Techniques for successful revegetation of native plants in Great Salt Lake wetlands to prevent Phragmites reinvasion and restore avian habitat

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Introduction

Invasive *Phragmites australis* presents a serious threat to Great Salt Lake wetlands (Kettenring et al. 2012, Rohal et al. 2018). Since 2012, we (PI Kettenring and graduate students) have been evaluating different herbicide and mowing techniques for controlling *Phragmites*. Results from our research suggest that a summer mow to prevent seed production followed by a three year sequence of a fall glyphosate spray with a winter mow is most effective at reducing *Phragmites* cover (Rohal et al. 2017). However, even after *Phragmites* is effectively killed, substantial *Phragmites* litter remains for at least another 2 years; this litter blocks light from reaching the soil surface and can prevent native plant seed germination. Great Salt Lake wetland managers have recently developed a number of methods for *Phragmites* litter removal. The "roll and crush" approach (a large roller attached to heavy duty wetland track equipment) is likely more logistically feasible but potentially requires additional years for the crushed litter to break down. A "mow and remove" approach (mow litter and remove it with a "rake", again with heavy duty machinery) is likely more time intensive but may lead to the best conditions for native plants to establish. These recently developed techniques have not been widely evaluated by managers and therefore ***in a field experiment, we evaluated different techniques for enhancing the breakdown and removal of Phragmites litter to encourage native plant establishment.***

Still, once dead *Phragmites* has largely decomposed, native vegetation did not return to *Phragmites* control research plots (Rohal et al. 2017). Our findings suggest that active revegetation will be important to rapidly reestablish lost native plant diversity, to prevent the reinvasion of *Phragmites*, and to restore avian habitat (Rohal et al. 2017). Managers in Utah rarely reintroduce native vegetation following *Phragmites* control due to cost and time constraints, a lack of understanding of the importance of this step in a successful *Phragmites* management plan, and incomplete knowledge about how to effectively reintroduce important habitat-forming species (Rohal et al. 2018). Some of the most important native plants in these wetlands are perennial bulrushes, namely alkali bulrush (*Bolboschoenus maritimus*, formerly *Schoenoplectus maritimus*), hardstem bulrush (*Schoenoplectus acutus*), and threesquare bulrush (*S. americanus*). These species often occur in large, monotypic stands; provide important nesting and resting habitat for a variety of bird species; and serve as a food source for many birds (Intermountain West Joint Venture 2013, Downard et al. 2017). These species can also limit the spread of *Phragmites*. In a recent experiment, we (PI Kettenring and graduate student Jimmy Marty) grew native bulrushes from rhizomes in large wetland mesocosms (basins) and sowed in *Phragmites* seeds. We found that the bulrushes, particularly hardstem bulrush, were able to suppress the growth of *Phragmites* seedlings. These results suggest promising solutions for wetland restoration; by fostering the recovery of native bulrushes we may be able to greatly limit the reinvasion of *Phragmites*. The field experiment described below focused on these critical bulrush species, and then also included two additional wetland species—salt grass (*Distichlis spicata*) and Baltic rush (*Juncus balticus*)—because their seeds are relatively easy to germinate (compared with the bulrushes) and they confer additional habitat benefits to a wider array of bird species.

Revegetation of native bulrushes can take many forms—such as seeding, planting "plugs" of seedlings, transplanting rhizomes, and laying out wetland "sod mats". But the only logistically feasible approach, given the scale of the restoration effort needed in Great Salt Lake wetlands, is seeding. Nonetheless, seeding presents numerous challenges to managers because wetland seeds can float and wash away and moisture conditions in the restoration site may not be conducive to seed germination and seedling survival. ***This research sought to address these issues by (1) evaluating the use of a tackifier for keeping seeds in place in wetland restorations and (2) evaluating the utility of a mulch for maintaining moist soil conditions in wetlands despite increasingly dry early summer germination conditions.*** We will discuss these challenges in greater detail below.

Regarding seeds floating away in wetland restorations, covering sown seeds with soil is not a good approach because many wetland seeds require light to trigger seed germination (Kettenring et al. 2006, Tilley 2007, Kettenring 2016, Marty 2016). One option for keeping seeds in place on the soil surface is to use tackifier, an adhesive substance that is non-toxic and can bind seeds to the soil in restorations. However, tackifier, which was developed for upland applications, has not been broadly applied in wetland restorations and therefore warrants assessment of its effectiveness in moist and flooded soil situations. In a previous greenhouse experiment by M.S. student David England, we identified the most effective tackifier type and concentration for enhancing bulrush seed germination and seedling survival under dynamic water levels. ***In a field experiment, we evaluated the most effective tackifier type and concentration under field conditions that are more realistic (i.e., harsh) to determine whether they enhance native seedling survival.***

