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Ninemile Sod Transplants and Willow Monitoring

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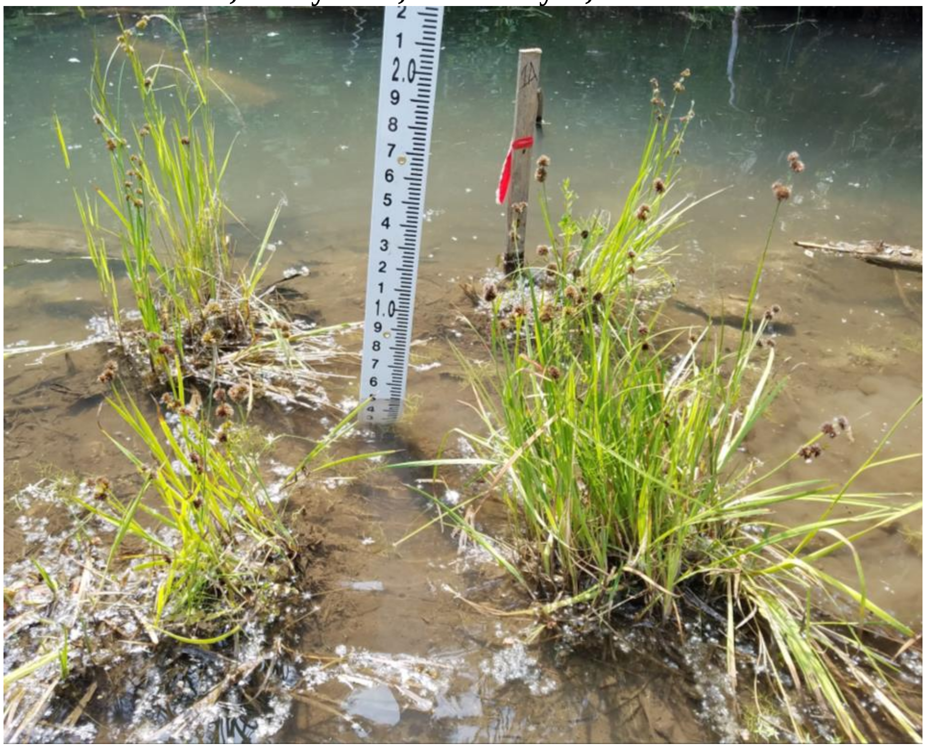


Abstract

Headwater streams are important for providing nutrient transport and removal, flood and flow control, a buffer for water temperature, and trout habitat. The Ninemile watershed contains headwater streams that were drastically impacted by placer mining activity. Placer mining in the Ninemile valley caused extensive damage, leaving behind 30-foot high mine tailing piles, a straightened river channel, and loss floodplain and wetland habitat. Trout Unlimited (TU), a non-profit organization, has set out to restore functionality to the Ninemile Valley watershed. TU's most recent restoration, in 2016, included the creation of a wetland complex that is located adjacent to where the stream restoration was performed. To restore wetland functionality, vegetation needed to re-establish, but this is be challenging due to a lack of seed bank at the site, herbivory, and associated costs. Wetland revegetation efforts performed by TU included planting willow cuttings and seeding in the summer of 2016, however, our experiment examined the potential of sod transplants as an alternative re-vegetation method. Our project implemented wetland sod transplants and willow stand monitoring in the summer of 2017. We monitored growth, mortality and wetland hydrologic function over the course of the summer and into the fall of 2017. We found mortality on average to be 37.75% per plot of sod transplant with the factor of shallowest depth of water to be significant. We observed a positive correlation between depth and mortality. Among our plots within the wetland, water levels on averaged decreased by 2.57 cm over the course of summer with a range of gaining 12 cm to losing 43.18 cm. We found that 53% of willow cutting leafs remained by the end of the growing season. Overall, we found gradual progress toward natural vegetative communities within the wetland.

Introduction

Mining was the vein through which capital flowed in the west and Montana, but the nostalgia for mining soon became dim in the shadow of politics and scarce resources (Murphy, 1997). The claims in Montana brought riches to the industrialized world, but largely impacted ecosystems to their detriment. Nine Mile Valley near Huson Montana was among the areas that were placer mined and heavily disturbed. Placer mining involves the removal of river bottoms to access gold containing sediments deposited below the river bed cobble. After the collection of sediment, high-density metals are separated via sluicing and the leftover sediments are often dumped into large waste piles and left behind by the miners (Wagener and Laperriere 1985). The Montana Chapter of Trout Unlimited, a nonprofit group based in Missoula, is implementing a large-scale restoration project along the Ninemile creek and its tributaries. The group attempts to restore functionality to this disturbed riverine system. As part of a recent restoration of the river in 2016 TU created a wetland complex adjacent to the river. Willow cuttings and sod transplants were planted throughout the wetland complex to bring back native communities, however the efficacy and establishment of these revegetation techniques are not well understood. In this paper, we analyze the success of willow cuttings and sod transplants to determine effectiveness and overall success of the wetland restoration.

The loss of wetlands as a result of mining has reduced beneficial ecosystem services. Wetlands provide important ecosystem services like water purification through the trapping of sediments and the retention of excess nutrients along with other pollutants within those sediments. They reduce flow rates in the river system by absorbing excess water during flooding or storm events. This prevents erosion and increased sedimentation caused by high flow rates. Water retention also serves as a function of water release back into the river system during low flow periods (Flanagan et. al. 2010). The establishment of vegetation is essential for the success of wetland functions like increased soil stability and water retention (Angers and Caron 1998).

The reestablishment of vegetation in degraded wetland ecosystems can be accomplished by spreading seed mixes or planting seedlings. These methods effectively increase local species diversity (Myers and Harms 2009). However, nursery bought seed mixes and seedlings become costly for large scale projects and the use of cheaper alternative means of revegetating may be just as effective.

Sod transplant are used as an alternative method for revegetating landscapes. This revegetation alternative has been used for a variety of landscapes such as wet prairies, freshwater wetlands, moss bogs, and seagrasses (Fraser & Kindscher 2005, Jarman et al. 1991, Sliva & Pfadenhauer 1999, Paling et al. 2009). Restoration practitioners attempt to introduce reproductively active and intact vegetative communities through sod transplants and later establishment of native communities. The success of these communities depends upon ecological requirements that are still imperfectly understood (Haselwandter 1997). Sod recipient sites may differ from donor sites hydrologically, and in their amount of exposure to sunlight (Allen 1994), with this the driving determinant of establishment and mortality of plants in the transplanted sod is the difference in environmental factors from donor to recipient sites (Hoag and Melvin 2017, Łuczaj & Sadowska 1997)..

