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Mechanical and Chemical Control of Smooth Cordgrass in Willapa Bay, Washington

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ABSTRACT

We evaluated four methods to control smooth cordgrass (*Spartina alterniflora* Loisel), hereafter spartina, in Willapa Bay, Washington: mowing, mowing plus herbicide combination, herbicide only for clones, and aerial application of herbicide for meadows. We used a single-hand application of Rodeo® formulated at 480 g L^{-1} acid equivalence (ae) of the isopropylamine salt of glyphosate (Monsanto Agricultural Co., St. Louis, MO; currently Dow AgroSciences, Indianapolis, IN) with the non-ionic surfactant LI 700® (2.0% v/v) on clones, and a single aerial application with X-77 Spreader® (0.13% v/v) on large meadows. We compared efficacy using changes in stem density and stem height 1 yr post-treatment. Stem densities and heights within clones were reduced by all treatments. The mowing plus herbicide combination and single-hand spray were equally more efficacious than repeated mowing at two sites, whereas at a third site, the mowing plus herbicide combination was the most efficacious. Aerial application of the herbicide resulted in an average of 91% of intended deposition, but both treatment and control plots showed similar increases in stem density and decreases in stem height. A subsequent aerial application of glyphosate with the non-ionic surfactant, R-11® to the study area the following year resulted in no statistically significant change in stem density on our former treated plot, but stem height decreased. However, on our former control plot, stem density significantly decreased, whereas stem height increased. We conclude that the mowing plus herbicide combination consistently provided the best control of clones, but hand application of the herbicide was almost as efficacious. The aerial herbicide applications we monitored provided little or no control indicating the need to improve efficacy if aerial treatment is to be a viable control strategy.

Key words: estuary, glyphosate, herbicide, mowing, Rodeo®, *Spartina alterniflora*.

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INTRODUCTION

Willapa Bay, located in the southwest corner of Washington State, is a bar-built estuary formed between a barrier beach to the west and the mouths of several rivers to the east. The Bay is a shallow, geologically young estuary with a water area of 347 km^2 at mean high high water (MHHW) of which 55% are inter-tidal lands (Sayce 1988). The inter-tidal area has a range between MHHW and mean low low water (MLLW) of 2.3 m at the entrance (north end) to 3.4 m at the opposite end (Sayce 1988), and has historically been an exceptionally productive and important environment for native fauna. This productivity and biodiversity has been protected by the Bay's generally shallow water depth, twice daily low tides, and deep, muddy substrate in many areas, restricting heavy shipping and industry. Current human uses include oyster culture (private and commercial), recreational shellfish harvest, waterfowl hunting and various types of over-water recreational activities.

In the late 1800's, spartina was accidentally introduced into the Bay either as discarded packing material for eastern oysters (*Crassostrea virginica*) or through seeds blown into open barrels of eastern oysters awaiting shipment (Sayce 1988). By the mid-1980's, the grass had successfully established itself ca. 1.8 to 2.8 m above MLLW (Sayce 1988) and up some of the rivers within areas of saline tidal influence (Kunz and Martz 1993). As an exotic marine monocot, spartina has been very efficient at supplanting other inter-tidal plant species. Eelgrasses (*Zostera japonica* and *Z. marina*) have been replaced at lower elevations, while salt marsh species (e.g., *Salicornia virginica, Triglochin maritmum* and *Fucus distichus*) have been out-competed at higher elevations (Wiggins and Binney 1987, Simenstad and Thom 1995). With an expansion rate in the diameter of clones of ca. 0.8 to 1.5 m yr^{-1} (Riggs 1992, Simenstad and Thom 1995, Feist and Simenstad 2000) and a rate of sediment entrapment of ca. 2 to 7 mm yr^{-1} (Gleason et al. 1979, Thom 1992, Simenstad and Thom 1995), spartina has the potential to convert sparsely vegetated mud flat to higher elevation marsh within a relatively short time.

In 1979, 50 yrs after local oyster growers voiced concern to the Willapa National Wildlife Refuge (NWR) about the spread of spartina, field biologists with the Washington State Department of Wildlife became concerned about the loss of shoreline habitat and recommended that the grass be eradicated from the Bay (Sayce 1990). Ten yrs later, the Washington State Weed Board declared spartina a noxious weed in seven western Washington counties. After a year of permit reviews for mechanical and chemical control by local, state and federal agencies and further explosive spread of the plant, particularly at the southern end of the Bay (Willapa NWR), the Pacific County Board of County Commissioners declared the presence of spartina an environmental emergency (Sayce 1990).

