A Comparison of Mechanical Treatments for the Control of *Spartina densiflora* at Jacoby Creek Unit, Humboldt Bay National Wildlife Refuge

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Introduction and Purpose

Spartina densiflora, a cordgrass native to South America, is an ecosystem engineer that has invaded 90% of the salt marshes in the Humboldt Bay region. Between 2004 and 2009, a pilot control project for *Spartina* was carried out at the Lanphere and Ma-le'l Dune Units of the refuge, resulting in a successful mechanical treatment method, called "grinding," which utilizes brushcutters to carry out above ground cutting and shallow subsurface grinding of rhizomes. Based on the success of this pilot, The U.S. Fish and Wildlife Service (USFWS) initiated a $1-million refuge-wide control program for this species in 2010. As a part of the project, a relatively large-scale experimental program was carried out at the refuge's Jacoby Creek Unit, which was characterized by 6.2-acre (2.5-ha) relatively homogeneous area of dense *Spartina* colonizing low marsh. The purpose of this project was to maximize the experimental value of an area targeted for control by designing large scale plots in which existing and proposed refinements of the brushcutter treatment could be compared for efficacy, including costs, degree of impact, and time to recovery.

Site Selection

The study was carried out at the Jacoby Creek Unit of Humboldt Bay National Wildlife Refuge (Fig. 1). This site, consisting primarily of intertidal salt marsh, had a number of features that made it suitable for the experiment, notably its easy access and large expanse of relatively homogenous, dense *Spartina*. The portion of the site used for this experiment was relatively level, although a range in variation in tidal elevation of approximately 39.6 cm (1.3 ft) was present, influenced by tidal creek configuration and distance from the adjacent high marsh. Vegetation on the site had been previously mapped by USFWS (Grazul and Rowland 2010) and all experimental areas fell within the highest cover class of 75-100% (Fig. 1).

Methods

In September 2010 a total of 11 square treatment areas, measuring 20 m (65.6 ft) on a side, were delineated in the field, with corners marked by PVC pipe and pin flags. Four types of treatment were assigned: control (no treatment), shallow grind, deep grind, and 2-step deep grind. Due to budgetary constraints, only two replicates were initially assigned per treatment. An additional replicate was subsequently added to the control, shallow and deep grind methods. However, not all measurements were consistently taken on these extra replicates due to time and budget constraints. The experimental design is shown in Fig. 2.