In addition to using sod for revegetating the landscape, willow cuttings have been commonly used in revegetation. Willow cuttings are stems taken from already established willow bushes, an advantageous method for restoration as they are cheap and easily sourced from established shrubs. Willows are quick to establish in new environments as demonstrated by their display of superior growth and productivity among woody species, making them ideal for a variety of restoration practices (Kuzovkina and Quigley 2005). Willow cuttings establish new roots through the use of stored nutrients to produce a new fibrous root system (Kuzovkina & Quigley 2005). Quick establishment from cuttings allow willows to provide desired benefits, such as soil stability, in substantially less time than seeds would. The main factors determining willow planting success have been shown to be position on the bank, soil textures ability to retain water, and lack of heavy herbivore browse on stands (Pezeshki et al 2007). For these willow stands, Trout Unlimited used a method that differs from methods previously used to install willow stands during other restorations along the Ninemile creek.

In order to test the effects of transplant size, water depth placement, and month of planting on sod survival, and to test the survival of willows we aimed to select methods that are both cost efficient and effective at interpreting the long-term success of wetland restoration. Through these methods we address the following question, 1) To what extent do water depth, sod transplant size, and/or date of planting influence sod? 2) To what extent do these factors affect mortality? 3) How is the water table changing throughout our sites? 4) How successful are willow cuttings producing and maintaining leaves through the growing season?

Methods

Site Description

Our study site is located in the Ninemile valley in Huson, Montana. The site is within a newly created wetland adjacent to the main stream of Ninemile Creek that was created in the summer of 2016 as part of a river restoration project. By removal of mine piles and reconfiguration of the stream, a functional floodplain adjacent to the channel was created. A wetland seed mix was spread and planted following the creation of the wetland complex, although during our project much of the ground was still bare soil. Willow cuttings were also planted along the main channel in the wetland complex to stabilize the banks and prevent erosion.

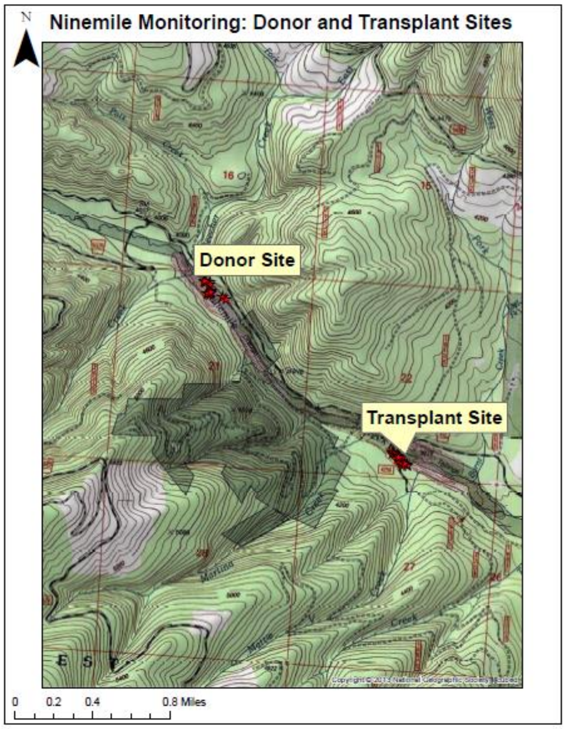


FIG. 1. Previously restored donor site and newly created wetland transplant site along Ninemile Creek, Huson Montana.

Before collecting sod, we consulted with Trout Unlimited and used their knowledge of the Ninemile Creek system to choose a site that would provide healthy wetland plant communities for sod extraction. The donor site was previously restored by Trout Unlimited in the summer of 2015 and is located about a mile upstream from the transplant site. This site was ideal for sod extraction because of its proximity to the transplant site, its representation of a wetland community similar to which we wanted to create in the new wetland, as well as making the physical demands of transplanting easier. The donor wetland complex was seeded by a native seed mix and natural seed dispersal from wildlife, such as bear scat. This complex is well established with an abundance of wetland vegetation. To minimize the variation in species composition we selected sods that were between 0-10 cm of standing water. We extracted sod from several pockets of wetland communities within the donor site to diffuse the degree of impact from extraction and to optimize chances of regrowth. Suitability requirements for the donor site plots included soil saturation and the presence of wetland species, such as rushes and sedges. Transplant plots were selected based on water depth and likelihood that the plot would remain hydrated throughout the summer.

