RIPARIAN FOREST VEGETATION PATTERNS AND HISTORIC CHANNEL DYNAMICS OF THE BIG SIOUX RIVER, SOUTH DAKOTA

By

Matt J. Ley

B.S., University of Wyoming, 2009

A Thesis Submitted in Partial Fulfillment of
The Requirements for the Degree of
Masters of Science

In the Graduate School
The University of South Dakota
May, 2012

The members of the Committee appointed to examine

the thesis of Matt Ley find it

satisfactory and recommend that it be accepted.

Chairperson, Mark Dixon

Jake Kerby

Gary Larson

Mark Sweeney

December 9, 2011

Acknowledgements

First and foremost, I would like to thank my advisor, Dr. Mark Dixon, for his guidance, advice, encouragement, and friendship over the last two years. His experience and insight in riparian ecology and statistics added greatly to my time at USD. Dr. Dixon is a true mentor that allowed me the freedom to exact my own interpretations on the project without prejudice, but was always prepared to provide invaluable feedback when necessary.

My thesis was greatly improved by valuable input from committee members, Dr. Jake Kerby, Dr. Mark Sweeney, and Dr. Gary Larson. Each brought their own level of expertise and contribution to this project and without their collective knowledge and leadership, the merits of this project would not have been fully realized. Thank you for your time and assistance.

Acknowledgements would not be complete without recognizing my field technician, Brian Viger, for providing invaluable assistance with data collection and analysis during the duration of the project. Few people have ever been so excited and willing to sample vegetation in the sometimes unpleasant conditions the Big Sioux so often provided.

Funding from this project came primarily from a State Wildlife Grant provided by the South Dakota Game, Fish, and Parks Department. Specifically, I would like to thank Dave Ode from the SDGF&P for his guidance and assistants with project scope and design. Additionally, I would like to thank the numerous private landowners, state agencies, conservation partnerships, and the Flandreau-Santee Sioux Tribe for allowing us access to their properties for data collection purposes.

Most importantly, I would like to thank my fiancée, Casey, for her motivation, support, love, and enthusiasm. This thesis is a testament to your love and devotion. Thank you to our families for their constant support and encouragement. A special thanks to my parents, Dan and Pat Ley, for providing me the many educational opportunities throughout my life and for instilling the work ethic that has always been at the center of my various pursuits. Thank you.

Riparian Forest Vegetation Patterns and Historic Channel Dynamics of the Big Sioux River, South Dakota

Matt J. Ley

Abstract

The Big Sioux River, a major tributary to the Missouri River, drains approximately 22,550 km^2 in South Dakota, Iowa, and Minnesota. Compared to many other Great Plains rivers, the Big Sioux is relatively natural and free-flowing, with a largely intact riparian corridor and little flow regulation. Along its course, the river flows through a largely agriculturally dominated matrix that contains several major population centers. The close proximity to these agricultural and urban land uses have contributed to a number of water quality problems during the last 50 years that have threatened the ecologically integrity of the Big Sioux. In order to conserve and properly manage the Big Sioux corridor, it will be important to gain an improved scientific understanding of ecological patterns and their environmental correlatives along the river. This thesis is an attempt to provide these data.

Using modern aerial imagery and ground-truthing techniques, I quantified the current extent of riparian forest communities along a 576 km stretch of the Big Sioux River. In total, there were 7 dominant riparian forest community types along the river that contributed to 6.85% of the total Big Sioux basin land cover. Riparian forest extent increased from north to south and was dominated by the Silver Maple-Elm-Cottonwood Forest community type (41% of total). In addition, 35 riparian forest sites and 5 upland forest sites were sampled to examine the typical vegetative characteristics of forest within the basin. In general, floristic quality and basal area decreased from south to north and % exotics increased. These findings provided data on riparian forest habitats along the river and can be used to assess future forest restoration efforts.

Streamflow has increased dramatically over the last 30 years in the Big Sioux basin (122% increase in mean annual flow) resulting in a highly significant, 62% increase in channel planform area, a 4% decrease in channel length and sinuosity, and a 69% increase in channel width. These channel adjustments were highly correlated with increasing mean annual flows and baseflow. To examine why these increases have occurred, the relative effects of land use change and climatic variation were examined, with findings from these analyses lending support towards land use change, specifically agricultural intensification, being a more important driver of increased streamflow and channel adjustments than changes in the climatic regime. These results are in line with findings from similar studies of agriculturally dominated basins throughout the Upper Midwest.

The final chapter examines potential pitfalls and uncertainties associated with using the Floristic Quality Assessment (*FQA*) across state boundaries. In total, results from 18 riparian and upland forest sites along the South Dakota/Iowa border were compared using Coefficients of Conservatism (*C*-values) from each state. Findings indicated that for the 141 observed species, South Dakota mean *C*-values were higher (3.57) than Iowa (2.50) and that there were 98 *C*-value divergences between states with 20 being equal to +/- 4. *FQA* values calculated using Iowa *C*-values were consistently lower than South Dakota and highlight the subjective nature of assigning *C*-values at the individual state level. This thesis provides several recommendations that would improve the utility of the *FQA* and allow it to become more widely standardized as a valuable ecological assessment tool.

This thesis provides baseline data critical to targeting current and future management efforts along the Big Sioux and provides an improved scientific understanding of ecological patterns in habitats along this valuable watershed in eastern South Dakota and northwestern Iowa.

Table of Contents

Acknowledgments…….....iii

Abstract…….....iv

List of Tables…….....viii

List of Figures……xi

List of Appendix……xv

Chapter 1: Classification and mapping of riparian forest communities along the Big Sioux River, South Dakota

Introduction…….....1

Study Area……...5

Methods……8

Results……22

Discussion…….34

References…….……38

Appendix A.1…..……..63

Appendix A.2…….71

Appendix A.3……..…107

Chapter 2: The interactive effects of climatic variation and land use change on increased streamflow and channel adjustment within an agricultural watershed

Introduction…….....113

Methods……119

Results…….…….126

Discussion……131

References……134

Chapter 3: Pitfalls and uncertainties associated with using the Floristic Quality Assessment (*FQA*) at state boundaries

Introduction…….....154

Methods……158

Results……..163

Discussion……165

References……169

List of Tables

Table 1.1 Land cover categories used for GIS mapping of 2008 land cover……...…….44

Table 1.2 Floristic analysis summary table and results from one-way ANOVA analysis comparing differences between site level $\overline{C}$, *FQI*, $\overline{C}_i$, FQI_i, $w\overline{C}$, $w\overline{C}_i$, mean basal area (m^2/ha), mean species richness/site, mean trees/ha, mean shrubs/ha, mean % shrub cover, and mean % exotic values for riparian and upland sites sampled within the Big Sioux basin. Means (± SE) are provided by study segment as well as for all riparian site and all sites sampled within the basin (riparian + upland). $w\overline{C}$ values are weighted by relative cover and $w\overline{C}_i$, $\overline{C}_i$, and FQI_i calculations included all species (including exotics) while $w\overline{C}$, $\overline{C}$, and *FQI* included only native species. An * indicates significant differences ($p < 0.05$) and ^{T} indicates marginal significant difference ($0.05 < p < 0.10$). For significant results, the Tukey's HSD post-hoc test was conducted with letters denoting significant differences between segments within each analysis..45

Table 1.3 Summary of herbaceous data for 168 species from 536 riparian quadrats across the entire study area. Importance value (IV) was calculated by summing relative frequency and relative cover for each species. An asterisk (*) indicates the species is considered non-native…46

Table 1.4 Comparison of the average $\overline{C}_i$ and $\overline{C}$ values for plots within the five dominant community types sampled within the Big Sioux basin. Standard error values are provided for all means and the total number of plots sampled within each community type are provided.……....46

Table 1.5 Results from the one-way ANOVA analysis comparing differences in plot level $\overline{C}$, $\overline{C}_i$, and mean basal area (m^2/ha) values within the Green Ash/Boxelder forest community types between the upper, middle, and lower river study segments. Standard error values are provided for all means and * indicate significant differences (p < 0.05). For significant ANOVA results, the Tukey's HSD post-hoc test was conducted with letters denoting significant differences between segments..……...……..47

Table 1.6 Summary of herbaceous data for 45 species from 8 plots in the Coyote Willow Temporarily Flooded Shrubland (CEGL001197) community type. Importance value (IV) was calculated by summing relative frequency and relative cover for each species. An asterisk (*) indicates the species is considered non-native……..……..47

Table 1.7 Summary of herbaceous data for 65 species from 17 plots in the Cottonwood-Peachleaf Willow Floodplain Woodland (CEGL000659) community type. Importance value (IV) was calculated by summing relative frequency and relative cover for each species. An asterisk (*) indicates the species is considered non-native..……48

Table 1.8 Summary of herbaceous data for 81 species from 28 plots in the Silver Maple-Elm-Cottonwood Forest (CEGL002586) community type. Importance value (IV) was calculated by summing relative frequency and relative cover for each species. An asterisk (*) indicates the species is considered non-native……..……48

Table 1.9 Summary of herbaceous data for 131 species from 73 plots in the Green Ash/Boxelder community type. Importance value (IV) was calculated by summing relative frequency and relative cover for each species. An asterisk (*) indicates the species is considered non-native....49

Table 1.10 Summary of herbaceous data for 57 species from 8 plots in the Cottonwood-Green Ash Floodplain Forest (CEGL000658) community type. Importance value (IV) was calculated by summing relative frequency and relative cover for each species. An asterisk (*) indicates the species is considered non-native……49

Table 1.11 Summary of herbaceous data for 101 species from 88 upland quadrats across the 5 upland sites. Importance value (IV) was calculated by summing relative frequency and relative cover for each species. An * indicates the species is considered non-native……50

Table 2.1 List of USGS gauging stations used in this study……...139

Table 2.2 Information on aerial photographs used during this study. Dates marked with an * represented a midpoint year as imagery for this date spanned several years……....139

Table 2.3 Results of the Indicators of Hydrologic Alteration analysis for the Big Sioux River at USGS gauging station (06485500) at Akron, Iowa. Changes in flow were compared for two time periods (1950-1979 and 1980-2008). Standard errors are provided for means……...140

Table 2.4 Comparison of pre- (1950-1979) and post-1980 (1980-2008) annual and seasonal mean discharge (m^3/sec), basin wide precipitation (cm/year or season) and streamflow-to-precipitation (Q:P) ratios at the Akron, Iowa, USGS gauging station (06485500). Significant increases in Q:P ratios were found since 1980 using the Mann-Whitney *U*-test across all seasons and on an annual basis. These increase in Q:P ratios have occurred without corresponding increases in precipitation and may illustrate the potential influence of changing land use patterns and increased drainage alterations throughout the basin…….....141

Table 2.5 Multiple regression analysis comparing flow parameters with observed channel adjustments as well as the relative direct and indirect effects of land use change (measured as the amount of corn and soybean acres in production) and climatic variation (measured as the PPT:PET ratio) on increasing flow parameters and the channel adjustments. Significant results (p <0.05) are denoted with * while marginally significant results ($0.05 < p < 0.10$) are denoted with **. A plus (+) or minus (-) indicates if the relationship is positive or negative……..142

Table 3.1 Species list for 145 species encountered along the lower Big Sioux River with *C*-values from South Dakota, Iowa, and study area averages being provided. Null values indicate species that were not assigned *C*-values in that state (4 total) and an asterisk (*) indicates the species is considered non-native. Note that a 0 was used for * when calculating averages or differences. Study area average *C*-values, with standard error, are provided……...…...172

Table 3.2 Study site descriptions for 18 sites located along the lower Big Sioux River, including site name, sampling year, state location, general location description, type of site (riparian or upland), and the total number of plots used to sample vegetation within each site. In addition, the total number of species is provided with total native species in parenthesis. Index calculations for $\overline{C}_i$ (mean *C*, all species), $\overline{C}$ (mean *C*, native only), FQI_i (all species), and *FQI* (native only) are given with overall differences between South Dakota and Iowa index calculations shown in bold. Significant differences (paired t-test, $p \leq 0.05$) in $\overline{C}_i$ and $\overline{C}$ between each state and state averages are indicated with an *……..…….……..176

Table 3.3 Results from the one-way ANOVA analysis comparing differences in site level $\overline{C}$, *FQI*, $\overline{C}_i$, and *FQI*, values between South Dakota, Iowa, and the state average. Standard error values are provided for all means and * indicate significant differences ($p \leq 0.05$). For significant results, the Tukey's HSD post-hoc test was conducted with letters denoting significant differences within each analysis……...……...…178

Table 3.4 Comparison of *C*-value distribution of the total flora from each state. Overall, South Dakota and Iowa distributions are similar to other states within the Midwest……....178

Table 3.5 $\overline{C}_i$ (all species) state site rank values for 18 study sites along the lower Big Sioux River. Differences between each states site rankings and differences between each state and the state average are provided with overall mean differences in bold. Site rankings between states and state averages are not significantly different at the 0.05 level (Wilcoxon signed-rank, $p>0.05$)…….…….179

Table 3.6 FQI_i (all species) state site rank values for 18 study sites along the lower Big Sioux River. Differences between each states site rankings and differences between each state and state averages are provided with overall mean differences in bold. Site rankings between states and state averages are not significantly different at the 0.05 level (Wilcoxon signed-rank, $p>0.05$)…….…….....180

Table 3.7 $\overline{C}$ (native only) state site rank values for 18 study sites along the lower Big Sioux River. Differences between each states site rankings and differences between each state and state averages are provided with overall mean differences in bold. Site rankings between states and state averages are not significantly different at the 0.05 level (Wilcoxon signed-rank, $p>0.05$)……..……....181

Table 3.8 *FQI* (native only) state site rank values for 18 study sites along the lower Big Sioux River. Differences between each states site rankings and differences between each state and state averages are provided with overall mean differences in bold. Site rankings between states and state averages are not significantly different at the 0.05 level (Wilcoxon signed-rank, $p>0.05$)……..……182

List of Figures

Figure 1.1 The Big Sioux basin drains approximately 22,550 km^2 in Minnesota, Iowa, and South Dakota, including the Coteau des Prairies and much of South Dakota's Prairie Pothole region. It originates in southern Roberts Co., South Dakota, and flows 676 km southward to its mouth at the Missouri River at Sioux City, Iowa. The study area stretches from Watertown, SD, to Sioux City, IA, and was divided longitudinally into three distinct study segments creating an upper, middle and lower portion of the river. Breaks between these three study segments represented changes between level IV Ecoregions boundaries as well as major tributary inputs. The basin was further subdivided into eight study subreaches (shown in alternating red and blue)……..51

Figure 1.2 Level IV Ecoregions of South Dakota including dominant drainage basins. The Big Sioux River flows through three Ecoregions including 46m (Big Sioux Basin), 47a (Loess Hills), and 47d (Missouri River Alluvial Plain). Figure courtesy of Bryce et al. (1998)…….52

Figure 1.3 Hydrograph for the Big Sioux River at Akron, Iowa (USGS gauging station 06485500) for the years of this study (2010 and 2011). The mean annual flow (38.91 m^3/sec) for the 83 year period of record (1928-2011) is shown in yellow and the approximate flood stage at the Akron gauge (212.38 m^3/sec) is highlighted in red. Multiple, prolonged flooding events occurred during the summers of 2010 and 2011, severely curtailing the sampling effort during the two years.……....53

Figure 1.4 The lower river study segment consisted of two subreaches (7 and 8) and stretched 132 river km from the Rock River confluence to the mouth of the Big Sioux River at Sioux City, IA. Ten riparian forest sites and one upland forest site were sampled within this part of the basin……54

Figure 1.5 The middle river study segment consisted of three subreaches (4, 5, and 6) and stretched 253 river km from Flandreau, SD, to the Rock River confluence. Fourteen riparian forest sites and three upland forest sites were sampled within this part of the basin……..55

Figure 1.6 The upper river study segment consisted of three subreaches (1, 2, and 3) and stretched 122 river km from Watertown, SD, to Flandreau, SD. Eleven riparian forest sites and one upland forest site were sampled within this part of the basin……..56

Figure 1.7 Relative area of different land classes for the entire study area. Land cover in the Big Sioux basin is dominated by agriculture cropland with grassland representing the next most important land cover. Riparian forest occupied 6.8% of the total land area. A trend towards increased forest cover was observed from the upper basin to the middle and lower river segments……..57

Figure 1.8 Percent of total riparian forest cover by each of eight Big Sioux study subreaches. The upper three subreaches contained the lowest percent of riparian forest with subreach 7, in the lower river segment, containing the largest percent. An overall trend in riparian forest cover increasing from the upper basin to the lower basin was observed……..…58

Figure 1.9 Relative areas of different riparian forest types across the study area and by the upper, middle, and lower river study segments ...……..……..…….59

Figure 1.10 Relative density for the ten most common tree (dbh ≥ 10cm) species sampled within the thirty five riparian forest sites within the upper, middle, and lower river study segments of the Big Sioux River. An asterisk (*) indicates a non-native species……...60

Figure 1.11 Mean percent shrub cover by different species and overall mean shrub cover by community type for forest within the Big Sioux basin. Estimates of total shrub cover may be inflated because of overlapping cover of different species along the transect segments. There were no shrub measurements taken within the Cottonwood-Green Ash Forest community type..61

Figure 1.12 Comparison of relative importance values (sum of relative frequency and relative cover; maximum value of 200) for 10 dominant understory species in plots sampled within the Green Ash/Boxelder Forest community type within the upper, middle, and lower river study segments. An * indicates a non-native species……..62

Figure 1.13 Percent totals for the most common tree (dbh > 10cm) species sampled within the five upland forest sites.…….……..62

Figure 2.1 The Big Sioux basin drains 22,550 km^2 in Minnesota, Iowa, and South Dakota including the Coteau des Prairies and much of South Dakota's Prairie Pothole region. It originates in southern Roberts Co., South Dakota, and flows 676 km southward to its mouth at the Missouri River at Sioux City, Iowa. The study area for this project (in red) stretches 220 river km along the South Dakota/Iowa border. The locations of U.S. Geologic Survey gauging stations included in the IHA analyses are depicted. All Q:P ratios were calculated using data from the Akron, Iowa, gauge (6485500) as this represented the most downstream station within the basin and had the longest continuous period of record dating back to 1928……..……....143

Figure 2.2 Conceptual model adapted from Tomer and Schilling (2009) of an ecohydrologic shift associated with climatic variation or land use change. The basis of this analysis is that land use change directly affects ET but not PPT or PET (acknowledging that such effects could be indirect at large scales) and that changes in land use would results in shifts towards increased or decreased P_{ex} and E_{ex} while changes in climate would result in increased P_{ex} and decreased E_{ex} (due to PPT/PET increases) or decreased P_{ex} and increased E_{ex} (due to PPT/PET decreases. Changes parallel along either axis indicate that the influence of climatic variation and land use change are approximately similar…….…144

Figure 2.3 The results of 70 years (1938-2008) of channel adjustments along the lower 220 river km of the Big Sioux River. There has been a 62% increase in channel planform area, a 4% decrease in channel length (approximately 9 km decrease), a 4% decrease in channel sinuosity, and a 69% increase in average channel width, with most of the changes occurring within a 19 year period between 1976 and 1995.…….…...145

Figure 2.4 Annual mean daily discharge for 10-year periods (e.g., 1930-1939 and 1940-1949) from 1930 to 2010 at the Akron, Iowa, USGS gauging station (06485500). Flows remained relatively constant from the 1930s to 1970s but increased abruptly in the 1980s and remained higher through the end of the time period. Error bars represent the 95% confidence interval…145

Figure 2.5 Results of the IHA analysis comparing baseflow index (the proportion of total mean flow represented as baseflow) across 10-year time intervals (e.g., 1930-1939 and 1940-1949) from 1930 to 2010 at the Akron, Iowa, USGS gauging station (06485500)……...…….146

Figure 2.6 Results of regression analyses examining the effects of varying flow parameters to changes in channel area and length. Significant results (p <0.05) are denoted with * while marginally significant results (0.05 < p < 0.10) are reported as **……..147

Figure 2.7 Trends in annual average streamflow-to-precipitation (Q:P) ratios per time interval (average ratio for all years in interval; e.g., 1930-1938, 1939-1950, etc.) from 1929-2010 at the USGS gauging station (06485500) at Akron, Iowa. Increases in Q:P ratios may be indicative of changing basin land use and increased drainage alteration…..…….……148

Figure 2.8 Comparison of annual pre- and post-1980 (1950-1979, 1980-2008) streamflow-to-precipitation (Q:P) ratios at the Akron, Iowa, USGS gauging station (06485500). The slope of the regression line has increased approximately 4-fold and the explanatory power of the relationship has increased nearly 3-fold from the pre- to post-1980 intervals…….….148

Figure 2.9 Comparison of pre and post 1980 (1950-1979, 1980-2008) winter (Dec.-Feb.) streamflow-to-precipitation (Q:P) ratios at the Akron, Iowa, USGS gauging station (06485500). Slopes of the regression lines are relatively similar between periods but there is a higher discharge per unit of precipitation in the post-1980 period indicating the possible effects of land use alteration of drainage efficiency…….……....149

Figure 2.10 Analysis comparing mean time interval average annual PET (cm/month) and PPT (cm/month) values through time from 1929 to 2008. There has been a slight decline in PET since 1929 while PPT values have increased during the 80-year period……...……149

Figure 2.11 Changes in mean annual PPT:PET ratios per time interval from 1929 to 2008. There has been an increase since 1929 indicating that climatic variation has played a role in increasing discharge in the Big Sioux basin…….…...….150

Figure 2.12 Analysis comparing mean annual excess water (P_{ex}) and excess evaporative demand (E_{ex}) per time interval from 1929 to 2008. There has been an increase in both excess precipitation and excess evaporative demand, meaning that while there is more water available to be discharged each year due to variation in the PPT:PET ratio, the increased evaporative demand (due to changes in ET from land use conversion) may make up the difference…….……..150

Figure 2.13 Analysis comparing the relationship between mean annual excess water (P_{ex}) and excess evaporative demand (E_{ex}) per time interval. There have been increases in both parameters indicating that an ecohydrologic shift has occurred, resulting more excess water and more excess energy. Because of this, any change or increase in streamflow patterns within the basin would indicate that changing land use, not climatic variation, is the primary driver of these changes……..151

Figure 2.14 Percent of the total drainage basin land area in agricultural production from 1928 to 2008. Agricultural crop production (not including livestock grazing) occupied approximately 67% of the drainage basin area in 2008, increasing 12% since 1928……...151

Figure 2.15 While total basin land area occupied by agricultural production has increased over the last 80 years, the proportion of perennial cover crops/small grains (e.g., alfalfa, wheat, rye, barley, etc.) has decreased by 79% since 1928. Annual row-crop production, expressed as the percent of the total basin land area in corn and soybean production, has increased dramatically over this time period and now occupies 59% of the basin area, increasing 132% since 1928.....152

Figure 2.16 Corn production has increased 5.8% since 1928 while soybean production has increased 1800%. Corn and soybean production currently occupy approximately 30% and 28%, respectively, of the total basin land area and together represents the dominant land use within the Big Sioux basin……...……..152

Figure 2.17 Analysis comparing the relationship between mean corn and soybean acres with mean evapotranspiration rates (cm/month) per time interval. As corn and soybean production have increased throughout the basin, the relative rates of ET have decreased potentially leading to excess water available to be discharged. It should be noted that there cannot be negative ET values and that this relationship is expressing only that rates of ET have decreased due to land use conversion from perennial cover crops and native grasses (which have higher annual water demand) to annual row-crops (which have a lower annual water demand; see Dinnes 2004; Brye et al. 2000).……...……153

Figure 3.1 The lower Big Sioux River study area extending 220 river km from south of Brandon, SD, to the river's confluence with the Missouri River at Sioux City, IA. Location of 18 study sites is depicted with 15 riparian (alluvial) forest sites (dots) and 3 upland forest sites (stars)……183

Figure 3.2 Comparison of overall *C*-value distribution by state for 141species encountered along the lower Big Sioux River. Species were assigned coefficients from Iowa and South Dakota. Non-native species were assigned an *……...…….....184

Figure 3.3 Histogram comparing the distribution of South Dakota and Iowa *C*-values within each *C*-value range cohort (0-3, 4-7, 8-10). Distribution differed across the 0-3 and the 8-10 range with Iowa assigning roughly 12% more species a *C*-value of 0-3 than South Dakota and South Dakota assigning approximately 13% more species a score of 8-10 compared to Iowa. Values in the non-native (*) and 4-7 ranges were approximately equal between the two state lists……184

Figure 3.4 Comparison of South Dakota and Iowa *C*-value divergence for 141 species encountered along the lower Big Sioux River. Divergence based on a species by species basis with 20 (14%) species having a divergence value ≥ ± 4. In total, there were 98 C-value divergences with 35 (36%) being equal to 1…….….…...185

Appendix Tables and Figures

Appendix A.1 Total species list for 205 species encountered during vegetation sampling within the Big Sioux basin. 175 species were found within the riparian sites and 108 species were observed within the upland forest with 30 species being unique to these upland areas. An asterisk (*) was used to denote non-native species. *C*-values are provided for all species using a list developed for the vascular flora of North and South Dakota (NGPFQAP 2001). For species that were not found in the Dakota's database, Iowa *C*-values were used and a ^{T} adjacent to the *C*-value was used to denote these species. Wetland indicator status values are provided for the relevant region (Region 4) and were obtained from the USDA NRCS PLANTS Database (http://plants.usda.gov/, USDA, NRCS 2011)……63

Appendix A.2 Site level summary data for 35 riparian forest sites along the Big Sioux River. A legend explaining the GIS land cover classes is provided at the end of Appendix A.2……....71

Appendix A.3 Site level summary data for 5 upland forest sites along the Big Sioux River. A legend explaining the GIS land cover classes is provided at the end of Appendix A.2……..…107

Chapter 1: Classification and Mapping of Riparian Forest Communities along the Big Sioux River, South Dakota

Introduction

Riparian corridors represent an ecologically distinct transitional zone between aquatic ecosystems and associated terrestrial habitats (Gregory et al. 1991). These areas are influenced by surface and subsurface hydrologic processes of lotic environments and are affected by varying degrees of periodic over-bank flooding. Flooding serves as the primary disturbance within riparian zones as erosive and depositional forces help to create dynamic heterogeneous environments (Naiman and Décamps 1997). Vegetation within these zones is uniquely adapted to tolerate these environmental conditions and is typically dominated by woody species, as riparian forest communities represent the dominant component of many riparian corridors (USFWS 2009). Riparian forests provide a host of ecologically beneficial services including aquatic and terrestrial wildlife habitat, water quality protection, stabilization of stream banks, and conservation of plant and wildlife diversity, as well as providing aesthetic enjoyment and recreational amenities (Naiman et al. 1993; National Research Council 2002).

The ecotonal nature of riparian areas makes them particularly vulnerable to anthropogenic alteration, with potential impacts from changes in the aquatic or adjacent upland habitats. Perhaps the most pervasive human impacts occur on regulated rivers where dams, levees, channelization, and bank stabilization measures threaten riparian habitats by disconnecting the floodplain from dynamic river processes. These activities directly restrict river-floodplain connections and may limit the ability for riparian vegetation to become established, as well as altering the system's resistance to invasion by exotic species (Naiman and Décamps 1997; Gergel et al. 2002). These in-stream modifications have been conducted along a majority of major North American river systems and have often been accompanied by large-scale

land use conversions. This is particularly evident in the U.S. Midwest where large tracts of native riparian vegetation were removed and converted for agricultural use since the onset of Euro-American settlement (Bragg and Tatschl 1977; Brinson et al. 1981; Naiman and Décamps 1997; National Research Council 2002; Allan 2004; Dixon et al. 2012). The disruption and loss of the natural flow regime in combination with major changes in adjacent land use (e.g., agricultural intensification) have dramatically altered the ecological integrity of riparian areas (Poff et al. 1997). These threats, in combination with the importance of riparian corridors for conserving plant and wildlife diversity, providing aesthetic and recreational amenities, and protecting water quality, suggest the importance of understanding and conserving these areas. An understanding of these factors could enable prioritization of areas for special management or conservation and may provide a tool for predicting the distribution of species of plants and animals of greatest conservation concern along a river. This thesis is an attempt to provide these data on South Dakota and Iowa's Big Sioux River.

The Big Sioux River, a major tributary to the Missouri River, provides drainage for approximately 22,550 km^2 of South Dakota, Iowa, and Minnesota including the Coteau des Prairies and much of South Dakota's Prairie Pothole region (Westin and Malo 1978; SDDENR 2010). Compared to many other Great Plains rivers, the Big Sioux is relatively natural and free-flowing, with a largely intact riparian corridor and little flow regulation with the exception of several run-of-the-river, low head dams. This riparian corridor and the aquatic ecosystem that it borders provide key ecosystem services to the people of eastern South Dakota and northwestern Iowa, including drinking water, water quality protection, recreational opportunities, aesthetic enjoyment, and biodiversity protection (EDWDD 2010). Along its course, the river flows through a largely agriculturally dominated matrix that contains several major population centers in eastern South Dakota and northwestern Iowa, including Watertown, Brookings, and Sioux

Falls, South Dakota, and Sioux City, Iowa. The presence of these urban areas makes the Big Sioux the most highly populated basin in South Dakota (Milewski et al. 2001; EDWDD 2010).

The cumulative effects of agricultural and urban land uses throughout the basin have contributed to a number of water quality problems during the last 50 years. This trend was highlighted by the river being considered one of the most degraded waterways in the United States during the 1960's due to municipal waste water and agricultural non-point source pollution (USEPA 1978; Dieterman and Berry 1998). Currently, several studies are being completed by the South Dakota Department of Environment and Natural Resources (DENR) and U.S. Geological Survey (USGS) to assess water quality issues and ways to limit contaminants throughout the basin (Milewski et al. 2001; South Dakota DENR 2010). These threats have also garnered the attention of various conservation and watershed management groups (e.g., East Dakota Water Development District, Northern Prairies Land Trust) hoping to protect the integrity of the Big Sioux (EDWDD 2010).

In order to conserve and properly manage the Big Sioux corridor, it will be important to understand the spatial extent and composition of different habitat types along the river, particularly riparian forest. Hence, GIS-based mapping of the riparian cover types will provide a much needed tool for natural resource managers and stakeholder groups alike. Equally important will be to understand the plant species composition and habitat structure within each of the forested habitat types along the river. There have been several previous efforts to sample and characterize riparian forest along the Big Sioux River. Vander Zee (1979) conducted a complete inventory of the vascular flora of Gitchie Manitou State Preserve in extreme northwest Iowa. Knupp Moore and Flake (1994) sampled and characterized eight riparian forest sites along the Big Sioux River. They characterized forest within the upper river (five sites from Brookings, SD to Dell Rapids, SD) as green ash (*Fraxinus pennsylvanica*) and boxelder (*Acer negundo*) forest, while sites within the lower river (three sites from Hawarden, IA to Jefferson, SD) were classified

as silver maple (*Acer saccharinum*), boxelder, and green ash forest. Smith and Flake (1983) sampled several forested sites along a 40 km stretch of the Big Sioux through Brookings County, SD, as part of a study analyzing the effects of grazing on riparian plant communities. They found that riparian forests along this segment of the river were dominated by boxelder and green ash forests with sandbar willow (*Salix interior*) shrublands and peachleaf willow (*S. amygdaloides*) forest also comprising a significant component of those areas. Aside from these studies and an unpublished study by Johnson in Brookings County (W.C. Johnson, personal communication), I know of no systematic attempt to map or characterize the riparian plant communities along the entire Big Sioux River corridor.

Vegetation sampling and analyses have been conducted within several upland sites (e.g., Newton Hills State Park, SD, and Stone State Park, IA) along the Big Sioux (Carter 1963; Hanson and Hazlett 1971; Hegstad 1992; Knupp Moore and Flake 1994), including studies on the expansion of upland forest communities into prairie areas under the absence of fire (Tieszen and Pfau 1995; Spencer et al. 2009). Areas along the Big Sioux have also been used in a number of fisheries (Sinning 1968; Dieterman and Berry 1998; Kirby 2001; Milewski et al. 2001; Morey and Berry 2003) and wildlife studies (Parrish 1981; Dieter 1987, 1992; Dieter and McCabe 1989; Coughlin and Higgins 1993; Usgaard 1994; Granfors and Flake 1999; Lane et al. 2003; Kiesow and Dieter 2005; Jungwirth et al. 2005), including research on the use of riparian forests as habitat for breeding and migratory songbirds (Dean 1999; Swanson et al. 2005; Gentry et al. 2006).

The overall goal of this study was to map and classify current riparian forest habitats along the Big Sioux River and to characterize plant species composition, structure, extent, and floristic quality within the mapped vegetation types. Data and conclusions from this project will be used by the South Dakota Department of Game, Fish, and Parks as part of their State Wildlife Action Plan (SDGFP 2006). This study provides information critical to targeting conservation

efforts and will yield a better scientific understanding of ecological patterns and their environmental correlatives along the river. Specific objectives of this project include:

(1) Mapping of the land cover along the Big Sioux River corridor from Watertown, SD, to Sioux City, IA, including riparian forest vegetation extent and distribution.

(2) Sampling vegetation within representative riparian forest stands with the goal of characterizing vegetation structure, composition, and floristic quality within each forest type and along the entire study segment.

Study Area

The Big Sioux River is located in eastern South Dakota and northwestern Iowa, with the southern portion (220 river km) of the river forming the South Dakota-Iowa border (Figure 1.1). With its origins in southern Roberts Co. in South Dakota, the Big Sioux flows 676 km southward to its eventual confluence with the Missouri River at Sioux City, Iowa. The climate of eastern South Dakota represents a typical continental climate with four distinct seasons ranging from cold, dry winters to hot, sub-humid summers. Mean annual precipitation increases from north to south and varies between 51 and 64 cm annually (Bryce et al. 1998). The dominant soil types are Mollisols which are derived from a variety of parent materials. Uplands soils are relatively fine-grained soils that have developed over glacial till or thin loess deposits (EDWDD 2010). Lowland soils are relatively coarse-grained soils that are derived from glacial outwash or alluvial sediments (McCormick and Hammond 2004; Schulz and Jarrett 2009; EDWDD 2010).

The Big Sioux River flows through the Northern Glaciated Plain (46) and Western Corn Belt Plain (47) Level III Ecoregions (Omernik 1987; Figure 1.2). Ecoregions are used to denote areas of general similarity in ecosystem type and environmental resources such as geology, physiography, vegetation, climate, soils, land-use, wildlife, and hydrology (Bryce et al. 1998).

They are designed to provide a spatial framework for research, assessment, management, and monitoring of ecosystem components at a regional or landscape scale. Level III Ecoregions are further sub-divided into state-level Level IV Ecoregions. The Big Sioux flows through three Level IV Ecoregions (Figure 1.2) including the Big Sioux Basin (46m), Loess Prairie (47a), and the Missouri Alluvial Plain (47d). These splits between Level IV Ecoregions represent changes in geology, physiography, and climate within the basin.

Big Sioux Basin Ecoregion

The Big Sioux Basin (46m) Level IV Ecoregion (Figure 1.2) is an elongated trough penetrating the core of the Prairie Coteau plateau. The basin begins near the headwaters of the Big Sioux in Roberts Co. and extends south to Dell Rapids, SD, covering approximately 3,986 km^2. Elevation ranges from 495 to 607 m above sea level with a local relief between 6 and 61 m. The basin is a lightly glaciated, erosional landscape with rolling topography and an incised stream drainage network with few wetlands (Bryce et al. 1998). The dominant surficial material is glacial till overlaying Cretaceous Pierre Shale bedrock. The principal soil types are Mollisols and the temperature and moisture regimes are frigid and udic, respectively. Mean annual precipitation ranges from 51 to 56 cm and the frost free period is between 110-140 days annually.

Loess Prairies Ecoregion

The Loess Prairies (47a) Level IV Ecoregion (Figure 1.2) begins near Dell Rapids, SD, and extends south to Richland, SD, covering approximately 2,860 km^2. This ecoregion derives its name from thick deposits of windblown sediments that accumulated throughout this area during the Pleistocene epoch. Much of this area was formed from glacial end moraines that resulted in a distinct morphology of relatively steep, sharply ridged loess-blanketed hills (McCormick and Hammond, 2004).

The Loess Prairie is split between northern and southern regions, connected by the thin riparian corridor of the Big Sioux River. The northern area is distinguished from neighboring regions by its rock-free soils and a relative lack of wetlands, while the southern area is more highly dissected with steeper slopes and numerous morainal hills (Bryce et al. 1998). Elevation of the Loess Prairie Ecoregion ranges from 365 to 520 m above sea level with a local relief ranging from 12 to 37 m. Geologic materials include loess and glacial till deposits blanketed over Cretaceous sandstone, Carlile shale, Niobrara chalk, and Precambrian Sioux Quartzite. The dominant soil types are Mollisols and the temperature and moisture regimes are mesic and udic, respectively. This area receives between 58 and 64 cm of mean annual precipitation and has approximately 135-165 frost free days annually.

Missouri Alluvial Plain Ecoregion

The Missouri Alluvial Plain (47d) Level IV Ecoregion (Figure 1.2) begins near Richland, SD, and ends at Sioux City, IA, covering approximately 905 km^2. A distinct change in topography occurs at this location where rolling morainal hills are replaced by the broad, flat historic floodplain of the Missouri River. Changes are also seen in surficial geologic material where thick loess deposits are replaced by alluvial deposits overlying Cretaceous aged Dakota sandstone and Carlile shale (Bryce et al. 1998). Dominant soil types of the Missouri Alluvial Plain include both Entisols and Mollisols. Elevation varies from 335 to 365 m above sea level with the local relief ranging from 0.5 to 7.5 m. Temperature and moisture regimes are characterized as mesic and udic, respectively, and the area has between 135 and 165 frost free days annually. Mean annual precipitation for the Missouri Alluvial Plain varies from 58 to 64 cm.

Methods

GIS Mapping

Current (2008) land cover was mapped along the 576 km (358 mile) study area from Watertown, SD, to Sioux City, IA, using ArcGIS 10.0 (Figure 1.1). The upper 100 km of the river (above Watertown) were excluded from this study given the diminutive nature of the headwater stream as well as a scarcity of woody riparian vegetation within this area. Land cover was mapped using an on screen (heads-up) digitizing approach based on direct interpretation of the 2008 county mosaic orthophotography from the National Agricultural Imagery Project (NAIP), obtained from the USDA NRCS Geospatial Data Gateway (http://datagateway.nrcs.usda.gov). The projection for this imagery and all subsequent geodatabases and shapefiles in ArcGIS 10.0 was NAD 1983 UTM Zone 14N. Extensive training was conducted beforehand and a list of digitizing protocols was developed to improve accuracy in identification of feature types and to provide consistency throughout the mapping project.

A minimum mapping unit of 0.25 ha was used for all digitizing, although some important features (i.e., sandbars, island features, individual forest communities within the upper river basin) smaller than this were also digitized. All polygons were retained in a vector format and most patches, other than the features listed above, smaller than 0.25 ha were merged with the surrounding dominant land cover (e.g., cropland). Mapping began by digitizing a channel center-line from Watertown to Sioux City at a scale of 1:2000. This centerline was used to create a 1000 m study area buffer on either side of the channel centerline. The channel planform, excluding island features and sandbars (these features were added later), was then digitized for the entire length of the study area at a scale of 1:2000. Finally, land cover within the 2000 m wide riparian corridor was interpreted and digitized for the entire study reach. Most digitizing was done at a

1:5000 scale although finer and coarser levels were used depending on feature type, size, and overall complexity.

A land cover classification system was specifically developed for the vegetation encountered along the Big Sioux River based on the resolution of the imagery and the ability to correctly identify feature types. The initial classification system included 14 land cover class codes (Table 1.1). Several types of imagery (2008 and 2010 NAIP, Google Earth, high resolution oblique imagery available from Bing Maps "Bird's Eye View") were utilized to assist in the interpretation of the initial land cover layer (e.g., grassland vs. agriculture; forest vs. shrubland). Additionally, digital elevation models (DEMs), digital raster graphics (DRGs), and LIDAR elevation data (along the lower river in Iowa only) were used to assist in distinguishing riparian (alluvial) forest and upland forest. Ground-truthing was used to assess and revise (as needed) the provisional classification of land cover within the mapping project and to move from the initial coarse (physiognomic) classification of vegetation types to a finer (floristic or community type) scale classification of forests. Ground-truthing consisted of boating the river or driving roads in the floodplain adjacent to the river in order to compare the initial land cover classifications with on the ground observations. Changes and revisions were noted while in the field and were later added to GIS map to create a more accurate and consistent product. Given the iterative nature of land cover mapping and the fact that all results were incorporated into the final data, I did not conduct any formal assessment of classification error rates.

Community Type Classification

Extensive training was conducted during the 2011 field season in order to correctly classify Big Sioux River forest community types using the Plant Communities of the Midwest subset of the National Vegetation Classification (NVC) system guidelines (Faber-Langendoen 2001). Some generalizations were used when classifying individual forest types as they did not

always align perfectly with NVC community descriptions. Stands were classified using ground-truthing methods and often required classification of forest community types from a distance (e.g., through binoculars), utilizing such visual cues as general shape, size, color, and texture of individual tree canopies to identify individual species. These observations were compared across several growth forms (e.g., saplings-mature trees) of each species and were later confirmed by visiting known specimens. The ability to correctly classify forest community types using these ground-truthing methods was tested as individual forests were assigned to an NVC community type from a distance and then were walked/sampled in order to confirm or revise initial observations. The ground-truthed observations of NVC community types from each riparian forest stand were added into the GIS land cover layer, providing baseline information on the geographic extent and community type designation of a majority of the stands within the study area.

In general, there were six distinct woody riparian community types mapped along the Big Sioux River (Table 1.1). The youngest early successional shrublands were dominated by sandbar willow (*S. interior*), along with varying abundances of peachleaf willow (*S. amygdaloides*) and eastern cottonwood (*Populus deltoides*) saplings. This community frequently occurred along the river margin and was typically inundated by the persistent flooding that occurred during the summers of 2010 and 2011 (Figure 1.3). Overall, this community type aligned well with the Coyote Willow Temporarily Flooded Shrubland (CEGL001197). The next community type was dominated by immature peachleaf willow and eastern cottonwood trees between 6 and 12 m tall. This community type was found adjacent to the temporarily flooded shrublands and represented the next successional stage of that community type. These forests were best represented by the Cottonwood-Peachleaf Willow Floodplain Woodland (CEGL000659).

Three community types followed the immature cottonwood - peachleaf willow woodland. These included the Mature Cottonwood Forest, the Silver Maple (*Acer saccharinum*)-Elm (*Ulmus*

americana)-Cottonwood Forest (CEGL002586), and the Cottonwood-Green Ash (*Fraxinus pennsylvanica*) Floodplain Forest (CEGL000658). The common theme among these three observed community types was the presence of mature cottonwoods. Stands that exhibited silver maple dominance (> 50% of relative density) were classified as the Silver Maple-Elm-Cottonwood Forest (CEGL002586) community type. Forest that lacked a significant silver maple component but were dominated by green ash and boxelder (*A. negundo*) were classified under the Cottonwood-Green Ash Floodplain Forest (CEGL000658). Mature cottonwood stands that lacked a significant presence of other species were classified as Mature Cottonwood Forest. This community type did not align with a published NVC community type for South Dakota or Iowa but is most similar to the Cottonwood /Western Snowberry (*Symphoricarpos occidentalis*) Woodland (CEGL000660), or it may also be considered a mature version of the Cottonwood-Peachleaf Willow Floodplain Woodland (CEGL000659).

The final community type observed on the Big Sioux is a conglomerate of several green ash community types. The most common type was represented as the Green Ash-Elm-Hackberry (*Celtis occidentalis*) Forest (CEGL002014). Similar to this type was the more northerly and species-poor Northern Ash-Elm Floodplain Forest (CEGL002089). Other potential community types that were included under the general green ash type included the Great Plains Ash-Elm-Snowberry Forest (CEGL002088) and the Boxelder Floodplain Forest (CEGL005033). Given the relatively subtle differences (i.e., differences in proportion of co-dominant species, variation in understory plants, location, and topographic position on floodplain which determines the effect and extent of flooding) between these four community types and the *ex situ* method (aerial photograph interpretation and ground-truthing observations) of classifying each forested stand, I felt it was appropriate to aggregate all green ash forests under one type (Green Ash/Boxelder Forest) for the mapping project.

Upland forests along the Big Sioux were not assigned a NVC community type during the mapping portion of the project due to increased diversity within these stands and the stronger focus on floodplain communities in this study. I did attempt to designate community types for a small number (5) of individual upland study sites, using vegetation data from plots sampled within the upland areas. A narrative describing these observations is located in the upland vegetation portion of the results.

Study Reaches

The Big Sioux River was divided longitudinally into three distinct study segments, delineating upper, middle, and lower segments of the river (Figure 1.1). Breaks between these three study segments represented Level IV Ecoregion boundaries, as well as major tributary inputs. In order to adequately stratify vegetation sampling throughout the basin, each study segment was subdivided into three (two in the lower river segment) study subreaches, again based largely on Level IV Ecoregions boundaries, sub-watershed inputs, and a desire to have subreaches of roughly equal lengths (57 - 94 km; Figure 1.1). The first study subreach extended approximately 57 km from Watertown, SD, to near Estelline, SD, where inputs from Lake Poinsett and Hidewood Creek dramatically increase the discharge of the Big Sioux. The second subreach stretched 79 km from near Estelline to the confluence of Sixmile Creek with the Big Sioux southwest of Brookings, SD. The third subreach stretched approximately 64 km from the Sixmile Creek confluence to the boundary between Ecoregion 46m (Big Sioux Basin) and 47a (Loess Prairies) northeast of Flandreau, SD. These first three study subreaches together defined the upper river study segment of the basin.

The middle river study segment extended from near Flandreau, SD, to the confluence of the Big Sioux with its largest tributary, the Rock River, near Hudson, SD (Figure 1.1). This middle river segment of the basin encompassed three study subreaches including subreach 4,

which extended 55 km from Flandreau, SD, to near Dell Rapids, SD, where the river begins to interact with the Sioux Quartzite outcrop that commonly occurs at or near the surface throughout this part of the state (Westin and Malo 1978). The fifth subreach covered 93 km from Dell Rapids to near Brandon, SD, including the greater Sioux Falls area. Brandon represents the approximate end of the Sioux Quartzite interactions with the Big Sioux as well as where significant flow inputs from Split Rock Creek occur. The sixth subreach covered the rest of the segment, extending 94 km from near Brandon, SD, to the confluence with Iowa's Rock River.

The lower river segment included everything downstream of the Rock River confluence. Below the confluence, the annual discharge of the Big Sioux approximately doubles and the size of the river and its floodplain area increase dramatically. Subreach 7 extended 70 km from the Rock River confluence to near Richland, SD, where a Level IV Ecoregion boundary between 47a (Loess Prairies) and 47d (Missouri River Alluvial Plain) occurs (Figures 1.1 and 1.2). The final subreach extended 61 km across the broad Missouri River floodplain to the confluence of the Big Sioux River with the Missouri River at Sioux City, IA.

Vegetation sampling

Thirty-five riparian forest sites and five upland forest sites were sampled opportunistically across the entire study area between June 10 and August 31 of 2010 and 2011 (Figure 1.4 -1.6). Vegetation was sampled with the aim to map and classify the current extent of forested habitats along the Big Sioux River from Watertown, SD, to Sioux City, IA, and to characterize plant species composition, structure, and floristic quality within the mapped vegetation types. The sampling effort between the two years was severely curtailed by the prolonged flooding events that occurred on the river during the summers of 2010 and 2011 (Figure 1.3). A majority of the river's floodplain was inundated at some point during the two time periods and almost all riparian sites sampled had at least a portion of the site recently

affected by flooding. Sampling was stratified to provide approximately equal coverage across each of the 8 study subreaches and on private vs. public land. A minimum site size of 0.25 ha was used and all sites met the criteria of having unmanaged or "natural" overstory, shrub, and herbaceous layers, with little or no selective clearing and no campgrounds or sites with an otherwise managed understory. Sites with prior grazing, flooding, and other vegetative alterations were sampled and evidences of these past disturbances were noted.

Sampling included characterization of dominant overstory composition and structure using 10 m x 20 m rectangular plots placed within different forest patch types; shrub/sapling composition, cover and stem density using line intercept and belt transect methods; and herbaceous species composition and cover using 1 m x 1 m quadrats, with the shrub transects and herbaceous quadrats nested within the larger overstory plot. Sampling plots were arrayed along a transect running in a perpendicular direction from the river to the outer edge of the forested floodplain. The starting point of the transect was established *a priori* by dividing the site area adjacent to the river into fourths using aerial imagery within ArcGIS 10.0. A random numbers generator was used to pick which fourth in which to place the transect starting point, and the geographic coordinates (UTM) of the center of this area were determined in ArcGIS. These coordinates were located in the field and an azimuth heading, running perpendicular to the river, was used to approximate the transect.

Each transect was divided into different forest or shrubland patch types based on dominant species composition, structure, and major changes in age/size class. Transects usually included one or two patch types with some sites having as many as five unique patches. Patch width estimates and patch delineations were initially approximated using ArcGIS 10.0 and were refined in the field when the entire transect was walked, prior to sampling. Approximate patch width was used to stratify the sampling effort with one plot placed in patches ≤ 50 m wide, two plots in 50-200 m wide patches, and three plots in patches ≥ 200 m wide. Each site had a

minimum of three plots. On a select number (5) of sites in the upper and middle river segments where the forested area width was too narrow to accommodate three plots, I added plots upstream or downstream parallel to the river within each available patch type until the three plot rule was met. These additional plots were orientated parallel to the river in the approximate middle of the forested stand. All other sampling protocols were identical. Plot locations within each patch were selected via a stratified random procedure, with estimated patch width used to determine the number of plots per patch and a random numbers generator used to determine exact plot location (number of steps) along the transect line. The point selected along the transect represented the bottom right hand corner (as I walked outward from the river) of the plot with the short axis (10 m) of the plot orientated approximately perpendicular to the river and in line with the transect azimuth.

In addition to the floodplain forest sampling, five upland forest sites were sampled as part of a pilot study for the SDGFP. Plot locations were determined by a stratified random procedure along a transect that was established *a priori* using aerial imagery and ArcGIS 10.0 on each upland site. This transect was located so as to capture as much topographic and environmental variation as possible within an individual drainage. In general, plots were placed along the bottom slope, mid-slope area, and finally at the top of the slope on each side of the drainage. Plot sampling methodology was otherwise identical to the riparian sampling.

Within each rectangular plot, I measured the diameter at breast height (dbh) of all trees ≥ 10 cm in trunk diameter. For trees with multiple trunks, I measured and recorded all stems that equaled or exceeded 5 cm dbh as long as the main bole exceeded 10 cm dbh. Woody plants occupying the shrub layer (shrubs and saplings ≥ 1 m tall and < 10 cm dbh) were identified and sampled using the line-strip method (Lindsey 1955) with two sampling strips (2 m x 10 m) established 5 m from either end of the long axis of the plot and running parallel to the short axis. Woody stem density (#/ha) in the shrub layer was estimated by counting all individual shrubs,

saplings, and woody vines rooted within 1 m of either side of the sampling strip centerline. Percent cover was estimated by recording cover by shrubs, saplings, or woody vines that intercepted the sampling strip centerline at or above 1 m off the ground. The total distance intercepted along the 10-meter tape length was noted for each species and summed to get a total cover estimate for each plot. It was possible that all species cover values added together could exceed 100%. Plants in the herbaceous layer (herbs and woody seedlings < 1 m tall) were sampled using a 1 m x 1 m sampling frame (quadrat), with four quadrats placed randomly within each plot using random numbers. Care was taken to avoid trampling on the area prior to understory sampling. All species of non-woody vascular plants and woody seedlings/shrubs (< 1 m) were noted and their aerial percent cover within the 1-m^2 quadrat was recorded to the nearest 5%. Species with trace occurrences were recorded as 1% cover. A rough estimate of percent bare ground was also recorded.

Unknown species were noted and numbered (e.g., Unk. #1) and photographs and collections were taken from individuals outside of the quadrat, if possible. These unknowns were later pressed, dried, and identified using herbarium specimens and keys or other guides to the vascular flora of the region (e.g., *Flora of the Great Plains* (Great Plains Flora Association 1986); *The Vascular Plants of South Dakota* (Van Bruggen 1976)). Species that could not be reliably identified using these techniques were submitted to Dr. Gary Larson of South Dakota State University for assistance with identification. Voucher specimens were deposited at the C. A. Taylor Herbarium at South Dakota State University, Brookings, SD. Conventions for plant nomenclature follow those found at the USDA NRCS PLANTS Database (http://plants.usda.gov/java/, USDA, NRCS 2011).

Data Reduction and Analysis

These sampling protocols produced the following basic information: plot- and site-level plant (vascular plant) species lists; frequency, percent cover, and overall importance value (IV, created by summing relative cover with relative frequency, total maximum score of 200 per species) of each species in the herbaceous layer; frequency, percent cover, and density of each species in the shrub layer; and the frequency, density, and basal area (m^2/ha) of each tree species. By assigning published Coefficient of Conservatism values (*C*-values; Swink and Wilhelm 1994; Taft et al. 1997; Northern Great Plains Floristic Quality Assessment Panel (NGPFQAP) 2001) to species of plants, an assessment was made of the overall floristic quality of the vegetation within each site.

A master species list was developed that listed the Latin names of each species encountered during sampling, acronyms used to identify that species in the data, whether the species is native or introduced, its wetland indicator status (*W*-score) for the relevant region, and its Coefficient of Conservatism (*C*-value, Appendix A.1). Wetland Indicator status codes (Reed 1988 and later updates) have been standardized by region and were obtained from the USDA NRCS PLANTS Database (http://plants.usda.gov/, USDA, NRCS 2011). Coefficients of Conservatism are most often used in Floristic Quality Assessment (*FQA*) which was developed by Swink and Wilhelm (1979, 1994) as an ecological assessment tool to examine the floristic quality of natural vs. disturbed plant communities in the Chicago region. The index was later refined and modified for use across Illinois (Taft et al. 1997) and has since been utilized across much of the United States and recently into areas of Canada (Bowers and Boutin 2008), China (Tu et al. 2009), and Italy (Bonanno and Giudice 2010). The system is based upon the concept that native plant species will display varying degrees of tolerance to anthropogenic disturbance as well as having varying degrees of fidelity towards a specific habitat type. While the nature of "floristic quality" is largely a human concept that is not a true ecosystem property (Bourdaghs

2004; Bourdaghs et al. 2006), it has still been shown to be an effective tool for assessing anthropogenic impacts to an area, prioritizing sites for restoration efforts, making comparisons among sites regardless of community type, monitoring and tracking the performance of reclamation and mitigation efforts through time, and identifying areas of high natural value (Swink and Wilhelm 1994; Bourdaghs et al. 2006; Matthews et al. 2009).

To use the index, all native plant species are assigned a Coefficient of Conservatism (*C*-value, hereafter) which is essentially a ranking based on the likelihood that the species will be encountered in a disturbed or natural area. These values range between 0 and 10, with *C*-values of 0 assigned to generalist species with a high degree of tolerance to disturbances and *C*-values of 10 assigned to plants occurring only in undisturbed, "pristine" habitats. All non-native plant species are assigned an asterisk (*) and are either excluded or treated as a 0 for each index calculation (Taft et al. 1997). Weedy species with *C*-values of 0-1 align closely with Grime's ruderal species (Grime 1974; Taft et al. 1997) with examples in my study area (eastern South Dakota and western Iowa) including *Urtica dioica*, *Ambrosia sp.*, and *Amaranthus sp*. Coefficients ranging from 2-3 are considered ruderal-competitive species that occur commonly in highly degraded sites but are also found in relatively natural areas (e.g., *Vitis riparia*, *Symphoricarpos occidentalis*, and *Salix interior*). These two guilds (0-1, 2-3) represent species that are adapted to frequent, severe disturbances and are able to expand and persist under a variety of environmental conditions.

Species with *C*-values of 4-6 correspond roughly with Grime's competitor species and are indicative of species that occur commonly in "natural" or unmanaged areas and have a decreased tolerance towards disturbances (Grime 1974; Taft et al. 1997). Examples from my study area include *Poa palustris* and *Carex laeviconica*. Coefficients between 7 and 10 are less closely aligned with Grime's third guild, the stress tolerators (Grime 1974, 1988; Taft et al. 1997). Many of the species assigned a *C*-value of 7-10 do not fall under Grime's definition for

the stress tolerator group as many of the species are not long lived or slow growing (e.g., annuals and biennials) and many are not restricted to later successional habitats (Duffey 1986; Taft et al. 1997). Species with coefficients of 7-8 represent species that occur only in "natural" habitats and that will decrease in abundance with moderate habitat disturbances. Finally, species with *C*-values of 9-10 are restricted to undisturbed, relatively intact natural habitats. Examples from my study area of species in these final two guilds (7-8, 9-10) include *Botrychium virginianum*, *Festuca subverticillata*, and *Sanguinaria canadensis*. There are several methods used to quantify floristic quality at the site level, including mean Coefficient of Conservatism ($\bar{C}$), which is an average of the *C*-values for all species found at the site. This can be calculated using:

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

where $\bar{C}$ is equal to the summation of all *C*-values ($\sum C$) at the site or plot level and N is the total number of species encountered within each site or plot. The *FQI* (Floristic Quality Index) has been further developed to take into account species richness at the site level using:

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

where *FQI* is equal to the mean Coefficient of Conservatism ($\bar{C}$) times the square root of the total number of species ($\sqrt{N}$, species richness) found at the site or plot. A final method is the weighted $\bar{C}$ ($w\bar{C}$) which takes into account the relative abundance of each species within the plot or site. This is calculated by:

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

where $w\bar{C}$ is equal to summation of the proportional abundance (*p*, expressed as relative percent cover) multiplied by the *C*-value for the species, summed for all species at the site or plot.

There are several variations of each method that can be used to examine different aspects of floristic quality at each site. The traditional approach, as prescribed by Swink and Wilhelm (1994), for calculating $\bar{C}$, $w\bar{C}$, and *FQI* at the site or plot level is to include only native species, as adventive (exotic) species did not evolve within the native plant community and should therefore not be included in *FQA* calculations (Bourdaghs et al. 2006). An alternative method has been adopted, however, that argues that non-native species, while not evolving within the native plant community, still have an important impact on a site's floristic integrity (Taft et al. 1997; Lopez and Fennessy 2002; Rooney and Rodgers 2002; Rothrock and Homoya 2005). Under this approach, non-natives are assigned a *C*-value of 0. Today, the standard method is to perform the *FQA* calculations twice, once using only native species (denoted as $\bar{C}$, $w\bar{C}$, and *FQI*) and the second including all taxa present (including non-natives) within the site or plot (denoted as $\bar{C}_i$, $w\bar{C}_i$, *and* FQI_i; NGPFQAP 2001; Rothrock and Homoya 2005). Descriptions of each method and reasoning behind their development and use have been detailed in the original *FQA* documents (Swink and Wilhelm 1994; Taft et al. 1997) as well as in numerous studies addressing the effectiveness of these indices across a range of locations and ecological conditions (NGPFQAP 2001; Bourdaghs et al. 2006; Matthews et al. 2009).

Swink and Wilhelm (1994) addressed a qualitative *FQA* rating system that rates sites attaining a $\bar{C}$ value of 3.5 or higher as being of natural quality while sites of 4.5 or greater are considered high quality natural sites. Sites receiving *FQI* values of 35 or higher are considered natural sites and sites with values of 45 or higher are “noteworthy” remnant natural areas (Swink and Wilhelm 1994; Rothrock and Homoya 2005). Site $\bar{C}$ and *FQI* rankings below 3.5 or 35, respectively, are considered to be somewhat degraded, are dominated by lower *C*-value species, and typically are affected by periodic anthropogenic disturbances.

C-values developed for the flora of North and South Dakota (excluding the Black Hills) were obtained from the Northern Great Plains Floristic Quality Assessment Panel (NGPFQAP

2001) available at http://www.npwrc.usgs.gov/resource/plants/fqa/index.htm. As the Big Sioux River forms the South Dakota - Iowa border for approximately 1/3 of the study area, the use of Iowa *C*-values might also be appropriate for some portions of the river. My work (see chapter 3), however, suggests that some Iowa *C*-values for the same species tended to be biased toward lower values, relative to the South Dakota scores. Hence, for consistency purposes, only South Dakota *C*-values were used for index calculations regardless of which state (which side of the river) the site was actually in. For two species that were not found in the Dakota's database, however, I did use scores from a list compiled for Iowa flora (http://www.public.iastate.edu/%7Eherbarium/coeffici.html). Overall $\overline{C}$ and *FQI* and $\overline{C}_i$ and FQI_i values were computed based on the complete list of species sampled at each stand (across the herb, shrub, and tree strata), while $w\overline{C}$ and $w\overline{C}_i$ (weighted by relative cover) were computed using only species found in the herbaceous layer.

A one-way analysis of variance (ANOVA) approach was used to analyze differences in site level $w\overline{C}$, $w\overline{C}_i$ $\overline{C}$, *FQI*, $\overline{C}_i$, FQI_i, mean basal area (m^2/ha), mean species richness, mean trees/ha, mean % shrub cover, mean shrubs/ha, and mean % exotic values amongst the upper, middle, and lower river study area segments. With this approach, each segment was used as the treatment and sites were treated as replicates. For all statistical tests, $p \leq 0.05$ was considered significant, while *p*-values between 0.05 and 0.10 were considered marginally significant. All means were reported with standard error values. All data entry, error checking, index calculations, and production of graphics were done using MS-Excel. All statistical analyses were completed using the Statistical Analysis System software (SAS®, version 9.1).

