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Seeding Treatments to Enhance Seedling Performance of the Bulrushes Bolboschoenus Maritimus, Schoenoplectus Acutus and S. Americanus in Wetland Restorations

David M. England

SEEDING TREATMENTS TO ENHANCE SEEDLING PERFORMANCE OF THE BULRUSHES *BOLBOSCHOENUS MARITIMUS*, *SCHOENOPLECTUS ACUTUS*, AND *S. AMERICANUS* IN WETLAND RESTORATIONS

by

David M. England

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ABSTRACT

Seeding treatments to enhance seedling performance of the bulrushes

Bolboschoenus maritimus, Schoenoplectus acutus,

and *S. americanus* in wetland restorations

by

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A major goal in ecological restoration is to reestablish native plant communities. In many cases, achieving this goal requires some sort of active revegetation. A major challenge in wetland revegetation is preventing seeds from washing away before they have a chance to establish. In upland areas, tackifiers have been used to bind seeds to the soil to prevent the loss of seeds. However, the use of tackifiers has not been widely implemented in wetland restorations. In these greenhouse studies, we tested the effectiveness of different tackifier types and concentrations on *Bolboschoenus maritimus* seedling emergence; the influence of soil moisture and flooding on the duration of tackifier effectiveness; the effect of a mulch and tackifier on *Bolboschoenus maritimus, Schoenoplectus acutus* and *S. americanus* seedlings; the effectiveness of pre-germination in enhancing *Bolboschoenus maritimus* seedling emergence using a tackifier; and the duration of tackifier effectiveness. We determined that the use of a tackifier was effective

at keeping seeds of all bulrushes from washing away, tackifier could keep seeds in place for at least 15 days, a mulch addition did not enhance tackifier effectiveness, and pre-germination did not benefit *B. maritimus* seedling emergence. The results from this study provide strong evidence that the use of a tackifier could be effective in establishing bulrush species in wetlands.

(35 pages)

PUBLIC ABSTRACT

Seeding treatments to enhance seedling performance of the bulrushes

Bolboschoenus maritimus, Schoenoplectus acutus,

and *S. americanus* in wetland restorations

David M. England

A major goal in restoration is to reestablish native plant communities. There are several ways to reestablish species, but for large areas the most logistically feasible approach is to sow seed of desirable species. However, most wetland seeds are buoyant and are extremely difficult to establish in designated areas before floating away. In upland areas, tackifiers have been used to stabilize hill slopes from erosion and to keep seeds in place. The tackifier works as an adhesive that binds the seeds to the soil. However, the use of a tackifier has not been widely employed in wetland restorations, and prior to its broad implementation into wetland restoration practice, it is important to determine if tackifiers will hold up in wetland conditions. In greenhouse studies, we tested the effectiveness of different tackifier types and concentrations on *Bolboschoenus maritimus* seedling emergence, the influence of soil moisture and flooding on the duration of tackifier effectiveness, the effect of a mulch addition on tackifier effectiveness (*Bolboschoenus maritimus, Schoenoplectus acutus* and *S. americanus*), the effectiveness of pre-germination in enhancing *Bolboschoenus maritimus* seedling emergence using a tackifier, and the effectiveness of tackifier over time. We concluded that the use of a tackifier was effective at keeping seeds from washing away for at least 15 days, a mulch addition did not enhance tackifier effectiveness, and pre-germination did not benefit *B. maritimus* seedling emergence. The results from this study provide

strong evidence that the use of a tackifier could be an effective solution to establish bulrush species in designated areas in wetland restorations.

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INTRODUCTION

A major goal of ecological restoration is to reestablish native plant communities in degraded landscapes in order to restore biodiversity, recreate wildlife habitat, and prevent unwanted species from establishing (Galatowitsch 2012). Active revegetation with native plant propagules is necessary to reestablish certain desired species due to factors limiting their natural recolonization (Galatowitsch and van der Valk 1996; Bay and Sher 2008). Specifically, there are often fewer natural propagule sources in degraded landscapes, and distances between restored sites and propagule sources are greater than in intact landscapes due to landscape fragmentation (Holl et al. 2000; Kettenring and Galatowitsch 2011b; Holmes and Richardson 1999). To overcome these limitations to natural recolonization and to reestablish native plant communities quickly, land managers need guidance on the most effective revegetation methods.

For large-scale restorations, seeding is the most logistically and economically feasible revegetation approach compared to other types of propagules which require more intensive efforts, such as planting plugs and rhizomes. However, revegetation through seeding presents various challenges, particularly in wetlands. Direct seeding can be ineffective due to seed buoyancy, a natural seed dispersal mechanism for many wetland plants (Cronk and Fennessey 2001), that in restorations can result in seeds floating out of target revegetation areas. A possible solution is using adhesive substances known as tackifiers that can bind seeds to the soil. Tackifiers are commonly used in upland areas for slope stabilization and dust control (Brindle 2003) and hold promise for application in wetlands (Tilley 2007). However, it is unknown if commonly used tackifiers in terrestrial restoration are able to withstand the flooded conditions often present in wetlands and, if

so, if tackifier manufacturer recommendations (specific for upland use) are appropriate for seeding in moist and flooded conditions. Two studies evaluating the use of tackifiers for hydroseeding in wetland revegetation have been done, with one focusing on *Juncus balticus* (Baltic rush) and another on *Carex nebrascensis* (Nebraska sedge) (Tilley 2007; Tilley and St. John 2013). These studies found that the use of tackifiers reduced seed loss from target revegetation areas and yielded 2-3 times higher seedling establishment. While these studies suggest that tackifiers could be a possible solution to prevent wetland seeds from washing away, further research is needed on how to increase successful plant establishment. For example, what are the best concentrations for tackifiers in wetlands? Will higher tackifier concentrations inhibit wetland seed germination? Is there variation in effectiveness of different tackifier types? Also, how does soil moisture affect the duration of tackifier adhesion? The proposed study will address these questions.

