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Tamzen Stringham

Riparian vegetation is an essential component for the maintenance and/or repair of channel stability and function. Sedges within low-gradient riparian systems provide the structure necessary for sediment trapping leading to channel narrowing through bank building processes. Planting success in riparian restoration projects has often failed due to inappropriate species selection, planting locations and/or methodologies. Stream restoration efforts utilizing channel reconstruction methods are increasing in number across the West thus emphasizing the need for knowledge on revegetation methods. Planting success in a recently constructed channel is essential because the lack of vegetation makes the channel highly susceptible to erosion. Sedges play an important role in the stability of low gradient, fine-textured stream channels. Two native sedges, *Carex nebrascensis* (Nebraska sedge) and *Carex utriculata* (beaked sedge) are often used in riparian restoration within the West because they have extensive root systems that can provide bank stability in fine-sediment channels. Survival and vegetative reproduction were evaluated on greenhouse grown plugs of these two sedge species following transplanting within a reconstructed NE Oregon meadow stream. Sedge plugs were planted on two fluvial surfaces along the stream: depositional (point bars) and erosional surfaces (straight) at or below bankfull level. A second study was performed to evaluate the effect of *Cirsium arvense* (Canada thistle) presence on sedge transplant survival and vegetative reproduction. This was performed only on erosional planting locations. Depths to groundwater and soil moisture were also recorded at each planting location.

Survival at the end of the first growing season in the first study was the same for both species, but shoot numbers were greater for *Carex nebrascensis* (98 shoots/m²) compared with *Carex utriculata* (84 shoots/m²). No differences were observed between shoot numbers by species at the end of the second growing season. Greater shoot numbers also occurred on depositional planting locations (117 and 165 shoots/m²) compared to erosional planting locations (65 and 59 shoots/m²) at the end of the first and second growing seasons. Transplant loss due to scour from high flows was greater at erosional planting locations (48%) than at depositional planting surfaces (19%). Sedge transplant loss from scour during high flows was greater for *Carex utriculata* transplants (44%) than for *Carex nebrascensis* transplants (23%).

Presence of *Cirsium arvense* was observed to be associated with a reduction in vegetative reproduction during the first growing season but not at the end of the second growing season. *Carex nebrascensis* produced more shoots than *Carex utriculata* regardless of thistle presence for both growing seasons probably due to depth to groundwater. Transplant loss due to scour from high flows was greater for *Carex utriculata* (55%) compared to *Carex nebrascensis* (28%).

These results suggested that revegetation success will be increased if sedges are planted on depositional geomorphic surfaces within reconstructed meadow channels. *Cirsium arvense* may be controlled following sedge transplanting during the first growing season to increase vegetative growth. These results also suggested that *Carex nebrascensis* is an appropriate species for transplanting at sites with water tables deeper than 30 cm.

Revegetation with *Carex nebrascensis* and *Carex utriculata* Following Reconstruction in a NE Oregon Meadow Stream

by
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I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

Sarah E. Quistberg, Author

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Dr. Tamzen Stringham aided in interpretation and discussion of the data and edited all chapters. Dr. Lisa Ganio provided help with some of the SAS code and some data interpretation.

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GENERAL INTRODUCTION

Riparian systems are transitional areas that are seasonally influenced by freshwater (Naiman 2005). Riparian areas are one of the most dynamic ecosystems because of the seasonal fluctuation in stream water levels. Riparian ecosystems generally account for a small land area in arid regions but they contain a large percentage of the biodiversity (Naiman & Decamps 1997). In eastern Oregon they have a significant impact on the surrounding landscape by providing temperature regulation and instream habitat (Wissmar 2004). Riparian systems have been altered by human activities for many years. Such alterations and impacts include water diversions, dams, channelization, grazing, mining, timber harvest, and urban development.

Recently riparian restoration projects have become important due to riparian ecosystems crucial contributions to watershed function. Stream restoration projects have varying degrees of human involvement that can range from removing the stressor on the system to reconstructing entire lengths of stream channel. Channel reconstruction makes stream banks highly susceptible to erosion because much of the riparian vegetation is removed. Planting success in a recently constructed channel is extremely important. Sedges are used extensively in riparian revegetation because of their capacity to bind the soil matrix with their dense network of fibrous roots (Hoag 2003). Stream alteration in Oregon has lowered the water tables of many streams. Areas with lowered water tables cannot support obligate wetland species so they are replaced by upland species that do not provide the bank stability of rhizomatous sedges.

Bank Stabilization

Species with a dense network of fibrous roots, such as sedges, provide more soil cohesion than a sparse network of woody roots, although the two root structures combined provide more cohesion than either alone (Thorne 1990). However, the importance of sedges in streambank stabilization has largely been ignored by the scientific community compared to the research on the significance of willows in streambank stabilization. There is a small amount of literature on the methods of revegetating meadow streams and the relationship between bank stabilization and vegetation has been difficult to quantify (Thorne 1990).

Vegetated stream banks are known to provide greater resistance to flow and erosion than unvegetated banks (Clary et al. 1996; Thorne 1990) and roots play an important role in strengthening non-cohesive sandy soils (Kleinfelder et al. 1992). Vegetation is effective at trapping fine sediment carried in the water column and leaf cover provides protection to the soil when stream banks are inundated during high flows (Clary et al. 1996; Thorne 1990). Beeson and Doyle (1995) compared bank erosion of vegetated and non-vegetated channel bends and found that those without riparian vegetation were much more likely to erode during flood events. Plant roots, particularly herbaceous roots in bank sediment have an important effect in reducing erosion rates of channel bank material (Smith 1976), as well as developing new streambanks and providing stability to mature banks (Kleinfelder et al. 1992). Research indicates that the extensive root and rhizome structure of sedges provide stabilization to fine sediment stream banks (Steed & DeWald 2003) by binding the soil and adding extra cohesion (Thorne 1990). Zimmerman et al. (1967) found that meadow channels in Vermont were not affected by extreme floods because of the low width to depth ratios of sedge dominated streams because of the cohesive structure provided by sedge root systems. Swanson (1996) also found this to be true in western Nevada. The riparian vegetation roots provided a high level of erosion resistance that Swanson (1996) hypothesized stabilize meadow streams.

Carex nebrascensis Dewey (Nebraska sedge) and *Carex utriculata* Boott (beaked sedge) are often used in restoration projects because of their capacity to occupy a site rapidly through their extensive root systems (Hoag 2003) and they provide bank stability (Manning et al. 1989). Riparian meadow communities dominated by sedges and rushes have much greater root densities than grasses (Manning et al. 1989). Manning et al. (1989) found *C. nebrascensis* to have, on average, a root density of 95.6 cm cm^3 in the upper 40 cm of soil and *Poa nevadensis* Vasey ex Scribn. (Nevada bluegrass) had 8.8 cm cm^3 of roots in the upper 40 cm of soil. This difference in density between *C. nebrascensis* and *P. nevadensis* suggests that sedges have a greater influence on bank stability than grasses growing in similar areas. In another study that quantified root length density of herbaceous sites and forested sites, Wynn et al. (2004) observed that herbaceous site contained 75% of their roots in the upper 30 cm of soil and forested systems about 55% indicating that herbaceous species may provide more bank stability in the top soil layer.

Despite their importance to channel stability, little is known about the planting success of sedges in restoration projects, particularly in reconstructed streams. Establishing deep rooted vegetation on bare streambanks is important to maintain the stability of a reconstructed stream. Two bank features in natural meadow channels are meander bends and overhanging banks between meander bends. Meander bends are exposed to both erosion and deposition (Knighton 1998). Point bars along the inside bank of meanders are a repository for sediment while the outside of meanders are prone to erosion (Knighton 1998). As long as erosion and deposition is in balance, no sediment loss is expected from the system. Banks between meander bends are usually characterized by overhanging banks and are the straight reach of the stream (Knighton 1998). In a typical meadow channel straight reaches are generally narrow and deep and the overhanging bank is stabilized by a network of sedge and grass roots. Neither erosion nor deposition should predominate in this area. Straight areas do erode, but generally by undermining the overhanging bank (cantilever failure) and the banks either fall into the stream as a block or slump (Knighton 1998). Erosional areas and rates may not be the same in reconstructed channels and this makes establishing bank stabilizing vegetation important in these new channels.

***Carex nebrascensis* and *Carex utriculata* Ecology**

Carex nebrascensis is dominant in the riparian ecosystems of the Intermountain West and throughout the Great Basin and eastern Oregon (Hoag et al. 2001b; Crowe et al. 2004). It is generally associated with low gradient streams, trough and U-shaped valleys, and in streams that are C3, E6, and F6 Rosgen types (Chambers et al. 2004; Crowe et al. 2004). *Carex nebrascensis* is often found in fine-textured organic loams, in streams with small channel particle sizes, fine-textured banks and low width to depth ratios (Chambers et al. 2004; Crowe et al. 2004). *Carex nebrascensis* is heavily rhizomatous and forms dense stands that are often dominant in the plant community (Hoag & Zierke 1998). Shoots from rhizomes are produced throughout the growing season into late fall. *Carex nebrascensis* shoots can live for two or more growing seasons and may remain vegetative or develop reproductive structures (Ratliff 1983; Ratliff & Westfall1992). Ratliff and Westfall (1992) found that 60% of the shoots they observed produced flowers. *Carex nebrascensis* is rarely found where the water table drops more than 1 meter below the rooting zone. It is a wetland obligate that grows in a wide range of soils (Hoag & Zierke 1998; Hoag et al. 2001a), and can tolerate inundation for about 3 months (Wetland Plant Sheet: *Carex nebrascensis*).

Carex utriculata is a common riparian plant that is present in one of the wettest plant associations (Crowe et al. 2004; Hoag & Zierke 1998) and it is capable of growing in areas with a fluctuating water table and is tolerant of flooding (Hultgren 1988). It occurs in Rosgen C3, C4, E3, E4, and F6 channels (Crowe et al. 2004). It is a rhizomatous, sod forming sedge (Ewing 1996) and will produce both long and short rhizomes that form large stands (Hoag & Zierke 1998; Bernard 1976; Bernard 1990). It will spread at a rate of over one foot per year (Hoag et al. 2001a). *Carex utriculata* will produce shoots to over-winter in autumn for growth in the spring, though peak shoot emergence is between June and August (Allen & Marlow 1994). Shoots have been found to live up to two years in Minnesota (Bernard 1976; Bernard 1990).

Sedges have morphological characteristics that allow them to grow in saturated and anaerobic conditions such as aerenchyma tissue and the growth of roots into well aerated soil (Steed et al. 2002). Aerenchyma is specialized material within the stem that allows oxygen to move from the atmosphere to the root system to create an aerobic layer around the roots (Hoag et al. 2001a). *Carex utriculata* prevents anoxia in the roots by developing large air spaces in the rhizomes and roots (Fagerstedt 1992).

The primary mechanism for reproduction in sedges is through vegetative growth in rhizomes (Ratliff 1983; van der Valk et al. 1999). Eriksson (1989) found that seedling establishment is rare in clonal plants, such as many sedges, and they are generally maintained vegetatively. Disturbance is often needed for seedlings to establish in the clonal plant communities (Eriksson 1989). Seedlings are not often found naturally (Budelsky & Galatowitsch 1999; van der Valk et al. 1999), and Ratliff (1983) never observed a seedling in the field. This is likely because there is a loss of seed viability over time and in poor environmental conditions for germination and growth (van der Valk et al. 1999). Because sedges often persist vegetatively and have lower seed production this makes them less likely to disperse by seed into a new area after disturbance (Galatowitsch & van der Valk 1996). Although seedling establishment is rare, it is possible if the conditions for germination are met (Bernard 1990; van der Valk et al. 1999; Yetka & Galatowitsch 1999). Specifically, Jones et al. (2004) found that from spring to late summer water levels and temperatures in northern Utah were adequate for seedling germination.

Transplanting

Planting sedge plugs is currently the most effective method for reestablishing sedge species (Hoag 2003). Sedges generally reproduce vegetatively, although they can reproduce by seed if the conditions are favorable (van der Valk et al. 1999). Seeding is less successful than transplanting when physical stressors predominate the site, such as high water velocities and erosion (Steed & DeWald 2003) and germination requirements are not often met in a field setting.

The methods commonly used to reintroduce sedges into restoration projects are: transplanting greenhouse grown plugs, rhizomes or harvesting wild sedge communities or wildlings (Hoag et al. 2001b; Jones et al. 2004; van der Valk et al. 1999). Evidence suggests that greenhouse grown plants may be superior to naturally harvested plants. Harvesting from natural populations can be damaging to the natural system if harvested incorrectly. Plants grown in the greenhouse are larger and can be produced in greater quantities, although they are more expensive due to nursery cost and labor (Hoag et al. 2001b; Tilley & Hoag 2005). Direct seeding has also been attempted in many projects because of its simplicity and potential lower cost than transplanting, although the success rate has been poor (Jones et al. 1999; van der Valk et al. 1999). The high rate of failure has been attributed to planting on unsuitable seedbeds, low seed viability, and low germination rates (van der Valk et al. 1999). Sedge transplants are also more sensitive to water table depths than the natural communities and they should be planted when the groundwater is high or where the water table is close to the surface during the growing season (Steed & DeWald 2003). *Carex nebrascensis* transplants may have a lower tolerance for deeper water tables than established stands (Steed et al. 2002). Harvesting wetland or riparian plants from natural populations is commonly used because of the ease of transplanting. Their root systems are already well established and the harvest area may fill in quickly, leaving little damage to the harvest area if the sedges harvested were not large clumps. Rhizomes can also be harvested at a natural riparian area and should be collected in the early spring before the plants break dormancy or after the growing season. Hoag et al. (2001c) provides detailed instructions on harvesting and planting of rhizomes.

Transplanting season and size also affect the success of transplanting and establishment of wildlings (Steed & DeWald 2003). Steed and DeWald (2003) transplanted sedges in Arizona during two different seasons, summer and fall. They found that summer transplants had a higher survival rate which may be attributed to higher rainfall in the summer in this region. Groundwater was probably more accessible during the summer season and surface soil moisture levels were also generally higher during summer than fall. The Aberdeen Plant Materials Center was able to plant plugs from April through late October (Hoag 2003), although planting in the fall and winter resulted in significant mortality from frost heaving.

Environmental Factors Affecting Revegetation Success

Water availability is often the primary factor affecting riparian species distribution (Allen-Diaz 1991; Chambers et al. 2004; Martin & Chambers 2001). Immature sedges are sensitive to both abiotic and biotic conditions, particularly in the first growing season (Budelsky & Galatowitsch 2000). Water table depth is the predominant abiotic factor affecting transplant survival (Steed et al. 2002; Steed &

DeWald 2003). Steed et al. (2002) found that sedge transplants respond to constant water levels by adjusting rooting depth to the level of the established water table. *Carex utriculata* can allocate more root growth to saturated areas, which indicates that it can transport oxygen into its roots easily and tolerate anaerobic conditions (Steed et al. 2002). *Carex utriculata* generally favors more saturated conditions while *C. nebrascensis* can tolerate drier conditions and deeper water tables (Steed et al. 2002). Law et al. (2000) found that *C. utriculata* communities grow on sites with a average water depth of 0.2 m in Montana (see also Martin & Chambers 2001). *Carex nebrascensis* can be found across a wide range of water depths and is generally a dependable indicator of average water table depth (Allen-Diaz 1991; Chambers et al. 2004). Castelli et al. (2000) found that *C. nebrascensis* occurs within 30 cm of surface water and within a range of 0 to 30 cm (see also Chambers et al. 2004). Steed and DeWald (2003) found that transplant survival in *C. nebrascensis* and *C. utriculata* was restricted to areas where the maximum depths were from 28 to 47 cm and 8 to 27 cm, respectively. They also found that survival was poor for all species where maximum depth was less than 7 cm or deeper than 60 cm (Steed & DeWald 2003).

