

Article

Comparable Riparian Tree Cover in Historical Grasslands and Current Croplands of the Eastern Great Plains, with Model Expansion to the Entire Great Plains, U.S.A

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Abstract: One question about historical grassland ecosystems in the Great Plains region of central North America is the percentage of tree cover overall and near major rivers, compared to current tree cover. Here, I assessed tree cover in reconstructions of historical grasslands in the eastern Great Plains, isolating tree cover adjacent to major rivers, and then compared historical land cover to current (year 2019) land cover. As an extension to supply information for the entire Great Plains region, I modeled historical cover. For the 28 million ha extent of the eastern Great Plains, historical land cover was 86% grasslands and 14% trees, but 57% grasslands and 43% trees within 100 m of rivers. Tree cover near rivers ranged from 5.4% to 90% for 15 large river watersheds, indicating that any amount of tree cover could occur near rivers at landscape scales. Currently, the overall extent was 3.6% herbaceous vegetation and 6.6% forested, with 82% crops and pasture and 8% development. Within 100 m of rivers, crop and pasture decreased to 44% of cover, resulting in 14% herbaceous cover and 38% forested cover. Current tree cover ranged from 6.2% to 66% near rivers in 15 watersheds, which was relatively comparable to historical tree cover (ratios of 0.6 to 1.5). Results generally were similar for combined tree and shrub cover modeled for the entire Great Plains. Variability, even at landscape scales of large watersheds, was the normal condition for tree cover in grasslands and riparian ecosystems of the Great Plains. In answer to the question about tree cover in historical grassland ecosystems in the eastern Great Plains, tree cover typically was about three-fold greater near rivers than tree cover throughout grasslands. Combined tree and shrub cover near rivers was more than two-fold greater than tree and shrub cover throughout the Great Plains. Riparian forest restoration, as a management practice to reduce streambank erosion, overall has been effective, as indicated by current tree cover (38% near rivers in the eastern Great Plains) comparable to historical tree cover (43% near rivers in the eastern Great Plains), albeit as measured at coarse landscape scales with dynamics in vegetation and river locations. As a next step, restoration of grassland vegetation and non-riparian wetlands likely will help reestablish infiltrative watersheds, augmenting riparian forest restoration.

Keywords: agroecology; erosion; floodplain; imagery; land use change; land management; riparian buffer; riparian zone



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1. Introduction

Globally, rivers and wetland ecosystems have been modified by flow regulation of rivers. Channelization, dams, levees, irrigation withdrawals, and agricultural conversion of floodplains and other wetlands have altered hydrological networks that sustained historical ecological functions and biodiversity [1]. Furthermore, crop cultivation results in

soil erosion due to soil disturbance and bare ground exposure, with low water infiltration rates [2,3]. In the United States, primarily to increase agricultural production, drainage laws and drainage districts were established in the late 1800s to drain water, with ditches and tile drainage, from fertile lowlands [4]. Subsequently, concentrated water flows were diverted to channels deepened to increase carrying capacity and straightened to shorten the route and time to remove water, diminishing wetlands [4]. Conversion from infiltrative hydrological networks of wetlands embedded in historical vegetation to drainage channels of semi-imperious surfaces around current agricultural land use results in less percolation into soils and greater overland flow or drainage tile flow, which rapidly moves surface water to streams and increases flooding and erosion [2,5–7].

Riparian ecosystems are wetlands that occur at the intersection between uplands and rivers. Riparian ecosystems, and wetlands in general, represent a small percentage of landscapes but are disproportionately productive and contain diverse vegetation and wildlife communities [8–12]. Animal species richness typically is greater, and communities are different in riparian ecosystems than in uplands [8–12]. In grassland ecosystems, forested riparian areas support biodiversity by providing resources, such as thermal cover, food sources, and host plants, not available in grasslands with limited tree presence [9]. For instance, emerging aquatic insects supply a concentrated food source for bats and birds, which may have greater activity and species richness around riparian vegetation [13,14]. Other ecosystem services provided by riparian vegetation include reduced soil erosion by stabilizing streambanks and improved water quality by diminishing sediment loads and pollutants [15,16]. Riparian forest buffers or zones are a long-standing best management practice to reduce erosion and improve water quality, and, for example, may be widely mandated or incentivized with monetary payments [17,18].

The Great Plains grasslands region of central North America stretches from the Rocky Mountains to the forests of eastern North America (Figure 1). According to pollen reconstructions, grasslands were present 11,000 years ago, after deglaciation and warming [19] and the arrival of native humans, with a capacity to ignite vegetation [20]. Fires, with increased ignitions from humans and spread by strong westerly winds, removed most tree presence to promote herbaceous vegetation, while large herbivores helped maintain herbaceous vegetation [21]. At least 300 endemic plant species occur in the Great Plains [22]. Plant species change from the shortgrass prairies of the drier, western Great Plains in the rain shadow of the Rocky Mountains to the tallgrass prairies of the more productive eastern Great Plains [23]. Correspondingly, grassland conversion to crop cultivation increases with precipitation along a gradient from west to east in the Great Plains, with greater livestock production in less arable lands. Non-native species are common in grasslands [2,24].

However, the amount of historical tree cover in riparian ecosystems of the Great Plains is unclear. Riparian forests predominantly were composed of cottonwood (*Populus deltoides*) and willows (*Salix*), with other tree species typical of eastern North American riparian wetlands, such as elms (*Ulmus*), maples (*Acer*), bur oak (*Q. macrocarpa*), hackberry (*Celtis occidentalis*), and green ash (*Fraxinus pennsylvanica* [25–28]). For overall spatial distribution, both the number of trees and tree species were more abundant historically in riparian ecosystems along major rivers of the eastern Great Plains, near forests of the eastern U.S.A., but were increasingly uncommon in the western part of the region, particularly Colorado [25,29,30]. Historically, riparian forests were present in Illinois, Iowa, Minnesota, and central and western Oklahoma [27,31], with dense tree growth at the northern Missouri–Kansas border, along the Missouri River [28], the Missouri River of the Dakotas [32], and most of the major rivers of western Nebraska and Kansas at least before 1905 (e.g., Cimarron, Arkansas, Smoky Hill, Republican, and Platte Rivers [25]). The Platte River of Nebraska may have been forested [25,33], intermittently bordered by trees [26], or

relatively treeless [34]. While Sass and Keane [16] documented woody riparian corridors in three counties of northeastern Kansas, few trees were recorded in adjacent areas [35]. Therefore, riparian systems were not continuously forested in either space or time [2].

