NORTH DAKOTA GAME AND FISH DEPARTMENT

FINAL REPORT

Cottonwood Restoration in North Dakota Riparian Forests

Project T-42-R

April 1, 2014 – December 31, 2016

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Submitted by
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Project Title: Cottonwood restoration in North Dakota riparian forests

Species of Conservation Priority: Species that use riparian cottonwood as habitat: Swainson's hawk, Golden Eagle, Bald Eagle, Peregrine Falcon, Piping Plover, Least Tern, Black-billed Cuckoo, Red-headed Woodpecker, Loggerhead Shrike, Canadian Toad, River Otter, Pallid Sturgeon, Flathead Catfish.

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Activity Period: *Timeframe April 1, 2014 – December 31, 2016*

Location: The Oahe Wildlife Management Area (WMA).

1. Need:

Plains cottonwood, *Populus deltoides* Bartr. ex Marsh, is a widely distributed riparian forest species typically found in mixed and pure species stands along the banks of streams and rivers of the Great Plains (Farrar 1995). The widespread distribution of cottonwood, and its dominant position in riparian forests, has resulted in its classification as a foundation species (Whitham *et al.* 2006). Foundation species are those species which play an important role structuring plant and animal communities within an ecosystem (Dayton 1972). There is a large body of research supporting the role of cottonwood as a foundation species in riparian forests (Whitham *et a*l. 2006; Bailey *et al*. 2004; Schweitzer *et al*. 2005; LeRoy *et al*. 2006; Martinsen & Whitham 1994; Schuster *et al*. 2006). This research indicates that changes in the abundance and distribution of cottonwood trees can have far reaching impacts on riparian ecosystem processes and biodiversity (Whitham *et al*. 2006).

The ecological role of cottonwood in riparian ecosystems. There are a variety of examples of how variation of plant traits in cottonwood trees impacts the associated plant and animal communities in riparian ecosystems. For example, the concentration of condensed tannins in leaf and bark material, a plant trait under strong genetic control, has been reported to impact a variety of riparian ecosystem features. Bailey *et al*. (2004) reported that condensed tannins impacted the foraging behavior of beavers in riparian cottonwood forests. Beavers preferentially selected trees with lower levels of condensed tannins resulting in their selective removal from these ecosystems (Bailey *et al*. 2004). Condensed tannins have also been shown to impact feeding behavior of insects (Schweitzer *et al*. 2005). High levels of condensed tannins reduce arthropod fecundity resulting in their preferential selection of trees with lower levels of these phytochemicals (Wimp *et al*. 2005). However, the selective removal of trees with low levels of condensed tannins by beavers will eliminate this option, potentially resulting in lower arthropod abundance (Wimp *et al*. 2005). These effects have been shown to cascade into the next trophic level impacting the abundance and diversity of birds feeding on these arthropods (Bangert *et al.* 2006).

Variation in condensed tannin concentration, not only impacts food webs in riparian forest ecosystems but has also been shown to affect nutrient cycling. LeRoy *et al*. (2006) demonstrated that the concentration of condensed tannins in leaf litter falling into streams determined which aquatic invertebrate species were present in those streams. The type and diversity of aquatic invertebrates impacts two aspects of stream ecology. Specifically, different feeding guilds of invertebrates will impact the decomposition rate of leaf litter falling into streams with corresponding impacts on nutrient cycling (LeRoy *et al*. 2006; Schweitzer et al. 2005). The species of aquatic invertebrates may also impact diversity and abundance of fish populations due to preferential feeding of different fish species on different invertebrates (LeRoy *et al*. 2006). The decline in the abundance of plains cottonwood threatens these ecosystems and their associated plant and animal communities.

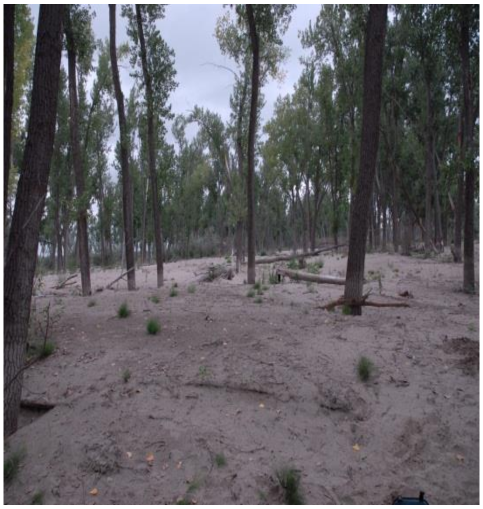

Fig. 1. Mature cottonwood stand following flooding and sediment deposition.