Competition from exotic species (Budelsky & Galatowitsch 2000) also affects transplant survival, particularly in the first year of growth. Budelsky and Galatowitsch (2000) found that competition reduced sedge transplant growth during the first season of growth and the effects of competition decreased during the second and third year of their study. This suggests that other plants present at the planting site may determine survival of sedges during the first year of growth. *Cirsium arvense* (L.) Scop. is an invasive thistle that can increase in density at streams following disturbance. Channel reconstruction is a large disturbance and if re-planting native vegetation is not successful, it may become a dominant part of the plant community. It is a highly invasive perennial forb that spreads quickly through horizontal roots (Moore 1975). It does not survive well in saturated conditions (Moore 1975), but it can be present in riparian plant communities. Root growth in this thistle has been reported up to 6 meters in one season (Hayden 1934). Roots can also penetrate deep into the soil profile to depths up to 2 to 3 meters (Moore 1975). This underground root structure suggests that it may be competitive with sedges that have similar growth patterns.

Project Goal

Riparian revegetation is an essential component for the maintenance and/or repair of channel stability and function. Sedges within low-gradient riparian systems provide the structure necessary for sediment trapping leading to channel narrowing through bank building processes. Planting success in riparian restoration projects has often failed due to inappropriate species selection, planting locations and/or methodologies (van der Valk et al. 1999). Stream restoration efforts utilizing channel reconstruction methods are increasing in number across the West (Bernhardt et al. 2007) thus emphasizing the need for knowledge on revegetation methods.

The goal for this project was to determine the appropriate planting location for *C. nebrascensis* and *C. utriculata* in a reconstructed meadow channel in Northeastern Oregon. The objectives of this study were to (1) quantify survival and vegetative response, by species, relative to the geomorphic surface planting location, (2) to describe the growing season water table patterns relative to channel morphology along Bear Creek and (3) to determine if *Cirsium arvense* presence is associated with sedge growth and survival.

TRANSPLANTING *CAREX NEBRASCENSIS* AND *CAREX UTRICULATA* IN A NE OREGON RECONSTRUCTED MEADOW STREAM

ABSTRACT

Revegetation of sedges after channel reconstruction has been problematic because of inappropriate species selection or planting location. In this study, greenhouse grown plugs of *Carex nebrascensis* (Nebraska sedge) and *Carex utriculata* (beaked sedge) were transplanted in early summer (late June) onto two different channel geomorphic surfaces: depositional and erosional. Sedge transplant survival, vegetative reproduction (shoot number) and transplant scour loss were recorded over 2 years. Depth to groundwater and soil moisture was also recorded at each planting location during the first growing season. Survival during the first growing season was the same for both species, but shoot numbers were greater for *Carex nebrascensis* (98 shoots/m^2) compared with *Carex utriculata* (84 shoots/m^2) at the end of the first growing season. Greater shoot numbers also occurred on depositional planting locations (117 and 165 shoots/m^2) compared to erosional planting locations (65 and 59 shoots/m^2) at the end of the first and second growing seasons (respectively). Transplant loss due to scour from high flows was also greater at erosional planting locations (48%) than at depositional planting surfaces (19%). Transplant loss was also greater for *Carex utriculata* (44%) than for *Carex nebrascensis* (23%). No differences were observed between species at the end of the second growing season. These results suggested that revegetation success will be increased if sedges are planted on depositional geomorphic surfaces within reconstructed meadow channels.

INTRODUCTION

Riparian vegetation is an essential component for geomorphic stability and function of fine-sediment channels. Sedges within low-gradient riparian systems provide the structure necessary for sediment trapping leading to channel narrowing through bank building processes (Clary et al. 1996) and they provide bank stability through their root structure promoting the development of overhanging banks (Micheli & Kirchner 2002). Two native sedges, *Carex nebrascensis* Dewey (Nebraska sedge) and *Carex utriculata* Boott (beaked sedge) are often used in riparian restoration projects within the West because they have extensive root systems that can provide bank stability in fine-sediment channels. Planting success in riparian restoration projects has often failed due to inappropriate species selection, planting locations and/or methodologies (van der Valk et al. 1999). Channel reconstruction is highly invasive and leaves streambanks bare, therefore planting success in a recently constructed channel is essential because the lack of vegetation makes the channel highly susceptible to erosion.

Research indicates that the extensive root and rhizome structure of sedges provides stabilization to fine sediment stream banks by binding the soil and adding cohesion (Thorne 1990). Vegetated streambanks are known to provide greater resistance to flow and erosion than unvegetated banks (Clary et al. 1996; Thorne 1990). Vegetation is effective at trapping fine sediment carried in the water column and leaf cover provides protection to the soil when stream banks are inundated during high flows (Clary et al. 1996; Thorne 1990). Beeson and Doyle (1995) compared bank erosion of vegetated and non-vegetated channel bends and found that those without riparian vegetation were much more likely to erode during flood events. Plant roots, particularly herbaceous roots, have an important role in reducing erosion rates of channel bank material (Smith 1976), as well as developing new streambanks and providing stability to mature banks (Kleinfelder et al. 1992). Zimmerman et al. (1967) found that sedge-dominated meadow channels in Vermont were not affected by extreme floods because the low width-to-depth ratio of the channels, created by the cohesive structure of the sedge root systems, forced flood water onto the floodplain reducing the erosional force of water.

Riparian meadow communities dominated by sedges and rushes have much greater root densities than those dominated by grasses (Manning et al. 1989) and provide bank reinforcement through their root systems (Micheli & Kirschner 2002). *Carex nebrascensis* has been found to have, on average, a root density of 95.6 cm cm^3 in the upper 40 cm of soil while *Poa nevadensis* (Nevada bluegrass) had only 8.8 cm cm^3 of roots at the same depth (Manning et al. 1989). The significant difference in density between *C. nebrascensis* and *P. nevadensis* suggests that sedges have a greater influence on bank stability than grasses growing in similar areas. In another study that quantified root length density of herbaceous sites and forested sites, Wynn et al. (2004) observed that herbaceous dominated sites had a higher density of roots compared to woody dominated floodplains and herbaceous sites contained 75% of their roots in the upper 30 cm of soil while forested systems contained 55%.

Establishing deep rooted vegetation on bare streambanks, especially those of fine-sediment channels, is important to maintain the stability of a reconstructed stream. Two bank features in natural meadow channels are meander bends and overhanging banks between meander bends. Meander bends are exposed to both erosion and deposition. Point bars along the inside bank of meanders are a repository for sediment while the outside of meanders are prone to erosion (Knighton 1998). As long as erosion and deposition is in balance, no sediment loss is expected from the system. Banks between meander bends are usually characterized by overhanging banks and are the straight reaches of the stream (Knighton 1998). In a typical meadow channel straight reaches are generally narrow and deep and the overhanging bank is stabilized by a network of sedge and grass roots (Micheli & Kirchner 2002). Erosion of straight sections is uncommon but can occur through undermining the overhanging bank (cantilever failure) and the banks either fall or slump into the stream (Knighton 1998). Width-depth ratios, slope, sinuosity and meander belt widths can be created within a reconstructed channel (Rosgen 1996) however formation of overhanging banks and stabilization of point bars requires vegetation (Micheli & Kirchner 2002). Establishment of vegetation in new channels is necessary for channel function and development and maintenance of channel form.

Despite sedges importance to channel stability, little is known about their planting success in restoration projects, particularly in reconstructed streams. Sedges generally reproduce vegetatively, although they can reproduce by seed if the conditions are favorable for germination (Bernard 1990; Jones et al. 2004; van der Valk et al. 1999; Yetka & Galatowitsch 1999) but germination requirements are not often met in the field (van der Valk et al. 1999). Eriksson (1989) found that seedling establishment is rare in rhizomatous plant communities and disturbance is often needed for seedlings to establish. However, sedges are less likely to disperse by seed into a disturbed area because they have lower seed production and often persist vegetatively (Galatowitsch & van der Valk 1996). Seedlings are not often found naturally (Budelsky & Galatowitsch 1999; van der Valk et al. 1999), and Ratliff (1983) had not yet identified a *C. nebrascensis* seedling throughout the Sierra Nevadas. The rarity of natural seedlings in some rhizomatous sedges is likely due to the loss of seed viability over time and the prevalence of poor environmental conditions for germination and growth (van der Valk et al. 1999). For these reasons, seeding in restoration projects is less successful than transplanting. Planting plugs or harvested wildlings is currently the most effective method for reestablishing sedges at a restoration site (Hoag 2003).

Once sedges are transplanted at a restoration project site, many environmental factors effect survival and growth including surface and groundwater availability. Sedges naturally form associations based on water availability because they are differentially tolerant of certain groundwater depths (Castelli et al. 2000). *Carex utriculata* generally favors more saturated conditions while *C. nebrascensis* can tolerate drier conditions and deeper water tables (Steed et al. 2002). Immature sedges are also sensitive to the amount of water available, particularly in the first growing season (Budelsky & Galatowitsch 2000). Steed et al. (2002) found that sedge transplants respond to constant water levels by adjusting rooting depth to the level of the established water table.

Stream restoration efforts utilizing channel reconstruction methods are increasing in number across the West (Bernhardt et al. 2007), thus emphasizing the need for knowledge on effective revegetation methods. The objectives of this study were 1) to determine the appropriate geomorphic surface for transplanting *C. nebrascensis* and *C. utriculata* in a low gradient, reconstructed channel in NE Oregon based on sedge survival and growth, 2) establish a relationship between sedge growth, groundwater depth and soil moisture and 3) describe the growing season water table patterns relative to channel morphology.

SITE DESCRIPTION

The study site was on a meadow stream in the upper Grande Ronde River Basin in western Union County, Oregon. The site is located at 45°18’5” north latitude and 118°17’4” west longitude (Appendix A). Bear Creek is a first order intermittent stream characterized by high spring flows and continual water loss into early July when the channel dries. Late summer and fall rains may initiate channel flow. The channel drains a 20.2 square kilometer watershed and flows north into the Grande Ronde River.

The study site was located in a pasture historically used for grazing. Oregon Department of Fisheries and Wildlife (ODFW) believe Bear Creek once provided spawning and rearing habitat for summer steelhead. In-stream habitat was rated as fair to poor by Confederated Tribes of the Umatilla Indian Reservation (CTUIR) and ODFW. In 1999 the Grande Ronde Model Watershed partnered with ODFW, CTUIR, Natural Resources Conservation Service and the private landowner to improve fisheries habitat within Bear Creek. Approximately 5,500 feet of stream was reconstructed during the winter of 2003. The goal of the project was to restore Bear Creek into a stable meandering channel connected to the adjacent floodplain. Willows, sedge wildlings, and a standard meadow seed mix (*Pascopyrum smithii* 23%, *Leymus cinereus* 16%, *Phleum pratense* 10%, *Poa secunda* 10%, *Festuca idahoensis* 10%, *Festuca ovina* 9%, *Elymus lanceolatus* spp. *lanceolatus* 10%, *Medicago sativa* 5%, *Melilotus officinalis* 5%) were planted in 2003 after stream reconstruction. The channel currently supports sparse riparian vegetation. There also appear to be many unstable banks between meander bends in straight reaches of the stream. Many banks are being undermined by high flows and bank failure is prevalent. This may be due to the lack of deep rooted graminoids on the banks. Bear Creek’s current vegetation is composed of meadow foxtail, timothy, Canada thistle, and a mix of native and non-native meadow species (Appendix B).

The study reach encompassed approximately 0.62 km (1 mi.) of a constructed Rosgen “C/E” channel type, located within a gently sloped meadow (1.12%). The elevation of the floodplain ranged from 941 to 949 meters and the streambed material consisted mainly of silty clay and gravel deposits. Rosgen "C/E" channel types within the Blue Mountain Ecoregion are expected to support a healthy and dense *C. nebrascensis* community.

The floodplain and surrounding meadow soil are classified in two different soil map units with Veazie-Voats complex dominating on the floodplains and downstream meadow section and La Grande silt loam mainly in the upstream section of the site (Soil Survey Staff 2007). The Veazie unit is classified as a cumulic haploxeroll and Voats as a fluventic haploxeroll. The Veazie-Voats complex is well drained, formed in mixed alluvium with a restrictive layer occurring between 51 to 102 centimeters (cm) for Veazie unit and 25 to 51 cm for the Voats unit. The Veazie and Voats unit profiles are similar with loam or fine sandy loam in the top 81 to 41 cm, respectively, with very gravelly sand below. The La Grande silt loam is somewhat different from the Veazie-Voats complex. It is moderately well drained, also formed in mixed alluvium with a restrictive layer at more than 203 cm below the surface. The soil profile is silt loam to 35 cm, silty clay loam to 112 cm and extremely gravelly loam underlying. The water holding capacity for the soil ranges from very low (5.8 cm) to high (26.9 cm).

Long term (1931-2002) average annual temperature and precipitation was obtained from the nearby weather station, in Ukiah, Oregon (45°08'N 118°56'W elevation 1036.3 m; OCS 2007). The average annual temperature is 6.1°C. The maximum and minimum temperatures range from 32.8°C in the summer to -24.4°C in the winter. The average annual precipitation is 43 cm, with much coming in the winter months as snow. Hydrographs from the Grande Ronde River in Troy, Oregon (USGS gauge #13333000) from 2006 and 2007 indicate that 2006 was an average water year and 2007 was a below average water year (Appendix C).

METHODS

Experimental Design

A two factor completely randomized split-plot design was used to test the effects of planting location and species on sedge survival and growth after transplanting (Appendix C). The planting location had two levels (erosional and depositional) and the species factor had two levels (*Carex nebrascensis* and *C. utriculata*). Nine channel erosional and nine depositional plots were randomly located in the study site; these locations served as the whole plot. Erosional surfaces were located between meander bends in the straight reaches of the stream. Depositional surfaces were located on the inside of meander bends, typically known as point bars. Within each whole plot, subplots were randomly assigned to be planted with one sedge species.

Plants other than the sedge plugs growing in all subplots were removed using hand tools. The whole plots laid parallel to the stream flow and the sub-plots were oriented perpendicular to the stream so each treatment received similar stream and groundwater influence.