Obtaining optimal moisture conditions for seed germination is extremely challenging. Many wetland plants will not germinate under flooded conditions but instead require moist seed microsites (i.e., the environment around the seed). However, those optimal moisture conditions in arid land wetlands can be short-lived because following spring flooding due to snowmelt run-off, water levels often decline rapidly. These falling water levels are more extreme than historical conditions due to upstream diversions and climate change (Downard and Endter-Wada 2013, Welsh et al. 2013, Downard et al. 2014). Therefore, maintaining moist germination microsites in wetlands will be important for supporting high seed germination rates and seedling survival in wetlands, particularly because seeds and seedlings are the most limiting life stages of plants. In other words, if we can achieve high rates of seed germination and seedling survival in wetlands, then those seedlings should be able to mature to adult plants at high percentages. As part of David England's M.S. thesis research, we conducted a series of greenhouse experiments to evaluate different mulch application rates for enhancing native seedling survival without limiting light levels for seed germination. ***In a field experiment, we applied the most effective mulch techniques to field restoration plots to determine their value under harsher field conditions.*** We also evaluated different timings of seed sowing in case the moisture and / or temperature conditions were more suitable earlier or later in the first part of the growing season.

Our broad goal is to restore native plant-dominated Great Salt Lake wetlands following *Phragmites* control. Our specific objectives were to evaluate the effectiveness of (a) *Phragmites* litter removal treatments, (b) the addition of a tackifier, (c) a mulch addition, and (d) timing of seed sowing for enhancing native plants in Great Salt Lake wetlands. Here we report on the results of our Farmington Bay Waterfowl Management Area (FBWMA) field experiment through the end of 2017.

Methods

In a field experiment at FBWMA along the Great Salt Lake, we evaluated different combinations of *Phragmites* litter removal and seeding treatments: two sowing timings × the addition of mulch. We established five plots that were split between two *Phragmites* litter removal treatments—either “mow and remove” or “roll and crush”. We hypothesized that the “mow and remove” treatment would lead to the greatest native plant stem density and cover because it would create a high light “seed bed” favored by native plant seeds. We also hypothesized that the “roll and crush” treatment would be more logistically feasible to implement on a large scale, but would have lower native plant density and cover due to the remaining litter preventing the high light levels required by native plant seeds. An important part of our study was to evaluate trade-offs between the effectiveness of different treatments vs. their logistical/cost requirements. The litter treatments were implemented in January and February 2017 with the assistance of Chad Cranney, Jason Jones, and David England.

In May and June 2017, we seeded in target native wetland plants into these plots. All seeds were collected from Great Salt Lake wetland sites in 2015 or 2016 and were thoroughly mixed into a single seed mix for all plots. Prior to seeding in the field, we broke dormancy for these species in the lab by cold stratifying salt grass, hardstem bulrush, and threesquare bulrush seeds for 30 days under moist, cold conditions (4˚C) following methods previously developed by PI Kettenring and M.S. student Jimmy Marty (Marty and Kettenring 2017). We broke dormancy of alkali bulrush by weakening the seed coat with a 24 hour bleach treatment, the most effective technique that we have developed for this species (Kettenring 2016, Marty and Kettenring 2017). Baltic rush seeds were not pre-treated because it has no seed dormancy based on the published literature (reviewed in Baskin and Baskin 2014) and our preliminary germination trials in the greenhouse in February 2017.

Within each 30m x 10m litter treatment, we established five 6m x 10m subplots for our different tackifier, mulch, and sowing timing treatments. An untreated control subplot did not receive any seed addition to determine background levels of emergence in these species from natural seed dispersal and seed bank emergence. In the remaining four subplots, the seed mix was applied with an M-binder tackifier at the manufacturer’s recommended concentration for upland systems, which is the most effective tackifier type and concentration based on David England’s greenhouse trials. In addition, two of the four plots received a mulch addition. We hypothesized that the mulch might maintain a moister environment to enhance native seedling emergence.

We examined two sowing dates to span the variation in spring and early summer germination microsite conditions that occur following the recession of early spring floods. Because the soil moisture conditions ideal for germination may be short-lived with rapidly falling water levels, it was important to pinpoint the ideal seed germination period as well as to attempt seeding at a less-than-ideal time to determine if the mulch might enhance germination in the target species. The sowing dates occurred for the first round on May 3 and 5, 2017, and for the second round on May 30 and June 1, 2017, and reflected the range of temperature and moisture conditions based on that year’s weather patterns. Seed sowing densities for the seed mix of five species reflected standard rates used for each species for restoration in the region (Marty and Kettenring 2017). Within each seed treatment subplot, we established five 1m x 1m quadrats for data collection. These quadrats ran parallel through the center of each seed treatment subplot. We measured seeding outcomes during the 2017 field season by monitoring stem density and percent cover of seeded species and *Phragmites*.

Results

Stem density

Alkali bulrush

Alkali bulrush stem density in June and August was significantly higher in the seed vs. control treatments, but only when litter was removed from the site (i.e., “mow and remove” litter treatment). However, there were no differences *among* the seed treatments (T1, T2, TM1, TM2) in alkali bulrush stem density in the “mow and remove” treatment plots.

These findings suggest that higher alkali bulrush stem density can be achieved with a “mow and remove” litter treatment in conjunction with the addition of seeds, but the timing of sowing and the addition of mulch do not matter. Management implications of these results:

- The use of a mulch is logistically challenging and expensive and is not needed to increase alkali bulrush stem density.
- Given that the timing of seed sowing did not affect stem density, managers now have a wider time frame in which to sow seeds to achieve the same outcomes.
- The logistical challenges of the “mow and remove” treatment are quite significant, but these data suggest that seeding without litter removal is a waste of time.