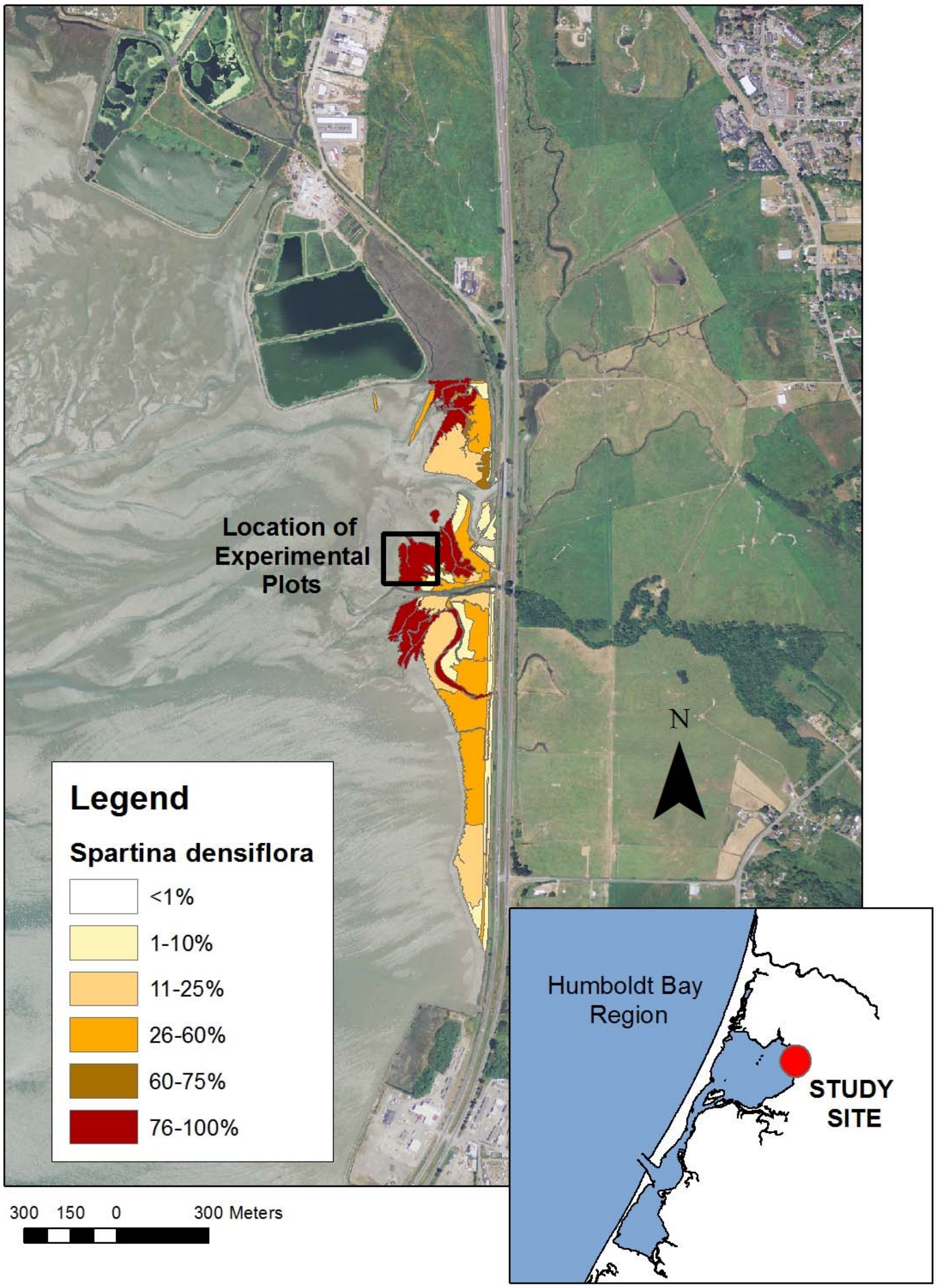

Figure 1. Location of Jacoby Creek salt marsh showing dense *Spartina* and experimental area.

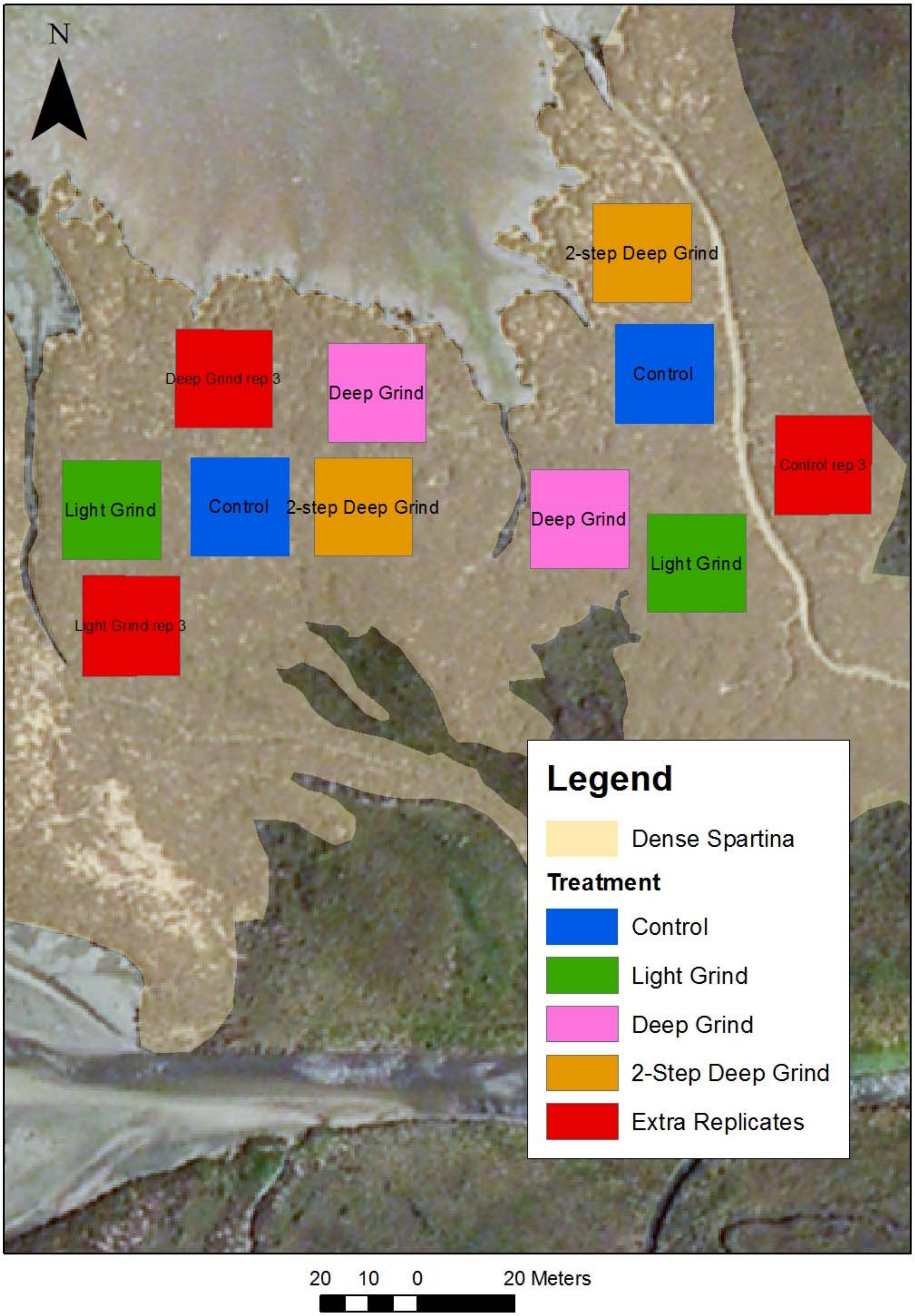

Figure 2. Layout of treatment plots.

Treatments

Treatments are discussed in detail in the experimental design (Pickart 2012a). The main treatment variable evaluated was the depth of grind. A modified two-stroke brushcutter with a metal, three-point blade was used in keeping with past practices. Prior experience had shown that there is a trade-off between efficiency and impacts. A deeper grind will destroy more rhizomes and require less follow up time, but takes longer and lowers marsh elevation more than a shallow grind. The deep grind could potentially have more detrimental impacts through lowering of the elevation, including impact to benthic invertebrates, and could also slow recovery time. The two depths tested were 8 cm (3 in) for the shallow grind and 13-15 cm (5-6 in)for the deep grind. These depths were chosen based on the depths of rhizomes and past observations of differential responses to different depths of grinding. In reality it is difficult to maintain an exact depth with the brushcutters and there is much variation, but the operators attempted to achieve an average depth close to the target.