Inundation also affects seedling emergence in wetlands (Budelsky and Galatowitsch 2004; Tilley and St. John 2013). Most wetland seeds require specific moisture levels to trigger germination, but those moisture conditions may not be met within restorations with somewhat novel (drier, or potentially highly fluctuating moisture) germination microsite conditions (Kettenring and Galatowitsch 2011a; Tilley and St John 2013; Kettenring 2016). To overcome this potentially limiting plant life stage, restoration practitioners could instead pre-germinate seeds before sowing them in the field. Pre-germinated seeds are seeds that are intentionally treated to start the germination process wherein the radicle is emerged from the seed coat. Results from a recent study found that soaking *Bolboschoenus maritimus* (alkali bulrush) seeds in water for fourteen days yielded 13% higher germination than unsoaked seeds (Marty 2017).

However, Tilley (2013) compared stratified seed with pre-germinated seeds of *Carex nebrascensis* (Nebraska sedge) and found no significant difference in establishment. Based on the conflicting results of these two studies, additional evaluation of pre-germination, within the context of seed sowing with a tackifier, for other wetland species is necessary to determine if pre-germination could provide an advantage in areas where water levels are unpredictable (Tilley 2013).

The addition of mulch to a tackifier could also improve seedling emergence by maintaining more consistent moisture levels that seeds require to germinate. Such an approach has been suggested, but not rigorously evaluated, for enhancing seedling emergence in wetland restorations (van der Valk et al. 1999; Kettenring and Galatowitsch 2011a). However, there are some potential obstacles that could limit the effectiveness of a mulch addition. Specifically, many wetland seeds are light sensitive and need high light levels to germinate (Kettenring et al. 2006; Kettenring 2016). Tilley (2007) compared seedling emergence of wetland seeds sown with straw and wood mulch relative to a no mulch treatment and found that seedling emergence with a mulch addition was less than half of the no mulch treatment. He hypothesized that the mulch may have covered the seeds thereby limiting light required to trigger germination.

This research addresses these restoration questions to inform Great Salt Lake (GSL) wetland revegetation efforts. In the western United States, some of the most important wetlands, including those requiring extensive restoration, surround the GSL. The wetlands around the GSL make up approximately 75% of all the wetlands in Utah and provide crucial habitat for millions of migratory birds that depend on these wetlands as a refueling station (Aldrich and Paul 2002). *Phragmites australis* (hereafter

phragmites), an invasive grass rapidly spreading in wetlands across North America (Kettenring et al. 2012), has expanded to over 10,521 hectares around GSL (Long et al. 2017). Phragmites develops dense monocultures that outcompete native plants and reduce the habitat that waterfowl and other migratory birds depend on (Kettenring et al. 2012; IWJV 2013). Every year, GSL wetland managers treat hundreds of hectares of phragmites to restore lost habitat (Long et al. 2017, Rohal et al. 2018). However, regardless of the control techniques being used, the native plants are slow to return post-treatment while in many locations phragmites returns quickly (Kettenring et al. 2015).

Wetland managers around the GSL manage for three foundational native bulrush species—*Bolboschoenus maritimus* (alkali), *Schoenoplectus acutus* (hardstem), and *S. americanus* (threesquare)—that form large monotypic stands that provide crucial habitat to migratory birds along the Pacific and Central Flyways of North America (Pederson and Pederson 1983, Hohman et al. 1990, Olson et al. 2004). These species provide nutritious seeds, tuber production, nesting habitat, and vegetative cover, particularly for waterfowl (Evans and Martinson 2008; IWJV 2013). Recent research efforts have identified effective means for breaking seed dormancy in these species through cold stratification and/or bleach scarification (Kettenring 2016; Marty 2017), but additional steps are needed to keep treated, non-dormant seeds in place in wetlands and to determine if pre-germination and/or a mulch addition might enhance seedling emergence.

