U.S. Fish and Wildlife Service

Humboldt Bay National Wildlife Refuge

Humboldt County, California

Control of Invasive *Spartina densiflora* in a High-elevation Salt Marsh, Mad River Slough, Humboldt Bay National Wildlife Refuge

Prepared by: Andrea Pickart, Ecologist
Humboldt Bay National Wildlife Refuge
6800 Lanphere Rd.
Arcata, CA 95521

Submitted to:
Sheila Semans
California State Coastal Conservancy

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INTRODUCTION and GOALS

Dense-flowered cordgrass (*Spartina densiflora*) has been recognized since 1984 as an invasive species in Humboldt Bay's salt marshes (Spicher and Josselyn 1985). Present since the mid-1800s, the species has been documented to displace native salt marsh species through competition (Kittelson and Boyd 1997). A bay-wide inventory in 1999 revealed that *Spartina* was present in 94% of Humboldt Bay's salt marshes, and occurred at dense concentrations (>70% cover) in 68% of the total salt marsh area (Pickart 2001). From 1989-1997, frequency of *Spartina* at one high-elevation salt marsh island (a habitat previously thought to be invasion-resistant) increased from 1-48% (Pickart 1997). However, due to the inherent difficulty of controlling a tidally-dispersed, seed- and tiller-producing species, only very limited, experimental control efforts have previously been attempted (Walston 2000, Pickart 2001). These early efforts consisted of manual digging of *Spartina* plants, with or without revegetation, in a relatively newly-invaded, high-elevation salt marsh. Although limited in scope and duration, these experiments indicated that manual removal could be effective in reducing or eliminating *Spartina* under these conditions. Given that labor-intensive, manual methods have been used successfully in the dune habitats at Humboldt Bay, there existed justification to attempt similarly intensive methods for *Spartina*. Despite the fact that manual removal of the rhizomatous, invasive European beachgrass (*Ammophila arenaria*) costs as much as $40,000/ac (Pickart and Sawyer 1998), Humboldt Bay land managers have been successful in obtaining millions of dollars in restoration funds to date (Baker 2004).

The use of a manual technique was preferred for European beachgrass for several reasons, including a strong community objection to the use of herbicides, the negative impact of heavy equipment on semi-pristine sites, and the relatively lower cost of control in early-invaded sites. Applying this logic to *Spartina* control, the potentially more resistant, recently invaded high-elevation salt marsh islands present a feasible target for restoration through the removal of *Spartina* using manual methods. The probability for re-invasion exists, but re-invasion at the original invasion rate is not a given, based on invasion theory, which predicts a temporal "window" of invasion susceptibility for a given invasive species and target ecosystem. The goals of this experimental restoration project were to test manual methods (digging and mowing) for their initial success, and to document costs. The potential for long-term resistance of the restored site to re-invasion will be evaluated through long-term monitoring of the site, and is not included in this report.

METHODS

Site Selection

The experimental restoration was carried out on a high elevation salt marsh island located within the boundaries of the Lanphere Dunes Unit, Humboldt Bay National Wildlife Refuge, on the Mad River Slough, Humboldt Bay (Fig. 1). The island (actually two separate islets at high tide) is 3.7 ac in size, and represents 15% of the total salt marsh in the Lanphere Dunes Unit (22.5 ac). An additional 27 ac were recently added as part of the Ma-le'l addition funded by the Coastal Conservancy and USFWS.