A second modification evaluated was separating the deep grind treatment into two steps to potentially improve efficiency. Traditionally, the grind treatment is done by one operator using the brushcutter first to cut horizontally through the standing *Spartina* plants in a localized area in the immediate vicinity, cutting through the plants repeatedly at increasingly lower heights to reduce the size of fragments in resulting wrack. Rafts of *Spartina* wrack are known to have the potential to smother native salt marsh vegetation when they become stranded at he upper edges of salt marshes (Kittelson and Boyd 1997). The operator then applies the brushcutter to the surface in short, vertical motions, to grind through the shallow rhizomes of *Spartina*. The side of the brushcutter blade that is rotating away from the worker contacts the ground (the right side of the brushcutter blade is lowered 30˚). An experienced operator is able to work in parallel strips, neatly casting the cut material over the previously ground substrate (Fig. 3). The refinement of this technique tested in this experiment was to first have the operator(s) cut all above ground portions of the plant (essentially mowing), without trying to reduce wrack texture. Then, crews would rake the *Spartina* into piles that were subsequently “mulched” with the brushcutters (Fig. 4). This refinement was intended to 1) create a finer-textured wrack more easily dispersed and less likely to raft, and 2) present a fairly clean surface for grinding, allowing operators to fine tune the depth of grind, and avoid missing areas. Treatments were carried out between February and April, 2011, and were accomplished by trained crews overseen by experienced brushcutter operators. Timekeepers logged hours by activity.

Figure 3. The grinding technique being employed in dense *Spartina*. As the operator moves to new areas on the left, the mud and wrack from the new strip is cast to the right and covers the previous area.

Figure 4. *Spartina* raked into piles after a top mow is mulched with a brushcutter as part of the 2-step grind method.

Monitoring

Baseline monitoring of vegetation was carried out near the end of the growing season in September 2010, while abiotic variables were first monitored in Feb. 2011 just prior to the application of treatments. Vegetation sampling consisted of 20 plots per treatment area, each .5 x .5 m (3.3 x 3.3 ft). Plots were placed systematically with a different random start at each sampling interval, at 4-m (13 ft) intervals (i.e. 5 transects, 4-m apart, each with 4 plots, 4-m apart). A quadrat with wires creating a 1-dm 3.3-ft)grid was placed along the transects. The percent cover by species was estimated visually with the help of the grid, and included categories of algae and bare mud. Cover classes of 10% (with an additional class for $\leq$ 1%) were used to increase accuracy and reduce bias among samplers. The midpoints of the classes were used in all analyses. A subsample of *Spartina* density (culms) was measured in a 20 x 20 cm (8 x 8 in) corner of each plot. Subsequent vegetation monitoring was carried out annually for two years (2011 and 2012), with the intent of monitoring both the reduction in *Spartina* cover and density, and the recovery of native species.

A one-time sample of the short-term response of *Spartina* to treatment was conducted in July 2011, to detect both mortality of *Spartina* and emergence of new *Spartina* seedlings. A seedling flush is frequently encountered in the spring following first treatment (Pickart 2012b), and the current control methodology calls for treating seedlings in the first spring. The July 2011 sample used different transects in order to avoid trampling in the vicinity of the long-term vegetation sample plots. Each treatment area had a total of 15 systematically placed, 0.25 x 0.25 m (.8 x .8 ft) plots. Within each plot the total number of resprouting culms and new seedlings was counted.

Monitoring was also carried out for two abiotic variables: elevation and redox (oxidation-reduction potential). Baseline abiotic monitoring was completed in February

2011, prior to treatment, and repeated annually in September 2011 and 2012. An additional elevation sample was collected immediately after treatment in April 2011 so that short term elevation loss could be discerned from longer term changes. Elevation was measured using a laser level, with elevations tied to a permanent benchmark surveyed in at a nearby upland. Redox measurements were collected using a Thermo Scientific Orion 3-star Plus redox meter. Abiotic measurements were collected at a total of 10 systematically located, permanent locations per treatment area.

Results

Labor Requirements by Treatment

A comparison of labor requirements (in person-hours/acre) by treatment is shown in Fig. 5. Although the deep grind treatment had the highest mean labor, it also had the largest variation in labor (ranging from 203 – 355 ph/acre). Due to the labor intensity of the experiment, a small sample size was necessary, which reduced the statistical power of the experiment. For this reason, the alpha significance level was set at p=.20. There was no significant difference among all 3 treatments when ANOVA was performed (p=.64). Because the 2-step test had the smallest sample size (2), the Light Grind was then compared only with Deep Grind using a t-test. A statistically significant difference occurred only with a significance level of p=.23.