The broad goals of these experiments were to identify the most effective and efficient means for restoring bulrush-dominated wetland habitat by seeding after the removal of phragmites. These experiments specifically assess different methods of seeding native bulrush species (*B. maritimus, S. acutus* and *S. americanus*) by evaluating:

1. The effectiveness of tackifier type and concentration on seedling emergence, aboveground biomass, and flower production (Experiment 1)
2. The influence of soil moisture and flooding on the duration of tackifier effectiveness (Experiment 1)
3. Whether a mulch addition with tackifier benefits seedling emergence, biomass production, and flower production (Experiment 2)
4. The effectiveness of pre-germination in enhancing seedling emergence, aboveground biomass, and flower production with a tackifier application (Experiment 3)
5. The effectiveness of tackifier over time (Experiment 4)

METHODS

Seed collection and sample sizes

Seeds of the three bulrush species were collected the last week of August through mid-September 2015 from multiple sites throughout southern Idaho and Utah (Figure 1). Seeds were hand-collected in monoculture stands of a single bulrush species that were at least 10m x 10m in size. At every site, at least three different single-species stands were sampled broadly to ensure sampling of representative genetic diversity. Seeds were stored in paper bags until cleaned using a professional-grade seed cleaning facility (Sterner Seed) in January 2016. In all four experiments, seeds were weighed out to approximately 100 seeds for each replicate per treatment (*B. maritimus* 0.309 g per 100 seeds, *S. acutus* 0.126 g, *S. americanus* 0.120 g). Weights were determined by counting out 10 samples

of 100 seeds and averaging the weights together for each species, although not all species were evaluated in all experiments, as indicated below.

Breaking physiological seed dormancy

To break physiological seed dormancy in *B. maritimus* prior to their use in experiments, seeds were soaked in a 3% sodium hypochlorite solution for 24 hours, followed by a thorough rinsing with tap water to remove any bleach (Kettenring 2016; Marty and Kettenring 2017). Cold stratification was used to break dormancy of *S. acutus* and *S. americanus* seeds following the methods developed by Marty and Kettenring (2017). Specifically, individual replicate samples of each species were wrapped in mesh and all samples were then buried in a 3.8-L bucket with a 4:1 mixture by volume of sand and sphagnum peat moss. The buckets were held at 4°C for 30 days for cold stratification.

Experiment 1: Effects of water level and tackifier type and concentration

In this experiment, we tested the effects of different tackifier types (psyllium based M-Binder and anionic polyacrylamide based Turbo Tack), three tackifier concentrations (1x, 7x, and 13x the recommended manufacturer concentrations for both M-Binder and Turbo Tack), and two different water levels (saturated: water level at soil surface or inundated to 2 cm above soil surface) on *B. maritimus* seedling emergence. Each tackifier was mixed in a 19-L bucket with water to reach the desired concentration, and then stirred vigorously for 15 minutes with a whisk to fully dissolve the tackifier. Then 200 ml of the assigned tackifier concentration along with 0.309 g of *B. maritimus* seeds were poured over the substrate surface and spread evenly using a lab spatula in

individual 33 cm × 22 cm aluminum trays (= the experimental unit). In addition to evaluating all factorial combinations of the three treatment types (tackifier type, tackifier concentration, water levels), an additional two controls (seeds added without a tackifier and then maintained at either saturated or inundated following the "pulse flood", which is described below). Each treatment combination, including the controls, was replicated five times in the greenhouse. The greenhouse average daytime temperature was 35℃ and nighttime was 28℃. Seeds were given supplemental lighting using 1000 W high-pressure sodium lamps for 14 hour a day photoperiod with photosynthetic photon flux (PPF) ranging between 800 and 1600 μmol m^{-2} s^{-1} (the optimal germination conditions for the study species (Kettenring 2016; Marty and Kettenring 2017)). The greenhouse conditions were identical for experiments 2–4 described below.

The experimental substrate consisted of a 1:1:1 mixture by volume of peat, vermiculite, and sand. Each tray was placed in separate 53.34 cm × 27.94 cm plastic tubs that served as a water reservoir to maintain consistent water level treatments (saturated or inundated) when trays were not subjected to the "pulse flood." All trays were given 24 hours to dry and then were exposed to a pulse flood that would wash away any seed not adhered to the soil. The pulse flood consisted of taking a garden hose and filling the plastic tubs up with water for 2 minutes as the water flowed over the sides. After the pulse flood, water levels were brought to the levels that corresponded to the assigned water level treatment—saturated or inundated.

The number of emerged seedlings were tallied every day for the first two weeks of the experiment and then every three days until the end of the 6-week experimental period. At the end of 6 weeks, flowers (which act as a measure of potential reproductive

output and therefore as an indicator of fitness) were counted and aboveground biomass was clipped from the entire tray, dried for 24 hours at 32°C, and weighed.

In a one-way ANOVA, we tested the effects of the seed treatments (14 levels)—comprised of the different tackifier types (2) × tackifier concentrations (3) × water levels (2) plus controls with no tackifier addition (2)—on seedling emergence, aboveground biomass, and number of flowers, in a separate model for the three response variables. The flower data were square root transformed to meet the model assumptions of normality and homogeneity of variance. We used student t-tests (i.e., no correction for multiple comparisons) to compare treatment means *post-hoc*, rather than a more conventional Tukey's HSD comparison. We made this choice because from a restoration perspective, it is more important to minimize a Type II error (i.e., increase our probability to detect an effect that is present) rather than a Type I error (i.e., decrease our probability to detect an effect that is not present). All analyses, here and below, were conducted in JMP 13.0 (SAS Institute Inc.).

