Peak Flow	31.4^{a}	273.6^{b}	428.0^{c}	**<0.001**
Stream Power	16.8^{a}	61.9^{b}	110.7^{c}	**<0.001**
Base Flow	0.049^{b}	0.011^{a}	0.049^{b}	**<0.001**
Zero Days	13.5^{b}	16.5^{b}	1.3^{a}	**<0.001**
High pulse count	7.5^{a}	12.4^{b}	8.4^{a}	**<0.001**
High pulse length	6.7^{a}	4.7^{a}	6.7^{a}	**0.037**
Low pulse count	6.7^{b}	6.1^{ab}	4.8^{a}	**0.008**
Low pulse length	7.9^{a}	12.2^{ab}	13.3^{b}	**0.013**

ANOVA analyses found no significant differences in average annual flow for the gages near Oglala and Kadoka ($p=0.20$ and $p=0.58$, respectively) among historical periods (**Tables 23 and 24**). There were trending differences ($p=0.075$) found among historical periods at the gage near Oacoma (**Table 25**). Mean annual flows in the 1960s-80s and 1990s-2004 periods were different, with the 1960s-80s having lower flow and 1990s-2004 having higher flow. There were no statistical differences among the other periods.

At the Oglala gage, baseflow was found to differ significantly among periods, specifically between the higher baseflow of the 1930s-60s and lower baseflow of the 1960s-80s and 1980s-90s (**Table 23**). No significant differences were found among periods for baseflow at the Kadoka gage in the Badlands (**Table 24**). At the Oacoma gage, the baseflow in the 1990s-2004 period was greater than the 1960s-80s (**Table 25**). No other differences were found among periods in baseflow.

The Oglala gage had significantly more zero-flow days per year in the 2004-2010 period than the rest of the periods (**Table 23**). No other significant differences were found among periods. The Kadoka gage has significant differences among historical periods with the 1960s-80s having more zero-flow days than the 1930s-60s, 1990s-2004, and

2004-2010 (**Table 24**). Days with no flow were not common at the Oacoma gage for all periods and there were no differences among periods (**Table 25**).

No differences were found at any gage in peak discharge among historical periods (p=0.44, p=0.75, and p=0.54 for Oglala, Kadoka, and Oacoma, respectively), or 3-day maxima, or 7-day maxima (**Tables 23-25**). High flows over extended periods (30 and 90 day maximums) were not analyzed because initial calculations of these found that they were too variable and showed no trends over time.

The Oglala gage had a significantly greater occurrence of high flood pulses in the 1930s-60s than 2004-2010, with no further significance found among periods (**Table 23**). The difference in the duration of high flood events was significant with 1990s-2004 trending (p-values<0.1) higher than the 1930s-60s, 1960s-80s, and 2004-2010. For low flood pulse numbers, the only difference among groups was that the 1960s-80s was higher than 1990s-2004. The duration of the low flood pulses varied with low pulses in the 1980s-90s longer than the 1930s-60s, 1960s-80s, and 1990s-2004. At the Kadoka gage there were no significant differences among periods for the number of high and low flood pulses, and low flow pulse length (**Table 24**). There were differences in the high pulse length between the longer length pulses of the 1930s-60s and shorter pulses of the 1960s-80s, but not other periods. Like the Kadoka gage, the Oacoma gage found no differences among periods in the frequency of high flood pulses and there were no differences found in the length of the high flood events (**Table 25**). Differences were found for the number of low flood pulses with the 1990s-2004 having fewer low flood events than the 1930s-60s, 1960s-80s, and 2004-2010, and a trending difference (p=0.10) with the 1980s-90s. Similarly to the high flood events, there were no differences among periods for the Oacoma gage's low flood events.

Table 23. ANOVAs run for various flow measurements for the entire year at the Oglala gage. Mean annual flow and peak discharge were analyzed directly from USGS stream data; other values were taken from analysis in IHA. Letters indicate significant differences among groups.

Oglala	**1930-60**	**1960-80**	**1980-90**	**1990-2004**	**2004-2010**	**p-value**
Mean annual flow (cms)	1.7	1.3	1.4	1.9	0.99	0.20
Peak discharge (cms)	35.9	30.9	26.5	37.2	16.6	0.44
Baseflow	0.094[b]	0.031[a]	0.019[a]	0.045[ab]	0.033[ab]	**0.0042**
No flow days/yr	1.1[a]	11.6[a]	16.4[a]	8.5[a]	56.6[b]	**<0.001**
3 day max	26.0	22.5	20.9	25.2	12.2	0.64
7 day max	18.5	17.0	16.3	18.2	9.3	0.78
High pulse count	9.3[b]	8.0[ab]	6.2[ab]	6.5[ab]	4.6[a]	**0.0038**
High pulse length	4.8[a]	5.1[a]	10.4[a]	11.1[a]	2.9[a]	**0.0092**
Low pulse count	6.2[ab]	9.0[b]	6.1[ab]	4.6[a]	6.3[ab]	**0.050**
Low pulse length	6.0[a]	6.5[a]	14.8[b]	6.9[a]	8.1[ab]	**0.010**

Table 24. ANOVAs run for various flow measurements for the entire year at the Kadoka gage. Mean annual flow and peak discharge were analyzed directly from USGS stream data; other values were taken from analysis in IHA. Letters indicate significant differences among groups.

Kadoka	**1930-60**	**1960-80**	**1980-90**	**1990-2004**	**2004-2010**	**p-value**
Mean annual flow (cms)	8.1	7.3	7.0	8.4	6.0	0.58
Peak discharge (cms)	297.7	286.9	270.6	239.5	240.7	0.75
Baseflow	0.009	0.005	0.016	0.022	0.008	0.29
No flow days/yr	12.6[a]	28.8[a]	12.8[a]	11.2[a]	6.3[b]	**0.019**
3 day max	137.8	146.8	134.1	113.9	113.6	0.71
7 day max	94.7	102.7	82.3	75.9	64.1	0.43
High pulse count	12.1	12.7	12.2	13.0	11.7	0.92
High pulse length	6.3[a]	3.9[b]	3.6[ab]	5.0[ab]	4.1[ab]	**0.031**
Low pulse count	5.9	6.4	7.1	4.2	7.4	0.31
Low pulse length	11.5	14.6	4.8	16.1	19.3	0.33

Table 25. ANOVAs run for various flow measurements for the entire year at the Oacoma gage. Mean annual flow and peak discharge were analyzed directly from USGS stream data; other values were taken from analysis in IHA. Letters indicate significant differences among groups.

Oacoma	**1930-60**	**1960-80**	**1980-90**	**1990-2004**	**2004-2010**	**p-value**
Mean annual flow (cms)	16.1[ab]	14.3[a]	15.6[ab]	23.4[b]	16.2[ab]	**0.075**
Peak discharge (cms)	391.0	367.9	424.8	537.9	495.3	0.54
Baseflow	0.052[ab]	0.026[a]	0.060[ab]	0.073[b]	0.050[ab]	**0.019**
No flow days/yr	0.0	2.5	2.8	0.0	1.3	0.27
3 day max	264.7	233.8	210.1	325.7	279.0	0.70
7 day max	195.9	179.0	147.0	221.2	192.4	0.82
High pulse count	8.6	8.0	7.7	8.8	9.4	0.68
High pulse length	7.3	6.2	6.2	8.1	4.5	0.49
Low pulse count	6.1[b]	4.9[b]	4.9[ab]	2.2[a]	5.7[b]	**0.0015**
Low pulse length	10.4	18.4	10.7	15.1	8.1	0.15

Discussion

Over the past seven decades the land cover of the White River floodplain has been dynamic as the river has moved, shaping new communities while eroding others. Land cover change occurred to different extents and varying rates depending on type of cover, time period, and location on the river, compared by ecoregion.

By and large, the most stable portion of the river's floodplain was the area farthest upstream in the Pine Ridge/Pierre Shale Ecoregion. The vast majority of the herbaceous and forestland cover that existed in the late 1930s remained in 2010. Among historic mapping periods the changes that occurred were very small, showing that the Pine Ridge/Pierre Shale White River floodplain has been quite stable over the last 80 years. This has connotations for riparian forests of the ecoregion as few new forests are being established, so the existing forests are ageing without new recruitment occurring. Not surprisingly, forests on this ecoregion are dominated by later successional species (e.g., *Acer negundo* and *Fraxinus pennsylvanica*) with lower relative dominance by pioneer riparian species (e.g., *Populus deltoides*) than segments of the river in the other ecoregions (see Part III below).

Although the changes in cover of the Pine Ridge/Pierre Shale Ecoregion were the most stable over time, various flow metrics here were the most dynamic across historical periods. Despite significant variation in mean base flow, zero-flow days, and high and low flows among time periods, these did not appear to be related strongly to changes in land cover over time. It is likely that the channel lacked the power needed to significantly affect terrestrial communities on the large scale, as the river's flow in this section was significantly lower than the rest of the river and lateral mobility of the river may be limited by channel incision and the stabilizing force of the forested banks.

Greater changes in the floodplain's cover occurred in the Badlands and continued through the River Breaks. Discharge in the Badlands was five times that of the Pine Ridge/Pierre Shale, with a similar magnitude increase in stream power and nearly ten-fold increase in peak discharge. These results are even more amplified when comparing the River Breaks with the Pine Ridge/Pierre Shale. Higher discharge, stream power, and peak flows may be more important to White River community formation and conversion than variation in other metrics such as high and low flow days and short term high and low flow periods.

The Badlands had significantly lower baseflow than the other ecoregions, as well as the least amount of forest cover. A decreased amount of flow from groundwater could be the reason for the smaller area and more open woodland cover in the Badlands. Lite and Stromberg (2005) report depth-to-ground water requirements for *Populus fremontii* (a similar cottonwood species to *P. deltoides*) to maintain dense stands. It is reasonable to assume that the water levels in the Badlands are the limiting factor in to the size and density of the riparian forests.

Discharge, peak flow, and stream flow in the River Breaks Ecoregion were all about twice that of the Badlands. The River Breaks also has the greatest amount of cover change in its forestland and herbaceous cover. The River Breaks had twice the area formed by channel abandonment than the Badlands (Part I), which was likely caused by the greater power of the River Breaks' flow.

Similarly to the Badlands, the River Breaks saw a decrease in channel area over time. The area of the channel across both decreased by 23% over 73 years, which was only half of what occurred on the Little Missouri River in a similar amount of time (Miller and Friedman 2009). The Little Missouri River is a similar river to the White, mostly unmanaged and running through the North Dakota Badlands.

These results are much different that a similar study performed on the Big Sioux River in eastern South Dakota, which saw expansion of the river channel area over time. That study area was much different and experienced significant land cover change due to increased agricultural pressure, as well as increased discharge over time, possibly linked with changes in crops and increased tile drainage (Ley 2011).

Part III – Vegetation Patterns across Associations, Communities, and Ecoregions

Vegetation was surveyed on a total of 299 sites throughout all four segments in May-July 2012 and June-August 2013. Sites were spread unevenly through the ecoregion segments, with 41% of sites (124) in the River Breaks, 24% (71) in the Badlands, 19% (57) in the Delta, and 16% (47) in the Pine Ridge/Pierre Shale (**Figure 28**). For five of the sites from the Badlands, herbaceous cover was not measured; only a species list and woody data were recorded.

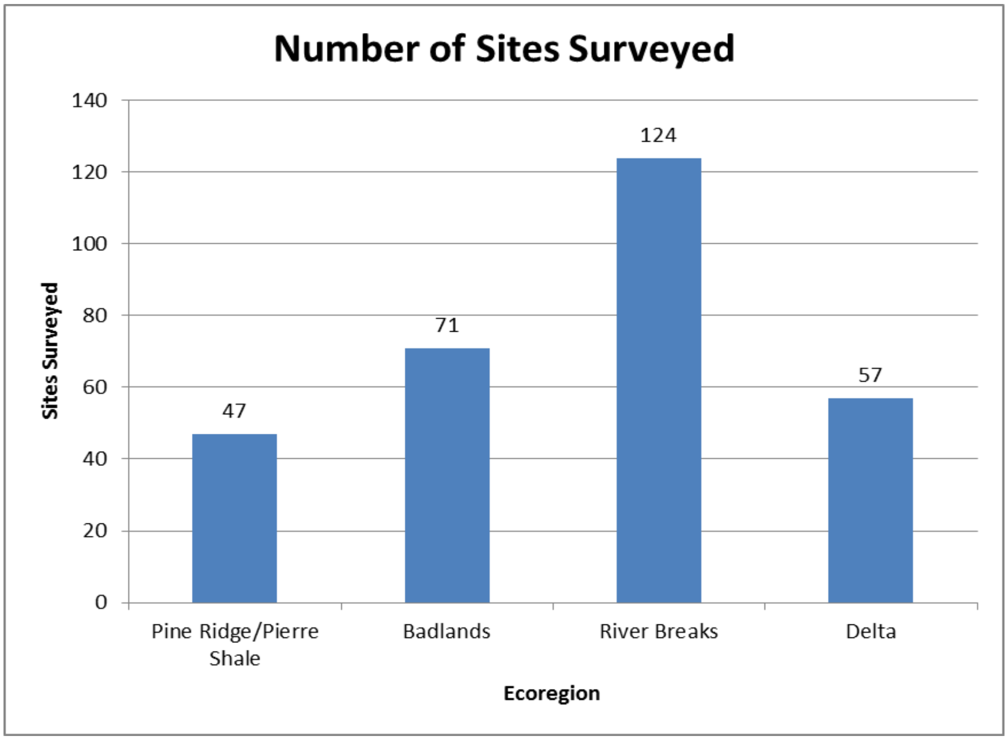

Figure 28. Number of sites surveyed for riparian vegetation in each segment during the summers of 2012 and 2013.

Thirty-three different plant associations were surveyed. Twenty-one existing plant associations were surveyed (**Table 26**), although three of these were not listed in the South Dakota subset of "Plant Communities of the Midwest" (Faber-Langendoen 2001). Twelve new association types were created because the vegetation did not closely enough match existing association types (**Table 27**). For ease of the reader, associations have been labeled with their common names throughout the report. For a list of both common and Latin names for associations, and the community types within which they were grouped, see Appendix **Table A2**. For a list of numbers of plots sampled in each plant association, by ecoregion segment, see Appendix **Table A3**.

Table 26. Existing plant associations surveyed along the White River. Associations with asterisks are missing from the South Dakota subset of *Plant Communities of the Midwest* (Faber-Langendoen 2001b).

Existing Associations
Big Bluestem - Switchgrass - Sunflower Herbaceous Vegetation*
Box-elder / Choke Cherry Forest
Cattail Species - Hardstem bulrush - Mixed Herbs Midwest Herbaceous Vegetation
Common Spikerush Herbaceous Vegetation
Coyote Willow Temporarily Flooded Shrubland
Eastern Cottonwood - (Peachleaf Willow) / Coyote Willow Woodland
Eastern Cottonwood / Green Ash Forest
Eastern Cottonwood / Rocky Mountain Juniper Woodland
Eastern Cottonwood / Switchgrass - Little Bluestem Woodland
Eastern Cottonwood / Western Snowberry Woodland
Foxtail Barley Herbaceous Vegetation
Green Ash - (American Elm) / Western Snowberry Forest
Green Ash - American Elm - Choke Cherry Woodland
Peachleaf Willow Woodland
Riverine Sand Flats-Bars Sparse Vegetation*
Sandbar Willow / Mesic Graminoid Shrubland*
Silver Sagebrush / Western Wheatgrass Shrubland
Switchgrass - (Western Wheatgrass) Herbaceous Vegetation
Western Snowberry Shrubland
Western Wheatgrass - Green Needlegrass Herbaceous Vegetation
Western Wheatgrass Herbaceous Vegetation

Table 27. Created associations surveyed along the White River and their descriptions.

Created Association	Association Description
Common Reed Herbaceous Vegetation	Communities that are mostly dominated by *Phragmites australis*, often with *Salix interior* and various herbaceous species subdominant.
Eastern Cottonwood / Choke Cherry Forest	*Populus deltoides* forest with *Prunus virginiana* as the primary shrub/small tree of the understory.
Eastern Cottonwood / Herbaceous Woodland	Similar to the cottonwood/switchgrass association but more inclusive with *Stipa viridula*, *Bromus inermis*, *Melilotus officinalis*, and *Bouteloua* spp., and herbaceous species.
Eastern Cottonwood / Russian Olive Woodland	*Populus deltoides* woodland with *Elaeagnus angustifolia* as a co-dominant species throughout the understory.
Eastern Cottonwood / Smooth Brome Woodland	*Populus deltoides* woodland that has an understory completely dominated by *Bromus inermis.*
Green Ash Forest	*Fraxinus pennsylvanica* dominated lacking any dominant *Populus deltoides*. The understory is similar to that of the cottonwood/green ash forest.
Red Cedar Woodland	Woodland dominated by *Juniperus virginiana*.
Reed Canary Grass Herbaceous Vegetation	Communities that are mostly dominated by *Phalaris australis*, often as a monoculture.
Russian Olive Woodland	Woodland in which *Elaeagnus angustifolia* is dominant, or the only species.
Smooth Brome Herbaceous Vegetation	Communities that are mostly dominated by *Bromus inermis*; sometimes with subdominant grasses.
Western Wheatgrass (Smooth Brome) Herbaceous Vegetation	Herbaceous vegetation similar to *Pascopyrum smithii* Herbaceous Vegetation, but co-dominated by *Bromus inermis.*
Wet Meadow Mixed Herbaceous Vegetation	Herbaceous vegetation in heterogeneous mixed meadow communities. Species include, but are not limited to, *Melilotus officinalis*, *Amorpha fruticosa*, *Pascopyrum smithii*, *Schizachyrium scoparium*, *Glycyrrhiza lepidota*, *Bromus tectorum*, and *Solidago* spp.

As noted in the Methods, we also created broader categories that we called "community types" that lumped together similar associations (particularly for forests) based on dominant canopy species. The occurrence of associations varied widely throughout the ecoregions, but most community types were surveyed in all of the segments (**Table 28**), albeit not evenly. Most sites were forested, with cottonwood (49% of sites) or green ash as the dominant canopy species, followed by various herbaceous and sandbar willow types. Box elder forests were only surveyed in the Pine Ridge/Pierre Shale ecoregion, peachleaf willow communities were only surveyed in the River Breaks and Delta, red cedar woodlands were only surveyed in the Badlands, Russian olive woodlands were only surveyed in the River Breaks, and shrublands were surveyed in all ecoregions except for the Delta. Although some associations were only found few times, the only community types surveyed only a single time were red cedar woodlands and Russian olive woodlands.

Table 28. Number of each community type surveyed throughout each segment.

Community Type	**Pine Ridge/ Pierre Shale**	**Badlands**	**River Breaks**	**Delta**	**Total**
Box Elder Forest	9	0	0	0	9
Cottonwood Forest	19	40	58	29	146
Green Ash Forest	7	4	11	2	24
Herbaceous Vegetation	9	12	38	12	71
Peachleaf Willow	0	0	1	1	2
Red Cedar Woodland	0	1	0	0	1
Russian Olive Woodland	0	0	1	0	1
Sandbar Willow	2	11	13	13	39
Shrubland	1	3	2	0	6

Species Composition - Entire Study Area

Across all sites and study segments, the most common tree and shrub species found, by far, were *Populus deltoides* and *Fraxinus pennsylvanica,* in both frequency and basal area (**Table 29**). For the herbaceous layer, grasses were the most frequent species of plants found throughout the floodplain (**Table 30**). *Pascopyrum smithii* and *Bromus inermis* had the highest frequency and importance values, and other grass species were frequent with relatively high importance values. After *P. smithii* and *B. inermis*, some of the most common plant species sampled in the herbaceous layer were *Symphoricarpos occidentalis* (a sprawling shrub that behaved more like a herbaceous plant and was, therefore, categorized with herbaceous species), and *F. pennsylvanica* and *Salix interior* seedlings. The most common forbs were *Equisetum arvense, Solidago canadensis*, and *Apocynum cannabinum*. *Vitis riparia* was the most frequently found vine. A list of all species encountered during sampling, along with C-values and wetland indicator scores, is provided in the Appendix, **Table A4** and all non-species taxa are listed in **Table A6**. A list of species encountered by ecoregion segment is provided in the Appendix, **Table A5**.

Table 29. Summary of woody data for all sites in study area.

Species	Frequency	Relative Frequency	Relative Basal Area
Populus deltoides	44.8%	38.1%	51.8%
Fraxinus pennsylvanica	31.1%	26.4%	28.6%
Salix amygdaloides	13.0%	11.1%	7.8%
Elaeagnus angustifolia	6.4%	5.4%	1.4%
Juniperus virginiana	6.0%	5.1%	2.5%
Prunus virginiana	4.3%	3.7%	0.1%
Ulmus americana	4.3%	3.7%	2.6%
Acer negundo	3.7%	3.1%	5.1%
Salix interior	3.7%	3.1%	NA
Rhus aromatica	0.3%	0.3%	NA

Table 30. Summary of herbaceous data for all sites and communities across the entire floodplain. Importance value (IV) was calculated by summing relative frequency and relative cover for each species.

