AN ABSTRACT OF THE THESIS OF

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Title: Effects of Environmental Variables and Grazing on Planted Willow (*Salix boothii* Dorn) Cuttings

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John C. Buckhouse

The influence of streambank location and timing of herbivory on success of planted Booth's willow (*Salix boothii* Dorn) cuttings along a Rosgen C5-type stream in an eastern Oregon meadow was determined. Willow cuttings were planted on two morphological locations (i.e. point bar and floodplain) in May of 2002 and 2003. Gravimetric soil moisture and depth to water table data were collected periodically on each planting location during the growing season, May through September, in both years. Three grazing treatments, early season, late season, and none (control) were conducted. Percent survival, leader density, and number of browsed leaders of willows were recorded prior to and after each grazing treatment, as well as stubble height of forage species. Simple linear regression was used to determine if a relationship between residual stubble height and percent willow browse existed. Multiple linear regression was used in an attempt to develop a predictive equation for percent browse based on pre-grazing stubble and willow heights.

It was hypothesized that depth to water table and percent soil moisture throughout the growing season would significantly influence willow survival and growth; that survival would be higher on point bar locations; and that willows would be browsed at different intensities according to season of grazing.

Soil moisture content at point bar locations was greater than that of floodplain locations for the majority of the growing season in both years. In 2003, groundwater levels were higher on point bar than floodplain locations from May through September. Willow survival was higher for point bar locations than floodplain locations, in both years, regardless of grazing treatment.

Willows were browsed more intensively later in the growing season. Results from the simple linear regression suggest that percent browse of willows was related to the residual stubble height, but did not explain the variability observed. An attempt to develop a predictive equation, i.e., expected browse based on pre-grazing stubble height, was made, however no apparent relationship between the willow height, stubble height, and percent browse was found. Grazing treatment did influence willow survival; survival on floodplain locations within the late grazing treatment was less than that of the ungrazed floodplain locations.

Our results suggest that planting willows in locations where the planting depth remains within 40 cm of the groundwater depth will increase planting success. Protection from grazing for at least the first year of growth is recommended for optimum planting survival; grazing early in the season is more favorable to survival than grazing later in the season.

# Effects of Environmental Variables and Grazing on Planted Willow (*Salix boothii* Dorn) Cuttings

by

Katherine L. Lowson

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Katherine L. Lowson, Author

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# CONTRIBUTION OF AUTHORS

Dr. John C. Buckhouse was involved in the design of the project, analysis of data, and interpretation of results. Dr. Tamzen K. Stringham was involved in the design of the project, analysis of data, and interpretation of results. Dr. Chad Boyd was involved in the design of the project, analysis of data, and interpretation of results.

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To Dad.

Who taught me how to love it all

in the first place.

# EFFECTS OF ENVIRONMENTAL VARIABLES AND GRAZING ON PLANTED WILLOW (*SALIX BOOTHII* DORN) CUTTINGS

## CHAPTER 1

## INTRODUCTION

Across the western United States, destabilized stream channels and new management challenges related to multiple use have illustrated the importance of properly functioning riparian systems (Rosgen 1996, Swanson 1989, Carlson et al. 1991). Maintenance of a healthy riparian system is dependent upon the natural stability of the streambanks and the watershed as a whole.

Healthy riparian systems are structurally dynamic, moving laterally across valley floors in a healthy balance of channel aggradation and degradation (Winward and Padgett 1987). Riparian vegetation plays a key role in the channel stability of highly erodable alluvial systems (Swanson 1989, Rosgen 1996), aiding in the streams ability to maintain dimension, pattern and profile while withstanding its flow and efficiently transporting the sediment produced by its watershed (Rosgen 1996). Riparian vegetation is of particular importance in channels in which streambanks are composed of non-consolidated alluvial materials (Rosgen 1996). Streambank stability in alluvial systems is influenced by the composition of the bank material, which includes not only the sediment but also the vegetation within it (Dunaway et al. 1994). In the Alexandra Valley, Alberta, Smith (1976) found bank sediments with 16% to 18% scrub willow and meadow grass roots by volume with a five centimeter root mat were 20,000 times more resistant to erosion than banks without. Manning et al. (1989) found plant communities dominated by *Carex nebrascensis* Dewey had an average of more than 2 meters of roots per cubic centimeter of soil within the top 10 centimeters of the soil profile.

The type of vegetation found in riparian systems is dependent upon elevation, geology, topography, soils and climate (Bedell et al 1997). Rosgen C3, C4, C5 and C6 channels are stabilized and maintained by riparian vegetation (Rosgen 1996). E3, E4, E5, and E6 channels, which are hydrologically efficient, are typically very stable due to dense rootmats formed by riparian vegetation including grass, grass-like and woody riparian species (Rosgen 1996). Riparian vegetation increases the surface roughness of the channel, reducing the velocity and erosive capabilities of the flow (Swanson 1989). A stable channel will moderate stream flows by buffering the force of peak seasonal and storm flows, and allowing more storage in wet seasons and the subsequent release of water in drier months. Riparian vegetation can also moderate winter temperatures, prevent ice buildup and scour and buffer impact of waves on banks.

Altering the structural complexity of stream channels, particularly reducing the roughness of the channel through the removal of riparian vegetation, increases water velocity and resulting erosive forces. A destabilized channel can respond with horizontal or vertical instability. Horizontal instability is common in stream channels with a consolidated bed layer; the channel erodes outwards and widens, and the width:depth ratio increases (Rosgen 1996). Vertical instability in unconsolidated bed material results in incisement, when the stream cuts down into the channel bed material, decreasing the width:depth ratios. Channel alteration that results in either vertical or horizontal instability simplifies it; structural diversity is reduced as stream length and bank irregularity is altered. If riparian vegetation is removed from the channel and the channel widens, the depth of water within the channel declines, which can lead to an associated drop in the groundwater levels. Lower groundwater levels can make conditions unsuitable for riparian species, which are replaced by less stabilizing upland species. As the channel widens, the loss of streambank materials results in a loss of stream access to the floodplain; without the floodplain to dissipate energy, the energy confined to the channel accelerates the erosion process. This cycle is continued in a positive feedback loop as the site becomes less and less suitable for riparian species with high water requirements, and is replaced with upland species, with less stabilizing root masses.

Dunaway et al. (1994) found removal of vegetation can alter the hydrograph; how water is captured, stored and released. Altering streamflow can impact the biota as well; more 'flashy' streamflow can limit the time available for spawning and other life stages and may make for unsuitable habitat for some fish species. The removal of shade-providing species and channel widening associated with erosion can also influence water temperature by producing a more shallow water column. Temperature alterations, especially in the warmer months, may interfere with many biological and chemical processes dependent upon a narrow temperature range. Increased sedimentation and turbidity can be problematic as chemicals and waterborne pathogens can be adsorbed onto the fine particles (Dunaway et al. 1994).

Woody species provide stability and allow other stabilizing species like sedges and rushes to establish. Willows and sedges have strong root systems that hold streambanks together; their stems and foliage increase channel roughness and slow the velocity of the water (Bedell et al. 1997). The structural type of vegetation required to stabilize streambanks is a function of channel slope, and water velocity and discharge. It has been suggested that woody species are adequate for stabilizing streams with maximum velocities less than 2.4 meters per second; woody and herbaceous species for velocities less than 1.5 meters per second; while herbaceous species alone are sufficient for velocities less than one meter per second (Hoag 1993).

Willow communities can be a critical factor in maintaining streambank stability, especially during periods of high flow, serving to capture sediment and debris and dissipate the energy of overland flows (Kovalchik and Elmore 1991). Willow root biomass corresponds to aboveground growth, and as a result larger species are better able to reinforce streambanks and diffuse the force of high water flows (Winward 1989).

Willows often occur in mixed-species stands that are closely associated with unique soil and water table features (Hudak and Ketcheson 1991, Winward and Padgett 1987), elevation, temperature, and soil aeration (Brunsfeld and Johnson 1985).

Generally shrub and tree species are found in river valleys, dwarf creeping shrubs are found in high elevation or exposed sites, and a broad spectrum of growth forms from shrubs to trees are found in damp areas (Newsholme 1992, Winward 1989).

Willows propagate sexually by seed or asexually by rhizomes or branches and twigs that break off the plant and take root downstream (Newsholme 1992). Seed dispersal is important in distribution of these species, as the small tufted seeds are wind-dispersed over wide areas. Willows are poor competitors as seedlings and thereby favor the dynamic nature of riparian systems for disturbed sites to establish (Winward and Padgett 1987, Winward 1989). Tolerance for nutrient-poor conditions, and rapid germination and growth ensures these species are one of the earliest colonizers of disturbed areas. As willows establish and mature, they are better able to withstand competition from a variety of other species and are often found in complexes containing a number of other species (Winward 1989).

Their often-dense growth habit creates valuable habitat for a variety of wildlife species, including many species of fish and aquatic invertebrates. Dense canopies are important sources of food for birds that feed on insects, and are a source of pollen and nectar for bees (Newsholme 1992). Willows themselves are consumed by many other herbivores, including insects, birds, small mammals and many ungulates.

Willows (*Salix* sp.) are phreatophytes, having high moisture requirements that limit their distribution to riparian areas, lowlands with shallow water tables, or in high elevation areas receiving water inputs from snowmelt (Brunsfeld and Johnson 1985, Busch et al. 1992). Snyder and Williams (2000) found *Salix gooddingii* Ball drew moisture from groundwater sources only, even during rainy periods, from at much as 4 meters deep in the soil profile. Because willows are reliant on groundwater for moisture uptake, they are potentially sensitive to management activities that may impact groundwater levels.

As understanding of the function and importance of riparian vegetation has grown, research examining the use of planted willows in revegetation efforts has been initiated (Conroy and Svejcar 1991, Svejcar et al. 1991, Watson et al.1997). The self sustaining nature of riparian vegetation makes natural streambank stabilizing structures an attractive option for rehabilitation, from an ecosystem, and economic, perspective.

Many factors must be considered prior to revegetation efforts to ensure the best possible outcome. If there are native willows in the area, and there is sufficient time for establishment to stabilize the site, planting willows may be a good option (Hoag 1993). An inventory of current management, streamflow velocity, the shape of the banks and the stratigraphy of the banks should be examined prior to planting efforts (Hoag 1993). Choosing species that are growing in the moisture regime and soil types and conditions of the area to be vegetated will enhance success. Growth form is an important consideration depending on the goal of the revegetation project. Large species can be effective in buffering the force of streamflow, and tall and large canopy species can provide shade for fish habitat and water temperature management. If choosing plants for erosion control, or where debris or ice buildup may occur, choosing a species with flexible stems will be important to survival and persistence. For bank stabilization, cuttings up to one meter in height will provide immediate bank protection (Hoag 1993).

It is important to note not all stream systems require woody vegetation for stream channel stability. Systems with very low slopes and low streamflow velocities, and anaerobic soil conditions are not conducive to woody species survival (Winward 2000). In these systems, herbaceous vegetation is often sufficient to stabilize the channel. When developing a planting design, the entire section of the reach needs to be considered. Planting only parts of the reach may result in erosion behind the plantings, further exacerbating erosion problems. Planting species in appropriate ecological zones along the stream channel will improve chances of success (Carlson et al 1991). Rhizomatous species favor inside curves, i.e. point bars of a stream channel, while shrubby species provide a barrier on outside curves, where the forces of the water are stronger, but the inundation period is generally shorter (Hoag 1993).

Large unrooted stems are suggested for ease of planting and affordability, and it is recommended that the planting depth be within the summer groundwater depth for optimum survival (Hoag 1993, Crowder 1995). In a study examining the use of tree revetments to capture sediments and provide suitable substrate for willow establishment, Burton et al. (1989) found more than 80% of willow cuttings planted into the groundwater survived. Planting in early spring, after spring runoff, is the preferred time of planting, though willows have been planted successfully from spring through fall (Hoag 1993). To ensure establishment, a protected growth period of up to three years is recommended; seedlings should be protected from large browsing animals during that time (Carlson et al. 1991).

Domestic livestock and wildlife can have significant impacts on willow establishment, growth and survival, the impacts being largely related to the season and nature of use. Roath and Krueger (1982) found that shrub use by cattle was low in the first few weeks of the grazing season, but tended to increase as the season progressed. It is critical to consider wildlife impacts on willow communities as land managers are less able to exert control over and thereby mitigate the effects of wildlife. Shrubs are preferentially browsed later in the season when herbaceous vegetation becomes coarse or unavailable (Roath and Krueger 1982, Kauffman et al. 1983). Late season browsing of willows results in a decrease in density and reduced recruitment (Kauffman et. al. 1983, Kovalchik and Elmore 1991).

Singer et al. (1994) found browsed willows exhibited a depressed chemical defense system; tannin levels were reduced, which may improve the palatability of the browse. This study reported percent leader use by elk was greatest on willows suppressed by previous browsing, suggesting that shrubs having received prior browse are preferred and therefore more susceptible to future browsing. Continuous heavy browsing can restrict plant height and lateral spread (Peinetti et al. 2001, Shaw 1991). Peinetti et al. (2001) found browsed *S. monticola* Bebb produced fewer shoots than unbrowsed plants, though the shoot length in the browsed plants was longer and the leaf size and mean leaf:stem ratio was larger. Catkin production was inhibited, both by removal of the axillary buds with potential to form reproductive parts, and as the plant redirected resources to vegetative growth and not reproduction. He also reported that browsed plants produced more shoot biomass per unit of leaf biomass or leaf area. Because browsing stimulates thicker and longer shoots, and a lower shoot position, it is thought that browsing keeps the woody species within reach of wild ungulates, in a positive feedback loop (Peinetti et al. 2001, Danell et al. 1985). Shaw (1991) reported survival of willow seedlings was uncertain until their height exceeded 150 to 170 cm, due to the crown of the plant being within reach of browsing animals; once plants grew above the reach of browsing animals, spreading crowns developed. Rapid vertical growth has been proposed as a defense mechanism that enables willows to escape herbivory (Shaw 1991), therefore protection from browsing wildlife species may promote survival if plants are allowed to grow beyond the reach of browsing animals.