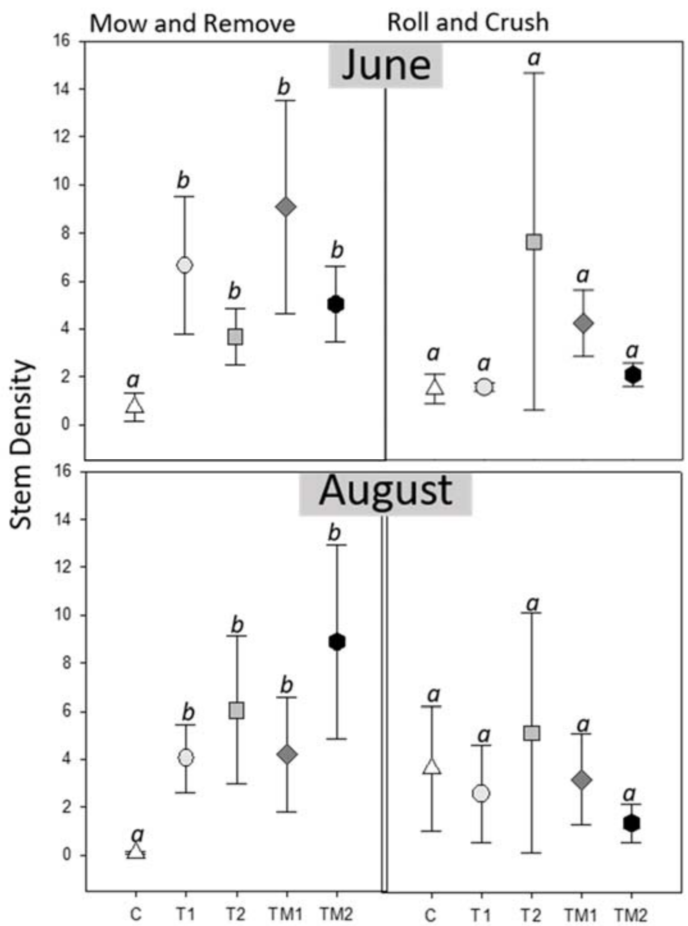

Figure 1. Alkali bulrush stem density (mean ± 1 standard error) in June and August 2017. The treatments denoted on the x-axis were ***C*** *for control and the four seed treatments:* ***T1*** *(sowing #1, no mulch),* ***T2*** *(sowing #2, no mulch),* ***TM1*** *(sowing #1, mulch added),* ***TM2*** *(sowing #2, mulch added). Symbols denoted with different lowercase letters were significantly different based on statistical tests.*

Hardstem bulrush

Initially in June, hardstem bulrush stem density was higher for seeds sown in the first time period (T1 and TM1) regardless of a mulch addition when litter was removed. This pattern could indicate that hardstem bulrush germinates more readily and establishes earlier in the spring when temperatures are cooler, which aligns with findings from Marty and Kettenring (2017) for hardstem bulrush seed germination temperature requirements.

Similar to alkali bulrush, by August, the highest stem density occurred in the "mow and remove" plots, regardless of a mulch addition or timing of seed sowing.

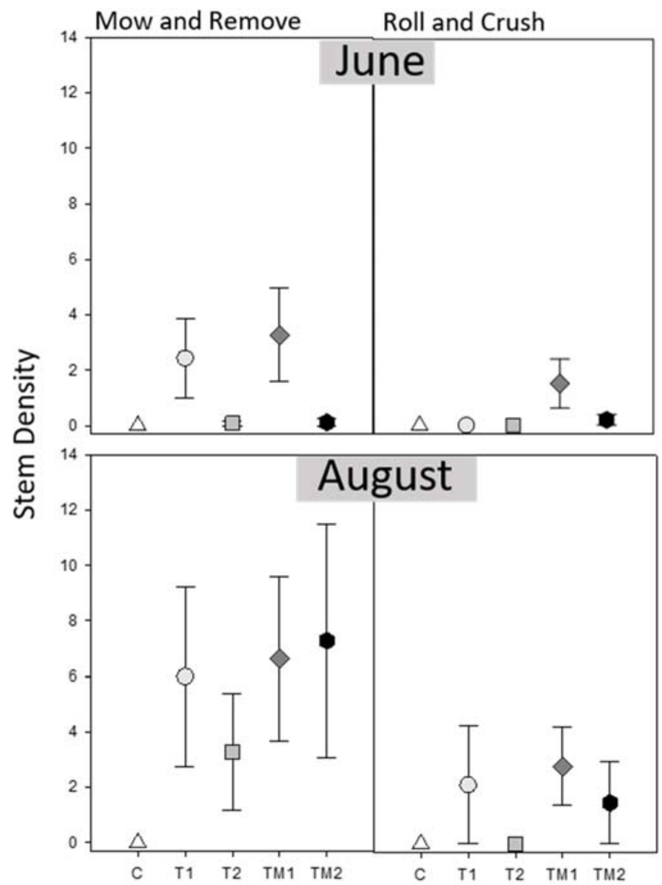

*Figure 2. Hardstem bulrush stem density (mean ± 1 standard error) in June and August 2017. The treatments denoted on the x-axis were **C** for control and the four seed treatments: **T1** (sowing #1, no mulch), **T2** (sowing #2, no mulch), **TM1** (sowing #1, mulch added), **TM2** (sowing #2, mulch added).*

