Padilla Bay
National Estuarine Research Reserve

Technical Report No. 7

EFFECTS OF APPLICATION OF GLYPHOSATE ON CORDGRASS, *SPARTINA ALTERNIFLORA*, AND ADJACENT NATIVE SALT MARSH VEGETATION IN PADILLA BAY, WASHINGTON

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December 1993

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WASHINGTON STATE DEPARTMENT OF ECOLOGY

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ABSTRACT

Bulthuis, D.A. and B.A. Scott. 1993. Effects of application of glyphosate on cordgrass, Spartina alterniflora, and adjacent native salt marsh vegetation in Padilla Bay, Washington. Washington Department of Ecology, Padilla Bay National Estuarine Research Reserve Technical Report No. 7, Mount Vernon, Washington. 29 pp.

The herbicide, glyphosate (Rodeo® with X-77® spreader), was applied with a backpack sprayer at a concentration of 2 quarts per acre on five experimental plots of Spartina alterniflora and adjacent native salt marsh vegetation in Padilla Bay Washington. Glyphosate was applied in July 1992 during a relatively low tide to maximize the time of exposure before inundation of the vegetation by high tide. Glyphosate had no effect on S. alterniflora, Salicornia virginica or Distichlis spicata in one, two or twelve months following application as measured by density, percent cover of live and dead plants or biomass of plants. Application of glyphosate did have an effect on Atriplex patula. A. patula had significantly lower percent cover and lower biomass in treatment plots than in control plots two months after application of glyphosate. It is suggested that the lack of any effect of glyphosate on S. alterniflora, S. virginica and D. spicata is due to the short time of exposure (about 8 hours) to the herbicide; and that the effect on A. patula is due to the location of A. patula at this site, higher in the intertidal, so that exposure to the herbicide was longer than for the other three species.

INTRODUCTION

Cordgrass, Spartina alterniflora was introduced to the Pacific Northwest from the east coast of North America (Mumford et al. 1991, Frenkel et al. 1988, Frenkel and Kunze 1984, Sayce 1988). Recently, S. alterniflora has spread rapidly in Willapa Bay, has become a perceived threat to native estuarine habitats and fauna in Washington State, and has been listed as a noxious weed throughout most of the State of Washington (Sayce 1988, Mumford et al. 1991, Washington State Noxious Weed Board 1989, Hauger 1992). Application of the herbicide, glyphosate, is one of the methods being considered for control of Spartina spp. in Washington (Ebasco Environmental 1992).

The effects of glyphosate on intertidal emergent salt marsh plants may differ from most other plants on which glyphosate has been tested because of the effects of periodic inundation by the tide. Glyphosate has been tested and used to control emergent and floating aquatic weeds such as Phragmites autralis, Juncus effusus, Typha spp., Eichhornia crassipes and Nuphar spp. (Barrett 1985, Kroll 1991). Glyphosate also has been tested for its efficacy in treating Spartina alterniflora (Crockett undated, Monsanto undated, Pritchard 1992, Ebasco Environmental 1992). The limited information regarding the effectiveness of glyphosate on Spartina is conflicting. Crockett reported 99% control of S. alterniflora 60 days after application. On the other hand Pritchard (1992) reported 1 to 3% "brownout" 50 days after treatment and 0 to 12% control of Spartina spp. 13 months after treatment with glyphosate. Pritchard also found that efficacy of treatment was affected in intertidal Spartina spp. by the interval between application of the glyphosate and immersion by the flooding tide. Control varied from 0% with a 2 hour interval to 55% with a 10 hour interval as measured 70 days after treatment. Therefore, one of the objectives of the present study was to test the effectiveness of glyphosate as it may be used in Washington State (Rodeo® with X-77® spreader) on S. alterniflora in Padilla Bay during one of the lowest tides of the year.

Native salt marsh plants grow adjacent to Spartina alterniflora and intermixed with S. alterniflora in Padilla Bay and at some locations in Willapa Bay (Sayce 1988, Riggs 1992). If glyphosate is used to control Spartina spp. the adjacent native salt marsh plants may also be exposed to glyphosate. The effects of glyphosate on specific native salt marsh plants does not appear to have been tested because such plants usually are not considered weeds or nuisance vegetation. However, because glyphosate is a broad spectrum herbicide (Barrett 1985, Grossbard and Atkinson 1985), glyphosate is likely to affect native salt marsh plants. Therefore, a second objective of the present study was to test the effects of application of glyphosate (Rodeo® and X-77® spreader) on the native salt marsh species, Salicornia virginica, Distichlis spicata and Atriplex patula that are growing adjacent to Spartina alterniflora in Padilla Bay.

STUDY SITE

Padilla Bay is a 5000 hectare (12,000 acre) embayment located in Washington State, north of Puget Sound proper and east of the San Juan Islands and the channels linking the straits of Juan de Fuca and Georgia. The bay has extensive intertidal sandflats and mudflats dissected by dendritic channels that drain and distribute water to the flats during the mixed diurnal 4 m (12 ft) tides. Seagrasses cover extensive portions of the intertidal flats (Bulthuis 1991) and provide important refuge and food source (Thom 1990) for fish (Simenstad et al. 1988, Caine 1991), crabs (Dinnel et al. 1986; 1993), waterfowl (Reed et al. 1989, Jeffrey 1976) and other marine life.

Spartina alterniflora is located in several sites along the southern shore of Padilla Bay (Wiggins and Binney 1987, Bulthuis 1991, Riggs 1992). Riggs (1992) reported a total of about 4.8 hectares (11.9 acres) of S. alterniflora in the bay. Most of the native salt marshes in the Padilla Bay watershed prior to white settlement have been replaced by agriculture through diking and drainage. Salicornia virginica, Distichlis spicata and Atriplex patula still occur alone and in mixed stands in strips along the base of the dikes and in small pockets along the shores covering a total of about 60 hectares (150 acres) in Padilla Bay (Granger and Burg 1986, Bulthuis 1991).

The experimental site was located near the southwestern end of Dike Island, latitude 48°27'50"N, longitude 122°29'26"W (Fig. 1). This site was selected because the most extensive stand of Spartina alterniflora in Padilla Bay occurs on the southern side of Dike Island (Riggs 1992), the growth of S. alterniflora was comparatively homogeneous and a relatively uniform strip of native saltmarsh occurred on the upland side of the S. alterniflora.

At the experimental site a 60 m baseline was established parallel to the shoreline at about the extreme high tide mark as indicated by the drift line (1.82 m above mean sea level). Eight 1.8 m wide experimental plots extended twenty-five to forty perpendicular from the baseline to the lower boundary of Spartina alterniflora, (Fig. 2). Each plot was separated by six meters to insure no treatments overlapped between plots. The plots were separated into three distinct zones (A, B, and C) based on the type of vegetation. Zone A extended from the baseline to the upper limit of S. alterniflora. Vegetation cover consisted of native salt marsh plants, including Atriplex patula, Distichlis spicata, and Salicornia virginica. Zone B extended to the lower limit of S. virginica and vegetative cover consisted of S. virginica and S. alterniflora. Zone C extended to the lower depth limit of S. alterniflora and vegetative cover consisted entirely of S. alterniflora.

