THE DECLINE OF A RIPARIAN GALLERY FOREST IN DEVILS TOWER, WYOMING: CAUSATION AND MANAGEMENT TECHNIQUES FOR RESTORATION

by

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APPROVAL

of a thesis submitted by

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This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citation, bibliographic style, and consistency and is ready for submission to The Graduate School.

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April 2013

DEDICATION

I dedicate this document to my grandfather, Laurel Anderson, who has always instilled in me a deep appreciation for the natural world, hard work, and dedication for my passions in life.

ACKNOWLEDGEMENTS

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VITA

Jacob Michael Anderson was born May 4, 1989 in Sioux Falls, South Dakota. He is the son of Rhon and Sarah Anderson. He attended school in Sioux Falls and graduated Lincoln High School in the spring of 2007. Jacob received a Bachelor's of Arts in Biology from Augustana College, Sioux Falls, South Dakota in the spring of 2011.

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ABSTRACT

Devils Tower National Monument, Wyoming, (DT) has experienced a decline in cottonwood recruitment along the Belle Fourche River, leaving the remaining riverine forest in danger of disappearing. The National Park Service has requested information about the mechanisms behind this decline and possible management methods that could be used to restore forests to the Belle Fourche riparian corridor. Previous research has indicated that cottonwood seedlings require flood-deposited sediments and high initial groundwater for survival. A dam located 12 miles upstream of Devils Tower could be impacting the recruitment success of cottonwoods because of a decrease in seasonal flooding. If this decline is due to factors that managers have little control over, other methods should be explored to increase the success of future restoration efforts. This case study examined the physical attributes of the Devils Tower riparian area in comparison to a healthy, functioning, riparian gallery forest located on the nearby Powder River (PR) to learn the complex mechanisms that help support and sustain these healthy riparian ecosystems. Soil field tests, cottonwood surveys, and measurements of local groundwater patterns were used to compare the two sites. To determine the restoration potential of cottonwood gallery forests at Devils Tower, planting trials were conducted to provide a methodology for greater seedling survival, testing effects of residual herbicide, species planted, preliminary soil preparation including disking, herbaceous understory control, and irrigation. We observed higher groundwater and greater cottonwood age class diversity at the Powder River site, in contrast to the DT site. At DT, tree health was significantly higher (p=.0003) with shallower groundwater. Tree mortality was highest among boxelder and bur oak in sites with deepest groundwater levels. At the same time, irrigation at economically feasible levels had no significant effect on tree survival. This research suggests that site potential for cottonwood re-establishment is poor along the Belle Fourche riparian corridor due to deep groundwater tables (1.7-2.2m) and regulated flow patterns with limited sediment delivery to the floodplain environment. A successional shift resulting from regulated streamflow conditions now favors green ash over any other species.

LITERATURE REVIEW

Introduction

Cottonwood (*Populus* spp.) gallery forests dominate many western riparian ecosystems (Taylor, 2001). These forests provide wildlife habitat, recreational benefit, and many ecosystem services in the otherwise treeless landscape of the semi-arid west (Rood et al., 1995, Scott et al., 1999). However, recent declines in riparian cottonwood stands have been observed in many areas where anthropogenic alterations to streamflow have occurred, especially in semi-arid conditions where flow rates are highly seasonally variable (Scott et al., 1999, Shafroth et al., 1998, Willms et al., 1998). This could have serious consequences because cottonwoods depend on seasonal flow variations for growth and reproduction.

Populus species have evolved to cope and proliferate with physical disturbances such as flood events in riverine systems (Shafroth et al., 2002). Disturbance, such as flood events, in semi-arid riparian ecosystems deposit new sediments and temporarily increase groundwater tables (Greet et al., 2011). Hence, flood disturbance is likely required for the viability of many of these cottonwood stands.

Cottonwood Growth and Requirements

Plains cottonwoods (*Populus deltoides* ssp. *monilifera* [Marshall]) require moist, freshly deposited soils for germination (Gladwin & Roelle, 1998). As a riparian pioneer species, cottonwoods are often the first to inhabit fresh fluvial deposits after floodwaters recede (Kalischuk et al., 2001, Harner & Stanford, 2003). Reproductively mature cottonwoods of 10 years or older often release seeds following summer flood events (Gladwin & Roelle, 1998) and seed germination is prolific and rapid in areas where suitable nurseries are located in fresh sediment deposits (Mahoney & Rood, 1998).

These young cottonwood seedlings continue to survive as long as their roots maintain contact with groundwater (Kalischuk et al., 2001, Willms et al., 1998). Cottonwood roots can maintain growth rates of 0.5 to 1 cm per day (60 to 100 cm) in their first year (Mahoney & Rood, 1998, Stromberg, 2001). Therefore, because young cottonwood stands are highly dependent on groundwater for survival, the rate of stream decline is crucial for stand survival. Groundwater declines in fresh sediments must not exceed 2.5 cm per day for adequate seedling survival (Mahoney & Rood, 1998, Rood et al., 1998, Stromberg, 2001). Generally speaking, cottonwoods are considered a short-lived, dominant, riparian species and are well suited to ever-changing riverine systems (Hansen et al., 1988). The short-lived cottonwoods often give rise to other riparian woody species if disturbance does not occur.

Western Riparian Successional Species

Riparian species are often given a wetland indicator status describing how frequently a species is found in riparian settings. For example, obligate wetland species occupy riparian areas >99% of the time, facultative wetland species are located in riparian areas 67-99% of the time, while facultative species occupy wetland areas 34-66% of the time (USDA NRCS Plant Database).

In the mountain west, *Populus deltoides* is considered to be a facultative species because of its fluctuating groundwater requirements (USDA NRCS Plants Database) and is a pioneer tree species in the semi-arid west (Hansen et al., 1988). Later seral species found in riparian settings throughout the western Dakotas, southeastern Montana, and northeastern Wyoming include green ash (*Fraxinus pennsylvanica* [Marshall]), bur oak (*Quercus macrocarpa* [Marshall]) and boxelder (*Acer negundo* [Pursh]). Green ash is typically an understory species that eventually replaces cottonwoods, making it a later seral species and occasionally a climax species (Hansen et al., 1988, Gucker, 2005). Boxelder is a co-dominant species with green ash, and is slightly less tolerant of flooding (Hansen et al., 1988, USDA NRCS Plants Database). Both green ash and boxelder are considered facultative and tolerate moderate shade (USDA NRCS Plants Database, Gucker, 2005) explaining their occurrence at later stages in riparian succession. Bur oak in Wyoming, the western Dakotas, and southeastern Montana, is a shade intolerant, facultative species that is considered a late seral or post climax species (USDA NRCS Plants Database, Gucker, 2011). Based on this information, a generalized successional pathway for woody species in the semi-arid west would first be cottonwoods, followed by green ash or boxelder, and conclude with bur oak. One would expect to see this transition in a natural flowing river that is actively migrating across its floodplain with cottonwoods near the bank and bur oak furthest from the water's edge. This model is compromised however, when riverine systems are controlled by upstream dams or diversions.

Effects of Dams on Riparian Succession

Suitable environments for cottonwood regeneration can be produced by three main fluvial processes: narrowing of the river channel, meandering, and sedimentary deposition (Scott et al., 1996). Floods can cause either sediment deposition or scour floodplains, which, in turn, provide suitable habitat for cottonwoods and other species reliant on riparian disturbance for recruitment (Scott et al., 1996). However, dams created for water retention and hydroelectric power reduce flooding and change the flow of water which disrupts natural riverine processes such as sediment deposition, flow dynamics, and hydraulic energy (Ligon et al., 1995). This has serious consequences for riparian community stability because about 67% of the Earth's freshwater is obstructed by dams and other man-made water detention structures before it reaches the oceans (Nilsson & Berggren, 2000). Dams are reported to have mixed results on downstream riparian forests. Cottonwood gallery forests have declined in Alberta, Canada, but increased in Nebraska and Colorado (Friedman et al., 1998). These mixed results are a function of channel geometry and dominant fluvial processes on large rivers (greater than 1400 cubic meters per second) and may reflect landform characteristics that influence the amount of sediment transport in a river (Friedman et al., 1998). Cottonwood recruitment, therefore, does not always decline after a dam is constructed, and the effects of dams on downstream riparian gallery forests may be strongly site or region dependent. Nonetheless, when managing regulated riverine systems for riparian woody species such as cottonwoods, consideration should be given to the effects of flow alterations and downstream impacts that may hinder successful recruitment (Scott et al., 1996, Friedman et al., 1998, Ligon et al., 1995).

Purpose

The main objective of this study was to develop a management approach that will help managers for the National Park Service promote cottonwood recruitment along the Belle Fourche River within Devils Tower National Monument, Wyoming. The secondary objective was to determine the root cause for the decline of this species along the Belle Fourche reach within the park, so that future efforts could focus on actions to stimulate natural recruitment of riparian species. To meet these objectives, we integrated new planting techniques, inclusion of other successional species, and a comparison of the physical structure of the Belle Fourche to its unregulated counterpart, the Powder River, to study the influence of streamflow regulation on riparian gallery forest regeneration. Accomplishment of these objectives should enable the National Park Service to re-establish a healthy, functioning system that will require little direct effort to maintain.

INTRODUCTION

For over a century Devils Tower National Monument (Figure 1) has been used both for religious purposes and recreation. Located in northeast Wyoming, campers, hikers, and climbers have enjoyed the peaceful atmosphere under the shade of the mature cottonwood stands near the Belle Fourche River. In recent times, significant qualitative evidence has shown that these riparian stands are declining at astounding rates (Scott et al., 1999, Shafroth et al., 1998, Willms et al., 1998, Shafroth et al., 2002). Historically, declines in such species have been observed in areas where water management activities have increased, resulting in less variation of surface flows in rivers and streams.

Figure 1: A map of Devils Tower, Wyoming. The insert in the lower left corner is a larger image of Wyoming with the red star signifying the location of Devils Tower National Monument.

Previous studies across the Western United States have indicated that *Populus* and similar riparian tree species require temporal flood events for reproduction and stand management. Flow variability often results in sedimentation, which provides for recruitment of new individuals on fresh soils uninhibited by intra and interspecies competition for resources. The wet environment created after flood events also results in higher groundwater levels within the floodplain allowing new plant species easy access to water sources. When seasonal flood events are controlled, disruption of biological and physical processes in the riparian environment can be expected including forest recession, a decrease in biodiversity, and increased stream entrenchment.

The Plains Cottonwood is of particular concern along riparian corridors because the reproduction and management of this species is almost solely dependent on temporal variations of streamflow. Cottonwood seeds germinate in freshly deposited sediments following flood events, so frequent flooding is necessary to ensure a continuum of age classes within these stands. Mixed age stands are important for the replacement of trees that are no longer reproductively viable, damaged, or diseased. Thus, a mixed age stand indicates a stable, self-sustaining population. A heterogeneous stand also has a greater chance of surviving disease as a whole because individual fitness enables certain trees to survive while cohorts succumb to disease and stress.

The Keyhole Reservoir project, upstream of Devils Tower, commissioned in 1952 under the federal Flood Control Act was to control seasonal flooding and to provide water resources for South Dakota and Wyoming. Over time the reservoir has reduced seasonal flooding caused by heavy rain events and spring snow melt in many downstream communities. This has changed the riparian processes along downstream reaches of the Belle Fourche. When floods do occur, they are often short and river levels decline to average flow rates quickly. Cottonwood germination has been observed at Devils Tower after these short flood events, but there are no reports of these seedlings surviving beyond one or two years. In this work, we selected an unregulated reach of the nearby Powder River for comparison to the Belle Fourche (Figure 2).

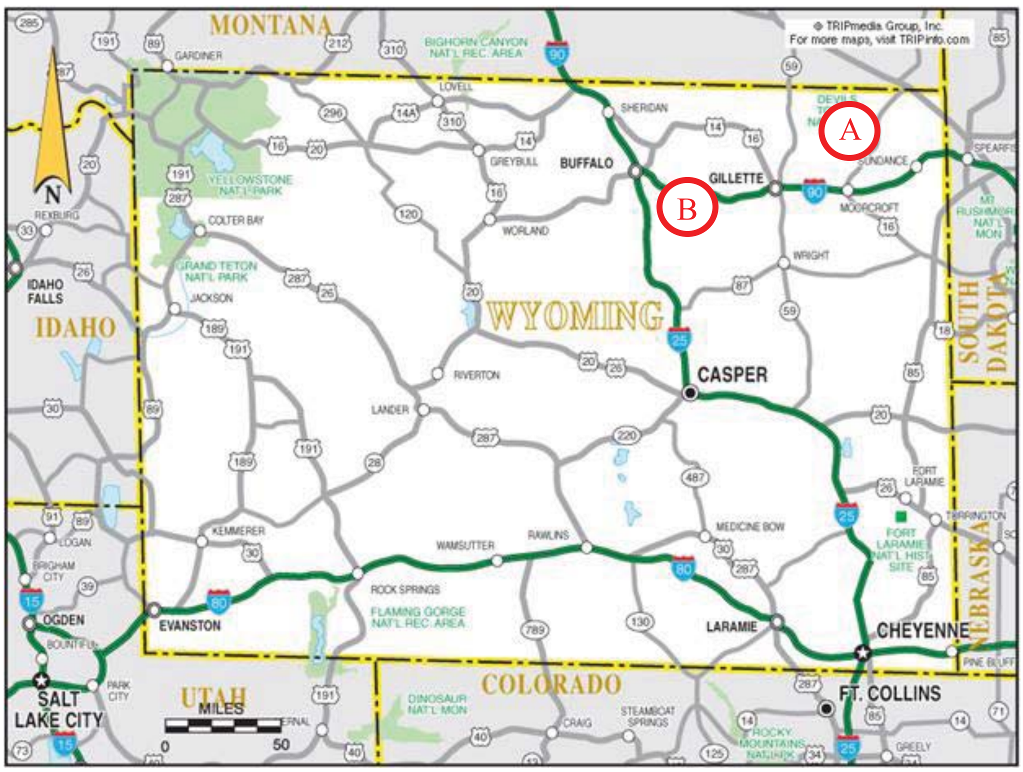

Figure 2: A map of Wyoming indicating the locations of Devils Tower (A) and the Powder River study reach (B).