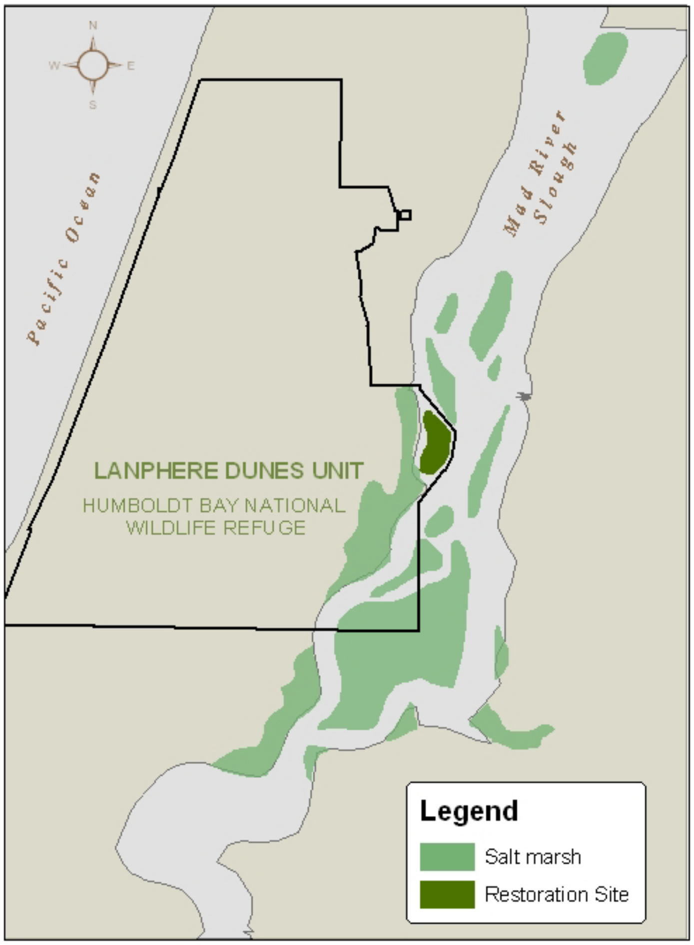

Fig. 1. Location of study site/restoration area.

Site Stratification

To provide a baseline measurement of *Spartina* cover and to facilitate experimental design, the site was first stratified into six *Spartina* cover classes: High Cover (H= 75-95 % cover), Medium-High Cover (MH= 50-74% cover), Medium cover (M= 25-49% cover), Medium-Low cover (ML=; 5-24% cover), Low cover (L=1-4% cover) and not present (NP= 0%). Areas of homogeneous cover were delineated in the field by mapping over an air photo using ocular estimation of cover. Due to the flat nature of the salt marsh, delineating a change in cover class required repeatedly walking around and through an area to observe it from several angles. The resolution of the air photos allowed for very accurate mapping, so a minimum polygon size of 10 m^2 was possible. Cover mapping was carried out in August 2004.

Experimental Design

Mowing and digging were the two treatments to be tested for their effectiveness in reducing the cover of *Spartina*. Two separate but simultaneous experiments were conducted, the first in High, Medium-High, and Medium strata using mowing; the second in Medium-Low and Low strata using digging. Experiments were designed compatibly so that results could be compared between as well as within experiments. Independent variables were treatment type. Only one treatment and a control were applied in each experiment. The dependent variables in both experiments were *Spartina* frequency and native species cover.

Plot placement and sample size

A total of 8 treatment and 8 control plots were placed in each cover stratum, for a total of 80 plots (Fig. 2). Plots were 1m x 1m, oriented such that two pieces of rebar marked the southwest and northeast corners (Fig. 3). Treatment plots were placed randomly, and control plots were placed near each treatment plot. The UTM coordinates of each southwest rebar was recorded with a Trimble XT GPS unit. A 0.25 m-wide buffer around each plot received the same treatment as the plot.