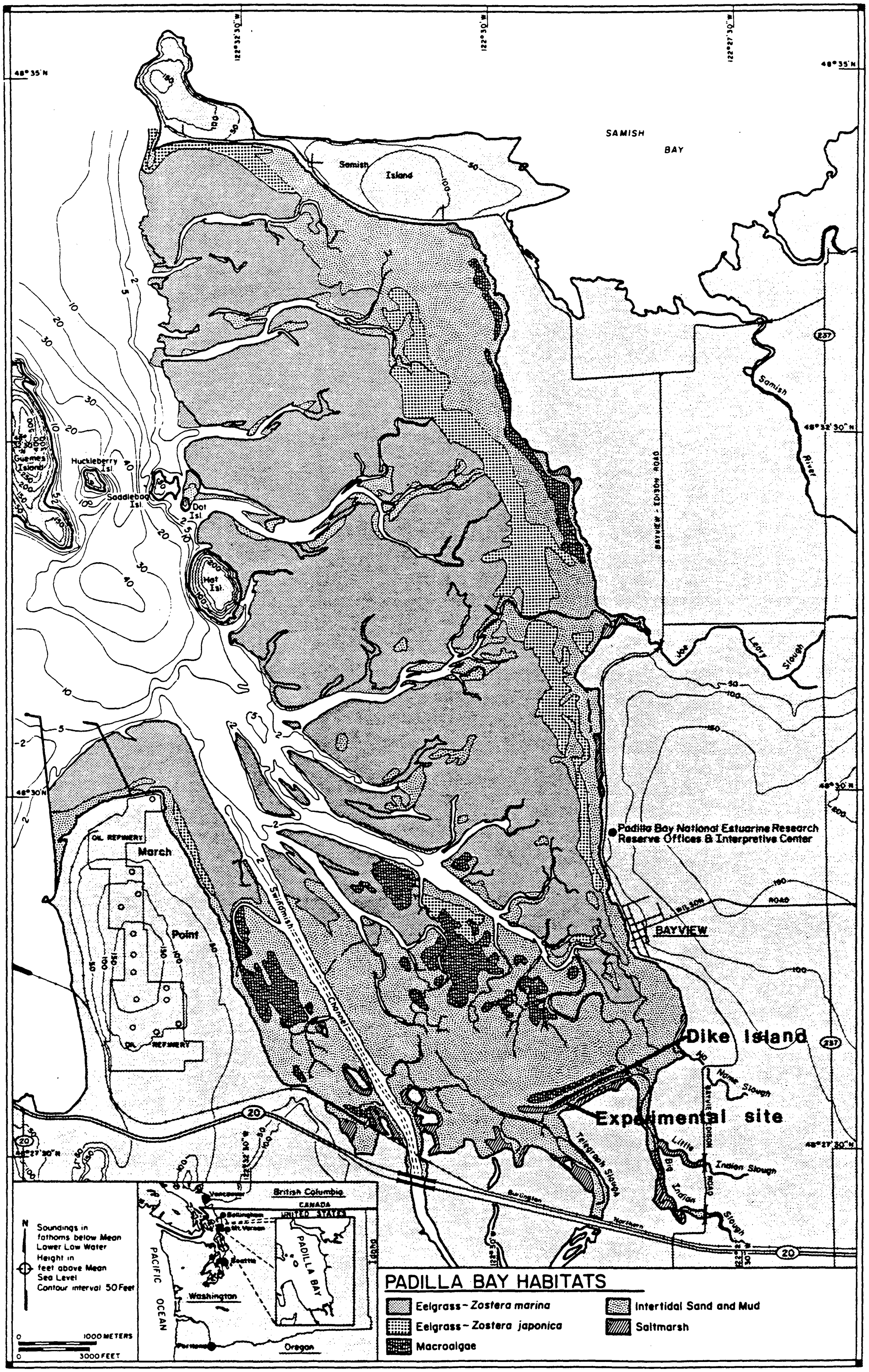

Figure 1. Location of experimental site near Dike Island in Padilla Bay. Vegetation cover within Padilla Bay intertidal flats is shown as mapped for the summer of 1989 (from Bulthuis 1991). The area designated 'salt marsh' on the southern side of Dike Island is primarily *Spartina alterniflora*.