Results

Patterns in Land Cover

The total land area measured in the GIS mapping project (within 1000 m to either side of the channel centerline) was approximately 89,500 ha (221,160 acres). Agricultural cropland (tilled land) dominated the land use/land cover in 2008 as it occupied 54% of the total area or about 48,500 ha (Figure 1.7). Grassland land cover constituted 16% of the total area (14,850 ha), while the urban land use areas (e.g., Watertown, Sioux Falls, Sioux City, other towns, roads, etc.) encompassed 11% (10,470 ha) of the total (Figure 1.7). Approximately 7% of the landscape (6,150 ha) was comprised of woody riparian vegetation (Forest = 6.5%, Shrubland = 0.5%; Figure 1.7). Upland forest represented 4.3% (3,900 ha) of the total land area and was located primarily south of Sioux Falls along the lower portion of the river (e.g., areas around Brandon, SD; Newton Hills State Park, SD; Stone State Park, IA). Farm woodlots were generally small forest fragments associated with farmsteads and/or woodlots that appeared to have been planted. These features represented 0.9% of the total land area, although this may be an underestimate as smaller woodlots (<0.25 ha) would have been lumped together with the dominant land cover (e.g., cropland, farmsteads) based on the digitizing protocol. The total area of the river channel, excluding island features and sandbars, constituted 2.3% or 2050 ha of the landscape. Unvegetated sandbars represented 0.3% of the total land area (235 ha; Figure 1.7).

Land cover varied considerably within the upper, middle, and lower Big Sioux River. Land cover of the upper river segment (Watertown, SD, to Flandreau, SD; Figure 1.1 and 1.6) was dominated by agriculture (tilled land), as it occupied approximately 62.5% (17,230 ha) of the total upper reach land area (Figure 1.7). Grasslands represented 26.2% (7,230 ha) of the landscape with urban areas occupying 2.35% (650 ha) of the area (Figure 1.7). Riparian forest covered 2.7% (740 ha) of the landscape and represented 12% of the total riparian vegetation

found within the Big Sioux basin (Figure 1.8). Upland forest represented only 0.15% (40 ha) of the total upper river study area with a majority being located just north of Flandreau, SD (e.g., Heinemann Site; Figure 1.6-1.7).

The middle river (Flandreau, SD, to near Hudson, SD) contained three study subreaches (4, 5, and 6) and represented the largest portion (42% of study area) of the river (Figure 1.1 and 1.5). Agricultural crop land was the dominant land cover, covering 48% (19,850 ha) of the middle river study segment area (Figure 1.7). Urban land use was much higher in the middle segment than the upper segment, occupying 20.3% (8,400 ha) of the total land area and including the cities of Dell Rapids, Canton, and the greater Sioux Falls area (all in South Dakota). Grassland cover was reduced through this middle river reach (13.6%; 5,600 ha) and upland forest cover increased as it occupied 6.0% (2,500 ha) of the total land area (Figure 1.7). Upland forest within this middle river segment represented 65% of the total upland forest mapped within the Big Sioux corridor. Riparian forest represented 6.2% (2,550 ha) of the total area in the middle river segment and represented 41.9 % of all riparian vegetation found within the Big Sioux basin (Figure 1.7-1.8).

The lower Big Sioux study segment (Rock River confluence to Sioux City, IA) contained the final two study subreaches (7, 8; Figure 1.1 and 1.4). Fifty-five percent (11,250 ha) of the land area was dominated by agricultural land use with grasslands and urban areas representing 9.8% (2,000 ha) and 7.0% (1,430 ha) of the area, respectively (Figure 1.7). Upland forest contributed 6.4% (1,300 ha) of the land area within this segment and represented 34% of the total upland forest cover within the basin. Riparian forest vegetation represented 13.8% of the lower river land area and approximately 46% of the total riparian forest cover found within the basin (Figure 1.7-1.8).

Geographic Patterns in Forest Community Types

Spatial trends in areas of different riparian forest types were observed between the upper, middle, and lower river study segments. The most common riparian community type mapped within the basin was the Silver Maple-Elm-(Cottonwood) Forest (CEGL002586) type, occupying 41% of the total riparian forest cover in the basin (Figure 1.9). While this community type dominated the lower river segment, (representing 59% of the total riparian forest cover) there was a sharp decline in its proportional abundance through the middle river reach (31% of total forest) until it eventually dropped out completely near Flandreau, SD, where the northern most boundary for silver maple within the basin and within the state of South Dakota occurs (Figure 1.9; Little 1971).

The Coyote Willow Temporarily Flooded Shrubland (CEGL001197) followed an inverse trend to the silver maple forests as this type occupied 18% of the total mapped riparian woody habitats in the upper river segment but decreased in abundance in the middle (2.5%) and lower river segments (1.7%; Table 1.9). A decreasing trend from north to south was also observed in the Green ash/Boxelder community types. These forests represented 36% of the total basin wide forest cover and represented 54% and 52% of the riparian woody cover in the upper and middle river areas, respectively, before decreasing in abundance in the lower river area to 17%, a trend most likely attributed to the relative dominance of the silver maple type through this reach (Table 1.9). The abundance of the immature Cottonwood-Peachleaf Willow Floodplain Woodland (CEGL000659) community type was lowest in the middle segment, occupying only 8% of the riparian forest cover, but occupied 25% and 16% of the riparian forest cover in the upper and lower segments, respectively (Figure 1.9). The Cottonwood-Green Ash Floodplain Forest (CEGL000658) community type was a minor component of the total riparian forest cover (4%) across the basin, representing 5% of the riparian woody area in both the lower and middle river areas, but absent within the upper segment. The final riparian community type mapped within the

study area was the Mature Cottonwood Forest. This type occupied only 1% of the woody riparian habitats in the basin and was not a significant component within any of the study segments (Figure 1.9).

Vegetation Data

Thirty-five riparian forest sites representing 134 total plots were sampled within the Big Sioux basin during the summers of 2010 and 2011 (Site level summary data available in Appendix A.2). The number of sites that could be sampled was limited due to the repeated, prolonged flooding events that inundated potential study sites, making access to these areas difficult and affecting vegetation composition and cover within each location (Figure 1.3). Of the 35 sites, 11 were sampled in the upper river segment, 14 in the middle river area and 10 in the lower river (Figure 1.4 – 1.6). A total of 175 plants species was sampled of which 131 (75%) were native and 44 (25%) were exotic (Appendix A.1). Site-level species richness values ranged from a low of 5 to a high of 56 with a basin-wide average of 27.8 (± 2.0). Average % exotic was 18% (± 2.0%) throughout the study area and ranged from a high of 60% to a low of 3.6% (Table 1.2). In total, 19 species of trees, 33 species of shrubs or saplings, and 168 species of herbs or woody seedlings were sampled. Some species were sampled in multiple layers during this study.

A total of 1,223 individual trees across 19 different species were sampled of which 15 (79%) were native and 4 (21%) were exotic. Of the 1223 trees, 332 (27%) were *Acer negundo*, 255 (21%) were *Fraxinus pennsylvanica*, 206 (17%) were *Populus deltoides*, and 161 (13%) were *Acer saccharinum* (Figure 1.10). Site level tree densities across the basin varied among the 35 sites from 67 trees/ha to 1017 trees/ha with an average of 470 (± 33) trees/ha (Table 1.2). Site level basal area (m^2/ha) ranged from 0.97 to 162.53 m^2/ha with an average of 57.37 (± 5.4) m^2/ha (Table 1.2). Of the 33 species sampled in the shrub layer, 28 were native and 5 were exotic. Site level shrub density averaged 3536 (±1086) stems/ha, and varied from 0 stems/ha to 27,917

stems/ha, while percent shrub cover ranged from 0% to 30% and averaged 4.7% (± 1.2; Table 1.2).

A total of 536 herbaceous cover quadrats were sampled within riparian forest sites in the Big Sioux basin. Within the herbaceous layer, a total of 168 species were sampled of which 41 (24%) were exotic. *Laportea canadensis* was the dominant species (IV = 34.63, maximum IV score is 200) as it had the highest frequency (occurred in 62% of the quadrats), highest total cover, and the highest mean cover (56%; Table 1.3). The next most important native species were *Phalaris arundinacea* (IV = 18.44, Freq. = 55.22%), Rudbeckia laciniata (IV = 6.90, Freq. = 43.28%), Cryptotaenia canadensis (IV = 5.34, Freq. = 32.09%), and Leersia virginica (IV = 4.78, Freq. = 30.60%; Table 1.3). *P. arundinacea* was assigned a native status based on USDA PLANTS designation although it should be noted that it's native status is a source of confusion and that others sources have consider it non-native due to the presences of invasive non-native cultivars that have largely supplemented the native varieties (see the following for a discussion: http://www.fs.fed.us/database/feis/plants/graminoid/phaaru/all.html#TAXONOMY). Exotic species were relatively common with four species having an IV greater than 2: *Bromus inermis* (IV = 6.63, Freq. = 20.15%), *Glechoma hederacea* (IV = 5.80, Freq. = 22.39%), *Rhamnus cathartica* (IV = 3.32, Freq. = 22.39%), and *Taraxacum officinale* (IV = 2.26, Freq. = 15.67%; Table 1.3).

The floristic integrity of the 35 riparian sites varied throughout the basin with $w\overline{C}_i$ (weighted by relative cover, herbaceous species only) values for all species (including exotics) averaging 2.93 (± 0.27) and ranging from a low of 0.04 to a high of 5.02, with the native only version ($w\overline{C}$) of this calculation ranging from 1.31 to 5.20 and averaging 3.60 (± 0.23; Table 1.2). Site $\overline{C}_i$ values (non-weighted, including exotics) ranged from 1.60 to 4.20 with an average of 2.83 (± 0.10), while the native only version ($\overline{C}$) was higher with values ranging from 2.12 to 4.50 and an average of 3.45 (± 0.09; Table 1.2). FQI_i values (including non-native species) varied from

3.58 to 25.93 with an average of 14.67 (± 0.76), while the *FQI* (native only) values had an average of 16.14 (± 0.82) and varied from a low of 5.66 to a high of 28.52 (Table 1.2).

Segment and Community Type Comparisons

Several interesting trends in riparian forest characteristics were evident when site level $w\overline{C}$, $\overline{C}$, *FQI*, $w\overline{C}_i$, $\overline{C}_i$, FQI_i, mean basal area, mean species richness, mean trees/ha, mean shrubs/ha, mean % shrub cover, and mean % exotic values were statistically compared between the upper, middle, and lower river study area segments using a one-way ANOVA approach. Non-significant differences were observed among segments for $\overline{C}$, *FQI*, FQI_i, mean species richness, mean trees/ha, mean shrubs/ha, and mean % shrub cover indicating that these values did not vary systematically throughout basin (although differences in FQI_i ($F_{(2,32)} = 2.94$, $p = 0.067$) were marginally significant; Table 1.2). Overall, significant differences ($p < 0.05$) were found among segments for $w\overline{C}$ ($F_{(2,32)} = 10.36$, $p = 0.0003$), $w\overline{C}_i$ ($F_{(2,32)} = 14.76$, $p = 0.0001$), $\overline{C}_i$ ($F_{(2,32)} = 7.24$, $p = 0.003$) , basal area ($F_{(2,32)} = 3.97$, $p = 0.02$), and % exotic ($F_{(2,32)} = 5.56$, $p = 0.008$; Table 1.2). Tukey's HSD post-hoc comparison tests were conducted for all significant differences in the ANOVA analyses and indicated that most of the observed variation between segments was due to differences between the upper basin area and the middle/lower river segments. No significant differences were found in the above vegetation characteristics between the middle and lower river areas. These results are summarized in Table 1.2.

In addition to comparing overall site values differences between the upper, middle, and lower river study segments, plot level $\overline{C}_i$ and $\overline{C}$ values were compared by forest community types, based on assignment of each of the 134 riparian plots to one of the community types used in the GIS mapping project. Data from these plots were used to approximate the typical vegetative characteristics of each community type within the study area. Of the 134 total plots, 8 were sampled within the Coyote Willow Temporarily Flooded Shrubland (CEGL001197), 17 in

the Cottonwood-Peachleaf Willow Floodplain Woodland (CEGL000659), 28 within the Silver Maple-Elm-Cottonwood Forest (CEGL002586) community type, 73 within the Green Ash/Boxelder forest, and 8 in the Cottonwood-Green Ash Floodplain Forest (CEGL000658). In general, the Silver Maple-Elm-Cottonwood Forest (CEGL002586) community type had higher $\overline{C}_i$ (3.32 ± 0.18) and $\overline{C}$ (3.53 ± 0.11) values than other community types and the Coyote Willow Temporarily Flooded Shrubland (CEGL001197) had the lowest $\overline{C}_i$ (2.60 ± 0.33) and $\overline{C}$ (3.12 ± 0.25) values. These values are summarized in Table 1.4.

Only one community type, the Green Ash/Boxelder Forest, had sufficient numbers of plots in each of the segments (20 plots in the upper river segment, 40 plots within the middle river segment, and 13 plots in the lower segment) to adequately examine differences among the three study area segments. Significant differences in plot level $\overline{C}_i$ ($F_{(2,68)} = 14.34$, $p = < 0.0001$) and $\overline{C}$ ($F_{(2,68)} = 9.38$, $p = 0.0003$) values were found among the three study segments within the Green Ash/Boxelder community type (Table 1.5). The Tukey's HSD post-hoc test indicated the observed variation in $\overline{C}_i$ and $\overline{C}$ between segments was due to significantly lower values in the upper basin area than in the middle or lower river segments (Table 1.5). Variation in basal area in the Green Ash/Boxelder forests among segments was not found to be significant.

Community Type Vegetative Characteristics

The vegetative characteristics of riparian forest communities within the Big Sioux basin varied substantially by community type. Dominant herbaceous species within the Coyote Willow Temporarily Flooded Shrubland (CEGL001197) community type included non-native species such as *Poa pratensis* (IV = 15.47), *B. inermis* (IV = 7.32), and *Euphorbia esula* (IV = 6.88) as well one native/adventive species (*P. arundinacea*, IV = 44.11; Table 1.6). Other dominant understory species included *Carex laeviconica* (IV = 14.33), *Salix interior* (IV = 12.15), *Polygonum amphibium* var. *emersum* (IV = 7.72), and *Anemone canadensis* (IV = 7.26; Table

1.6). Shrub cover was an important component within the Coyote Willow Temporarily Flooded Shrubland community type as mean shrub cover across all 8 plots averaged 37.2%. Dominant shrub and sapling species included *S. interior* (34.7% mean cover across all plots) and *Amorpha fruticosa* (2.0% mean cover; Figure 1.11).

Herbaceous species encountered in the Cottonwood-Peachleaf Willow Floodplain Woodlands (CEGL000659) were similar to the flooded shrubland species and most likely represent a later successional state of that community type. There were 17 plots sampled in this community type with dominant species including *P. arundinacea* (IV = 41.17), *P. pratensis* (IV = 15.04), *C. laeviconica* (IV = 10.51), *L. canadensis* (IV = 9.33), *B. inermis* (IV = 8.75), and *A. canadensis* (IV = 7.69; Table 1.7). Shrub cover represented a minor component within the Cottonwood-Peachleaf Willow Floodplain Woodlands as mean shrub cover averaged only 5.5% across all 17 plots. Important shrub and sapling species included *P. deltoides* (2.41% mean cover) and *A. negundo* (1.20% mean cover; Figure 1.11).

The Silver Maple-Elm-Cottonwood Forest (CEGL002586) was the most common type mapped in the GIS portion of the project and represented 28 (6 in the middle segment and 22 in the lower segment) of the 134 plots sampled along the river. *L. canadensis* was the dominant herbaceous species within plots of this community type (IV = 53.42) while *P. arundinacea* represented a more minor component in these forest (IV = 10.63). Other important herbaceous species included *Cryptotaenia canadensis* (IV = 10.39), *Rudbeckia laciniata* (IV = 8.34), *Pilea pumila* (IV = 8.03), and *Leersia virginica* (IV = 6.95; Table 1.8). There was one non-native herbaceous species, *Glechoma hederacea*, that was found readily throughout this community type (IV = 6.78; Table 1.8). Shrub cover occupied a minor component in these forests and averaged only 4.16% across all 28 plots. Important shrub and sapling species included *A. saccharinum* (2.81% mean cover) and *A. negundo* (0.66% mean cover; Figure 1.11).

The Green Ash/Boxelder Forest community type was the most common community type sampled within the basin (73 total plots) due to this community type being present throughout the upper, middle, and lower river study reaches while the most commonly mapped community type, the Silver Maple-Elm-Cottonwood Forest, was only present within the lower half (lower and middle river reach) of the basin (Figure 1.9). The herbaceous layer of the Green Ash/Boxelder community type was dominated by *L. canadensis* (IV = 40.79), *P. arundinacea* (IV = 14.46), *R. laciniata* (IV = 8.30), *Elymus virginicus* (IV = 6.46), *C. canadensis* (IV = 5.80), and *L. virginica* (IV = 5.75; Table 1.9). There were two dominant non-native herbaceous species, *G. hederacea* and *B. inermis*, that were also found readily throughout this community type (IV = 7.41 and IV = 8.10, respectively; Table 1.9). Shrub cover averaged only 3.05% across all 73 plots and was dominated by non-native *Rhamnus cathartica* (1.85% mean cover; Figure 1.11).

In addition to examining the typical basin-wide understory herbaceous composition common to the Green Ash/Boxelder community type, the herbaceous composition was also compared between the three study segments since there were a sufficient number of plots within each of the three areas. *L. canadensis* was most dominant species in the lower (IV = 40.90) and middle (IV = 53.02) rivers segments but represented a minor component (IV = 11.61) within the upper river area (Figure 1.12). *P. arundinacea* was also observed across all three segments with an IV of 28.03, 9.62, and 8.25 within the upper, middle, and lower river areas, respectively (Figure 1.12). Non-native *B. inermis* represented an important species in the upper river area (IV = 24.96) but not in the other two segments (middle river IV = 2.22; lower river IV = 0.00), while the inverse was true of *C. canadensis* (upper IV = 0.00; middle IV =6.90; lower IV = 12.93), *R. laciniata* (upper river IV = 4.65; middle river IV = 8.73; lower river IV = 15.21), and *E. virginicus* (upper river IV = 4.40; middle river IV = 6.21; lower river IV = 13.59; Figure 1.12).

The last sampled community type was the Cottonwood-Green Ash Floodplain Forest (CEGL000658). There were 8 plots sampled within this type throughout the basin (1 plot in the

upper river, 3 in the middle river, and 4 in the lower river). The dominant understory vegetation was similar to both the Silver Maple-Elm-Cottonwood Forest (CEGL002586) type and the Green Ash/Boxelder type with dominant species including *L. canadensis* (IV = 31.03), *P. arundinacea* (IV = 11.47), *P. pumila* (IV = 9.54), *Ageratina altissima* (IV = 9.13), and *Teucrium canadense* (IV = 7.77; Table 1.10). There were also two dominant non-native species, *G. hederacea* and *Rhamnus cathartica*, that were also found readily throughout this community type (IV = 9.07 and IV = 5.56, respectively; Table 1.10). Shrub species were not abundant within any of the plots sampled within this community type (Figure 1.11).

Upland Vegetation

A total of five upland forests sites and one upland plot adjacent to a riparian site (Oak Ridge GPA) were sampled within the Big Sioux basin, representing 22 total plots (88 total quadrats). A majority of these sites were located downstream of Sioux Falls, SD, with one site (Heinemann's Site) located northwest of Flandreau, SD (Figure 1.4 -1.6). One hundred-eight total species were sampled of which 18 (17%) were non-native. Of the 108 species, 30 were unique to upland forest sites and 78 species were found in both upland and riparian environments within the Big Sioux basin. There were 105 (18 exotics) species sampled in the herbaceous layer, 10 trees species and 12 (1 exotic) species of shrubs within the upland sites. Average species richness was 41 (± 6.4) and average % exotics was 12% (± 5%; Table 1.2). *Hydrophyllum virginanum* was the most important species (IV = 15.62) within the upland sites as it occurred in over 86% of the quadrats across the 5 sites (Table 1.11). The next most important species were *L. canadensis* (IV = 14.52, Freq. 40.91%), *Osmorhiza claytonii* (IV = 12.34, Freq. 45.45%), *Parthenocissus quinquefolia* (IV = 10.27, Freq. 72.73%), and *A. altissima* (IV = 6.33, Freq. 34.00%, Table 1.11). Only one non-native species had an IV greater than 2 (*R. cathartica*, IV = 6.38, Freq. 54.55%; Table 1.11).

Percent shrub cover ranged from 3.9% to 16% with an average of 7.24% (± 2.3%). Shrub and sapling stem densities averaged 1813 (± 1010) stems/ha and varied from 583 stems/ha to 6,750 stems/ha (Table 1.2). A total of 216 trees were sampled in the upland forest sites, including 101 (47%) *Quercus macrocarpa*, 31 (14%) *Ostrya virginiana*, 26 (12%) *Celtis occidentalis*, and 21 (10%) *Ulmus rubra* (Figure 1.13). Tree densities varied from 417 trees/ha to 583 trees/ha with an average of 493 (± 26) trees/ha, while basal area ranged from 43.8 to 171.64 m^2/ha and averaged 71.55 (± 20) m^2/ha (Table 1.2).

Upland forest sites $\overline{C}_i$ values ranged from 2.96 to 5.80 with an average of 4.50 (± 0.52) while $\overline{C}$ (native only) values were higher with values ranging from 3.83 to 6.07 and an average of 4.96 (± 0.39; Table 1.2). FQI_i values varied from 14.80 to 39.11 with an average of 28.70 (± 4.40), while *FQI* (based on natives only) averaged 30.10 (± 4.27) and varied from a low of 16.26 to a high of 39.90 (Table 1.2). $w\overline{C}_i$ values ranged from a low 2.37 to a high of 7.44 with an average of 5.06 (± 0.74). The native only version ($w\overline{C}$) was slightly higher with values ranging from 4.26 to 7.62 with an average of 5.78 (± 0.50; Table 1.2).

NVC community types for the five upland forest sites fell into three probable types (Site level summary data available in Appendix A.3). The most common type was represented by the Bur Oak/(Saskatoon Serviceberry, Roughleaf Dogwood)/Wild Sarsaparilla Northern Bur Oak Mesic Forest (CEGL002072). This type comprised most of the Heinemann Site (northwest of Flandreau, SD) and the Arbor's Edge Site (southeast of Sioux Falls, SD; Figure 1.4-1.6) as well as occurring within portions of the other three sites. The overstory of these areas was dominated by *Quercus macrocarpa* and other associates (*Ulmus* spp., *Celtis occidentalis*, and *Ostrya virginiana*) and the understory was dominated by common species including *Elymus villosus*, *Smilax tamnoides*, *Parthenocissus quinquefolia*, and O*smorhiza claytonia*.

Forest along the xeric ridge tops tended to resemble the Bur Oak/Big Bluestem-Porcupine Grass Western Tallgrass Bur Oak Woodland (CEGL002053), although this type may also be related to the Bur Oak/Eastern Hop-hornbeam Forest (CEGL000555) type (Faber-Langendoen 2001). These areas represented a transition between the rich mesic upland forest and the tallgrass prairie remnants commonly adjacent to these forests, with the overstory again being dominated by *Quercus macrocarpa* (*Ulmus* spp., *Juniperus virginiana*, and *Ostrya virginiana* also formed a significant component). The understory was a mixture of dry prairie species (*Schizachyrium scoparium, Sorghastrum nutans*, and *Bouteloua curtipendula*) and mesic upland species (*Elymus villosus*, *Smilax tamnoides*, and *Maianthemum stellatum*). This community type was observed at two sites located near Newton Hills State Park, SD, (e.g., Fish GPA, Mckee GPA) and was also observed along the ridge tops and north–facing, mid-slope areas at Stone State Park and Arbor's Edge.

Rich mesic forest sites found within the southern portion of the basin (e.g. Fish GPA, Mckee GPA, and Stone State Park; Figure 1.4-1.5) tended to have the mid/bottom slope areas dominated by the American Basswood-(Bur Oak)/Eastern Hop-hornbeam Forest (CEGL002012). This community type comprised a diverse overstory including *Tilia americana*, *Quercus macrocarpa*, Ce*ltis occidentalis*, *Fraxinus pennsylvanica*, *Juglans nigra*, *Ostrya virginiana*, and *Ulmus spp.* The understory was comprised of similar species to the riparian stands (e.g., *Laportea canadensis*, *Menispermum canadense*, *Rudbeckia laciniata*, *Maianthemum stellatum,* and *Urtica dioica*) but also contained species with a more eastern affinity including *Aquilegia canadensis*, *Sanguinaria canadensis*, *Smilax ecirrhata*, and *Arisaema triphyllum*. These community type designations should be viewed as preliminary as further study is needed of all five sites.

Discussion

This project provided two main types of data related to riparian forest communities within the Big Sioux River corridor. The GIS mapping project produced an estimate of the total current riparian forest cover within the basin as well as the approximate coverage of each of the six observed Big Sioux River riparian forest community types. The vegetation sampling portion of this project was used to identify the typical vegetative characteristics of each of these community types as well as describe the range of variability within the understory vegetation of the Green Ash/Boxelder community type. The riparian corridor along the Big Sioux represents a mosaic of patch types influenced by riverine hydrologic and geomorphic processes, disturbance history, basin geology, ecoregional context/geographic position, and human land use practices. These and other factors likely contribute to considerable variation in riparian forest communities throughout the basin in terms of floristic quality, composition, structure, % exotics, and geographic extent.

A number of geographic trends are apparent along the Big Sioux. Riparian forests within the upper study segment are small, narrow, and isolated (only 2.7% of the total land area) with patches lacking significant diversity in age structure or community types (average plots per site was 3.09). This pattern may be due to forests on this segment occurring on an immature floodplain where the river's natural flooding cycle does not have the ability to consistently create new habitats for colonization by riparian vegetation. If the low abundance of riparian forest is due to a lack of geomorphic dynamism, then the upper river area has likely never been heavily forested, although this is difficult to ascertain given the large extent of landscape alteration that has occurred (and continues to occur) in the basin and throughout the upper Midwest since the onset of Euro-American settlement (see Chapter 2; Brinson et al. 1981; Naiman and Décamps 1997; National Research Council 2002; Allan 2004). Intensive agricultural land use practices within the basin continue to remove or prevent establishment of riparian vegetation in an attempt

to increase acreage available for cultivation. In addition, most private land forests in the upper river segment are intensively grazed, thus further modifying these habitats and altering their ability to regenerate naturally (Smith and Flake 1983).

Lower river forests are dramatically different as they reside on a much larger floodplain surface where annual overbank flooding, dynamic lateral channel migration, and oxbow lake formation result in a dynamic and heterogeneous vegetative community with multiple age-classes and community types. Riparian forests occupied a greater percent of the total land area (approximately 14% within the 2000 m buffer) within this segment and agricultural land use was reduced slightly to 55% (Figure 1.7). These observations are consistent with previous studies on longitudinal variation in river basins that found that the simplest forests (i.e., lack of age class variation, lower diversity) tended to be found in upper river reaches and the more complex (i.e., larger areas, greater diversity in age classes and community types) forests were found in the downstream areas (Rosgen 1994; Naiman and Décamps 1997).

Forests within the middle river segment represent an intermediate (both geographically and in a river continuum sense) between the observed patterns in the upper and lower river segments, with riparian forest occupying 6.2% of the mapped area. Again, it is hypothesized that flood disturbances occur at intermediate levels through this reach both in terms of intensity and duration resulting in a smaller and less dynamic floodplain surface than the lower river, but one that is still capable of supporting diverse riparian vegetative communities that are otherwise not present within the upper river segment.

The observed trend in riparian forest area decreasing from south to north also coincided with trends in floristic quality, basal area, and the overall dominance by non-native species, measured as % exotics (number of species). On average, sites within the upper river study segment had lower mean basal area, $\overline{C}_i$, $w\overline{C}_i$, $w\bar{C}$, and FQI_i values and greater % exotic values

than the middle and lower river study segments (Table 1.2). These values reflect the dominance of low *C*-value and exotic species within the upper river segment and suggest that these areas may be influenced by their smaller patch sizes and closer proximity to agricultural areas, possibly resulting in decreased resiliency towards invasion by exotic species. Overall differences in $\overline{C}_i$, FQI_i, $w\overline{C}_i$, $w\overline{C}$, and mean % exotic values between the middle and lower river study segments were non-significant indicating greater similarity between riparian forest communities in these areas.

A trend towards lower basal area and increased shrub density (although not significant) was also observed from the lower and middle river study segments to the upper river area. Basal area (m^2/ha) decreased from the upper river to the middle and lower river segments, while mean tree density stayed relatively constant among the three segments (Table 1.2). Lower basal area illustrates the lack of age-class diversity and scarcity of mature forest in general within the upper river forest communities. Shrubs and saplings were a more important component in the upper river segment as shrub density decreased from the upper to the middle and lower river segments (although not significant; Table 1.2).

It will be important to understand these geographic patterns in the woody riparian habitats along the Big Sioux in order to assess differences in site potential for riparian forest restoration and regeneration within the basin and to provide reference conditions for future restoration targets. Further studies are needed to examine how riparian forests have and are changing in the Big Sioux basin, both historically (e.g., by examining pre-settlement General Land Office survey data) and into the future. An understanding of these data will be important in a changing landscape, as climate changes and potentially devastating exotic species migrate into the basin, potentially altering riparian forest communities. Species of particular concern include garlic mustard (*Alliaria petiolata*) and the emerald ash borer (*Agrilus planipennis*). *A. petiolata* was encountered regularly during this study along the Big Sioux in both Iowa and South Dakota.

This Eurasian species has had a devastating effect on forest understory habitats throughout much of eastern North America (Nuzzo 1993; Welk et al. 2002), due in part to its unique ability to invade, persist, and eventually dominate undisturbed forest communities (Nuzzo 1999; Von Holle et al. 2003; Stinson et al. 2007). The Big Sioux basin represents an invasion front for this species as it moves west into the Great Plains. Hence, strategic management efforts should be instituted quickly to help stem the spread of this exotic species before it becomes dominant in the forest communities along the Big Sioux and establishes within riparian and upland forest communities elsewhere in South Dakota.

Similarly, the spread of the emerald ash borer into South Dakota may have potentially devastating impacts to forests along the Big Sioux and elsewhere in the state (Johnson el al. 2012). This Asian beetle was first found in Michigan and Ontario in the early 2000's. Since then, tens of millions of ash trees have been killed as the pest has spread across the eastern United States (Poland and McCullough 2006; Moser et al. 2009). Green ash forests represent a significant component of the forest communities along the Big Sioux River, as well as the Missouri River and other riparian corridors throughout the state. These communities may be dramatically altered, given that the ash borer will likely arrive in South Dakota in the next 5-10 years (Johnson et al. 2012).

Given these and other potential threats to riparian ecosystems, this thesis provides baseline data critical to targeting current and future management efforts along the Big Sioux and provides an improved scientific understanding of ecological patterns in riparian forest communities along this valuable watershed in eastern South Dakota and northwestern Iowa.

References

Allan, J.D. 2004. Landscapes and riverscapes: the influence of land use on stream ecosystems. *Annual Review of Ecology, Evolution and Systematics* 35:257–284.

Bonanno, G. and R. Lo Giudice. 2010. Application of two quality indices as monitoring and management tools of rivers. Case study: The Imera Meridionale River, Italy. *Environ Management* 45(4):856-867.

Bourdaghs, M. 2004. Properties and performance of the floristic quality index in Great Lakes coastal wetlands. M.S. Thesis. University of Minnesota, Minneapolis, MN, USA.

Bourdaghs, M., C.A. Johnston, and R.R. Regal. 2006. Properties and performance of the floristic quality index in Great Lakes coastal wetlands. *Wetlands* 26:718–735.

Bowers, K. and C. Boutin. 2008. Evaluating the relationship between floristic quality and measures of plant biodiversity along stream bank habitats. *Ecological Indicators* 8:466–475.

Bragg, T. and A. Tatschl. 1977. Changes in flood-plain vegetation and land use along the Missouri River from 1826 to 1972. *Environmental Management* 1(4):343-348.

Brinson, M.M., B.L. Swift, R.C. Plantico and J.S. Barclay. 1981. Riparian ecosystems: their ecology and status. U.S. Fish and Wildlife Service Biological Service Program FWS/OBS-81/17.

Bryce, S., J.M. Omernik, D.E. Pater, M. Ulmer, J. Schaar, J. Freeouf, R. Johnson, P. Kuck and S.H. Azevedo. 1998. Ecoregions of North Dakota and South Dakota. Jamestown, ND: Northern Prairie Wildlife Research Center Online. http://www.npwrc.usgs.gov/resource/habitat/ndsdeco/index.htm

Carter, J.L. 1963. Plant communities of the loess bluffs of northwestern Iowa. *Proceedings of the Iowa Academy of Science* 70:45-59.

Coughlin, P.F. and K.F. Higgins. 1993. Riparian habitats relative to wood duck management in South Dakota. *Proceedings of the South Dakota Academy of Science* 72:111-113.

Dean, K. L. 1999. Stopover ecology of Neotropical migrant songbirds in riparian corridors in the northern Great Plains. Ph.D. dissertation, University of South Dakota, Vermillion, South Dakota.

Dieter, C.D. 1987. Habitat use by beaver along the Big Sioux River. M.S. Thesis. South Dakota State University, Brookings.

Dieter, C.D. 1992. Population characteristics of beaver in eastern South Dakota. *American Midland Naturalist* 128:191-196.

Dieter, C.D. and T.R. McCabe. 1989. Factors influencing beaver lodge-site selection on a prairie river. *American Midland Naturalist* 122:408-411.

Dieterman, D., and C.R. Berry. 1998. Fish community and water quality changes in the Big Sioux River. *The Prairie Naturalist* 30(4):199-224.

Dixon, M.D., W.C. Johnson, M.L. Scott, D. Bowen, and L.A. Rabbe. 2012. Dynamics of plains cottonwood (*Populus deltoides*) forests and historical landscape change along unchannelized segments of the Missouri River, USA. *Environmental Management.* (in press).

Duffey, E. 1986. Editorial. *Biological Conservation* 36:197-198.

East Dakota Water Development District (EDWDD). 2010. East Dakota riparian area restoration and protection project. Project Summary available at: http://denr.sd.gov/dfta/wp/319apps/2010/edwdd.pdf

Faber-Langendoen, D., editor. 2001. Plant communities of the Midwest: Classification in an ecological context. Association for Biodiversity Information, Arlington, VA. 61 pp. + appendix (705 pp.).

Gentry, D.J., D.L. Swanson, and J.D. Carlisle. 2006. Species richness and nesting success of migrant forest birds in natural river corridors and anthropogenic woodlands in southeastern South Dakota. *Condor* 108:140-153.

Granfors, D.A. and L.D. Flake. 1999. Wood duck brood movements and habitat use on prairie rivers in South Dakota. *Journal of Wildlife Management* 63:643-649.

Great Plains Flora Association. 1986. *Flora of the Great Plains*. University Press of Kansas, Lawrence.

Gergel, S.E., M.D. Dixon and M.G. Turner. 2002. Consequences of human-altered floods: levees, floods, and floodplain forests along the Wisconsin River. *Ecological Applications* 12(6):1755-1770.

Gregory, S.V., F.J. Swanson, W.A. McKee, and K.W. Cummins. 1991. An ecosystem perspective of riparian zones. *Bioscience* 41(8):540-551.

Grime JP. 1974. Vegetation classification by reference to strategies. *Nature* 250:26-31.

Grime, J.P., J.G. Hodgson and R. Hunt. 1988. *Comparative plant ecology: a functional approach to common British species*. Unwin & Hyman, London.

Hanson, R. and D. Hazlett. 1971. An ordination study of the forest vegetation of Newton Hills State Park. *Proceedings of the South Dakota Academy of Science* 50:280-285.

Hegstad, G.D. 1992. Vegetation analysis of a native hillside prairie within an oak woodland in Sioux County, Iowa. Proceedings of the Twelfth North American Prairie Conference.

Jungwirth, J.D., C.D. Dieter, A. Munsterman. 2005. Beaver (*Castor canadensis*) habitat use in eastern South Dakota, 2000-2001. *Proceedings of the South Dakota Academy of Science* 84:243-251.

Johnson, W.C., M.D. Dixon, M.L. Scott, L. Rabbe, G. Larson, M. Volke, and B. Werner. 2012. Forty years of vegetation change on the Missouri River floodplain. *BioScience* 62(2):123-135.

Kiesow, A. M. and C.D. Dieter. 2005. Availability of suitable habitat for northern river otters in South Dakota. *Great Plains Research* 15:31-43.

Kirby, D.J. 2001. An assessment of the channel catfish population in the Big Sioux River, South Dakota. M.S. Thesis. South Dakota State University, Brookings.

Knupp Moore, P. M., and L.D. Flake.1994. Forest characteristics in eastern and central South Dakota. *Proceedings of the South Dakota Academy of Science* 73:163-174.

Lane, J.E., C.L. Buck, and R.M. Brigham. 2003. The bat fauna of southeastern South Dakota. *The Prairie Naturalist* 35:247-256.

Lindsey, A.A. 1955. Testing the line-strip method against full tallies in diverse forest types. *Ecology* 36:485-494.

Little, E.L. Jr., 1971. *Atlas of United States trees, volume 1, conifers and important hardwoods*: U.S. Department of Agriculture Miscellaneous Publication 1146, 9 p., 200 maps.

Lopez, R.D. and M.S. Fennessy. 2002. Testing the floristic quality assessment index as an indicator of wetland condition. *Ecological Applications* 12:487-497.

Matthews, J.W., G. Spyreas, and A.G. Endress. 2009. Trajectories of vegetation-based indicators used to assess wetland restoration progress. *Ecological Applications* 19:2093–2107.

McCormick, K.A., and R.H. Hammond. 2004. Geology of Lincoln and Union Counties, South Dakota. Department of Environment and Natural Resources, Geologic Survey. Bulletin 39.

Milewski, C.L., C.R. Berry, and D. Dieterman. 2001. Use of the index of biological integrity in eastern South Dakota rivers. *The Prairie Naturalist* 33(3): 135-152.

Morey, N.M. and C.R. Berry. 2003. Biological characteristics of blue sucker in the James and Big Sioux River, South Dakota. *Journal of Freshwater Ecology* 18:33-41.

Moser, W.K., E.L. Barnard, R.F. Billings, S.J. Crocker, M.E. Dix, A.N. Gray, G.G. Ice, M-S. Kim, R. Reid, S.U. Rodman and W.H. McWilliams. 2009. Impacts of nonnative invasive species on US forests and recommendations for policy and management. *Journal of Forestry* 107(6): 320-327.

Naiman, R. J., and H. Décamps. 1997. The ecology of interfaces: riparian zones. *Annual Review of Ecology and Systematics* 28:621–658.

Naiman, R.J., H. Decamps and M, Pollock. 1993. The role of riparian corridors in maintaining regional biodiversity. *Ecological Applications* 3(2):209-212.

National Research Council (NRC). 2002. *Riparian areas: functions and strategies for management*. National Academy Press, Washington, D.C.

Nuzzo, V. 1993. Distribution and spread of the invasive biennial *Alliaria petiolata* (garlic mustard) in North America. Pp. 137-145, *In* B. McNight (Ed.). *Biological Pollution: The Control and Impact of Invasive Exotic Species.* Indiana Academy of Sciences, Indianapolis, IN.

Nuzzo, V. 1999. Invasion pattern of the herb garlic mustard (*Alliaria petiolata*) in high quality forests. *Biological Invasions* 1:169-179.

Omernik, J.M. 1987. Ecoregions of the conterminous United States. *Annual Association of American Geographers* 77:118-125.

Parrish, J.B. 1981. Woodpecker nesting habitat in a prairie river woodland. M.S. Thesis. South Dakota State University, Brookings.

Poff , N.L., D.J. Allan, M.B. Bain, J.R. Karr, K.L. Prestegaard, B.D. Richter, R.E. Sparks, and J.C. Stromberg. 1997. The natural flow regime: a paradigm for conservation and restoration of riverine ecosystems. *BioScience* 47:769-784.

Poland T.M. and D.G. McCullough. 2006. Emerald ash borer: invasion of the urban forest and the threat to North America's ash resource. *Journal of Forestry* 104(3):118-124.

Reed, P. B., Jr. 1988. National list of plant species that occur in wetlands: national summary. U. S. Fish and Wildlife Service Biological Report 88(24). 244 pp.

Rooney, T.P. and D.A. Rogers. 2002. The modified floristic quality index. *Natural Areas Journal* 22:340–344.

Rosgen, D.L. 1994. A classification of natural rivers. *Catena* 22:169–199.

Rothrock, P.E. and M. Homoya. 2005. An evaluation of Indiana's floristic quality assessment. *Proceedings of the Indiana Academy of Science*, 114:9-18.

SAS Institute Inc. 2004. SAS, version 9.1.3 [computer program]. SAS Institute Inc., Cary, N.C.

Schulz, L.D. and M.J. Jarrett. 2009. Geology of Brookings and Kingsbury Counties, South Dakota. Department of Environment and Natural Resources, Geologic Survey. Bulletin 40.

Sinning, J.A. 1968. Fishes of the Big Sioux River. M.S. Thesis. South Dakota State University, Brookings.

Smith, R.L. and L.D. Flake. 1983. The effect of grazing on forest regeneration along a prairie river. *The Prairie Naturalist* 15(1):41-44.

Spencer, C.N., S.L. Matzner, J. Smalley, M. Bukrey, J. Onberg, M. Chapman and M. Steck. 2009. Forest expansion and soil carbon changes in the Loess Hills of Eastern South Dakota. *The American Midland Naturalist* 161(2):273-295.

South Dakota Department of Environment and Natural Resources. 2010. The 2010 South Dakota integrated report for surface water quality assessment. Report 305(b) and 303(d).

South Dakota Department of Game, Fish, and Parks (SDGFP). 2006. South Dakota comprehensive Wildlife Conservation Plan. South Dakota Dept. of Game, Fish, and Parks, Wildlife Division Report 2006-08.

Stinson, K., S. Kaufman, L. Durbin, and F. Lowenstein. 2007. Impacts of garlic mustard invasion on a forest understory community. *Northeastern Naturalist* 14 (1):73-88.

Swanson, D.L., K.L. Dean, H.A. Carlisle, and E.T. Liknes. 2005. Riparian and woodlot landscape patterns and migration of Neotropical migrants in riparian forests of eastern South Dakota. Pages 541-549 *In*: C.J. Ralph and T.D. Rich (eds.), *Bird conservation implementation and integration in the Americas*: proceedings of the third international Partners in Flight conference 2002. Gen. Tech. Rep. PSW-GTR-191. Albany, CA: Pacific Southwest Research Station, Forest Service, USDA.

Swink, F. and G. Wilhelm. 1979. *Plants of the Chicago region.* Revised and expanded edition with keys. The Morton Arboretum, Lisle, Illinois.

Swink, F. A. and G. S. Wilhelm. 1994. *Plants of the Chicago region*. Fourth Edition. Indiana Academy of Sciences, Indianapolis. 921 pp.

Taft, J., G. Wilhelm, D. Ladd, and L. Masters. 1997. Floristic quality assessment for vegetation in Illinois. A method for assessing vegetation integrity. *Eriginia* 15(1):3-95.

The Northern Great Plains Floristic Quality Assessment Panel (NGPFQAP). 2001. Coefficients of conservatism for the vascular flora of the Dakotas and adjacent grasslands. U.S. Geological Survey, Biological Resources Division, Information and Technology Report USGS/BRD/ITR-2001-0001. 32 pp.

Tieszen, L. L. and Pfau, M. W. (1995). Isotopic evidence for the replacement of prairie forest in the Loess Hills of eastern South Dakota. In *Proceedings, 14th North American Prairie Conference: Prairie Biodiversity* (D. C. Hartnett, ed.), pp. 153-165.

Tu, W.-G., X.-F. Gao, N. Wu, and S.-H. Liu. 2009. A novel method for floristic quality assessment using the vegetation of the Jiuding Mountain, Sichuan, China as an example. *Nordic Journal of Botany* 27:61–68.

United States Environmental Protection Agency (EPA). 1978. Profile of environmental quality, Region 8. Denver CO.

U.S. Fish and Wildlife Service. 2009. A system for mapping riparian areas in the western United States. Division of Habitat and Resource Conservation, Branch of Resource and Mapping Support, Arlington, Virginia.

USDA, NRCS. 2011. The PLANTS Database (http://plants.usda.gov, 15 September 2011). National Plant Data Team, Greensboro, NC 27401-4901 USA.

Usgaard, R.E. 1994. Re-establishing bald eagle and osprey breeding populations in South Dakota through hacking: a feasibility study. M.S. Thesis. South Dakota State University, Brookings.

Van Bruggen, T. 1976. *The vascular plants of South Dakota*. The Iowa State University Press, Ames.

Vander Zee, D. 1979. The vascular flora of Gitchie Manitou State Preserve, Lyon County, Iowa. *Proceedings of the Iowa Academy of Science* 88(2):66-75.

Von Holle, B., H.R Delcourt and D. Simberloff. 2003. The importance of biological inertia in plant-community resistance to invasion. *Journal of Vegetation Science* 14:425-423.

Welk, E., K. Schubert and M.H. Hoffmann. 2002. Present and potential distribution of invasive garlic mustard (*Alliaria petiolata*) in North America. *Diversity and Distributions* 8:219-233.

Westin, F.C., and D.D. Malo. 1978. Soils of South Dakota. South Dakota State University Agricultural Experimental Station. Bulletin 656.

Table 1.1. Land cover categories used for GIS mapping of 2008 land cover.

100: **Big Sioux River main channel**

200: **Riparian Forests or Shrublands** (Woody habitats located on floodplain)
208: Coyote Willow Temporarily Flooded Shrubland (CEGL001197)
209: Cottonwood-Peachleaf Willow Floodplain Woodland (CEGL000659)
210: Mature Cottonwood Forest
211: Silver Maple-Elm-Cottonwood Forest (CEGL002586)
213: Green Ash-Boxelder Floodplain Forest
215: Cottonwood-Green Ash Floodplain Forest (CEGL000658)

299: **Upland Forest** (Upland areas not associated with river floodplain)
399: Upland Woodlands (Not associated with the river floodplain)
499: Upland Shrubland (Not associated with the river floodplain)

500: **Grassland and Pasture Lands** (Grasses and other herbaceous cover, non-tilled)

550: **Wetlands Areas** (Sloughs, bogs, fens and other wetland communities)

600: **Urban** (Cities, towns, gravel pits and other developed areas)

700: **Lakes** (Lakes, ponds, sewage treatment ponds and other standing water bodies)

800: **Woodlots** (Planted shelterbelts and woodlots)

900: **Farmsteads** (Farm houses and associated buildings and storage areas)

1000: **Tilled Land** (Row crops and actively cultivated land)

3000: **Tributaries** (Tributaries of Big Sioux River, Former Big Sioux channels and oxbow lakes)

4000: **Sandbars** (Unvegetated sandbars in the Big Sioux main channel)

Table 1.2. Floristic analysis summary table and results from one-way ANOVA analysis comparing differences between site level $\overline{C}$, *FQI*, $\overline{C}_i$, FQI_i, $w\overline{C}$, $w\overline{C}_i$, mean basal area (m^2/ha), mean species richness/site, mean trees/ha, mean shrubs/ha, mean % shrub cover, and mean % exotic values for riparian and upland sites sampled within the Big Sioux basin. Means (± SE) are provided by study segment as well as for all riparian site and all sites sampled within the basin (riparian + upland). $w\overline{C}$ values are weighted by relative cover and $w\overline{C}_i$, $\overline{C}_i$, and FQI_i calculations included all species (including exotics) while $w\overline{C}$, $\overline{C}$, and *FQI* included only native species. An * indicates significant differences ($p < 0.05$) and ^{T} indicates marginal significant difference ($0.05 < p < 0.10$). For significant results, the Tukey's HSD post-hoc test was conducted with letters denoting significant differences between segments within each analysis.

	Upper River	**Middle River**	**Lower River**	***p-value***	**Upland Sites**	**Riparian Site Total**	**Study Site Total**
Sites (#)	11	14	10	-	5	**35**	**40**
Plots (#)	34	50	50	-	22	**134**	**156**
$w\overline{C}_i$	1.34 (± 0.27)a	3.66 (± 0.37)b	3.64 (± 0.34)b	0.0001*	5.06 (± 0.74)	**2.93 (± 0.27)**	**3.24 (± 0.27)**
$w\overline{C}$	2.40 (± 0.37)a	4.28 (± 0.27)b	3.97 (± 0.30)b	0.0003*	5.78 (± 0.50)	**3.60 (± 0.23)**	**3.90 (± 0.23)**
$\overline{C}_i$	2.37 (± 0.16)a	3.03 (± 0.11)b	3.05 (± 0.18)b	0.003*	4.50 (± 0.52)	**2.83 (± 0.10)**	**3.07 (± 0.14)**
$\overline{C}$	3.21 (± 0.17)	3.55 (± 0.11)	3.56 (± 0.18)	0.195	4.96 (± 0.39)	**3.45 (± 0.09)**	**3.67 (± 0.13)**
FQI_i	12.09 (± 1.52)	15.77 (± 0.86)	15.97 (± 1.45)	0.067^T	28.70 (± 4.40)	**14.67 (± 0.76)**	**16.72 (± 1.18)**
FQI	13.87 (± 1.64)	17.07 (± 0.95)	17.32 (± 1.66)	0.17	30.10 (± 4.27)	**16.14 (± 0.82)**	**18.18 (± 1.19)**
Mean Basal Area (m^2/ha)	37.1 (± 8.3)a	63.6 (± 5.9)b	70.98 (± 12.3)b	0.02*	71.55 (± 20.26)	**57.37 (± 5.39)**	**59.45 (± 5.41)**
Mean % Exotics	26 (± 4.0)a	14 (± 2.0)b	14 (± 2.0)b	0.008*	12 (± 5.0)	**18 (± 2.0)**	**17 (± 2.0)**
Mean Richness/Site	26 (± 4.3)	28 (± 2.8)	29 (± 4.3)	0.88	41 (± 6.4)	**27.80 (± 2.08)**	**29.71 (± 2.10)**
Mean Trees/ha	483 (± 83)	454 (± 42)	477 (± 48)	0.93	493 (± 26)	**470 (± 33)**	**473 (± 28)**
Mean Shrub Cover (%)	4.5 (± 1.6)	5.4 (± 2.8)	5.9 (± 2.4)	0.82	7.24 (± 2.3)	**4.7 (± 1.2)**	**5.0 (± 1.0)**
Mean Shrubs/ha	6692 (± 2881)	2148 (± 889)	3322 (± 2105)	0.24	1813 (± 1010)	**3536 (± 1086)**	**3284 (± 940)**

Table 1.3. Summary of herbaceous data for 168 species from 536 riparian quadrats across the entire study area. Importance value (IV) was calculated by summing relative frequency and relative cover for each species. An asterisk (*) indicates the species is considered non-native.

Species	**Frequency (%)**	**Mean Cover (%)**	**Relative Frequency (%)**	**Relative Cover (%)**	**IV**
Laportea canadensis	62.69	56.34	5.54	29.09	34.63
Phalaris arundinacea	55.22	29.81	4.88	13.56	18.44
Rudbeckia laciniata	43.28	8.62	3.82	3.07	6.90
Pilea pumila	34.33	6.00	3.03	1.70	4.73
Fraxinus pennsylvanica	33.58	4.11	2.97	1.14	4.10
Cryptotaenia canadensis	32.09	5.50	2.83	2.51	5.34
Leersia virginica	30.60	8.24	2.70	2.08	4.78
Elymus virginicus	29.85	8.50	2.64	2.09	4.73
Vitis riparia	29.85	4.01	2.64	0.99	3.62
Urtica dioica	29.10	4.46	2.57	1.51	4.08
Viola sororia	27.61	6.39	2.44	1.45	3.89
Acer negundo	23.13	2.90	2.04	0.55	2.60
**Glechoma hederacea*	22.39	20.71	1.98	3.82	5.80
**Rhamnus cathartica*	22.39	7.28	1.98	1.34	3.32
Parthenocissus vitacea	20.90	5.66	1.85	0.97	2.82
**Bromus inermis*	20.15	5.00	1.78	4.85	6.63
Ranunculus abortivus	20.15	1.90	1.78	0.32	2.10
**Taraxacum officinale*	15.67	6.79	1.38	0.88	2.26
Bidens vulgata	15.67	1.27	1.38	0.16	1.55
Carex laeviconica	14.93	14.66	1.32	1.80	3.12
Acer saccharinum	14.93	1.26	1.32	0.15	1.47
**Chenopodium album*	14.18	1.66	1.25	0.19	1.45
Celtis occidentalis	14.18	1.59	1.25	0.19	1.44
Chenopodium simplex	14.18	2.50	1.25	0.29	1.54
Symphyotrichum ontarionis	13.43	5.02	1.19	0.56	1.74
Other (143 species)	-	-	42.19	24.73	66.92

Table 1.4. Comparison of the average $\overline{C}_i$ and $\overline{C}$ values for plots within the five dominant community types sampled within the Big Sioux basin. Standard error values are provided for all means and the total number of plots sampled within each community type are provided.

Community Type	**Plot #**	$\overline{C}_i$	$\overline{C}$
Coyote Willow Shrubland	8	2.60 (± 0.33)	3.12 (± 0.25)
Cottonwood-Peachleaf Willow Woodland	17	2.51 (± 0.20)	3.33 (± 0.25)
Silver Maple-Elm-Cottonwood Forest	28	3.32 (± 0.18)	3.53 (± 0.15)
Green Ash-Boxelder Forest	73	2.99 (± 0.13)	3.57 (± 0.11)
Cottonwood-Green Ash Forest	8	2.61 (± 0.20)	3.18 (± 0.26)

Table 1.5. Results from the one-way ANOVA analysis comparing differences in plot level $\overline{C}$, $\overline{C}_i$, and mean basal area (m^2/ha) values within the Green Ash/Boxelder forest community types between the upper, middle, and lower river study segments. Standard error values are provided for all means and * indicate significant differences ($p < 0.05$). For significant ANOVA results, the Tukey's HSD post-hoc test was conducted with letters denoting significant differences between segments.

Segment	**Plot (#)**	$\overline{C}_i$	$\overline{C}$	**Basal Area (m^2/ha)**
Upper River Segment	20	2.11 (± 0.21) a	2.89 (± 0.22) a	49.8 (± 9.5)
Middle River Segment	40	3.22 (± 0.14) b	3.81 (± 0.12) b	63.6 (± 6.4)
Lower River Segment	13	3.80 (± 0.28) b	3.95 (± 0.24) b	60.7 (± 13.8)
	$F_{(2,68)}$	14.34	9.38	0.72
	p-value	0.0001*	0.0003*	0.49

Table 1.6. Summary of herbaceous data for 45 species from 8 plots in the Coyote Willow Temporarily Flooded Shrubland (CEGL001197) community type. Importance value (IV) was calculated by summing relative frequency and relative cover for each species. An asterisk (*) indicates the species is considered non-native.

Species	**Frequency (%)**	**Mean Cover (%)**	**Relative Frequency (%)**	**Relative Cover (%)**	**IV**
Phalaris arundinacea	87.50	51.61	8.75	35.36	44.11
**Poa pratensis*	25.00	66.25	2.50	12.97	15.47
Carex laeviconica	62.50	16.50	6.25	8.08	14.33
Salix interior	75.00	7.92	7.50	4.65	12.15
Polygonum amphibium	50.00	6.94	5.00	2.72	7.72
**Bromus inermis*	50.00	5.75	5.00	2.32	7.32
Anemone canadensis	37.50	11.96	3.75	3.51	7.26
**Euphorbia esula*	12.50	57.50	1.25	5.63	6.88
Fraxinus pennsylvanica	25.00	17.19	2.50	3.36	5.86
Symphoricarpos occidentalis	12.50	42.50	1.25	4.16	5.41
Other (35 species)	-	-	56.25	17.24	73.49

Table 1.7. Summary of herbaceous data for 65 species from 17 plots in the Cottonwood-Peachleaf Willow Floodplain Woodland (CEGL000659) community type. Importance value (IV) was calculated by summing relative frequency and relative cover for each species. An asterisk (*) indicates the species is considered non-native.

Species	**Frequency (%)**	**Mean Cover (%)**	**Relative Frequency (%)**	**Relative Cover (%)**	**IV**
Phalaris arundinacea	81.25	49.44	8.02	33.15	41.17
**Poa pratensis*	31.25	47.50	3.09	11.96	15.04
Carex laeviconica	50.00	13.83	4.94	5.57	10.51
Laportea canadensis	31.25	24.80	3.09	6.24	9.33
**Bromus inermis*	37.50	16.71	3.70	5.05	8.75
Anemone canadensis	43.75	9.57	4.32	3.37	7.69
Vitis riparia	31.25	10.00	3.09	2.52	5.60
Solidago gigantea	25.00	14.06	2.47	2.83	5.30
Salix interior	37.50	2.85	3.70	0.86	4.57
Carex gravida	18.75	23.75	1.85	2.58	4.43
Other (55 species)	-	-	61.73	25.87	87.60

Table 1.8. Summary of herbaceous data for 81 species from 28 plots in the Silver Maple-Elm-Cottonwood Forest (CEGL002586) community type. Importance value (IV) was calculated by summing relative frequency and relative cover for each species. An asterisk (*) indicates the species is considered non-native.

Species	**Frequency (%)**	**Mean Cover (%)**	**Relative Frequency (%)**	**Relative Cover (%)**	**IV**
Laportea canadensis	96.15	49.26	8.09	45.33	53.42
Phalaris arundinacea	73.08	6.40	6.15	4.48	10.63
Cryptotaenia canadensis	50.00	12.92	4.21	6.18	10.39
Rudbeckia laciniata	53.85	7.39	4.53	3.81	8.34
Pilea pumila	46.15	9.40	3.88	4.15	8.03
Leersia virginica	50.00	5.74	4.21	2.75	6.95
**Glechoma hederacea*	26.92	17.54	2.27	4.52	6.78
Urtica dioica	38.46	5.06	3.24	1.86	5.10
Fraxinus pennsylvanica	46.15	2.28	3.88	1.01	4.89
Acer saccharinum	42.31	1.85	3.56	0.75	4.31
Other (71 species)	-	-	55.99	25.16	81.15

Table 1.9. Summary of herbaceous data for 131 species from 73 plots in the Green Ash/Boxelder community type. Importance value (IV) was calculated by summing relative frequency and relative cover for each species. An asterisk (*) indicates the species is considered non-native.

Species	**Frequency (%)**	**Mean Cover (%)**	**Relative Frequency (%)**	**Relative Cover (%)**	**IV**
Laportea canadensis	66.20	66.75	5.77	35.03	40.79
Phalaris arundinacea	42.25	32.20	3.68	10.78	14.46
Rudbeckia laciniata	49.30	10.25	4.29	4.00	8.30
**Bromus inermis*	18.31	44.81	1.60	6.50	8.10
**Glechoma hederacea*	26.76	23.92	2.33	5.07	7.41
Elymus virginicus	39.44	9.67	3.44	3.02	6.46
Cryptotaenia canadensis	36.62	9.00	3.19	2.61	5.80
Leersia virginica	36.62	8.83	3.19	2.56	5.75
Viola sororia	39.44	7.19	3.44	2.25	5.68
**Rhamnus cathartica*	35.21	6.30	3.07	1.76	4.83
Other (121 species)	-	-	66.01	26.40	92.42

Table 1.10. Summary of herbaceous data for 57 species from 8 plots in the Cottonwood-Green Ash Floodplain Forest (CEGL000658) community type. Importance value (IV) was calculated by summing relative frequency and relative cover for each species. An asterisk (*) indicates the species is considered non-native.

Species	**Frequency (%)**	**Mean Cover (%)**	**Relative Frequency (%)**	**Relative Cover (%)**	**IV**
Laportea canadensis	50.00	39.96	4.08	26.95	31.03
Phalaris arundinacea	50.00	16.28	4.08	7.39	11.47
Pilea pumila	62.50	6.61	5.10	4.44	9.54
Ageratina altissima	25.00	25.85	2.04	7.09	9.13
**Glechoma hederacea*	50.00	11.00	4.08	4.99	9.07
Teucrium canadense	37.50	11.63	3.06	4.71	7.77
Parthenocissus vitacea	62.50	7.95	5.10	1.35	6.45
Rudbeckia laciniata	37.50	8.42	3.06	2.87	5.93
Carex sartwellii	12.50	40.00	1.02	4.54	5.56
**Rhamnus cathartica*	12.50	40.00	1.02	4.54	5.56
Other (47 species)	-	-	67.35	31.13	98.48

Table 1.11. Summary of herbaceous data for 101 species from 88 upland quadrats across the 5 upland sites. Importance value (IV) was calculated by summing relative frequency and relative cover for each species. An * indicates the species is considered non-native.

