STREAMSIDE REVEGETATION AND REED CANARYGRASS SUPPRESSION AT SILVER CREEK PRESERVE

Project Completion Report

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INTERMOUNTAIN AQUATICS INC.
ENVIRONMENTAL CONSULTING & HABITAT RESTORATION

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Executive Summary

Part 1 – Streambank Revegetation

Channel constrictors, using biolog forms and dredged streambed material, were installed to increase in-stream habitat diversity at the Nature Conservancy's Silver Creek Preserve near Sun Valley, Idaho. In 2004, five channel constrictions (600 m^2) were revegetated using closely spaced (15 cm) wetland plants. Initial success of the wetland plants was poor, primarily due to inadequate depth of fill behind the biolog forms and subsequent prolonged inundation during the growing season.

In June, 2005, wetland sod (a pre-vegetated coir mat) was installed on the constrictions with no additional fill. Wetland sod contains plants that are larger, more mature, and more tolerant to flooding than the individual plants used in 2004. Planting success of the wetland sod was measured using estimates of cover in belt transects for two years. In September, 2005, the wetland sod was fully rooted and thriving, suggesting an impressive success. By September, 2006, however, the wetland sod was a mosaic of healthy vegetation and open areas attributed to muskrat herbivory and prolonged inundation. In August, 2007, plant loss and open areas increased and plants were thriving only in those locations that were originally constructed with adequate fill.

Fill elevation, hydrology and herbivory combined to limit the success of the revegetation efforts. The elevation of most of the constrictors was too low and consequently the majority of the plants were too deep to achieve successful establishment. In contrast to a typical snowmelt-driven stream, the depth of water within the planted areas was greatest during the height of the growing season due to resistance of flow caused by dense beds of aquatic vegetation. The increased water depths (anything >6") facilitated movement and herbivory by muskrat within revegetated areas.

We recommend addressing the following issues when trying to establish native riparian vegetation: 1) understand the hydrology of your site including seasonal stage variations unrelated to discharge; 2) plan and construct elevations to match the hydrology and plant tolerances; 3) consider controlling herbivory during establishment; 4) plan to monitor for a minimum of 3 years and implement adaptive management techniques to insure success. It may also be more successful to err "too dry" when building channel constrictors and supplement with irrigation until plants are established rather than to err "too wet".

Part 2 – Reed Canarygrass Suppression and Revegetation Study

Establishment of a native wetland plant community within a reed canarygrass (RCG) dominated site was investigated at the Silver Creek Preserve from 2005 – 2007. Review of research and management literature indicated that revegetation by seeding after RCG control was likely to fail and that higher intensity revegetation methods would be needed. Three revegetation treatments were used and replicated at six locations throughout the project.

1. Medium density plugs (10 cubic inch containers 8.25 inches deep) planted on 2' centers (MDP)
2. High density plugs (10 cubic inch containers 8.25 inches deep) planted on 8" centers in hydro-mulched plots (HDP)
3. Wetland sod (pre-vegetated coir mats) (SOD)

In 2005, all plots were mowed in May and sprayed with a non-selective herbicide (glyphosate) in June and August. Herbicide efficacy was evaluated in September, 2005, using ocular cover estimates. Prior to treatment, all study sites were strongly dominated by RCG and had dense RCG litter. Spraying with glyphosate quickly killed the existing RCG stands, consistent with experience reported in other locations. Substantial but uneven mortality was seen after four weeks. After two months, prior to the second herbicide application in late August, vegetation appeared dead except for occasional rushes and sedges. Four weeks after the second application, only trace amounts of RCG with green leaves remained. Immediately before planting experimental plot plant density was very low with an average 1.4 plants per square meter.

In May of 2006, plots were prepared for planting using the following techniques: HDP plots were hydro-mulched with EcoAegis® at 3500 lb/acre (80 lb/1000 ft^2); SOD plots were raked to remove litter, expose soil, and to create a relatively even surface; MDP plots had no additional preparation and litter was left in place. Plots were planted May 31-June 2, 2006. All three revegetation treatments used one-third *Carex utriculata*, one-third *C. nebrascensis*, and one-third *Juncus arcticus* with individuals of the three species alternating within the planting grid. Plots were watered daily during the first few weeks and then every 2-3 days using a high capacity pump and garden hose. Even with extensive watering, some of the SOD plots experienced extensive mortality due to a lack of consistent soil moisture during establishment. Plots with the most consistently wet hydrology did the best, and sites that were initially dryer and then wet later in the growing season were more susceptible to colonization by RCG.

Cover was estimated on September 27, 2006, to evaluate initial revegetation success and presence of RCG**.** Percent cover of the planted species was generally higher in HDP and SOD plots than MDP plots. Percent RCG cover was highest in MDP plots, lowest in SOD plots, and intermediate in the HDP plots. In SOD plots most of the visible RCG plants were in small gaps between the coir mats; overlapping mat edges could help exclude RCG plants that otherwise can grow through gaps. The results suggested that although the higher intensity revegetation methods (HDP and SOD) were more successful than the lower intensity methods (MDP and CON), RCG was still able to invade the higher intensity sites within one growing season. Consequently, long-term results for planted species may not follow these initial patterns and the success of the revegetation efforts may be compromised by RCG re-establishment. RCG was most abundant in study plots with groundwater nearest the surface. Together with observations of streambank sites, these results suggest that sites that are relatively wet but not subject to significant flooding may be more susceptible to reinvasion of by RCG.

Introduction

This study evaluated restoration techniques to address degraded habitat conditions at the Nature Conservancy, Silver Creek Preserve. The Silver Creek Preserve is comprised of 883 acres of riparian and upland habitats at the headwaters of Silver Creek in south-central Idaho. In-stream and riparian habitat conditions at the preserve have deteriorated over time due to land use, sediment accumulation, channel widening and the presence of *Phalaris arundinacea* (reed canary grass, RCG).

RCG is an aggressive rhizomatous grass, which dominates many riparian areas in the Silver Creek watershed and is thought to be expanding. It is a threat to native plant communities, aquatic habitat quality, and stream restoration projects because it forms dense stands that exclude native vegetation, reduce biodiversity, and limit establishment of shrubs. RCG can dominate in a wide range of hydrologic conditions from standing water to riparian sites with infrequent saturation. Once established, it is very difficult to control RCG and restore a native plant community. On stream banks, RCG is a rapid stabilizer and can suppress dynamic stream processes that promote in-stream habitat diversity.

In the fall of 2003, the Nature Conservancy initiated stream restoration work to enhance aquatic habitat in Stalker Creek. Objectives included constricting and deepening the channel to accelerate velocities, maintain spawning gravels, and create a more natural meander pattern. Five channel constrictors were constructed using biolog forms and back-filled with dredged streambed material. The channel constrictors were back-filled using a hand-held suction dredge. Due to limited time, the level of effort to fill the forms decreased as the crew moved downstream. Consequently many of the constrictors were constructed with less fill than originally specified by the design. Willow cuttings were inserted in some biologs and on selected reaches of existing streambanks, and herbaceous wetland species were planted on some of the constrictors.

The hydrology of Stalker Creek, like many low-gradient spring creeks, presents distinct challenges for revegetation because water levels rise significantly during the growing season when submerged aquatic plant biomass is at its greatest. Most of the herbaceous plants on the constrictors were overtopped by high water for long periods and died by the end of the 2004 growing season. The constrictors were also threatened with invasion by RCG.

The first part of this study investigated the revegetation of the channel constrictors using wetland sod, a pre-planted erosion control mat. Wetland sod contains plants that are larger and more tolerant to flooding than the individual plugs. Planting success of the wetland sod was measured using estimates of cover in belt transects for two years.

The second part of the study tested methods to suppress RCG and establish native sedges and rushes at off-channel locations adjacent to Stalker Creek. Published research and case studies indicated that repeated herbicide treatment (usually glyphosate) can suppress RCG but provided little information about the effectiveness of revegetation techniques following herbicide applications. This is surprising because suppression of RCG without reestablishing a native plant community often results in reinvasion. This study tested herbicide application in combination with three revegetation techniques and a control.

Project Task List

- **Compile background information related to stream and riparian restoration at Silver Creek Preserve.**
- **Revegetate sections of the Stalker Creek restoration project using wetland sod and evaluate the performance of this technique.**
- **Test reed canarygrass suppression and revegetation methods to guide future restoration of invaded riparian sites.**

Background Information

Silver Creek Preserve

The coldwater fishery in Silver Creek and its tributaries has been well studied (Appendix A). Records show that sediment accumulation and its effects on the fishery have been an on-going concern. Channel modifications for habitat enhancement and sediment removal started as early as 1956. Sediment retention and build up of submerged aquatic vegetation (SAV) has been attributed to low stream gradients and water velocities, and infrequent flushing flows. Stream locations on aerial photographs have been stable for the last 50 years; however, in-stream habitat conditions have been declining since the 1960s. Altered land and water use have been suggested as causes of siltation, nitrate enrichment, impacts to aquatic insects, and other changes. Riparian grazing, agricultural cultivation, dams and culverts have undoubtedly altered sediment loading, accumulation, and transport, but the degree to which current sediment dynamics reflect human impacts is not clear. Abundant SAV, low stream gradients, and steady, moderate flows may have acted to retain considerable mineral and organic sediment even before human impacts.

In contrast to aquatic resources, there is relatively little data for riparian or upland vegetation. Based on a list of plant species observed in a survey conducted after the Silver Creek Preserve was established, riparian communities probably included a mixture of native species, introduced pasture grasses, and weeds such as quackgrass and Canada thistle. RCG was not listed at that time (1977) although it may have been introduced. By 1985, a report on part of Wilson Creek indicated that RCG was abundant on stream banks and described clumps of RCG growing on top of *Chara* mats in the channel. Based on available information, it is most likely that invasive RCG populations at the Silver Creek Preserve are introduced agronomic varieties from commercial or government seed sources.

Summary of reed canarygrass management and research literature

RCG is a perennial, rhizomatous grass that dominates riparian areas throughout the mid-west and western United States (Appendix A). Invasion of RCG is often associated with disturbance and ecological degradation. The Soil Conservation Service helped plant RCG throughout the U.S. to combat soil erosion resulting from agricultural practices. RCG can rapidly occupy disturbed sites and quickly stabilize eroding soils. These same qualities that make RCG a great site stabilizer also result in near monocultures with low species richness, diversity and habitat quality. RCG can dominate in a wide range of hydrologic conditions and can suppress dynamic stream processes that promote in-stream habitat diversity. In watersheds where it is present, it is often the first species to colonize and occupy a site after a disturbance.

Invasive behavior of RCG has been attributed to many causes: introduction of exotic genotypes, opening of migration corridors such as roads, hydrologic alteration, physical disturbance, and nutrient enrichment in wetland and riparian ecosystems. Multiple factors are likely at work at Silver Creek Preserve and throughout reed canarygrass' North American range. Greenhouse and garden experiments have shown that RCG can outcompete and suppress native plants, especially with disturbance and high nutrients. Native sedges are favored over RCG only at very low nutrient levels; even modest nitrogen enrichment tips the competitive balance in favor of RCG. These factors, and the aggressive and tenacious nature of RCG, present a huge hurdle when trying to establish native herbaceous vegetation in infested watersheds.

Many methods to control RCG have been tested. These include: herbicides, burning, mowing, solarization ("tarping"), hand weeding, cultivation, flooding, topsoil removal, and carbon additions to deplete soil nutrients. Information from management experience and research indicates that herbicide treatment (usually glyphosate) is the most consistently effective practice. Herbicide efficacy is sometimes improved by combining with mowing, tilling, burning, or other cultural practices. However, mechanical practices and burning are not effective on their own and may even worsen infestations. Sustained, deep flooding after herbicide or mechanical control may be effective where water levels can be managed. Specific practices must be tailored to individual sites and practical realities. No one practice is believed to provide sustained RCG control. Persistent monitoring, follow-up treatments and active revegetation are required over many years to achieve desired results.

Establishment of a native wetland plant community after RCG suppression is difficult and has not been widely studied. Available information and our prior experience suggest that aggressive revegetation is necessary for successful RCG replacement. Passive revegetation of sedge meadows is generally unsuccessful and is risky when RCG or other undesirable species remain in the surrounding area. Seeding is also likely to be ineffective and expose sites to easy reinvasion. When passive revegetation or seeding is attempted, RCG control may allow other invasive plants or opportunistic natives to increase. Aggressive revegetation with desired species after RCG control has the potential improve success. Revegetation techniques using trees and shrubs recently have been found successful at shading out RCG once established. To our knowledge, tests of aggressive revegetation strategies have not been reported for herbaceous communities.

Methods

Project location

Restoration work and supporting research were performed in and next to Stalker Creek at the Nature Conservancy's Silver Creek Preserve. Silver Creek Preserve is located in Blaine County, Idaho, west of the town of Picabo. Stalker Creek is a low-gradient spring creek flowing through nearly level terrain at the foot of the Picabo Hills. The valley rises to the northwest at a slope of roughly 0.3%; Stalker Creek has a slope of about 0.02-0.05% in the project area. The creek derives its flow from springs that are fed, via groundwater, from the Big Wood River and irrigation transfers. It is an important tributary to Silver Creek. Below its confluence with Mud Creek, Stalker Creek's discharge ranged from 25 to 50 CFS at most times in 2005 and 2006. Stalker Creek and its tributaries have been altered by small dams, culverts, and other modifications, but the locations of most reaches have remained unchanged since at least 1951. The creek is bordered by wetlands, riparian shrublands, subirrigated flats, pasture, and cropland. The study site was approximately 0.5 mile (0.8 km) west-southwest of the Preserve headquarters. Locations of stream restoration work, plots used to evaluate RCG control and revegetation, and stream gauges are shown in (Figure 1).

Streambank Revegetation

Channel narrowing and revegetation: In the fall of 2003, channel constrictors were installed on a 0.4 mile (0.6 km) reach of Stalker Creek. Areas on channel edges were enclosed with coir rolls ("biologs") by the Nature Conservancy staff and volunteers. These streambank treatment areas varied in size and alternated between right and left banks to increase sinuosity while narrowing the channel. The upper five streambank treatment areas were backfilled with dredged sediment; the depth of fill generally thinned downstream. The five filled areas were planted with closely spaced seedlings of herbaceous wetland species, and willow cuttings were inserted in biologs. Willow cuttings were also planted on streambanks throughout the project reach, typically on upper banks within 6 ft (2 m) of the channel and 1-3 ft (0.3-1 m) above the summer high water level. By the end of the 2004 growing season, prolonged flooding during the growing season had killed most of the herbaceous plants.

In 2005, Intermountain Aquatics (IMA) was asked to review the existing site conditions and recommend a revegetation strategy. IMA proposed testing pre-vegetated coir mats ("wetland sod") in the five upper streambank treatment areas. Wetland sod has larger, more mature plants that can tolerate flooding better than seedlings. The wetland sod mats were installed in streambank treatment areas on June 2-3, 2005. Before planting, debris including concrete blocks and brush that extended above the sediment was removed from filled areas. Several clumps of RCG were also removed.

Volunteers and TNC staff installed 111 pieces of wetland sod covering an area of approximately 6000 ft^2 (660 m^2). Sixty percent of the sod contained a mixture of Nebraska sedge (*Carex nebrascensis*), beaked sedge (*Carex utriculata*), and arctic rush (*Juncus arcticus,* formerly *J. balticus*); this was installed on the higher areas. The other 40% contained hardstem bulrush (*Schoenoplectus acutus*, formerly *Scirpus acutus*) and was installed in lower areas. Approximately 360 linear ft (109 m) of streambanks were planted. Width of planted areas averaged 20 ft (6 m) from the base of the original banks to the biologs.