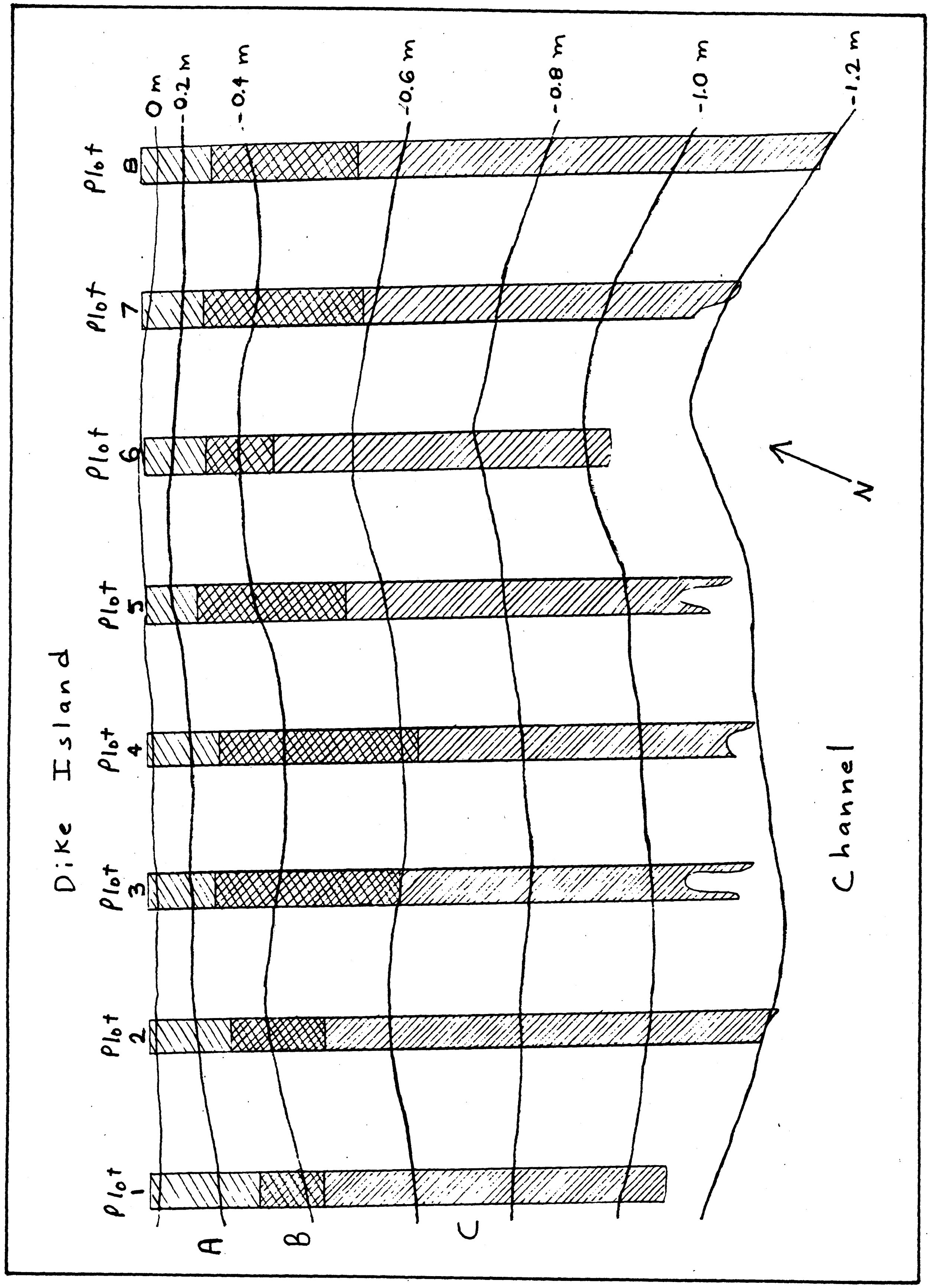

Figure 2. Plot location, salt marsh plant zonation and relative height (m) [0m is 1.82m above Mean Sea Level] of experimental plots on Dike Island, Padilla Bay that were treated with glyphosate in July 1992. Zone A (closest to Dike Island) contains a mixture of *Atriplex patula*, *Distichlis spicata* and *Salicornia virginica*; Zone B (hatched) contains a mixture of *Salicornia virginica* and *Spartina alterniflora*; Zone C (closest to the channel) has a monospecific stand of *Spartina alterniflora*.

The relative elevations (zero elevation in Fig. 2 is based on the height of the northwest corner of plot five) were measured for each zone and their height relative to Mean Sea Level (National Geodetic Vertical Datum) determined (Fig. 2). Atriplex patula inhabited the upper portion of the plots, occasionally extending upland of the baseline. Distichlis spicata grew intermixed throughout zone A, but mainly between A. patula at higher elevations and Salicornia virginica at lower elevations. S. virginica grew in the lower parts of zone A and extended throughout Zone B where it grew intermixed with Spartina alterniflora. Zone C was characterized by a monospecific stand of S. alterniflora which covered roughly two thirds of each plot. There was no macrovegetation seaward of the S. alterniflora. Patches of standing dead plants and areas of mud, along with healthy and robust plants, occurred within Zone C. The mean plant height of S. alterniflora was greater in zone C (84 $\pm$ 2 cm) than in zone B (66 $\pm$ 1 cm: mean $\pm$ s.d.).

METHODS

The effects of glyphosate (Rodeo® and X-77® spreader) were tested by application of the herbicide in five of the experimental plots (randomly allocated) and of distilled water in the other three plots. Plots were treated on July 3, 1992, by a professional licensed applicator using a backpack sprayer designed for research (the KC-2L Koke Kap® sprayer) with a six feet spray boom. Plots were treated at the recommended rate of 2 quarts of glyphosate (N-phosphonomethylglycine, in the form of the isopropylamine salt) per acre. A nonionic surfactant, Valent X-77®, was added (1% total volume) to aid in the absorption of the herbicide into the plants. The actual rate of application was measured independently by measuring the area of each plot, the time in seconds that the plot was treated and the volume that was sprayed. The glyphosate was applied between 11:10 and 11:33 a.m. as the tide was receding to allow maximum time for absorption of the herbicide.

The effects of the glyphosate treatment were measured quantitatively using three methods: percent cover, density and biomass of salt marsh plants. Three randomly allocated quadrats, 0.0625 m^2, were sampled in each of the three zones in each of the eight experimental plots before, one month after, two months after and twelve months after treatment. Living and dead plants were counted separately; plants which contained any visible photosynthetic pigment were considered to be alive. Percent cover measurements were taken prior to or within one week after the treatment (July 2-10, 1992), one month (July 29-30, 1992), and two months after the treatment (August 24-27, 1992). Density of Spartina alterniflora was measured prior to treatment, one month, two months and twelve months (July 22, 1993) after treatment. Biomass was measured prior to the treatment, two months after treatment and twelve months after treatment.

Percent cover was estimated using a point-intercept method with a grid containing twenty-five points in 0.0625 m^2. Each species was evaluated separately at each point so the total for any one sample quadrat could be greater than 100% if one species overlapped a second species. Density of Spartina alterniflora was determined by counting the number of culms of live and dead plants per quadrat. All aboveground biomass was cut at the sediment surface, sorted in the field by species and whether live or dead, stored in a cooler on ice for transport to the laboratory, and kept at 5^{o}C for no longer than seven days before being cleaned and dried. Plants were washed of mud and other debris, dried at 100^{o}C in a forced draft drying oven, weighed after twenty-four hours, replaced in the oven and weighed again after four to six hours to ensure drying to a constant weight. Dry weight was determined to the nearest 0.01g on a Mettler PJ 3000 electronic balance.

The relative elevation of upper and lower limits of Atriplex patula, Salicornia virginica and Spartina alterniflora were determined with a level-transit in each experimental plot and the height relative to National Geodetic Vertical Datum - Mean Sea Level by reference to Bench Mark 80-72B established by Lisser (1993).

Treatment and control means were compared at each date for each characteristic using the Student's t-test.

RESULTS

Application of glyphosate. The independent measurements of the rate of application indicated that the actual treatment was 1.74 quarts per acre, slightly less than the planned 2 quarts per acre (Appendix: Table A-1). Control plots were "treated" with distilled water using the same back pack spray apparatus. Inadequate flushing of the equipment prior to herbicide application resulted in distilled water diluting the glyphosate treatment in zones A and B of the first treatment plot (No. 8). Therefore, the results from zones A and B of plot 8 have not been used in this report. Estimated wind speed during application of glyphosate was three to seven miles per hour, under which conditions there was very little "drift" observed outside of the treatment plots. Air temperature was 18-21^{o}C (65-70^{o}F) at the time of treatment.

Seven hours elapsed between the time of application and the time the flooding tide first reached the base of the stems of the lowest Spartina alterniflora. Eight and one half hours after application the tops of the S. alterniflora at the lowest elevation were submerged and the tide was at the base of the plants in zone A. High tide occurred nine and one half hours after application at which time most of the plants in zone A were partially submerged.