Cottonwood on the North Dakota landscape. In North Dakota (ND) approximately 150 thousand acres of cottonwood and mixed cottonwood forest are present on the landscape (Haugen *et al*. 2005).Over the past 100 years land use changes have had significant impacts on these riparian cottonwood forests (Braatne *et al*. 1996). Some of these land use changes include livestock grazing, water diversion, domestic settlement, channelization, and agricultural clearing; all resulting in a loss of cottonwood habitat (Braatne *et al*. 1996). However, dam construction has had the single greatest impact on these ecosystems (Braatne *et al*. 1996). Regular flooding, and the resulting bare exposed mineral soil (Fig. 1), is essential to cottonwood regeneration. Dam control along the major riparian waterways of ND has virtually eliminated flooding disturbance from these ecosystems (Braatne *et al*. 1996). This has resulted in reduced cottonwood abundance and the absence of regeneration in many of these riparian habitats (Haugen *et al*. 2005). For example, Johnson *et al*. (1976) noted reduced cottonwood growth and fewer seedlings on the lower Missouri river floodplain. In a second survey, 18 years later, Johnson (1992) reported a further reduction in the number of regenerating saplings compared to the initial survey. These two studies suggested that construction of the Garrison Dam, completed in 1954 on the Missouri River, has impacted cottonwood regeneration by reducing flooding frequency (Johnson *et al*. 1976; Johnson 1992). The change in the flooding regime and corresponding reduction in cottonwood abundance has significant consequences for riparian ecosystems on the northern Great Plains. Unlike many wetter regions in eastern North America, there are very few alternative species to replace cottonwood in this arid region (Braatne *et al*. 1996) The potential loss of this foundation tree species threatens the conservation of many of the species of conservation priority, listed above, that use this habitat.

During the 2011 growing season in ND the first significant flood in many decades occurred on the lower Missouri River (Fig. 2). Using Geographic Information Systems (GIS) and tools for geospatial analysis, areas of flooded forest were estimated (Kotchman *et al.* 2011). Along the Missouri river approximately 25,015 acres of forestland was inundated (Kotchman *et al*. 2011).The disturbance caused by this flood, although extremely damaging too many municipalities, has created new cottonwood habitat along this drainage (Fig. 1). This habitat represents an opportunity to study the establishment and recruitment of cottonwood following flooding. This is particularly important given the impact that increased recreational use and competition from invasive weed species, absent following historic flooding, may have on cottonwood regeneration. Understanding the impacts of these two factors will allow for the development of best management practices to promote cottonwood regeneration following rare flooding events ensuring the continued health of the wildlife populations these important ecosystems support.


Fig. 2. Missouri River Flooding in Oahe Bottoms in 2011 (Photo courtesy: ND Game and Fish).

Restoration of cottonwood in the absence of flooding. Flooding is essential to natural cottonwood regeneration (Braatne *et al*. 1996). The reduced frequency of flooding along the lower reaches of the Missouri River requires that a different approach to cottonwood restoration be taken. In order for cottonwood seeds to germinate and grow they require bare exposed soil with minimal competition for light (Braatne *et al*. 1996). Flooding removes the competing vegetation and creates a seed bed of exposed river sediment ideal for seed germination (Braatne *et al*. 1996). Management strategies which successfully promote cottonwood regeneration need to emulate these conditions. In the absence of flooding the presence of competing vegetation would largely limit the regeneration success of cottonwood. In order to mitigate the impact of competing vegetation on cottonwood regeneration two options exist: (i) removal of competing vegetation; and (ii) planting of cottonwood trees. The removal of competing vegetation will result in microsites with bare exposed soil and eliminate competition for light promoting natural regeneration of cottonwood from seed. Planting of cottonwood trees eliminates the need for bare exposed soil and establishes trees able to compete with surrounding vegetation for light and resources. This approach is being undertaken in Utah and Arizona to restore their riparian cottonwood forests (http://poplar.nau.edu/).

Regardless of the effectiveness of the chosen strategy the resources necessary to undertake the restoration effort need to be considered. Although it would not be possible to remove vegetation from large areas along the banks of the Missouri and its tributaries or plant 1000’s of acres of riparian habitat with cottonwood trees it would be possible to strategically select areas for cottonwood forest restoration. Wildlife Management Areas (WMA’s) are an ideal target for these efforts. Much of the community using these areas has a vested interest in there protection and conservation. Furthermore, the proposed restoration approaches require a minimum of resources. Once sites have been selected for restoration it would be possible for volunteers to play an important role in the vegetation and/or planting efforts.

Objectives: The overall objective is to develop a management strategy to restore cottonwood habitat, used by wildlife species of conservation priority, along the Missouri river. The specific objectives are two-fold: (1) monitor the establishment, recruitment, and growth of riparian cottonwood forests following the 2011 floods in the Oahe WMA; and (2) test the effect of weed control and planting to restore cottonwood forests in the absence of flooding.

Expected Results or Benefits: The two objectives described above will provide data which can be used in the creation of a cottonwood conservation and restoration strategy for the lower Missouri River in ND. Objective 1 will provide information on the impact of recreational activity and weed competition on the successful regeneration of cottonwood. This information could be used to guide management decisions promoting cottonwood regeneration following flooding. For example, if cottonwood regenerates poorly on sites with heavy recreational activity resource managers could limit access to areas they are targeting for regeneration/restoration. Alternatively, if weed competition was a major limiting factor for cottonwood regeneration success then weed removal, targeted at specific locations, may be a viable option. The results from this objective will also indicate which sites and environmental factors impact the success of cottonwood regeneration. For example, if locations close to the river have greater cottonwood regeneration then perhaps these locations should be targeted for management action.