However, willows are very resilient. Peinetti et al. (2001) found that after only three years of protection from elk browsing, willows inside exclosures were almost twice as tall and had canopies more than double the size of adjacent browsed willows. Shaw (1991) reported emergence of new willow seedlings for four years in areas of reduced grazing with a history of season long grazing. This suggests that if the seedbed is sufficient, on-site resources are available and timing of grazing is appropriate, natural regeneration and recovery may readily occur.

Morphological features of a stream channel that must be maintained to ensure stable stream systems include bankfull width and the corresponding width-depth ratios, as well as the channel connection with the floodplain (Rosgen 1996). When woody plant species are removed from C- and E-type channels reliant upon vegetation for stability, width/depth ratios can change, altering channel dimensions and causing instability in the system. Width/depth ratios increase as stream channels widen, and decrease as stream channels deepen. The end result of altered width/depth ratios is decreased bank stability, increased erosion rates, and a loss of productive land. A loss of the canopy can decrease stream shading, and cause negative impacts on fish and wildlife habitat (Rosgen, 1996). Efforts to improve stream channel stability will be more effective if done while the stream still has access to the floodplain; streams where riparian vegetation is still stabilizing the banks are more likely to respond to management changes, due to the resiliency that adequate moisture provides to plants (Swanson 1989).

Understanding the relationship between riparian species and their physical habitat will improve our understanding of willow response to natural and man-induced changes to the physical environment. In addition understanding the physical habitat requirements of willows will improve management ability to plan successful restoration efforts. In the spring of 2002, a case study examining the use of Booth's willow (*Salix boothii*) cuttings in streamside plantings was initiated. The primary objectives of this study were to determine the impact of streambank location (i.e. point bar or floodplain) and three grazing regimes: early, late, and none (control), on willow planting survival.

# CHAPTER 2

# RESPONSE OF PLANTED WILLOWS TO ENVIRONMENTAL VARIABLES

**Katherine L. Lowson, John C. Buckhouse, Tamzen K. Stringham, and Chad S. Boyd**

**Abstract**

Depth to groundwater and percent soil moisture are key factors influencing the survival of willow cuttings in streamside plantings. Booth's willow (*Salix boothii* Dorn) cuttings were planted in the spring of 2002 and 2003 on point bar and floodplain locations of a Rosgen C-type stream in Eastern Oregon. Groundwater and soil moisture measurements were collected on each planting location periodically throughout the growing season. A census examining survival and growth (leader density) was conducted in late June and early August on first-year willows in both years. In 2003, percent survival of planted willow cuttings was collected concurrently with groundwater and soil moisture samples, every ten days. Groundwater levels and percent soil moisture declined at each planting location over the course of the growing season, and willow survival decreased. Willow survival was greatest (> 80%) on point bar locations throughout the growing season for both years. Survival declined dramatically on floodplain locations by early August. It appears that a groundwater threshold for willow survival may exist; willow survival declines rapidly once groundwater approaches a depth of 40 cm below the base of the planted cutting.

**Introduction**

Riparian vegetation plays a key role in the channel stability of highly erodable alluvial systems (Swanson 1989, Rosgen 1996) and is of particular importance in Rosgen C- and E-type channels in which streambanks are composed of non-consolidated, alluvial materials (Rosgen 1996). The type of vegetation found in riparian systems is dependent upon elevation, geology, topography, soils and climate (Bedell et al 1997). The type of vegetation required to stabilize streambanks is a function of channel slope, velocity and discharge. Woody species provide stability and allow other stabilizing species, like sedges, to establish. Willows and sedges have strong root systems to hold streambanks together; their stems and foliage increase channel roughness and slow the velocity of the water (Bedell et al. 1997). It has been suggested that woody and herbaceous plant species are adequate for stabilizing streams with maximum velocities between 1.0 and 2.5 meters per second (Newsholme 1992).

Willows are poor competitors as seedlings and thereby favor the dynamic nature of riparian systems for disturbed sites to establish (Winward and Padgett 1987, Winward 1989). Tolerance for nutrient-poor conditions, and rapid germination and growth ensures these species are one of the earliest colonizers of disturbed areas (Newsholme 1992). As willows establish and mature, they are better able to withstand competition from other riparian vegetation and are often found in complexes containing a number of other plant species (Winward 2000).

Willow communities can be a critical factor in maintaining streambank stability, especially during periods of high flow (Kovalchik and Elmore 1991), and often occur in mixed-species stands that are closely associated with unique soil and water table features (Hudak and Ketcheson 1991, Winward and Padgett 1987).

Willows (*Salix* sp.) are phreatophytes, relying on groundwater for moisture uptake even during rainy periods (Brunsfeld and Johnson 1985, Snyder and Williams 2000). Because willows are reliant on groundwater for moisture uptake, they are potentially sensitive to management activities that may impact groundwater sources.

In the spring of 2002, a case study examining the use of Booth's willow (*Salix boothii*) cuttings in streamside plantings was initiated. The primary objectives of this study were to determine the impact of streambank location (i.e. point bar or floodplain), soil moisture, and depth to water table on willow planting survival and growth.

**Site Description**

The study site was located in south central Grant County, Oregon. Grant County is situated in the Central Blue Mountains of east-central Oregon, and lies between 44° and 45° north latitude and 118° and 120° west longitude. The average summer and winter temperatures are 14 to –5°C, respectively, and the mean annual precipitation is 34 cm, the majority of inputs arriving as snow (OCS 2003). Soils are of the Damon silty clay loam series (Stringham 1996), and are poorly drained and formed in mixed alluvium.

The study site was located in a 64 ha (159 ac) pasture historically used for season long grazing of cattle. Flow regimes of this stream are moderated by irrigation control upstream, and the pasture is influenced by subsurface irrigation inputs of an adjacent pasture. The study reach is a 2.8 km length of a Rosgen C5-type channel (Table 2.1)

**Table 2.1** The study reach was classified as a C5 stream, based on the following criteria (Rogsen 1996).

| Classification Criteria | Value |
|---|---|
| Bankfull width | 7.3 m |
| Mean depth | 0.3 m |
| Bankfull cross-section area | 2.5 $m^2$ |
| Width/depth ratio | 21.4 |
| Maximum depth | 0.6 m |
| Width of flood-prone area | 24.7 m |
| Entrenchment ratio | 3.4 |
| Channel materials (D50) | 0.50mm |
| Water surface slope | 0.04% |
| Channel sinuosity | 1.3 |

C-type streams are low-gradient sinuous streams flowing through narrow to broad alluvial valleys (Rosgen 1996). A healthy C-type channel will have a balance of erosion and deposition of materials, which allows the channel to migrate laterally across the valley floor without significant changes to the channel profile. As the outside bank of a curve erodes, the corresponding point bar extends, effectively building the floodplain (Rosgen 1996). The channel is thus asymmetrical at the curve, with a mild slope at the point bar moving into the deeper part of the stream on the outside bend and a much steeper bank on the outside edge. Point bars are located below bankfull stage, the elevation at which the stream spills onto its floodplain; this channel-maintaining flow occurs on average every 1.5 years (Rosgen 1996). Therefore point bars are directly impacted by in-channel flow every year. The floodplain is less influenced by direct channel flow, and is accessed by the stream on average once every three years.

The vegetation community types along the study reach were sampled using the Greenline Sampling method (Winward 2000, pp. 12-17). Though the dominant vegetation on the greenline was *Carex rostrata* Stokes, a late successional species, and 61% of the vegetation on the greenline was classified as late seral, the absence of woody species lowered the successional status score to 41, a mid-seral rating. The capability rating for this stream, with a slope of 0.21%, and a consolidated sand (D50 = 0.60mm) substrate, is Group I (Winward 2000, pp. 34). This rating indicates that 98% or more of the greenline should be represented by late seral community types, and alerts to the concern that the greenline vegetation may be insufficient for streambank stabilization.

The point bar plant communities were dominated by grass-like species, with 65% of the plant community comprised of a combination of *C. rostrata* Stokes, *Juncus spp., Eleocharis spp.*, and trace amounts of *Carex nebrascensis* Dewey. Grasses accounted for 18% of the plant community, the most abundant species being *Alopecurus pratensis* L., *Beckmania syzachgne* (Steud.) Fern., and *Deschampsia caespitosa* (L.) Beauv., with trace amounts of *Agrostis stolonifera* L., *Phalaris arundinaceae* L., and *Poa arida* Vasey. Forbs accounted for 16% of the plant community and were represented primarily by *Artemisia ludoviciana* Nutt., and *Ranunculus occidentalis* Nutt.

Plant community composition on the floodplain locations was dominated by grass species, particularly *A. pratensis* L., which represented 77% of the entire plant population. Grasses as a whole made up 82% of the plant community composition and in addition to *A. pratensis* L. included *Hordeum brachyantherum* Nevsky, *P. arundinaceae* L., *P. arida* Vasey, and *Poa pratensis* L.

Although there are eight dominant species of willow in Bear Valley (Sanders 1995), this site is almost devoid of willows, with the exception of some old plants in the downstream end of the pasture. Local knowledge and historical photographs suggest this pasture once supported a woody species community in the 1930s (personal communication, J. Southworth 2003).

## Methods and Materials

### Study Design

We used a completely randomized design for this experiment. Twelve 25 by 12-meter exclosures were constructed along inside turns of the stream, encompassing point bars and their associated floodplains characteristic of C-type channel morphology. Areas were fenced to exclude cattle.

### Willow Collection and Planting

Booth's willow cuttings were collected in early April, and placed in cold storage for thirty days (USDA, NRCS 1993). The apical buds of each cutting were removed to direct growth to shoots and roots, and terminal ends of the cuttings were coated in a mixture of equal parts latex paint and water, to seal in moisture and to ensure the cuttings were planted right side up (USDA, SCS 1989). Once removed from cold storage, the cuttings were placed in a shady location outdoors and soaked in water for two days prior to planting in early May (Peterson and Phipps 1976). Forty cuttings were planted on a transect parallel to the stream on the point bar and floodplain within each exclosure, for a total of 80 plants per exclosure. Each willow was planted to a depth of 40 centimeters, at least one-half the average length of the cuttings, and identified with a numbered metal tag. Willow collection and planting was repeated in 2003, following the same method.

Gravimetric Soil Moisture and Depth to water table

Gravimetric soil moisture was measured at each planting location at 15 cm and 30 cm, every ten days from the time willows were planted until September 8, and oven dried to determine moisture (Gardner 1986). Soil moisture samples were not collected from ponded locations. An estimate of moisture conditions at ponded locations was obtained by collecting samples from the appropriate depths and saturating them in the lab. Free water was poured off and the samples processed according to the above procedure. This estimated value obtained was assumed for all ponded sites.

Wells were installed on a transect perpendicular to the stream in the center of each exclosure to monitor the depth to water table at each point bar and floodplain planting location. Wells were constructed with three-inch pvc perforated drainpipe fitted with a cap, and installed to a depth equal to that of the stream channel bottom. Gravel was packed around the well to allow free water movement and prevent the well from filling with sediment. Depth to water table was recorded every ten days from the time willows were planted until September 8. Measurements were obtained by lowering a steel metric measuring tape down the well to the water surface. It was discovered over the course of the first field season that the original well depths were insufficient, and that the water table had dropped below the depth of most of the wells by mid-June. Therefore all wells were deepened to a depth of 150 cm in October of 2002.

Willow Census

A census of the current-year planted willows was conducted prior to the grazing treatments in both years. Information collected included survival (plants were considered alive if any above ground growth was visible) and leader density (number of live shoots per plant).

Statistical Analysis

Two sample t-tests assuming equal variance were used to determine if within-year differences in soil moisture between point bar and floodplain planting locations existed. Paired t-tests assuming equal variance were used to determine if soil moisture conditions on floodplain locations differed across years. Simple linear regression was used to determine the relationship between soil moisture and depth to water table in the second year of the study. This relationship was used to estimate missing water table depth data for 2002.

Average water table depths for all wells on each planting position were calculated for each sample day. Two sample t-tests assuming equal variance were used to determine if within-date differences between 2003 point bar and floodplain groundwater depths existed.

Willow survival and growth data were analyzed by analysis of variance (ANOVA). Data were combined across years into two models; in the first model, survival was the dependent variable, and planting location, time of season and year were independent variables. In the second model, mean leader density (i.e., the mean number of shoots on each plant) was the dependant variable, with planting location, time of season and year as independent variables. When significant model ANOVA values were encountered we used Fisher's Least Significant Difference (LSD) to determine differences in treatment means.

In 2003, mean willow survival of each planting location in each exclosure was recorded on the same day as water table and soil moisture data was collected. Simple linear regression was used to determine the relationship between willow survival and the depth to groundwater below the base of the planted willows, and a paired t-test within date was conducted to determine when, over the course of the growing season, willow survival became different on point bar and floodplain locations. Slope comparison was used to determine if the rate of change in willow survival between and across planting locations was different.

**Results and Discussion**

Soil Moisture

Soil moisture content decreased over the course of the growing season. Two-sample comparisons within years across planting locations indicated soil moisture was different ($p < 0.05$) at both depths for the majority of the growing season for both years (Table 2.2). Raw data are presented in Appendix B. In 2002, soil moisture was different between both locations at both depths from early June through mid-August (Figure 2.1). In 2003, soil moisture was different between both locations at both depths from early May through late July (Figure 2.2).

**Table 2.2** Two-sample t-test results (p) between soil moisture on point bar and floodplain locations at 15 cm and 30cm depths.

| Year and Depth | Date and p value | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 2002 | 5/11 | 6/8 | 6/20 | 6/30 | 7/10 | 7/20 | 7/30 | 8/9 | 8/18 | 8/29 | 9/8 |
| 15 cm | 0.721 | 0.004 | <0.001 | <0.001 | <0.001 | 0.021 | 0.007 | 0.027 | 0.036 | 0.129 | 0.012 |
| 30 cm | <0.001 | <0.001 | 0.013 | 0.001 | <0.001 | 0.001 | 0.001 | 0.036 | 0.004 | 0.032 | 0.109 |
| 2003[1] | 5/10 | 6/10 | 6/21 | 7/2 | 7/10 | 7/20 | 7/31 | 8/9 | 8/19 | 8/27 | |
| 15 cm | 0.005 | 0.011 | 0.006 | 0.012 | <0.001 | 0.031 | 0.009 | 0.223 | 0.464 | 0.180 | |
| 30 cm | 0.001 | <0.001 | 0.003 | 0.029 | <0.001 | <0.001 | 0.001 | 0.226 | 0.057 | 0.078 | |

[1]Three data points from 2003 were eliminated from the analysis due to sampling error.