Species	**Frequency (%)**	**Mean Cover (%)**	**Relative Frequency (%)**	**Relative Cover (%)**	**IV**
Hydrophyllum virginianum	86.36	16.99	4.65	10.98	15.62
Parthenocissus quinquefolia	72.73	14.32	3.91	6.36	10.27
Celtis occidentalis	63.64	10.62	3.42	3.84	7.27
Sanguinaria canadensis	59.09	4.35	3.18	1.22	4.39
Maianthemum stellatum	54.55	5.87	2.93	1.12	4.06
Ostrya virginiana	54.55	9.23	2.93	3.30	6.23
**Rhamnus cathartica*	54.55	11.43	2.93	3.44	6.38
Ribes missouriense	54.55	6.77	2.93	1.04	3.97
Ageratina altissima	50.00	15.83	2.69	5.41	8.10
Elymus villosus	50.00	6.22	2.69	0.89	3.58
Fraxinus pennsylvanica	50.00	7.39	2.69	1.27	3.96
Smilax tamnoides	50.00	5.80	2.69	1.77	4.46
Osmorhiza claytonii	45.45	27.79	2.44	9.89	12.34
Carex blanda	40.91	5.99	2.20	1.01	3.21
Galium triflorum	40.91	8.95	2.20	2.19	4.39
Laportea canadensis	40.91	47.33	2.20	12.32	14.52
Vitis riparia	40.91	3.25	2.20	0.42	2.62
Phryma leptostachya	31.82	7.25	1.71	1.08	2.80
Sanicula marilandica	31.82	6.08	1.71	0.91	2.62
Smilax ecirrhata	31.82	4.86	1.71	0.43	2.15
Other (81 species)	-	-	45.98	31.09	77.05

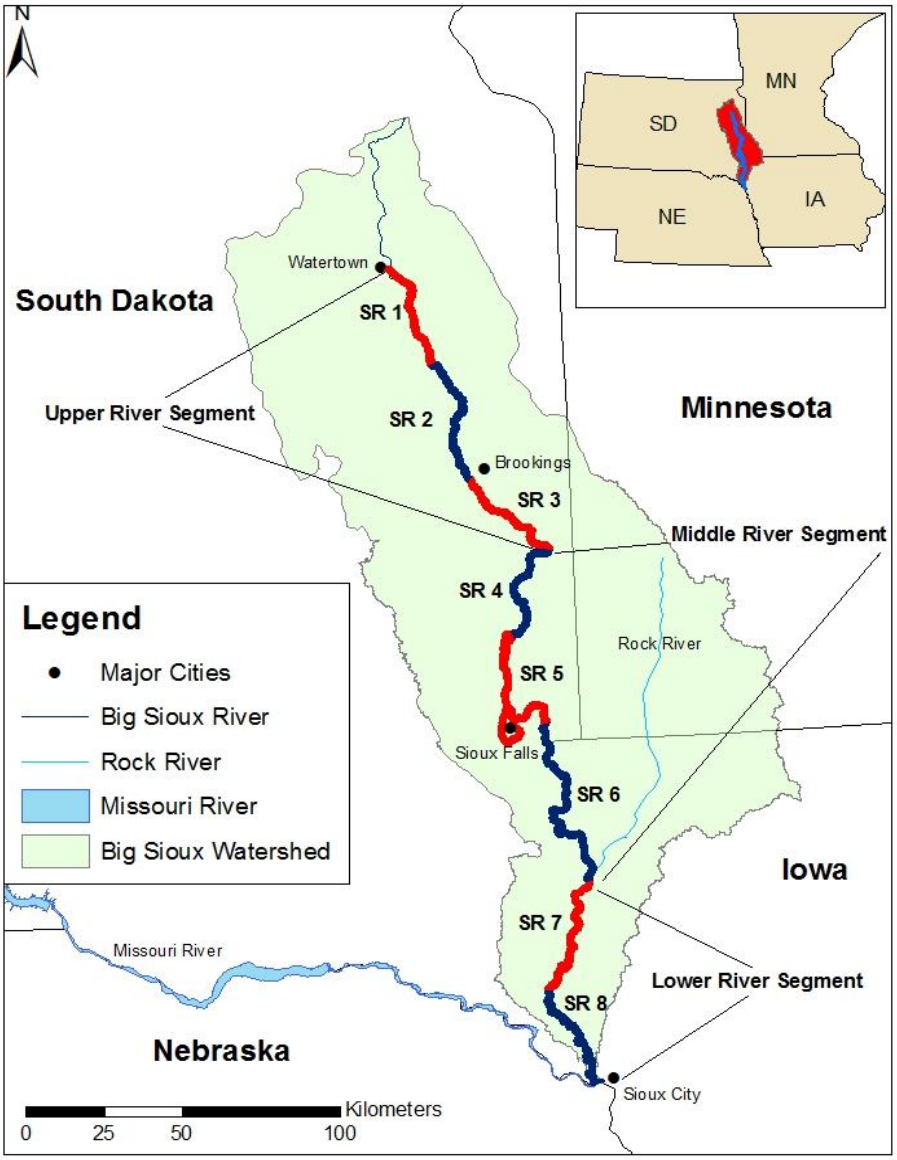


Figure 1.1. The Big Sioux basin drains approximately 22,550 km^2 in Minnesota, Iowa, and South Dakota, including the Coteau des Prairies and much of South Dakota's Prairie Pothole region. It originates in southern Roberts Co., South Dakota, and flows 676 km southward to its mouth at the Missouri River at Sioux City, Iowa. The study area stretches from Watertown, SD, to Sioux City, IA, and was divided longitudinally into three distinct study segments creating an upper, middle, and lower portion of the river. Breaks between these three study segments represented changes between level IV Ecoregions boundaries as well as major tributary inputs. The basin was further subdivided into eight study subreaches (shown in alternating red and blue).

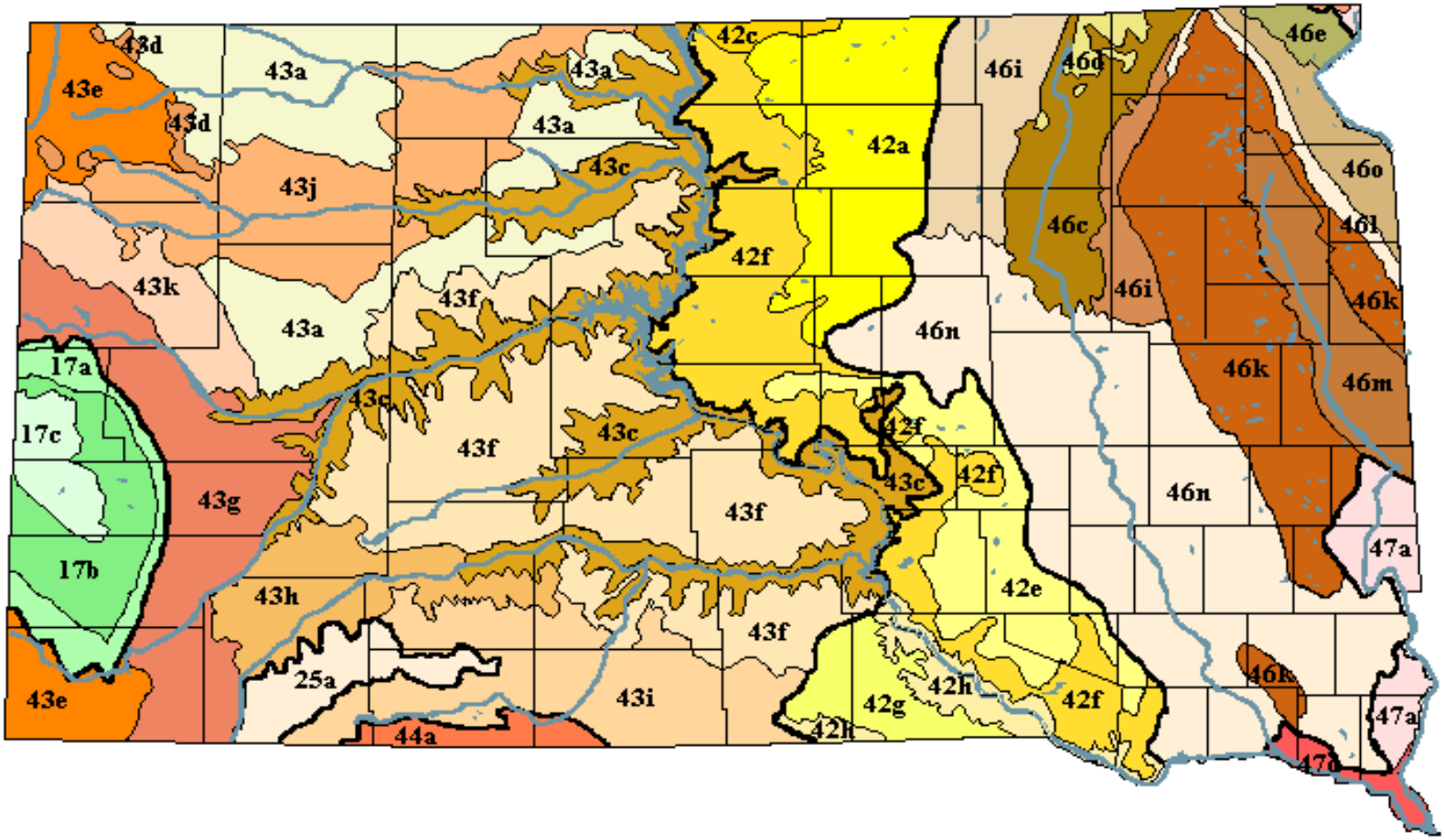


Figure 1.2. Level IV Ecoregions of South Dakota including dominant drainage basins. The Big Sioux River flows through three Ecoregions including 46m (Big Sioux Basin), 47a (Loess Hills), and 47d (Missouri River Alluvial Plain). Figure courtesy of Bryce et al. (1998).

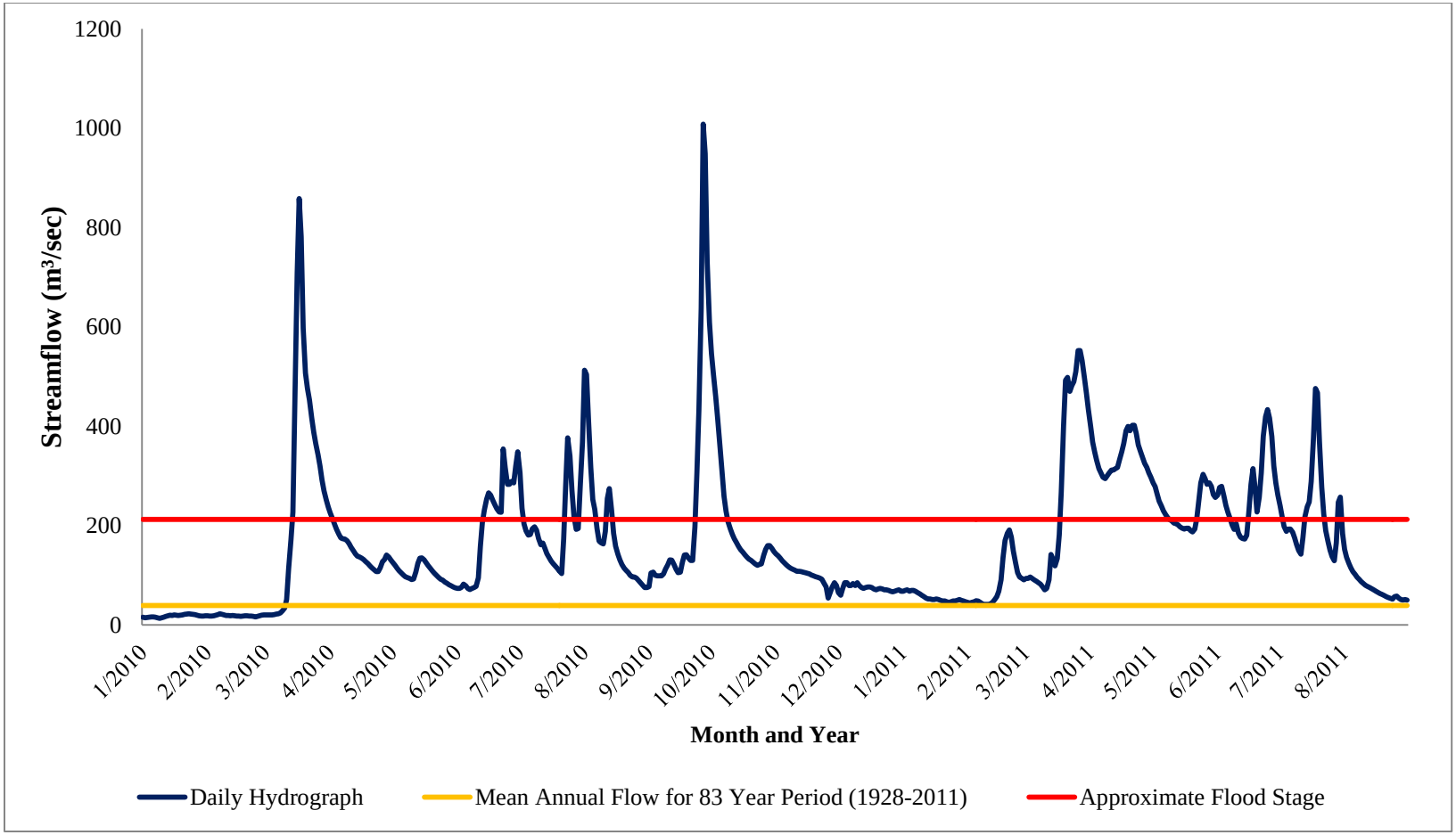


Figure 1.3. Hydrograph for the Big Sioux River at Akron, Iowa, (USGS gauging station 06485500) for the years of this study (2010 and 2011). The mean annual flow (38.91 m³/sec) for the 83 year period of record (1928-2011) is shown in yellow and the approximate flood stage at the Akron gauge (212.38 m³/sec) is highlighted in red. Multiple, prolonged flooding events occurred during the summers of 2010 and 2011, severely curtailing the sampling effort during the two years.

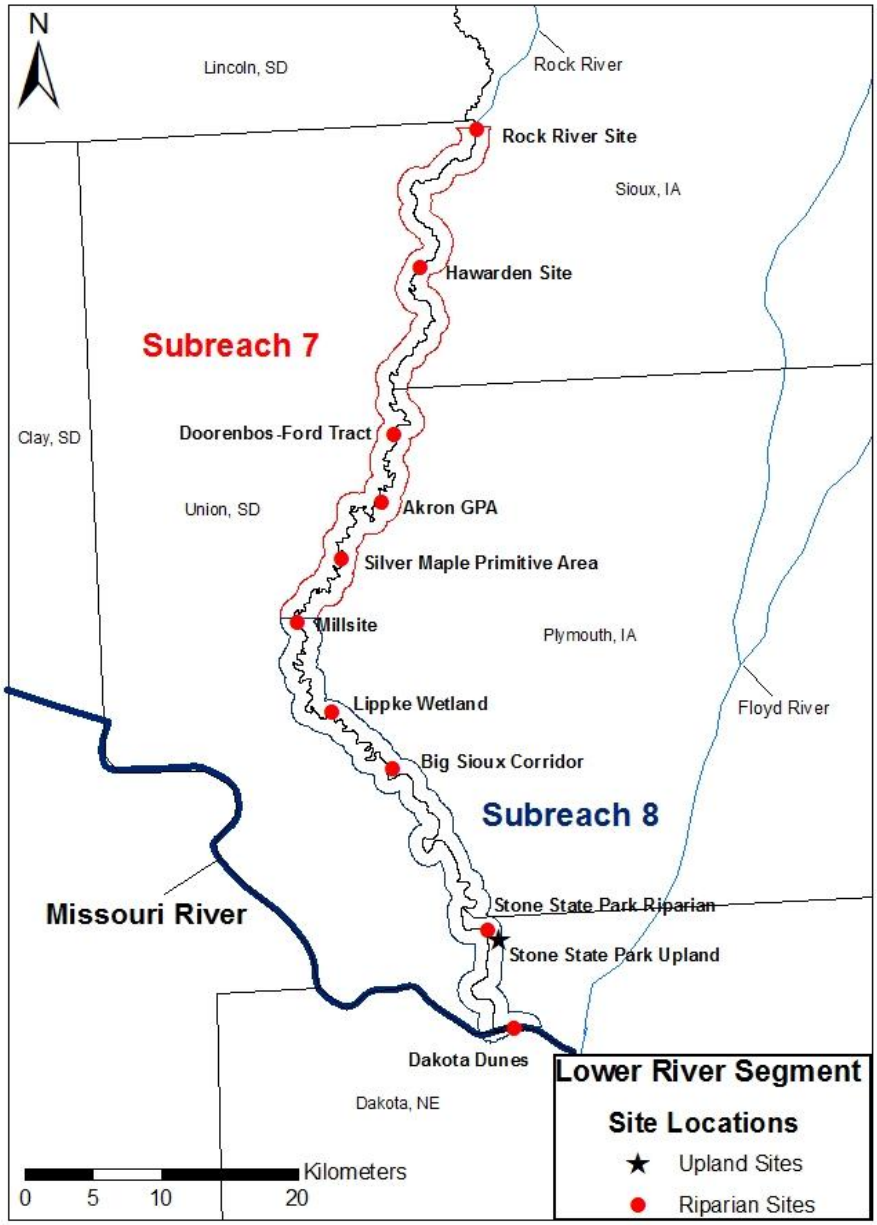


Figure 1.4. The lower river study segment consisted of two subreaches (7 and 8) and stretched 132 river km from the Rock River confluence to the mouth of the Big Sioux River at Sioux City, IA. Ten riparian forest sites and one upland forest site were sampled within this part of the basin.

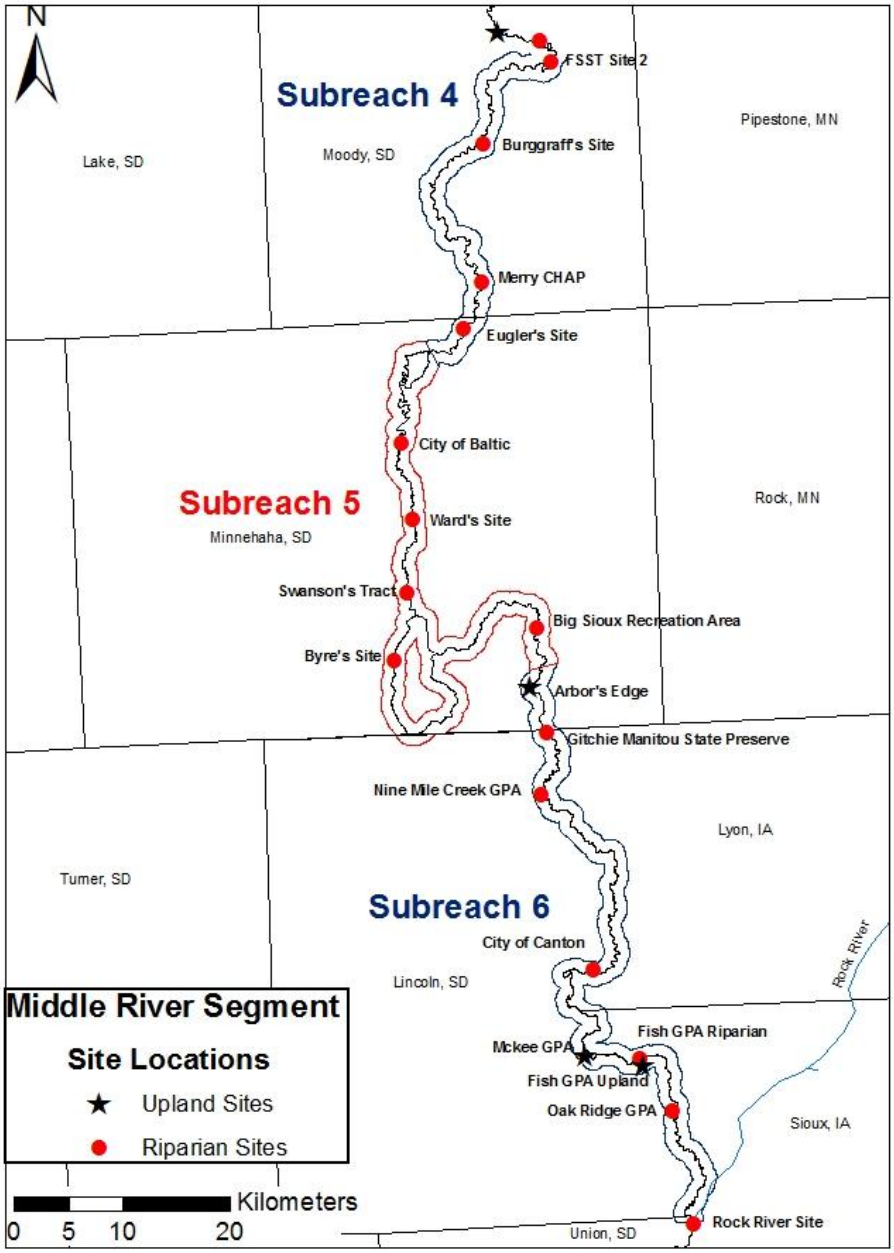


Figure 1.5. The middle river study segment consisted of three subreaches (4, 5, and 6) and stretched 253 river km from Flandreau, SD, to the Rock River confluence. Fourteen riparian forest sites and three upland forest sites were sampled within this part of the basin.

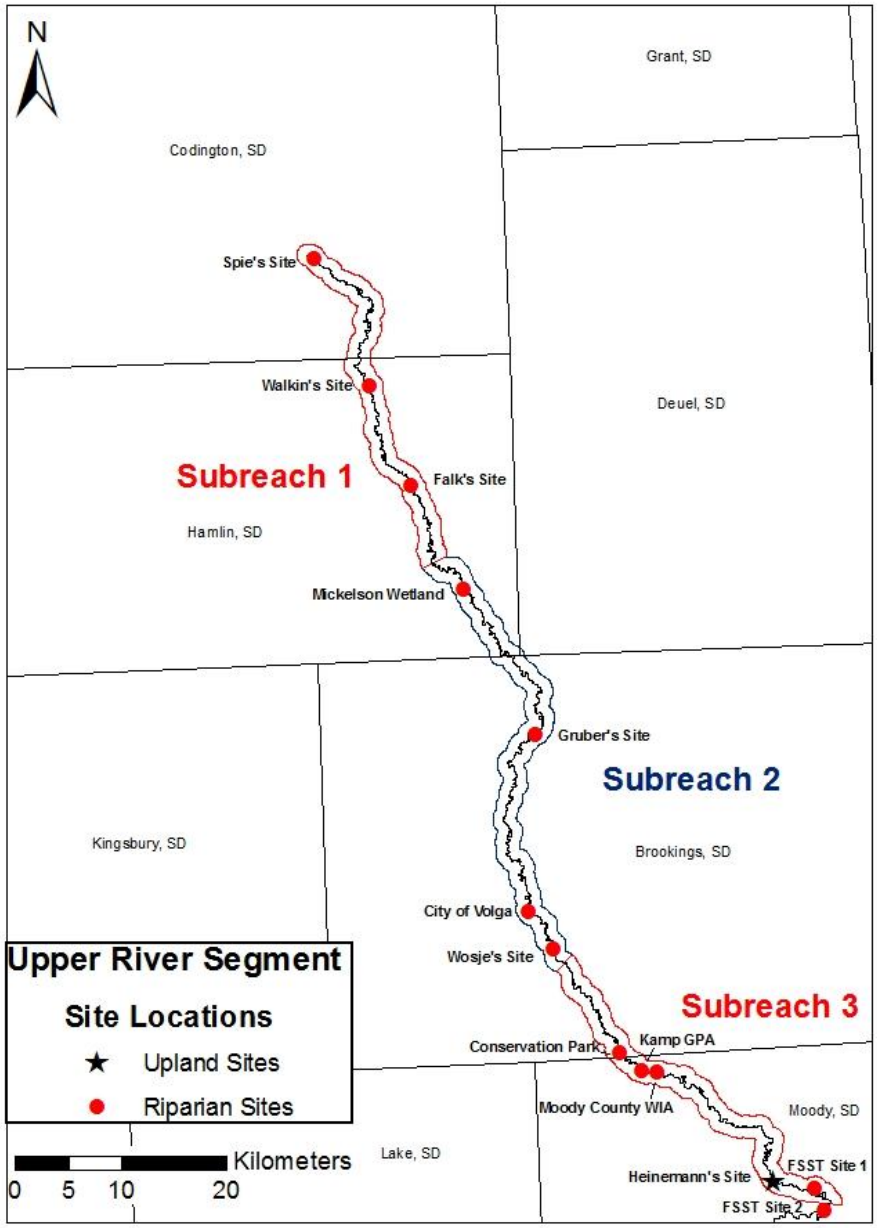


Figure 1.6. The upper river study segment consisted of three subreaches (1, 2, and 3) and stretched 122 river km from Watertown, SD, to Flandreau, SD. Eleven riparian forest sites and one upland forest site were sampled within this part of the basin.

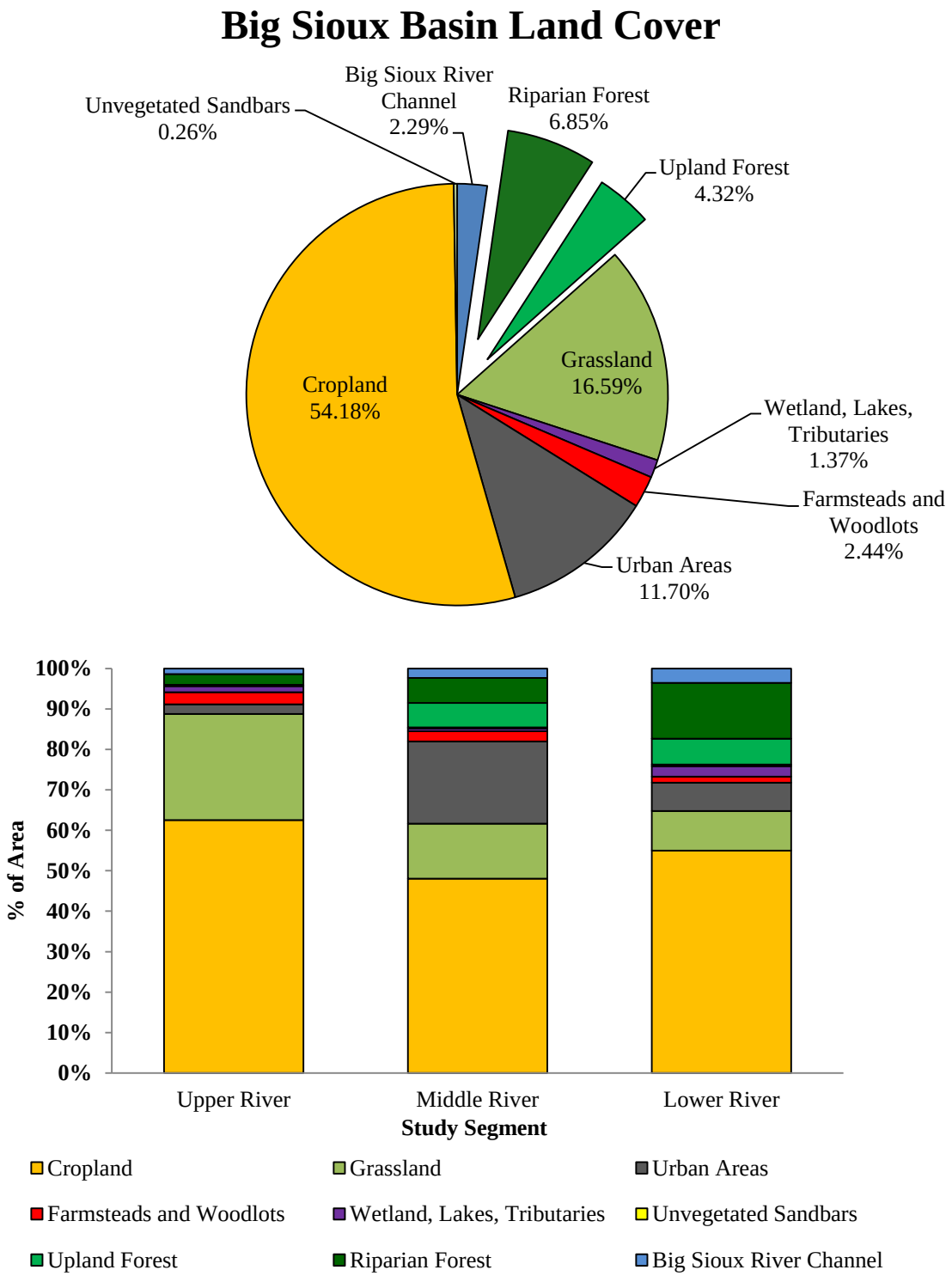


Figure 1.7. Relative area of different land classes for the entire study area. Land cover in the Big Sioux basin is dominated by agriculture cropland with grassland representing the next most important land cover. Riparian forest occupied 6.8% of the total land area. A trend towards increased forest cover was observed from the upper basin to the middle and lower river segments.

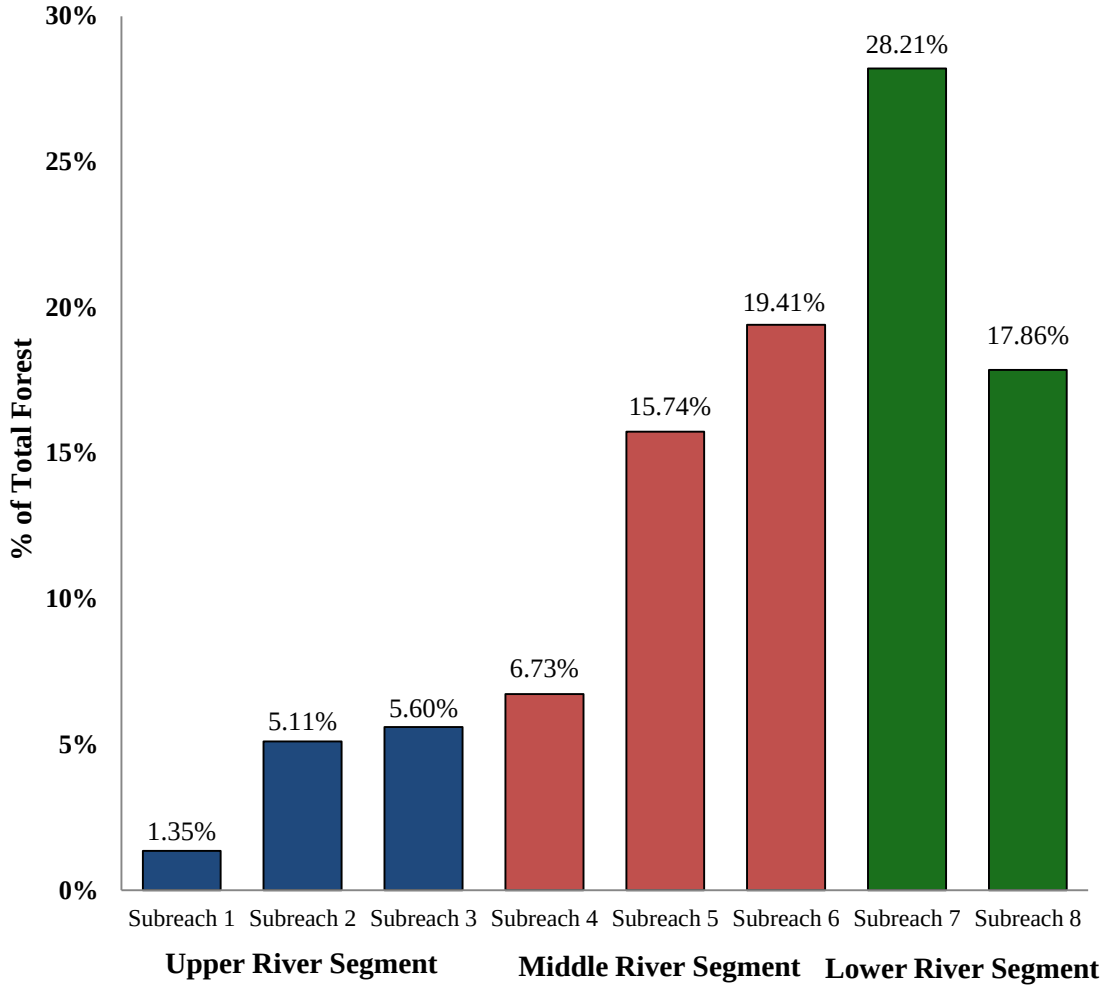


Figure 1.8. Percent of total riparian forest cover by each of eight Big Sioux study subreaches. The upper three subreaches contained the lowest percent of riparian forest with subreach 7, in the lower river segment, containing the largest percent. An overall trend in riparian forest cover increasing from the upper basin to the lower basin was observed.

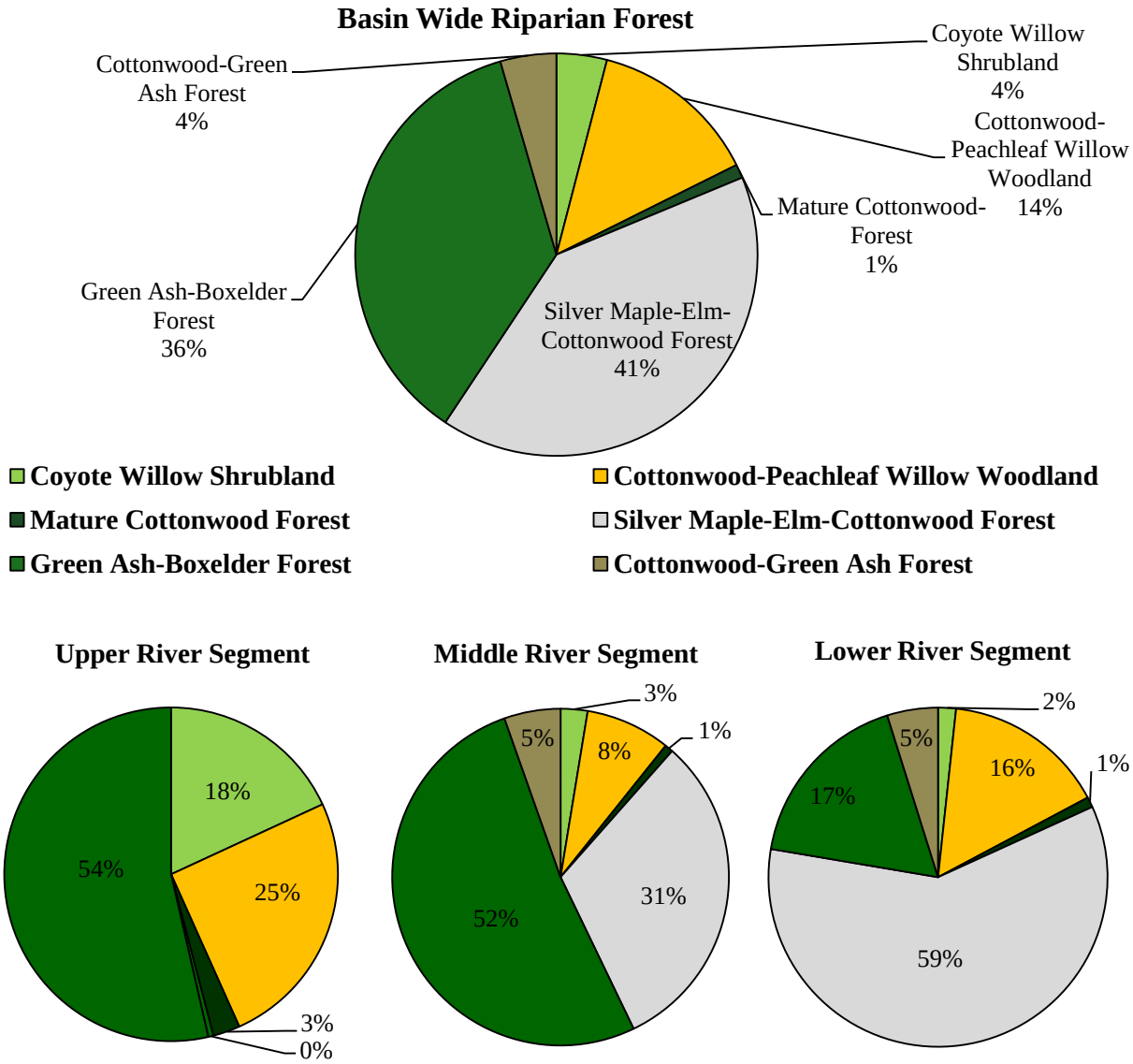


Figure 1.9. Relative areas of different riparian forest types across the study area and by the upper, middle, and lower river study segments.

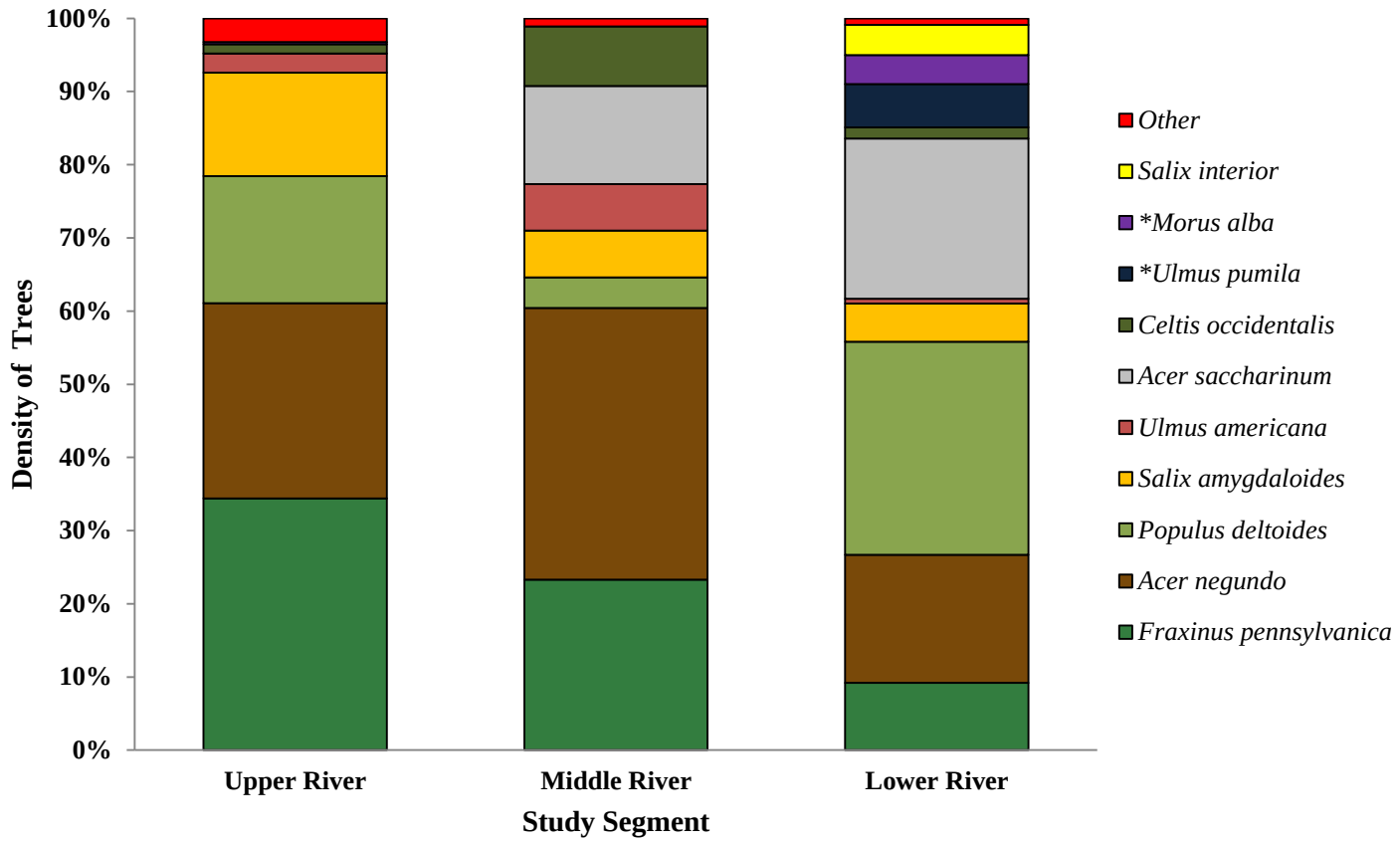


Figure 1.10. Relative density for the ten most common tree (dbh ≥ 10cm) species sampled within the thirty five riparian forest sites within the upper, middle, and lower river study segments of the Big Sioux River. An asterisk (*) indicates a non-native species.

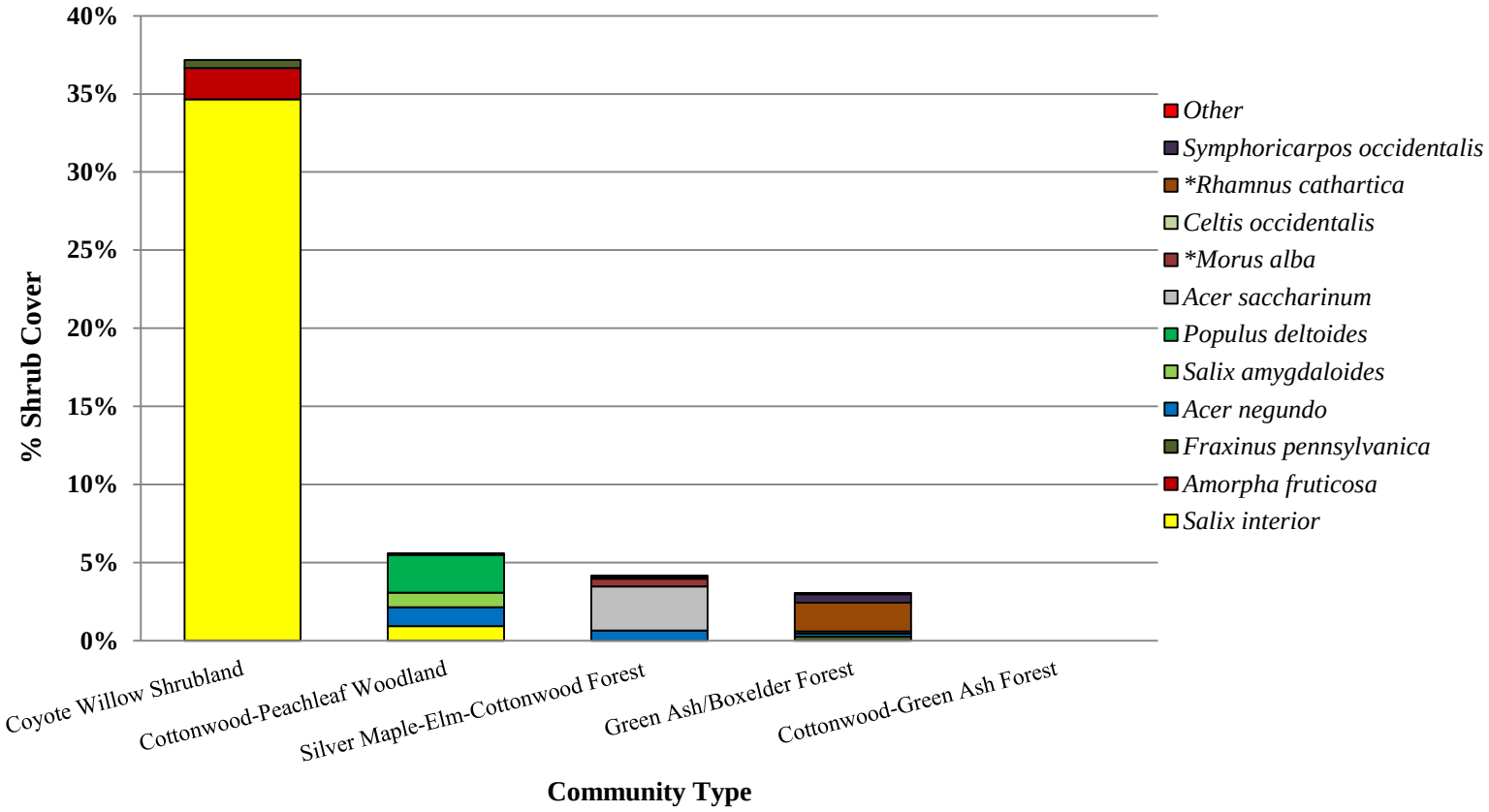


Figure 1.11. Mean percent shrub cover by different species and overall mean shrub cover by community type for forest within the Big Sioux basin. Estimates of total shrub cover may be inflated because of overlapping cover of different species along the transect segments. There were no shrub measurements taken within the Cottonwood-Green Ash Forest community type.

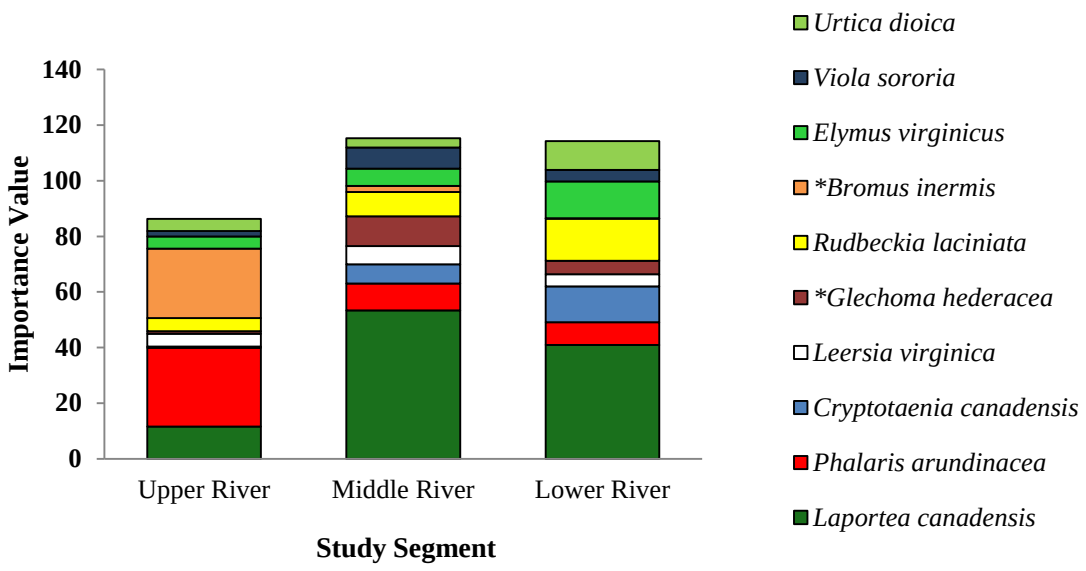


Figure 1.12. Comparison of relative importance values (sum of relative frequency and relative cover; maximum value of 200) for 10 dominant understory species in plots sampled within the Green Ash/Boxelder Forest community type within the upper, middle, and lower river study segments. An * indicates a non-native species.

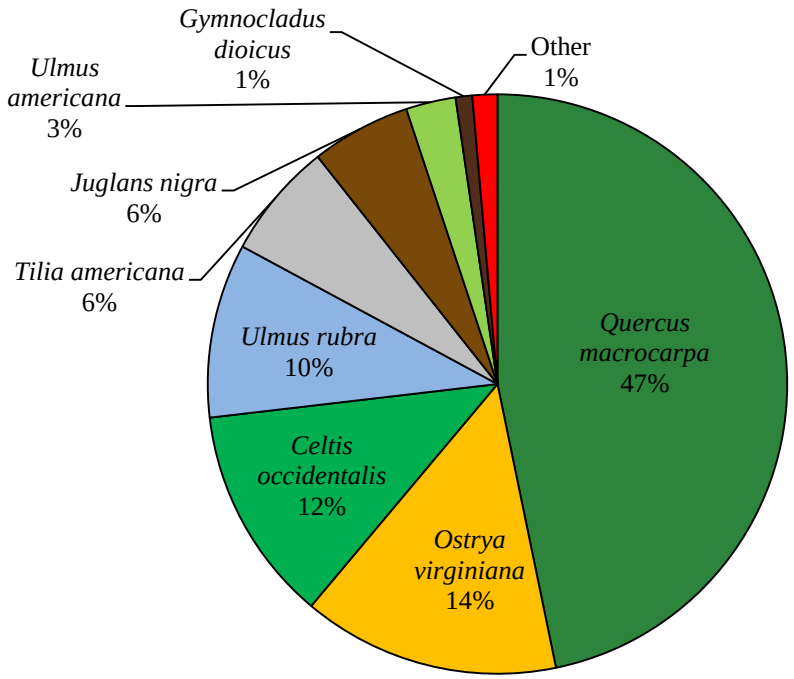


Figure 1.13. Percent totals for the most common tree (dbh > 10cm) species sampled within the five upland forest sites.

Appendix A.1. Total species list for 205 species encountered during vegetation sampling within the Big Sioux basin. 175 species were found within the riparian sites and 108 species were observed within the upland forest with 30 species being unique to these upland areas. An asterisk (*) was used to denote non-native species. *C*-values are provided for all species using a list developed for the vascular flora of North and South Dakota (NGPFQAP 2001). For species that were not found in the Dakota's database, Iowa *C*-values were used and a [T] adjacent to the *C*-value was used to denote these species. Wetland indicator status values are provided for the relevant region (Region 4) and were obtained from the USDA NRCS PLANTS Database (http://plants.usda.gov/, USDA, NRCS 2011).

Species	**Acronym**	**Physiognomy**	**C value**	**WIS R4**
Acalypha rhomboidea Raf.	ACARHO	A-Forb	0	FACU
Acer negundo L.	ACENEG	Tree	1	FAC
Acer saccharinum L.	ACESAC	Tree	4	FACW
Ageratina altissima (L.) King & H. Rob.	AGEALT	P-Forb	6	FAC
**Agrostis stolonifera* L.	AGRSTO	P-Grass	0	FAC
Alisma subcordatum Raf.	ALISUB	P-Forb	2	OBL
**Alliaria petiolata* (M. Bieb.) Cavara & Grande	ALLPET	A-Forb	0	FACU
Amaranthus sp.	-	-	-	-
Ambrosia artemisiifolia L.	AMBART	A-Forb	0	FACU
Ambrosia psilostachya DC.	AMBPSI	P-Forb	2	FAC
Ambrosia trifida L.	AMBTRI	A-Forb	0	FAC
Amorpha fruticosa L.	AMOFRU	Shrub	4	FACW
Andropogon gerardii Vitman	ANDGER	P-Grass	5	FACU
Anemone canadensis L.	ANECAN	P-Forb	4	FACW
Anemone virginiana L.	ANEVIR	P-Forb	8	UPL
Apocynum cannabinum L.	APOCAN	P-Forb	4	FAC
Aquilegia canadensis L.	AQUCAN	P-Forb	8	FAC
**Arctium minus* Bernh.	ARCMIN	B-Forb	0	UPL
Argentina anserina (L.) Rydb.	ARGANS	P-Forb	2	OBL
Arisaema triphyllum (L.) Schott	ARITRI	P-Forb	10	FACW
Asclepias speciosa Torr.	ASCSPE	P-Forb	4	FAC
Asclepias syriaca L.	ASCSYR	P-Forb	0	UPL
Beckmannia syzigachne (Steud.) Fernald	BECSYZ	A-Forb	1	OBL

Bidens cernua L.	BIDCER	A-Forb	3	OBL
Bidens frondosa L.	BIDFRO	A-Forb	1	FACW
Bidens tripartita L.	BIDTRI	A-Forb	2	FACW
Bidens vulgata Greene	BIDVUL	A-Forb	1	UPL
Botrychium virginianum (L.) Sw.	BOTVIR	Fern	7	FACU
Bouteloua curtipendula (Michx.) Torr.	BOUCUR	P-Grass	5	UPL
**Bromus arvensis* L.	BROARV	A-Grass	0	FACU
**Bromus inermis* Leyss.	BROINE	P-Grass	0	UPL
**Bromus tectorum* L.	BROTEC	A-Grass	0	UPL
Calystegia sepium (L.) R. Br.	CALSEP	Vine	0	FAC
Campanulastrum americanum (L.) Small	CAMAME	A-Forb	8	FAC
**Cannabis sativa* L.	CANSAT	A-Forb	0	FAC-
Carex alopecoidea Tuck.	CARALO	P-Sedge	7	OBL
Carex assiniboinensis W. Boott	CARASS	P-Sedge	8	UPL
Carex blanda Dewey	CARBLA	P-Sedge	5	FACU
Carex cristatella Britton	CARCRI	P-Sedge	7	FACW
Carex emoryi Dewey	CAREMO	P-Sedge	4	OBL
Carex gravida L.H. Bailey	CARGRA	P-Sedge	5	UPL
Carex laeviconica Dewey	CARLAE	P-Sedge	6	OBL
Carex molesta Mack. ex Bright	CARMOL	P-Sedge	3	FACW
Carex sartwellii Dewey	CARSAR	P-Sedge	5	FACW
Carex tenera Dewey	CARTEN	P-Sedge	7	FACW
Carex sp.	-	Sedge	-	-
Carex vulpinoidea Michx.	CARVUL	P-Sedge	2	OBL
**Catalpa speciosa* (Warder) Warder ex Engelm.	CATSPE	Tree	0	FACU
Celtis occidentalis L.	CELOCC	Tree	5	FACU
**Chenopodium album* L.	CHEALB	A-Forb	0	FAC
Chenopodium simplex (Torr.) Raf.	CHESIM	A-Forb	5	UPL
Cirsium altissimum (L.) Hill	CIRALT	B-Forb	3	UPL
**Cirsium arvense* (L.) Scop.	CIRARV	B-Forb	0	FACU
**Cirsium vulgare* (Savi) Ten.	CIRVUL	B-Forb	0	UPL

**Convolvulus arvensis* L.	CONARV	Vine	0	UPL
Conyza canadensis (L.) Cronquist var. *canadensis*	CONCAN	A-Forb	0	FACU
Cornus amomum Mill.	CORAMO	Shrub	6^{T}	FACW
Cornus drummondii C.A. Mey.	CORDRU	Tree	5	FAC
Cornus sericea L. ssp. sericea	CORSER	Tree	5	FACW
Crataegus succulenta Schrad. ex Link	CRASUC	Tree	5	UPL
Cryptotaenia canadensis (L.) DC.	CRYCAN	P-Forb	7	FACU
**Cynoglossum officinale* L.	CYNOFF	B-Forb	0	UPL
Cyperus esculentus L.	CYPESC	P-Sedge	0	FACW
Dichanthelium oligosanthes (Schult.) Gould var. *scribnerianum* (Nash) Gould	DICOLI	P-Grass	6	FACU
**Echinochloa crus-galli* (L.) P. Beauv.	ECHCRU	A-Grass	0	FACW
Echinocystis lobata (Michx.) Torr. & A. Gray	ECHLOB	Vine	3	FAC
**Elaeagnus angustifolia* L.	ELAANG	Tree	0	FAC-
Ellisia nyctelea (L.) L.	ELLNYC	A-Forb	0	UPL
Elymus canadensis L.	ELYCAN	P-Grass	3	FACU
Elymus hystrix L.	ELYHYS	P-Grass	8	UPL
**Elymus repens* (L.) Gould	ELYREP	P-Grass	0	FAC
Elymus villosus Muhl. ex Willd.	ELYVIL	P-Grass	4	FACU
Elymus virginicus L.	ELYVIR	P-Grass	4	FAC
Equisetum hyemale L.	EQUHYE	P-Forb	3	FACW
Erigeron philadelphicus L.	ERIPHI	B-Forb	2	FACW
**Euphorbia esula* L.	EUPESU	P-Forb	0	UPL
Festuca subverticillata (Pers.) Alexeev	FESSUB	P-Grass	10	FACU
Fragaria virginiana Duchesne	FRAVIR	P-Forb	4	FACU
Fraxinus pennsylvanica Marsh.	FRAPEN	Tree	5	FAC
Galium aparine L.	GALAPA	A-Forb	0	FACU
Galium boreale L.	GALBOR	P-Forb	4	FACU
Galium triflorum Michx.	GALTRI	P-Forb	7	FACU
Geum canadense Jacq.	GEUCAN	P-Forb	4	FACU
**Glechoma hederacea* L.	GLEHED	P-Forb	0	FACU
Gleditsia triacanthos L.	GLETRI	Tree	6	FACU

Gymnocladus dioicus (L.) K. Koch	GYMDIO	Tree	8	UPL
Hackelia deflexa (Wahlenb.) Opiz	HACDEF	B-Forb	0	UPL
Hackelia virginiana (L.) I.M. Johnst.	HACVIR	B-Forb	0	FACU
Helianthus annuus L.	HELANN	A-Forb	0	FACU
Helianthus tuberosus L.	HELTUB	P-Forb	2	FACU
Heracleum maximum Bartram	HERMAX	P-Forb	3	FAC
**Hesperis matronalis* L.	HESMAT	B-Forb	0	UPL
Hydrophyllum virginianum L.	HYDVIR	P-Forb	8	FAC
Impatiens capensis Meerb.	IMPCAP	A-Forb	4	FACW
Juglans nigra L.	JUGNIG	Tree	8	FACU
Juniperus virginiana L.	JUNVIR	Tree	0	FACU
Lactuca sp.	-	-	-	-
Laportea canadensis (L.) Weddell	LAPCAN	P-Forb	5	FAC
Leersia virginica Willd.	LEEVIR	P-Grass	5	FACW
**Leonurus cardiaca* L.	LEOCAR	P-Forb	0	FACU
Lobelia siphilitica L.	LOBSIP	P-Forb	7	OBL
**Lonicera tatarica* L.	LONTAT	Shrub	0	UPL
Lycopus uniflorus Michx.	LYCUNI	P-Forb	8	OBL
Lysimachia ciliata L.	LYSCIL	P-Forb	6	FACW
Maianthemum racemosum (L.) Link ssp. *racemosum*	MAIRAC	P-Forb	9	FAC
Maianthemum stellatum (L.) Link	MAISTE	P-Forb	5	FAC
**Melilotus officinalis* (L.) Lam.	MELOFF	B-Forb	0	FACU
Mentha arvensis L.	MENARV	P-Forb	3	FACW
Menispermum canadense L.	MENCAN	Vine	8	UPL
Mimulus ringens L.	MIMRIN	P-Forb	6	OBL
Monarda fistulosa L.	MONFIS	P-Forb	5	UPL
**Morus alba* L.	MORALB	Tree	0	FACU
Muhlenbergia frondosa (Poir.) Fernald	MUHFRO	P-Grass	4	FACW
Muhlenbergia racemosa (Michx.) Britton, Sterns & Poggenb.	MUHRAC	P-Grass	4	FACW
**Nepeta cataria* L.	NEPCAT	P-Forb	0	FACU
Osmorhiza claytonii (Michx.) C.B. Clarke	OSMCLA	P-Forb	10	FACU

Ostrya virginiana (Mill.) K. Koch	OSTVIR	Tree	9	FACU
Oxalis stricta L.	OXASTR	P-Forb	0	FACU
Oxalis sp.	-	-	-	-
Panicum capillare L.	PANCAP	A-Grass	0	FAC
Parietaria pensylvanica Muhl. ex Willd.	PARPEN	A-Forb	3	FACU
Parthenocissus quinquefolia (L.) Planch.	PARQUI	Vine	2	FAC
Parthenocissus vitacea (Knerr) Hitchc.	PARVIT	Vine	2	FACU
Phalaris arundinacea L.	PHAARU	P-Grass	0	FACW
**Phleum pratense* L.	PHLPRA	P-Grass	0	FACU
Phryma leptostachya L.	PHRLEP	P-Forb	8	FAC
Physalis longifolia Nutt.	PHYLON	P-Forb	0	UPL
Physostegia virginiana (L.) Benth.	PHYVIR	P-Forb	3	OBL
Pilea pumila (L.) A. Gray	PILPUM	A-Forb	4	FACW
**Plantago major* L.	PLAMAJ	P-Forb	0	FAC
Plantago rugelii Decne.	PLARUG	P-Forb	0	FACU
**Poa annua* L.	POAANN	A-Grass	0	FACU
Poa palustris L.	POAPAL	P-Grass	4	FACW
**Poa pratensis* L.	POAPRA	P-Grass	0	FACU
Polygonum amphibium L. var. *emersum* Michx.	POLAMP	P-Forb	0	OBL
**Polygonum convolvulus* L.	POLCON	Vine	0	FAC
Polygonum lapathifolium L.	POLLAP	A-Forb	1	OBL
**Polygonum persicaria* L.	POLPER	A-Forb	0	FACW
Populus deltoides Bartram ex Marsh.	POPDEL	Tree	3	FAC
Potentilla norvegica L.	POTNOR	A-Forb	0	FAC
Prunella vulgaris L.	PRUVUL	P-Forb	6	FACW
Prunus americana Marsh.	PRUAME	Shrub	4	UPL
Prunus virginiana L.	PRUVIR	Shrub	4	FACU
Quercus macrocarpa Michx.	QUEMAC	Tree	6	FACU
Ranunculus abortivus L.	RANABO	B-Forb	2	FACW
Ranunculus sceleratus L.	RANSCE	P-Forb	3	OBL
**Rhamnus cathartica* L.	RHACAT	Tree	0	FACU

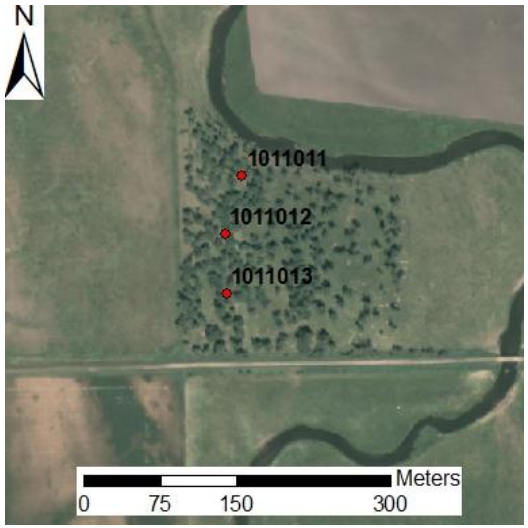
Rhus glabra L.	RHUGLA	Shrub	4	UPL
Ribes americanum Mill.	RIBAME	Shrub	7	FACW
Ribes missouriense Nutt.	RIBMIS	Shrub	4	FAC
Rorippa palustris L.	RORPAL	A-Forb	2	OBL
Rosa acicularis Lindl.	ROSACI	Shrub	8	FACU
Rosa arkansana Porter	ROSARK	Shrub	3	UPL
Rosa woodsii Lindl.	ROSWOO	Shrub	5	FACU
Rubus occidentalis L.	RUBOCC	Shrub	5	FACU
Rudbeckia laciniata L.	RUDLAC	P-Forb	6	FACU
**Rumex crispus* L.	RUMCRI	P-Forb	0	FACW
**Rumex patientia* L.	RUMPAT	P-Forb	0	UPL
Salix amygdaloides Andersson	SALAMY	Tree	3	FACW
Salix interior Rowlee	SALINT	Shrub	3	FACW
Sambucus nigra L. ssp. *canadensis* (L.) R. Bolli	SAMCAN	Shrub	4	FAC
Sanguinaria canadensis L.	SANCAN	P-Forb	10	UPL
Sanicula marilandica L.	SANMAR	P-Forb	7	FACU
Schizachyrium scoparium (Michx.) Nash	SCHSCO	P-Grass	6	FACU
Schoenoplectus pungens Vahl	SCHPUN	P-Sedge	4	OBL
Schoenoplectus tabernaemontani (C.C. Gmel.) Palla	SCHTAB	P-Sedge	3	OBL
**Setaria pumila* (Poir.) Roem. & Schult.	SETPUM	A-Grass	0	FACU
Sicyos angulatus L.	SICANG	Vine	2	FAC
Silene stellata (L.) W.T. Aiton	SILSTE	P-Forb	7	UPL
Sinapis sp.	-	-	-	-
**Sisymbrium loeselii* L.	SISLOE	A-Forb	0	UPL
Smilax ecirrhata (Engelm. ex Kunth) S. Watson	SMIECI	P-Forb	8	UPL
Smilax herbacea L.	SMIHER	Vine	8	FAC
Smilax tamnoides L.	SMITAM	Vine	8	FAC
**Solanum dulcamara* L.	SOLDUL	Vine	0	FACU
Solanum ptycanthum Dunal	SOLPTY	A-Forb	0	FACU
Solidago canadensis L.	SOLCAN	P-Forb	1	FACU
Solidago flexicaulis L.	SOLFLE	P-Forb	10	FACU

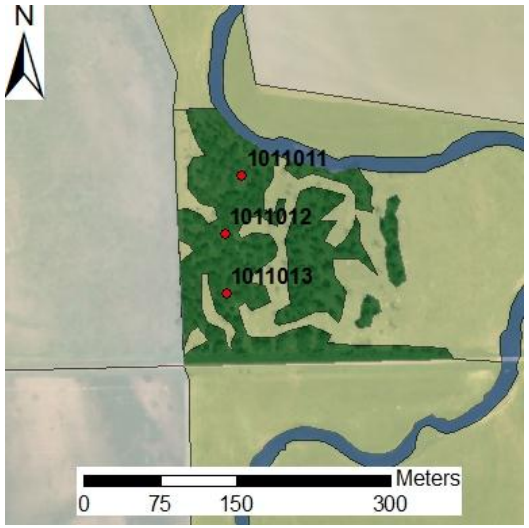
Solidago gigantea Aiton	SOLGIG	P-Forb	4	FACW
**Sonchus arvensis* L.	SONARV	P-Forb	0	FAC
Sorghastrum nutans (L.) Nash	SORNUT	P-Grass	6	FACU
Spartina pectinata Bosc ex Link	SPAPEC	P-Grass	5	FACW
**Stellaria media* (L.) Vill.	STEMED	A-Forb	0	UPL
Symphoricarpos occidentalis Hook.	SYMOCC	Shrub	3	UPL
Symphyotrichum lanceolatum (Willd.) G.L. Nesom ssp. *hesperium* (A. Gray) G.L. Nesom var. *hesperium*	SYMLAN	P-Forb	4	OBL
Symphyotrichum ontarionis (Wiegand) G.L. Nesom	SYMONT	P-Forb	10	FAC
**Taraxacum officinale* F.H. Wigg.	TAROFF	P-Forb	0	FACU
Teucrium canadense L.	TEUCAN	P-Forb	3	FACW
Thalictrum dasycarpum Fisch. & Avé-Lall.	THADAS	P-Forb	7	FAC
Thalictrum venulosum Trel.	THAVEN	P-Forb	6	UPL
**Thinopyrum intermedium* (Host) Barkworth & D.R. Dewey	THIINT	P-Grass	0	UPL
Tilia americana L.	TILAME	Tree	7	FACU
Toxicodendron radicans (L.) Kuntze	TOXRAD	Shrub	0^{T}	FACU
Toxicodendron rydbergii (Small ex Rydb.) Greene	TOXRYD	P-Forb	3	FACU
**Trifolium pratense* L.	TRIPRA	P-Forb	0	FACU
**Trifolium repens* L.	TRIREP	P-Forb	0	FACU
Ulmus americana L.	ULMAME	Tree	3	FAC
**Ulmus pumila* L.	ULMPUM	Tree	0	UPL
Ulmus rubra Muhl.	ULMRUB	Tree	5	FAC
Urtica dioica L.	URTDIO	P-Forb	0	FACW
**Verbascum thapsus* L.	VERTHA	B-Forb	0	UPL
Verbena hastata L.	VERHAS	P-Forb	5	FACW
Verbena stricta Vent.	VERSTR	P-Forb	2	UPL
Verbena urticifolia L.	VERURT	P-Forb	3	FACU
Vernonia fasciculata Michx.	VERFAS	P-Forb	3	FACW
Viola canadensis L.	VIOCAN	P-Forb	4	UPL
Viola sororia Willd.	VIOSOR	P-Forb	2	FAC
Viola sp.				