Experiment 2: Effects of mulch addition in tackifier applications

In this experiment, we tested if mulch integrated with a tackifier application affects bulrush seedling emergence relative to a tackifier-only treatment. Two different NaturesOwn organic jet mix paper mulch concentrations were used: half the recommended (840 kg/ha = "low mulch"; to potentially minimize any negative impacts on light needed for seed germination) and the manufacturer recommended (1681 kg/ha; "recommended mulch") concentrations. Experiment 2 used the same setup as Experiment 1 in terms of tray type, substrate, tackifier application, and the flood pulse but here we used all three bulrush species, which were seeded in separate species-specific trays. The

tackifier M-Binder at 7x the recommended dosage and inundated water levels (2 cm) were used here because this tackifier treatment and water level generally resulted in the highest *B. maritimus* performance in Experiment 1. The untreated control trays received no tackifier or mulch addition when seeds were added. Data collection timing and response variables were identical to Experiment 1.

We used a one-way ANOVA to test for the effects of seed treatment (control, tackifier with no mulch, tackifier with low mulch, or tackifier with manufacturer recommended mulch) on bulrush performance, with separate models for each bulrush species and response variable (seedling emergence, aboveground biomass, and flowers).

Experiment 3: Effects of pre-germination in tackifier applications

In this experiment, we evaluated the effects of different durations of pre-germination on *Bolboschoenus maritimus* seedling emergence. Seeds were first treated with bleach, as described earlier, to break dormancy. Then to pre-germinate the seeds, seeds were soaked in 2.5 cm of deionized water for 4, 7, 10, or 14 days in aluminum tins (11 *W* × 22 *L* × 8 cm *D*). Water levels were maintained to 2.5 cm by adding more water every one to two days, thus the water was likely well-aerated (i.e., not anaerobic). The vast majority of viable seeds germinated by 10 and 14 days (see Results section) and a key question for this experiment was whether emerging seedlings might be damaged by the tackifier application. At the same time, we sought to identify if this approach might speed up seedling establishment if seeds had already germinated when sown with a tackifier application.

Approximately 100 seeds were added to each tray (0.309 g). Following the pre-germination treatment, the *B. maritimus* seeds were treated with 7x M-binder tackifier

and grown under 2 cm inundation following a pulse flood in the same manner as Experiment 2. Data collection was also identical to Experiment 2. We used a one-way ANOVA to test for the effects of seed treatment (control, and 4, 7, 10, or 14 days of soaking) on *B. maritimus* performance, with separate models for each response variable (seedling emergence and aboveground biomass).

Experiment 4: Longevity of tackifier in seed treatments

In this experiment, we evaluated the effectiveness of M-binder over time with *B. maritimus* seeds. This experiment used the same greenhouse set up as Experiment 2 including the 7x M-binder tackifier except seed dormancy was not broken since we were not measuring germination. All trays were subject to one of three pulse floods at days 5, 10, or 15 and then maintained at a depth of 2 cm following the pulse flood treatment. Seeds that were carried off from the pulse floods were collected and counted to determine the effectiveness of the tackifier. We did not analyze the data for experiment 4 because only two seeds washed out in total, thus there was no potential for significant differences among treatments.

RESULTS

Experiment 1

Seed treatment had a significant effect on seedling emergence of *B. maritimus* (seed treatment: $F_{1, 13} = 5.69$; $p = <0.0001$). Seedling emergence was highest at 1x and 7x the recommended concentration of M-binder and 7x the recommended concentration of Turbo Tack under the flooded water level (Figure 2a). Seed treatment also had a significant effect on aboveground biomass ($F_{1, 13} = 5.49$; $p = <0.0001$). M-binder at 7x the

recommended concentration with a flooded water level yielded the highest biomass production, although it was not statistically distinguishable from levels achieved under M-binder 1x concentration (Figure 2b). There were also significant effects of the seed treatments on flower production ($F_{1, 13}$ =2.83; p= <0.004). M-binder treatments in almost all instances resulted in more flowers than the Turbo Tack treatments. M-binder 7x the recommended concentration with a flooded water level had the highest flower count (although it was not statistically distinguishable from the 1x and 13x M-binder concentration under flooding).

Experiment 2

Seedling emergence—Seed treatments had a significant effect on *S. acutus* ($F_{1, 3}$ = 12.0; p < 0.001) and *S. americanus* ($F_{1, 3}$ = 6.90; p = 0.003) but not *B. maritimus* ($F_{1, 3}$ = 2.77; p = 0.08) seedling emergence (Figure 3a). For *S. acutus* and *S. americanus*, seedling emergence was higher across all mulch/tackifier addition treatments relative to the control (Figure 3a) but there was no significant difference among the tackifier and mulch addition treatments.

Biomass—*Schoenoplectus acutus* biomass in the two mulch treatments was significantly higher than the control (biomass: $F_{1, 3}$ = 4.95; p = 0.01; Figure 3b). *Schoenoplectus americanus* biomass was higher across all mulch/tackifier addition treatments relative to the control but there was no significant difference among the tackifier and mulch addition treatments ($F_{1, 3}$ = 5.90; p = 0.01; Figure 3b). *Bolboschoenus maritimus* biomass showed no significant difference across all treatments (biomass: $F_{1, 3}$ = 1.43; p = 0.27; Figure 3b).

Flowers—*Schoenoplectus acutus and S. americanus* did not flower in this experiment (Figures 3a and 3b). For *B. maritimus*, there was no significant effect of seed treatment on the number of flowers produced (flowers: $F_{1, 3} = 1.98$; $p = 0.16$).