Though this study was conducted during two below-average rainfall years, the study reach experienced higher precipitation later in the spring during the second year of the study (Table 2.3).

**Table 2.3** Monthly precipitation for 2002 and 2003, recorded at Seneca weather station (OCS 2004).

| | Monthly Precipitation (cm) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Year | January | February | March | April | May | June | July | August |
| 2002 | 3.02 | 0.99 | 2.29 | 2.72 | 0.91 | 1.55 | 0.89 | 0.84 |
| 2003 | 4.14 | 3.12 | 6.35 | 7.14 | 3.76 | 0.18 | 0.99 | 0.71 |

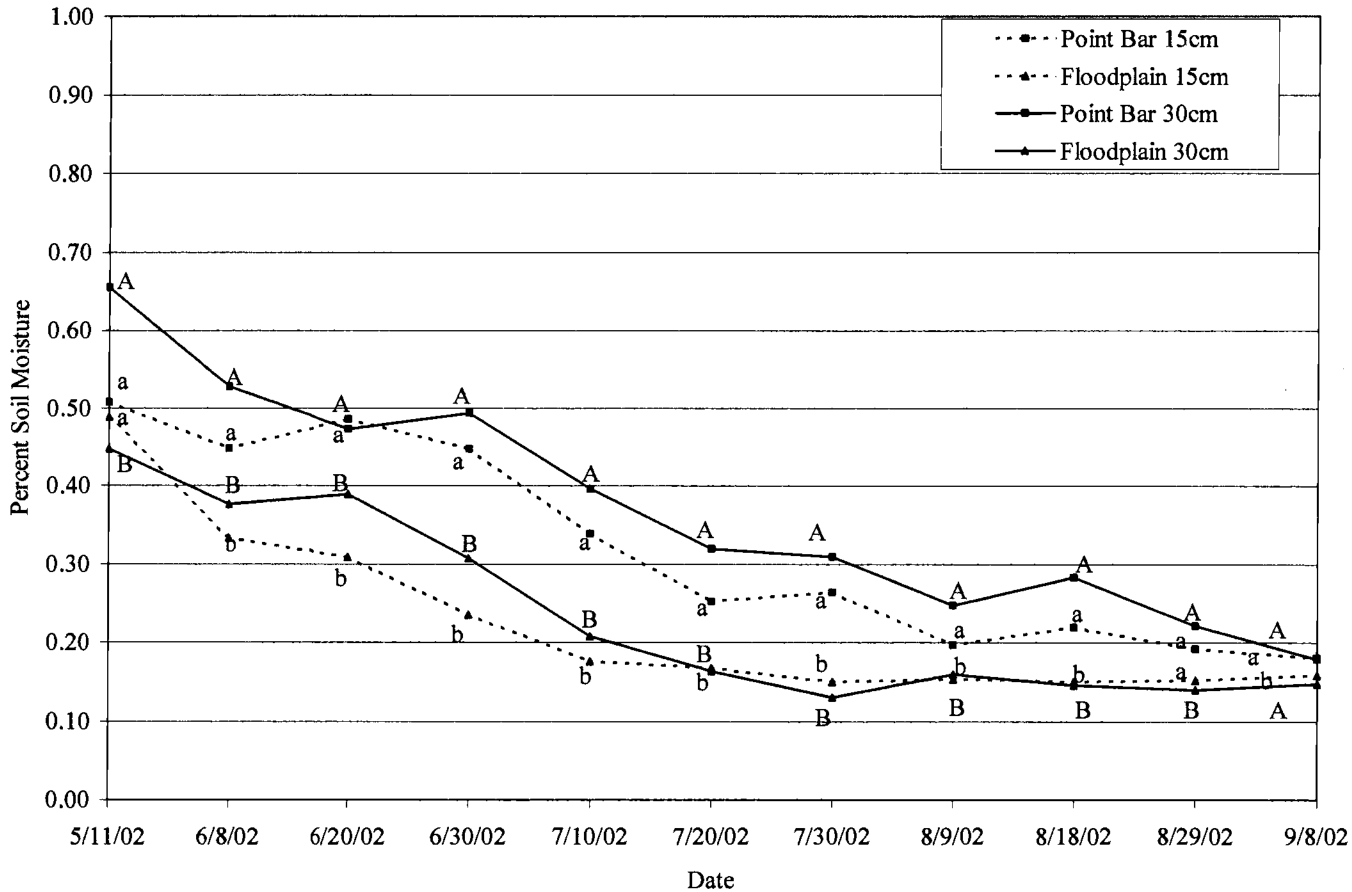


**Figure 2.1** Soil moisture in 2002 decreased at all depths on all locations over the growing season. Soil moisture was different between point bar and floodplain locations at the 15 cm depth from early June through late August; and at the 30 cm depth from early June through mid-August, with the exception of the August 9 sampling date, when no differences were noted. Soil moisture means without a common letter are significantly different ($p < 0.05$); 15 cm depths are denoted with lower-case letters; 30 cm depths are denoted with upper case letters.

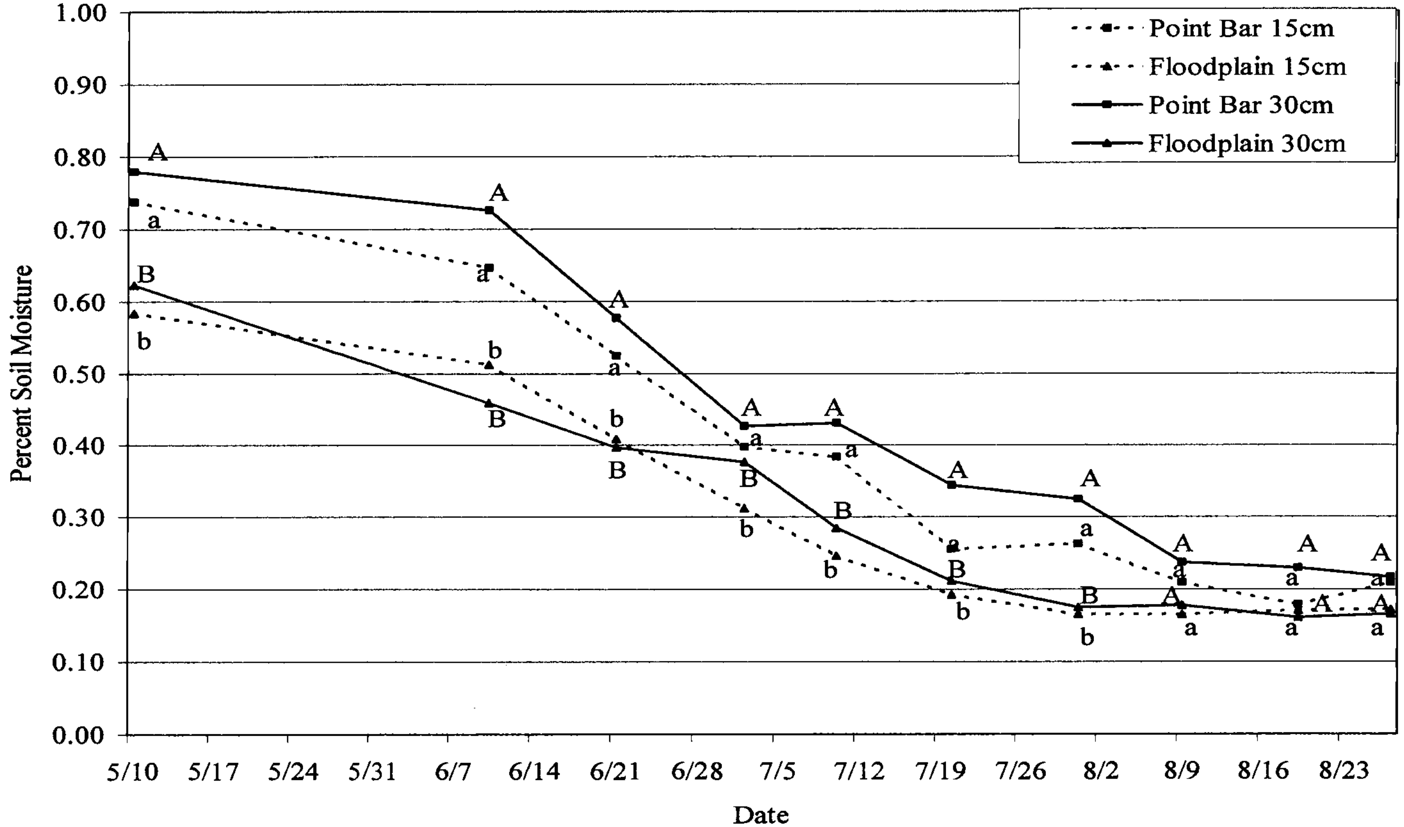


**Figure 2.2** Soil moisture in 2003 decreased at all depths on all locations over the growing season. Soil moisture was different between point bar and floodplain locations at the 15 cm depth from May through late July; and at the 30 cm depth from early May through late August, with the exception of the August 9 sampling date, when no differences were noted. Soil moisture means without a common letter are significantly different ($p < 0.05$); 15 cm depths are denoted with lower-case letters; 30 cm depths are denoted with upper case letters.

The greater amount of precipitation produced higher spring streamflow levels; ponding was observed at several point bar planting sites until early June in 2003, whereas ponding was observed only until early May of 2002. Paired t-tests assuming equal variance determined soil moisture conditions at 30 cm on floodplain locations differed across years from early May to late July ($p < 0.05$), with the exception of the June 20/21 sampling dates.

Groundwater Depth

In 2003, willows on the floodplain were within the water table until early June, while willows on the point bar locations were within the water table until late June (Figure 2.3). Raw data are presented in Appendix B. Groundwater depths were different ($p < 0.001$) between point bar and floodplain locations on every date sampled in 2003.

Though the 2002 groundwater record was incomplete, values estimated from simple linear regression conducted with 2003 soil moisture and groundwater values suggest the 2002 water table depth was below the planting depth (40 cm) of the willows on the floodplain location from the time of planting throughout the entire growing season. On the point bar location, the water table was below the planting depth of the willows by early June.

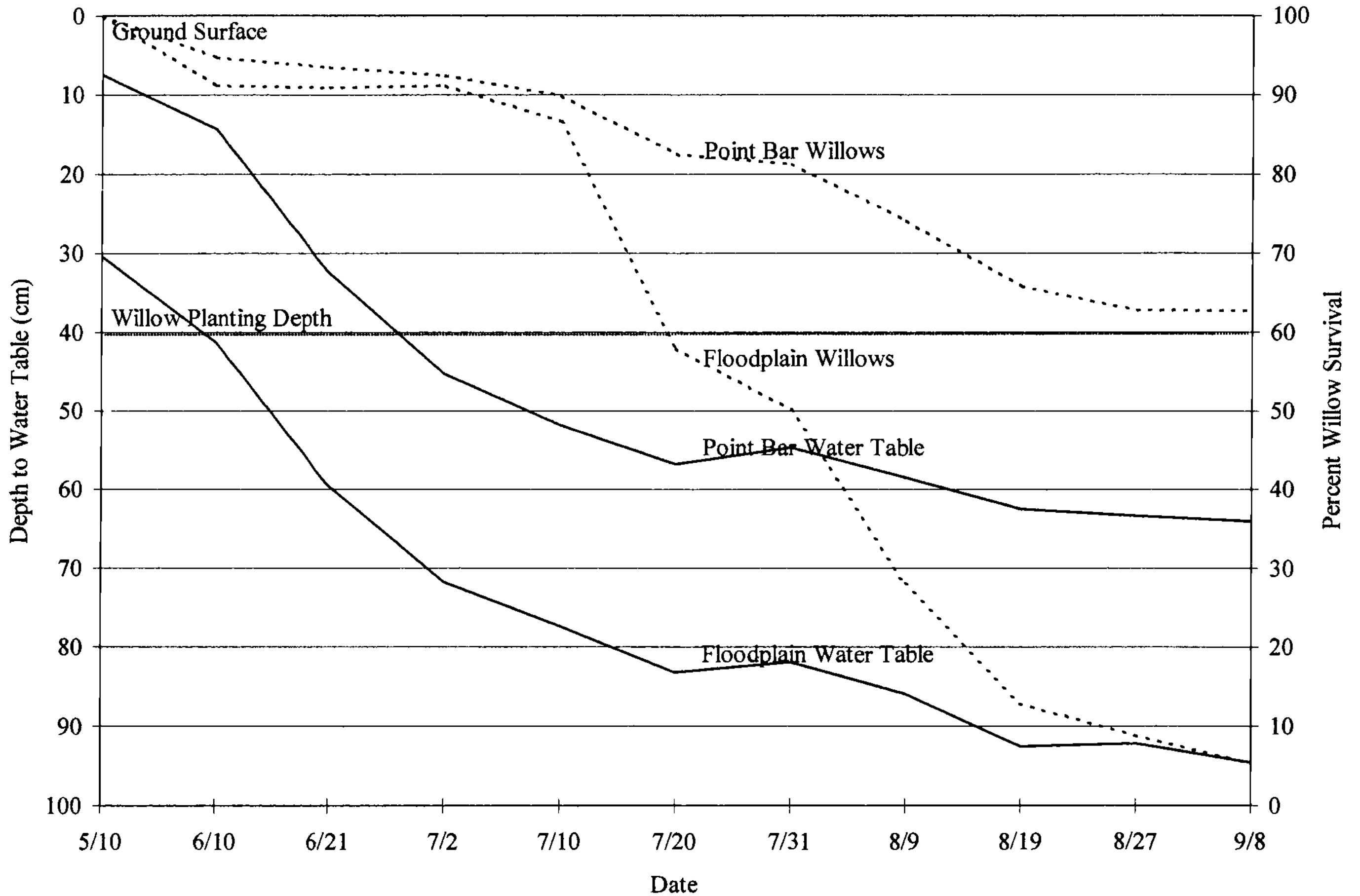


**Figure 2.3** Survival of willows planted in 2003 decreased with receding groundwater depths. It appears there is a threshold for willow survival when the water table reaches 40 cm below the base of the willow plant in the soil; willow survival declines sharply when the water table drops below this level, as shown by the rapid decline in floodplain willow survival.