Previous work and observation suggests that regulation of the Belle Fourche could be a factor in the reduced reproduction of cottonwoods, but there may be other factors that further hinder cottonwood recruitment.

Complicating riparian corridor ecological sustainability is historic pesticide application to control noxious weeds in the park. The overuse of particular pesticides (Tordon and 2,4-D) could leave residual compounds in the soil which would further impact tree recruitment.

If cottonwood forests have declined due to regulation of river flows or other large scale controls (like climate), other tree species may now be better suited to current site conditions at DT. Lower groundwater tables may result in site conditions more amenable to later successional stages (Hansen et al., 1988, Gucker, 2005).

In 2009 the National Park Service requested assistance to develop a management plan for the riparian corridor within Devils Tower National Monument (NM). They expressed interest in pin-pointing the causations that negatively affect cottonwood recruitment within the park, and to develop a cost effective methodology the Park Service staff could employ to re-establish a functioning riparian gallery forest. Regardless of the causes of decline of riparian forests within Devils Tower National Monument, methods need to be developed to re-establish trees in this area to restore and promote a healthy riparian ecosystem. The main focus of this two-year study was to develop methods for reintroduction of woody species into the park's riparian floodplain. The ultimate goal for this research has been to develop cost effective techniques coupled with high success rates that will enable Devils Tower NM personnel to trigger regeneration of riparian forest stands.

To address this goal, we developed several testable hypotheses to explain how this riparian system works given historical land management practices. The first hypothesis tested in this study was that residual herbicide, specifically Tordon, in Devils Tower NM soils are limiting cottonwood recruitment along the Belle Fourche riparian corridor. The null hypothesis for this aspect of our study is that residual herbicide does not limit cottonwood recruitment at Devils Tower NM.

The second hypothesis that will be tested in this research will determine the influence that Keyhole Reservoir has on downstream reaches of the Belle Fourche River, specifically in Devils Tower NM. We hypothesize that an unregulated river (Powder River) and a regulated river (Belle Fourche River) have similar characteristics, and produce similar riparian forests. To test this hypothesis we evaluated age distributions of cottonwoods, water table heights, and soil characteristics at the two sites.

The final hypothesis is that boxelder, green ash, and bur oak seedlings will survive and grow better in Devils Tower NM than cottonwood seedlings. The null hypothesis used for these tests predicts that in a functioning riparian area cottonwoods will have lowest mortality and highest growth rates. To test the potential of these species for successful restoration efforts, we identified four management steps as treatments to be evaluated in this work (till, no-till, spray, irrigation; Table 2).

METHODS

Study Sites

The Devils Tower NM study site was located along the Belle Fourche riparian corridor near the eastern boarder of the park (Figure 3). The elevation of the campground location was 1174.1m (3852’) above sea level, and the elevation of the primitive campground plots was 1172.9m (3848’) above sea level. The mean annual temperature is 6.1 C (43.0F) with an average of 44.7cm (17.6”) of precipitation occurring at this location each year (US Climate Data) (Table 1).

Table 1: Rainfall totals for two research summers at Devils Tower National Monument. Totals were recorded at an onsite weather station.

	Rainfall per Month in inches (cm)					
Year	April	May	June	July	August	September
2011	1.99 (5.05)	5.38 (13.66)	3.59 (9.12)	2.28 (5.79)	1.26 (3.20)	0.28 (1.47)
2012	2.46 (6.25)	1.97 (5.00)	0.84 (2.13)	1.52 (3.86)	1.42 (3.61)	0.0 (0.0)

The soils located at the southern end of the study, near the campground were excessively drained, Bankard loamy fine sand with a parent material of alluvial fill derived from igneous, metamorphic, and sedimentary rock. The soil type transitioned to a Glenberg fine sandy-loam series with similar parental origin near the primitive campground to the north (NRCS Web Soil Survey). The soils in the northern area of the Monument are well drained.

The unregulated Powder River site, used for the second hypothesis, was selected because of its close proximity to Devils Tower, similar vegetation community type, annual precipitation, and streamflow rate. The study area was located 75 miles southwest of Devils Tower (Figure 4) on a ranch owned by Anadarko Petroleum Company. The elevation at this site was 1204.6m (3952') above sea level. The mean average temperature for this area is 6.7C (44.1F) with an average of 43.4cm (17.1") of precipitation occurring annually (US Climate Data).

The soil along the Powder River study reach was a Draknab sandy-loam series. This soil type was derived exclusively from sandstone parent material and is excessively drained (NRCS Web Soil Survey).

Hypothesis 1: Testing for Residual Herbicide Within Soils at Devils Tower

Soil samples were gathered near permanent groundwater monitoring wells and other nearby areas along the Devils Tower NM floodplain at depths of 0-20cm and 20-40cm (0"-8" and 8"-16") on June 30, 2011. The samples were collected following laboratory protocol (samples sealed, placed on ice, and delivered within 24 hours of collection) and sent to Energy Laboratories, Billings, MT, for the determination of residual herbicides (Tordon, 2,4-D, Dicamba, Roundup, Plateau, and Milestone).

Hypothesis 2: Differences Between Regulated and Unregulated Rivers

We used soil characteristics and cottonwood age class structure data collected from the Belle Fourche and Powder Rivers to riparian forest characteristics on reaches with regulated (Devils Tower NM) and unregulated (Powder River) streamflow regulation.

Devils Tower NM Survey

Pediological features were examined in 2012 at Devils Tower to determine the soil characteristics within the riparian corridor. Three transects were established along the Belle Fourche river (Figure 3) to accomplish an ordered description of riparian soils. These transects were placed at least five times the width of the stream channel from one another. Three soil pits were excavated at the green line (where vegetation met the river's edge) and the first two breaks in slope progressing away from the active channel, indicating different floodplains of potentially different ages. A maximum distance of 50 meters from the active stream channel was observed. Each of the three soil pits were excavated to completion depths of at least 1.2m. Soil horizons were recorded and basic field observations of texture and color were observed to determine potential water infiltration patterns. Soils were graded on a scale from 0-10 (0=low apparent infiltration, 10=high apparent infiltration) based on relative particle size for potential infiltration (Appendices A-H).

Devils Tower Age Class Survey

All of the cottonwood trees within the perimeter of the Devils Tower NM Campground were counted and grouped based on developmental stage. Seedlings were grouped as trees shorter than 2m, poles as trees 2 to 5m in height with diameters less than 0.1m at breast height, and mature trees as larger. These measurements were recorded in the spring of 2011 with a total area of 3.6ha (9 acres) sampled (Figure 3).

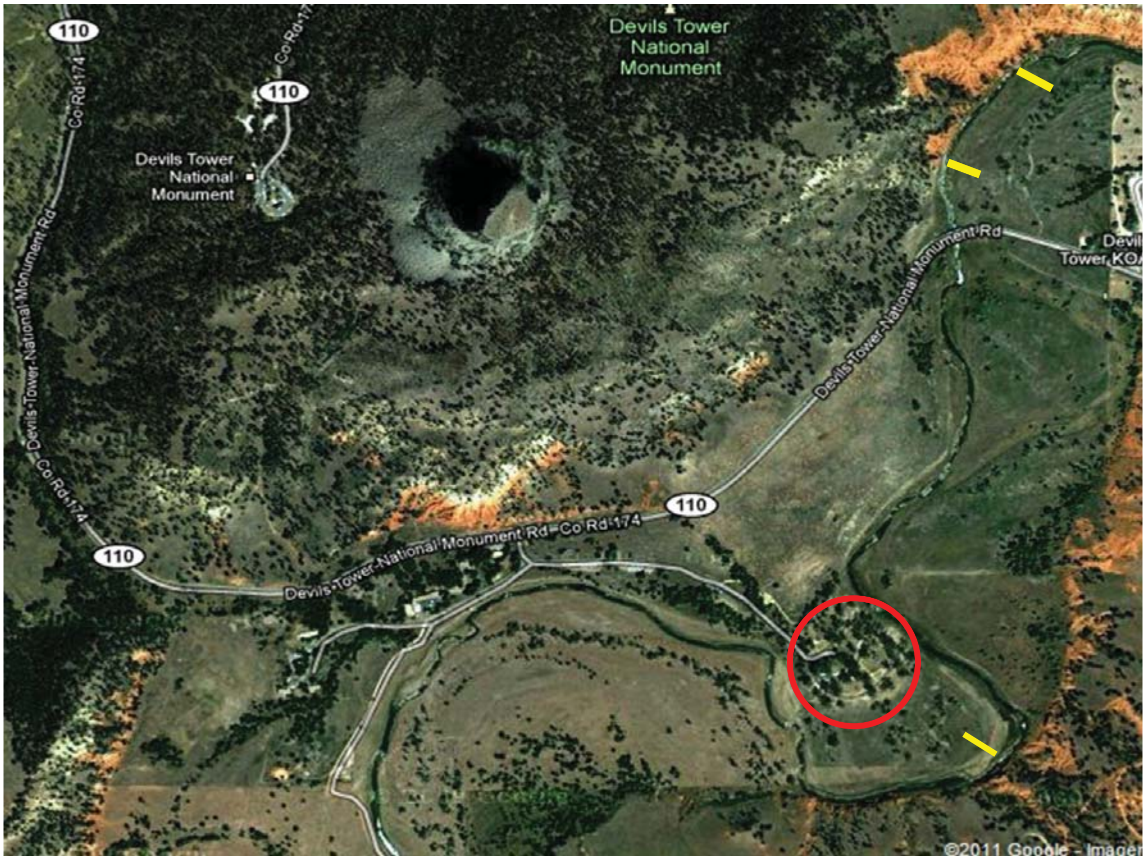

Figure 3: A map of Devils Tower indicating where the three soil transects were located and the campground where the cottonwood age class was sampled. The yellow lines indicate the presence of the 50m transects used for soil analysis, the red circle indicates where cottonwood trees were sampled.

Powder River Survey

A comparison study of a stream reach unaffected by man-made streamflow alterations was conducted in 2012. Three soil transects were measured using the same techniques applied to the Devils Tower site (Figures 4, 5). In addition, three 200m by 2m transects were constructed perpendicular to the river for cottonwood age class structure mapping. All trees were counted and measured in each transect to determine an approximate age class structure for the Powder River riparian gallery forest using the same classification criteria applied to the Devils Tower Campground. The age class structure values were converted into a tree/acre unit for comparison with the forest structure at Devils Tower to have equal units for comparison between the Belle Fourche and the Powder River. Soil data from soil pits along various floodplain features were textured and classified for potential infiltration rates similar to the Devils Tower site. We assumed this ecosystem to be a healthy, functioning riparian system because of little livestock grazing and unregulated streamflow. Simple tests including means and standard errors were calculated for site comparison.

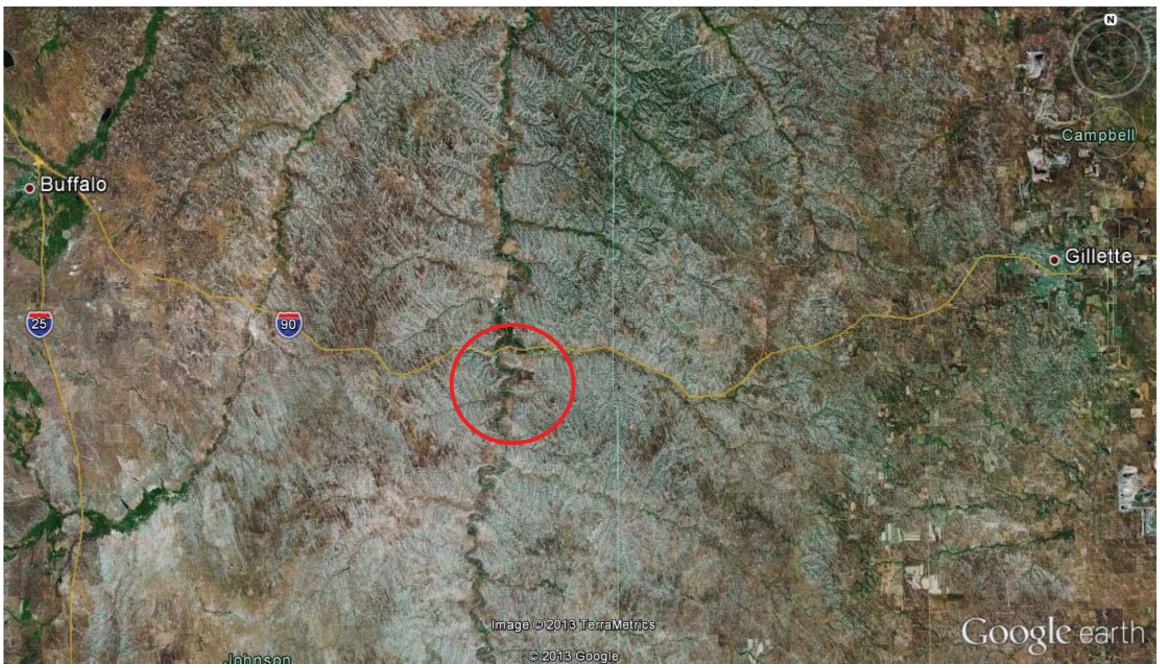

Figure 4: The Powder River site was located between Gillette, WY, and Buffalo, WY, south of I-90. The study reach was approximately 8km south of the I-90 Powder River rest area.