Experiment 3

Pre-germination of *B. maritimus* seeds had no significant effect on seedling emergence ($F_{1, 4} = 0.55$; $p = 0.70$) nor aboveground biomass production ($F_{1, 4} = 0.93$; $p = 0.47$). No flowers were produced by the end of the study.

Experiment 4

We determined that M-binder at 7x concentration could bind seeds to the soil for at least 15 days.

DISCUSSION

Revegetation is a crucial step in the wetland restoration process and seeding is the most logistically feasible revegetation approach given the large scale of many restoration efforts. However, there are challenges that prevent managers from successfully seeding wetland restorations, namely seeds washing away, slow germination, and inhospitable moisture conditions (Bohnen and Galatowitsch 2005; Tilley 2007). Therefore, our aim for this study was to evaluate potential techniques to overcome these challenges. We determined that using a tackifier prevents bulrush seeds from washing away without inhibiting seedling emergence. Specifically, *B. maritimus* seedling emergence and aboveground biomass production were generally highest with M-binder tackifier concentrations 1x and 7x and with flooded water levels (2cm). Also, *B. maritimus*

produced more flowers when treated with M-binder relative to Turbo Tack. In addition, a mulch addition to the tackifier slurry did not increase seedling emergence for any of the three bulrush species. Finally, we found that pre-germinated seeds had no advantage over untreated seeds in terms of seedling emergence with a tackifier application. Our results suggest that a tackifier could improve wetland restoration outcomes but mulch and pre-germination likely have limited benefits, especially given their logistical challenges.

The ability to keep seeds from washing out of wetland restoration areas is critical for achieving native plant species emergence in revegetation efforts (Bohnen and Galatowitsch 2005; Tilley 2007). Our findings suggest the use of a tackifier in wetland seeding can prevent seeds from washing away and foster seedling emergence. There was no significant difference between the M-binder recommended rate, 7x the recommended rate, and Turbo Tack at 7x the recommended rate. However, the M-binder 1x recommended rate would be the most cost effective restoration approach at $225 / acre relative to $1575 and $332 / acre for 7x M-binder and 7x Turbo Tack, respectively. We were also able to determine M-binder at the 7x rate could keep seed in place for at least 15 days allowing seedlings to establish. We observed that the majority of seedling emergence occurred in the first two weeks, which indicates the duration of M-binder effectiveness will exceed the time needed for seedling emergence. Future research could evaluate longer time periods to determine when M-binder starts to lose its effectiveness, especially for field situations where seedling emergence may be slower than more ideal greenhouse conditions. Our findings are corroborated by a previous study by Tilley (2007), which focused on the effectiveness of Turbo Tack in wetland revegetation. In that study, he used 5x the recommended rate and found that tackifier treatments had, in some

cases, over four times better seedling emergence than dry broadcast treatments in a greenhouse experiment. However, he found no difference between dry broadcast and tackifier treatments when these treatments were tested in an outdoor trial (Tilley 2007). Tilley did note the tackifier treatments might not have been mixed properly before applying to the plots, as large clumps of tackifier occurred in the plots. Therefore, a robust evaluation of tackifiers under realistic field conditions is warranted.

M-binder, as an organic tackifier, might have an advantage over Turbo Tack, a synthetic tackifier. Currently there are three different types of tackifiers on the market: psyllium-, guar-, and polyacrylamide-based types. M-binder is composed of psyllium from the *Plantago insularis* protective seed coating. *Plantago insularis* psyllium binds the seeds to the soil to increase seedling emergence. When psyllium tackifiers break down, given that they are composed of finely ground psyllium husk, they release soil nutrients for beneficial soil microbes. Polyacrylamide tackifiers such as Turbo Tack do not provide nutrients to biota after breaking down. Our results showed M-binder and Turbo Tack seedling emergence at 7x the recommended rate were not significantly different, however aboveground biomass and flower production were significantly higher with M-binder, likely due to the beneficial effects of this organic-based tackifier. This finding has important implications for restoration effectiveness in the context of invasive species removal. A major objective of revegetation is to rapidly reestablish continuous native plant cover to limit resource availability (mostly light) to prevent invasive seedling emergence (Byun et al. 2013; Peter and Burdick 2010; Iannone and Galatowitsch 2008). This restoration objective can be best facilitated with plants with higher aboveground

biomass, such as we found with the M-binder tackifier treatments relative to the Turbo Track ones.

Seed germination and seedling emergence of foundational wetland graminoids, such as sedges and bulrushes, are often sensitive to small differences in water levels. Even shallow flooding can lead to seedling mortality (Mandak and Pysek 2001; Elsey-Quirk et al 2009). For instance, Soley (2016) conducted a study evaluating *Schoenoplectus acutus* seedlings flooded at different depths (0 to 60 cm) and durations (0 to 100% of the day) and found that *S. acutus* seedlings flooded 40% at 20cm resulted in 20% seedling mortality. Soley recommended for successful establishment of *S. acutus* the soil surface should be exposed to air for 40% of the day. Tilley (2012) also showed that *S. acutus* and *B. maritimus* seedling survival and establishment have low success under flooded conditions. Although special adaptations (i.e., short term anaerobic respiration) allow wetland plants to tolerate periods of flooding, periods of long inundation can be too stressful for seedlings that have no access to oxygen if the stems do not emerge from the water and if only partially submerged, still do not yet have well-developed aerenchyma tissue to facilitate effective oxygen translocation to the root system for aerobic respiration (Soley 2015; Leck et al. 2008; Mitsch and Gosselink 2007). Interestingly, we found that shallowly flooded conditions (2cm) were better than saturated conditions for *B. maritimus* seedling emergence. This finding regarding flooding vs. saturated conditions benefiting *B. maritimus* seedlings gives wetland managers a target for what water level conditions to manage for after seeding. However, further research is needed to know at what water depth seedling emergence and survival will be negatively affected since we did not evaluate a range of water depths to identify lethal conditions. Nonetheless, the