Vitis riparia Michx.	VITRIP	Vine	3	FAC
Xanthium strumarium L.	XANSTR	A-Forb	0	FAC
Zanthoxylum americanum Mill.	ZANAME	Tree	3	UPL

Appendix A.2. Site level summary data for 35 riparian forest sites along the Big Sioux River. A legend explaining the GIS land cover classes is provided at the end of Appendix A.2.

Site Name	Date Sampled	Segment	Subreach	UTMx	UTMy	Plot #	Location Description
Walkin's Site	8/10/2010	Upper	1	653789	4960008	3	North of Castlewood, SD
$w\bar{C}_i$	$w\bar{C}$	$\bar{C}_i$	$\bar{C}$	*FQIi*	*FQI*	**Plot ID**	**Community Type**
0.035	3.00	1.60	4.00	3.57	5.66	1011011	Green Ash/Boxelder Forest
Species #	**% Exotics**	**Basal Area**	**Trees/ha**	**Shrubs/ha**	**Shrub Cover (%)**	1011012	Green Ash/Boxelder Forest
5	60.0	21.77	150	3500	0.00	1011013	Green Ash/Boxelder Forest

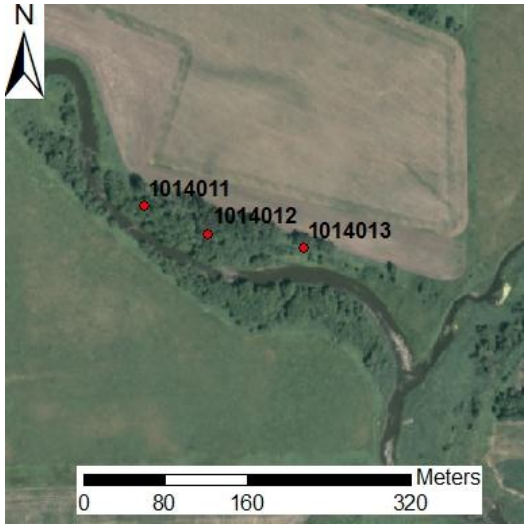


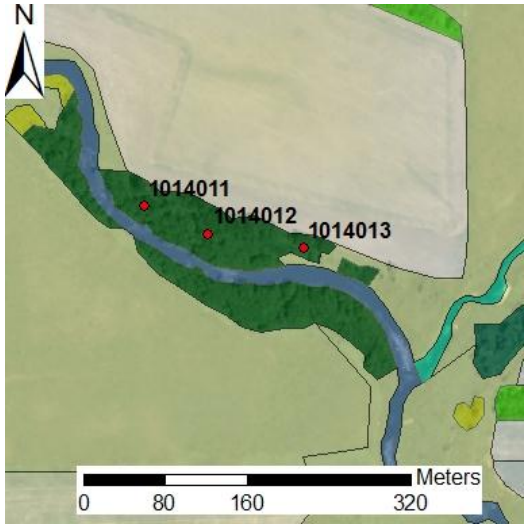


Species List

**Bromus inermis*
Symphoricarpos occidentalis
**Leonurus cardiaca*
**Taraxacum officinale*
Fraxinus pennsylvanica

Site Name	Date Sampled	Segment	Subreach	UTMx	UTMy	Plot #	Location Description
Falk's Site	8/11/2010	Upper	1	657643	4950539	3	Southwest of Castlewood, SD
$w\bar{C}_i$	$w\bar{C}$	$\bar{C}_i$	$\bar{C}$	*FQIi*	*FQI*	**Plot ID**	**Community Type**
0.74	1.31	2.47	3.00	10.19	11.23	1014011	Green Ash/Boxelder Forest
Species #	**% Exotics**	**Basal Area**	**Trees/ha**	**Shrubs/ha**	**Shrub Cover (%)**	1014012	Green Ash/Boxelder Forest
17	17.6	44.13	433	27,916	13.85	1014013	Green Ash/Boxelder Forest

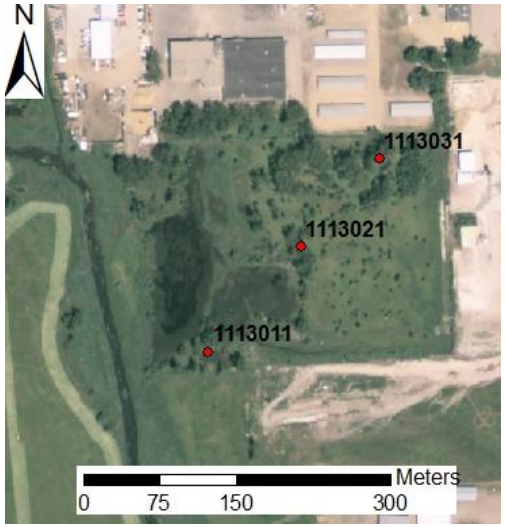


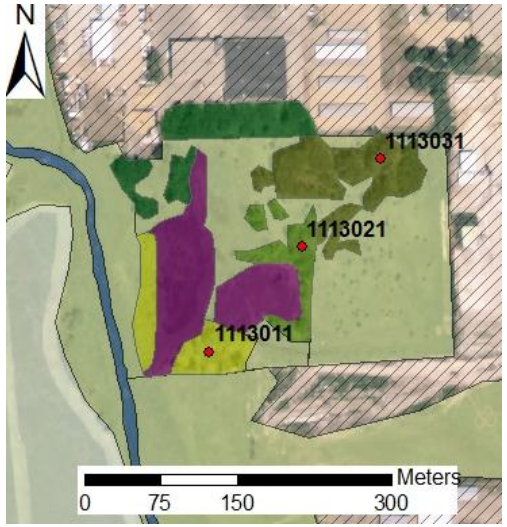


Species List

Acer negundo
Ambrosia trifida
Anemone canadensis
Apocynum cannabinum
**Arctium minus*
Asclepias speciosa
**Bromus inermis*
Chenopodium simplex
Echinocystis lobata
Fragaria virginiana
Phalaris arundinacea
Prunus americana
Ribes missouriense
Rosa woodsii
**Sonchus arvensis*
Symphyotrichum lanceolatum
Urtica dioica
Viola sp.

Site Name	Date Sampled	Segment	Subreach	UTMx	UTMy	Plot #	Location Description
Spie's Site	7/18/2011	Upper	1	648901	4972072	3	South of Watertown, SD
$w\bar{C}_i$	$w\bar{C}$	$\bar{C}_i$	$\bar{C}$	*FQIi*	*FQI*	**Plot ID**	**Community Type**
0.77	3.21	1.91	3.05	10.78	13.64	1113011	Coyote Willow Shrubland
Species #	**% Exotics**	**Basal Area**	**Trees/ha**	**Shrubs/ha**	**Shrub Cover (%)**	1113021	Cottonwood-Peachleaf Woodland
32	37.5	31.66	450	2833	8.50	1113031	Cottonwood-Green Ash Forest

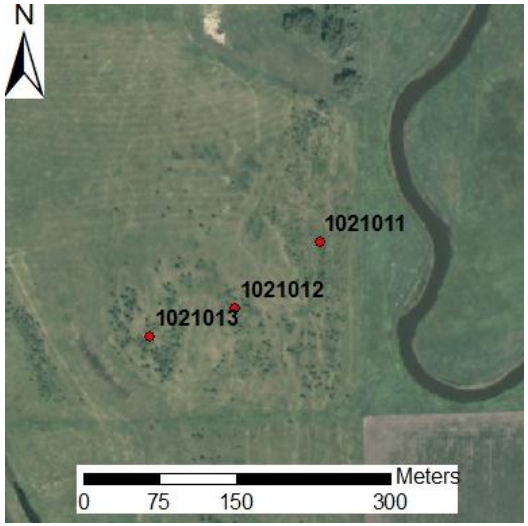


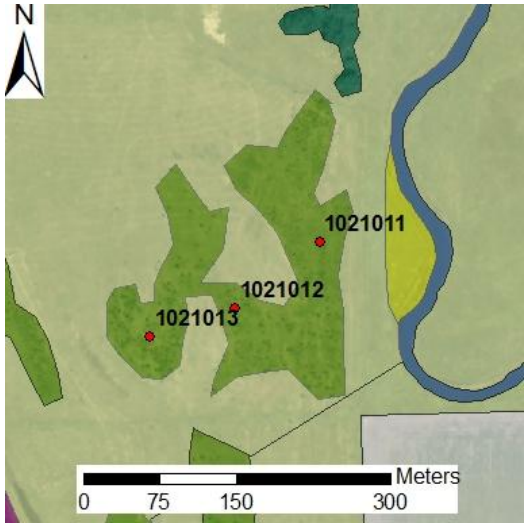


Species List

Acer negundo
**Agrostis stolonifera*
Anemone canadensis
Argentina anserina
**Bromus arvensis*
**Bromus inermis*
**Bromus tectorum*
Carex sartwellii
Carex vulpinoidea
Celtis occidentalis
**Cirsium arvensis*
**Elaeagnus angustifolia*
**Elymus repens*
Equisetum hyemale
Erigeron philadelphicus
**Euphorbia esula*
Fraxinus pennsylvanica
Helianthus annuus
**Melilotus officinalis*
Parthenocissus vitacea
Phalaris arundinacea
**Poa pratensis*
Populus deltoides
Potentilla norvegica
**Rhamnus cathartica*
Rhus glabra
Rosa acicularis
Rosa arkansana
Salix amygdaloides
Salix interior
**Taraxacum officinale*
Thalictrum venulosum

Site Name	Date Sampled	Segment	Subreach	UTMx	UTMy	Plot #	Location Description
Mickelson Wetland	8/10/2010	Upper	2	662593	4940123	3	West of Estelline, SD
$w\bar{C}_i$	$w\bar{C}$	$\bar{C}_i$	$\bar{C}$	*FQIi*	*FQI*	**Plot ID**	**Community Type**
0.46	0.59	1.92	2.56	6.64	7.67	1021011	Cottonwood-Peachleaf Woodland
Species #	**% Exotics**	**Basal Area**	**Trees/ha**	**Shrubs/ha**	**Shrub Cover (%)**	1021012	Cottonwood-Peachleaf Woodland
12	25.0	0.97	66.67	3250	0.00	1021013	Cottonwood-Peachleaf Woodland

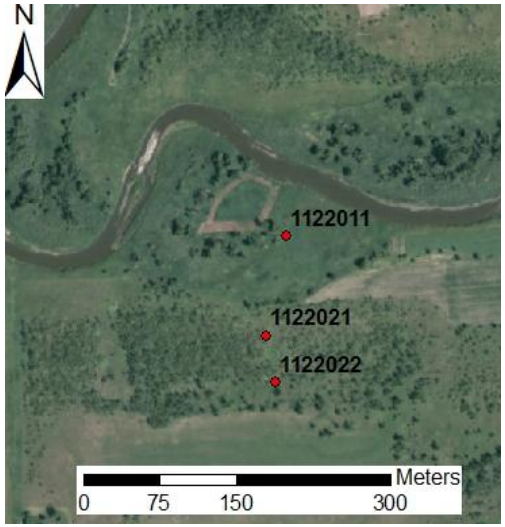


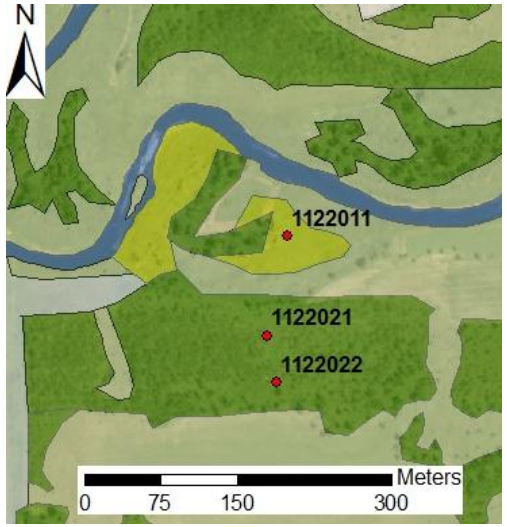


Species List

Ambrosia trifida
Anemone canadensis
Apocynum cannabinum
**Bromus inermis*
Carex laeviconica
**Cirsium vulgare*
Hackelia virginiana
Phalaris arundinacea
Populus deltoides
Salix amygdaloides
Salix interior
**Sonchus arvensis*
Viola sp.

Site Name	Date Sampled	Segment	Subreach	UTMx	UTMy	Plot #	Location Description
Gruber's Site	7/19/2011	Upper	2	669022	4926700	3	Northwest of Bruce, SD
$w\bar{C}_i$	$w\bar{C}$	$\bar{C}_i$	$\bar{C}$	*FQIi*	*FQI*	**Plot ID**	**Community Type**
1.58	3.59	2.62	3.45	14.11	16.20	1122011	Coyote Willow Shrubland
Species #	**% Exotics**	**Basal Area**	**Trees/ha**	**Shrubs/ha**	**Shrub Cover (%)**	1122021	Cottonwood-Peachleaf Woodland
29	24.1	3.87	375	500	2.40	1122022	Cottonwood-Peachleaf Woodland

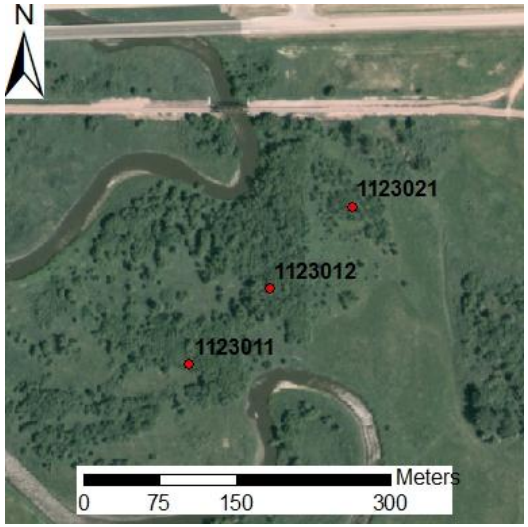


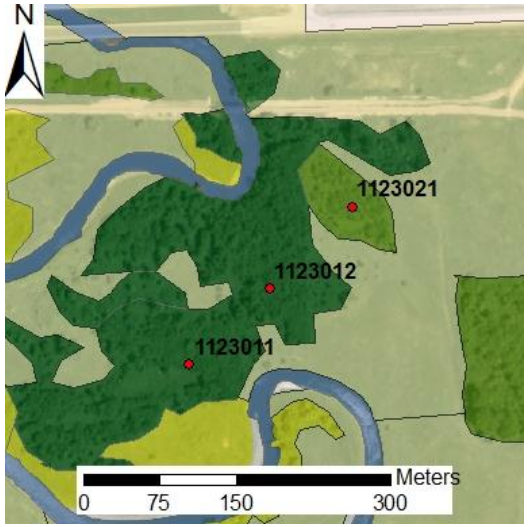


Species List

Acer negundo
Amaranthus sp.
Amorpha fruticosa
Anemone canadensis
Apocynum cannabinum
**Bromus inermis*
Carex gravida
Carex laeviconica
Carex molesta
**Cirsium arvensis*
Cornus sericea
**Elymus repens*
Equisetum hyemale
Lycopus uniflorus
**Melilotus officinalis*
Oxalis sp.
**Poa pratensis*
Polygonum amphibium var. *emersum*
Populus deltoides
Ranunculus sceleratus
Rosa arkansana
Rumex crispus
Salix amygdaloides
Salix interior
Solidago canadensis
Solidago gigantea
Symphoricarpos occidentalis
Symphyotrichum lanceolatum
**Taraxacum officinale*
Thalictrum venulosum
Urtica dioica

Site Name	Date Sampled	Segment	Subreach	UTMx	UTMy	Plot #	Location Description
City of Volga	7/19/2011	Upper	2	668290	4909926	3	East of Volga, SD
$w\bar{C}_i$	$w\bar{C}$	$\bar{C}_i$	$\bar{C}$	*FQIi*	*FQI*	**Plot ID**	**Community Type**
0.65	0.70	1.71	2.12	7.86	8.73	1123011	Green Ash/Boxelder Forest
Species #	**% Exotics**	**Basal Area**	**Trees/ha**	**Shrubs/ha**	**Shrub Cover (%)**	1123012	Green Ash/Boxelder Forest
21	19.1	25.09	800	166.67	0.00	1123021	Cottonwood-Peachleaf Woodland

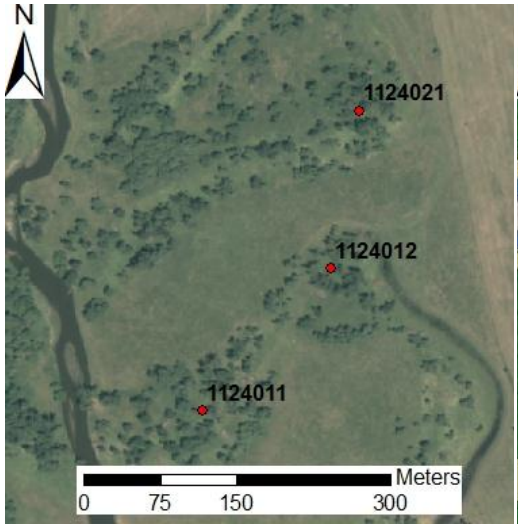


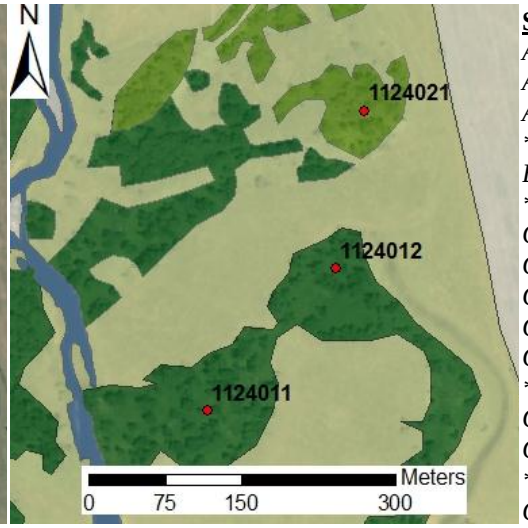


Species List

Acer negundo
Amaranthus sp.
Ambrosia artemisiifolia
Carex laeviconica
Hackelia virginiana
Oxalis sp.
Parthenocissus vitacea
Phalaris arundinacea
**Phleum pratense*
Pilea pumila
**Poa annua*
Polygonum amphibium var. *emersum*
Populus deltoides
Ranunculus sceleratus
**Rhamnus cathartica*
Ribes missouriense
Rorippa palustris
Salix amygdaloides
**Taraxacum officinale*
Ulmus americana
Urtica dioica
Viola sororia
Vitis riparia

Site Name	Date Sampled	Segment	Subreach	UTMx	UTMy	Plot #	Location Description
Wosje's Site	8/9/2011	Upper	2	670631	4906022	3	West of Brookings, SD
$w\bar{C}_i$	$w\bar{C}$	$\bar{C}_i$	$\bar{C}$	*FQIi*	*FQI*	**Plot ID**	**Community Type**
1.80	2.91	2.38	3.41	17.77	21.30	1124011	Green Ash/Boxelder Forest
Species #	**% Exotics**	**Basal Area**	**Trees/ha**	**Shrubs/ha**	**Shrub Cover (%)**	1124012	Green Ash/Boxelder Forest
56	30.4	62.32	666.67	17,500	10.23	1124021	Cottonwood-Peachleaf Woodland

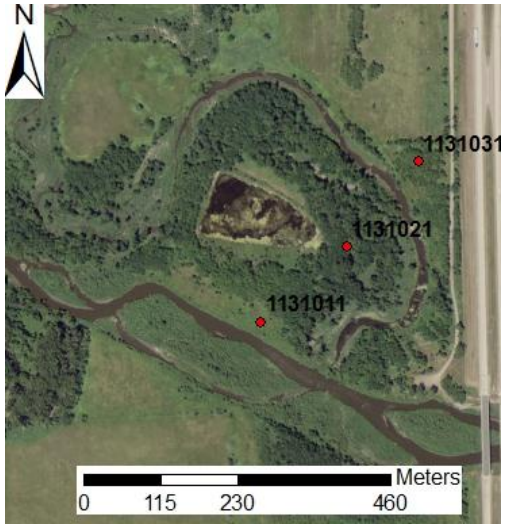


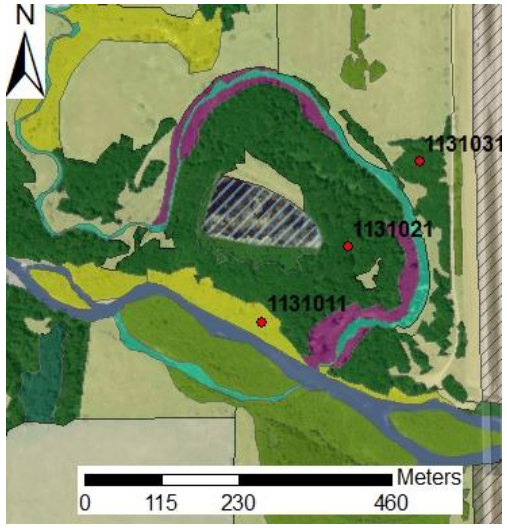


Species List

Acer negundo
Agrostis stolonifera
Alisma subcordatum
**Arctium minus*
Bidens cernua
**Bromus inermis*
Carex blanda
Carex gravida
Carex laeviconica
Carex sp.
Chenopodium simplex
**Cirsium vulgare*
Crataegus succulenta
Cryptotaenia canadensis
**Cynoglossum officinale*
Cyperus esculentus
**Elymus repens*
Elymus virginicus
Erigeron philadelphicus
Fraxinus pennsylvanica
Geum canadense
**Glechoma hederacea*
Hackelia virginiana
**Leonurus cardiaca*
Mimulus ringens
**Nepeta cataria*
Oxalis stricta
Panicum capillare
Phalaris arundinacea
**Phleum pratense*
Pilea pumila
**Poa annua*
**Poa pratensis*
Polygonum lapathifolium
Potentilla norvegica
Ranunculus abortivus
**Rhamnus cathartica*
Ribes americanum
Ribes missouriense
Rorippa palustris
**Rumex crispus*
Salix amygdaloides
Salix interior
Schoenoplectus pungens
Schoenoplectus tabernaemontani
Smilax herbacea
Spartina pectinata
Symphoricarpos occidentalis
Symphyotrichum ontarionis
**Taraxacum officinale*
Toxicodendron rydbergii
**Trifolium pratense*
**Trifolium repens*
Urtica dioica
Verbena hastata
Verbena urticifolia
Vernonia fasciculata
Viola sp.

Site Name	Date Sampled	Segment	Subreach	UTMx	UTMy	Plot #	Location Description
Kamp GPA	8/9/2011	Upper	3	678731	4894608	3	South of Brookings, SD
$w\bar{C}_i$	$w\bar{C}$	$\bar{C}_i$	$\bar{C}$	*FQIi*	*FQI*	**Plot ID**	**Community Type**
2.56	4.30	3.05	3.63	18.82	20.51	1131011	Coyote Willow Shrubland
Species #	**% Exotics**	**Basal Area**	**Trees/ha**	**Shrubs/ha**	**Shrub Cover (%)**	1131021	Green Ash/Boxelder Forest
38	15.8	25.44	366.67	8,500	5.41	1131031	Green Ash/Boxelder Forest

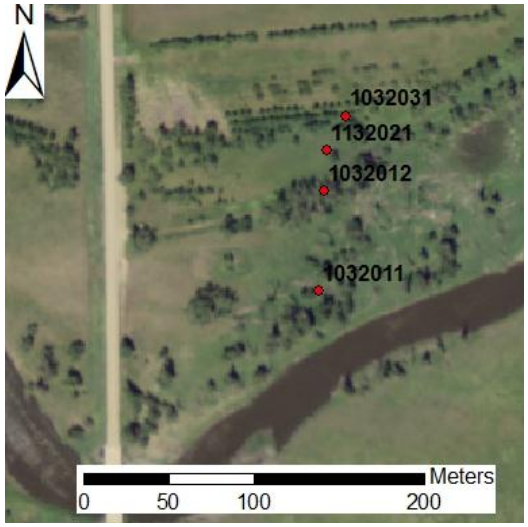


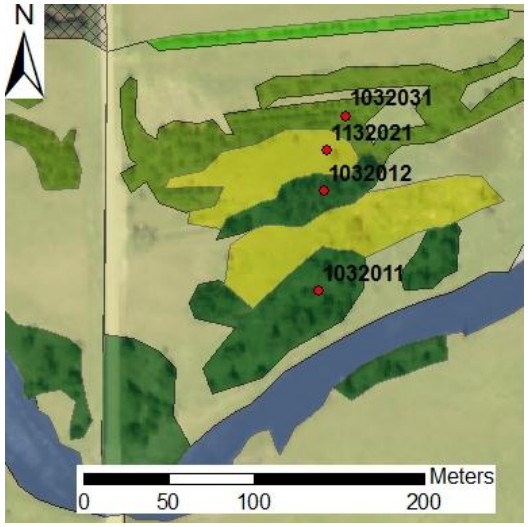


Species List

Acer negundo
**Agrostis stolonifera*
Amorpha fruticosa
Anemone canadensis
Apocynum cannabinum
Asclepias speciosa
Bidens cernua
**Bromus inermis*
Carex laeviconica
Carex sp.
Celtis occidentalis
Chenopodium simplex
**Cirsium vulgare*
Elymus virginicus
Fraxinus pennsylvanica
**Glechoma hederacea*
Juniperus virginiana
Laportea canadensis
Mimulus ringens
Parietaria pensylvanica
Parthenocissus vitacea
Phalaris arundinacea
Physostegia virginiana
**Poa pratensis*
Populus deltoides
Ranunculus abortivus
**Rhamnus cathartica*
Ribes americanum
Rosa arkansana
Rudbeckia laciniata
Salix interior
Schoenoplectus tabernaemontani
Smilax herbacea
Solidago canadensis
Symphoricarpos occidentalis
Symphyotrichum lanceolatum
Toxicodendron rydbergii
Vernonia fasciculata
Viola sp.
Vitis riparia

Site Name	Date Sampled	Segment	Subreach	UTMx	UTMy	Plot #	Location Description
Moody Co. WIA	8/30/2010	Upper	3	679997	4894473	4	South of Brookings, SD
$w\bar{C}_i$	$w\bar{C}$	$\bar{C}_i$	$\bar{C}$	*FQIi*	*FQI*	**Plot ID**	**Community Type**
1.43	1.58	2.40	2.82	10.73	11.64	1032011	Green Ash/Boxelder Forest
Species #	**% Exotics**	**Basal Area**	**Trees/ha**	**Shrubs/ha**	**Shrub Cover (%)**	1032012	Green Ash/Boxelder Forest
20	15.0	89.32	616.67	0	0	1032021	Coyote Willow Shrubland
						1032031	Cottonwood-Peachleaf Woodland

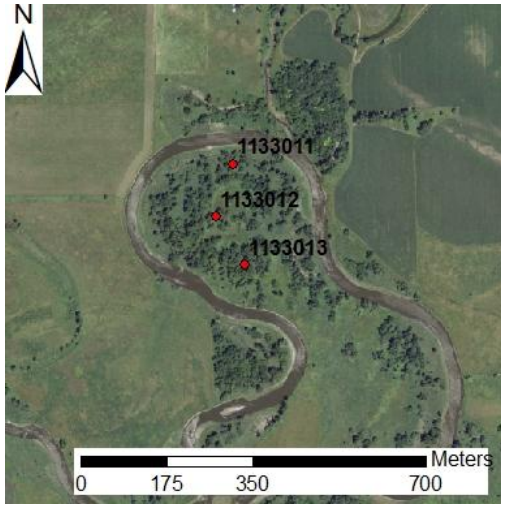


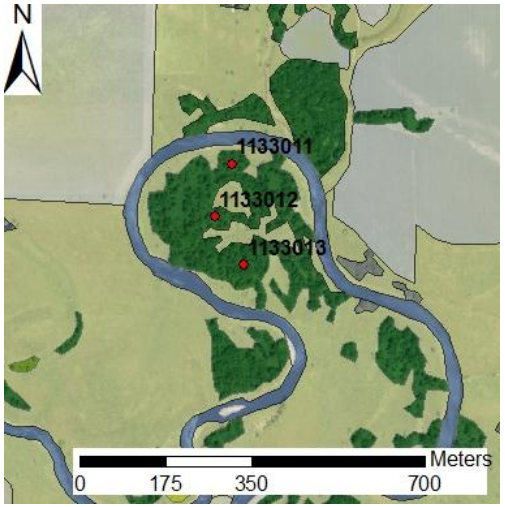


Species List

Acer negundo
Anemone canadensis
Apocynum cannabinum
**Bromus inermis*
Celtis occidentalis
Fraxinus pennsylvanica
Galium aparine
Leersia virginica
**Morus alba*
Phalaris arundinacea
Polygonum amphibian var. *emersum*
Populus deltoides
Rosa woodsii
Salix amygdaloides
Salix interior
**Sonchus arvensis*
Symphoricarpos occidentalis
Symphyotrichum lanceolatum
Ulmus americana
Viola sp.
Xanthium strumarium

Site Name	Date Sampled	Segment	Subreach	UTMx	UTMy	Plot #	Location Description
FSST Site 1	7/20/2011	Upper	3	694871	4883337	3	North of Flandreau, SD
$w\bar{C}_i$	$w\bar{C}$	$\bar{C}_i$	$\bar{C}$	*FQIi*	*FQI*	**Plot ID**	**Community Type**
2.87	3.12	3.05	3.77	18.58	20.63	1133011	Green Ash/Boxelder Forest
Species #	**% Exotics**	**Basal Area**	**Trees/ha**	**Shrubs/ha**	**Shrub Cover (%)**	1133012	Green Ash/Boxelder Forest
37	18.9	72.63	366.67	333.33	0.50	1133013	Green Ash/Boxelder Forest

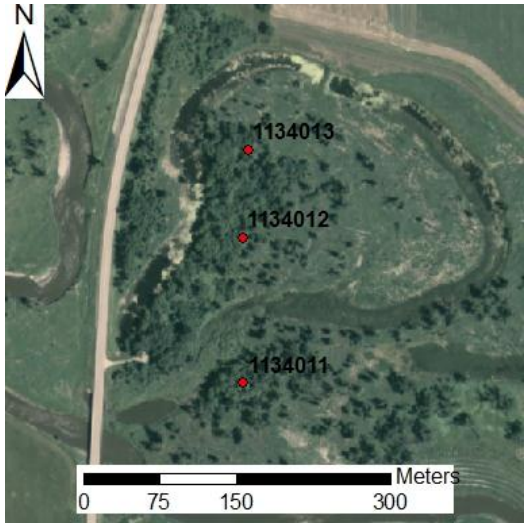


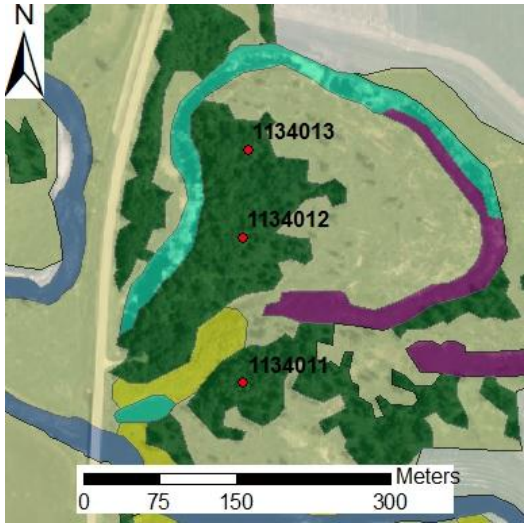


Species List

Acer negundo
Acer saccharinum
**Bromus inermis*
Carex alopecoidea
Carex blanda
Carex cristatella
Carex laeviconica
Carex molesta
Carex vulpinoidea
Celtis occidentalis
**Chenopodium album*
Chenopodium simplex
Elymus virginicus
Fraxinus pennsylvanica
Helianthus tuberosus
Hydrophyllum virginianum
Laportea canadensis
**Leonurus cardiaca*
Maianthemum stellatum
Parthenocissus vitacea
Phalaris arundinacea
Pilea pumila
**Plantago major*
**Poa pratensis*
Polygonum lapathifolium
Ranunculus abortivus
**Rhamnus cathartica*
Ribes missouriense
Rudbeckia laciniata
Sinapis sp.
Smilax herbacea
Solidago canadensis
Symphoricarpos occidentalis
**Taraxacum officinale*
Ulmus americana
Urtica dioica
Viola sororia
Viola sp.
Vitis riparia

Site Name	Date Sampled	Segment	Subreach	UTMx	UTMy	Plot #	Location Description
Conservation Park	8/9/2011	Upper	3	676797	4896235	3	South of Brookings, SD
$w\bar{C}_i$	$w\bar{C}$	$\bar{C}_i$	$\bar{C}$	*FQIi*	*FQI*	**Plot ID**	**Community Type**
1.83	2.04	2.91	3.53	13.97	15.37	1134011	Green Ash/Boxelder Forest
Species #	**% Exotics**	**Basal Area**	**Trees/ha**	**Shrubs/ha**	**Shrub Cover (%)**	1134012	Green Ash/Boxelder Forest
23	17.4	31.01	1016.7	2417	4.10	1134013	Green Ash/Boxelder Forest

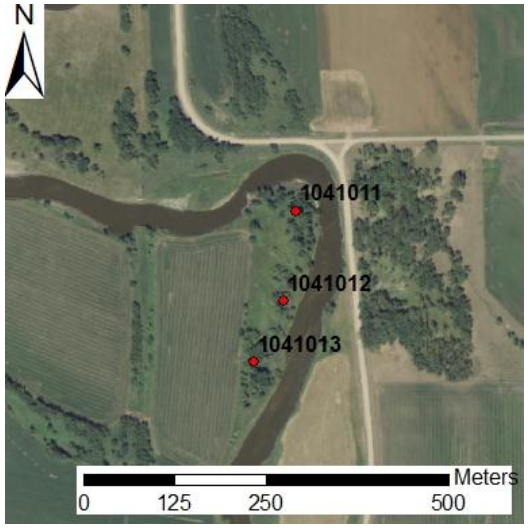


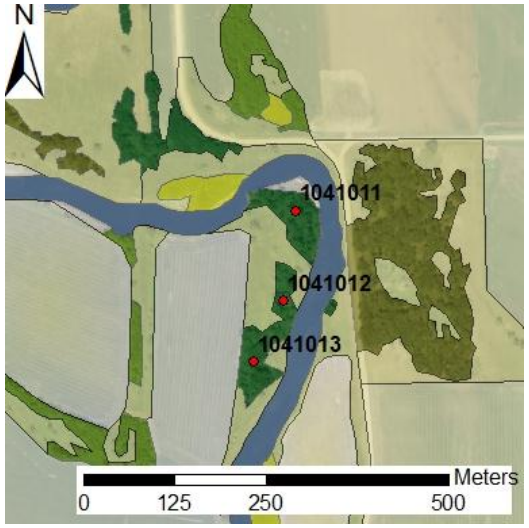


Species List

Acer negundo
Alisma subcordatum
Bidens cernua
Carex blanda
Carex sp.
**Cirsium arvense*
Cornus sericea
Fraxinus pennsylvanica
Geum canadense
Leersia virginica
Parthenocissus vitacea
Phalaris arundinacea
Pilea pumila
**Poa annua*
**Rhamnus cathartica*
Ribes americanum
Rosa arkansana
Rudbeckia laciniata
**Setaria pumila*
Smilax herbacea
Solidago canadensis
Ulmus americana
Urtica dioica
Vitis riparia

Site Name	Date Sampled	Segment	Subreach	UTMx	UTMy	Plot #	Location Description
Merry CHAP	8/30/2010	Middle	4	689122	4860825	3	Northeast of Dell Rapids, SD
$w\bar{C}_i$	$w\bar{C}$	$\bar{C}_i$	$\bar{C}$	*FQIi*	*FQI*	**Plot ID**	**Community Type**
0.97	1.16	2.86	3.33	10.69	11.55	1041011	Green Ash/Boxelder Forest
Species #	**% Exotics**	**Basal Area**	**Trees/ha**	**Shrubs/ha**	**Shrub Cover (%)**	1041012	Green Ash/Boxelder Forest
14	14.3	109.97	366.67	3500	6.08	1041013	Green Ash/Boxelder Forest

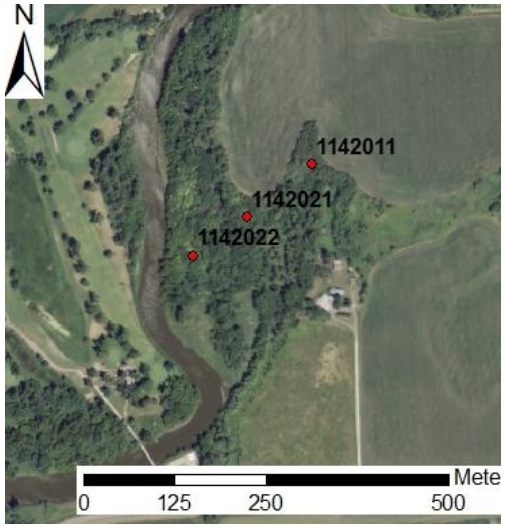


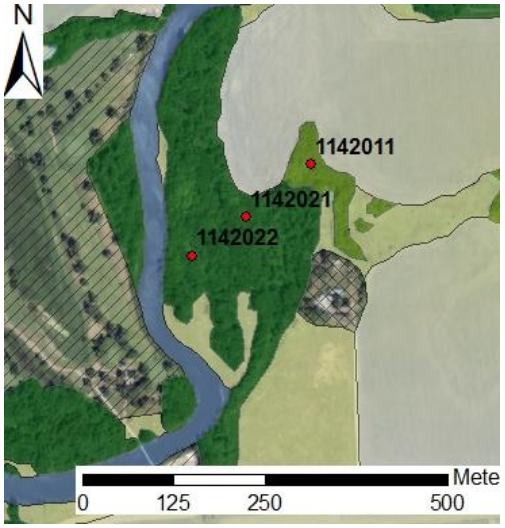


Species List

Acer negundo
Acer saccharinum
**Bromus inermis*
Echinocystis lobata
Elymus virginicus
Fraxinus pennsylvanica
Laportea canadensis
Leersia virginica
Phalaris arundinacea
Populus deltoides
Prunus virginiana
Symphoricarpos occidentalis
**Thinopyrum intermedium*
Ulmus americana
Viola sp.

Site Name	Date Sampled	Segment	Subreach	UTMx	UTMy	Plot #	Location Description
FSST Site 2	7/20/2011	Middle	4	695858	4880946	3	East of Flandreau, SD
$w\bar{C}_i$	$w\bar{C}$	$\bar{C}_i$	$\bar{C}$	*FQIi*	*FQI*	**Plot ID**	**Community Type**
4.32	4.35	3.03	3.62	16.88	18.44	1142011	Cottonwood-Peachleaf Woodland
Species #	**% Exotics**	**Basal Area**	**Trees/ha**	**Shrubs/ha**	**Shrub Cover (%)**	1142021	Green Ash/Boxelder Forest
31	16.1	55.72	850	667	4.50	1142022	Green Ash/Boxelder Forest

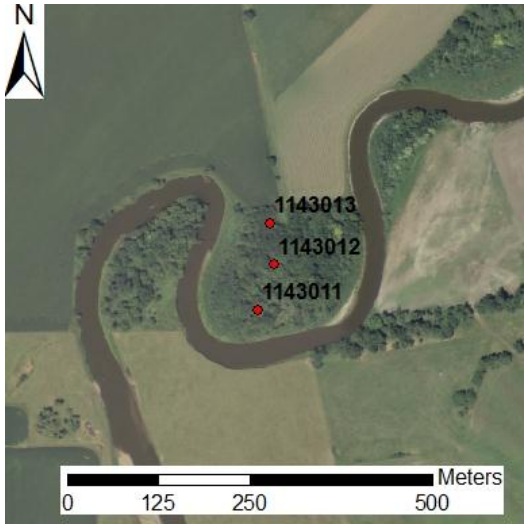


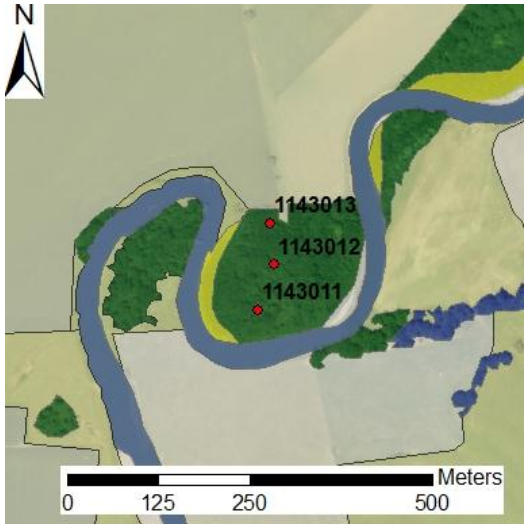


Species List

Acer negundo
Acer saccharinum
Bidens cernua
Carex sp.
Celtis occidentalis
**Chenopodium album*
Cryptotaenia canadensis
Erigeron philadelphicus
Laportea canadensis
Leersia virginica
**Leonurus cardiaca*
Lobelia siphilitica
Maianthemum stellatum
Parthenocissus vitacea
Phalaris arundinacea
Pilea pumila
**Plantago major*
Populus deltoides
Ranunculus abortivus
Ribes missouriense
Rorippa palustris
Rudbeckia laciniata
**Rumex patientia*
Salix amygdaloides
Salix interior
Solidago canadensis
**Stellaria media*
Symphyotrichum ontarionis
Ulmus americana
Urtica dioica
Viola sororia
Vitis riparia

Site Name	Date Sampled	Segment	Subreach	UTMx	UTMy	Plot #	Location Description
Eugler's Site	7/20/2011	Middle	4	687398	4856405	3	Northeast of Dell Rapids, SD
$w\bar{C}_i$	$w\bar{C}$	$\bar{C}_i$	$\bar{C}$	*FQIi*	*FQI*	**Plot ID**	**Community Type**
4.42	4.45	2.76	2.86	13.80	14.09	1143011	Green Ash/Boxelder Forest
Species #	**% Exotics**	**Basal Area**	**Trees/ha**	**Shrubs/ha**	**Shrub Cover (%)**	1143012	Green Ash/Boxelder Forest
25	4.0	54.14	533	2583	0.87	1143013	Green Ash/Boxelder Forest

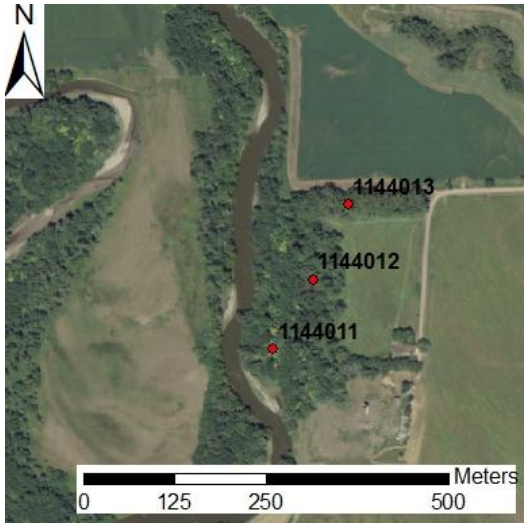


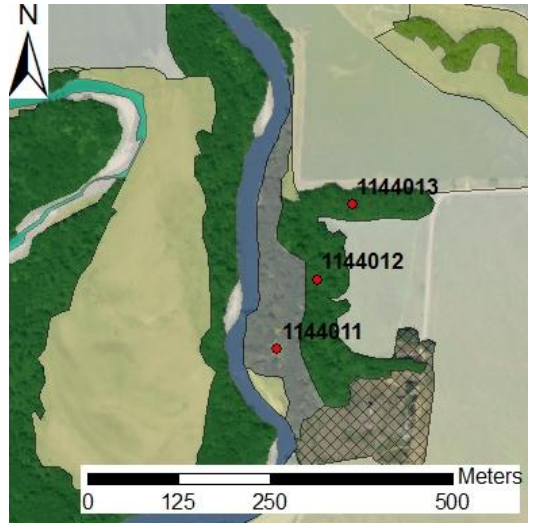


Species List

Acer negundo
Acer saccharinum
Amaranthus sp.
Asclepias syriaca
Bidens frondosa
Cryptotaenia canadensis
Elymus virginicus
Fraxinus pennsylvanica
Hydrophyllum virginianum
Laportea canadensis
Leersia virginica
Oxalis stricta
Parthenocissus vitacea
Phalaris arundinacea
Physalis longifolia
Pilea pumila
Ranunculus abortivus
**Rhamnus cathartica*
Ribes missouriense
Rudbeckia laciniata
Sicyos angulatus
Solanum ptycanthum
Symphyotrichum lanceolatum
Urtica dioica
Viola sororia
Vitis riparia

Site Name	Date Sampled	Segment	Subreach	UTMx	UTMy	Plot #	Location Description
Burggraff's Site	8/9/2011	Middle	4	689468	4873615	3	Southeast of Egan, SD
$w\bar{C}_i$	$w\bar{C}$	$\bar{C}_i$	$\bar{C}$	*FQIi*	*FQI*	**Plot ID**	**Community Type**
4.74	5.00	2.65	2.88	10.91	12.03	1144011	Silver Maple-Elm-Cottonwood Forest
Species #	**% Exotics**	**Basal Area**	**Trees/ha**	**Shrubs/ha**	**Shrub Cover (%)**	1144012	Green Ash/Boxelder Forest
17	17.7	91.63	483	83	0.00	1144013	Green Ash/Boxelder Forest



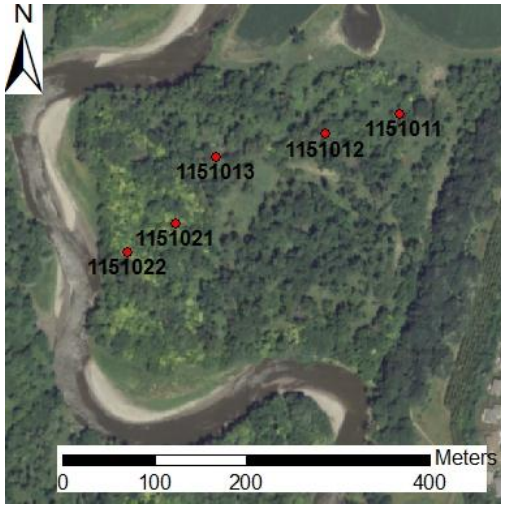


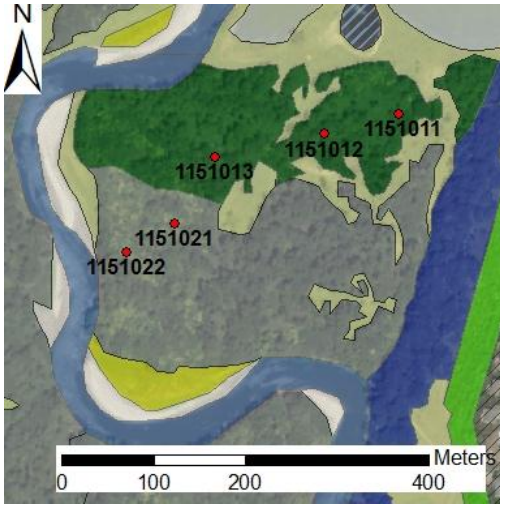
Species List

Acer negundo
Acer saccharinum
Bidens frondosa
**Chenopodium album*
Cryptotaenia canadensis
Fraxinus pennsylvanica
Geum canadense
**Glechoma hederacea*
Laportea canadensis
Leersia virginica
Oxalis sp.
Phalaris arundinacea
Ranunculus abortivus
**Rhamnus cathartica*
Rudbeckia laciniata
Ulmus americana
Urtica dioica
Viola sororia
Viola sp.