The second objective will provide information on the feasibility and success of several management actions designed to promote the restoration of cottonwood in the absence of flooding. Specifically we will test the impact of planting, vegetation control, and a combination of planting and vegetation control on cottonwood establishment. These results can be combined with objective 1 to determine the best sites to target for regeneration and restoration efforts. For example, as described above, objective 1 may indicate that proximity to the river is the greatest predictor of regeneration success. If this is the case then any targeted management actions should be conducted on sites close to the river to maximize their probability of success.

The ND Wildlife Action Plan promotes a comprehensive approach to habitat and wildlife management. Management strategies promoting the protection, conservation, and restoration of cottonwood, a foundation tree species, in the presence and absence of flooding will meet this goal. As described above results from the two objectives will provide information which will lead to the development of a restoration strategy for riparian cottonwood along the Missouri River. Conservation and restoration of these important ecosystems will protect a diversity of game and non-game species identified for conservation priority by the ND Wildlife Action Plan. For example: Swainson's Hawk, Golden eagle, Bald Eagle, Peregrine Falcon, Piping plover, Least Tern, Black-billed Cuckoo, Red-headed Woodpecker, Loggerhead Shrike, Canadian Toad, and Wild Turkeys (Hagen *et al*. 2005). Furthermore, riparian forests are extremely important for the health of rivers and streams in the region (Hagen *et al*. 2005). Aquatic vertebrates and fishes such as River Otter, Pallid Sturgeon, and Flathead Catfish, species identified in the ND Wildlife Action Plan rely on riparian forest to protect the quality of the water in the streams and rivers where they live (Hagen *et al*. 2005). Restoring and protecting riparian cottonwood forest habitat will benefit the survival of these and other game and non-game species protecting, conserving, and enhancing North Dakota's fish and wildlife resources (Hagen *et al*. 2005).

Approach: Following the 2011 flood, 18 photo points were created by the North Dakota Game and Fish Department (NDGFD), in the Oahe WMA (Fig. 3). At each of the 18 locations photos were taken in four cardinal directions (North, South, East, and West) to document the extent and severity of the flooding (Johnson pers. comm.). These 18 photo points will be used as study sites to meet the two Objectives described below.

Objective 1 **- Monitor the establishment, recruitment, and growth of riparian cottonwood forests following the 2011 floods in the Oahe WMA**. The 18 photo points, described above will be used as study sites to monitor riparian forest succession following flooding. Vegetation surveys will be conducted in a two-stage process. In the first stage, 4 fixed radius (25ft radius) sample plots centered on the photo point (North, South, East, and West) will be located, and their position recorded using GPS (72 plots in total). This objective was not completed due to time constraints. Based on discussion between North Dakota Game and Fish and the Researchers working on the project it was decided that we should focus our efforts on objective 2 cottonwood restoration in the absence of flooding.

Objective 2**- Test the effect of weed control, planting, and seeding to restore cottonwood forests in the absence of flooding.** Three additional sites will be identified in collaboration with William Haase of the NDGFD. At each of these sites the following three treatments will be applied: vegetation removal, planting, vegetation removal + planting, and an untreated control. The experimental design will be a randomized complete block design with each treatment being applied to a 100 ft^2 area. In the spring of 2014 seed will be collected from mature cottonwood trees in the area surrounding the study sites. This seed will be germinated and grown in the greenhouse. Trees will be placed outside in order to go dormant for the winter. In the fall of 2014 a brush saw will be used to cut down weeds to the soil surface in preparation for planting in early spring the following year. The stumps of the weeds will then be hand painted with glyphosate to limit re-sprouting. In spring of 2015, as early as environmental conditions allow, the dormant greenhouse grown trees will be planted at the three study sites. No further treatments will be applied for the remainder of the growing season. In the fall of 2015, growth and survival of the trees at all three study sites will be evaluated. Analysis of variance will be used to determine which treatment resulted in the greatest cottonwood establishment and survival. This information will be used to determine the success of the treatments in promoting cottonwood regeneration in the absence of flooding.

Accomplishments

Materials and Methods

Plant propagation: Trees planted in this study were propagated in a greenhouse from 10 - 13 cm long cuttings of native plains cottonwood; cuttings were made from whips taken from young, dormant trees near the Graner Bottoms site the winter preceding out planting in 2015. Cuttings were soaked for approximately 48 h in tap water prior to being planted. The growing medium used was SunGro Professional Mix number 8 (SunGro Horticulture Ltd., Agawam, MA). Growing medium was fortified initially with 12 g of Nutricote slow-release fertilizer (Scotts Osmocote Plus; Scotts Company Ltd., Marysville, OH) and after two months using a liquid fertilizer with a formulation of 20-20-20 (N-P-K) (Scotts Peters Professional; Scotts Company

Ltd.) Trees were watered daily after the first month because they began to grow and use water rapidly. Rooted cuttings (approx. 2,200) grew in the greenhouse for several months before being cut back so that only a few healthy buds remained. The trees were then stored at 4° C until they were transported to their respective sites for out planting. Trees were cut back to reduce moisture stress on the rooted cuttings following out planting.