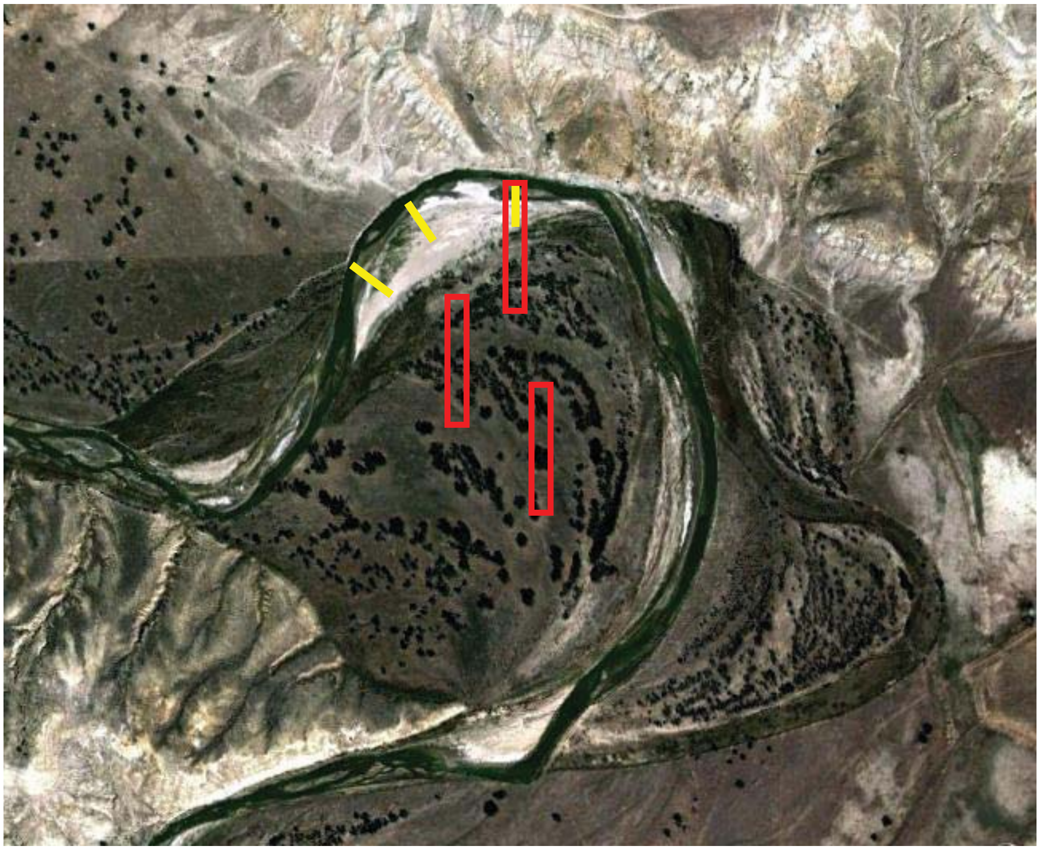

Figure 5. Powder River study site located on the Anadarko Petroleum Company's ranch. The yellow lines indicate the three soil transects and the red rectangles display where the random cottonwood age class observations were collected.

Hypothesis 3: Tree Planting to Determine Species and
Treatment Success at Devils Tower National Monument

To test methods for tree reintroduction within the park, seven sites were chosen for planting (Figure 6). These sites were located around groundwater monitoring wells that had been installed in 1996. The elevation of water in these wells has been recorded and kept on site at Devils Tower since 1997 (Larry Martin, National Park Service Hydrogeologist, personal communication). Current well locations include the campground (wells C1, C2, C3, & C4) and primitive campground sections of the park (wells P1, P2, & P3). Plot nomenclature was derived from the well designation present at the time of the study (Figure 7).

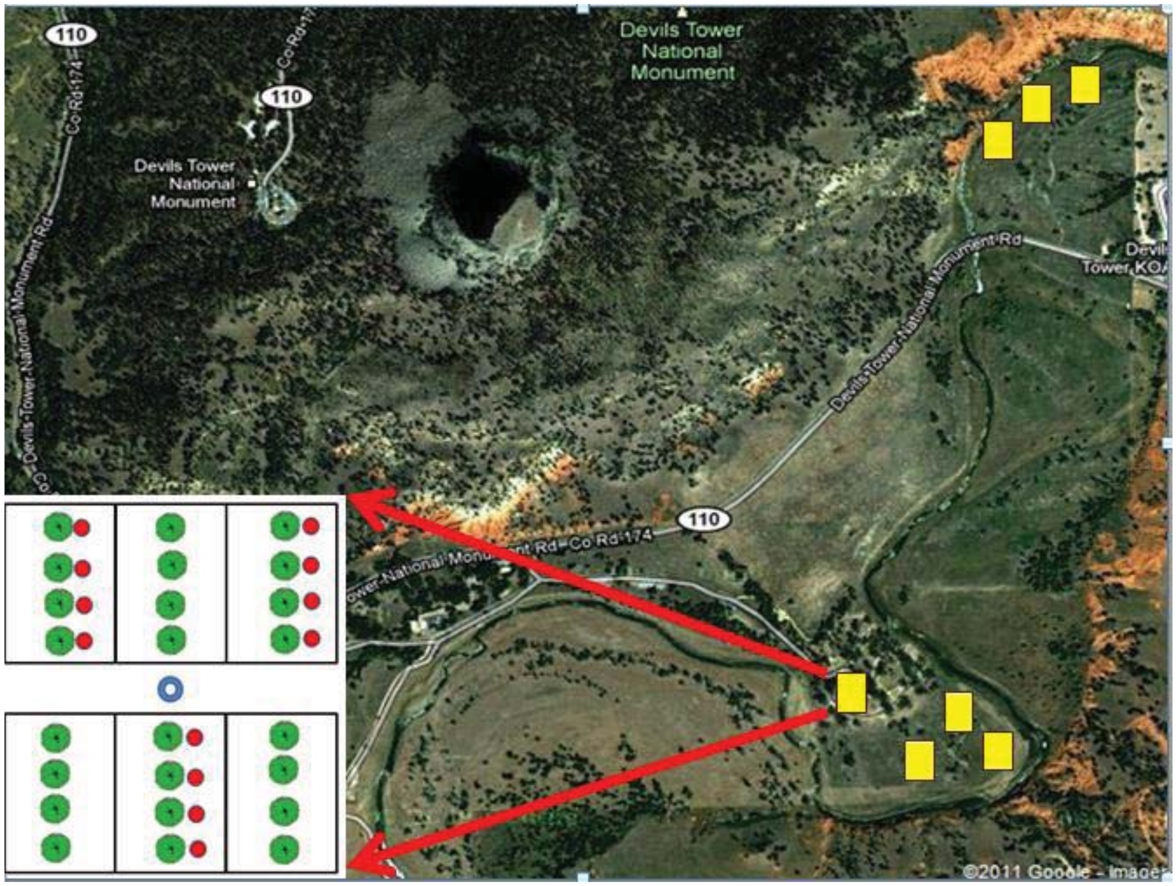

Figure 6. Study layout at Devils Tower National Monument, Wyoming. The four boxes in the southern end of the map indicate the study plots at the Campground unit, while the three boxes in the northern end of the park indicate the study plots at the Primitive campground unit. The insert in the lower left is a schematic showing the general layout of each plot design. Green tree pictures=tree planting location within each replicate, red circles=irrigation tube placement, and blue circle in the center of the insert=groundwater monitoring well.

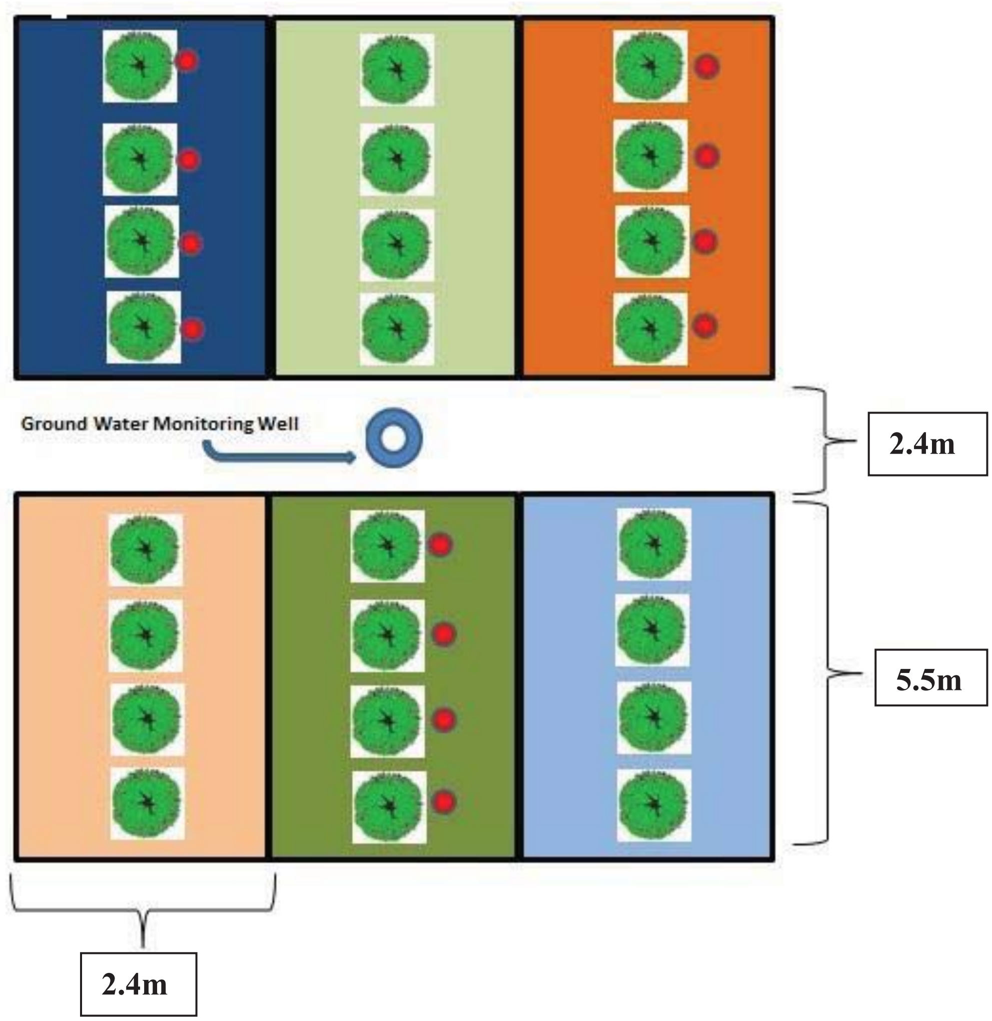

Figure 7. A detailed schematic for each 13.4m by 24m (44' by 24') plot with six treatments. Note the groundwater monitoring well located in the center, and the red irrigation tubes near each tree with an irrigation component. Each treatment was selected randomly so actual plot layout varied.

Treatments shown in Table 2 were compared to each other and a control planting to establish the effects of site conditions and management at Devils Tower NM on four tree species being considered for riparian restoration efforts. Rehabilitation plots measuring 7.3m by 13.4m (24' by 44') were established June 15, 2011, with the monitoring wells located in the exact center of each plot. All plot boundaries were at least

140m (150 yards) from the nearest adjacent plot and faced magnetic due north. Each plot was then divided into six replicates measuring 2.4m by 5.5m (8' by 18'), leaving a 1.2m (4') gap between the well and the nearest adjacent tree (Figure 7). Each replicate subplot within a given plot was randomly assigned a treatment. Six treatments were used in this study (Table 2). After the plots and their replicates had been surveyed and marked, each plot was mown using a handheld STIHL T90 string trimmer fitted with a brush cutting attachment on June 16, 2011. All replicates received an initial mowing treatment to simulate spring conditions when trees come out of dormancy and interspecies competition for sunlight and water is at a minimum. Continued mowing of the control plots was implemented throughout the duration of the summer.

Table 2. The six treatment types with their descriptions used at Devils Tower NM to test our third hypothesis. Site preparation began in early June, 2011.

Treatment Type	Definition
No Till (Control)	Mow when grass was greater than 30cm (12")
No Till with Irrigation[1]	Mow when grass was greater than 30cm (12"), irrigation tubes near trees
Spray[2]	Apply herbicide pre-planting
Spray with Irrigation[1]	Apply herbicide pre-planting, irrigation tubes near trees
Till[2,3]	Apply herbicide and disk soil surface
Till with Irrigation[1,2,3]	Apply herbicide and disk soil surface, irrigation tubes near trees

[1] 90cm (36") perforated irrigation tubes were inserted approximately 30cm (12") from each tree, a total of four tubes were integrated in each treatment replicate.
[2] Herbicide included RAZOR PRO and HIGHLIGHT at a rate of 7.8ml per L (1.27oz per gallon). The herbicide was given two weeks to kill all above-ground vegetation before further work was conducted.
[3] A 1.8m (6') pull-type disc was used to break up the soil surface after the herbicide had killed all above-ground vegetation.

Herbicide was applied to the “spray” and “till” replicates in each plot on June 22, 2011, to kill all of the vegetation that emerged after mowing. RAZOR PRO with HIGHLIGHT (a dye used for application accuracy at 60ml per 15L (2oz per 3 gallons)) was applied using a backpack sprayer, following the manufacturer’s suggested rate of 7.8ml per L (1.27oz per gallon). A total of 34ml (11.4oz) of RAZOR PRO were used to treat a total area equaling 0.04ha (1/10 of an acre) for all study plots. Sprayed vegetation started to show signs of stress about four days after application.

Replicates selected for the “till” treatment were cultivated using a 1.8m (6’), offset, pull-type disk with serrated blades. The disk was pulled twice over each “till” replicate with a small utility type vehicle (UTV) to break up the surface horizons of the soil and sod one time after the herbicide treatment.

<u>Tree Planting</u>

After initial site preparation was completed, tree planting began. Trees were obtained from the DNRC Montana State Forestry Nursery, Missoula, MT. Four different tree species were planted in each replicate (one individual per species, per replicate) resulting in a total of 168 observational units for this study. The species selected for testing were Bur Oak (*Quercus macrocarpa*[Marshall]), Boxelder (*Acer negundo*[Pursh]), Plains Cottonwood (*Populus deltoides*[Marshall]), and Green Ash (*Fraxinus pennsylvania*[Marshall]). All four species were identified as native species within Devils Tower NM and were located in various habitat types throughout the park. Seedlings were delivered as bare-root stock of approximately 2-3 years of age and ranged from 30cm-50cm (12”-20”) tall. Trees were planted in the center of each replicate with outside trees placed 90cm (3') from the replicate boundary on the north and south sides and 1.2m (4') from the east and west sides of the boundary. The minimum distance between trees allowed was 1.2m (4') to ensure that trees did not compete directly with one another. Individual species were selected in a random order to further increase statistical accuracy for future analysis.