In 1997, there were an estimated 1,312 solid ha of spartina in Willapa Bay (Washington State Department of Natural Resources [WDNR] 2000), which represented a 60% increase from 1994 (WDNR 2000). It is estimated that 4,758 to 6,091 ha (25 to 32%) of the 17,407 ha of inter-tidal mudflat have been affected by the grass (Willapa Bay Spartina Management Task Force 2001) and it is predicted that, if uncontrolled, spartina will cover more than 11,000 ha by the year 2030 (WDNR 2000).

An evaluation of efforts to control spartina in the Bay was initiated by the Washington State Department of Fish and Wildlife (WDFW), WDNR, US Fish and Wildlife Service (Willapa NWR) and the University of Washington (Washington Cooperative Fish and Wildlife Research Unit) in 1994. Here, we report the results of our evaluation of the efficacy of mowing, hand spraying with the herbicide glyphosate and a mowing plus herbicide combination on spartina clones (distinct, 5 to 15 m diameter patches of spartina); and aerial application of glyphosate on spartina meadows.

METHODS

Four study sites within the Bay: Lewis Unit, North River, Nemah Beach, and Kaffee Meadow on Long Island were chosen in order to compare the effectiveness of treatments within substrate type. Study sites were chosen based upon the mandates of the participating management agencies, degree of infestation, substrate type and location within the Bay.

The Lewis Unit was located at the southernmost part of the Bay on the Willapa NWR at ca. 46,20 N-124,00 W and was characterized by a deep, soft muddy substrate. A very heavy seed set during the previous 2 yrs had rapidly expanded the total spartina coverage at this site. Where spartina was absent, ca. 55% (visual interpretation) of the mudflat supported eelgrass (*Z. japonica*). The site was cut by several channels (≤1.5 m deep) that drained south to north from the meadow out into the Bay. Treatment was limited to clones (mean diameter 7.4 m [SE = 0.36], stem density 95.6 shoots 0.25 $m^{2\ -1}$ [4.3], maximum height 75.3 cm [4.6]).

The Nemah Beach site was located mid Bay at approximately 46,35 N-123,55 W and was characterized by a hard packed, sand substrate with an underlying clay layer at higher tidal elevations. There were no channels within this site, but a number of pools of standing water were present during low tide. Treatment was limited to clones (mean diameter 7.2 m [SE = 0.25], stem density 65.6 shoots 0.25 $m^{2\ -1}$ [2.5], maximum height 63.6 cm [2.5]). The study site extended ca. 1.2 km north and south along the beach. Where spartina was absent, ca. 65% of the substrate was covered by eelgrass.

The North River site was located at the north end of the Bay at 46,45 N-124,00 W and ca. 0.5 km SW of the confluence of Smith Creek and the North River. The substrate was a mixture of sand and mud. Treatment was limited to clones (mean diameter 6.9 m [SE = 0.29], stem density 38.5 shoots 0.25 $m^{2\ -1}$ [2.0], maximum height 99.4 cm [3.5]), with 55% of the uninfested areas containing eelgrass. There were a few small channels draining the site, but none more than 0.5 m deep.

Kaffee Meadow was located on the northeast side of Long Island at approximately 46,30 N-123,55 W between Kaffee and Lewis Sloughs. The meadow covered nearly 66 ha with greater than 90% being fully mature, homogenous spartina meadow. The substrate was soft mud and a number of deep (1 to 2 m) channels drained the site. Eelgrass was limited to the eastern edge of the meadow where it shared mudflat with a natural set of Pacific oysters (*Crassostrea gigas*). The study site consisted of two, 2-ha plots including the mudflat (eastern) edge of the meadow (treated: mean stem density 46.8 shoots 0.25 m^{2-1} [SE = 2.9], maximum height 165.0 cm [4.5]); control: mean stem density 74.1 shoots 0.25 m^{2-1} [SE = 4.3], maximum height 145.6 cm [3.5]).