Site selection: Two sites along the Missouri River in south central North Dakota, U.S.A. were selected in the spring of 2015. The first site was located in Schmidt Bottoms (46.685080, -100.762396) and the second site in Graner Bottoms (46.653435, -100.710408) (Fig. 3). Both sites were established within 500 meters of mature cottonwood and naturally regenerated cottonwood seedlings to ensure that a seed source was available nearby. The soil type was similar at each site; Havrelon loam (Typic Ustifluvent) was the primary soil in Schmidt Bottoms, while Graner Bottoms was classified mainly as Havrelon fine sandy loam (Typic Ustifluvent) (NRCS, 2016).

Experimental design: At each site the experimental design was a randomized complete block design with 3 blocks. Four treatments and an untreated control were compared. Each treatment and untreated control occurred once per block. The treatments were: tree planting (T), tree planting with tree shelters (TS), tree planting with tree shelters and synthetic weed barrier fabric (TSF), and conventional tillage (CT); a control, which was only mowed prior to initial planting, was also included in each block. The area of each treatment within a block was 21.34 m x 21.34 m (70 ft. x 70 ft.).

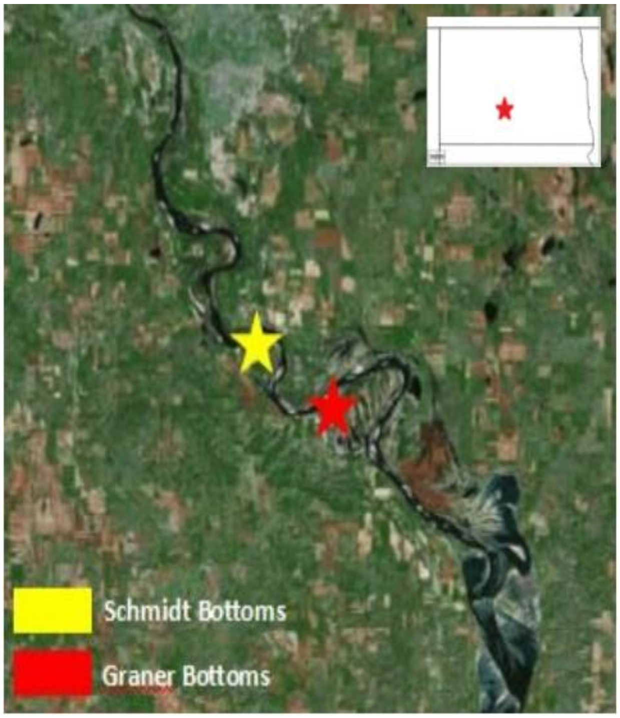

Fig. 3: Locations of Schmidt Bottoms and Graner Bottoms study sites. In set indicates approximate location of sites in North Dakota.

Site preparation: In April of 2015 both sites were mowed to a height of approximately 10 cm (4 in) with a brush mower. In May, the sites were sprayed with the herbicide glyphosate to minimize competing vegetation. The sole exception was that the control plot in each block, was not sprayed (Fig. 4). Synthetic weed barrier fabric (DeWitt Sunbelt Woven Ground Cover 5 x 600 ft. rolls, Sikeston, MO) was installed by hand, and secured with 25.4 cm (10 in) anchor pins (DeWitt Anchor Pins 10 x 2 x 10 in, Sikeston, MO). Anchor pins were inserted by hand approximately every 0.5 meters along both edges of the fabric and additional pins were used to secure the ends. Tree shelters used in the study were 1.5 m (60 in) tall (Tree Pro tree protectors purchased from Tree Pro; West Lafayette, IN) and were installed between late June and early July 2015. Support stakes for the tree shelters were made from 1.83 m (6 ft.) lengths of ¾ inch schedule 40 PVC pipe. For CT treatments, tillage was accomplished using a small tractor and tilling implement following the start of seed dispersal in mid-June of 2015.

Trees were planted by hand using a dibble bar on May 27th and 28th of 2015. A total of 49 trees were planted in each treatment at a 3.05 m (10 ft.) spacing. A border row of rooted *P. deltoides* cuttings was planted around each trial. The sites were replanted mid-June to replace trees that had not survived the original out planting with stock left over from the original planting dates.