Species	**Frequency**	**Mean Cover**	**Relative Frequency**	**Relative Cover**	**IV**
Pascopyrum smithii	28.9%	10.7%	7.4%	11.9%	19.3
Bromus inermis	22.5%	15.0%	5.8%	16.6%	22.4
Symphoricarpos occidentalis	16.4%	4.4%	4.2%	4.9%	9.1
Bromus tectorum	12.9%	3.8%	3.3%	4.2%	7.5
Fraxinus pennsylvanica	12.3%	1.4%	3.2%	1.5%	4.7
Salix interior	10.7%	1.3%	2.7%	1.4%	4.2
Poa pratensis	10.1%	3.5%	2.6%	3.9%	6.5
Indeterminable forb	9.1%	0.5%	2.3%	0.5%	2.9
Equisetum arvense	9.1%	3.0%	2.3%	3.3%	5.7
Vitis riparia	8.7%	1.7%	2.2%	1.9%	4.1
Solidago canadensis	8.0%	1.5%	2.0%	1.6%	3.7
Stipa viridula	8.0%	3.1%	2.0%	3.4%	5.5
Elymus canadensis	7.9%	1.6%	2.0%	1.8%	3.8
Apocynum cannabinum	7.7%	1.9%	2.0%	2.1%	4.0
Panicum virgatum	7.6%	2.4%	1.9%	2.6%	4.6
Spartina pectinata	7.6%	2.4%	1.9%	2.6%	4.6
Cirsium arvense	7.5%	1.3%	1.9%	1.4%	3.4
Melilotus officinalis	7.3%	1.6%	1.9%	1.7%	3.6
Solidago gigantea	6.6%	0.8%	1.7%	0.9%	2.6
Muhlenbergia racemosa	6.4%	1.7%	1.6%	1.9%	3.6
Helianthus petiolaris	5.7%	0.9%	1.5%	1.0%	2.4
Ambrosia artemisiifolia	5.5%	0.6%	1.4%	0.6%	2.0
Glycyrrhiza lepidota	5.3%	0.8%	1.4%	0.9%	2.2
Other (167 species)	-	-	40.6%	27.1%	67.7

Species Composition – Ecoregions

Pine Ridge/Pierre Shale Ecoregion

Patterns of abundance of woody and herbaceous plant species varied across ecoregions. The most frequent tree species in the Pine Ridge/Pierre Shale Ecoregion was *Fraxinus pennsylvanica* and the tree species with the greatest basal area was *Populus deltoides* (**Table 31**). The herbaceous layer was mostly dominated by the grasses *Bromus inermis* and *Pascopyrum smithii*, along with *Symphoricarpos occidentalis* and a number of forbs. Forb species tended to have lower importance values than the more dominant grass species (**Table 32**).

Table 31. Summary of woody data for all sites and community types within the Pine Ridge/Pierre Shale Ecoregion.

Species	**Frequency**	**Relative Frequency**	**Relative Basal Area**
Fraxinus pennsylvanica	46.8%	33.3%	25.0%
Populus deltoides	34.0%	24.2%	40.1%
Ulmus americana	21.3%	15.2%	10.5%
Acer negundo	19.1%	13.6%	19.7%
Juniperus virginiana	8.5%	6.1%	2.3%
Prunus virginiana	6.4%	4.5%	0.0%
Salix amygdaloides	4.3%	3.0%	2.4%

Table 32. Summary of herbaceous for all sites and community types within the Pine Ridge/Pierre Shale Ecoregion. Importance value (IV) was calculated by summing relative frequency and relative cover for each species.

Species	**Frequency**	**Mean Cover**	**Relative Frequency**	**Relative Cover**	**IV**
Bromus inermis	49.5%	38.6%	19.9%	40.0%	59.9
Pascopyrum smithii	32.9%	21.4%	13.2%	22.2%	35.4
Symphoricarpos occidentalis	22.9%	6.3%	9.2%	6.5%	15.8
Poa pratensis	17.0%	10.7%	6.9%	11.1%	17.9
Chenopodium album	13.2%	2.0%	5.3%	2.0%	7.4
Phalaris arundinacea	12.4%	6.1%	5.0%	6.3%	11.3
Medicago sativa	6.9%	0.6%	2.8%	0.6%	3.4
Solidago gigantea	6.7%	0.9%	2.7%	0.9%	3.6
Cirsium arvense	5.7%	0.8%	2.3%	0.8%	3.1
Chenopodium simplex	5.5%	0.5%	2.2%	0.5%	2.8
Other (75 species)	-	-	30.4%	9.1%	39.5

Badlands Ecoregion

Populus deltoides was the most frequent tree species in the Badlands, also with the greatest basal area, followed by *Fraxinus pennsylvanica* and *Juniperus virginiana* (**Table 33**). Similarly to the Pine Ridge/Pierre Shale, the Badlands was mostly dominated by two grass species, a variety of forbs and other grasses, and *Symphoricarpos occidentalis* (**Table 34**). The two dominant grass species were *Pascopyrum smithii* and *Stipa viridula*. *Melilotus officinalis* (sweet clover) was the most frequently found forb, with the highest importance value. Most of its occurrences were in the 2012 season.

Table 33. Summary of woody data for all sites and community types within the Badlands Ecoregion.

Species	Frequency	Relative Frequency	Relative Basal Area
Populus deltoides	49.3%	54.7%	64.6%
Fraxinus pennsylvanica	19.7%	21.9%	24.0%
Juniperus virginiana	15.5%	17.2%	9.5%
Elaeagnus angustifolia	2.8%	3.1%	0.5%
Prunus virginiana	1.4%	1.6%	0.1%
Salix amygdaloides	1.4%	1.6%	1.4%

Table 34. Summary of herbaceous data for all sites and community types within the Badlands Ecoregion. Importance value (IV) was calculated by summing relative frequency and relative cover for each species.

Species	Frequency	Mean Cover	Relative Frequency	Relative Cover	IV
Pascopyrum smithii	56.3%	17.8%	15.8%	23.3%	39.1
Stipa viridula	23.7%	10.0%	6.6%	13.1%	19.8
Melilotus officinalis	20.0%	4.2%	5.6%	5.5%	11.1
Symphoricarpos occidentalis	19.7%	5.8%	5.5%	7.6%	13.1
Bromus tectorum	17.8%	3.8%	5.0%	4.9%	9.9
Bouteloua curtipendula	16.8%	5.1%	4.7%	6.7%	11.4
Panicum virgatum	14.0%	3.9%	3.9%	5.1%	9.0
Sporobolus cryptandrus	12.9%	3.3%	3.6%	4.3%	8.0
Fraxinus pennsylvanica	12.3%	1.8%	3.4%	2.4%	5.8
Salsola tragus	10.6%	1.1%	3.0%	1.4%	4.4
Elymus canadensis	8.1%	1.1%	2.3%	1.5%	3.8
Other (95 species)	-	-	40.2%	24.0%	64.6

River Breaks Ecoregion

The River Breaks had similar tree cover as the Badlands, but with a greater number of less-frequent species, such as *Prunus virginiana, Ulmus americana,* and *Acer negundo* (**Table 35**). As in the other ecoregions, the River Breaks had a greater number of dominant grass species than other types of herbaceous species (**Table 36**). *Symphoricarpos occidentalis* and *Vitis riparia* were also common shrubs and vines, and *Solidago canadensis* was the most common forb, followed by *Helianthus petiolaris*.

Table 35. Summary of woody data for all sites and community types within the River Breaks Ecoregion.

Species	Frequency	Relative Frequency	Relative Basal Area
Populus deltoides	45.2%	38.4%	52.1%
Fraxinus pennsylvanica	29.8%	25.3%	33.3%
Salix amygdaloides	15.3%	13.0%	9.6%
Elaeagnus angustifolia	12.9%	11.0%	3.1%
Prunus virginiana	5.6%	4.8%	0.2%
Juniperus virginiana	2.4%	2.1%	0.0%
Salix interior	2.4%	2.1%	0.0%
Ulmus americana	2.4%	2.1%	0.3%
Acer negundo	1.6%	1.4%	1.5%

Table 36. Summary of herbaceous data for all sites and community types within the River Breaks Ecoregion. Importance value (IV) was calculated by summing relative frequency and relative cover for each species.

Species	Frequency	Mean Cover	Relative Frequency	Relative Cover	IV
Bromus inermis	30.5%	18.6%	6.6%	18.8%	25.4
Pascopyrum smithii	24.4%	7.2%	5.3%	7.3%	12.6
Bromus tectorum	19.8%	6.9%	4.3%	7.0%	11.2
Symphoricarpos occidentalis	19.5%	4.9%	4.2%	4.9%	9.1
Solidago canadensis	15.8%	3.2%	3.4%	3.2%	6.6
Vitis riparia	14.0%	3.0%	3.0%	3.1%	6.1
Spartina pectinata	13.0%	3.7%	2.8%	3.8%	6.6
Helianthus petiolaris	12.5%	2.0%	2.7%	2.1%	4.7
Fraxinus pennsylvanica	12.4%	0.9%	2.7%	0.9%	3.6
Muhlenbergia racemosa	11.7%	2.7%	2.5%	2.7%	5.2
Elymus canadensis	10.4%	2.3%	2.2%	2.3%	4.5
Ambrosia artemisiifolia	10.3%	1.2%	2.2%	1.2%	3.4
Equisetum arvense	10.1%	1.4%	2.2%	1.4%	3.6
Indeterminable forb	10.0%	0.5%	2.2%	0.5%	2.6
Panicum virgatum	10.0%	3.5%	2.2%	3.5%	5.7
Other (130 species)	-	-	50.7%	37.2%	88.9

Delta

The Delta had similar tree species composition as the Badlands and River Breaks (**Table 37**). The herbaceous species composition of the Delta differed greatly from the other ecoregion segments (**Table 38**). It was not dominated by grass species, but rather by a mix of *Salix interior* and *Fraxinus pennsylvanica* seedlings, forbs including *Equisetum arvense*, *Cirsium arvense*, and *Apocynum cannabinum*, and the vine *Vitis riparia*. *Poa pratensis* and *Phalaris arundinacea* were the most commonly found grasses.

Table 37. Summary of woody data for all sites and community types within the Delta.

Species	Frequency	Relative Frequency	Relative Basal Area
Populus deltoides	47.4%	36.0%	51.6%
Fraxinus pennsylvanica	35.1%	26.7%	29.0%
Salix amygdaloides	29.8%	22.7%	18.5%
Salix interior	14.0%	10.7%	0.0%
Prunus virginiana	3.5%	2.7%	0.1%
Elaeagnus angustifolia	1.8%	1.3%	0.8%

Table 38. Summary of herbaceous data for all sites and community types within the Delta. Importance value (IV) was calculated by summing relative frequency and relative cover for each species.

Species	Frequency	Mean Cover	Relative Frequency	Relative Cover	IV
Salix interior	27.6%	4.1%	7.2%	5.2%	12.4
Equisetum arvense	24.3%	12.2%	6.4%	15.2%	21.6
Fraxinus pennsylvanica	21.3%	2.9%	5.6%	3.7%	9.3
Cirsium arvense	16.8%	3.4%	4.4%	4.2%	8.6
Apocynum cannabinum	15.4%	3.0%	4.0%	3.7%	7.7
Indeterminable forb	13.9%	0.9%	3.7%	1.1%	4.7
Vitis riparia	13.8%	2.0%	3.6%	2.5%	6.1
Rumex crispus	12.2%	3.0%	3.2%	3.7%	6.9
Populus deltoides	11.8%	0.7%	3.1%	0.8%	3.9
Poa pratensis	10.0%	2.5%	2.6%	3.1%	5.7
Phalaris arundinacea	8.5%	3.4%	2.2%	4.2%	6.4
Kochia scoparia	8.0%	2.0%	2.1%	2.4%	4.5
Spartina pectinata	7.8%	3.5%	2.1%	4.4%	6.4
Other (108 species)	-	-	49.7%	45.8%	95.5

Species Composition – Community Types

Box Elder Forest Community

Acer negundo was, not surprisingly, the most frequently found tree in the box elder communities, along with *Fraxinus pennsylvanica* and *Salix amygdaloides* (**Table 39**). The most common and important, based on its importance value, herbaceous species in box elder communities was *Bromus inermis*, which was found in nearly all plots in this community (**Table 40**). After this the community was largely dominated by an assortment of forbs.

Table 39. Summary of woody data within the box elder forest community type for the entire floodplain.

Species	Frequency	Relative Frequency	Relative Basal Area
Acer negundo	88.9%	53.3%	72.2%
Fraxinus pennsylvanica	33.3%	20.0%	7.1%
Ulmus americana	33.3%	20.0%	15.9%
Salix amygdaloides	11.1%	6.7%	4.8%

Table 40. Summary of herbaceous data within the box elder forest community type for the entire floodplain. Importance value (IV) was calculated by summing relative frequency and relative cover for each species.

Species	Frequency	Mean Cover	Relative Frequency	Relative Cover	IV
Bromus inermis	92.9%	72.3%	56.8%	83.8%	140.6
Convolvulus arvensis	12.1%	1.6%	7.4%	1.9%	9.3
Symphoricarpos occidentalis	11.1%	5.9%	6.8%	6.8%	13.6
Chenopodium album	9.1%	1.4%	5.6%	1.6%	7.2
Urtica dioica	6.1%	0.5%	3.7%	0.5%	4.2
Chenopodium simplex	5.1%	0.1%	3.1%	0.2%	3.2
Verbascum thapsus	4.0%	0.1%	2.5%	0.1%	2.6
Cirsium arvense	3.0%	0.6%	1.9%	0.7%	2.5
Pascopyrum smithii	3.0%	1.4%	1.9%	1.6%	3.4
Other (11 species)	-	-	10.5%	2.8%	13.3

Cottonwood Forest Community

Populus deltoides and *Fraxinus pennsylvanica* were the two most common tree species found throughout the cottonwood communities (**Table 41**). With the exception of *Salix amygdaloides*, at 19% frequency, few other woody species were consistently found in most sites. The understory of the cottonwood communities was dominated by grasses including, but not limited to, *Pascopyrum smithii, Bromus inermis, Poa pratensis. Bromus* *tectorum*, and *Stipa viridula* (**Table 42**). Because of the variety of species found in these communities, the only species with importance values greater than 10 were *P. smithii* and *B. inermis*.

Table 41. Summary of woody data within the cottonwood forest community type for the entire floodplain.

Species	**Frequency**	**Relative Frequency**	**Relative Basal Area**
Populus deltoides	88.4%	48.1%	67.5%
Fraxinus pennsylvanica	40.4%	22.0%	21.6%
Salix amygdaloides	19.2%	10.4%	6.6%
Juniperus virginiana	9.6%	5.2%	1.5%
Elaeagnus angustifolia	8.9%	4.9%	1.4%
Prunus virginiana	6.8%	3.7%	0.1%
Salix interior	4.8%	2.6%	0.0%
Ulmus americana	3.4%	1.9%	0.7%
Acer negundo	1.4%	0.7%	0.7%
Rhus aromatica	0.7%	0.4%	0.0%

Table 42. Summary of herbaceous data within the cottonwood forest community type for the entire floodplain. Importance value (IV) was calculated by summing relative frequency and relative cover for each species.

Species	**Frequency**	**Mean Cover**	**Relative Frequency**	**Relative Cover**	**IV**
Pascopyrum smithii	29.9%	10.2%	7.7%	11.0%	18.7
Bromus inermis	24.2%	16.5%	6.2%	17.8%	24.0
Symphoricarpos occidentalis	18.5%	4.7%	4.8%	5.0%	9.8
Fraxinus pennsylvanica	16.4%	2.2%	4.2%	2.4%	6.6
Poa pratensis	12.1%	4.3%	3.1%	4.6%	7.7
Vitis riparia	11.7%	2.0%	3.0%	2.1%	5.1
Bromus tectorum	11.5%	3.5%	3.0%	3.8%	6.8
Stipa viridula	10.5%	4.2%	2.7%	4.6%	7.3
Panicum virgatum	10.0%	3.2%	2.6%	3.5%	6.1
Elymus canadensis	9.6%	1.5%	2.5%	1.7%	4.1
Equisetum arvense	9.0%	3.3%	2.3%	3.6%	5.9
Cirsium arvense	8.4%	1.5%	2.2%	1.6%	3.8
Muhlenbergia racemosa	8.2%	2.3%	2.1%	2.5%	4.6
Other (150 species)	-	-	53.6%	35.9%	89.5

Green Ash Forest Community

Green ash forests were dominated by *Fraxinus pennsylvanica* (**Table 43**). There were no *Populus deltoides* trees in these communities, as they would be labeled as a different community type. The understory was dominated by *F. pennsylvanica* seedlings, *Symphoricarpos occidentalis*, and a number of grasses including *Pascopyrum smithii*, *Poa pratensis*, and *Elymus virginicus* (**Table 44**). *P.smithii* had the highest importance value in the community.

Table 43. Summary of woody data within the green ash forest community type for the entire floodplain.

Species	Frequency	Relative Frequency	Relative Basal Area
Fraxinus pennsylvanica	100.0%	63.2%	85.6%
Ulmus americana	20.8%	13.2%	7.9%
Juniperus virginiana	12.5%	7.9%	2.0%
Prunus virginiana	12.5%	7.9%	0.4%
Salix amygdaloides	8.3%	5.3%	2.3%
Acer negundo	4.2%	2.6%	1.7%

Table 44. Summary of herbaceous data within the green ash forest community type for the entire floodplain. Importance value (IV) was calculated by summing relative frequency and relative cover for each species.

Species	Frequency	Mean Cover	Relative Frequency	Relative Cover	IV
Pascopyrum smithii	35.2%	20.2%	8.5%	20.6%	29.1
Fraxinus pennsylvanica	31.6%	1.8%	7.7%	1.9%	9.5
Symphoricarpos occidentalis	30.8%	8.3%	7.5%	8.5%	15.9
Poa pratensis	20.9%	9.6%	5.1%	9.8%	14.9
Elymus virginicus	16.2%	3.6%	3.9%	3.6%	7.6
Bromus inermis	15.4%	10.3%	3.7%	10.5%	14.3
Chenopodium album	15.0%	2.3%	3.6%	2.3%	5.9
Muhlenbergia racemosa	13.8%	5.2%	3.3%	5.3%	8.7
Indeterminable forb	12.3%	1.0%	3.0%	1.0%	4.0
Bromus tectorum	11.5%	3.5%	2.8%	3.6%	6.3
Cirsium arvense	11.1%	1.9%	2.7%	1.9%	4.6
Solidago canadensis	11.1%	1.2%	2.7%	1.3%	3.9
Vitis riparia	11.1%	0.8%	2.7%	0.8%	3.5
Other (71 species)	-	-	42.9%	28.9%	71.7

Herbaceous Community

Woody data were not summarized for the herbaceous communities as very few of the herbaceous plots had any tree species present. Although trees were not found in the plots, some of the most common herbaceous plants were *Populus deltoides* and *Salix interior* seedlings, showing potential development of forests or shrublands. The three most frequently occurring herbaceous species were *Pascopyrum smithii, Bromus inermis*, and *B. tectorum* (**Table 45**). Due to the variety of different associations that are included within the herbaceous communities, the importance values of most species were rather low.

Table 45. Summary of herbaceous data within the herbaceous community type for the entire floodplain. Importance value (IV) was calculated by summing relative frequency and relative cover for each species.

Species	Frequency	Mean Cover	Relative Frequency	Relative Cover	IV
Pascopyrum smithii	37.8%	14.3%	9.1%	15.2%	24.2
Bromus inermis	21.5%	14.4%	5.2%	15.2%	20.4
Bromus tectorum	18.2%	5.5%	4.4%	5.8%	10.2
Ambrosia artemisiifolia	12.5%	1.1%	3.0%	1.2%	4.2
Populus deltoides	11.6%	0.7%	2.8%	0.7%	3.5
Salix interior	11.4%	0.8%	2.7%	0.9%	3.6
Melilotus officinalis	10.7%	3.2%	2.6%	3.4%	5.9
Symphoricarpos occidentalis	10.0%	2.1%	2.4%	2.2%	4.6
Indeterminable forb	9.5%	0.5%	2.3%	0.5%	2.8
Panicum virgatum	9.5%	3.0%	2.3%	3.2%	5.4
Solidago canadensis	9.1%	2.3%	2.2%	2.4%	4.6
Helianthus petiolaris	8.7%	1.9%	2.1%	2.0%	4.1
Other (140 species)	-	-	59.1%	47.4%	106.4

Peachleaf Willow Community

The only two tree species found in the peachleaf willow community type were *Salix amygdaloides* and *Fraxinus pennsylvanica* (**Table 46**). Of these, *S. amygdaloides* stems accounted for the vast majority of the basal area, although *F. pennsylvanica* seedlings were frequently found in the understory. Unlike most of the other communities, this community's herbaceous cover was dominated by forbs, rather than grasses (**Table 47**). Common forbs included *Equisetum arvense*, *Apocynum cannabinum*, and *Cirsium arvense*. Unidentified immature thistle species were frequently found and were very likely immature *C. arvense.* Data for this community are based on only two sites.

Table 46. Summary of woody data within the peachleaf willow community type for the entire floodplain.

Species	Frequency	Relative Frequency	Relative Basal Area
Salix amygdaloides	100.0%	66.7%	98.8%
Fraxinus pennsylvanica	50.0%	33.3%	1.2%

Table 47. Summary of herbaceous data within the peachleaf willow community type for the entire floodplain. Importance value (IV) was calculated by summing relative frequency and relative cover for each species.

Species	Frequency	Mean Cover	Relative Frequency	Relative Cover	IV
Equisetum arvense	50.0%	11.0%	8.1%	12.8%	20.9
Apocynum cannabinum	45.5%	8.0%	7.4%	9.4%	16.7
Indeterminable forb	45.5%	4.6%	7.4%	5.4%	12.7
Thistle sp.	45.5%	5.4%	7.4%	6.3%	13.7
Fraxinus pennsylvanica	40.9%	2.6%	6.6%	3.0%	9.6
Cirsium arvense	36.4%	7.1%	5.9%	8.3%	14.2
Muhlenbergia racemosa	36.4%	4.9%	5.9%	5.7%	11.6
Lycopus americanus	31.8%	1.7%	5.1%	2.0%	7.2
Teucrium canadense	31.8%	3.3%	5.1%	3.8%	9.0
Other (17 species)	-	-	33.8%	43.2%	84.4

Red Cedar Woodland

Data for the red cedar woodland community are based on a single site. Red cedar woodland woody data were not summarized because the only tree species found was *Juniperus virginiana*. The understory of Red cedar woodland was similar to other communities with a mixture of grasses, *Symphoricarpos occidentalis*, and forbs (**Table 48**). Unlike other communities, one of the most common forbs was *Medicago lupulina*, which was not normally found as a dominant species.

Table 48. Summary of herbaceous data within the red cedar woodland community type for the entire floodplain. Importance value (IV) was calculated by summing relative frequency and relative cover for each species.