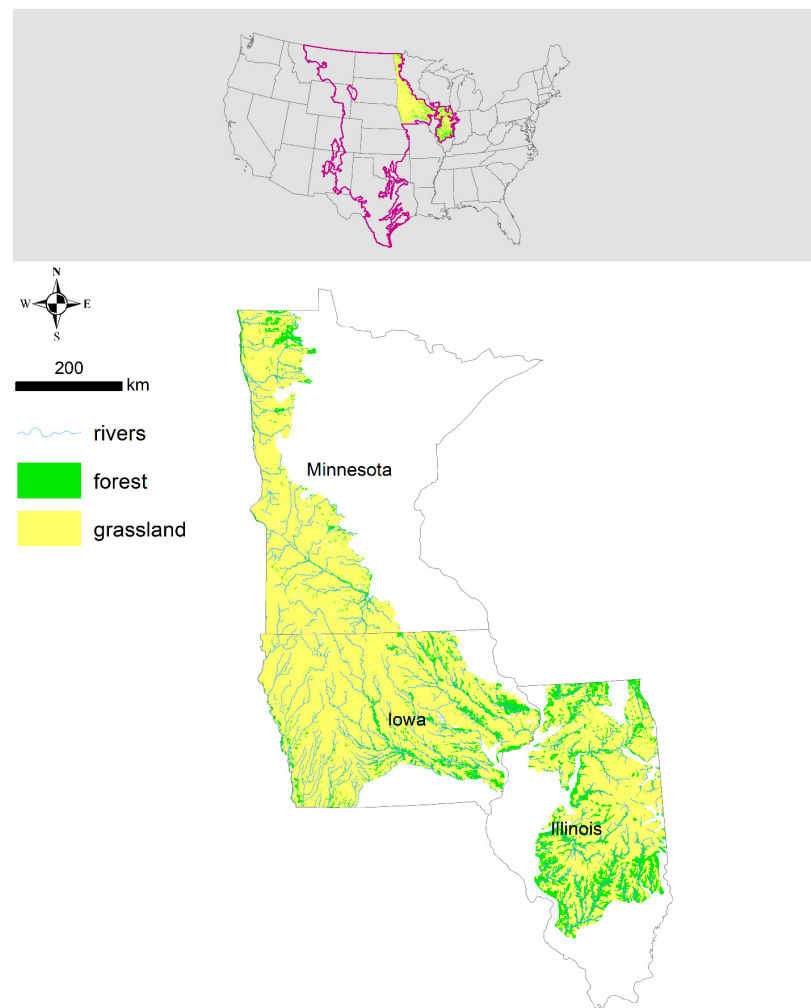


Figure 1. Reconstructed historical land cover in the study extent of the historical grasslands in the eastern Great Plains of Illinois, Iowa, and Minnesota. The inset panel delineates the Great Plains grasslands (purple outline) in the United States.

Since Euro-American settlement, riparian areas have experienced frequent modification and conversion and are now the focus of restoration efforts [15,16]. In the Great Plains, riparian forests may have been converted to agricultural development and other land uses or degraded due to factors such as altered hydrology and hydrological networks and lack of tree regeneration [4,7,9,15,16,32]. In contrast to tree removal, tree expansion has occurred in the Great Plains, particularly following riparian networks [25]. Trees have deep roots that are effective at maintaining bank stability against the shear stress of running water, resulting in benefits of trees compared to herbaceous vegetation in riparian locations [15,16]. Therefore, tree planting of riparian forest buffers is a common management tool to reduce streambank erosion and sediment loads in agriculturally dominated watersheds [15,16,36,37].

Reconstructions of historical vegetation can inform historical tree cover in the Great Plains grasslands and riparian ecosystems embedded within grasslands to help answer the question of whether riparian ecosystems were forested or grasslands and, relatedly, the amount of tree cover within grasslands [33,34]. The General Land Office conducted land surveys in most of the United States during the 1800s [38–40]. Surveyor notes described

and mapped land cover, and although designations are not precise, reconstructed historical vegetation maps supply tree cover at landscape scales [38–40]. Additionally, current land cover can demonstrate the status of concerted management for riparian vegetation by private landowners and management agencies [3,41,42].

Historical grassland ecosystems and embedded riparian ecosystems have been converted largely to agriculture and other land uses, with native plant replacement in the Great Plains. Here, my objectives were to assess the percentage of tree cover in reconstructions of historical grasslands in the eastern Great Plains (Illinois, Iowa, and Minnesota) and tree cover adjacent to major rivers within the grassland extents and then compare historical land cover to current (year 2019) land cover. As an expansion to indicate historical cover in the entire Great Plains extent, I modeled historical grasslands or non-grasslands cover of trees and shrubs, following [21,43]. To validate the model, I contrasted historical tree cover to reconstructions of historical grasslands in the eastern Great Plains (Illinois, Iowa, and Minnesota) and then compared historical land cover to current (year 2019) land cover. My questions about the eastern Great Plains and the Great Plains extent consisted of the following: what was the historical vegetation composition and what was the historical vegetation composition of riparian ecosystems, and how do they differ from current land use and land cover and riparian land use and land cover? Evidence of historical tree cover in grasslands and riparian ecosystems may help researchers and managers realize current vegetation departure and best management practices for grassland and riparian buffer management in the Great Plains.

2. Materials and Methods

2.1. Reconstructed Historical Vegetation in the Eastern Great Plains

Reconstructed historical vegetation for the eastern Great Plains was from Illinois (survey years 1804–1843 [39]), Iowa (survey years 1832–1859 [38]), and Minnesota (survey years 1847–1907 [40]; Figure 2; data processing with ArcGIS Pro 3.3.4, ESRI, Redlands, CA, U.S.A.). Given shapefiles, the resolution was unassigned, but probably less than 800 m, given that data entry included information at minimum every 800 m and the smallest area for a shape was 800 m². The vegetation layers were clipped to historical Great Plains grasslands, resulting in a 28 million ha extent (Olson et al. [44] in Iowa; Hanberry [45] for Illinois and Minnesota; Olson et al. [44] delineated a slightly smaller extent than Hanberry [45]). For riparian areas, the grassland extents were clipped to major rivers (1:5,000,000 scale in [46]), with a buffer of 100 m around the river lines, as a typical intermediate riparian buffer width [47]. The current land cover was from the year 2019 (30 m resolution [48]), also clipped to the same extent.