Plant zonation and elevation. Atriplex patula was distributed higher in the intertidal than any of the other salt marsh species at the study site. The upper limit of A. patula was approximately at the baseline (1.9 m ASL) for the plots although it extended landward of the straight baseline in some spots. The lower limit was about 1.3 m distance seaward from the baseline at a mean elevation 1.7 m ASL (Table 1). Distichlis spicata generally was distributed between A. patula and Salicornia virginica but was intermingled with both species throughout most of their range in elevation. A clear upper and lower limit for D. spicata could not be determined at the study site. S. virginica was distributed from an elevation of 1.3 to 1.7 m ASL and Spartina alterniflora from 0.65 to 1.52 m ASL. Zone A (A. patula, D. spicata and S. virginica) was about 4 m wide parallel to the shoreline of Dike Island (Fig. 2, Table 1). Zone B (S. virginica and S. alterniflora intermixed) was about 7 m wide and the monospecific stand of S. alterniflora (Zone C) about 20 m wide (Fig. 2, Table 1).

Percent cover. There was no difference between treated and control plots in percent cover of Spartina alterniflora, Salicornia virginica or Distichlis spicata one month and two months after treatment by glyphosate in zones A, B, or C (Fig.s 3, 4, and 5). In contrast, there was a decline in the percent cover of live Atriplex patula from about 25% to 5% after one month and significantly less percent cover in treatment plots than in control plots after two months (Fig. 3). No dead A. patula was encountered in the samples from control plots while about 25% of the sample area was dead A. patula in the treatment plots after one month (Fig. 3).

Density. There was no difference between control and treatment plots in the density of live Spartina alterniflora after one month, two months or twelve months (Fig. 6, Table 2). Similarly, the density of dead S. alterniflora was similar in both zones B and C, one month and two months after treatment with the exception of a greater density of dead S. alterniflora in zone C one month after treatment (Fig. 6, Appendix: Table A-5).

Aboveground biomass. The effect of treatment by glyphosate on plant biomass was similar to the effect on percent cover and density. There was no difference between treated and control plots in aboveground biomass of Salicornia virginica, Distichlis spicata or Spartina alterniflora in zones A, B, or C two months or twelve months after treatment (Tables 3 and 4). However, aboveground biomass of living Atriplex patula was only 11 gm^{-2} in control plots two months after treatment and no dead A. patula was sampled in control plots compared to 32 g m^{-2} in treated plots (Table 3). After twelve months, the biomass of A. patula was similar in treatment and control plots (Table 4).

Table 1. Mean distance from the baseline and elevation above mean sea level (ASL) of vegetation boundaries within the experimental site. Mean ± s.e. for distance, mean and upper and lower range for elevation, n=8 plots. Boundaries between zones indicated by "/". [Data for individual plots is presented in Appendix: Table A-2.]

Boundary	Zone	Distance (m)	Elevation (m ASL)	
			Range	mean
Base line	Dike Island/A	0	1.82-2.04	1.89
Lower *Atriplex patula*	A	1.3 ± 0.2	1.65-1.75	1.71
Upper *Salicornia virginica*	A	1.8 ± 0.3	1.60-1.75	1.67
Upper *Spartina alterniflora*	A/B	4.1 ± 0.3	1.48-1.60	1.52
Lower *Salicornia virginica*	B/C	11.4 ± 0.6	1.20-1.37	1.29
Lower *Spartina alterniflora*	C/Slough	31.9 ± 0.7	0.61-0.74	0.65

Table 2. Density (no m^{-2}) of Spartina alterniflora within Zones B and C in control and experimental plots one year after treatment with glyphosate. Mean ± s.e. (n = 3 control plots, 4 or 5 treatment plots). Neither of the paired comparisons (control vs treatment) are significantly ($P > 0.05$) different from each other by student's t-test.

	Control	Treatment
Zone B		
Spartina alterniflora (alive)	139 ± 37	164 ± 26
Zone C		
Spartina alterniflora (alive)	387 ± 137	197 ± 34