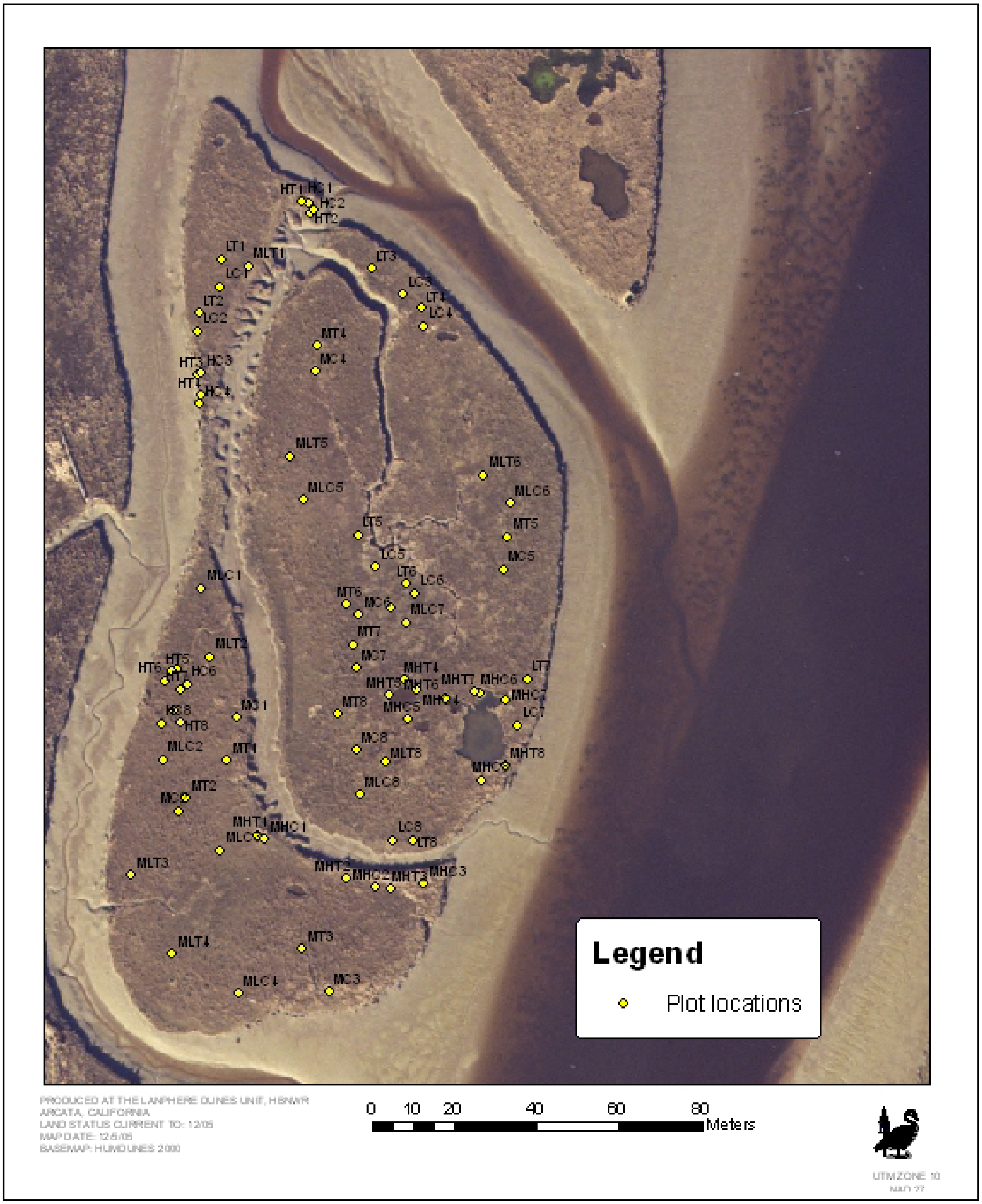

Figure 2. Location of experimental plots.

Monitoring

Baseline measurements were taken in June and July, 2004. A square-meter plot frame, subdivided into 100 10-cm x 10-cm subplots was placed over the two diagonal rebar plots (Fig. 3). The presence or absence of *Spartina* was recorded for each of the 100 subplots, resulting in 8 measures of *Spartina* frequency per treatment. Presence of *Spartina* was defined by rooting location (where shoots emerged from soil surface). In addition, presence/absence of other species was recorded for the entire plot. Monitoring was repeated in June 2005. However, for this period the presence/absence measurement was replaced by an ocular estimate of native species cover in 12 cover classes (<1, 1-5, 6-10, 11-20, 21-30, 31-40, 41-50, 51-60, 61-70, 71-80, 81-90, and 91-100). A third measurement will be taken in June 2006.

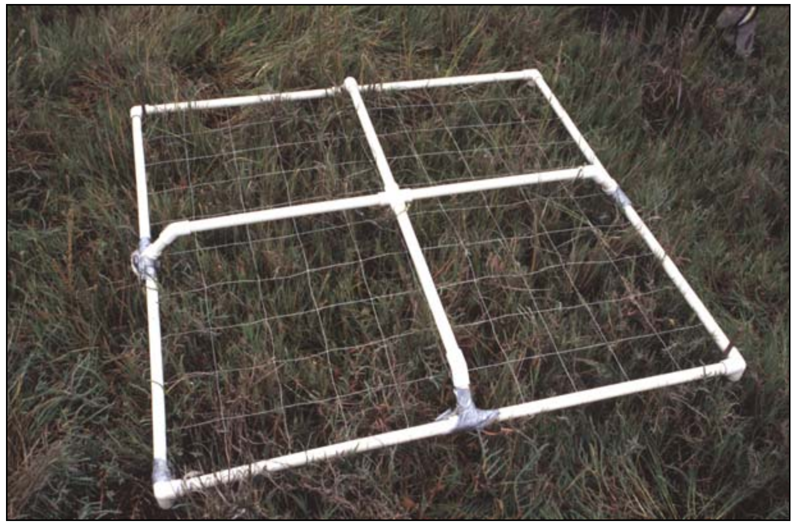

Fig. 3. 1-m^2 sampling frame with 100 subplots.