Planting holes were hand-dug and trees planted with the upper-most root node approximately 5cm below soil surface. A 10.16cm (4") diameter, 90cm (36") tall, plastic, translucent growth tube with ventilation holes was placed around every tree (to limit grazing by local herbivores) and held upright by a single fiberglass rod. Replicates with an irrigation component were fitted with hand-made PVC irrigation tubes (Appendix I). The irrigation tubes were constructed using 5cm (2") diameter PVC pipe cut to 1m (40") lengths. Eight, 9.5mm (3/8") holes were drilled in the bottom length of each tube to allow for slow water dissipation to the seedling root system at below ground depths. An 86cm (34") deep pit was dug using a post-hole tool approximately 30cm (12") upslope of each "irrigated" tree. A tube was then inserted into each pit and open spaces around the tube loosely filled with excavated soil. Concrete was poured into the bottom 5cm (2") of each irrigation tube to limit vertical water flow and to increase lateral migration of water when each tube was filled.

Tree Measurements and Maintenance

Post planting, all new trees were watered three times per week for three weeks to ensure increased initial survival of the plantings. During this time, water was also added to irrigation tubes (until each was filled to the top) to ensure that sub surface soils remained saturated. After three weeks, watering was limited to twice per week for the irrigated treatments only, for the remainder of the summer. Watering was conducted using a UTV-mounted water tank and a type 6 Park Service fire engine. The irrigation tubes were slowly watered until completely full.

Growth measurements were conducted several times during the summer on a quantitative and qualitative scale to discern individual tree growth rates, health, and mortality. A measuring regime (seedling height) was created for initial measurements one week after planting and once per month for the duration of the growing season in 2011 and 2012. Height measurements were taken with a tape measure to the nearest 0.5cm (1/4"). A qualitative measure of tree health was also taken for each observational unit. Health was assigned based on approximate foliar development, vegetative pliability, and color. Foliage was rated by a single observer as complete, partial, or non-foliated. A health description was then given to each tree as either healthy, stressed (partial yellowing of foliage), dying (yellowing and browning of foliage), or dead (no foliage present). Numerical values were assigned to each individual on a monthly basis on a scale from 0 (dead) to 7 (healthy). Weekly site comments were recorded for each plot concerning surrounding vegetation growth patterns, general soil moisture, and ruderal/primary successional species (weed) presence.

<u>Statistics and Data Analysis</u>

Statistica version 10.0 (Statsoft Corp., 2011) was used to analyze data collected at both study locations (Devils Tower NM and the Powder River). Devils Tower NM tree response measures were summarized for both years and median values were calculated for each tree. This was accomplished by taking four similar measures from each individual for each year and calculating a median value. Median values were chosen to represent trees in the middle of summer, and to eliminate bias caused from growth rate variation by time of year. Tree height, health, maximum depth to groundwater, minimum depth to groundwater (measured monthly, max and minimum values used for analysis), and potential infiltration rate based on field texture assessment were compared against species, location (campground or primitive campground), treatment, and year using analysis of variation tests at p=0.1 confidence level. Median values for tree health were tested by species and site against location, treatment, and groundwater maxima and minima using simple statistics (ANOVA) to test apparent differences between these groups.

RESULTS

Hypothesis 1: Testing for Residual Herbicide Within Soils at Devils Tower NM

With one exception, we did not detect residual herbicide in DT soils. The initial null hypothesis that residual herbicide was a limiting factor regarding cottonwood recruitment was rejected. Laboratory results indicated that only one sample had trace amounts of residual herbicide. We concluded that this value (Dicamba=0.112 mg/kg, 2,4-D=9.08 mg/kg) was probably from more recent spot spraying activities conducted by the park service, and the amounts within the sample would not limit seed germination.

Hypothesis 2: Differences Between Regulated and Unregulated Rivers

The second null hypothesis, stating that there was no difference among sites located downstream from a dam (Devils Tower floodplain) and those with natural flow regimes (Powder River floodplain) was also rejected. The Devils Tower riparian reach appeared to differ from the Powder River reach in depth to groundwater, soil texture, and cottonwood age class structure (Tables 3, 4). Devils Tower had a very high percentage of trees in the mature stage, and relatively few in the seedling stage. The Powder River site contained a majority of trees in a pole and seedling stage. The Powder River site also had an absence of decadent trees in the location sampled, verifying that this was a younger stand.

Table 3: Age class structure for cottonwood trees at two sites. The Devils tower analysis was completed at the campground in the spring of 2011. The Powder River site was classified using three 200m x 2m transects.

	Site	
Age Class	Devils Tower[1]	Powder River[1]
Seedling	0.3	33.7
Pole	1.4	91.1
Mature	11.2	16.9
Decadent	1.3	0

[1] Measures in trees per acre

Soils differed primarily in terms of texture (Schoeneberger et al., 1998) and depth to the observed water table. The depth to groundwater in the Devils Tower riparian corridor fell very sharply as we moved further away from the river at the same distance from the active channel as at the Powder River (Table 4). The soil texture at Devils Tower was generally finer with clay present further from the river. This indicated that recent flood events at Devils Tower NM were low in energy.

Soil samples gathered from the Powder River indicated that stream channel migration has been occurring on a regular basis because of a lack of observed soil development across the full 50m transect. Sands and large cobbles indicated that flood events tend to be higher in energy and active scouring and deposition events had occurred in recent years. The groundwater at this site was also closer to the surface than at Devils Tower, even at the 50m extent of the transects (Table 4). There seemed to be a more direct interaction with groundwater between the Powder River and its floodplain at this site, although without river stage height and groundwater elevation for multiple periods we don’t have supporting evidence.

Table 4: Depth to groundwater measures and relative soil textures for two sites. These values and observations were averaged over three transects located on each reach.

	Depth to Groundwater[1]		Soil Texture[2]	
	Devils Tower	Powder River	Devils Tower	Powder River
Green line	52.3 (5.9)	27.0 (7.4)	Coarse gravel/clay	Large cobble/sand
1st Break in Slope[3]	>120.0	61.3 (4.7)	Sandy/clay	Sand
2nd Break in Slope[3]	>120.0	61.6 (3.8)	Sandy/clay	Sand

[1]Depth to groundwater in cm (SE)
[2]Soil texture field tested only by hand, using NRCS Field Guide version 2.0
[3]First and second break in slope as identified by slight elevation changes, also referred to as the break between the most recent hydrologic and later topographic floodplains. All of these measures were located within 50m of the active channel.

Hypothesis 3: Tree Planting to Determine Species and Treatment Success at Devils Tower NM

The final hypothesis, stating that there was no difference between tree species success (health, height, or mortality) for a given treatment was partially rejected. The tree planting study indicated that there was no significant difference between tree health and treatment pooled across both sites and species ($p > 0.1$ for all treatments). Tree height varied by species, as a result of individual species morphology. For example, bur oak was shorter than the other species, but differences in height were not significant among boxelder, cottonwood, or green ash.

When health median scores for individual species were compared by site (campground vs. primitive campground) (Appendices J, K), cottonwoods were the only species that varied by site. Cottonwood trees were significantly healthier in the primitive campground ($p = .0003$). Cottonwood health averaged 6.0 in the primitive campground and 3.0 in the campground site.

Some of the variance between tree health and site could have been attributed to differences in groundwater elevation between the campground and the primitive campground. There was significantly higher groundwater in the primitive campground in both 2011 ($p<0.0001$) and 2012 ($p<0.0001$). Throughout 2011, there was a significant difference in maximum depth to groundwater between sites ($p=0.018$). The campground had an average maximum depth to groundwater of 219.9cm (SE=21.5) while the groundwater only subsided to an average of 164.7cm (SE=22.9) at the primitive campground site. In the second year of the study, 2012, well-monitoring data indicated that the groundwater elevation in the primitive campground dropped to a maximum average depth of 145.49cm (SE=28.6) while levels fell to an average of 228.8cm (SE=22.32) at the campground.

The differences between groundwater depths grouped by site were correlated to species health. There was a large standard error when tree health medians were compared, individually by species, between the two sites. Health values did not take into account individual trees that had died during the study. To reduce confusion in our data when comparing tree health, we calculated the percentage of tree mortality for each species and compared sites (Table 5). In 2011, we saw a very small percentage of trees die. However, in 2012, we saw a sharp increase in the percentage of boxelder and bur oak that died, especially at the campground site.

Table 5: Tree deaths by species for the two Devils Tower sites, as observed in 2011 and 2012. Deaths were recorded at the end of each field season.

		Year[2]	
Species	Site[1]	2011	2012
Green Ash	Campground	0	8.3
	Primitive Campground	0	0
Boxelder	Campground	4.2	83.3
	Primitive Campground	16.7	27.8
Bur Oak	Campground	0	66.7
	Primitive Campground	0	11.1
Cottonwood	Campground	0	16.7
	Primitive Campground	0	5.6

[1] The campground site was comprised of 4 plots while the primitive campground site contained 3 plots. The total number of trees in each site was not equal.
[2] Values represented as a percentage of total. N(Campground)=24, N(Primitive campground)=18

When species were segregated by treatment and site, mortality did not differ among treatments for cottonwood, green ash, and bur oak. However, tillage with irrigation limited boxelder mortality (p=0.0524) in the campground plots (Table 6). In the primitive campground, we observed a decrease in tree mortality when irrigation was added to spray and no tillage treatments.

Table 6: Tree deaths for all species by treatment within each site at DT for two study years. Each observed death was recorded at the end of each respective field season.

		Year[2]	
Treatment	Site[1]	2011	2012
Till	Campground	6.3	31.3
	Primitive Campground	8.3	8.3
No Till	Campground	0	68.8
	Primitive Campground	0	33.3
Spray	Campground	0	43.8
	Primitive Campground	8.3	25.0
Till + Irrigation	Campground	0	37.5
	Primitive Campground	8.3	8.3
No Till + Irrigation	Campground	0	31.3
	Primitive Campground	0	0
Spray + Irrigation	Campground	0	43.8
	Primitive Campground	0	0

[1] The campground site was comprised of 4 plots while the primitive campground site contained 3 plots. The total number of trees in each site was not equal.
[2] Values represented as a percentage of total. N(Campground)=16, N(Primitive campground)=12

Regardless of species, site, or treatment, the highest tree mortality was observed during the 2012 study year in the campground sites (p=0.000). Each of the tree species was compared with each treatment by site in 2012 to learn if percent mortality could be attributed to treatment (Table 7). In general, we noted a slight decrease in mortality percentage when irrigation was added in the campground site. However, this data was only significant for boxelder (p=0.0524) when species were separated by site and year. Mortality by treatment was not found to have significance in any year (2011 p=0.8963; 2012 p=0.9494) or by species when site was pooled (2011 p=0.7532; 2012 p=0.6364).

Table 7: Mortality for both sites at Devils Tower during the summer of 2012. Mortality was recorded at the end of the field season.

		2012 Mortality by Site	
Species	Treatment	Campground mortality (%)[1]	Primitive Campground mortality (%)[2]
Green Ash	No Till	1 (25)	0 (0)
	Till	0 (0)	0 (0)
	Spray	0 (0)	0 (0)
	No Till + Irrigation	0 (0)	0 (0)
	Till + Irrigation	0 (0)	0 (0)
	Spray + Irrigation	1 (25)	0 (0)
Boxelder	No Till	3 (75)	1 (33.3)
	Till	0 (0)	0 (0)
	Spray	1 (25)	0 (0)
	No Till + Irrigation	1 (25)	0 (0)
	Till + Irrigation	0 (0)	0 (0)
	Spray + Irrigation	0 (0)	0 (0)
Bur Oak	No Till	4(100)	1 (33.3)
	Till	2 (50)	1 (33.3)
	Spray	4 (100)	2 (66.7)
	No Till + Irrigation	2 (50)	0 (0)
	Till + Irrigation	3 (75)	1 (33.3)
	Spray + Irrigation	3 (75)	0 (0)
Cottonwood	No Till	4 (100)	1 (33.3)
	Till	2 (50)	0 (0)
	Spray	2 (50)	1 (33.3)
	No Till + Irrigation	2 (50)	0 (0)
	Till + Irrigation	3 (75)	0 (0)
	Spray + Irrigation	3 (75)	0 (0)

[1] N=4
[2] N=3

DISCUSSION

Hypothesis 1: Residual Herbicide Within Floodplain Soils Limit Cottonwood Regeneration

Initial communications and Park Service records indicated that heavy herbicide application occurred at Devils Tower in the late 1950's with an extensive leafy spurge outbreak. Much of the invasive plant management focused on the riparian areas of the park, where new weeds were able to flourish in the wet soil (Figure 8).

Soil analysis from several areas within the riparian corridor indicated that very little residual herbicide is present within the soil. We expect that what little herbicide was found is residual from much more recent applications by the Park Service. The porous, well-drained soils located in much of Devils Tower riparian area probably have aided in the flushing of these herbicides within a relatively short time period. Our data suggest that past herbicide use is not a current cause for current declines of woody species recruitment within the park's riparian corridor.

Though we postulate that herbicide is not a current issue of concern for the Park Service, aggressive weed control measures could have been an accelerant for the degraded condition of the riparian gallery forest that we observed during this study. Leafy spurge was heavily sprayed with Tordon and 2,4-D using a broadcast method similar to Figure 4. This method of weed control was probably conducted along much of the riparian area in the park, though we have no record of where this spraying actually took place. We did note several photographs of spraying efforts in close proximity to our current day campground plots. Chemicals used for leafy spurge would have most likely

Figure 8: A National Park Service employee spraying the Devils Tower riparian corridor. Photo circa 1956, courtesy of the Devils Tower National Monument, Department of Natural Resource Management. Note the young, woody species intermixed with leafy spurge in the area where herbicide is being applied.

killed much of the other broadleaf plants it came in contact with, including young cottonwoods, willows, and green ash.

Records from the National Park Service suggest most of this control took place in the 1950's, the last years that the Belle Fourche River was able to flow naturally. The Keyhole Reservoir was constructed in 1952 (Linenberger, 1996). Assuming that the Belle Fourche riparian gallery forest at that point had positive recruitment of young cottonwoods, many of the young trees would have been killed by herbicide application. Mass young tree mortality coupled with new flow regimes could have expedited the decline of cottonwood regeneration in a few years following the construction of the Keyhole Reservoir dam.