Transplant Material

The two sedges, *Carex nebrascensis* and *C. utriculata*, were purchased from Wildlife Habitat Nursery in Princeton, Idaho in the form of 10 cubic inch plugs. This size was chosen because research has shown smaller plugs to be more susceptible to death due to environmental conditions than larger plugs (Steed and DeWald 2003). These sedges are often found intermixed naturally, but *C. nebrascensis* generally tolerates drier conditions while *C. utriculata* generally grows in saturated conditions (Hultgren 1988). The *C. utriculata* plugs were found to be contaminated with a different sedge species, *Carex bebbii*. This contamination was not apparent until the second growing season when the two sedges displayed different inflorescences. Juvenile *C. utriculata* has narrower leaves than the mature plant and is similar morphologically to *C. bebbii* when it is young, although *C. bebbii* retains narrow leaves and a cespitose growth form as it matures. The initial percentage of *C. bebbii* stems is unknown because many new shoots have grown since planting. The percentage of contamination at the beginning of the second growing season was on average 6%, although the range was between 0-48% per plot. The percentage of contamination, however is over-estimated, because 44% of the *C. utriculata* transplants were lost due to scouring prior to the second growing season. There is a possibility *C. bebbii* established from seed during the study, but observation of the growing location within the *C. utriculata* plots suggests it was planted with the *C. utriculata* plugs. *Carex nebrascensis* plots did not contain any *C. bebbii.*

Transplanting

A total of 540 sedge plugs were transplanted at the field site in June of 2006. Plants were transplanted into randomly selected erosional and depositional surfaces. Plots were located below bankfull level to increase plant access to water. The transplants were planted with a dibble that was made to fit the diameter of the sedge plug. Each transplant was spaced 20 cm by 25 cm apart within each sub-plot with 15 sedge plugs per subplot. Each sedge transplant was marked with a ring of coated electrical wire placed around the base of the sedge plug so that new shoots and the transplanted sedge could be distinguished.

All of the erosional plots were planted on June 24, 2006 and the depositional plots were planted over a period of three days (June 24, 25, and 27, 2006) because those locations had deeper water over the planting surface. A few transplants were initially submerged on depositional surfaces, however, the stream levels dropped quickly and within two weeks of planting no transplants were submerged.

Vegetation Measurements

Sedge shoot numbers per subplot were measured weekly to assess transplant response to planting location. Cumulative number of sedge stems was used as a surrogate for plant performance. Above ground sedge stems were counted instead of the number of individual plants because of the rhizomatous nature of these species. Cumulative stem emergence and shoot presence was measured weekly.

Sedge survival was measured weekly July through September 2006. The transplants were considered alive if one green shoot was present and green tissue was present at least at the center of the plant (Ratliff and Westfall 1992). A transplant was considered dead if green tissue was absent. Measurements during the second season included survival of transplanted sedge plugs and shoot counts in June and September of 2007. Loss of sedge transplants due to scour was also measured June of 2006. Transplant root exposure was measured (cm) for sedge transplants that were scoured from their original planting location but were not carried downstream (Appendix E). These transplants remained anchored in the plots by small fibrous roots.

Stream Channel Measurements

Standard channel survey methods (Harrelson et al. 1994) were used to survey 18 non-permanent cross sections at each planting location. The channel cross sections were placed perpendicular to stream flow and to the planting sites. All major breaks in slope were measured including terrace, floodplain, streambank, thalweg elevations and the elevation of the transplanting plots recorded relative to the other stream channel measurements. Channel cross sections at each planting location were re-surveyed August of 2007. WinXSPRO Version 3.0 (Hardy et al. 2005) was used to determine cross sectional area change between years and to estimate the amount of erosion or deposition that occurred during the study. WinXSPRO uses a repeated Simpson's Rule to calculate the difference in areas (Hardy et al. 2005). If the cross sectional area from 2007 is below the cross section from 2006 in a given area, the area in that region will be positive indicating degradation. If the cross section is higher, the area of that region will be negative indicating aggradation. Because the cross sections from 2006 were not permanent, the cross sections in 2007 were placed as closely as possible to the 2006 location. The placement of the cross sections in 2006 was described adequately in notes and placing the 2007 cross sections was generally accurate.

Soil Moisture Measurements

Soil moisture was measured weekly at each plot from July to early September. Gravimetric soil moisture was determined using the method described by Hillel (1998). Two gravimetric soil moisture measurements were taken at each planting location and averaged for each plot. Each sample was taken at a depth of 15 cm. Soil from the plot was collected and weighed in the field to determine wet weight. The samples were dried in an oven at 105°C for 24 hours and re-weighed to determine dry weight.

Groundwater Measurements

Eighteen groundwater wells were placed approximately one meter away from the plots on the floodplain to protect the well from flood events. The wells were constructed of three inch diameter perforated PVC pipe. Perforated PVC pipes were chosen over piezometers to ensure actual measurements of the groundwater level instead of head pressure. The wells were capped with a three inch PVC cap. The well depth was variable depending on the soil material; plots with coarser material had shallower wells. The well depth ranged between 1.2 and 2 meters (Table 2.1).

Table 2.1. Groundwater well depths at each planting location.

Location	Well #	Well Depth (cm)	Location	Well #	Well Depth (cm)
Depositional	27	178	Erosional	26	172
	24	179		25	169
	19	167		22	160
	14	176		17	162
	11	181		16	150
	8	161		9	118
	6	94		5	169
	4	133		3	164
	2	141		1	103

Groundwater depth was measured biweekly from late June to early September by extending a metal metric tape down the well to the water surface. Measurements were corrected for the difference between the top of the well and ground level and for the elevation change from the well to the associated planting surface.

DATA ANALYSIS

A two-factor completely randomized split-plot ANOVA ($\alpha = 0.10$) was used to detect differences among location treatments and differences between species for number of shoots and transplant mortality using a linear mixed model (Proc Mixed) in SAS (SAS Institute, Cary, NC, U.S.A.). Number of shoots was expressed on a per sub-plot basis. Analysis of variance was performed using the Type 3 estimation method and the Satterthwaite method for degrees of freedom (Littel et al. 2006). Random effects accounted for variation among plots and variation among subplots were also used. To detect differences in groundwater and soil moisture between planting locations, a general linear model was used with groundwater or soil moisture as the response variable (groundwater/soil moisture = planting location + error). Soil moisture was used as a covariate (ANCOVA) to account for variability between locations. All means were obtained using LS means statement in SAS.

To determine if plot surfaces eroded or degraded a one-tailed Wilcoxon Signed Rank test was used to determine if plot elevations decreased from 2006 to 2007. T-tests were also performed to detect differences between elevation change, plug root exposure, and the number of plugs with exposed roots per location.

RESULTS

Effect of Location on Transplant Vegetative Reproduction

Shoot numbers were counted two weeks after transplanting. Differences between planting location and species were already apparent two weeks after transplanting (mid-July 2006). Shoot numbers on depositional locations were greater than on erosional locations ($F_{1,16} = 4.38$; $p = 0.0527$). There was also a difference between species shoot numbers ($F_{1,16} = 11.24$; $p = 0.0040$) with *C. nebrascensis* producing more shoots than *C. utriculata* (Table 2.2).

Shoot numbers, on average, continued to increase throughout the first growing season for both planting locations (Fig. 2.1). Shoot numbers for depositional locations were significantly greater than for erosional planting locations at the end of the first growing season ($F_{1,16} = 4.41$; $p = 0.0518$). Shoot numbers at the end of the first growing season also varied among the two sedge species ($F_{1,16} = 10.26$; $p = 0.0055$). Mean shoot numbers were significantly greater for *C. nebrascensis* than for *C. utriculata* at the end of the first growing season (Table 2.2).

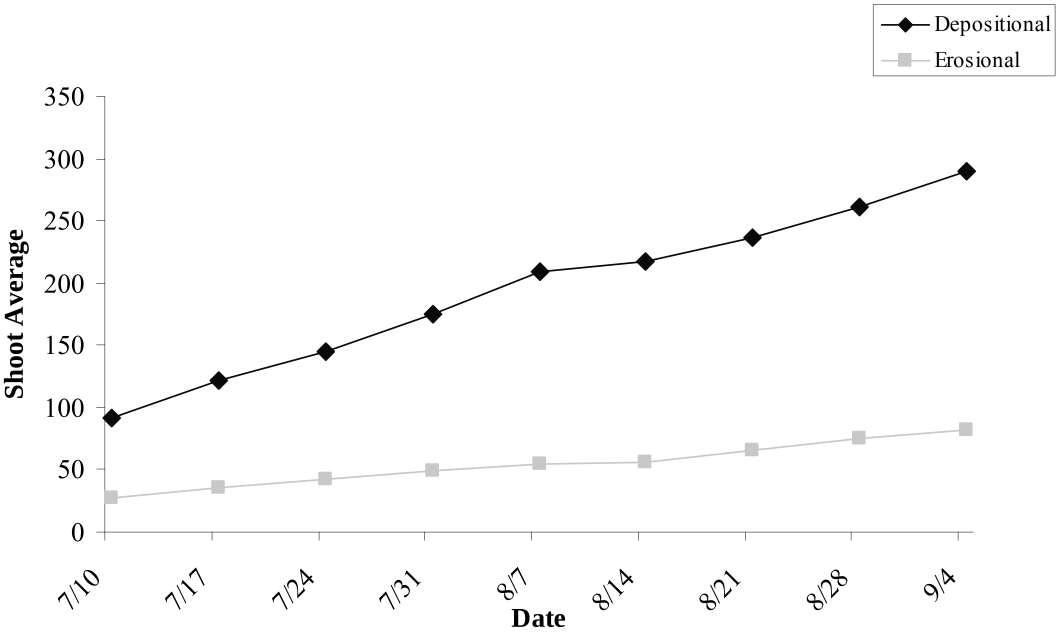


Figure 2.1. Average shoot numbers for depositional and erosional planting locations for the 2006 growing season.

Depositional planting locations were found to have a greater number of shoots per plot than erosional locations in June and September of the second growing season ($F_{1,16} = 8.91$, $p = 0.0088$; $F_{1,16} = 6.26$, $p = 0.0235$, respectively). Depositional plots had between 130 and 150 more shoots per plot than erosional planting locations at both sample dates. There was no statistical difference between species shoot numbers at either sample date during the second growing season. There was also no interaction between planting location and species.

Table 2.2. Average values (means ± SE) for sedge shoot numbers for 2006 and 2007. *Not significantly different at $\alpha = 0.10$

	Shoots 2006		Shoots 2007	
Factor	July	September	June	September
Location				
Depositional	45.5 ± 6.2	144.6 ± 21.4	204.5 ± 30.9	250.8 ± 42.5
Erosional	27.0 ± 6.2	81.0 ± 21.4	73.8 ± 30.9	100.2 ± 42.5
Species				
C. nebrascensis	44.3 ± 5.0	121.2 ± 15.3	n.s.*	n.s.*
C. utriculata	28.3 ± 5.0	104.5 ± 15.3	n.s.*	n.s.*

Mortality due to Scour

Sedge transplant mortality at the beginning of the second growing season was greatest erosional plots that exhibited a mean mortality of 48% (7.2 transplants out of 15) and depositional surfaces 19% (2.9 transplants out of 15) ($F_{1,16} = 7.49$; $p = 0.0146$). Mortality was also different between species ($F_{1,16} = 10.65$; $p = 0.0049$) (Table 2.3). Mean transplant loss was greater for *Carex utriculata* (44%) than for C. *nebrascensis* (23%) transplants.

Table 2.3. Average values (means ± SE) for sedge transplant mortality June 2007 (*n* = 15).

Factor	Mortality
Location	
Depositional	2.9 ± 1.1
Erosional	7.2 ± 1.1
Species	
C. nebrascensis	3.4 ± 0.9
C. utriculata	6.6 ± 0.9

The mortality at the end of the second season was not significant between location or species despite the fact that 37% of the remaining sedge plugs were nearly uprooted during the spring flow event and appeared as though they would not survive through the second growing season. The sedges that remained in the plots, with some intact roots, were able to establish new roots in the soil and survive. No differences were found between how much of the transplants roots were exposed and the how many transplants out of 15 (per subplot) that were uprooted between the two planting locations.

Groundwater Depth and Soil Moisture

Mean groundwater depth at both planting locations displayed similar trends over the first growing season (Fig. 2.2). Mean groundwater depth for the first growing season averaged 22 cm for depositional locations and 28 cm for erosional planting locations although the difference between the two planting locations was not statistically significant. Water depth may not have been different between planting locations but water depths falling below planting depth may have caused plant stress.

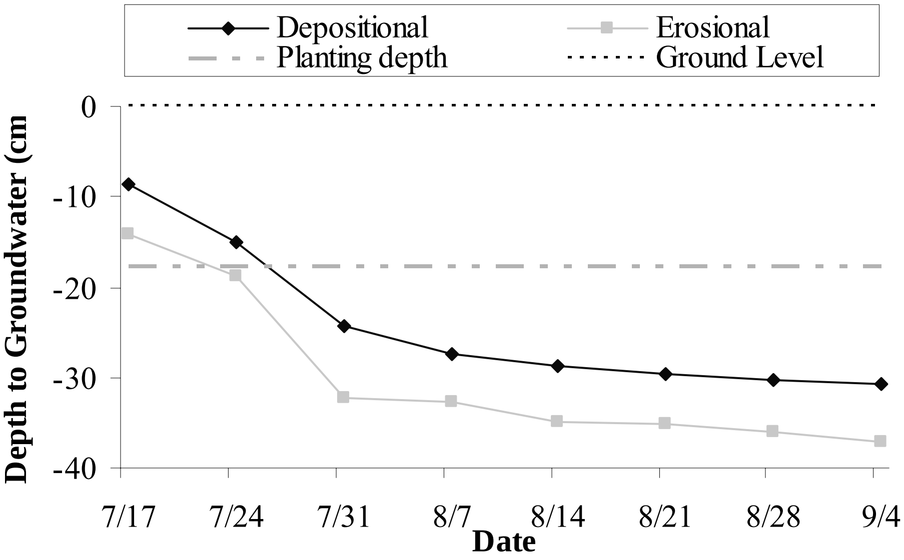


Figure 2.2. Groundwater depths for depositional and erosional planting locations throughout the 2006 growing season: zero is the ground surface.

Mean percent soil moisture for the first growing season was higher at depositional planting locations than at erosional locations (p = 0.0357, Fig. 2.3). Average soil moisture through the season for depositional locations was 35% (±2.1%) while the average soil moisture for erosional locations were 28% (±2.1%).

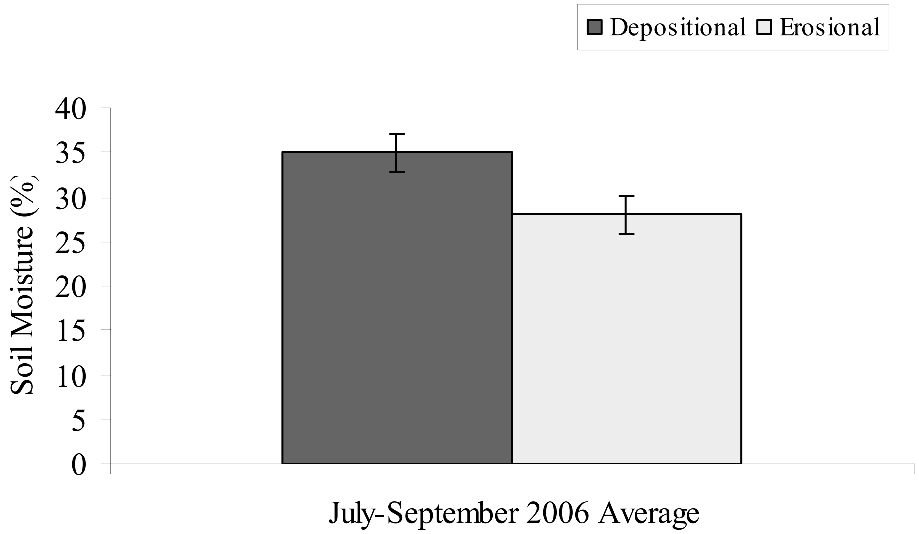


Figure 2.3. Average gravimetric soil moisture (%) and SE bars for July through September 2006 on depositional and erosional plots.