Species	Frequency	Mean Cover	Relative Frequency	Relative Cover	IV
Indeterminable grass	36.4%	1.5%	16.7%	20.9%	37.6
Symphoricarpos occidentalis	36.4%	1.5%	16.7%	20.9%	37.6
Poa pratensis	27.3%	0.9%	12.5%	12.4%	24.9
Medicago lupulina	18.2%	1.0%	8.3%	14.4%	22.7
Pascopyrum smithii	18.2%	0.4%	8.3%	5.2%	13.6
Taraxacum officinale	18.2%	0.2%	8.3%	2.6%	10.9
Bouteloua curtipendula	9.1%	0.3%	4.2%	3.9%	8.1
Bromus tectorum	9.1%	0.1%	4.2%	1.3%	5.5
Carex sp.	9.1%	0.5%	4.2%	6.5%	10.7
Indeterminable forb	9.1%	0.1%	4.2%	1.3%	5.5
Lepidium densiflorum	9.1%	0.1%	4.2%	1.3%	5.5
Maianthemum racemosum	9.1%	0.5%	4.2%	6.5%	10.7
Stipa viridula	9.1%	0.2%	4.2%	2.6%	6.8

Russian Olive Woodland

Like the red cedar woodland community, the Russian olive woodland's only tree species was its namesake, *Elaeagnus angustifolia*. Other than *Bromus inermis*, herbaceous cover was mostly dominated by a variety of forbs including *Thlaspi arvense*, *Chenopodium simplex*, and *Convolvulus arvensis* (**Table 49**). Like the red cedar community, data for the Russian olive woodland community are from only a single site.

Table 49. Summary of herbaceous data within the Russian olive woodland community type for the entire floodplain. Importance value (IV) was calculated by summing relative frequency and relative cover for each species.

Species	Frequency	Mean Cover	Relative Frequency	Relative Cover	IV
Bromus inermis	72.7%	29.1%	11.8%	21.3%	33.1
Thlaspi arvense	63.6%	14.5%	10.3%	10.6%	20.9
Chenopodium simplex	54.5%	11.1%	8.8%	8.1%	16.9
Convolvulus arvensis	54.5%	4.3%	8.8%	3.1%	12.0
Cirsium arvense	36.4%	18.3%	5.9%	13.4%	19.3
Oxalis stricta	36.4%	2.8%	5.9%	2.1%	7.9
Stipa viridula	36.4%	6.5%	5.9%	4.8%	10.7
Bromus tectorum	27.3%	12.1%	4.4%	8.9%	13.3
Carex hystericina	27.3%	7.7%	4.4%	5.7%	10.1
Equisetum arvense	27.3%	4.5%	4.4%	3.3%	7.7
Nepeta cataria	27.3%	7.1%	4.4%	5.2%	9.6
Vitis riparia	27.3%	0.3%	4.4%	0.2%	4.6
Other (10 species)	-	-	20.6%	13.3%	33.9

Sandbar Willow Community

Salix interior was left out of the summary of woody data because it was found at and dominated every sandbar willow community. Of the tree species found, *Populus deltoides* and *S. amygdaloides* were the most frequent, with *S. amygdaloides* occupying the largest basal area (**Table 50**). The understory was dominated by *S. interior* seedlings and a variety of forbs including *Apocynum cannabinum*, *Equisetum arvense*, *Glycyrrhiza lepidota*, and *Melilotus officinalis* (**Table 51**). Unlike most of the other communities, forbs were much more dominant than grasses in the sandbar willow communities.

Table 50. Summary of woody data within the sandbar willow community type for the entire floodplain.

Species	Frequency	Relative Frequency	Relative Basal Area
Populus deltoides	12.8%	33.3%	6.7%
Salix amygdaloides	12.8%	33.3%	80.7%
Fraxinus pennsylvanica	7.7%	20.0%	12.6%
Elaeagnus angustifolia	5.1%	13.3%	0.0%

Table 51. Summary of herbaceous data within the sandbar willow community type for the entire floodplain. Importance value (IV) was calculated by summing relative frequency and relative cover for each species.

Species	Frequency	Mean Cover	Relative Frequency	Relative Cover	IV
Salix interior	39.3%	5.6%	10.3%	8.5%	18.9
Apocynum cannabinum	19.3%	6.0%	5.1%	9.1%	14.2
Equisetum arvense	17.0%	5.2%	4.5%	7.9%	12.4
Glycyrrhiza lepidota	17.0%	3.1%	4.5%	4.7%	9.2
Melilotus officinalis	14.1%	2.7%	3.7%	4.2%	7.9
Solidago gigantea	13.0%	1.7%	3.4%	2.6%	6.0
Spartina pectinata	12.3%	3.6%	3.2%	5.5%	8.7
Solidago canadensis	12.0%	2.3%	3.2%	3.6%	6.7
Indeterminable forb	11.1%	0.6%	2.9%	0.9%	3.8
Pascopyrum smithii	10.5%	1.4%	2.7%	2.1%	4.8
Other (102 species)	-	-	56.5%	51.0%	107.5

Shrubland Community

No tree species were found in shrubland communities. Most of the shrub species were recorded with herbaceous data because they were acaulescent or exhibited herbaceous characteristics that made recording them more like herbaceous plants appropriate. The most common shrub species found were *Symphoricarpos occidentalis*, *Artemisia cana*, and *Rhus aromatica*. Most of the herbaceous plants found were grasses, including *Pascopyrum smithii*, *Bromus tectorum*, and *Stipa viridula*. Forbs were found much less frequently than grasses (**Table 52**).

Table 52. Summary of herbaceous data within the shrubland community type for the entire floodplain. Importance value (IV) was calculated by summing relative frequency and relative cover for each species.

Species	Frequency	Mean Cover	Relative Frequency	Relative Cover	IV
Symphoricarpos occidentalis	68.2%	30.2%	17.5%	26.1%	43.6
Pascopyrum smithii	54.5%	28.7%	14.0%	24.7%	38.7
Bromus tectorum	37.9%	9.4%	9.7%	8.1%	17.8
Stipa viridula	28.8%	9.8%	7.4%	8.4%	15.8
Bromus inermis	21.2%	3.9%	5.4%	3.4%	8.8
Ambrosia artemisiifolia	16.7%	8.6%	4.3%	7.5%	11.7
Solidago canadensis	13.6%	2.4%	3.5%	2.1%	5.6
Bouteloua curtipendula	12.1%	4.8%	3.1%	4.2%	7.3
Spartina pectinata	10.6%	2.2%	2.7%	1.9%	4.6
Artemisia cana	9.1%	2.8%	2.3%	2.4%	4.7
Poa pratensis	7.6%	1.8%	1.9%	1.5%	3.5
Rhus aromatica	7.6%	1.6%	1.9%	1.4%	3.3
Other (28 species)	-	-	26.1%	8.5%	34.5

Species Richness, Diversity, and Floristic Quality by Ecoregions

A total of 195 species was observed throughout the entire White River floodplain. 19 taxa were recorded more broadly than species level; including genus, family, etc. The Pine Ridge/Pierre Shale ecoregion had 97 species, along with 6 broader taxa. The Badlands had more species at 117, with 16 broader taxa. The most species were found in the River Breaks with 150 species and 15 other taxa. The Delta had 123 species, along with 17 non-species taxa.

Total richness at the site level (incidental species included) varied from 3 to 47 with an average of 18.86 and median of 18 across the entire floodplain. Mean site-level species richness varied significantly ($p<0.001$) among the ecoregions (**Table 53**). Pine Ridge/Pierre Shale sites had significantly lower richness than sites in the other ecoregions. The Badland had higher richness than Pine Ridge/Pierre Shale, but lower than River Breaks and the Delta, which had the highest total richness. There was no significant difference in richness between River Breaks and the Delta. Differences among ecoregions were similar for plot richness (incidental species excluded), which ranged from 1 to 35 species, with an average of 13.92 and median of 13.

Diversity, calculated from the herbaceous cover with the Shannon Weiner Diversity Index, differed significantly among ecoregions (**Table 53**). Similarly to richness, Pine Ridge/Pierre Shale had lower diversity than all other ecoregions.

Table 53. Species richness compared among ecoregions and the Delta for total richness, plot richness, and Shannon Weiner Diversity Index. Standard deviation is in parentheses. Letters indicate significant differences among groups.

Richness	**Pine Ridge/ Pierre Shale**	**Badlands**	**River Breaks**	**Delta**	**p-value**	**Total**
n (sites)	47	66	124	57	-	299
Mean sites richness	12.47[a] (5.96)	16.15[b] (4.69)	21.48[c] (7.31)	21.79[c] (8.19)	**<0.001**	18.86 (7.61)
n (plots)	47	69	124	57	-	294
Mean plots richness	8.47[a] (5.01)	12.21[b] (4.22)	16.63[c] (6.64)	14.53[bc] (6.04)	**<0.001**	13.92 (6.48)
Shannon Weiner	0.813[a] (0.683)	1.541[b] (0.442)	1.718[b] (0.662)	1.541[b] (0.543)	**<0.001**	1.504 (0.674)

The mean (unweighted) Coefficients of Conservatism were calculated for each site with (total) and without (plot) incidental species and with and without non-native species. Differences among ecoregions were mostly consistent among the different calculation methods (**Table 54**). The least inclusive group, plot without non-native, had the least differences among groups. In all comparisons of Coefficients of Conservatism, The Badlands consistently had higher Coefficient of Conservatism values than the other ecoregions across all calculation methods. Pine Ridge/Pierre Shale and the Delta nearly always had the lowest values. In most cases, River Breaks' Coefficient of Conservatism values were intermediate.

Table 54. Mean Coefficients of Conservatism values compared among ecoregions and the Delta. Standard deviations are in parentheses. Non-native species were assigned a value of 0 when included in calculations. Letters indicate significant differences among groups.

Coefficient of Conservatism	**Pine Ridge/ Pierre Shale**	**Badlands**	**River Breaks**	**Delta**	**p-value**	**Total**
Total n	47	71	124	57	-	299
Total (with non-native)	1.85[a] (0.66)	2.89[c] (0.80)	2.23[b] (0.50)	1.94[a] (0.57)	**<0.001**	2.37 (0.72)
Total (without non-native)	3.14[b] (0.87)	3.68[c] (0.72)	3.04[b] (0.53)	2.67[a] (0.61)	**<0.001**	3.14 (0.73)
Plot n	47	66	124	57	-	294
Plot (with non-native)	1.94[a] (0.88)	2.99[c] (0.86)	2.29[b] (0.60)	2.19[ab] (0.63)	**<0.001**	2.37 (0.80)
Plot (without non-native)	3.24[a] (1.19)	3.78[b] (0.80)	3.11[a] (0.59)	2.94[a] (0.63)	**<0.001**	3.25 (0.82)

The results of ANOVAs run for cover-weighted Coefficients of Conservatism were, with Pine Ridge/Pierre Shale always having the lowest values and Badlands always with the highest (**Table 55**). When including non-native species, with 0 as their value, mean values for River Breaks and the Delta were intermediate to the other ecoregions. Without non-native species they had lower weighted Coefficient of Conservatism values than the Badlands but did not differ significantly from Pine Ridge/Pierre Shale. The Pine Ridge/Pierre Shale Ecoregion had 10 fewer sites included in its "without non-native" values because all herbaceous species at those sites were non-native.

Table 55. Weighted Coefficients of Conservatisms compared among ecoregions and the Delta. Standard deviations are in parentheses. Non-native species were assigned 0 for their calculations. Letters indicate significant differences among groups.

Weighted CoC	**Pine Ridge/ Pierre Shale**	**Badlands**	**River Breaks**	**Delta**	**p-value**	**Total**
n (with non-native)	47	66	124	57	-	294
Weighted CoC (with non-native)	1.27[a] (1.30)	3.52[c] (1.17)	2.16[b] (1.16)	2.16[b] (1.05)	**<0.001**	2.32 (1.36)
n (without non-native)	37	66	124	57	-	284
Weighted CoC (without non-native)	1.63[a] (1.27)	3.52[b] (1.15)	2.15[a] (1.15)	2.17[a] (1.09)	**<0.001**	2.41 (1.31)

Floristic Quality Index (FQI) results were similar to the Coefficient of Conservatism (CoC) results (**Table 56**), which is to be expected as the FQI incorporates Coefficients of Conservatism. The major difference between FQI and CoC results is that, not only the Badlands, but also the River Breaks, had significantly higher values than the other ecoregions. This is likely because FQI incorporates species richness, which was highest in the River Breaks. The Delta also had higher values than the Pine Ridge/Pierre Shale due to its high richness. Pine Ridge/Pierre Shale maintained the lowest values. Differences among groups were mostly consistent among the different ways of calculating FQI.

Table 56. Floristic Quality Index compared among ecoregions and the Delta. Standard deviations are in parentheses. Non-native species were assigned 0 for their calculations. Letters indicate significant differences among groups.

FQI	**Pine Ridge/ Pierre Shale**	**Badlands**	**River Breaks**	**Delta**	**p-value**	**Total**
Total n	47	71	124	57	-	299
Total (with non-native)	6.31[a] (2.90)	10.87[c] (3.16)	9.82[c] (2.91)	8.34[b] (2.24)	**<0.001**	9.24 (3.23)
Total (without non-native)	8.15[a] (3.23)	12.29[c] (3.30)	11.38[c] (2.82)	9.76[b] (2.30)	**<0.001**	10.78 (3.24)
Plot n	47	66	124	57	-	294
Plot (with non-native)	5.57[a] (3.14)	9.60[c] (2.81)	8.78[bc] (3.07)	7.65[b] (2.52)	**<0.001**	8.23 (3.20)
Plot (without non-native)	7.04[a] (3.44)	10.84[c] (2.97)	10.13[c] (3.04)	8.81[b] (2.55)	**<0.001**	9.54 (3.25)

Species Richness, Diversity, and Floristic Quality by Community Types

Total richness (p=0.005) and plot richness (p=0.006) varied significantly among community types (**Table 57**). Box elder forests had lower total richness than all other communities. Cottonwood forests, herbaceous vegetation, and sandbar willow communities had significantly higher total richness than box elder forests. No significant differences in richness occurred among the other communities. Similar patterns among community types occurred for plot richness.

Box elder communities also had the lowest level of species diversity (**Table 57**). With the exception of the single red cedar community, all communities were significantly more diverse than box elder. Sandbar willow communities had the highest level of diversity.

Coefficient of Conservatism and Floristic Quality Index scores were also compared among community types (**Tables 58-60**). Box elder communities consistently had the lowest unweighted Coefficients of Conservatism mean scores, regardless of calculation type (**Table 58**). Cottonwood communities consistently had higher scores. Other communities varied greatly depending on calculation type, and did not vary significantly among other communities.

Differences in weighted Coefficients of Conservatism among community types followed the same trends as the unweighted CoC calculations, with box elder communities having significantly lower values than most other communities (**Table 59**). Communities with few sites (e.g., red cedar woodland and Russian olive woodland had only one site each, peachleaf willow had only two) showed no significant differences from other communities. Box elder and cottonwood communities had differences in the number of sites compared between the calculations including or not including non-native species due to lack of native herbaceous species at a number of sites.

Floristic Quality Index results were also compared among community types (**Table 60**). In general, FQI values were less variable than Coefficients of Conservatism, creating a clearer picture of the differences among community types. Box elder communities had significantly lower FQI scores than most other communities and cottonwood communities had higher values. Green Ash, Herbaceous, Sandbar Willow, and Shrubland all had significantly higher values of FQI than Box Elder communities.

Wetland Indicator Status by Ecoregions and Community Types

We calculated mean wetland indicator scores (1=Obligate Wetland, 5 = Upland) across sites and compared them by ecoregion (**Table 61**) and community types (**Table 62**) using Analysis of Variance (ANOVA). For ecoregions, results were consistent between calculation methods, regardless of inclusion of incidental species or species without wetland indicator scores. The Pine Ridge/Pierre Shale and Badlands Ecoregions had significantly higher wetland indicator values (that is, lower wetland affinity) than the River Breaks or Delta, showing that their species are less dependent on wet conditions. River Breaks had intermediate values and the Delta had the lowest, or most wet (highest wetland affinity), values. The higher values obtained from calculating with missing species assigned a value of 5 (UPL or upland wetland score) were likely more accurate, as the reason that some species are missing wetland indicator scores is that they never occur in wetlands.

Among community types, wetland values varied depending on calculation type (**Table 62**). In general, sandbar willow consistently had the lowest (wettest) values, with cottonwood forests, green ash forests, herbaceous, and shrublands having higher (drier values). ANOVA comparisons among community types using weighted wetland scores differed from those using the unweighted average scores. Sandbar willow communities still had low values, but box elder community scores were greater when weighted by relative cover. In general there was much more variation, and trends were less clear, with the weighted scores.

Table 57. Species richness compared among community types for total richness, plot richness, and Shannon Weiner Diversity Index. Standard deviations are in parentheses. Letters indicate significant differences among groups.

Richness	Box Elder	Cotton-wood	Green Ash	Herb-aceous	Peachleaf Willow	Red Cedar	Russian Olive	Sandbar Willow	Shrub-land	p-value	Total
n (sites)	9	146	24	71	2	1	1	39	6	-	299
Mean sites richness	9.44^{a} (4.3)	18.54^{b} (7.21)	18.04^{ab} (4.38)	20.52^{b} (9.48)	18.5^{ab} (4.95)	17^{ab} (NA)	30^{ab} (NA)	19.92^{b} (5.56)	16^{ab} (9.1)	**0.005**	18.86 (7.61)
n (plots)	9	144	23	69	2	1	1	39	6	-	294
Mean plots richness	5.56^{a} (3.4)	14.07^{b} (6.0)	13.69^{b} (4.67)	13.81^{b} (7.57)	15.5^{ab} (6.36)	14^{ab} (NA)	24^{ab} (NA)	15.67^{b} (6.14)	11.67^{ab} (8.0)	**0.006**	13.93 (6.48)
Shannon Weiner	0.364^{a} (0.486)	1.432^{b} (0.66)	1.633^{bc} (0.473)	1.530^{bc} (0.672)	2.189^{bc} (0.41)	2.190^{abc} (NA)	2.513^{bc} (NA)	1.850^{c} (0.54)	1.388^{bc} (0.646)	**<0.001**	1.504 (0.674)

Table 58. Mean Coefficients of Conservation values compared among community types. Standard deviations are in parentheses. Non-native species were assigned a value of 0 when included in calculations. Letters indicate significant differences among groups.

Coefficient of Conservatism	Box Elder	Cotton-wood	Green Ash	Herb-aceous	Peachleaf Willow	Red Cedar	Russian Olive	Sandbar Willow	Shrub-land	p-value	Total
Total n	9	146	24	71	2	1	1	39	6	-	299
Total (with non-native)	1.35^{a} (0.50)	2.47^{b} (0.74)	2.16^{ab} (0.56)	2.04^{ac} (0.66)	2.65^{ab} (0.92)	2.57^{ab} (NA)	2.00^{ab} (NA)	2.18^{bc} (0.61)	2.62^{bc} (0.84)	**<0.001**	2.37 (0.72)
Total (without non-native)	2.51^{a} (0.91)	3.36^{b} (0.64)	3.29^{ab} (0.39)	2.83^{a} (0.87)	3.03^{ab} (0.90)	4.00^{ab} (NA)	2.90^{ab} (NA)	2.86^{a} (0.57)	3.40^{ab} (0.72)	**<0.001**	3.14 (0.73)
Plot n	9	144	23	69	2	1	1	39	6	-	294
Plot (with non-native)	1.20^{a} (0.67)	2.58^{b} (0.75)	2.34^{bc} (0.60)	2.09^{c} (0.82)	2.83^{abc} (0.64)	2.36^{abc} (NA)	1.91^{abc} (NA)	2.30^{bc} (0.66)	2.61^{bc} (1.17)	**<0.001**	2.37 (0.80)
Plot (without non-native)	2.23^{a} (1.10)	3.47^{c} (0.69)	3.51^{cd} (0.54)	2.92^{ab} (0.99)	3.20^{ac} (0.69)	3.71^{ac} (NA)	2.93^{ac} (NA)	3.03^{abd} (0.58)	3.57^{bc} (1.10)	**<0.001**	3.25 (0.82)

Table 59. Weighted Coefficients of Conservatism (CoC) compared among community types. Standard deviations are in parentheses. Non-native species were assigned 0 for their calculations. Letters indicate significant differences among groups.

Weighted CoC	**Box Elder**	**Cotton -wood**	**Green Ash**	**Herb-aceous**	**Peachleaf Willow**	**Red Cedar**	**Russian Olive**	**Sandbar Willow**	**Shrub-land**	**p-value**	**Total**
n (with non-native)	9	144	23	69	2	1	1	39	6	-	294
Weighted CoC (with non-native)	0.55^{a} (0.76)	2.41^{b} (1.39)	2.63^{b} (1.13)	2.30^{b} (1.36)	2.18^{ab} (0.67)	4.90^{b} (NA)	0.89^{ab} (NA)	2.12^{b} (1.03)	3.14^{b} (2.18)	**0.001**	2.32 (1.36)
n (without non-native)	5	138	23	69	2	1	1	39	6	-	284
Weighted CoC (without non-native)	0.46^{a} (0.86)	2.62^{b} (1.42)	2.47^{b} (0.97)	2.05^{ab} (1.25)	2.66^{ab} (1.57)	1.75^{ab} (NA)	1.25^{ab} (NA)	2.42^{b} (0.94)	3.05^{b} (1.17)	**0.004**	2.41 (1.31)

Table 60. Floristic Quality Index compared among community types. Standard deviations are in parentheses. Non-native species were assigned 0 for their calculations. Letters indicate significant differences among groups.