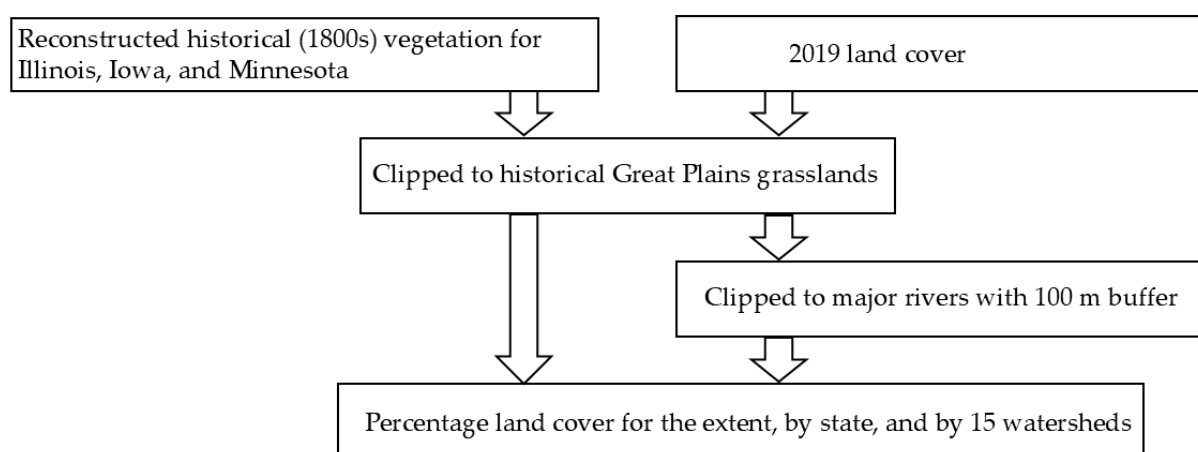


Figure 2. Workflow for comparing reconstructed historical vegetation to current land cover.

Land cover classes, both in the past and currently, have various definitions and terms. Classes of wetlands to uplands are on a continuum, for example, marshes (i.e., wetlands dominated by graminoids), wet prairies, to dry prairies. Tree densities also are on a continuum, from grasslands to savannas to open forests to closed forests. Therefore, for classes, I determined percentage of treed cover for which forests were most abundant class, including wetlands of bottomlands, swamps, and woody wetlands; percentage of herbaceous cover for which prairies were the most abundant class, encompassing wet prairies, marshes, herbaceous wetlands, herbaceous, savannas, and openings; percentage land use cover of crops, hay/pastures, and fields; and percentage developed cover. Any other class types (e.g., shrub, barren) for the eastern Great Plains were <1.5% of the total cover and were excluded.

The comparisons were the tree cover within the grasslands and tree cover near rivers with a 100 m buffer within grassland extents for different spatial scales of the eastern Great Plains. The scales were (1) the entire eastern Great Plains extent, (2) administrative units of the three states, and (3) 15 hydrological units of watershed boundaries at the subregion level, delineating large river basins (i.e., HUC4 or about 50,000 km², [46]). The large river basins allow expression of spatial variability but within the constraints of the landscape resolution of reconstructed vegetation. The temporal comparisons were the historical land cover to the current (year 2019) land cover. Each coarse landscape comparison is at least 775 km, the minimum length of all large rivers within the smallest large river basin clipped to the eastern Great Plains.

2.2. Modeled Vegetation for Great Plains

The modeling extent was Great Plains region with an additional surrounding 400 km buffer to cover a range of conditions (Figure 3). For samples of the historical vegetation cover, I used the LANDFIRE Biophysical Settings database (30 m resolution [49]), which is a model of expert-informed historical vegetation types but not necessarily proportional to historical ecosystem cover [43]. I supplemented this data source with the reconstructed historical vegetation from Illinois, Iowa, and Minnesota. After generating 120,000 random points for the Great Plains region with a 400 km buffer, out of 12,300 points that intersected historical vegetation from Illinois, Iowa, and Minnesota, I changed 1951 points from forested in LANDFIRE BPS to grasslands based on reconstructed historical vegetation and, equally, changed 780 samples from non-grasslands in LANDFIRE BPS to forested based on reconstructed historical vegetation. From the initial samples, for modeling, I selected 45,000 grassland samples, including all 10,600 grassland samples from the reconstructed historical vegetation, and 45,000 non-grassland samples, consisting of 15,000 samples each of broadleaf trees, needle-leaf trees, and shrublands. While sample sizes can be too small, 90,000 randomly distributed samples are unlikely to result in a poor model. Due to increased shrub cover (i.e., *Artemisia*) in the western modeling extent, non-grassland cover may be trees or shrubs. Minor vegetation types were not modeled, and so were classified as either grasslands or trees and shrubs.

Predictor variables for the Great Plains region model were wind speed and topography to represent fire compartments for the spread of fire [21,43]. Wind speed values were from the Global Wind Atlas (250 m resolution [50]). The topographic measure was roughness, with smaller values equal to flatter areas that have less topographic difference (250 m resolution [51]). I applied the ensemble model of the C5.0 classifier, which generates explicit rules and 10-fold cross-validation [52,53]. Moisture indices alone can only delineate a section of grassland biomes, unlike wind speed alone [21], and delineation with two moisture indices requires tens to hundreds of unclear rules, unlike wind speed and topography, which required 10 rules total in this model that clearly explained that

greater wind speeds were required as topographies became rougher, for grasslands to be predicted. I modeled the full dataset (i.e., without reserved samples for accuracy estimation compared to LANDFIRE BPS, as the model was not intended to duplicate LANDFIRE BPS) to predict the potential cover. For the model of the full dataset, classification accuracy was 0.89 (sensitivity = 0.91, specificity = 0.86), although, to be clear, the model was not a simple replication of LANDFIRE BPS and the reconstructed vegetation.

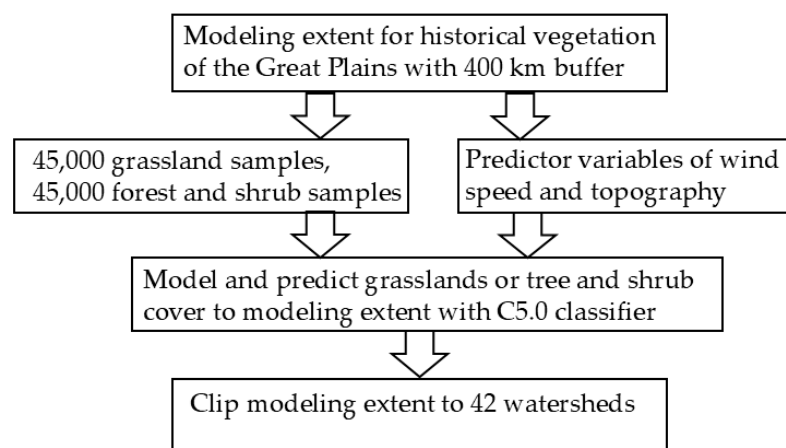


Figure 3. Workflow for modeling grassland or tree and shrub cover in 42 watersheds of the Great Plains.