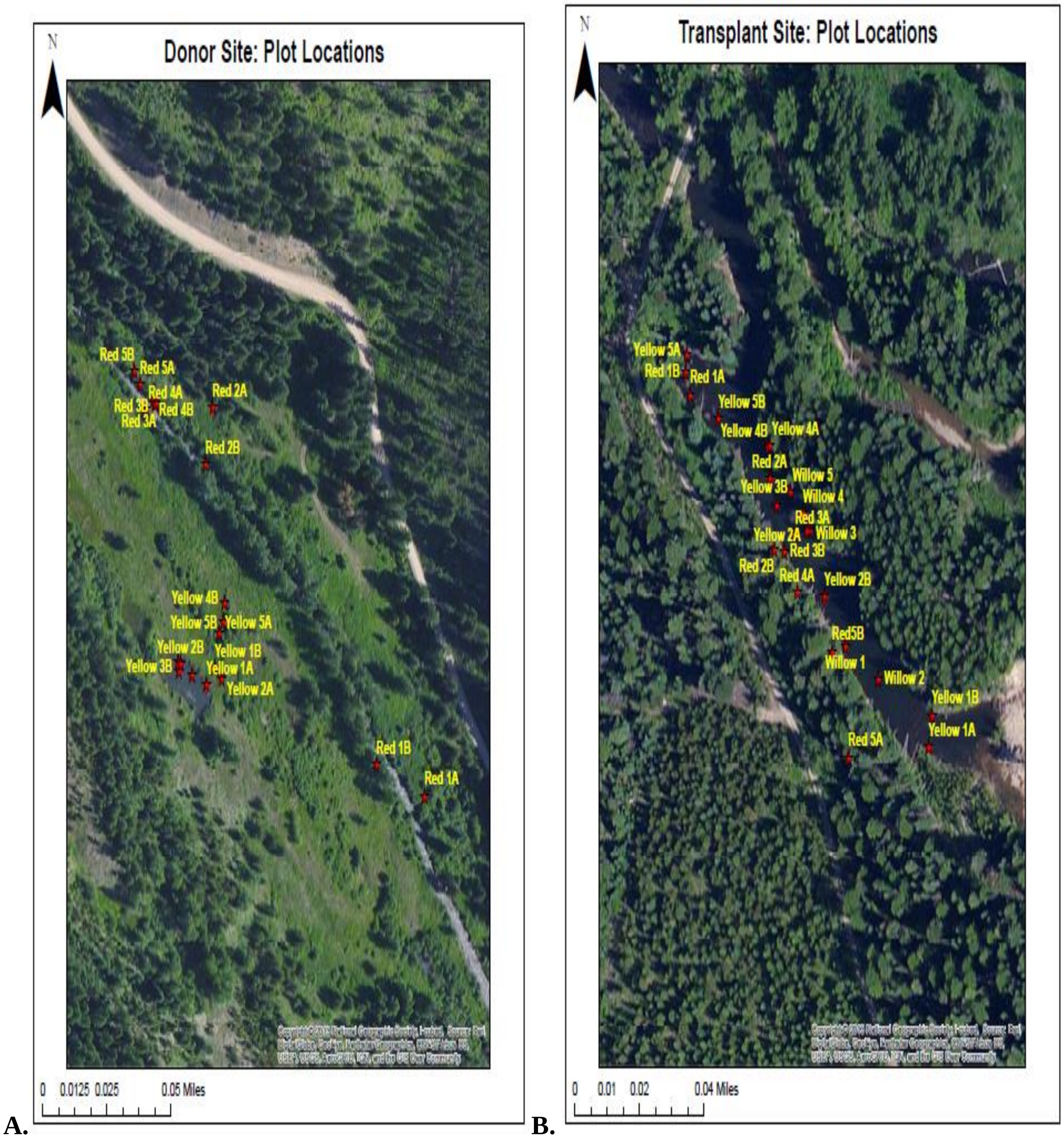


FIG. 2: Panel A represents the donor site plot locations for both the first and second extractions (red labels represent first extraction/planting time and yellow labels represent second extraction/planting time). Panel B represent the transplant site sod plot locations and willow stand monitoring plots 1-5.

Wetland Water Retention

We used Sleeping Woman SNOTEL site, a 783 yearly precipitation long term data set as a proxy for precipitation in the watershed and to see where our sampling term fit within historical precipitation, in order to best interpret the water retention levels within the wetland complex during the summer of 2017. Sleeping Woman SNOTEL site is at an elevation of 6150 feet and its latitude and longitude are 47.18 and -114.33 respectively (NRCS 2018). It lies north east from our sampling location.

We took depth measurements at each of our transplant sites to track changes in depth. We measured from the middle of the plot each time and did this monthly on 6/24 (half the sites), 7/15, 8/28, 9/30, 11/5 (excluding 2 sites due to snow cover). Data collected from plot water depths across the wetland site gave an average monthly change throughout the wetland.

Sod Transplant Extraction and Placement

To establish the impacts of the sod-transplant size on mortality, sod was extracted in one of two size classes: 0.25 x 0.25 m, or 0.25 x 0.5 m (Figure 4). After the removal of sod slabs, we transported the sod materials to the transplant site and arranged them in the plots similar to the design in which we removed them.

To examine the effect of water depth on sod mortality and to account for uncertainty in the hydrology of the wetland complex over the growing season, transplants were placed in varying water depths throughout the created wetland. The four corners of each plot were marked with wooden stakes and labeled with plot number and date planted. We created two sets of ten plots totaling to 20 plots. The first set of 10 transplants were created on June 17, 2017 and marked with red flags, while the second 10 transplants occured on July 15, 2017 and were marked with blue and yellow flags. We recorded GPS coordinates for 18/20 sod transplants, two of them were not found due to snow cover at the end. We also took photo points of each of our sods transplants to record progress during each sampling event. We took photo points and depth measurements on 6/24, 7/15, 8/28, 9/30 and partially on 11/5.

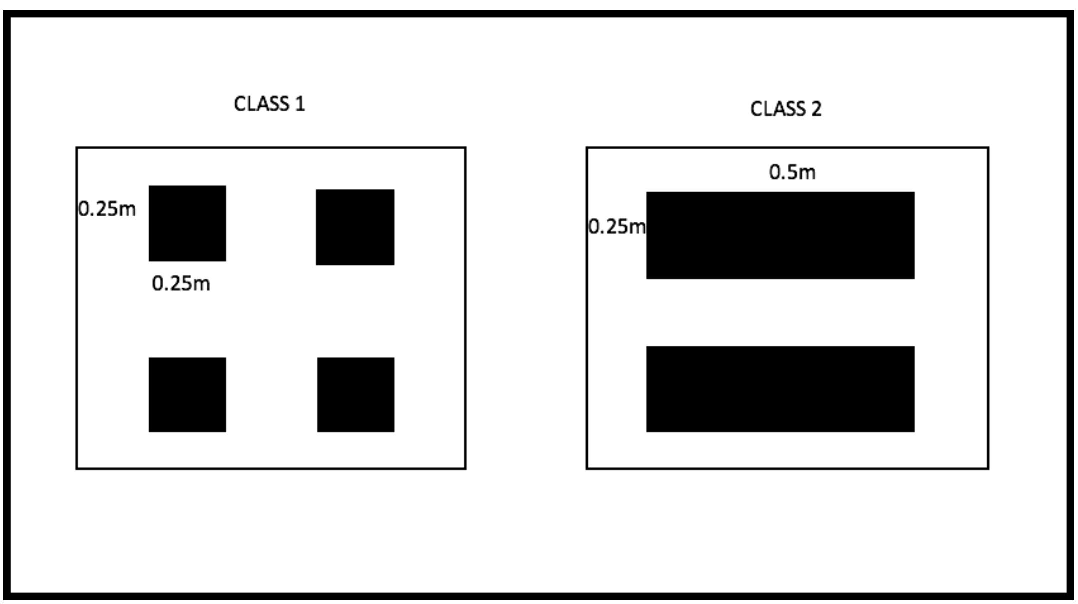


FIG. 3. Representation of our different size and shape classes for sod transplants. Class 1 was in the shape of a square measuring approximately 0.25 meters by 0.25 meters. Class 2 was in the shape of a rectangle measuring approximately 0.25 meters by 0.5 meters.