Channel Dimension Change and Erosion

All channel cross-sections either showed no change between years or showed a positive change in cross-sectional area. Erosional locations cross-section change for 2007 were generally positive, indicating degradation while depositional locations either showed no change or some degradation taking place, generally occurring on the outside of the bend, although the difference between the locations was not significant. Erosional planting elevations positively changed between 2006 and 2007 ($p = 0.0029$), suggesting erosion. Erosional planting locations on average lost 10 cm of soil from the planting surface.

DISCUSSION

This study found that the success of revegetation using sedge transplants in a reconstructed meadow stream appears to vary between species and planting location. The greatest number of sedge stems in this study was observed for *C. nebrascensis* planted on depositional fluvial surfaces. The lowest number of sedge stems observed in this study was *C. utriculata* planted on erosional fluvial surfaces. Overall, regardless of planting location, *C. utriculata* produced less shoots than did *C. nebrascensis.*

Differences between species

Difference in water depth tolerances between *C. utriculata* and *C. nebrascensis* could explain the difference in vegetative reproduction for these two species, although they have similar morphological and rooting characteristics. *Carex nebrascensis* has a wide range of water depth tolerances (Allen-Diaz 1991; Chambers et al. 2004). Castelli et al. (2000) found that it generally occurs where water tables are within 0.3 m below the ground surface. Steed and DeWald (2003) found that transplants had high survival with groundwater depths between 0.28 to 0.47 m below the ground surface. The water table depths within *C nebrascensis* plots in this study were well within these ranges. *Carex utriculata* is generally associated with saturated conditions (Crowe et al. 2004) and often found growing in streams. While *C. utriculata* can be found growing in a range of water depths, it is generally found in wetter locations than *C. nebrascensis.* A number of studies have found that *C. utriculata* is tolerant of saturated conditions where groundwater tables infrequently fall below the rooting zone (Ewing 1996; Fagerstedt 1992; Law et al 2000) because of this, *C. utriculata* has been found to exhibit a low tolerance to water stress (Steed et al. 2002). Steed and DeWald (2003) found *C. utriculata* transplants had an optimal survival range when water table depths were within 0.08 and 0.27 m from the ground surface. The water depths *C. utriculata* experienced in this study would be at the deeper end of this water depth range which may be the cause for the lower vegetative reproduction. The groundwater characteristics at this site suggest that *C. nebrascensis* is more suitable for revegetation of this channel. This observation emphasizes the importance of planting the appropriate sedge for particular water regimes.

Mortality due to transplant scour was also different between the two species. This higher mortality may be in part due to the presence of *C. bebbii* that came in with the *C. utriculata* plugs. This sedge has a different morphology than either *C. utriculata* or *C. nebrascensis*, although it is similar to *C. utriculata* in tolerance to saturated soils and is considered a wetland obligate (NRCS Plants Database 2007). *Carex bebbii* is densely cespitose from short fibrous rootstocks (Herman 1970). This would make *C. bebbii* more susceptible to scour than *C. nebrascensis* or *C. utriculata*; both of which exhibit a rhizomatous underground stem structure and ability to expand outside of the original planting location. Since this sedge is similar to *C. utriculata* in its high tolerance to anaerobic conditions, the presence of this sedge on the species performance results during the first growing season was assumed to be neutral.

Differences between planting locations

Transplanted sedges produced more shoots on depositional locations than on erosional planting locations, regardless of species. Soil moisture differences at rooting depth may have contributed to shoot production differences between planting locations. Average soil moisture at depositional planting locations was higher than at erosional locations indicating more moisture for plant growth at depositional locations. The stream channel at meander bends, where depositional planting surfaces were located, generally exhibited pooled water for most of the growing season whereas erosional planting locations were associated with channel riffles or runs that ceased to flow by early July.

Soil texture in the planting surfaces ranged from sandy clay, silty clay to clay. Soils that have a high clay content retain more water than sandy textured soil, although this water may not be available for growth (Hillel 1998). Percent soil water at wilting in a clay soil is much higher than that of a sandy soil indicating that percent soil water can be higher in a clay soil and still cause plant stress (Hillel 1998). The high clay content at the study site may have influenced plant growth because plant stress was observed as soil moisture decreased throughout the growing season. While no transplant mortality was observed in the first growing season, a third of the transplants at the erosional planting locations were stressed. The leaf tips of the sedges within these plots began to desiccate and were yellow or brown by the end of the growing season although the center remained green. This trend was possibly due to lower soil moisture on erosional planting locations than on depositional planting locations.

Plants within the depositional planting locations also displayed some yellowing, but not to the extent of the plants at the erosional locations.

Differences observed during the second season could be attributed to erosion and actual transplant scour from the planting location (34% total loss). Depositional planting locations experienced both erosion and deposition therefore there was no apparent difference in deposition between years. Erosional locations eroded and no deposition was observed. Depositional surfaces experienced a 19% loss in sedge transplants while erosional surfaces experienced a 48% loss. Nearly half of the remaining transplants on the erosional surfaces were uprooted (47%) and holding on to the soil by small fibrous roots, but most of the uprooted sedges survived through the second growing season. Depositional surfaces had only 27% of the remaining transplants with exposed roots. The sedges remaining on erosional planting locations surprisingly produced more shoots during the second season than in the first season despite the fact they were uprooted. While this result is encouraging and exhibits how tolerant and adapted to disturbance these sedges are, it is also important to note that these sedges are at risk of being completely uprooted and removed during the next high flow event.

Differences may also be attributed to other environmental characteristics that were not measured, such as soil bulk density and nutrients. Traffic from farming practices in agricultural lands are known to increase soil compaction and bulk density, especially in clay soils (Hillel 1998). This may be related to the practice of stream reconstruction where heavy machinery is used to create a new channel. Steed and DeWald (2003) found that undisturbed meadows had lower bulk density than disturbed meadows. Higher bulk density may create an environment that is difficult for plant establishment. Soils with high bulk density hinders rhizome growth (Landhausser et al. 1996) and roots are generally unable to enter soil pores narrower than the root caps (Hillel 1998). Compact soil on the erosional locations could make it difficult for the sedge rhizomes to expand outside of the original transplant location. The channel was also constructed to be incised an average of one meter below the elevation of the meadow so the stream would have access to groundwater longer in to the summer. Topsoil was removed from the channel and not replaced. Plants were transplanted directly into B and C horizons. These horizons at this location have very little organic content and nutrients (Soil Survey 2007). Transplant growth may have increased if the original top soil had been utilized on the planting locations. Shoot expansion was observed to be less on erosional locations than depositional locations where shoots began to expand outside of the planting area. Sedges transplanted on depositional surfaces were observed to laterally spread about 0.25 m while sedges transplanted on erosional surfaces did not spread laterally more than a few centimeters. This growth pattern would give sedge transplants on depositional surfaces an advantage over sedges on erosional surfaces during high flows.

Depositional surfaces also receive sediment inputs from upstream that may contain more nutrients and may have a lower bulk density than the erosional locations making the depositional locations more appropriate for plant establishment. This difference is apparent at Bear Creek in areas that were not selected for planting. Colonizer riparian species, such as *Eleocharis* spp., were establishing on depositional features, while the visually dominant plant at erosional surfaces was *Cirsium arvense* (Canada thistle) that grows well in clay soils (Detmers 1927). This hypothesis needs to be tested further by comparing bulk density and soil nutrients at depositional and erosional features in a reconstructed channel.

CONCLUSIONS

Research at this location indicated that revegetation success was increased on depositional surfaces and *Carex nebrascensis* was a more vigorous species as indicated by greater shoot production than *C. utriculata*. Mortality was also due to scour during high flows rather than site conditions during the growing season. It is important to note that no transplants died in the first growing season due to site conditions although *C. utriculata* was probably not an appropriate choice for revegetation of this channel given the groundwater fluctuations. Establishing sedges on the depositional surfaces was not difficult and many of the depositional locations that were not selected for planting had early colonizing riparian species establishing.

Establishing deep rooted, soil binding sedges is important on erosional surfaces where the stream has the greatest risk for widening and down cutting. The upstream subplots generally had greater loss from scour than the downstream subplots suggesting the sedges planted on the upstream section of the plot buffered the sedges planted at the downstream section of the plot from erosional forces. A closer planting configuration or utilization of sedge mats may increase planting success on erosional locations, however this concept needs to be tested in the field.

REFERENCES

Allen-Diaz, B. H. 1991. Water table and plant species relationships in Sierra Nevada meadows. American Midland Naturalist 126: 30-43.

Beeson, C. E. and P. F. Doyle. 1995. Comparison of bank erosion at vegetated and non-vegetated channel bends. Water Resources Bulletin 31: 983-990.

Bernard J. M. 1990. Life history and vegetative reproduction in *Carex*. Canadian Journal of Botany 68: 1441-1448.

Bernhardt E. S., E. B. Sudduth, M. A. Palmer, J. D. Allan, J. L. Meyer, G. Alexander, et al. 2007. Restoring rivers one reach at a time: results from a survey of U.S. river restoration practitioners. Restoration Ecology 15:482–493.

Budelsky, R. A. and S. M. Galatowitsch. 1999. Effects of moisture, temperature, and time on seed germination of five wetland Carices: Implications for restoration. Restoration Ecology 7: 86-97.

Budelsky, R. A. and S. M. Galatowitsch. 2000. Effects of water regime and competition on the establishment of a native sedge in restored wetlands. Journal of Applied Ecology 37: 971-985.

Castelli, R. M., J. C. Chambers, and R.J. Tausch. 2000. Soil-plant relations along a soil-water gradient in Great Basin riparian meadows. Wetlands 20: 251-266.

Chambers, J. C., R. J. Tausch, J. L. Korfmacher, D. Germanoski, J. R. Miller, and D. Jewett. 2004. Effects of geomorphic processes and hydrologic regimes on riparian vegetation. In: Chambers, J. C. and J. R. Miller (eds.). Great Basin Riparian Ecosystems: Ecology, management, and restoration. Washington: Island Press. pp 196-231.

Clary, W. P., C. I. Thornton, and S. R. Abt. 1996. Riparian stubble height and recovery of degraded streambanks. Rangelands 18:137-140.

Crowe, E. A., B. L. Kovalchik, and M. J. Kerr. 2004. Riparian and Wetland Vegetation of Central and Eastern Oregon. Oregon State University, Portland, OR. 473 pp.

Detmers, F,. 1927. Canada thistle, *Cirsium arvense* Tourn. field thistle, creeping thistle. Bulletin of the Ohio Agricultural Experimental Station 414: 1-45.

Eriksson, O. 1989. Seedling dynamics and life histories in clonal plants. Oikos 55: 231-238.

Ewing K. 1996. Tolerance of four wetland plant species to flooding and sediment deposition. Environmental and Experimental Botany 36: 131-146.

Fagerstedt, K. V. 1992. Development of aerenchyma in roots and rhizomes of *Carex rostrata* (Cyperaceae). Nordic Journal of Botany 12: 115-120.

Galatowitsch, S. M. and A. G. van der Valk. 1996. The vegetation of restored and natural prairie wetlands. Ecological Applications 6: 102-112.

Hardy, T, P. Panja, and D. Mathias. 2005. WinXSPRO, A channel cross section analyzer, user's manual, Version 3.0. Gen. Tech. Rep. RMRS-GTR-147. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 95 p.

Harrelson, C. C., C. L. Rawlins, and J. P. Potyondy. 1994. Stream channel reference sites: an illustrated guide to field technique. GTR-RM- 245. USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado.

Hermann, F. J. 1970. Manual of the *Carices* of the Rocky Mountains and Colorado Basin. U.S. Department of Agriculture, Forest Service Handbook 374. U.S. Department of Agriculture, Forest Service, Washington, D.C.

Hillel, D. 1998. Environmental soil physics. Academic Press: San Diego, California.

Hoag, J. C. 2003. Harvesting, propagating, and planting wetland plants. Idaho Plant Materials Technical Note No. 13. USDA Natural Resources Conservation Service, Boise, ID. 11 p.

Hultgren, A. B. C. 1988. A demographic study of aerial shoots of *Carex rostrata* in relation to water level. Aquatic Botany 30: 81-93.

Jones, K. L, B. A. Roundy, N. L. Shaw, and J. R. Taylor. 2004. Environmental effects on germination of *Carex utriculata* and *Carex nebrascensis* relative to riparian restoration. Wetlands 24: 467-479.

Kleinfelder, D., S. Swanson, G. Norris, and W. Clary. 1992. Unconfined compressive strength of some streambank soils with herbaceous roots. Soil Science Society of America Journal 56: 1920-1925.

Knighton, D. 1998. Fluvial Forms and Processes: A new perspective. Oxford University Press Inc.

Landhausser, S. M., K. J. Stadt, V. J. Lieffers, and D. H. McNabb. 1996. Rhizome growth of *Calamagrostis canadensis* in response to soil nutrients and bulk density. Canadian Journal of Plant Science 76:545–550.

Law, D. J., C. B. Marlow, J. C. Mosley, S. Custer, P. Hook, and B. Leinard. 2000. Water table dynamics and soil texture of three riparian plant communities. Northwest Science 74: 234-241.

Littell, R. C, G. A. Milliken, W. W. Stroup, R. D. Wolfinger, O. Schabenberger. 2006. SAS® for Mixed Models, Second Edition. Cary, NC: SAS Institute Inc.

Manning, M. E., S. R. Swanson, T, Svejcar, and J. Trent. 1989. Rooting characteristics of four intermountain meadow community types. Journal of Range Management 42: 309-312.

Micheli, E. R. and J. W. Kirchner. 2002. Effects of wet meadow riparian vegetation on streambank erosion. 2. Measurements of vegetated bank strength and consequences for failure mechanics. Earth Surface Processes and Landforms 27: 687-697.

NRCS Plants Database. 2007. *Carex bebbii*. http://plants.usda.gov/ accessed [10/03/2007]

Oregon Climate Service. 2007. NOAA Cooperative data for Ukiah, Oregon. Corvallis, Oregon. http://www.ocs.orst.edu/index.html accessed [08/14/2007]

Ratliff, R. 1983. Nebraska sedge (*Carex nebraskensis* Dewey): Observations on shoot life history and management. Journal of Range Management 36: 429-430.

Ratliff, R. D. and S. E. Westfall. 1992. Nebraska sedge (*Carex nebraskensis* Dewey): Phenology and life history at Tule Meadow, Sierra National Forest, California. Journal of Range Management 45: 210-215.

Rosgen, D. 1996. Applied River Morphology. Wildland Hydrology, Pagosa Springs, CO, USA.

Smith, D. G. 1976. Effect of vegetation on lateral migration of anastomosed channels of a glacier meltwater river. Geological Society of American Bulletin 87: 857-860.

Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture. Web Soil Survey. Available online at http://websoilsurvey.nrcs.usda.gov/ accessed [08/14/2007].

Steed, J. E, L. E. DeWald, and T. E. Kolb. 2002. Physiological and growth responses of riparian sedge transplants to groundwater depth. International Journal of Plant Science 163: 925-936.

Steed, J. E. and L. E. DeWald. 2003. Transplanting sedges (*Carex* spp.) in southwestern riparian meadows. Restoration Ecology 11: 247-256.