After predicting grassland or tree and shrub cover in the Great Plains region with the surrounding 400 km buffer, I clipped the extent to 42 hydrological units of watershed boundaries at the subregion level that had predominantly grassland cover, resulting in a 193 million ha extent in the Great Plains. I then calculated percentage tree cover including all area and near rivers for the entire extent, in the 42 large watersheds, and the eastern Great Plains extent. Likewise, I calculated the same percentages for the current (2019) land cover. Lastly, I examined the Platte River in Nebraska and northeastern Kansas to resolve discrepancies.

3. Results

3.1. Reconstructed Historical Vegetation in the Eastern Great Plains

For the entire 28 million ha extent of the eastern Great Plains, the historical land cover was 86% grasslands and 14% trees, based on the reconstruction of historical vegetation. Within 100 m of rivers, grassland cover reduced by 30 percentage points to 57% grassland cover and consequently, tree cover increased by 30 percentage points to 43% tree cover, or three-fold greater than in the entire extent. In contrast to historical land cover, current land cover for the overall extent was 3.6% herbaceous vegetation and 6.6% forested, with 76% crops, 6.0% pasture, and 8.0% development. Within 100 m of rivers, crop and pasture decreased to 44% of cover from 36% crops and 7.4% pasture, resulting in 14% herbaceous cover and 38% forested cover, or six-fold greater than in the entire extent.

By the administrative unit of states in the eastern Great Plains, herbaceous cover in the grassland extents ranged from 74% in Illinois to 89% in Iowa to 93.5% in Minnesota, which meant that tree cover ranged from 25% in Illinois to 6.5% in Minnesota (Table 1). Tree cover adjacent to rivers was about 20% in Minnesota's historical grasslands, 37% in Iowa's historical grasslands, and 75% in Illinois' historical grasslands. Tree cover typically was about three-fold greater adjacent to rivers than throughout grasslands. Current land cover was predominantly in crops, ranging from 77% to 85% of cover, and residential development, ranging from 5% to 13% of cover, leaving little herbaceous vegetation and

about half the tree cover as historically. However, near rivers, current tree cover was relatively comparable to historical tree cover, at ratios of 0.7 to 1.2 of historical percentages. Therefore, current tree cover typically was almost six-fold greater adjacent to rivers than throughout the extents.

Table 1. Percentage of land classes in the historical grassland extents of Illinois, Iowa, and Minnesota of the eastern Great Plains and within 100 m of rivers in the grassland extents during historical and current (year 2019) intervals.

Extent	Historical			Current			
	Tree	Herbaceous	Crop/Pasture/ Developed	Tree	Herbaceous	Crop/ Pasture	Developed
Illinois grasslands	25.9	73.7	0.4	10.0	0.5	76.7	12.8
Illinois 100 m near rivers	76.1	23.8	0.2	55.9	1.8	35.4	7.0
Iowa grasslands	10.4	89.4	0.2	5.9	2.7	84.7	6.7
Iowa 100 m near rivers	38.2	61.7	0.1	34.5	13.4	47.7	4.4
Minnesota grasslands	6.5	93.5	0.0	4.3	8.8	82.2	4.8
Minnesota 100 m near rivers	24.6	75.4	0.0	28.4	24.4	42.6	4.5

For the 15 watersheds, historical tree cover ranged from 5.4% to 90% near rivers, conveying nearly the full range of potential tree cover (Table 2, Figure 4). Historically, tree cover near rivers generally was three-fold to four-fold greater than throughout the watersheds, with the exception of a sparsely treed watershed that had 5.4% tree cover. Current tree cover ranged from 6.2% to 66% near rivers, at ratios of 0.6 to 1.5 of historical percentages, but with a median and mean ratio of about 0.9. Currently, tree cover near rivers generally was five-fold to six-fold greater than throughout the watersheds.

Table 2. Percentage of tree cover or percentage ratios in large watersheds within 100 m of rivers in historical and current extents and within historical and current extents of Illinois, Iowa, and Minnesota in the eastern Great Plains.

Watershed	Historical			Current			Current and Historical
	Near Rivers	All	Ratio	Near Rivers	All	Ratio	Ratio near Rivers
Wabash	81.9	31.5	2.6	60.6	11.8	5.1	0.7
Mississippi Headwaters	28.9	7.6	3.8	32.8	4.4	7.4	1.1
Minnesota	23.0	3.7	6.3	27.3	2.5	10.8	1.2
Upper Mississippi– Maquoketa–Plum	57.9	26.2	2.2	49.2	9.4	5.2	0.8
Upper Mississippi–Iowa– Skunk–Wapsipinicon	50.4	14.5	3.5	45.7	6.5	7.0	0.9
Rock	55.0	26.8	2.1	39.6	7.2	5.5	0.7
Des Moines	42.3	7.7	5.5	37.1	5.7	6.5	0.9
Upper Illinois	56.8	15.4	3.7	48.3	6.3	7.6	0.9
Lower Illinois	79.4	23.0	3.5	55.0	8.0	6.8	0.7
Upper Mississippi– Kaskaskia–Meramec	90.0	36.4	2.5	65.7	16.4	4.0	0.7
Red	29.7	11.1	2.7	34.7	6.9	5.0	1.2
Missouri–Big Sioux	5.4	0.5	11.0	6.2	1.2	5.2	1.1
Missouri–Little Sioux	6.2	3.0	2.0	9.2	3.3	2.8	1.5
Missouri–Nishnabotna	20.9	5.7	3.6	20.5	4.5	4.6	1.0
Chariton–Grand	46.4	8.6	5.4	29.9	9.4	3.2	0.6