For both the donor and transplant site we took monthly photos as a visual representation of establishment and regrowth (see Appendix A, figures 11, 12, 13). We visually tracked the transplant site to record the extent of mortality. We estimated percent mortality of transplanted sods at the end of the summer through two group members discussing and comparing visual detection of percent mortality per plot. Mortality of plants was determined through rotting of leafy tissue, discoloration and lack of vigor. Mortality was determined on 9/30/2017.

Willow Stand Monitoring

To monitor the success of willow plantings we took monthly photo-points throughout the summer at the five permanently selected sites, marked with GPS coordinates (see Appendix A, Figure14). We selected five stands within the wetland and flagged them. We determined photo-points by staking a reference point into the ground 2.5 meters from the middle of the stand, opposite from the planting angle of the willows. From each stand we selected 3 willow stems at random and counted number of branches along the stems and leaves present and noted herbivory through observation munched on leaves and clipped stems. We tracked this throughout the summer on the days 7/15, 8/28 and 9/30. We determined a combined monthly average of stem and leaf loss to track differences throughout the summer.

Statistical Analysis

In order to test for the effect of the factors transplant size and date of transplants, while controlling for the effect of the continuous variable of water depth, we used the Rcmnder package for the R Statistical Computing Platform (R core team 2016, Fox & Bouchet-Valat 2018). For all analyses, R was run using the R Commander Graphical User Interface. We grouped our data by the two planting months and the two planting arrangements. We then ran an ANCOVA with those groupings as well as the continuous variable of shallowest depth of the plot. We used shallowest depth because it represented the minimum amount of water inundation our sod plots experienced throughout our sampling. We ran the ANCOVA analysis with interactions and without interactions to splice out significant factors. Then ran a linear regression upon significant factors to determine their influence on mortality.
In order to track the leaf counts of the willows, we grouped the willow leaf counts for each month we recorded them (July, August, September). We then ran an ANOVA and Tukey HSD to see if there will significant declines in leaf count as the months progressed.

Results

Hydrology

The 2017 water year annual precipitation at Sleeping Woman SNOTEL site was 45 inches (NRCS 2018). In the past 15 years the average has been 35.84 inches (NRCS 2018). At our site we found the water table in the wetland decreased by an average of 2.57 cm. (figure 7). There were significant amounts of variation in change in water depth within our plots, as observed from some plots gaining 12 cm. in depth or others losing 12 cm. in depth. There was no apparent pattern for this variation. Two of our sods transplants saw water depth loss of more than 20 cm, both were placed on the edge of the wetland farthest from the river channel.

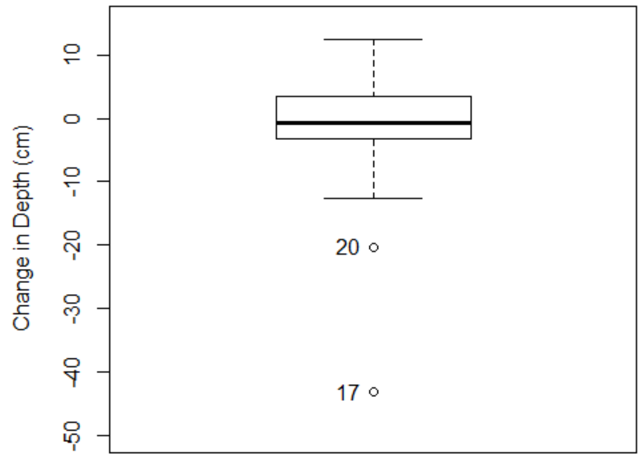


FIG. 7. Box plot of change in water table levels of wetland over the 2017 summer in all transplant sod plots n=20

Sod Transplants

On average there was 37.8% mortality per plot. There were no interactions between XX and XX in thefull ANCOVA analysis, wherein we tested the main effects and interactions of shallowest depth, month of planting, and plot arrangement; subsequent analysis with the interactions removed suggested that the shallowest depth at a site was the only variable that significantly affected the variance of mortality (f=23.43, p=0.00018). Both plot arrangement (f=0.647, p=0.432) and month of planting (f=0.3734, p=0.549) were found to not be significant in affecting the variance of mortality (Figure 5).

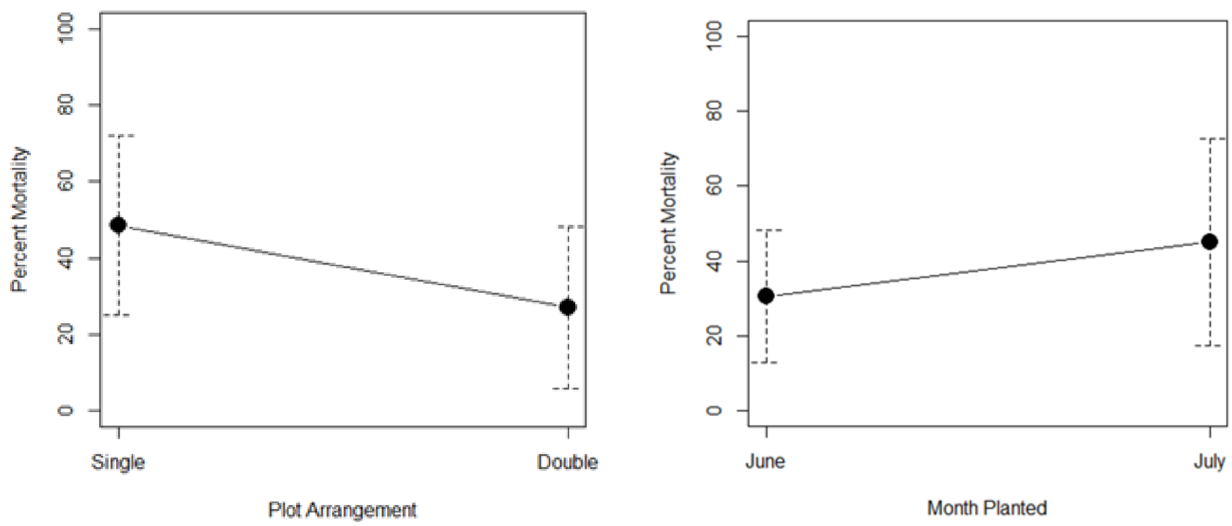


FIG. 5. Means with 95% confidence intervals of mortality among variables month of planting and plot arrangement. There was no significant difference between means for each graph. Single plot arrangement is four 0.25 m^2 sod squares whereas double is two 0.25 by 0.5 m. sod rectangles n=20