Floristic Quality Index	**Box Elder**	**Cotton -wood**	**Green Ash**	**Herb-aceous**	**Peachleaf Willow**	**Red Cedar**	**Russian Olive**	**Sandbar Willow**	**Shrub -land**	**p-value**	**Total**
Total n	9	146	24	71	2	1	1	39	6	-	299
Total (with non-native)	4.19^{a} (1.93)	9.85^{b} (3.13)	8.88^{b} (2.73)	8.69^{b} (3.32)	10.84^{ab} (5.54)	9.62^{a}b (NA)	10.77^{ab} (NA)	9.05^{b} (2.72)	9.99^{b} (4.17)	**<0.001**	9.24 (3.23)
Total (without non-native)	5.72^{a} (2.66)	11.44^{b} (3.07)	10.81^{b} (2.30)	10.16^{b} (3.52)	11.57^{ab} (5.63)	12.00^{ab} (NA)	12.97^{ab} (NA)	10.35^{b} (2.64)	11.32^{b} (4.11)	**<0.001**	10.78 (3.24)
Plot n	9	144	23	69	2	1	1	39	6	-	294
Plot (with non-native)	2.91^{a} (2.05)	8.96^{c} (2.95)	8.27^{b}c (2.67)	7.20^{b} (3.25)	10.31^{bc} (5.08)	7.84^{a}bc (NA) c	9.17^{abc} (NA)	8.42^{bc} (2.83)	8.35^{b}c (4.41)	**<0.001**	8.23 (3.20)
Plot (without non-native)	3.97^{a} (2.84)	10.30^{c} (2.93)	9.95^{bc} (2.27)	8.42^{b} (3.44)	10.97^{abc} (5.35)	9.83^{abc} (NA)	11.36^{abc} (NA)	9.58^{bc} (2.79)	9.62^{bc} (4.44)	**<0.001**	9.54 (3.25)

Table 61. Average wetland indicator status compared among ecoregions and the Delta. Standard deviations are in parentheses. Missing wetland scores were assigned the value 5 (the same as upland) for their calculations. Letters indicate significant differences among groups.

Wetland Indicator Status	**Pine Ridge/ Pierre Shale**	**Badlands**	**River Breaks**	**Delta**	**p-value**	**Total**
n (total)	47	71	124	57	-	299
Total (with missing values)	3.91^{c} (0.56)	3.87^{c} (0.53)	3.62^{b} (0.47)	3.10^{a} (0.37)	**<0.001**	3.63 (0.56)
Total (no missing values)	3.71^{c} (0.52)	3.62^{b} (0.48)	3.40^{c} (0.42)	2.96^{a} (0.34)	**<0.001**	3.42 (0.50)
n (plot)	47	66	124	57	-	294
Plot (with missing values)	3.91^{c} (0.56)	3.85^{c} (0.52)	3.62^{b} (0.47)	3.10^{a} (0.37)	**<0.001**	3.62 (0.55)
Plot (no missing values)	3.86^{c} (0.56)	3.84^{c} (0.55)	3.60^{b} (0.50)	2.99^{a} (0.42)	**<0.001**	3.58 (0.60)
n (weighted)	47	66	124	57	-	294
Weighted (all species)	4.26^{c} (0.88)	3.80^{ab} (0.82)	3.72^{b} (0.82)	2.71^{a} (0.67)	**<0.001**	3.63 (0.93)
Weighted (no missing values)	4.18^{c} (0.89)	2.90^{b} (0.82)	3.05^{b} (0.98)	2.64^{a} (0.66)	**<0.001**	3.12 (1.00)

Table 62. Average wetland indicator status compared among community types. Standard deviations are in parentheses. Missing wetland scores were assigned the value 5 (the same as upland) for their calculations. Letters indicate significant differences among groups.

Wetland Indicator Status	Box Elder	Cotton-wood	Green Ash	Herb-aceous	Peachleaf Willow	Red Cedar	Russian Olive	Sandbar Willow	Shrub-land	p-value	Total
n (total)	9	146	24	71	2	1	1	39	6	-	299
Total (with missing values)	3.89^{ab} (0.30)	3.63^{b} (0.53)	3.79^{b} (0.45)	3.68^{b} (0.66)	2.98^{ab} (0.04)	3.21^{ab} (NA)	3.45^{ab} (NA)	3.31^{a} (0.38)	4.13^{b} (0.53)	**<0.001**	3.63 (0.56)
Total (no missing values)	3.72^{b} (0.24)	3.44^{b} (0.47)	3.53^{b} (0.44)	3.44^{b} (0.60)	2.77^{ab} (0.07)	3.08^{ab} (NA)	3.13^{ab} (NA)	3.10^{a} (0.33)	3.90^{b} (0.56)	**<0.001**	3.42 (0.50)
n (plot)	9	144	23	69	2	1	1	39	6	-	294
Plot (with missing values)	3.89^{ab} (0.30)	3.62^{b} (0.53)	3.76^{b} (0.42)	3.68^{b} (0.66)	2.98^{ab} (0.04)	4.21^{ab} (NA)	3.45^{ab} (NA)	3.31^{a} (0.38)	4.13^{b} (0.53)	**<0.001**	3.62 (0.55)
Plot (no missing values)	3.90^{ac} (0.38)	3.59^{ac} (0.57)	3.65^{bc} (0.42)	3.65^{ac} (0.70)	2.76^{ab} (0.19)	4.27^{bc} (NA)	3.52^{bc} (NA)	3.22^{b} (0.44)	4.23^{c} (0.49)	**<0.001**	3.58 (0.60)
n (weighted)	9	144	23	69	2	1	1	39	6	-	294
Weighted wetland (all species)	4.91^{c} (0.10)	3.73^{b} (0.90)	3.65^{b} (0.68)	3.61^{b} (0.99)	2.36^{ab} (0.76)	3.06^{abc} (NA)	4.14^{abc} (NA)	2.94^{a} (0.71)	4.38^{bc} (0.45)	**<0.001**	3.63 (0.93)
Weighted wetland (no missing values)	3.80^{c} (0.25)	3.17^{a} (1.01)	3.31^{ab} (0.94)	2.99^{ab} (1.00)	2.14^{ab} (0.45)	2.86^{abc} (NA)	2.87^{abc} (NA)	2.65^{b} (0.66)	3.46^{abc} (0.32)	**<0.001**	3.12 (1.00)

Forest Structure by Ecoregions

For total plot tree stem density (trees of any size), a significant difference (p=0.033) occurred between the Pine Ridge/Pierre Shale and River Breaks ecoregions, with the forests of the Pine Ridge/Pierre Shale ecoregion being significantly less dense than the River Breaks (**Table 63**). Tree stem densities from the Badlands and Delta did not differ significantly from any of the other ecoregions. No significant differences were found among the ecoregions for the average stem density of large trees (dbh > 3 cm, p=0.22) or small trees (dbh < 3 cm, p=0.49).

Table 63. Woody stem density compared among ecoregions and the Delta for all tree stems, large stems, and small stems. Standard deviations are in parentheses. Letters indicate significant differences among groups.

Woody Density	**Pine Ridge / Pierre Shale**	**Badlands**	**River Breaks**	**Delta**	**p-value**	**Total**
n (all stem sites)	35	43	83	37	-	198
All stems (stems/ha)	708.1[a] (408.5)	1177.7[ab] (1191.8)	1476.1[b] (1554.6)	1366.5[ab] (1361.1)	**0.033**	1255.2 (1328.3)
n (large tree sites)	35	40	72	36	-	183
Large density (stems/ha)	628.6 (407.1)	746.0 (646.7)	945.6 (971.1)	833.3 (646.7)	0.218	819.2 (771.3)
n (small stem sites)	9	26	53	21	-	109
Small density (stems/ha)	311.1 (508.2)	800.0 (995.6)	1027.2 (1461.8)	979.1 (1601.8)	0.492	904.6 (1339.0)

There were no significant differences in total plot basal area among ecoregions (p=0.112), although differences were found in the average DBH of trees among ecoregions (**Table 64**). The Pine Ridge/Pierre Shale had significantly larger DBH for all species, for cottonwood, and for non-cottonwood. For all species, River Breaks had the smallest trees, with the Badlands intermediate.

Table 64. Large tree data compared among ecoregions and the Delta for plot basal area, all tree DBH, cottonwood DBH, and non-cottonwood DBH. Standard deviations are in parentheses. Letters indicate significant differences among groups.

Large Trees	**Pine Ridge/ Pierre Shale**	**Badlands**	**River Breaks**	**Delta**	**p-value**	**Total**
n (large tree sites)	35	40	72	36	-	183
Plot basal area (m^2/ha)	142.0 (74.3)	111.3 (65.8)	110.37 (59.05)	108.8 (82.7)	0.112	116.3 (69.2)
n (all large trees)	275	373	851	375	-	1874
DBH, cm (all species)	22.6[c] (22.8)	12.9[b] (14.6)	11.67[a] (13.91)	13.1[ab] (12.4)	<0.001	14.2 (15.8)
n (cottonwood)	50	155	237	130	-	572
DBH, cm(cottonwood)	49.8[b] (36.1)	23.2[a] (18.8)	21.83[a] (22.02)	19.12[a] (17.62)	<0.001	24.1 (23.3)
n (non-cottonwood)	225	218	614	245	-	1302
DBH, cm (non-cottonwood)	16.5[a] (12.1)	9.1[ab] (5.6)	7.65[c] (5.12)	9.7[b] (6.3)	<0.001	9.9 (7.8)

Canopy cover of plots within forest and woodland cover types was compared among ecoregions to see if the openness of the forests varied by location (**Table 65**). Forest canopy cover differed among ecoregions, with the highest values in River Breaks and Pine Ridge/Pierre Shale and the lowest in the Badlands.

Table 65. Mean densiometer readings in forestland community types and % canopy cover (densiometer/24) among ecoregions.

Canopy Cover	**Pine Ridge/ Pierre Shale**	**Badlands**	**River Breaks**	**Delta**	**Total**
Densiometer reading	19.3	13.9	20.4	15.4	17.2
% cover	80.4%	57.9%	85%	64.2%	71.7%

Forest Structure by Community Types

Significant differences (p=0.002) were found in total plot tree stem densities (p=0.002) and large tree densities (p=0.001) among community types (**Table 66**). Peachleaf willow communities had significantly denser forests than all but red cedar and Russian olive woodlands (which only had one site each) and had the highest large tree densities overall, although there were only two plots of this community type. Sandbar willow had the lowest density of large trees among the woody community types. There was no significant difference (p=0.22) found in the site density for small trees.

There were significant differences in basal area among community types (p=0.002) (**Table 67**). Of the community types with more than one or two plots, sandbar willow communities had significantly lower basal area than the other communities. Average DBH for all species was significantly different (p<0.001) with box elder communities having the largest DBH and peachleaf willow communities having the smallest average DBH. Analyses of only cottonwood and non-cottonwood tree measurements were not performed among community types because cottonwood trees were the defining species of the cottonwood community and not found in other communities.

Canopy cover was compared among some community types (**Table 68**). Sandbar willow communities were excluded because the heights of the plants were above and below the height of the densiometer so measurements would have been inconsistent. Red cedar and Russian olive communities were excluded because there were too few sites. The results of the ANOVA were significant (p<0.001) with herbaceous and shrubland cover having the lowest canopy cover and green ash and peachleaf willow communities having the highest. Other communities were intermediate.

Table 66. Woody density compared among community types for all tree stems, large stems, and small stems. Standard deviations are in parentheses. Letters indicate significant differences among groups.

Woody Density	Box Elder	Cottonwood	Green Ash	Herbaceous	Peachleaf Willow	Red Cedar	Russian Olive	Sandbar Willow	p-value	Total
n (all stem sites)	9	142	24	6	2	1	1	13	-	198
All stems (stems/ha)	764.44^{a} (334.93)	1179.15^{a} (1263.0)	1570.0^{a} (1293.58)	350.0^{a} (481.62)	4560.0^{b} (791.96)	3200.0^{ab} (NA)	560.0^{ab} (NA)	1656.92^{a} (1893.28)	**0.002**	1255.15 (1328.32)
n (large tree sites)	9	138	24	1	2	1	1	7	-	183
Large density (stems/ha)	729.89^{ab} (333.33)	754.2^{bc} (715.08)	1253.33^{a} (921.75)	80.0^{ab} (NA)	2240.0^{ac} (1810.19)	2320.0^{ab} (NA)	480.0^{ab} (NA)	262.86^{b} (183.1)	**0.001**	819.24 (771.25)
n (small stem sites)	3	76	10	5	2	1	1	11	-	109
Small density (stems/ha)	106.67 (46.18)	833.68 (1314.62)	760.0 (850.2)	404.0 (517.76)	2320.0 (1018.23)	880.0 (NA)	80.0 (NA)	1790.91 (1957.29)	0.215	904.59 (1338.97)

Table 67. Large tree data compared among community types for plot basal area and all tree DBH. Standard deviations are in parentheses. Letters indicate significant differences among groups.

	Box Elder	Cottonwood	Green Ash	Herbaceous	Peachleaf Willow	Red Cedar	Russian Olive	Sandbar Willow	p-value	Total
n (large tree sites)	9	138	24	1	2	1	1	7	-	183
Plot basal area (m^2/ha)	143.45^{b} (86.98)	118.34^{b} (67.45)	118.89^{b} (59.7)	8.08^{ab} (NA)	168.28^{ab} (15.33)	237.44^{b} (NA)	73.28^{ab} (NA)	22.05^{a} (19.87)	**0.002**	116.31 (69.2)
n (all large trees)	82	1301	376	1	56	29	6	23	-	1874
DBH (all species)	19.68^{c} (16.30)	15.69^{bc} (17.77)	9.49^{a} (6.52)	10.10^{ac} (NA)	7.51^{a} (6.61)	10.23^{ac} (4.95)	15.27^{ac} (4.73)	8.39^{ab} (3.61)	**<0.001**	14.20 (15.82)

Table 68. Mean densiometer readings and % canopy cover (densiometer/24) among community types.

Canopy Cover	Box Elder	Cotton-wood	Green Ash	Herb-aceous	Peachleaf Willow	Shrub-land	Total
Densiometer reading	19.4	16.0	21.2	1.0	23.1	0.3	11.4
% cover	80.8%	66.7%	88.3%	4.2%	96.3%	1.3%	47.5%

Discussion

Plant Associations

Vegetation surveys identified a number of plant associations from the Plant Communities of the Midwest (Faber-Langendoen 2001a,b) found along the White River, although three communities were missing from the South Dakota subset. The missing associations were Big Bluestem - Switchgrass - Sunflower Herbaceous Vegetation, Riverine Sand Flats-Bars Sparse Vegetation, and Sandbar Willow / Mesic Graminoid Shrubland. These associations should be added to the state list and further studies should examine all associations found in the Plant Communities of the Midwest to ensure similar omissions do not occur in the future.

In addition, existing associations were found to be inadequate in describing a number of the communities found. Because of this, we created 12 new associations to better describe the communities that were seen throughout the White River floodplain. Several of these associations were created to describe communities dominated by non-native species, which are not otherwise included in the existing community type designations. These include Common Reed Herbaceous Vegetation, Reed Canary Grass Herbaceous Vegetation, Russian Olive Woodland, and Smooth Brome Herbaceous Vegetation. New associations composed of non-native species should be described and used to provide a more complete and accurate description of existing communities on the landscape. Other associations were created because existing associations, although similar, lacked non-native species in their descriptions. These associations include Eastern Cottonwood / Russian Olive Woodland, Eastern Cottonwood / Smooth Brome Woodland, and Western Wheatgrass (Smooth Brome) Herbaceous Vegetation. Existing associations should have their descriptions broadened to include non-native species, or new associations should be created that better describe communities that exist with non-native species.

Creation of non-native species dominated groupings is already being done on a project specific level. The USGS-NPS Vegetation Mapping Program incorporated Russian Olive Semi-natural Woodland and Introduced Grassland groupings into their mapping project, in the same way that this project did (Van Loh et al. 1999). More of these non-native groupings need to not only be created, but should also be considered for incorporation into the national system. Grassland should be species specific, rather than just a broad categorization based on non-native species.

Finally, we created other new associations from similar existing associations, only without cottonwood as a dominant species in the forests, because existing associations all included cottonwood. These include Red Cedar Woodland and Green Ash Forest. Eastern Cottonwood / Choke Cherry Forest was created because these forests did not fit within an existing association. This association could either be incorporated into another with a change in the original's description, or kept as a new association. The Wet Meadow Mixed Herbaceous Vegetation association shows some of the difficulty of using specific associations to describe riparian non-woody vegetation. There was a variety of herbaceous species that occurred in various combinations that did not match the descriptions of existing herbaceous wet meadow associations. The best remedy for this project was to create a catch-all category based more on habitat than dominant or co-dominant species. This issue of overly specific association descriptions should be addressed and it should be determined if more specific descriptions or fewer broad descriptions should be created for these communities.

In our study, the large number of associations found throughout the floodplain, with small numbers of sites for some associations, made it difficult to do statistical comparisons among all associations. Because of this, it was necessary to group different associations into community types, with community types for woodland and forested habitats based on the dominant tree species. All cottonwood forest associations were lumped together, regardless of other subdominant species. Other forest types, such as green ash or box elder, consisted only of associations that lacked cottonwoods. Shrubland associations were grouped into two community types, sandbar willow communities and other shrubby communities. The least natural grouping of associations was the herbaceous community type, which simply included all non-wooded associations. Data should be used from numerous studies, such as this one, in order to best describe communities and associations.

Compositional and Structural Patterns among Ecoregions and Community Types

Survey findings constitute a significant advancement over previous work in describing the riparian vegetation found along the river (Fryda 2001). Common and dominant species found along the White River were consistent with those found in a similar floodplain in North Dakota. The mostly unregulated Little Missouri River flows through similar habitats, including the North Dakota Badlands, and was also dominated by the woody species *Populus deltoides*, *Salix amygdaloides*, *S. interior*, and *Symphoricarpos occidentalis*. One major difference between the rivers in dominant tree species is the lack of *Fraxinus pennsylvanica* on the Little Missouri. Both floodplains had similar herbaceous dominant species including *Melilotus officinalis*, *Pascopyrum smithii*, and *Nassella viridula* (Miller and Friedman 2009).

Vegetation results in the Badlands were congruent with and add needed detail to the USGS-NPS Vegetation Mapping Program at Badlands National Park, whose riparian descriptions were broad, only accounting for dominant species. The scope of that program focused solely on the National Park, not on the rest of the floodplain within the ecoregion, and did not account for private land (Van Loh et al. 1999).

The species data showed a number of consistent trends among ecoregions. Plant species richness was highest in the River Breaks and lowest in the Pine Ridge/Pierre Shale, with intermediate values in the Badlands and Delta. These trends continue when examining indices of diversity, coefficients of conservatism, and floristic quality values. The Pine Ridge/Pierre Shale Ecoregions consistently had lower values than the other ecoregions in terms of species diversity, coefficients of conservatism, and floristic quality. Differences among the Badlands, River Breaks, and Delta ecoregions varied depending on the type of value, but all were typically greater than Pine Ridge/Pierre Shale. Comparison of wetland indicators also showed the Pine Ridge/Pierre Shale floodplain had the lowest wetland affinity (more upland species) in its flora and the Delta had the highest wetland affinity (more wetland species), with the other two ecoregions intermediate.

Forest structure and composition varied among ecoregions. Tree density averaged least within the forestland in the Pine Ridge/Pierre Shale ecoregion and was significantly lower there than in the River Breaks, which had the highest densities. Although there was no significant difference, the Pine Ridge/Pierre Shale had fewer sites that contained small stem (younger trees), relative to the total number of wooded plots or large tree plots, which may imply older or more developed forests. The fact that the average DBH of all trees and of cottonwoods were larger in the Pine Ridge/Pierre Shale than all of the other ecoregions further supports the conclusion that the forests there averaged older. This larger tree size, and particularly cottonwood size, is consistent with historical land cover analyses, which suggest that this segment is has been geomorphologically more static than segments of the White River in other ecoregions over the last 75 years.

Trends among community types were not as strong as they were among ecoregions. Some of the community types did not have enough plots for statistically valid comparisons. In general, box elder communities had consistently lower values for richness, diversity, conservatism coefficients, and floristic quality than cottonwood, green ash, herbaceous, sandbar willow, and shrubland. Other than the lower values in the box elder community, few other consistent trends were found among community types.

Few statistical differences in forest structure and density existed among community types as well. Peachleaf willow communities had the highest overall woody stem density and large tree density, although these conclusions are based on only two peachleaf willow sites. For large tree density green ash (*Fraxinus pennsylvanica*) communities, which represent a later successional stage, were denser than sandbar willow and cottonwood communities.

Green ash was the second most common tree species found throughout the floodplain and with its seedlings was one of the most common species in the herbaceous layer, so the species plays an important factor in the ecology of the White River forests. This may be threatened due to the spreading of the emerald ash borer (*Agrilus planipennis*) from the eastern United States. The emerald ash borer has been shown to decimate ash trees as it has spread from Michigan and Ontario since the early 2000s (Poland and McCullough 2006). As the species spreads west it may become a major threat to the riparian ecosystems of the White River and other riparian areas throughout the Great Plains, where green ash is often a dominant species (Johnson et al. 2012).

Part IV – Landscape Dynamics and Vegetation Patterns in the White River Delta

Formation of the Delta

The lower White River and its confluence with Lake Francis Case (Fort Randall Reservoir) experienced high rates of channel and floodplain aggradation and associated geomorphic change during the post-dam era. Between 1953/1954 and 2011, thalweg elevation increased at all cross sections along the lower 31 km of the White River and at the White River-Missouri River confluence on Lake Francis Case (**Figure 29**). The amount of thalweg aggradation was greatest at the most downstream cross sections, and declined in the upstream direction (**Table 69**, **Figure 30**). Total increases in thalweg elevation over the study period ranged from 0.61 m at river-km 30.9 to nearly 12 m at river-km 3.1. In addition to increases in thalweg elevation, post-dam changes to the channel and floodplain environment included: the active channel generally narrowed and smoothed, the floodplain aggraded to a similar degree as the thalweg and became relatively uniform in elevation, and at some cross sections, prominent natural levees formed adjacent to the active channel (**Figure 31**).

Rates of aggradation for most cross sections were greatest during the first measurement interval following dam closure (1953/1954-1973), sharply declined during the second measurement interval (1973-1996), and moderately increased during the third measurement interval (1996-2011) (**Table 69**, **Figure 32**). Between 1953/1954 and 1973, rates of thalweg aggradation were greatest at the most downstream cross sections and declined in the upstream direction. Conversely, rates of thalweg aggradation between 1973 and 1996 were greatest at the two most upstream cross sections. Between 1996 and 2011, thalweg aggradation rates were generally greatest at the most downstream cross sections and decreased in the upstream direction.