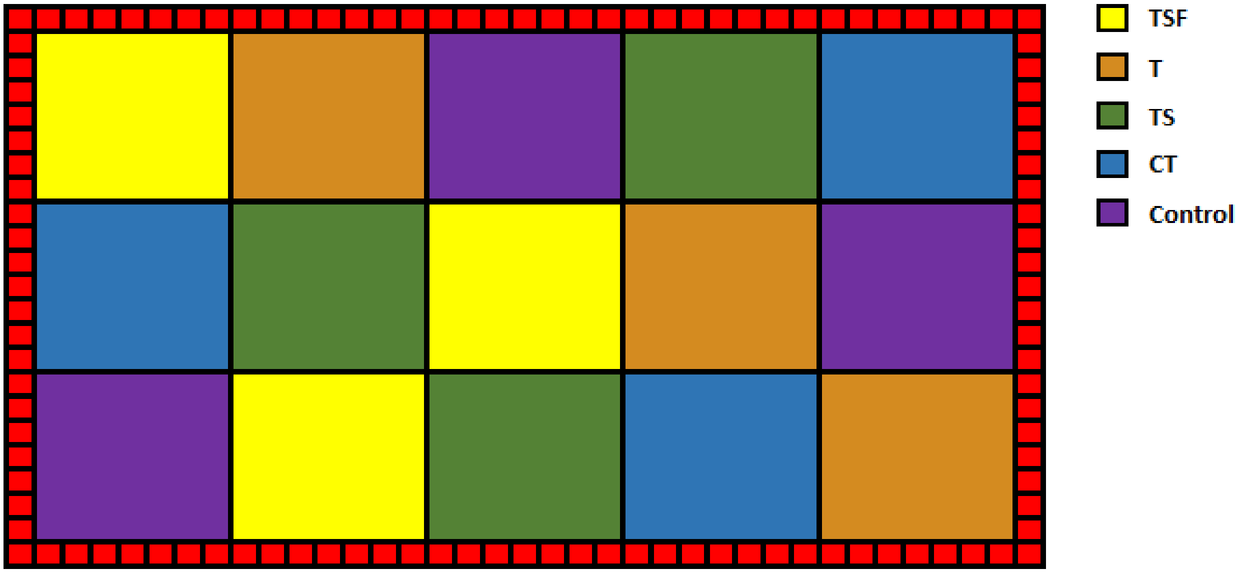

Fig. 4. General layout of the Graner Bottoms trial. Red boxes outlining the trial represent the single border row of P. deltoides.

Data collection: First year tree mortality was evaluated in T, TS, and TSF treatments during September 2015. Cottonwood recruitment in control and CT plots was estimated using five 1 m^2 quadrats. Quadrats were randomly placed throughout each CT and control plot. The number of living cottonwood seedlings was tallied for each individual quadrat.

A final survey of both sites was done in September of 2016. Survival, height, height to live crown, caliper, and damaging agents (e.g. Melampsora rust) in the T, TS, and TSF treatments were recorded. The height to live crown measurement was taken along the main stem, beginning at the soil line and terminating at the base of the first living branch, lateral shoot, or lateral bud. Calipers were measured approximately 15 cm (6 in) from the ground surface; a height of six inches was recommended by *The American Standard for Nursery Stock* (2014) for field grown trees of this diameter class. In the control and CT plots, plains cottonwood, green ash (*Fraxinus pennsylvanica* Marshall), and boxelder (*Acer negundo* L.) seedlings were tallied as described above.

Common tree problems assessed were those that caused losses of growth, deformation, premature defoliation, and other dysfunctions in the associated host tree. Trees were considered to be girdled only if cambium had been damaged by abrasion, resulting in dead areas along the primary leader. If rubbing had resulted primarily in cosmetic damage and had not affected the cambium, the condition was noted as bark rub. Damage was assumed to be the result of browsing whenever foliage had been severed from a tree by means of an irregular cut.

Analysis: All statistical analyses were done using the program ‘R’ version 3.3.2 (R Foundation for Statistical Computing. Vienna, Austria). Multiple comparisons among treatment means were conducted using the lsmeans() function in the ‘lsmeans’ package (Lenth, 2016). P-values were adjusted for multiple comparisons using the Tukey correction.

Analyses began with the full model and the likelihood ratio chi-square test was used to test the significance of each parameter. The initial statistical model was the same for all response variables: $Y_{ijk} = \mu + S_i + B_j + T_k + S_i*B_j + S_i*T_k + B_j*T_k + S_i*B_j*T_k + \mathcal{E}_{ijk}$. In the initial model, S denotes site, B denotes block, T denotes treatment, and i, j, and k signify the ith site (1-2), the jth block (1-3), and the kth treatment (1-5), respectively.

Three separate analyses were conducted. In the first analysis, the effects of the T, TS, and TSF treatments on height, height to live crown, and caliper were tested. Data from the two sites were combined for this analysis because all of the statistical assumptions were satisfied. A second analysis was conducted to determine the effects of T, TS, and TSF treatments on survival. Survival was analyzed separately for each site due to unequal variances. In a third analysis, Welch t-tests were used to compare the estimated mean recruitment of cottonwood, green ash, and boxelder between the CT treatment and the control. T-tests were done on combined data from both Graner and Schmidt Bottoms (n = 6 for each treatment). Data from both sites was combined both to increase the sample sizes and because data had been pooled for analyses of most other response variables.