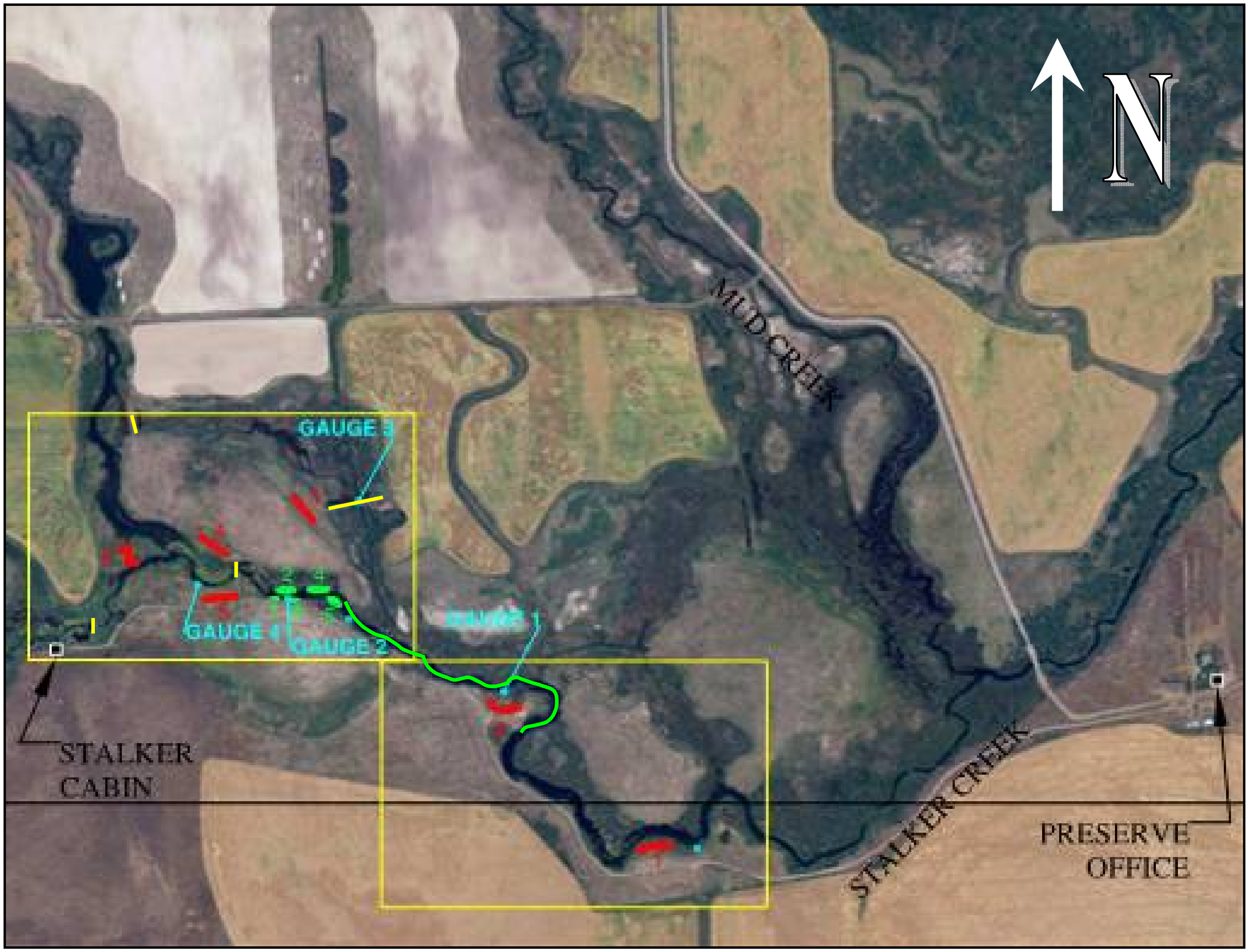


Figure 1. Study site locations on Stalker Creek at Silver Creek Preserve. Streams flow from left to right of page. Streambank Treatment Areas are shown in green, Reed Canarygrass Study areas are in red, and staff gauges are in blue. Detailed views of the two areas outlined in yellow are shown on the next page.

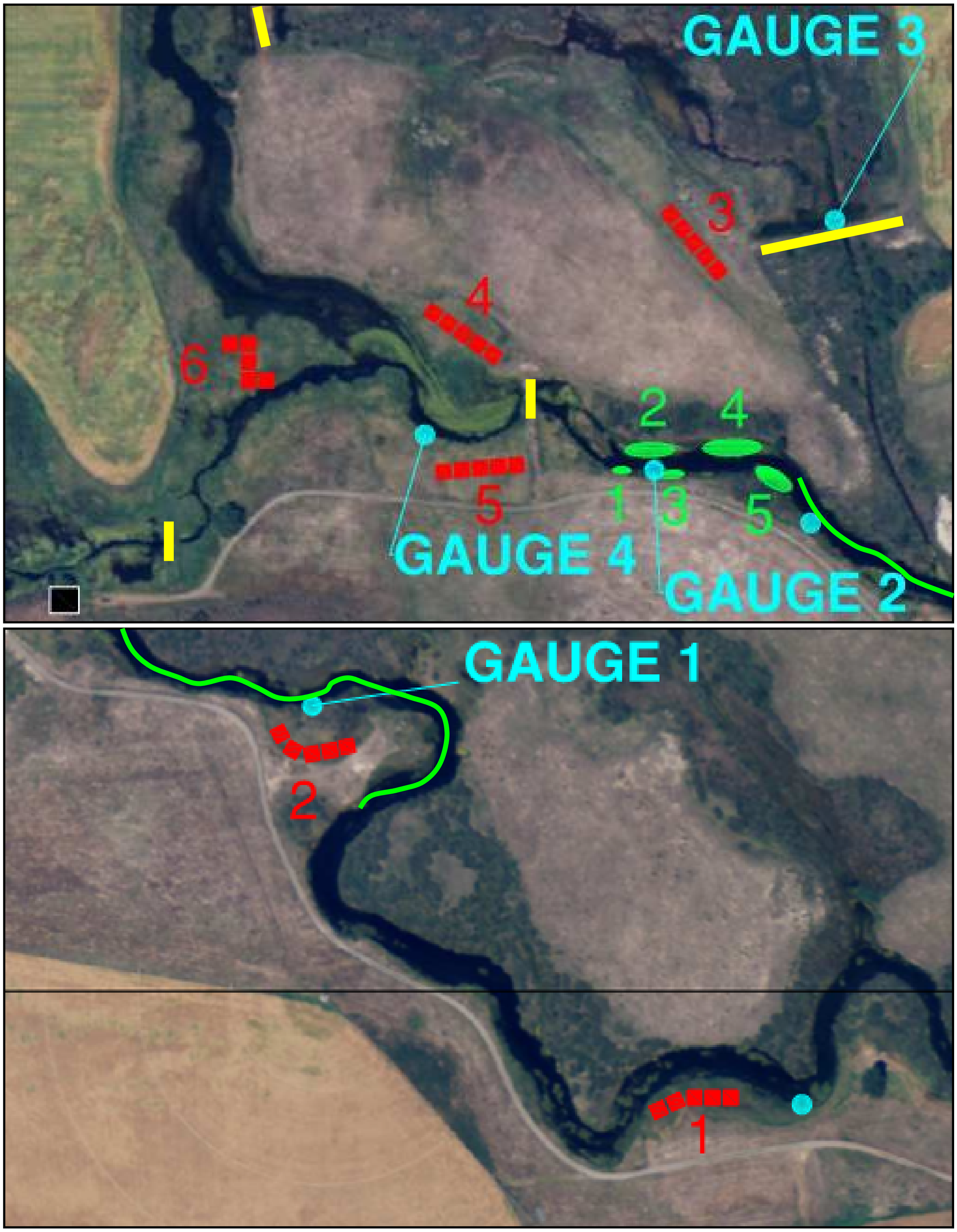


Figure 1 continued. Detailed views of study site locations on Stalker Creek. Green ellipses represent the Streambank Treatment Areas studied in this project; the green line represents the rest of the reach treated in the restoration project. Red rectangles represent Reed Canarygrass Study plots. Staff gauges are blue; the two unnumbered gauges were already present. Manmade dams are represented by yellow bars; additional beaver dams and stream-restricting culverts occur upstream.

Vegetation monitoring: Plant cover, wildlife damage, and weeds were evaluated at the end of the first and second growing seasons on September 22-23, 2005, and September 28, 2006. The entire planted area was sampled by subdividing each streambank treatment area into 2-m wide belts perpendicular to streambanks and estimating cover and wildlife damage visually in each belt. Presence and location of any RCG or other undesirable plants were also recorded. Though not a part of this study, the condition of willow cuttings planted during initial revegetation efforts was evaluated informally. Upstream and downstream ends of streambank treatment areas were monumented with permanent stakes to facilitate relocation of sampling belts for vegetation monitoring.

Stream cross-sections: Nine cross-sections were set up and monumented with permanent metal stakes to allow long-term monitoring of the streambank treatments and the stream channel. Cross-sections spanned the stream channel, streambank treatment areas, and adjacent stream banks. Cross-sections were surveyed June 3, 2005, immediately after installation of wetland sod (except cross-section 9 which was not surveyed until September due to severe weather) and again September 26-27, 2006. Elevations were measured at 1 m intervals in stream bank and planted areas, 2 m intervals in the channel, and at abrupt changes such as steep banks and biologs.

Reed Canarygrass Suppression and Revegetation Study

Plot layout and treatments: Thirty plots clustered at six sites (replicate statistical "blocks") were set up to test control and replacement of RCG. Review of research and management literature indicated that seeding after RCG control was likely to fail and that relatively high intensity revegetation methods would be needed (Appendix A). Four revegetation treatments were used:

1. Unplanted Control (passive revegetation, "CON");
2. Medium Density Plugs planted on 2 ft centers ("MDP");
3. High Density Plugs planted on 8 inch centers in hydromulched plots ("HDP");
4. Wetland Sod (pre-vegetated coir mats, "SOD").

A Reference plot ("REF"), which was left untouched, was also set up at each site. The rationale for choice of experimental treatments is documented in Appendix A.

In 2005 all plots except Reference plots were mowed and sprayed with a non-selective herbicide on the following schedule to control RCG:

1. Mowed with rotary weed trimmer May 26-31.
2. Sprayed with glyphosate June 25-26, when re-growth reached 8-10 inch height, using backpack sprayers.
3. Re-sprayed August 24-25.

Glyphosate was applied as 1oz/gal of AquaNeat®, a formulation for aquatic applications, 0.25 oz/gal surfactant, and 0.38 oz/gal blue dye to confirm coverage.

In 2006, plots were prepared for planting as needed for each revegetation treatment:

1. High Density Plug plots were hydromulched May 22, 2006, with EcoAegis® at 3500 lb/acre (80 lb/1000 ft^2), the manufacturers recommended rate. Site 3 was not accessible by truck due to wet ground, and its HDP plot was not hydromulched.
2. Wetland Sod plots were raked to remove litter, expose soil, and improve root-soil contact. Large hummocks were removed with a mattock to create a relatively even surface.
3. Medium Density Plug and Control plots had no additional preparation. Litter was left in place.

Revegetated plots were planted May 31-June 2, 2006. All three revegetation treatments used one-third *Carex utriculata*, one-third *Carex nebrascensis*, and one-third *Juncus arcticus* with individuals of the three species alternating within the planting grid. Revegetated plots were watered generously daily during the first few weeks and every 2 day after that through mid-July using a pump and garden hose. Buffers were spot sprayed on July 3 and August 14 to control RCG around the plots.

1. High and Medium Density Plug plots were planted with container-grown plants supplied by Rocky Mountain Native Plants and delivered May 31. The 10T tubelings (grown in 10 in^3 conical Ray Leach "Cone-tainers™", 1.5-inch diameter, 8.25-inch deep) were inserted in holes made with a dibble. In High Density plots plants were arranged in a 25×25 row grid (625 plants/plot, 0.2 m [8 inch] spacing). In Medium Density Plug plots plants were arranged in a 9×9 row grid (81 plants/plot, 0.6 m [2 ft] spacing).
2. Wetland sod supplied by Native Sod Solutions was delivered and planted June 2, 2006. Five 1×5 m (≈3×16 ft) pieces covered each Sod plot. In the nursery each piece of wetland sod had been planted with 100 plants which were then grown out in plastic lined ponds. Roots were concentrated on the lower face of the mats requiring good contact with the soil surface for establishment. Six wooden stakes held each piece in place.

Vegetation monitoring: Initial vegetation composition was sampled in late June, 2005. Sampling was done after mowing and subsequent re-growth to reduce the large amount of standing dead plant material and improve visibility and identification of live plants. Cover was estimated using a laser-pointer method with 25 points per plot; point-based methods are among the most objective available for characterizing herbaceous vegetation.

Herbicide efficacy was evaluated at the end of the growing season, on September 22, 2005, using ocular cover estimates. To describe vegetation present immediately before planting, the number of individual plants (separate stems or shoots) in each control, MDP, HDP, and SOD plot was counted on June 1, 2006. Litter mass was also sampled using an 8-inch (20-cm) diameter cylinder to cut litter to the soil surface.

Ocular cover estimates on September 27, 2006, were used to evaluate initial revegetation success and presence of RCG and other species that were not planted. These rapid sampling methods were used because September 2005 and June 2006 cover was extremely low, making point or quadrat sampling inefficient, and because September 2006 cover largely reflected initial planting intensity rather than differences in success. Future monitoring should use more rigorous methods.

September 2006 data were analyzed statistically as a randomized block experimental design. Analysis of variance used rank-transformed data to mitigate heterogeneous variances (results differed only slightly between analyses using raw versus rank-transformed data or including versus excluding Site 3).

Hydrologic monitoring

Surface and groundwater levels were recorded approximately biweekly from spring through fall of 2005 and 2006. The main objective was to characterize hydrologic environments as background for evaluating streambank treatments and RCG control and revegetation. Staff gauges were located in free-flowing reaches of Stalker Creek next to RCG Study Site 2 and at Streambank Treatment Area 3, in the ponded reach of Stalker near RCG Study Sites 4-6, and in the off-stream pond near RCG Study Site 3. To evaluate the possible influence of submerged aquatic vegetation (SAV) on stream water levels, relative abundance of SAV was observed when staff gauges were read. Shallow groundwater wells were located centrally in each RCG Study Site.

SAV abundance was rated on a scale of 0 to 3 using the criteria below. The purpose was to describe the general seasonal pattern of aquatic plant growth as related to stream water level.

0: Absent, no rooted or floating aquatic plants apparent

0.5: Trace, Small individuals (up to a few inches) visible on channel bed or in water column. Not conspicuous.

1: Low, Small to medium-sized plants (up to 0.5 ft long/tall) easily seen.

2: Moderate, Abundant medium-sized to large plants, but relatively large areas of channel bed still visible and channel not appearing “choked”.

3: High, Plants dense, covering much of the channel area and obscuring much of the channel bed. Channel may appear choked in places.

Observations were for submerged and floating aquatic plants only (shoots suspended mostly in or on top of the water column, either free-floating or rooted in the channel bed). Both higher plants, such as *Potamageton*, and algae that resemble higher plants, such as *Chara* were included. Emergent, perennial wetland plants on channel margins, such as sedges, rushes, and cattails, were not included.

Results and Discussion

Streambank revegetation

Channel and streambank cross-sections: Constrictors narrowed the channel by an average of 23 ft (7 m) or 36% at the cross-sections (Table 1). For these estimates, the original channel was measured as the distance between the top of the original banks, and the reconfigured channel was measured to the outside of the biolog. The estimated change in channel width is slightly greater than the width of the planted area reported in Table 2 because it includes the biolog and the sloped lower part of the original bank. This change represents narrowing of the channel at low stage, as well as narrowing the relatively open area of the channel at high stage. At high stage the flooded area includes planted Streambank Treatment Areas, but vegetation limits flow through these areas. In principle these changes should result in narrower, deeper, faster water during winter and spring when flow is not restricted by aquatic vegetation; when aquatic vegetation retards flow and raises the water level, however, changes in channel cross-sections probably will not affect water velocity.

2005 plant cover, wildlife damage, and reed canarygrass establishment: At the end of the first growing season, plant cover averaged 67% in planted areas (Table 2). Cover of the sedge/rush mixture was higher than cover of bulrush due mainly to inherent differences in growth habit and rate. Cover in Streambank Treatment Area 1, the highest elevation of the five areas planted, was greater than other areas because it was planted entirely with the sedge/rush mixture and because it had less muskrat damage than the other areas. Overall, first year vegetation development was remarkably fast compared to more conventional, lower intensity methods. However, conventional methods can also produce excellent results within two to three years where they work; the most important benefit of the pre-planted coir was that it overcame the barriers to survival that plagued the initial revegetation attempt using small plugs.

Although initial growth and survival were excellent, two potential problems were observed. First, significant areas of grazing by muskrats were seen, especially in the deepest areas of the sedge/rush mixture. The main signs of damage were abundant detached leaves and stubs of shoots that had been grazed. Muskrat damage was moderate and sporadic, with about 11% of the planted area showing signs of damage. However, damage was intense in some localized patches and was generally greater where standing water was deepest. Sedges had been grazed much more heavily than rushes and bulrushes.

Second, there were early signs of RCG invasion that appeared to originate from floating plant fragments or from extensive neighboring RCG stands that had not been controlled. Nine small RCG plants were found on biologs and four were found within the planted area of Streambank Treatment Area 4. Several of the RCG plants were directly next to stakes used to hold the biologs in place and appeared to have floated in and lodged on the stakes. Fragments of RCG rhizomes with green shoots were seen floating downstream attached to aquatic plant detritus. All visible RCG plants were grubbed out and removed from Streambank Treatment Areas before planting, so the RCG plants in the interior of Area 4 presumably floated in, too. Dense RCG surrounded most of the Streambank Treatment Areas on the original stream bank, and RCG rhizomes had extended a short distance into filled areas from these existing stands; this happened almost exclusively where the fill was not covered with wetland sod.