Sedimentation during the post-dam period led to a flattening of the stream gradient within the delta, creating a “sediment wedge” within the lower 31 km of the White

River (**Figure 33**). In 1954 (2 years post-dam), the mean stream gradient was 70 cm/km ($p<0.0001$). By 2011 (59 years post-dam), the average gradient declined to 29 cm/km ($p=0.0004$). This sediment wedge was thickest in the lowermost 13 river-km of the White River where the gradient approached 0 cm/km.

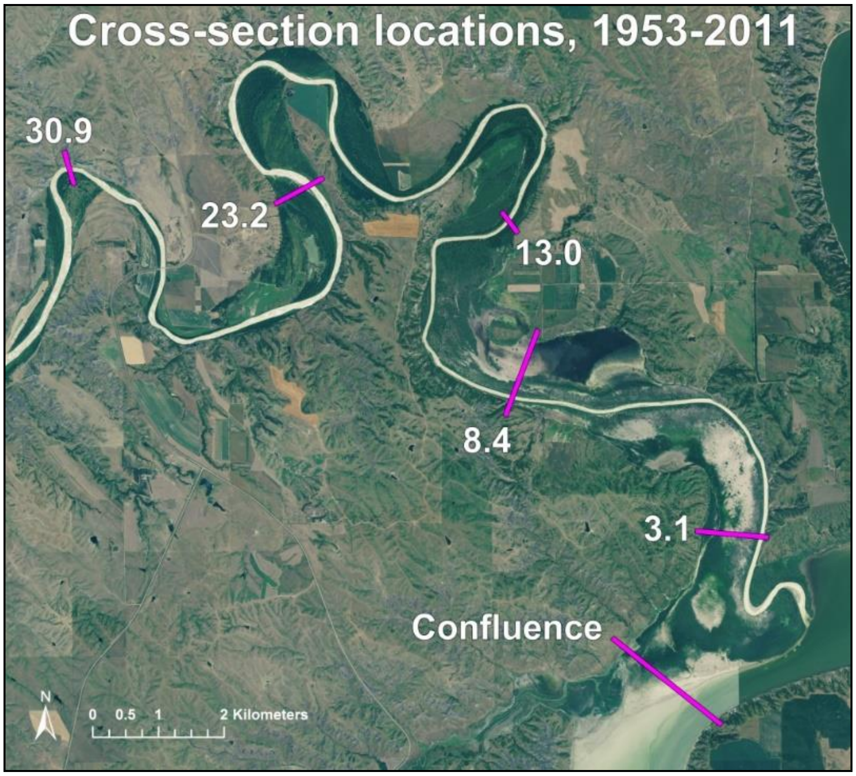

Figure 29. Locations of six selected cross sections (magenta) and corresponding river-km (white) along the lower White River and its confluence with the Missouri River (Lake Francis Case).

Table 69. Change in thalweg elevation (m) and mean rate of change in thalweg elevation (m/year) for six cross sections along the lower White River and at the White River-Missouri River confluence.

	Change in thalweg elevation (m)				Mean rate of change in thalweg elevation (m/year)		
Cross section	1953/4-1973	1973-1996	1996-2011	Total net	1953/4-1973	1973-1996	1996-2011
Confluence	9.94	0.21	0.37	10.52	0.52	0.01	0.02
3.1	9.69	0.12	2.13	11.95	0.48	0.01	0.14
8.4	7.41	0.24	1.10	8.75	0.37	0.01	0.07
13.0	5.58	-0.06	0.33	5.85	0.28	0.00	0.02
23.2	1.04	0.70	0.52	2.26	0.05	0.03	0.03
30.9	-0.03	0.76	-0.12	0.61	0.00	0.03	-0.01

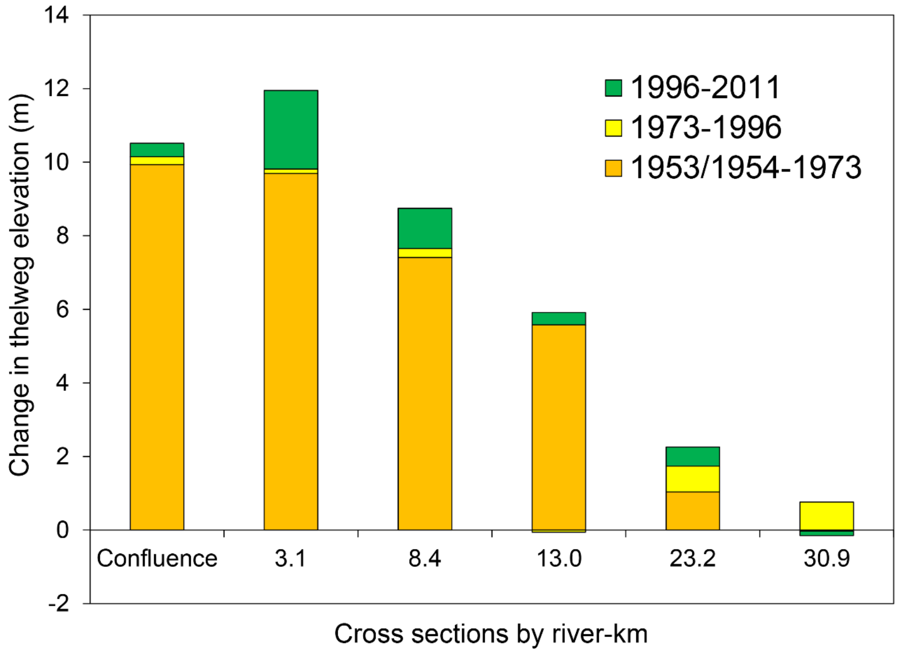

Figure 30. Change in thalweg elevation (m) at six cross sections for each measurement interval.

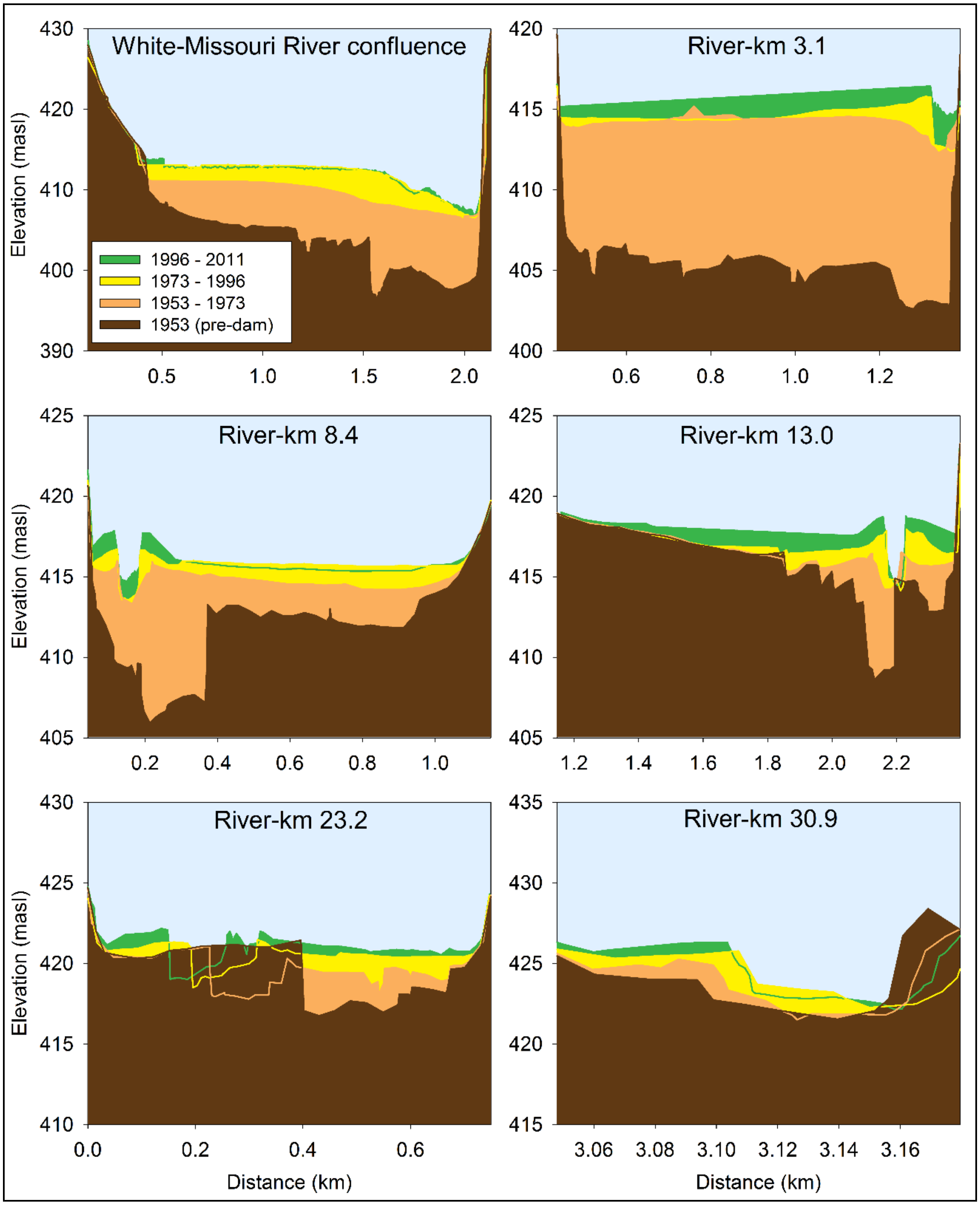

Figure 31. Sedimentation history at six cross sections from the lower 31 km of the White River and from the White River-Missouri River (Lake Francis Case) confluence.

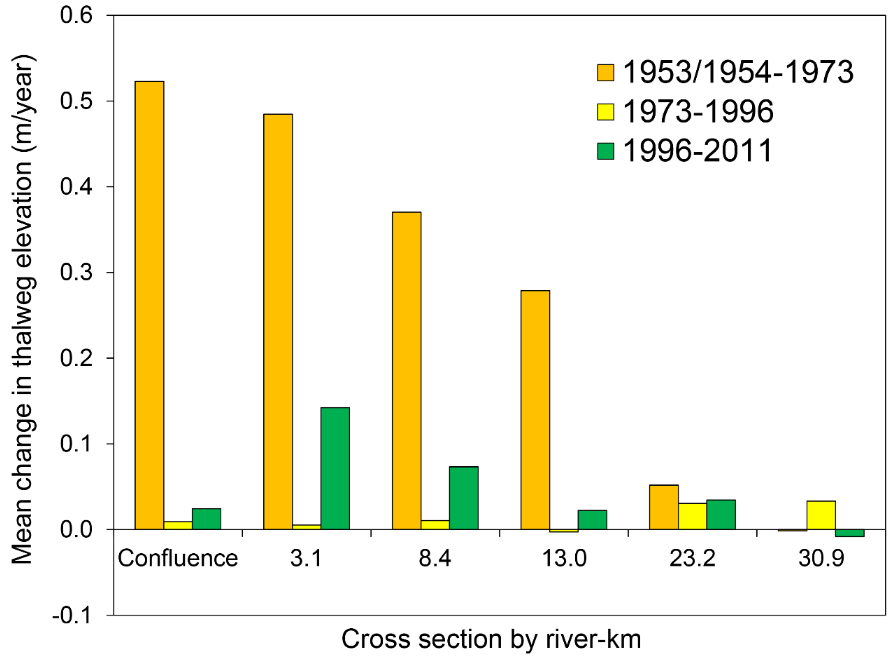

Figure 32. Mean rate of change in thalweg elevation (m/year) at six cross sections for each measurement interval.

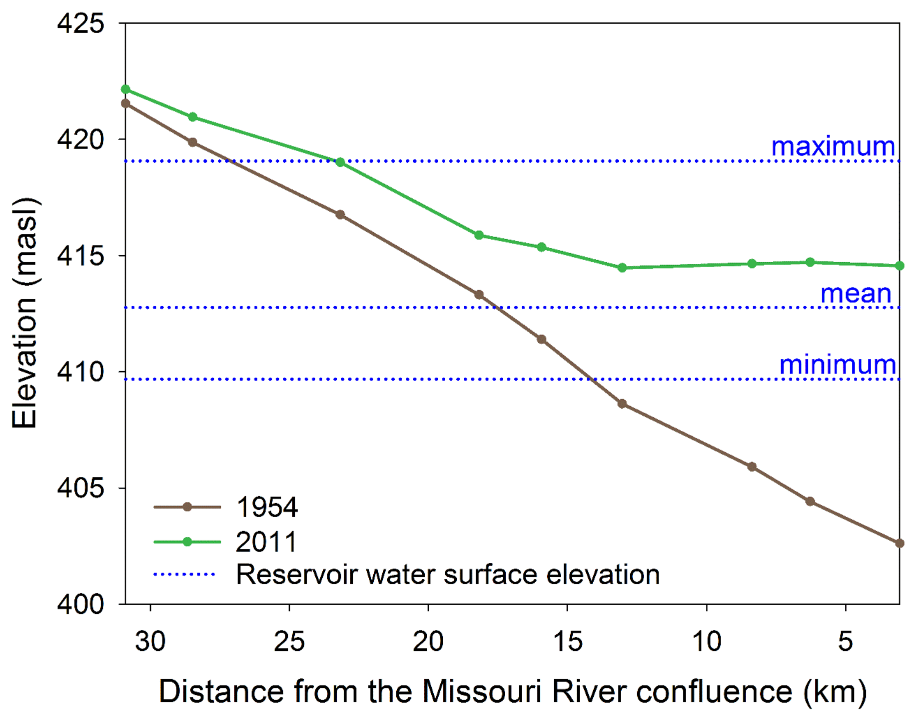

Figure 33. Stream gradient of the lowermost 31 km of the White River in 1954 and 2011, depicting the formation of a sediment wedge within the delta zone.

Historical Changes in Riparian Woodland Area

The area of riparian woodland (note: "woodland" here is more congruent with definition of forest from parts I-III, that is, woody land cover with ≥50% canopy cover) within the White River delta (defined here as lower 29 km of river) generally increased during the post-dam period (**Table 70**, **Figure 34**). Woodland area was 782 ha in 1948, four years prior to complete closure of Fort Randall Dam. By 1983, woodland area had grown to 968 ha. Woodland area peaked at 1,230 ha in 2004, and declined to 1,164 ha in 2012. This represents a total increase in woodland area of 381 ha (49 percent) during the post-dam study period.

Although overall woodland area expanded between 1948 and 2012, it declined during intervals spanning major flood years on the regulated Missouri River. Between 1991 and 1998, an interval that included the 1997 Missouri River flood (the second highest stage on record for Lake Francis Case), there was a net loss of 101 ha of woodland (**Table 70**). Visual inspection of the 1991-1998 overlay (**Figure 35**) indicated that woodland declined throughout the longitudinal range of the study reach, but the greatest declines occurred between river-km 0 and km 15 along the woodland edge opposite the active channel. Between 2004 and 2010, an interval that included the high water year of 2010 (the third highest stage on record for Lake Francis Case), there was a net loss of 22 ha of woodland (**Table 70**). Woodland loss during this interval was likely the result of high stages of Lake Francis Case in 2010 that inundated portions of the woodland in the lower delta during the time of aerial photo acquisition. A similar mortality pattern was observed following the 2011 Missouri River flood (the record high stage for Lake Francis Case), as indicated by complete mortality or flood damage in many woodland patches between 2010 and 2012 (**Figure 36**). A total of 45 ha of woodland experienced complete mortality and 55 ha experienced flood damage related to the 2011 flood. Nearly 5 percent of the total woodland area in 2012 was flood damaged. Visual inspection of the 2010-2012 overlay (**Figure 36**) indicated that woodland that was lost or damaged by the 2011 flood was again concentrated between river-km 0 and 15. Field reconnaissance in 2013 revealed that delayed woodland mortality occurred in the lower delta in the time since the 2012 aerial photo was acquired, indicating that much of the flood damaged woodland in 2012 likely transitioned into a state of complete mortality by June 2013 (**Figure 37**).

Table 70. Area of riparian woodland within the White River delta by year. Dashed lines indicate no data.

Riparian woodland area (ha)					
Year	Total	Young	Medium	Old	Flood damaged
1948	782	195	52	535	0
1983	968	445	335	188	0
1991	1,102	-	-	-	0
1998	1,001	-	-	-	0
2004	1,230	-	-	-	0
2010	1,209	-	-	-	0
2012	1,164	141	539	484	55

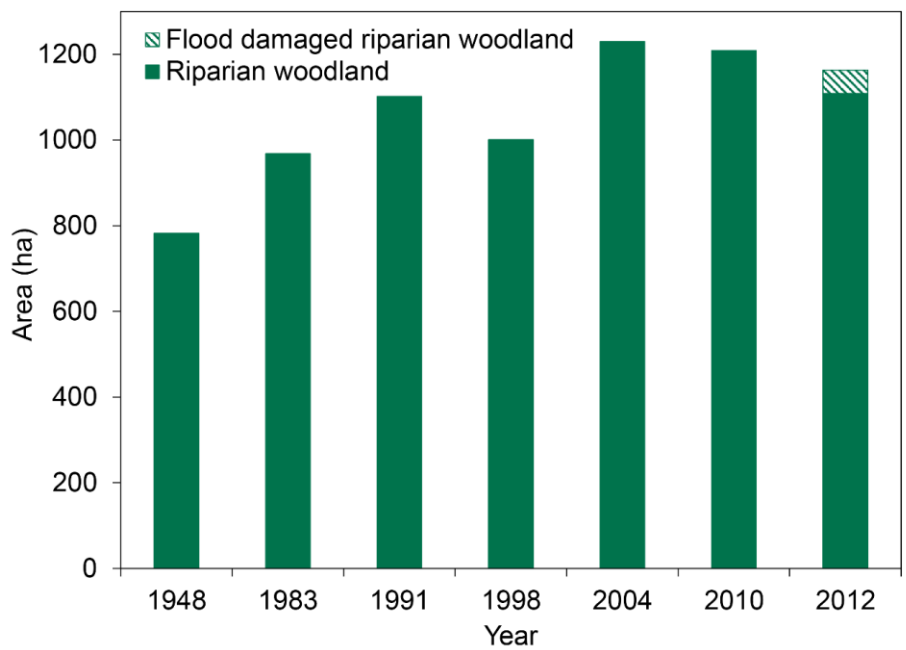

Figure 34. Total riparian woodland area (ha) within the lowermost 29 km of the White River by year.

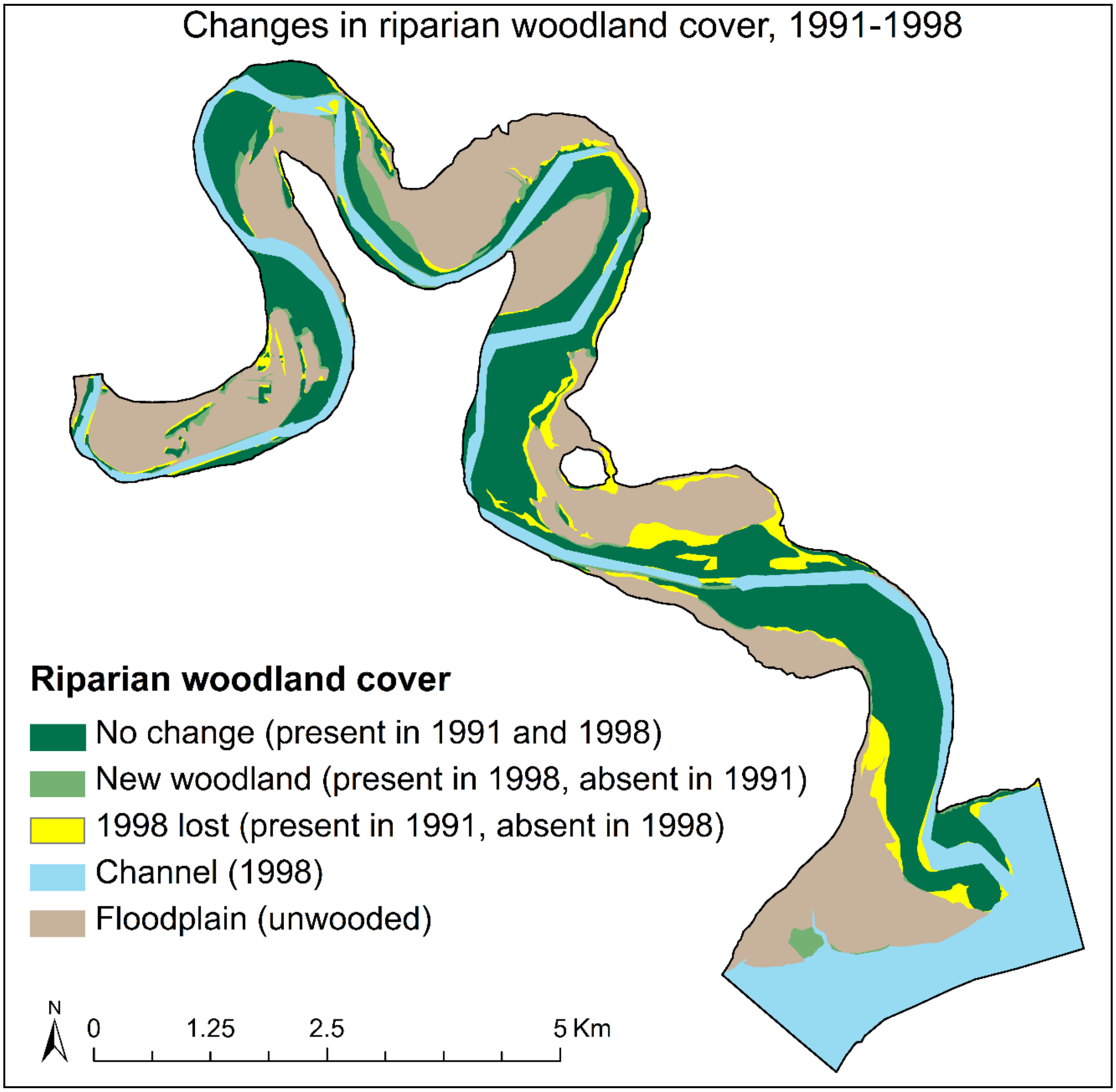

Figure 35. GIS map of riparian woodland cover changes between 1991 and 1998 from aerial photographs of the lowermost 29 km of the White River.