Threesquare bulrush

Although initially seeding of threesquare bulrush led to increased stem density in the "mow and remove" plots in June, by August there were no differences among the litter removal treatments or seed treatments. These findings indicate that there are likely other factors driving threesquare bulrush stem density over the growing season, and there was likely a fair amount of seedling mortality (due to unknown factors) between the June and August sampling periods.

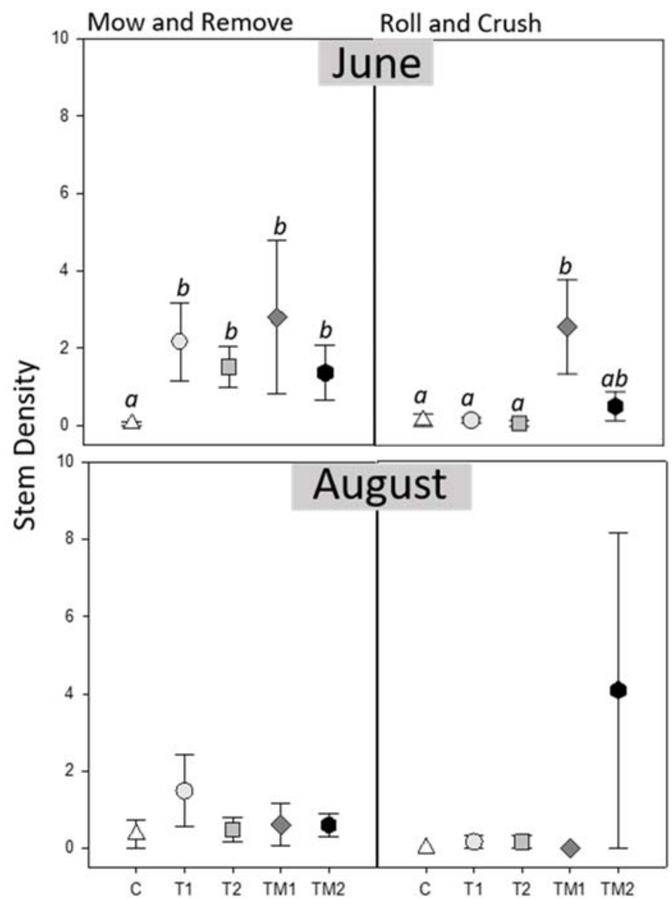

*Figure 3. Threesquare bulrush stem density (mean ± 1 standard error) in June and August 2017. The treatments denoted on the x-axis were **C** for control and the four seed treatments: **T1** (sowing #1, no mulch), **T2** (sowing #2, no mulch), **TM1** (sowing #1, mulch added), **TM2** (sowing #2, mulch added). Symbols denoted with different lowercase letters were significantly different based on statistical tests. The size of the error bar for the TM2 treatment in August in the "roll and crush" plot indicates that these data were highly variable and require more replicates to better understand the effect of this treatment combination.*

Salt grass

In both June and August, there was a significant increase in salt grass stem density with the various seed treatments, particularly in the “mow and remove” plots. These findings suggest that active revegetation is effective at increasing salt grass stem density as opposed to not seeding at all (i.e., relative to the control plots).