Willow Survival and Growth

Results from ANOVA (Appendix D) indicate an interaction between year, planting location, and season on survival ($p = 0.07$). Mean survival was not different by location or year in late June (Table 2.4), which suggests that resources for growth (i.e., soil moisture and groundwater) were adequate on both planting locations at that time. Survival on floodplain locations was less than that of point bar locations by early August for both years, as soil moisture and groundwater levels dropped. However, survival was greater on the floodplain in early August of 2003, perhaps because of the higher soil moisture and shallower groundwater depths associated with the late spring moisture of 2003.

**Table 2.4** Means and standard errors (in parenthesis) of percent survival of first year willows by year, location and season, measured in late June (June 20 to 23), and early August (July 28 to August 2).

| Year | Location | Season | |
|---|---|---|---|
| | | Late June | Early August |
| 2002 | Point Bar | 0.93 (0.02)a[1] | 0.84 (0.05)a |
| | Floodplain | 0.83 (0.03)a | 0.14 (0.10)b |
| 2003 | Point Bar | 0.92 (0.01)a | 0.85 (0.06)a |
| | Floodplain | 0.90 (0.04)a | 0.55 (0.10)c |

n = 8
[1]treatment means without a common letter are significantly different ($p < 0.10$)

There were interactions between year and planting location ($p < 0.001$) and planting location and season ($p = 0.06$) for growth. Growth (mean leader density) was less on floodplain locations in 2002 (Table 2.5); reduced growth and vigor of willows on the floodplain may reflect the drier conditions of 2002.

**Table 2.5** Means and standard errors (in parentheses) of leader density of willows across years and planting locations.

| | Planting Location | |
|---|---|---|
| Year | Point Bar | Floodplain |
| 2002 | 7.84 (0.49)a[1] | 5.48 (0.70)b |
| 2003 | 7.13 (0.30)a | 7.56 (0.37)a |

n = 8
[1]treatment means without a common letter are significantly different ($p < 0.10$)

Early season (late June) growth was not different on point bar or floodplain locations, but dropped on both point bar and floodplain locations later in the season (Table 2.6). The overall decrease in leader density may reflect slowed growth as plants began to senesce toward the end of the growing season. However, the greater decline in growth on floodplain locations may reflect reduced vigor due to insufficient water resources.

**Table 2.6** Means and standard errors (in parentheses) of growth (leader density) of willows across planting location and season.

| | Season | |
|---|---|---|
| Location | Late June | Early August |
| Point Bar | 8.23 (0.46)a[1] | 6.73 (0.25)b |
| Floodplain | 8.00 (0.39)a | 5.04 (0.57)c |

N = 8
[1]treatment means without a common letter are significantly different ($p < 0.10$)

Willow survival on both point bar ($p = 0.001$, $R^2 = 0.91$) and floodplain ($p = 0.002$, $R^2 = 0.92$) locations was inversely associated with depth to water table (Figure 2.3). The willow survival lines on Figure 2.3 illustrate a dramatic shift in willow survival rates after July 10. Results from two-sample t-tests indicate mean willow survival between point bar and floodplain planting locations was not different for each sampling date from time of planting to July 10, 2003, but was different between point bar and floodplain planting locations for each sampling date after July 10 through to early September ($p < 0.05$). To further examine the differences in rates of survival on point bar and floodplain planting locations, the slopes of the survival lines before and after July 10 were compared. Slope comparison confirmed rate of survival up to July 10 was not different between point bar and floodplain locations ($p = 0.128$), which suggests moisture resources were sufficient for survival on floodplain locations up to that time. After July 10, survival rates between point bar and floodplain locations were different ($p < 0.001$). Rate of survival on point bar locations was also different before and after July 10 ($p < 0.001$), however, rate of survival on floodplain locations surprisingly showed no difference before and after July 10 ($p = 0.46$). This apparent anomaly may be due to the small sample size and observed variation in the survival data on floodplain locations after July 10.

Groundwater levels remained within 25 cm of planting depth on point bar locations throughout the growing season, whereas groundwater levels on floodplain locations dropped more than 50 cm below the planting depth by early September (Table 2.7). The rate of change in survival on point bar locations did not exceed one percent per day on point bar locations, and ranged from 0.1 to 0.9 percent per day. However, rate of change in survival on floodplain locations peaked at 2.9 percent, when the water table was 43 cm below the planting depth. Rate of change in survival appeared to stabilize for a short period, but increased again when the groundwater level was 46 cm below the planting depth. The rate of change in survival decreased after this point, likely due to the fact that very few live plants remained on floodplain locations.

**Table 2.7** Change in rate of survival and corresponding water table depth relative to willow planting depth between sampling dates for point bar and floodplain planting locations in 2003.

| | Point Bar | | Floodplain | |
|---|---|---|---|---|
| | Groundwater depth relative to planting depth[1] | Survival rate of change[2] | Groundwater depth relative to planting depth[1] | Survival rate of change[2] |
| 06/10 – 06/21 | 8 | 0.1 | -20 | 0.0 |
| 06/21 – 07/02 | -5 | 0.1 | -32 | 0.0 |
| 07/02 – 07/10[3] | -12 | 0.3 | -37 | 0.6 |
| 07/10 – 07/20 | -17 | 0.7 | -43 | 2.9 |
| 07/20 – 07/31 | -15 | 0.1 | -42 | 0.7 |
| 07/31 – 08/09 | -19 | 0.7 | -46 | 2.2 |
| 08/09 – 08/19 | -23 | 0.9 | -53 | 1.7 |
| 08/19 – 08/27 | -23 | 0.3 | -52 | 0.4 |
| 08/27 – 09/08 | -24 | 0.0 | -55 | 0.3 |

[1]Groundwater depth relative to planting depth; positive numbers indicate the groundwater levels were higher than the planting depth, negative numbers indicate groundwater levels were below the planting depth.
[2]Survival rate of change is the difference in percent survival for the number of days between the sampling dates indicated.
[3]The dashed line indicates the period of time after which survival rates changed, as shown in Figure 2.3.

In a similar study examining the survival of Geyer's willow plantings, Conroy and Svejcar (1991) found survival was highest in planting locations within 50 cm (horizontal distance) of the stream edge, while survival was significantly less in upland positions. They concluded establishment was more likely to be successful when the base of the willow cutting was planted within 20 to 30 cm of the water table. The results of this study are similar to Conroy and Svejcar's findings and suggest a threshold may exist; floodplain willow survival declined, and the rate of change in survival increased when the groundwater depth approached 40 cm below the planting depth. It is possible the rate of survival is related to the unique photosynthetic patterns Svejcar et al. (1991) found willows to exhibit. Although leaf growth was initiated in early April, photosynthesis did not peak until July and August, and until that time, carbon uptake would have been minimal, and may have impeded root growth. It is possible that if root growth does not coincide with the diminishing water table, and is insufficient to keep roots within 40 cm of groundwater levels, survival could be compromised. Inadequate root growth may have contributed to the rapid death observed in July on floodplain locations in this study.

**Conclusions**

Depth to groundwater and soil moisture are key factors determining success of willow growth and survival. As the groundwater receded further from the planting depth, and the percent soil moisture decreased over the season, willow plantings began to exhibit signs of moisture stress and death. Where groundwater levels were greater than 40 cm below planting depth, willow plants exhibited an increased death rate and a late August survival of less than 10%.

Planting efforts were more successful when plants were placed in locations where the groundwater stayed within 40 cm of the planting depth. It is possible that planting success could be improved on floodplain locations if cuttings were long enough to allow the plant to remain within 40 cm of the water table. Knowledge of the growing season water table is imperative to best direct planting efforts and maximize survival. Due to the unique nature of the soil moisture and water table characteristics of the point bar and floodplain, these planting locations serve as an indicator of the soil moisture and groundwater conditions.

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# CHAPTER 3

## RESPONSE OF PLANTED WILLOWS TO GRAZING

**Katherine L. Lowson, John C. Buckhouse, Tamzen K. Stringham, and Chad S. Boyd**

**Abstract**

Planting location is the key factor determining the success of planted willow cutting establishment. In May of 2002 and 2003 Booth's willow (*Salix boothii* Dorn) cuttings were planted on point bar and floodplain locations of a Rosgen C-type stream in Eastern Oregon. Plantings were randomly assigned to one of three grazing treatments; early (late June), late (early August), and control (no grazing). A complete population census of the willows was conducted prior to, and after, each grazing treatment. Willows were browsed at a higher intensity in August in both years of the study. Percent browse for the early and late grazing treatments was 34% and 71% in 2002, and 46% and 75% in 2003. Mean willow survival was greater on point bar locations than floodplain locations in both years of the study. Mean willow survival dropped significantly on floodplain locations after the late grazing treatment. This decline may be a function of water-stress and more severe browse damage incurred in the late grazing treatment.

**Introduction**

Willows (*Salix* sp.) are phreatophytes, having high moisture requirements that limit their distribution to riparian areas, lowlands with shallow water tables, or in high elevation areas receiving water inputs from snowmelt (Brunsfeld and Johnson 1985, Smith et al 1992). Because willows are reliant on groundwater for moisture uptake, they are potentially sensitive to management activities that may impact the groundwater sources. Willows often occur in mixed-species stands that are closely associated with unique soil and water table features (Hudak and Ketcheson 1991, Winward and Padgett 1987) elevation, temperature, and soil aeration (Brunsfeld and Johnson 1985).

Willow communities can be critical to maintaining streambank stability, especially during periods of high flow, serving to capture sediment and debris and dissipate the energy of overland flows (Kovalchik and Elmore 1991). Their often-dense growth habit creates valuable habitat for a variety of wildlife, including many species of fish and aquatic invertebrates; dense canopies are important sources of food for birds that feed on insects, and are a source of pollen and nectar for bees (Newsholme 1992).

Domestic livestock and wildlife can have significant impacts on willow establishment, growth and survival, the impacts being largely related to the season and nature of use. Roath and Krueger (1982) found that shrub use by cattle was low in the first few weeks of the grazing season, but tended to increase as the season progressed. Shrubs are more susceptible to browsing later in the season when the herbaceous vegetation becomes coarse or unavailable (Roath and Krueger 1982, Kauffman et al. 1983). When compared to sites excluded from cattle grazing, late season browsing of willows can reduce stem density and height (Kauffman et. al. 1983) and inhibit recruitment (Kovalchik and Elmore 1991). Heavy browsing can restrict vertical development and lateral spread of willow seedlings. However, willows have been observed to be very resilient, when protected from browsing animals. Peinetti et al (2001) found that after only three years of protection from elk browsing, willows inside exclosures were almost twice as tall and had canopies more than double the size of adjacent browsed willows. Shaw (1991) reported new willow seedlings were recorded every year in areas of reduced grazing with a history of season long grazing. This suggests that if the seedbed is sufficient, on-site resources are available and timing of grazing is appropriate, natural regeneration can readily occur.

Improved understanding of the relationship between riparian species and their physical habitat and interactions with browsing animals will increase our ability to anticipate willow responses to changes in management. In the spring of 2002, a case study examining the use of Booth's willow (*S. boothii* Dorn) cuttings in streamside plantings was initiated. Our primary objectives were to determine the impact of streambank location (i.e. point bar or floodplain) and timing of herbivory on willow planting survival.

**Site Description**

The study site was located in south central Grant County, Oregon. Grant County is situated in the Central Blue Mountains of east-central Oregon, and lies between 44° and 45° north latitude and 118° and 120° west longitude. The average summer and winter temperatures are 14 to –5°C, respectively, and the mean annual precipitation is 34 cm, the majority of inputs arriving as snow (OCS 2003). Soils are of the Damon silty clay loam series (Stringham 1996), and are poorly drained and formed in mixed alluvium.

The study site was located in a 64 ha (159 ac) pasture historically used for season long grazing of cattle. Flow regimes of this stream are moderated by irrigation control upstream, and the pasture is influenced by subsurface irrigation inputs of an adjacent pasture. The study reach is a 2.8 km length of a Rosgen C5-type channel (Table 3.1)

**Table 3.1** The study reach was classified as a C5 stream, based on the following criteria (Rogsen 1996).

| Classification Criteria | Value |
|---|---|
| Bankfull width | 7.3 m |
| Mean depth | 0.3 m |
| Bankfull cross-section area | 2.5 $m^2$ |
| Width/depth ratio | 21.4 |
| Maximum depth | 0.6 m |
| Width of flood-prone area | 24.7 m |
| Entrenchment ratio | 3.4 |
| Channel materials (D50) | 0.50mm |
| Water surface slope | 0.04% |
| Channel sinuosity | 1.3 |

C-type streams are low-gradient sinuous streams flowing through narrow to broad alluvial valleys (Rosgen 1996). A healthy C-type channel will have a balance of erosion and deposition of materials, which allows the channel to migrate laterally across the valley floor without significant changes to the channel profile. As the outside bank of a curve erodes, the corresponding point bar extends, effectively building the floodplain (Rosgen 1996). The channel is thus asymmetrical at the curve, with a mild slope at the point bar moving into the deeper part of the stream on the outside bend and a much steeper bank on the outside edge. Point bars are located below bankfull stage, the elevation at which the stream spills onto its floodplain; this channel-maintaining flow occurs on average every 1.5 years. Therefore point bars are directly impacted by in-channel flow every year. The floodplain is less influenced by direct channel flow, and is accessed by the stream on average once every three years.