Sampling Design

Our sampling design was developed within the context of the operational control programs of the cooperating state and federal agencies and focused on comparisons among treatments within sites. Comparable treatment controls (clones of similar size without manipulation) were lacking at the Lewis, Nemah and North River sites because of the urgent need for the cooperating agencies to control spartina to prevent seed set. In addition, at the Lewis Unit, the number of clones of the desired size (diameter = 5 to 15 m) and interclonal distance (20 m) in areas that had not been previously sprayed with herbicide was limited (see Kilbride at al. 1995). The mowing plus herbicide combination treatment was a secondary consideration in our design as the management agencies indicated an operational preference at the time for the single treatments and therefore the number of clones within this treatment is smaller than that for the others.

We were able to select 7 to 31 clones per treatment at the three sites. Each clone was marked with a stake at the center of the clone that was numbered and color-coded to treatment type. We then divided each clone with four equidistant transects extending from the center to the perimeter. Each transect contained a sampling point for spartina marked with a PVC pole 1 m in from the clone edge. A single entry point to each clone was established and these remained consistent in their direction of approach within a given site. Travel within and around a clone during sampling was limited, and when necessary was restricted to the inside edge of the perimeter where no sampling occurred.

To determine spartina stem densities and stem heights at each sampling location, a 0.25-m^2 hoop was centered about the PVC marker and the number of individual shoots was counted. Height was measured on the tallest shoot within the hoop. Data for the four sampling points were averaged for each clone. Clone diameters were the average of two measurements taken from the clone edge in a straight line through the center and across opposite sampling markers. Sampling dates are given in Table 1.

Monitoring at Kaffee Meadow was conducted within two plots (treatment and control; 50 by 400 m) separated by 400 m along the water edge of the meadow. Within each plot, we created a buffer zone 5 m inside from the edges and randomly selected 25 points within this core area for sampling. At each point, we placed a PVC pole as a marker for repeated measurements of stem density, stem height, and, in the case of the treated plot, herbicide deposition. Five points were also located along the nearest edge of the control plot to monitor for long-range drift of the herbicide. Spartina shoot density and stem height were measured at each of the sampling points within each of the 2-ha plots using protocols described for clones. Pre-spray data collection occurred on 3 August 1995 and 1-yr post data were collected approximately 7 wks early because of an impending subsequent herbicide application to Kaffee Meadow. Times of data collection were similar on treatment and control plots.

We used glass fiber filter papers (Whatman Inc., Clifton, NJ) to monitor deposition of the herbicide from the first aerial spray and potential drift onto the control plot. Immediately prior to spray, we affixed the circular (9-cm diameter) glass fiber filter papers to the PVC poles throughout the study site at a height just above that of the surrounding spartina (n = 25). All filter papers had been previously paper clipped on four sides to a folded 10.2 by 15.2 cm index card and stored in bundles of five in double Ziploc™ bags. Once in the field, the filter papers were mounted to a cork in the top of each pole with a plastic headed thumbtack. Immediately following application of the herbicide, we removed the spray cards and placed them individually inside a separate Ziploc™ bag. Each of these bags was then double-bagged for protection. Additionally, all double-bagged spray cards were placed in a larger Ziploc™ bag before being placed on ice. All filter papers were removed and handled by field personnel wearing clean surgical gloves in a manner which reduced the possibility of cross contamination from other cards or contact with other contaminated surfaces. Filter papers were stored at -20 C prior to analyses.

Treatments

Clones. Mechanical treatment (mowing) of clones was carried out by personnel from the Willapa NWR (Lewis Unit)

TABLE 1. DATES OF SAMPLING AND TREATMENT OF SPARTINA CLONES. SAMPLING FOR THE MOW+HAND SPRAY COMBINATION COINCIDED WITH THAT OF THE MOW TREATMENT. MOWING FOR THE MOW+HAND SPRAY COMBINATION OCCURRED AT THE TIME OF THE FIRST MOWING FOR THE MOW TREATMENT. SIMILARLY, SPRAYING FOR THE COMBINATION TREATMENT COINCIDED WITH THE HAND SPRAY ONLY TREATMENT AT EACH SITE.