2006 plant cover, wildlife damage, and reed canarygrass distribution: Cover of sedge/rush vegetation changed slightly in two of the Streambank Treatment Areas and decreased 20-50% in the other Streambank Treatment Areas. Openings caused by a combination of muskrat damage and deep water expanded. There was no change in the total cover of bulrush, and only slight visible muskrat damage to bulrush plants. There were large increases in the height and vigor of plants of all species; this is not reflected in the cover data. RCG plants persisted in most but not all locations where they were seen in 2005; one new plant was found. Some RCG plants had expanded from a few stems in 2005 to clumps 0.5-1.5 ft (15-45 cm) across, others appeared stressed and in decline, and several had died. Few plants of other unplanted species were present. High use of the Streambank Treatment Areas by frogs, birds, fish, and insects was observed during site visits.

These early results suggest that some of the areas planted with sedges and rushes were too deep, at least in combination with muskrat grazing. This could have been avoided if information on seasonal water levels had been gathered before planting, or if more fill had been placed to raise these sites. Bulrush will likely spread into the open areas, and sediment deposition may eventually raise their surfaces. The potential for RCG to further invade and increase in the Streambank Treatment Areas is not yet clear. On higher sites, the question is whether dense sedge/rush vegetation can prevent invasion. On lower sites with sparse bulrush, the question is whether deep water can prevent invasion. The vigor and composition of vegetation in planted areas, its possible expansion or contraction, and invasion by RCG should be monitored for at least several more years.

Willow cuttings. Survival of willow cuttings planted in biologs was low, and surviving plants typically had one or two live, unbranched shoots <30 cm (1 ft) tall. Survival of willows planted on streambanks was fairly good, and surviving plants typically had several live, branching shoots 0.6-1.2 m (2-4 ft) tall. Weed barrier squares installed to suppress RCG competition remained in place around some willows but not others. It is too early to judge success of willow plantings, but their rate of growth has been very slow.

Reed canarygrass invasion on other area streams: In a parallel study, TNC and IMA surveyed additional cross-sections on Stalker Creek and two other tributaries to Silver Creek, Mud and Wilson Creeks (August et al. 2006). All three are spring creeks but they differ in slope, flow, and other characteristics. The extent of RCG differed greatly, with RCG infrequent on Mud Creek, very abundant on the banks of Stalker Creek, and thick both on the banks and in the channel of Wilson Creek. In-channel RCG was associated with relatively shallow water (<2-ft deep), dense SAV mats, and deposits of silt or organic muck. RCG appeared to have grown out onto mats of aquatic vegetation in Wilson Creek, increased in density over time, and stabilized the underlying silt and muck deposits. RCG apparently has prevented washout of the aquatic vegetation and sediment deposits that would normally occur during high flows or when aquatic vegetation becomes too thick or dies back. The infestation in Wilson Creek has promoted sediment accumulation and a wide, shallow, poorly-defined, grass-choked channel. Wilson Creek had been dredged and reshaped previously for sediment removal and habitat restoration but RCG undid much of this restoration work within a decade. Shallow, low-velocity channels that support dense aquatic vegetation and do not experience strong seasonal water level fluctuations may be particularly vulnerable to invasion.

Table 1. Original and reconfigured channel widths. The difference between the original and reconfigured widths measures channel narrowing by installation of biologs.

Cross-section	**Original channel width**		**Reconfigured channel width**		**Difference**	
	m	ft	m	ft	m	ft
1	18.8	61.5	15.8	51.7	3.0	9.8
2	16.7	54.8	6.0	19.7	10.7	35.1
3	18.3	60.0	11.8	38.7	6.5	21.3
4	18.2	59.7	15.0	49.2	3.2	10.5
5	20.4	66.9	13.7	44.9	6.7	22.0
6	22.5	73.8	13.2	43.3	9.3	30.5
7	22.0	72.2	11.1	36.4	10.9	35.8
8	20.0	65.6	13.6	44.6	6.4	21.0
9	18.5	60.7	12.6	41.3	5.9	19.4
Average	19.5	63.9	12.5	41.1	7.0	22.8
Percent width reduction						35.7%

Table 2: Summary of Streambank Treatment Areas planted in 2005 and vegetation at the end of the first and second growing seasons. Average elevation, plant cover, and muskrat damage values were weighted by area; average width was weighted by the length of each Streambank Treatment Area. Estimates of area affected by muskrat damage in 2006 included open areas that may be perpetuated by flooding.

		Streambank Treatment Area					**Total**
		1	**2**	**3**	**4**	**5**	
Number of pieces installed							
	Sedge/rush	6	19	5	26	11	67
	Bulrush	0	5	2	25	12	44
	Total	6	24	7	51	23	111
Area installed (m2)							
	Sedge/rush	30	95	25	130	55	335
	Bulrush	0	25	10	125	60	220
	Total	30	120	35	255	115	555
Area installed (ft2)							
	Sedge/rush	323	1023	269	1399	592	3606
	Bulrush	0	269	108	1345	646	2368
	Total	323	1292	377	2745	1238	5974
Length of streambank (m)		16.2	17.9	17.2	31.2	26.7	109
Length of streambank (ft)		53	59	56	102	88	358
		Streambank Treatment Area					**Weighted Average**
		1	**2**	**3**	**4**	**5**	
Width at cross-sections (m)		3.0	5.8	4.0	9.5	5.3	6.0
Width at cross-sections (ft)		10	19	13	31	17	20
Average elevation (ft)		14.64	14.14	14.37	14.05	13.87	14.15
Percent cover 2005							
	Sedge/rush areas	84	74	71	72	69	73
	Bulrush areas	NA	35	62	61	62	58
	Total	84	66	68	67	65	67
	Muskrat damage (all areas)	1	17	6	12	10	11
Percent cover 2006							
	Sedge/rush areas	96	67	50	41	21	51
	Bulrush areas		19	86	62	70	60
	Total	96	60	58	51	45	56
	Muskrat damage (all areas)	4	28	36	32	41	31
Change from 2005 to 2006 (% cover)							
	Sedge/rush areas	+12	-7	-21	-31	-48	-23
	Bulrush areas	NA	-16	+24	+2	+8	+2
	Total	+12	-9	-10	-16	-21	-10
	Muskrat damage (all areas)	+3	+11	+30	+20	+31	+21

Reed Canarygrass Suppression and Revegetation Study

Vegetation composition before planting: Before herbicide application, all study sites were strongly dominated by RCG and had dense litter that was mainly from RCG (Table 3). RCG cover was 45-61% as measured with the laser-point technique and comprised 70-85% of total plant cover. Sedges and rushes made up as much as 10 and 20 percent of cover, respectively, at some study sites. Thistles and other forbs were present at some sites. Plant litter was abundant and covered nearly the entire soil surface (because the point method measures the first item "hit" by the laser beam, the litter cover values shown do not include litter beneath a plant canopy hit and are low estimates). Litter mass sampled immediately before planting ranged from 0.2 to 0.5 lb/ft^2 (0.8 - 2.6 kg/m^2) across sites, while depth ranged from 1 to 3 inches (2 - 8 cm); differences between sites were not related to groundwater depth. Most of the litter was present before mowing and spraying plots, and litter was deep in most reference plots. Very little bare soil was exposed.

Spraying with glyphosate controlled RCG quickly and effectively, consistent with experience reported in other locations (Table 4). Substantial but uneven mortality was seen after four weeks. After two months, prior to the second herbicide application in late August, vegetation appeared dead except for occasional rushes and sedges. Four weeks after the second application, only trace amounts of RCG with green leaves remained. A small fraction of sedges and rushes appeared to be alive, as well as occasional thistle or horsetail plants.

Immediately before planting experimental plots, plant density was very low with an average of 34 plants per plot (0.13 plants/ft^2, 1.4 plants/m^2). The most abundant plants were RCG, arctic rush, field sowthistle, Kentucky bluegrass and Canada thistle (Table 5). RCG, at very low density, was observed at four sites. No sedges were observed in plots. Plants of perennial species, including RCG, probably had survived the herbicide. There were no systematic differences in overall plant density among sites. The total number of plants tended to be lower on High Density Plug plots, which had been hydromulched, but this was not statistically significant.

Table 3. Initial vegetation composition of RCG Study sites, June 27-28, 2005. Point-based cover estimates are means (standard deviations in parentheses) of 5 plots per site, with 25 laser-point observations per plot.

Site	Reed canarygrass	Sedges	Arctic rush	Canada thistle	Other forbs	Litter	Bare soil
1	45.6 (8.3)	8 (10.2)	5.6 (6.7)	0 (0)	1.6 (2.2)	38.4 (16.1)	0.8 (1.8)
2	45.6 (8.8)	4 (6.9)	10.4 (7.3)	4 (4.9)	1.6 (3.6)	32.8 (12.1)	0.8 (1.8)
3	49.8 (16.5)	0 (0)	8.8 (5.9)	0.8 (1.8)	0 (0)	42 (19.2)	0 (0)
4	52 (5.7)	0.8 (1.8)	20 (2.8)	0 (0)	0 (0)	25.6 (2.2)	0 (0)
5	60.8 (10.4)	10.4 (10.4)	4.8 (3.3)	0 (0)	0 (0)	24 (2.8)	0 (0)
6	48 (7.5)	0.8 (1.8)	8 (4.9)	0 (0)	0 (0)	43.2 (8.7)	0 (0)
Mean	50.3 (5.7)	4 (4.3)	9.6 (5.5)	0.8 (1.6)	0.5 (0.8)	34.3 (8.2)	0.3 (0.4)

Table 4. Herbicide efficacy, September 22, 2005. Ocular cover estimates are means (standard deviations in parentheses) of 5 plots per site. All plant values are for still-green plants thought to be alive.

Site	Reed canary-grass	Sedges	Arctic rush	Canada thistle	Other forbs	Horse-tails	Plant total	Litter+ dead
1	0.1 (0.3)	1.6 (2.3)	0.9 (0.3)	0 (0)	0 (0)	0.3 (0.3)	2.9 (2.8)	97.1 (2.8)
2	0.3 (0.3)	0.3 (0.3)	0.8 (0.3)	0.1 (0.3)	0 (0)	0 (0)	1.4 (0.6)	98.6 (0.6)
3	0.1 (0.3)	0 (0)	0.5 (0)	0 (0)	0 (0)	0 (0)	0.6 (0.3)	99.4 (0.3)
4	0.5 (0)	0.5 (0)	7.5 (2.9)	0 (0)	0 (0)	0 (0)	8.5 (2.9)	91.5 (2.9)
5	0.5 (0)	0.8 (0.3)	0.6 (0.3)	0 (0)	0 (0)	0 (0)	1.9 (0.5)	98.1 (0.5)
6	0.5 (0)	0.4 (0.3)	3 (2.3)	0 (0)	0 (0)	0 (0)	3.9 (2.2)	96.1 (2.2)
Mean	0.3 (0.2)	0.6 (0.6)	2.2 (2.8)	0 (0.1)	0 (0)	0 (0.1)	3.2 (2.8)	96.8 (2.8)

Table 5. Plant counts before revegetation. Number of individuals per 5×5 m plot, by site and by experimental treatment. Averages are shown in shaded rows, standard deviations in unshaded rows.

Species	Site								Treatment			
	1	2	3	4	5	6	Mean		CON	HDP	MDP	SOD
Phalaris arundinacea	0.0	0.3	0.0	6.8	0.8	11.8	3.3		3.5	0.8	4.5	4.2
(reed canarygrass)	0.0	0.5	0.0	9.1	1.5	9.7	4.9		5.1	1.6	10.1	8.0
Juncus arcticus	6.3	0.0	0.0	0.0	0.0	2.3	1.4		0.0	0.3	3.3	2.0
(arctic rush)	7.5	0.0	0.0	0.0	0.0	2.1	2.5		0.0	0.8	6.1	4.0
Sonchus arvensis	10.8	26.5	23.8	12.5	32.5	11.8	19.6		21.7	8.5	29.7	18.7
(field sowthistle)	13.9	37.3	6.3	10.4	23.3	8.7	9.2		8.8	11.6	28.6	21.0
Poa pratensis	2.0	0.0	0.0	9.3	0.8	10.8	3.8		8.3	0.0	3.5	3.3
(Kentucky bluegrass)	2.4	0.0	0.0	8.1	1.0	19.6	4.9		15.6	0.0	6.7	6.1
Cirsium arvense	0.8	1.8	3.5	1.3	3.0	1.5	2.0		2.5	1.7	1.8	1.8
(Canada thistle)	1.0	1.3	2.5	1.0	2.2	3.0	1.1		2.8	2.4	1.3	1.6
Amaranthus retroflexus	0.0	4.0	0.5	0.0	2.8	0.0	1.2		2.5	0.5	0.8	1.0
(redroot amaranthus)	0.0	4.9	1.0	0.0	2.6	0.0	1.7		4.2	0.8	2.0	2.4
Equisetum laevigatum	0.0	3.0	0.5	1.5	0.0	1.5	1.1		0.3	1.2	0.8	2.0
(smooth horsetail)	0.0	4.2	1.0	1.0	0.0	1.3	1.2		0.8	1.3	1.3	3.5
Camassia quamash	0.0	3.3	0.8	0.0	0.0	0.0	0.7		0.8	0.0	1.8	0.0
(common camas)	0.0	4.3	1.0	0.0	0.0	0.0	1.3		1.6	0.0	3.6	0.0
Taraxacum officinale	2.3	0.0	0.0	0.0	0.0	0.0	0.4		0.0	0.0	1.5	0.0
(common dandelion)	4.5	0.0	0.0	0.0	0.0	0.0	0.9		0.0	0.0	3.7	0.0
Descuriana sophia	0.0	0.0	0.0	0.3	0.0	0.0	0.0		0.0	0.0	0.0	0.2
(herb sophia)	0.0	0.0	0.0	0.5	0.0	0.0	0.1		0.0	0.0	0.0	0.4
Unknown broadleaf species	0.5	0.0	3.5	0.0	0.0	0.0	0.7		0.2	0.0	0.5	2.0
	0.6	0.0	5.7	0.0	0.0	0.0	1.4		0.4	0.0	0.8	4.9
Total	23	39	33	32	40	40	34		40	13	48	35
	10	40	12	26	24	31	7		20	14	25	23

Vegetation composition at end of first growing season after planting: Cover of planted species (*Carex utriculata, Carex nebrascensis, Juncus arcticus*) differed significantly among revegetation treatments ($p = 0.001$) but not sites ($p = 0.12$) (Figure 2). Average cover was generally higher in High Density Plug and Wetland Sod plots than Medium Density Plug plots (Figures 3 and 4). These differences were a direct result of initial abundance of plants (i.e. differences in density of plugs or the high cover of plants in wetland sod grown in a nursery). Consequently, long-term results may not follow these initial patterns. Though not statistically significant, cover was consistently low at Site 3, the driest site.

RCG cover differed significantly among revegetation treatments ($p = 0.005$) and sites ($p = 0.001$) (Figures 2 and 3). Average RCG cover was highest in Medium Density plots, lowest in Sod plots, and intermediate in Control and High Density plots. Higher cover in the relatively open Medium Density plots than control plots likely resulted from irrigation of the planted plots. Differences among revegetated plots likely resulted from differences in competition with planted species and from the physical barrier of the coir mats in Sod plots. Hydromulch in High Density plots may also have had an effect. Differences in RCG between sites largely reflected low cover at Sites 2 and 3 and higher cover at Sites 4, 6, and especially 5. In Wetland Sod plots most of the visible RCG plants were in small gaps between the coir mats, though some had emerged through the mats. Future emergence through mats or expansion into mats should be monitored. Overlapping mat edges could help exclude RCG plants that otherwise can grow through gaps.

Cover of other unplanted species ("volunteers") differed significantly among revegetation treatments ($p = 0.003$) and sites ($p = 0.004$). Average cover was highest but extremely variable in Control plots and lowest in Sod plots. Volunteers were least abundant at Sites 1 and 2. Differences in species and abundance of volunteers among sites seemed random. Volunteers were generally more abundant in unplanted buffers around plots. However, they were clearly limited in the 1-2 ft wide area outside of High Density plots that was hydromulched but not planted.

RCG in study plots generally increased as depth to groundwater decreased; this relationship was strong for Control and Sod plots and moderately strong for Medium Density plots (Figure 5). These relationships were found even if Site 3, by far the driest site, was removed from the analysis. Effects of site water levels on planted species were weak except for Medium Density plots. Nonetheless, the effect of water level was conspicuous in the High Density plot at Site 1 (Figure 6). By chance, the ground's elevation changed abruptly in the middle of this plot, with one half lying about 0.3 ft above the other half. RCG was more than double and planted species cover 12 times greater in the lower, wetter half than the higher, drier half.

Dense residual litter appeared to have little effect on survival and growth of plugs, and litter removal did not appear to help growth of roots from the pre-planted coir mats into the soil. The 2006 growing season was exceptionally dry. Rainfall from June through August totaled only 0.4 inches (1.0 cm), while September and October had ≤1 inch (2.5 cm) each. Even with watering, many plants in the pre-planted coir died or failed to grow due to drought stress. In a climate of strong summer drought, 8-inch deep plugs may outperform pre-planted coir in some years because their roots have better contact with the soil and are somewhat buffered from drying. Planting the wetland sod in spring when soils were wetter probably would have improved initial establishment, but the dry summer still would have limited growth, particularly at higher elevation sites where groundwater was further below the surface.