Site Name	Date Sampled	Segment	Subreach	UTMx	UTMy
Big Sioux Rec. Area	7/7/2011	Middle	5	693947	4828784
$w\bar{C}_i$	$w\bar{C}$	$\bar{C}_i$	$\bar{C}$	*FQIi*	*FQI*
3.20	3.97	2.61	3.19	17.34	19.17
Species #	**% Exotics**	**Basal Area**	**Trees/ha**	**Shrubs/ha**	**Shrub Cover (%)**
44	18.2	36.00	430	625	0.00

Plot #	Location Description
5	Southwest of Brandon, SD
Plot ID	**Community Type**
1151011	Green Ash/Boxelder Forest
1151012	Green Ash/Boxelder Forest
1151013	Green Ash/Boxelder Forest
1151021	Silver Maple-Elm-Cottonwood Forest
1151022	Silver Maple-Elm-Cottonwood Forest

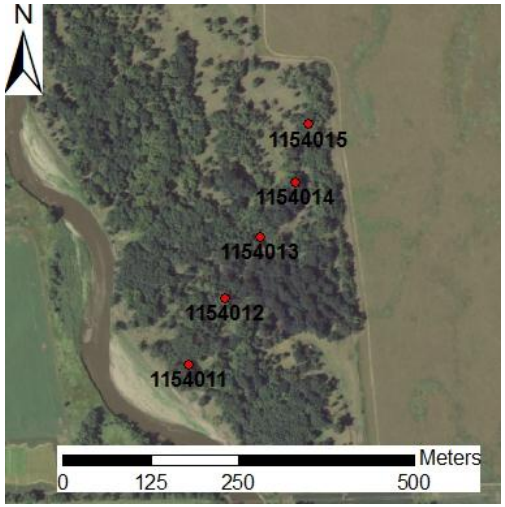


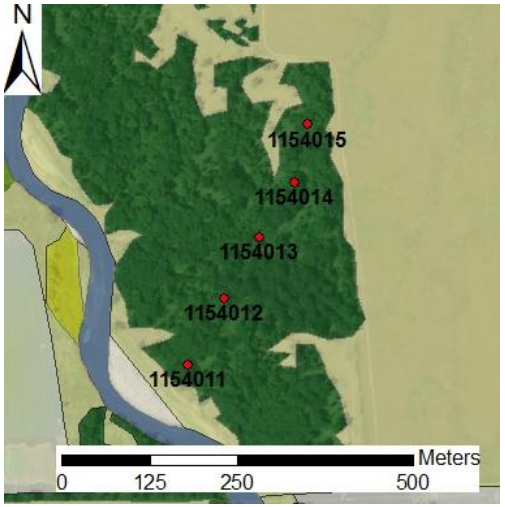


Species List

Acer negundo
Acer saccharinum
**Alliaria petiolata*
Ambrosia artemisiifolia
Bidens comosa
Bidens vulgata
**Bromus inermis*
Calystegia sepium
**Cirsium arvensis*
Cryptotaenia canadensis
Echinocystis lobata
Elymus virginicus
Fraxinus pennsylvanica
Galium aparine
**Glechoma hederacea*
Hackelia sp.
Hydrophyllum virginianum
Impatiens capensis
Lactuca sp.
Laportea canadensis
Leersia virginica
Mentha arvensis
Parthenocissus vitacea
Phalaris arundinacea
Pilea pumila
Polygonum lapathifolium
**Polygonum persicaria*
Populus deltoides
Prunus americana
Ranunculus abortivus
Ranunculus sceleratus
**Rhamnus cathartica*
Ribes missouriense
Rudbeckia laciniata
**Rumex crispus*
Smilax herbacea
**Solanum dulcamara*
Solidago canadensis
Solidago gigantea
Symphoricarpos occidentalis
Symphyotrichum ontarionis
Teucrium canadense
Urtica dioica
Viola sororia
Vitis riparia
Xanthium strumarium

Site Name	Date Sampled	Segment	Subreach	UTMx	UTMy	Plot #	Location Description
Swanson's Tract	7/13/2011	Middle	5	681820	4831924	5	North of Sioux Falls, SD
$w\bar{C}_i$	$w\bar{C}$	$\bar{C}_i$	$\bar{C}$	*FQIi*	*FQI*	**Plot ID**	**Community Type**
2.24	3.98	3.08	3.79	22.39	24.86	1154011	Green Ash/Boxelder Forest
Species #	**% Exotics**	**Basal Area**	**Trees/ha**	**Shrubs/ha**	**Shrub Cover (%)**	1154012	Green Ash/Boxelder Forest
53	18.9	52.20	390	10,000	30.06	1154013	Green Ash/Boxelder Forest
						1154014	Green Ash/Boxelder Forest
						1154015	Green Ash/Boxelder Forest



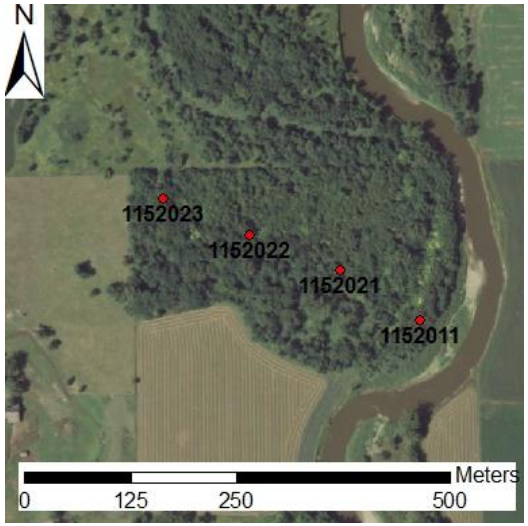


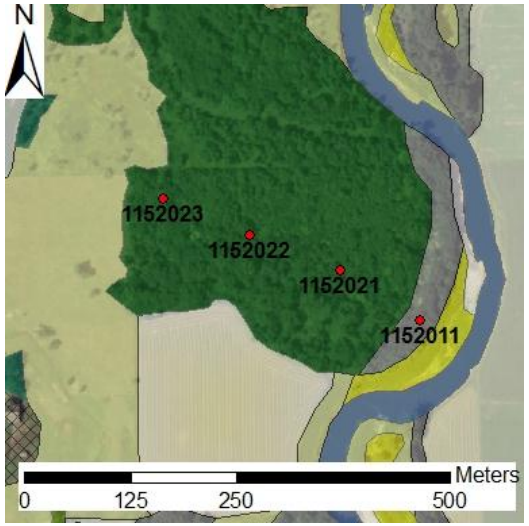
Species List

Acalypha rhomboidea
Acer negundo
Acer saccharinum
**Agrostis stolonifera*
Amaranthus sp.
Ambrosia artemisiifolia
Bidens comosa
Bidens frondosa
Carex alopecoidea
Carex blanda
Celtis occidentalis
**Chenopodium album*
Chenopodium simplex
Cryptotaenia canadensis
**Echinochloa crus-galli*
**Elymus repens*
Elymus virginicus
Erigeron philadelphicus
Fraxinus pennsylvanica
Geum canadense
**Glechoma hederacea*
Hydrophyllum virginianum
Impatiens capensis
Laportea canadensis
Leersia virginica
Mentha arvensis
Oxalis stricta
Parietaria pensylvanica
**Phleum pratense*
Pilea pumila
Plantago rugelii
Poa palustris
**Poa pratensis*
Polygonum lapathifolium
**Polygonum persicaria*
Prunella vulgaris
Prunus americana
Quercus macrocarpa
Ranunculus abortivus
Ranunculus sceleratus
**Rhamnus cathartica*
Ribes missouriense
Rudbeckia laciniata
Sanicula marilandica
Smilax herbacea
Solanum ptycanthum
Symphoricarpos occidentalis
Symphyotrichum ontarionis
**Taraxacum officinale*
Thalictrum dasycarpum
Ulmus americana
Urtica dioica
Viola sororia
Vitis riparia

Site Name	Date Sampled	Segment	Subreach	UTMx	UTMy
Ward's Site	7/13/2011	Middle	5	682397	4838806
$w\bar{C}_i$	$w\bar{C}$	$\bar{C}_i$	$\bar{C}$	*FQIi*	*FQI*
4.68	5.20	3.33	3.75	17.32	18.37
Species #	**% Exotics**	**Basal Area**	**Trees/ha**	**Shrubs/ha**	**Shrub Cover (%)**
27	11.1	86.17	525	83	0.00

Plot #	Location Description
4	North of Renner, SD
Plot ID	**Community Type**
1152011	Silver Maple-Elm-Cottonwood Forest
1152021	Green Ash/Boxelder Forest
1152022	Green Ash/Boxelder Forest
1152023	Green Ash/Boxelder Forest

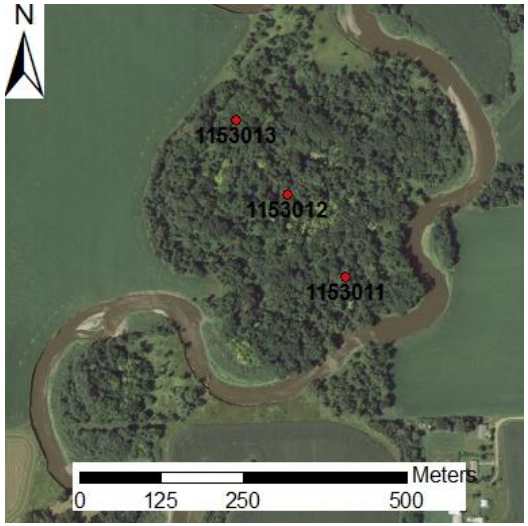


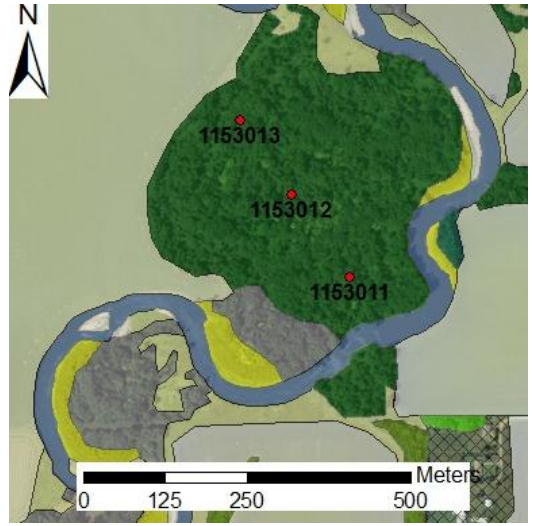


Species List

Acer saccharinum
Carex blanda
Celtis occidentalis
**Chenopodium album*
Cryptotaenia canadensis
Echinocystis lobata
Fraxinus pennsylvanica
**Glechoma hederacea*
Hackelia virginiana
Hydrophyllum virginianum
Impatiens capensis
Laportea canadensis
Leersia virginica
Parthenocissus vitacea
Pilea pumila
Populus deltoides
Ranunculus abortivus
**Rhamnus cathartica*
Rudbeckia laciniata
Salix amygdaloides
Sanicula marilandica
Solanum ptycanthum
Solidago gigantea
Ulmus americana
Urtica dioica
Viola sororia
Vitis riparia

Site Name	Date Sampled	Segment	Subreach	UTMx	UTMy	Plot #	Location Description
City of Baltic	8/2/2011	Middle	5	681405	4846022	3	South of Baltic, SD
$w\bar{C}_i$	$w\bar{C}$	$\bar{C}_i$	$\bar{C}$	*FQIi*	*FQI*	**Plot ID**	**Community Type**
4.82	5.00	3.54	3.70	17.35	17.72	1153011	Green Ash/Boxelder Forest
Species #	**% Exotics**	**Basal Area**	**Trees/ha**	**Shrubs/ha**	**Shrub Cover (%)**	1153012	Green Ash/Boxelder Forest
24	4.2	70.69	483	1050	2.29	1153013	Green Ash/Boxelder Forest

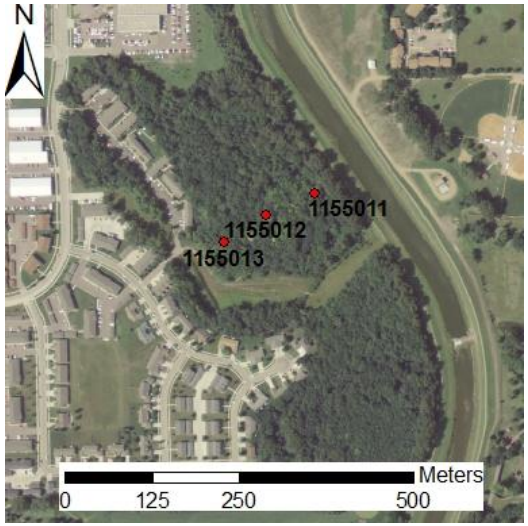


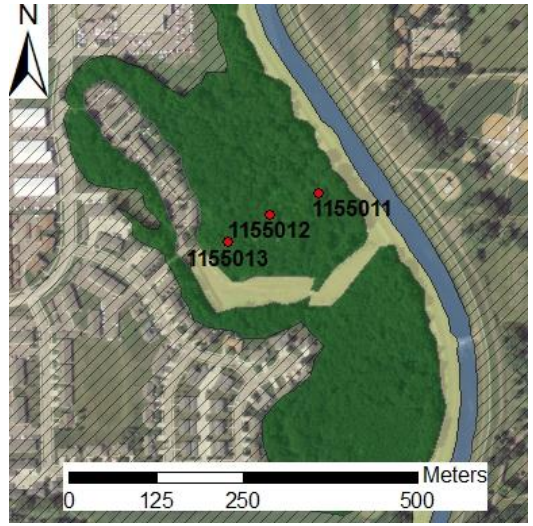


Species List

Acer negundo
Acer saccharinum
Bidens vulgata
Carex blanda
Celtis occidentalis
Cryptotaenia canadensis
Elymus virginicus
Fraxinus pennsylvanica
Geum canadense
Hydrophyllum virginianum
Laportea canadensis
Parthenocissus vitacea
Phalaris arundinacea
Pilea pumila
Ranunculus abortivus
**Rhamnus cathartica*
Ribes missouriense
Rudbeckia laciniata
Sicyos angulatus
Smilax herbacea
Ulmus americana
Urtica dioica
Viola sororia
Vitis riparia

Site Name	Date Sampled	Segment	Subreach	UTMx	UTMy	Plot #	Location Description
Byre's Site	8/4/2011	Middle	5	680169	4823262	3	In Sioux Falls, SD
$w\bar{C}_i$	$w\bar{C}$	$\bar{C}_i$	$\bar{C}$	*FQIi*	*FQI*	**Plot ID**	**Community Type**
1.00	3.77	3.14	3.88	14.40	16.00	1155011	Green Ash/Boxelder Forest
Species #	**% Exotics**	**Basal Area**	**Trees/ha**	**Shrubs/ha**	**Shrub Cover (%)**	1155012	Green Ash/Boxelder Forest
21	19.1	64.05	300	4000	15.40	1155013	Green Ash/Boxelder Forest

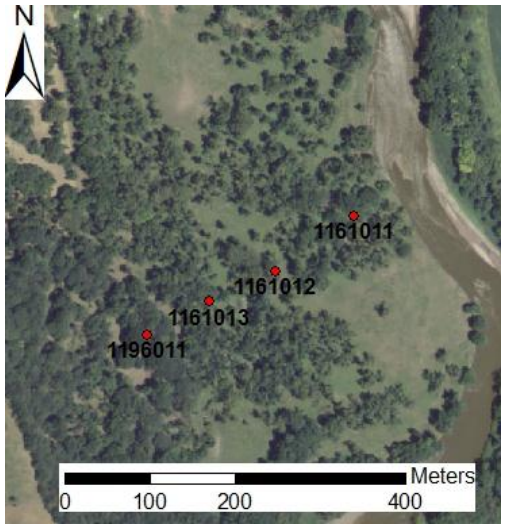


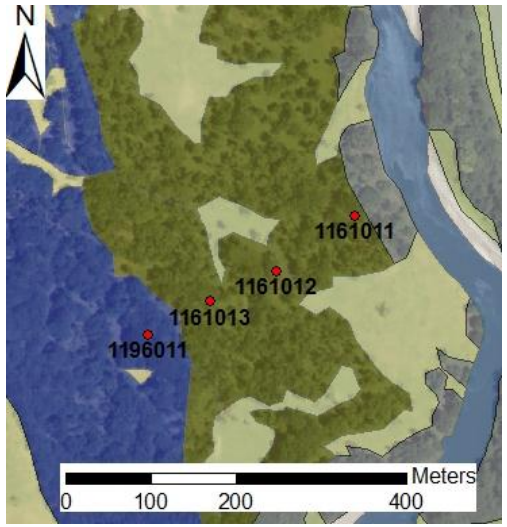


Species List

Acer negundo
Acer saccharinum
**Arctium minus*
Carex blanda
Chenopodium simplex
Fraxinus pennsylvanica
Geum canadense
Hackelia virginiana
**Hesperis matronalis*
Juglans nigra
Laportea canadensis
Leersia virginica
Menispermum canadense
Oxalis sp.
Parthenocissus vitacea
**Rhamnus cathartica*
Smilax herbacea
**Solanum dulcamara*
Toxicodendron radicans
Ulmus americana
Viola sp.
Vitis riparia
Xanthium strumarium

Site Name	Date Sampled	Segment	Subreach	UTMx	UTMy	Plot #	Location Description
Oak Ridge GPA	8/4/2011	Middle	6	705843	4781975	3	North of Hudson, SD
$w\bar{C}_i$	$w\bar{C}$	$\bar{C}_i$	$\bar{C}$	*FQIi*	*FQI*	**Plot ID**	**Community Type**
3.18	3.82	2.74	3.27	15.27	16.67	1161011	Cottonwood-Green Ash Forest
Species #	**% Exotics**	**Basal Area**	**Trees/ha**	**Shrubs/ha**	**Shrub Cover (%)**	1161012	Cottonwood-Green Ash Forest
31	16.1	65.93	200	0	0.00	1161013	Cottonwood-Green Ash Forest

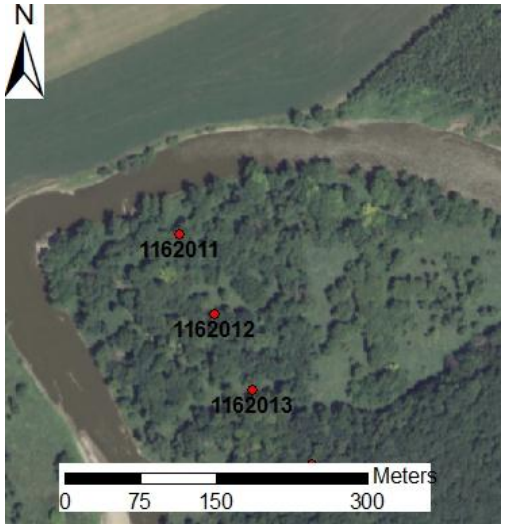


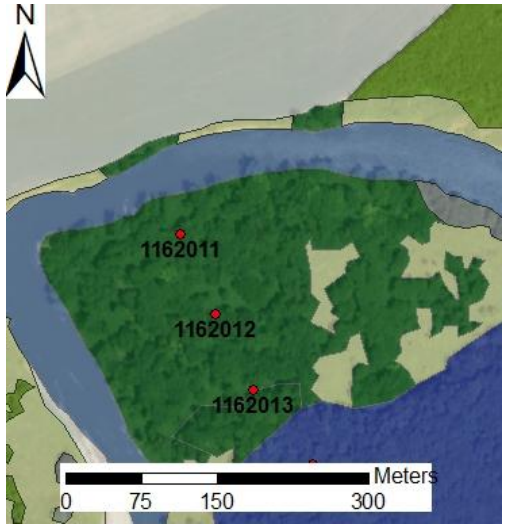


Species List

Acer negundo
Acer saccharinum
Amaranthus sp.
Ambrosia artemisiifolia
Bidens comosa
Bidens vulgata
**Cannabis sativa*
Carex emoryi
Carex laeviconica
Celtis occidentalis
**Chenopodium album*
Cirsium altissimum
Cryptotaenia canadensis
Fraxinus pennsylvanica
**Glechoma hederacea*
Laportea canadensis
Oxalis sp.
Parthenocissus vitacea
Phalaris arundinacea
Pilea pumila
Polygonum lapathifolium
Populus deltoides
Rudbeckia laciniata
**Rumex crispus*
Salix amygdaloides
Sinapis sp.
Solidago gigantea
Symphyotrichum ontarionis
**Taraxacum officinale*
Teucrium canadense
Ulmus americana
Urtica dioica
Vitis riparia
Xanthium strumarium

Site Name	Date Sampled	Segment	Subreach	UTMx	UTMy	Plot #	Location Description
Fish GPA	6/27/2011	Middle	6	702470	4788380	3	East of Fairview, SD
$w\bar{C}_i$	$w\bar{C}$	$\bar{C}_i$	$\bar{C}$	*FQIi*	*FQI*	**Plot ID**	**Community Type**
4.40	4.45	3.42	4.19	19.67	21.75	1162011	Green Ash/Boxelder Forest
Species #	**% Exotics**	**Basal Area**	**Trees/ha**	**Shrubs/ha**	**Shrub Cover (%)**	1162012	Green Ash/Boxelder Forest
33	18.2	29.91	300	166	0.00	1162013	Green Ash/Boxelder Forest

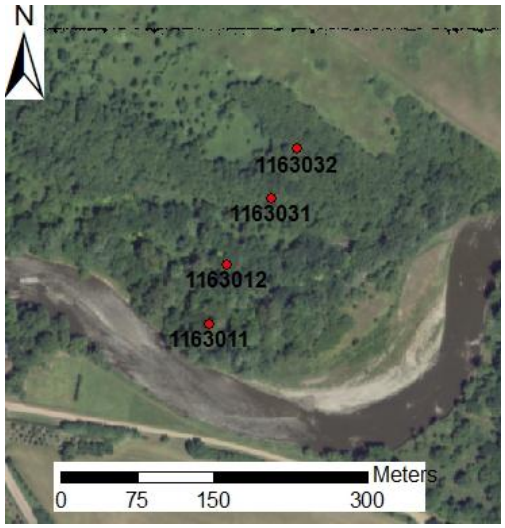


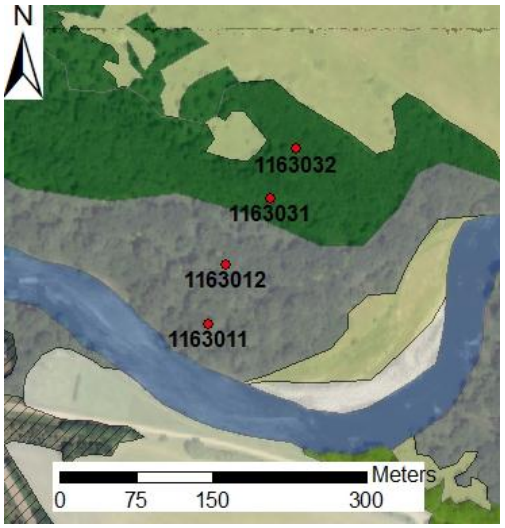


Species List

Acer negundo
Acer saccharinum
**Alliaria petiolata*
Ambrosia trifida
**Arctium minus*
Bidens vulgata
Carex blanda
Celtis occidentalis
**Chenopodium album*
Chenopodium simplex
Cryptotaenia canadensis
Elymus virginicus
Festuca subverticillata
Fraxinus pennsylvanica
Galium aparine
**Glechoma hederacea*
Hydrophyllum virginianum
Laportea canadensis
**Leonurus cardiaca*
Oxalis sp.
Phalaris arundinacea
Pilea pumila
Rudbeckia laciniata
**Rumex crispus*
Sanicula marilandica
Smilax tamnoides
Solidago canadensis
Solidago gigantea
Symphyotrichum ontarionis
Ulmus americana
Ulmus rubra
Urtica dioica
Viola sororia
Viola sp.
Vitis riparia

Site Name	Date Sampled	Segment	Subreach	UTMx	UTMy	Plot #	Location Description
Gitchie Manitou	6/28/2011	Middle	6	694460	4818461	4	Southwest of Rowena, IA
$w\bar{C}_i$	$w\bar{C}$	$\bar{C}_i$	$\bar{C}$	*FQIi*	*FQI*	**Plot ID**	**Community Type**
3.43	4.53	2.55	3.04	14.19	15.49	1163011	Silver Maple-Elm-Cottonwood Forest
Species #	**% Exotics**	**Basal Area**	**Trees/ha**	**Shrubs/ha**	**Shrub Cover (%)**	1163012	Silver Maple-Elm-Cottonwood Forest
31	16.1	77.22	412.5	0	0.00	1163031	Green Ash/Boxelder Forest
						1163032	Green Ash/Boxelder Forest



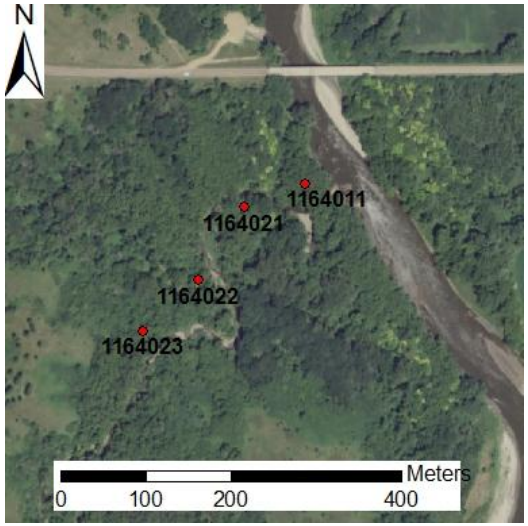


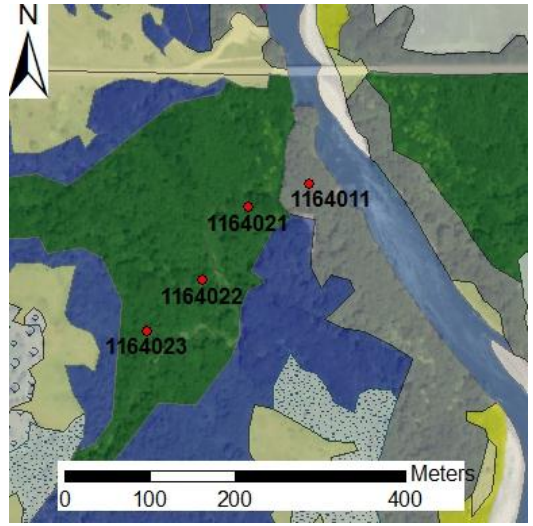
Species List

Acer negundo
Acer saccharinum
**Alliaria petiolata*
Ambrosia artemisiifolia
Ambrosia trifida
Bidens vulgata
Botrychium virginianum
Celtis occidentalis
**Chenopodium album*
Elymus virginicus
Fraxinus pennsylvanica
Galium aparine
**Glechoma hederacea*
Hackelia virginiana
Hydrophyllum virginianum
Laportea canadensis
Leersia virginica
Maianthemum stellatum
Oxalis sp.
Parthenocissus vitacea
Phalaris arundinacea
Pilea pumila
Populus deltoides
Ranunculus abortivus
**Rhamnus cathartica*
Rudbeckia laciniata
**Sisymbrium loeselii*
Solidago gigantea
Teucrium canadense
Ulmus americana
Urtica dioica
Viola sororia
Viola sp.

Site Name	Date Sampled	Segment	Subreach	UTMx	UTMy
Nine Mile Creek GPA	6/29/2011	Middle	6	694061	4813231
$w\bar{C}_i$	$w\bar{C}$	$\bar{C}_i$	$\bar{C}$	*FQIi*	*FQI*
4.86	5.02	2.86	3.75	13.09	15.00
Species #	**% Exotics**	**Basal Area**	**Trees/ha**	**Shrubs/ha**	**Shrub Cover (%)**
21	23.8	42.36	587	875	0.00

Plot #	Location Description
4	East of Harrisburg, SD
Plot ID	**Community Type**
1164011	Silver Maple-Elm-Cottonwood Forest
1164021	Green Ash/Boxelder Forest
1164022	Green Ash/Boxelder Forest
1164023	Green Ash/Boxelder Forest

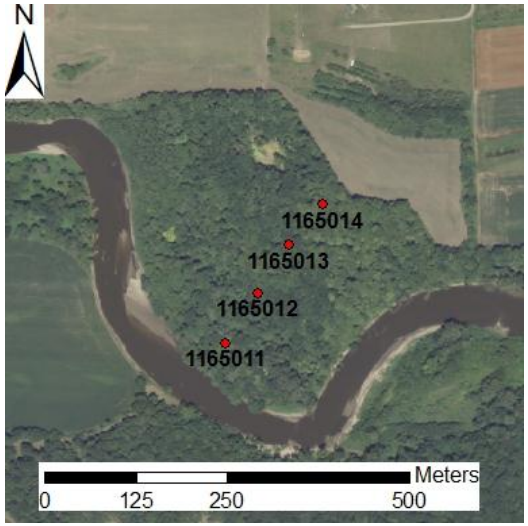


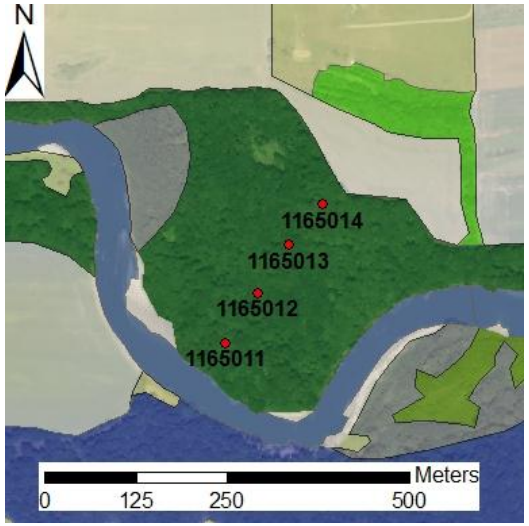


Species List

Acer negundo
Acer saccharinum
**Arctium minus*
**Chenopodium album*
Cryptotaenia canadensis
Elymus virginicus
Fraxinus pennsylvanica
Heracleum maximum
Hydrophyllum virginianum
Laportea canadensis
**Lonicera tatarica*
Parthenocissus vitacea
Prunus americana
Ranunculus abortivus
**Rhamnus cathartica*
Ribes missouriense
Rudbeckia laciniata
**Taraxacum officinale*
Ulmus americana
Urtica dioica
Viola sororia
Viola sp.

Site Name	Date Sampled	Segment	Subreach	UTMx	UTMy	Plot #	Location Description
City of Canton	7/14/2011	Middle	6	698439	4796351	4	East of Canton, SD
$w\bar{C}_i$	$w\bar{C}$	$\bar{C}_i$	$\bar{C}$	*FQIi*	*FQI*	**Plot ID**	**Community Type**
5.02	5.20	3.90	4.11	17.44	17.89	1165011	Green Ash/Boxelder Forest
Species #	**% Exotics**	**Basal Area**	**Trees/ha**	**Shrubs/ha**	**Shrub Cover (%)**	1165012	Green Ash/Boxelder Forest
20	5.00	53.97	500	0	0.00	1165013	Green Ash/Boxelder Forest
						1165014	Green Ash/Boxelder Forest

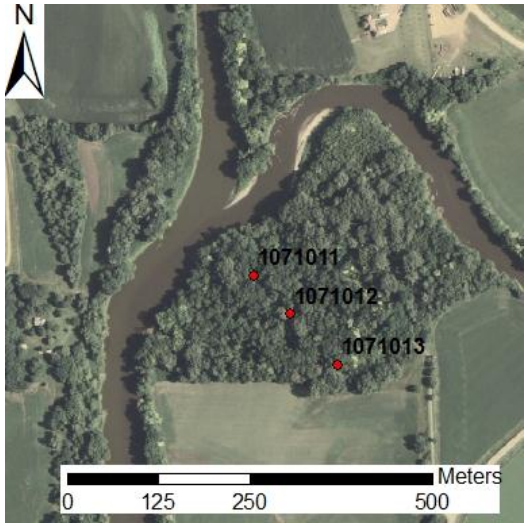


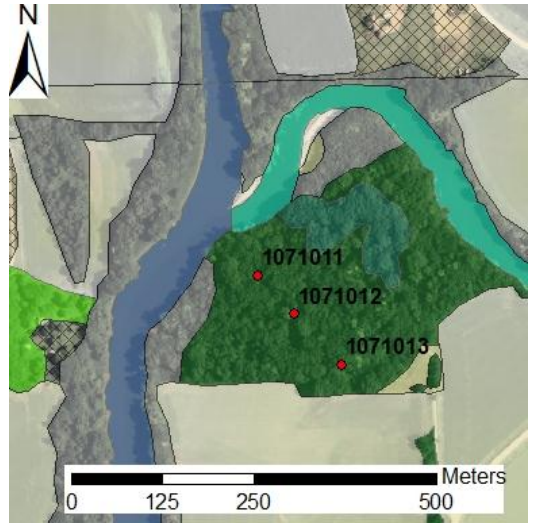


Species List

Acer negundo
Acer saccharinum
Bidens frondosa
Celtis occidentalis
Cryptotaenia canadensis
Elymus virginicus
Fraxinus pennsylvanica
**Glechoma hederacea*
Hydrophyllum virginianum
Impatiens capensis
Laportea canadensis
Leersia virginica
Pilea pumila
Ranunculus abortivus
Rudbeckia laciniata
Salix amygdaloides
Solidago canadensis
Symphyotrichum ontarionis
Urtica dioica
Vitis riparia

Site Name	Date Sampled	Segment	Subreach	UTMx	UTMy	Plot #	Location Description
Rock River	7/20/2010	Lower	7	707282	4773018	3	South of Hudson, SD
$w\bar{C}_i$	$w\bar{C}$	$\bar{C}_i$	$\bar{C}$	*FQIi*	*FQI*	**Plot ID**	**Community Type**
4.95	4.96	4.20	4.50	16.27	16.84	1071011	Green Ash/Boxelder Forest
Species #	**% Exotics**	**Basal Area**	**Trees/ha**	**Shrubs/ha**	**Shrub Cover (%)**	1071012	Green Ash/Boxelder Forest
15	6.7	51.15	400	333	0.00	1071013	Green Ash/Boxelder Forest

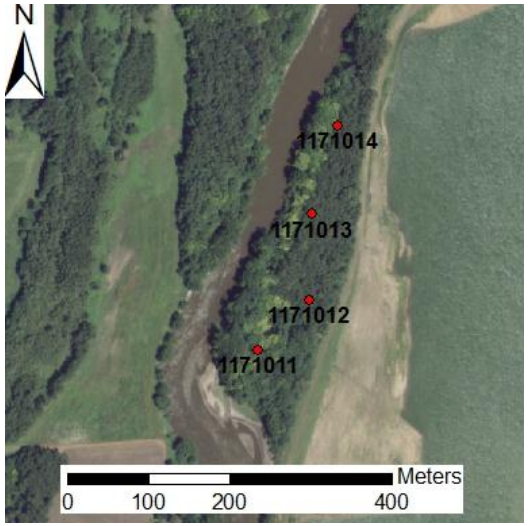


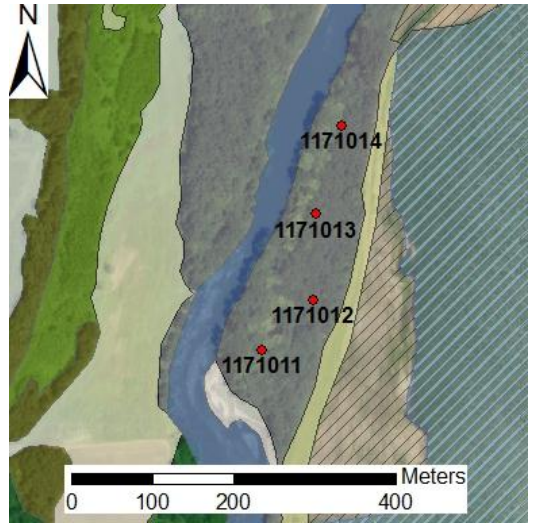


Species List

Acer negundo
Campanulastrum americanum
Cryptotaenia canadensis
Elymus virginicus
Fraxinus pennsylvanica
Hackelia virginiana
Laportea canadensis
Leersia virginica
**Morus alba*
Rudbeckia laciniata
Sanicula marilandica
Symphyotrichum ontarionis
Urtica dioica
Viola sororia
Vitis riparia

Site Name	Date Sampled	Segment	Subreach	UTMx	UTMy	Plot #	Location Description
Silver Maple Primitive Area	6/16/2011	Lower	7	696910	4741722	4	Southwest of Akron, IA
$w\bar{C}_i$	$w\bar{C}$	$\bar{C}_i$	$\bar{C}$	*FQIi*	*FQI*	**Plot ID**	**Community Type**
4.67	4.69	2.40	2.67	10.73	11.31	1172011	Silver Maple-Elm-Cottonwood Forest
Species #	**% Exotics**	**Basal Area**	**Trees/ha**	**Shrubs/ha**	**Shrub Cover (%)**	1172012	Silver Maple-Elm-Cottonwood Forest
20	10.0	162.53	650	1968	4.24	1172013	Silver Maple-Elm-Cottonwood Forest
						1172014	Silver Maple-Elm-Cottonwood Forest



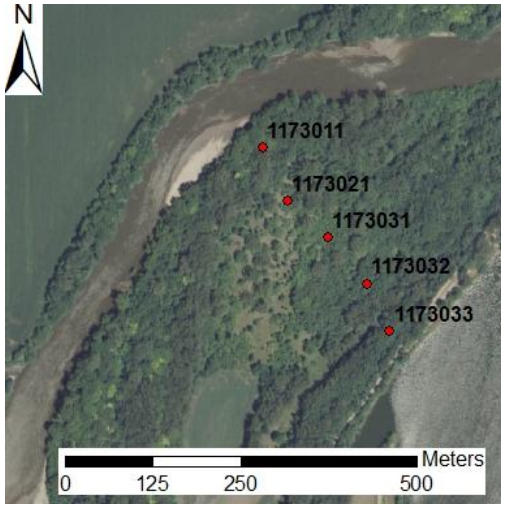


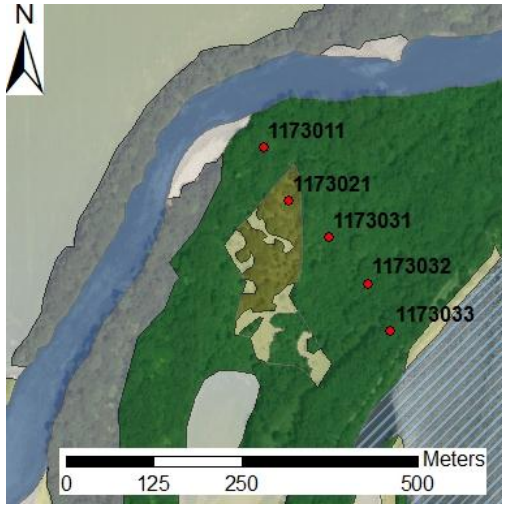
Species List

Acer negundo
Acer saccharinum
Ambrosia artemisiifolia
Ambrosia trifida
Bidens vulgata
Chenopodium simplex
Cryptotaenia canadensis
Galium aparine
**Glechoma hederacea*
Laportea canadensis
**Morus alba*
Phalaris arundinacea
Pilea pumila
Populus deltoides
Rudbeckia laciniata
Salix amygdaloides
Solidago gigantea
Urtica dioica
Viola sororia
Viola sp.
Vitis riparia

Site Name	Date Sampled	Segment	Subreach	UTMx	UTMy
Hawarden	7/6/2011	Lower	7	703113	4763346
$w\bar{C}_i$	$w\bar{C}$	$\bar{C}_i$	$\bar{C}$	*FQIi*	*FQI*
2.08	3.62	2.46	3.31	14.54	16.87
Species #	**% Exotics**	**Basal Area**	**Trees/ha**	**Shrubs/ha**	**Shrub Cover (%)**
35	25.7	77.83	590	2416	17.92

Plot #	Location Description
5	West of Hawarden, IA
Plot ID	**Community Type**
1173011	Green Ash/Boxelder Forest
1173021	Cottonwood-Green Ash Forest
1173031	Green Ash/Boxelder Forest
1173032	Green Ash/Boxelder Forest
1173033	Green Ash/Boxelder Forest

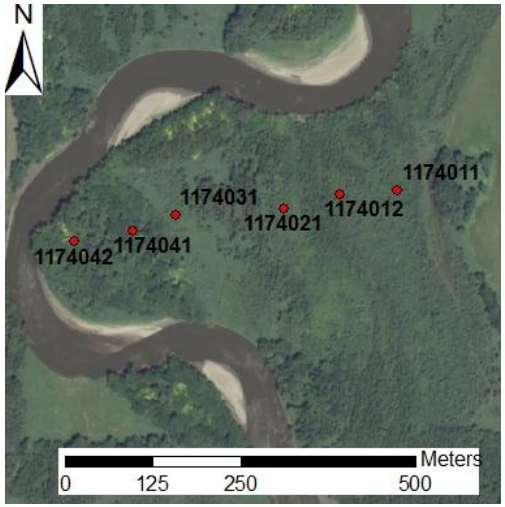


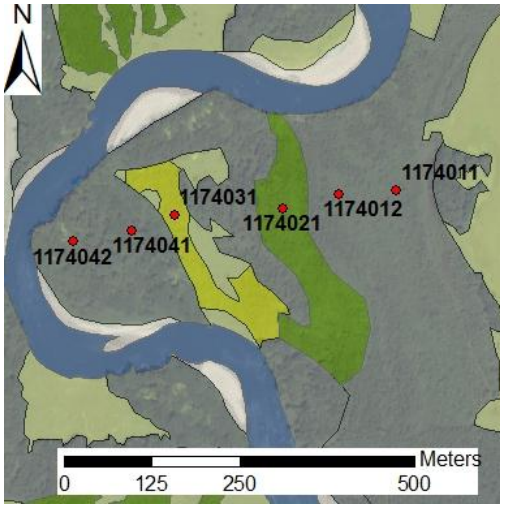


Species List

Acer negundo
Acer saccharinum
Ageratina altissima
**Alliaria petiolata*
Bidens vulgata
Carex blanda
Celtis occidentalis
**Chenopodium album*
Cryptotaenia canadensis
Elymus virginicus
**Euphorbia esula*
Fraxinus pennsylvanica
**Glechoma hederacea*
Hackelia deflexa
Laportea canadensis
**Leonurus cardiaca*
**Morus alba*
Oxalis stricta
Parthenocissus vitacea
Physalis longifolia
Pilea pumila
Poa palustris
**Poa pratensis*
Populus deltoides
Prunella vulgaris
Ranunculus abortivus
Rudbeckia laciniata
Solidago gigantea
**Taraxacum officinale*
Teucrium canadense
Ulmus americana
**Ulmus pumila*
Urtica dioica
Verbena urticifolia
Vitis riparia

Site Name	Date Sampled	Segment	Subreach	UTMx	UTMy	Plot #	Location Description
Doorenbos-Ford Tract	7/8/2011	Lower	7	701137	4750851	6	North of Akron, IA
$w\bar{C}_i$	$w\bar{C}$	$\bar{C}_i$	$\bar{C}$	*FQIi*	*FQI*	**Plot ID**	**Community Type**
2.00	2.01	2.82	2.93	14.93	15.20	1174011	Silver Maple-Elm-Cottonwood Forest
Species #	**% Exotics**	**Basal Area**	**Trees/ha**	**Shrubs/ha**	**Shrub Cover (%)**	1174012	Silver Maple-Elm-Cottonwood Forest
28	3.6	47.57	517	938	0.00	1174021	Cottonwood-Peachleaf Woodland
						1174031	Coyote Willow Shrubland
						1174041	Silver Maple-Elm-Cottonwood Forest
						1174042	Silver Maple-Elm-Cottonwood Forest



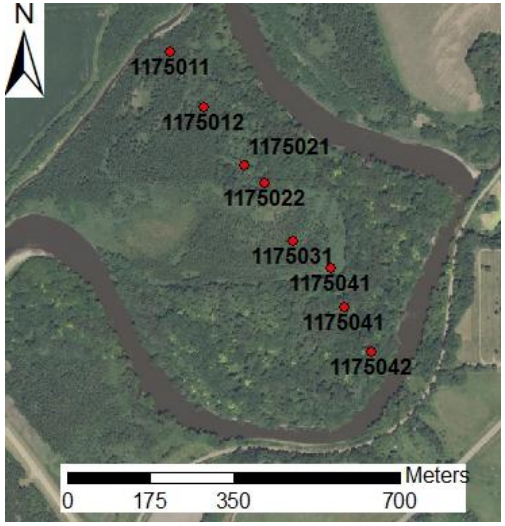


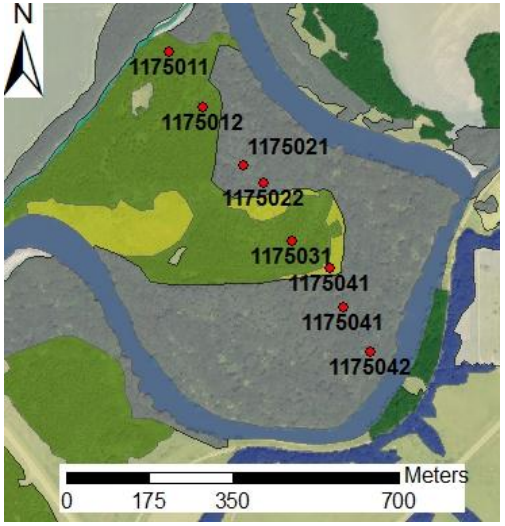
Species List

Acer negundo
Acer saccharinum
Ambrosia artemisiifolia
Bidens comosa
Bidens vulgata
Carex laeviconica
Celtis occidentalis
**Chenopodium album*
Cryptotaenia canadensis
Elymus virginicus
Fraxinus pennsylvanica
Laportea canadensis
Leersia virginica
Phalaris arundinacea
Pilea pumila
Polygonum amphibium var. *emersum*
Polygonum lapathifolium
Populus deltoides
Ranunculus sceleratus
Rudbeckia laciniata
Salix amygdaloides
Salix interior
Solanum ptycanthum
Teucrium canadense
Ulmus americana
Viola sororia
Vitis riparia
Xanthium strumarium

Site Name	Date Sampled	Segment	Subreach	UTMx	UTMy
Akron GPA	7/11/2011	Lower	7	699714	4746316
$w\bar{C}_i$	$w\bar{C}$	$\bar{C}_i$	$\bar{C}$	*FQIi*	*FQI*
3.46	3.64	3.11	3.84	21.30	23.68
Species #	**% Exotics**	**Basal Area**	**Trees/ha**	**Shrubs/ha**	**Shrub Cover (%)**
47	19.2	42.38	406	1167	11.11

Plot #	Location Description
8	Northwest of Akron, IA
Plot ID	**Community Type**
1175011	Cottonwood-Peachleaf Woodland
1175012	Cottonwood-Peachleaf Woodland
1175021	Silver Maple-Elm-Cottonwood Forest
1175022	Silver Maple-Elm-Cottonwood Forest
1175031	Cottonwood-Peachleaf Woodland
1175041	Coyote Willow Shrubland
1175051	Silver Maple-Elm-Cottonwood Forest
1175052	Silver Maple-Elm-Cottonwood Forest



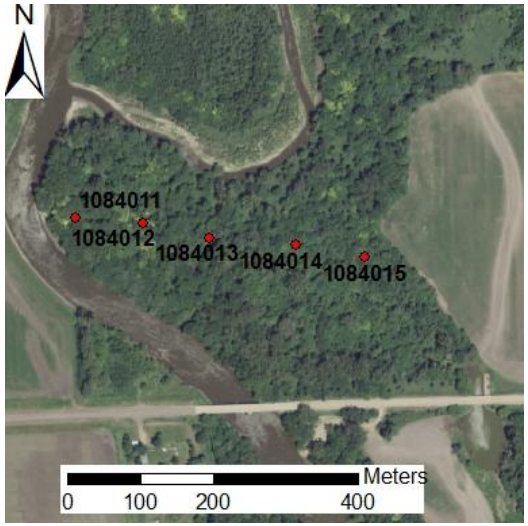


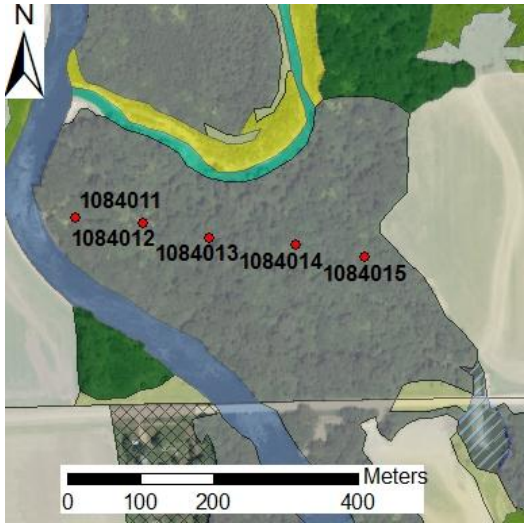
Species List

Acer negundo
Acer saccharinum
Apocynum cannabinum
Bidens frondosa
Bidens vulgata
**Bromus inermis*
Calystegia sepium
**Cannabis sativa*
Carex blanda
Carex laeviconica
Celtis occidentalis
**Chenopodium album*
Chenopodium simplex
**Convolvulus arvensis*
Cryptotaenia canadensis
Elymus virginicus
Equisetum hyemale
Festuca subverticillata
Fraxinus pennsylvanica
Geum canadense
Gleditsia triacanthos
Helianthus tuberosus
Impatiens capensis
Laportea canadensis
Leersia virginica
Lysimachia ciliata
Mentha arvensis
**Morus alba*
Oxalis sp.
Parthenocissus vitacea
Phalaris arundinacea
Pilea pumila
**Poa pratensis*
**Polygonum convolvulus*
Populus deltoides
Ribes americanum
Rudbeckia laciniata
**Rumex crispus*
Salix amygdaloides
Salix interior
Smilax herbacea
Solidago canadensis
Solidago gigantea
Teucrium canadense
Ulmus americana
**Ulmus pumila*
Urtica dioica
Vitis riparia

Site Name	Date Sampled	Segment	Subreach	UTMx	UTMy
Millsite	7/14/2010	Lower	8	693544	4737363
$w\bar{C}_i$	$w\bar{C}$	$\bar{C}_i$	$\bar{C}$	*FQIi*	*FQI*
4.51	4.51	3.50	3.73	13.10	13.59
Species #	**% Exotics**	**Basal Area**	**Trees/ha**	**Shrubs/ha**	**Shrub Cover (%)**
14	7.1	85.72	230	700	5.63

Plot #	Location Description
5	East of Richland, SD
Plot ID	**Community Type**
1084011	Silver Maple-Elm-Cottonwood Forest
1084012	Silver Maple-Elm-Cottonwood Forest
1084013	Silver Maple-Elm-Cottonwood Forest
1084014	Silver Maple-Elm-Cottonwood Forest
1084015	Silver Maple-Elm-Cottonwood Forest

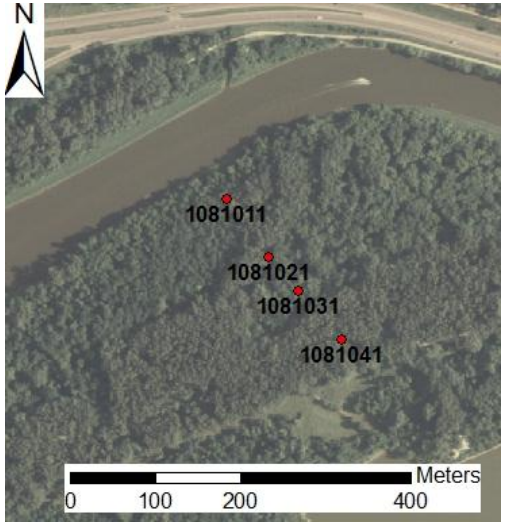


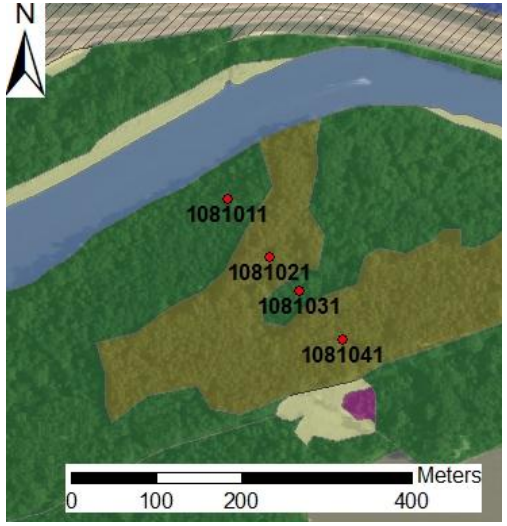


Species List

Acer saccharinum
Cryptotanenia canadensis
Elymus virginicus
Fraxinus pennsylvanica
Laportea canadensis
Leersia virginica
Maianthemum stellatum
**Morus alba*
Phalaris arundinacea
Populus deltoides
Ranunculus abortivus
Rudbeckia laciniata
Ulmus americana
Urtica dioica

Site Name	Date Sampled	Segment	Subreach	UTMx	UTMy	Plot #	Location Description
Dakota Dunes	7/21/2010	Lower	8	708742	4707402	4	West of Sioux City, IA
$w\bar{C}_i$	$w\bar{C}$	$\bar{C}_i$	$\bar{C}$	*FQIi*	*FQI*	**Plot ID**	**Community Type**
3.94	4.52	2.78	3.33	11.79	12.91	1081011	Green Ash/Boxelder Forest
Species #	**% Exotics**	**Basal Area**	**Trees/ha**	**Shrubs/ha**	**Shrub Cover (%)**	1081021	Cottonwood-Green Ash Forest
18	16.7	57.94	413	50	0.00	1081031	Green Ash/Boxelder Forest
						1081041	Cottonwood-Green Ash Forest



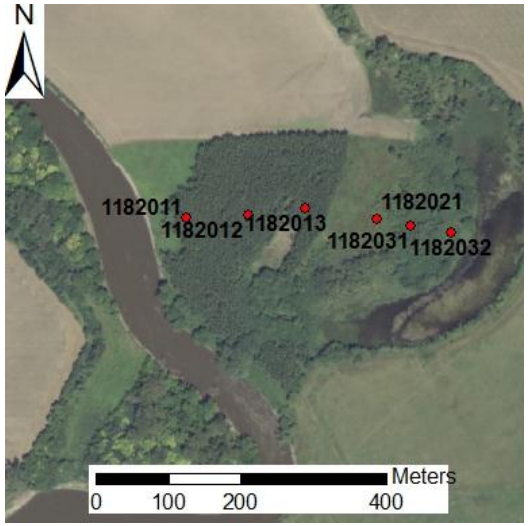


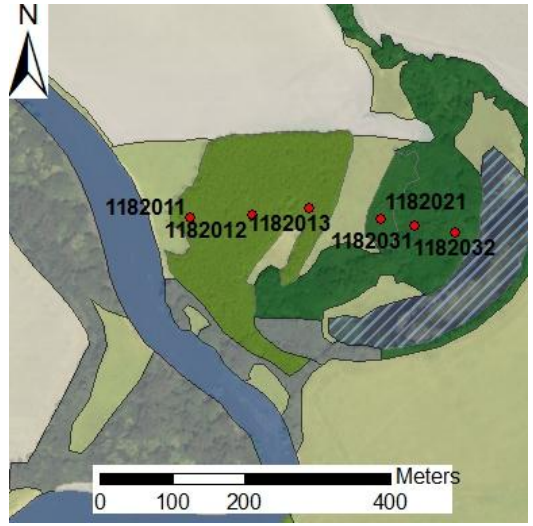
Species List

Acer negundo
Ageratina altissima
**Cannabis sativa*
Chenopodium simplex
Cornus drummondii
Fraxinus pennsylvanica
Galium aparine
**Glechoma hederacea*
Leonurus cardiaca
Oxalis sp.
Parthenocissus vitacea
Populus deltoides
Prunus virginiana
Rudbeckia laciniata
Sanicula marilandica
Solidago canadensis
Teucrium candense
Toxicodendron radicans
Viola sororia
Viola sp.

Site Name	Date Sampled	Segment	Subreach	UTMx	UTMy
Big Sioux Corridor	6/9/2011	Lower	8	700369	4726704
$w\bar{C}_i$	$w\bar{C}$	$\bar{C}_i$	$\bar{C}$	*FQIi*	*FQI*
3.42	3.67	2.95	3.61	13.86	15.32
Species #	**% Exotics**	**Basal Area**	**Trees/ha**	**Shrubs/ha**	**Shrub Cover (%)**
22	18.2	18.31	750	1625	0.00

Plot #	Location Description
6	North of Sioux City, IA
Plot ID	**Community Type**
1182011	Cottonwood-Peachleaf Woodland
1182012	Cottonwood-Peachleaf Woodland
1182013	Cottonwood-Peachleaf Woodland
1182021	Green Ash/Boxelder Forest
1182031	Green Ash/Boxelder Forest
1182032	Green Ash/Boxelder Forest



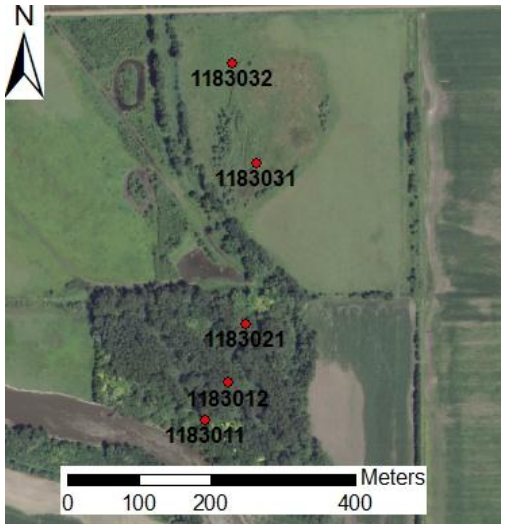


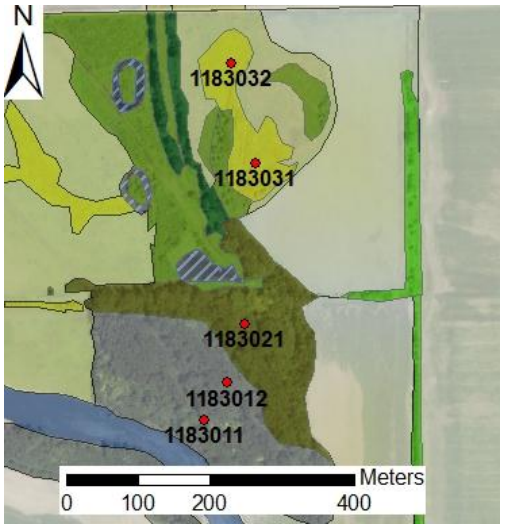
Species List

Acer negundo
Acer saccharinum
Apocynum cannabinum
Bidens vulgata
Carex laeviconica
Celtis occidentalis
**Convolvulus arvensis*
Cornus stolonifera
Fraxinus pennsylvanica
Laportea canadensis
**Morus alba*
Phalaris arundinacea
Physalis longifolia
Populus deltoides
Rudbeckia laciniata
**Rumex crispus*
Salix amygdaloides
**Sonchus arvensis*
Symphyotrichum ontarionis
Teucrium canadense
Urtica dioica
Viola sp.
Vitis riparia

Site Name	Date Sampled	Segment	Subreach	UTMx	UTMy
Lippke Wetland	6/13/2011	Lower	8	696196	4730603
$w\bar{C}_i$	$w\bar{C}$	$\bar{C}_i$	$\bar{C}$	*FQIi*	*FQI*
2.74	3.10	2.73	3.30	17.23	18.97
Species #	**% Exotics**	**Basal Area**	**Trees/ha**	**Shrubs/ha**	**Shrub Cover (%)**
40	17.5	84.41	367	22,150	18.85

Plot #	Location Description
5	Northeast of Elk Point, SD
Plot ID	**Community Type**
1183011	Silver Maple-Elm-Cottonwood Forest
1183012	Silver Maple-Elm-Cottonwood Forest
1183021	Cottonwood-Green Ash Forest
1183031	Coyote Willow Shrubland
1183032	Coyote Willow Shrubland

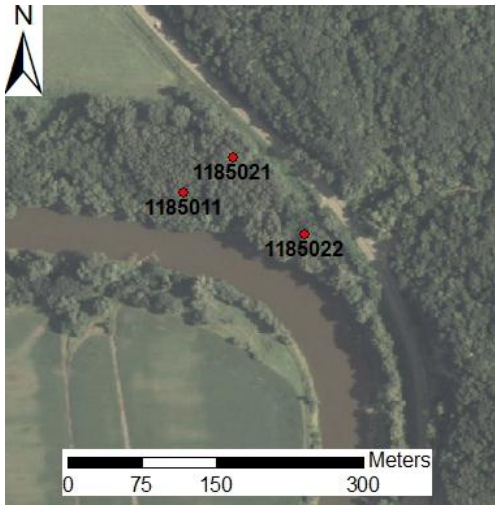


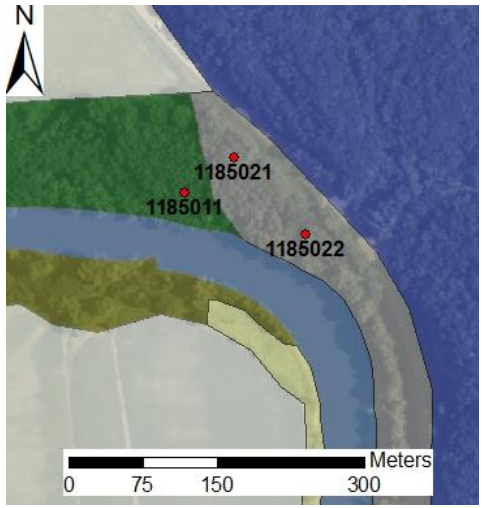


Species List

Acer negundo
Acer saccharinum
Ambrosia trifida
Amorpha fruticosa
Andropogon gerardii
Anemone canadensis
Apocynum cannabinum
Asclepias speciosa
Bidens comosa
Bidens vulgata
**Bromus inermis*
Calystegia sepium
Carex emoryi
Carex laeviconica
Celtis occidentalis
Chenopodium album
Chenopodium simplex
**Convolvulus arvensis*
Ellisia nyctelea
Fraxinus pennsylvanica
Galium aparine
Galium triflorum
Hackelia virginiana
Laportea canadensis
**Leonurus cardiaca*
Lysimachia ciliata
**Morus alba*
Oxalis sp.
Phalaris arundinacea
Pilea pumila
Polygonum amphibian var. *emersum*
Populus deltoides
Ranunculus sceleratus
Rudbeckia laciniata
**Rumex crispus*
Salix interior
Symphyotrichum ontarionis
**Taraxacum officinale*
Ulmus americana
Viola sororia
Vitis riparia

Site Name	Date Sampled	Segment	Subreach	UTMx	UTMy	Plot #	Location Description
Stone State Park Riparian	8/11/2011	Lower	8	707099	4714672	3	North of Sioux City, IA
$w\bar{C}_i$	$w\bar{C}$	$\bar{C}_i$	$\bar{C}$	*FQIi*	*FQI*	**Plot ID**	**Community Type**
4.62	4.99	3.60	4.35	25.93	28.52	1185011	Green Ash/Boxelder Forest
Species #	**% Exotics**	**Basal Area**	**Trees/ha**	**Shrubs/ha**	**Shrub Cover (%)**	1185021	Silver Maple-Elm-Cottonwood Forest
52	17.3	82.00	450	1875	0.91	1185022	Silver Maple-Elm-Cottonwood Forest





Species List

Acer negundo
Acer saccharinum
Ageratina altissima
Ambrosia trifida
Beckmannia syzigachne
**Bromus inermis*
Campanulastrum americanum
Carex blanda
Carex molesta
**Catalpa speciosa*
Celtis occidentalis
**Chenopodium album*
**Cirsium vulgare*
Conyza canadensis
Cornus drummondii
Cryptotaenia canadensis
Elymus virginicus
Erigeron philadelphicus
Fraxinus pennsylvanica
Hackelia deflexa
Hydrophyllum virginianum
Impatiens capensis
Juglans nigra
Laportea canadensis
Leersia virginica
Lysimachia ciliata
Maianthemum racemosum
Maianthemum stellatum
Menispermum canadense
**Morus alba*
**Nepeta cataria*
Parthenocissus quinquefolia
Plantago rugelii
Populus deltoides
Ribes missouriense
Rubus occidentalis
Rudbeckia laciniata
Sambucus nigra ssp. *canadensis*
Sanicula marilandica
**Setaria pumila*
Smilax herbacea
Smilax tamnoides
Solanum ptycanthum
Solidago canadensis
Solidago gigantea
Symphyotrichum ontarionis
**Taraxacum officinale*
Toxicodendron radicans
Ulmus americana
Ulmus rubra
**Verbascum thapsus*
Viola sp.
Vitis riparia

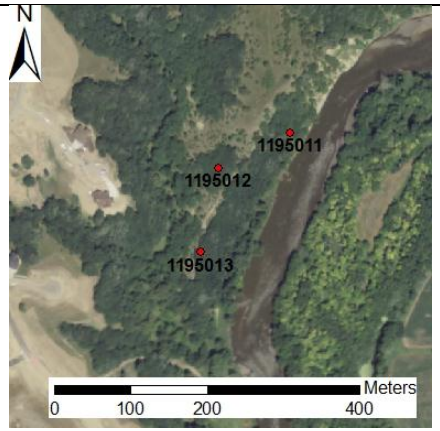
Appendix A.2. GIS landcover legend.

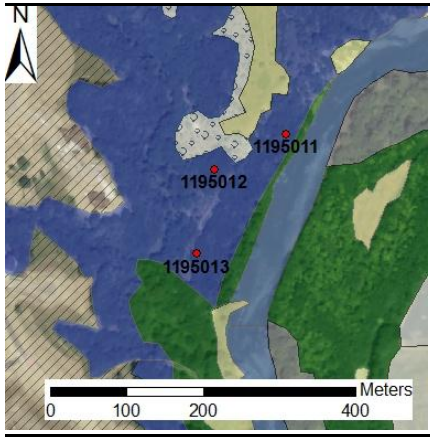
Land Cover Classes

- Big Sioux River
- Coyote Willow Floodplain Shrubland
- Cottonwood/Willow Floodplain Woodland
- Mature Cottonwood Forest
- Silver Maple/Elm/Cottonwood Forest
- Green Ash/Boxelder Forest
- Cottonwood/Green Ash Forest
- Upland Forest
- Upland Woodland
- Upland Shrubland
- Grassland
- Wetland
- Urban Area
- Lakes
- Farm Woodlots
- Farmstead
- Cropland
- Tributaries and Oxbow lakes
- Non-vegetated Sandbar

Appendix A.3. Site level summary data for 5 upland forest sites along the Big Sioux River. A legend explaining the GIS land cover classes is provided at the end of Appendix A.2.