	Mow			Spray[1]		
Site	Pre-treatment (1995)	Treatment (1995)	Post-treatment (1996)	Pre-treatment (1995)	Treatment (1995)	Post-treatment (1996)
Lewis	May 18, 19	Jun 2, 9, 12 Aug 8, 9	May 25, 26	Jul 2, 3	Jul 19, 27, 28	Jun 20
Nemah	May 23-25	June 8 Jul 24 Aug 24	May 27-29	Jul 5, 6	Jul 18, 19	Jun 22
North River	June 7,8	Jun 2, 9, 12	Jun 30, 31	Jul 7	Jul 20	Jun 24

[1]Glyphosate applied at 20.2 kg ae ha^{-1} in 842 L water ha^{-1} with the non-ionic surfactant, LI 700® at 2.0% v/v following label directions of "spray to wet".

and WDFW (North River, Nemah Beach) using various hand-held brush cutters. Depending on the substrate and spartina density, a variety of cutting attachments were used including steel and plastic blades, and heavy duty plastic line. All mowing was to within 10 cm of the substrate. Each clone at Nemah and North River was mowed three times, once in June, July and August. However, due to logistical constraints, the clones on the Lewis Unit were mowed only twice (June and August).

At the Lewis Unit, herbicide was applied using a hovercraft equipped with a Model 60-Spotlyte® agricultural sprayer (Falkenberg, Inc., Clackamas, OR) with a hand-held wand and adjustable brass nozzle. The Nemah Beach and North River sites were sprayed using Solo® (Solo-USA, Newport News. VA), 15-L backpack sprayers. Both types of hand spray application used glyphosate at 20.2 kg ae ha^{-1} in 842 L of water ha^{-1} with the non-ionic surfactant, LI 700® (Loveland Industries, Inc., Greeley, CO) at 2.0% v/v following label directions of "spray to wet". We increased the volume of LI 700 in the tank mix above the maximum label recommendation (0.5%) because the higher volume was previously associated with an increase in efficacy of the herbicide to control spartina on small experimental plots in the Bay (Norman and Patten 1996). The combination treatment of mowing and spraying utilized the two techniques described above, except clones were only mowed once. Clones were first mowed, then allowed to recover for approximately 6 wks before being treated once with glyphosate in July (Table 1). All chemical treatments were made at low tides allowing 5 to 6 h of drying time before inundation of 50% of the plant. Weather conditions were optimal with air temperatures ranging between 19 and 29 C and wind speeds of 0 to 8 km h^{-1} (occasional gusts to 16 km h^{-1} at one site).

Meadow. A Soloy Bell® helicopter with a 9.1-m toe-mounted boom applied glyphosate to the meadow at 0915 on 13 August 1996. The tank mix included glyphosate at 4.2 kg ae ha^{-1} in 93 L of water ha^{-1} with X-77 Spreader® (Loveland Industries, Inc., Greeley, CO) at 0.13% v/v. Application occurred 1 h before low tide, allowing for ≥6 h drying time before inundation of 50% of the plant. Weather conditions for the spray were optimal with winds ranging from 0 to 8 km h^{-1} from the south, and an ambient air temperature of 14.5 C.

Chemical Analyses

APT Labs, Inc., Wyomissing, PA analyzed the filter papers for glyphosate using the methodology described in Kilbride et al. (1995) with a detection limit of 0.05 ug. Because of the high percent recovery of glyphosate from the filter papers (99.8%, SD = 3.2%), sample residues were not corrected for percent recovery. Deposition (ae glyphosate) on the filter papers was reported as ug dry weight and converted to a percentage of the expected deposition of glyphosate (ae) based on the nominal application rate.

Statistical Analyses

We used analysis of variance (ANOVA) to assess differences (pre and post-treatment) in the response variables (stem density and maximum stem height) among clone treatments within sites. T-tests were used to compare response variables between the aerially sprayed and control plots. Assumptions of normality and homogeneity of variance were tested first, and the former was met in nearly every case. When variances were unequal, we used a t-test (Welch's) or ANOVA accommodating variance heterogeneity (Zar 1999). Data were log transformed and the differences between the log values at each of the two sampling times (pre- and post-treatment) were used as the response variable. This is equivalent to using the log of the ratio, with 1.0 added to the original response to accommodate zero values. When overall differences were detected, means were separated using the Tukey-Kramer Honestly Significant Difference test. In all tests, differences were considered statistically significant if the probability associated with the test statistic was ≤0.05.