Hypothesis 2: The Dam Located Upstream of Devils Tower Has No Effect on the Riparian Corridor at Devils Tower. No Difference in Forest Structure Exists Between the Belle Fourche River Riparian Area and the Powder River Riparian Area.

Primary visual observations at the Powder River study location indicated that this riparian area was functioning in a very different manner than that of the Belle Fourche River. The most notable feature of the Powder River was the structure of the riparian area, both in landform and vegetation.

Small cottonwood trees were located near the stream in freshly deposited material (Figure 9). These new seedlings formed a continuum as we moved further from the river. The forest structure followed the floodplain geography and created gradients from seedlings, to pole-sized trees, and into the mature forest (Figure 10). This point was quantified when an age classification was conducted at this site. The Powder River had a mixed age class structure with a large population of sampled trees only a few years old. The Belle Fourche River age class structure was far less mixed and contained mostly mature trees. These numbers indicated that the Powder River has a cottonwood gallery forest that is diverse in age class so that new generations of trees exist to replace mature individuals until site conditions change. The only place along the Belle Fourche riparian corridor where young cottonwood seedlings were located was far from the campground in an old oxbow wetland that flooded the spring of 2011. This localized population of young cottonwoods was important because it proved that Devils Tower cottonwoods have a seed bank that is viable and able to germinate if conditions are appropriate.

Figure 9: Cottonwood seedlings observed on a fresh sediment deposit along the Powder River, Wyoming, 2012.

Figure 10: An example of cottonwood age class structure at the Powder River, Wyoming, 2012. Note the mature stand of cottonwood trees in the left and the younger, pole sized cottonwoods on the right, near the river.

Another observation that can be used to explain the variation between the two rivers is stream channel morphologic features. The Powder River has many sandbars and often an undefined stream channel. Though these measures were strictly qualitative and not quantified, it was a stark contrast to the structure of the Belle Fourche River. The reach located at Devils Tower has a very well defined, constrained stream channel and very few sediment bars. This observation suggested that the Powder River is an actively migrating river with alternating erosion and deposition patterns. The Belle Fourche is, by contrast, a very confined river flowing along a similar path. The absence of sediment bars also suggested that the Belle Fourche is transporting sediment away from the Devils Tower riparian area leaving little sediment for cottonwood establishment.

Soil pits excavated at both reaches indicated that hydrological influences also varied between the Powder River and the Belle Fourche River. Groundwater was observed close to the soil surface at the Powder River (at a maxima of 62cm), even at soil pits furthest from the green line. Groundwater at Devils Tower was difficult to find when pits were greater than 5m from the green line (depths greater than 120cm). Soil structure and particle size also were different between the sites. At the Powder River, soil was classified as having a coarse, sandy texture. Texture at the Devils Tower riparian area was classified as being a sandy-clay loam, with finer texture.

Basic soil texture information, coupled with stream channel morphology and vegetative distribution can offer clues into the functional nature of both of these reaches. Though they are similar in elevation, discharge, mean annual precipitation, and mean annual temperature, distinct differences occur in both sites which produce different riparian gallery forests.

Our observations conclude that the Powder River, an unregulated river, has frequent, high-energy flood events. These violent floods continually erode banks and create new habitat sites for cottonwoods that are quickly filled by young trees. The young trees are able to survive primarily off of the shallow groundwater flowing through the coarse bank material. As the young trees grow from year to year, the Powder River continues to erode and migrate, drifting further and further from the now established trees. As the river meanders further from the trees, groundwater falls, allowing the larger trees to survive to maturity. The mature trees produce seeds which fall onto new sediments deposited in other reaches, thus the cycle begins again.

The Belle Fourche River, a regulated river, functions quite differently. Floods that occur are often short-lived and are dependent on water storage releases from the Keyhole Reservoir. These rare floods are fairly low in energy and deposit fine silts sparingly before the discharge rates decline. Furthermore, the Belle Fourche flows at a constant rate and stays confined to its channel (Linenberger, 1996). Sediments are simply swept downstream, resulting in a “clean” channel free of sediment deposits. As the river cuts vertically, depth to groundwater becomes greater away from the green line, in many locations far beyond the reach of new cottonwood seedlings. The cottonwood trees present today at Devils Tower are a function of the Belle Fourche before it was regulated more than 60 years ago. The Devils Tower riparian corridor may have been very similar in structure and function to the Powder River before Keyhole Reservoir was constructed.

Hypothesis 3: Trees Planted with Little Care or Soil Preparation Will Perform Best with High Survival and Growth Rates

The results from the planting trial at Devils Tower suggested that soil preparation had little impact on the health of the four species that we planted. Prior to planting, we hypothesized that killing or disrupting above-ground vegetation would eliminate interspecific competition for water resources, giving young trees an advantage. The trial results indicated that in most cases, tree health and height did not significantly benefit from measures taken to reduce competition with other herbaceous species.

The control treatment for this study implemented a mowing only treatment. The reason that mowing was conducted on these plots was out of necessity for a balanced plot maintenance regime. The National Park Service staff has a vested interest in maintaining and regenerating a gallery forest in the campground for recreation purposes. This area of the park (where one of the plots is located) is actively mown by staff. Therefore it was necessary for all other plots to be mown as well to eliminate confounding variables between mowing and not mowing plots. Some of the tree species studied in this research would not cope well with herbaceous species unless the area was actively mown.

Green ash for example, does not compete well as a seedling when a thick overstory of grasses, sedges, and forbs choke out sunlight and water resources (Gucker, 2005). Once free of the competing herbaceous overstory, green ash grows well under shade of existing trees, while cottonwoods do not germinate or survive as seedlings under the canopy of other mature trees (Taylor, 2001). Based on trial outcomes we recommend that the Park Service mow all sites before planting, and continue mowing regimes until trees have reached a height sufficient to overcome surrounding herbaceous vegetation growth maxima.

The purpose for incorporating an irrigation component into this study was to learn if supplemental watering fostered seedling health and growth sufficiently to overtop the herbaceous layer. By applying water through a perforated irrigation tube, we hoped to saturate soil subsurface and stimulate root development while minimizing the amount of water that was needed to sustain tree health. Deep water irrigation was also meant to simulate the elevated groundwater that occurs after flood events. On average, 300 to 750 gallons of water were required twice per week to saturate all of the irrigation tubes. With this minimal investment of water, considering the 84 total irrigated trees, this method was deemed possible for small scale restoration (less than 100 plantings).

However, the irrigation treatments did not significantly alter tree health or height as a whole. We could find no evidence suggesting that the irrigation method we used was beneficial to the growth of any trees studied, though we can conclude that when tree mortality was separated from overall health measures, some species did benefit from additional water. A slight decrease in tree mortality was observed in 2012 when irrigation was implemented in the campground plots, probably a combination of deep groundwater and dry conditions that year.

We postulate that the extremely dry summer in 2012 caused an increase in tree mortality (Table 1). The summer of 2012 had an abnormally dry period in May, June, July, and again in September. This was compounded by very infrequent rain events through the summer. From June, 2012, to the end of September, 2012, only eight rain events were recorded, many of which were less than one-tenth of an inch. This dry, hot summer was reflected in death loss of many of the trees that were studied. Most of the tree mortality was observed in July and August of 2012. It is worth noting that had this study begun in 2012, we would expect much higher tree mortality rates when the plantings would not have been acclimated to their site nor had more substantial root systems. We did however note an interaction between species when mortality was calculated following the dry year of 2012. Conversely, the summer of 2011 provided excellent growing conditions for the newly planted seedlings with several rain events each month to stimulate healthy tree growth.

At the conclusion of the planting it was clear that green ash and boxelder retained healthier average scores throughout the two-year period. Bur oak seedlings did not survive the dry summer of 2012 with sufficient numbers to suggest planting this species in either site. We also concluded that cottonwood seedlings were healthier when planted in the shallower groundwater at the primitive campground site, but struggled their second year in the campground where groundwater levels were much deeper. Boxelder had high average health scores, but suffered high mortality rates as conditions in the field got drier. Boxelder also responded slightly to irrigated treatments, suggesting that this species was more dependent on supplemental water than the other species. Overall, green ash health was highest in all sites and all treatments when compared against other species.

The primary reason we based our conclusions on tree health scores alone was due to extreme variability in height measurements and differing physiology among species. Bur oak were shorter at planting than the other seedlings and they also grew much more slowly over the two years. Also, several of the trees suffered above-ground vegetative losses during the winter, but regrew from the roots the following spring. This phenomenon produced healthy trees during the 2012 field season, but produced "negative growth" when statistical analysis was used to compare height from one year to another. When field health measures were preformed, the same researcher was used for both years, producing uniform scoring for the duration of the study. Health measures were therefore a more reliable measure of seedling survival and growth.

When comparing tree health for several species, we noticed a significant difference between individuals growing at the campground and primitive campground study sites. The analysis of groundwater monitoring data indicated that the campground site tended to have deeper groundwater elevation, often with depths exceeding 2m. The primitive site had consistently higher groundwater levels, even during the dry summer of 2012. This difference of groundwater by site was reflective on observed tree health and mortality. Simply put, trees of all species had higher health scores overall when groundwater tables were closer to the soil surface. Boxelder, bur oak, and cottonwood species were better able to survive drought conditions when groundwater was closer to the surface as was the situation at the primitive campground. This point could prove invaluable to managers as they decide where to restore gallery forests in the Devils Tower riparian corridor.

CONCLUSION

The decline of the riparian gallery forest in Devils Tower NM is not a causation of mismanagement by National Park Service staff. Rather this decline in the plant community's natural regeneration results from altered conditions created by river regulation. The current floodplain woody vegetation at Devils Tower is functioning in response to its management. The processes important to riparian ecosystem function at Devils Tower have been constrained and almost eliminated. Areas that were flourishing riparian areas 60 or more years ago now resemble upland ecosystem types. Without significant changes to current Belle Fourche discharge rates and flood timing, the remaining riparian area will continue to decrease in size.

MANAGEMENT RECOMMENDATIONS

It is unlikely that managers could expect frequent, severe floods with high hydraulic energy from the Keyhole Reservoir. Therefore our management suggestions are simple and brief. Based on this study, we conclude that further exploits to restore a healthy, reproductively successful cottonwood gallery forest will largely fail. Instead, the National Park Service should focus its efforts on planting tree species more conducive to upland or transitional riparian ecosystems. This work, along with previous literature, suggests that planting cottonwood trees along riverine systems with streamflow regulations should not be a management objective. Results from this study suggest that green ash would have highest survival rates and require the least maintenance to maintain viable stands.

Previous research indicates that green ash survives under a mature canopy of cottonwoods, as long as surrounding herbaceous vegetation does not exceed the height of new trees. Therefore, we recommend planting green ash within the campground, under existing cottonwoods. Sites should be cleared and continually mown as the trees grow. We are unable to prove that the watering technique as described in this study was beneficial, but additional water during the first few months after planting, and especially during dry summer conditions, may help survival rates. Planting green ash or cottonwoods in the primitive campground site is more advantageous to tree health and survival than planting at the campground. This study found that groundwater in the primitive campground is probably sufficient for cottonwood survival and establishment and that no additional water resources are required at this location if planting is completed in the spring months when water tables are closer to the surface. The only artificial intervention required at this site is clearing of surrounding herbaceous vegetation.

Green ash produce taller canopies than boxelder, and the wood is harder than cottonwood making this species better suited to severe storms that often occur at Devils Tower NM. Green ash are also fire tolerant once established. Herbaceous material could be cleared by initially control burning in the riparian area with limited damage to established green ash trees.

Though we did see some positive health trends with boxelder and cottonwood, we would not recommend planting either species. The Belle Fourche does not have a flood regime conducive to cottonwood regeneration (lack of sediment deposition and fluctuating groundwater). Attempts to restore a cottonwood gallery forest would be expensive, time consuming, and constant. This species would have to be continually planted and natural recruitment is very unlikely with current riparian conditions. Though boxelder grew well in some locations, our results concluded that this species was heavily dependent on irrigation during dry summer months. Therefore, boxelder would be more expensive to maintain. The growth characteristics of boxelder would not produce a tree structure beneficial for campers in the Devils Tower Campground. This tree species has a low canopy and a very shrub-like structure that would not provide adequate shade or protection for recreational use.

Soil tests indicated that no further soil remediation needs to be completed to rid the soil of residual herbicide before planting trees. Future efforts on weed control should apply similar techniques to current weed management efforts to limit harmful herbicide residuals.

A low cost, successful management direction should focus on planting green ash in desired areas. Continued maintenance efforts should focus on reducing herbaceous competition within newly planted sites. Given time, a well-established green ash stand could replace aging cottonwoods within the park while conserving the recreational and aesthetic benefits that the cottonwoods once provided visitors.