fact that the M-binder tackifier was so effective at keeping seeds in place, wetland managers now have the ability to shallowly flood their sites after seeding to benefit seedling emergence without seeds washing away.

The seed and seedling stage of a plant's life cycle is its most vulnerable (Leck et al. 2008). Therefore, small changes in moisture availability could shift the balance away from optimal germination and seedling emergence conditions to seed or seedling mortality (van der Valk et al. 1999; Kettenring and Galatowitsch 2011). Nugteren (1991) compared the effects of different soil moisture on seedling germination of *Carex* species and discovered *Carex* seedling emergence was highest with slightly flooded or saturated conditions compared to the driest treatments, which resulted in no seedling emergence. We hypothesized that a mulch addition might enhance seedling emergence by creating consistently moist conditions ideal for seedlings. However, contrary to our hypothesis, we found that mulch had no significant effects on seedling emergence. Knowing that a mulch addition to tackifier is not critical to seedling emergence saves wetland managers time and money. However, even though mulch did not enhance seedling emergence and biomass in this study it could still be useful to managers that do not have the ability to control water levels and are working under harsher field conditions than the greenhouse conditions used in our experiment. As part of the *Phragmites* management sequence managers often mow herbicide treated *Phragmites*. However, this mowed *Phragmites* is too coarse to serve as a mulch to potentially enhance seed germination. A fine mulch addition could provide more consistent seedling moisture conditions in the field for a short duration of fluctuating water level changes. However, Tilley (2007) found considerably lower seedling emergence with wood and straw mulch compared to Turbo

Tack and suggested the wood and straw mulch was too thick, prohibiting seedling emergence. To maximize seedling emergence, managers should consider using a paper mulch that is transparent as opposed to other mulches (wood and straw) that could block light to seeds. Further research is needed in the field to investigate the effects of mulch on seedling emergence.

Rapid native plant establishment in restorations is vital to prevent undesirable plant species from emerging and to reduce the time native seeds experience environmental conditions that could lead to mortality. Pre-germinating seeds before sowing could avoid many challenges associated with seeding in the field. Previous studies showed that soaking *B. maritimus* seeds improved germination (Tilley 2013, Clevering 1995). However, in the present study, pre-soaking the seeds to pre-germinate them did not provide an advantage over non-soaked seeds. Differences in results between prior studies and ours could be due to suboptimal lighting and lower greenhouse temperatures in our study. Pre-soaking seeds in a growth chamber—with more control of light and temperature than a greenhouse—could enhance seed germination. Further research is needed on pre-germination of *B. maritimus* seeds to determine if there are any scenarios where soaking might provide an advantage over untreated seeds.

CONCLUSION

Results of this study provide wetland managers with strategies to improve restoration success of *B. maritimus*, *S. acutus*, and *S. americanus*, three bulrush species commonly targeted by wetland managers. We were able to determine that tackifiers can prevent seeds from washing away with 1x and 7x recommended rates of application.

Also, M-binder treated plants produce more biomass and flowers than those treated with Turbo Tack. We determined that a mulch addition in conjunction with a tackifier application is not necessary, which will save wetland managers time and money. However, it is possible that mulch still could be beneficial in areas where moisture levels are more dynamic than in the controlled greenhouse conditions of our experiment. Finally, pre-germinating seeds of *B. maritimus* before sowing provided no advantage over untreated seeds. While the use of a tackifier shows promise based on this greenhouse research, follow-up experimentation with tackifier is needed under more realistic (harsher) field conditions.