The vegetation community types along the study reach were sampled using the Greenline Sampling method (Winward 2000, pp. 12-17). Though the dominant vegetation on the greenline was beaked sedge (*Carex rostrata* Stokes), a late successional species, and 61% of the vegetation on the greenline was classified as late seral, the absence of woody species lowered the successional status score to 41, a mid-seral rating. The capability rating for this stream, with a slope of 0.21%, and a consolidated sand (D50 = 0.60mm) substrate, is Group I (Winward 2000, pp. 34). This rating indicates that 98% or more of the greenline should be represented by late seral community types, and alerts to the concern that the greenline vegetation may be insufficient for streambank stabilization.

The point bar plant communities were dominated by grass-like species, with 65% of the plant community comprised of a combination of *C. rostrata* Stokes, *Juncus spp., Eleocharis spp.*, and trace amounts of *Carex nebrascensis* Dewey. Grasses accounted for 18% of the plant community, the most abundant species being *Alopecurus pratensis* L., *Beckmania syzachgne* (Steud.) Fern., and *Deschampsia caespitosa* (L.) Beauv., with trace amounts of *Agrostis stolonifera* L., *Phalaris arundinaceae* L., and *Poa arida* Vasey Forbs accounted for 16% of the plant community and were represented primarily by *Artemisia ludoviciana* Nutt., and *Ranunculus occidentalis* Nutt.

Plant community composition on the floodplain locations was dominated by grass species, particularly *A. pratensis* L., which represented 77% of the entire plant population. Grasses as a whole made up 82% of the plant community composition and in addition to *A. pratensis* L. included *Hordeum brachyantherum* Nevsky, *P. arundinaceae* L., *P. arida* Vasey, and *Poa pratensis* L.

Although there are eight dominant species of willow in Bear Valley (Sanders 1995), this site is almost devoid of willows, with the exception of some old plants in the downstream end of the pasture. Local knowledge and historical photographs suggest this pasture historically supported a woody species community in the 1930s (personal communication, J. Southworth 2003).

## Methods and Materials

### Study Design

We used a completely randomized design for this experiment. Twelve 25 by 12-meter exclosures were constructed along inside turns of the stream, encompassing point bars and their associated floodplains characteristic of C-type channel morphology. Areas were fenced to exclude cattle.

Gravimetric Soil Moisture and Groundwater Depth

Gravimetric soil moisture was measured at each planting location at 15 cm and 30 cm, every ten days from the time willows were planted until September 8 of 2002 and 2003, and oven dried to determine moisture (Gardner 1986). Depth to water table was recorded concurrently. Because well depths were insufficient in 2002, water table data from 2003 only is reported.

Willow Collection and Planting

In each year Booth's willow cuttings were collected in early April, upstream from the planting site, and put in cold storage for thirty days (USDA, NRCS 1993). The apical buds of each cutting were removed to direct growth to shoots and roots, and terminal ends of the cuttings were coated in a mixture of equal parts latex paint and water, to seal in moisture and to ensure the cuttings were planted right side up (USDA, SCS 1989). Once removed from cold storage, the cuttings were placed in a shady location outdoors and soaked in water for two days prior to planting in early May (Peterson and Phipps 1976). Forty cuttings were planted on the point bar and floodplain within each exclosure, for a total of 80 plants per exclosure. Each willow was planted to a depth of 40 centimeters, at least one-half the average length of the cuttings, and identified with a numbered metal tag.

Willows were planted on two morphological locations, point bar and floodplain, in early May, which allowed a six-week establishment period prior to the late June grazing treatment. Due to the unique nature of the soil moisture and water table characteristics of the point bar and floodplain, these planting locations serve as an indicator of the soil moisture and groundwater conditions.

Grazing and Vegetation Sampling

Cattle were turned into the study pasture on June 22, 2002, and June 23, 2003, resulting in a grazing period in the pasture of 47 and 46 days for 2002 and 2003, respectively, for 125 yearling cattle. Hereford cattle grazed the area in 2002, while Angus and Tarentaise crossbred cattle grazed the area in 2003. Grazing treatments occurred at three levels, control (no grazing), early and late. At the start of each grazing treatment, fence wire was removed from the exclosure for the duration of the grazing treatment; fence posts were left in place. Early grazing occurred over a 12-day period beginning in late June on the day cattle were introduced into the pasture. Late grazing occurred over a six-day period in early August. Each grazing treatment occurred at the same time, and for the same duration in both years of the study. It was anticipated that willows would be grazed differently depending on herbaceous forage availability. Therefore to address the confounding factors of timing and intensity of grazing, grazing treatments were to be considered complete the percentage of leaders browsed during each grazing treatment reached approximately 50%. Percent utilization did not reach 50% during the early grazing treatment, and surpassed 50% during the late treatment, for both years.

Plant species were recorded for each plant at 10 cm intervals along a 15 m transect on each point bar and floodplain planting location. Stubble height was measured for forage species, but not for forbs.

In 2002, willow plants in the late exclosures were grazed very heavily. This raised the concern that declining forage availability in the surrounding pasture may have resulted in artificially high grazing pressure on the late exclosures, and that differing forage quality inside versus outside the exclosures may have influenced grazing preference and thus exposure of planted willows to herbivory. To determine if forage quality inside the exclosures was higher than that outside the exclosures, and that the height of the forage within the exclosure may have acted as an attractant, samples were collected inside and outside the control and treatment exclosures prior to grazing. Samples were collected from point bar locations only, as there were few willow plants left on floodplain locations by late summer and the influence of grazing on willow plants could only be observed on point bar locations (Lowson et al. 2004). Three locations were randomly located along each stubble height transect and a 0.25 $m^2$ frame used to collect forage samples to be analyzed for crude protein content (LECO CN2000) prior to each grazing treatment. In the 2003 late grazing treatment, exclosures were mowed to a height equal to the stubble height of the forage outside the exclosure prior to clipping in an effort to prevent a visual attractant.

Willow Census

A complete population census of the current-year planted willows was conducted prior to and after each grazing treatment for both years. Information collected included survival, leader density (number of live shoots), and the number of browsed leaders. Plants were considered alive if any above ground growth was visible. In 2003, a final survival assessment of both one and two year old plants to determine final survival was conducted in early September; and the aforementioned information was collected for all willows within all exclosures.

**Statistical Analysis**

Simple linear regression was conducted to determine the relationship between residual stubble height and percent willow browse existed. Multiple linear regression was conducted to determine if there was a relationship between pre-grazing stubble height, pre-grazing willow height and percent browse, and to attempt to develop a predictive equation for management purposes. These analyses were done across July and August sampling dates for both years.

A paired t-test was conducted to determine if the forage quality inside the exclosures was different than that outside of the exclosures at the time of each grazing treatment. This test was done for all control and grazing exclosures.

The final survival assessment analysis for willows planted in 2003 was conducted on the mean survival. Because comparatively few 2002-planted willows survived into 2003, and not every planting location contained live 20020-planted willows, analysis for those plants was conducted on the total number of live plants.

Willow survival and percent browse data within and between treatments and years were analyzed by analysis of variance (ANOVA). Data were combined across years into two models; in the first model, survival was the dependent variable, and planting location, timing of grazing and year were independent variable. In the second model, percent browse was the dependent variable, with planting location, timing of grazing and year as independent variables. When significant ($p<0.05$) model ANOVA values were encountered we used Fisher's Least Significant Difference (LSD) to determine differences in treatment means.

## Results and Discussion

Percent Browse and Forage Quality

There was an interaction between year and grazing treatment ($p = 0.05$). Browsing was evident in each exclosure where cattle were excluded, and there were signs that animals, likely deer, were bedding down in the exclosures overnight. However, this browsing was not different over the course of the season or between years (Table 3.2), and suggests that an endemic level of browse may occur in the absence of cattle that must be factored into management decisions. Kauffman et al. (1983) reported big game utilization on exclosed gravel bar communities, though at a lower level of 5%, which may be due to the type of wildlife and the type of exclosure.

**Table 3.2** Means and standard errors (in parentheses) of percent browsing of first-year willows after each grazing treatment. Percent browse refers to the number of leaders browsed during the course of the grazing treatment, divided by the total number of leaders.

| | Early Grazing Treatment | | Late Grazing Treatment | |
|---|---|---|---|---|
| Year | Control | Early | Control | Late |
| 2002 | 0.10 (0.01)a[1] | 0.34 (0.70)b | 0.18 (0.05)a | 0.71 (0.05)c |
| 2003 | 0.08 (0.01)a | 0.46 (0.04)b | 0.10 (0.02)a | 0.75 (0.03)c |

n = 4

[1]treatment means without a common letter are significantly different ($p<0.10$).

As anticipated, willows were browsed more intensely later in the season, even though the late grazing period was shorter than the early grazing period. Percent browsing was greater in the early grazing treatment than in the control treatments, and higher in late grazing treatment than all others. The control (no grazing) exclosures experienced browse, likely due to deer. Crude protein content of the forage was different inside as compared to outside the exclosures (10.0% and 8.95%, respectively) prior to the early grazing treatment ($p = 0.06$). However, at the time of the late grazing treatment, there was no difference in the quality of forage inside or outside (8.47% and 7.26%, respectively) the exclosures ($p = 0.27$). Despite the mowing treatment of the late exclosures in 2003, there was no difference in the percent browse from the late grazing treatments between the two years, therefore the issue of the forage inside the exclosures being an attractant can be discounted.

Results from the simple linear regression suggest that percent browse of willows was related to the residual stubble height, but did not explain large portions of the observed variability (2002 $p = 0.03$, $R^2 = 0.32$; 2003 $p = 0.03$, $R^2 = 0.31$). We developed a predictive equation for expected browse based on pre-grazing willow and stubble height, however no apparent relationship between the pre-grazing willow height, stubble height, and percent browse ($p = 0.51$, $R^2 = 0.20$) was found, therefore we conclude there is no apparent visual cue between pre-grazing willow and stubble heights. It is possible that such a relationship exists, but was not evident in the data collected in this study, due to the small sample size and variability of the data.

The pasture in which this study is located has been seeded to Meadow foxtail (*A. pratensis* L.) and is managed for heavy grazing later in the season. If grazing animals shift to riparian shrubs as the forage becomes less palatable, riparian shrubs in pastures with less palatable forage species may experience greater browsing pressure than would species in pastures with more palatable forage. A study investigating the seasonal palatability of willow species may be beneficial to understand if the browse pressure on willows is a direct result of the surrounding vegetation, or of the willow plants themselves.

<u>Willow Survival</u>

Percent soil moisture at a depth of 30 cm was different ($p < 0.05$) on point bar locations than floodplain locations from early May (66% and 45%) through late August (23% and 14%) in 2002 and from early May (78% and 62%) through late August (22% and 17%) in 2003 (Lowson et al. 2004). The average groundwater depth of floodplain locations was deeper than point bar locations ($p<0.05$) from early May through early September in 2003; average groundwater depth did not exceed 65 cm at point bar locations, but dropped to 95 cm on floodplain locations at the end of the growing season (Lowson et al. 2004).

Though this study was conducted during two below-average rainfall years, the study reach experienced higher precipitation and streamflow levels later in the spring during the second year of the study (Lowson et al. 2004 ). More precipitation and higher streamflow volumes that left soils saturated for a longer period into the growing season may account for the interaction observed between year and planting location ($p=0.004$); survival of first-year willows on point bar locations was higher than that of floodplain locations for both years (Table 3.3), but survival on floodplain locations was higher in 2003 than in 2002.

**Table 3.3** Means and standard errors (in parentheses) of survival of first-year willows on point bar and floodplain locations for 2002 and 2003 in grazed exclosures. Survival was greater on point bar locations for both years.

| Location | 2002 | 2003 |
|---|---|---|
| Point Bar | 0.86 (0.04)a[1] | 0.84 (0.04)a |
| Floodplain | 0.37 (0.09)b | 0.59 (0.09)c |

n = 4
[1]treatment means without a common letter are significantly different ($p<0.10$).

Differences in willow survival were associated with the unique environmental conditions of the planting location. The planting locations closest to the stream (i.e. point bar) experienced higher soil moisture and shallower groundwater depths. Conroy and Svejcar (1991) reported similar results; Geyer's willow cuttings planted within 50 cm of the stream edge exhibited higher survival rates than those planted farther from the stream channel. It is possible that lower survival on floodplain locations may be related to the rate of root growth in relation to the increasing groundwater depth.

There was an interaction between planting location and grazing treatment ($p<0.001$); survival was greater on point bar locations than floodplain locations when willows of the late grazing treatment were sampled for survival in early August, likely attributed to different soil moisture content of point bar locations. There was no difference in first year survival for point bar locations regardless of grazing treatment (Table 3.3). There was no difference in mean survival on floodplain locations in late June for grazed and ungrazed exclosures. While survival was different on floodplain locations by early August for both grazed and ungrazed exclosures, grazed exclosures experienced lower survival than ungrazed exclosures. While there appears to have been sufficient soil moisture and groundwater for growth throughout the season on point bar locations, conditions for survival declined rapidly on floodplain locations later in the season. The declining soil moisture and increasing depth to groundwater observed on the floodplain locations (Lowson et al. 2004) are the likely cause of the reduced survival observed in the ungrazed exclosures measured in early August.

**Table 3.4** Means and standard errors (in parentheses) of survival of first-year willows, measured after early grazing (late June) and late grazing (early August).

| Location | Early Grazing (Late June) | | Late Grazing (Early August) | |
|---|---|---|---|---|
| | Ungrazed (control) | Grazed | Ungrazed (control) | Grazed |
| Point Bar | 0.97 (0.01)a[1] | 0.86 (0.02)a | 0.79 (0.09)a | 0.78 (0.03)a |
| Floodplain | 0.84 (0.05)a | 0.74 (0.08)a | 0.27 (0.11)b | 0.08 (0.03)c |

n = 4

[1]treatment means without a common letter are significantly different ($p<0.10$).

Survival was lowest on grazed floodplain locations after the late grazing treatment, indicating grazing later in the season, when plants are moisture-stressed, may be detrimental to survival. This may be a combination of higher percent browse (Table 3.2), causing greater physical damage at a time in the season when moisture resources were insufficient.