Given that the shallowest depth was the only factor that explained mortality in our study, we switched from an ANCOVA framework to using linear regression of percent mortality and shallowest depth. This regression had an intercept of 2.32 (t=0.27, p=0.79) and a slope of 2.58 (t=4.979, $p < 0.001$; Figure 6). The regression had an adjusted R-squared value of 0.56 and a F-statistic of 24.8 with p-value of <0.001. The depth for which 50% of the sod transplant died was at 18.48 cm. While measuring recovery of sod from our donor site was out of the scope of the study, our photo points indicate sods were readily reestablishing into the removed soils.

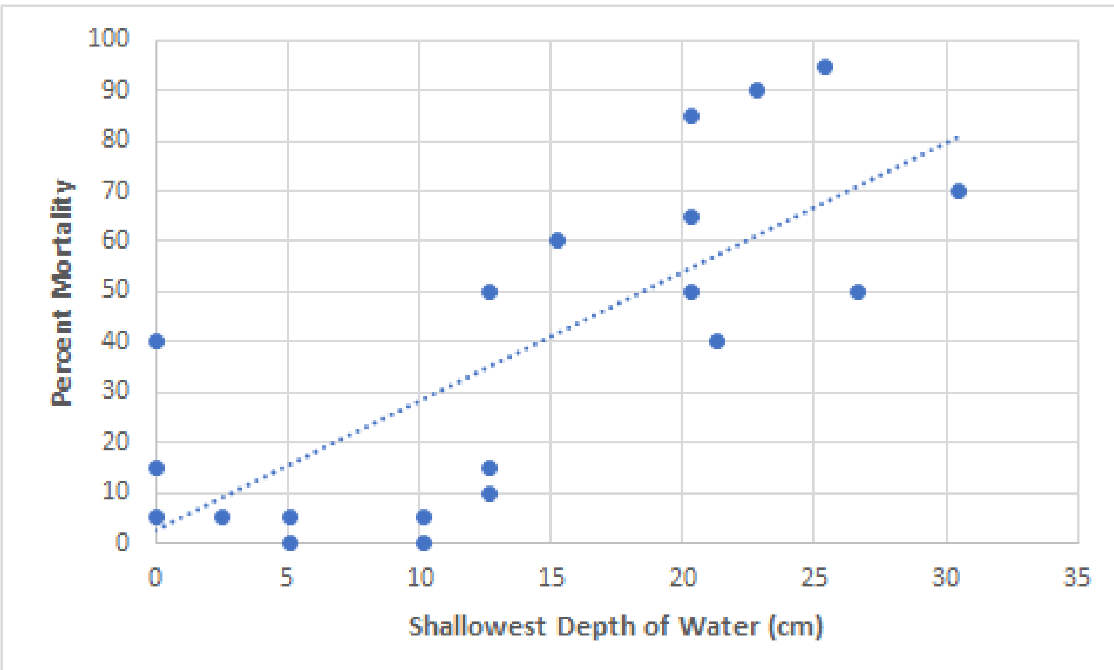


FIG. 6.
Percent mortality plotted against shallowest depth of water at a plot. Adjusted R-Squared= 0.5559 with n = 20.

Willow Stands

We found on average 47% of the willow leaves were not found on the willow before the start of winter (Figure 8). This had a range from 100% of the leaves remaining to 0% of the stems remaining. We see this loss of leaves was fairly consistent throughout the months (Figure 9). Our ANOVA on month and leaf count found differences between groups of months at a p=0.0529 (f= 3.154), and Tukey HSD post-hoc testing found significant differences in leaf count between July and September (p= 0.044).

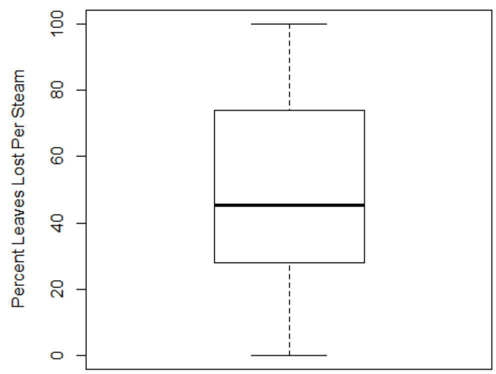


FIG. 8. Box plot of average percent loss of stems and leaves on willow stalks from July to September, 2017.

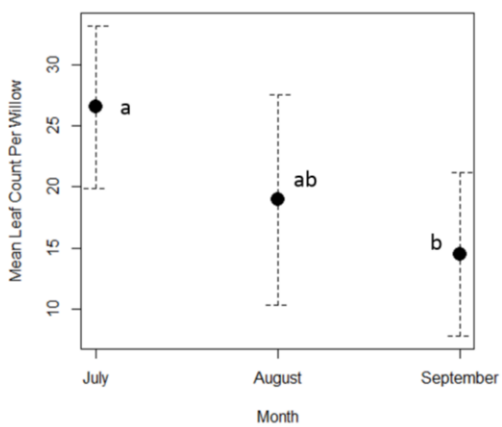


FIG. 9. Plot of the means with 95% confidence intervals of mean leaf counts for all individual willows through the sampling months. Months with the same letters (a or b) indicate there is no significant difference between them.

Discussion

The re-establishment of wetland plant communities is necessary for the restoration of wetland function. Factors such as improved sediment retention, flood control, water filtration, and the creation of wildlife habitat (Mitsch & Gosselink, 2010). Much of the restoration of wetland plant communities is accomplished by spreading native seed mixes across the landscape and planting willow cuttings. Our experiment focused on examining the success of willow cutting establishment, as well as determining the potential of wetland sod transplants as a possible alternative to using costly seed mixes. Specifically, we examined potential drivers of sod mortality, including sod arrangement and placement within the wetland complex. We found that sod transplant mortality was positively correlated to water depth, and herbivory on willow cuttings is high, even in the absence of large ungulates, and likely needs to be monitored over a time interval greater than one season to determine actual establishment and growth. We suggest future monitoring to determine if the transplants survive into the subsequent growing season and whether or not they produce seeds for distribution.