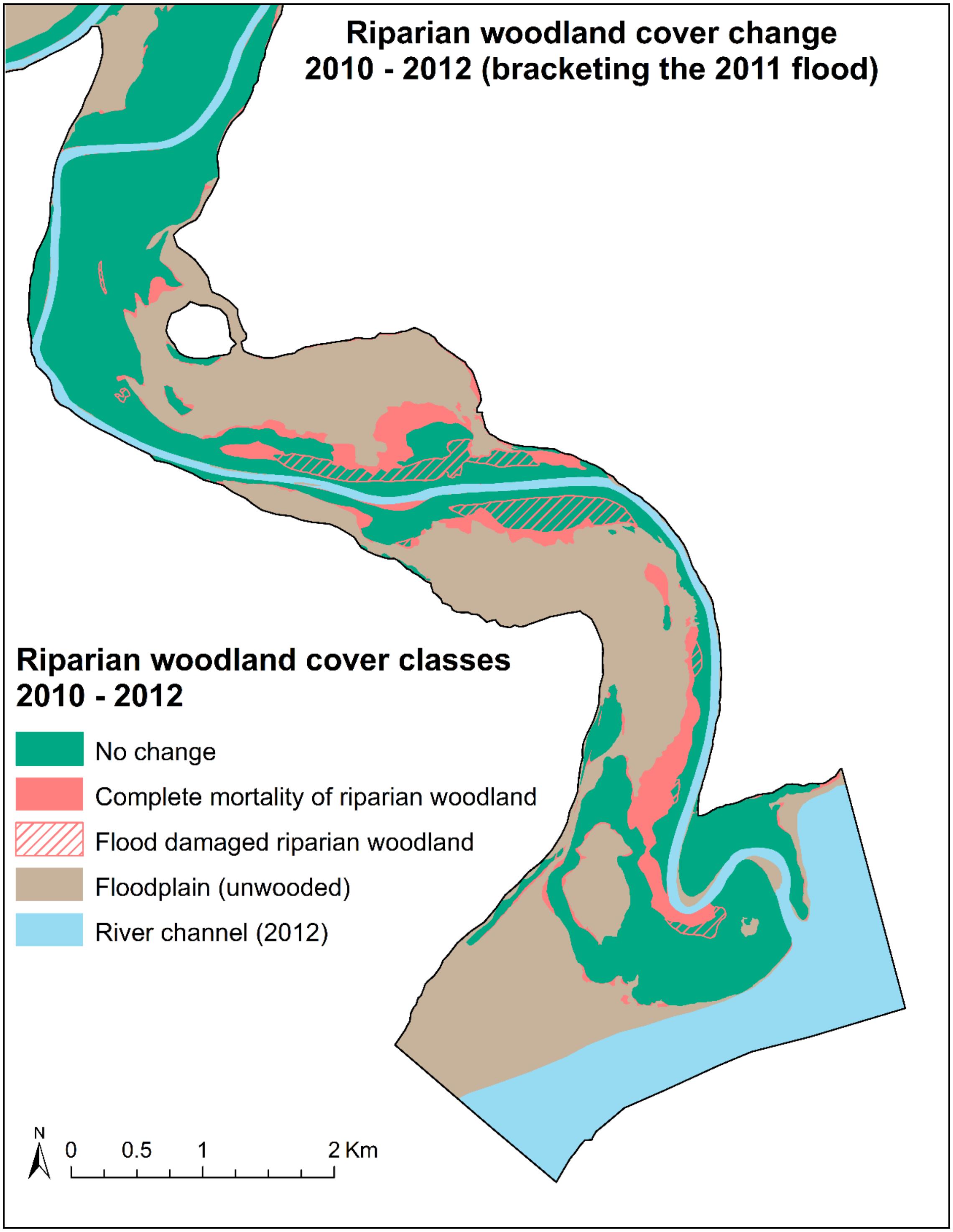

Figure 36. GIS map of riparian woodland cover changes between 2010 and 2012 from aerial photographs of the White River delta.


Figure 37. Photograph of the White River delta in June 2013, showing riparian woodland mortality (grey colored standing dead trees) caused by the 2011 Missouri River flood.

During the post-dam period, riparian woodland expansion occurred not only near the confluence of the White and Missouri Rivers, but also throughout most of the 29 km study reach where Lake Francis Case influenced stream flow and sediment regimes (**Figure 38**). Pre-dam woodland was mostly concentrated in narrow bands near the active channel, but during the post-dam era, woodland expanded landward.

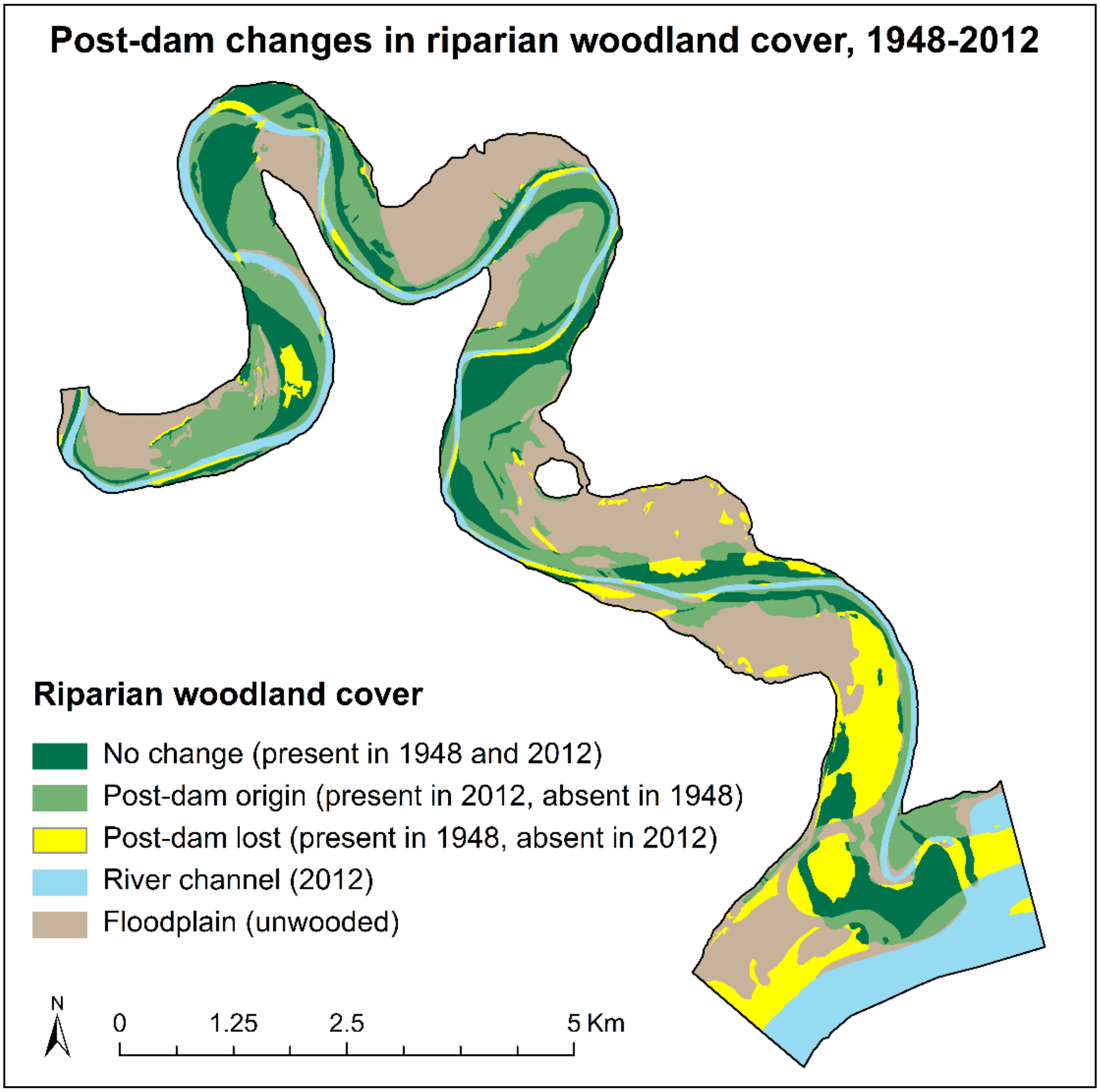

Figure 38. GIS map of riparian woodland cover changes between 1948 (pre-dam) and 2012 (post-dam) from aerial photographs of the White River delta.

The majority of woodland losses throughout the study period were concentrated over river-km 0-10 where reservoir inundation was either permanent or was most variable and extreme, but losses also occurred further upstream where there was channel migration or woodland clearing by private landowners through the 1990s (**Figure 38**).

Age class proportions of the riparian woodland summed for the study area changed markedly during the post-dam era (**Table 70**, **Figure 39**). Pre-dam (1948) woodland was dominated by the old age class (535 ha, 68 percent), post-dam woodland at the midpoint of the study period (1983) was dominated by the young age class (445 ha, 46 percent), and post-dam woodland at the end of the study period (2012) was dominated by the medium age class (539 ha, 46 percent). The medium age class was the least common at the pre-dam (1948) measurement (7 percent), but was the most common in 2012 (46 percent).

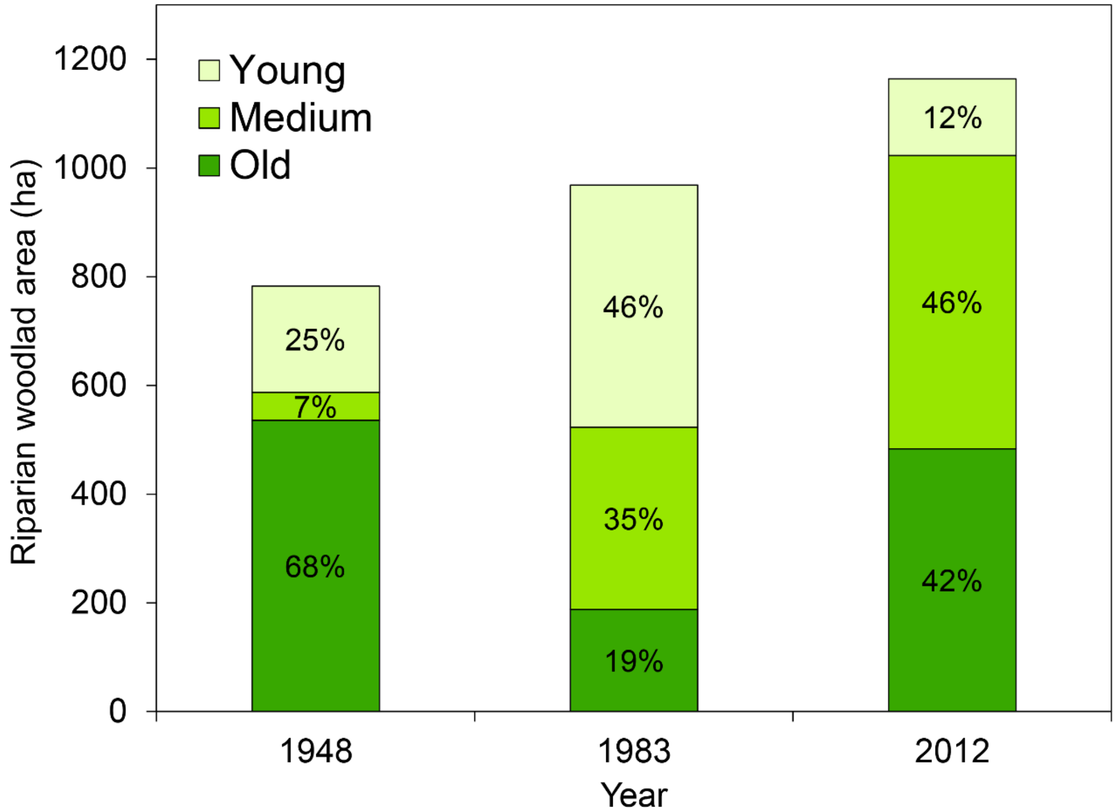

Figure 39. Total riparian woodland area (ha) within the lower 29 km of the White River by age class and year.

The longitudinal distribution of riparian woodland age classes throughout the study reach changed considerably during the post-dam era (**Figure 40**). Prior to damming (1948), the old age class dominated (≥49%) all 4.8 km long sub-segments of the reach, without any distinct longitudinal pattern. However, at the midpoint of the study period (1983), woodland age was dominated by the young age class in the lowermost sub-segments, but gradually transitioned to the medium and old age classes in the upstream direction. At the end of the study period (2012), the medium age class dominated the lower half of the reach, but the old age class dominated the upper half of the reach. Young woodland was most common in river-kms 0-4.8 and 24-28.8.

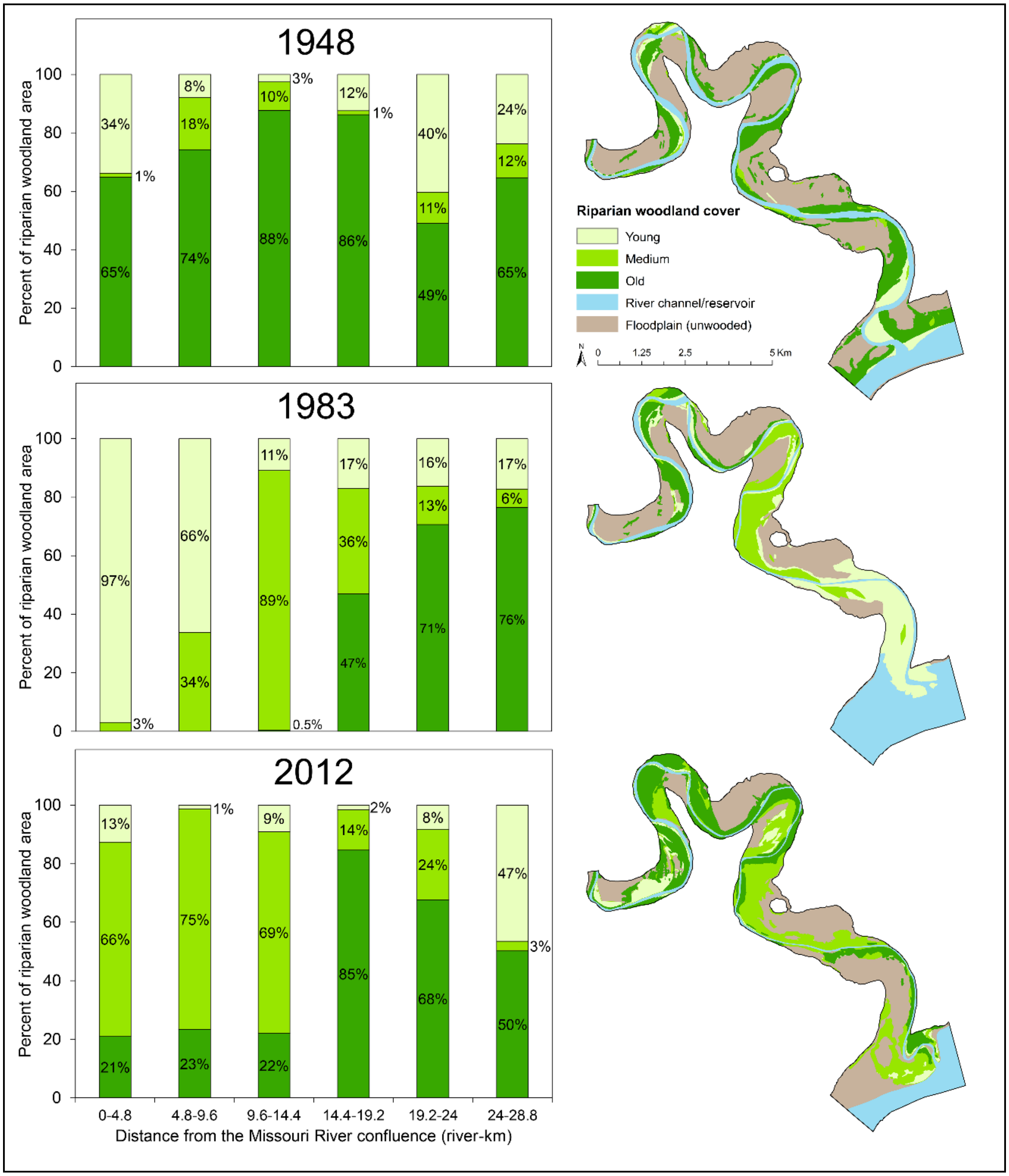

Figure 40. Distribution of young, medium, and old age classes of riparian woodland throughout the lower 29 km of the White River in 1948, 1983, and 2012. The stacked bar graphs (at left) display the proportion of each age class within 4.3-km long segments of the study reach for each measurement period. The maps (at right) display the location of riparian woodland age classes for each measurement period. River-km are based on the 2012 channel, and do not necessarily coincide with the US Army Corps of Engineers' distance values.

Vegetation Patterns and Cottonwood Recruitment in the Delta

Summary data on vegetation sampling results for the delta are presented in **Tables 71-75** and **Figures 41** and **42** below. Note that the definition of the delta here is the lower 29 km of the White River as it enters Lake Francis Case on the Missouri River. Hence, this represents the entire Delta segment (17 km), plus the lower 12 km of the River Breaks segment, as defined in earlier analyses in Parts I-III.

Cottonwood (*Populus deltoides*) was the dominant species across 34 stands sampled on the lower White River, occurring on all 25 tree-sized sites, composing 89% of tree stems and 93% of basal area (**Table 71**). Unlike on the other segments, peachleaf willow was the second most abundant tree species, rather than green ash (although green ash was more abundant in the Delta sites sampled in Part III, using different methods). Within shrub-sized (predominantly younger) stands, cottonwood, peachleaf willow, and sandbar willow dominated the shrub layer; while in tree-sized stands, green ash was the dominant shrub/sapling species (**Table 72**). Similarly, seedlings of peachleaf willow, cottonwood, and sandbar willow were abundant in the understory of shrub-sized stands; whereas green ash, sandbar willow, and riverbank grape were the most abundant species of woody seedlings in forest understories (**Table 73**). High densities of cottonwood, sandbar willow, and peachleaf willow saplings (**Figure 41, Table 75**) and seedlings (**Figure 42, Table 74**) occurred on both the delta itself and on the adjacent lower White River, predominantly in stands <50 years old.

Table 71. Summary values for all overstory species occurring in the 25 tree-size stands sampled on the White River delta. Importance value is the sum of the relative value of density and dominance; maximum = 200. Yellow willow (*Salix lutea*) rarely attained tree size and hence was not included in the overstory summaries.

Species	Presence (%)	Average density (trees/ha)	Average basal area (m^2/ha)	Average importance value
Box elder	10	0.4	0.01	0.2
Cottonwood	100	279.5	13.82	172.2
Green ash	60	9.9	0.14	5.6
Peachleaf willow	60	13.3	0.39	15.9
Russian olive	40	10.9	0.55	6.0
Total		314.0	14.91	200.0

Table 72. Summary values for all shrub layer species occurring in the 34 stands sampled on the White River delta. Importance value is the sum of the relative value of frequency, density and dominance; maximum = 300.

Species	Presence (%)	Average density (stems/ha)	Average importance value
Shrub size stands			
Cottonwood	83	2,476.4	63.9
Peachleaf willow	67	9,204.2	111.8
Sandbar willow	100	4,472.9	124.3
Total		16,153.5	300.0
Tree size stands			
Cottonwood	44	85.6	46.7
False indigo	22	18.5	5.2
Green ash	67	833.3	122.5
Peachleaf willow	22	23.1	13.0
Riverbank grape	56	46.3	21.0
Russian olive	11	4.6	1.6
Sandbar willow	67	2946.8	73.9
Yellow willow	44	64.8	16.2
Total		4023.1	300.0

Table 73. Summary values for all seedling species occurring in the 34 stands sampled on the White River delta. Importance value is the sum of the relative value of frequency, density and dominance; maximum = 300.