The fact that seasonal water level patterns for these floodplain sites was virtually the reverse of that for the Streambank Treatment Areas highlights the difficulties of planning and implementing revegetation. Off-stream hydrology differed radically from on-stream hydrology. Hydrology directly next to streams can be estimated at least roughly from informal site observations or descriptions by land owners or managers. However, hydrology of floodplain sites away from streams is rarely observed directly in preparation for restoration and can be surprising, as this example shows. Even if site hydrology were known in advance, scheduling planting around the conflicting seasonal conditions in streambank and floodplain areas on Stalker Creek would be difficult and increase costs.

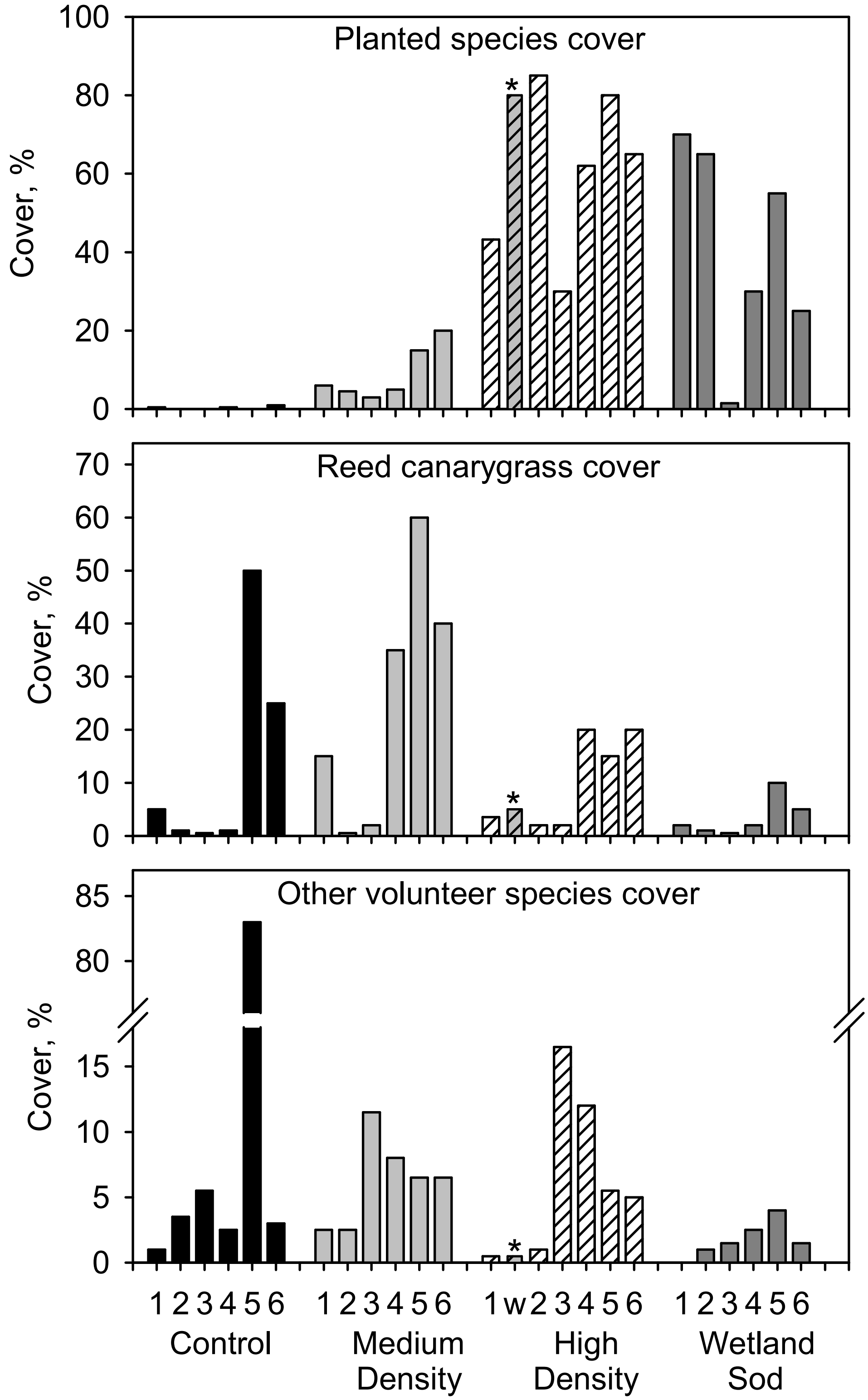


Figure 2. Plant cover in RCG Study plots, organized by revegetation treatment and Study Sites (numbered 1-6). *The High Density Plug bar labeled "w" and shaded gray represents the lower, western half of the Site 1 HDP plot; the elevation of this half of the plot is close to the site average, whereas the eastern half is substantially higher and drier.

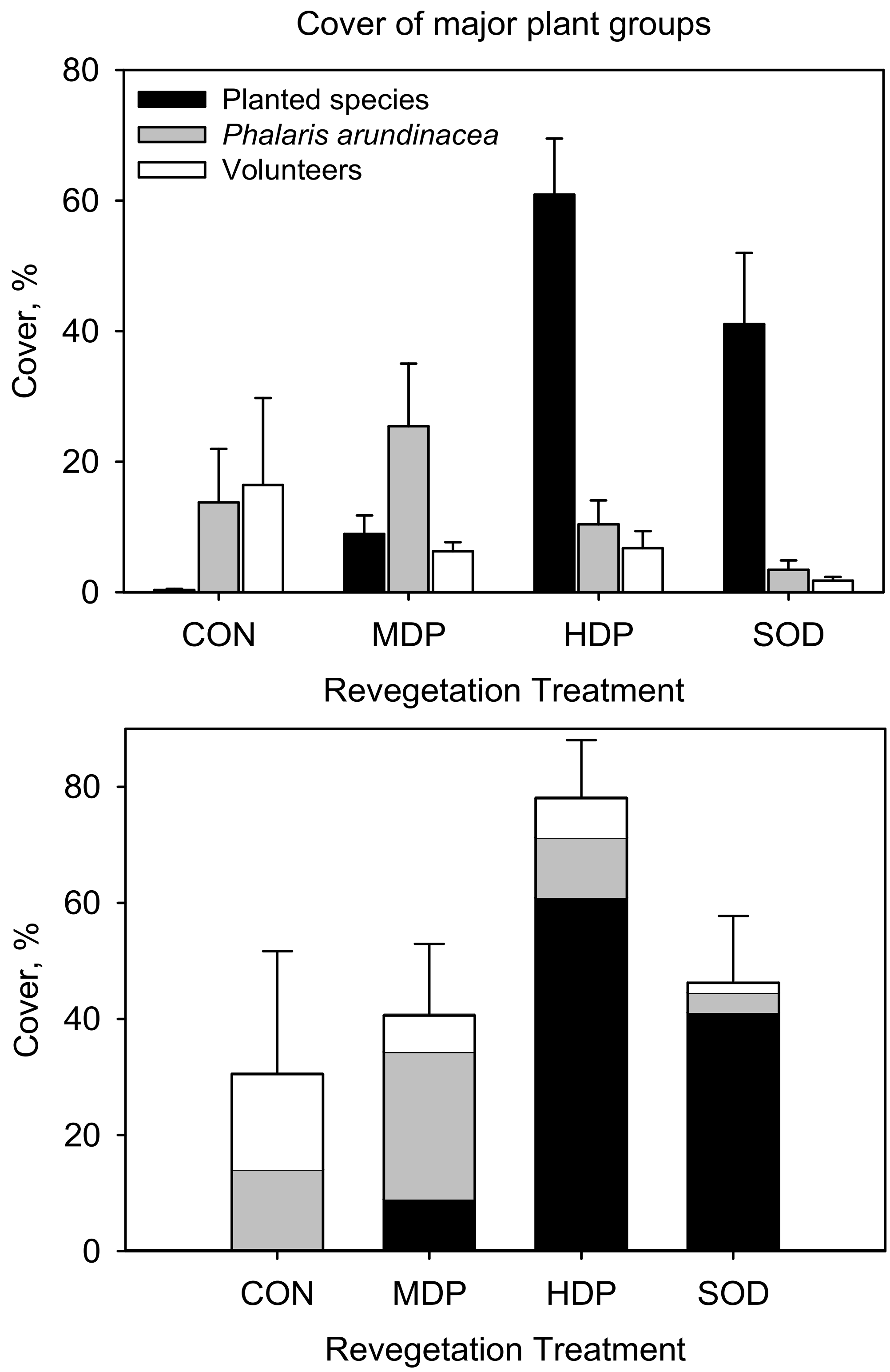
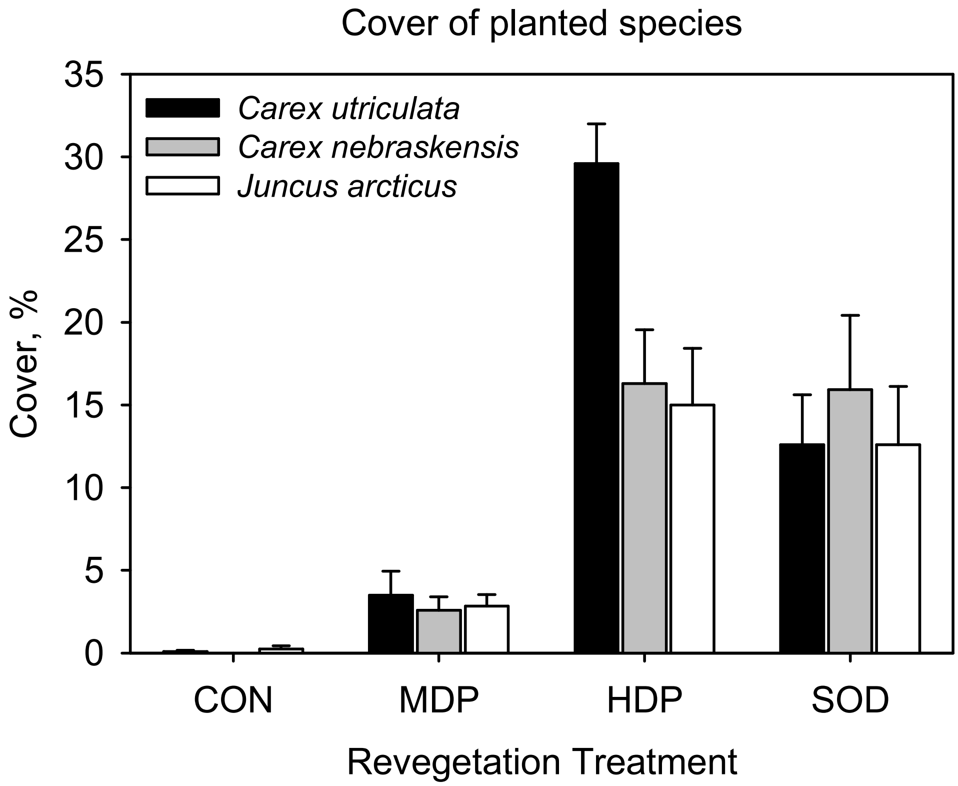


Figure 3. Average effects of revegetation methods on planted species, RCG, and other species. Treatment effects are statistically significant for all three plant categories.



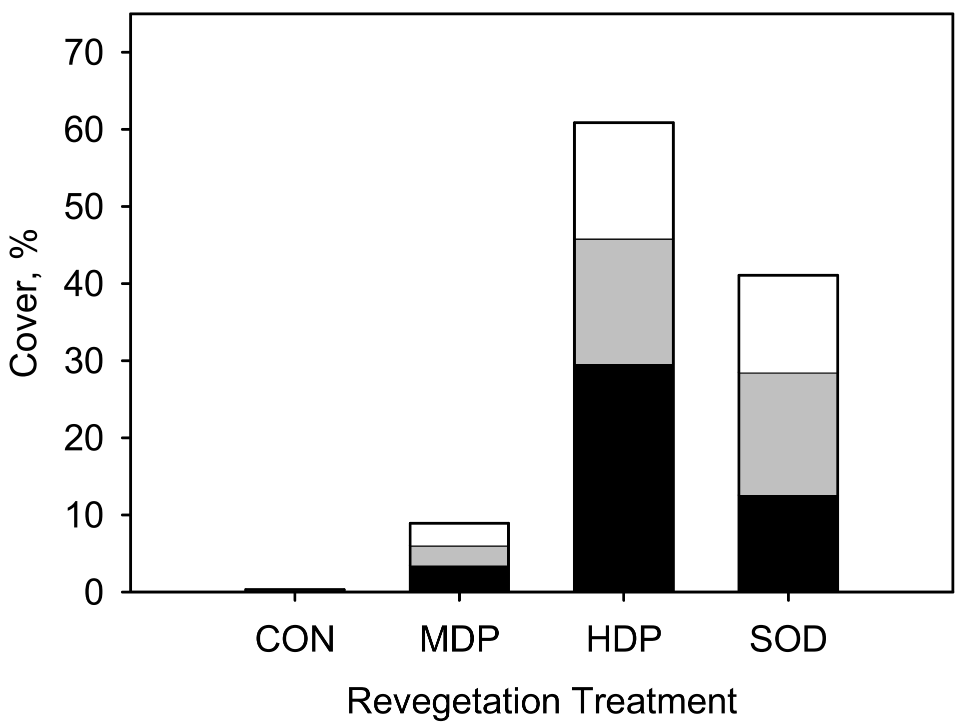


Figure 4. Average effects of revegetation methods on the three planted species.

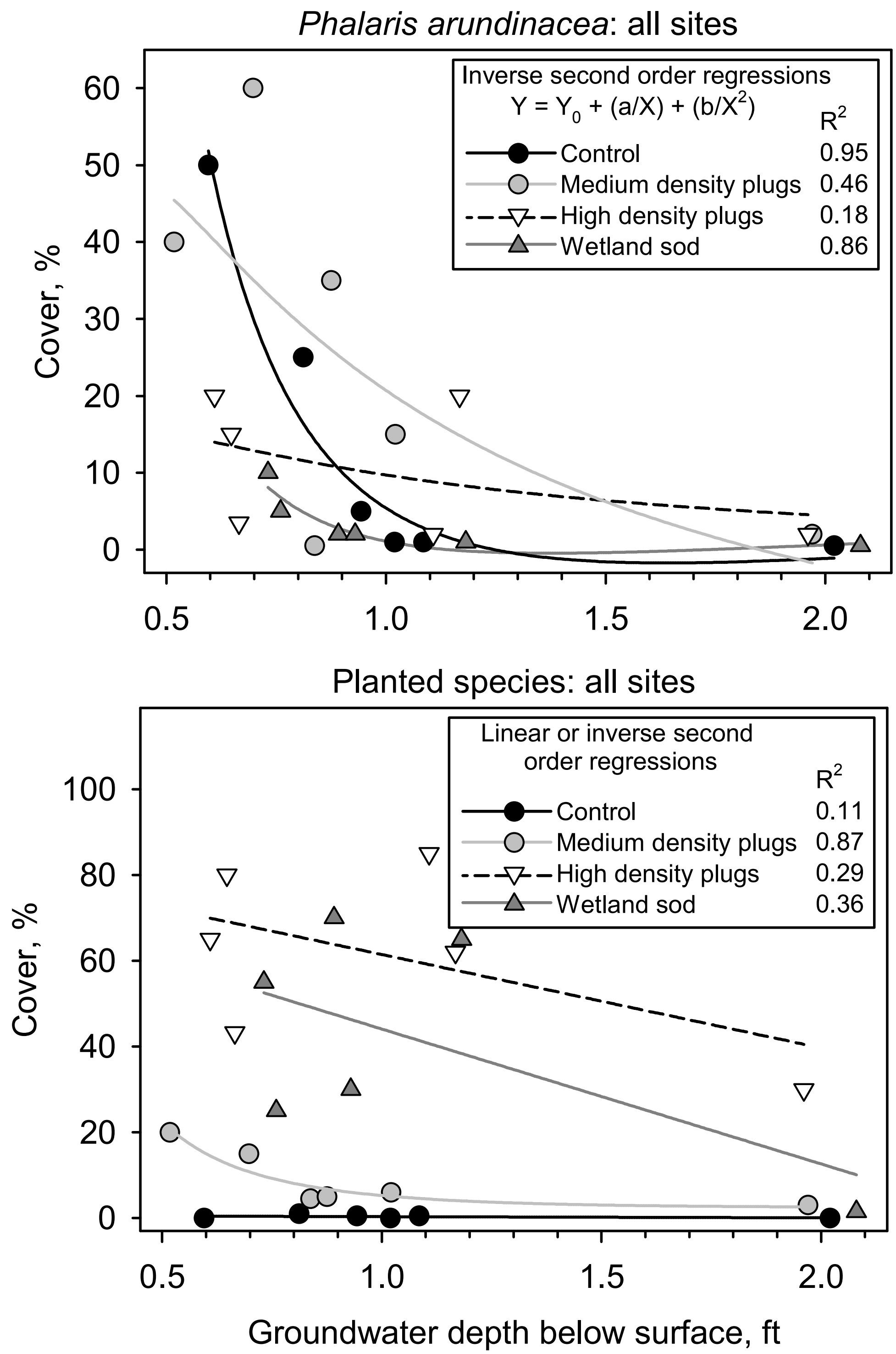


Figure 5. Relationships between groundwater depth below the soil surface (X axis) and cover of RCG (top) and planted species (bottom). Wetness decreases from left to right. Depth to groundwater is the average of all observations for each plot.