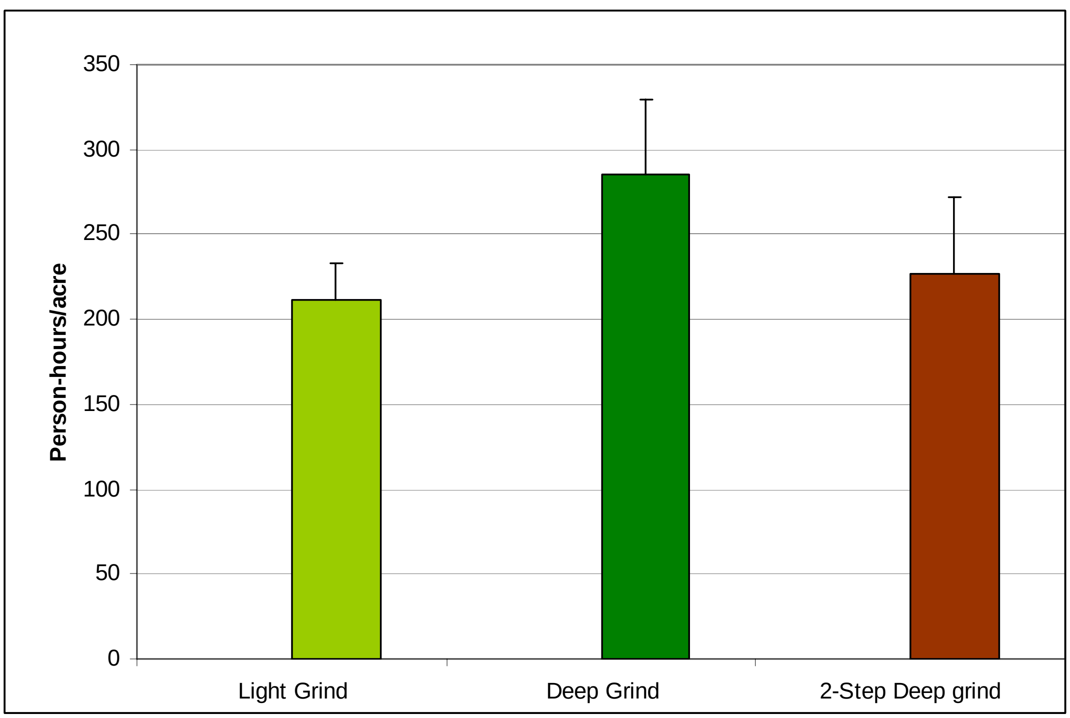

Figure 5. Mean person-hours per acre required for each treatment. Error bars = standard error.

Response of Elevation to Treatment

Elevation change was measured as the change in elevation between time periods normalized to the change in mean elevation of the control plots for the same time period. This approach was used for two reasons: 1) There was an apparent error in the measurement of absolute (but not relative) elevation during one time interval, causing a consistent shift in elevations after one point in time and 2)this approach eliminates the influence of ambient sediment conditions, thus focusing on treatment effects. Deep grind and 2-step deep grind plots were lumped to create a better sample size.

Both types of treated plots (light and deep grind) dropped in elevation up to 5.1 cm (2 in) following the initial treatment in March 2012, and maintained or slightly increased this loss by 6 months (September 2012). The elevation measurements are lacking at one year and were interpolated. By 1.5 years, elevations had recovered to within +/- 1.3 cm (0.5 in) of the baseline elevation. Although there was a slight decline in deep grind at 2 years, all treatments maintained elevations less than1.3 cm (0.5 in) above or below baseline (Fig. 6).

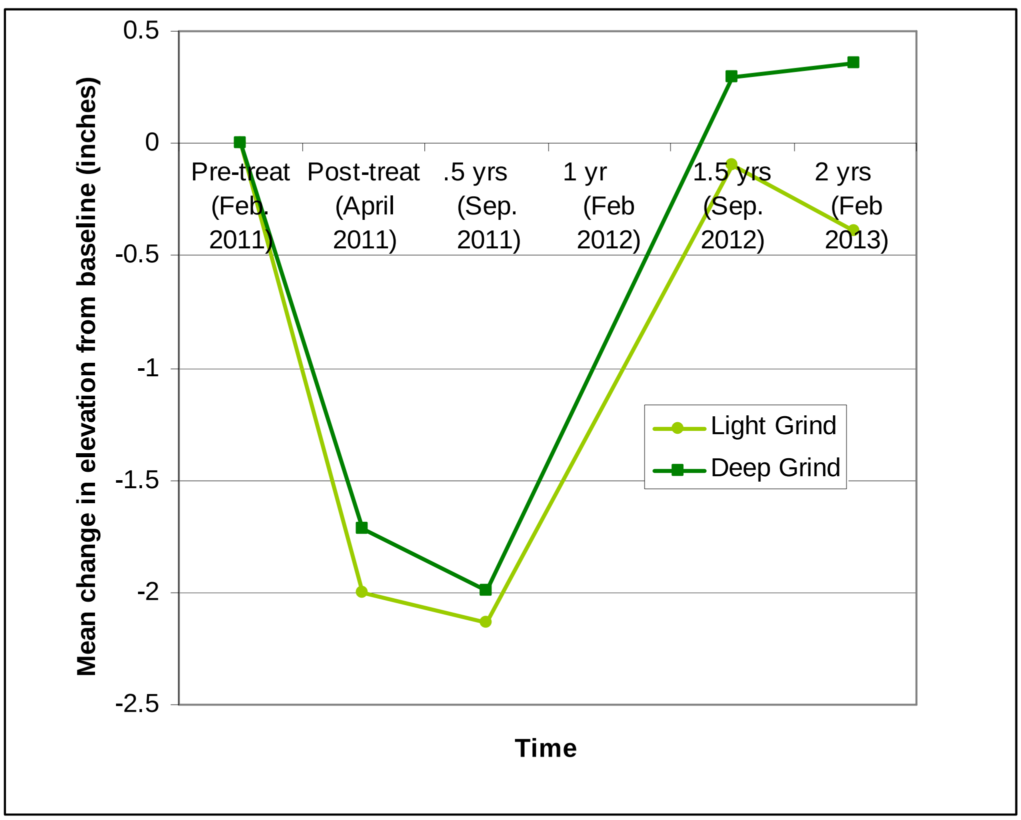

Figure 6. Change in mean elevation (inches) by treatment from baseline (pretreatment) over time. Data have been normalized to zero at baseline.