Final Survival Assessment

In the final survival assessment (conducted September 2003) of willows planted in 2003, planting location influenced survival ($p < 0.001$) though grazing did not ($p = 0.57$). Mean survival for willows planted in 2003 was 62% on point bar locations and 6% on floodplain locations (Table 3.5).

**Table 3.5** Means and standard errors (in parentheses) of percent survival of 2003-planted willows in early September, 2003.

| Location | Mean survival of 2003-planted willows |
|---|---|
| Point bar | 62.33 (0.07) |
| Floodplain | 5.67 (0.02) |

Considering that grazing did appear to exert some influence over survival at the time of the late grazing treatment (Table 3.4), this may suggest that the willows were in a weakened state and that grazing pressure accelerated death.

Willows planted in 2002 exhibited delayed signs of growth in 2003; some only initiating aboveground growth in mid-August. Planting location was significant ($p = 0.02$), but grazing was not ($p = 0.57$). The absence of a grazing-related difference may be due to the small sample size remaining.

**Table 3.6** Means and standard errors (in parentheses) of number of 2002-planted willows in early September, 2003.

| Location | Mean survival of 2003-planted willows |
|---|---|
| Point bar | 6.25 (2.59) |
| Floodplain | 0.25 (0.18) |

While grazing did not appear to influence within-year survival, the distribution of 2002-planted willows that survived into 2003 warrants further investigation (Table 3.7).

**Table 3.7** Number of live 2002-planted willows in ungrazed and late-grazed exclosures in September 2002 and May 2003. Willows in the early grazing treatment were not measured in September 2002 and therefore are not presented here.

| | Number of 2002-planted willows alive in September 2002 | Number of 2002-planted willows alive in May 2003 |
|---|---|---|
| Control (ungrazed) | 125 | 42 |
| Late grazed | 123 | 3 |

After the late grazing treatment in 2002, the total number of willows alive on point bar locations in ungrazed and late-grazed exclosures was virtually the same (125 and 123, respectively). However, in May of 2003, the number of live willows in those exclosures appeared to be very different (42 in ungrazed and 3 in late-grazed). In total, only 78 willows planted in 2002 were alive in September 2003. Of these 78 plants, only three had been planted on floodplain locations. Of 75 plants on the point bar locations, 52 were in ungrazed exclosures. This suggests that if plants that survived the grazing regimes of the first year survived the first winter, they were likely to survive the second growing season.

**Conclusions**

In our study, planting location was the critical factor determining the successful establishment and survival of planted willow cuttings. Willow cuttings planted on point bar locations, with consistently higher soil moisture and groundwater levels (Lowson et al. 2004), exhibited higher survival, despite being planted in densely rooted riparian vegetation. If environmental variables such as depth to water table and soil moisture override the influence of plant competition and browsing pressure, plant species composition (i.e. the distribution of hydrophytic species including sedges and rushes) may be a valuable indicator of preferred planting location for optimum willow planting survival. Svejcar et al. (1991) found survival of Geyer's and Lemmon's willow were highest in sites dominated by *C. nebrascensis* Dewey and *Juncus nevadensis* S. Wats., where the water table level was highest. Therefore an examination of the vegetation may serve as a 'quick and dirty' management tool to select the best planting locations for survival.

The proportion of 2002-planted willows that survived into 2003 that were in ungrazed exclosures suggests that grazing may influence the number of plants that survive into the next growing season. Exclosures protected from grazing showed the greatest number of plants surviving into the second growing season, and suggest it may be prudent to protect willows from grazing for at least one season after planting for optimum survival.

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# CHAPTER 4

# CONCLUSIONS

**Katherine L. Lowson, John C. Buckhouse, Tamzen K. Stringham, and Chad S. Boyd**

Riparian systems and the willow communities within them have been modified, and in some instances lost through historical agriculture practices and other human activities. Removal of woody riparian plant species from stream channels requiring riparian vegetation for stability has resulted in a positive feedback loop of channel erosion, lowering groundwater levels, and subsequent further loss of riparian vegetation. This cycle has resulted in destabilized channels and a loss of productive land and other economic and aesthetic values. Recent interest in maintaining and improving watershed health has resulted in restoration efforts focused on the reintroduction of willows into riparian systems.

We found that planting location was the primary factor determining survival and establishment of a reintroduced willow community. Willow survival was greater on point bar than floodplain planting locations. The point bar planting locations exhibited higher percent soil moisture and groundwater levels than did the floodplain locations for most of the growing season for both year. Percent soil moisture and groundwater depths are a function of proximity to and morphology of the channel. Willows are phreatophytes, reliant on the water table for moisture uptake. It appears that a groundwater depth threshold influencing willow survival may exist; once the groundwater reached 30 cm to 40 cm below the planting depth of willows, survival declined dramatically. Therefore knowledge of the summer water table depth would be extremely helpful in the planning stages of revegetation efforts. Planting willow cuttings into the mid-summer groundwater depth may provide the best opportunity for success. Managers can obtain groundwater depth information prior to planting efforts by simply digging a hole to determine the depth to groundwater. Examination of the plant communities for hydrophytic species such as sedges and rushes will provide additional information of where water resources are most plentiful and persistent.

Cattle appear to have a differing preference for willows over the course of the growing season; as the season progressed and vegetation in the surrounding pasture matured, intensity of browse pressure on willows was increased, over a much shorter time period. Higher intensity browsing later in the growing season was associated with the high mortality observed on floodplain locations. Results also suggested that plants having survived the first winter were likely to survive the second growing season.

Many studies have shown willows to be very resilient when grazing management is modified from season-long use (Shaw 1991, Peinetti et al. 2001). With sufficient soil moisture and groundwater levels, and modified grazing management, riparian systems and willow communities in particular may recover.

Management activities that promote healthy, stable riparian systems also promote clean water sources and improved forage values for domestic livestock and wildlife. Therefore improved understanding of how riparian species interact with biotic and abiotic components of their ecosystems will improve our ability to anticipate riparian system responses to changes in management. Further studies examining the palatability of willow species over the course of the growing season may provide further insight into browse pressure later in the season. Studies examining the long-term impacts of grazing on the establishment and growth of planted willows will enhance revegetation efforts. Studies examining the palatability of different willow species, in relation to other riparian plant species, and over the course of the growing season, would be insightful. A closer look at the relationship of planted willow cuttings and groundwater dynamics, particularly with larger pole plantings, may further improve revegetation success. Filling this knowledge gap will provide wisdom into what restoration activities are possible, and aid in designing programs and management strategies compatible with riparian system capabilities and management objectives.

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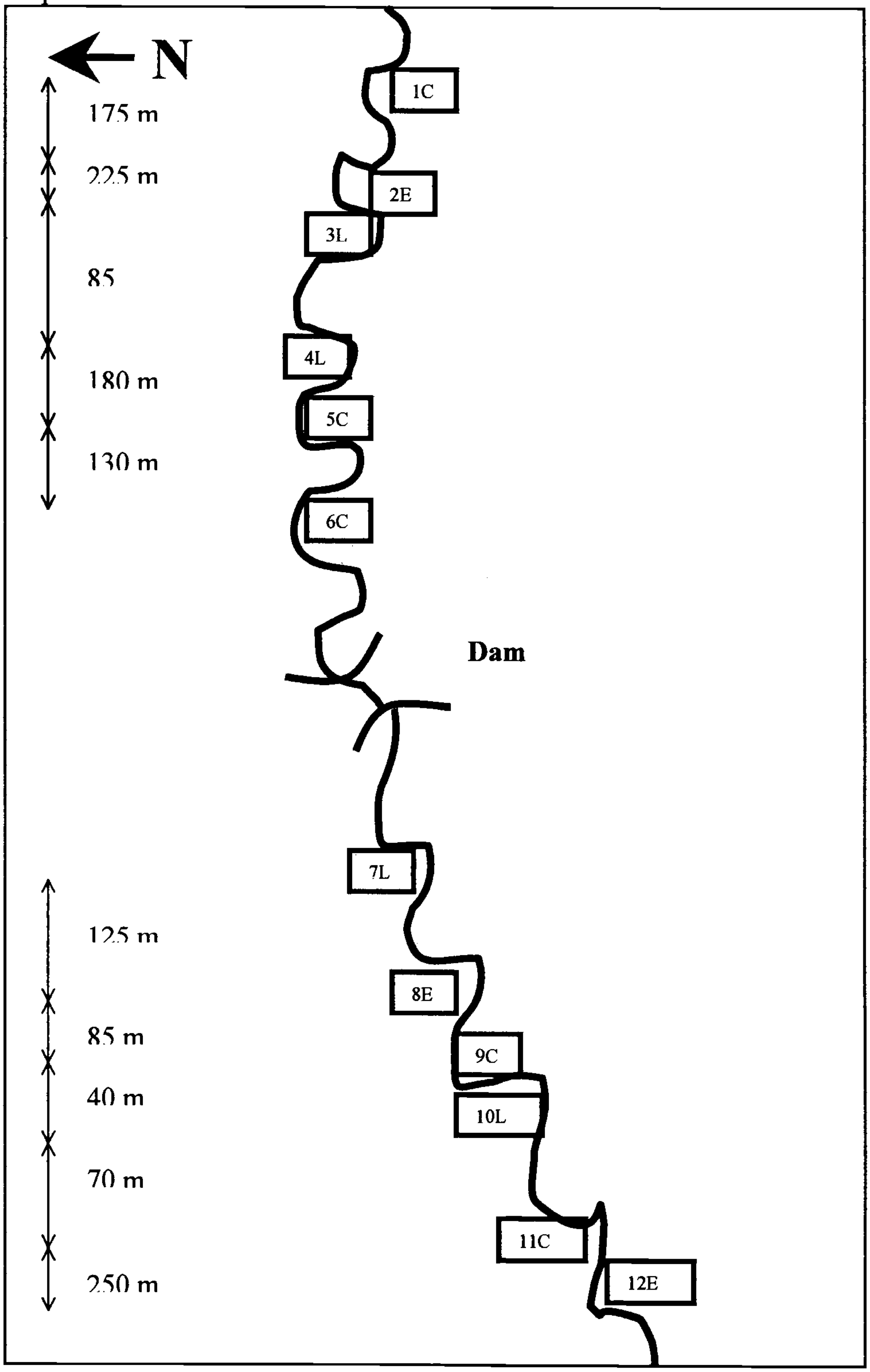
# APPENDICES

# APPENDIX A. STUDY REACH OVERVIEW MAP.

Exclosure Layout. Each box represents an exclosure, with the exclosure number and grazing treatment. Stream reach length distance (m) between exclosures is marked on left. Map not to scale.



# APPENDIX B. GRAVIMETRIC SOIL MOISTURE.

2002 Point Bar 15cm Depth Soil Moisture Values

| | 5/11/02 | 6/8/02 | 6/20/02 | 6/30/02 | 7/10/02 | 7/20/02 | 7/30/02 | 8/9/02 | 8/18/02 | 8/29/02 | 9/8/02 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.39 | 0.47 | 0.52 | 0.38 | 0.27 | 0.16 | 0.15 | 0.15 | 0.15 | 0.13 | 0.13 |
| 2 | 0.65 | 0.31 | 0.55 | 0.58 | 0.43 | 0.42 | 0.51 | 0.21 | 0.37 | 0.17 | 0.19 |
| 3 | 0.52 | 0.44 | 0.48 | 0.49 | 0.44 | 0.22 | 0.22 | 0.23 | 0.23 | 0.18 | 0.18 |
| 4 | 0.38 | 0.45 | 0.38 | 0.30 | 0.31 | 0.19 | 0.13 | 0.14 | 0.14 | 0.14 | 0.17 |
| 5 | 0.42 | 0.32 | 0.53 | 0.41 | 0.40 | 0.51 | 0.48 | 0.38 | 0.47 | 0.44 | 0.20 |
| 6 | 0.50 | 0.56 | 0.57 | 0.61 | 0.44 | 0.40 | 0.57 | 0.21 | 0.29 | 0.16 | 0.17 |
| 7 | 0.51 | 0.50 | 0.49 | 0.51 | 0.35 | 0.18 | 0.19 | 0.17 | 0.16 | 0.15 | 0.17 |
| 8 | 0.53 | 0.44 | 0.32 | 0.35 | 0.20 | 0.19 | 0.17 | 0.20 | 0.15 | 0.16 | 0.16 |
| 9 | 0.52 | 0.50 | 0.50 | 0.39 | 0.22 | 0.19 | 0.17 | 0.17 | 0.22 | 0.22 | 0.19 |
| 10 | 0.45 | 0.59 | 0.41 | 0.47 | 0.27 | 0.18 | 0.12 | 0.13 | 0.13 | 0.19 | 0.19 |
| 11 | 0.44 | 0.38 | 0.48 | 0.43 | 0.33 | 0.20 | 0.18 | 0.20 | 0.18 | 0.16 | 0.21 |
| 12 | 0.78 | 0.41 | 0.60 | 0.45 | 0.40 | 0.20 | 0.30 | 0.20 | 0.15 | 0.19 | 0.22 |
| Average | 0.51 | 0.45 | 0.49 | 0.45 | 0.34 | 0.25 | 0.26 | 0.20 | 0.22 | 0.19 | 0.18 |