Species	Presence (%)	Average density (seedlings/ha)	Average importance value
Shrub size stands			
Box elder	17	69.4	0.9
Cottonwood	83	28,069.4	72.8
False indigo	17	69.4	2.4
Peachleaf willow	67	7,291.7	151.2
Sandbar willow	67	21,770.8	66.4
Woods' rose	17	277.8	6.3
Total		57,548.6	300.0
Tree size stands			
American elm	44	277.8	5.7
Box elder	22	740.7	4.7
Cottonwood	33	34,884.3	23.3
False indigo	22	138.9	6.1
Green ash	78	35,138.9	89.8
Peachleaf willow	11	138.9	1.8
Riverbank grape	89	4,976.9	47.1
Roughleaf dogwood	11	46.3	2.5
Russian olive	33	1,504.6	20.5
Sandbar willow	56	10,518.3	57.9
Western snowberry	44	2,156.1	25.8
Woodbine	44	787.0	11.0
Yellow willow	22	92.6	3.7
Total		91,401.3	300.0

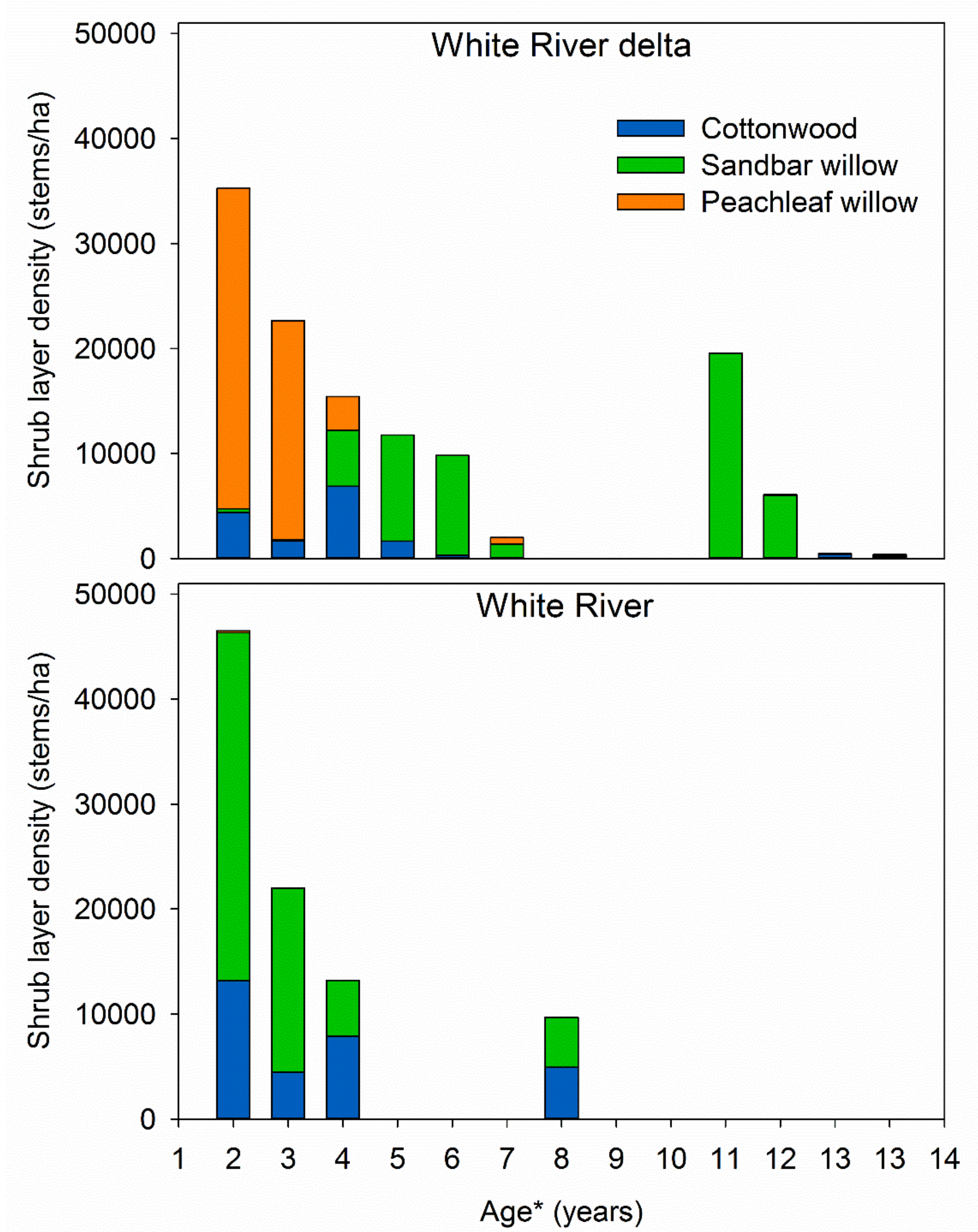

Figure 41. Density (stems/ha) of pioneer species in the shrub layer of stands ≤13 years old on the White River delta and along the White River. *On the delta, age was estimated for stands <10 years old, and along the White River, age was estimated for stands <8 years old.

Table 74. Mean seedling density (seedlings/ha) on the White River delta by stand age class. Dashes indicate no applicable data.

Age class (years)	Mean seedling density (seedlings/ha)
Cottonwood	
0-9	28,069
10-19	125
30-39	0
40-49	104,444
50-59	-
60-69	-
70-79	-
80-89	-
130-139	-
140-149	-
160-169	-
Peachleaf willow	
0-9	7,292
10-19	0
30-39	0
40-49	417
50-59	-
60-69	-
70-79	-
80-89	-
130-139	-
140-149	-
160-169	-
Sandbar willow	
0-9	21,771
10-19	11,683
30-39	0
40-49	12,083
50-59	-
60-69	-
70-79	-
80-89	-
130-139	-
140-149	-
160-169	-

Table 75. Mean shrub layer density (stems/ha) on the White River delta by stand age class. Dashes indicate no applicable data.

Age class (years)	Mean shrub layer density (stems/ha)
Cottonwood	
0-9	2,476
10-19	154
30-39	0
40-49	0
50-59	-
60-69	-
70-79	-
80-89	-
130-139	-
140-149	-
160-169	-
Peachleaf willow	
0-9	9,204
10-19	42
30-39	0
40-49	0
50-59	-
60-69	-
70-79	-
80-89	-
130-139	-
140-149	-
160-169	-
Sandbar willow	
0-9	4,473
10-19	5,121
30-39	0
40-49	306
50-59	-
60-69	-
70-79	-
80-89	-
130-139	-
140-149	-
160-169	-

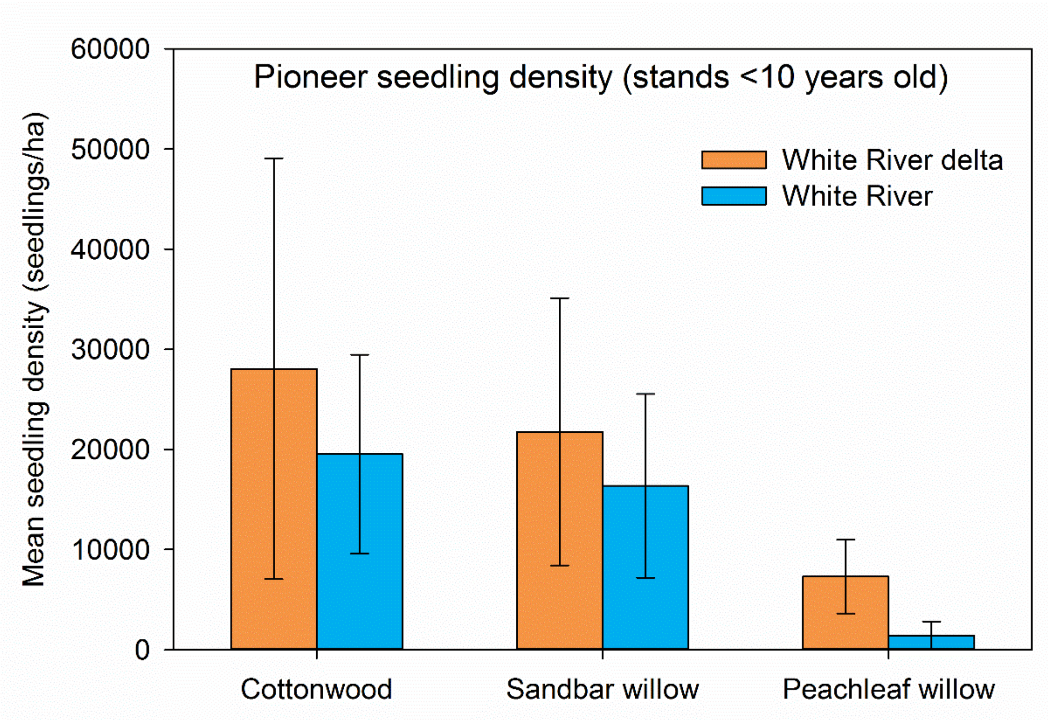

Figure 42. Mean seedling density (seedlings/ha) of the three pioneer species in stands <10 years old on the White River delta and along the White River. Error bars represent standard error.

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APPENDIX

Table A1. Unconsolidated 2010 Cropland Data Layer cover in hectares in the White River floodplain among ecoregions. Percent cover for each crop within each ecoregion is in parentheses.

CropScape Cover	Pine Ridge/ Pierre Shale	Badlands	River Breaks	Delta	Total
Alfalfa	1549.2 (12.8%)	121.6 (0.7%)	593.8 (2.0%)	1.8 (0.1%)	2266.4 (3.8%)
Barley	2.5 (0.0%)	4.8 (0.0%)	70.6 (0.2%)	0.0 (0.0%)	77.9 (0.1%)
Barren	6.8 (0.1%)	820.6 (4.9%)	198.9 (0.7%)	0.2 (0.0%)	1026.4 (1.7%)
Canola	0.0 (0.0%)	0.0 (0.0%)	9.1 (0.0%)	0.0 (0.0%)	9.1 (0.0%)
Corn	24.3 (0.2%)	15.3 (0.1%)	456.6 (1.5%)	7.0 (0.4%)	503.2 (0.8%)
Double Crop Winter Wheat/ Corn	0.0 (0.0%)	0.0 (0.0%)	59.7 (0.2%)	0.0 (0.0%)	59.7 (0.1%)
Deciduous Forest	48.1 (0.4%)	35.4 (0.2%)	374.3 (1.3%)	254.3 (15.8%)	712.0 (1.2%)
Developed/ High Intensity	12.7 (0.1%)	0.5 (0.0%)	1.7 (0.0%)	0.0 (0.0%)	14.9 (0.0%)
Developed/ Low Intensity	184.9 (1.5%)	88.8 (0.5%)	169.1 (0.6%)	0.4 (0.0%)	443.2 (0.7%)
Developed/ Medium Intensity	25.3 (0.2%)	6.4 (0.0%)	23.7 (0.1%)	0.1 (0.0%)	55.4 (0.1%)
Developed/ Open Space	306.8 (2.5%)	93.3 (0.6%)	465.8 (1.6%)	16.0 (1.0%)	881.9 (1.5%)
Dry Beans	4.5 (0.0%)	0.0 (0.0%)	2.1 (0.0%)	0.0 (0.0%)	6.7 (0.0%)
Durum Wheat	0.0 (0.0%)	0.0 (0.0%)	0.2 (0.0%)	0.0 (0.0%)	0.2 (0.0%)
Evergreen Forest	112.7 (0.9%)	8.7 (0.1%)	56.2 (0.2%)	38.4 (2.4%)	216.0 (0.4%)
Fallow/ Idle Cropland	231.8 (1.0%)	124.5 (0.7%)	366.5 (1.2%)	0.3 (0.0%)	723.0 (1.2%)
Flaxseed	0.0 (0.0%)	0.3 (0.0%)	0.4 (0.0%)	0.0 (0.0%)	0.6 (0.0%)
Forest	0.0 (0.0%)	0.0 (0.0%)	0.4 (0.0%)	0.6 (0.0%)	1.1 (0.0%)

CropScape Cover	Pine Ridge/ Pierre Shale	Badlands	River Breaks	Delta	Total
Grassland Herbaceous	7085.3 (58.5%)	13174.3 (79.3%)	14437.7 (48.4%)	204.9 (12.7%)	34902.2 (58.0%)
Herbaceous Wetlands	245.6 (2.0%)	39.6 (0.2%)	63.4 (0.2%)	89.1 (5.5%)	437.7 (0.7%)
Herbs	0.0 (0.0%)	0.0 (0.0%)	58.0 (0.2%)	0.0 (0.0%)	58.0 (0.1%)
Millet	12.2 (0.1%)	94.6 (0.6%)	679.1 (2.3%)	7.0 (0.4%)	792.9 (1.3%)
Mixed Forest	1.9 (0.0%)	0.4 (0.0%)	0.4 (0.0%)	0.0 (0.0%)	2.7 (0.0%)
Oats	4.6 (0.0%)	70.7 (0.4%)	193.8 (0.7%)	0.0 (0.0%)	269.1 (0.4%)
Open Water	9.9 (0.1%)	649.9 (3.9%)	3165.3 (10.6%)	280.9 (17.4%)	4106.0 (6.8%)
Other Hay/Non Alfalfa	51.4 (0.4%)	437.5 (2.6%)	2052.1 (6.9%)	66.4 (4.1%)	2607.4 (4.3%)
Pasture/Hay	3.3 (0.0%)	2.3 (0.0%)	391.2 (1.3%)	143.6 (8.9%)	540.5 (0.5%)
Peas	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.7 (0.0%)	21.8 (0.0%)
Pop or Orn Corn	0.0 (0.0%)	0.0 (0.0%)	6.8 (0.0%)	0.0 (0.0%)	6.8 (0.0%)
Potatoes	0.2 (0.0%)	0.0 (0.0%)	21.0 (0.1%)	0.0 (0.0%)	0.2 (0.0%)
Rye	0.0 (0.0%)	0.0 (0.0%)	2.5 (0.0%)	0.0 (0.0%)	2.5 (0.0%)
Safflower	0.1 (0.0%)	40.3 (0.2%)	2.5 (0.0%)	0.0 (0.0%)	42.9 (0.1%)
Shrubland	3.2 (0.0%)	1.3 (0.0%)	0.6 (0.0%)	0.0 (0.0%)	5.1 (0.0%)
Sod/ Grass Seed	0.0 (0.0%)	0.3 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.3 (0.0%)
Sorghum	0.8 (0.0%)	21.2 (0.1%)	526.4 (1.8%)	4.4 (0.3%)	552.9 (0.9%)
Soybeans	0.0 (0.0%)	0.9 (0.0%)	182.1 (0.6%)	0.9 (0.1%)	184.0 (0.3%)
Spring Wheat	3.2 (0.0%)	64.8 (0.4%)	339.9 (1.1%)	4.3 (0.3%)	412.1 (0.7%)
Sugarbeets	0.4 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.4 (0.0%)

CropScape Cover	Pine Ridge/ Pierre Shale	Badlands	River Breaks	Delta	Total
Sunflower	2.4 (0.0%)	58.6 (0.4%)	393.0 (1.3%)	0.0 (0.0%)	454.1 (0.8%)
Switchgrass	0.0 (0.0%)	0.0 (0.0%)	4.9 (0.0%)	0.0 (0.0%)	4.9 (0.0%)
Triticale	10.4 (0.1%)	2.1 (0.0%)	5.5 (0.0%)	0.9 (0.1%)	19.0 (0.0%)
Wetlands	0.0 (0.0%)	0.0 (0.0%)	0.8 (0.0%)	1.0 (0.1%)	1.8 (0.0%)
Winter Wheat	570.2 (4.7%)	218.2 (1.3%)	1122.0 (3.8%)	12.2 (0.8%)	1922.7 (3.2%)
Woody Wetlands	1602.0 (13.2%)	421.6 (2.5%)	3315.4 (11.1%)	474.6 (29.5%)	5813.6 (9.7%)
Grand Total	12116.6	16618.8	29813.5	1610.0	60159.0

Table A2. List of all plant associations surveyed along the White River, their common names, and the community type they were categorized into. *Indicates new association created for this project.

Association Name	Community Common Name	Community Type
Acer negundo / Prunus virginiana Forest	Box-elder / Choke Cherry Forest	Box Elder Forest
Andropogon gerardii - Panicum virgatum - Helianthus grosseserratus Herbaceous Vegetation	Big Bluestem - Switchgrass - Sunflower Herbaceous Vegetation	Herbaceous Vegetation
Artemisia cana / Pascopyrum smithii Shrubland	Silver Sagebrush / Western Wheatgrass Shrubland	Shrubland
Bromus inermis Herbaceous Vegetation*	Smooth Brome Herbaceous Vegetation*	Herbaceous Vegetation
Elaeagnus angustifolia Woodland*	Russian Olive Woodland*	Russian Olive Woodland
Eleocharis palustris Herbaceous Vegetation	Common Spikerush Herbaceous Vegetation	Herbaceous Vegetation
Fraxinus pennsylvanica - Ulmus americana / Prunus virginiana Woodland	Green Ash - American elm - Choke Cherry Woodland	Green Ash Forest
Fraxinus pennsylvanica - (Ulmus americana) / Symphoricarpos occidentalis Forest	Green Ash - (American Elm) / Western Snowberry Forest	Green Ash Forest
Fraxinus pennsylvanica Forest*	Green Ash Forest*	Green Ash Forest
Hordeum jubatum Herbaceous Vegetation	Foxtail Barley Herbaceous Vegetation	Herbaceous Vegetation
Juniperus virginiana Woodland*	Red Cedar Woodland*	Red Cedar Woodland
Panicum virgatum - (Pascopyrum smithii) Herbaceous Vegetation	Switchgrass - (Western Wheatgrass) Herbaceous Vegetation	Herbaceous Vegetation
Pascopyrum smithii (Bromus inermis) Herbaceous Vegetation*	Western Wheatgrass (Smooth Brome) Herbaceous Vegetation*	Herbaceous Vegetation
Pascopyrum smithii - Nassella viridula Herbaceous Vegetation	Western Wheatgrass - Green Needlegrass Herbaceous Vegetation	Herbaceous Vegetation
Pascopyrum smithii Herbaceous Vegetation	Western Wheatgrass Herbaceous Vegetation	Herbaceous Vegetation
Phalaris arundinacea Herbaceous Vegetation*	Reed Canary Grass Herbaceous Vegetation*	Herbaceous Vegetation
Phragmites australis Herbaceous Vegetation*	Common Reed Herbaceous Vegetation*	Herbaceous Vegetation

Association Name	**Community Common Name**	**Community Type**
Populus deltoides - (Salix amygdaloides) / Salix exigua Woodland	Eastern Cottonwood - (Peachleaf Willow) / Coyote Willow Woodland	Cottonwood Forest
Populus deltoides / Bromus inermis Woodland*	Eastern Cottonwood / Smooth Brome Woodland*	Cottonwood Forest
Populus deltoides / Elaeagnus angustifolia Woodland*	Eastern Cottonwood / Russian Olive Woodland*	Cottonwood Forest
Populus deltoides / Fraxinus pennsylvanica Forest	Eastern Cottonwood / Green Ash Forest	Cottonwood Forest
Populus deltoides / Herbaceous Woodland*	Eastern Cottonwood / Herbaceous Woodland*	Cottonwood Forest
Populus deltoides / Juniperus scopulorum Woodland	Eastern Cottonwood / Rocky Mountain Juniper Woodland	Cottonwood Forest
Populus deltoides / Panicum virgatum - Schizachyrium scoparium Woodland	Eastern Cottonwood / Switchgrass - Little Bluestem Woodland	Cottonwood Forest
Populus deltoides / Prunus virginiana Forest*	Eastern Cottonwood / Choke Cherry Forest*	Cottonwood Forest
Populus deltoides / Symphoricarpos occidentalis Woodland	Eastern Cottonwood / Western Snowberry Woodland	Cottonwood Forest
Riverine Sand Flats-Bars Sparse Vegetation	Riverine Sand Flats-Bars Sparse Vegetation	Herbaceous Vegetation
Salix amygdaloides Woodland	Peachleaf Willow Woodland	Peachleaf Willow
Salix exigua / Mesic Graminoid Shrubland	Sandbar Willow / Mesic Graminoid Shrubland	Sandbar Willow
Salix exigua Temporarily Flooded Shrubland	Coyote Willow Temporarily Flooded Shrubland	Sandbar Willow
Symphytocarpus occidentalis Shrubland	Western Snowberry Shrubland	Shrubland
Typha spp. - *Schoenoplectus acutus* - Mixed Herbs Midwest Herbaceous Vegetation	Cattail Species - Hardstem bulrush - Mixed Herbs Midwest Herbaceous Vegetation	Herbaceous Vegetation
Wet Meadow Mixed Herbaceous Vegetation*	Wet Meadow Mixed Herbaceous Vegetation*	Herbaceous Vegetation

Table A3. Number of plant associations surveyed throughout each ecoregion segment.

Association	**Pine Ridge / Pierre Shale**	**Badlands**	**River Breaks**	**Delta**	**Total**
Big Bluestem - Switchgrass - Sunflower Herbaceous Vegetation	0	0	1	0	1
Box-elder / Choke Cherry Forest	9	0	0	0	9
Cattail Species - Hardstem bulrush - Mixed Herbs Midwest Herbaceous Vegetation	2	0	0	0	2
Common Reed Herbaceous Vegetation	0	0	0	1	1
Common Spikerush Herbaceous Vegetation	0	1	0	0	1
Coyote Willow Temporarily Flooded Shrubland	0	7	0	6	13
Eastern Cottonwood - (Peachleaf Willow) / Coyote Willow Woodland	0	1	7	10	18
Eastern Cottonwood / Choke Cherry Forest	0	0	1	0	1
Eastern Cottonwood / Green Ash Forest	13	12	25	18	68
Eastern Cottonwood / Herbaceous Woodland	0	15	11	1	27
Eastern Cottonwood / Rocky Mountain Juniper Woodland	1	4	0	0	5
Eastern Cottonwood / Russian Olive Woodland	0	1	5	0	6
Eastern Cottonwood / Smooth Brome Woodland	4	0	6	0	10
Eastern Cottonwood / Switchgrass - Little Bluestem Woodland	0	3	0	0	3
Eastern Cottonwood / Western Snowberry Woodland	1	4	3	0	8
Foxtail Barley Herbaceous Vegetation	0	0	1	0	1
Green Ash - (American Elm) / Western Snowberry Forest	3	1	3	0	7
Green Ash - American elm - Choke Cherry Woodland	0	0	3	0	3

Association	Pine Ridge / Pierre Shale	Badlands	River Breaks	Delta	Total
Green Ash Forest	4	3	5	2	14
Peachleaf Willow Woodland	0	0	1	1	2
Red Cedar Woodland	0	1	0	0	1
Reed Canary Grass Herbaceous Vegetation	2	0	0	0	2
Riverine Sand Flats-Bars Sparse Vegetation	0	0	2	7	9
Russian Olive Woodland	0	0	1	0	1
Sandbar Willow / Mesic Graminoid Shrubland	2	4	13	7	26
Silver Sagebrush / Western Wheatgrass Shrubland	0	1	0	0	1
Smooth Brome Herbaceous Vegetation	2	0	8	0	10
Switchgrass - (Western Wheatgrass) Herbaceous Vegetation	0	2	5	0	7
Western Snowberry Shrubland	1	2	2	0	5
Western Wheatgrass - Green Needlegrass Herbaceous Vegetation	0	4	1	0	5
Western Wheatgrass (Smooth Brome) Herbaceous Vegetation	0	1	9	1	11
Western Wheatgrass Herbaceous Vegetation	2	0	0	0	2
Wet Meadow Mixed Herbaceous Vegetation	1	4	11	3	19

Table A4. Total species list for 195 species found during vegetation sampling of the White River floodplain. C-values were taken from the South Dakota list and wetland indicator statuses were taken from the Great Plains list. C-values with an asterisk are non-native species.