Response of Redox to Treatment

There was no significant difference in redox among treatments in the baseline ($p=.59$), so actual redox values (rather than change from baseline) were used in the analysis. GLM was performed to locate significant changes in redox among time intervals (date) and the treatments light grind, deep grind, and control. Redox values were significantly more negative at the 6 month time period, and significantly less negative at the 2 yr time period ($p<.05$). The deep grind treatment exhibited significantly more negative redox values than the control and light grind. Change in redox over time by treatment is shown in Fig. 7. One-way ANOVA performed for each treatment by date revealed that in control plots, redox didn't rise significantly until the last time period ($p=.05$). Redox in deep grind plots was most negative in the middle of the experiment, but was no longer significantly different than the baseline after 2 years (although it was significantly lower than both light grind and control plots at that time). Light grind plots were somewhat anomalous, exhibiting a significantly lower value at 1.5 yrs but recovering to values less negative than baseline and no different than controls by 2 years.

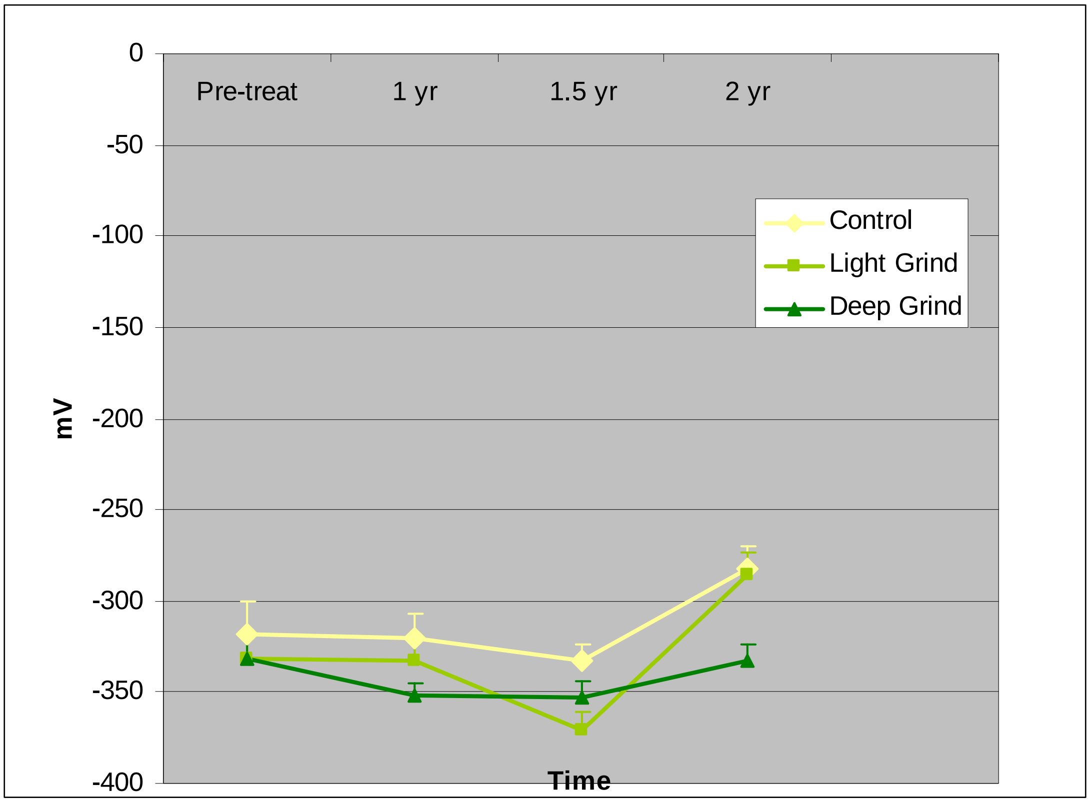

Figure 7. Change in mean oxidation-reduction potential (mV) by treatment over time (note that redox measurements were not collected immediately post-treatment).

Response of Vegetation to Treatment

A two-way GLM showed a significant difference ($p \leq .001$) for total native cover, *Spartina* cover, and algal cover for treatment, date, and their interaction. The significant interaction in the GLM was due to the differing response of the controls compared to other treatments. One-way ANOVA was then performed for each treatment to identify significant differences among dates for both total native and *Spartina* cover, and followed by post hoc range tests (SNK) at p=.05. Results for these three response variables are shown in Figs. 8-10. Homogeneous subsets for percent *Spartina* cover and percent total native cover at different time periods are displayed in Tables 1-2.