Results

Preliminary and final findings: In 2015, survival was 98% for T, 97% for TS, and 91% for TSF treatments in Graner Bottoms. At the Schmidt Bottoms site, mean survival was 90% for the T treatment, 95% for the TS treatment, and 99% for the TSF treatment (Fig. 6). Mean recruitment estimates for *P. deltoides* in 2015 were 6,000 tph in CT plots and 333 tph in M plots (Table 3.)

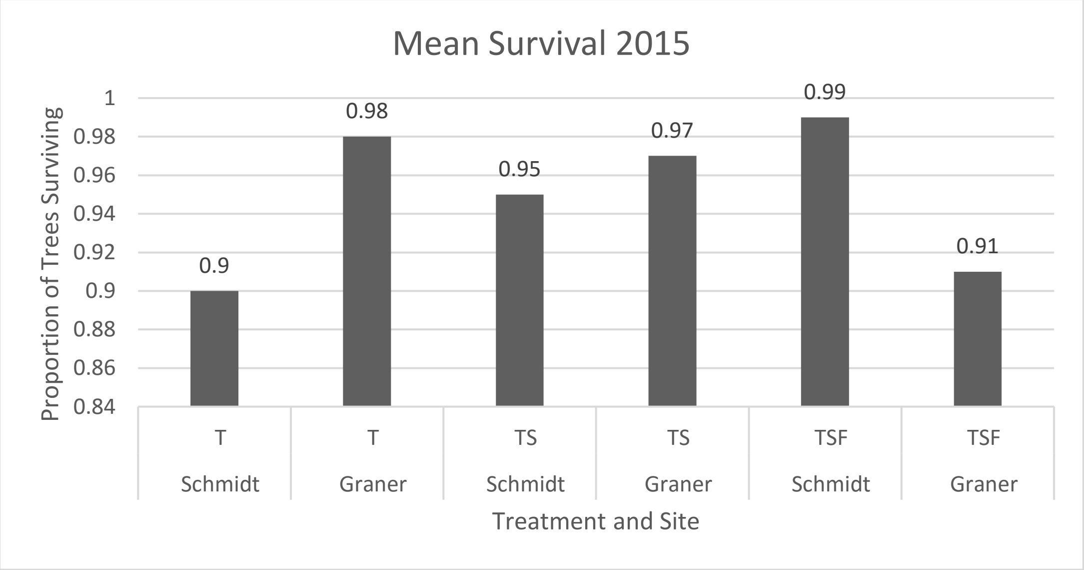

Fig. 5. Mean survival proportions by treatment at each site in 2015.

Table 1. A summary of the final models used for statistical analyses.

Mean Response	Final Model
Survival - Schmidt	$Yjk = \mu + Rj + Tk + \varepsilon jk$
Survival - Graner	$Yjk = \mu + Rj + Tk + \varepsilon jk$
Height	$Yijk = \mu + Si + Rj + Tk + Si*Tk + Rj*Tk + \varepsilon ijk$
Height to Live Crown	$Yijk = \mu + Si + Rj + Tk + Si*Rj + Si*Tk + Rj*Tk + Si*Rj*Tk + \varepsilon ijk$
Caliper	$Yijk = \mu + Si + Rj + Tk + Si*Tk + \varepsilon ijk$

In 2016, mean survival in Schmidt bottoms was 60.67%, 90.00%, and 98.00% for T, TS, and TSF treatments, respectively (Figure 2). Comparisons of the mean survival between treatments indicated significant differences between T and TS (p-value = 0.0266), and T and TSF (p-value = 0.0101), where the planting only treatment (T) had lower mean survival than both the TS and TSF treatments. Mean survival was similar between TS and TSF treatments (p-value = 0.5783).

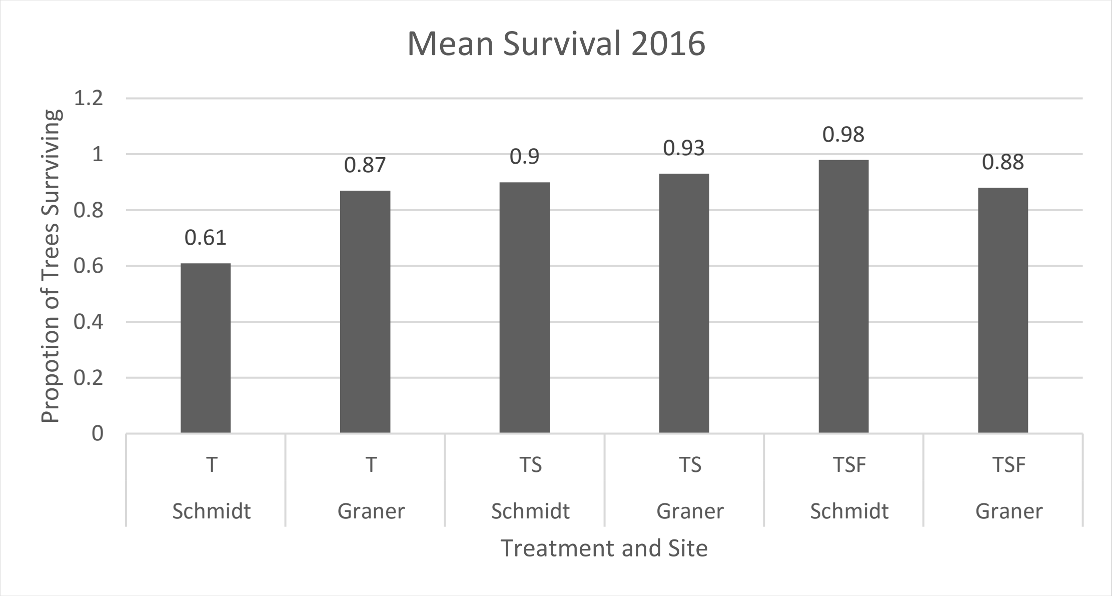

Fig. 6. Mean survival proportions by treatment at each site in 2016.