Site Name	Date Sampled	Segment	Subreach	UTMx	UTMy	Plot #	Location Description
Arbor's Edge	8/19/2011	Upland	9	696116	4712135	3	East of Sioux Falls, SD
$w\bar{C}_i$	$w\bar{C}$	$\bar{C}_i$	$\bar{C}$	*FQIi*	*FQI*	**Plot ID**	
2.37	4.26	3.27	4.32	25.78	29.61	1195011	
Species #	**% Exotics**	**Basal Area**	**Trees/ha**	**Shrubs/ha**	**Shrub Cover (%)**	1195012	
62	24.2	51.57	583	950	11.25	1195013	

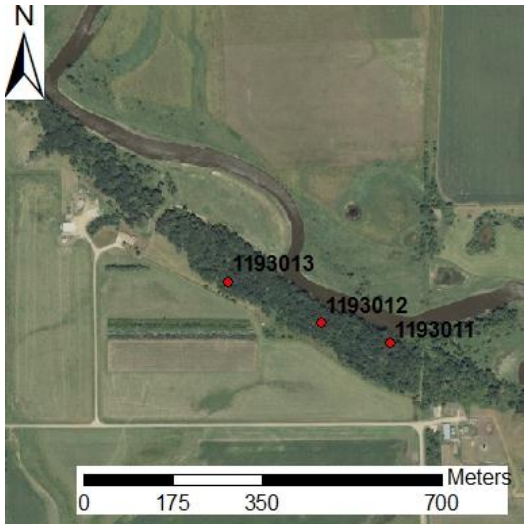


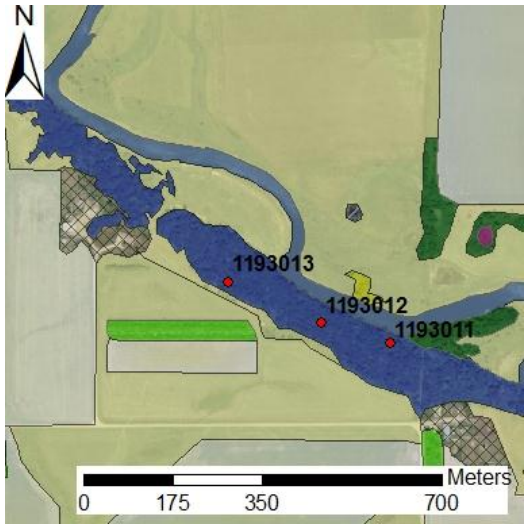


Species List

Acalypha rhomboidea
Acer negundo
Ageratina altissima
**Alliaria petiolata*
Ambrosia psilostachya
Apocynum cannabinum
Aquilegia canadensis
Botrychium virginianum
Bouteloua curtipendula
**Bromus inermis*
Campanulastrum americanum
Carex blanda
Carex tenera
Celtis occidentalis
**Chenopodium album*
Chenopodium simplex
**Cirsium vulgare*
Dichanthelium oligosanthes
Elymus canadensis
Elymus villosus
Erigeron philadelphicus
Fraxinus pennsylvanica
Galium triflorum
**Glechoma hederacea*
Gleditsia triacanthos
Hackelia deflexa
**Hesperis matronalis*
Hydrophyllum virginianum
Impatiens capensis
Juniperus virginana
Laportea canadensis
**Leonurus cardiaca*
Maianthemum stellatum
Muhlenbergia racemosa
**Nepeta cataria*
Oxalis stricta
Parthenocissus vitacea
Phryma leptostachya
**Poa pratensis*
Quercus macrocarpa
Ranunculus abortivus
**Rhamnus cathartica*
Ribes americanum
Ribes missouriense
Sanicula marilandica
Schizachyrium scoparium
**Setaria pumila*
Smilax herbacea
Solanum ptycanthum
Solidago gigantea
Sorghastrum nutans
**Stellaria media*
Symphoricarpos occidentalis
**Taraxacum officinale*
**Trifolium repens*
Ulmus americana
Ulmus rubra
**Verbascum thapsus*
Verbena stricta
Vernonia fasciculata
Viola sororia
Viola sp.
Vitis riparia

Site Name	Date Sampled	Segment	Subreach	UTMx	UTMy	Plot #	Location Description
Heinemann's Site	7/20/2011	Upland	9	696116	4712135	3	Northeast of Flandreau, SD
$w\bar{C}_i$	$w\bar{C}$	$\bar{C}_i$	$\bar{C}$	*FQIi*	*FQI*	**Plot ID**	
4.07	5.21	3.90	4.32	17.89	18.81	1193011	
Species #	**% Exotics**	**Basal Area**	**Trees/ha**	**Shrubs/ha**	**Shrub Cover (%)**	1193012	
21	9.5	43.38	4.17	1600	6.06	1193013	



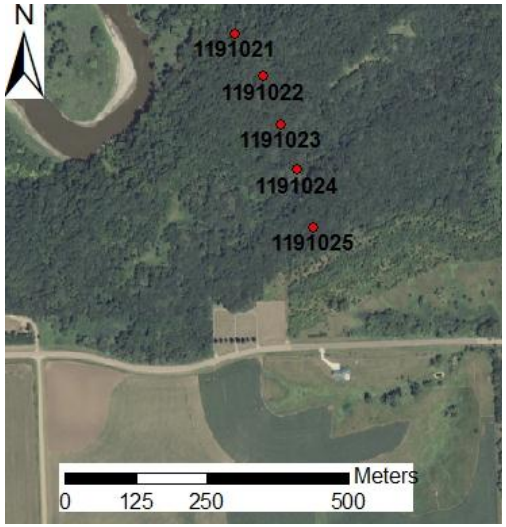


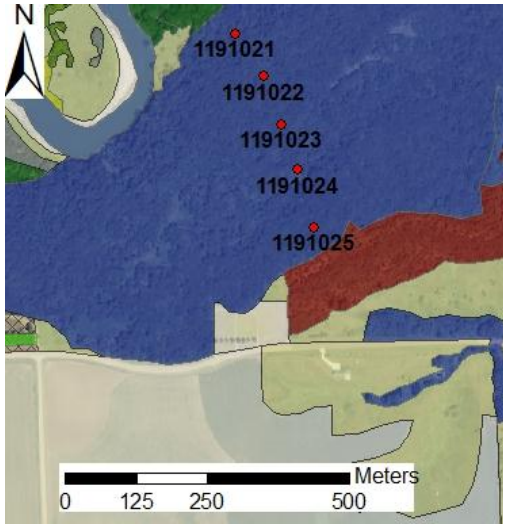
Species List

Aquilegia canadensis
**Arctium minus*
Elymus villosus
Fraxinus pennsylvanica
Galium boreale
Hackelia virginiana
Hydrophyllum virginianum
Laportea canadensis
Maianthemum stellatum
Oxalis sp.
Parthenocissus quinquefolia
Pilea pumila
Quercus macrocarpa
**Rhamnus cathartica*
Ribes missouriense
Sinapis sp.
Smilax ecirrhata
Solanum ptycanthum
Symphoricarpos occidentalis
Thalictrum dasycarpum
Ulmus rubra
Urtica dioica
Viola canadensis

Site Name	Date Sampled	Segment	Subreach	UTMx	UTMy	Plot #	Location Description
Fish GPA Upland	7/20/2011	Upland	9	702634	4788128	5	West of Fairview, SD

$w\bar{C}_i$	$w\bar{C}$	$\bar{C}_i$	$\bar{C}$	*FQIi*	*FQI*	Plot ID	
7.44	7.62	5.65	5.79	35.73	36.19	1191021	1191024
Species #	**% Exotics**	**Basal Area**	**Trees/ha**	**Shrubs/ha**	**Shrub Cover (%)**	1191022	1191025
40	2.5	42.97	520	6750	15.79	1191023	



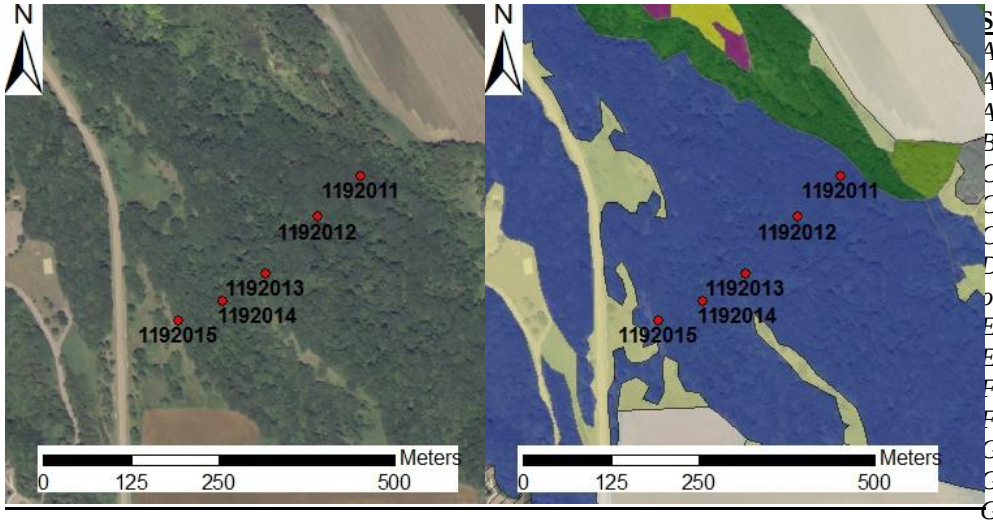


Species List

Acer negundo
Ageratina altissima
Arisaema triphyllum
Botrychium virginianum
Carex blanda
Celtis occidentalis
Cryptotaenia canadensis
Echinocystis lobata
Elymus hystrix
Elymus villosus
Festuca subverticillata
Fraxinus pennsylvanica
Galium aparine
Galium triflorum
Gymnocladus dioicus
Hydrophyllum virginianum
Juglans nigra
Juniperus virginana
Lactuca sp.
Laportea canadensis
Maianthemum stellatum
Osmorhiza claytonii
Ostrya virginiana
Parietaria pensylvanica
Parthenocissus quinquefolia
Phryma leptostachya
Prunus virginiana
Quercus macrocarpa
**Rhamnus cathartica*
Ribes missouriense
Sanguinaria canadensis
Sanicula marilandica
Silene stellata
Smilax ecirrhata
Smilax tamnoides
Solidago flexicaulis
Tilia americana
Ulmus rubra
Urtica dioica
Viola sp.
Vitis riparia
Zanthoxylum americanum

Site Name	Date Sampled	Segment	Subreach	UTMx	UTMy	Plot #	Location Description
Mckee GPA Upland	7/14/2011	Upland	9	697834	4788540	5	South of Canton, SD

$w\bar{C}_i$	$w\bar{C}$	$\bar{C}_i$	$\bar{C}$	*FQIi*	*FQI*	Plot ID	
6.58	6.62	5.80	6.07	38.91	39.80	1192011	1192014
Species #	**% Exotics**	**Basal Area**	**Trees/ha**	**Shrubs/ha**	**Shrub Cover (%)**	1192012	1192015
45	4.4	62.37	420	1000	6.44	1192013	



Species List

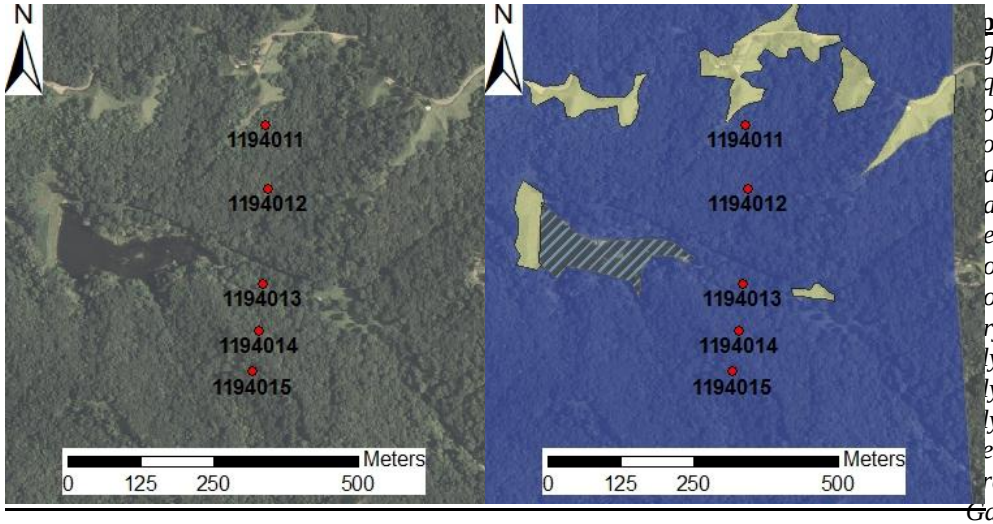
Ageratina altissima
Anemone virginiana
Aquilegia canadensis
Botrychium virginianum
Carex assiniboinensis
Celtis occidentalis
Cryptotaenia canadensis
Dichanthelium oligosanthes
Elymus hystrix
Elymus villosus
Festuca subverticillata
Fraxinus pennsylvanica
Galium boreale
Galium triflorum
Geum canadense
Gymnocladus dioicus
Hydrophyllum virginianum
Juglans nigra
Juniperus virginana
Laportea canadensis
Maianthemum racemosum
Maianthemum stellatum
Menispermum canadense
Osmorhiza claytonii
Ostrya virginiana
Parthenocissus quinquefolia
Phryma leptostachya
Pilea pumila
Quercus macrocarpa
Ranunculus abortivus
**Rhamnus cathartica*
Rhus glabra
Ribes missouriense
Sanguinaria canadensis
Sanicula marilandica
Silene stellata
Smilax ecirrhata
Smilax tamnoides
Sorghastrum nutans
**Taraxacum officinale*
Tilia americana
Ulmus rubra
Urtica dioica
Viola sp.
Vitis riparia
Zanthoxylum americanum

Site Name	Date Sampled	Segment	Subreach	UTMx	UTMy	Plot #	Location Description
Stone S.P. Upland	8/3/2011	Upland	9	707794	4714201	5	North of Sioux City, IA

$w\bar{C}_i$	$w\bar{C}$	$\bar{C}_i$	$\bar{C}$	*FQIi*	*FQI*
5.08	5.28	5.42	5.64	39.11	39.88

Species #	% Exotics	Basal Area	Trees/ha	Shrubs/ha	Shrub Cover (%)
52	3.9	57.38	520	583	3.90

Plot ID	
1194011	1194014
1194012	1194015
1194013	



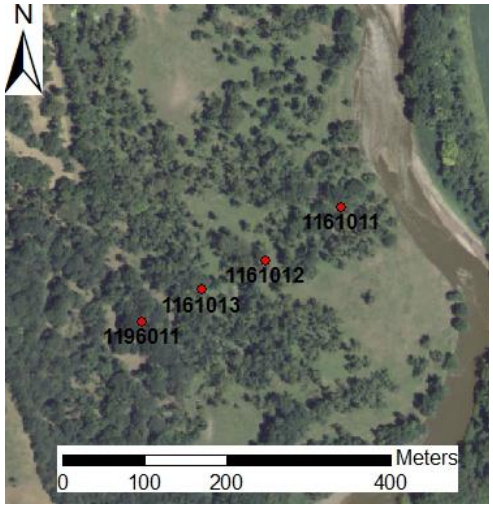
pecies List

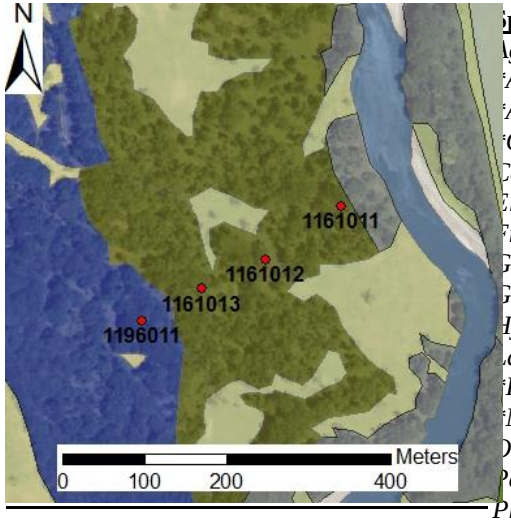
geratina altissima
quilegia canadensis
otrychium virginianum
outeloua curtipendula
arex blanda
arex sp.
eltis occidentalis
ornus amomum
ornus drummondii
ryptotaenia canadensis
lymus canadensis
lymus hystrix
lymus villosus
estuca subverticillata
raxinus pennsylvanica
Galium aparine
Galium boreale
Galium triflorum
Geum canadense
**Glechoma hederacea*
Gleditsia triacanthos
Gymnocladus dioicus
Hydrophyllum virginianum
Juglans nigra
Laportea canadensis
Leersia virginica
Maianthemum stellatum
Menispermum canadense
Monarda fistulosa
Muhlenbergia frondosa
Osmorhiza claytonii
Ostrya virginiana
Parthenocissus quinquefolia
Phryma leptostachya
Prunus americana
Quercus macrocarpa
**Rhamnus cathartica*
Ribes missouriense
Rubus occidentalis
Sanguinaria canadensis
Sanicula marilandica
Schizachyrium scoparium
Smilax ecirrhata
Smilax herbacea
Smilax tamnoides
Teucrium canadense
Tilia americana
Toxicodendron radicans
Ulmus americana
Ulmus rubra
Viola sororia
Viola sp.
Vitis riparia
Zanthoxylum americanum

Site Name	Date Sampled	Segment	Subreach	UTMx	UTMy	Plot #	Location Description
Oak Ridge GPA Upland	6/20/2011	Upland	9	705506	4781986	1	North of Hudson, SD

$w\bar{C}_i$	$w\bar{C}$	$\bar{C}_i$	$\bar{C}$	*FQIi*	*FQI*	Plot ID
4.85	5.09	2.96	3.83	14.8	16.26	1196011

Species #	% Exotics	Basal Area	Trees/ha	Shrubs/ha	Shrub Cover (%)
25	28	171.64	500	0	0.00





Species List

Ageratina altissima
*Alliaria petiolata
*Arctium minus
*Cannabis sativa
Celtis occidentalis
Ellisia nyctelea
Fraxinus pennsylvanica
Galium aparine
Galium triflorum
Hydrophyllum virginianum
Laportea canadensis
*Leonurus cardiaca
*Morus alba
Ostrya virginiana
Parthenocissus vitacea
Phalaris arundinacea
Pilea pumila
Quercus macrocarpa
**Rhamnus cathartica*
Ribes missouriense
Ulmus rubra
Urtica dioica
Viola sororia
Viola sp.
Vitis riparia
Zanthoxylum americanum

Chapter 2: The Interactive Effects of Climatic Variation and Land Use Change on Increased Streamflow and Channel Adjustment within an Agricultural Watershed

Introduction

Rivers are often viewed as the report card of a drainage basin as the effects of surrounding land uses across multiple spatial and temporal scales influence the overall health and functionality of the riverine ecosystem (Hynes 1975; Vannote et al. 1980). Trends toward increased pollution, channel degradation, and loss of biological diversity have all increased since Euro-American settlers cleared and cultivated the native landscape and altered river ecosystems through the implementation of numerous channel management techniques including dams, levees, bank stabilization measures, and channelization (Poff et al. 1997). These modifications have been conducted along a majority of the major rivers worldwide and have effectively limited the dynamic nature of these riverine systems (Dynesius and Nilsson 1994; Graf 1999; Nilsson et al. 2005). It is this dynamic nature that is critical to maintaining the health and functionality of adjacent ecosystems as actively migrating channels and meander bend cutoffs provide biological diversity and landscape heterogeneity to riparian corridors and aquatic habitats (Hupp and Osterkamp 1996; Scott et al. 1996; Greco 1999).

While instream channel management structures may cause the most evident and direct impacts on riverine ecosystems, changes in adjacent land use within the watershed may be more detrimental and long lasting. Land use change occurs across much broader spatial and temporal scales, influencing basin wide drainage patterns and altering natural flow characteristics. Changing land use patterns and the resulting environmental impacts can take years to manifest and because of this, are often not perceived as a management problem (Harding et al. 1998; Allan 2004). Further complicating these complex issues, land use changes often occur concurrently with climate changes, with the interactive effects of these basin wide alterations leading to dramatically different environments than were common in the pre-Columbian era.

Nowhere has large scale landscape alteration been more evident than in the U.S. upper Midwest, where large tracts of native perennial vegetation were removed and land was converted for agricultural use since the onset of Euro-American settlement (Curtis 1956). While initial conversion of the landscape occurred over 100 years ago, landscape alteration has continued throughout the region, especially with the advent of modern agriculture techniques and the resulting shift from small grain/perennial cover crop agroecosystems to annual row-crop cultivation (Schilling and Libra 2003; Zhang and Schilling 2006). Annual row-crops systems are dominated by corn (*Zea mays* L.) and soybean (*Glycine max* (L.), Merr) production, and these crops now represent the primary land use within agricultural systems of the upper Midwest (Donner 2003; Zhang and Schilling 2006).

Numerous studies have documented the negative consequences of agricultural intensification, particularly row-crop agriculture, within riverine drainage basins. These impacts include declines in water quality, loss of species diversity, and increased hydrologic alteration resulting in the disruption and loss of the natural flow regime (Hill 1978; Lenat 1984; Cooper 1993; Richards et al. 1996; Roth et al. 1996; Johnson et al. 1997; Poff et al. 1997; Wang 1997; Sponseller et al. 2001; Gergel et al. 2002; Allan 2004). Changes in river hydrology due agricultural intensification are variable but usually result in changes in rainwater infiltration and increased streamflow (Knox 1977, 2001; Schilling and Libra 2003; Zhang and Schilling 2006; Raymond et al. 2008). These increases in streamflow occur through several pathways. The first pathway represents changes in the basin wide evapotranspiration (ET) rates depending on the dominant vegetation type (i.e., native cover, perennial crops, annual crops) within the watershed. Different types of vegetation transpire at different rates at different times of the year. Dinnes (2004) found in Iowa that perennial cool and warm season vegetation had an approximately 72% greater annual water demand than annual row-crops. Similarly, Brye et al. (2000) found that perennial grasses in a native prairie environment had higher ET, maintained greater soil moisture

content, and had significantly less drainage through the soil profile than cultivated corn. These results suggest that at a basin wide scale, a shift in land cover from small grains and perennial vegetation to an annual row-crops agricultural system would increase available surplus water resulting in increased streamflow over time.

The second pathway by which agricultural intensification affects streamflow patterns is through improved drainage efficiency through the utilization of an extensive network of surface drainage ditches and subsurface drainage tile. These land use practices have been used extensively throughout the Midwest as a way to increase the acreage available for cultivation by lowering the water table and draining soils that are seasonally or perennially wet, as well as allowing for earlier planting and providing the farmer more control over field operations (Spaling and Smit 1995; Zucker and Brown 1998). Historically, agricultural drainage (specifically subsurface drainage tile) was used only to strategically target temporary and seasonally wet areas in cultivated fields where water tended to pond (i.e., ephemeral wetlands). Recently, however, modern subsurface drainage tile has been improved and designed to lower the water table across the entire field (i.e., pattern tiling) in an attempt to provide uniform crop yields, which in turn encourages the planting of high-value crops like corn and soybeans (Hubbard 2005; Blann et al. 2009). An improved drainage network increases drainage area, density, and connectiveness between hydrologically isolated basins, resulting in increased streamflow as water that would otherwise be retained on the landscape is routed into streams and rivers more quickly (Leopold 1968; Poff et al. 1997; Magner et al. 2004).

The cumulative effect of agricultural intensification through these two pathways has the potential to drastically affect basin wide hydrology over time. One method that has been used recently to examine landscape level changes in agricultural cropping systems through time is the annual county and state level crop statistics available from the National Agricultural Statistics Service (NASS 2011). The NASS data provides current and historic information on the

proportion of annual row-crops, perennial cover crops, and other small grains within the basin and can be a useful tool for analyzing historic land use change and has the potential to be used as a possible surrogate for estimating the degree of agricultural drainage usage in a basin (Schilling and Libra 2003; Schilling and Helmers 2008).

There is a growing need to understand the extent to which changing streamflow regimes in the upper Midwest can be attributable to land use change, climatic variability or the interactive effects of the two. Observed increases in streamflow over the second half of the 20th Century within agriculturally dominated watersheds of the upper Midwest have been disproportionately greater, for the most part, than increases in annual precipitation (Schilling and Libra 2003; Lenhart et al. 2011a). Increasing streamflow within these watersheds has been explained as being indicative of changes in basin wide water use, land use, or drainage patterns and not climate change (Schilling and Libra 2003; Schilling 2004; Raymond et al. 2008). Even in the absence of substantial increases in annual precipitation, however, climate change may still be an important driver of increased discharge as changes in the seasonality, intensity, and duration of precipitation may affect streamflow patterns. A changing climatic regime may also influence the basin wide water budget, even in the absence of increased annual precipitation, as variation in temperature may influence potential evapotranspiration (PET) resulting in excess surplus water available to be discharged (Tomer and Schilling 2009). Overall, the interactive effects of climate change and land use change appear to be potentially important drivers of increasing streamflow within agricultural watersheds of the upper Midwest. Therefore, it is necessary to examine the interactions of all components of the hydrologic cycle to understand how a watershed may continue to respond to future climate changes and ongoing land use changes (Tomer and Schilling 2009).

Determining why increases in streamflow have occurred is only one part of understanding the basin wide environmental impacts associated with heavily modified

agricultural watersheds. A number of studies have analyzed the effects of increased discharge on water quality, sediment transport, and aquatic biota within agricultural watersheds (Richards et al. 1996; Roth et al. 1996; Allan 2004). Often under-emphasized is the role of increased discharge on stream geomorphic change and compensatory channel adjustments as the river seeks to establish a new dynamic equilibrium between the movement of water and the movement of sediment (Dunne and Leopold 1978; Poff et al. 1997; Blann et al. 2009). Natural channel adjustments to increased discharge include increased bank erosion, channel widening, channel incision, channel straightening, and decreased stream length (Hammer 1972; Knox 1987; Brookes 1988; Faulkner 1998; Fitzpatrick et al. 1999). Several studies have observed these channel adjustments related to increased streamflow within upper Midwestern agricultural watersheds, specifically in Wisconsin (Knox 1977; Trimble 1983; Fitzpatrick et al. 1999), Iowa (Odgaard 1987), and Minnesota (Lenhart et al. 2011b). Understanding and observing these channel adjustments and other geomorphic processes in agricultural watersheds has been difficult, historically, due to the various spatial and temporal scales at which they occur. Recently, analysis of historic aerial photography through modern GIS technology has been used to improve the understanding of channel planform adjustment and other spatiotemporal changes in channel patterns and processes on a variety of rivers worldwide (Brizga and Finlayson 1990; Gurnell et al. 1997; Micheli et al. 2004; Miller and Friedman 2009).

Here, I utilize similar methods to quantify historic changes in channel planform adjustments within the agricultural watershed of the Big Sioux River. The Big Sioux is a dynamic, relatively unregulated river (Miller and Nudds 1996) providing key ecosystem services to the people of eastern South Dakota and northwestern Iowa. The cumulative effects of agricultural and urban land uses throughout the basin have contributed to a number of water quality issues during the last 50 years, with the river being considered one of the most degraded waterways in the United States during the 1960's due to municipal waste water and agricultural

non-point source pollution (USEPA 1978; Dieterman and Berry 1998). Currently, a number of studies have been or are being completed by the South Dakota Department of Environment and Natural Resources (SDDENR) and U.S. Geological Survey (USGS) to assess current water quality and to examine ways to meet the Total Maximum Daily Load (TMDL) requirements, as well as to implement several bank stabilization projects designed to reduce excessive erosion and sediment transport throughout the basin (Milewski et al. 2001; Bankhead and Simon 2009; SDDENR 2010). These studies have focused largely on finer scale, site-specific processes affecting TMDL levels and bank stability and have failed, in most part, to analyze the influence of landscape level changes in basin land use and the potential interactive effects of climatic variability.

Little is known about the role of increased streamflow on channel dynamics within the Big Sioux River. Many watersheds throughout the upper Midwest underwent extensive drainage modification in the latter half of the 20th century as perennial/small grain cover crop agricultural systems were converted to annual row-crop (corn and soybean) monocultures. This study will determine if the geomorphic trends (i.e., increases in channel width, incision and decreased stream length) observed in other watersheds throughout the upper Midwest (i.e., Odgaard 1987; Lenhart et al. 2011b) have occurred on the Big Sioux River in recent decades. Additionally, this study will also attempt to disentangle the relative effects of land use and climatic changes on streamflow and its effects on channel adjustments. The Big Sioux basin lies farther west than most of the previously studied watersheds and has lagged behind these watersheds with regard to agricultural intensification and drainage alteration. This study will yield a better scientific understanding of geomorphic patterns on the Big Sioux and will highlight potential effects of current land use practices and recent climatic trends on channel adjustment within the basin. Specific objectives of this project are to:

1. Quantify historic changes in channel morphology in the Big Sioux River between 1938 and 2008.
2. Examine the relative direct effects of land use change and climatic variation on increasing streamflow within the basin and assess the indirect effects of each on channel adjustments.

Methods

Study Area

The Big Sioux River flows through eastern South Dakota and northwestern Iowa with the southern portion of the river forming the border between the states (Figure 2.1). With its origins in southern Roberts Co., South Dakota, the Big Sioux flows 676 km southward to its mouth at the Missouri River near Sioux City, Iowa, draining 22,550 km^2 of Minnesota, Iowa, and South Dakota (Westin and Malo 1978; SDDENR 2010). Along its course, the river flows through several population centers (e.g., Watertown, Brookings, and Sioux Falls, South Dakota, and Sioux City, Iowa) within an otherwise agriculturally dominated matrix. The Big Sioux River basin is the most highly populated basin in South Dakota, with its close proximity to both urban and agricultural areas contributing to a number of declines in water quality during the last 50 years (Milewski et al. 2001). This study was conducted along the lower third of the Big Sioux, a 220 km stretch of river extending from south of Brandon, South Dakota, to Sioux City, Iowa. The river valley widens and local relief increases through this reach, with an approximate gradient of 0.452 m/km. Compared to many other Great Plains rivers, the Big Sioux is relatively natural and free-flowing, with erosive and depositional forces helping to create a variety of aquatic and riparian habitats that support a diverse array of wildlife and fish species. The river is partially constrained with several areas of bank stabilization and channelization as well as a few run-of-the-river dams occurring within the study area.

The climate of eastern South Dakota is sub-humid, typified by alternating cycles of wet and dry years, with mean annual precipitation varying between 51 and 64 cm (Bryce et al. 1998). The dominant soil types are coarse grained Mollisols that are derived from glacial outwash or alluvial sediments. A detailed report examining the underlying geology of the study area in South Dakota is available from McCormick and Hammond (2004).

Channel Adjustments Observations

Historic aerial photographs of the study area were examined from 1938, 1949-51, 1962, 1976, 1984, 1994-96, 2002, and 2008 (Table 2.2). Imagery was obtained from a variety of sources, with black-and-white digital county mosaic orthophotography from 1938, 1949-51, and 1962 and color infrared imagery from 2002 obtained from the Iowa Department of Natural Resources GIS Library (Iowa DNR 2011). Non-rectified imagery from 1976, 1984, and 1995 were obtained as digital scans from the USDA Aerial Photography Field Office (Salt Lake City, Utah). 2008 National Agricultural Imagery Project (NAIP) county mosaic orthophotographs were obtained from the USDA NRCS Geospatial Data Gateway (USDA, NRCS 2011). For imagery that spanned multiple years, a midpoint year was created and used for all analysis (e.g., 1950 represents 1949-51). The projection for this imagery and all subsequent geodatabases and shapefiles in ArcGIS 10.0 was NAD 1983 UTM Zone 14N. Original photo image scales ranged from 1:20,000 to 1:58,000. Photography dates ranged from 17 April to 28 November. Daily river flows ranged from 3.03 to 133.09 m^3/s across photography dates, with historic flow exceedances (i.e., probability of flow being equaled or exceeded, estimated between 1928-2008) ranging from 0.16 to 0.80. Using the 2008 NAIP orthophotos as a base map, non-georeferenced aerial photos were georectified in ArcGIS 10.0 to put them on a common scale and geographic reference. An average of 12 ground control points was used to georectify each image, with control points concentrated around the area of interest within the floodplain and including such features as trees, grain silos, bridges, corners of buildings, and road intersections. Because the

control points and interpretation were centered within the low relief floodplain area, I did not correct for topographic differences in the rectification process. First and second-order transformations were used for rectification with the average total root mean square error (RMS) value for a rectified image ranging from 0.8 to 3.0 m.

Channel dynamics were quantified by estimating changes in channel planform area, width, and position between dates from the time series of historic aerial photographs. Interpretation and delineation of the active channel area was done by creating a channel polygon for each photo date across the entire study reach at a scale of 1:2000. The active channel area was used as it could be consistently defined across all photo dates, with the channel-floodplain boundary defined by an increase in the density of vegetation and a break in the slope (Osterkamp and Hedman 1982; Miller and Friedman 2009). This area included the channel as well as non-vegetated island features and sandbars. Extensive training was conducted beforehand and a list of digitizing protocols was developed to ensure consistency and accuracy in identifying the active channel area. The channel centerline was also delineated at 1:2000 scale, representing the mid-point of the active channel area for each photo date. This centerline provided a standardized estimate of channel length and sinuosity (i.e., river length/valley length) for each photo date.

Discharge Data

Daily discharge data were analyzed from four USGS gauging stations within the Big Sioux River watershed (Figure 2.1). These gauging stations were used because of their location within or just upstream from the study area and for their continuous period of record dating back to the 1950's and earlier (Table 2.1). The Indicators of Hydrologic Alteration (IHA) suite of statistical analysis software was used to examine how streamflow within the Big Sioux basin changed between the pre-(1950-1979) and post-1980 (1980-2008) time periods (reasoning for two time periods provided in results; Richter et al. 1996). The IHA can be used to quantify

ecologically significant changes in discharge either through time (continuously) or by comparing two time periods before and after a chosen alteration (e.g., a dam) has occurred. The software calculates a total of 67 statistical parameters which are subdivided into two groups, the IHA parameters and Environmental Flow Components (EFC). The IHA parameters include metrics of streamflow magnitude, duration, frequency, timing, and rate of change. The EFC provides more ecologically meaningful metrics, including low flows, extreme low flows, high flow pulses, small floods, and large floods. Non-parametric (percentile) statistics were used for all IHA calculations since hydrologic datasets tend to be skewed and thus do not meet the normality requirements of parametric statistics.

Streamflow-to-precipitation (Q:P) ratios were calculated to assess how the responsiveness of the watershed to precipitation has changed through time, potentially indicating effects of land use change on hydrologic processes. All else being equal, disproportionate increases in discharge relative to precipitation represent greater runoff per unit of precipitation and are indicative of a "flashier" system. The Akron, Iowa, gauge was used for this analysis as it represents the most downstream gauge in the basin and had the longest continuous period of record, dating back to the 1920's. Monthly precipitation values were obtained from the climate division data, provided by the South Dakota State Climatologist office (SDSC 2011). An area-weighted version of the climate division data was calculated as the Big Sioux basin intercepts five climate divisions (three in South Dakota, and one each in Iowa and Minnesota; Figure 2.1). Cumulative, basin wide precipitation values were calculated both on an annual and seasonal basis and were converted to volume (e.g., m^3) by multiplying values by the upstream drainage basin area. Mean precipitation volumes over the basin were then compared to mean annual and seasonal discharge values creating the Q:P ratio. The Mann-Whitney *U* test was used to compare annual and seasonal median values of the Q:P ratios between two time periods (i.e., 1950-1979 and 1980-2008). Seasons were defined as winter (December, January, and February), spring

(March, April, and May), summer (June, July, and August) and fall (September, October, and November).

Ecohydrologic Analysis

An ecohydrologic analysis was conducted using methods from Tomer and Schilling (2009) to assess the relative contributions of land use change and climate change on streamflow patterns within the Big Sioux basin. Initially, an estimate of basin wide annual potential evapotranspiration (PET) was calculated using the Thornthwaite method (Thornthwaite 1948). While not the most accurate method for calculating PET, the Thornthwaite method has still been shown to provide reasonably accurate estimates of PET through time (Palmer and Havens 1958). This method was also chosen because the data required (i.e., records of solar radiation, humidity, wind, etc.) for other more robust PET methods (i.e., Hargreaves method, Penman method) were not available on a basin wide scale and would not extend back to the beginning of the period of record. The simple annual water budget equation was expressed as:

$$PPT = ET + Q + D + \Delta S$$

where precipitation (PPT) can be accounted for as the sum of actual evapotranspiration (ET), annual discharge (Q), deep groundwater losses (D) and the change in water storage (ΔS) on the landscape. Given the coarse (basin wide) level of my analysis and the fact the several types of underlying geology occur throughout the basin, I assumed D to be zero (as did Tomer and Schilling 2009). Additionally, changes in soil water storage (ΔS) were also regarded as zero (even though they may be substantial) given the large scale and the inability to accurately provide an estimate throughout the basin. Hence, ET was estimated as PPT - Q. By ignoring these variables, error is introduced into the model and, over time, will lead to an overestimation of ET. Even with this potential overestimation of ET, Tomer and Schilling (2009) regarded the error as being essentially constant in time and therefore having little impact on discerning temporal trends

in changing PPT, Q, and ET values and the influences of these values on the ecohydrologic analysis. Additionally, variation between years was limited as annual values were averaged over photography date time intervals (e.g., 1930-38, 1939-50, 1951-62, 1963-76, 1977-84, 1985-1995, 1996-02, and 2002-08).

Several variables were calculated from this ecohydrologic analysis and were used to examine the relative effects of climate change and land use change on changing streamflow patterns within the basin (Tomer and Schilling 2009). The main components of this analysis are calculating the excess yearly proportions of available water (denoted as P_{ex} = (PPT-ET)/PPT) and energy (denoted as E_{ex} = (PET-ET)/PET) and plotting them against one another, as shifts in these parameters through time are indicative of changes in climate, vegetation management, and/or landscape alterations (Tomer and Schilling 2009). I also examined temporal trends in annual PPT:PET ratios, as change in this ratio through time has been shown to be an effective indicator of the influence of climate change within a basin. Reasons for this are based on the conceptual foundation of the ecohydrologic approach in that land use change directly affects ET but not PPT or PET (although indirect effects could occur at regional scales). Overall, these shifts are best understood through the use of a conceptual model that was adapted from Tomer and Schilling (2009; Figure 2.2). Changes in land use would result in shifts toward increased or decreased P_{ex} and E_{ex} in the same direction, while changes in climate would result in increased P_{ex} and decreased E_{ex} (due to PPT/PET increases) or decreased P_{ex} and increased E_{ex} (due to PPT/PET decreases; Tomer and Schilling 2009). Changes parallel along either axis indicate that the influence of climatic variation and land use change are approximately similar. A complete description of the methodology used in this analysis can be found in Tomer and Schilling (2009).

Land Use Data

Annual county agricultural statistics for acres planted between 1928 and 2008 for portions of the 24 counties within the Big Sioux basin were obtained from the National Agricultural Statistics Service (NASS) database (NASS 2011). Of particular concern was the amount of corn and soybean acres planted each year, since these annual row-crops may provide a surrogate for the degree of hydrologic alteration of the landscape. An area-weighted estimate of annual row-crop area for the basin was created for each year using the county cropland statistics and the proportion of each county contained within the watershed area. Areas of perennial/annual cover crops/small grains (i.e., wheat (*Triticum* spp.), oats (*Avena sativa* L.), and barley (*Hordeum* spp.)) were also examined to see how the proportions of these crops have changed within the basin through time.

Statistical Analysis

Simple linear and multiple regression analyses were used to examine the relationship between channel adjustments (area, width, length, and sinuosity) and flow parameters (mean annual discharge, mean baseflow index, and mean peak flow). The flow parameters were averaged over aerial photo date intervals (e.g., 1930-38, 1939-50, 1951-62, 1963-76, 1977-84, 1985-1995, 1996-02, and 2002-08) in order to examine the prior streamflow characteristics that would have contributed to the morphology of the channel by the end of the interval. Additionally, I examined the relationship between mean ET and mean corn and soybean acres planted over each time interval to evaluate if the basin wide conversion to row-crop agriculture has reduced ET rates, which could result in more surplus water. Mean corn and soybean acres were also compared with mean annual and seasonal Q:P ratios (again averaged across the time intervals) to examine the relationship between land use change and the responsiveness of the basin to precipitation. Finally, I compared the mean corn and soybean acres and the mean

PPT:PET ratio per time interval with all of the mean flow parameters to estimate the relative direct contributions of land use change or climatic variation on streamflow patterns. Other models (using these and other parameters) should be developed to further examine the complex land use/climatic interactions and their effect on basin hydrology. The development of these models represents a useful avenue for future research.

For all statistical analysis, $p \leq 0.05$ was used to indicate significance, while p-values between 0.05 and 0.10 were considered marginally significant. Data entry, error checking, and production of graphics were done using MS-Excel. All statistical analyses were completed using the Statistical Analysis System software (SAS®, version 9.1).

Results

Channel Adjustment and Changes in Discharge Patterns

The lower Big Sioux River has undergone substantial channel adjustment during the last 70 years, resulting in a 62% increase in channel planform area, a 69% increase in average channel width, a 4% decrease in channel length (approximately 9 km decrease), and a 4% decrease in channel sinuosity (Figure 2.3). In order to evaluate the influence of discharge on these observed channel changes, I used the IHA method to compare streamflow patterns across 10 year increments (e.g., 1930-1939, 1940-1949, etc.) from 1930 to 2010 at the Akron, Iowa, USGS gauging station (06485500). Mean annual flows remained relatively constant from the 1930s to 1970s but changed abruptly in the 1980s, with substantially higher flows from the 1980s through the end of the time period (Figure 2.4).

Based on this step function increase in flow from 1980 to present, I split the flow record into pre- (1950-1979) and post-1980 (1980-2008) periods for analysis with the IHA method (split into equal number of pre and post years). From the pre- to the post-1980 period, mean annual

flow increased 122% (Figure 2.4) and the baseflow index (the proportion of total mean flow represented as baseflow) increased 78% (Figure 2.5). Related to this, but not part of the IHA results, was a 218% increase in the frequency of high flow events in excess of 89 m^3/s (10% exceedance flow for the 81-year period) at the Akron, Iowa, gauge (Table 2.3). Dramatic increases in median flow (200%-416%) occurred in all seasons between the pre- and post-1980 periods with the greatest increase occurring during the low flow winter period (Table 2.3). Almost all flow durations metrics (e.g., 1-day, 3-day, 7-day, 30-day, and 90-day minimum and maximum) showed increases between the two time periods, with particularly strong increases (300-480%) in minimum flows (Table 2.3). Additionally, the rise and fall rates, measured as the mean flow rate change/day, increased 321% and 213%, respectively, since 1980, indicating that the watershed has gotten flashier during this time period. Table 2.3 summarizes the Akron, Iowa, IHA results.

The relationships between the various flow parameters results from the IHA method and the observed channel adjustments were analyzed using simple linear regression. The relationship between channel planform area and mean annual flow over the time intervals between each aerial photo date (e.g., 1930-38, 1939-50, 1951-62, 1963-76, 1977-84, 1985-1995, 1996-02, and 2002-08), resulted in a highly significant, nearly perfect positive correlation (R^2 = 96%, p= 0.0001; Figure 2.6A). The relationship between mean annual flow and channel length was more variable (most likely due to channel cutoff events being more episodic in nature) but still showed a marginally significant negative linear fit (R^2 = 49%, p= 0.053; Figure 2.6B). Relationships between channel planform area and mean peak flow per time interval showed a weak, non-significant linear relationship (R^2 = 22%, p= 0.24; Figure 2.6C) and there was no relationship between mean peak flow per time interval and channel length (R^2 = 3%, p= 0.65; Figure 2.6D). There was a significant positive relationship between the baseflow index per time interval and channel area (R^2=53%, p=0.04; Figure 2.6E) and a significant negative relationship between

baseflow index and channel length (R^2=74%, p=0.005; Figure 2.6F). These results suggest that increases in mean annual flow and the baseflow percentage are the primary drivers of the observed channel adjustments within the Big Sioux basin.

In order to better understand why increases in streamflow have occurred within the watershed, the relative effects of land use change and climate variability were examined to provide potential causation for the observed trends. Annual and seasonal streamflow-to-precipitation (Q:P) ratios were examined at the Akron, Iowa, gauge to assess how watershed sensitivity to precipitation has changed through time within the Big Sioux basin (Table 2.4; Figure 2.7). Significant increases (R^2=74%, p=0.006) in mean annual Q:P ratios were observed, with a 96% increase between the pre- and post-1980 periods, indicating that changes on the landscape have created a flashier system that produces more runoff per unit of precipitation (Table 2.4; Figures 2.7-2.8). Median seasonal Q:P ratios all showed significant increases (p=0.001 to 0.03) in the post-1980 era with the largest difference (279% increase) being observed during the baseflow dominated winter (Dec.-Feb.) time period (Table 2.4; Figure 2.9). Mean annual precipitation increased 10.5% between the pre- and post-1980 periods. Fall precipitation increased almost 26% while spring and summer values increased 9.5 and 6.9%, respectively, and winter precipitation decreased (12%) between the pre- and post-1980 periods (Table 2.4).

Ecohydrologic Analysis

In order to examine the relative influence of climatic variation and land use change on increasing streamflow within the Big Sioux basin, an ecohydrologic analysis was conducted using methods similar to Tomer and Schilling (2009). Mean annual PET values have remained relatively constant since 1929 showing no significant (R^2=25%, p=0.21) temporal trend, while mean annual PPT has increased significantly (R^2=66%, p=0.01; Figure 2.10). The PPT:PET ratio increased slightly (12% increase between pre- and post-1980 periods), but significantly (R^2=64%,

p=0.02) with time, suggesting an increase in available precipitation relative to the evaporative demand (Figure 2.11). To further examine potential trends in these variables, mean excess precipitation (P_{ex}) per time interval and excess evaporative demand (E_{ex}) were plotted with time (Figure 2.12). The results suggest that both variables have increased concurrently with time, indicating that while there is more available water to be discharged each year due to the potential effects of climatic variation (i.e., increasing PPT:PET), the evaporative demand has also increased, potentially making up for the difference (Figure 2.12). This trend becomes especially evident by plotting these two parameters (P_{ex} and E_{ex}) against one another with the results indicating a highly significant (R^2=97%, p=0.00001; Figure 2.13) linear relationship between the two variables and an upward shift in the ecohydrologic model (see Figure 2.2) toward an increase in both excess water and evaporative demand between the two time intervals.

Land Use Change

I also examined the relationship between increasing discharge and land use change in the Big Sioux basin. Agricultural crop production occupied approximately 67% of the drainage basin area in 2008, an increase of 12% since 1928 (55% of drainage basin area; Figure 2.14). While total land area in production has increased over the last 80 years, the proportional area of perennial cover crops/small grains (e.g., wheat, rye, barley, etc.) has decreased by approximately 79% (Figure 2.15). Annual row-crop (corn and soybean) production has increased throughout the basin with most of this due to an 1800% increase in basin wide soybean production from 1948 to 2008 (soybean crop statistics were not reported for counties in South Dakota until 1948; Figure 2.16). Corn production has remained relatively constant since 1928, as it currently occupies approximately 30% of the total basin land area, increasing only 5.8% over the 80-year period (24.4% of land area in 1928; Figure 2.16). When corn and soybean acreage are combined, these annual row-crops currently occupy approximately 59% of the total basin land area and have increased 132% since occupying only 25% of the basin land area in 1928 (Figure 2.15).

The relationship between annual row-crop production and estimated rates of evapotranspiration (ET) throughout the basin were examined to see if the large increases in corn and soybean acres have affected ET rates in the watershed. Results indicate a significant (R^2=68%, p=0.01) negative relationship between the variables, suggesting that as corn and soybean production in the basin has increased, the relative rates of ET have decreased (given that annual row-crops have a lower water demand than perennial crops/small grains and native grasses; see Dinnes 2004; Brye et al. 2000), potentially leading to excess (unused) water available to be discharged and an unsatisfied (excess) evaporative demand (Figure 2.17).

Relationships between Discharge, Land Use, Climatic Variation and Channel Adjustment

A multiple regression approach was used to examine the direct effects of land use change and climatic variation on increasing mean annual flow and the baseflow within the basin as well as to compare the indirect effects of land use/climate change on the observed channel adjustments. The total acreage of corn and soybeans was used as the land use variable in the model (as together they represent the dominant land use in the basin) and the PPT:PET ratio was used as the climate variable. The first model examined the effects of corn and soybean acres and PPT:PET ratio on mean annual flow. This model resulted in a significant relationship (R^2=84%) with a significant, positive effect from corn and soybean acres (p=0.01) and a non-significant, positive effect from the PPT:PET ratio (p=0.85; Table 2.5). The next model examined the influence of the same two predictors on the baseflow index. This model again resulted in a highly significant relationship (R^2=90%), with a significant, positive effect from corn and soybean acres (p=0.002) and a non-significant, negative effect from the PPT:PET ratio (p=0.16; Table 2.5). The next two models examined the indirect effects of land use (corn and soybean acres) and climate change (PPT:PET ratio) on the observed channel adjustments (channel area and channel length). In the first model, corn and soybean acres and PPT:PET ratio explained 92% of the variation in channel area through time, with the corn and soybean acres having a significant,

positive effect (p=0.01) and the PPT:PET ratio having a marginally significant, positive effect (p=0.09; Table 2.5). In the last model, 76% of the variation in channel length was explained by the two predictor variables, with a significant, negative effect (p=0.05) from corn and soybean production and a non-significant, negative effect (p=0.79) from the PPT:PET ratio (Table 2.5). While these were the only models examined for this project, it should be noted that there are other potential candidate models that should also be considered. The development of these models should be the focus of future research.

Discussion

Increased streamflow over the last 30 years has led to dramatic channel adjustments on the lower Big Sioux River, resulting in a shorter, straighter, and particularly wider river (Figure 2.3). Increases in mean annual flow and baseflow appear to be the main drivers of this channel adjustment as peak flow discharge had no significant relationship with any of the channel changes (although the frequency of high flow events certainly may; Figure 2.6). Most of the changes in channel patterns occurred rapidly over a 19-year period between 1976 and 1995 and were accompanied by step increases in mean annual flow and baseflow (Figure 2.4-2.5), as well as a moderate increase in precipitation (10.5%) and a major expansion of annual row-crop production (particularly soybeans) throughout the basin (Figure 2.15-2.16). The observed trends in channel change are similar to those of other upper Midwestern river basins which, like the Big Sioux, are largely dominated by annual row-crop agriculture and have undergone extensive drainage modification over the last 3 decades (Lenhart et al. 2011a). Increased drainage alteration (e.g., tile drainage, surface ditches) has been shown to increase baseflow and mean annual flow in other upper Midwestern watersheds (Schilling and Libra 2003).

Increasing Q:P ratios provided further evidence of the effects of altered basin wide land use, water use, and drainage efficiency on the Big Sioux flow regime, as more water is being

discharged per unit of precipitation. Increases in discharge during the typically low flow winter period are particularly suggestive of an effect of land use change as the potential contributions of climatic variation (i.e., increased or decreased evaporative demand and excess water) are minimal during these months. Winter precipitation decreased 12% between the pre- and post-1980 periods but Q:P ratios increased 279% (Figure 2.9), providing strong evidence that trends in land use change, especially drainage efficiency, have influenced basin wide hydrology and may be the primary driver of increased winter streamflow. The result of the ecohydrologic analysis provide further support to this notion as both the excess water (P_{ex}) and excess evaporative demand (E_{ex}) have increased since 1980, indicating that while there is more available water to be discharged each year due to the potential effects of climatic variation (i.e., increasing PPT:PET), the evaporative demand has increased at a similar rate, potentially making up the differences (Figure 2.12). According to Tomer and Schilling (2009), an ecohydrologic shift in this direction (see Figure 2.13) is indicative of the removal of perennial cover, increased tillage and deforestation (or in this case agricultural intensification, see conceptual model in Figure 2.2) with changes in the annual water budget explained more by land use change than climatic variation.

To examine this potential trend more closely, the relative effects of climate and land use change on streamflow patterns and channel adjustments were examined together. Land use change explained more variation in both mean annual flow and baseflow than did climatic change (Table 2.5). Additionally the land use signal also had a stronger indirect effect on observed channel adjustments than did climate change (Table 2.5). This land use change signal was also observed in the analysis of rates of ET throughout the basin. As the annual row-crops have become the dominant land use in the basin (today occupying 59% of the basin land area), there has been a shift towards lower ET rates, potentially resulting in more water available to be discharged (Figure 2.17). The overall conclusion of this study is that although climate changes have occurred within the Big Sioux basin during the last 80 years, landscape alteration and

agricultural intensification have had an increasingly important effect on watershed hydrology and the observed channel adjustments during the last 30 years.

Results throughout the upper Midwest suggest that the relative effects of land use change and climate change on increasing streamflow may not be consistent spatially or temporally across the region. River basins farther to the east (e.g., Minnesota, Wisconsin, and Iowa) were converted to an annual row-crop system earlier than the Big Sioux and have therefore been artificially drained longer (Lenhart et al. 2011a). By conducting studies in these other watersheds, we may be able to understand how the Big Sioux River could potentially respond to the continuation of current land management practices throughout the basin. These findings shed light on the cumulative effects of landscape alteration within the Big Sioux basin and the impacts these changes have had on streamflow patterns and channel adjustments. These findings highlight several potential (and significant) management issues that have not been perceived in the past and that may have some bearing on current and future conservation efforts on the Big Sioux. This is particularly important as answers for TMDL impairment and bank erosion problems continue to be sought. The current solutions to these problems (e.g., bank stabilization for bank erosion) may not recognize the importance of basin wide changes in land use and the impacts these changes have had on water quality and erosion. Management efforts should focus more attention on landscape level issues within the basin or they may fall short of conservation goals. Further research is needed to gain an understanding of other potential side effects associated with land use change within the Big Sioux basin and other watersheds of South Dakota and the upper Midwest.

References

Allan, J.D. 2004. Landscapes and riverscapes: the influence of land use on stream ecosystems. *Annual Review of Ecology, Evolution and Systematics* 35:257–284.

Bankhead, N. and A. Simon. 2009. Analysis of bank stability and potential load reduction along reaches of the Big Sioux River, South Dakota. U.S. Department of Agriculture, Watershed Physical Process Research Unit. Report Number 64.

Blann, K., J. Anderson, G. Sands and B. Vondracek. 2009. Effects of agricultural drainage on aquatic ecosystems: a review. *Critical Reviews in Environmental Science and Technology* 39:909-1001.

Brinson, M.M., B.L. Swift, R.C. Plantico and J.S. Barclay. 1981. Riparian ecosystems: their ecology and status. U.S. Fish and Wildlife Service Biological Service Program FWS/OBS-81/17.

Brizga, S.O., and B.L. Finlayson. 1990. Channel avulsion and river metamorphosis: The case of the Thompson River, Victoria, Australia. *Earth Surface Processes and Landforms* 15:391-394.

Brookes, A. 1988. Channelized rivers, perspectives for environmental management. New York: John Wiley & Sons.

Bryce, S., J.M. Omernik, D.E. Pater, M. Ulmer, J. Schaar, J. Freeouf, R. Johnson, P. Kuck and S.H. Azevedo. 1998. Ecoregions of North Dakota and South Dakota. Jamestown, ND: Northern Prairie Wildlife Research Center Online. http://www.npwrc.usgs.gov/resource/habitat/ndsdeco/index.htm

Brye, K.R., J.M. Norman, L.G. Bundy and S.T. Gower. 2000. Waterbudget evaluation of prairie and maize ecosystems. *Soil Science Society of America Journal* 64:715-724.

Cooper, C.M. 1993. Biological effects of agriculturally derived surface water pollutants on aquatic systems—a review. *Journal of Environmental Quality* 22:402-408.

Curtis, J. T. 1956. The modification of mid-latitude grasslands and forests by man. pp. 721-736, In: W. L. Thomas Jr. (ed.). *Man's role in changing the face of the earth*. University of Chicago Press.

Dieterman, D., and C.R. Berry. 1998. Fish community and water quality changes in the Big Sioux River. *The Prairie Naturalist* 30(4):199-224.

Dinnes, D.L. 2004. Assessments of practices to reduce nitrogen and phosphorus nonpoint source pollution of Iowa's surface waters. Iowa Department of Natural Resources, Des Moines, IA.

Donner, S.D. 2003. The impact of cropland cover on river nutrient levels in the Mississippi River basin. *Global Ecology and Biogeography*12:341-355.

Dunne T. and L.B. Leopold. 1978. Water in Environmental Planning. San Francisco: W. H. Freeman and Co.

Dynesius, M. and C. Nilsson. 1994. Fragmentation and flow regulation of river systems in the northern third of the world. *Science* 266:753-762.

Faulkner, D.J. 1998. Variable historical alluviation and channel incision in West-Central Wisconsin. *Annals of the Association of American Geographers* 88:666-685.

Fitzpatrick, F.A., J.C. Knox and H.E. Whitman. 1999. Effects of historical landcover changes on flooding and sedimentation, North Fish Creek, Wisconsin. Water-Resources Investigations Report 99–4083. U.S. Department of Interior, U.S. Geological Survey, Arlington, VA.

Friedman, J.M. and V.J. Lee. 2002. Extreme floods, channel change and riparian forests along ephemeral streams. *Ecological Monographs* 72:409-425.

Gergel S.E., M.G. Turner, J.R. Miller, J.M. Melack and E.H. Stanley. 2002. Landscape indicators of human impacts to riverine systems. *Aquatic Sciences.* 64:118-128.

Gore, J.A. and G.E. Petts. 1989. Alternatives in regulated river management. CRC Press, Boca Raton, Florida. pp. 4-24.

Graf, W.L. 1999. Dam nation: a geographic census of American dams and their large-scale hydrologic impacts. *Water Resources Research* 35:1305-1311.

Greco, S.E. 1999. Monitoring riparian landscape change and modeling habitat dynamics of the Yellow-billed Cuckoo on the Sacramento River, CA. PhD thesis, University of California, at Davis, Department of Ecology.

Gurnell, A.M. 1997. Channel change on the River Dee meanders, 1946-1992, from the analysis of air photographs. *Regulated Rivers: Research & Management* 13(1):13-26.

Hammer, T.R. 1972. Stream channel enlargement due to urbanization. *Water Resources Research* 8:1530-1540.

Harding J.S., E.F. Benfield, P.V. Bolstad, G.S. Helfman and E.B.D. Jones. 1998. Stream biodiversity: The ghost of land use past. *Proceedings of the National Academy of Sciences* 95:14843-14847.

Hill, A.R. 1978. Factors affecting the export of nitrate-nitrogen from drainage basins in southern Ontario. Water Resources Research 12:1045-1057.

Hubbard, D.E. 2005. A review of the effects of pattern tiling on wetlands and receiving waters. Department of Wildlife and Fisheries Sciences, South Dakota State University.

Hupp, C.R., and W.R. Osterkamp. 1996. Riparian vegetation and fluvial geomorphic processes. *Geomorphology* 14:277-295.

Hynes, H.B.N. 1975. The stream and its valley. *Verhandlungen der Internationalen Vereinigung für Theoretische und Angewandte Limnologie* 19:1-15.

Iowa Department of Natural Resources Geographic Information Systems Library. 2011. http://www.igsb.uiowa.edu/webapps/nrgislibx, retrieved April 2011.

Johnson, L.B., C. Richards, G.E. Host and J.W. Arthur. 1997. Landscape influences on water chemistry in Midwestern stream ecosystems. *Freshwater Biology* 37:193-208.

Knox, J.C. 1977. Human impacts on Wisconsin stream channels. *Annals of the Association of American Geographers* 67:323-342.

Knox, J.C. 1987. Historical valley floor sedimentation in the Upper Mississippi Valley. *Annals of the Association of American Geographers* 77: 224-244.

Knox, J.C. 2001. Agricultural influence on landscape sensitivity in the upper Mississippi river valley. *Catena* 42:193-224.

Lenat, D.R. 1984. Agriculture and stream water quality; a biological evaluation of erosion control practices. *Environmental Management* 8:333-343.

Lenhart C., H. Peterson and J. Nieber. 2011a. Increased streamflow in agricultural watersheds of the Midwest: implications for management. *Watershed Science Bulletin* Spring 2011: 25-31.

Lenhart, C.F., E.S. Verry, K.N. Brooks and J.A. Magner. 2011b. Adjustment of prairie pothole streams to land-use, drainage and climate changes and consequences for turbidity impairment. *River Research and Applications* doi: 10.1002/rra.1549.

Leopold, L.B. 1968. Hydrology for urban land planning: a guidebook on the hydrologic effects of land use. Reston (VA): US Geological Survey. Circular nr 554.

Magner, J.A., G.A. Payne and L.J. Steffen. 2004. Drainage effects on stream nitrate-N and hydrology in south-central Minnesota (USA). *Environmental Monitoring and Assessment* 91:183-198.

McCormick, K.A., and R.H. Hammond. 2004. Geology of Lincoln and Union Counties, South Dakota. Department of Environment and Natural Resources, Geologic Survey. Bulletin 39.

Micheli, E.R., J.W. Kirchner, and E.W. Larsen. 2004. Quantifying the effect of riparian forest versus agricultural vegetation on river meander migration rates, Central Sacramento River, California, USA. *River Research and Applications* 20:537-548.

Milewski, C.L., C.R. Berry and D. Dieterman. 2001. Use of the index of biological integrity in eastern South Dakota rivers. *The Prairie Naturalist* 33(3): 135-152.

Miller, J.R. and J.M. Friedman. 2009. Influence of flow variability on floodplain formation and destruction, Little Missouri River, North Dakota. *GSA Bulletin* 121:752-759.

Miller, M.W. and T.D. Nudds. 1996. Prairie landscape change and flooding in the Mississippi River Valley. *Conservation Biology* 10: 847–853.

National Agricultural Statistics Service (NASS). 2011. http://www.nass.usda.gov, retrieved October 2011.

National Research Council (NRC). 2002. Riparian areas: functions and strategies for management. National Academy Press, Washington, D.C.

Naiman, R. J., and H. Décamps. 1997. The ecology of interfaces: riparian zones. *Annual Review of Ecology and Systematics* 28:621–658.

Nilsson, C., C.A. Reidy, M. Dynesius and C. Revenga. 2005. Fragmentation and flow regulation of the world's large river systems. *Science* 308:405-408.

Odgaard, A.J. 1987. Streambank erosion along two rivers in Iowa. *Water Resources Research* 23: 1225-1236.

Omernik, J.M. 1987. Ecoregions of the conterminous United States. *Annual Association of American Geographers* 77:118-125.

Osterkamp, W.R. and E.R. Hedman.1982. Perennial-streamflow characteristics related to channel geometry and sediment in Missouri River Basins: U.S. Geological Survey Professional Paper 1242, 37 p.

Palmer, W.C. and A.V. Havens. 1958. A graphical technique for determining evapotranspiration by the Thornthwaite method. *Monthly Weather Review* 86:123-128.

Poff , N.L., D.J. Allan, M.B. Bain, J.R. Karr, K.L. Prestegaard, B.D. Richter, R.E. Sparks, and J.C. Stromberg. 1997. The natural flow regime: a paradigm for conservation and restoration of riverine ecosystems. *BioScience* 47:769-784.

Raymond, P.A., N.H. Oh, R.E. Turner and W. Broussard. 2008. Anthropogenically enhanced fluxes of water and carbon from the Mississippi River. *Nature* 451(24):449-452.