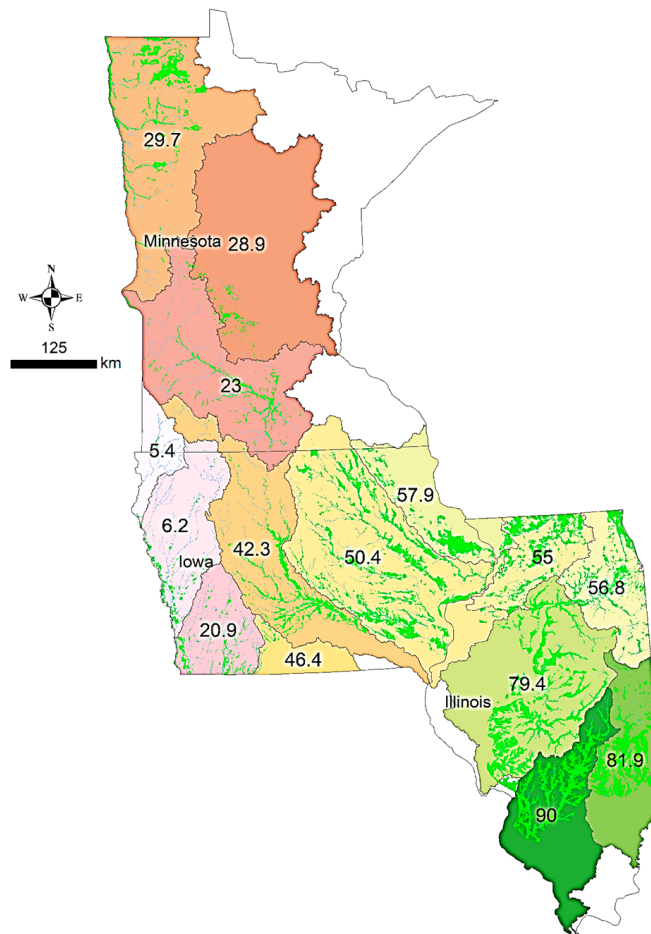


Figure 4. Percentage historical tree cover near rivers (green lines), ranging from 5.4% to 90%, in 15 large river watersheds of the eastern Great Plains.

3.2. Modeled Vegetation for Great Plains

Similar to the 86% grasslands and 14% trees in the 28 million ha extent of the eastern Great Plains from reconstructed historical vegetation, historical land cover was 90% grasslands and 10% trees or shrubs in the eastern Great Plains, based on modeled historical land cover. Instead of 43% tree cover near rivers for this extent from reconstructed historical vegetation, 33% tree or shrub cover near rivers was predicted by the modeled historical land cover. For the large watersheds, only two watersheds were completely within the extent of the eastern Great Plains. For these watersheds (Upper Mississippi–Iowa–Skunk–Wapsipinicon in Iowa and Lower Illinois in Illinois), the differences between the reconstructed historical vegetation and modeled historical land cover were -6.8 percentage points and $+7.0$ percentage points.

For the entire 193 million ha extent of the Great Plains, historical land cover was 84% grasslands and 16% trees and shrubs, based on modeled historical land cover. Within 100 m of rivers, grassland cover reduced to 66% grassland cover, and tree and shrub cover increased to 34% of total cover or more than two-fold greater than tree and shrub cover throughout the Great Plains. Current land cover for the same extent was 33% herbaceous vegetation, 7.5% forests, and 13% shrubs (20.5% tree and shrub cover), with 37% crops and 4.7% pasture, and 4.3% development. Within 100 m of rivers, crop and pasture decreased to 23% of cover, from 17% crops and 5.4% pasture, resulting in 37% herbaceous vegetation, 24% forests, and 14% shrubs (38% tree and shrub cover), or less than two-fold greater than tree and shrub cover throughout the Great Plains.

Historically, tree and shrub cover ranged from 0.3% to 50% for the 42 watersheds in the entire Great Plains. Tree and shrub cover near rivers generally was two-fold to three-fold greater than throughout the watersheds, with ratio values ranging from 1.2 to 7.7. For the 42 watersheds, historical tree cover ranged from 2% to 89% near rivers, expressing a full range of potential tree cover (Figure 5).

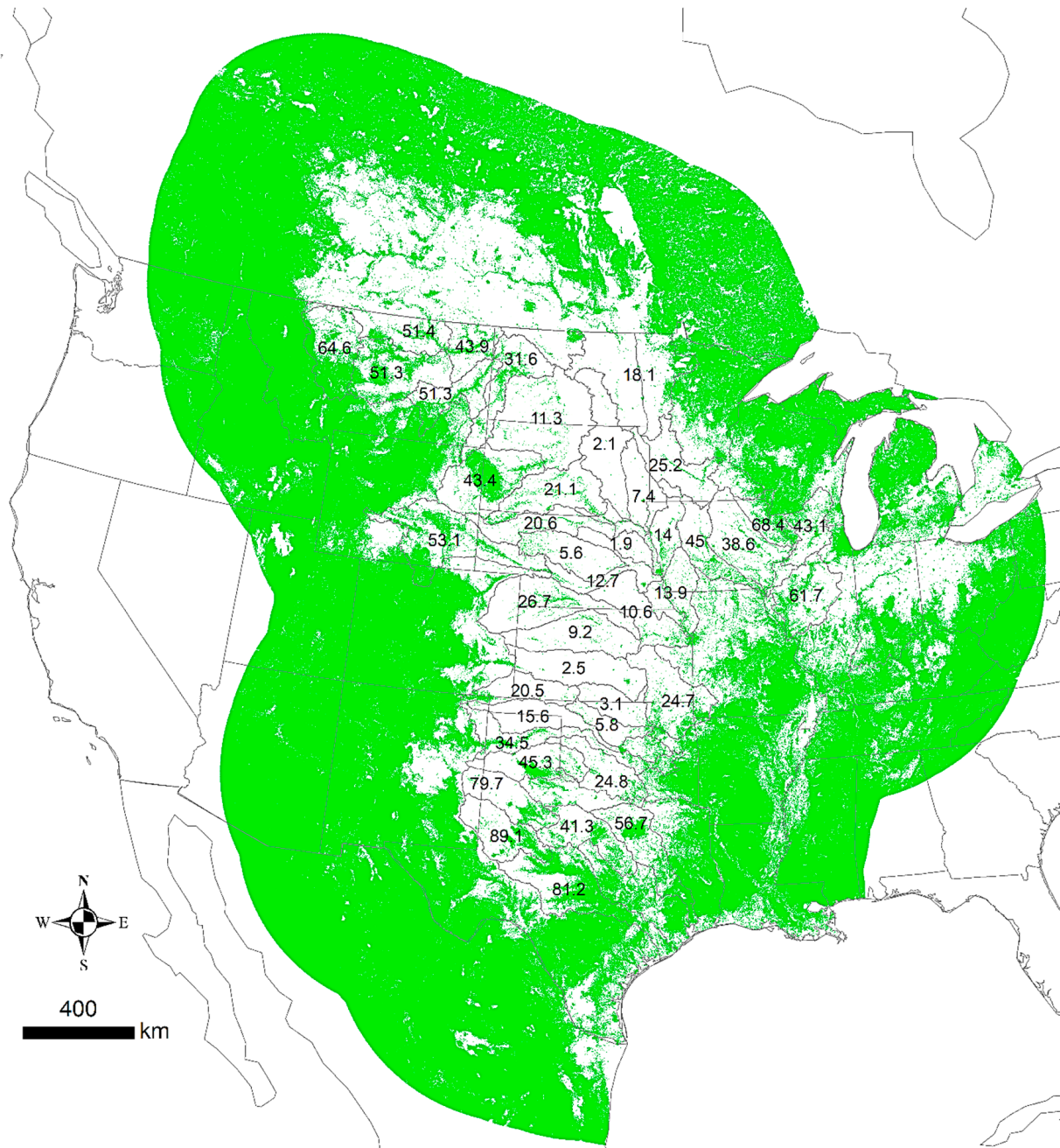


Figure 5. For modeled historical cover of the Great Plains and surrounding 400 km buffer, predictions for tree and shrub cover (green) compared to grasslands (white), and percentage tree and shrub cover near rivers, ranging from 2% to 89%, in 42 large watersheds of the Great Plains. Forests and shrublands (green) surround the Great Plains grasslands (white).