In Graner Bottoms, the mean survival was 87.33% in T treatments, 92.67% in TS treatments, and 88.00% in TSF treatments (Fig. 6); there were no significant differences in survival between T and TS (p-value = 0.3682), T and TSF (p-value = 0.9810), and TS and TSF (p-value = 0.4499) treatments. Significant differences (p-value < 0.0001) in mean height and height to live crown were observed among T, TS, and TSF treatments. Mean caliper values were significantly different between T and TSF treatments (p-value < 0.0001), and between TS and TSF treatments (p-value < 0.0001), but not between T and TS treatments (p-value = 0.0852) (Table 2).

Table 2: Mean values for height, height to live crown, and caliper listed according to site and treatment. Values with different letters are significantly different from each other (alpha = 0.05).

Treatment	Mean Height (m)	Mean Crown (m)	Mean Caliper (cm)
Only Trees (T)	0.69a	0.27a	0.505a
Trees & Shelters (TS)	1.27b	0.385b	0.595a
Trees, Shelters, & Weed Barrier (TSF)	2.78c	0.775c	1.725b

Significant differences in recruitment between CT and control treatments were not detected for cottonwood, green ash, or boxelder in 2016. The p-values from comparisons between the average number of stems recruited in each treatment are provided in parentheses next to the respective species: green ash (p-value = 0.246), boxelder (p-value = 0.094), and cottonwood (p-value = 0.363). Mean recruitment estimates for CT and control treatments, respectively, were as follows: green ash (11,667;25,667), boxelder (1,000;10,333), and cottonwood (2,000;0) (Table 3).

Table 3: Seedling recruitment in M and CT plots – 2015 and 2016.

	Conventional Tillage 2015	Control 2015	Conventional Tillage 2016	Control 2016
P. deltoides (tph)	6,000	333	2,000	0
F. pennsylvanica (tph)	N/A	N/A	11,667	25,667
A. negundo (tph)	N/A	N/A	1,000	10,333

Damaging agents: The most common damaging agents were Melampsora rust (*Melampsora spp.*), bark rub, browsing, and girdling. Most incidences of bark rub and girdling occurred as a result of main stem abrasion against exposed edges along the tops of tree protectors, but the actual proportions of such incidents were not recorded. Results are summarized in Table 4.

Table 4: Summary of damaging agents on T, TS, and TSF treatments at each site.

Damaging Agent	# Surviving Affected(Schmidt)	% Surviving Affected(Schmidt)	# Surviving Affected (Graner)	% Surviving Affected (Graner)
Melampsora rust	357	97.81%	392	99.75%
Bark rub	100	27.40%	72	18.32%
Browsing	24	6.58%	9	2.29%
Girdling	24	6.58%	6	1.53%

Discussion

Site differences: Land use history and competing vegetation were different between the two sites, which may have influenced treatment effects. The trial in Graner Bottoms was established on a site that had been left in fallow starting in 2008; prior to that the field had been planted to alfalfa. This site also received mild sand deposition following a flood in 2011, which potentially decreased moisture-holding capacity near the soil surface. The site selected in Schmidt Bottoms had been used to grow supplemental food for wildlife since 2012, with the most recent crop having been a cover crop mix planted in 2014. When sites were surveyed in September of 2016, competing herbaceous vegetation was abundant in nearly every plot. Common weeds at the Schmidt Bottoms site included Canada thistle (*Cirsium arvense* (L.) Scop.), mares tail (*Conyza canadensis* (L.) Cronquist), and Russian thistle (*Salsola kali* L.). In the Graner Bottoms trial, sweet-clover (*Melilotus officinalis* (L.) Lam.), Kentucky bluegrass (*Poa pratensis* L.), and Canada thistle were the most prevalent weeds.

When the Schmidt Bottoms site was surveyed for mortality in September of 2015, many trees in the T plots had become lodged along with oats that had volunteered in the site. The oats, which had established following the cover crop from the previous year, appeared to cause extensive shading of lodged trees and may have contributed to the lower overall survival in 2016 (60.67%) observed in the T treatment at this site compared to Graner Bottoms (87.33%) (p-value = 0.059). Significant differences observed in survival between T and TS (p-value = 0.0266), and T and TSF (p-value = 0.0101) treatments in Schmidt Bottoms, but not in Graner, were likely due to mortality attributed to lodging in the T treatments. While lodging may not be a common issue in plantation forestry, it is a frequent problem in the production of cereal grains an. In cereals, lodging associated losses can be as high as 75%, although they are typically lower (Baker et al. 2014).