Richards, C., L.B. Johnson and G.E. Host. 1996. Landscape-scale influences on stream habitats and biota. *Canadian Journal Fisheries and Aquatic Science* 53:295-31.

Richter B.D., J.V. Baumgartner, J. Powell and D.P. Braun. 1996. A method for assessing hydrologic alteration within ecosystems. *Conservation Biology* 10:1163-1174.

Roth, N.E., J.D. Allan and D.L. Erickson. 1996. Landscape influences on stream biotic integrity assessed at multiple spatial scales. *Landscape Ecology* 11:141-56.

Scott, M.L., J.M. Friedman, and G.T. Auble. 1996. Fluvial process and the establishment of bottomland trees. *Geomorphology* 14:327-339.

Schilling, K.E. 2004. Relation of baseflow to row crop intensity in Iowa. *Agriculture, Ecosystems and Environment* 105:433–438.

Schilling, K. and M. Helmers. 2008. Effect of subsurface drainage tiles on streamflow in Iowa agricultural watersheds: Exploratory hydrograph analysis. *Hydrologic Processes* 22: 4497-4506.

Schilling, K.E., M.K. Jha, Y.K. Zhang, P.W. Gassman and C.F. Wolter. 2008. Impact of land use and land cover change on the water balance of a large agricultural watershed: historical effects and future directions. *Water Resources Research* doi: 4410.1029/ 2007WR006644

Schilling, K.E. and R.D. Libra. 2003. Increased baseflow in Iowa over the second half of the 20th century. *Journal of the American Water Resources Association* 39:851–860.

Smith, R.L. and L.D. Flake. 1983. The effect of grazing on forest regeneration along a prairie river. *The Prairie Naturalist* 15(1):41-44.

Spaling, H. and B. Smit. 1995. Conceptual model of cumulative environmental effects of agricultural land drainage. *Agriculture, Ecosystems and Environment* 53: 299-308.

Sponseller, R.A., E.F. Benfield and H.M. Valett. 2001. Relationships between land use, spatial scale and stream macroinvertebrate communities. *Freshwater Biology* 46:1409-1424.

South Dakota Department of Environment and Natural Resources. 2010. The 2010 South Dakota integrated report for surface water quality assessment. Report 305(b) and 303(d).

South Dakota State Climatologist Office (SDSC). 2011. http://climate.sdstate.edu/climate_site/, retrieved July 2011.

Thornthwaite, C.W. 1948. An approach toward a rational classification of climate. *Geographic Review* 38:55-94.

Tomer, M. D. and K.E. Schilling. 2009. A simple approach to distinguish land-use and climate-change effects on watershed hydrology. *Journal of Hydrology* 376:24–33.

Trimble, S.W. 1983. A sediment budget for Coon Creek basin in the Driftless Area, Wisconsin. 1853–1977. *American Journal of Science* 283:454-474.

United States Environmental Protection Agency (EPA). 1978. Profile of environmental quality, Region 8. Denver CO.

Vannote, R.L, W.G. Minshall, K.W. Cummins, J.R. Sedell and C.E. Cushing. 1980. The river continuum concept. *Canadian Journal Fisheries and Aquatic Science.* 37:130-137.

Wang, L., J. Lyons, P. Kanehl and R. Gatti. 1997. Influences of watershed land use on habitat quality and biotic integrity in Wisconsin streams. *Fisheries* 22:6-12.

Westin, F.C., and D.D. Malo. 1978. Soils of South Dakota. South Dakota State University Agricultural Experimental Station. Bulletin 656.

Zhang, Y.-K. and K.E. Schilling. 2006. Increasing streamflow and baseflow in Mississippi River since 1940's: Effect of land use change. *Journal of Hydrology* 324:412-422.

Zucker, L.A. and L.C. Brown. 1998. Agricultural drainage: Water quality impacts and subsurface drainage studies in the Midwest. Ohio State University Ext. Bulletin. 871. Ohio State University Extension, Columbus.

Table 2.1. List of USGS gauging stations used in this study.

Station ID	USGS Gauging Station Name	Period of Record	Drainage Area (km^2)
6485500	Big Sioux River at Akron, IA	1929-Present	20,400
6481000	Big Sioux River at Dell Rapids, SD	1948-Present	10,170
6480000	Big Sioux River near Brookings, SD	1953-Present	8,650
6483500	Rock River at Rock Valley, IA	1949-Present	4,125

Table 2.2. Information on aerial photographs used during this study. Dates marked with an * represented a midpoint year as imagery for this date spanned several years.

Source	Program	Year	Photo Range Date	Color	Original Scale
Iowa DNR	AAA[a]	1938	8/23 - 11/28	B/W	1:20,000
Iowa DNR	FSA	1950*	6/6/1949 - 10/1/1951	B/W	1:20,000
Iowa DNR	FSA	1962	8/25 - 8/26	B/W	1:20,000
USDA	FSA	1976	5/11 - 6/20	B/W	1:40,000
USDA	NHAP1	1984	5/17 - 11/1	CIR	1:58,000
USDA	NAPP2	1995*	5/20/1994 - 4/23/1996	B/W	1:40,000
Iowa DNR	NAPP3	2002	5/13, 5/19	CIR	1:40,000
USDA	NAIP	2008	10/30, 10/31	Color	1:40,000

[a] Agricultural Adjustment Administration (USDA-AAA)

Table 2.3. Results of the Indicators of Hydrologic Alteration analysis for the Big Sioux River at USGS gauging station (06485500) at Akron, Iowa. Changes in flow were compared for two time periods (1950-1979 and 1980-2008). Standard errors are provided for means.

Parameter	**Pre-period (1950-1979)**	**Post-period (1980-2008)**	**% Change**
Mean Annual Flow (m^3/sec)	25.77 (±0.73)	57.20 (±0.91)	122%
Base Flow Index	0.076	0.136	78%
Winter Median Flow (m^3/sec)	2.92	15.09	416%
Spring Median Flow (m^3/sec)	23.39	70.17	200%
Fall Median Flow (m^3/sec)	12.80	39.30	207%
Summer Median Flow (m^3/sec)	5.97	20.93	250%
1-day minimum (m^3/sec)	1.42	8.21	480%
3-day minimum (m^3/sec)	1.50	8.21	444%
7-day minimum (m^3/sec)	1.61	8.21	411%
30-day minimum (m^3/sec)	1.84	9.33	406%
90-day minimum (m^3/sec)	4.73	18.90	300%
1-day maximum (m^3/sec)	229.93	291.66	27%
3-day maximum (m^3/sec)	200.62	284.87	42%
7-day maximum (m^3/sec)	149.03	248.54	67%
30-day maximum (m^3/sec)	68.36	159.31	133%
90-day maximum (m^3/sec)	43.61	97.16	123%
Low pulse count	3	0	-100%
Low pulse duration	10	7.5	-25%
High pulse count	3.5	4	14%
High pulse duration	8.5	16	88%
Rise rate	14.25	60	321%
Fall rate	-16	-50	213%
Frequency (#/year) ≥89 m^3/sec*	19.38	61.57	218%

* 89 m^3/sec represents 10% exceedance flow for 81 year period (1928-2008), calculated separately from IHA methods.

Table 2.4. Comparison of pre- (1950-1979) and post-1980 (1980-2008) annual and seasonal mean discharge (m^3/sec), basin wide precipitation (cm/year or season) and streamflow-to-precipitation (Q:P) ratios at the Akron, Iowa, USGS gauging station (06485500). Significant increases in Q:P ratios were found since 1980 using the Mann-Whitney *U*-test across all seasons and on an annual basis. These increases in Q:P ratios have occurred without corresponding increases in precipitation and may illustrate the potential influence of changing land use patterns and increased drainage alterations throughout the basin.

	Mean Discharge (m^3/sec)			**Mean Precipitation (cm)**			**Q:P Ratio**				
	Pre-1980	Post-1980	% Change	Pre-1980	Post-1980	% Change	Pre-1980	Post-1980	% Change	***U-Stat***	***p* Value**
Annual	25.8	57.2	122.0%	59.57	65.62	10.5%	0.064	0.125	96.0%	11.03	0.001
Spring	61.2	106.6	74.1%	17.55	19.40	9.5%	0.554	0.812	46.6%	4.57	0.033
Summer	26.4	71.1	169.5%	25.00	26.65	6.9%	0.151	0.375	149.0%	12.16	0.001
Fall	9.3	31.4	239.3%	12.17	15.14	25.5%	0.121	0.294	142.0%	14.37	0.001
Winter	6.3	19.5	209.8%	4.90	4.35	-12.0%	0.196	0.744	278.7%	27.20	0.001

Table 2.5. Multiple regression analysis comparing flow parameters with observed channel adjustments as well as the relative direct and indirect effects of land use change (measured as the amount of corn and soybean acres in production) and climatic variation (measured as the PPT:PET ratio) on increasing flow parameters and the channel adjustments. Significant results ($p < 0.05$) are denoted with * while marginally significant results ($0.05 < p < 0.10$) are denoted with **. A plus (+) or minus (-) indicates if the relationship is positive or negative.

Dependent Variable	**Independent Variable**	***p* value**	**R^2**	**Adj. R^2**	***df***
Mean annual flow	Corn and soybean acres (+)	0.01*	0.84	0.78	2, regression
	PPT:PET ratio (+)	0.85			5, residual
Baseflow index	Corn and soybean acres (+)	0.002*	0.90	0.86	2, regression
	PPT:PET ratio (-)	0.16			5, residual
Channel area	Corn and soybean acres (+)	0.01*	0.92	0.89	2, regression
	PPT:PET ratio (+)	0.09**			5, residual
Channel Length	Corn and soybean acres (-)	0.046*	0.76	0.66	2, regression
	PPT:PET ratio (-)	0.79			5, residual

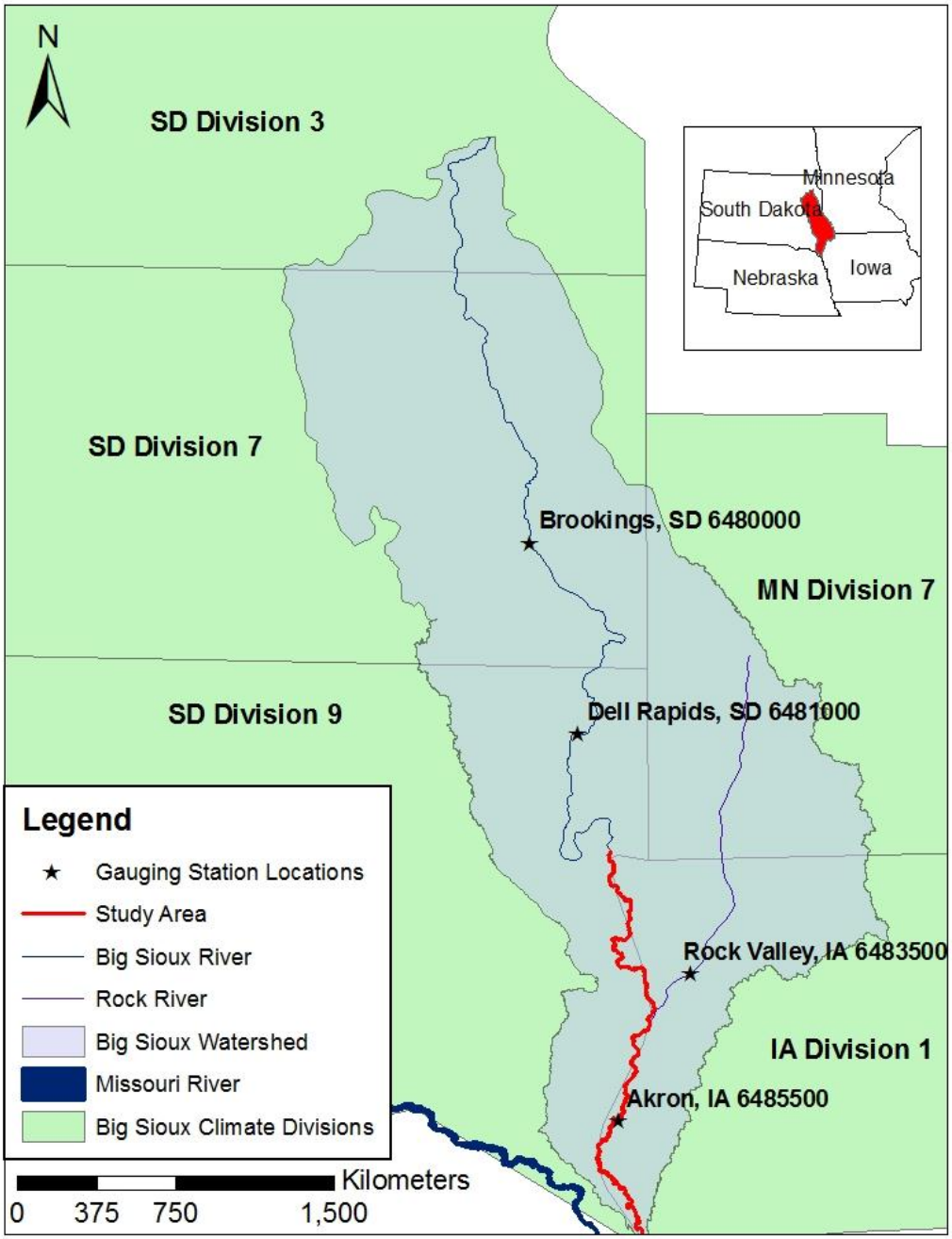


Figure 2.1. The Big Sioux basin drains 22,550 km^2 in Minnesota, Iowa, and South Dakota including the Coteau des Prairies and much of South Dakota's Prairie Pothole region. It originates in southern Roberts Co., South Dakota, and flows 676 km southward to its mouth at the Missouri River at Sioux City, Iowa. The study area for this project (in red) stretches 220 river km along the South Dakota/Iowa border. The locations of U.S. Geologic Survey gauging stations included in the IHA analyses are depicted. All Q:P ratios were calculated using data from the Akron, Iowa, gauge (6485500) as this represented the most downstream station within the basin and had the longest continuous period of record dating back to 1928.

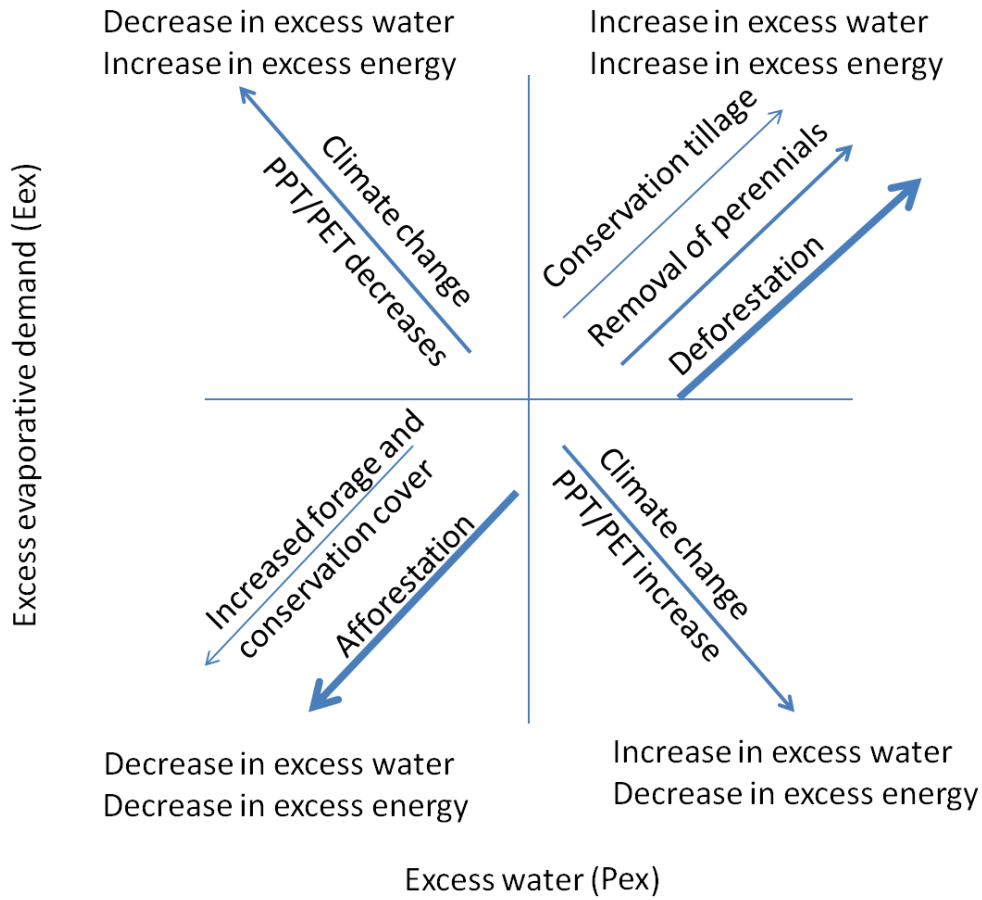


Figure 2.2. Conceptual model adapted from Tomer and Schilling (2009) of an ecohydrologic shift associated with climatic variation or land use change. The basis of this analysis is that land use change directly affects ET but not PPT or PET (acknowledging that such effects could be indirect at large scales) and that changes in land use would results in shifts towards increased or decreased P_{ex} and E_{ex} while changes in climate would result in increased P_{ex} and decreased E_{ex} (due to PPT/PET increases) or decreased P_{ex} and increased E_{ex} (due to PPT/PET decreases. Changes parallel along either axis indicate that the influence of climatic variation and land use change are approximately similar.

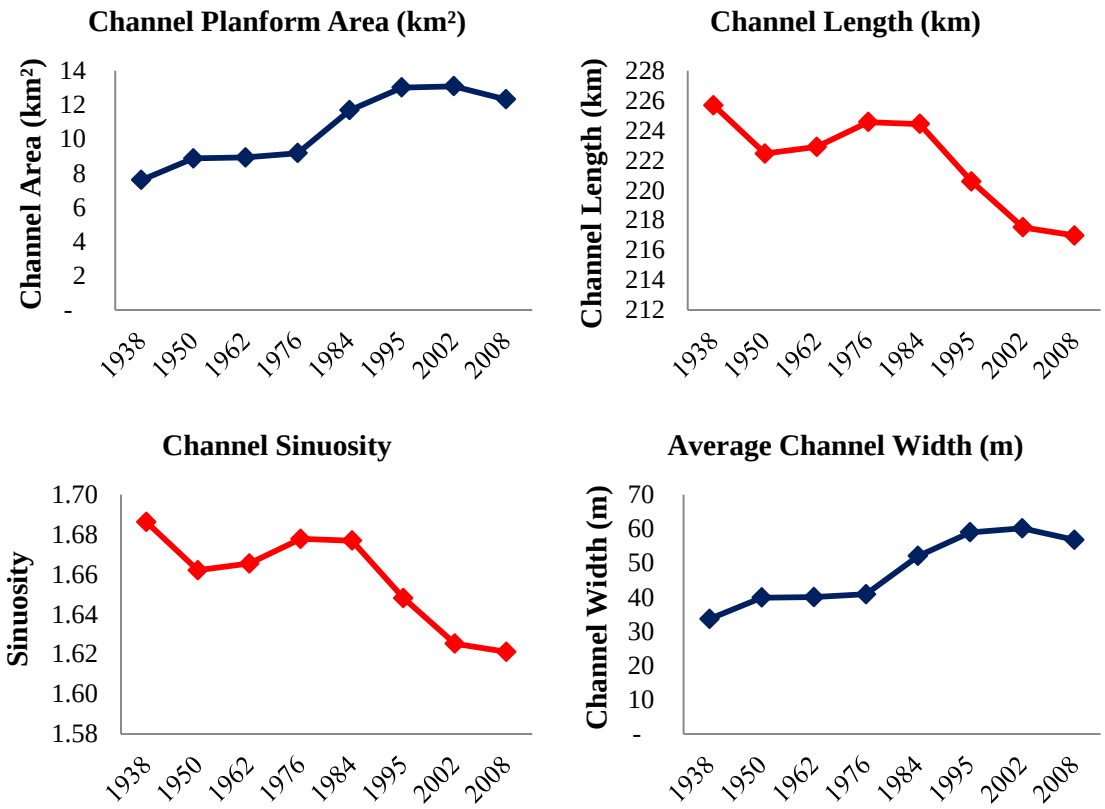


Figure 2.3. The results of 70 years (1938-2008) of channel adjustments along the lower 220 river km of the Big Sioux River. There has been a 62% increase in channel planform area, a 4% decrease in channel length (approximately 9 km decrease), a 4% decrease in channel sinuosity, and a 69% increase in average channel width, with most of the changes occurring within a 19 year period between 1976 and 1995.

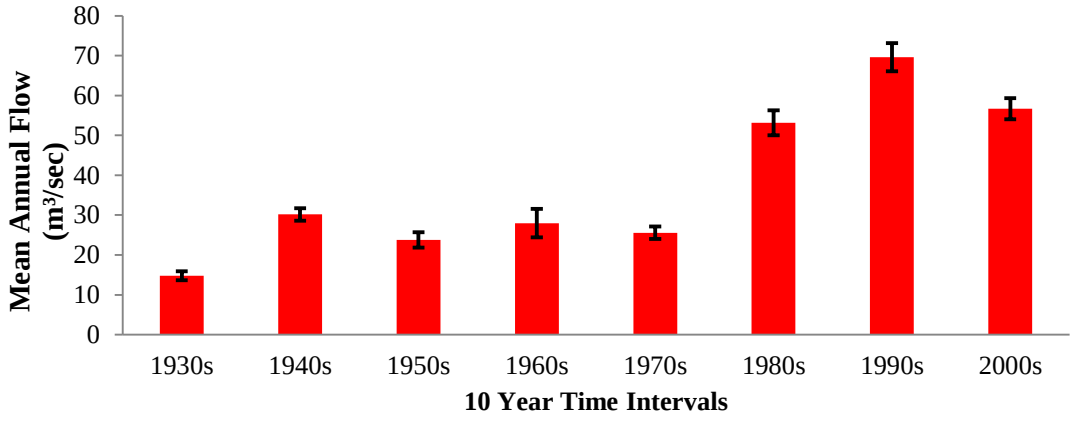


Figure 2.4. Annual mean daily discharge for 10-year periods (e.g., 1930-1939 and 1940-1949) from 1930 to 2010 at the Akron, Iowa, USGS gauging station (06485500). Flows remained relatively constant from the 1930s to 1970s but increased abruptly in the 1980s and remained higher through the end of the time period. Error bars represent the 95% confidence interval.

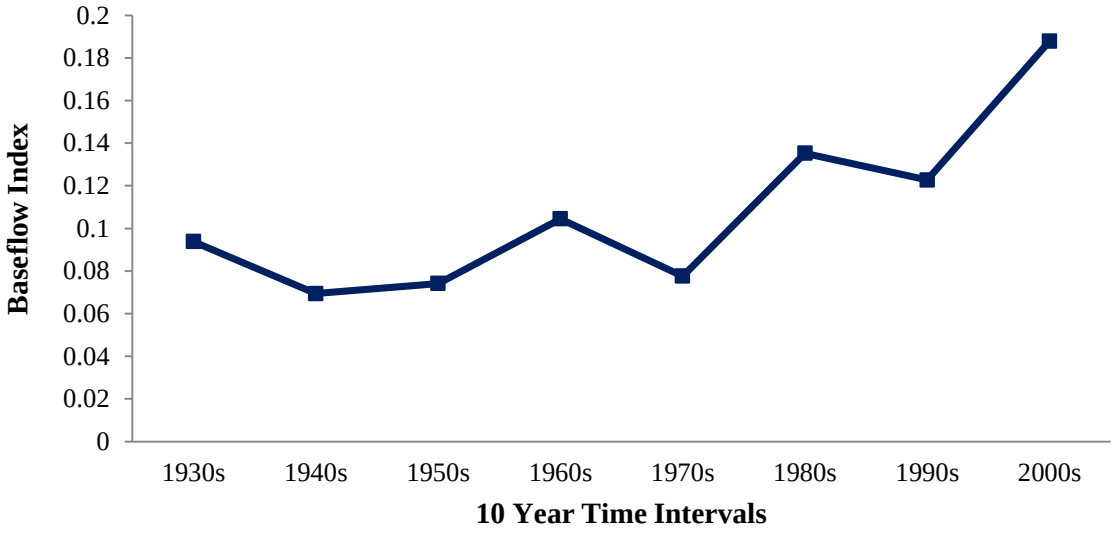


Figure 2.5. Results of the IHA analysis comparing baseflow index (the proportion of total mean flow represented as baseflow) across 10-year time intervals (e.g., 1930-1939 and 1940-1949) from 1930 to 2010 at the Akron, Iowa, USGS gauging station (06485500).

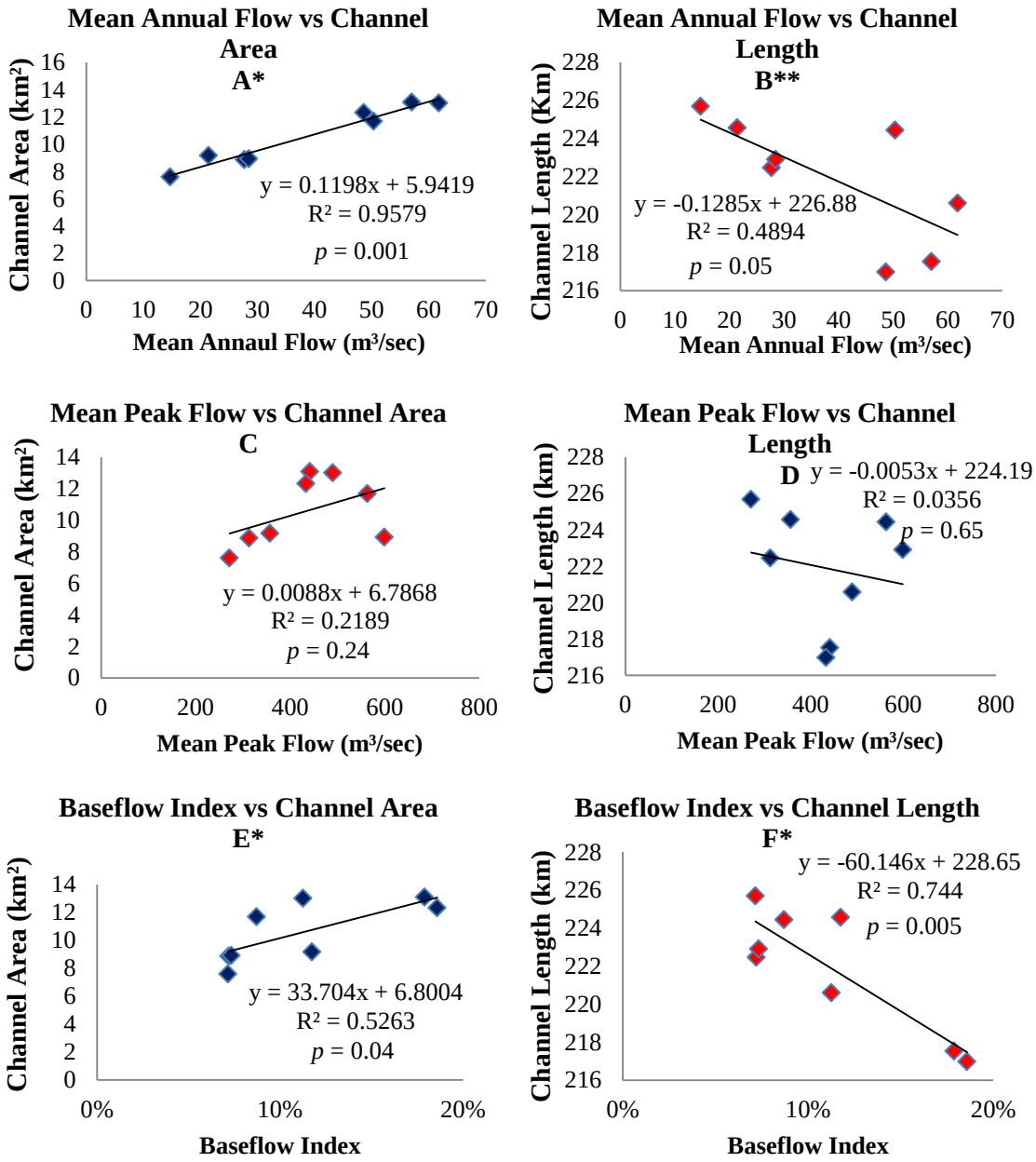


Figure 2.6. Results of regression analyses examining the effects of varying flow parameters to changes in channel area and length. Significant results (p <0.05) are denoted with * while marginally significant results (0.05 < p < 0.10) are reported as **.

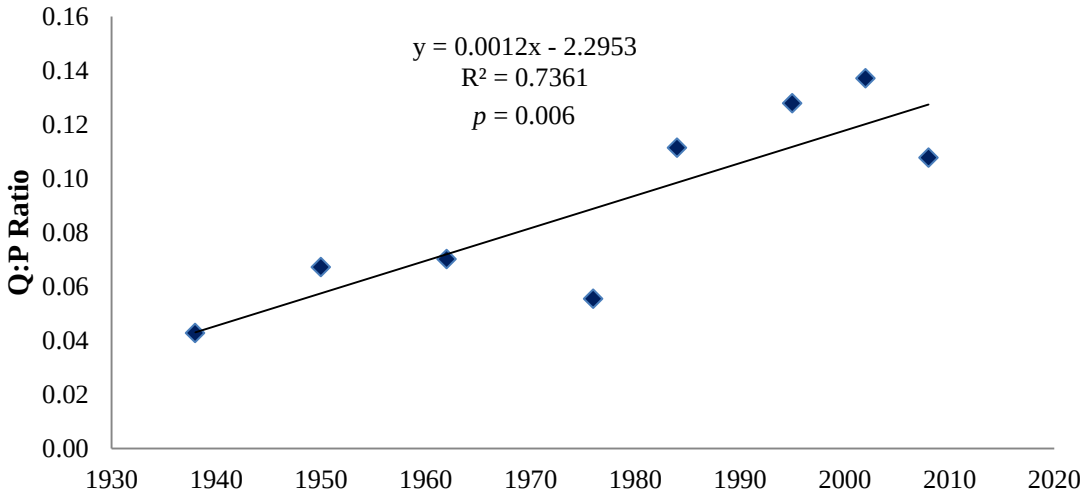


Figure 2.7. Trends in annual average streamflow-to-precipitation (Q:P) ratios per time interval (average ratio for all years in interval; e.g., 1930-1938, 1939-1950, etc.) from 1929-2010 at the USGS gauging station (06485500) at Akron, Iowa. Increases in Q:P ratios may be indicative of changing basin land use and increased drainage alteration.

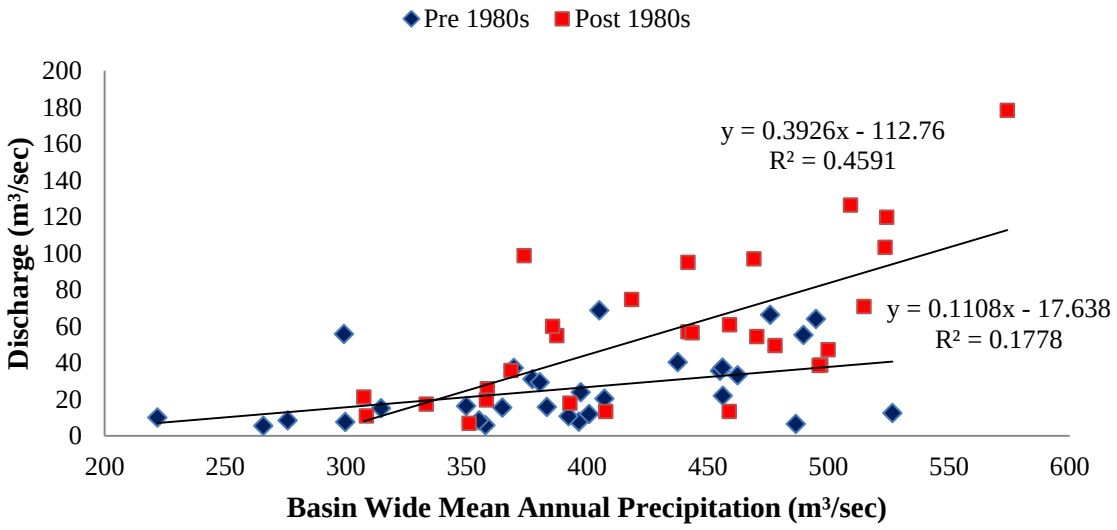


Figure 2.8. Comparison of annual pre- and post-1980 (1950-1979, 1980-2008) streamflow-to-precipitation (Q:P) ratios at the Akron, Iowa, USGS gauging station (06485500). The slope of the regression line has increased approximately 4-fold and the explanatory power of the relationship has increased nearly 3-fold from the pre- to post-1980 intervals.

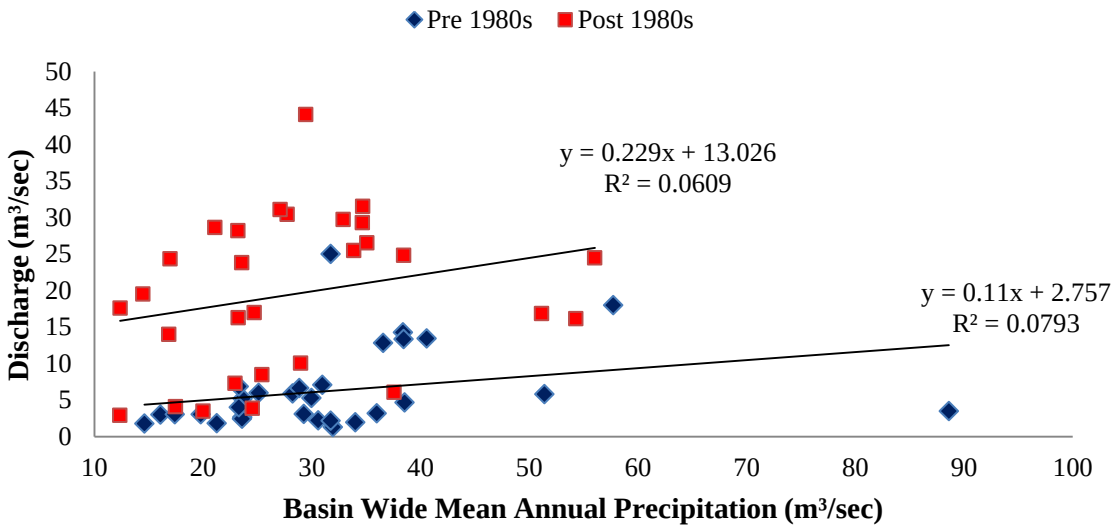


Figure 2.9. Comparison of pre and post 1980 (1950-1979, 1980-2008) winter (Dec.-Feb.) streamflow-to-precipitation (Q:P) ratios at the Akron, Iowa, USGS gauging station (06485500). Slopes of the regression lines are relatively similar between periods but there is a higher discharge per unit of precipitation in the post-1980 period indicating the possible effects of land use alteration of drainage efficiency.

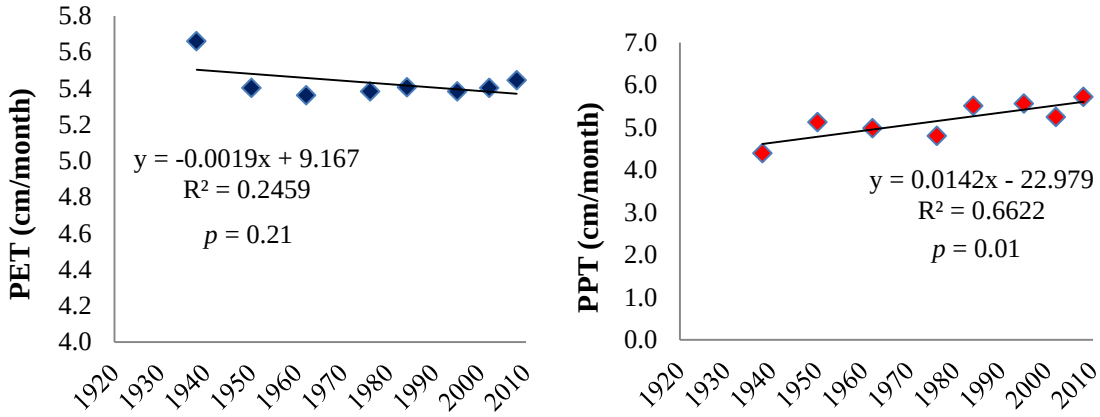


Figure 2.10. Analysis comparing mean time interval average annual PET (cm/month) and PPT (cm/month) values through time from 1929 to 2008. There has been a slight decline in PET since 1929 while PPT values have increased during the 80-year period.

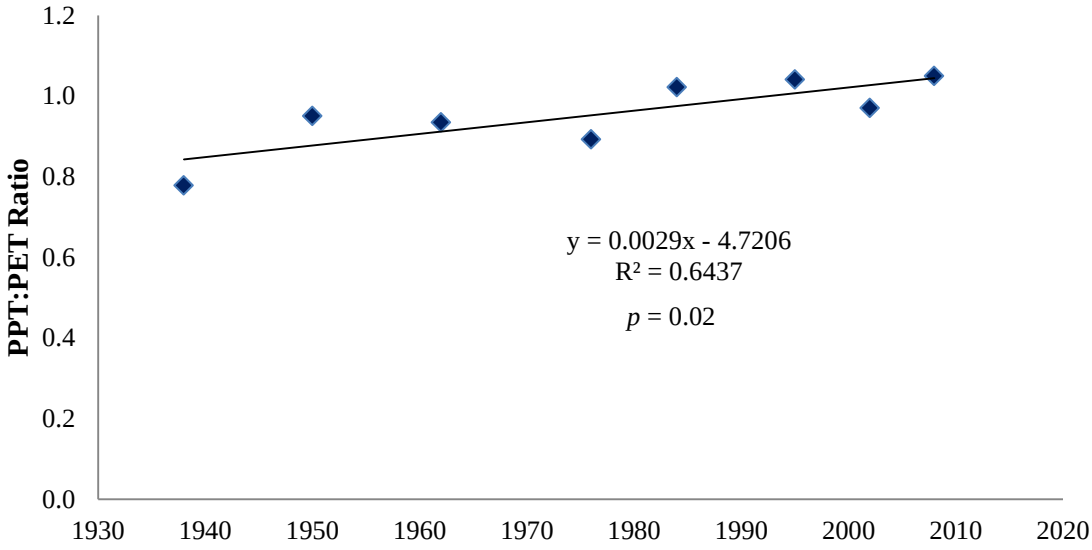


Figure 2.11. Changes in mean annual PPT:PET ratios per time interval from 1929 to 2008. There has been an increase since 1929 indicating that climatic variation has played a role in increasing discharge in the Big Sioux basin.

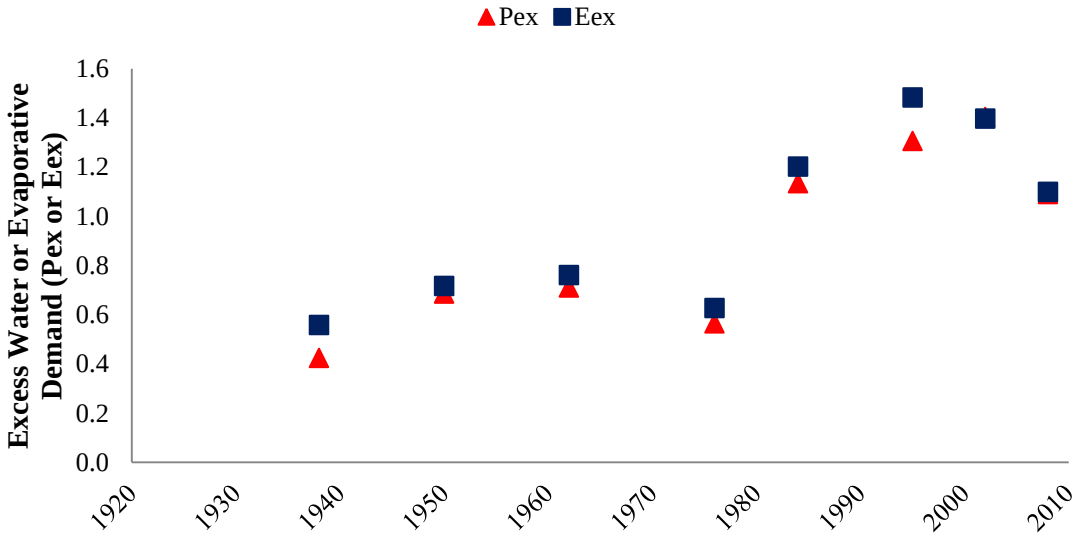


Figure 2.12. Analysis comparing mean annual excess water (P_{ex}) and excess evaporative demand (E_{ex}) per time interval from 1929 to 2008. There has been an increase in both excess precipitation and excess evaporative demand, meaning that while there is more water available to be discharged each year due to variation in the PPT:PET ratio, the increased evaporative demand (due to changes in ET from land use conversion) may make up the difference.

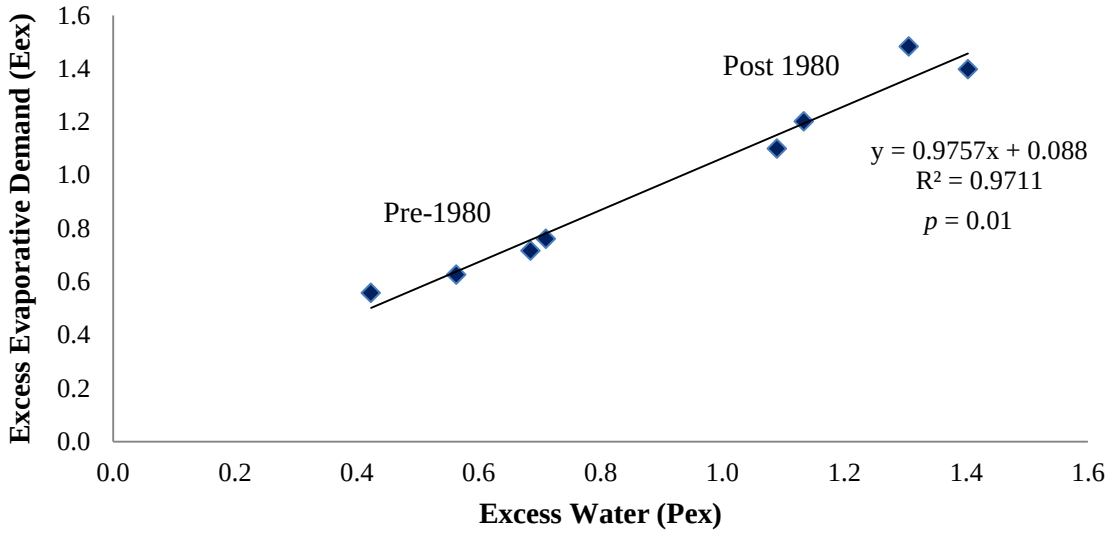


Figure 2.13. Analysis comparing the relationship between mean annual excess water (P_{ex}) and excess evaporative demand (E_{ex}) per time interval. There have been increases in both parameters indicating that an ecohydrologic shift has occurred, resulting more excess water and more excess energy. Because of this, any change or increase in streamflow patterns within the basin would indicate that changing land use, not climatic variation, is the primary driver of these changes.

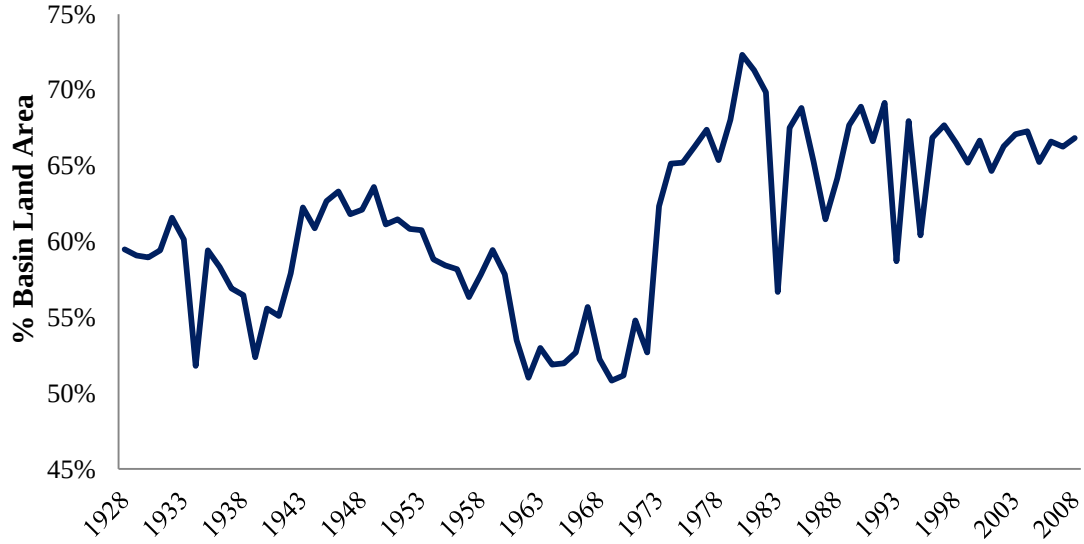


Figure 2.14. Percent of the total drainage basin land area in agricultural production from 1928 to 2008. Agricultural crop production (not including livestock grazing) occupied approximately 67% of the drainage basin area in 2008, increasing 12% since 1928.

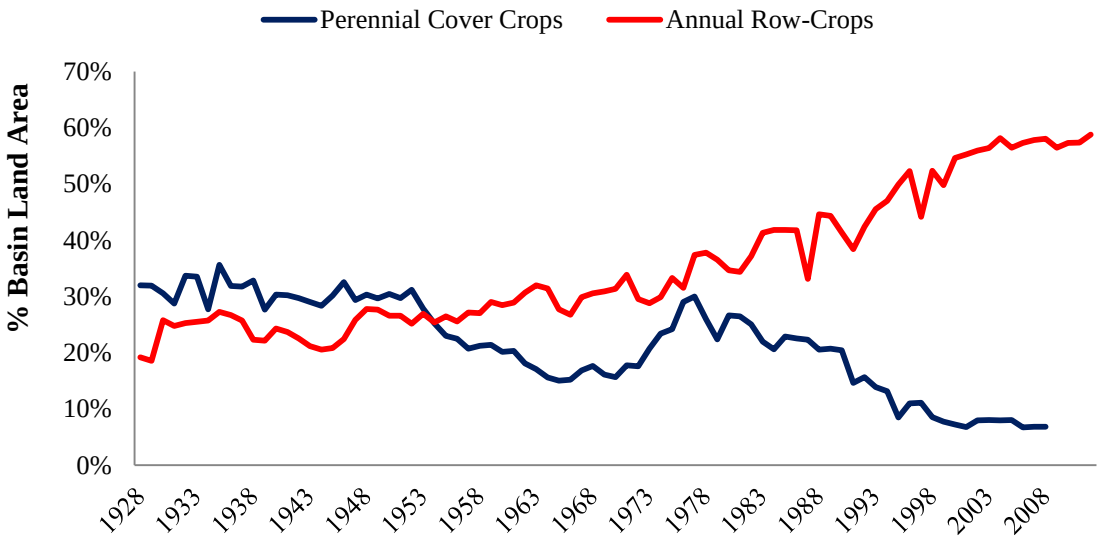


Figure 2.15. While total basin land area occupied by agricultural production has increased over the last 80 years, the proportion of perennial cover crops/small grains (e.g., alfalfa, wheat, rye, barley, etc.) has decreased by 79% since 1928. Annual row-crop production, expressed as the percent of the total basin land area in corn and soybean production, has increased dramatically over this time period and now occupies 59% of the basin area, increasing 132% since 1928.

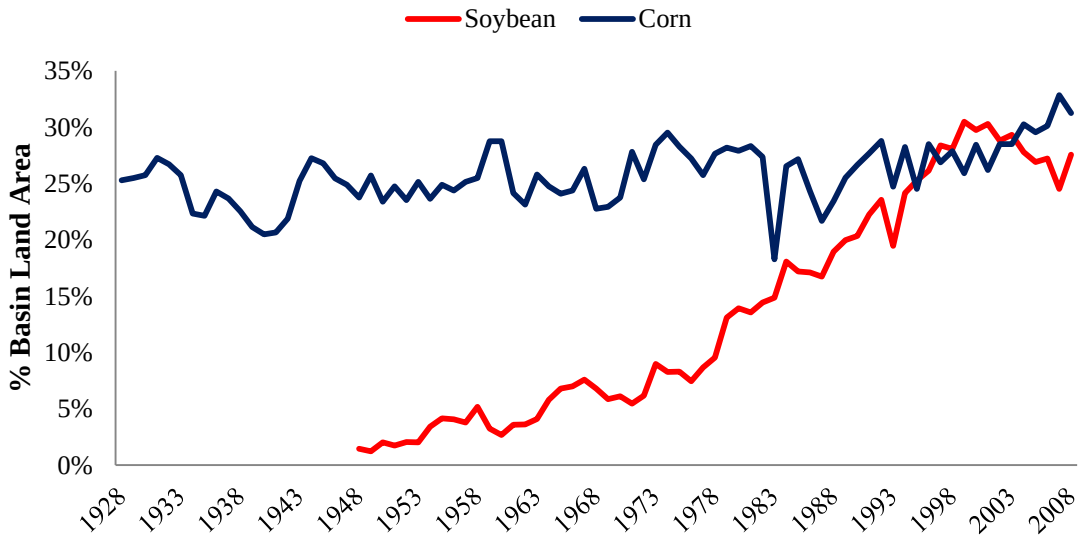


Figure 2.16. Corn production has increased 5.8% since 1928 while soybean production has increased 1800%. Corn and soybean production currently occupy approximately 30% and 28%, respectively, of the total basin land area and together represents the dominant land use within the Big Sioux basin.

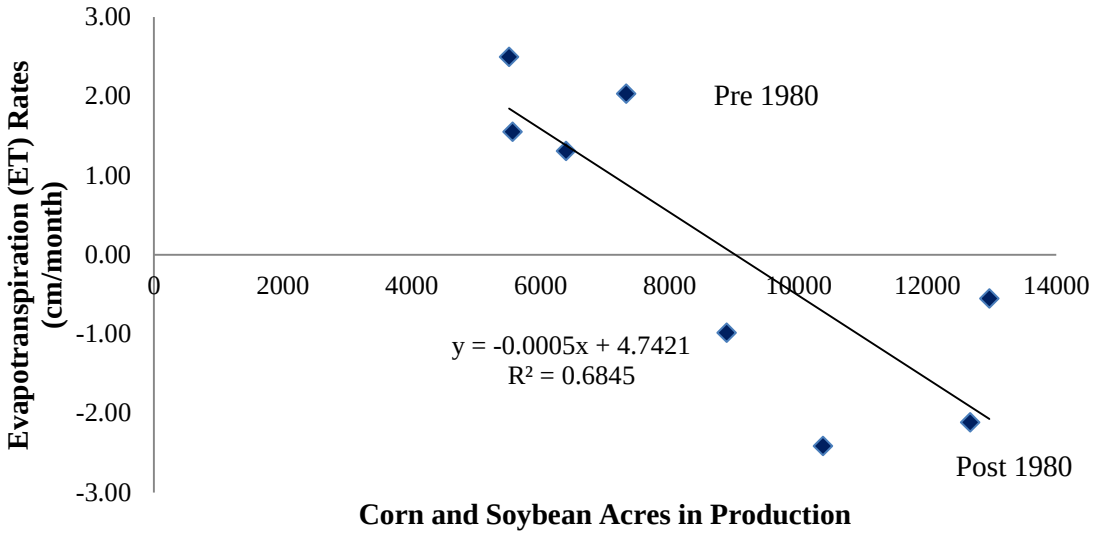


Figure 2.17. Analysis comparing the relationship between mean corn and soybean acres with mean evapotranspiration rates (cm/month) per time interval. As corn and soybean production have increased throughout the basin, the relative rates of ET have decreased potentially leading to excess water available to be discharged. It should be noted that there cannot be negative ET values and that this relationship is expressing only that rates of ET have decreased due to land use conversion from perennial cover crops and native grasses (which have higher annual water demand) to annual row-crops (which have a lower annual water demand; see Dinnes 2004; Brye et al. 2000).

Chapter 3: Pitfalls and Uncertainties Associated with using the Floristic Quality Assessment (FQA) at State Boundaries

Introduction

Floristic Quality Assessment (*FQA*) was developed by Swink and Wilhelm (1979; 1994) as an ecological assessment tool to examine the floristic quality of natural vs. disturbed plant communities in the Chicago region. The index was later refined and modified for use across Illinois (Taft et al. 1997) and has since been utilized across much of the United States and recently into areas of Canada (Bowers and Boutin 2008), China (Wei-Guo et al. 2009), and Italy (Bonanno and Giudice 2010). The system is based upon the concept that native plant species display varying degrees of tolerance to anthropogenic disturbance as well as having varying degrees of fidelity towards a specific habitat type. While the nature of "floristic quality" is largely a human concept that is not a true ecosystem property (Bourdaghs 2004; Bourdaghs et al. 2006), it still has still been shown to be an effective tool for assessing anthropogenic impacts to an area, prioritizing sites for restoration efforts, making comparisons among sites regardless of community type, monitoring and tracking the performance of reclamation and mitigation efforts through time, and identifying areas of high natural value (Swink and Wilhelm 1994; Bourdaghs et al. 2006; Matthews et al. 2009).

To use the index, all native plant species are assigned a Coefficient of Conservatism (*C*-value, hereafter) which is essentially a ranking based on the likelihood that the species will be encountered in a disturbed or natural area. These values range between 0 and 10, with *C*-values of 0 assigned to generalist species with a high degree of tolerance to disturbances and *C*-values of 10 assigned to plants occurring only in undisturbed, "pristine" habitats. Weedy species with *C*-values of 0-1 align closely with Grime's ruderal species (Grime 1974; Taft et al. 1997) with examples in my study area (the Big Sioux River corridor in eastern South Dakota and northwestern Iowa) including *Urtica dioica*, *Ambrosia sp.*, and *Amaranthus sp*. Coefficients

ranging from 2-3 are considered ruderal-competitive species that occur commonly in highly degraded sites but are also found in relatively natural areas (e.g., *Vitis riparia*, *Symphoricarpos occidentals*, and *Salix interior*). These two guilds (0-1, 2-3) represent species that are adapted to frequent, severe disturbances and are able to expand and persist under a variety of environmental conditions. Species with *C*-values of 4-6 correspond roughly with Grime's competitor species and are indicative of species that occur commonly in "natural" or unmanaged areas and have a decreased tolerance towards disturbances (Grime 1974; Taft et al. 1997). Examples from my study area include *Poa palustris* and *Carex laeviconica*. Coefficients between 7 and 10 are less closely aligned with Grime's third guild, the stress tolerators (Grime 1974, 1988; Taft et al. 1997). Many of the species assigned a *C*-value of 7-10 do not fall under Grime's definition for the stress tolerator group as many of the species are not long lived or slow growing (e.g., annuals and biennials) and many are not restricted to later successional habitats (Duffey 1986; Taft et al. 1997). Species with coefficients of 7-8 represent species that occur only in "natural" habitats and that will decrease in abundance with moderate habitat disturbances. Finally, species with *C*-values of 9-10 are restricted to undisturbed, relatively intact natural habitats. Examples from my study area of species in these final two guilds (7-8, 9-10) include *Botrychium virginianum*, *Festuca subverticillata*, and *Sanguinaria canadensis.* Lastly, all non-native plant species are assigned an asterisk (*) and are either excluded or treated as 0s for each index calculation (Taft et al. 1997).

There are several measures used to quantify floristic quality at the site level including mean Coefficient of Conservatism ($\bar{C}$), which is an average of the *C*-values for all species found at the site. This can be calculated using:

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

where $\sum C$ is the summation of all *C*-values at the site or plot level and N is the total number of species encountered within each site or plot. *FQI* (Floristic Quality Index) has been further developed to take into account species richness at the site level using:

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

where $\sqrt{N}$ is the square root of total number of species (species richness) found at the site or plot. The traditional approach, as prescribed by Swink and Wilhelm (1994), for calculating $\bar{C}$ and *FQI* is to include only native species as adventive species (exotics) did not evolve within the native plant community and should therefore not be included in *FQA* calculations (Bourdaghs et al. 2006). An alternative method has been adopted that argues that non-native species, while not evolving within the native plant community, still have an important impact on a site's floristic integrity (Taft et al. 1997; Lopez and Fennessy 2002; Rooney and Rodgers 2002; Rothrock and Homoya 2005). Under this approach, non-natives are assigned a *C*-value of 0. Today, the standard method is to perform the *FQA* calculations twice, once using only native species (denoted as $\bar{C}$ and *FQI*) and the second including all taxa present (including non-natives) within the site or plot (denoted as $\bar{C}_i$ and FQI_i; NGPFQAP 2001; Rothrock and Homoya 2005). Descriptions of each method and reasoning behind their development and use have been detailed in both the original *FQA* documents (Swink and Wilhelm 1994; Taft et al. 1997) and in numerous studies addressing the effectiveness of these indices across a range of locations and ecological conditions (NGPFQAP 2001; Bourdaghs et al. 2006; Matthews et al. 2009).

Swink and Wilhelm (1994) addressed a general *FQA* rating system that rates sites attaining a $\bar{C}$ value of 3.5 or higher as being of natural quality while sites of 4.5 or greater are considered high quality natural sites. Sites receiving *FQI* values of 35 or higher are considered natural sites and sites with values of 45 or higher are “noteworthy” remnant natural areas (Swink and Wilhelm 1994; Rothrock and Homoya 2005). Site $\bar{C}$ and *FQI* rankings below 3.5 or 35,

respectively, are considered to be somewhat degraded, are dominated by lower *C*-value species, and typically are affected by periodic anthropogenic disturbances.

C-values are defined at the state level for all native species by a local team of experts on the flora of that state. This subjective nature of assigning *C*-values has been presented as a possible inconsistency when using the *FQA* as it can result in *C*-value assignment varying greatly between states (Rothrock and Homoya 2005; Bourdaghs et al. 2006). These differences are amplified when state boundaries occur within close proximity to ecoregion boundaries as the relative abundance/rarity of certain species may vary considerably between states. One of these breaks occurs along the Big Sioux River on the South Dakota/Iowa border where a transition between the Eastern Deciduous Forest and Tall Grass Prairie is observed (Gleason and Cronquist 1964). A number of species occur at the edge of their range in this area, providing a melting pot of vegetation with more eastern or western affinities that is unique relative to the adjacent state (Vander Zee 1979). While differences between state *C*-value assignments may be attributed to certain species behaving differently across different parts of their respective ranges, it is more likely that differences between states are related to human judgments or biases (Rothrock and Homoya 2005). One method that can be employed to examine this possible subjectivity and bias is to sample vegetation at state boundaries and compare *FQA* calculations using *C*-values derived from each state.

Similar approaches have been utilized recently by Bourdaghs et al. (2006) to examine differences in state *C*-value assignments between Michigan and Wisconsin in wetland communities along these state borders. Findings from this study indicated that on average, Wisconsin's mean *C*-values for 403 species were greater (6.01) than Michigan (5.42) and that site $\overline{C}$ and *FQI* calculations for 54 total sites were greater on 51 and 53 sites, respectively, when calculated using Wisconsin coefficients. This study provides evidence for how differences in state *C*-value assignments can affect *FQA* calculations, although overall mean *C*-values

differences (0.59) between Michigan and Wisconsin were relatively minor (Bourdaghs 2004; Bourdaghs et al. 2006).

Differences in *C*-value designations between Iowa and South Dakota could influence the assessment of floristic quality in my study of vegetation patterns within wooded riparian habitats along the Big Sioux River, with possible implications for how sites are rated for conservation value. To investigate these effects, I analyzed the influence of differences in *C*-value assignment between South Dakota and Iowa on floristic quality assessment using vegetation data from 15 riparian sites and 3 upland forested sites located along the South Dakota/Iowa border. Sites within my study area are particularly suited to address this question, as all sites are within a few hundred meters of the border between the two states. Specific objectives included:

(1) Examining possible differences between Iowa and South Dakota *C*-values assignments and their effects on *FQA* index calculations ($\bar{C}$ and *FQI*) at the site level.

(2) Evaluating the usefulness of using average *C*-values between the two states as a simple solution for *C*-value divergence.

(3) Comparing site rank values of various *FQA* index calculations ($\bar{C}$ and *FQI*) to determine the extent to which differences in state *C*-value assignments can lead to rank-order differences in floristic quality between sites. Such differences would be particularly relevant for ecosystem managers using the *FQA* to prioritize sites for restoration efforts.

Methods

Study Area

The lower Big Sioux River is located in eastern South Dakota and northwestern Iowa, providing the border between the states (Figure 3.1). The Big Sioux is a largely unregulated river

draining approximately 22,550 km^2 of Minnesota, Iowa, and South Dakota, including the Coteau des Prairies and much of South Dakota's Prairie Pothole region (Westin and Malo 1978; South Dakota DENR 2010). Compared to many other Great Plains rivers, the Big Sioux is relatively natural and free-flowing, with only a few run-of-the-river mainstem dams and a largely intact riparian corridor. This riparian corridor and the aquatic ecosystem that it borders provides key ecosystem services to the people of eastern South Dakota and northwestern Iowa including water quality protection, recreational opportunities, aesthetic enjoyment, and biodiversity protection. Along its course, the river flows near or through several population centers (e.g., Watertown, Brookings, and Sioux Falls, South Dakota, and Sioux City, Iowa) within an otherwise agriculturally dominated matrix.