The lowest values for tree and shrub cover occurred in the central Great Plains, although this may be a function of whether shrub cover did increase in the western Great Plains. Nevertheless, variability in tree cover along rivers occurred in the central Great Plains, in northeastern Kansas, and in the Platte River of Nebraska (Figure 6). Within

100 m of the Platte River of Nebraska, 35% tree and shrub cover occurred, or relatively average values.

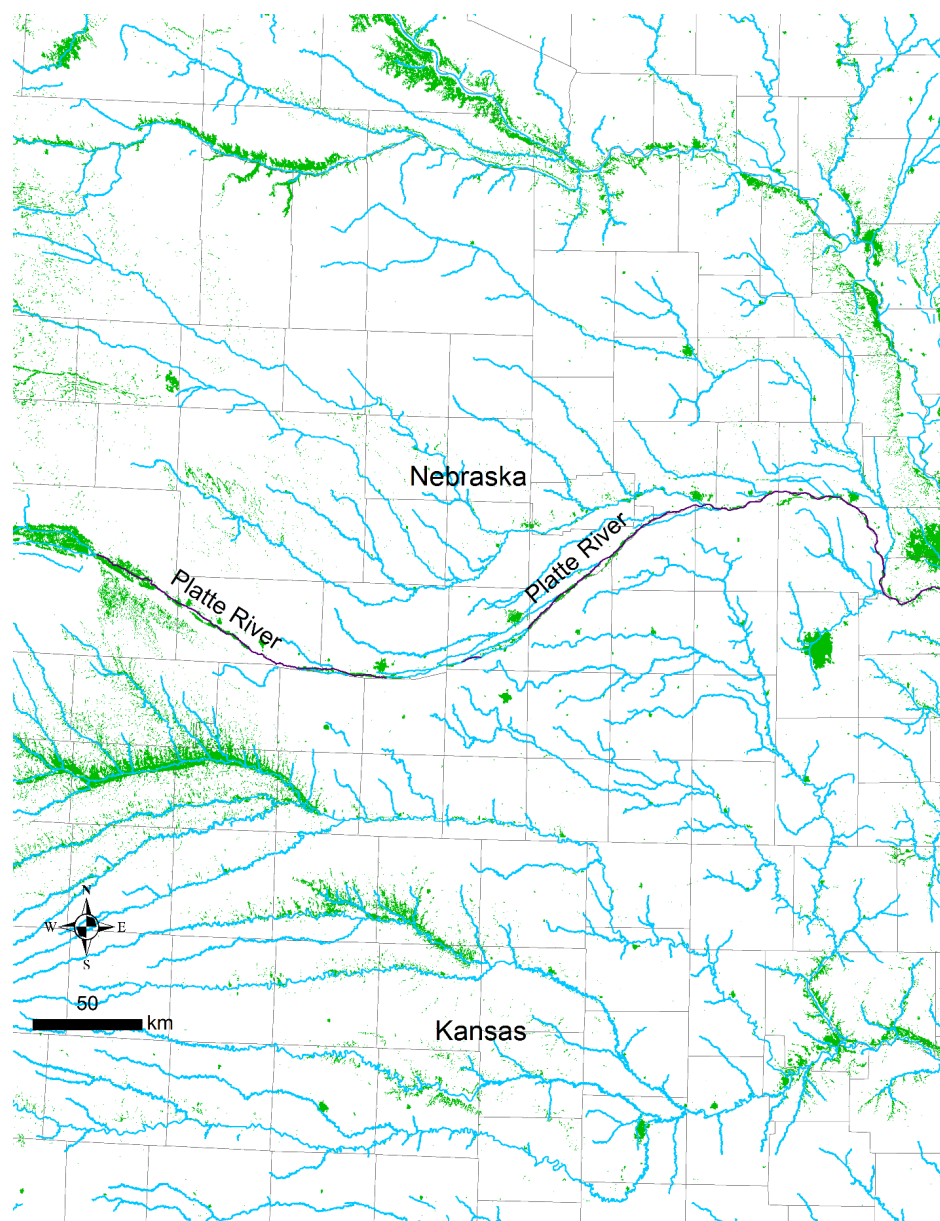


Figure 6. Tree and shrub cover displayed variability along rivers, such as in northeastern Kansas and the Platte River of Nebraska, in the central Great Plains.

Current tree and shrub cover ranged from 3.9% to 88% near rivers. Tree and shrub cover near rivers generally was two-fold to four-fold greater than throughout the watersheds, with ratio values ranging from 1.0 to 14.4. Current tree and shrub cover had ratios of 0.2 to 9.8 relative to historical percentages but with a median ratio of 1.2 and a mean ratio of 2.0 (Figure 7).