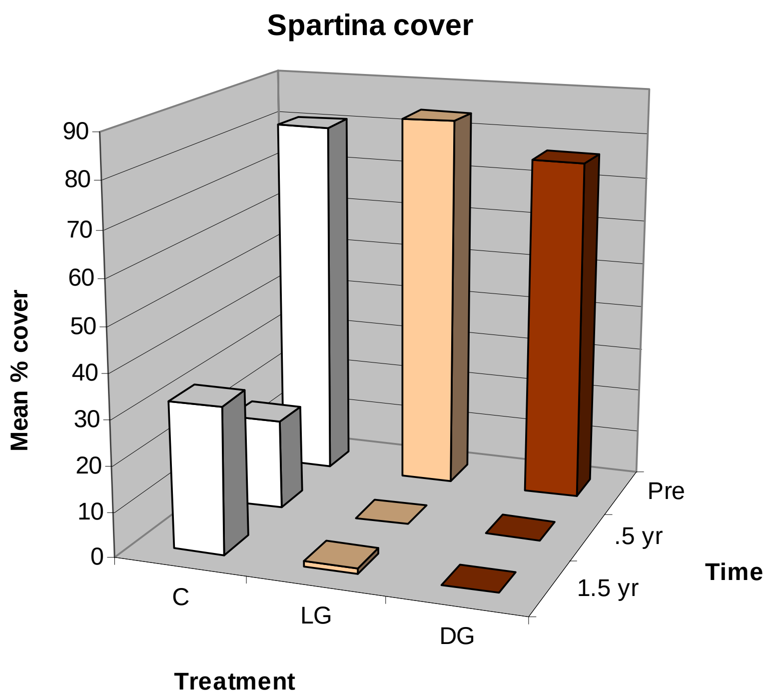

Figure 8. Change in *Spartina* cover over time (pre-treatment, .5 yrs and 1.5 yrs) by treatment (C = control, LG = light grind, DG = deep grind).

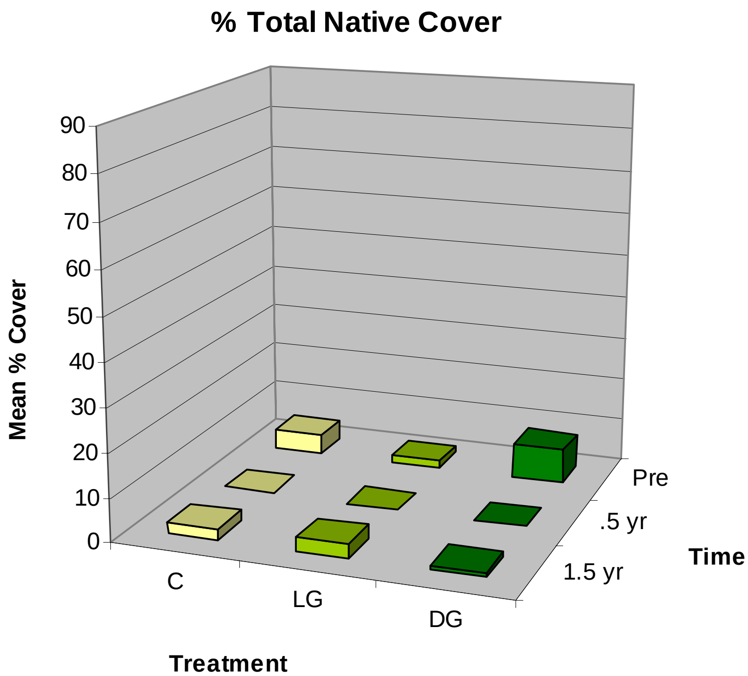

Figure 9. Change in total native cover over time (pre-treatment, .5 yrs and 1.5 yrs) by treatment (C = control, LG = light grind, DG = deep grind).

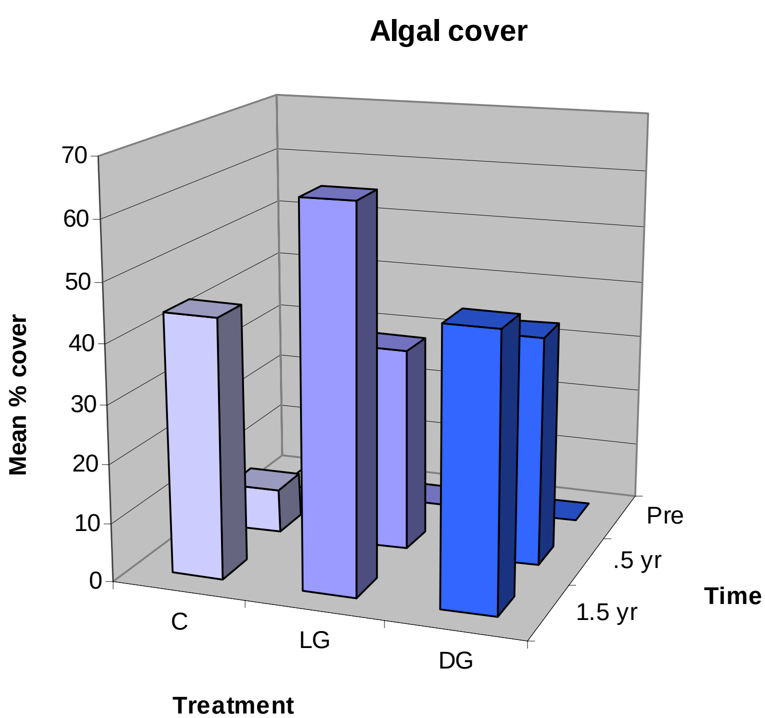

Figure 10. Change in algal cover over time (pre-treatment, .5 yrs and 1.5 yrs) by treatment (C = control, LG = light grind, DG = deep grind).