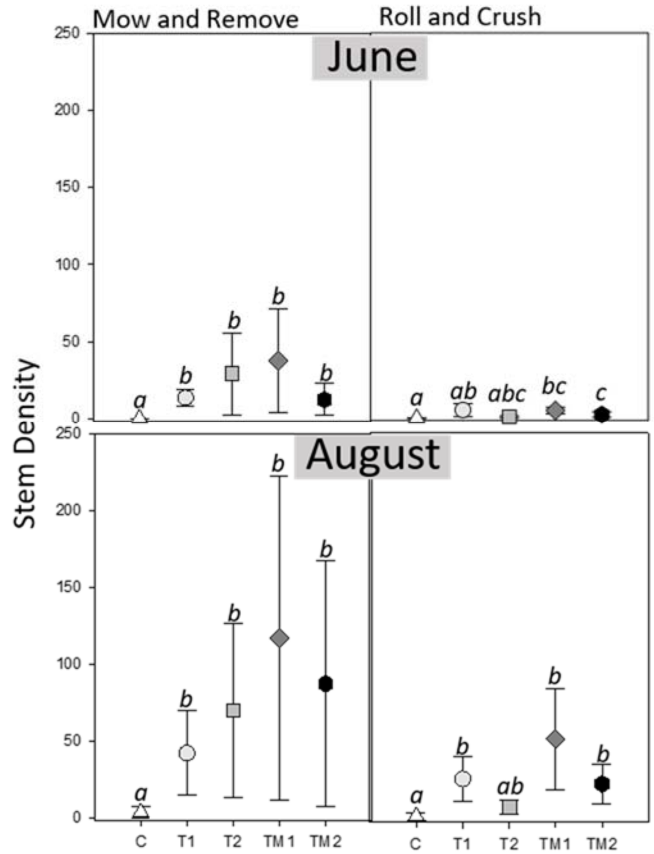

*Figure 4. Salt grass stem density (mean ± 1 standard error) in June and August 2017. The treatments denoted on the x-axis were **C** for control and the four seed treatments: **T1** (sowing #1, no mulch), **T2** (sowing #2, no mulch), **TM1** (sowing #1, mulch added), **TM2** (sowing #2, mulch added). Symbols denoted with different lowercase letters were significantly different based on statistical tests.*

Baltic rush

Baltic rush stem density was quite low overall and there were no significant differences among the seed and litter treatments in June. We were surprised by these findings given the rapid germination of this species that occurred in previous greenhouse trials. One problem that may have occurred in the field is that—due to their small size—the Baltic rush seeds may have been buried underneath tackifier or mulch.

By August, all seedlings had died (data not shown) due to unknown factors such as unsuitable abiotic conditions and/or competition among other establishing plants.

Overall these findings suggest that Baltic rush may not be a promising species for future revegetation efforts under similar conditions.

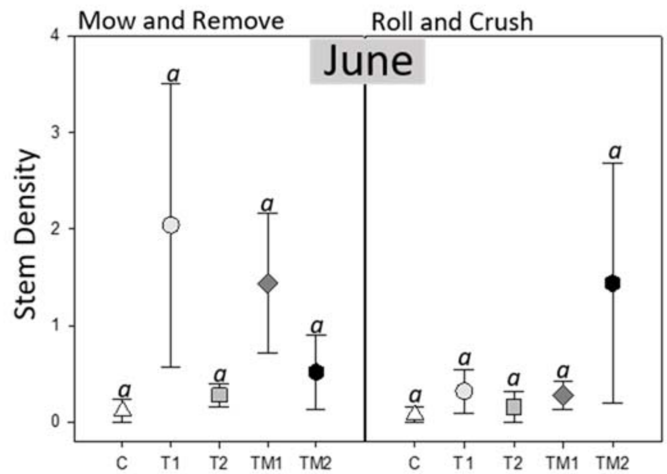

Figure 5. Baltic rush stem density (mean ± 1 standard error) in June and August 2017. The treatments denoted on the x-axis were ***C*** *for control and the four seed treatments:* ***T1*** *(sowing #1, no mulch),* ***T2*** *(sowing #2, no mulch),* ***TM1*** *(sowing #1, mulch added),* ***TM2*** *(sowing #2, mulch added). Symbols denoted with different lowercase letters were significantly different based on statistical tests.*

Phragmites

There was no significant difference in *Phragmites* stem density in June in any of the plots, although there was a trend towards higher stem density in the "mow and remove" plots. At the end of the growing season, the stem density of *Phragmites* was statistically indistinguishable between litter and seed treatments.

These findings indicate that seeding of native plants—at the relatively low density used in this study—will not appreciably reduce *Phragmites* stem density.

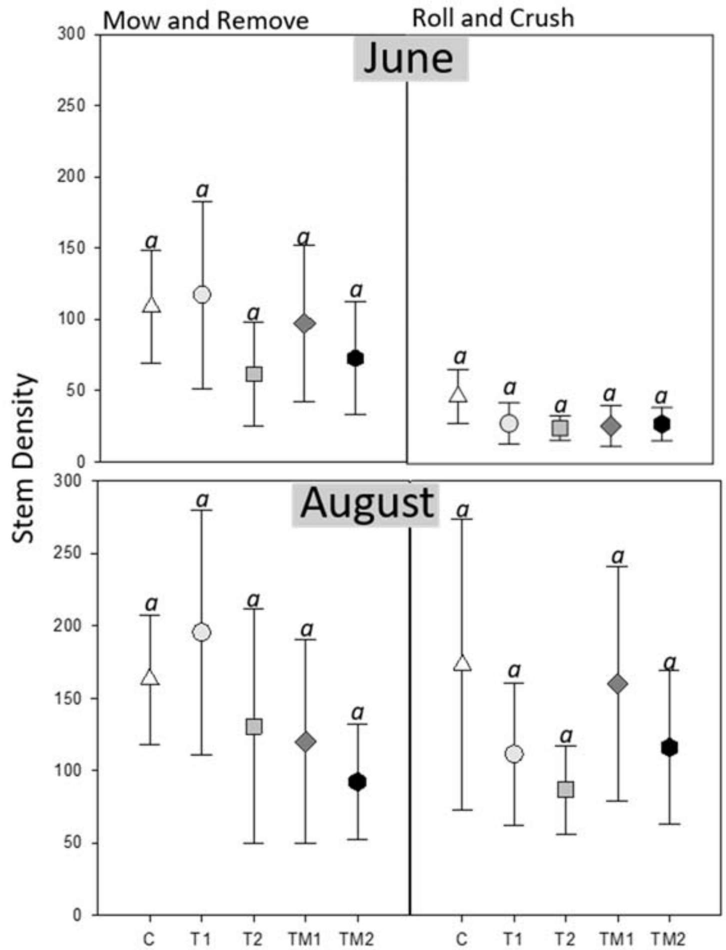

*Figure 6. Phragmites stem density (mean ± 1 standard error) in June and August 2017. The treatments denoted on the x-axis were **C** for control and the four seed treatments: **T1** (sowing #1, no mulch), **T2** (sowing #2, no mulch), **TM1** (sowing #1, mulch added), **TM2** (sowing #2, mulch added). Symbols denoted with different lowercase letters were significantly different based on statistical tests.*