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Figures

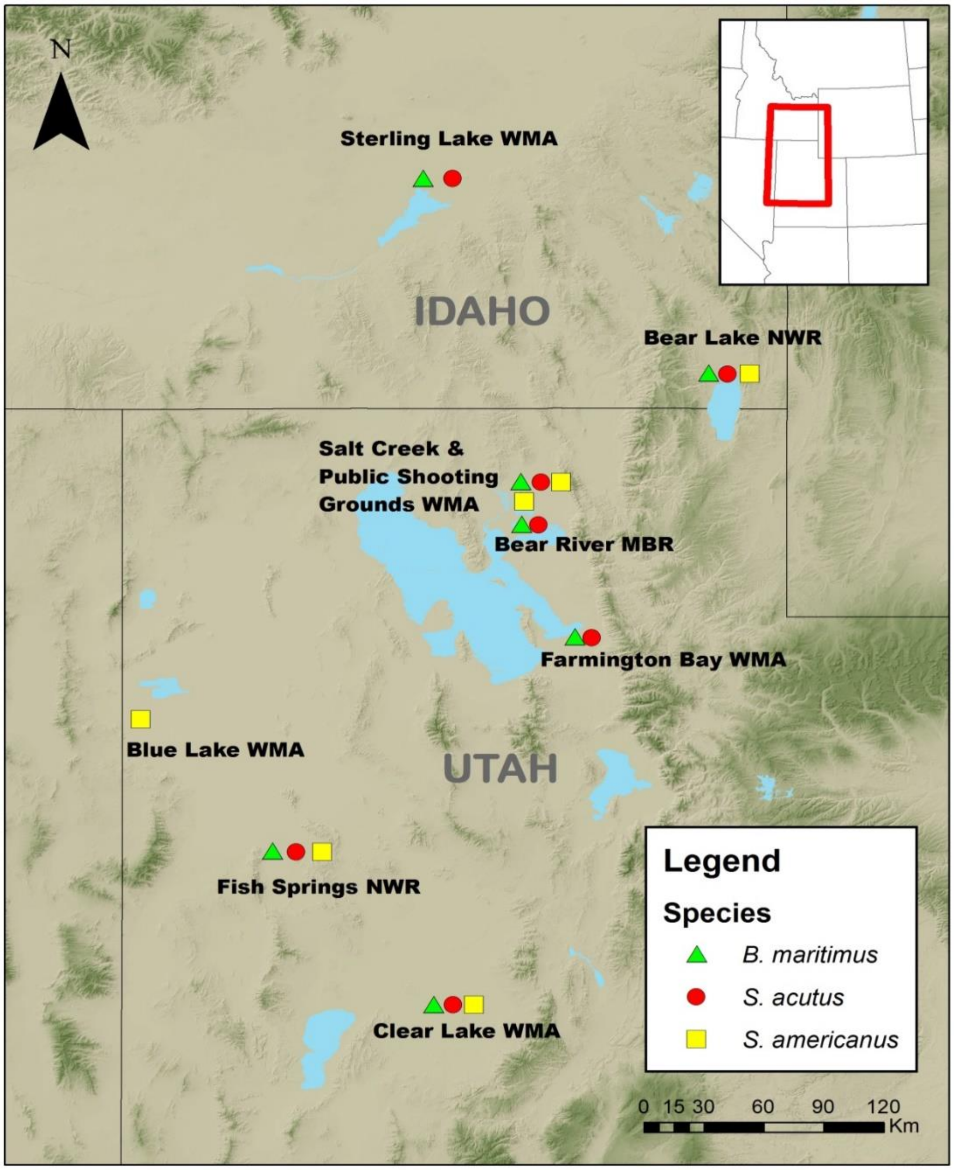

Figure 1. Locations of bulrush seed collection sites in the Intermountain West. WMA=Waterfowl Management Area, MBR=Migratory Bird Refuge, and NWR=National Wildlife Refuge.