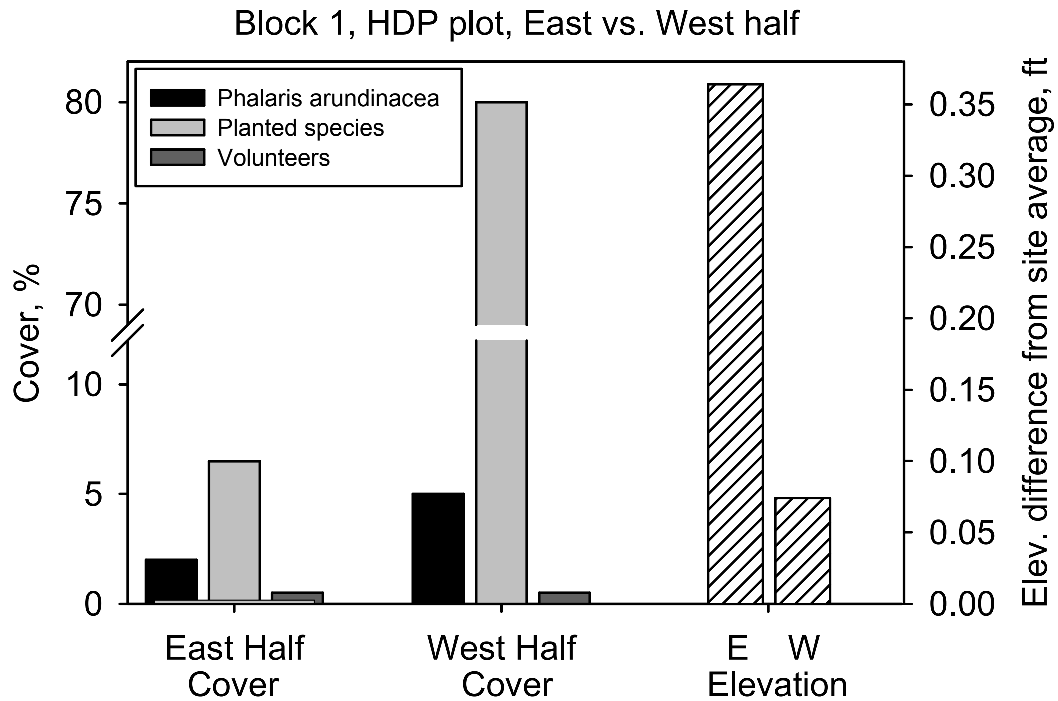


Figure 6. Variation between west and east halves of the High Density Plug plot at Site 1. Elevation of the west half was close to the Site average, while the east half was about 0.3 ft higher and substantially drier.

Hydrology

Hydrologic monitoring documented a distinctive seasonal pattern of stream levels and confirmed the wide range of hydrologic environments occupied by reed canarygrass. Water levels in Stalker Creek increased during the growing season, peaking in August; levels were correlated with aquatic plant density. RCG occupied sites spanning diverse hydrologic environments ranging from relatively dry to flooded and differing in seasonal moisture patterns. Water levels peaked during the growing season on streambank sites but during the dormant season on floodplain sites.

Stream and pond hydrographs: In the free flowing reaches below the dam, Stalker Creek rose 1.5-2.1 ft between early May and mid-August in both 2005 and 2006 then declined gradually (Figure 7). Changes in water levels did not track discharge except during a major runoff event in April, 2006. Instead, water level changes generally followed the same pattern as abundance of submerged aquatic vegetation (Figure 8). Water levels at Gauges 1 and 2 correlated positively with an index of relative abundance of aquatic vegetation in the channel ($r = 0.77$ at both gauges).

In the absence of seasonal changes in aquatic vegetation and channel roughness, a five- to ten-fold or greater increase in flow would be needed to account for the observed increases in stage during the growing season (based on Manning equation calculations). Stream flow data for 2006 showed a roughly 30% decrease in flow over the 2005 growing season and no change in flow over the 2006 growing season. If, however, a large increase in channel roughness is assumed, these large increases in stage can be explained with no increase in flow. For example, a Manning roughness coefficient of around 0.03 is reasonable for Stalker Creek without SAV, while a value of around 0.15 is reasonable for a stream with dense aquatic vegetation based on research by Champion and Tanner (2000). Different roughness values can, in concept, account for the water level rise from May to August, 2006. Observed high water levels in April, 2006 accord well with measured flows even if no increase in roughness is assumed, as would be expected in the absence of SAV. These results argue for a direct effect of aquatic plants on growing season water levels. We have observed similar increases in growing season water levels on the Teton River near Driggs; these rises follow major growth of aquatic vegetation and occur while discharge declines.

Water levels in the pond above the dam on Stalker Creek and the off-stream pond fluctuated relatively little (0.3 and 0.1 ft), presumably due to the buffering effect of the storage volume in both ponds and the low flows through the off-stream pond. Water levels in the pond on Stalker Creek were weakly associated with aquatic vegetation abundance ($r = 0.55$).

Water levels in Streambank Treatment Areas*:* Due to seasonal patterns of Stalker Creek water levels, Streambank Treatment Areas planted with wetland sod were wettest from midsummer through early fall. Modest differences in surface elevation (up to 1.4 ft due to differences in amount of fill), resulted in large differences in duration and depth of flooding (Figure 9). Between-year differences added to variation in site hydrology. For example, the highest areas were not flooded at all in 2005 (water got no higher than 0.3 ft below the soil surface in these areas) and flooded only briefly in 2006. In contrast, the lowest areas were flooded for about half of both years including all but the early growing season. Variation relevant to revegetation included:

- For the average sediment elevation in planted areas, water level was 9 inches below the surface when the site was planted at the beginning of June, 2005, at the surface by late July, and 5 inches above the surface by late August. Conditions were initially slightly dryer than ideal for planting, but were favorable at other times.
- In the highest locations water level was 18 inches below the surface when planted and never less than 3 inches below the surface in 2005. Later in the growing season these areas were wet enough for healthy growth of well-rooted sedges and rushes, but initially they were too dry for establishment, requiring supplemental irrigation.
- In the lowest locations water was at the surface when sites were planted and 13 inches deep by late July. This flooding is acceptable for hardstem bulrush but too deep for the sedges and arctic rush.

Floodplain groundwater hydrographs: At RCG Study Sites conditions ranged from infrequently flooded to deeply sub-irrigated (water at 2-3 ft depth, surface dry). Groundwater levels in the five RCG Study Sites along Stalker Creek were generally 0.5-1.5 ft below the soil surface and 0-1 ft below the stream's level for most of the growing season; occasionally water levels were higher (Figure 10). At the sixth site, RCG Study Site 3, water was usually 2-3 ft below the soil surface and the level of the adjacent pond.

Except at Site 6, groundwater levels were usually lower than would be expected if riparian groundwater was tightly linked to stream water levels (Figure 10). Groundwater levels appeared to be lowered by growing season evapotranspiration. At several of these sites water levels were similar to stream or pond levels early or late in the year. At Site 6, next to the pond on Stalker Creek, groundwater elevations remained within 2 inches of pond water levels at most times. Site 3 was at nearly the same elevation as the adjacent pond and separated from it by only 100 ft (30 m) and a low rise about 1 ft high; however, groundwater levels appeared to be entirely disconnected from that pond. Instead, groundwater elevations at site 3 were similar to those at Sites 4 and 5 despite being separated by 460 ft (140 m).

Summary – Hydrology of sites with reed canarygrass: The diversity of sites occupied by RCG underscores how broad a threat it is for riparian areas and how challenging revegetation may be. RCG was abundant on relatively dry sites (up to 3.7 ft above the Stalker Creek's high water level), seasonally saturated sites on the floodplain, lower stream banks, and in margins of stream channels. Seasonal water level patterns ranged from sites with maximum levels in mid-season to sites with minimum levels in mid-season. Observations on other area streams, summarized above, indicate an even wider hydrologic spectrum. For example, RCG chokes much of the channel of Wilson Creek.

Typical Streambank Treatment Areas revegetated on Stalker Creek were dry early in the growing season and flooded later, which is challenging for initial plant establishment. Plantings of wetland sod in Streambank Treatment Areas were successful across a wide range of water levels partly because different species were used for higher and lower areas and partly because dryer areas were initially hand-watered with buckets. However, future monitoring should evaluate potential effects of elevation differences on plant survival and growth, community composition, RCG and other weeds, and muskrat damage. In contrast to the Streambank Treatment Areas, planting of wetland sod in off-channel RCG Study plots was less successful due to dry mid-summer conditions. In spite of irrigation, surface soils at these floodplain sites were apparently too dry for reliable rooting.

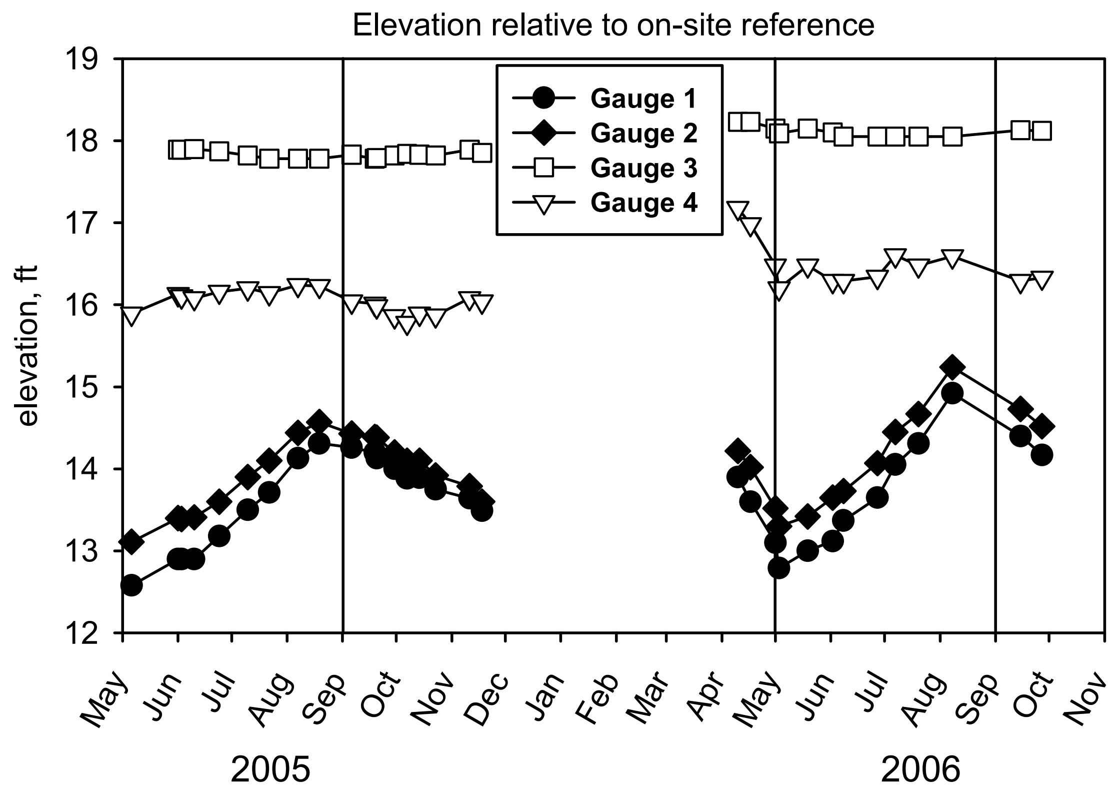


Figure 7. Surface water level variation on free-flowing reaches of Stalker Creek (Gauges 1 and 2) and ponds behind dams (Gauges 3 and 4). Staff gauges are: Gauge 1, Stalker Creek at RCG Study Site 2; Gauge 2, Stalker Creek at the Streambank Treatment Study Area below the dam; Gauge 3, off-stream pond above dam on tributary; Gauge 4, Stalker Creek pond above dam. Elevations are relative to the arbitrary reference elevation of 20 ft at the "reference rock" at the north end of the dam and bridge. Zero readings of staff gauges correspond to the following elevations: Gauge 1, 11.80 ft; Gauge 2, 12.72 ft; Gauge 3, 16.14 ft; Gauge 4, 14.78 ft.

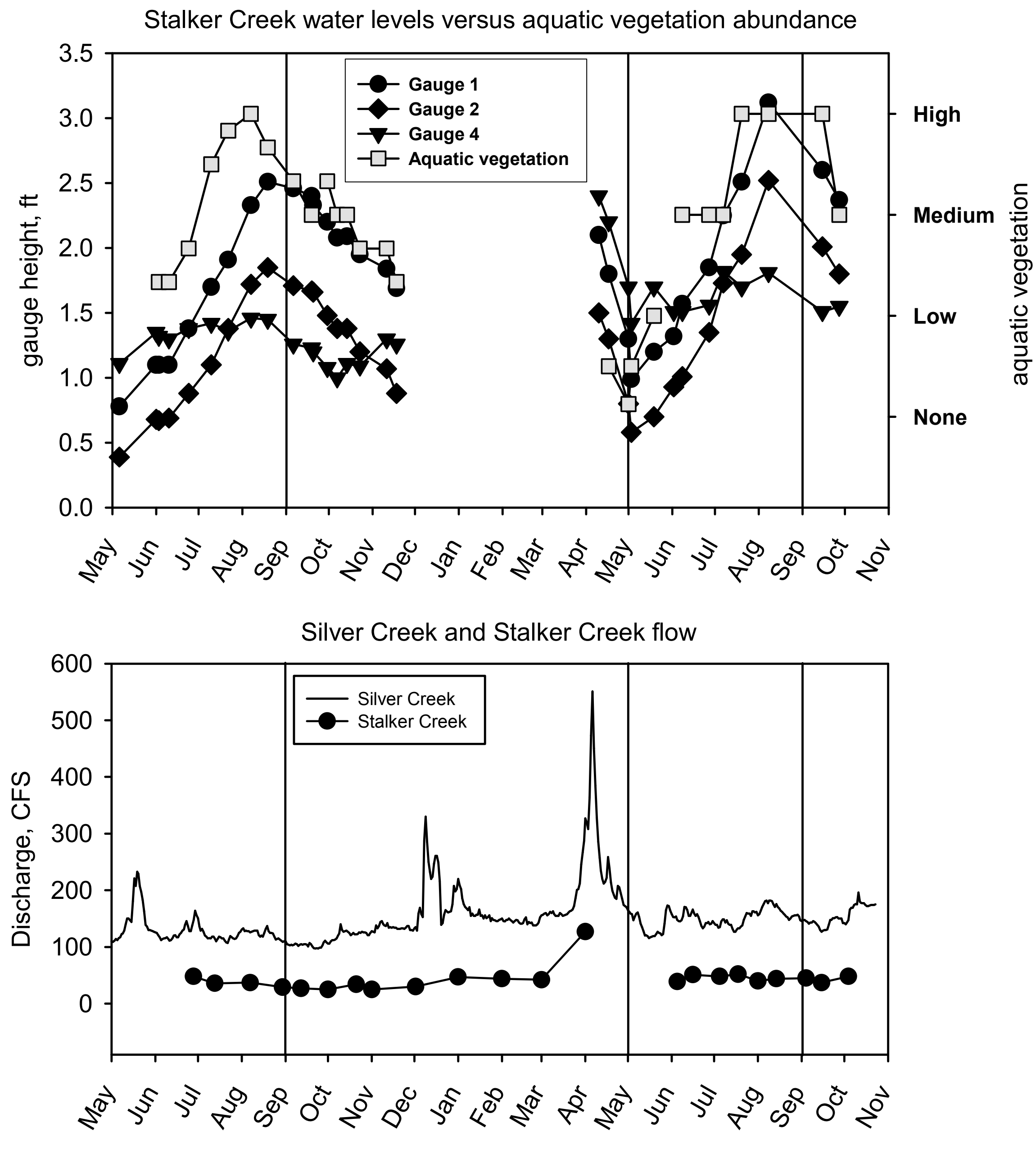


Figure 8. Stalker Creek water levels relative to seasonal variation in submerged aquatic vegetation (SAV, top) and Stalker Creek and Silver Creek flows (bottom). Aquatic vegetation values are the average of observations at three locations on Stalker Creek. A scale of 0 (absent) to 3 (high density) was used. Stalker Creek flows were measured by TNC staff below the Stocker Creek Road bridge, approximately 2100 ft (640 m) below the study reach. Silver Creek (USGS Gauge 13150430 at Sportsman's Access), is shown as a proxy to represent daily variations in flow in area streams and the spring, 2006, runoff event.