RESULTS AND DISCUSSION

Initial stem densities and stem heights for the clones varied among sites and treatments. For example, the Lewis site had the densest clones (for all three treatments), whereas Nemah, with the exception of the mowing plus herbicide treatment had the shortest stem heights. The North River site had the least dense clones and the greatest stem heights for all three treatments. We assumed that by the earliest sampling date (18 May), all clones at all sites had achieved maximum stem densities, but not stem heights. Consistent measurements of percent change in clone diameter were only possible for the mow treatment. In most cases, reductions in stem density 1yr post-treatment were ≥75% (on-site visual estimation) for the two other treatments making this measurement too inaccurate. The mow treatment, while showing reductions in stem density and maximum stem height showed a slight 'spreading' of the treated clones with statistically significant increases in diameter at Lewis (31%) and Nemah (21%), but not North River (8%).

All clone treatments resulted in reductions in stem densities and maximum stem heights at all sites 1 yr after treatment. Averaged across the three sites, stem density and maximum stem height for the mow treatment decreased 41 and 44%, 84 and 81% for the mowing plus herbicide combination and 59 and 73% for the hand spray treatment, respectively (Table 2).

Based on the Tukey's HSD multiple comparisons test of means, the efficacy of clone treatments was ranked for each variable (stem density and maximum stem height) at each site (Table 3). Measurements of stem density indicate that the mowing plus herbicide combination and the hand spray treatment were statistically more efficacious than the mow treatment alone at the Lewis and North River sites, but not statistically different from each other. At Nemah, reductions in stem density on the mow and hand spray treatments were not statistically different from each other, but both were less efficacious than the mowing plus herbicide combination. Measurements of maximum stem height at all three sites repeated the pattern described above for stem density at the Lewis and North River sites.

Initial stem density and maximum stem height on the aerial spray and control plots were statistically different with the spray plot less dense (-36%) but taller (13%) than the

Table 2. Average changes (%) in stem density and maximum stem height within spartina clones (1 yr post-treatment-pre-treatment) following one of three treatments: mowing, hand spraying, and a mow+hand spray combination. Pre- and post-treatment stem density (stems $0.25m^{2-1}$ and maximum height (cm) are given in parentheses.

Site	Mow[1]		Spray[2]		Mow + Spray	
	Stem Density	Stem Height	Stem Density	Stem Height	Stem Density	Stem Height
Lewis	-46	-30	-82	-73	-94	-78
	(99 ± 7, 53 ± 7)	(54 ± 4, 38 ± 1)	(82 ± 5, 15 ± 6)	(103 ± 5, 28 ± 3)	(111 ± 11, 7 ± 2)	(54 ± 4, 12 ± 2)
Nemah	-8	-41	-7	-59	-68	-78
	(71 ± 4, 65 ± 5)	(51 ± 2, 30 ± 1)	(56 ± 3, 52 ± 8)	(80 ± 4, 33 ± 4)	(76 ± 7, 24 ± 8)	(58 ± 4, 13 ± 3)
North River	-68	-62	-89	-88	-89	-88
	(40 ± 4, 13 ± 3)	(89 ± 4, 34 ± 4)	(37 ± 2, 4 ± 1)	(155 ± 5, 14 ± 4)	(37 ± 6, 4 ± 4)	(89 ± 6, 11 ± 8)
All Sites	-41	-44	-59	-73	-84	-81

[1]Number of mowings: Lewis = 2; Nemah and North River = 3.
[2]Glyphosate applied at 20.2 kg ae. ha^{-1} in 842 L water ha^{-1} with the non-ionic surfactant, LI 700® at 2.0% v/v following label directions of "spray to wet".

control (Table 4). However, changes (%) in stem density and maximum stem height 1yr after the aerial application did not differ significantly between the treated and control plots (stem density: P = 0.737; stem height: P = 0.997) (Table 4). The sprayed plot received an average of 3.84 kg glyphosate (ae) ha^{-1} on the day of spray. This represented 91.2% of intended deposition. Spray deposition at sample sites within the treatment plot varied between 1.30 and 5.67 kg ae ha^{-1}. No glyphosate was detected in the control plot.