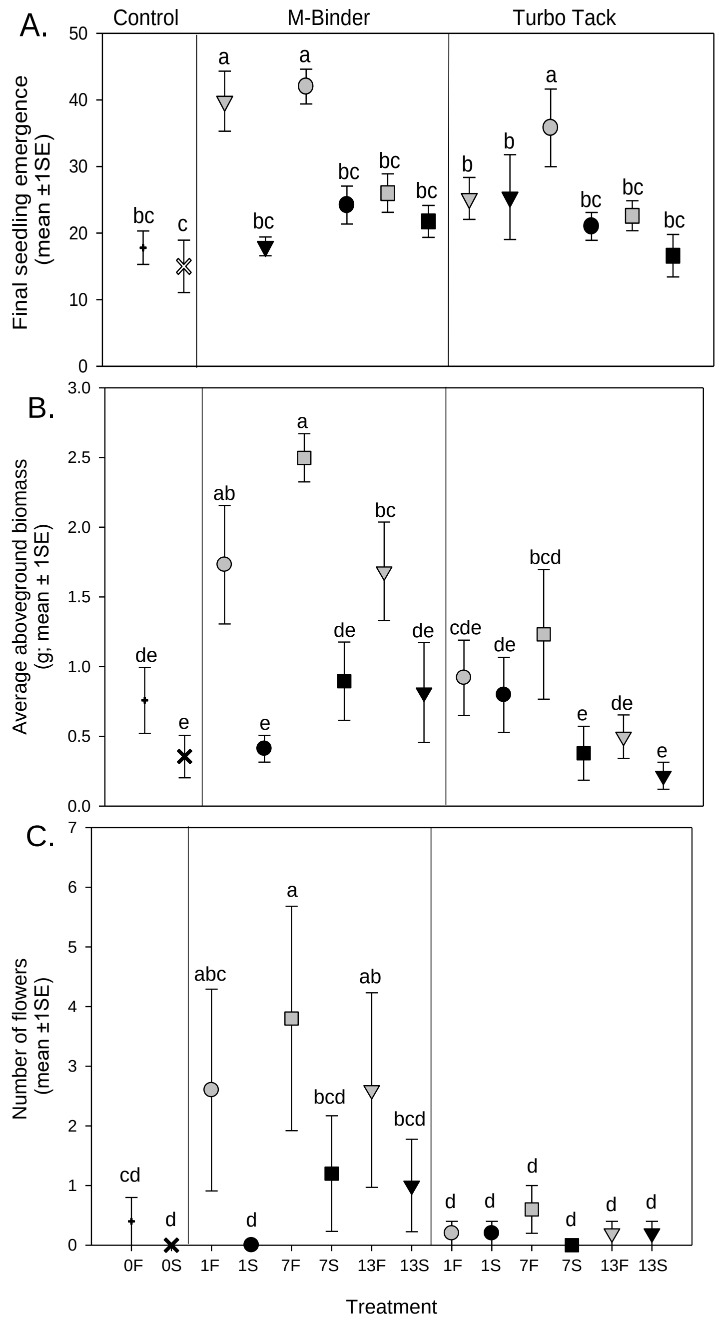

Figure 2. The effects of tackifier concentration and water level on *B. maritimus* (A) seedling emergence, (B) average biomass, and (C) number of flowers produced in Experiment 1. The treatments were 0F = no tackifier flooded, 0S = no tackifier saturated, 1F = manufacturer recommended rate flooded, 1S = manufacturer recommended rate saturated, 7F = 7 x manufacturer recommended rate flooded, 7S = 7x manufacturer recommended rate saturated, 13F = 13x manufacturer recommended rate flooded, and 13S = 13x manufacturer recommended rate saturated. Means and standard errors were computed from the raw data.

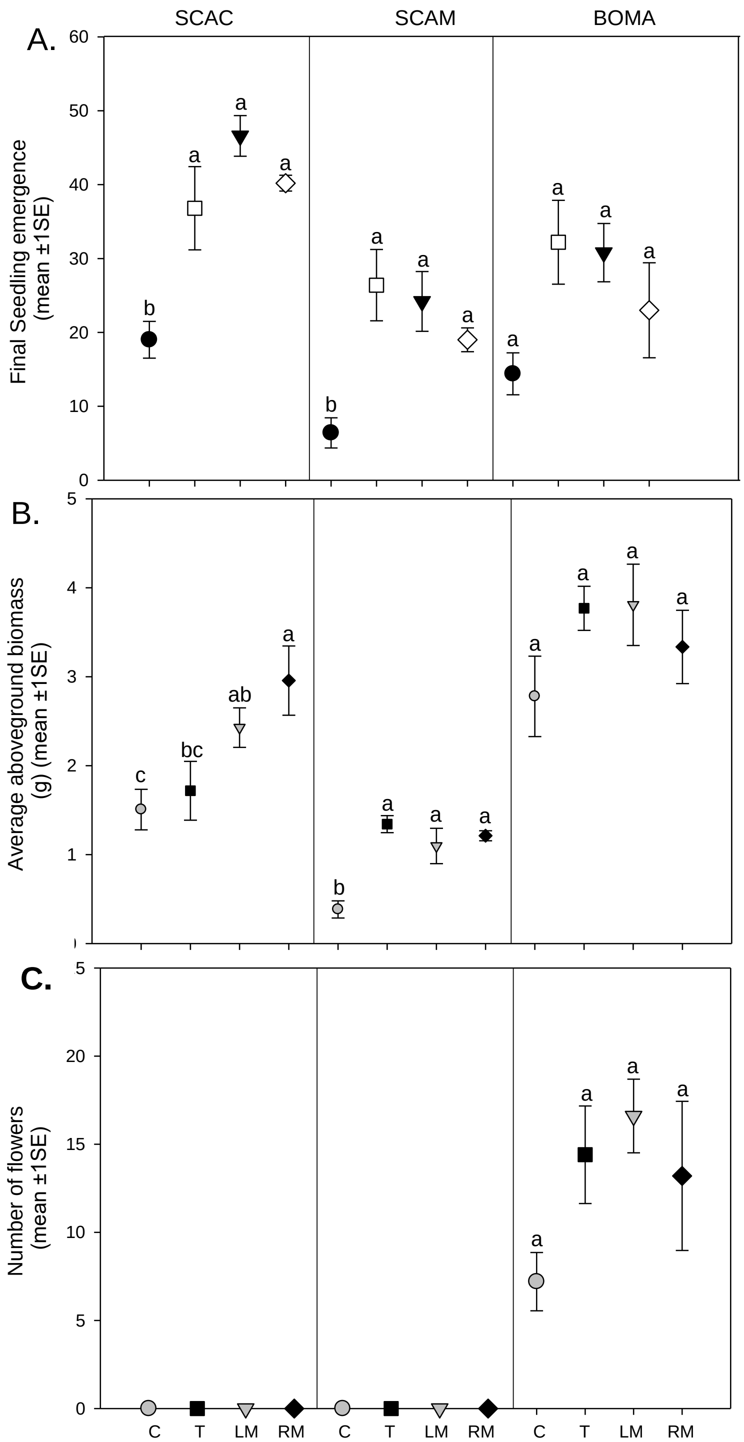

Figure 3. The effects of mulch concentration on *S. acutus* (SCAC), *S. americanus* (SCAM), and *B. maritimus* (BOMA) (A) seedling emergence, (B) average biomass, and (C) number of flowers produced in Experiment 2. The treatments were C = no tackifier/mulch, T = M-binder, LM = low mulch rate plus M-binder, and RM = recommended mulch rate plus M-binder. Means and standard errors were computed from the raw data.