Treatments

Mowing. The mowing (weedeater) treatment was applied to High, Medium-High plots, and Medium plots (Fig. 4). Timing and type of treatment and retreatment varied by stratum in order to allow for enhanced competitiveness of native species and protection of rare species (Table 1). High and Medium-High plots, with relatively little cover of native species (and no rare plants), were first mowed in August, 2004. High cover plots were completely mowed to ground level during this first treatment. In Medium-High plots, distinct clumps of *Spartina* were mowed to ground level while scattered *Spartina* plants were mowed only to height of native vegetation. Medium plots, which

Figure 4. Mowing treatment.

contained more native cover and in some cases rare annual plants (*Castilleja ambigua* ssp. *ambigua* and *Cordylanthus maritimus* ssp. *palustris*) were first mowed in October 2004, after rare plants had dispersed seed. The Medium plots were spot-mowed to ground level for *Spartina*, leaving native vegetation untouched. During the winter, High and Medium-High plots were re-treated quarterly (October and December) by mowing all vegetation to ground level. Medium plots were re-treated in December by spot mowing of *Spartina* to ground level. For the 2005 growing season, all plots were treated monthly from March through October, 2005. During this period, High cover plots were always mowed to ground level, while Medium-High and Medium plots were spot-mowed to the height of native vegetation (thus insuring the successful growth and reproduction of rare plants, which germinate in January (Bivin et al. 1991). Treatments were not always needed, particularly in Medium-Low and Low plots, where resprouts did not always occur. Beginning in December 2005, treatments will be confined to digging of any remaining *Spartina* as needed.

Figure 5. A hand trowel is used to selectively remove a *Spartina* plant in a Low cover area.

Digging The digging treatment applied to Medium-Low and Low cover plots consisted of the use of hand towels to remove *Spartina* and any attached rhizomes (Fig. 5). Since rhizomes are relatively short (Kittelson 1993) it was possible to remove most plants successfully the first time. Plots were first treated in July, 2004, and then checked for resprouts on the same schedule as the Mowing treatments (October, December, and then monthly from April through October). All excavated plants were removed from the island for disposal.

Restoration

In addition to the experimental plots, restoration was carried out in the remainder of the island using the same treatments as prescribed for the experiment. Volunteer labor for large areas of Low and Medium-Low cover was recruited from local conservation and recreation organizations (Fig. 6). A total of 5 workdays were conducted, resulting in over 200 ph of labor. Given the difficulty of accessing the site (kayaks or canoes are necessary), it was difficult to obtain sufficient volunteer labor. For this reason, some of the low cover areas remain to be dug, although all of the mowing treatments have been completed to date.

Figure 6. Volunteers digging *Spartina* in Low and Medium Low areas.

Table 1. Schedule of treatments by stratum. M = mowed to ground level, S = Spot-mowed to ground level, sparse *Spartina* mowed to height of native vegetation, V = All *Spartina* spot-mowed to height of native vegetation, D = Dug.

Stratum	Month Treated											
	Jul 2004	Aug 2004	Oct 2004	Dec 2004	Mar 2005	Apr 2005	May 2005	June 2005	July 2005	Aug 2005	Sep 2005	Oct 2005
High		M	M	M	M	M	M	M	M	M	M	M
Medium-High		S	M	M	M	S	S	S	S	S	S	S
Medium			S	S	S	V	V	V	V	V	V	S
Medium-Low	D	D	D	D	D	D	D	D	D	D	D	D
Low	D	D	D	D	D	D	D	D	D	D	D	D

MAPPING RESULTS

The completed map showing distribution of *Spartina* cover classes (strata) before treatment is shown in Fig.7.