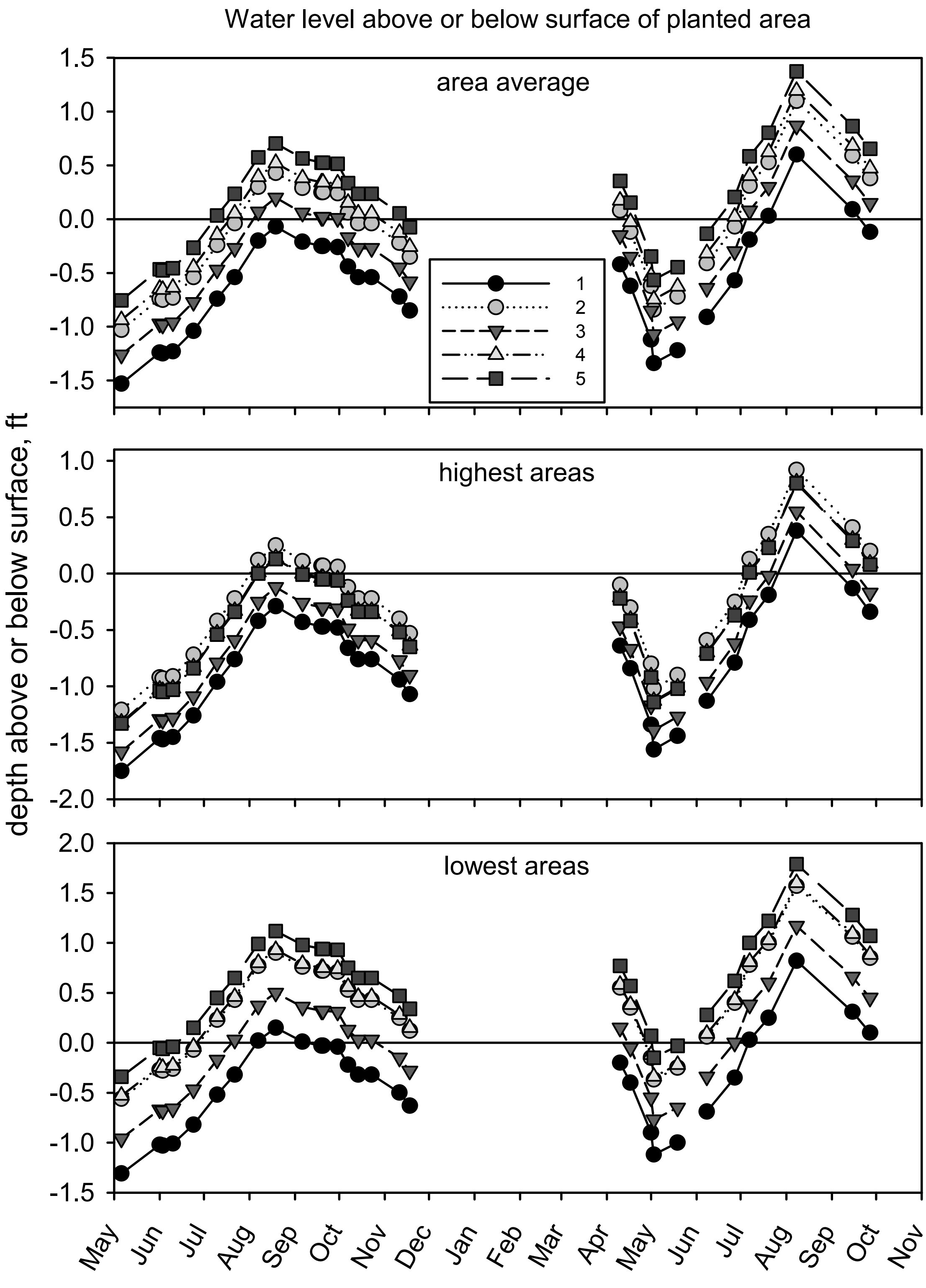


Figure 9. Water levels in Streambank Treatment Areas 1-5 in 2005 and 2006. The sediment surface elevation is represented by the horizontal lines at zero ft.

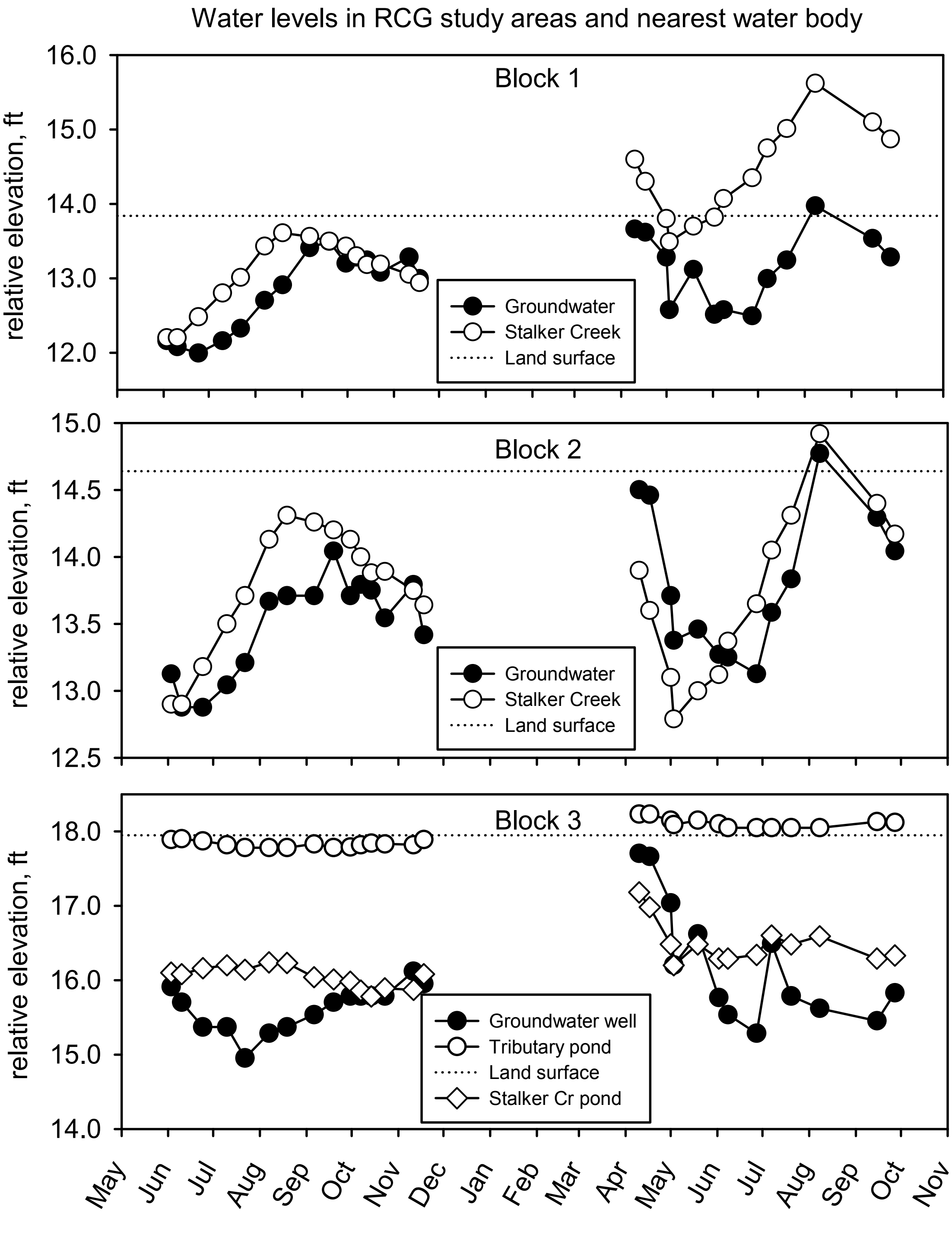


Figure 10. Groundwater levels in RCG Study Sites relative to each site's average ground elevation and water levels in the nearest surface water body.

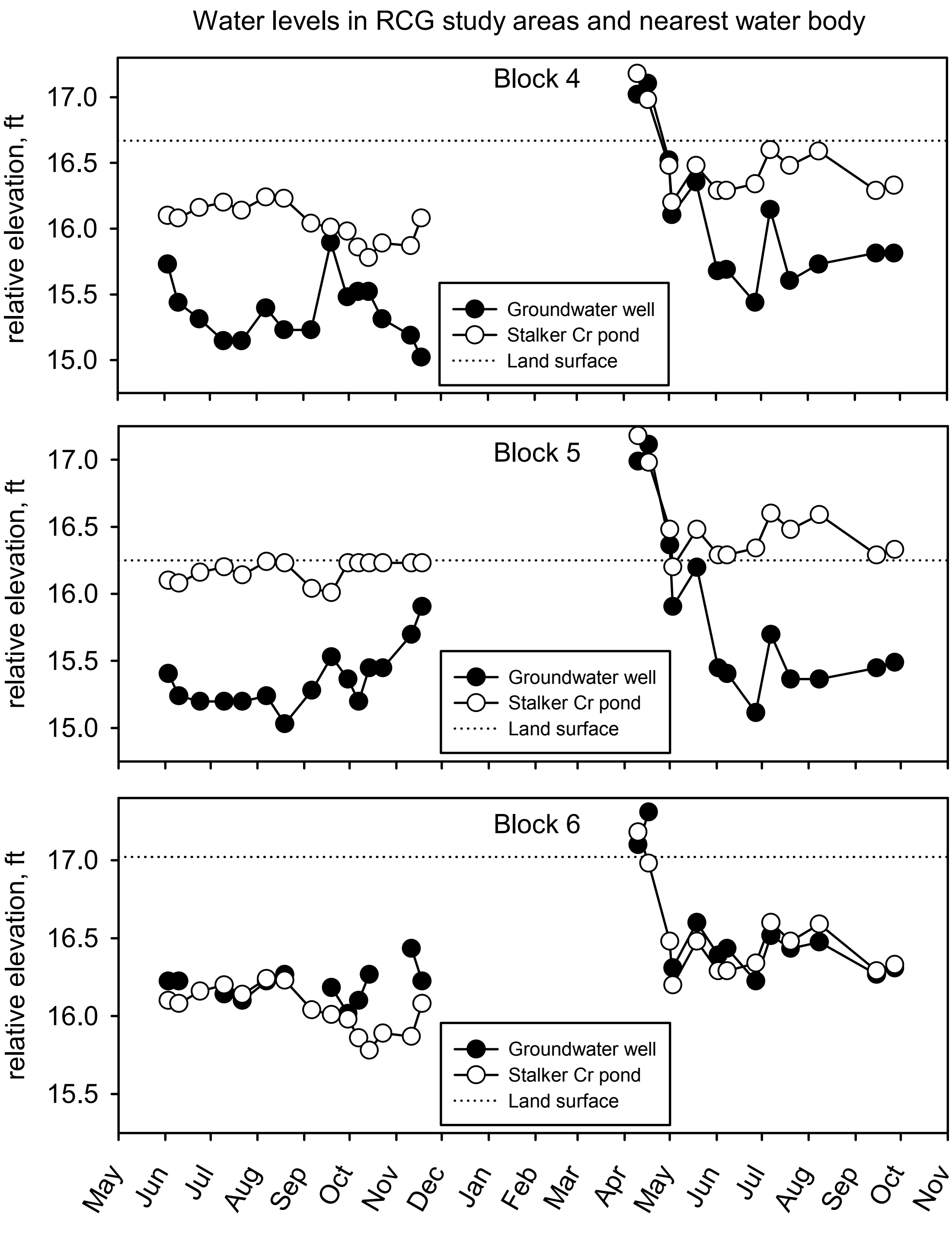


Figure 10 continued.

Conclusions

Streambank Revegetation

Success of revegetation of channel constrictors with wetland sod differed between sedge/rush and bulrush sod and depended strongly on water depth. After two years, sedge/rush sod was highly successful at just one of five streambank treatment areas, with fair to very poor performance at the other sites. Sedge/rush establishment during the first growing season was very successful at all five sites, but a significant portion of the vegetation had been removed by muskrats by the end of the second growing season. The site with the best results had been backfilled behind the biologs to a higher level than the others; lower depths of fill in the remaining areas were apparently due to limitations of dredging equipment or labor. Water levels at the lower sites were greater than 6” for prolonged periods during the growing season. This extended flooding was caused by the combination of inadequate fill behind the biologs and high growing-season water levels in Stalker Creek due to abundant submerged aquatic vegetation. Water levels greater than 6” appeared to facilitate muskrat movement, leaving lower sites susceptible to severe muskrat herbivory. Plants apparently were stressed both by muskrat herbivory and flooding; plants that were cropped were generally overtopped by water, limiting plant metabolism and regrowth and ultimately causing death. The highest, most successful site did not experience prolonged inundation > 6”; although the sedge/rush sod needed to be irrigated for a short period after planting, muskrat damage was avoided. Bulrush sod experienced less muskrat damage and will likely expand into former sedge/rush areas; however, bulrush stands in deeper water may affect channel form and habitat differently than sedge/rush stands on higher ground. The results indicate that understanding stream hydrology is crucial to revegetation success. The results also suggest that when specifying channel constriction elevations, one should try to keep water depths less than 6” to prevent muskrat herbivory and irrigate if necessary. It is too early to evaluate effects of fill elevation and revegetation on RCG invasion.

Reed Canarygrass Suppression and Revegetation Study

In the short term, RCG control was highly effective, but success of revegetation varied widely among methods and study sites. Mowing followed by two glyphosate applications initially suppressed RCG at all sites; however, a few plants apparently survived, probably as rhizomes. Although the most aggressive revegetation methods (wetland sod and high density plugs with hydromulch) were more successful than the lower intensity methods (unplanted controls and medium density plugs without hydromulch), RCG was able to start reinvading sites within one growing season regardless of revegetation method. Hydrology varied among the study sites and affected treatment success. Groundwater at many of the sites was much lower than adjacent stream levels during the growing season. Even with supplemental irrigation, revegetation of areas with unfavorable hydrology was moderately successful at best and failed entirely in some cases. Cover of planted species was generally higher in high density plug and wetland sod plots than medium density plug plots and virtually zero in areas that were not planted after RCG control. RCG cover was highest in medium density plots, lowest in sod plots, and intermediate in control and high density plots. Because short-term revegetation results partly reflect initial planting intensity rather than growth, and because there are already signs of RCG reinvasion, long-term results may not follow these initial patterns. Future restoration efforts should focus on identifying sites with optimal hydrologic conditions (saturated soils throughout the growing season) or modifying sites to re-create these conditions. Ongoing monitoring and RCG weed control are both essential to insure long-term success. However, even with the most aggressive revegetation techniques used here, ultimate success in the face of RCG pressure is not assured.

Interpretations and Recommendations

The interpretations and recommendations below are intended to help select and plan stream and riparian restoration projects at Silver Creek Preserve and similar areas. In addition to the studies and observations on Stalker Creek, we have drawn on our previous restoration experience, information from resource managers, and the research literature summarized in Appendix A. Collectively, these sources indicate significant challenges, high costs and effort, and uncertain outcomes and, therefore, argue for a cautious, strategic approach to restoration. Two general themes across recommendations are (1) to give priority to places where high-value aquatic resources are imperiled, where resource enhancement is likely to succeed, or relatively low-cost practices are feasible and (2) to understand and plan around site hydrology the maximum degree possible.

1. Exercise caution when considering stream restoration based on reshaping the channel.

The goal of narrowing the channel of Stalker Creek and creating new riparian habitat required significant dredging. Incomplete transfer of sediment from the channel to behind biologs resulted in initially unsuccessful revegetation of the Streambank Treatment Areas that were backfilled, as well as questionable longevity of other biolog areas that were not filled. Compared to snowmelt dominated streams, the low-gradient, steady discharge, and strong SAV influence in upper Stalker Creek are not favorable for transforming it into a narrow, deep, swift-running stream. Changing the channel depth and width may have habitat benefits, and the deeper and narrower channel may enhance occasional springtime flushing flows. However, existing aquatic habitat in this part of Stalker Creek appears to be relatively high quality, so expensive and labor-intensive channel reshaping may not be justified.

Recommendation. When considering stream restoration by reshaping a channel into a narrower, deeper form, prioritize stream reaches with the most favorable physical conditions and conduct a hydraulic analysis of proposed channel designs. Stream gradients, bed substrates, flow regimes, sediment loads and transport, and other physical conditions should be considered. Low-gradient, low-energy spring creeks are poor candidates for this expensive approach when hydraulic alteration is central to objectives. Higher gradient spring creeks may be suitable but also require careful evaluation of the potential of reconfigured channels to maintain their form and enhance fish habitat. To assess potential biological benefits, projected fish habitat should be compared realistically to current habitat quality, including cover provided by aquatic vegetation, food resources, and thermal conditions.