Percent cover

We present the end-of-season (August) percent cover for the seeded native species and invasive *Phragmites*.

Alkali bulrush

Alkali bulrush cover was low overall and was only slightly impacted by the various treatments. For the "mow and remove" plots, there was a slightly higher percent cover in the seeded plots relative to the control treatment, with the two highest covers in the second seed treatments (T2 and TM2). Alkali bulrush seeds germinate to higher percentages under hotter temperatures, which may translate to a greater alkali bulrush cover relative to the first seed treatment (Kettenring 2016, Marty and Kettenring 2017).

In the "roll and crush" plots, the highest percent cover of alkali bulrush, albeit quite low, was found in the control plots. This finding suggests that the alkali bulrush in the control plots was not seeded and likely regenerated from remnant rhizome fragments in the soil. Seeds likely would be inhibited by the remaining litter in the "roll and crush" treatment, but plants emerging from rhizomes are likely not affected by this litter (Kettenring 2016, Marty and Kettenring 2017).

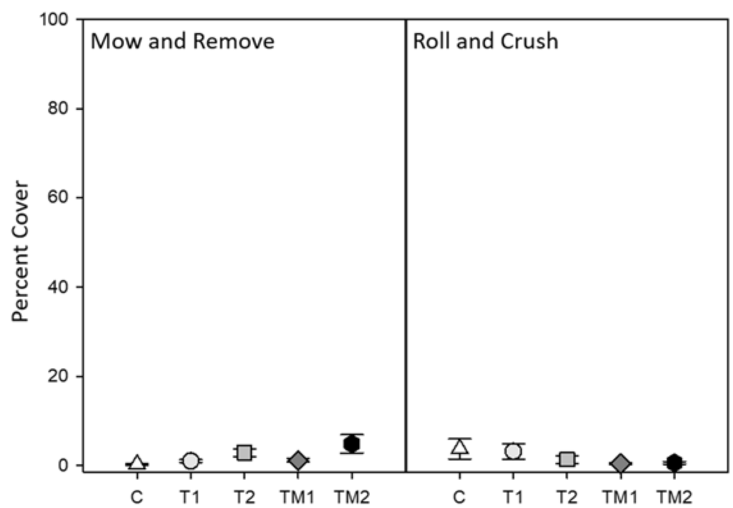

Figure 7. Percent cover (mean ± 1 standard error) of alkali bulrush in August 2017. The treatments denoted on the x-axis were ***C*** *for control and the four seed treatments:* ***T1*** *(sowing #1, no mulch),* ***T2*** *(sowing #2, no mulch),* ***TM1*** *(sowing #1, mulch added),* ***TM2*** *(sowing #2, mulch added).*

Hardstem bulrush

Hardstem bulrush cover was low overall and was only slightly affected by the various treatments. For the “mow and remove” plots, there was a slightly higher percent cover in the seeded plots versus the control plot, though the difference between seeded treatments was small. Percent cover for hardstem bulrush in the “roll and crush” treatment was low and did not seem to vary by seed treatment.

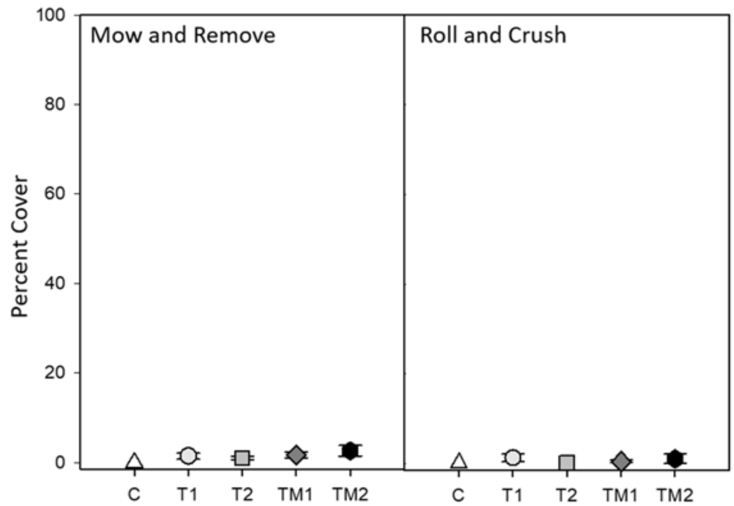

*Figure 8. Percent cover (mean ± 1 standard error) of hardstem bulrush in August 2017. The treatments denoted on the x-axis were **C** for control and the four seed treatments: **T1** (sowing #1, no mulch), **T2** (sowing #2, no mulch), **TM1** (sowing #1, mulch added), **TM2** (sowing #2, mulch added).*

Threesquare bulrush

Threesquare bulrush cover was low overall and differences among treatments were negligible. Overall, this species did not establish well at the site (also see stem density data above). This poor establishment may be the result of biotic pressure (i.e., competition) from other species as well as abiotic factors (e.g., low light levels) that prevented seeds from germinating.