Thorne, C. R. 1990. Effects of vegetation on riverbank erosion and stability. In: Thornes, J. B. (ed.). Vegetation and Erosion. John Wiley and Sons Ltd. pp 125-144.

van der Valk, A. G., T. L. Bremholm, and E. Gordon. 1999. The restoration of sedge meadows: seed viability, seed germination requirements, and seedling growth of *Carex* species. Wetlands 19: 756-764.

Wynn, T. M., S. Mostaghimi, J. A. Burger, A. A. Harpold, M. B. Henderson, and L. Henry. 2004. Variation in root density along stream banks. Journal of Environmental Quality 33: 2030-2039.

Yetka, L. A. and S. M. Galatowitsch. 1999. Factors affecting revegetation of *Carex lacustris* and *Carex stricta* from rhizomes. Restoration Ecology 7: 162-171.

Zimmerman, R. C., J. C. Goodlett, and G. H. Comer. 1967. Influence of vegetation on channel form of small streams. Symposium on river morphology. International Association of Scientific Hydrology 75: 255-275.

EFFECT OF *CIRSIUM ARVENSE* PRESENCE ON *CAREX NEBRASCENSIS* AND *CAREX UTRICULATA* TRANSPLANT GROWTH IN A RECONSTRUCTED MEADOW STREAM

ABSTRACT

Sedge transplanting success in a recently constructed channel is essential because the lack of vegetation makes the channel highly susceptible to erosion and non-native plant invasion. *Cirsium arvense* (Canada thistle) is an invasive forb that is suspected to reduce sedge transplant growth at restoration sites because of its similar rhizomatous growth structure. In this study, greenhouse grown plugs of *Carex nebrascensis* (Nebraska sedge) and *Carex utriculata* (beaked sedge) were transplanted in early summer (late June) onto channel erosional surfaces in the presence and absence of *Cirsium arvense*. Sedge transplant survival, vegetative reproduction (shoot number) and scour loss were recorded over 2 years. Depth to groundwater and soil moisture was also recorded at each planting location during the first growing season. Presence of *Cirsium arvense* was observed to reduce vegetative reproduction during the first growing season but not at the end of the second growing season. *Carex nebrascensis* produced more shoots than *Carex utriculata* regardless of thistles presence for both growing seasons probably due to depth to groundwater. Transplant loss due to scour from high flows was greater for *Carex utriculata* (55%) compared to *Carex nebrascensis* (28%). These results suggested that *Cirsium arvense* should be controlled following sedge transplanting during the first growing season. These results also suggested that *Carex nebrascensis* is an appropriate species for transplanting at sites with water tables are deeper than 30 cm.

INTRODUCTION

Riparian revegetation techniques are important to the success of channel restoration. Two native sedges, *Carex nebrascensis* Dewey (Nebraska sedge) and *Carex utriculata* Boott (beaked sedge) are often used in riparian restoration within the western United States because they have extensive root systems that can provide bank stability in fine-sediment channels. Factors affecting the success of riparian planting are competition (Budelsky & Galatowitsch 2000), water availability (Steed & DeWald

2003; Yetka & Galatowitsch 1999) and erosion. A national survey of restoration projects estimated 10% comprised channel reconstruction (Bernhardt et al. 2007) and in the Grande Ronde River Basin in north eastern Oregon an estimated 421 miles of stream have had instream work, including channel reconstruction (Grande Ronde Model Watershed 2007). Channel reconstruction is highly invasive and can leave streambanks bare. Planting success in a recently constructed channel is essential because the lack of vegetation makes the channel highly susceptible to erosion and non-native plant invasion.

Cirsium arvense (L.) Scop (Canada thistle) is an invasive perennial forb that colonizes rapidly in the absence of vegetation and may become a problem plant at restoration sites. It has been considered an invasive species in North American since the eighteenth century (Moore 1975). *Cirsium arvense* control is difficult because it colonizes rapidly by the growth of horizontal roots and has the ability to produce new buds and shoots at any time of year if the correct growing conditions are present (McAllister & Haderlie 1985; Moore 1975). The horizontal roots can grow up to 5 meters long and 0.6 to 6.75 m deep (Moore 1975; Morishita 1999) and this underground root structure suggests that it may be competitive with sedges that have similar growth patterns, such as *Carex nebrascensis* and *C. utriculata*. While *Cirsium arvense* can grow in a wide variety of habitats and environmental conditions (Morishita 1999) it generally does not grow well in saturated soils (Hayden 1934). It can, however, be found growing along stream and ditch banks (Hayden 1934). Certain perennial grasses and forbs can successfully compete with *C. arvense* (Wilson & Kachman 1999), raising the question of whether perennial native sedges used in restoration projects can successfully compete with *Cirsium arvense*.

Juvenile sedges are often used in revegetation of restoration sites. Immature sedges may be more susceptible to competition than established stands (Budelsky & Galatowitsch 2000). Budelsky and Galatowitsch (2000) found that competition reduced sedge transplant growth during the first season of growth but the effects of competition decreased during the second and third year of their study. This suggests that other plants present at the planting site may determine growth of sedges during the first year following transplanting but they have little effect after the sedges are established.

The objective of this study was to determine if *Cirsium arvense* presence is associated with survival and vegetative growth of transplanted *Carex nebrascensis* and *C. utriculata* in a reconstructed channel in NE Oregon.

SITE DESCRIPTION

The study was conducted on a meadow stream in the Blue Mountains in western Union County, Oregon. The study site was historically used for grazing and haying. The site is located at 45°18’5” north latitude and 118°17’4” west longitude (Appendix A). Bear creek is a first order, intermittent stream characterized by high flows in the spring and low flows mid-summer. The channel drains a 20.2 square kilometer watershed and flows north into the Grande Ronde River.

The study reach encompasses one mile of a reconstructed Rosgen “C/E” channel type, located within a gently sloped meadow (1.12%). The elevation of the floodplain ranged from 941 to 949 meters and the streambed material consisted mainly of silty clay and gravel deposits. Rosgen “C/E” channel types within the Blue Mountain Ecoregion are expected to support a healthy and dense *C. nebrascensis* community (Crowe et al. 2004). The meadow soils are a complex of cumulic and fluventic haploxerolls (Soil Survey Staff 2007).

Long term (1931-2002) average annual temperature and precipitation was obtained from the nearby weather station, in Ukiah, Oregon (45°08’N 118°56’W elevation 1036.3 m; OCS 2007). The average annual temperature is 6.1°C. The maximum and minimum temperatures range from 32.8°C in the summer to -24.4°C in the winter. The average annual precipitation is 43 cm, with the majority coming in the winter months as snow.

METHODS

Experimental Design

A randomized block design with a 2X2 factorial arrangement was used to test the effects of thistle presence and species on sedge plug survival and growth after transplanting (Appendix D). The thistle treatment had two levels (herbicide and no-herbicide) and the species factor had two levels (*Carex nebrascensis* and *Carex utriculata*). Planting locations were randomly selected and these locations served as blocks. Species were randomly assigned within blocks. The blocks were parallel to the stream flow and species plots were oriented perpendicular to the stream so each treatment received similar stream and groundwater influence. A total of nine blocks were located along the one mile length of the reconstructed stream.

Thistles were controlled using Milestone ™ Herbicide (Dow AgroSciences) using the recommended application rate. This herbicide was used because it targets broadleaf species and can be used along water sources that are not used for irrigation. In June 2006, prior to sedge planting, the herbicide treatment was applied to *Cirsium arvense* plants with a backpack sprayer to limit herbicide exposure to adjacent subplots. A combination of herbicide application and clipping was used to maintain the herbicide plots the remainder of the season. Plants other than the sedge plugs and thistles growing in all plots were also removed with hand tools.

Transplant Material

The two sedges, *Carex nebrascensis* and *C. utriculata*, were purchased from Wildlife Habitat Nursery in Princeton, Idaho in the form of 10 cubic inch plugs. This size was chosen because research has shown smaller plugs to be more susceptible to death due to environmental conditions than larger plugs (Steed & DeWald 2003). These sedges are often found intermixed naturally, but *C. nebrascensis* generally tolerates drier conditions while *C. utriculata* typically grows in saturated conditions (Hultgren 1988). The *C. utriculata* transplants had contamination of *Carex bebbii,* a cespitose wetland-obligate sedge. The initial percentage of contamination is unknown because the presence of this species was not apparent until the beginning of the second growing season. The percentage of contamination at the beginning of the second growing season was on average 5% per plot and the range was between 0-48% per plot. The percentage of contamination however, is overestimated because 55% of the *C. utriculata*/*C. bebbii* transplants were lost to scour prior to the second growing season. It is possible that *C. bebbii* established from seed during the study, but observation of the growing location within the *C. utriculata* plots suggests it was planted with the *C. utriculata* transplants. *Carex nebrascensis* plots did not contain any *C. bebbii*. *Carex bebbii* shoots were excluded from observation during the second year.

Transplanting

A total of 540 sedge plugs were transplanted at the field site in June of 2006. Planting locations were located in the straight reaches of the channel. Sedge plugs were planted below bankfull level to increase transplant access to water because the stream ceases flow by mid-July.

The transplants were planted with a dibble that was made to fit the diameter of the sedge plug. Each transplant was spaced 20 cm by 25 cm apart within each plot with 15 sedge plugs planted per treatment. Each plot within a block was separated by a 25 cm buffer to reduce treatment effects from adjacent plots. Each sedge transplant was marked with a ring of coated electrical wire placed around the base of the sedge plug. The average plot size including the buffer was 1.24 m^2.

Vegetation Measurements

Cirsium arvense stems and sedge shoot stems were counted weekly in each plot. Plants that were rooted directly under the top and left sides of the plot were recorded, those rooted under the bottom and right of the plot were not counted to reduce overestimation of density. Borders of the plot were determined by plot orientation to the flow of the water looking downstream. Densities were calculated according to the area of the plot. *Cirsium arvense* and sedge above ground stems were counted instead of the number of individuals because of the rhizomatous nature of these species.

Sedge survival was measured weekly July through September 2006. The transplants were considered alive if one green shoot was present and green tissue was present at least at the center of the plant (Ratliff & Westfall 1992). A transplant was considered dead if green tissue was absent. Cumulative stem emergence and shoot presence was measured weekly. Each transplant was marked with coated wire around the sedge base so that new shoots and the transplanted sedge could be distinguished.

Measurements during the second season included survival of transplanted sedge plugs, shoot counts and *C. arvense* stem counts in June and September of 2007. Above bankfull flows during spring runoff led to loss of sedge transplants due to scour in spring of 2007. Sedges that were not completely removed from the planting location were measured for root exposure using a metric ruler (Appendix F). These transplants remained anchored in the plots by small fibrous roots.

Groundwater Measurements

Groundwater depth was measured to estimate the depth to water the sedges experienced throughout the study. Depth to water was measured biweekly from late June to early September. Groundwater depths were obtained by extending a metal metric tape down the well to the water surface. The difference from the top of the well and ground level were subtracted from the groundwater depth. Actual depth to groundwater measurements were made relative to the average elevation of each planting surface.

Wells were placed at each block approximately one meter away from the plots on the floodplain to protect the wells from flood events. The wells were constructed of three inch perforated PVC pipe. Perforated PVC pipes were chosen over piezometers to ensure actual measurements of groundwater levels instead of head pressure. The wells were capped with a three inch PVC cap. The well depth was variable depending on the soil material; plots with coarser material had shallower wells. The well depth ranged between 1.2 and 2 meters.

DATA ANALYSIS

A two-factor completely randomized block design model ($\alpha = 0.05$) was used to detect differences among herbicide treatments for number of sedge shoots at the end of the first and second growing seasons and mortality in June 2007. The analyses were performed using Proc Mixed (SAS Institute, Cary, NC, U.S.A.) using the Type 3 estimation method and the Satterthwaite method for degrees of freedom (Littell et al. 2006). Random effects to account for variation among blocks and among plots within blocks were also included. The fixed effects for the model were species, herbicide and species/herbicide interaction. The random effect was plot. All means were obtained by using LSMEANS statement in SAS.

RESULTS

Presence of *C. arvense* was associated with a reduction in vegetative reproduction (shoot numbers) for both species ($F_{1,24} = 10.01$; $p = 0.0042$) (Table 3.1). The mean sedge shoot count was lower in the presence of *Cirsium arvense* than in the absence of *Cirsium arvense*. There was no interaction between species and thistle treatment. The average thistle density at the end of the season was 31 thistles per m². The range was from 14 to 53 thistles per m².

Species vegetative production was different between the two sedge species regardless of herbicide treatment. *Carex nebrascensis* had greater shoot numbers at the end of the first growing season than *C. utriculata* ($F_{1,24} = 6.08$; $p = 0.0212$) (Table 3.1).

Table 3.1. Average values (means ± SE) for sedge shoot numbers for September 2006 and 2007.
*Not significant at 0.10 level

Factor	2006	2007
Herbicide		
No-herbicide	61.4 ± 6.4	n.s.*
Herbicide	81.0 ± 6.4	n.s.*
Species		
C. nebrascensis	78.9 ± 6.4	134.3 ± 32.1
C. utriculata	63.5 ± 6.4	71.6 ± 32.1

No transplant mortality was observed during the first growing season. Transplant loss from scour occurred during above bankfull flows prior to the second growing season. Transplant loss from scour measured in June 2007 was significantly different between species ($F_{1,24} = 15.06$; $p = 0.0007$). *Carex nebrascensis* had less transplant loss out of the 15 sedges transplanted per plot (4.2 ± 1.2) than *C. utriculata* (8.2 ± 1.2; $n = 15$). Overall loss from the plots after high spring flows receded was 41% with 55% of the loss in the *C. utriculata* plots. Transplant loss, however, did not produce differences between species shoot numbers ($p = 0.0922$). Despite greater *C. utriculata* losses, there was no significant difference in the amount of shoot numbers between species at the beginning of the second growing season. Average transplant root exposure was not significantly different between treatments.

There was no association between *Cirsium arvense* and vegetative reproduction at the end of the second growing season, although thistle densities were similar to the first season with an average density of 29 thistles per m^2 (range 6 to 69 thistles per m^2). Differences between species performance were significant regardless of thistle presence ($F_{1,24} = 14.62$; $p = 0.0008$). *Carex nebrascensis* produced more shoots by the end of the second growing season than did *C. utriculata* (Table 3.1).

Stream flow steadily declined from mid-June until late July, when the remaining water was confined to small pools. The average groundwater depth throughout the growing season was 28 cm. The range of groundwater depths through the season was 12 cm above the planting surface early in the growing season and 40 cm below the planting surface at the end of the growing season (Fig. 3.1).