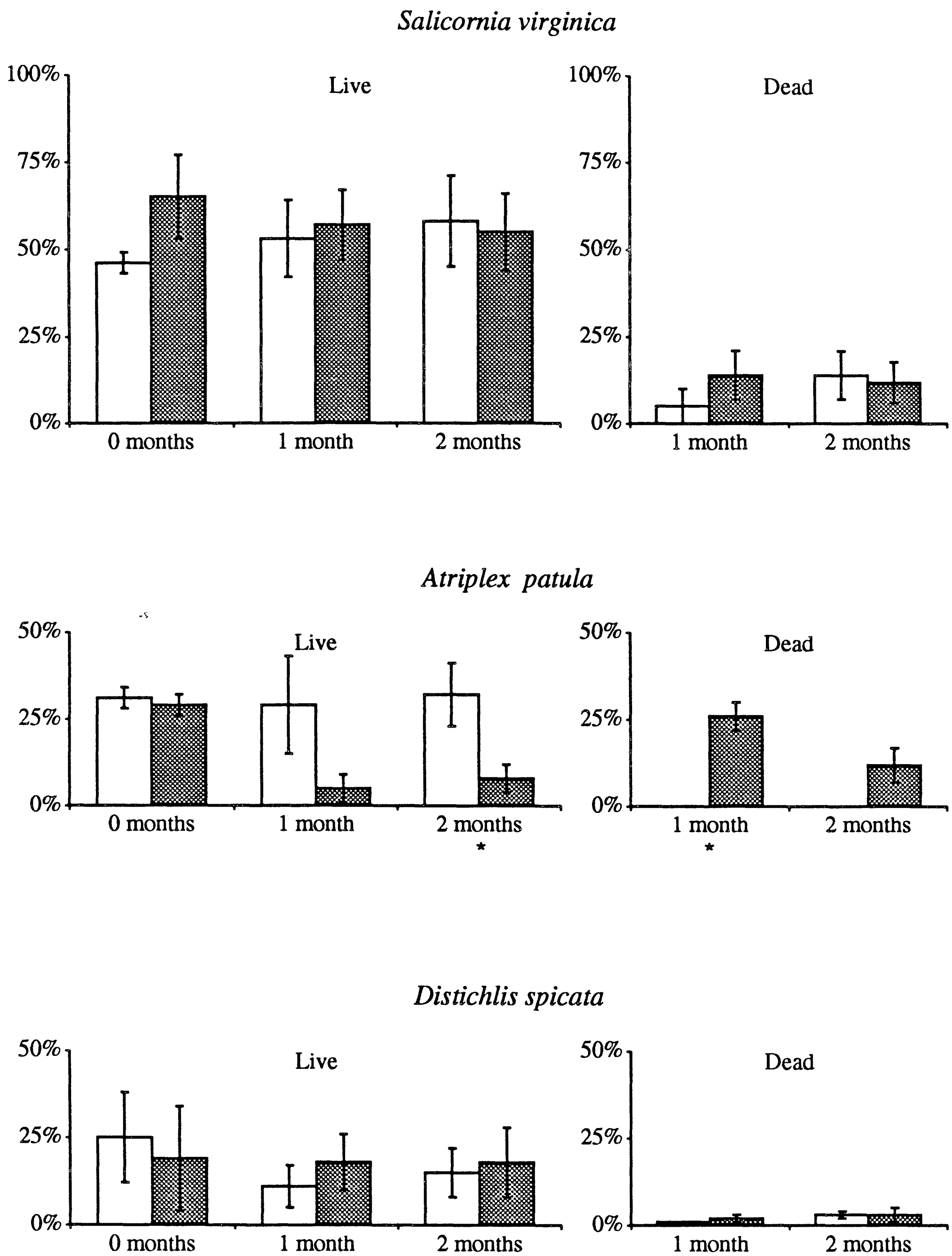

Figure 3. Percent cover (live and dead) of three salt marsh species within Zone A in control (clear) plots and in experimental (shaded) plots before, one month and two months after treatment with glyphosate. Mean ± s.e. of the mean (n=3 for controls, 4 for treatments). Control vs treatment comparisons that are significantly (0.05 level) different from each other by t-test are asterisked. [Data are presented in tabular form in Appendix: Table A-3.]

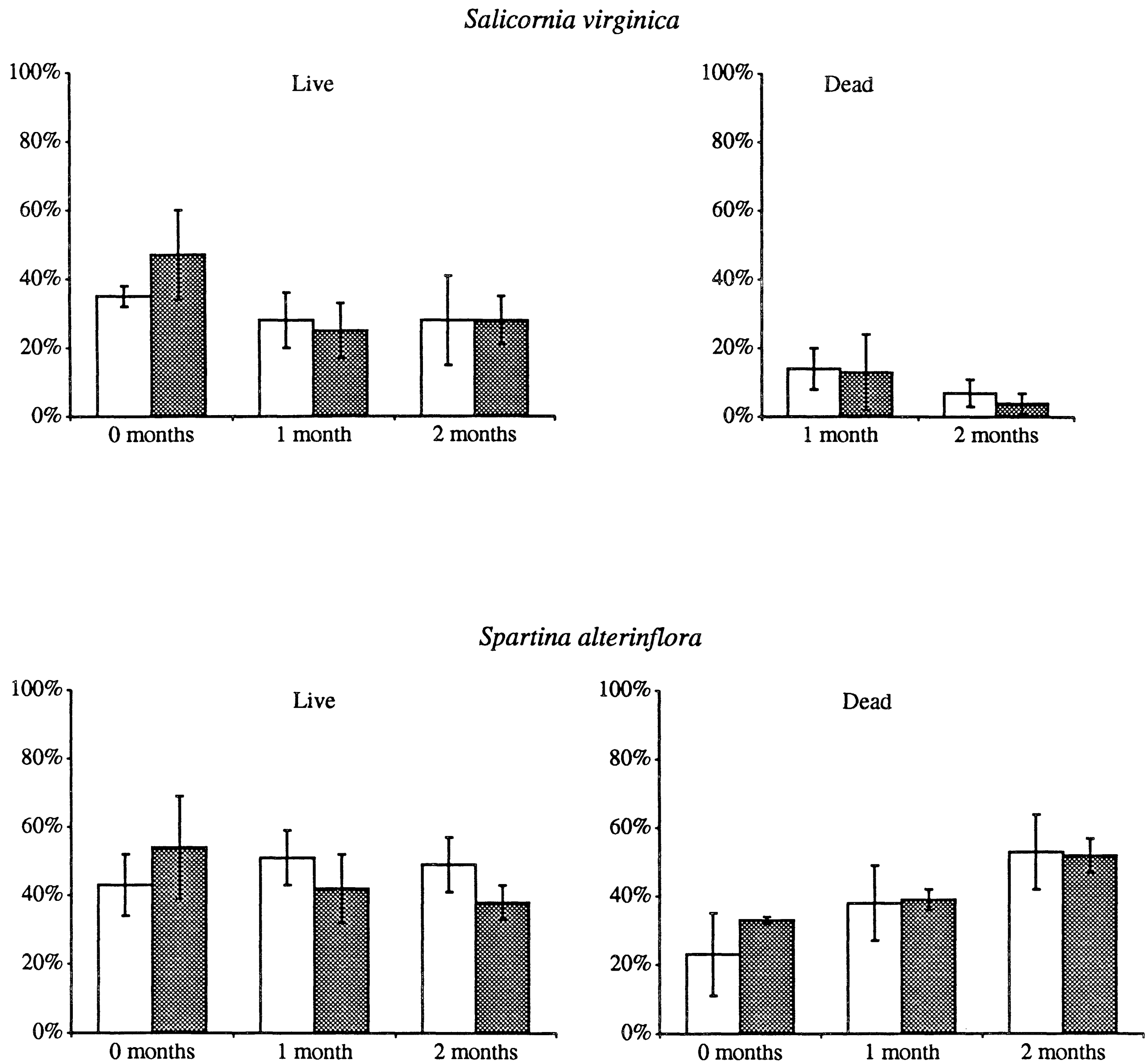

Figure 4. Percent cover (live and dead) of *Salicornia virginica* and *Spartina alterniflora* within Zone B in control (clear) plots and in experimental (shaded) plots before, one month and two months after treatment with glyphosate. Mean ± s.e. of the mean (n=3 for controls, 4 for treatments). None of the control vs treatment comparisons are significantly (0.05 level) different from each other by t-test. [Data are presented in tabular form in Appendix: Table A-3.]