The study area extended along a 220 km stretch of river extending from south of Brandon, SD, to Sioux City, IA (Figure 3.1). The river valley widens and local relief increases through this reach with an approximate gradient of 0.452 m/km. The river is highly dynamic with erosive and depositional forces helping to create a variety of aquatic and riparian habitats that support a diverse array of wildlife and fish species. This dynamic nature has helped create and support diverse deciduous riparian forest communities that are common throughout the study area. Additionally, areas of upland mixed hardwood and bur oak (*Quercus macrocarpa*) forest are common along the bluffs bordering the river. A complete description of the study area can be found in Chapters 1 and 2.

Vegetation Sampling

Fifteen riparian forest sites and three upland forest sites were sampled between June 10 and August 31 of 2010 and 2011. Vegetation was sampled as part of an ongoing study to map and classify forested habitats along the Big Sioux River from Watertown, SD, to Sioux City, IA, and to characterize plant species composition, structure, and floristic quality within the mapped

vegetation types. Data and conclusions from this project will be used by the South Dakota Department of Game, Fish and Parks for strategic conservation planning and assessment as part of their State Wildlife Action Plan (SDGFP 2006). I utilized forested sites along the South Dakota / Iowa border due to the close proximity to both states, providing the ability to directly compare state *C*-value assignments. Sampling included characterization of dominant overstory composition and structure using 10 m x 20 m rectangular plots placed in stratified random fashion within different forest patch types; shrub/sapling composition, stem density and cover using line intercept and belt transect methods; and herbaceous species composition and cover using 1 x 1 m^2 quadrats. More details on vegetation sampling methodologies are provided in Chapter 1.

Upland forest sites were sampled as part of a pilot study for the SDGFP. Five plots were established within each upland site across a range of elevations, aspects, and environmental conditions. Plots locations were determined by a stratified random procedure along a transect that was established *a priori* on each site using ArcGIS 10.0. The transect was located so as to capture as much environmental variation as possible within an individual drainage. In general, plots were placed along the bottom slope, mid-slope area, and finally at the top of the slope on each side of the drainage. Plot sampling methodology was otherwise identical to the riparian sampling.

Unknown species were noted and numbered (e.g., Unk. #1) and photographs and collections were taken from individuals outside of the quadrat, if possible. These unknowns were later pressed, dried, and identified using herbarium specimens and keys or other guides to the vascular flora of the region (e.g., *Flora of the Great Plains* (Great Plains Flora Association 1986); *The Vascular Plants of South Dakota* (Van Bruggen 1976)). Species that could not be reliably identified using these techniques were submitted to Dr. Gary Larson of South Dakota State University for assistance with identification. Specimens that still could not be identified were disregarded for the analyses in this paper as I thought it was inappropriate to assign *C*-values

across higher taxonomic levels (e.g., *Amaranthus* sp.). Plant nomenclature followed the USDA PLANTS database (http://plants.usda.gov/java/, USDA NRCS 2011).

Index Calculations and Comparisons

A master species list was generated from the plot data from each of the 18 study sites and all species were assigned *C*-values from a list developed for the flora of North and South Dakota (excluding the Black Hills; referred to as the South Dakota list hereafter; The Northern Great Plains Floristic Quality Assessment Panel (NGPFQAP) 2001) and a list developed for the flora of Iowa (available at http://www.iowaplants.info/flora/pinv.html). Additionally, I calculated an average state *C*-value (the mean between the Iowa and South Dakota *C*-values for each species) in order to evaluate the recommendation by Bourdaghs et al. (2006) that averaging *C*-values can be a simple solution for dealing with differences between state *C*-value assignments. These three sources of *C*-values were used to calculate several variations of $\bar{C}$ and *FQI* at the site and plot level for plant species in the herbaceous, shrub, or tree layers. Calculations included (1) using all species (including non-natives as 0s, $\bar{C}_i$ and FQI_i) as well as a (2) "native only" version ($\bar{C}$ and *FQI*) of each of the indices.

$\bar{C}$ (and $\bar{C}_i$) values at the site level were compared using coefficients for each species from Iowa, South Dakota, and the states average using a paired t-test approach (i.e., individual significance test at every site). Additionally, across all sites, a one-way analysis of variance (ANOVA) approach was used to analyze differences in the average site level $\bar{C}$, *FQI*, $\bar{C}_i$, and FQI_i values calculated using coefficients from South Dakota, Iowa, or the average of the two. The Tukey's HSD post hoc comparison was used to further examine significant differences between these 3 groups. In addition to comparing site level indices, I also compared the overall study area species list and the overall study area distribution of *C*-values as a way to examine how each state viewed the same set of species. These analyses were conducted using paired t-test

and a chi-square distribution approaches. In addition, I also examined the overall distributions of *C*-values for all native flora within each state (including those found in only one state or the other). This analysis was conducted to determine if differences in *C*-value scores in the study area level species lists could be attributed to differences in how each state viewed a shared set of species or if *C*-values were consistently higher or lower across the entire flora (regardless of which species they were) of one state than the other. With this analysis, I included the total flora list from South Dakota (i.e., the Dakota database list) as well as the list for the Iowa flora. Additionally, I compared the distribution of South Dakota and Iowa values with lists developed for the floras of Michigan (Herman et al. 1997), Indiana (Rothrock 2004), Nebraska (Rolfsmeier and Steinauer 2003), Ohio (Andreas et al. 2004), and Wisconsin (Bernthal 2003) to see how the relative *C*-value distributions varied between states.

The final calculation focused on how using different states' *C*-value assignments could potentially lead to differences in the rank-order of site level $\overline{C}$ or *FQI* values. The practice of ranking sites may be an important tool for conservation managers as they wish to prioritize areas for restoration or reclamation efforts. The possibility that site rankings could be sensitive to which state's coefficients were used made this particularly important to examine. Site rankings were completed for all 18 sites for each of the index calculation variations using South Dakota, Iowa, and state average *C*-values. Site rank comparisons were conducted using the Wilcoxon signed-rank test with significance being determined with this and all other statistical tests at $p \leq 0.05$, while *p*-values between 0.05 and 0.10 were considered marginally significant. All means were reported with standard error values. All data entry, error checking, index calculations, and production of graphics were done using MS-Excel. All statistical analyses were completed using the Statistical Analysis System software (SAS®, version 9.1).

Results

A total of 145 species were encountered across 82 plots at the 18 sites. One hundred and fifteen species were sampled within the 15 riparian sites with 75 species unique to these areas. A total of 70 species were found within the three upland sites with 30 species unique to these sites. Of the 145 total species, 24 (17 %) were classified as introduced in both states with three other species (*Phalaris arundinacea*, *Prunella vulgaris*, and *Xanthium strumarium*) considered exotics in Iowa but not in South Dakota. I compared the native/exotic status to the USDA National PLANTS database (http://plants.usda.gov/java/, USDA NRCS 2011) to confirm these three species as native. There were four instances in which one of the states did not supply a *C*-value for a particular species, including South Dakota not providing values for *Toxicodendron radicans* and *Cornus amomum* and Iowa not providing coefficients for *Carex assiniboinensis* and *Physalis longifolia*. Because of this, these species were not included in the index calculations and the resulting species list contained only 141 species. A complete species list with the associated *C*-values from each state can be found in Table 3.1.

Average *C*-values for the 141 species sampled were significantly different between South Dakota and Iowa lists (paired t-test, two-tail, $p<0.0001$) with a total species list $\overline{C}$ of 3.57 (±0.26) for South Dakota and 2.50 (± 0.20) for Iowa (Table 3.1). Additionally, the *C*-value distribution for the 141 species was found to be significantly different between Iowa and South Dakota (χ^2 = 18.61, df = 10, p=0.005; Figure 3.2). Overall, South Dakota assigned a *C*-value of 0-3 to approximately 33% of the sampled species compared to Iowa assigning these values to 45% of the species. The states were relatively similar in their assignment of *C*-values in the 4-7 range (36% for South Dakota, 34% for Iowa) but differed strongly in their assignment of values in the 8-10 range (14% for South Dakota, 1% for Iowa; Figure 3.3). Of the 141 species, 98 had *C*-value differences between the two states (43 species (30%) were assigned the same *C*-value) with 35 (25%) having differences equal to 1 (in either direction; Figure 3.4). There were 20 species

(14%) with *C*-value differences greater than or equal to 4, with 3 of these species having differences equal to 6 (*Arisaema triphyllum*, *Gleditsia triacanthos*, and *Prunella vulgaris*) and 3 other species having a *C*-value difference equal to 7 (*Beckmannia syzigachne*, *Osmorhiza claytonia*, and *Symphyotrichum ontarionis*; Table 3.1). The largest difference between states was 10, in which South Dakota assigned *Hackelia deflexa* a 0 and Iowa assigned it a 10 (Table 3.1).

Floristic quality indices ($\bar{C}$, *FQI*, $\bar{C}_i$, and FQI_i) were computed for each of the 18 sites using *C*-values derived from both Iowa and South Dakota regardless of in which state the site actually occurred. All 18 sites had significantly greater (paired t-test, two-tail, $p<0.05$) $\bar{C}_i$ and $\bar{C}$ values when calculated using South Dakota coefficients rather than Iowa *C*-values (Table 3.2). The average $\bar{C}_i$ and FQI_i difference (SD-IA) between the South Dakota and Iowa ratings for the 15 riparian sites was 1.23 and 6.40 respectively with the greatest difference at an individual site being 1.75 for $\bar{C}_i$ and 9.57 for FQI_i. The average $\bar{C}_i$ and FQI_i differences for the three upland sites were 1.97 and 12.99 with the greatest difference being 2.11 for $\bar{C}_i$ and 14.02 for FQI_i. A complete summary of all site index calculations and general site descriptions can be found in Table 3.2. Several interesting trends arose when site $\bar{C}$, *FQI*, $\bar{C}_i$, and FQI_i, values from South Dakota, Iowa, and the state averages were compared using a one-way ANOVA approach. Significant differences among state scores were observed for all variables including $\bar{C}_i$ ($F_{(2,51)}$ = 13.9, p = 0.0001), $\bar{C}$ ($F_{(2,51)}$ = 9.27, p = 0.0004), FQI_i ($F_{(2,51)}$ = 4.41, p = 0.02), and *FQI* ($F_{(2,51)}$ = 4.02, p = 0.02; Table 3.3). The results from Tukey's HSD post-hoc comparisons for the $\bar{C}$, *FQI*, $\bar{C}_i$, and *FQI*, values across sites indicated that South Dakota and Iowa values were significantly different from one another for all index calculations and that South Dakota values were also significantly different from the state average for $\bar{C}$, *FQI*, $\bar{C}_i$, and *FQI*, values (Table 3.3). Significant differences between Iowa and the state average were observed only for $\bar{C}_i$ values (Table 3.3). These results indicate that using an average coefficient between the two states may be an effective way for dealing with *C*-value divergences at state boundaries.

To further examine differences between each state's *C*-value assignments and to better understand why indices calculated using South Dakota values were consistently greater than those for Iowa, I looked at the overall distribution of *C*-values for the flora of each state, expecting the distribution to be biased toward lower scores in Iowa than in South Dakota. This notion did not hold true as $\overline{C}$ values across all native taxa are approximately equal between Iowa ($\overline{C}$ = 6.04 (± 0.08), 1,488 total species) and South Dakota (i.e., the Dakota database; $\overline{C}$ = 6.14 (± 0.09), 1,308 species total; Table 3.4). These average *C*-values appear to be consistent with those found in Michigan ($\overline{C}$ = 6.48 (± 0.07), 1,815 total species; Herman et al. 1997), Indiana ($\overline{C}$ = 6.00 (± 0.07), 2,006 total species; Rothrock 2004), Nebraska ($\overline{C}$ = 5.15 (± 0.06), 1,545 total species; Gerry Steinauer, personal communication), Ohio ($\overline{C}$ = 5.76 (± 0.06), 1,795 total species; Andreas et al. 2004), and Wisconsin ($\overline{C}$ = 6.36 (± 0.06), 1,648 total species; Bernthal 2003; Table 3.4). These results indicate that while there are substantial differences between Iowa and South Dakota at the study reach level, the overall average distributions of *C*-values assigned to the flora of each state are similar.

Site rank comparison for all $\overline{C}$ and *FQI* index variations were not significantly different between states using the Wilcoxon signed-rank test at the 0.05 level. Mean differences in site ranks values between Iowa and South Dakota for $\overline{C}_i$ and FQI_i were 2.11 and 0.89, respectively, with the largest difference in site rank being 6 for $\overline{C}_i$ and 3 for FQI_i (Table 3.5-3.6). Site ranks differences for $\overline{C}$ and *FQI* were greater than for $\overline{C}_i$ and FQI_i with mean values of 3.11 and 1.22, respectively, with largest difference in site rank being 7 for $\overline{C}$ and 4 for *FQI* (Table 3.7-3.8).

Discussion

Results from this study highlight a number of potential pitfalls associated with using the *FQA* across state boundaries and draw attention to the potential subjective nature of assigning *C*-values. Overall mean *C*-value differences between South Dakota and Iowa were substantial

(1.07). Of the 141 total species, 14% (20 species) had a mean divergence value ≥ ± 4 with only a quarter (25%, 35 species) being equal to ± 1 (Figure 3.4), although 43 species (30%) had no difference between the *C*-value assignments of the two states. These *C*-value differences between states affected all of the index calculations with Iowa coefficients yielding consistently lower *FQA* index values than South Dakota (Table 3.2). Using the state average *C*-value may be a compromise, although if differences in state assignments are high, the state average may also differ significantly from either state (as is the case with the $\overline{C}_i$ calculation for this study; Table 3.3). Finally, state differences in *C*-values assignments also affected the general rank-orders of scores for the 18 study sites, albeit not significantly, highlighting a potential issue for land managers wishing to prioritize sites for reclamation efforts along state borders (Table 3.5-3.8). These impacts beg the question of why *C*-value divergence is so high between South Dakota and Iowa for the species found in my study sites.

While species can behave differently across different parts of their respective ranges, it is unlikely that South Dakota populations are more "conservative" than populations of the same species from Iowa. The overall floristic *C*-value distributions for South Dakota and Iowa were relatively similar to each other and to those found in other states across the Midwest (Table 3.4). While total *C*-value distributions appear similar between South Dakota and Iowa they are substantially different for species encountered in my study area (paired t-test, two-tail, $p<0.0001$). A likely reason for this relates to relative abundance/rarity of species within each state. While rarity is not a formal measure for *C*-value assignment, it is often inevitably included when evaluating rare taxa known to occur in only a few locations within a state (Taft et al. 1997). Geographically rare species (i.e., species that have a more eastern or western affinity in their ranges relative to each state) are often assigned high *C*-values regardless of their relative growth habitat or fidelity towards undisturbed, "natural" environments. Examples of such species within the study area include *Symphyotrichum ontarionis*, *Arisaema triphyllum*, and *Osmorhiza claytonii*

which only occur in a few select locations in South Dakota, one being the lower Big Sioux River basin, but occur commonly throughout Iowa (USDA NRCS 2011). These geographically rare species were all assigned *C*-values of 10 in South Dakota but were given relatively low *C*-values of 3 and 4 in Iowa. It should be noted that species assigned a *C*-value of 10 in South Dakota were regarded as being "reserved for those taxa virtually restricted to natural, undisturbed habitats in the Dakotas and that would have nearly 100% confidence in knowing that a sample brought to the herbarium would have been collected from a high quality, natural remnant" (NGPFQAP 2001). These three species may not exhibit this high degree of "conservatism" required for a score of a 10 as, for example, *Symphyotrichum ontarionis* was found readily along recently disturbed/flooded alluvial surfaces and *Osmorhiza claytonii* is a common species found within a variety of forest communities under a range of environmental conditions common to the Eastern Deciduous Forests (Pavek 1992).

These overall trends may be attributed, in part, to what habitats were sampled along the Big Sioux. The riparian and upland forest habitats contain species more characteristic of the Eastern Deciduous Forest that are located along the edge of their range (Gleason and Cronquist 1964). Species within these habitats have a more eastern affinity and, because of this, are relatively rare in South Dakota and more common in Iowa. If I had sampled within prairie ecosystems along the Big Sioux, where species have a more western affinity, the opposite trend might have been observed, with lower *C*-values in South Dakota and higher values in Iowa given that a majority of the prairie species are more common in South Dakota than in Iowa.

It is not the purpose of this paper to highlight every potential error in *C*-value assignment or to critique/judge how well each state did or did not do. The botanists charged with the task of assigning *C*-values to all naturally occurring species within a state were faced with a daunting task. They utilized their collective knowledge of patterns of occurrence and relative growth habitat to assign suitable coefficients. These decisions were based upon their current knowledge

of each individual species at the time of assignment. *C*-value assignments for each state should therefore be viewed as preliminary and should be open for adjustment, corrections, and additions as new information pertaining to the flora of that state is gathered (Gary Larson, personal communication).

Bourdaghs et al. (2006) expressed the view that *C*-values should be assigned across ecologically meaningful units such Ecological Provinces or Sections (Keys et al. 1995), Level III Ecoregions (Omernik 1987) or Wetland Indicator Status Regions rather than at the state level. By assigning *C*-values across these broader ranges it would reasonable to assume that species should behave relatively consistently across that range and would therefore provide more consistency and accuracy to *C*-value assignments (Bourdaghs et al. 2006). While assigning *C*-values across these ecological meaningful units may improve the utility of the *FQA*, there still may be major differences across boundaries, creating similar situations to the one highlighted in this paper. Additionally, it may be difficult to coordinate *C*-value assignment efforts between states as most natural resources management organizations are organized at the state level (Bourdaghs et al. 2006). These goals will likely only become met at a scale useful across the United States if *FQA* becomes federally mandated, as in the case of Wetland Indicator Status (Reed 1988, 1997). In order to accomplish these goals it would require the *FQA* to get past its relative "grass-roots" stage and become more widely standardized as a valuable and important ecological assessment tool.

References

Bonanno, G. and R. Lo Giudice. 2010. Application of two quality indices as monitoring and management tools of rivers. Case study: The Imera Meridionale River, Italy. *Environ. Management* 45(4): 856-867.

Bourdaghs, M. 2004. Properties and performance of the floristic quality index in Great Lakes coastal wetlands. M.S. Thesis. University of Minnesota, Minneapolis, MN, USA.

Bourdaghs, M., C.A. Johnston, and R.R. Regal. 2006. Properties and performance of the floristic quality index in Great Lakes coastal wetlands. *Wetlands* 26:718–735.

Bowers, K. and C. Boutin. 2008. Evaluating the relationship between floristic quality and measures of plant biodiversity along stream bank habitats. *Ecological Indicators* 8: 466–475.

Bryce, S., J.M. Omernik, D.E. Pater, M. Ulmer, J. Schaar, J. Freeouf, R. Johnson, P. Kuck and S.H. Azevedo. 1998. Ecoregions of North Dakota and South Dakota. Jamestown, ND: Northern Prairie Wildlife Research Center Online. http://www.npwrc.usgs.gov/resource/habitat/ndsdeco/index.htm

Duffey, E. 1986. Editorial. *Biological Conservation* 36:197-198.

Gleason, H.A. and A. Cronquist. 1964. The natural geography of plants. Columbia University Press, New York, New York, USA.

Grime JP. 1974. Vegetation classification by reference to strategies. *Nature* 250:26–31.

Grime, J.P., J.G. Hodgson, and R. Hunt. 1988. Comparative plant ecology: a functional approach to common British species. Unwin & Hyman, London.

Herman, K.D., L.A. Masters, M.P. Penskar, A.A. Reznicek, G.S. Wilhelm, W.W. Brodovich, and K.P. Gardiner. 2001. Floristic quality assessment with wetland categories and examples of computer applications for the state of Michigan, second edition. Michigan Department of Natural Resources, Wildlife Division, Natural Heritage Program, In partnership with U.S. Department of Agriculture Natural Resources Conservation Service, Rose Lake Plant Materials Center, East Lansing, MI, USA.

Keys, J.E., Jr., C.A. Carpenter, S.L. Hooks, F.G. Koeneg, W.H. McNab, W. Russell, and M.L.Smith. 1995. Ecological units of the eastern United States: first approximation. Map (scale 1:3,500,000). U.S. Dept. of Agriculture, Forest Service, Atlanta, GA, USA. Technical Publication R8-TP 21.

Lindsey, A.A. 1955. Testing the line-strip method against full tallies in diverse forest types. *Ecology* 36: 485-494.

Lopez, R.D. and M.S. Fennessy. 2002. Testing the floristic quality assessment index as an indicator of wetland condition. *Ecological Applications* 12:487-497.

Matthews, J.W., G. Spyreas, and A.G. Endress. 2009. Trajectories of vegetation-based indicators used to assess wetland restoration progress. *Ecological Applications* 19:2093–2107.

McCormick, K.A. and R.H. Hammond. 2004. Geology of Lincoln and Union Counties, South Dakota. Department of Environment and Natural Resources, Geologic Survey. Bulletin 39.

Milewski, C.L., C.R. Berry and D. Dieterman. 2001. Use of the index of biological integrity in eastern South Dakota rivers. *The Prairie Naturalist* 33(3):135-152.

Omernik, J.M. 1987. Ecoregions of the conterminous United States. *Annual Association of American Geographers* 77:118-125.

Pavek, D.S. 1992. Osmorhiza claytonii. In: fire effects information system. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. http://www.fs.fed.us/database/feis/ retrieved November 2011.

Reed, P.B., Jr. 1988. National List of Plant Species that Occur in Wetlands: 1988 National Summary. U.S. Fish and Wildlife Service, Washington, DC, USA. Biol. Rep. 88 (24).

Reed, P.B., Jr. 1997. Revision of the National List of Plant Species that Occur in Wetlands. In Cooperation with the National and Regional Interagency Review Panels: U.S. Fish and Wildlife Service, U.S. Army Corps of Engineers, U.S. Environmental Protection Agency, and Natural Resources Conservation Service. Department of Interior, U.S. Fish and Wildlife Service, Washington, DC, USA.

Rolfsmeier, S. and G. Steinauer. 2003. Vascular plants of Nebraska (Ver. I). Nebraska Natural Heritage Program. Nebraska Game and Fish Commission, Lincoln, NE.

Rooney, T.P. and D.A. Rogers. 2002. The modified floristic quality index. *Natural Areas Journal* 22:340–344.

Rothrock, P.E. and M. Homoya. 2005. An evaluation of Indiana's floristic quality assessment. *Proceedings of the Indiana Academy of Science*, 114:9-18.

SAS Institute Inc. 2004. SAS, version 9.1.3 [computer program]. SAS Institute Inc., Cary, N.C.

South Dakota Department of Environment and Natural Resources. 2010. The 2010 South Dakota integrated report for surface water quality assessment. Report 305(b) and 303(d).

South Dakota Department of Game, Fish, and Parks (SDGFP). 2006. South Dakota Comprehensive Wildlife Conservation Plan. South Dakota Dept. of Game, Fish, and Parks, Wildlife Division Report 2006-08.

Swink, F. and G. Wilhelm. 1979. Plants of the Chicago region. Revised and expanded edition with keys. The Morton Arboretum, Lisle, Illinois.

Swink, F. A. and G. S. Wilhelm. 1994. Plants of the Chicago region. Fourth Edition. Indiana Academy of Sciences, Indianapolis. 921 pp.

Taft, J., G. Wilhelm, D. Ladd, and L. Masters. 1997. Floristic quality assessment for vegetation in Illinois. A method for assessing vegetation integrity. *Eriginia* 15(1):3-95.

The Northern Great Plains Floristic Quality Assessment Panel. 2001. Coefficients of conservatism for the vascular flora of the Dakotas and adjacent grasslands. U.S. Geological Survey, Biological Resources Division, Information and Technology Report USGS/BRD/ITR-2001-0001. 32 pp.

Tu, W.-G., X.-F. Gao, N. Wu, and S.-H. Liu. 2009. A novel method for floristic quality assessment using the vegetation of the Jiuding Mountain, Sichuan, China as an example. *Nordic Journal of Botany* 27: 61–68.

USDA, NRCS. 2011. The PLANTS Database (http://plants.usda.gov, 31 August 2011). National Plant Data Center, Baton Rouge, LA 70874-4490 USA.

Vander Zee, D. 1979. The vascular flora of Gitchie Manitou State Preserve, Lyon County, Iowa. *Proceedings of the Iowa Academy of Science* 88(2):66-75.

Westin, F.C., and D.D. Malo. 1978. Soils of South Dakota. South Dakota State University Agricultural Experimental Station. Bulletin 656.

Table 3.1. Species list for 145 species encountered along the lower Big Sioux River with *C*-values from South Dakota, Iowa, and study area averages being provided. Null values indicate species that were not assigned *C*-values in that state (4 total) and an asterisk (*) indicates the species is considered non-native. Note that a 0 was used for * when calculating averages or differences. Study area average *C*-values, with standard error, are provided.

Scientific Name	**SD *C*-value**	**IA *C*-value**	**Study Area *C*-value**
Acer negundo L.	1	0	0.5
Acer saccharinum L.	4	1	2.5
Ageratina altissima (L.) King & H. Rob.	6	2	4
Alliaria petiolata (M. Bieb.) Cavara & Grande	*	*	*
Ambrosia artemisiifolia L.	0	0	0
Ambrosia trifida L.	0	0	0
Amorpha fruticosa L.	4	5	4.5
Andropogon gerardii Vitman	5	4	4.5
Anemone canadensis L.	4	2	3
Anemone virginiana L.	8	4	6
Apocynum cannabinum L.	4	1	2.5
Aquilegia canadensis L.	8	6	7
Arctium minus Bernh.	*	*	*
Arisaema triphyllum (L.) Schott	10	4	7
Asclepias speciosa Torr.	4	6	5
Beckmannia syzigachne (Steud.) Fernald	1	8	4.5
Bidens frondosa L.	1	3	2
Bidens tripartita L.	2	3	2.5
Bidens vulgata Greene	1	1	1
Botrychium virginianum (L.) Sw.	7	6	6.5
Bouteloua curtipendula (Michx.) Torr.	5	6	5.5
Bromus inermis Leyss.	*	*	*
Calystegia sepium (L.) R. Br.	0	0	0
Campanulastrum americanum (L.) Small	8	4	6
Cannabis sativa L.	*	*	*
Carex assiniboinensis W. Boott	8		8
Carex blanda Dewey	5	2	3.5
Carex emoryi Dewey	4	6	5
Carex laeviconica Dewey	6	6	6
Carex molesta Mack. ex Bright	3	2	2.5
Catalpa speciosa (Warder) Warder ex Engelm.	*	*	*
Celtis occidentalis L.	5	2	3.5
Chenopodium album L.	*	*	*
Chenopodium simplex (Torr.) Raf.	5	0	2.5
Cirsium altissimum (L.) Hill	3	4	3.5

Table 3.1. Continued.

Scientific Name	**SD *C*-value**	**IA *C*-value**	**Study Area *C*-value**
Cirsium vulgare (Savi) Ten.	*	*	*
Conyza canadensis (L.) Cronquist var. *canadensis*	0	0	0
Cornus amomum Mill.		6	6
Cornus drummondii C.A. Mey.	5	6	5.5
Cornus sericea L. ssp. sericea	5	7	6
Cryptotaenia canadensis (L.) DC.	7	4	5.5
Dichanthelium oligosanthes (Schult.) Gould var. *scribnerianum* (Nash) Gould	6	5	5.5
Echinocystis lobata (Michx.) Torr. & A. Gray	3	2	2.5
Ellisia nyctelea (L.) L.	0	1	0.5
Elymus canadensis L.	3	5	4
Elymus hystrix L.	8	5	6.5
Elymus villosus Muhl. ex Willd.	4	5	4.5
Elymus virginicus L.	4	3	3.5
Equisetum hyemale L.	3	1	2
Erigeron philadelphicus L.	2	2	2
Euphorbia esula L.	*	*	*
Festuca subverticillata (Pers.) Alexeev	10	7	8.5
Fraxinus pennsylvanica Marsh.	5	3	4
Galium aparine L.	0	1	0.5
Galium boreale L.	4	7	5.5
Galium triflorum Michx.	7	7	7
Geum canadense Jacq.	4	2	3
Glechoma hederacea L.	*	*	*
Gleditsia triacanthos L.	6	0	3
Gymnocladus dioicus (L.) K. Koch	8	5	6.5
Hackelia deflexa (Wahlenb.) Opiz	0	10	5
Hackelia virginiana (L.) I.M. Johnst.	0	0	0
Helianthus tuberosus L.	2	0	1
Heracleum maximum Bartram	3	4	3.5
Hydrophyllum virginianum L.	8	3	5.5
Impatiens capensis Meerb.	4	3	3.5
Juglans nigra L.	8	4	6
Juniperus virginiana L.	0	1	0.5
Laportea canadensis (L.) Weddell	5	3	4
Leersia virginica Willd.	5	6	5.5
Leonurus cardiaca L.	*	*	*
Lonicera tatarica L.	*	*	*
Lysimachia ciliata L.	6	4	5

Table 3.1. Continued.

Scientific Name	**SD *C*-value**	**IA *C*-value**	**Study Area *C*-value**
Maianthemum racemosum (L.) Link ssp. *racemosum*	9	4	6.5
Maianthemum stellatum (L.) Link	5	5	5
Mentha arvensis L.	3	4	3.5
Menispermum canadense L.	8	5	6.5
Monarda fistulosa L.	5	2	3.5
Morus alba L.	*	*	*
Muhlenbergia frondosa (Poir.) Fernald	4	3	3.5
Nepeta cataria L.	*	*	*
Osmorhiza claytonii (Michx.) C.B. Clarke	10	3	6.5
Ostrya virginiana (Mill.) K. Koch	9	5	7
Oxalis stricta L.	0	0	0
Parietaria pensylvanica Muhl. ex Willd.	3	3	3
Parthenocissus quinquefolia (L.) Planch.	2	2	2
Parthenocissus vitacea (Knerr) Hitchc.	2	1	1.5
Phalaris arundinacea L.	0	*	0
Phryma leptostachya L.	8	4	6
Physalis longifolia Nutt.	0		0
Pilea pumila (L.) A. Gray	4	3	3.5
Plantago rugelii Decne.	0	0	0
Poa palustris L.	4	5	4.5
Poa pratensis L.	*	*	*
Polygonum amphibium L. var. *emersum* Michx.	0	3	1.5
Polygonum convolvulus L.	*	*	*
Polygonum lapathifolium L.	1	0	0.5
Populus deltoides Bartram ex Marsh.	3	1	2
Prunus americana Marsh.	4	2	3
Prunus virginiana L.	4	2	3
Prunella vulgaris L.	6	*	6
Quercus macrocarpa Michx.	6	4	5
Ranunculus abortivus L.	2	0	1
Ranunculus sceleratus L.	3	4	3.5
Rhamnus cathartica L.	*	*	*
Rhus glabra L.	4	0	2
Ribes americanum Mill.	7	6	6.5
Ribes missouriense Nutt.	4	3	3.5
Rubus occidentalis L.	5	1	3
Rudbeckia laciniata L.	6	4	5
Rumex crispus L.	*	*	*
Salix amygdaloides Andersson	3	1	2

Table 3.1. Continued.

Scientific Name	**SD *C*-value**	**IA *C*-value**	**Study Area *C*-value**
Salix interior Rowlee	3	0	1.5
Sanguinaria canadensis L.	10	7	8.5
Sanicula marilandica L.	7	5	6
Schizachyrium scoparium (Michx.) Nash	6	5	5.5
Setaria pumila (Poir.) Roem. & Schult.	*	*	*
Silene stellata (L.) W.T. Aiton	7	4	5.5
Sisymbrium loeselii L.	*	*	*
Smilax ecirrhata (Engelm. ex Kunth) S. Watson	8	6	7
Smilax herbacea L.	8	5	6.5
Smilax tamnoides L.	8	4	6
Solidago canadensis L.	1	0	0.5
Solidago flexicaulis L.	10	6	8
Solidago gigantea Aiton	4	3	3.5
Solanum ptycanthum Dunal	0	0	0
Sonchus arvensis L.	*	*	*
Sorghastrum nutans (L.) Nash	6	4	5
Symphyotrichum ontarionis (Wiegand) G.L. Nesom	10	3	6.5
Taraxacum officinale F.H. Wigg.	*	*	*
Teucrium canadense L.	3	4	3.5
Tilia americana L.	7	5	6
Toxicodendron radicans (L.) Kuntze		0	0
Ulmus americana L.	3	2	2.5
Ulmus pumila L.	*	*	*
Ulmus rubra Muhl.	5	2	3.5
Urtica dioica L.	0	0	0
Verbascum thapsus L.	*	*	*
Verbena urticifolia L.	3	2	2.5
Viola sororia Willd.	2	1	1.5
Vitis riparia Michx.	3	1	2
Xanthium strumarium L.	0	*	0
Zanthoxylum americanum Mill.	3	3	3
Mean	**3.57**	**2.50**	**3.04**
Standard Error	**0.26**	**0.20**	**0.21**

Table 3.2. Study site descriptions for 18 sites located along the lower Big Sioux River, including site name, sampling year, state location, general location description, type of site (riparian or upland), and the total number of plots used to sample vegetation within each site. In addition, the total number of species is provided with total native species in parenthesis. Index calculations for $\overline{C}_i$ (mean *C*, all species), $\overline{C}$ (mean *C*, native only), FQI_i (all species), and *FQI* (native only) are given with overall differences between South Dakota and Iowa index calculations shown in bold. Significant differences (paired t-test, $p \leq 0.05$) in $\overline{C}_i$ and $\overline{C}$ between each state and state averages are indicated with an *.

Site	State	Species #	$\overline{C}_i$	$\overline{C}$	FQI_i	*FQI*
Dakota Dunes (2010, SD)	SD	17 (14)	2.94*	3.57*	12.13	13.36
Confluence of Big Sioux and Missouri River	IA	17 (14)	1.76*	2.14*	7.28	8.02
Riparian, 4 Plots	AVE	17 (14)	2.35*	2.86*	9.70	10.69
		SD-IA Diff	**1.18**	**1.43**	**4.85**	**5.35**
Rock River (2010, IA)	SD	15 (14)	4.20*	4.50*	16.27	16.84
Confluence of Rock River and Big Sioux River	IA	15 (14)	2.47*	2.64*	9.55	9.89
Riparian, 3 Plots	AVE	15 (14)	3.33*	3.57*	12.91	13.36
		SD-IA Diff	**1.74**	**1.86**	**6.71**	**6.95**
Oak Ridge GPA (2011, SD)	SD	27 (22)	2.63*	3.23*	13.66	15.14
North of Hudson, SD	IA	27 (20)	1.85*	2.50*	9.62	11.18
Riparian, 3 Plots	AVE	27 (22)	2.24*	2.75*	11.64	12.90
		SD-IA Diff	**0.78**	**1.19**	**4.04**	**3.96**
Millsite (2010, IA)	SD	14 (13)	3.50*	3.77*	13.10	13.59
West of Westfield, IA	IA	14 (12)	2.29*	2.67*	8.55	9.24
Riparian, 5 Plots	AVE	14 (13)	2.89*	3.12*	10.82	11.23
		SD-IA Diff	**1.21**	**1.10**	**4.54**	**4.35**
City of Canton (2011, SD)	SD	20 (19)	3.90*	4.11*	17.44	17.89
East of Canton, SD	IA	20 (19)	2.15*	2.26*	9.62	9.86
Riparian, 4 Plots	AVE	20 (19)	3.03*	3.18*	13.53	13.88
		SD-IA Diff	**1.75**	**1.84**	**7.83**	**8.03**
Doorenbos-Ford (2011, IA)	SD	28 (27)	2.82*	2.93*	14.93	15.20
Southwest of Chatsworth, IA	IA	28 (25)	2.00*	2.24*	10.58	11.20
Riparian, 6 Plots	AVE	28 (27)	2.41*	2.50*	12.76	12.99
		SD-IA Diff	**0.82**	**0.69**	**4.35**	**4.00**
Nine Mile Creek GPA (2011, SD)	SD	21 (16)	2.86*	3.75*	13.09	15.00
East of Lake Alvin State Rec. Area, SD	IA	21 (16)	1.62*	2.13*	7.42	8.50
Riparian, 4 Plots	AVE	21 (16)	2.24*	2.94*	10.26	11.75
		SD-IA Diff	**1.24**	**1.63**	**5.67**	**6.50**
Fish GPA Riparian (2011, SD)	SD	33 (27)	3.42*	4.19*	19.67	21.75
West of Fairview, SD	IA	33 (26)	1.76*	2.23*	10.10	11.37
Riparian, 3 Plots	AVE	33 (27)	2.59*	3.17*	14.88	16.45
		SD-IA Diff	**1.67**	**1.95**	**9.57**	**10.37**

Table 3.2. Continued.

Site	State	Species #	$\bar{C}_i$	$\bar{C}$	FQI_i	FQI
Silver Maple Primitive Area (2011, IA)	SD	20 (18)	2.40*	2.67*	10.73	11.31
Southwest of Akron, IA	IA	20 (17)	1.20*	1.41*	5.37	5.82
Riparian, 4 Plots	AVE	20 (18)	1.80*	2.00*	8.05	8.49
		SD-IA Diff	**1.20**	**1.25**	**5.37**	**5.49**
Lippke Wetland (2011, IA)	SD	40 (33)	2.73*	3.30*	17.23	18.97
East of Elk Point, SD	IA	40 (32)	1.98*	2.47*	12.49	13.97
Riparian, 5 Plots	AVE	40 (33)	2.38*	2.85*	15.02	16.36
		SD-IA Diff	**0.75**	**0.83**	**4.74**	**5.01**
Big Sioux Corridor (2011, IA)	SD	21 (17)	3.05*	3.76*	13.97	15.52
West of 5 Ridge Prairie State Preserve, IA	IA	21 (16)	1.81*	2.38*	8.29	9.50
Riparian, 6 Plots	AVE	21 (17)	2.43*	3.00*	11.13	12.37
		SD-IA Diff	**1.24**	**1.39**	**5.67**	**6.02**
Akron GPA (2011, SD)	SD	47 (38)	3.11*	3.84*	21.30	23.68
Northwest of Akron, IA	IA	47 (38)	1.85*	2.29*	12.69	14.11
Riparian, 8 Plots	AVE	47 (38)	2.48*	3.07*	16.99	18.90
		SD-IA Diff	**1.26**	**1.55**	**8.61**	**9.57**
Hawarden (2011, IA)	SD	34 (25)	2.53*	3.44*	14.75	17.20
West of Hawarden, IA	IA	34 (24)	1.68*	2.38*	9.78	11.64
Riparian, 5 Plots	AVE	34 (25)	2.10*	2.86*	12.26	14.30
		SD-IA Diff	**0.85**	**1.07**	**4.97**	**5.97**
Gitchie Manitou (2011, IA)	SD	31 (26)	2.55*	3.04*	14.19	15.49
Southeast of Sioux Falls, SD	IA	31 (25)	1.71*	2.12*	9.52	10.60
Riparian, 4 Plots	AVE	31 (26)	2.13*	2.64*	11.85	13.46
		SD-IA Diff	**0.84**	**0.92**	**4.67**	**4.89**
Stone State Park Riparian (2011, IA)	SD	51 (42)	3.67*	4.45*	26.19	28.85
North of Sioux City, IA	IA	51 (42)	2.41*	2.93*	17.22	18.98
Riparian, 3 Plots	AVE	51 (42)	3.04*	3.69*	21.70	23.92
		SD-IA Diff	**1.25**	**1.52**	**8.96**	**9.88**
Mckee GPA Upland (2011, SD)	SD	44 (42)	5.75*	6.02*	38.14	39.04
East of Newton Hills State Park, SD	IA	44 (42)	3.64*	3.81*	24.12	24.69
Upland, 5 Plots	AVE	44 (42)	4.69*	4.92*	31.13	31.86
		SD-IA Diff	**2.11**	**2.21**	**14.02**	**14.35**
Fish GPA Upland (2011, SD)	SD	41 (40)	5.63*	5.78*	36.08	36.52
West of Fairview, SD	IA	41 (40)	3.54*	3.63*	22.65	22.93
Upland, 5 Plots	AVE	41 (40)	4.59*	4.70*	29.36	29.73
		SD-IA Diff	**2.10**	**2.10**	**13.43**	**13.60**
Stone State Park Upland (2011, IA)	SD	50 (48)	5.52*	5.75*	39.03	39.84
North of Sioux City, IA	IA	50 (48)	3.72*	3.88*	26.30	26.85
Upland, 5 Plots	AVE	50 (48)	4.62*	4.81*	32.67	33.34
		SD-IA Diff	**1.80**	**1.88**	**12.73**	**12.99**

Table 3.3. Results from the one-way ANOVA analysis comparing differences in site level $\bar{C}$, *FQI*, $\bar{C}_i$, and *FQI*, values between South Dakota, Iowa, and the state average. Standard error values are provided for all means and * indicate significant differences ($p \leq 0.05$). For significant results, the Tukey's HSD post-hoc test was conducted with letters denoting significant differences within each analysis.

State	$\bar{C}$	$\bar{C}_i$	***FQI***	FQI_i
South Dakota	3.51 (± 0.26) a	4.00 (± 0.23) a	19.62 (± 2.15) a	20.84 (± 2.14) a
Iowa	2.19 (± 0.17) b	2.56 (± 0.15) b	12.35 (± 1.44) b	13.24 (± 1.47) b
State Average	2.85 (± 0.21) b	3.26 (± 0.19) c	15.93 (± 1.79) b	17.00 (± 1.78) b
$F_{(2,51)}$	9.27	13.9	4.02	4.41
p-value	0.0004*	<0.0001*	0.02*	0.02*

Table 3.4. Comparison of *C*-value distribution of the total flora from each state. Overall, South Dakota and Iowa distributions are similar to other states within the Midwest.

State	**Number of Species**	$\bar{C}$	**SE**
Iowa	1,488	6.04	0.08
South Dakota	1,308	6.14	0.09
Michigan	1,815	6.48	0.07
Ohio	1,795	5.76	0.06
Indiana	2,006	6.00	0.07
Nebraska	1,545	5.15	0.06
Wisconsin	1,648	6.36	0.06

Table 3.5. $\overline{C}_i$ (all species) state site rank values for 18 study sites along the lower Big Sioux River. Differences between each states site rankings and differences between each state and the state average are provided with overall mean differences in bold. Site rankings between states and state averages are not significantly different at the 0.05 level (Wilcoxon signed-rank, p>0.05).

Site	**IA $\overline{C}_i$ Rank**	**SD $\overline{C}_i$ Rank**	**Ave $\overline{C}_i$ Rank**	**SD-IA Rank Diff**	**SD-Ave Rank Diff**	**IA-Ave Rank Diff**
Stone State Park Upland	1 (3.72)	3 (5.52)	2 (4.62)	2	1	1
Mckee GPA Upland	2 (3.68)	1 (5.75)	1 (4.71)	1	0	1
Fish GPA Upland	3 (3.59)	2 (5.63)	3 (4.61)	1	1	0
Rock River	4 (2.47)	4 (4.20)	4 (3.33)	0	0	0
Stone State Park Riparian	5 (2.35)	6 (3.67)	6 (3.01)	1	0	1
Millsite	6 (2.29)	7 (3.50)	7 (2.89)	1	0	1
City of Canton	7 (2.15)	5 (3.90)	5 (3.03)	2	0	2
Doorenbos-Ford	8 (1.96)	13 (2.86)	11 (2.41)	5	2	3
Lippke Wetland	9 (1.95)	15 (2.73)	14 (2.35)	6	1	5
Oak Ridge GPA	10 (1.85)	12 (2.89)	12 (2.37)	2	0	2
Akron GPA	11 (1.83)	9 (3.13)	9 (2.48)	2	0	2
Dakota Dunes	12 (1.76)	11 (2.94)	13 (2.35)	1	2	1
Big Sioux Corridor	13 (1.76)	10 (3.10)	10 (2.43)	3	0	3
Fish GPA Riparian	14 (1.76)	8 (3.42)	8 (2.59)	6	0	6
Gitchie Manitou	15 (1.68)	16 (2.58)	16 (2.13)	1	0	1
Hawarden	16 (1.65)	17 (2.56)	17 (2.10)	1	0	1
Nine Mile Creek GPA	17 (1.62)	14 (2.86)	15 (2.24)	3	1	2
Silver Maple Primitive Area	18 (1.20)	18 (2.40)	18 (1.80)	0	0	0
			Mean Diff	**2.11**	**0.44**	**1.78**

Table 3.6. *FQI* $_i$ (all species) state site rank values for 18 study sites along the lower Big Sioux River. Differences between each states site rankings and differences between each state and state averages are provided with overall mean differences in bold. Site rankings between states and state averages are not significantly different at the 0.05 level (Wilcoxon signed-rank, p>0.05).

Site	**IA *FQI*$_i$ Rank**	**SD *FQI*$_i$ Rank**	**Ave *FQI*$_i$ Rank**	**SD-IA Rank Diff**	**SD-Ave Rank Diff**	**IA-Ave Rank Diff**
Stone State Park Upland	1 (26.30)	1 (39.03)	1 (32.67)	1	0	1
Mckee GPA Upland	2 (23.24)	2 (36.37)	2 (29.80)	1	0	1
Fish GPA Upland	3 (22.96)	3 (36.08)	3 (29.52)	2	1	1
Stone S.P. Riparian	4 (16.80)	4 (26.19)	4 (21.49)	0	0	0
Oak Ridge GPA	5 (12.69)	6 (19.84)	6 (16.26)	3	0	3
Akron GPA	6 (12.54)	5 (21.44)	5 (16.99)	2	0	2
Lippke Wetland	7 (12.33)	9 (17.23)	8 (14.86)	0	0	0
Doorenbos-Ford	8 (10.39)	11 (15.12)	11 (12.76)	0	0	0
Fish GPA Riparian	9 (10.10)	7 (19.67)	7 (14.88)	1	0	1
City of Canton	10 (9.62)	8 (17.44)	9 (13.53)	2	1	1
Hawarden	11 (9.60)	12 (14.92)	12 (12.26)	0	0	0
Rock River	12 (9.55)	10 (16.27)	10 (12.91)	1	0	1
Gitchie Manitou	13 (9.34)	13 (14.37)	13 (11.85)	0	0	0
Millsite	14 (8.55)	15 (13.10)	15 (10.82)	1	0	1
Big Sioux Corridor	15 (8.07)	14 (14.18)	14 (11.13)	2	0	2
Nine Mile Creek GPA	16 (7.42)	16 (13.09)	16 (10.26)	0	0	0
Dakota Dunes	17 (7.28)	17 (12.13)	17 (9.70)	0	0	0
Silver Maple Primitive Area	18 (5.37)	18 (10.73)	18 (8.05)	0	0	0
			Mean Diff	**0.89**	**0.11**	**0.78**

Table 3.7. $\bar{C}$ (native only) state site rank values for 18 study sites along the lower Big Sioux River. Differences between each states site rankings and differences between each state and state averages are provided with overall mean differences in bold. Site rankings between states and state averages are not significantly different at the 0.05 level (Wilcoxon signed-rank, p>0.05).

Site	**IA $\bar{C}$ Rank**	**SD $\bar{C}$ Rank**	**Ave $\bar{C}$ Rank**	**SD-IA Rank Diff**	**SD-Ave Rank Diff**	**IA-Ave Rank Diff**
Stone State Park Upland	1 (3.88)	3 (5.75)	2 (4.81)	2	1	1
Mckee GPA Upland	2 (3.87)	1 (6.05)	1 (4.96)	1	1	0
Fish GPA Upland	3 (3.68)	2 (5.78)	3 (4.73)	1	0	1
Stone S.P. Riparian	4 (2.86)	5 (4.45)	4 (3.65)	1	0	1
Millsite	5 (2.67)	10 (3.77)	8 (3.12)	5	3	2
Rock River	6 (2.64)	4 (4.50)	5 (3.57)	2	1	1
Oak Ridge GPA	7 (2.49)	12 (3.68)	16 (2.53)	5	9	4
Lippke Wetland	8 (2.44)	15 (3.30)	14 (2.83)	7	6	1
Hawarden	9 (2.33)	14 (3.48)	12 (2.86)	5	3	2
Big Sioux Corridor	10 (2.31)	9 (3.82)	10 (3.00)	1	0	1
City of Canton	11 (2.26)	7 (4.11)	6 (3.18)	4	5	1
Akron GPA	12 (2.26)	8 (3.87)	9 (3.07)	4	3	1
Fish GPA Riparian	13 (2.23)	6 (4.19)	7 (3.17)	7	6	1
Doorenbos-Ford	14 (2.20)	17 (2.96)	17 (2.50)	3	3	0
Dakota Dunes	15 (2.14)	13 (3.57)	13 (2.86)	2	2	0
Nine Mile Creek GPA	16 (2.13)	11 (3.75)	11 (2.94)	5	5	0
Gitchie Manitou	17 (2.08)	16 (3.08)	15 (2.64)	1	2	1
Silver Maple Primitive Area	18 (1.41)	18 (2.67)	18 (2.00)	0	0	0
			Mean Diff	**3.11**	**2.78**	**1.00**

Table 3.8. *FQI* (native only) state site rank values for 18 study sites along the lower Big Sioux River. Differences between each states site rankings and differences between each state and state averages are provided with overall mean differences in bold. Site rankings between states and state averages are not significantly different at the 0.05 level (Wilcoxon signed-rank, $p>0.05$).

Site	**IA *FQI* Rank**	**SD *FQI* Rank**	**Ave *FQI* Rank**	**SD-IA Rank Diff**	**IA-Ave Rank Diff**	**SD-Ave Rank Diff**
Stone State Park Upland	1 (26.85)	1 (39.84)	1 (33.34)	0	0	0
Mckee GPA Upland	2 (23.85)	2 (37.31)	2 (30.58)	0	0	0
Fish GPA Upland	3 (23.24)	3 (36.52)	3 (29.88)	0	0	0
Stone S.P. Riparian	4 (18.52)	4 (28.85)	4 (23.69)	0	0	0
Oak Ridge GPA	5 (14.49)	6 (22.05)	8 (18.08)	1	3	2
Akron GPA	6 (13.77)	5 (23.54)	5 (18.90)	1	1	0
Lippke Wetland	7 (13.58)	8 (18.69)	7 (16.28)	1	0	1
Hawarden	8 (11.43)	10 (17.40)	9 (14.30)	2	1	1
Fish GPA Riparian	9 (11.37)	7 (21.75)	6 (16.45)	2	3	1
Doorenbos-Ford	10 (11.00)	14 (15.40)	13 (12.99)	4	3	1
Gitchie Manitou	11 (10.40)	13 (15.69)	11 (13.46)	2	0	2
Rock River	12 (9.89)	11 (16.84)	12 (13.36)	1	0	1
City of Canton	13 (9.86)	9 (17.89)	10 (13.88)	4	3	1
Big Sioux Corridor	14 (9.25)	12 (15.76)	14 (12.37)	2	0	2
Millsite	15 (9.24)	16 (13.59)	16 (11.23)	1	1	0
Nine Mile Creek GPA	16 (8.50)	15 (15.00)	15 (11.75)	1	1	0
Dakota Dunes	17 (8.02)	17 (13.36)	17 (10.69)	0	0	0
Silver Maple Primitive Area	18 (5.82)	18 (11.31)	18 (8.49)	0	0	0
			Mean Diff	**1.22**	**0.89**	**0.67**

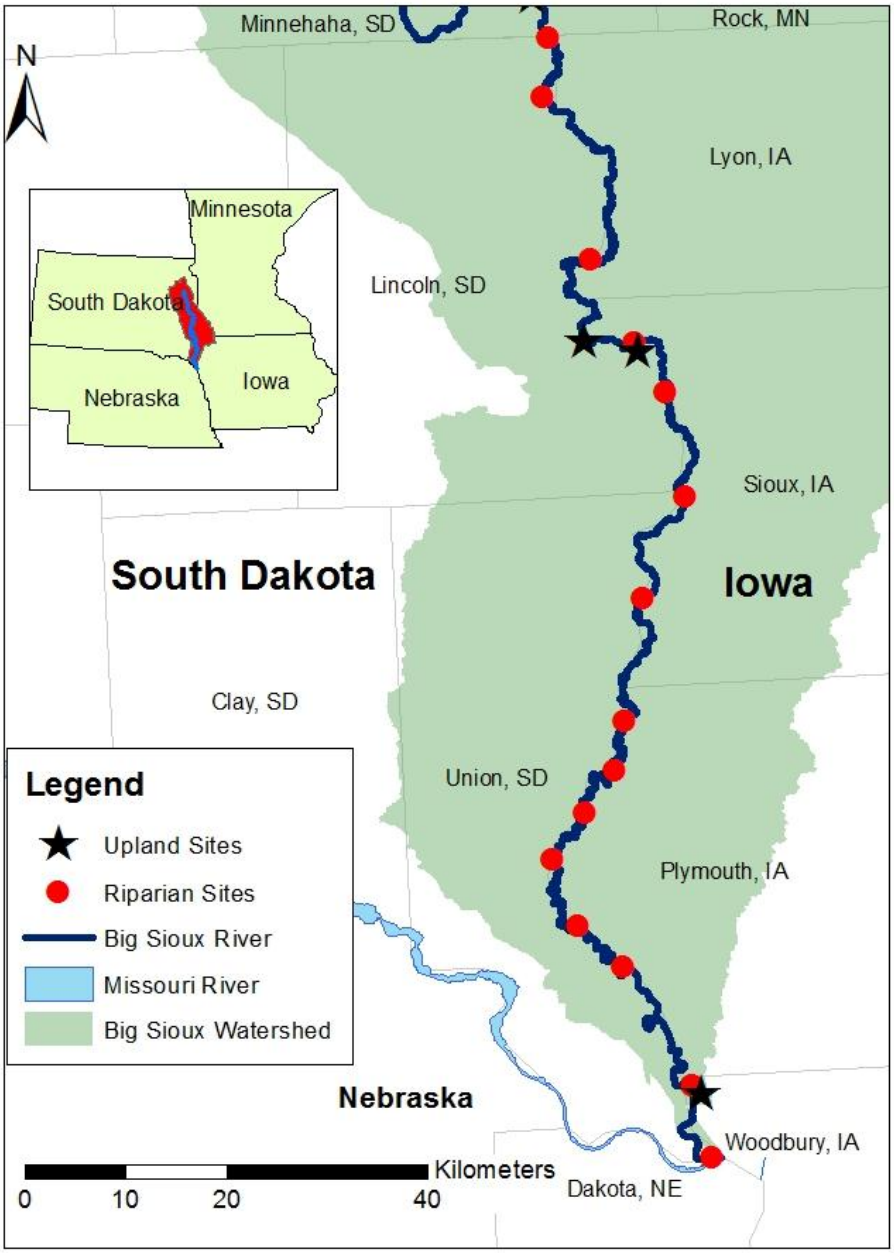


Figure 3.1. The lower Big Sioux River study area extending 220 river km from south of Brandon, SD, to the river's confluence with the Missouri River at Sioux City, IA. Locations of 18 study sites are depicted with 15 riparian (alluvial) forest sites (dots) and 3 upland forest sites (stars).

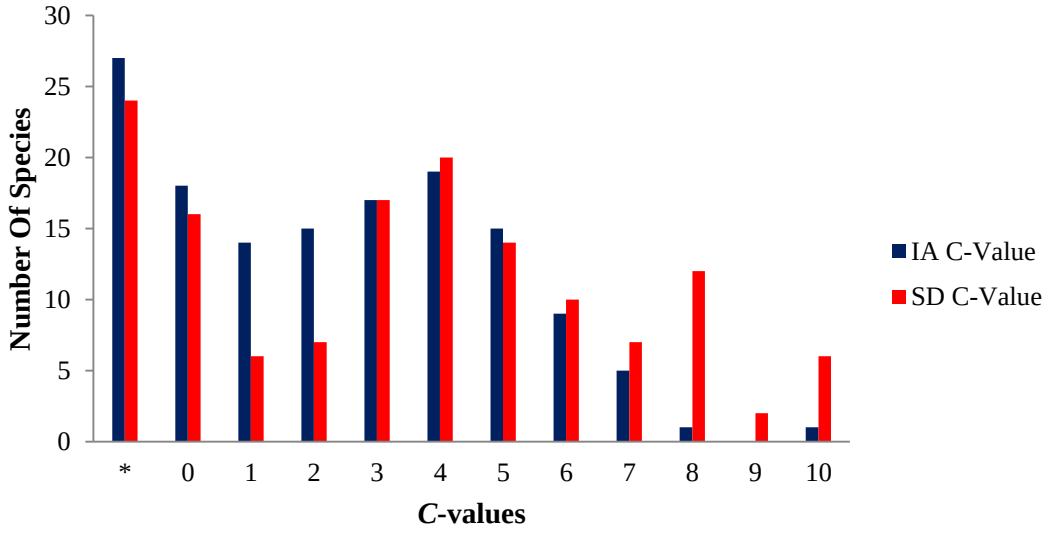


Figure 3.2. Comparison of overall *C*-value distribution by state for 141species encountered along the lower Big Sioux River. Species were assigned coefficients from Iowa and South Dakota. Non-native species were assigned an *.

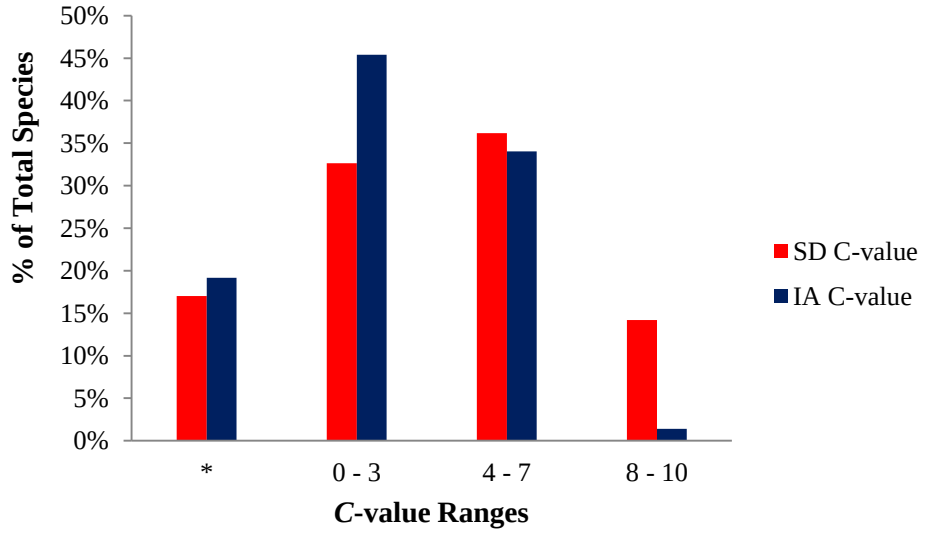


Figure 3.3. Histogram comparing the distribution of South Dakota and Iowa *C*-values within each *C*-value range cohort (0-3, 4-7, 8-10). Distribution differed across the 0-3 and the 8-10 range with Iowa assigning roughly 12% more species a *C*-value of 0-3 than South Dakota and South Dakota assigning approximately 13% more species a score of 8-10 compared to Iowa. Values in the non-native (*) and 4-7 ranges were approximately equal between the two state lists.

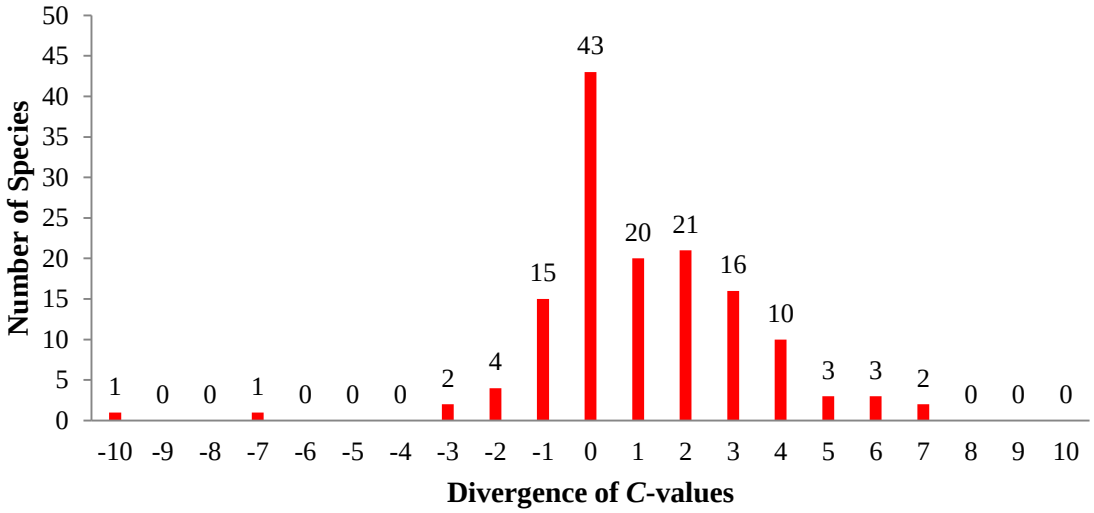


Figure 3.4. Comparison of South Dakota and Iowa (SD-IA) *C*-value divergence for 141 species encountered along the lower Big Sioux River. Divergence based on a species by species basis with 20 (14%) species having a divergence value ≥ ± 4. In total, there were 98 *C*-value divergences with 35 (36%) being equal to 1.