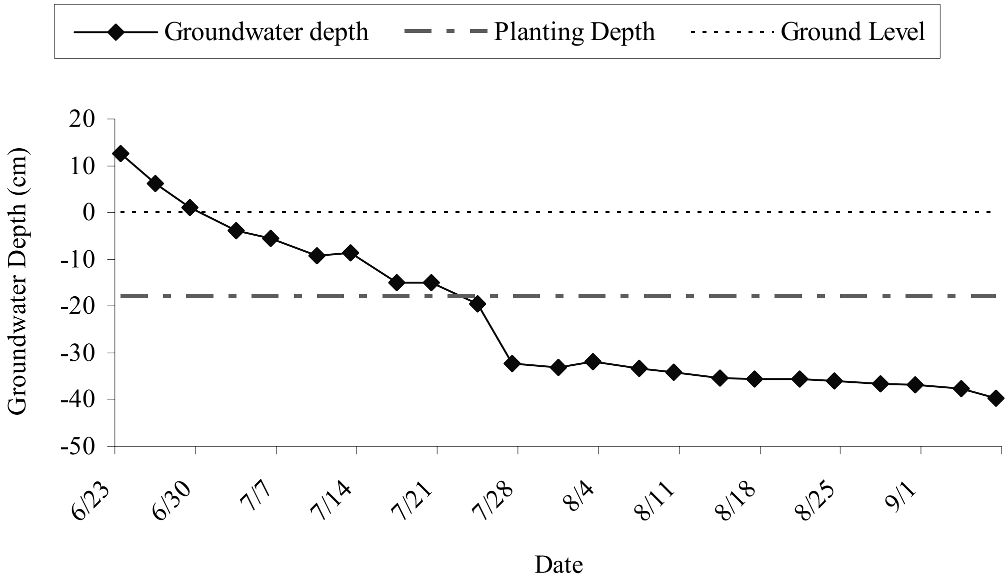


Figure 3.1. Average groundwater depths throughout the 2006 growing season. The transplant depth is the dashed line.

DISCUSSION

Study results indicated that the success of revegetation using sedge transplants in a reconstructed meadow stream is associated with the species of sedge transplanted and the presence of *Cirsium arvense*. The greatest vegetative growth was observed for sedges grown in the absence of *Cirsium arvense*. *Carex nebrascensis* also produced more shoots than *C. utriculata* regardless of thistle presence. High transplant loss was observed to be due to scour during bankfull flows and not directly due to environmental conditions during the growing season.

Presence of *Cirsium arvense* was associated with sedge vegetative reproduction the first year after planting but no effect was observed at the end of the second growing season. Many studies have been performed on the effects of *C. arvense* on annual plants specifically crops. Thistle densities in this study were similar to other studies on *Cirsium arvense* (Reece & Wilson 1983; Wilson & Kachman 1999). *Cirsium arvense* is known to reduce wheat yields and be competitive with many cereal crops (Mamolos & Kalburtji 2001), but it may not have the same effects on perennial plants. Stachon and Zimdahl (1980) found that it reduced annual plant growth although its effect was not tested on perennial species. Wilson and Kachman (1999) found that certain perennial grass species effectively compete and reduce biomass of *C. arvense*. Established stands of sedges may be able to compete with *C. arvense* better than annual plants. Juvenile sedges in this study appeared to be more sensitive to *C. arvense* presence than the established transplants in the second year of growth. A similar result was found by Budelsky and Galatowitsch (2000) who also found that other plants present at a revegetation site reduced *Carex lacustris* growth only in the first year except in the presence of *Phalaris arundinacea*. This invasive perennial grass reduced growth of *Carex lacustris* all three years of the study (Budelsky & Galatowitsch 2000).

Difference in water depth tolerances between *Carex utriculata* and *C. nebrascensis* could explain the difference in vegetative reproduction observed for these two species during the first growing season. *Carex nebrascensis* has a wide range of water depth tolerances when compared to *C. utriculata* (Allen-Diaz 1991; Chambers et al. 2004). Steed and DeWald (2003) found that *C. nebrascensis* transplants had highest survival with groundwater depths between 0.28 to 0.47 m below the ground surface. The water table depths within this study were within these ranges for *C. nebrascensis,* although some depths exceeded this range. *Carex utriculata* is generally associated with saturated conditions (Crowe et al. 2004) and often found growing in streams. Steed and DeWald (2003) also found *C. utriculata* transplants had an optimal survival range between 0.08 and 0.27 m from the ground surface. The water depths *C. utriculata* experienced in this study, on average, exceeded this water depth range which may be the cause for the lower vegetative reproduction. *Carex utriculata* transplants were observed to have more discoloration of leaves due to drying than *C. nebrascensis* although both visually displayed stress. Generally about one-fourth of the sedge leaves were yellow and beginning to desiccate by the end of the first season. The ephemeral nature of the stream flow and resulting groundwater characteristics at this site appear make *C. nebrascensis* more suitable for successful revegetation.

Loss of transplants was due primarily to hydrologic scouring instead of transplant stress. This result is different from the high levels of mortality due to site conditions observed in other studies during the first year of growth (Budelsky & Galatowitsch 2000; Steed & DeWald 2003; Yetka & Galatowitsch 1999). While water was limiting at this site and reduced vegetative growth, it did not lead to transplant mortality in the first growing season. Plant stress during the first season may have lead to an increase in transplant loss from scour during the second season because the sedges, particularly *C. utriculata*, were unable to extend roots in the surrounding soil. Transplants that did survive bankfull flows were left with much of their roots exposed (Appendix F). These transplants were anchored only through small fibrous roots. No further transplant loss due to scour or water availability was observed by the end of the second season. Although the sedges were able to reestablish roots and rhizomes in the soil during the second growing season it is unlikely that they will provide sufficient anchoring to survive another bankfull flow event.

Carex utriculata transplants did contain *C. bebbii* that has a cespitose growth form. The cespitose nature of *C. bebbii* could make it more susceptible to scour relative to the rhizomatous growth form of mature stands of *C. nebrascensis* or *C. utriculata*. The sedges that were transplanted were grown from seed and were immature when transplanted. Many of the transplants at the end of the first growing season had not extended rhizomes and shoots more than a few centimeters into the surrounding soil. The differences in growth form between *C. utriculata* and *C. bebbii* were not apparent at that early growth stage, making them equally susceptible to scour. Despite the presence of *C. bebbii*, it is unlikely that this was the driving the differences in transplant loss between species. Transplant stress was observed to be greater in the *C. utriculata* transplants than in the *C. nebrascensis* as noted from the difference between desiccation of the leaves between species. This apparent stress may have lead to insufficient root extension and biomass and an inability to withstand high flows.

CONCLUSIONS

Cirsium arvense presence was associated with a reduction in vegetative growth of *Carex nebrascensis* and *C. utriculata* during the first season after transplanting. This suggested that *Cirsium arvense* may be controlled during the first year of planting to increase sedge vegetative reproduction during the first year of growth. A formal competition study should be conducted to gain a better understanding of the affect that *Cirsium arvense* has on sedge vegetative growth . *Carex nebrascensis* produced more shoots for the duration of the study and was able to better tolerate environmental conditions at the site than *C. utriculata*. *Carex nebrascensis* is more suited for transplanting following reconstruction at this site. Sedges were not lost during the study directly due to water stress but were lost due to erosion and scour that may have been exacerbated by plant stress during the first growing season. It is apparent that *Carex nebrascensis* and *C. utriculata* are tolerant to disturbance because transplants that were partially uprooted and anchored in the soil only by small fibrous roots were able to reestablish and continued to produce new shoots. Tighter planting configurations or utilization of sedge mats may lead to a decrease in transplant loss from scour however this concept needs to be field tested.

REFERENCES

Allen-Diaz, B. H. 1991. Water table and plant species relationships in Sierra Nevada meadows. American Midland Naturalist 126: 30-43.

Bernhardt E. S., E. B. Sudduth, M. A. Palmer, J. D. Allan, J. L. Meyer, G. Alexander, et al. 2007. Restoring rivers one reach at a time: results from a survey of U.S. river restoration practitioners. Restoration Ecology 15:482–493.

Budelsky, R. A. and S. M. Galatowitsch. 2000. Effects of water regime and competition on the establishment of a native sedge in restored wetlands. Journal of Applied Ecology 37: 971-985.

Chambers, J. C., R. J. Tausch, J. L. Korfmacher, D. Germanoski, J. R. Miller, and D. Jewett. 2004. Effects of geomorphic processes and hydrologic regimes on riparian vegetation. In: Chambers, J.C. and J.R. Miller (eds.). Great Basin Riparian Ecosystems: Ecology, management, and restoration. Washington: Island Press. pp 196-231.

Crowe, E. A., B. L. Kovalchik, and M. J. Kerr. 2004. Riparian and Wetland Vegetation of Central and Eastern Oregon. Oregon State University, Portland, OR. 473 pp.

Grande Ronde Model Watershed. 2007. Selected Accomplishments for Grande Ronde Basin Restoration Projects from 1982-present. Online: http://grmw.org/projects/projects_inventory.shtml#sa accessed [10/25/2007].

Hayden, A. 1934. Distribution and reproduction of Canada thistle in Iowa. American Journal of Botany 21: 355-373.

Hultgren, A. B. C. 1988. A demographic study of aerial shoots of *Carex rostrata* in relation to water level. Aquatic Botany 30: 81-93.

Littell, R. C, G. A. Milliken, W. W. Stroup, R. D. Wolfinger, O. Schabenberger. 2006. SAS® for Mixed Models, Second Edition. Cary, NC: SAS Institute Inc.

Mamolos, A. P. and K. L. Kalburtji. 2001. Competition between Canada thistle and winter wheat. Weed Science 49: 755-759.

McAllister, R. S. and L. C. Haderlie. 1985. Seasonal variation in Canada thistle (*Cirsium arvense*) root bud growth and root carbohydrate reserves. Weed Science 33: 44-49.

Moore, R. J. 1975. The biology of Canadian Weeds. 13: *Cirsium arvense* (L.) Scop. Canadian Journal of Plant Science 55: 1033-48.

Morishita, D. W. 1999. Canada thistle. In: Sheley, R. L. and J. K. Petroff (eds.). Biology and Management of Noxious Rangeland Weeds. Oregon State University Press, Corvallis, OR. pp. 162-174.

Oregon Climate Service. 2007. NOAA Cooperative data for Ukiah, Oregon. Corvallis, Oregon. http://www.ocs.orst.edu/index.html. accessed [08/14/2007]

Ratliff, R. D. and S. E. Westfall. 1992. Nebraska sedge (*Carex nebraskensis* Dewey): Phenology and life history at Tule Meadow, Sierra National Forest, California. Journal of Range Management 45: 210-215.

Reece, P. E. and R. G. Wilson. 1983. The effect of Canada thistle (*Cirsium arvense*) and musk thistle (*Carduus nutans*) control on grass herbage. Weed Science 31: 488-492.

Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture. Web Soil Survey. Available online at http://websoilsurvey.nrcs.usda.gov/ accessed [08/14/2007].

Stachon, W. J. and R. L. Zimdahl. 1980. Allelopathic activity of Canada thistle (*Cirsium arvense*) in Colorado. Weed Science 28: 83-86.

Steed, J. E. and L. E. DeWald. 2003. Transplanting sedges (*Carex* spp.) in southwestern riparian meadows. Restoration Ecology 11: 247-256.

Wilson, R. G. and S. D. Kachman. 1999. Effect of perennial grasses on Canada thistle (*Cirsium arvense*) control. Weed Technology 13: 83-87.

Yetka, L. A. and S. M. Galatowitsch. 1999. Factors affecting revegetation of *Carex lacustris* and *Carex stricta* from rhizomes. Restoration Ecology 7: 162-171.

REVEGETATION AND RESTORATION SUGGESTIONS

The success of revegetation using sedge transplants in a reconstructed meadow stream appears to vary between species and planting location. Sedge transplanting success is increased on depositional surfaces and *Carex nebrascensis* produces more shoots than *C. utriculata*. The greatest vegetative growth in this study was observed for *C. nebrascensis* planted on depositional fluvial surfaces. The lowest vegetative growth observed in this study was *C. utriculata* planted on erosional fluvial surfaces. Overall, regardless of planting location, *C. utriculata* produced less shoots than did *C. nebrascensis.* The groundwater characteristics at this site suggested that *C. nebrascensis* is more suitable for revegetation of this channel. This observation emphasizes the importance of planting the appropriate sedge for particular water regimes.

Success of revegetation using sedge transplants in a reconstructed meadow stream also appears to vary between presence of *Cirsium arvense* and sedge species although no interaction exists between treatments. This suggests that *Cirsium arvense* should be controlled during the first year of planting to increase success of revegetation after channel reconstruction. The greatest vegetative growth observed were for sedges grown in the absence of *Cirsium arvense*. *Carex nebrascensis* also produced more shoots than *C. utriculata* regardless of thistle presence. Mortality was also due to scour during high flows rather than directly caused by site conditions during the growing season.

It is apparent that these sedges are tolerant to disturbance. Transplants that were partially uprooted and anchored in the soil by small fibrous roots in both studies were able to reestablish and continue to produce new shoots. Although the sedges were able to reestablish roots and rhizomes in the soil during the second growing season it is unlikely that they will provide sufficient anchoring to survive another bankfull flow event. Establishing deep rooted, soil binding sedges is important on erosional surfaces where the stream has the greatest risk for widening and down cutting. Combing knowledge in several fields in restoration including fluvial geomorphology and riparian ecology at the beginning of the restoration process could increase stability in channel form, function, and success of revegetation.

BIBLIOGRAPHY

Allen, D. R. and C. B. Marlow. 1994. Shoot population dynamics of beaked sedge following cattle grazing. Journal of Range Management 47: 64-69.

Allen-Diaz, B. H. 1991. Water table and plant species relationships in Sierra Nevada meadows. American Midland Naturalist 126: 30-43.

Beeson, C. E. and P. F. Doyle. 1995. Comparison of bank erosion at vegetated and non-vegetated channel bends. Water Resources Bulletin 31: 983-990.

Bernard, J. M. 1976. The life history and population dynamics of shoots of *Carex rostrata*. The Journal of Ecology 64: 1045-1048.

Bernard J. M. 1990. Life history and vegetative reproduction in *Carex*. Canadian Journal of Botany 68: 1441-1448.

Bernhardt E. S., E. B. Sudduth, M. A. Palmer, J. D. Allan, J. L. Meyer, G. Alexander, et al. 2007. Restoring rivers one reach at a time: results from a survey of U.S. river restoration practitioners. Restoration Ecology 15:482–493.

Budelsky, R. A. and S. M. Galatowitsch. 1999. Effects of moisture, temperature, and time on seed germination of five wetland Carices: Implications for restoration. Restoration Ecology 7: 86-97.

Budelsky, R. A. and S. M. Galatowitsch. 2000. Effects of water regime and competition on the establishment of a native sedge in restored wetlands. Journal of Applied Ecology 37: 971-985.

Castelli, R. M., J. C. Chambers, and R. J. Tausch. 2000. Soil-plant relations along a soil-water gradient in Great Basin riparian meadows. Wetlands 20: 251-266.

Chambers, J. C., R. J. Tausch, J. L. Korfmacher, D. Germanoski, J. R. Miller, and D. Jewett. 2004. Effects of geomorphic processes and hydrologic regimes on riparian vegetation. In: Chambers, J. C. and J. R. Miller (eds.). Great Basin Riparian Ecosystems: Ecology, management, and restoration. Washington: Island Press. pp 196-231.

Clary, W. P., C. I. Thornton, and S. R. Abt. 1996. Riparian stubble height and recovery of degraded streambanks. Rangelands 18:137-140.

Crowe, E. A., B. L. Kovalchik, and M. J. Kerr. 2004. Riparian and Wetland Vegetation of Central and Eastern Oregon. Oregon State University, Portland, OR. 473 pp.

Detmers, F,. 1927. Canada thistle, Cirsium arvenseTourn. field thistle, creeping thistle. Bulletin of the Ohio Agricultural Experimental Station 414: 1-45.

Eriksson, O. 1989. Seedling dynamics and life histories in clonal plants. Oikos 55: 231-238.