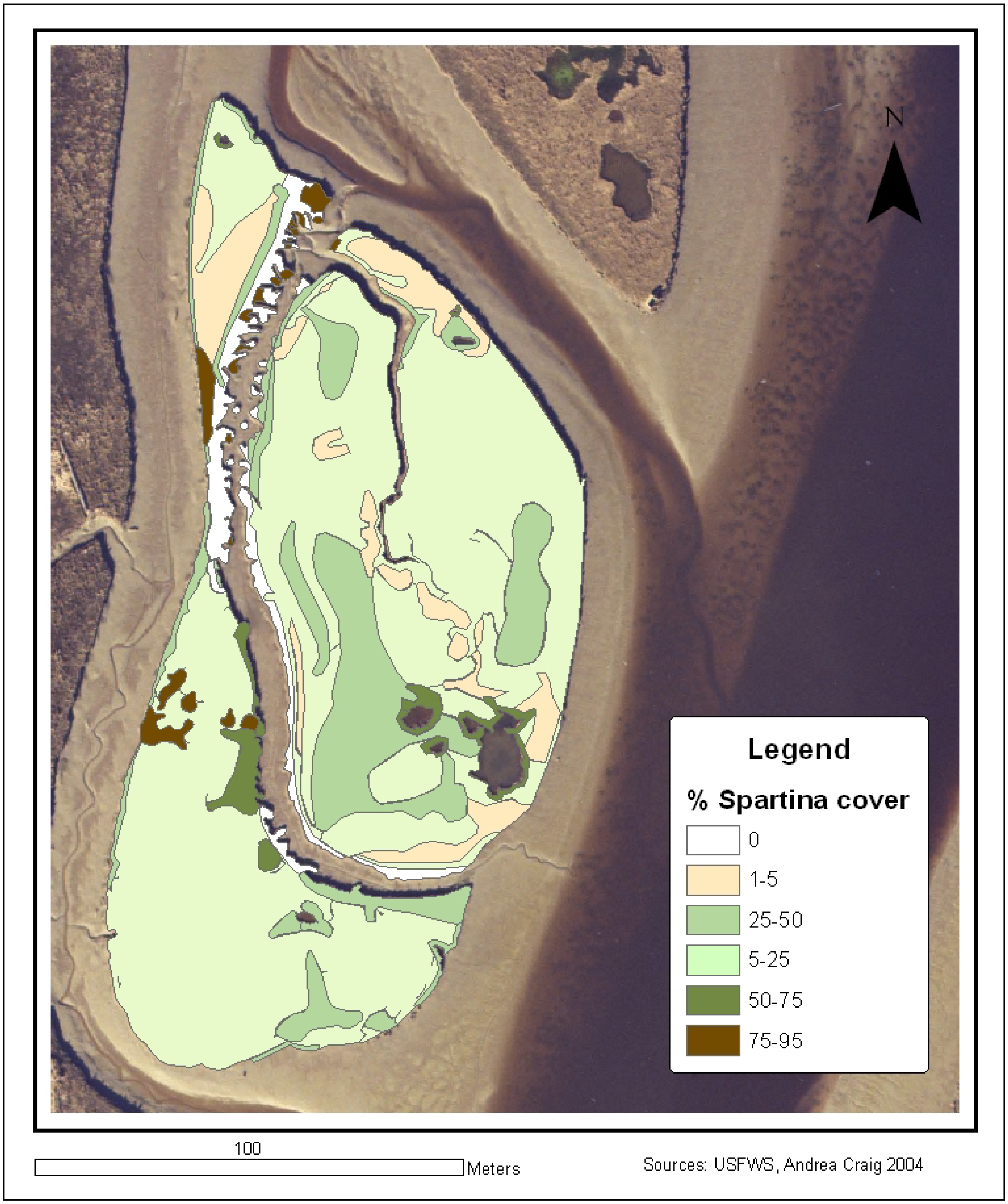

Figure 7. Distribution of *Spartina* cover classes on the island.