Restored Wetland Retained Water:

The wetlands water table varied across the area but overall saw a minimal decrease. This is a promising sign that the wetland will be able to support aquatic vegetation as water is remaining in it throughout the low flows of the summer. However, through the precipitation data on Sleeping Woman, this year during our sampling may have been uncharacteristically wet. It was around 9 inches above average precipitation which may have overall increased the water table levels throughout the valley. The retention of water within the wetland may be more attributed to increased rainfall over all rather than successful habitat creation. We suggest continual monitoring of the site through proceeding summers to see if the wetland will retain water during lower precipitation years.

Sod mortality driven by water depth:

Sod mortality on average didn't exceed 50% but seemed consistent with limited effectiveness of transplants in general (Fahselt 2007). The lack of effectiveness could be a result of differing site conditions. We found level of exposure to have no effect at all suggesting localized conditions at the edges of these wetland sods had little impact. Additionally, the timing of planting didn't show any effect on mortality which suggest there can be some flexibility on when plantings can be done within early summer planting. Conversely, we found with increasing shallowest depth there was significantly more sod mortality with an apparent spike of mortality after 10cm. This make intuitive sense as the maximum depth of our donor site was around 10 cm and by planting them in deeper water we put them in different range of conditions that had adverse effects. This observation matches with USDA delineation of wetland plants with rushes and sedges, which made up most of our sod, to be found in long term saturated soils but to only be inundated with water during high flows (Hoag and Melvin 2007).

This long term deep inundation of water puts many stressors on these sod transplants that they are not accustomed in dealing with. A minor consequence is a slight decrease of light availability for the sod. As light goes through water some energy is absorbed by the water which leaves the plant with less available energy to photosynthesize (Pegau et al. 1997). Whether enough light was reflected for substantial inhibition of photosynthesis is doubtful as sods were only at the most 31 cm deep in the water and the water only slightly turbid. Another negative consequence occurs during gas exchange in plant stomata, since air and water have different properties that may limit the ability of stomata opening and affect nutrient transfer. Nutrient transfer of plants from soil to leaves through the xylem depends on an increasing negative matric potential as you move up the plant. If the surfaces of the leaves have zero potential then the chain of nutrient transfer may collapse which can lead to cellular death. Additionally, the exchange and uptake of carbon dioxide may be affected which could alter the energy production of plants. Aquatic plants uptake carbon dioxide through diffusion because of the consequences of opening stomata in a submerged environment (Raven et al 1985). Continually inundated plants have adapted to this in a multitude of ways to acquire CO_2 through the medium of water (Keeley 1998, Raven et al. 1985). We suspect our wetland sod transplants to not be adapted to these conditions and only relied on stomata uptake of CO_2 which can only be done with the atmosphere. This would have prevented deeply inundated plants from acquiring CO_2 and producing sugars.

For future transplants, it is suggested sods are not planted any deeper than 10 cm as to allow the leaves to be out of the water enough to be able to perform their basic functions. This area corresponds with the USDA distinction of the draw-down zone (Hoag and Melvin 2007). However, determining what areas will experience this drawdown zone is difficult to predict in a newly established wetland and may need field site sampling before of water level changes to track what areas would be suitable for sod transplants.

Willow leaves lost prior to fall senescence:

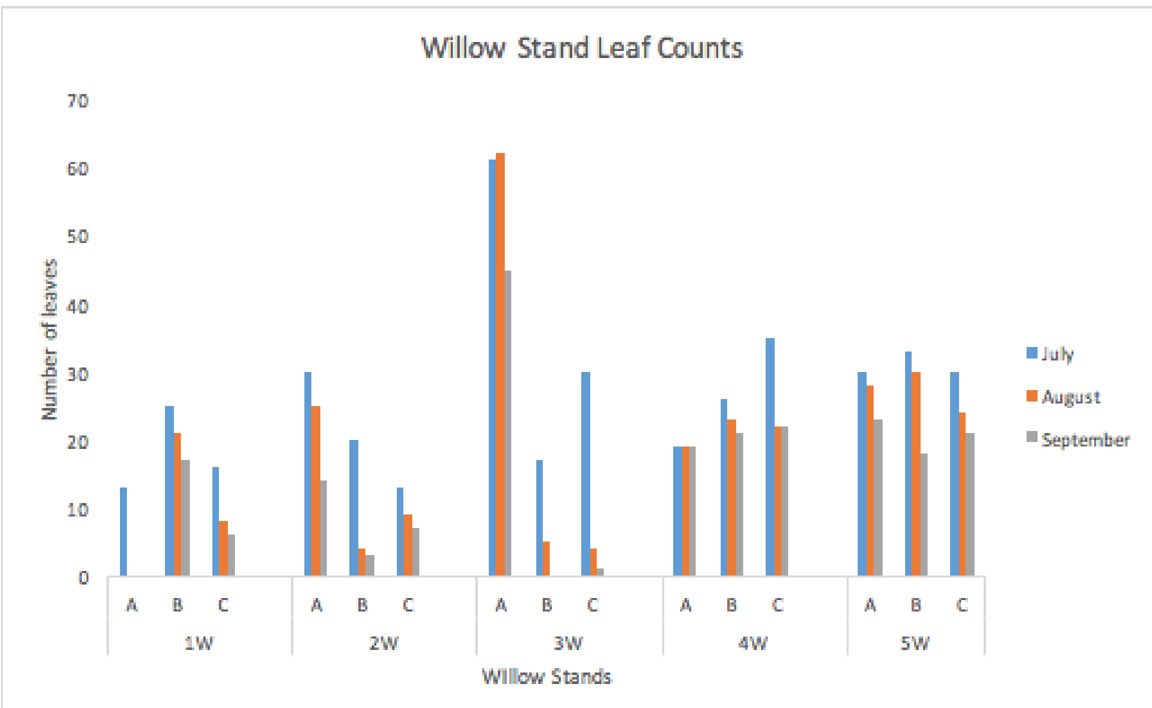
We came across several limitations in determining the survivability of willow stands on the site. Originally, we planned to measure the height of the stands, but due to the horizontal orientation of the stands we were unable to do so. We chose leaf counts as an indicator of post-transplant, first year success and establishment. The presence of buds or leaves communicates that the cuttings are non-dormant and were cut with enough stored nutrients to use for establishment in a new environment (Pezeshki et al., 2005). The production of leaves indicates that the willow stands on our site had enough stored nutrients to allocate towards the production of leaves but does not necessarily denote the successful establishment of the cuttings. (Pezeshki et al., 2005). Among the five willow stands we observed differences in change of leaf abundance over the course of the summer. We also saw a steady decrease in leaf abundance across all stands over the course of the summer, which can either indicate leaf loss due to seasonal changes or actual mortality caused by ineffective willow transplant methods or herbivory. Also, willow cuttings are buried without an intact root system present. These unrooted cuttings are especially vulnerable to low soil moisture as they may lack developed vascular tissues in their root systems (Grange & Loach 1983). Conversely, excess moisture can fill air spaces in the soil. This leads to the depletion of available oxygen to plants. Oxygen deficient soils can negatively impact plant roots and soil microorganisms (Mitsch & Gosselink 2000). This phenomenon may be causing an imbalance of oxygen and water in the willow stands at our site, which may have lead to early senescence of leaves throughout the growing season. It is of importance to note the presence of wooly bear caterpillars on several stands, which may contribute to a portion of leaf mortality through herbivory. With the data we collected and only one season of growth observed we cannot definitively determine the success or failure of Trout Unlimited willow planting methods. All we can conclude is that the willow cuttings did not go into dormancy.