Species Name	Common name	$\bar{C}$	WIS
Abutilon theophrasti	Velvetleaf	*	UPL
Acer negundo	Box Elder	1	FAC
Achillea millefolium	Common Yarrow	3	FACU
Agropyron cristatum	Crested Wheatgrass	*	None
Agrostis gigantea	Redtop Bentgrass	*	FACW
Alliaria petiolata	Garlic mustard	*	FACU
Amaranthus albus	Tumble Pigweed/ Prostrate Pigweed	0	FACU
Amaranthus blitoides	Mat amaranth	0	FAC
Amaranthus retroflexus	Redroot Pigweed/Redroot Amaranth	0	FACU
Ambrosia artemisiifolia	Common Ragweed	0	FACU
Ambrosia trifida	Giant Ragweed	0	FAC
Amorpha canescens	Leadplant	9	None
Amorpha fruticosa	Wild Indigo	4	FACW
Andropogon gerardii	Big Bluestem	5	FACU
Apocynum cannabinum	Dogbane/Indian Hemp	4	FAC
Arctium minus	Lesser burdock	*	FACU
Argemone polyanthemos	Crested Pricklypoppy	4	None
Artemisia cana	Silver Sagebrush	7	FACU
Asclepias incarnata	Swamp Milkweed	5	OBL
Asclepias speciosa	Showy Milkweed	4	FAC
Asclepias syriaca	Common Milkweed	0	UPL
Asclepias verticillata	Whorled Milkweed	3	FACU
Astragalus laxmannii var. *robustior*	Prairie milkvetch	8	None
Astragalus racemosus	Creamy Poisonvetch	7	None
Beckmannia syzigachne	American Sloughgrass	1	OBL
Berteroa incana	Hoary alyssum/False alyssum	*	None
Bidens tripartita	Swamp Tickseed	2	FACW
Bolboschoenus fluviatilis	River Bulrush	2	OBL
Bouteloua curtipendula	Sideoats grama	5	UPL
Bouteloua dactyloides	Buffalograss	4	FACU
Bouteloua gracilis	Blue grama	7	None
Bromus inermis	Smooth Bromegrass	*	UPL
Bromus tectorum	Cheatgrass	*	None
Calylophus serrulatus	Raven Yellow Sundrops	7	None
Camelina microcarpa	Small-seeded False Flax/Littlepod False Flax	*	UPL
Cardaria draba	Hoary Cress/Whitetop	*	None
Carduus nutans	Musk Thistle	*	FACU

Species Name	Common name	$\bar{C}$	WIS
Carex brevior	Fescue Sedge	4	FAC
Carex cristatella	Crested sedge	7	FACW
Carex gravida	Heavy sedge	5	FACW
Carex hystericina	Bottlebrush Sedge	7	OBL
Carex pellita	Wooly Sedge	4	OBL
Chenopodium album	White Goosefoot	*	FACU
Chenopodium glaucum	Oak-leaf Goosefoot	*	FACW
Chenopodium incanum	Mealy goosefoot	2	None
Chenopodium simplex	Maple-leaf Goosefoot	5	None
Chorispora tenella	Blue Mustard/Crossflower	*	None
Cicuta maculata	Water Hemlock	4	OBL
Cirsium arvense	Canada Thistle	*	FACU
Cirsium vulgare	Bull Thistle	*	UPL
Cleome serrulata	Rocky Mountain beeplant	2	FACU
Conium maculatum	Poison hemlock	*	FACW
Convolvulus arvensis	Field Bindweed	*	None
Conyza canadensis	Horseweed	0	FACU
Cyperus esculentus	Yellow Nutsedge	0	FACW
Dalea candida	White Prairie Clover	8	None
Descurainia pinnata	Western Tansy Mustard	1	None
Distichlis spicata var. *stricta*	Inland Saltgrass/Greene Saltgrass	2	FACW
Echinochloa muricata	Barnyard Grass	0	OBL
Elaeagnus angustifolia	Russian Olive	*	FACU
Eleocharis palustris	Creeping Spikerush	4	OBL
Ellisia nyctelea	Aunt Lucy	0	FACU
Elymus canadensis	Canada Wildrye	3	FACU
Elymus elymoides	Squirreltail	6	UPL
Elymus virginicus	Virginia Wild-rye	4	FAC
Epilobium palustre	Willow-herb	10	OBL
Equisetum arvense	Field Horsetail	4	FAC
Equisetum hyemale	Common Scouring Rush	3	FACW
Erigeron strigosus	Daisy Fleabane	3	FACU
Erysimum asperum	Western Wallflower	3	None
Eupatorium maculatum	Spotted Joe-Pye Weed	9	OBL
Euphorbia maculata	Spotted Surge	0	FACU
Euphorbia marginata	Snow-on-the-Mountain	2	FACU
Fraxinus pennsylvanica	Green Ash	5	FAC
Galium aparine	Bedstraw/Catchweed	0	FACU
Gaura coccinea	Scarlet gaura/Scarlet Beeblossom	4	None
Gaura parviflora	Small-flowered Gaura	1	UPL
Glycyrrhiza lepidota	American licorice	2	FACU
Grindelia squarrosa	Curlycup Gumweed	1	UPL
Gutierrezia sarothrae	Broom Snakeweed	6	None

Species Name	Common name	$\overline{C}$	WIS
Hedeoma hispida	Rough False Pennyroyal	2	None
Helianthus annuus	Common Sunflower	0	FACU
Helianthus petiolaris	Prairie sunflower	0	None
Hesperis matronalis	Dame's Rocket	*	FACU
Hordeum jubatum	Foxtail Barley	0	FACW
Juncus dudleyi	Dudley's Rush	4	FACW
Juncus marginatus	Grass-leaf Rush	10	FACW
Juncus torreyi	Torrey's rush	2	FACW
Juniperus virginiana	Eastern Redcedar	0	UPL
Kochia scoparia	Burningbush	*	FACU
Lactuca serriola	Prickly Lettuce	*	FAC
Lappula squarrosa	European stickseed	*	None
Lathyrus polymorphus	Hoary vetchling/Manystem Pea	7	None
Lepidium densiflorum	Greenflower Pepperweed/Common Pepperweed	0	FAC
Linum rigidum	Stiffstem Flax	5	None
Lycopus americanus	Water Horehound	4	OBL
Lygodesmia juncea	Rush Skeletonplant	2	None
Maianthemum racemosum	False Solomon's-seal	9	FAC
Maianthemum stellatum	Starry False Lily of the Valley	5	FACU
Medicago lupulina	Black Medick	*	FACU
Medicago sativa	Alfalfa	*	UPL
Melilotus officinalis	Yellow Sweet Clover	*	FACU
Mentha arvensis	Field Mint	3	FACW
Monarda fistulosa	Wild Bergamot	5	UPL
Muhlenbergia racemosa	Marsh Muhly	4	FACW
Nepeta cataria	Catnip	*	FACU
Neslia paniculata	Ball Mustard	*	None
Oenothera biennis	Common Evening-primrose	0	FACU
Opuntia humifusa	Eastern Prickly Pear/Devil's tongue	5	None
Opuntia polyacantha	Plains Pricklypear	3	None
Oxalis stricta	Yellow Woodsorrel	0	FACU
Panicum capillare	Witchgrass	0	FAC
Panicum oligosanthes	Scribner's rosette grass	6	FACU
Panicum virgatum	Switchgrass	5	FAC
Parthenocissus vitacea	Thicket Creeper	2	FACU
Pascopyrum smithii	Western Wheatgrass	4	FACU
Pediomelum argophyllum	Silverleaf Scurfpea/Silverleaf Indian breadroot	4	None
Penstemon gracilis	Lilac Penstemon	6	FACU
Penstemon grandiflorus	Large Beardtongue	5	None
Phalaris arundinacea	Reed Canarygrass	0	FACW
Phleum pratense	Timothy grass	*	FACU

Species Name	Common name	$\bar{C}$	WIS
Phragmites australis	Common Reed	0	FACW
Physalis longifolia	Longleaf groundcherry	0	None
Plantago major	Broadleaf Plantain	*	FAC
Poa compressa	Canada Bluegrass	*	FACU
Poa palustris	Fowl Bluegrass	4	FACW
Poa pratensis	Kentucky Bluegrass	*	FACU
Poa secunda	Sandberg's bluegrass	8	FACU
Polygala alba	White Milkwort	5	None
Polygonum amphibium	Water Smartweed	0	OBL
Polygonum pensylvanicum	Pennsylvania Smartweed	0	FACW
Polypogon monspeliensis	Rabbitfoot Grass	*	OBL
Populus deltoides	Cottonwood	3	FAC
Prunus virginiana	Chokecherry	4	FACU
Psoralidium lanceolatum	Lemon Scurfpea	6	None
Ranunculus abortivus	Kidney-leaf Buttercup	2	FAC
Ranunculus cymbalaria	Shore Buttercup	3	OBL
Ranunculus pensylvanicus	Bristly Buttercup	4	FACW
Ranunculus sceleratus	Cursed Buttercup	3	OBL
Ratibida columnifera	Prairie Coneflower	3	None
Rhus aromatica	Skunkbrush	7	UPL
Ribes missouriense	Missouri Gooseberry	4	None
Rorippa palustris	Bog Yellowcress	2	OBL
Rosa arkansana	Prairie Rose	3	FACU
Rumex crispus	Curly Dock/Sour Dock	*	FAC
Rumex maritimus	Golden Dock	1	FACW
Salix amygdaloides	Peachleaf Willow	3	FACW
Salix exigua	Sandbar Willow	3	FACW
Salix fragilis	Crack Willow	*	FAC
Salsola tragus	Tumbleweed	*	FACU
Schedonnardus paniculatus	Tumblegrass	1	None
Schizachyrium scoparium	Little Bluestem	6	FACU
Schoenoplectus pungens	Common Threesquare	4	OBL
Schoenoplectus tabernaemontani	Softstem Bulrush	3	OBL
Scutellaria galericulata	Marsh Skullcap	7	OBL
Setaria glauca	Yellow Foxtail	*	None
Setaria viridis	Green bristlegrass	*	None
Shepherdia argentea	Silver Buffalo Berry	5	UPL
Sisymbrium altissimum	Tumbling Mustard	*	FACU
Sisymbrium loeselii	Tall Hedge Mustard	*	None
Solanum rostratum	Buffalobur/Buffalobur Nightshade	0	None
Solidago canadensis	Canada Goldenrod	1	FACU
Solidago gigantea	Late Goldenrod	4	FACW

Species Name	Common name	$\overline{C}$	WIS
Solidago mollis	Velvety Goldenrod	6	None
Sonchus arvensis	Sow Thistle	*	FAC
Sorghastrum nutans	Indiangrass	6	FACU
Spartina pectinata	Prairie Cordgrass	5	FACW
Sphaeralcea coccinea	Scarlet Globemallow	4	None
Sporobolus cryptandrus	Sand Dropseed	6	FACU
Sporobolus heterolepis	Prairie Dropseed	10	UPL
Stipa comata	Needle and Thread Grass	6	None
Stipa viridula	Green Needle Grass	5	None
Symphoricarpos occidentalis	Western Snowberry	3	UPL
Taraxacum officinale	Common Dandelion	*	FACU
Teucrium canadense	American germander/Woodsage	3	FACW
Thinopyrum intermedium	Intermediate Wheatgrass	*	None
Thlaspi arvense	Field pennycress	*	FACU
Toxicodendron radicans	Poison Ivy	3	FACU
Tradescantia bracteata	Small-bracted Spiderwort	7	FACU
Tragopogon dubius	Goatsbeard	*	None
Typha angustifolia	Narrow-leaved Cat-tail	*	OBL
Typha latifolia	Broadleaf cat-tail	2	OBL
Ulmus americana	American Elm	3	FAC
Urtica dioica	Stinging Nettle	0	FAC
Verbascum thapsus	Common mullein	*	UPL
Verbena bracteata	Prostrate vervain	0	FACU
Verbena hastata	Blue Verbena	5	FACW
Verbena stricta	Wooly verbena	2	None
Verbena urticifolia	White vervain	3	FAC
Vernonia fasciculata	Ironweed	3	FACW
Veronica anagallis-aquatica	Water Speedwell	*	OBL
Vitis riparia	Wild Grape	3	FAC
Xanthium strumarium	Gray Cocklebur	0	FAC
Yucca glauca	Soapweed Yucca	6	None
Zigadenus venenosus	Meadow Deathcamas	7	None

Table A5. Species list for species detected through sampling in each ecoregion segment on the White River floodplain. P denotes a species is present in the ecoregion and a dash indicates its absence.

Species Name	**Pine Ridge/ Pierre Shale**	**Badlands**	**River Breaks**	**Delta**
Abutilon theophrasti	-	-	P	P
Acer negundo	P	P	P	-
Achillea millefolium	-	-	P	-
Agropyron cristatum	P	P	P	P
Agrostis gigantea	P	-	-	-
Alliaria petiolata	-	-	P	-
Amaranthus albus	P	-	-	-
Amaranthus blitoides	-	-	-	P
Amaranthus retroflexus	P	-	-	P
Ambrosia artemisiifolia	P	P	P	P
Ambrosia trifida	-	-	P	P
Amorpha canescens	-	-	-	P
Amorpha fruticosa	-	P	P	P
Andropogon gerardii	-	P	P	-
Apocynum cannabinum	P	P	P	P
Arctium minus	-	-	-	P
Argemone polyanthemos	-	P	-	-
Artemisia cana	P	P	P	P
Asclepias incarnata	-	P	P	-
Asclepias speciosa	P	P	P	-
Asclepias syriaca	-	P	P	P
Asclepias verticillata	-	-	P	-
Astragalus laxmannii var. *robustior*	P	P	-	-
Astragalus racemosus	-	P	P	-
Beckmannia syzigachne	-	-	-	P
Berteroa incana	-	-	P	-
Bidens tripartita	-	-	P	P
Bolboschoenus fluviatilis	P	-	P	P
Bouteloua curtipendula	P	P	P	-
Bouteloua dactyloides	-	P	P	-
Bouteloua gracilis	P	P	-	-
Bromus inermis	P	P	P	P
Bromus tectorum	P	P	P	P
Calylophus serrulatus	P	-	-	-
Camelina microcarpa	-	-	P	-
Cardaria draba	-	-	P	-
Carduus nutans	P	P	P	P

Species Name	**Pine Ridge/ Pierre Shale**	**Badlands**	**River Breaks**	**Delta**
Carex brevior	-	P	P	P
Carex cristatella	-	P	P	P
Carex gravida	-	-	P	P
Carex hystericina	P	-	P	P
Carex pellita	P	P	-	-
Chenopodium album	P	P	P	P
Chenopodium glaucum	P	P	P	P
Chenopodium incanum	-	P	-	P
Chenopodium simplex	P	P	P	P
Chorispora tenella	-	-	P	-
Cicuta maculata	-	-	P	P
Cirsium arvense	P	P	P	P
Cirsium vulgare	P	-	P	-
Cleome serrulata	-	P	-	-
Conium maculatum	-	-	P	-
Convolvulus arvensis	P	P	P	P
Conyza canadensis	P	P	P	P
Cyperus esculentus	-	-	-	P
Dalea candida	-	P	-	-
Descurainia pinnata	-	P	P	-
Distichlis spicata var. *stricta*	-	P	P	P
Echinochloa muricata	-	-	P	P
Elaeagnus angustifolia	-	P	P	P
Eleocharis palustris	P	P	P	P
Ellisia nyctelea	-	P	P	P
Elymus canadensis	P	P	P	P
Elymus virginicus	P	P	P	P
Epilobium palustre	-	-	P	P
Equisetum arvense	P	P	P	P
Equisetum hyemale	P	P	P	P
Erigeron strigosus	-	P	P	P
Erysimum asperum	-	-	P	-
Eupatorium maculatum	-	-	P	P
Euphorbia maculata	-	P	P	P
Euphorbia marginata	P	P	P	P
Fraxinus pennsylvanica	P	P	P	P
Galium aparine	P	-	P	P
Gaura coccinea	-	P	-	-
Gaura parviflora	P	P	P	P
Glycyrrhiza lepidota	P	P	P	P

Species Name	**Pine Ridge/ Pierre Shale**	**Badlands**	**River Breaks**	**Delta**
Grindelia squarrosa	-	P	P	P
Gutierrezia sarothrae	-	P	-	-
Hedeoma hispida	-	-	P	P
Helianthus annuus	-	P	P	P
Helianthus petiolaris	P	P	P	P
Hesperis matronalis	P	-	-	-
Hordeum jubatum	-	P	P	P
Juncus dudleyi	P	-	-	P
Juncus marginatus	-	-	P	-
Juncus torreyi	-	-	P	P
Juniperus virginiana	P	P	P	P
Kochia scoparia	P	P	P	P
Lactuca serriola	P	P	P	P
Lappula squarrosa	-	P	P	-
Lathyrus polymorphus	-	-	P	-
Lepidium densiflorum	-	P	-	-
Linum rigidum	-	P	P	-
Lycopus americanus	-	P	P	P
Lygodesmia juncea	-	P	P	-
Maianthemum racemosum	P	P	P	P
Maianthemum stellatum	-	-	-	P
Medicago lupulina	P	P	P	P
Medicago sativa	P	P	P	P
Melilotus officinalis	P	P	P	P
Mentha arvensis	P	-	P	P
Monarda fistulosa	-	-	P	-
Muhlenbergia racemosa	P	P	P	P
Nepeta cataria	P	P	P	P
Neslia paniculata	P	P	P	-
Oenothera biennis	P	P	P	P
Opuntia humifusa	P	P	P	-
Opuntia polyacantha	P	-	-	-
Oxalis stricta	-	-	P	-
Panicum capillare	P	-	P	P
Panicum oligosanthes	-	P	-	-
Panicum virgatum	P	P	P	P
Parthenocissus vitacea	P	P	P	P
Pascopyrum smithii	P	P	P	P
Pediomelum argophyllum	P	P	P	-
Penstemon gracilis	-	P	-	-

Species Name	Pine Ridge/ Pierre Shale	Badlands	River Breaks	Delta
Penstemon grandiflorus	-	P	P	-
Phalaris arundinacea	P	P	P	P
Phleum pratense	-	-	P	-
Phragmites australis	-	-	P	P
Physalis longifolia	P	-	P	-
Plantago major	-	-	P	P
Poa compressa	-	-	-	P
Poa palustris	P	P	-	-
Poa pratensis	P	P	P	P
Poa secunda	-	-	-	P
Polygala alba	-	P	-	-
Polygonum amphibium	-	-	-	P
Polygonum pensylvanicum	-	-	P	P
Polypogon monspeliensis	-	-	P	P
Populus deltoides	P	P	P	P
Prunus virginiana	P	P	P	P
Psoralidium lanceolatum	P	P	-	-
Ranunculus abortivus	-	-	P	-
Ranunculus cymbalaria	-	-	P	P
Ranunculus pensylvanicus	-	-	P	P
Ranunculus sceleratus	-	-	-	P
Ratibida columnifera	P	P	P	P
Rhus aromatica	P	P	P	-
Ribes missouriense	P	P	P	P
Rorippa palustris	-	-	-	P
Rosa arkansana	P	P	P	P
Rumex crispus	P	P	P	P
Rumex maritimus	-	-	P	P
Salix amygdaloides	P	P	P	P
Salix interior	P	P	P	P
Salix fragilis	P	-	-	-
Salsola tragus	P	P	P	P
Schedonnardus paniculatus	-	P	-	-
Schizachyrium scoparium	-	P	P	-
Schoenoplectus pungens	P	P	P	P
Schoenoplectus tabernaemontani	P	-	P	P
Scutellaria galericulata	-	-	P	P
Setaria glauca	-	-	P	P
Setaria viridis	-	-	P	-
Sisymbrium altissimum	P	-	P	P

Species Name	Pine Ridge/ Pierre Shale	Badlands	River Breaks	Delta
Sisymbrium loeselii	P	P	P	P
Solanum rostratum	-	-	P	-
Solidago canadensis	-	P	P	P
Solidago gigantea	P	P	P	P
Solidago mollis	-	P	-	-
Sonchus arvensis	P	-	P	P
Sorghastrum nutans	-	P	-	-
Spartina pectinata	P	P	P	P
Sphaeralcea coccinea	-	P	-	-
Sporobolus cryptandrus	P	P	P	-
Sporobolus heterolepis	-	P	-	-
Stipa comata	-	P	P	-
Stipa viridula	P	P	P	P
Symphoricarpos occidentalis	P	P	P	P
Taraxacum officinale	P	P	P	P
Teucrium canadense	-	-	P	P
Thinopyrum intermedium	-	P	P	-
Thlaspi arvense	P	P	P	P
Toxicodendron radicans	P	P	P	-
Tradescantia bracteata	-	-	P	-
Tragopogon dubius	P	P	P	P
Typha angustifolia	P	-	P	P
Typha latifolia	P	-	-	-
Ulmus americana	P	-	P	P
Urtica dioica	P	-	-	P
Verbascum thapsus	P	-	P	P
Verbena bracteata	-	P	P	P
Verbena hastata	-	-	P	P
Verbena stricta	P	P	P	P
Verbena urticifolia	-	-	P	P
Vernonia fasciculata	-	-	P	-
Veronica anagallis-aquatica	P	-	-	-
Vitis riparia	P	-	P	P
Xanthium strumarium	P	P	P	P
Yucca glauca	-	P	-	-
Zigadenus venenosus	-	P	-	-

Table A6. Non-species taxa list for 19 taxa found during vegetation sampling of the White River floodplain.

Species Name	**Common name**	**Level**
Apiaceae sp.	Carrot Family	Family
Asclepias sp.	Milkweed	Genus
Asteraceae sp.	Sunflower Family	Family
Brassicaceae sp.	Mustard Family	Family
Carex sp.	Sedge	Genus
Chenopodium sp.	Goosefoot	Genus
Cyperaceae sp.	Sedge Family	Family
Euphorbiaceae sp.	Spurge Family	Family
Fabaceae sp.	Pea Family	Family
Indeterminable forb	Indeterminable forb	Other
Indeterminable grass	Indeterminable grass	Family
Indeterminable species	Indeterminable species	Other
Lamiaceae sp.	Mint Family	Family
Poa sp.	Bluegrass	Genus
Ranunculus sp.	Buttercup	Genus
Solidago sp.	Goldenrod	Genus
Sporobolus sp.	Dropseed	Genus
Thistle sp.	Thistle species	Other
Verbena sp.	Vervain species	Genus
Viola sp.	Violet	Genus