Table 1. Results of post-hoc range tests (Sudent-Newman-Keuls) showing percent *Spartina* cover means for groups in homogenous subsets (means in the same group are not significantly different between/among time periods).

Treatment	Time	n	Homogeneous subsets at p <.05		
			1	2	3
Control	.5 yr	40	20%		
	1.5 yr	40		33%	
	pre	40			81%
Light Grind			1	2	
	1.5 yr	40	0%		
	.5 yr	40	0%		
	pre	40		77%	
Deep Grind			1	2	
	1.5 yr	40	0%		
	.5 yr	40	1%		
	pre	40		77%	

Table 2. Results of post-hoc range tests (Sudent-Newman-Keuls) showing percent total native cover means for groups in homogenous subsets (means in the same group are not significantly different between time periods).

Treatment	Time	n	Homogeneous subsets at p <.05	
			1	2
Control	.5 yr	40	0%	
	pre	40	3%	3%
	1.5 yr	40		5%
Light Grind			1	2
	.5 yr	40	0%	
	pre	40	2%	2%
	1.5 yr	40		3%
Deep Grind			1	2
	.5 yr	40	0%	
	1.5 yr	40	1%	
	pre	40		8%

Spartina Seedling and Resprout Response to Treatment

Seedling emergence differed significantly in the light grind compared with the deep grind treatment (p=.002). Light grind plots had a mean of 101.5 seedlings/m^2 (SE 14), which was significantly higher than the mean of 46.3 seedlings/m^2 (SE 9) for the deep grind treatment.

Resprouting in both light and deep grind plots was low compared to seedling emergence. In light grind plots, mean resprouts/m^2 was 0.7 (SE 0.34), while in deep grind plots the mean/m2 was 0.2 (SE .12). Despite the higher numbers in light grind plots, the difference was not significant (p=.155).

Relationship between Abiotic and Biotic Variables

Because elevation data were normalized and relative, the analysis of relationships between abiotic and vegetation was restricted to redox. These relationships changed over time. At the first time period, before any *Spartina* was removed, the only significant correlation was a negative correlation between *Spartina* cover and total native cover (Table 3); an expected result since *Spartina* is known to suppress native species. Neither *Spartina* cover nor native cover exhibited any significant correlations with redox pre-treatment. By 6 months post-treatment, only the control plots still contained *Spartina* (although the *Spartina* in those plots had been top-mowed annually to prevent seed set). At this time period (6 months), positive correlations were found between redox and both *Spartina* and native cover (Table 3). By 1.5 years, there was still a positive correlation between *Spartina* and redox.

Table 3. Significant correlations between vegetation and redox variables. Vegetation data for the second year had not yet been collected.

Date	Significantly correlated variables	r	p	n
Pretreatment	Total native cover-*Spartina* cover	-.16	.039	160
6 months	*Spartina* cover-redox	.28	.003	110
	Native cover-redox	.20	.039	110
1.5 years	*Spartina* cover-redox	.26	.002	80

Discussion

Labor Requirements

Although the differences in mean labor requirements were statistically significant only at the 0.23 significance level, these differences are still worth noting given the low sample size and poor statistical power of the test. This experiment suggests that the deep grind treatment may require greater labor than the shallow grind, which is an intuitive result. However, when comparing treatment costs, it is important to take into account any differences in follow up treatment, which would affect the cost difference. The greater seedling densities that occurred in the light grind plots would at least offset savings realized in the primary treatment. Another factor to consider in evaluating treatment efficiency is the time required for native plant recovery. The experiment needs to run longer before this response is substantial enough to evaluate. Overall, the lack of consistent and substantial differences in labor for the three primary treatments indicates that other factors than labor (e.g. impacts, recovery rate) should probably outweigh the labor needs in deciding which treatment to select.

Response of Abiotic Variables to Treatment

The treated plots experienced an initial elevation loss persisting for at least six months (April through September 2011). Because elevation data are lacking for the one year mark, the subsequent recovery in elevation may have occurred at any point between 6 months (April 2011) and 1.5 years (Sept. 2012), but photo-documentation over time indicates that the recovery occurred at the latter part of this period (i.e. during 2012, see Appendix A). Surprisingly, the light grind treatment experienced a slightly greater initial elevation loss than the deep grind treatment, and this effect was maintained throughout the experiment. The most plausible explanation for this is that the deep grind treatment resulted in a greater post-treatment accumulation of less compacted sediments, simply because more sediment was affected in this treatment. In the grind treatments, sediments are side-cast as the brushcutter proceeds, backfilling areas after treatment (Fig. 3). Both treatments had a temporary effect on elevation, with a maximum loss of 2.1 in (5.3cm). Although the elevation loss was recovered by 1.5 years, it represents a temporary detrimental impact due to resuspension of sediments and potential direct mortality of invertebrates. A Master's thesis is in progress, addressing the shift in abundance and composition of microbiota that occurred during the first year of the experiment (Kelly 2011). The elevation loss also resulted in a slower recovery period for native species. These impacts should be weighed against the benefits of rapid mortality and low seedling emergence of *Spartina* when evaluating treatments.

Redox also responded to treatments. The deep grind treatment resulted in the most negative values (with the exception of the anomalous drop in light grind), but had recovered to baseline levels after two years. Light grind treatments declined at 1.5 years but rose to values higher than baseline and no different than controls after two years. The control plots also showed an increase in redox, just at the end of the experiment. The higher-than-baseline increase in both control and light grind plots but not in deep grind plots is difficult to interpret without absolute elevation data. Changes in redox could well be caused by elevation changes.