2. When planning riparian revegetation, take account of the unusual hydrology of low-gradient spring creeks that are strongly affected by submerged aquatic vegetation.

The distinctive hydrology of Stalker Creek creates significant challenges for revegetation. Due to low gradient and dense aquatic vegetation, water levels fluctuate by 1-2 ft seasonally and are highest from midsummer through early fall. Lower-lying riparian sites are inundated for much of the growing season, which limits conditions favorable for seedling establishment to spring and early summer and imposes flooding stress from mid-summer through early fall when plants are still small and vulnerable. This was the case in most of the new riparian habitat in the Streambank Treatment Areas, and nearly all of the plugs that were initially planted died. Sites near the upper extent of flooding are more favorable, providing moist soil in early summer followed by saturation or shallow flooding during the remainder of the growing season; they are also less vulnerable to damage by muskrats. Seasonal hydrology of Stalker Creek was not well understood when revegetation was planned, which is a very common shortcoming in stream restoration projects.

Recommendation. Several practices can enhance revegetation of newly created riparian habitat on spring creeks such as Stalker Creek that experience high water during the growing season.

- On higher ground near the upper limit of inundation, plugs or seed (for appropriate species) may be used successfully if planted when weather or water levels keep soil moist.
- In lower areas subject to lengthy flooding, older, more robust plants are needed. Pre-planted coir products such as wetland sod can tolerate these conditions during the establishment phase. Alternatively, large individuals of species that tolerate relatively deep season-long flooding may be used. *Schoenoplectus acutus* is one example; wild transplants or nursery stock with well developed rhizomes can establish well on submerged sites. Muskrat control during the establishment phase may improve success.

A good understanding of site hydrology is needed to define areas suited for different revegetation methods, species selection, and timing of planting. At a minimum, general information about seasonal water levels and visible indicators of high or low water levels are essential.

3. Evaluate long-term success of stream restoration projects.

Revegetation of the Stalker Creek streambank treatment areas with pre-planted coir mats appeared very effective after one growing season but less successful after two years. Localized muskrat damage and deep flooding of some sedge/rush sod in year one developed into extensive losses in year two. These losses can probably be made up by bulrush expansion but this is speculative. Presence of occasional RCG plants may or may not result in full blown invasion. While 1-2 years of monitoring is common for restoration projects, these observations indicate a need for ongoing monitoring.

Recommendation. Monitor long-term performance of channel modifications and riparian revegetation to learn what is effective in the Silver Creek watershed and similar areas. The combination of spring creek hydrology and abundant RCG makes this area different from most streams described in the stream restoration literature. Formal research using systematic monitoring of vegetation and hydrology should be continued on Stalker Creek and extended to other sites if feasible. Rapid, qualitative observations to track changes in restored streams entail much less effort and should be strongly encouraged. Low intensity, long-term monitoring could be conducted using Nature Conservancy staff, interns, or volunteers and partnering with private landowners and provide valuable information.

4. Reed canarygrass control can use simple methods but should be approached as a multiyear effort. Assume that reestablishment of reed canarygrass will be a problem when attempting to restore communities where it is dominant.

Field experiments in other places have shown that simple methods can be used to control RCG but several years are required for best results (Appendix A). Glyphosate applied in mid- to late summer is effective. Prior mowing or burning can enhance herbicide contact and efficacy, but mechanical treatments and burning are not effective on their own. Control of established plants is improved by up to three years of herbicide treatment. Follow up spot spraying or weeding may be needed to deal with plants that continue to emerge from the seedbank; required effort will decrease over time. In the current study, RCG was present at low levels in many of the treated plots one year after spraying and four months after revegetation; RCG will probably increase.

Recommendation. Apply glyphosate in middle or late growing season to control RCG. If feasible, mow first to remove standing dead material and allow regrowth before spraying. Delay revegetation 2-3 years after the start of RCG control and re-spray annually rather than the one year in the current study. Monitor restoration projects and use spot spraying or hand weeding to prevent RCG invasion. The study plots established at Silver Creek Preserve should be monitored for several years to evaluate changes in both RCG and native species; this will provide a much-needed test of whether aggressive revegetation can restore a native herbaceous community.

5. Consider focusing on shrubs and trees to improve streamside sites infested with reed canarygrass.

Recent anecdotal reports and research suggest that planting trees and tall shrubs has better odds of success than revegetation with herbaceous plants on sites dominated by RCG (Appendix A). With temporary, localized control of RCG, planted shrub and trees can grow above and shade-out or coexist with RCG. Survival is often poor with non-rooted cuttings, but is better with rooted material. Larger, better developed plants also require less ongoing weed control than small plants or cuttings, especially if planted close to groundwater.

Recommendation. Consider focusing on woody vegetation in restoration projects. Where shrubs or trees are wanted for stream shade or bird and insect habitat, use fewer, larger, rooted plants in preference to many non-rooted cuttings. Kill RCG locally with herbicide, remove detritus, and staple down a durable weed barrier several feet in radius. Plant well-rooted cuttings, large container-grown plants, or transplants. Alternatively, excavate and transplant willow clumps.

6. Prioritize effort. Conditions in the Silver Creek watershed work against effective restoration of ecosystems dominated by reed canarygrass.

The Silver Creek watershed features all or most of the conditions thought to contribute to RCG invasion: deliberate introduction, possibly of agronomic or exotic genotypes; a network of roads; a history of physical disturbance by grazing, farming, and other activities; nutrient enrichment by agricultural fertilizer use; altered hydrology and sediment dynamics; and presence of manmade and beaver dams (Appendix A). None of these can be wholly reversed. Restoration of large areas currently dominated by RCG will be difficult due to these factors, the effort and expense involved, and the likelihood that some landowners will not make it a priority. Because elimination of RCG from the watershed is virtually impossible, it will remain a threat to restored sites which may require ongoing inputs.

Recommendation. When selecting sites and goals for restoration, practice "ecological triage" based on the value of threatened or damaged resources, the probability of success, and the costs of potential projects. Priority resources may include the fishery and other aquatic resources and, perhaps, birds or plant species of concern. Criteria for success may vary for different sites or resources. In some cases, for example, partial control of RCG may be enough to maintain reduced populations of subordinate plant species, establish more shrubs and trees, and enhance habitat. In other cases, more complete control of RCG and reestablishment of pre-invasion stream conditions may be sought. Some areas dominated by RCG may be sacrificed as impractical to restore.

7. Preventing invasion of stream channels by reed canarygrass, and restoring channels that have been invaded should be a priority, and this threat should be evaluated further.

Protection and enhancement of streams at Silver Creek Preserve is a clear priority considering the importance of the high desert, cold spring aquatic ecosystem and the exceptional fishery. Invasion of stream channels (versus riparian zones) by RCG is an extraordinary problem because it can thoroughly transform the stream ecosystem. For example, in-channel infestations in Wilson Creek appear to increase sediment accumulation, reduce channel definition, retard flow, and change aquatic habitat structure dramatically. Though not documented, these changes undoubtedly alter organic matter production and retention, aquatic invertebrate communities, and local fish populations. The extent of this problem and the processes by which it occurs are not known.

Recommendation. In the Silver Creek Watershed, special efforts should be made to control RCG where it threatens to occupy the channel, and to remove it where it already has. In addition to chemical weed control or mechanical removal of RCG, this may require channel modifications to reduce shallow water areas and dense aquatic vegetation beds and to enhance channel depth and water velocities (August et al. 2006 in Appendix A). This type of stream rehabilitation may not return streams to their original state because, for example, the final channel may be deeper than the original one and support less aquatic vegetation. The threat of in-channel RCG and methods to correct it deserve additional investigation.

8. Develop revegetation plans specifically for floodplain sites where water levels are not closely connected to stream hydrology.

Along Stalker Creek, and in other places IMA has worked, site moisture at some floodplain sites does not track stream water levels. Successful revegetation requires at least a general understanding of seasonal moisture patterns.

Recommendation. Treat off-stream revegetation as a different problem than on-stream revegetation. If time allows, install one or more shallow observation wells and check water levels periodically during the year before planting. Very inexpensive wells made from PVC pipe can be used, and observations take only minutes. Schedule revegetation to fit hydrology, and use supplemental irrigation if needed during early establishment. Ideally planting of floodplain and streambank sites would be coordinated for efficiency, but the requirements of each type of site must be met. On Stalker Creek, spring planting might work well at both streamside and off-stream sites, with differing irrigation regimes to deal with differences in timing of low water (spring in streamside areas versus summer at off-stream sites).

Appendix A: Review of Preserve Records and Research Literature

Relevant events at Silver Creek Preserve and vicinity

The sources used to describe history, resources, and studies at and near the Preserve included research and restoration project reports, TNC and government agency monitoring reports and raw data, TNC project records, and personal communications. Most of the reports used have been indexed in a TNC bibliography and are available via the Save Silver Creek web site (www.savesilvercreek.org). References related to hydrology, geology, and fisheries have been compiled by the USGS ("Preliminary bibliography of the Wood River Valley and surrounding area" (http://id.water.usgs.gov/projects/wood_river_valley/pubs. html#null). References are not reproduced here.

1880s: Settlement of Silver Creek/Picabo area by European Americans, beginning of major land use and hydrologic alterations including livestock grazing (major use), cultivation (minor use), stream damming, and diversion of water for flood irrigation.

1940-1975: Silver Creek property (Sun Valley Ranch) used as a hunting and fishing retreat.

1956: Report on Silver creek improvements describes in-channel structures installed to create pools and improve fishery.

1950s: Shift of agricultural land use towards more cultivation and less grazing on property. Draining and leveling of upstream marsh areas in valley.

1960s: Cattle grazing on Silver Creek property stops.

1970s-1990s: Major shift from flood irrigation to sprinkler irrigation in watershed. Groundwater pumping for irrigation doubles.

1970s: Probable time of reed canarygrass introduction for streambank stabilization by TNC staff. Information not available to assess earlier presence or introduction or introduction by other land owners.

1976: Purchase of 479-acre core area of the Preserve by the Nature Conservancy.

1982-1983: Pilot test of sediment dredging to enhance fish habitat in Mud Creek.

1990: Loose sediment in slackwater areas above dams and culverts on Stalker and Chaney Creeks removed by suction dredging. Objective is to enhance fishery and aquatic vegetation and to rejuvenate sediment trapping capacity.

1990 and 1992: Stream rehabilitation projects on Wilson Creek above Stocker Cr. Rd. and below Highway 20 narrow, deepen, and increase sinuosity of channels and create deep pools, riparian wetlands, and other habitat features.

2002/2003: Sediment dredged on Cain/Chaney Creek above culvert at Preserve boundary.

Relevant studies and observations at Silver Creek Preserve and vicinity

Riparian and upland vegetation surveys: A preliminary biophysical inventory of the Preserve including plants, fish, birds, mammals, insects, hydrology, water quality, soils, and climate was compiled in 1977. Reed canarygrass was not listed in a detailed plant inventory. Sedges and other typical native riparian and aquatic plants were listed; northern reedgrass was described as common on stream banks. Deliberately introduced grasses and exotic weeds were abundant, with Canada thistle noted as a particular problem. The report gives an anecdotal summary of the perceived decline in quality of aquatic habitat and the trout fishery in the 1960s and their relation to land use changes, especially the shift to cultivation during 1950s and associated increases in siltation. A 1979 report presenting a concept of natural vegetation patterns also did not mention reed canarygrass. Reed canarygrass was abundant in the riparian zone of Wilson Creek below highway 20 in 1985. A 2006 aerial photo comparison suggested that riparian shrub and tree cover had increased along Silver Creek from 1951 to 2003 (Reports in 1977, 1979, and 2005).

Submerged aquatic vegetation: Surveys of submerged aquatic vegetation (SAV) in Silver Creek and tributaries have found that *Chara* is dominant and *Potamageton* and *Veronica* are also abundant seasonally; 29 vascular and non-vascular aquatic plants have been recorded. Aquatic vegetation typically peaks in July or August (sometimes June) and varies significantly form year to year. SAV sometimes survives over winter. A major SAV decline in 1953 triggered closure to fishing. Tendency for *Chara* to form mats, accumulate silt, and slow water flow was noted in 1956 and in later reports, as were effects of freezing, drying, and water flows on flushing out SAV. The tendency of SAV mats to roll up into balls and wash out when they became too thick and dammed up flows was also described. A 1982 Study of aquatic vegetation, organic detritus, and sediment deposits in upper Silver Creek reported that: asynchronous water level peaks (June or August) on different streams indicated that SAV affects water levels; sediment depth peaked in August at most locations; major sediment scouring and SAV wash out occurred in spring of 1982. Major scouring of SAV was also recorded in 1993. A 1984 survey of stream cross-sections on Stalker, Grove, and Silver Creeks found that "silt" (probably a loose mix of mineral sediment and organic detritus) was 0.5-1.5 ft deep in many places and up to 2 ft deep, and observed that many deposits were associated with aquatic plant beds. In 1985 a rapid survey of Wilson Creek below highway 20 documented reed canarygrass as clumps on top of *Chara* mats. (Reports in 1953, 1956, 1977-1979, 1982, 1993, and 2001).

Sediment studies: Estimates of sediment loading indicated that Stalker Creek contributed a disproportionate amount of sediment to Silver Creek (1979). Agriculture was rated the primary sediment source. Depths and composition of sediment have been monitored in Silver Creek and several tributaries periodically. Stalker Creek sediments were predominantly finer than sand. A 2006 sediment analysis using existing datasets was mostly inconclusive, but historical aerial photo analysis indicated little change in channel location and width between 1951 and 2003. Thus major channel avulsion has probably not been a factor in sediment dynamics. (Reports in 1979, 1991-1992, and 2006). A large runoff event in spring 1993 scoured streambeds exposing more gravel and transporting sediment.

Groundwater and surface water investigations: On average, flows in Silver Creek peak in March-April, reach their minimum in June-July, then rise to a second, smaller peak in October-November. Because groundwater is the main source of water, seasonal variation is typically small except for occasional large runoff events. Silver Creek is connected to Big Wood River via groundwater and water transfer for irrigation, which also recharges groundwater and feeds springs. Possible effects of changes in irrigation practices are a concern. A major USGS field study was initiated in 2006 to evaluate hydrology and water quality. (Reports in 1938, 1959, 1960, 1977, 1986, 1987, 1994, 1999-2001, and 2006). Water quality monitoring has shown that nitrate levels are above levels typically observed in unpolluted natural streams in the region and nationwide. (Reports in 1991-1994; ongoing). A 1996 NRCS *Preliminary Investigation Report for Silver Creek Watershed* summarized results of previous studies. Conclusions included: nitrate levels reflect elevated concentrations in groundwater and may contribute to aquatic nuisance problems; high nutrients may also contribute to very high aquatic invertebrate populations; sediment loads derive from agriculture; limited flushing flows allow sediment to remain in channels; and riparian vegetation data are inadequate. The report recommended several stream enhancement practices including dredging.

Reed canarygrass literature review

Reed canarygrass control: Research and management experience supports two general conclusions about reed canarygrass control: (1) regardless of control methods used, repeated treatments over several to many years are required; (2) re-establishment of reed canarygrass (though not necessarily dominance) should be treated as a risk in any restoration project where reed canarygrass is initially present or occurs in adjacent areas (Antieau 1998 and 1999, Lyons 1998, Reinhardt and Galatowitsch 2004, Tu 2004, Reinhardt Adams and Galatowitsch 2006).

Reinhardt and Galatowitsch (2004, Reinhardt Adams and Galatowitsch 2006) recently published results of the most comprehensive, well designed field test of reed canarygrass control yet reported. Late-August and September glyphosate applications were more effective (>90% control) than mid-May application (75% control). Late-season efficacy was associated with seasonal transport of carbohydrates to rhizomes. Spring burning alone did not control reed canarygrass, and herbicide efficacy was not enhanced by a spring burn. However, burning did reduce the reed canarygrass seed bank, probably by inducing germination before herbicide application, and this might aid restoration by limiting recolonization from seed.

Selective herbicides show some promise for reed canarygrass control, but effective use has not been demonstrated. Annen et al. (2005) tested the grass-selective, systemic herbicide sethoxydim ("Vantage") on a reed canarygrass-dominated community in Wisconsin. Reed canarygrass biomass was reduced by 50% compared to controls in the year of application, and seed head density was reduced by over 90%. However, these effects did not persist into the next year and non-target species including native sedges did not increase significantly. Though short-term benefits were limited, results suggest that repeat applications over several years could be more effective and should be tested.

Practices that attempt to draw down plants' carbohydrate reserves by damaging them physically (mowing, grazing, disking, burning), shading them (synthetic mulches such as weed barriers), or flooding them deeply may require several years to reduce reed canarygrass and may not eliminate it (Antieau 1998). These practices are more effective if combined with herbicide. Flooding may need to be deep and sustained over 2-3 years or more to eliminate stands.

Depletion of reed canarygrass in the seedbank is also desirable and may be attempted by repeated disking, herbicide application, and fallowing over several growing seasons (Antieau 1998). This may also help reduce other weeds that can replace reed canarygrass after short-term herbicide control (NRCS 2005).