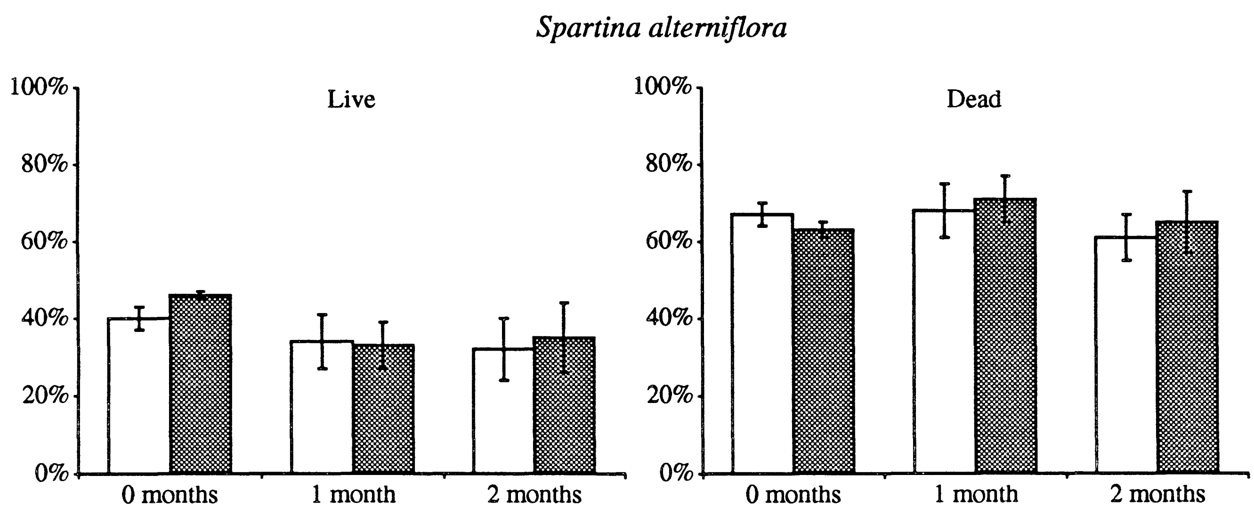

Figure 5. Percent cover (live and dead) of *Spartina alterniflora* within Zone C in control (clear) plots and in experimental (shaded) plots before, one month and two months after treatment with glyphosate. Mean ± s.e. of the mean (n=3 for controls, 5 for treatments). None of the control vs treatment comparisons are significantly (0.05 level) different from each other by t-test. [Data are presented in tabular form in Appendix: Table A-3.]

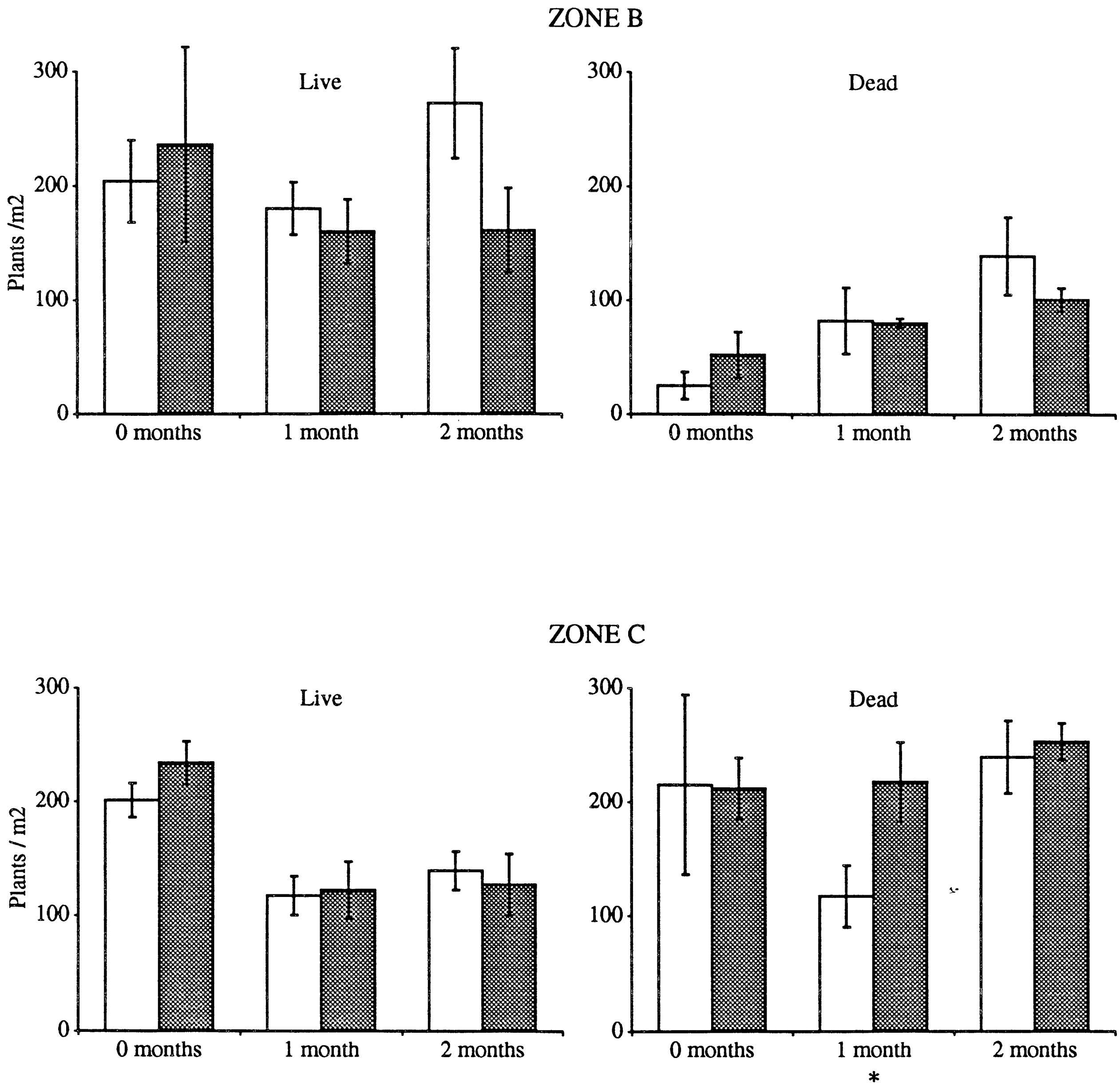

Figure 6. Density of *Spartina alterniflora* within Zones B and C in control (clear) plots and in experimental (shaded) plots before, one month and two months after treatment with glyphosate. Mean ± s.e. of the mean (n=3 for controls, 4 or 5 for treatments). Control vs treatment comparisons that are significantly (0.05 level) different from each other by t-test are asterisked. [Data are presented in tabular form in Appendix: Table A-4.]

Table 3. Above ground biomass (g m-2) of vegetation in experimental plots in August, two months after treatment with glyphosate. Mean ± s.e. of the mean (n=3 control plots, 4 or 5 treatment plots). Paired comparisons that are significantly ($p<0.05$) different from each other by Student's t-test are asterisked.

	Control		Treatment
Zone A			
Atriplex patula (alive)	71 ± 58		11 ± 9
Atriplex patula (dead)	0	*	32 ± 11
Distichlis spicata (alive)	51 ± 30		69 ± 48
Distichlis spicata (dead)	0		28 ± 25
Salicornia virginica (alive)	583 ± 44		522 ± 188
Salicornia virginica (dead)	62 ± 51		72 ± 19
Dead organic matter	255 ± 42		365 ± 46
Total in Zone A	1023 ± 105		1098 ± 138
Zone B			
Salicornia virginica (alive)	136 ± 72		157 ± 40
Salicornia virginica (dead)	61 ± 46		118 ± 73
Spartina alterniflora (alive)	726 ± 243		354 ± 71
Spartina alterniflora (dead)	442 ± 66		322 ± 57
Total in Zone B	1385 ± 177		963 ± 44
Zone C			
Spartina alterniflora (alive)	303 ± 109		368 ± 106
Spartina alterniflora (dead)	540 ± 31		659 ± 83
Total in Zone C	843 ± 129		1026 ± 78

Table 4. Above ground biomass (g m-2) of vegetation collected from experimental plots in July, 1993, one year after treatment with glyphosate. Mean ± standard error of the mean (n=3 control plots, 4 or 5 treatment plots). None of the paired comparisons (control vs treatment) are significantly ($P>0.05$) different from each other by Student's t-test.