Ewing K. 1996. Tolerance of four wetland plant species to flooding and sediment deposition. Environmental and Experimental Botany 36: 131-146.

Fagerstedt, K. V. 1992. Development of aerenchyma in roots and rhizomes of *Carex rostrata* (Cyperaceae). Nordic Journal of Botany 12: 115-120.

Galatowitsch, S. M. and A. G. van der Valk. 1996. The vegetation of restored and natural prairie wetlands. Ecological Applications 6: 102-112.

Grande Ronde Model Watershed. 2007. Selected Accomplishments for Grande Ronde Basin Restoration Projects from 1982-present. Online: http://grmw.org/projects/projects_inventory.shtml#sa accessed [10/25/2007].

Hardy, T, P. Panja, and D. Mathias. 2005. WinXSPRO, A channel cross section analyzer, user's manual, Version 3.0. Gen. Tech. Rep. RMRS-GTR-147. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 95 p.

Harrelson, C. C., C. L. Rawlins, and J. P. Potyondy. 1994. Stream channel reference sites: an illustrated guide to field technique. GTR-RM- 245. USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado.

Hayden, A. 1934. Distribution and reproduction of Canada thistle in Iowa. American Journal of Botany 21: 355-373

Hermann, F. J. 1970. Manual of the *Carices* of the Rocky Mountains and Colorado Basin. U.S. Department of Agriculture, Forest Service Handbook 374. U.S. Department of Agriculture, Forest Service, Washington, D.C.

Hillel, D. 1998. Environmental soil physics. Academic Press: San Diego, California.

Hoag, J. C. 2003. Harvesting, propagating, and planting wetland plants. Idaho Plant Materials Technical Note No. 13. USDA Natural Resources Conservation Service, Boise, ID. 11 p.

Hoag, J. C. and M. Zierke. 1998. A reference guide for the collections and use of ten common wetland plants of the Great Basin and Intermountain West. Aberdeen (ID): USDA NRCS, Plant Materials Center. Riparian/Wetland Project Information Series #13. 13 p.

Hoag, J. C., F. E. Berg, S. K. Wyman, and R. W. Sampson. 2001a. Riparian planting zones in the Intermountain West. Aberdeen (ID): USDA NRCS, Plant Materials Center. Riparian/Wetland Project Information Series #16. 24 p.

Hoag, J. C., R. K. Dumroese, and M. E. Sellers. 2001b. Perigynium removal and cold, moist, stratification improve germination of *Carex nebrascensis* (Nebraska sedge). Native Plants Journal 2:63-66.

Hoag, J. C., S. K. Wyman, G. Bentrup, L, Holzworth, D. G. Ogle, J. Carleton, F. Berg, and B. Leinard. 2001c. Users guide to description, propagation and establishment of wetland plant species and grasses for riparian areas in the Intermountain West. Idaho Plant Materials Technical Note No. 38. USDA Natural Resources Conservation Service, Boise, ID. 46 p.

Hultgren, A. B. C. 1988. A demographic study of aerial shoots of *Carex rostrata* in relation to water level. Aquatic Botany 30: 81-93.

Jones, K. L, B. A. Roundy, N. L. Shaw, and J. R. Taylor. 2004. Environmental effects on germination of *Carex utriculata* and *Carex nebrascensis* relative to riparian restoration. Wetlands 24: 467-479.

Kleinfelder, D., S. Swanson, G. Norris, and W. Clary. 1992. Unconfined compressive strength of some streambank soils with herbaceous roots. Soil Science Society of America Journal 56: 1920-1925.

Knighton, D. 1998. Fluvial Forms and Processes: A new perspective. Oxford University Press Inc.

Landhausser, S. M., K. J. Stadt, V. J. Lieffers, and D. H. McNabb. 1996. Rhizome growth of *Calamagrostis canadensis* in response to soil nutrients and bulk density. Canadian Journal of Plant Science 76:545–550.

Law, D. J., C. B. Marlow, J. C. Mosley, S. Custer, P. Hook, and B. Leinard. 2000. Water table dynamics and soil texture of three riparian plant communities. Northwest Science 74: 234-241.

Littell, R. C, G. A. Milliken, W. W. Stroup, R. D. Wolfinger, O. Schabenberger. 2006. SAS® for Mixed Models, Second Edition. Cary, NC: SAS Institute Inc.

Mamolos, A. P. and K. L. Kalburtji. 2001. Competition between Canada thistle and winter wheat. Weed Science 49: 755-759.

Manning, M. E., S. R. Swanson, T, Svejcar, and J. Trent. 1989. Rooting characteristics of four intermountain meadow community types. Journal of Range Management 42: 309-312.

Martin D. W. and J. C. Chambers. 2001. Effects of water table, clipping, and species interactions on *Carex nebrascensis* and *Poa pratensis* in riparian meadows. Wetlands 21: 422-430.

McAllister, R. S. and L. C. Haderlie. 1985. Seasonal variation in Canada thistle (*Cirsium arvense*) root bud growth and root carbohydrate reserves. Weed Science 33: 44-49.

Micheli, E. R. and J. W. Kirchner. 2002. Effects of wet meadow riparian vegetation on streambank erosion. 2. Measurements of vegetated bank strength and consequences for failure mechanics. Earth Surface Processes and Landforms 27: 687-697.

Moore, R. J. 1975. The biology of Canadian Weeds. 13: *Cirsium arvense* (L.) Scop. Canadian Journal of Plant Science 55: 1033-48.

Morishita, D. W. 1999. Canada thistle. In: Sheley, R. L. and J. K. Petroff (eds.). Biology and Management of Noxious Rangeland Weeds. Oregon State University Press, Corvallis, OR. pp. 162-174.

Naiman, R. J., H. Decamps, and M. E. McClain. 2005. Riparia: Ecology, conservation, and management of streamside communities. Academic Press, San Diego, California.

Naiman, R. J. and H. Decamps. 1997. The Ecology of Interfaces: Riparian Zones. Annual Review of Ecology and Systematics. 28: 621-658.

NRCS Plants Database. 2007. *Carex bebbii*. http://plants.usda.gov/ accessed [10/03/2007]

Oregon Climate Service. 2007. NOAA Cooperative data for Ukiah, Oregon. Corvallis, Oregon. http://www.ocs.orst.edu/index.html accessed [08/14/2007]

Ratliff, R. 1983. Nebraska sedge (*Carex nebraskensis* Dewey): Observations on shoot life history and management. Journal of Range Management 36: 429-430.

Ratliff, R. D. and S. E. Westfall. 1992. Nebraska sedge (*Carex nebraskensis* Dewey): Phenology and life history at Tule Meadow, Sierra National Forest, California. Journal of Range Management 45: 210-215.

Reece, P. E. and R. G. Wilson. 1983. The effect of Canada thistle (*Cirsium arvense*) and musk thistle (*Carduus nutans*) control on grass herbage. Weed Science 31: 488-492.

Rosgen, D. 1996. Applied River Morphology. Wildland Hydrology, Pagosa Springs, CO, USA.

Smith, D. G. 1976. Effect of vegetation on lateral migration of anastomosed channels of a glacier meltwater river. Geological Society of American Bulletin 87: 857-860.

Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture. Web Soil Survey. Available online at http://websoilsurvey.nrcs.usda.gov/ accessed [08/14/2007].

Stachon, W. J. and R. L. Zimdahl. 1980. Allelopathic activity of Canada thistle (*Cirsium arvense*) in Colorado. Weed Science 28: 83-86.

Steed, J. E, L. E. DeWald, and T. E. Kolb. 2002. Physiological and growth responses of riparian sedge transplants to groundwater depth. International Journal of Plant Science 163: 925-936.

Steed, J. E. and L. E. DeWald. 2003. Transplanting sedges (*Carex* spp.) in southwestern riparian meadows. Restoration Ecology 11: 247-256.

Swanson, S. 1996. Simulated stream bank erosion of surface and subsurface samples from three meadow plant communities. Proceedings of the Sixth Federal Interagency Sedimentation Conference, March 10-14.

Thorne, C. R. 1990. Effects of vegetation on riverbank erosion and stability. In: Thornes, J. B. (ed.). Vegetation and Erosion. John Wiley and Sons Ltd. pp 125-144.

Tilley, D. J and J. C. Hoag. 2005. Comparison of methods for seeding Nebraska sedge (*Carex nebrascensis* Dewey [Cyperaceae]) and Baltic rush (*Juncus balticus* Willd. [Juncaceae]). Aberdeen (ID): USDA NRCS, Plant Materials Center. 6 p.

van der Valk, A. G., T. L. Bremholm, and E. Gordon. 1999. The restoration of sedge meadows: seed viability, seed germination requirements, and seedling growth of *Carex* species. Wetlands 19: 756-764.

Wetland Plant Fact Sheet: Nebraska sedge (*Carex nebrascensis*). Aberdeen (ID): USDA NRCS, Plant Materials Center. Riparian/Wetland Project. 3 p.

Wilson, R. G. and S. D. Kachman. 1999. Effect of perennial grasses on Canada thistle (*Cirsium arvense*) control. Weed Technology 13: 83-87.

Wissmar, R. C. 2004. Riparian corridors of Eastern Oregon and Washington: Functions and sustainability along lowland-arid to mountain gradients. Aquatic Science 66: 373-387.

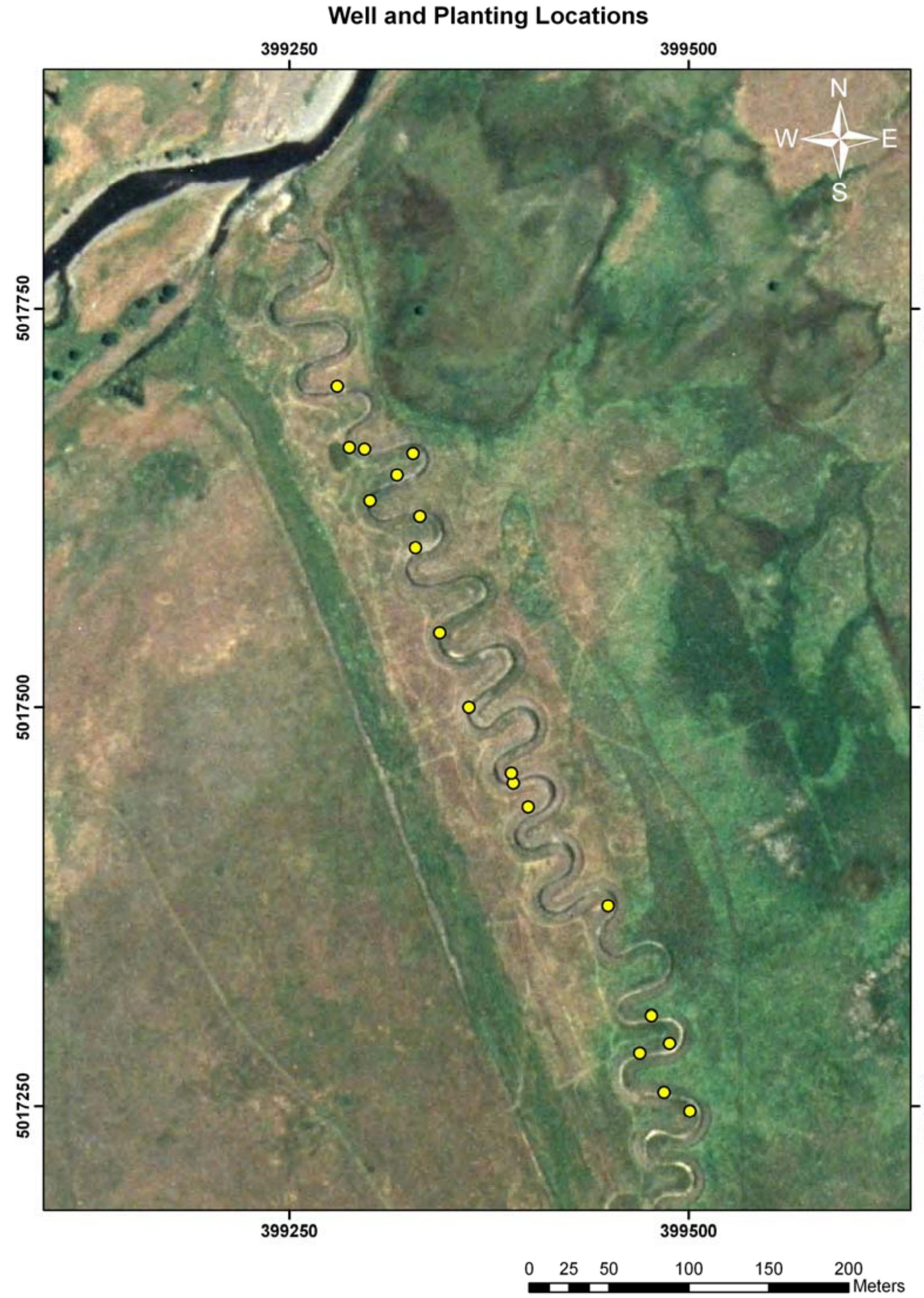
Wynn, T. M., S. Mostaghimi, J. A. Burger, A. A. Harpold, M. B. Henderson, and L. Henry. 2004. Variation in root density along stream banks. Journal of Environmental Quality 33: 2030-2039.

Yetka, L. A. and S. M. Galatowitsch. 1999. Factors affecting revegetation of *Carex lacustris* and *Carex stricta* from rhizomes. Restoration Ecology 7: 162-171.

Zimmerman, R. C., J. C. Goodlett, and G. H. Comer. 1967. Influence of vegetation on channel form of small streams. Symposium on river morphology. International Association of Scientific Hydrology 75: 255-275.

APPENDICES

APPENDIX A: AERIAL PHOTO SHOWING RESCONSTRUCTED CHANNEL, WELL AND PLANTING LOCATIONS.