2002 Point Bar 30cm Depth Soil Moisture Values

| | 5/11/02 | 6/8/02 | 6/20/02 | 6/30/02 | 7/10/02 | 7/20/02 | 7/30/02 | 8/9/02 | 8/18/02 | 8/29/02 | 9/8/02 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.78 | 0.44 | 0.37 | 0.40 | 0.29 | 0.15 | 0.13 | 0.15 | 0.16 | 0.15 | 0.19 |
| 2 | 0.78 | 0.58 | 0.39 | 0.58 | 0.50 | 0.46 | 0.54 | 0.27 | 0.55 | 0.19 | 0.09 |
| 3 | 0.40 | 0.60 | 0.64 | 0.75 | 0.36 | 0.53 | 0.51 | 0.54 | 0.52 | 0.14 | 0.17 |
| 4 | 0.78 | 0.47 | 0.44 | 0.32 | 0.36 | 0.25 | 0.16 | 0.10 | 0.12 | 0.12 | 0.11 |
| 5 | 0.78 | 0.58 | 0.53 | 0.49 | 0.59 | 0.51 | 0.52 | 0.48 | 0.39 | 0.49 | 0.20 |
| 6 | 0.48 | 0.78 | 0.56 | 0.78 | 0.48 | 0.47 | 0.46 | 0.25 | 0.36 | 0.17 | 0.12 |
| 7 | 0.54 | 0.51 | 0.49 | 0.56 | 0.40 | 0.20 | 0.17 | 0.23 | 0.23 | 0.20 | 0.22 |
| 8 | 0.41 | 0.44 | 0.43 | 0.41 | 0.26 | 0.21 | 0.19 | 0.16 | 0.18 | 0.17 | 0.19 |
| 9 | 0.78 | 0.47 | 0.51 | 0.49 | 0.44 | 0.28 | 0.22 | 0.21 | 0.33 | 0.47 | 0.20 |
| 10 | 0.57 | 0.53 | 0.48 | 0.32 | 0.26 | 0.21 | 0.20 | 0.11 | 0.21 | 0.15 | 0.12 |
| 11 | 0.78 | 0.49 | 0.55 | 0.49 | 0.45 | 0.31 | 0.27 | 0.26 | 0.21 | 0.20 | 0.29 |
| 12 | 0.78 | 0.44 | 0.29 | 0.33 | 0.37 | 0.27 | 0.36 | 0.21 | 0.14 | 0.20 | 0.26 |
| Average | 0.66 | 0.53 | 0.47 | 0.49 | 0.40 | 0.32 | 0.31 | 0.25 | 0.28 | 0.22 | 0.18 |

2002 Floodplain 15cm Depth Soil Moisture Values

| | 5/11/02 | 6/8/02 | 6/20/02 | 6/30/02 | 7/10/02 | 7/20/02 | 7/30/02 | 8/9/02 | 8/18/02 | 8/29/02 | 9/8/02 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.91 | 0.38 | 0.33 | 0.23 | 0.16 | 0.15 | 0.12 | 0.11 | 0.14 | 0.15 | 0.14 |
| 2 | 0.45 | 0.40 | 0.44 | 0.26 | 0.17 | 0.16 | 0.17 | 0.16 | 0.14 | 0.16 | 0.16 |
| 3 | 0.42 | 0.44 | 0.27 | 0.15 | 0.18 | 0.18 | 0.17 | 0.15 | 0.14 | 0.12 | 0.16 |
| 4 | 0.38 | 0.19 | 0.31 | 0.20 | 0.14 | 0.18 | 0.13 | 0.16 | 0.13 | 0.14 | 0.16 |
| 5 | 0.38 | 0.41 | 0.37 | 0.34 | 0.22 | 0.18 | 0.14 | 0.15 | 0.15 | 0.15 | 0.17 |
| 6 | 0.42 | 0.21 | 0.32 | 0.33 | 0.18 | 0.19 | 0.16 | 0.17 | 0.16 | 0.15 | 0.17 |
| 7 | 0.50 | 0.28 | 0.30 | 0.17 | 0.14 | 0.15 | 0.15 | 0.16 | 0.16 | 0.12 | 0.15 |
| 8 | 0.41 | 0.26 | 0.27 | 0.25 | 0.16 | 0.14 | 0.15 | 0.16 | 0.14 | 0.15 | 0.16 |
| 9 | 0.53 | 0.36 | 0.28 | 0.21 | 0.19 | 0.19 | 0.15 | 0.18 | 0.17 | 0.19 | 0.17 |
| 10 | 0.40 | 0.26 | 0.31 | 0.21 | 0.17 | 0.16 | 0.13 | 0.14 | 0.15 | 0.17 | 0.13 |
| 11 | 0.52 | 0.35 | 0.29 | 0.24 | 0.21 | 0.17 | 0.16 | 0.17 | 0.16 | 0.17 | 0.16 |
| 12 | 0.55 | 0.46 | 0.21 | 0.23 | 0.20 | 0.17 | 0.16 | 0.14 | 0.15 | 0.16 | 0.18 |
| Average | 0.49 | 0.33 | 0.31 | 0.23 | 0.18 | 0.17 | 0.15 | 0.15 | 0.15 | 0.15 | 0.16 |

2002 Floodplain 30cm Depth Soil Moisture Values

| | 5/11/02 | 6/8/02 | 6/20/02 | 6/30/02 | 7/10/02 | 7/20/02 | 7/30/02 | 8/9/02 | 8/18/02 | 8/29/02 | 9/8/02 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.50 | 0.36 | 0.44 | 0.25 | 0.25 | 0.15 | 0.16 | 0.14 | 0.13 | 0.15 | 0.15 |
| 2 | 0.33 | 0.39 | 0.43 | 0.32 | 0.20 | 0.17 | 0.11 | 0.21 | 0.16 | 0.15 | 0.14 |
| 3 | 0.38 | 0.39 | 0.30 | 0.35 | 0.24 | 0.15 | 0.13 | 0.17 | 0.16 | 0.12 | 0.14 |
| 4 | 0.43 | 0.34 | 0.43 | 0.18 | 0.17 | | 0.12 | 0.16 | 0.14 | 0.14 | 0.08 |
| 5 | 0.41 | 0.37 | 0.45 | 0.38 | 0.24 | 0.18 | 0.11 | 0.17 | 0.17 | 0.14 | 0.16 |
| 6 | 0.48 | 0.35 | 0.39 | 0.46 | 0.28 | 0.20 | 0.15 | 0.15 | 0.16 | 0.15 | 0.16 |
| 7 | 0.52 | 0.44 | 0.40 | 0.20 | 0.18 | 0.15 | 0.16 | 0.17 | 0.17 | 0.15 | 0.17 |
| 8 | 0.50 | 0.36 | 0.40 | 0.38 | 0.15 | 0.14 | 0.15 | 0.12 | 0.14 | 0.15 | 0.16 |
| 9 | 0.56 | 0.37 | 0.40 | 0.33 | 0.22 | 0.17 | 0.14 | 0.18 | 0.15 | 0.17 | 0.17 |
| 10 | 0.41 | 0.36 | 0.35 | 0.37 | 0.17 | 0.15 | 0.07 | 0.14 | 0.10 | 0.15 | 0.13 |
| 11 | 0.42 | 0.45 | 0.34 | 0.26 | 0.21 | 0.17 | 0.15 | 0.16 | 0.13 | 0.13 | 0.15 |
| 12 | 0.45 | 0.33 | 0.33 | 0.22 | 0.19 | 0.16 | 0.12 | 0.14 | 0.15 | 0.12 | 0.16 |
| Average | 0.45 | 0.38 | 0.39 | 0.31 | 0.21 | 0.16 | 0.13 | 0.16 | 0.15 | 0.14 | 0.15 |

2003 Point Bar 15cm Depth Soil Moisture Values[1]

| | 5/10/03 | 6/10/03 | 6/21/03 | 7/2/03 | 7/10/03 | 7/20/03 | 7/31/03 | 8/9/03 | 8/19/03 | 8/27/03 |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.55 | 0.52 | | 0.29 | 0.38 | 0.29 | 0.14 | 0.15 | 0.14 | 0.14 |
| 2 | 0.78 | 0.78 | 0.49 | 0.41 | 0.32 | 0.49 | 0.43 | 0.59 | 0.19 | 0.14 |
| 3 | 0.78 | 0.69 | 0.58 | 0.48 | 0.48 | 0.22 | 0.32 | 0.19 | 0.17 | 0.17 |
| 4 | 0.78 | 0.59 | 0.45 | 0.32 | 0.31 | 0.24 | 0.12 | 0.13 | 0.16 | 0.14 |
| 5 | 0.78 | 0.78 | 0.54 | 0.47 | 0.44 | 0.15 | 0.41 | 0.17 | 0.17 | 0.25 |
| 6 | 0.78 | 0.78 | 0.44 | 0.44 | 0.41 | 0.34 | 0.29 | 0.21 | 0.17 | 0.22 |
| 7 | 0.78 | 0.60 | 0.54 | 0.51 | 0.42 | 0.21 | 0.19 | 0.19 | 0.28 | 0.24 |
| 8 | 0.51 | 0.44 | 0.44 | 0.40 | 0.37 | 0.20 | 0.19 | 0.18 | 0.17 | 0.19 |
| 9 | 0.78 | 0.64 | 0.57 | 0.46 | 0.35 | **0.09** | 0.17 | 0.20 | 0.17 | 0.18 |
| 10 | 0.78 | 0.52 | 0.50 | 0.33 | 0.24 | 0.20 | 0.21 | 0.19 | 0.17 | 0.17 |
| 11 | 0.78 | 0.65 | 0.62 | 0.30 | 0.48 | 0.20 | 0.22 | 0.18 | 0.18 | 0.19 |
| 12 | 0.78 | 0.78 | 0.59 | 0.35 | 0.39 | 0.27 | 0.45 | 0.15 | 0.17 | 0.48 |
| Average | 0.74 | 0.65 | 0.52 | 0.40 | 0.38 | 0.26 | 0.26 | 0.21 | 0.18 | 0.21 |

2003 Point Bar 30cm Depth Soil Moisture Values[1]

| | 5/10/03 | 6/10/03 | 6/21/03 | 7/2/03 | 7/10/03 | 7/20/03 | 7/31/03 | 8/9/03 | 8/19/03 | 8/27/03 |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.78 | 0.41 | 0.42 | 0.37 | 0.36 | 0.32 | 0.11 | 0.14 | 0.14 | 0.12 |
| 2 | 0.78 | 0.78 | 0.46 | **0.33** | 0.48 | 0.47 | 0.37 | 0.67 | 0.22 | 0.19 |
| 3 | 0.78 | 0.78 | 0.51 | **0.26** | 0.39 | 0.27 | 0.50 | 0.23 | 0.17 | 0.17 |
| 4 | 0.78 | 0.78 | 0.44 | 0.37 | 0.37 | 0.34 | 0.19 | 0.15 | 0.15 | 0.14 |
| 5 | 0.78 | 0.78 | 0.78 | 0.50 | 0.61 | 0.29 | 0.58 | 0.22 | 0.19 | 0.44 |
| 6 | 0.78 | 0.78 | 0.78 | | 0.30 | 0.37 | 0.31 | 0.21 | 0.18 | 0.24 |
| 7 | 0.78 | 0.78 | 0.51 | 0.50 | 0.54 | 0.44 | 0.21 | 0.24 | 0.54 | 0.25 |
| 8 | 0.78 | 0.50 | 0.43 | 0.42 | 0.39 | 0.21 | 0.18 | 0.19 | 0.19 | 0.18 |
| 9 | 0.78 | 0.78 | 0.46 | 0.42 | 0.44 | 0.31 | 0.28 | 0.15 | 0.20 | 0.17 |
| 10 | 0.78 | 0.78 | | 0.43 | 0.44 | 0.39 | 0.34 | 0.16 | 0.39 | 0.13 |
| 11 | 0.78 | 0.78 | 0.78 | 0.39 | 0.38 | 0.36 | 0.36 | 0.17 | 0.17 | 0.21 |
| 12 | 0.78 | 0.78 | 0.78 | 0.45 | 0.46 | 0.35 | 0.45 | 0.31 | 0.25 | 0.35 |
| Average | 0.78 | 0.73 | 0.58 | 0.43 | 0.43 | 0.34 | 0.32 | 0.24 | 0.23 | 0.22 |

[1]soil moisture values in bold type were removed from analysis due to sampling error

2003 Floodplain 15cm Depth Soil Moisture Values

| | 5/10/03 | 6/10/03 | 6/21/03 | 7/2/03 | 7/10/03 | 7/20/03 | 7/31/03 | 8/9/03 | 8/19/03 | 8/27/03 |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.53 | 0.45 | 0.44 | 0.33 | 0.26 | 0.18 | 0.18 | 0.15 | 0.15 | 0.16 |
| 2 | 0.48 | 0.43 | 0.25 | 0.19 | 0.19 | 0.18 | 0.17 | 0.16 | 0.17 | 0.15 |
| 3 | 0.58 | 0.43 | 0.39 | 0.33 | 0.20 | 0.18 | 0.13 | 0.16 | 0.17 | 0.17 |
| 4 | 0.42 | 0.84 | 0.26 | 0.26 | 0.18 | 0.17 | 0.16 | 0.16 | 0.16 | 0.16 |
| 5 | 0.96 | 0.37 | 0.49 | 0.40 | 0.34 | 0.23 | 0.16 | 0.14 | 0.15 | 0.17 |
| 6 | 0.67 | 0.47 | 0.43 | 0.40 | 0.39 | 0.24 | 0.20 | 0.18 | 0.16 | 0.17 |
| 7 | 0.49 | 0.48 | 0.26 | 0.31 | 0.26 | 0.19 | 0.15 | 0.19 | 0.17 | 0.18 |
| 8 | 0.59 | 0.48 | 0.37 | 0.23 | 0.20 | 0.17 | 0.15 | 0.14 | 0.17 | 0.17 |
| 9 | 0.62 | 0.53 | 0.47 | 0.36 | 0.20 | 0.19 | 0.17 | 0.20 | 0.18 | 0.17 |
| 10 | 0.48 | 0.48 | 0.45 | 0.25 | 0.23 | 0.18 | 0.16 | 0.16 | 0.17 | 0.18 |
| 11 | 0.55 | 0.56 | 0.57 | 0.36 | 0.17 | 0.19 | 0.15 | 0.16 | 0.19 | 0.19 |
| 12 | 0.63 | 0.61 | 0.53 | | 0.32 | 0.20 | 0.19 | 0.19 | 0.20 | 0.19 |
| Average | 0.58 | 0.51 | 0.41 | 0.31 | 0.25 | 0.19 | 0.16 | 0.16 | 0.17 | 0.17 |