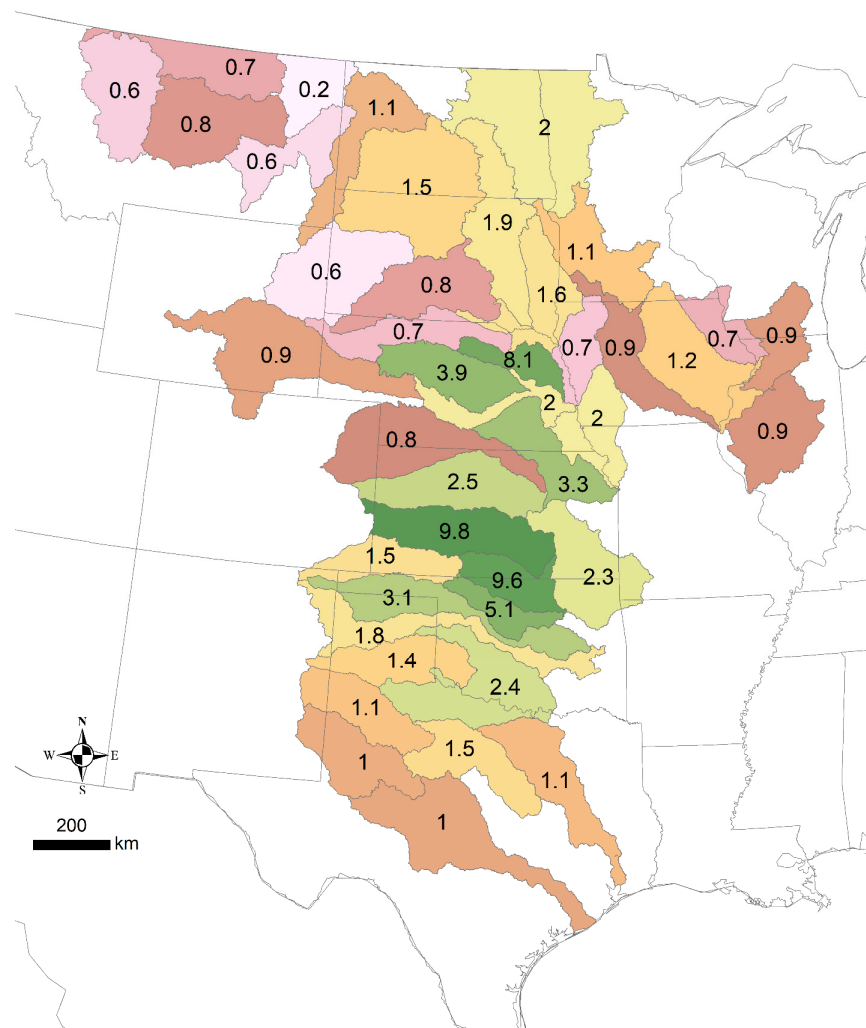


Figure 7. Ratios of current percentage tree and shrub cover near rivers to historical percentage tree and shrub cover near rivers.

4. Discussion

Reconstructions of land survey notes at the time of Euro-American settlement supply a spatially continuous characterization of riparian and grassland ecosystems at landscape scales [38–40]. Reconstructions and models can help answer what the percentage of tree cover overall and near major rivers was, compared to current tree cover, in the Great Plains region, albeit at landscape scales and with measurement error, particularly due to river movement. Based on vegetation reconstructions in historical grasslands of the eastern Great Plains (Illinois, Iowa, and Minnesota), which encompassed a 28 million ha extent, historical land cover was 86% grasslands and 14% trees. Tree cover in grasslands was about one third of tree cover near major rivers, at 43% tree cover within 100 m of rivers. However, historical tree cover ranged from 5.4% to 90% near rivers in 15 large river watersheds, indicating that any amount of tree cover could occur near rivers at landscape scales, although generally retaining the same ratio of about three-fold greater tree cover near rivers than tree cover throughout grasslands, including riparian tree cover. While historical grasslands were not similar to current croplands of the eastern Great Plains (Illinois, Iowa, and Minnesota), riparian tree cover was relatively equivalent, at 43% historical tree cover and 38% current tree cover near rivers. Modeled historical tree and shrub cover throughout the Great Plains provide another line of evidence to support these results. Current tree cover along streams likely reflects the success of a cooperative campaign to control riparian erosion rates through

the management practice of planting trees or allowing trees to be established without removal and replacement by crops, with, for example, 98% of land parcels compliant with buffers in Minnesota [3,6,18,41,42]. Following Euro-American settlement, erosion increased after the widespread conversion of floodplains to crop production, with crops planted to streambanks, leaving no riparian vegetation to protect soils [2,6,11].

The most similar comparison between historical and current land cover is forested cover near rivers. Currently, the eastern Great Plains is an agriculturally dominated region, with 76% of land cover in crops and about the same cover in combined crop and pasture as historically was grasslands. However, within 100 m of rivers, crop cover diminished to 36% crops, resulting in 14% grassland cover and 38% forested cover. Current forested cover near rivers was comparable to historical forested cover near rivers, with ratios of 0.6 to 1.5 of historical percentages. While 6 of the 15 watersheds only had 0.6 to 0.9 of the historical riparian tree cover, these watersheds currently had at least 30% riparian tree cover, with a mean of 50% riparian tree cover. Similarly, for the modeled Great Plains, of the 12 large watersheds out of 42 watersheds that had current riparian tree cover less than historical riparian tree or shrub cover, only 7 watersheds had less than 30% riparian tree cover, with a mean of 27% riparian tree cover. Riparian tree cover is likely a testament to concerted best management practices by landowners and land management agencies to maintain vegetation along waterways [5,15,16,18,41,42].

Spatial variability occurred in tree cover for both the study extent of the eastern Great Plains and the modeled entire Great Plains. Predicted tree and shrub cover diminished within the center of the Great Plains, which is most distant from forests of the eastern U.S.A. and forests and shrublands of the western U.S.A. However, this result is contingent on shrub cover increasing in the western Great Plains, which occurred in the samples for historical vegetation models but may not accurately reflect historical shrub cover inside the Great Plains. For similar tree cover variability, in the central Great Plains, Sass [2] recorded discontinuous riparian corridors during 1857 along the Black Vermillion River in northeastern Kansas, and Rothenberger [26] mapped variable tree concentration during 1855–1857 along the Platte River in eastern Nebraska. The model predictions were 35% tree and shrub cover along the Platte River of Nebraska. Due to a mixture of tree densities, interpretations of the pre-Euro-American settlement Platte River in Nebraska at either the extreme of a prairie or wooded river likely are correct at some spatial and temporal extents [33,34]. Similarly, variation in tree cover explains why Sass and Keane [16] detailed historical woody riparian corridors in three counties of northeastern Kansas, but few trees occurred in adjacent counties [35]. Historical tree variation typically was due to disturbance factors from fire, flooding, and herbivory, with influences from climate, weather events, and soils [33,54].

Tree cover near rivers in the past represented a dynamic between tree propagule pressure and establishment, likely with dispersal and planting by wildlife and humans, and disturbance primarily through flooding, fire, and herbivory [21,33]. Historically, hydrological networks connected streams, lakes and ponds, wetlands, and groundwater [5]. Flooding from inflows created a disturbance regime that interacted with topography to filter and distribute tree species in riparian ecosystems, for example, cottonwoods in frequently flooded locations with unstable substrates [25]. Frequent surface fires occurred in the grasslands of the Great Plains, which is a relatively flat region with strong westerly winds and abundant fine fuels from herbaceous plants to ignite and spread fire [21]. Fires removed small-diameter trees, and although water is a firebreak, trees bordering rivers have been exposed to fire, which particularly reduced forest width along major streams and eliminated trees along small streams [2,25,55]. Despite fire, floods, and herbivory, tree species of the eastern U.S.A. were able to establish along riparian networks.