	Control	Treatment
Zone A		
Atriplex patula (alive)	128 ± 16	157 ± 29
Distichlis spicata (alive)	22 ± 17	94 ± 54
Salicornia virginica (alive)	334 ± 56	353 ± 201
Zone B		
Salicornia virginica (alive)	90 ± 87	173 ± 51
Spartina alterniflora (alive)	161 ± 80	170 ± 37
Zone C		
Spartina alterniflora (alive)	665 ± 302	401 ± 58

DISCUSSION

Two aspects of the results are particularly noteworthy: first, the apparent lack of any effect of application of glyphosate on Spartina alterniflora, Distichlis spicata and Salicornia virginica after two months; and second, the contrasting effect on Atriplex patula, 75% of which was dead after two months. Glyphosate is a broad spectrum herbicide (Grossbard and Atkinson 1985) whose effectiveness as a control agent has been demonstrated for floating and emergent plants (Barrett 1985) and has been used to control Phragmites spp. in a tidal environment (Kroll 1991) as well as Spartina alterniflora (Crockett 1991, Monsanto undated, Crockett undated). Possible explanations for the lack of any measured effect on three of the species include: low rate of application of the herbicide, dust or debris on the plants preventing penetration of the herbicide into the plants, inappropriate timing of the application with regard to seasonal growth and scenescense of the salt marsh plants and a short interval between spraying and inundation by the tide. Each of these explanations are considered and evaluated below:

The rate of application was 2 quarts per acre using the usual methods of determining the rate of application. However, we also measured the rate of application with a post-application measurement of residual glyphosate and measurement of the area covered with a tape measure. These detailed post-application measurements showed the actual average rate of application was about 1.7 quarts per acre. Crockett (undated) reported 92% control of Spartina alterniflora two months after treatment with 2 quarts per acre. The difference between 1.7 and 2 quarts per acre is unlikely to explain the lack of treatment effect. There is no evidence for a sharp cutoff rate below which Rodeo® is ineffective.

Dust or debris on plants can prevent or retard absorption of the herbicide into the plant. Glyphosate absorbs rapidly to soil within the first hour (Torstensson 1985), and Crockett (1991) advised against application of glyphosate when plants are covered by dust or debris. At the time of application none of the salt marsh plants appeared to have excessive dust or debris on them. Atriplex patula, Distichlis spicata and Salicornia virginica all appeared green with very little standing dead biomass. Standing dead Spartina alterniflora was present in zones B and C and more than half of the sample area in zone C was covered with standing dead S. alterniflora (Figure 5). However, the live green shoots that were among the standing dead had very little dust or debris clinging to them except for the lowest 2-5 cm of the culm. Therefore, absorption of the glyphosate onto dust or debris does not explain the apparent lack of effect of the herbicide in these experiments.

Inappropriate timing of the application with regard to seasonal growth of the plants may partially explain the lack of an observed effect, particularly for Spartina alterniflora. There were a lot of standing dead plants of S. alterniflora and these may have intercepted some of the spray that otherwise would have been adsorbed and absorbed by living plants. In addition, translocation of glyphosate in the plants may have been inadequate if the plants were in an early stage of growth. Glyphosate's effectiveness as an herbicide is related to its extensive translocation in the plant and its inhibition of the biosynthesis of critical proteins and secondary compounds (Cole 1985). Barrett (1985) reported poor levels of control of aquatic weeds by glyphosate when applied too early in the season. " Early treatments may be ineffective because of inadequate leaf area for herbicide absorption and . . . because translocation into the rhizome system is inadequate during the early stages of growth when new stems and leaves are being formed." (Barrett 1985). Similarly, Monsanto (undated) recommends control of established stands of Spartina spp. in late summer and fall as Rodeo® is translocated from leaves into roots and rhizomes. However, this factor is unlikely to be the sole cause of the results observed in the present study. By early July when the glyphosate was applied, Spartina had been growing actively during the spring and early summer. Riggs (personal communication, unpublished data) in a study of aboveground productivity of S. alterniflora on Dike Island, Padilla Bay, reported clum elongation increased during spring and peaked in May. Therefore, although the application of glyphosate in early July may not be optimum for control of Spartina spp. in Washington, early treatment does not explain the lack of any measurable or observable effect on S. alterniflora in the present study.

The most likely explanation for the lack of any measured effect on Spartina alterniflora, Distichlis spicata, and Salicornia virginica is that the tidal inundation seven to nine hours after application removed the glyphosate from the plant surface before it was able to be absorbed by the plants. The 2.8 m (9.3 ft) higher high spring tide on July 3 covered most of the S. alterniflora and major portions of the D. spicata and S. virginica. Atriplex patula occurs higher in the intertidal than the other three plants and most of the aboveground portions of A. patula were not submerged by the first tide following application.

The high percentage dead Atriplex patula observed within two months of application of glyphosate is consistent with this explanation. Pritchard (1992) reported decreased percent control of Spartina spp. in Victoria, Australia as the interval between application of glyphosate and immersion by the flooding tide decreased from 10 hours to 2 hours. However, at intervals of 6 hours and 8 hours, Pritchard reported 4.3% and 45% control of Spartina spp. ten weeks after treatment; whereas in the present study, with an interval of 7 hours, 0% control of S. alterniflora was measured eight weeks and one year after treatment. The difference between the two studies may be due to the degree of submergence of the plants during the initial tide. In the present study some plants were completely submerged and all S. alterniflora were submerged for at least more than half of their height. The depth of submergence of Spartina spp. was not stated in Pritchard's (1992) notes.

The present study has shown that application of glyphosate at a rate of 2 quarts per acre with a period of emergence of the plants of seven to nine hours had no measurable effect on standing crop or percent cover of Spartina alterniflora. A native salt marsh plant, Atriplex patula, that occurred higher in the intertidal and had a longer time of emergence was substantially killed within two months of the herbicide application, but recovered one year after application.

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APPENDICES

Table A-1. Actual rate of application of Rodeo on five treatment plots on Dike Island based on measured rate of spray from individual nozzles (nozzle calculation) and based on the total volume of liquid sprayed on each plot (volume calculation).