EXPERIMENTAL RESULTS

Spartina Control

Monitoring covered the period from July 2004 though July 2005, although treatments continued until October 2005 and the experiment will run until May 2006. Despite the fact that monitoring covered only one of the two years of planned treatments, significant success was demonstrated towards the eradication of *Spartina* in experimental plots (Fig. 8). Based on independent t-tests, mean *Spartina* frequency declined significantly ($p \leq .005$) in treated plots for all 5 strata (Table 2). A decline was also apparent in some of the lower cover strata control plots, however, there was still a significant difference between *Spartina* in control vs. treated plots for all stratum in 2005 (Table 3). The fluctuation in frequency in control plots is not clearly understood, but additional data in 2006 will help identify trends. By July, *Spartina* was virtually eliminated in all dug plots, declining from 5% to zero in Low cover and from 20% to 0.6% in Medium-Low plots. In mowed plots, mean *Spartina* frequency declined from 47% to 6.3% in Medium plots, from 47% to 27% in Medium-High plots, and from 85% to 46% in High cover plots (Figs. 8 and 9). The contract did not allow for an end-of-contract measurement (because it would have occurred at the wrong time of year). Instead, the true "after" measurement will be made in summer 2006. Significant but unmeasured declines in Spartina cover in the higher cover classes were qualitatively observed by December 2005, but won't be measured until next summer. As of October 2005, *Spartina* frequency was sufficiently low in all plots to merit a change in treatment from mowing to digging the few remaining plants.

Native Species Recovery

Because only presence/absence data were collected in the first year, recovery of native species was assessed by comparing cover of native species in treated vs. control plots in 2005. There was no significant difference ($p<.05$) between treated and control plots in the Low and Medium-Low plots, which were dug. The small amount of *Spartina* in these plots made it unlikely that effects would be statistically significant since cover classes are used and cover can sum to over 100%. However, in the Medium and Medium-High plots, native cover in July 2005 was substantially higher in control plots (Fig. 10). This was most likely due to the "mow to ground level" treatment these plots received during the winter, which knocked back both native and non-native plants. However, a significant amount of recovery has been observed in the treated Medium and Medium-High plots between July and October (Fig. 11), but won't be quantified until next summer. In High plots there was again no significant difference between control and treated plots. Trends will be clearer after the 2006 monitoring.

Table 2. Results of paired (2004 v 2005) t-tests by stratum for treated plots only.

Stratum	mean frequency 2004	mean frequency 2005	sample size (n)	significance level (p)
Low	5	0	8	.004
Medium-Low	20	2	8	.003
Medium	47	6	8	.000
Medium-High	43	11	8	.000
High	85	46	8	.005