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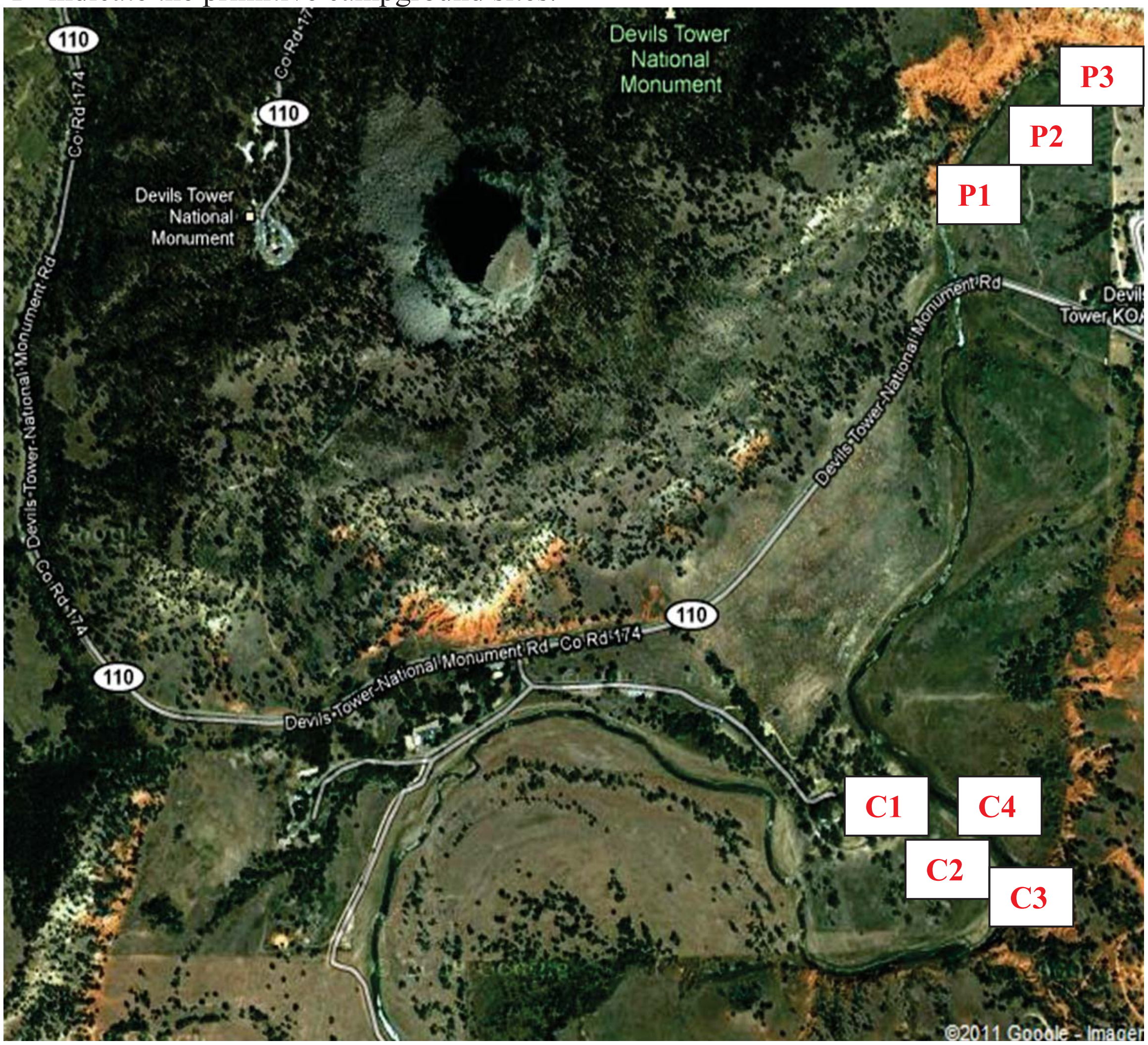
APPENDICES

APPENDIX A

DEVILS TOWER NATIONAL MONUMENT MAP OF PLOTS TESTED FOR THE TREE GROWTH STUDY

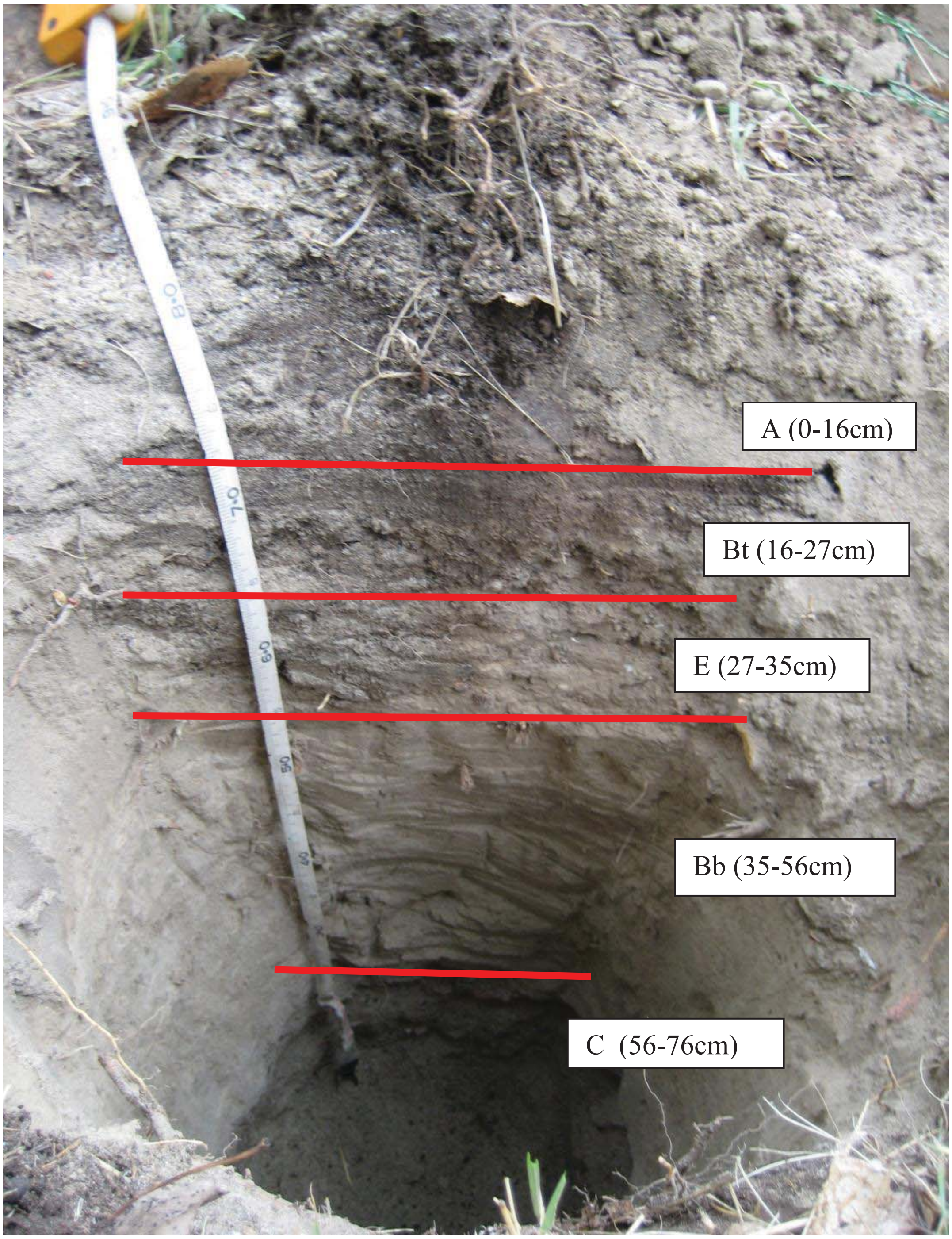
Appendix A. A map of the Devils Tower tree planting plots. Plot abbreviations are used in the map. An abbreviation of 'C' indicates a campground plot while abbreviations of 'P' indicate the primitive campground sites.



APPENDIX B

SOIL PROFILE OF PLOT C1

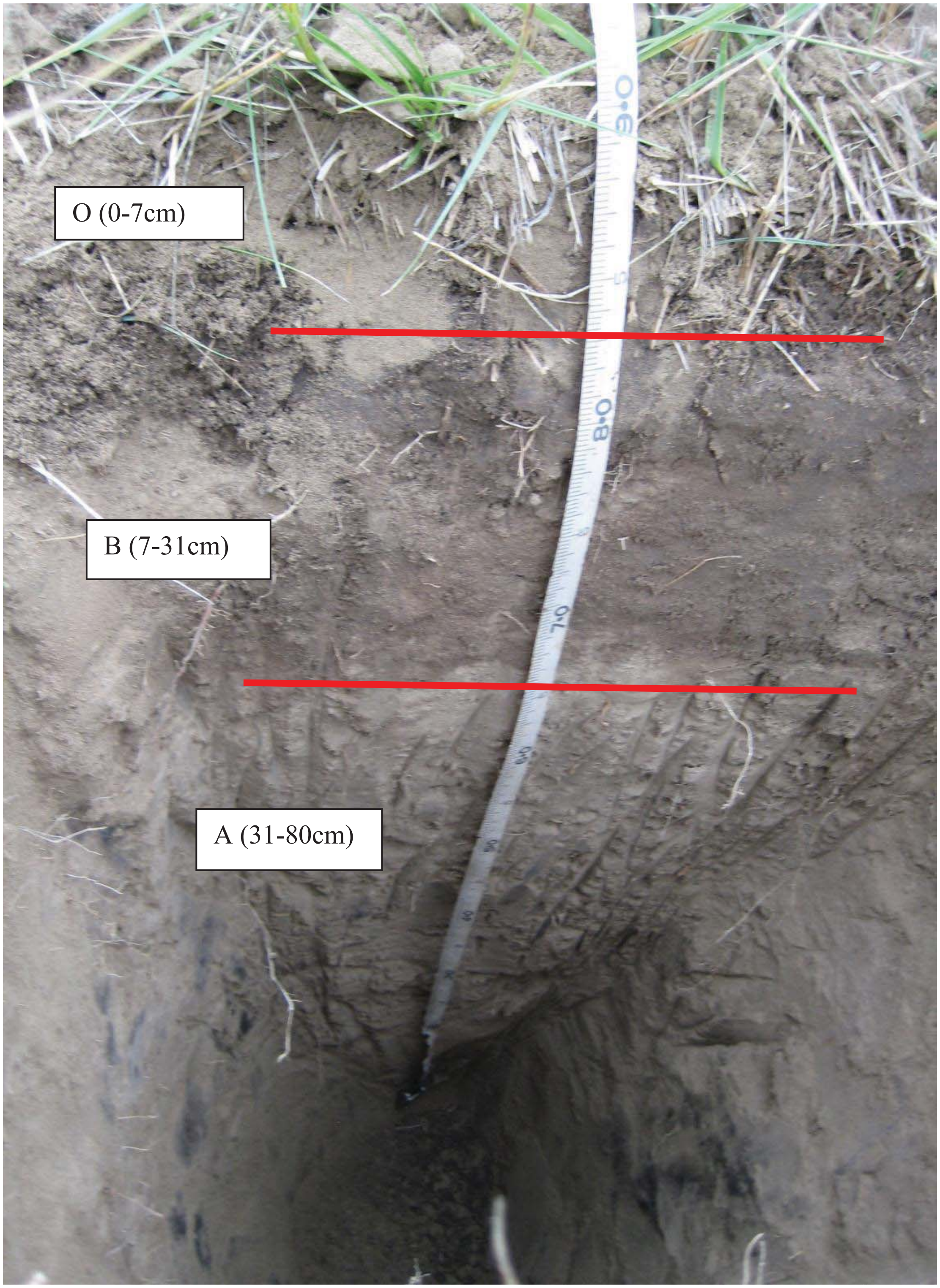
Appendix B. Soil profile of plot C1.



APPENDIX C

SOIL PROFILE OF PLOT C2

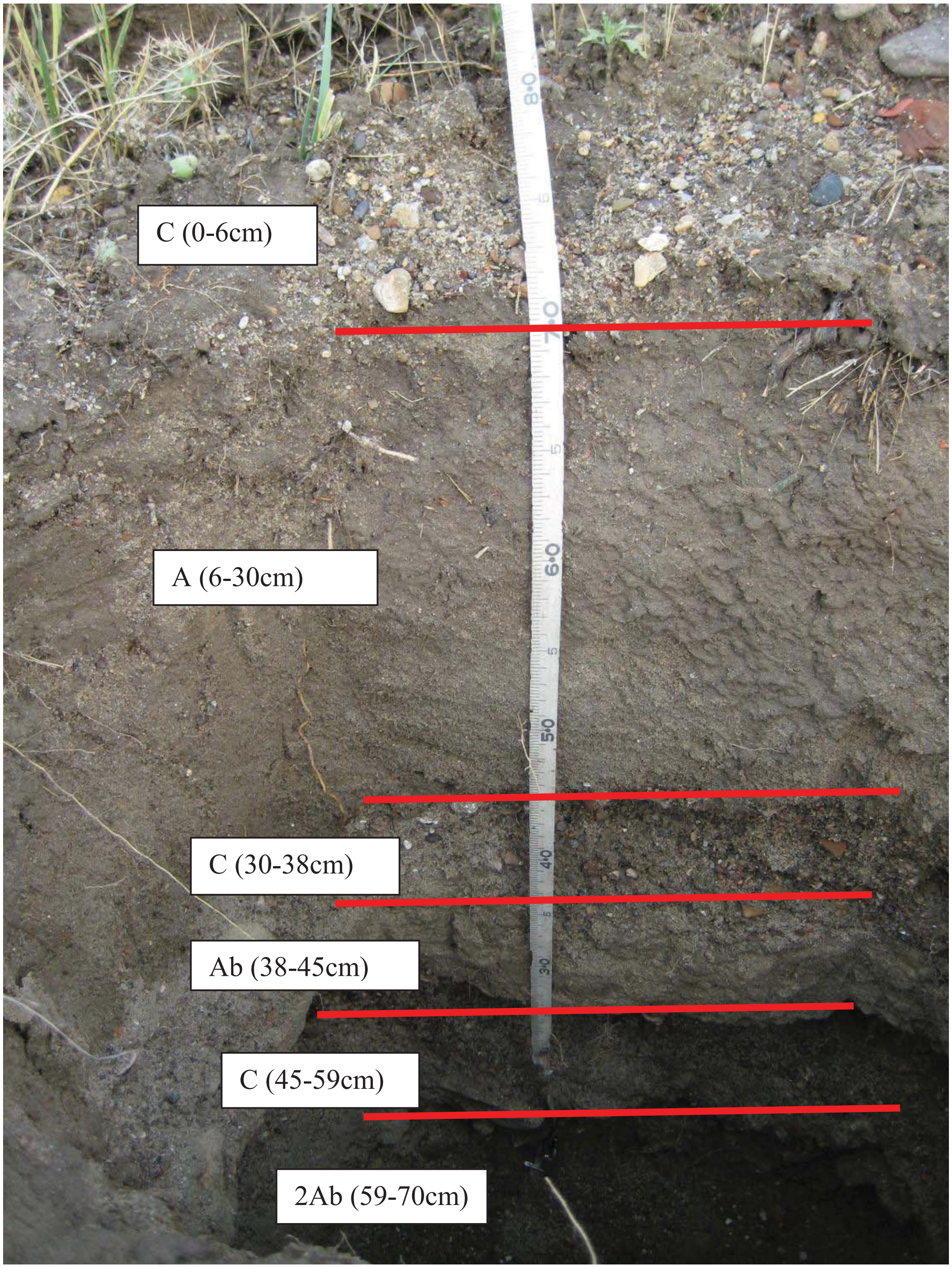
Appendix C. Soil profile of plot C2.