Revegetation after reed canarygrass control: Good initial control of reed canarygrass typically does not translate into longer-term success. Where control with glyphosate is incomplete, shoots may grow back at even greater density (Kilbride and Paveglio 1999). Reed canarygrass can produce abundant seed, creating a large seedbank (Galatowitsch and van der Valk 1996) that may allow rapid reestablishment after existing plants are killed. Surviving rhizome fragments may also allow reestablishment. In spite of apparently effective control in Reinhardt and Galatowitsch's (2004) experiment, reed canarygrass recolonized rapidly and prevented establishment of native species. Even extremely high rates of seeding with native species (15,000 seeds/m^2) did not suppress recruitment of reed canarygrass from seed when reed canarygrass seed density was very low (10 seeds/m^2). Because shading inhibits reed canarygrass germination, rapid establishment of other plants using vegetative plant materials might be able to suppress its establishment from seed (Lindig-Cisneros and Zedler 2001, 2002a, 2000b).

Foster and Wetzel (2005) tried to establish native plants from seed and transplants after a single herbicide application or burning. Herbicide resulted in better initial native plant establishment than burning, but reed canarygrass increased rapidly while planted natives declined over the two year study period. The authors concluded that native species "needed more than two growing seasons to become established enough to compete with *P. arundinacea* sprouting from the seed bank or surviving rhizomes." Seeding and exclusion of deer resulted in at least short-term (3 year) increases in species richness after "non-catastrophic" disturbances that did not reduce reed canarygrass abundance (Kellogg and Bridgham 2004); communities were still dominated by reed canarygrass. The USDA initiated a study to identify native grasses, sedges, and forbs that can establish rapidly and resist re-invasion, or co-exist with, reed canarygrass (Darris 2000).

Tests of a cover crop strategy were not promising. Perry and Galatowitsch (2003) evaluated use of two transitional cover crops to suppress reed canarygrass during sedge meadow restoration. One cover crop suppressed reed canarygrass successfully, but it also suppressed native sedges as badly as reed canarygrass did.

Mark Stannard and colleagues at the USDA's Pullman, Washington, Plant Materials Center are currently testing several control and revegetation strategies. Results have not been published but include (M. Stannard, personal communication, NRCS 2005):

- Poor revegetation success with grasses, legumes and forbs, with recolonization by reed canarygrass after a few years.
- Some success with rooted woody plants, but limited success with cuttings.
- Success with woody plants has required use of a weed barrier, in addition to initial herbicide application, because control by legal herbicides does not persist long enough. Without a weed barrier reed canarygrass recolonizes or other weeds such as Canada thistle take over. However, installing weed barrier properly is very labor intensive.

Tim Miller and Craig MacConnell of Washington State University Cooperative Extension tested methods to control reed canarygrass and establish riparian trees in Western Washington (unpublished results summarized by Dobrowolski and Miller 2004). They achieved good tree establishment after chemical control of reed canarygrass if follow-up maintenance was done to limit regrowth of reed canarygrass and broadleaf weeds. Follow-up weed treatments included spot application of glyphosate, which had the best results, clipping, which was effective but used 30% more labor, and mulching with wood chips, which only worked if initial reed canarygrass control was complete. Tree protectors aided survival and growth. Other restorationists have also reported promising results with tree planting or transplanting (Moore et al. 2000, Naglich 2000).

A trial using willow cuttings after reed canarygrass control showed promising results for a high intensity approach (Kim et al. 2006). During one year, test plots were mowed twice, sprayed with glyphosate three times, and covered with 10-15 cm of woodchip mulch. The next year 3-ft long willow cuttings were planted at high density (spaced 2, 3, or 4 ft apart). Willows grew well and shaded reed canarygrass, reducing its biomass by 45-68% within two years.

Evaluation of 41 prairie pothole restorations that relied on passive recolonization found high levels of reed canarygrass, Canada thistle and other weedy species (Mulhouse and Galatowitsch 2003). Most native wet prairie and sedge meadow species were present only at low levels, whereas reed canarygrass was present at every site, often at 75–100% cover.

There has been an unconfirmed report of sedges and rushes replacing reed canarygrass (Zamora interview cited in Harrison et al. 1996), but no other mentions of unassisted reversion from reed canarygrass to native dominance were found. European research on common reed (*Phragmites australis*) in fens found that many reed populations were fluctuating from year to year rather than increasing over time (Gusewell et al. 2000), lending credence to the possibility of long-term coexistence of reed canarygrass and native plant species in some communities.

Origin and planting of reed canarygrass in North America: Reed canarygrass populations in North America are a mixture of native and introduced genotypes (Harrison et al. 1996, Merigliano and Lesica 1998). Reed canarygrass was present in the inland Pacific Northwest, including Idaho, before settlement by European peoples (Merigliano and Lesica 1998), with large stands at low elevations and smaller stands in the mountains. The question of whether the arrival of exotic, aggressive genotypes is responsible for invasion is, consequently, very difficult to answer. Invasion by exotic genotypes of native species has been called "cryptic invasion" and has been documented for the common reed *Phragmites australis* (Lavoie et al. 2005). A study to evaluate genetic differences between wild and pasture populations of reed canarygrass and their possible role in invasion was inconclusive (Gifford et al. 2002). A reed canarygrass population sampled from a single Vermont pasture included many distinct genotypes (Morrison and Molofsky 1998, Molofsky et al. 1999). Early survival, growth, and ability to compete with existing vegetation differed among genotypes, implying that some genotypes may be more invasive than others.

Agricultural use of reed canarygrass dates to at least the 1830s in the United States and the 1880s in the Pacific Northwest; in the U.S. systematic agronomic research began before 1920, and named varieties were released in the 1940s (Stannard and Crowder 2001, 2002, Tu 2004). Seed for pastures was initially harvested locally, but commercial seed produced in Europe and the U.S. (from either European or North American genotypes) was the main source later. Thus reed canarygrass populations now include (a) "wild" native genotypes, (b) cultivars that have been developed by deliberate selection using native or exotic genotypes, and (c) probably crosses between wild and cultivated genotypes (Lyons 1998, Casler 2003). Development of varieties more suitable for livestock grazing has contributed to widespread use of reed canarygrass in pastures, a practice that continues in some states.

The USDA and other agencies have recommended reed canarygrass for pasture improvement and ditch and streambank stabilization for many years and continue to do so in some areas (Stannard and Crowder 2002, Casler 2003). Some agencies, including in Idaho, currently recommend use of reed canarygrass in applications such as stormwater filtration (e.g. Ogle and Hoag 2000), riparian buffers, and even wildlife habitat improvement. Concerns about invasiveness are not always mentioned. Current interest in using reed canarygrass for bioenergy production and wastewater and stormwater treatment could result in increased planted acreage and assist spread along waterways.

Planting of reed canarygrass at or near Silver Creek Preserve in the 1970s or before would have been consistent with mainstream practice. Massive expansion from small initial populations can occur over one or two decades (Barnes 1999, Mulhouse and Galatowitsch 2003, Lavergne and Molofsky 2004), so the current abundance of reed canarygrass at Silver Creek could have resulted from planting in the 1970s.

Reed canarygrass effects on plant communities: Reed canarygrass can reduce native floristic diversity drastically (Barnes 1999, Maurer et al. 2003). Some authors have suggested that invasion by reed canarygrass and similar exotic species merely replace one dominant, such as a native sedge or cattail, with another (Harrison et al. 1996, Houlahan and Findlay 2004). However, Werner and Zedler (2002) found much lower diversity in reed canarygrass-dominated communities than those dominated by sedges or cattails. Kercher et al. (2004) found a negative relationship between species richness and reed canarygrass cover. Houlahan and Findlay (2004) found that lower diversity of native plants in communities strongly dominated by reed canarygrass was mainly due to exclusion of rare native species. In some cases endangered species are at risk (Lesica 1997). Antieau (1998) suggested that reed canarygrass infestations may form "neo-climax communities" that take hold through human disturbance and then prevent recovery of the natural community.

Reed canarygrass effects on aquatic ecosystems: Reed canary grass is "associated with reduced biotic condition of fauna in western US streams" (Ringold et al. 2007). Stream vertebrate and macroinvertebrate communities were sampled in more than 1000 stream reaches, and presence of riparian weeds was recorded. In some regions, indices of biotic condition were significantly lower where reed canarygrass, Himalayan blackberry, or salt cedar were present.

Reed canarygrass is typically limited to stream banks and channel margins that are exposed periodically during low water periods. Though rarely noted in publications, reed canarygrass can sometimes affect instream conditions directly. Dense stands in stream channels or ditches can retard water flow (Antieau 1998). In western Washington, Coho salmon migrating up a poorly defined channel choked with reed canarygrass were stranded in the grass after waters rose then receded during a flood event (Carrasco 2000).

Intermountain Aquatics and the Nature Conservancy investigated reed canarygrass stands in the channel of Wilson Creek in a reconnaissance-level study done in parallel to the current project (August et al. 2006; see Results and Discussion section). Reed canarygrass appeared to have grown onto mats of aquatic vegetation and stabilized the mats and associated sediment. Reed canarygrass stands in the channel drastically reduced open channel areas and appear to alter channel hydraulics, sediment transport, and aquatic habitat. A similar hydraulic and geomorphic effect has been observed with *Arundo donax* (giant reed) in California, though supporting data have not been reported (Dukes and Mooney 2004).

Hydrologic environments of reed canarygrass: Reed canarygrass thrives and is highly competitive under a wide range of hydrologic environments (Kercher and Zedler 2004, Magee and Kentula 2005 Mahaney et al. 2005, Miller and Zedler 2003), including some upland sites (Harrison et al. 1996). Suitable water levels are narrower for initial establishment than subsequent growth and persistence. Young seedlings do not survive or grow well with any flooding above the soil surface (Fraser and Karnezis 2005).

In Great Lakes coastal wetlands, reed canarygrass and other exotic or invasive plants were more abundant in diked than undiked wetlands (Herrick and Wolf 2005). This was attributed to altered water level regimes (shallower, more variable) and higher nutrient levels, soil organic matter content, and pH. Hydrologic environment can also modify the ecological effects of reed canarygrass. In an Oregon study, reed canarygrass strongly reduced species richness in wetlands created by beaver dams, but not in impoundments at debris jams or unimpounded sites (Perkins and Wilson 2005). This may have resulted from the physical and hydrologic disturbance caused by beaver, including bare moist soil left when dams breach.

Mahaney et al. (2005) concluded that where restoration relies on seed, reed canarygrass is likely to dominate a wide range of sites regardless of hydrologic conditions, sedimentation, or nutrient enrichment. Orr and Koenig (2006) reported invasion of mudflats formed by breaching dams even though reed canarygrass was probably absent from the initial seedbank and sites were planted with seed or seedlings.

Competitive ability and invasiveness of reed canarygrass, and environmental factors contributing to invasion: The extraordinary competitive ability of reed canarygrass against a wide range of species and over a wide range of conditions is well documented (Lavergne and Molofsky 2004, Reinhardt and Galatowitsch 2004, Reinhardt Adams and Galatowitsch 2006). It is highly competitive even by the standards of aggressive, rhizomatous weeds, sometimes out-competing quackgrass (*Elytrigia repens*) (Harrison et al. 1996). As an adult, reed canarygrass is well adapted to expand vegetatively from existing populations into areas not conducive to establishment from seed. Parent clones apparently subsidize growth of tillers into shaded microsites (Maurer and Zedler 2002).

Reinhardt Adams and Galatowitsch (2005) suggest that rapid initial shoot growth may be important to reed canarygrass' competitive advantage when establishing on disturbed sites such as newly planted restoration projects. Over the first six months of growth, reed canarygrass had the greatest proportion of biomass allocated to shoot growth (the lowest root-to-shoot ratio) of fourteen wetland plants compared (Fraser and Karnezis 2005). Where rapidly growing native plants are present, its competitive ability could be poorer during the first two months after germination due to delayed tillering (Antieau 1998). In a three-year-long restoration experiment, *Carex stricta* seedlings were able to outgrow all species recruited from the seedbank except reed canarygrass (Budelsky and Galatowitsch 2004).

In a Danish riparian wetland complex, reed canarygrass was more abundant on sites with high soil concentrations of phosphorus and base cations as well as large groundwater level fluctuations; the opposite was found for *Carex rostrata* (Schröder et al. 2005). Nutrient-rich environments appear to favor reed canarygrass invasion, especially where sites are disturbed (Wetzel and van der Valk 1998, Green and Galatowitsch 2001, Maurer et al. 2003, Kercher et al. 2006), whereas nutrient-poor environments appear to retain native wetland plants (Perry and Galatowitsch 2002). High nutrient levels increase the proportion of biomass allocated to shoot growth and enhance growth of tillers into shaded areas (Maurer and Zedler 2002). Reed canarygrass responds more than native sedges to nutrient additions (Wetzel and van der Valk 1998, Gusewell 2005). A native sedge out-competed reed canarygrass in nitrogen-poor environments in a greenhouse study, but the outcome was reversed with even modest increases in N (Perry et al. 2004). These observations suggest that nutrient enrichment and sediment deposition from agricultural and urban runoff may be an important factor in reed canarygrass invasions, and that N fertilization should be avoided in restoration projects.

Reed canarygrass seeds germinate better on exposed soil than flooded sites and seedlings also grow faster under exposed conditions (Coops and van der Velde 1995). The common reed *Phragmites australis*, which is ecologically similar to reed canarygrass and is considered invasive in Quebec, colonized Saint Lawrence River marshes more quickly during or following low water years (Hudon et al. 2005), and there is evidence for similar expansion of reed canarygrass during low water periods (Lavoie 2005).

A reconstruction of the history of reed canarygrass in Quebec indicated that its overall geographic range had not expanded in the twentieth century, but that many new sites had been colonized, especially since the 1960s (Lavoie et al. 2005). This invasion of new sites was attributed to increased road construction and nitrogen pollution as well as periods of drought and low water levels. Agricultural use of reed canarygrass has been uncommon in Quebec and probably was not responsible for the invasion.

Rationale for RCG control and revegetation methods selected for testing

As summarized above, research and management literature indicated that herbicide treatment (usually glyphosate) is the most consistently effective practice to control reed canarygrass and that control is sometimes improved by combining herbicide with mowing or other physical practices. Revegetation after control is not well studied, but available information suggested that intensive revegetation would be necessary to have any chance of success.

Recent field studies provided evidence for better reed canarygrass control by late-season than early-season herbicide application. This was attributed to seasonal patterns of carbohydrate translocation and redistribution of systemic herbicide within the plant. Ideally, treatment is repeated over several years. Alternatively, multiple herbicide applications during the same season may be effective. The current study used early-growing-season mowing, followed by mid-season and late-season herbicide applications.

Three active revegetation practices were implemented (Table C-1). Two of the three active revegetation methods were much more aggressive than conventional practice both in attempting to establish dense native plant stands rapidly and in trying to limit establishment of reed canarygrass and other weeds. Wetland sod maximizes potential for reed canarygrass suppression by combining well-developed plant cover and a coir blanket for weed and erosion control. Combining high-density individual transplants with hydromulching provides less initial plant cover than Sod but is more aggressive than standard practice and includes a mulch for seedbank suppression. Use of moderate-density individual transplants without a mulch is a conventional practice and provides a comparison to current revegetation practices; it at the more intensive end of conventional methods. Seeding was not tested. Although seeding is a common revegetation practice, our previous research and studies in the northern Great Plains have shown that seeding is generally ineffective for restoring sedge meadows.

Revegetation was implemented in early June. In our experience in this region plugs planted in the fall do not have time to establish adequate root systems before being subjected to frost heaving; many plants can be ejected from the soil and die. Planting early in the growing season avoids this problem and maximizes potential growth during the first growing season. (In retrospect, planting should have been done even earlier because there is very little summer precipitation at Silver Creek and groundwater levels were generally low during summer in the floodplain study sites used. Site hydrology was not known in advance of study design and was assumed, incorrectly, to parallel Stalker Creek's seasonal water levels with wetter conditions during the growing season). .

In addition to the active revegetation practices, passive revegetation was tested as an experimental control. In passive revegetation, a site is not planted after preparation; the seedbank, seed rain, and surviving parts of native plants are assumed adequate for revegetation. Although passive revegetation of sedge meadows has been found unsuccessful following reed canarygrass control, it remains a common practice. Untreated reference plots (no reed canarygrass control or revegetation) were also included to monitor reed canarygrass levels with no active management.

This study focused on herbaceous vegetation and did not evaluate shrub establishment. Recent information suggesting potential strategies for willow establishment was not available when the study was designed in fall 2008-winter 2009.

Table C-1. Summary of experimental treatments

Treatment code	RCG control? (mow/spray)	Revegetated?	Descriptive name
REF	no	no	Untreated reference
CON	yes	no	Experimental control for testing revegetation practices
MDP	yes	yes	Moderate density plugs
HDP	yes	yes	High density plugs with hydromulch
SOD	yes	yes	Wetland Sod

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