Response of Vegetation to Treatment

All of the treatments (light grind, deep grind and 2-step deep grind) were very successful in terms of mortality of *Spartina*. Resprouting was very low compared with past control efforts. Mean resprout density was $0.7/m^2$ in light grind and $0.2/m^2$ in deep grind plots (the difference between treatments wasn't significantly different). These numbers are far lower than those documented in the Lanphere *Spartina* control program, initiated in 2006, of 6.4/m^2, and in the Ma-le'l control effort beginning in 2008, of 5.6/m^2 (Pickart 2012b).

The depth of the grind affected seedling emergence, with the deep grind reducing the mean number of seedlings by half. This result suggests that the deeper grind affected more stored seeds and that either the disturbance itself caused seed mortality or seeds were displaced and dispersed off-site. Seedlings, like resprouts, were far less abundant in this experiment than in other control efforts. Mean seedling density was 46.3/m^2 in light grind plots, and 101.5/m^2 in deep grind plots. This contrasts with past efforts that have resulted in seedling densities of 577/m^2 (Lanphere control program) and 410/m^2 (Ma-le'l control program, in dense *Spartina* areas). Treatment method explains the much lower resprout and seedling response in this experiment. In both of the earlier control programs, treatments were much shallower, and/or lacked the "grind" approach (instead relying on horizontal slicing through the rhizomes). The treatments used in this experiment were both deeper and more consistent. The consistency of the treatment over each of the treatment areas resulted from better training as well as close supervision of workers. Based on past experience, this level of consistency would not be attained in a non-experimental context. However, it seems evident that with less consistent effort, even the shallow grind treatment is far more effective at reducing seedlings and rhizomes than past variations on treatment.

Redox measurements supported the premise that the deeper treatments created conditions anoxic enough to limit *Spartina* regrowth. However, these conditions similarly affected the return of native species. The recovery rate of natives has been much slower at this site compared with other restored sites. Native species cover was extremely low 1.5 years after treatment ($\leq$8%) although algal cover was high. However, based on the recovery of pre-treatment elevations and redox values by the second year, native cover should experience significant growth in the upcoming growing season. If not, revegetation should be considered.

The control plots experienced a positive increase in native cover and reduction in *Spartina* cover and density over the two-year course of the study. This is explained by annual top-mowing that was performed to prevent seed set. Top-mowing has previously been shown to suppress *Spartina* and increase native cover and diversity (Pickart 2012b).

An interesting and significant observation was that native species outside of the plots recovered substantially more than in the light grind plots during the course of the experiment, although this effect was greatest in areas farthest from the marsh edge (and presumably highest in elevation). The areas between plots were theoretically treated with the same light grind treatment as inside the plots, but without the supervision and scrutiny that was provided inside plots. There are two factors that may have contributed to this effect. First, the operators may have actually performed a more shallow grind when they were not being overseen closely and attempting to achieve a uniform depth. Second, the monitoring activities inside plots continued to churn up sediments and may have slowed the recovery of redox levels inside plots relative to outside plots.

Conclusions

- The different treatments (light, deep, and 2-step deep grind) were not distinguishable from each other in terms of labor requirements, although the low sample size may have masked an effect and the light grind likely takes less time. However, any savings in the initial treatment are probably balanced by the longer time it takes to treat seedlings in the light grind.

- The lack of consistent and substantial differences in labor for the three primary treatments suggests that other factors than labor (e.g. impacts, recovery rate) should probably outweigh the labor needs in selecting a treatment approach.

- All treatments (light, deep, and 2-step deep grind) were extremely effective at killing existing plants. Resprout density was lower than recorded in any previous effort (less than 1 culm/m^2) with no significant difference between treatments.

- Seedling emergence was substantially lower in this experiment than previous projects. The deep grind treatment resulted in approximately 50% fewer seedlings than the light grind, suggesting that depth of grind is tied to seed mortality, or alternatively to dispersal of seed off-site.

- Recovery of native species in treated plots was negligible after 1.5 yrs, a much slower response than in other restoration efforts, indicating that the depth of treatment, while increasing success of *Spartina* mortality and reducing seedling emergence, also inhibited native species recovery. Recovery of elevation and redox to baseline levels by 2 years suggests that native vegetation recovery may follow in the summer of 2013. Cover should be assessed at that time and revegetation considered if progress is not observed.

- After treatments were applied, redox was positively correlated with cover (both native and non-native). Although a causal relationship can not be claimed, it seems reasonable that soils in all treatments initially became too anoxic to support vegetation. Redox and elevation data could not be analyzed through correlation analysis, but both showed a similar trend of reduction after treatment, with gradual recovery by two years. It is reasonable to conclude that redox changes followed elevation changes, since increased submergence would lead to more anoxia.

- Given the results to date, both the light and deep grind treatments applied in this experiment resulted in enough elevation loss to delay recovery of native species, compared with the brushcutter treatments applied at other sites. Although both treatments resulted in lower resprouting and seedling emergence than past restoration efforts, this benefit was likely outweighed by the slower recovery time. Although elevation and redox had recovered to baseline levels after two years, the delay in native recovery argues for a shallower treatment, at least in similar low-elevation marshes, to balance efficiency and impacts.

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