APPENDIX D

SOIL PROFILE OF PLOT C3

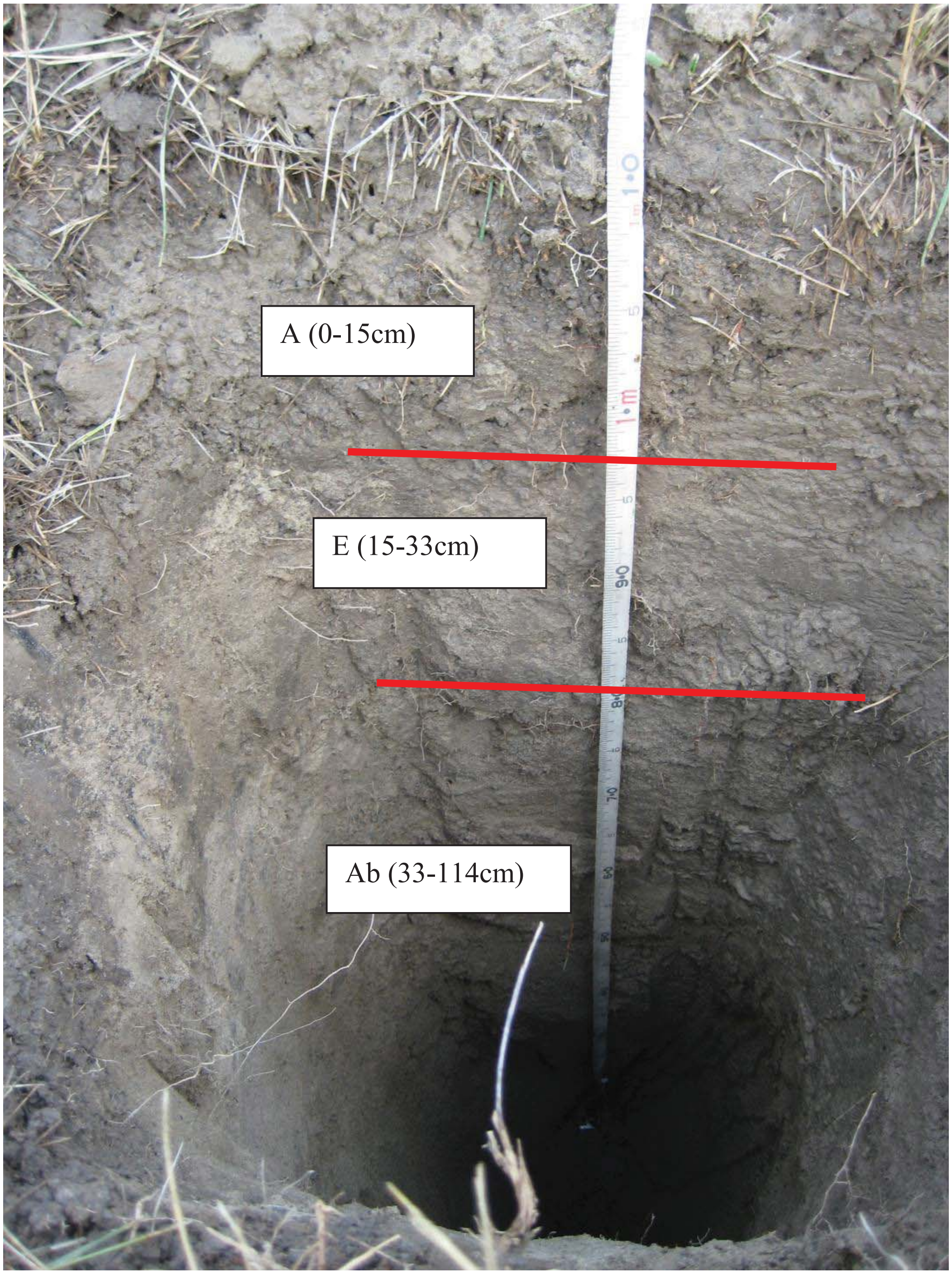
Appendix D. Soil profile of plot C3



APPENDIX E

SOIL PROFILE OF PLOT C4

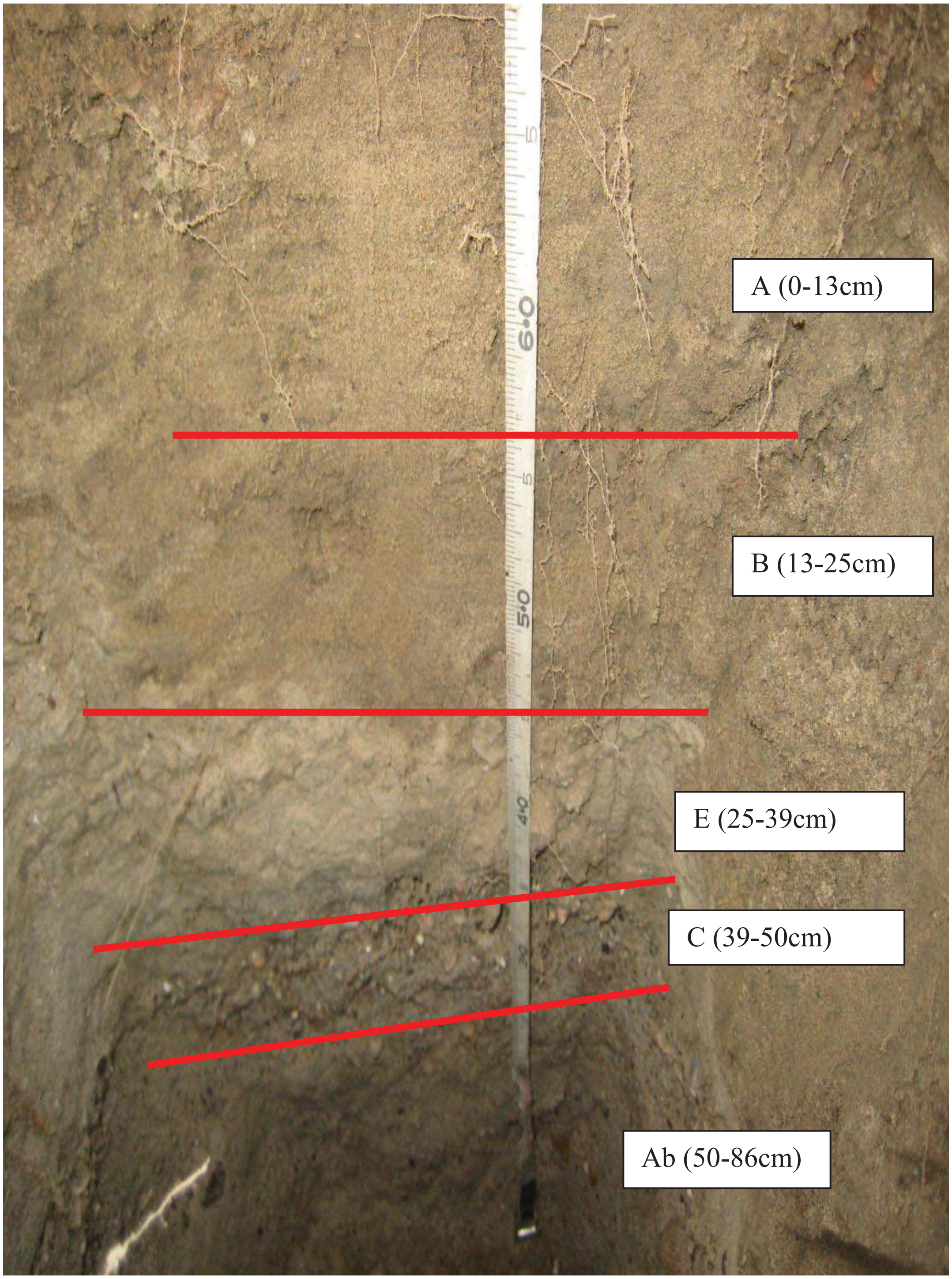
Appendix E. Soil profile of plot C4



APPENDIX F

SOIL PROFILE OF PLOT P1

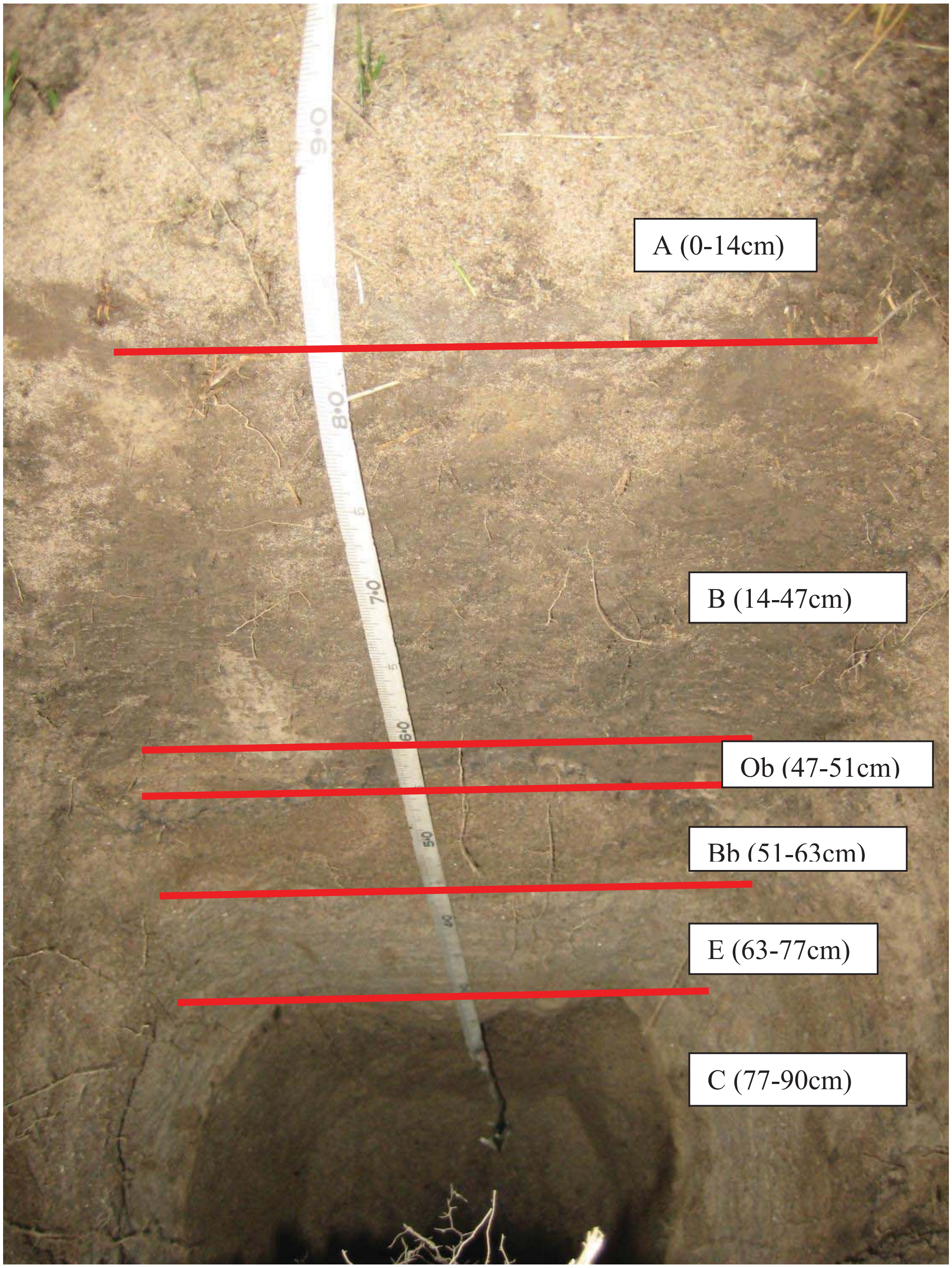
Appendix F. Soil profile of Plot P1



APPENDIX G

SOIL PROFILE OF PLOT P2

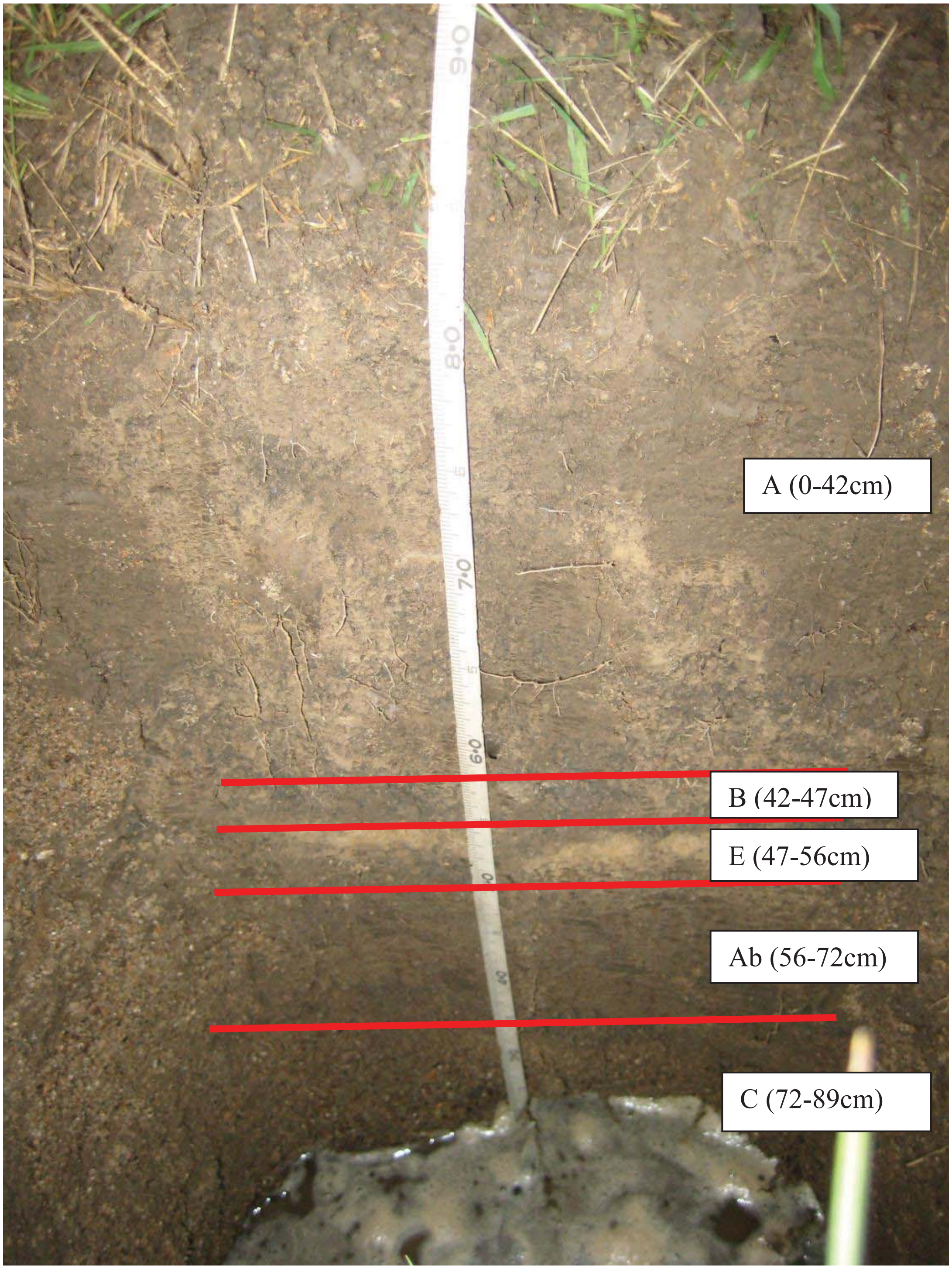
Appendix G. Soil profile of plot P2



APPENDIX H

SOIL PROFILE OF PLOT P3

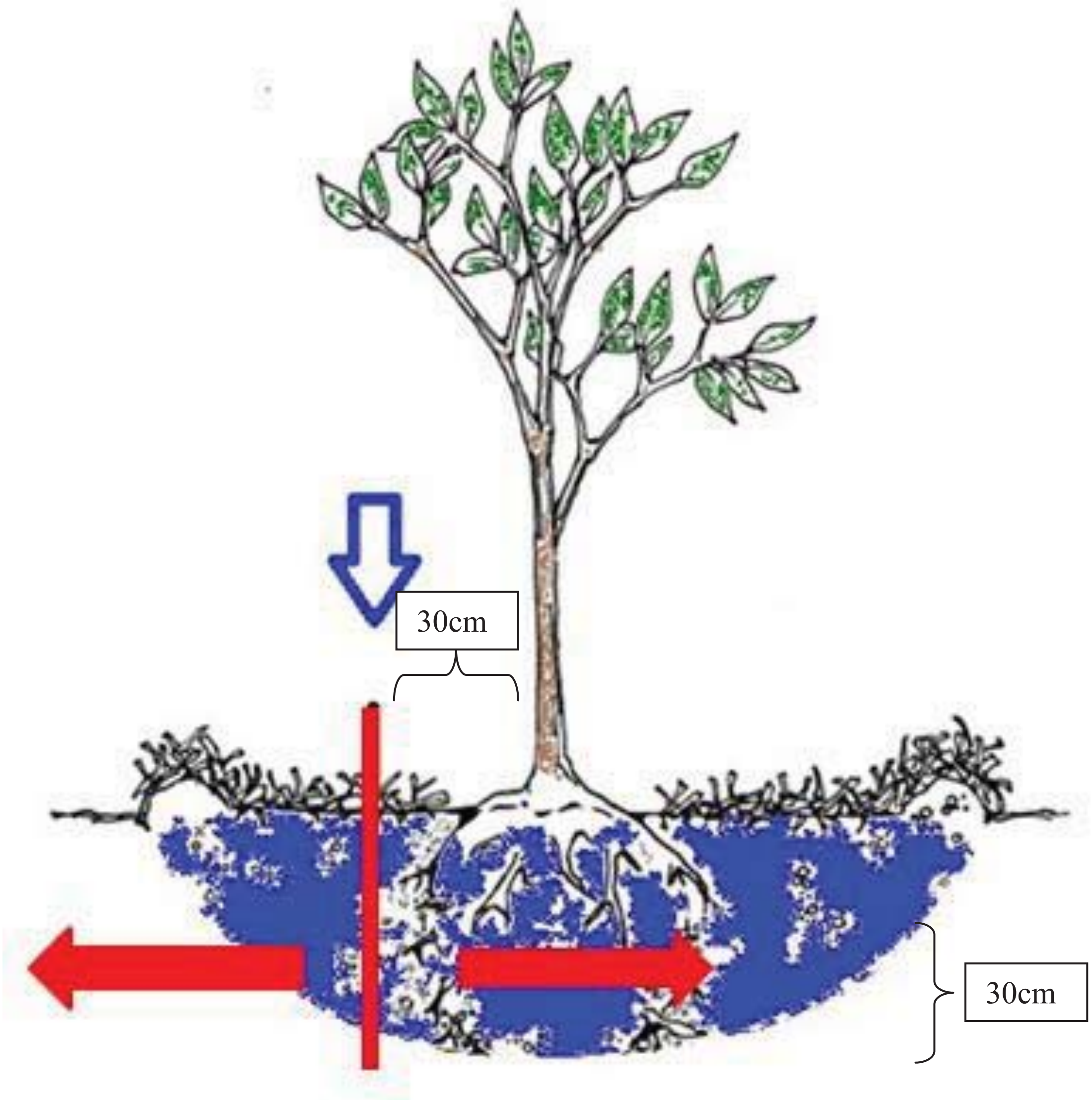
Appendix H. Soil profile of plot P3.



APPENDIX I

IRRIGATION COMPONENT DIAGRAM
FOR THE DEVILS TOWER NM
TREE PLANTING STUDY

Appendix I. Irrigation component diagram for the Devils Tower NM tree planting study. The blue shaded area indicates the theoretical water table, while the red arrows indicate the movement of water through the red irrigation tube. Eight holes were drilled in the bottom 30cm of the tube.



APPENDIX J

DATASHEET FOR CAMPGROUND MEASURES OF HEIGHT AND HEALTH, 2011 AND 2012 AT DEVILS TOWER NM

Appendix J. Datasheet for campground measures of height and health, 2011 and 2012 at Devils Tower NM. Data displayed was collected at the end of both field seasons.

			Height		Health	
Species	Treatment	Plot	2011	2012	2011	2012
Green Ash	No Till	C1	24	22.75	7	7
		C2	25.5	26	7	7
		C3	19.5	20	7	0
		C4	24.25	26.5	7	7
Boxelder	No Till	C1	26.25	12	5	0
		C2	36	36.5	7	7
		C3	36	27	6	0
		C4	27.5	28	4	0
Bur oak	No Till	C1	16	17	5	0
		C2	9.75	8	7	0
		C3	17.75	18	6	7
		C4	15	17	4	0
Cottonwood	No Till	C1	24.7	27.5	7	0
		C2	20.25	7	7	0
		C3	25.5	25	6	0
		C4	24	26	5	0
Green ash	Till	C1	18.5	21.5	7	7
		C2	28	24.5	7	7
		C3	26.5	22	7	5
		C4	27.75	18	7	7
Boxelder	Till	C1	27	52	7	7
		C2	34	37.5	7	7
		C3	22.5	10.25	7	3
		C4	39	24.5	7	7
Bur oak	Till	C1	7.5	7.5	1	0
		C2	18.75	12	7	7
		C3	13	14	7	0
		C4	16	7.5	7	7
Cottonwood	Till	C1	25	52	7	0
		C2	24.75	33.5	7	7
		C3	24.5	27	6	0
		C4	29.75	12	7	0
Green ash	Spray	C1	27.75	48.5	7	7
		C2	30	28.75	7	7

Green ash	Spray	C3	27.5	22.5	7	7
		C4	26.75	26	7	7
Boxelder	Spray	C1	34.5	48.5	7	7
		C2	35.25	39.5	7	7
		C3	41.25	11.5	5	3
		C4	33	22	6	7
Bur oak	Spray	C1	12	7.75	7	7
		C2	13.25	12	7	7
		C3	14.5	16	7	0
		C4	16.75	17	7	0
Cottonwood	Spray	C1	29.25	27	7	0
		C2	18	38	7	7
		C3	24.5	26	7	0
		C4	27	19.75	7	7
Green ash	No Till + Irr	C1	24.5	23	7	7
		C2	31.5	24.5	7	7
		C3	21.75	14.5	7	7
		C4	23	23.5	7	0
Boxelder	No Till + Irr	C1	23.75	20.5	7	7
		C2	35.5	36.5	7	7
		C3	24	8	5	5
		C4	36.25	13.5	4	7
Bur oak	No Till + Irr	C1	11.5	12	7	0
		C2	17.5	15	7	7
		C3	14.75	15	5	0
		C4	14.5	15	4	0
Cottonwood	No Till + Irr	C1	28.25	20.5	7	0
		C2	29.75	31	7	7
		C3	25	25	6	0
		C4	20.75	15	4	0
Green ash	Till + Irr	C1	17	39	7	7