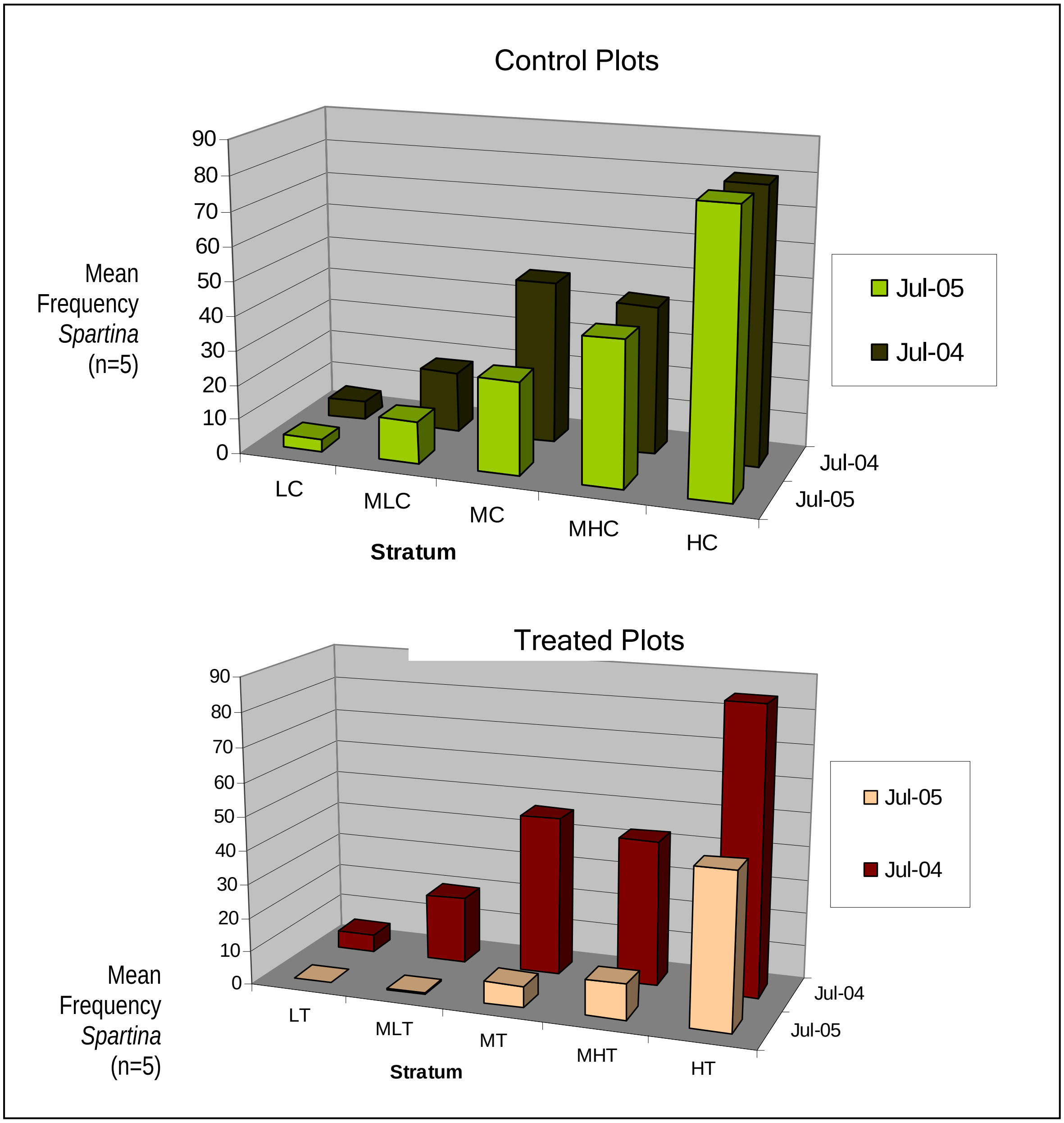

Figure 8. Change in mean frequency of *Spartina* by stratum from July 2004 - July 2005 for control (above) and treated plots (below).

Table 3. Results of independent (control vs. treated) t-tests by stratum for 2005 only.

Stratum	mean frequency Control	mean frequency Treated	sample size (n)	significance level (p)
Low	4	0	8	.009
Medium-Low	12	1	8	.004
Medium	27	6	8	.000
Medium-High	41	11	8	.000
High	81	46	8	.008

Figure 9. Medium Cover Plot before treatment (June 2004) (above) and 10 months after mowing treatment began (April 2005) (below)