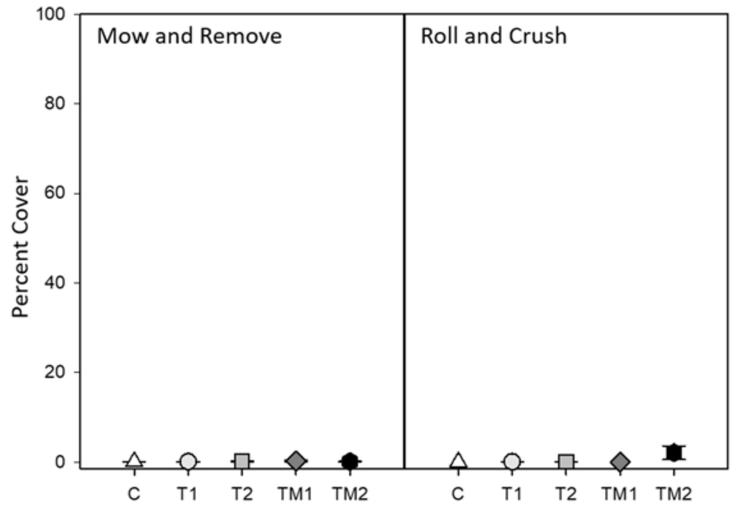

*Figure 9. Percent cover (mean ± 1 standard error) of threesquare bulrush in August 2017. The treatments denoted on the x-axis were **C** for control and the four seed treatments: **T1** (sowing #1, no mulch), **T2** (sowing #2, no mulch), **TM1** (sowing #1, mulch added), **TM2** (sowing #2, mulch added).*

Salt grass

Salt grass had the highest cover of all the sown species. In the “mow and remove” plots, there was higher percent cover of salt grass in the seeded versus control plots but no difference among the four seed treatments. The percent cover of salt grass in the “mow and remove” plots was higher than what was found in the “roll and crush” plots indicating that litter removal is important for increasing cover of this species.

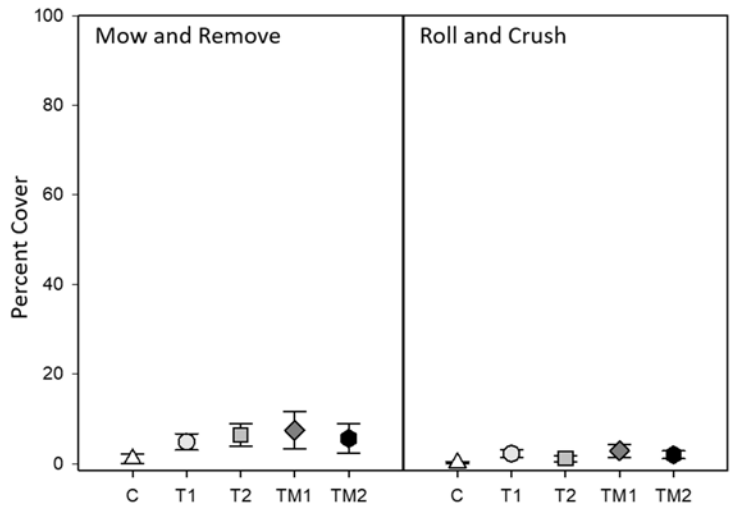

*Figure 10. Percent cover (mean ± 1 standard error) of salt grass in August 2017. The treatments denoted on the x-axis were **C** for control and the four seed treatments: **T1** (sowing #1, no mulch), **T2** (sowing #2, no mulch), **TM1** (sowing #1, mulch added), **TM2** (sowing #2, mulch added).*

Baltic rush

Balti rush had very low cover in all treatments. Low establishment in this species may be the result of biotic pressure (i.e., competition) from other species or abiotic factors that limited germination and establishment.