Although the impact of treatment on survival differed between the two sites; treatment impacts on height, height to live crown, and caliper were readily apparent (Table 2). As a result, it may be in the best interest of land managers to consider utilizing more costly treatments in certain contexts where faster growth and better survival are desired. Increased vigor could be particularly valuable on sites where competition is substantial, as was evidenced in Schmidt bottoms where mean survival was 60.67% for T treatments compared to 90.00% and 98.00% in TS and TSF treatments, respectively. Atchison and Geyer (2002) reported a similar survival trend from their plains cottonwood studies in Kansas; planting into live sod resulted in 27.8% survival after three years compared to 71.4% survival in treatments where sunbelt weed barrier fabric was used. Significant differences in mean caliper between T and TSF (p-value < 0.0001) but not T and TS (p-value = 0.0852) treatments imply that extended weed control (e.g. synthetic weed barrier fabric) may have a more substantial effect than tree shelters on caliper diameter growth in *P. deltoides* in North Dakota, at least during the first two growing seasons. This may be due to the extended period of weed control provided by the synthetic weed barrier fabric, which enables additional water and nutrient availability for growing trees.

Treatments: To estimate the cost per tree for T, TS, and TSF treatments, the combined costs of greenhouse rental and the materials purchased specifically for each treatment were considered. Total greenhouse costs associated with each tree were determined by dividing the total cost of greenhouse rental for the five months preceding out planting of stock by the total number of trees initially planted (1,702 trees). For TS and TSF treatments, tree shelter costs and tree shelter, fabric, and anchor pin costs were factored into cost per tree estimates, respectively. The cost of applying glyphosate was not included for any treatments, as a professional applicator was hired for the purposes of this study and it was assumed that this method of herbicide application is not necessarily typical for land managers.

The low cost of simply planting trees (T) makes this treatment a tempting option for situations where competing vegetation is minimal and juvenile trees will be able to compete for sunlight and nutrients. Results of this study indicated that tree planting without the use of tree shelters or weed barrier fabric was efficacious in terms of survival where trees were not lodged by high winds and volunteer weeds, but that there may be advantages in growth and height to live crown associated with more involved treatments (Table 2). Trees grown without tree shelters or weed barrier generally appeared to be less vigorous compared with trees grown using TS and TSF treatments. This was believed to have been largely a function of light availability in the TS treatments and light, water, and nutrient availability in the TSF treatments. While no attempt was made to quantify the local population of white-tailed deer (*Odocoileus virginianus*), the primary herbivore of concern in this study, browsing damage appeared to be low at both study sites. The tree planting only (T) treatment was the least expensive of the three planting treatments tested at an estimated $0.47 (USD) per tree.

Planting and later adding 1.5 meter tree shelters (TS) was estimated to cost $4.24 (USD) per tree. Although this was approximately nine times more expensive than the planting only treatment (T), trees in Schmidt bottoms were better able to survive the lodging issues in TS treatments than in T treatments on average (p-value = 0.0266). At both sites, tree shelters were observed preventing trees from being shaded by tangled masses of competing vegetation. As a result, we hypothesize that the treatment effect was a function of both the tree shelters preventing the young trees from becoming lodged and of light being able to reach cottonwood leaves through the opening in the top of the tree shelters. Where herbivore damage is expected to be high, the use of tree shelters may be necessary for successful establishment.

At an estimated cost of $6.54 (USD) per tree, the TSF treatment was the most expensive, but also provided the greatest mean response in height, height to live crown, and caliper of the three planted treatments (see Table 2). As a result, this treatment may be best suited for situations where relatively few trees need to be established quickly from juvenile planting stock. Biodegradability of tree shelters and synthetic fabric are often a concern when using these items for conservation and/or restoration purposes. Therefore, it may be of value to explore the use and efficacy of more readily biodegradable products for weed control and tree protection, such as those manufactured from organic substrates. Woven weed barrier fabric will girdle trees if not removed in a timely manner.

The CT treatment was not considered to be an effective method of establishing *P. deltoides* in this study. No significant differences were detected between tilled plots and controls at the conclusion of the study in 2016 (p-value = 0.363). Costs per tree estimates were not attempted for the CT treatment because the primary cooperating agency tilled the site at no cost to the investigators.

Limitations and need for future work: The two aspects of experimental design most limiting to scope of inference in this study were the study duration and the small geographic area within which both trials were located. Trials were only monitored for two growing seasons following planting. Final response variable means might have been significantly different if data were collected after one or more additional growing seasons rather than in 2016.

The straight-line distance between the two sites was approximately 5.3 km (3.3 mi), which limits the geographic area to which the results of this study can be directly applied; however, trends observed in this study may prove to be similar to those observed in future studies elsewhere in the Great Plains Region. Under such circumstances, the results could potentially have some level of predictability outside of the geographic range of the study sites.

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