With the disruption of flooding and fire regimes after the Euro-American settlement, successful tree expansion became evident, which was anticipated by MacBride [55] and Kellogg [25] as a response to the lack of fire and flood disturbance [21,56]. Streamflows have been regulated and altered [32], and wetlands have been drained and tiled, dredged, plowed, and planted [5], allowing greater stability for tree establishment by less flood-tolerant species. Fire exclusion followed land use changes associated with Euro-American settlement, including reduced amount of herbaceous vegetation due to grazing and crop harvesting and loss of vegetation continuity due to roads, which occurred by 1860 in Illinois, by 1880 in Iowa, and by 1900 in Minnesota [56]. For example, by 1905, the Platte River in Nebraska was portrayed as primarily forested, albeit with localized gaps in tree cover [25]. In Kansas, riparian forests expanded from 1858 to 1978. Abrams [35] and Sass and Keane [16] detected greater tree cover in some riparian corridors between 1857 and 1956, followed by declines in tree cover by 2002 and increases by 2006.

After Euro-American settlement and land conversion to agriculture, tree cover near rivers represents a dynamic between tree propagule pressure and establishment, with support from wildlife and humans, and disturbance primarily through crop cultivation and livestock. Crop cultivation to streambanks and unrestrained livestock grazing reduces tree regeneration [16,25]. Fertile and flat floodplains typically have been cleared of native vegetation for agricultural cultivation, which results in a lack of vegetation cover after crop harvest [7]. Due to subsequent upland and streambank erosion after agricultural cultivation, best management practices include planting and maintenance of riparian cover to encourage water infiltration, decelerate water velocity, capture soil and sediments, and enhance stream bank shear strength [16]. Trees, in particular, due to deep roots, increase the shear strength of stream banks against shear stress or the force along stream banks [15,16]. The reason that current forested cover near rivers is comparable to historical conditions is likely because of widespread management to protect land along streambanks from erosion and prevent sedimentation of reservoirs [5,15,16].

Extensive and intensive crop cultivation is unlike historical land use and may require continuous tree cover along rivers to improve soil retention, particularly due to water channelization. Despite increased riparian management, the 2013–2014 United States assessment of national rivers and streams found that 22% of total length was of poor quality for sediments, 24% was of poor quality for vegetative cover, and 23% was of poor quality for disturbance [57], although erosion rates have reduced over time [58]. Altered waterways encompass artificial paths, canal ditches, connectors, drainageways, pipelines, and underground conduits (in the National Hydrologic Dataset [46]). To illustrate the purpose of these water-conducting pathways, Moore [59] stated that water flow rates increased from six days to travel a long path historically to six hours to travel a newly completed shortened path. In agriculturally intensive watersheds, concentrated water flows via overland and drainage tile flow cause erosion and flooding [5,15,16,60].

Although intensively managed agricultural landscapes may benefit from even greater tree retention, specifically near rivers, increased tree cover proportional to herbaceous vegetation is an issue for the maintenance of remaining grasslands [21,45,56]. Due to lesser current tree cover than historically in the eastern Great Plains, current tree cover typically was about six-fold greater near rivers than throughout the croplands of Illinois, Iowa, and Minnesota. While a lesser percentage of tree cover than historically in the eastern Great Plains may appear to indicate that tree encroachment has not occurred, the current tree cover occurred on a very small land base that was not agricultural, that is, not the 28 million ha extent but 5 million ha without agricultural conversion. Out of current wildland vegetation, the forest was 65% of vegetation cover, and herbaceous vegetation was 35% of vegetation cover, which was a reversal from 84% grasslands and 16% forests

historically. Indeed, for the entire Great Plains, most of the watersheds with current low tree or shrub cover occurred in the western Great Plains, and most of the watersheds with great tree or shrub cover occurred in the eastern Great Plains, probably reflecting tree expansion from eastern forests [21,45,56]. The transition of grasslands to forests through natural afforestation and planting is another pressure on decreasing grassland ecosystems.

Now that riparian forest restoration has become a relatively effective campaign [3,41,42,58], with riparian forest cover near historical levels, repairing riparian connections to upland grassland vegetation and non-riparian wetlands may become the next mechanism to reestablish infiltrative landscapes for control of sediment loads. Grassland vegetation and wetlands also have great infiltration capacity, limiting erosion [5] and retaining valuable surface water and groundwater, which are becoming an increasingly scarce commodity for both agricultural and residential needs [61,62]. In addition to increased water supply, water quality, flow regulation, and erosion control, grassland vegetation also provides other ecosystem services, such as support of biodiversity, pollination services, forage, aesthetic beauty, tourism and recreation, stable carbon sinks, and preparation for climate change [43,63]. Herbaceous grassland vegetation is resistant and resilient to drought, heat, windstorms, flooding, fires, and insect outbreaks, both due to tolerance traits that provide resistance and a life form that can rapidly reestablish aboveground growth, allowing resilience [63]. Grassland restoration has the greatest rate of return on investments out of nine different ecosystems [64].

Limitations of this tree and shrub cover assessment include errors in the mapping of vegetation reconstructions and modeling of tree and shrub cover, comparison to more accurate modern remotely sensed imagery, class assignments, and specifically river locations. Historical hand-drawn field maps and written notes translate to relatively accurate fidelity at landscape scales [30]. While the modern land cover from remotely sensed imagery is accurate and at finer resolution than reconstructions, the 30 m imagery for modern comparison appropriately is not at the resolution of individual trees (i.e., tree-scale imagery would not be the suitable resolution for comparison to reconstructions [3]). Disagreement occurs about thresholds to separate continuous vegetation type classes, and so I limited the number of classes. However, distinguishing crops, pastures, and herbaceous vegetation in current land cover classification results in some class assignment errors. River locations are dynamic, particularly over time and after river modification, such as channelization, and river placement may not represent rivers at all time intervals [3]. Measurements of large rivers at large landscape scales are coarse, so despite errors from river location due to dynamics and channelization, overall measurements appeared correct, as indicated by appropriate increases in tree cover measurements along large rivers.

5. Conclusions

Knowledge of historical conditions provides baseline information about patterns and processes in historical ecosystems, including hydrological connectivity. Answering the question about tree cover in historical grassland ecosystems in the eastern Great Plains, tree cover typically was three-fold greater near rivers than tree cover throughout grasslands, which ranged from 6.5% tree cover in Minnesota to 25% tree cover in Illinois and from 0.5% to 36% tree cover in large watersheds. The addition and maintenance of riparian tree cover is a well-known and commonly applied management practice to reduce erosion in agricultural landscapes. This study, while at coarse scales to encompass river dynamics, indicated that current riparian tree cover is relatively close to historical tree cover, although current land use is different than historical grasslands. The next stage in river restoration may incorporate repairing watershed connections among uplands, wetlands, and streams

to slow water flow and retain valuable water by infiltrative networks rather than an isolated focus on riparian tree vegetation.

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