Future Directions

We recognize that sod transplanting may not be an appropriate method for revegetation efforts in every restoration project but should be considered as an alternative in sites where it is viable. To definitively conclude the success level of sod transplant establishment and the factors controlling it, more time and monitoring is necessary. Our main concern this season was survival versus mortality of the transplants as we did not expect to observe significant growth during the first year, because sod removal exerts a high-level of stress on the plants. The combination of transplant and seasonal change stress contribute to significant plot mortality in the future. It is important that these effects be documented for further determination of wetland sod transplant success. In addition to stress from transplant and seasonal changes, each sod piece was composed of differing species compositions which could also play a significant role in the success of sod transplant establishment and mortality. Wetland water retention in terms of water depth at each transplant location was the overarching cause of mortality seen throughout the wetland sod transplants. We suggest that future studies consider these confounding factors as well.

Additionally, it is necessary for TU or others who may take on this project to identify a reliable metric for evaluating willow establishment success. Vertical growth was not included as a metric in our study as the angle and placement of the willow stands prevented accurate or usable data. The metric of counting the number of stems and leaves present could have potential confounding factors. We also suggest observing whether or not the willow stands produce reproductive structures this spring as these structures are costly to the plant and primarily produced when the plant is healthy. Herbivory exclosures should be considered as a control to limit browsing on some stands to determine whether or not browsing is a causation of mortality, or if mortality is primarily due to stress of plant relocation.

Continuation of wetland water retention monitoring is important to fully understand the structure and function of the newly created wetland complex. We suggest installing a stream flow gauge or soil moisture meter to accurately capture the inputs and outputs of the system. Determining water storage and retention within the wetland will provide a more accurate description of climatic changes throughout the wetland and will lead to improved sod location and willow stand placement in the future.



Appendix A

FIG. 10. Change in number of stems and leaves present on willow stalks over the course of three months at each of our 5 permanent willow stand s

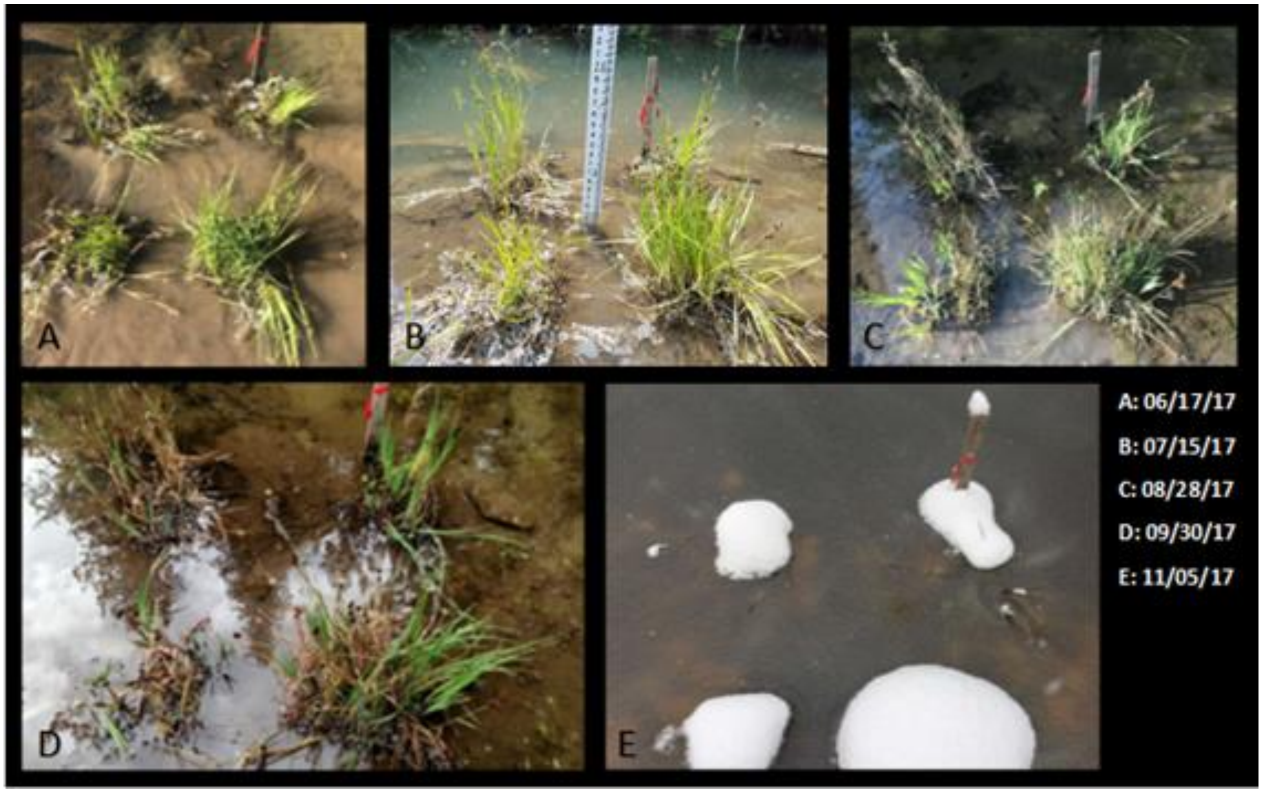


FIG. 11. Photos of growth progression for transplant site plot Red 1A (first planting transplants). A) June 17th, 2017 B) July 15th, 2017 C) August 28th, 2017 D) September 30th, 2017 E) November 5th, 2017.