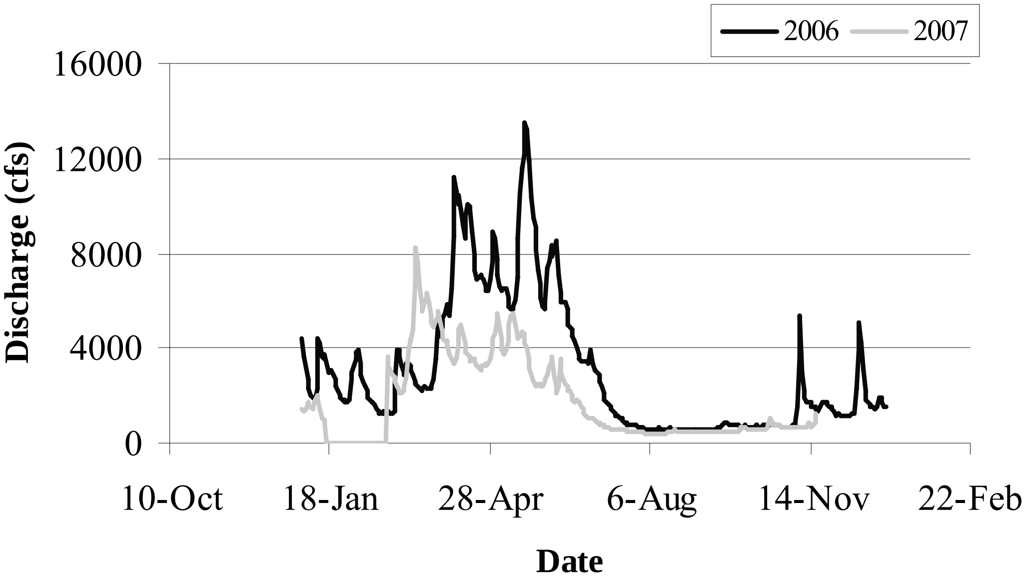


APPENDIX B: SITE SPECIES LIST

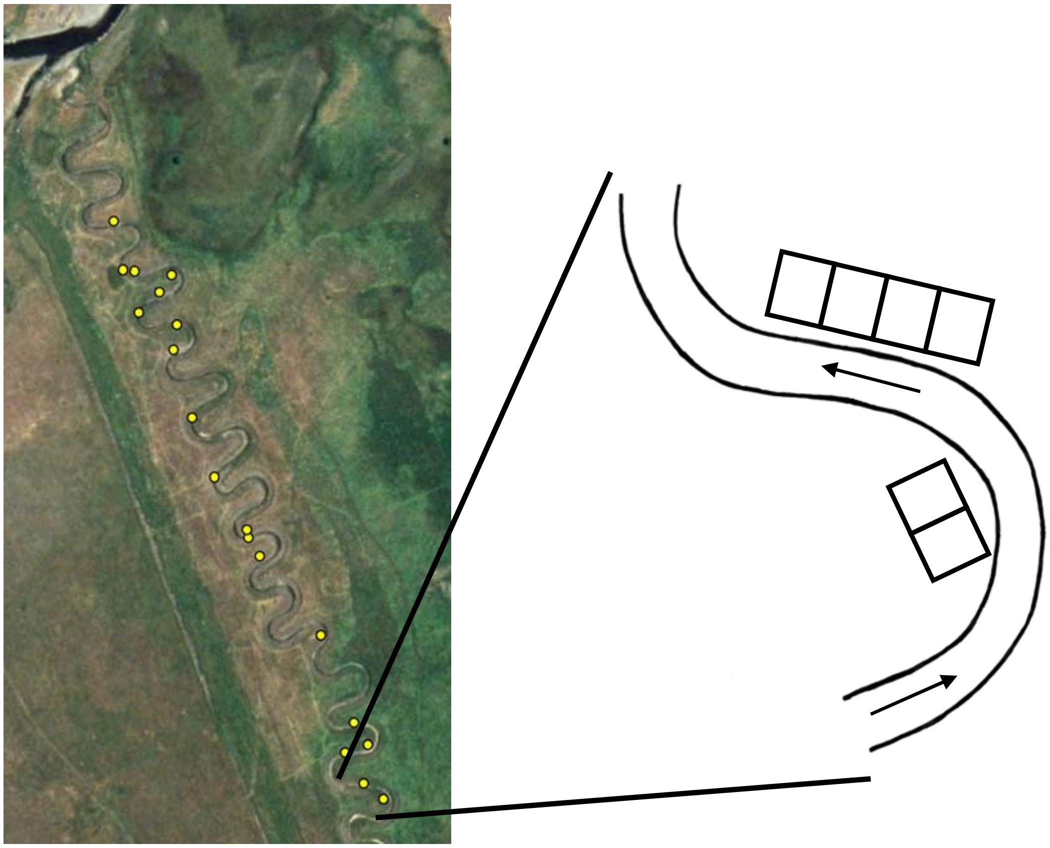
Scientific Name	Common Name
Agrostis stolonifera	creeping bentgrass
Alopecurus pratensis	meadow foxtail
Carex aquatalis	aquatic sedge
Carex microptera	smallwing sedge
Carex nebrascensis	Nebraska sedge
Carex stipata	owlfruit sedge
Carex utriculata	beaked sedge
Deschampsia caespitosa	tufted hairgrass
Epilobium brachycarpum	tall annual willowherb
Epilobium glaberrimum	glaucus willowherb
Erigeron spp.	fleabane
Festuca spp.	Fescue
Gentiana glauca	pale gentian
Glyceria grandis	American mannagrass
Hypericum perforatum	common St. Johnswort
Juncus balticus	Baltic rush
Juncus bufonius	toad rush
Juncus orthophyllus	straightleaf rush
Leymus cinereus	basin wildrye
Melilotus officinalis	yellow sweetclover
Microsteris gracilis var. *gracilis*	slender phlox
Mimulus guttatus	seep monkeyflower
Navarretia spp.	pincushionplant
Phalaris arundinacea	reed canarygrass
Poa pratensis	Kentucky bluegrass
Polemonium occidentale	Western polemonium
Polygonum watsonii	fruitleaf knotweed
Potentilla recta	sulphur cinquefoil
Prunella vulgaris	common selfheal
Ranunuculus repens	creeping buttercup
Rumex spp.	dock
Schoneoplectus acutus	hardstem bulrush
Scirpus microcarpus	panicled bulrush
Scrophularia lanceolata	lanceleaf figwort
Sidalcea oregana	Oregon checkerbloom
Sisymbrium altissimum	tall tumblemustard
Solidago canadensis	Canada goldenrod

Spiranthes romanzoffiana	hooded lady's tresses
Thermopsis montana var. *montana*	mountain goldenbanner
Torreyochloa pallida var. *pauciflora*	pale false mannagrass
Tragopogon dubius	yellow salsify
Trifolium repens	white clover
Veratrum californicum	California false hellebore
Verbascum thapsus	common mullein

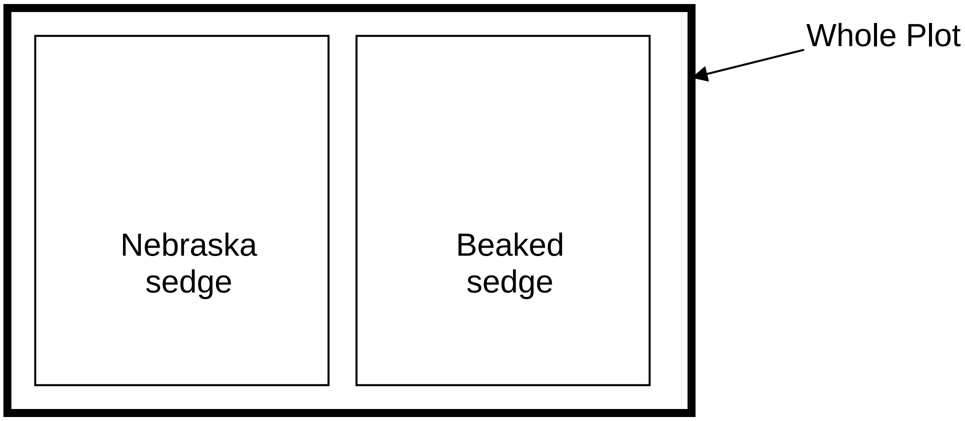
APPENDIX C: USGS HYDROGRAPH AT TROY, OREGON, 2006 and 2007

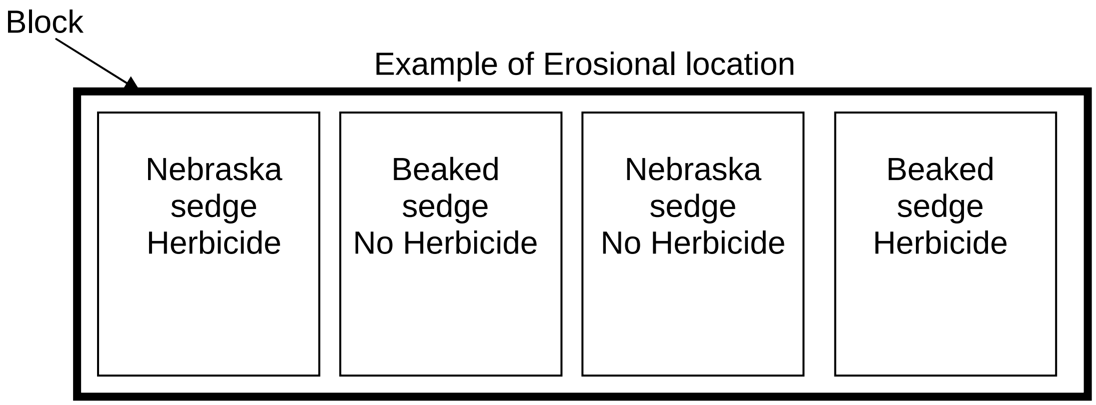


APPENDIX D: EXPERIMENTAL DESIGN



Example of erosional location




Block
Example of Erosional location
Nebraska sedge Herbicide
Beaked sedge No Herbicide
Nebraska sedge No Herbicide
Beaked sedge Herbicide

APPENDIX E: ANALYSIS OF VARIANCE TABLES

Test: Location (Depositional and Erosional) effect between species shoot numbers and mortality

Split-plot ANOVA Table proc mixed
Dependant Variables: Shoot number and mortality for 2006 and 2007

Source	Degrees of Freedom
Location	1
Species	1
Location*Species	1
Plot(Location)	16
Residual	16

Type 3 Tests of Fixed Effects

Effect	Numerator DF	Denominator DF
Location	1	16
Species	1	16
Location*Species	1	16

Test: Groundwater Difference between Planting Locations

Groundwater ANOVA proc GLM
Dependant Variable: Depth to Groundwater

Source	Degrees of Freedom
Location	1
Error	16
Corrected Total	17

Test: Soil Moisture Difference between Planting Locations

Soil moisture ANOVA proc GLM
Dependant Variable: Soil moisture

Source	Degrees of Freedom
Location	1
Error	16
Corrected Total	17

Test: Soil Moisture effect on Shoot numbers by Location

Location Split-plot ANCOVA proc mixed
Dependant Variable: Shoot number September 2006

Source	Degrees of Freedom
Soil*Location*Species	2
Plot(Location)	14
Residual	14

Type 3 Tests of Fixed Effects

Source	Numerator DF	Denominator DF
Location*Species	3	14.3
Soil*Location*Species	4	14

Test: Herbicide Treatment effects between species shoot numbers and mortality

Randomized Block ANOVA proc mixed
Dependant Variables: Shoot number and mortality for 2006 and 2007

Source	Degrees of Freedom
Species	1
Herbicide	1
Species*Herbicide	1
Plot	8
Residual	24

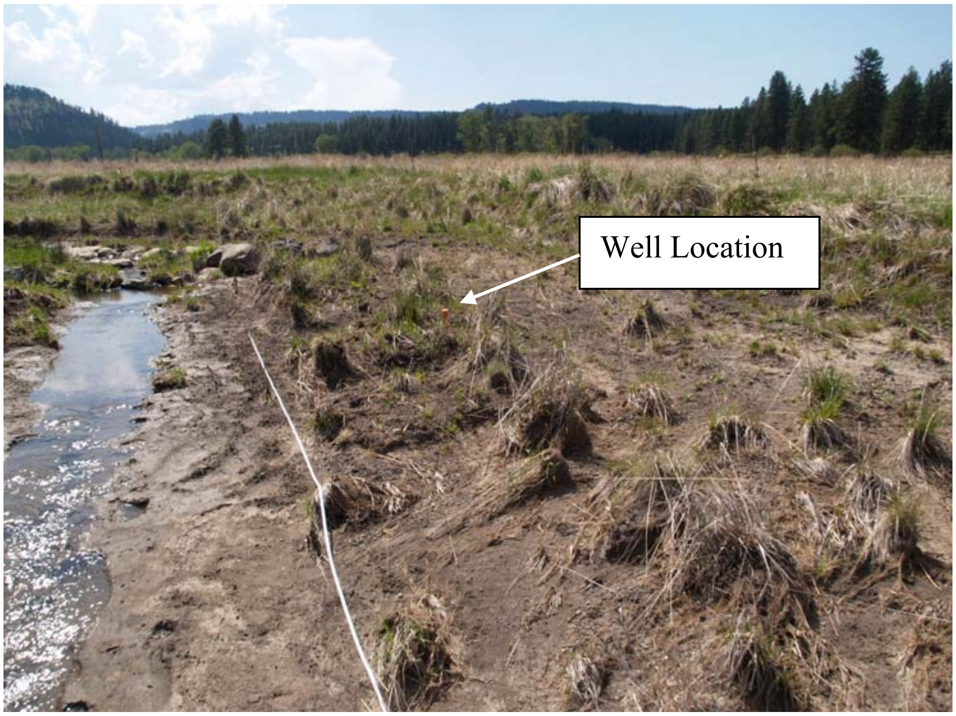
Type 3 Tests of Fixed Effects

Effect	Numerator DF	Denominator DF
Species	1	24
Herbicide	1	24
Species*Herbicide	1	24

APPENDIX F: SITE PHOTOS

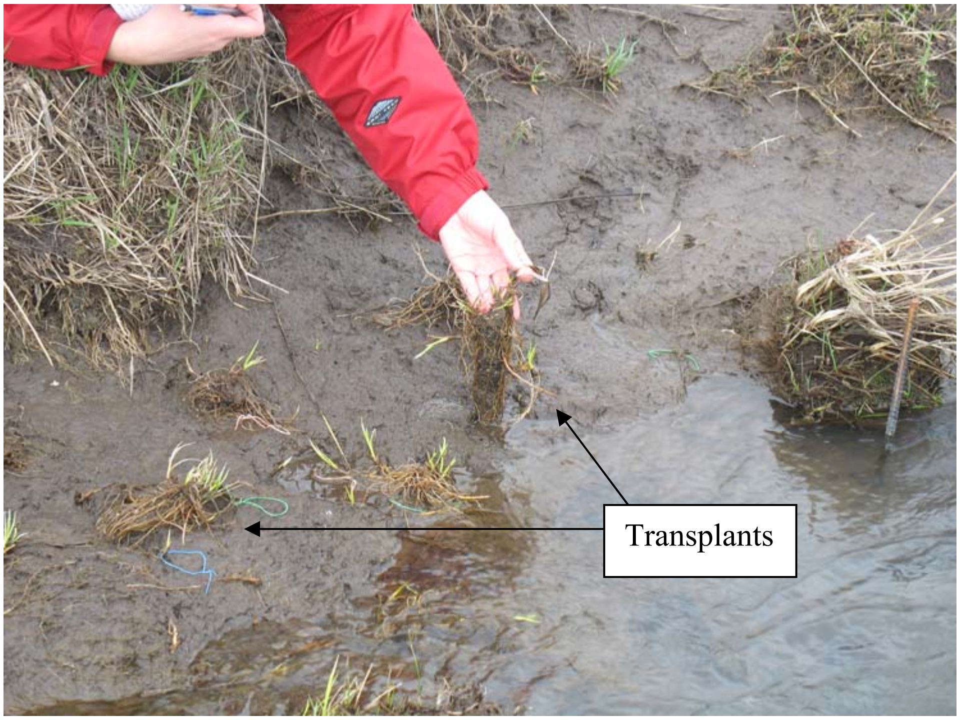
E.1: Depositional planting surface. *Carex nebrascensis* is on the left and *C. utriculata* is on the right. Date of photo: August 15, 2006

E.2: Erosional planting surface. *Carex nebrascensis* is on the left and *C. utriculata* is on the right. Note that the channel is dry. Date of photo: August 15, 2006



E.3: Erosional planting surface prior to planting. Orange stake near the center of the photo is the current groundwater well location. Date of photo: May 2006

E.4: Erosional planting surface April 2007. Note the rocks in the background are the same as the rocks in the background in photo E.3.



E.5: Transplant root exposure in spring (April) of 2007.

E.6: Close-up of transplant root exposure. Date of photo: June 26, 2007