2003 Floodplain 30cm Depth Soil Moisture Values

| | 5/10/03 | 6/10/03 | 6/21/03 | 7/2/03 | 7/10/03 | 7/20/03 | 7/31/03 | 8/9/03 | 8/19/03 | 8/27/03 |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.42 | 0.43 | | 0.35 | 0.29 | 0.21 | 0.18 | 0.16 | 0.17 | 0.14 |
| 2 | 0.56 | 0.42 | 0.29 | 0.48 | 0.16 | 0.19 | 0.18 | 0.16 | 0.15 | 0.17 |
| 3 | 0.78 | 0.46 | 0.36 | 0.39 | 0.32 | 0.19 | 0.18 | 0.18 | 0.16 | 0.18 |
| 4 | 0.47 | 0.39 | 0.35 | 0.31 | 0.21 | 0.16 | 0.15 | 0.38 | 0.16 | 0.17 |
| 5 | 0.78 | 0.49 | 0.44 | 0.33 | 0.36 | 0.25 | 0.18 | 0.18 | 0.16 | 0.15 |
| 6 | 0.78 | 0.49 | 0.43 | 0.44 | 0.47 | 0.35 | 0.21 | 0.18 | 0.15 | 0.17 |
| 7 | 0.49 | 0.50 | 0.32 | 0.31 | 0.38 | 0.23 | 0.18 | 0.19 | 0.18 | 0.18 |
| 8 | 0.56 | 0.43 | 0.36 | 0.42 | 0.23 | 0.15 | 0.16 | 0.13 | 0.15 | 0.16 |
| 9 | 0.55 | 0.57 | 0.40 | 0.36 | 0.21 | 0.18 | 0.17 | 0.18 | 0.16 | 0.17 |
| 10 | 0.53 | 0.37 | 0.44 | 0.33 | 0.27 | 0.18 | 0.17 | 0.13 | 0.17 | 0.16 |
| 11 | 0.78 | 0.46 | 0.49 | 0.40 | 0.23 | 0.18 | 0.16 | 0.08 | 0.15 | 0.17 |
| 12 | 0.78 | 0.49 | 0.47 | 0.38 | | 0.26 | 0.18 | 0.17 | 0.18 | 0.15 |
| Average | 0.62 | 0.46 | 0.40 | 0.38 | 0.28 | 0.21 | 0.17 | 0.18 | 0.16 | 0.17 |

# APPENDIX C. GROUNDWATER DEPTH.

2002 Point Bar Groundwater Depth (cm)[1]

| Creek Surface | 5/11/02 | 6/8/02 | 6/20/02 | 6/30/02 | 7/10/02 | 7/20/02 | 7/30/02 | 8/9/02 | 8/18/02 | 8/29/02 | 9/8/02 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 28 | **56** | 56 | 59 | **73** | **88** | **88** | **91** | **89** | **88** | **89** |
| 2 | 18 | 27 | 30 | 42 | 44 | 42 | **45** | **76** | **44** | **84** | **85** |
| 3 | 42 | 52 | 58 | **22** | **65** | **47** | **49** | **45** | **47** | **90** | **87** |
| 4 | 29 | **53** | 59 | **69** | **65** | **77** | **88** | **94** | **92** | **92** | **93** |
| 5 | 28 | 16 | 23 | 32 | 34 | 31 | **48** | **52** | **62** | **51** | **83** |
| 6 | 43 | 27 | 35 | 45 | 48 | 47 | **54** | **78** | **65** | **87** | **92** |
| 7 | 34 | 45 | 48 | 59 | **61** | **83** | **87** | **80** | **80** | **83** | **81** |
| 8 | 49 | 60 | 61 | 71 | **77** | **82** | **84** | **88** | **86** | **87** | **85** |
| 9 | **18** | **52** | **48** | **51** | **56** | **75** | **81** | **82** | **69** | **53** | **83** |
| 10 | 32 | 44 | 51 | **70** | **76** | **82** | **84** | **93** | **82** | **89** | **92** |
| 11 | 30 | **51** | 48 | 56 | **56** | **71** | **76** | **77** | **82** | **83** | **73** |
| 12 | 13 | **56** | 41 | **69** | **64** | **76** | **66** | **82** | **90** | **84** | **77** |
| Average | 31 | 45 | 46 | 58 | 60 | 65 | 74 | 80 | 78 | 79 | 84 |

2002 Floodplain Groundwater Depth (cm)

| Creek Surface | 5/11/02 | 6/8/02 | 6/20/02 | 6/30/02 | 7/10/02 | 7/20/02 | 7/30/02 | 8/9/02 | 8/18/02 | 8/29/02 | 9/8/02 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 35 | 40 | 69 | 74 | **78** | **88** | **88** | **90** | **91** | **88** | **89** |
| 2 | 55 | **62** | 72 | 79 | **83** | **86** | **94** | **82** | **88** | **89** | **90** |
| 3 | 35 | **62** | 45 | 56 | 62 | 62 | **91** | **87** | **87** | **92** | **89** |
| 4 | 42 | 58 | 58 | 65 | **87** | **105** | **92** | **88** | **90** | **89** | **97** |
| 5 | 53 | 54 | 61 | 70 | 72 | 71 | 79 | **86** | **86** | **90** | **87** |
| 6 | 76 | 69 | 75 | 85 | 92 | 95 | 101 | **89** | **88** | **89** | **88** |
| 7 | 49 | **57** | 67 | 76 | 80 | 81 | 82 | **86** | **87** | **89** | **86** |
| 8 | 32 | **65** | 60 | 72 | 73 | 73 | 73 | 73 | 74 | 74 | 74 |
| 9 | 29 | 38 | 51 | **69** | **81** | **87** | **90** | **85** | **88** | **87** | **87** |
| 10 | 40 | **65** | 62 | 67 | **87** | **89** | **98** | **89** | **95** | **89** | **91** |
| 11 | 41 | **56** | 65 | **77** | **82** | **86** | **89** | **87** | **91** | **91** | **89** |
| 12 | 44 | **68** | 71 | 75 | 76 | 76 | 77 | 78 | **89** | **92** | **87** |
| Average | 44 | 58 | 63 | 72 | 79 | 81 | 87 | 85 | 88 | 88 | 88 |

[1]numbers in boldface are estimates of groundwater depth calculated from equation obtained from simple linear regression of 2003 soil moisture and groundwater values

2003 Point Bar Groundwater Depth (cm)[1]

| | 5/11/02 | 6/8/02 | 6/20/02 | 6/30/02 | 7/10/02 | 7/20/02 | 7/30/02 | 8/9/02 | 8/18/02 | 8/29/02 | 9/8/02 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Creek Surface[1] | | | | | | | | | | | |
| 1 | 15 | 21 | 33 | 47 | 54 | 60 | 61 | 65 | 73 | 76 | 80 |
| 2 | -1 | 3 | 22 | 34 | 36 | 40 | 37 | 38 | 40 | 42 | 40 |
| 3 | 13 | 22 | 40 | 54 | 55 | 58 | 53 | 55 | 59 | 58 | 54 |
| 4 | 18 | 26 | 46 | 53 | 58 | 65 | 64 | 69 | 73 | 72 | 77 |
| 5 | -11 | -7 | 11 | 23 | 39 | 43 | 42 | 45 | 48 | 49 | 47 |
| 6 | 1 | 2 | 23 | 36 | 52 | 59 | 65 | 69 | 72 | 79 | 78 |
| 7 | 13 | 18 | 39 | 58 | 62 | 64 | 57 | 65 | 69 | 68 | 69 |
| 8 | 30 | 38 | 57 | 70 | 74 | 82 | 78 | 83 | 88 | 89 | 100 |
| 9 | 3 | 14 | 32 | 49 | 54 | 59 | 57 | 61 | 67 | 65 | 63 |
| 10 | 10 | 24 | 42 | 51 | 54 | 59 | 57 | 60 | 59 | 64 | 65 |
| 11 | 2 | 11 | 17 | 25 | 31 | 36 | 35 | 39 | 41 | 43 | 43 |
| 12 | -3 | 0 | 27 | 44 | 53 | 57 | 50 | 53 | 61 | 56 | 53 |
| Average | 8 | 14 | 32 | 45 | 52 | 57 | 55 | 59 | 63 | 63 | 64 |

[1]groundwater depth measured as distance to the water from the ground surface; negative numbers indicate ponding at the well site

2003 Floodplain Groundwater Depth (cm)

| | 5/11/02 | 6/8/02 | 6/20/02 | 6/30/02 | 7/10/02 | 7/20/02 | 7/30/02 | 8/9/02 | 8/18/02 | 8/29/02 | 9/8/02 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Creek Surface[1] | | | | | | | | | | | |
| 1 | 34 | 40 | 52 | 67 | 75 | 82 | 84 | 88 | 95 | 97 | 103 |
| 2 | 31 | 30 | 58 | 67 | 70 | 74 | 76 | 79 | 85 | 86 | 87 |
| 3 | 30 | 41 | 60 | 72 | 75 | 81 | 77 | 80 | 84 | 80 | 82 |
| 4 | 28 | 42 | 63 | 66 | 65 | 68 | 69 | 80 | 90 | 93 | 98 |
| 5 | 20 | 31 | 48 | 62 | 73 | 79 | 77 | 80 | 83 | 83 | 84 |
| 6 | 31 | 43 | 57 | 70 | 86 | 94 | 97 | 102 | 108 | 111 | 115 |
| 7 | 38 | 47 | 66 | 80 | 85 | 91 | 90 | 94 | 101 | 101 | 105 |
| 8 | 37 | 47 | 67 | 78 | 83 | 89 | 84 | 91 | 98 | 100 | 104 |
| 9 | 32 | 44 | 62 | 79 | 84 | 90 | 88 | 81 | 101 | 97 | 97 |
| 10 | 37 | 51 | 70 | 81 | 86 | 93 | 87 | 93 | 97 | 94 | 95 |
| 11 | 21 | 37 | 52 | 64 | 66 | 71 | 70 | 74 | 76 | 75 | 76 |
| 12 | 25 | 42 | 60 | 75 | 80 | 87 | 84 | 89 | 93 | 89 | 89 |
| Average | 30 | 41 | 60 | 72 | 77 | 83 | 82 | 86 | 93 | 92 | 95 |

# APPENDIX D. ANALYSIS OF VARIANCE SUMMARY TABLES.

Analysis of variance conducted on data collected prior to grazing treatments.

| Dependent Variable: Percent survival of planted willows before grazing treatment | |
|---|---|
| Source of Variation | Degrees of Freedom |
| Year | 1 |
| Location | 1 |
| Season | 1 |
| Location across years | 1 |
| Season across years | 1 |
| Location across seasons | 1 |
| Location across seasons and years | 1 |
| Total | 7 |

| Dependent Variable: Average growth (leader density) per plant before grazing treatment | |
|---|---|
| Source of Variation | Degrees of Freedom |
| Year | 1 |
| Location | 1 |
| Season | 1 |
| Location across years | 1 |
| Season across years | 1 |
| Location across seasons | 1 |
| Location across seasons and years | 1 |
| Total | 2[1] |

[1]At the time of sampling, all plants were dead on five planting locations, resulting in missing values for those locations. Missing growth values were estimated according to Steel and Torrie (1980) to facilitate analysis; degrees of freedom were adjusted accordingly.

Analysis of variance conducted on data collected after grazing treatments.

| Dependent Variable: Percent survival of planted willows after grazing treatment | |
|---|---|
| Source of Variation | Degrees of Freedom |
| Year | 1 |
| Location | 1 |
| Grazing | 2 |
| Location across years | 1 |
| Grazing across years | 3 |
| Location across grazing | 3 |
| Location across grazing and years | 3 |
| Total | 15 |

| Dependent Variable: Average browse (percent of shoots browsed) per plant after grazing | |
|---|---|
| Source of Variation | Degrees of Freedom |
| Year | 1 |
| Location | 1 |
| Browse | 3 |
| Location across years | 1 |
| Browse across years | 3 |
| Browse across location | 3 |
| Browse across location and years | 3 |
| Total | 9[1] |

[1]At the time of sampling, all plants were dead on six planting locations, resulting in missing values for those locations. Missing growth values were estimated according to Steel and Torrie (1980) to facilitate analysis; degrees of freedom were adjusted accordingly.

Analysis of variance conducted on data collected in the final survival assessment; conducted September 7-9, 2003.

| Dependent Variable: Number of live willows that were planted in 2002. | |
|---|---|
| Source of Variation | Degrees of Freedom |
| Location | 1 |
| Grazing | 2 |
| Grazing across location | 2 |
| Total | 5 |

| Dependent Variable: Percent survival of willows that were planted in 2003. | |
|---|---|
| Source of Variation | Degrees of Freedom |
| Location | 1 |
| Grazing | 2 |
| Grazing across location | 2 |
| Total | 5 |

# APPENDIX E. FINAL WILLOW SURVIVAL COUNT, SEPTEMBER 2003.

| Exclosure[1] | Number of live willows observed during final survival assessment on September 9, 2003. | | | |
|---|---|---|---|---|
| | Willows planted in 2002[2] | | Willows planted in 2003 | |
| | Point Bar | Floodplain | Point Bar | Floodplain |
| 1C | 6 | 0 | 7 | 0 |
| 2E | 12 | 0 | 33 | 3 |
| 3E | 0[3] | 2 | 35 | 0 |
| 4E | 0 | 0 | 18 | 0 |
| 5C | 33 | 0 | 32 | 5 |
| 6E | 6 | 1 | 24 | 4 |
| 7L | 2 | 0 | 32 | 0 |
| 8E | 0 | 0[4] | 8 | 0 |
| 9C | 5 | 0 | 37 | 11 |
| 10L | 1 | 0 | 17 | 0 |
| 11C | 9 | 0 | 34 | 2 |
| 12E | 2 | 0 | 24 | 1 |

[1]The grazing treatment applied to each exclosure is denoted by an uppercase letter. C for control (no grazing); E for early; and L for late.

[2]In the event these exclosures are revisited, willows with tags numbered 1 to 500 and 1000 to 1500 were planted in 2002; willows with tags numbered 501 to 999 and 1501 to 2000 were planted in 2003.

[3]One willow plant on this transect is growing from remnant rootstock and was not planted for this experiment.