Within a month after completion of sampling for our study, the Washington State Department of Agriculture (WDA) applied a second aerial application of glyphosate to Kaffee Meadow. The application rate of the active ingredient was consistent with that previously used in our study, but with the non-ionic surfactant, R-11® (Wilbur-Ellis Co., Fresno, CA) at 0.5% v/v. The WDA treatment encompassed a much larger portion of the meadow and included both our treatment and control plots. This provided an opportunity to evaluate the effects of a repeat treatment on our sprayed plot and a single application to our control plot. Average stem densities (stems 0.25 m^{2-1}) and maximum stem heights (cm) prior to the WDA spray were ca. 47 and 165, and 99 and 86 for the repeat and single applications, respectively. Following the repeat application, there was no significant change in stem density (-6%, P = 0.454), but there was a small but statistically significant decrease in maximum stem height (-15%, P = 0.003). Changes in stem density and maximum stem height following the single application by WDA were both statistically significant, but not consistent (stem density: -32%, P = 0.0004; maximum stem height: +50%, $P \leq 0.0001$) (Table 4).

Our study was designed to compare the efficacy of spartina control techniques already occurring in the Bay or those that were thought feasible based upon the available budgets and manpower of the participating resource management agencies. In addition, we evaluated only those methods being employed for the control of 'clone-sized' and larger infestations. Other methods (pulling or "punching" below the sediment surface) are available for the control of seedling sprouts and first year growth (Jim Hidy, Willapa NWR; pers. comm.). The lack of appropriate controls for our clone treatments was dictated by the mandates for treatment by the cooperating agencies and at one site, avoidance of sites that had been previously chemically treated. We believe our results represent real differences in efficacy among the treatments for clones and that inter-annual variation in stem density and stem height within clones are much less than the differences we observed among treatments. Kilbride et al. (1995) reported differences of 18.9% in stem density at the Lewis Unit between 1992 and 1993. Unfortunately, additional inter-annual comparisons in which methods were consistent between years are lacking. However, during our study, spartina continued to expand at an alarming rate (17% yr^{-1}) within the Bay (Murphy 2001), and photographs of treated clones and adjacent untreated spartina (Figure 1) clearly illustrate treatment effects.

Mowing appeared to be the least efficacious, the most labor intensive, and on soft mud sites (e.g., Lewis), the most destructive to the surrounding mudflat (Major et al., unpublished MS). Efficacy was based on two or three mowings. Because this method has been previously determined to be very cost effective (Norman and Patten 1996), it is possible that more frequent mowing would increase efficacy. Subsequent to our study, mowing by the Willapa NWR, utilizing a large, sickle type tractor mower (Quality Industries, Thibodaux, LA) has produced good results on a much larger scale than is possible with hand-held mowing equipment (Kim Patten, Washington State University, Long Beach, WA; pers. comm.). In 2000 and 2001, there was an increase in mechanical control of spartina using tracked utility vehicles (Otter Remote Access Tracked Vehicle and Bombardier) with various implements: tandem disk harrows, rollers, sub-soilers and rototillers. These efforts were focused on large meadows with the goal of suppressing seed production and dispersal and reducing re-growth the following season (Murphy 2001). However, more frequent mowing and the use of larger machinery may increase damage to the associated mudflat.

Table 3. Ranking of efficacy of treatments for spartina clones based on the Tukey HSD comparison of average changes (1 yr post-treatment-pre-treatment) in stem density and maximum stem height. Treatments within brackets are not statistically different.

Site	Stem Density	Stem Height
Lewis	[Mow+Spray, Spray] > Mow	[Mow+Spray, Spray] > Mow
Nemah	Mow+Spray > [Spray, Mow]	[Mow+Spray, Spray] > Mow
North River	[Mow+Spray, Spray] > Mow	[Mow+Spray, Spray] > Mow

TABLE 4. STEM DENSITY (0.25 M$^{2-1}$) AND MAXIMUM HEIGHT (CM) WITHIN SPARTINA MEADOWS BEFORE AND 1 YR AFTER AERIAL APPLICATION OF GLYPHOSATE. VALUES GIVEN ARE MEANS ± SE. CHANGES (POST-TREATMENT-PRE-TREATMENT) ARE EXPRESSED AS A PERCENT. SUPERSCRIPTS (A, B) REPRESENT IDENTICAL TEST PLOT LOCATIONS.