Table A-2. Distance (m) from baseline and elevation above mean sea level (m) of vegetation boundaries in eight experimental plots on Dike Island in July, 1992.

Table A-3. Percent cover (live and dead) of four salt marsh species within three zones (A, B, and C) in control plots (n>3) and in experimental plots (n=4 or 5) before, one month and two months after treatment with glyphosate. Mean ± s.e. of the mean.

Table A-4. Density (no m^{-2}) of Spartina alterniflora within zones B and C in control plots (n=3) and in experimental plots (n=4 or 5) before, one month after and two months after treatment with glyphosate. Mean ± s.e. of the mean.

Table A-5. Density (no m^{-2}) of dead Spartina alterniflora and new shoots (<10 cm tall) within zones B and C in control plots (n=3) and in experimental plots (n=4 or 5) twelve months (July 1993) after treatment with glyphosate. Mean ± s.e. of the mean.

Table A-1. Actual rate of application of Rodeo® on five treatment plots on Dike Island based on measured rate of spray from individual nozzles (nozzle calculation) and based on the total volume of liquid sprayed on each plot (volume calculation).

				Nozzle calculation				Volume calculation
Treatment plots	Time (sec)	Volume sprayed (ml)	Length of plot (ft)	Speed (mph)	Rate of spray (gal/min)	Total volume sprayed (gal/acre)	Volume sprayed of Rodeo® (qts/acre)	Volume sprayed of Rodeo® (qts/acre)
1	28.8	837	92	2.18	0.115	17.43	1.74	1.74
3	31.5	913	95	2.06	0.115	18.41	1.84	1.84
5	30.6	896	105	2.34	0.116	16.35	1.63	1.63
6	26.5	753	83	2.14	0.112	17.38	1.73	1.74
8	37.8	1102	121	2.18	0.115	17.45	1.74	1.74
Average	31.0	900	99	2.18	0.115	17.40	1.74	1.74

Table A-2. Distance (m) from baseline and elevation above mean sea level (m) of vegetation boundaries in eight experimental plots on Dike Island in July, 1992.

	plot 1		plot 2		plot 3		plot 4		plot 5		plot 6		plot 7		plot 8	
	Distance	Elevation	Distance	Elevation	Distance	Elevation	Distance	Elevation	Distance	Elevation	Distance	Elevation	Distance	Elevation	Distance	Elevation
Base Line	0.00	1.860	0.00	1.842	0.00	1.853	0.00	1.931	0.00	1.820	0.00	1.819	0.00	1.921	0.00	2.035
Lower Atriplex	1.15	1.752	1.53	1.729	0.95	1.731	1.30	1.713	1.20	1.645	1.00	1.679	1.40	1.746	2.05	1.660
Upper Salicornia	2.60	1.664	2.30	1.642	2.15	1.595	1.30	1.713	1.20	1.645	1.00	1.679	1.40	1.746	2.05	1.660
Upper Spartina	5.79	1.512	4.88	1.481	3.76	1.605	4.18	1.518	3.03	1.534	3.52	1.511	3.53	1.533	4.12	1.488
Lower Salicornia	9.73	1.373	9.78	1.329	13.80	1.250	14.91	1.205	11.01	1.262	7.30	1.347	12.34	1.249	11.96	1.292
Lower Spartina	28.07	0.725	34.45	0.607	32.53	0.632	33.06	0.611	31.73	0.627	25.49	0.745	32.48	0.628	37.30	0.623

Table A-3. Percent cover (live and dead) of four salt marsh species within three zones (A, B and C) in control plots (n>3) and in experimental plots (n=4 or 5) before, one month and two months after treatment with glyphosate. Mean ± s.e. of the mean.

	Prior	1 month	2 months
Zone A			
Atriplex patula (alive)			
Control	31 ±3	29 ±14	32 ±9
Treatment	29 ±3	5 ±4	8 ±4
Atriplex patula (dead)			
Control	no data	0	0
Treatment	no data	26 ±4	12 ±5
Distichlis spicata (alive)			
Control	25 ±13	11 ±6	15 ±7
Treatment	19 ±15	18 ±8	18 ±10
Distichlis spicata (dead)			
Control	no data	1	2 ±1
Treatment	no data	3 ±1	3 ±2
Salicornia virginica (alive)			
Control	46 ±3	53 ±11	58 ±13
Treatment	65 ±12	57 ±10	55 ±11
Salicornia virginica (dead)			
Control	no data	5 ±5	14 ±7
Treatment	no data	14 ±7	12 ±6
Zone B			
Salicornia virginica (alive)			
Control	35 ±3	28 ±8	28 ±13
Treatment	47 ±13	25 ±8	28 ±7
Salicornia virginica (dead)			
Control	no data	14 ±6	7 ±4
Treatment	no data	13 ±11	4 ±3
Spartina alterniflora (alive)			
Control	43 ±9	51 ±8	49 ±8
Treatment	54 ±15	42 ±10	38 ±5
Spartina alterniflora (dead)			
Control	23 ±12	38 ±11	53 ±11
Treatment	33 ±1	39 ±3	52 ±5
Zone C			
Spartina alterniflora (alive)			
Control	40 ±3	34 ±7	32 ±8
Treatment	46 ±1	33 ±6	35 ±9
Spartina alterniflora (dead)			
Control	67 ±3	68 ±7	61 ±6
Treatment	63 ±2	71 ±6	65 ±8

Table A-4. Density (no m^{-2}) of *Spartina altermiflora* within zones B and C in control plots (n=3) and in experimental plots (n=4 or 5) before, one month after and two months after treatment with glyphosate. Mean ± s.e. of the mean.

	Prior	1 month	2 months
Zone B			
Spartina alterniflora (alive)			
Control	204 ± 36	180 ± 23	272 ± 48
Treatment	236 ± 85	160 ± 28	161 ± 37
Spartina alterniflora (dead)			
Control	25 ± 12	82 ± 29	139 ± 34
Treatment	52 ± 20	80 ± 4	101 ± 10
Zone C			
Spartina alterniflora (alive)			
Control	201 ± 15	117 ± 17	139 ± 17
Treatment	234 ± 19	122 ± 25	127 ± 27
Spartina alterniflora (dead)			
Control	215 ± 79	117 ± 27	240 ± 32
Treatment	212 ± 27	218 ± 35	254 ± 16

Table A-5. Density (no m^{-2}) of dead *Spartina alterniflora* and new shoots (<10 cm tall) within zones B and C in control plots (n=3) and in experimental plots (n=4 or 5) twelve months (July 1993) after treatment with glyphosate. Mean ± s.e. of the mean.

		No. Dead	No. <10 cm
Zone B			
	Control	181 ±66	35 ±15
	Treatment	216 ±22	16 ±6.5
Zone C			
	Control	123 ±52	96 ±80
	Treatment	203 ±30	72 ±29