		C2	26	24.5	7	7
		C3	22.25	8	7	7
		C4	23.75	27	7	7
Boxelder	Till + Irr	C1	30.75	38	7	7
		C2	28	33	7	7
		C3	18.5	8	5	0
		C4	41	39	7	7

Bur oak	Till + Irr	C1	17	6.5	7	7
		C2	18.75	19	0	7
		C3	13.5	14	5	0
		C4	9.5	11	7	0
Cottonwood	Till + Irr	C1	13.75	25	7	0
		C2	24.25	14	7	7
		C3	21.5	21	5	0
		C4	25.25	31	7	0
Green ash	Spray + Irr	C1	24.75	27	7	7
		C2	25.25	23	7	7
		C4	21.25	24	7	0
Boxelder	Spray + Irr	C1	34	37.5	7	7
		C2	29	37	7	7
		C3	36.5	25.5	6	3
		C4	36	36	7	7
Bur Oak	Spray + Irr	C1	19.5	10	7	7
		C2	12	11.5	7	7
		C3	14.25	15.5	6	0
		C4	19.75	20	7	0
		C3	18	19	7	0
Cottonwood	Spray + Irr	C1	23.25	25	5	0
		C2	28.75	36.5	7	7
		C3	25.75	26.5	7	0
		C4	21.25	24	5	0

APPENDIX K

DATASHEET FOR PRIMITIVE CAMPGROUND MEASURES OF HEIGHT AND HEALTH, 2011 AND 2012 AT DEVILS TOWER NM

Appendix K. Datasheet for Primitive Campground measures of height and health, 2011 and 2012 at Devils Tower NM. Data displayed was collected at the end of each field season.

			Height		Health	
Species	Treatment	Plot	2011	2012	2011	2012
Green ash	No Till	P1	22	16.5	7	7
		P2	26	27.25	7	7
		P3	26.25	36.5	7	7
Boxelder	No Till	P1	29.25	22	5	0
		P2	26.5	27.5	7	7
Bur oak	No Till	P1	16.25	16.5	4	0
		P2	15.25	15.5	7	7
		P3	13	12.5	7	7
Cottonwood	No Till	P1	26.75	30	7	0
		P2	24	21	7	7
		P3	20	28	7	7
		P3	21	30.5	7	7
Green ash	Till	P1	23.5	32	7	7
		P2	22	32.5	7	7
		P3	30.25	28.5	7	0
		P3	26.75	31	7	7
Boxelder	Till	P1	36	36.5	7	7
		P2	36	37	7	7
Bur oak	Till	P1	13.25	14.5	7	7
		P2	11.5	13	7	6
		P3	12	12	7	0
Cottonwood	Till	P1	23.75	34.5	7	7
		P2	29.75	37.5	7	7
		P3	28	11	7	3
Green ash	Spray	P1	19.25	30.5	7	7
		P2	25	30.5	7	7
		P3	29.25	36.25	7	7
Boxelder	Spray	P1	36.25	26.5	7	7
		P2	40	31	7	7
		P3	33.25	37	7	7
Bur oak	Spray	P1	16	16	7	7
		P2	12	12	0	0
		P3	17.5	27	7	7

Cottonwood	Spray	P1	27.5	23	7	0
		P2	30.5	26	7	7
		P3	28.5	38	7	7
Green ash	No Till + Irr	P1	21	34.5	7	7
		P2	19.5	31.5	7	7
		P3	21.25	29.5	7	7
Boxelder	No Till + Irr	P1	38.5	34.75	7	7
		P2	39	38	6	7
		P3	32.75	36.75	7	7
Bur oak	No Till + Irr	P1	14	14.5	7	7
		P2	17	13.5	7	7
		P3	13.5	15	7	7
Cottonwood	No Till + Irr	P1	28	35	7	7
		P2	22.5	20	7	7
		P3	28.75	29.5	7	7
Green ash	Till + Irr	P1	28	36	7	7
		P2	23	35.5	7	7
		P3	31.5	11.5	7	3
		P3	34.75	29.5	7	3
Boxelder	Till + Irr	P1	36	36.75	7	7
		P2	39.5	38.75	7	7
		P3	29.25	11.5	7	7
Bur oak	Till + Irr	P1	14	18	7	7
		P2	12.5	12	7	7
Cottonwood	Till + Irr	P1	30	37.5	7	7
		P2	29	37	7	7
		P3	28.5	37	7	7
Green ash	Spray + Irr	P1	29	32	7	7
		P2	30.5	31	7	7
		P3	29	37.5	7	7
Boxelder	Spray + Irr	P1	36.5	35.5	7	7
		P2	30	37.25	7	7
		P3	42	38	7	7
Bur oak	Spray + Irr	P1	15	9.5	7	7
		P2	15.25	15.5	7	7
		P3	11.25	16.5	7	7
Cottonwood	Spray + Irr	P1	31.75	37	7	7
		P2	20	29.5	7	7

Cottonwood	Spray + Irr	P3	26	36.5	7	7