	Pre-treatment		Post-treatment		Percent Change	
Treatment	Stem Density	Stem Height	Stem Density	Stem Height	Stem Density	Stem Height
Single Application [a] (1995-1996)[1]	47 ± 3	165 ± 5	61 ± 4	97 ± 3	30	-41
Control [b] (1995-1996)	74 ± 4	146 ± 3	99 ± 7	86 ± 2	34	-42
Repeat Application [a] (1996-1997)[2]	47 ± 3	165 ± 5	44 ± 3	14 ± 6	-6	-15
Single Application [b] (1996-1997) [2]	99 ± 7	86 ± 2	67 ± 4	126 ± 3	-32	50

[1]Glyphosate applied at 4.2 kg ae ha^{-1} in 93 L water ha^{-1} with X-77® Spreader at 0.13% v/v.
[2]Glyphosate applied at 4.2 kg ae ha^{-1} in 93 L water ha^{-1} with R-11® at 0.5% v/v.

Hand spraying, which was similar in efficacy to the mowing plus herbicide combination, appeared to be more efficient, but inconsistent between applicators. Although all equipment had been equally calibrated, the directions of "spray to wet" did not appear to be uniformly interpreted by the different licensed applicators. We also noted that different personnel used different strategies for moving through a clone in an attempt to achieve complete spray coverage. No dyes were used to delineate sprayed vs. unsprayed areas. Quite often, clones showed patterns of re-growth 1-yr post-spray that suggested areas within a clone had been unequally sprayed or not treated at all. More recent experimentation with various combinations of other herbicides and adjuvants in small plot tests are providing good results, with greater