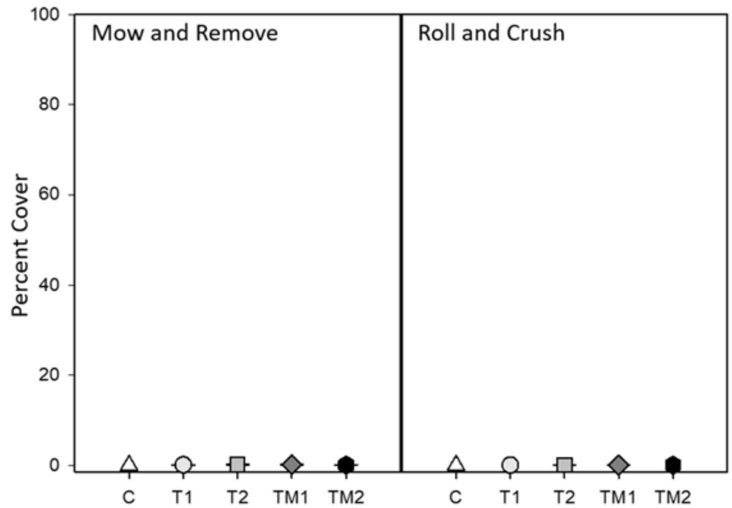

Figure 11. Percent cover (mean ± 1 standard error) of Baltic rush in August 2017. The treatments denoted on the x-axis were ***C*** *for control and the four seed treatments:* ***T1*** *(sowing #1, no mulch),* ***T2*** *(sowing #2, no mulch),* ***TM1*** *(sowing #1, mulch added),* ***TM2*** *(sowing #2, mulch added).*

Phragmites

In general, the percent cover of *Phragmites* was higher in the “mow and remove” plots, particularly in the untreated control treatment. This trend could be the result of higher *Phragmites* seed germination with the bare ground and high light conditions from the removal aspect of this treatment. Interestingly, there was a lower percent cover of *Phragmites* in the “mow and remove” plots when seeds were added to the site, which indicates that there may be some low levels of competition occurring to slightly inhibit *Phragmites* return.

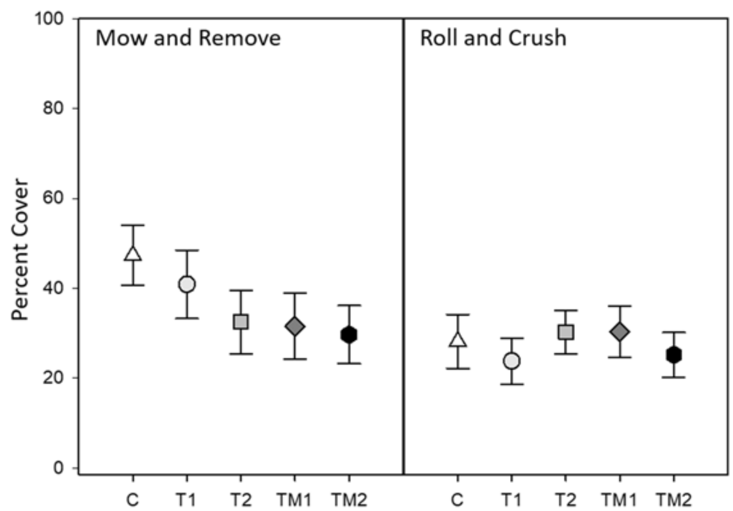

Figure 12. Percent cover (mean ± 1 standard error) of Phragmites in August 2017. The treatments denoted on the x-axis were ***C*** *for control and the four seed treatments:* ***T1*** *(sowing #1, no mulch),* ***T2*** *(sowing #2, no mulch),* ***TM1*** *(sowing #1, mulch added),* ***TM2*** *(sowing #2, mulch added).*

Summary and conclusions

Stem density take home points

- The “mow and remove” litter treatment is superior to the “roll and crush” treatment in enhancing native plant stem density for alkali bulrush, hardstem bulrush, salt grass, and to a lesser extent threesquare bulrush. Litter treatment did not affect Baltic rush and *Phragmites*.
- Seeding increased stem density of the native species overall with the exception of Baltic rush, which had very low stem density overall.
- The timing of seed sowing and the mulch treatment did not have a large effect on stem density for all native species.
- *Phragmites* stem density was relatively high overall and not impacted by increasing stem density of any native species.

Cover data take home points

- The cover of native species was quite low across all treatments except for salt grass.

- Salt grass cover was higher in the “mow and remove” litter treatment regardless of the seed treatment.
- *Phragmites* cover was somewhat reduced in the “roll and crush” treatment relative to the “mow and remove” treatment. In the “mow and remove” treatment, *Phragmites* cover was slightly reduced when native species were added.

Implications for management and next steps

- Based on the results of this study, we conclude that the “mow and remove” *Phragmites* litter treatment is important for establishing any appreciable amount of native plants.
- The different seed treatments (timing × mulch addition) did not matter for native plant stem density or cover. Therefore managers can avoid the logistically challenging step of adding a mulch to their seed mix and can sow seeds over a wider time frame without affecting native plants.
- Native plant covers were low overall despite their introduction through seeding. Given the one year time frame for this first stage of the study, we do not yet know if native plant covers (and stem densities) might increase in subsequent years. But, given the relatively high cover and stem density of *Phragmites* by the end of this field season (2017), we expect that it will likely rapidly expand to outcompete the natives if untreated.
- The abundance of *Phragmites* in the research plots highlights the importance of greatly reducing *Phragmites* in the seed bank and existing rhizome networks prior to seed sowing. This experiment has shown that even with seeding native species, if *Phragmites* is present on the site in any considerable amount, it will quickly rebound.
- We also think it is important to consider the density of native seeds sown on a site. We followed standard restoration seeding densities for this study, but future work needs to quantitatively determine what native seed density is required for rapid native plant community establishment to best outcompete any reinvading *Phragmites*.

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