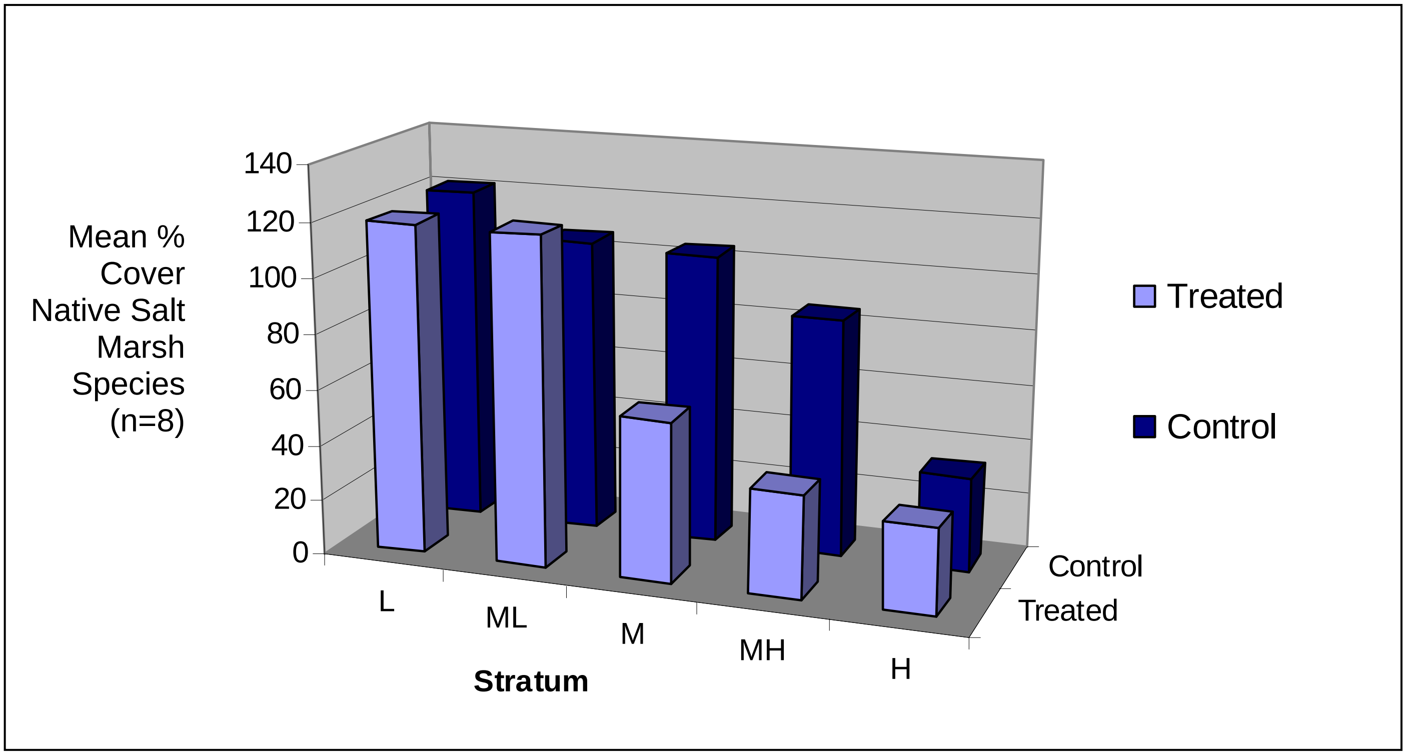

Figure 10. Changes in native salt marsh species cover in treated vs. control plots by stratum (July 2005)

Figure 11. Native *Salicornia* (reddish color) colonizing bare space from mowing of Medium-High plots, October 2005 (15 months after treatment began

COSTS

Based on labor logs, it requires between 400 and 800 ph/acre to dig Low to Medium-Low cover *Spartina*, excluding transportation time to and from the island. Mowing required approximately 96 ph/acre in predominantly Medium-High cover areas. High cover areas were very limited in extent, and extrapolating to a larger area wouldn't be meaningful solely from this study. These rates compare quite favorably with *Ammophila* removal, which requires 1,858 ph/acre excluding transportation (Pickart and Sawyer 1998). Of course, these Spartina removal rates do not include re-treatments, but labor needs drop precipitously after the first treatment.

DISCUSSION and CONCLUSIONS

The study clearly points toward the feasibility of manual removal of invasive *Spartina densiflora* from relatively recently-invaded, high-elevation salt marshes. *Spartina* was effectively eradicated from Low and Medium-Low plots by July, while Medium and Medium-High plots appeared to be nearly eradicated by October. In July 2006 the final monitoring will be completed, and a more conclusive statement can be made on the success of eradication efforts in the higher density strata, but qualitative observations are promising. Results showing an initial decline in native species cover in treated areas of higher *Spartina* cover indicate that revegetation earlier in the process may be beneficial (after the first season's treatment). For this experiment, it is recommended that revegetation will be carried out as a second phase of the experiment, during which resistance to re-invasion can be evaluated. It is also recommended that all control plots be prevented from flowering until they can be eliminated, so as to slow spread from these areas into treated areas.

Pending final results, it appears that two years are sufficient to eradicate *Spartina* using the treatments applied here. However, mowing was needed only through the first 19 months, after which only minor digging treatments are needed. Based on our labor tracking the cost to remove *Spartina* from a similar marsh (based on labor rates of $15/hr) is $6,000-12,000 /acre. Revegetation would add an unknown amount to achieve full restoration. The cost of removing *Spartina* is therefore comparable to that of removing other managed invasive species in the Humboldt Bay area. Given the imminent threat of *Spartina* invasion to remaining native salt marshes in Humboldt Bay, it is recommended that this methodology be employed elsewhere around the bay where new invasions have not yet created monotypic stands of *Spartina.* Extensive, monotypic stands of *Spartina*, such as those occurring on much of Indian Island, require additional study to develop efficient, feasible methods of eradication.

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