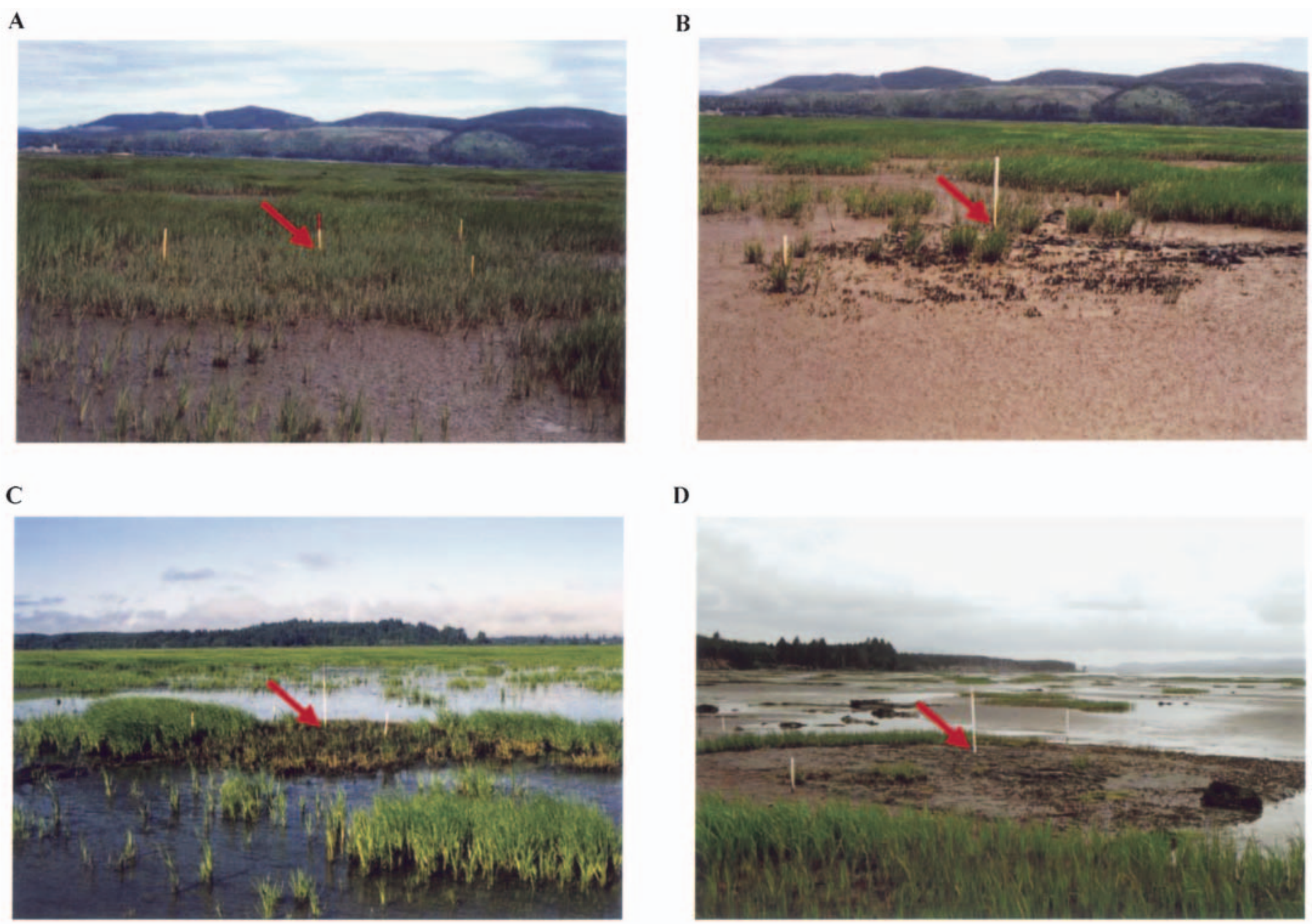

Figure 1. Treated clones (center denoted by red arrow) and adjacent untreated spartina: (A-C) mow, mow-spray and hand-spray at Lewis Unit, respectively, (D) mow-spray at Nemah.

cost effectiveness (Kim Patten, Washington State University, Long Beach, WA, pers. comm.). However, many of the chemicals and application rates being studied will require aquatic labels and therefore, are not likely to be approved for general use to control spartina in the Bay in the near future.

The mowing plus herbicide combination (mowing once and then spraying the re-growth once ca. 6 wks later) appeared to have several operational advantages in addition to high efficacy. The one time mowing appeared to help obtain a more consistent and uniform application of the herbicide and likely provides an initial reduction in the plant's energy reserves before chemical treatment. Whereas this could be achieved by spraying early in the season when the plant is shorter, it is believed that this would allow too much of the growing season to remain during which the plant could recover. Important considerations for this combination treatment include allowing sufficient re-growth for the chemical to be adequately absorbed, maximum dry time post-application to avoid the incoming tide washing chemical off the shorter stems, and enough re-growth to minimize direct spraying of the sediment below the plant.

The results of the aerial applications present a management dilemma. While it may be the only treatment suitable for large spartina infestations, especially those on very soft substrate, it does not appear to be efficacious. After reviewing the label, dry times, and weather conditions, we do not know why our specific application had no effect. Norman and Patten (1996) found that a simulated aerial spray (hand spraying with aerial tank mixes and application rates) using glyphosate at 4.2 kg ae ha^{-1} in 93 L of water ha^{-1} with X-77® at 0.5% v/v provided a maximum of 29% reduction in stem densities 1yr later. Not surprisingly, Kilbride et al. (1995) found no effect on stem densities 1 yr after an aerial application of glyphosate with X-77 Spreader® at half the maximum recommended concentration of glyphosate. The subsequent WDA spray, which occurred the year following our aerial spray using the same herbicide and application rate, but a different surfactant, resulted in some decrease in stem density, but a simultaneous increase in stem height. Utilizing data from the two sprays combined to assess the effects of a repeated spray, we found no statistically significant decreases in stem density and only a small decrease in maximum stem height. These data suggest that more than two annual applications will be needed to control large meadows, and/or chemical application techniques/rates must be modified. Possible modifications include: 1) improving post-spray exposure time by spraying on an outgoing low-high tide, 2) spraying at an earlier point in the season before the vegetation becomes mature and dense, and 3) increasing the maximum allowable application rates of chemical (currently being evaluated by WDA). Finally, our data and experience indicate that control of spartina in Willapa Bay will need to be addressed from a multi-agency, multi-year perspective using an adaptive management approach. Monitoring of off-target impacts should accompany treatment methods, as it is likely that a long-term, integrated management program will be necessary for effective control.

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