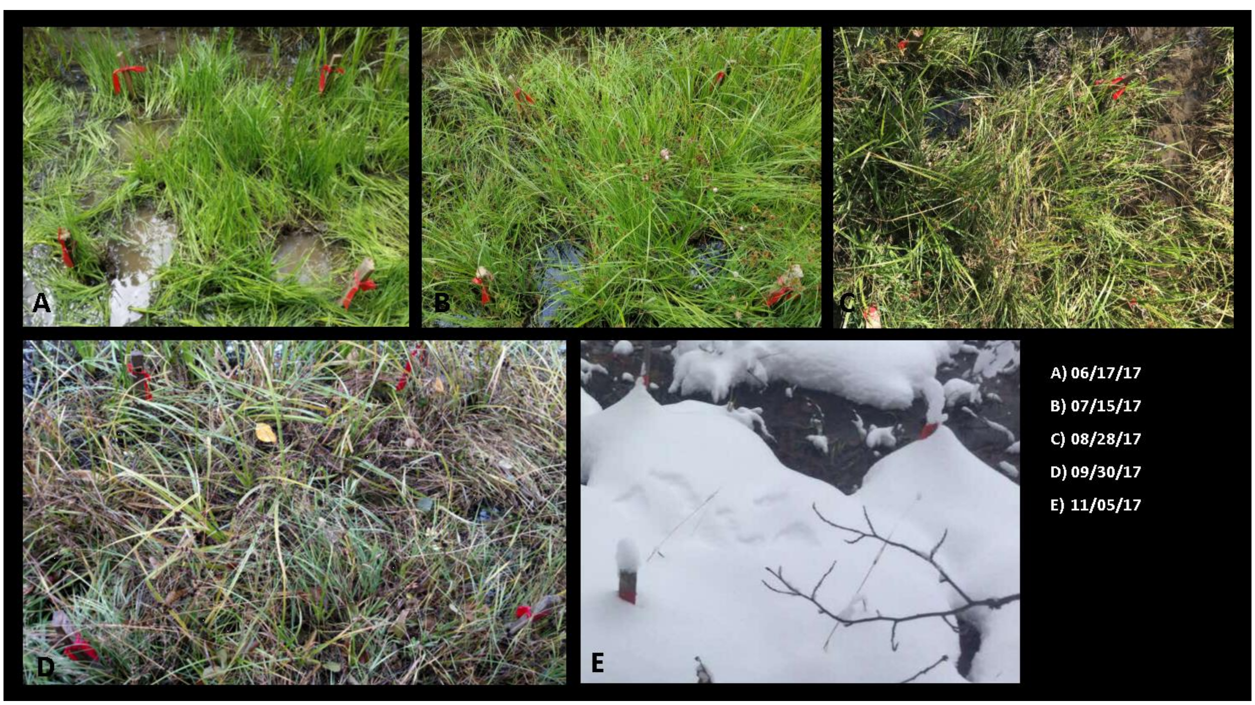


FIG. 12. Growth progression monitoring photos for reference (donor) site Red 3A (first planting transplants).

A) June 17th, 2017 B) July 15th, 2017 C) August 28th, 2017 D) September 30th, 2017 E) November 5th, 2017.

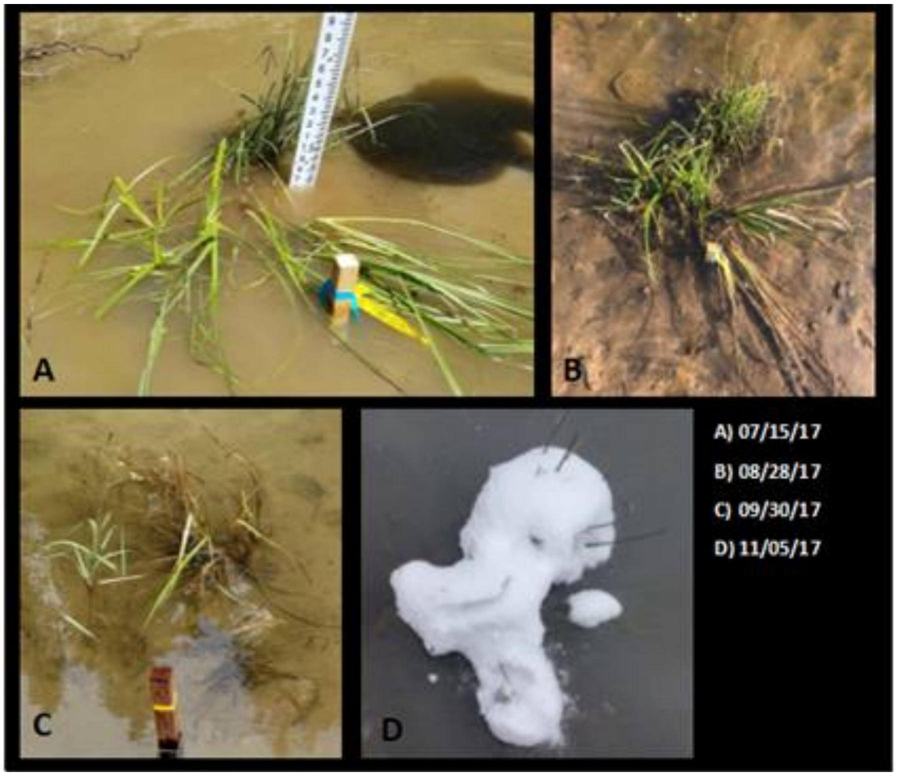


FIG. 13. Growth progression monitoring photos for transplant site Yellow 1B (second planting transplants). A) July 15th, 2017 C) August 28th, 2017 D) September 30th, 2017 E) November 5th, 2017.

FIG. 14. Willow stand growth monitoring photos for stand 2W. A) July 15th, 2017 C) August 28th, 2017 D) September 30th, 2017 E) November 5th, 2017.

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