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Effects of sand fences on revegetation in a disturbed dune ecosystem

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EFFECTS OF SAND FENCES ON REVEGETATION

IN A DISTURBED DUNE ECOSYSTEM

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ABSTRACT

EFFECTS OF SAND FENCES ON REVEGETATION IN A DISTURBED DUNE ECOSYSTEM

By Valerie L. Layne

Sand fences were used to enhance revegetation efforts at Pismo Dunes State Vehicular Recreation Area. Revegetation success was compared with double fence, single fence, or no fence treatments. Areas behind the fences were divided into zones to evaluate the effect of distance. Success was defined as no decline in either the survival of two species (*Camissonia cheiranthifolia* and *Ambrosia chamissonis*) or in percent ground cover of major plant species.

Results indicated that fences had no effect on the survival of *C. cheiranthifolia* and *A. chamissonis,* or on ground cover composition, and had a minimum impact on abundance. However, distance from the foredunes was a significant factor. Overall survival and rate of survival for both species increased with distance from the foredunes. Bare ground decreased with increasing distance from the foredunes.

Sand fences may not be as important as selecting appropriate species and starting revegetation efforts at least 120 m from the initial foredunes.

ACKNOWLEDGEMENTS

This study would not have been possible were it not for the assistance of many people. I would like to thank the members of my committee: Drs. Bill Bros, Wanna Pitts, Michael Kutilek, and Rodney Myatt for their enthusiasm and patience, and for keeping me on my toes with their questions. I would especially like to thank Bill Bros for his guidance, support and unfailing cheerfulness in the face of minor malfunctions, and Wanna Pitts for her invaluable scrutiny of this project as it drew to a conclusion.

Many other people were instrumental in this research: Bernie Wone, and Glenn Smith assisted with data collection; Elaine Harding-Smith not only helped with field-work, but furnished much appreciated companionship; Roy Woodward, Ken Anderson, and Dan Blankenship of State Parks and Recreation provided assistance in designing the study; the staff of Pismo Dunes State Vehicular Recreation Area and Pismo State Beach provided generous assistance and the use of their facilities; Karleskint & Crum Construction built the sand fences and hydroseeded the study area; and S & S Seed collected the native plant seed.

Finally, I would like to thank Kathy Duncan for listening.

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INTRODUCTION

Revegetation is a commonly used tool in restoring disturbed coastal sand dune ecosystems (Cowan 1975). When the vegetative cover of stable sand dunes is damaged by wind, storms, foot traffic (human and equestrian), motor vehicle traffic and/or human development, sand dunes become unstable. Blowouts (i.e., wind blown gaps or depressions in dunes which enhance erosion) become more common, neighboring vegetation is inundated with sand beyond recovery, and animal habitat and valuable natural resources are lost (Liddle and Greig-Smith 1975, Hosier and Eaton 1980, Chipping and McCoy 1982, Anders and Leatherman 1987).

Pismo Dunes State Vehicular Recreation Area (SVRA) has been heavily impacted by Off-Highway Vehicle (OHV) use (Smith 1976). As a result, foredunes that once blocked the wind, and thus sand movement, have been eroded away, in some areas completely. Sand movement into Oso Flaco Lake, a naturally occurring fresh-water lake near the dunes, is filling the lake and destroying the habitat around the lake.

In January 1990, the Off-Highway Motor Vehicle Recreation Division (OHMVR) of the California Department of Parks and Recreation initiated a revegetation program in Pismo Dunes SVRA to limit sand movement. Revegetation of dunes is a slow process easily defeated by constant sand movement. Once stable dunes become active, they can take hundreds to thousands of years to stabilize naturally (Keen and Shane 1990). Burial by sand drastically reduces the germination of seeds and the emergence and establishment of seedlings (Zhang and Maun 1990, Maun and Lapierre 1984, 1986).

Cowles (1899) and Olson (1958) both observed that dune building required some sort of an obstacle such as driftwood or vegetation to trap sand. Dunes themselves act as barriers for sand and can slow sand movement. Sand fences build dunes by trapping sand, and have been used to enhance revegetation efforts by slowing sand movement (Pye, 1990; Psuty, 1990). Native plant seedlings should have a better chance to become established if primary dunes impede sand movement. Ideally, at some point the plants would take over the dune building process. At Pismo Dunes SVRA, both sand fences and native plant seeds were used to re-build foredunes that had been damaged by OHV recreation.

The purpose of this project was to determine whether or not sand fences enhanced revegetation success. Indigenous plant seeds were planted in a disturbed dune habitat behind a series of sand fences erected in single and double rows. If the revegetation were successful, several of the species would become established and be able to survive on their own. Percent ground cover of plant species was measured to determine whether or not ground cover (i.e., plant species, seedlings, litter or bare ground) may also be influenced by sand fences. Fencing was determined successful if there was no decrease in the number of survivors, or in the rate of survival, and if there was no decrease in the abundance of plant species or in the percent cover of plant species in the experimental plots compared with the controls.

Distance from the fences might affect survival of the plants and ground cover composition. To test this idea, the study area was divided into zones. Success in this case was defined as no decrease in the number of survivors or in the abundance of plant species or in the percent cover of plant species in each zone and a positive rate of survival, when compared with the control plots.

METHODS

The study area is in southern San Luis Obispo County, California, in Pismo Dunes State Vehicular Recreation Area (SVRA). The study site occupies approximately 15 acres in the southwest portion of the park, northwest of Oso Flaco Lake, and has been closed to motor vehicle traffic since 1982.

The site is classified as coastal dune by Barbour and Major (1988). The prevailing wind is from the northwest but occasionally blows from the southeast. The dominant vegetation on the dunes is *Carpobrotus chilensis* and *Abronia maritima*; that on the lower areas is *Cakile maritima* and *Camissonia cheiranthifolia*. Nomenclature for all original work in this study follows that of Hoover (1970).

The study area was revegetated approximately 200 m behind the foredune remnants. The seed mix consisted of indigenous plant species collected within a 150 mile radius of the study site and contained the following species: *Abronia latifolia, A. maritima, Ambrosia chamissonis, Artemisia californica, Camissonia cheiranthifolia, Corethrogyne filicifolia, Eriastrum densifolium, Ericameria ericoides, Eriophyllum staechadifolium* var.

artemisiaefolium, and *Lotus scoparius.* Straw mulch was spread over the re-seeded area. Only two of the plant species became established: *C. cheiranthifolia* and *A. chamissonis*, and these were the species focused on in the survival study.

Three fence treatments (double fence, single fence, or no fence) were used to evaluate various fence strategies on revegetation success. Fences were constructed with black high-density polyethylene plastic with an aperture size of approximately 9.9 cm x 1.5 cm. Each fence was approximately 1.2 m in height and 12 m in length. Fences were placed immediately in front of the foredunes and perpendicular to the prevailing winds. For the double fence treatment, the two fences were approximately 3 m apart with one directly behind the other.

To evaluate the effect of distance, areas behind the fences were divided into three equal zones. Zone 1 was immediately behind the fence, Zone 2 behind Zone 1, and Zone 3 behind Zone 2. Each zone was approximately 60 m in length and 12 m in width. Eighteen plots, or six replications were included in the experiment. Six plots were bordered on the northwest side by double fences, six were bordered by single fences, and six had no fences and acted as a control (Fig. 1).

For the ground cover composition study, thirty 2 m x 2 m quadrats were counted in each treatment-zone combination four times over the course of the study.

To evaluate the effects of the fences on the survival of seedlings in the study, survival was measured in each of the fence and zone combinations.

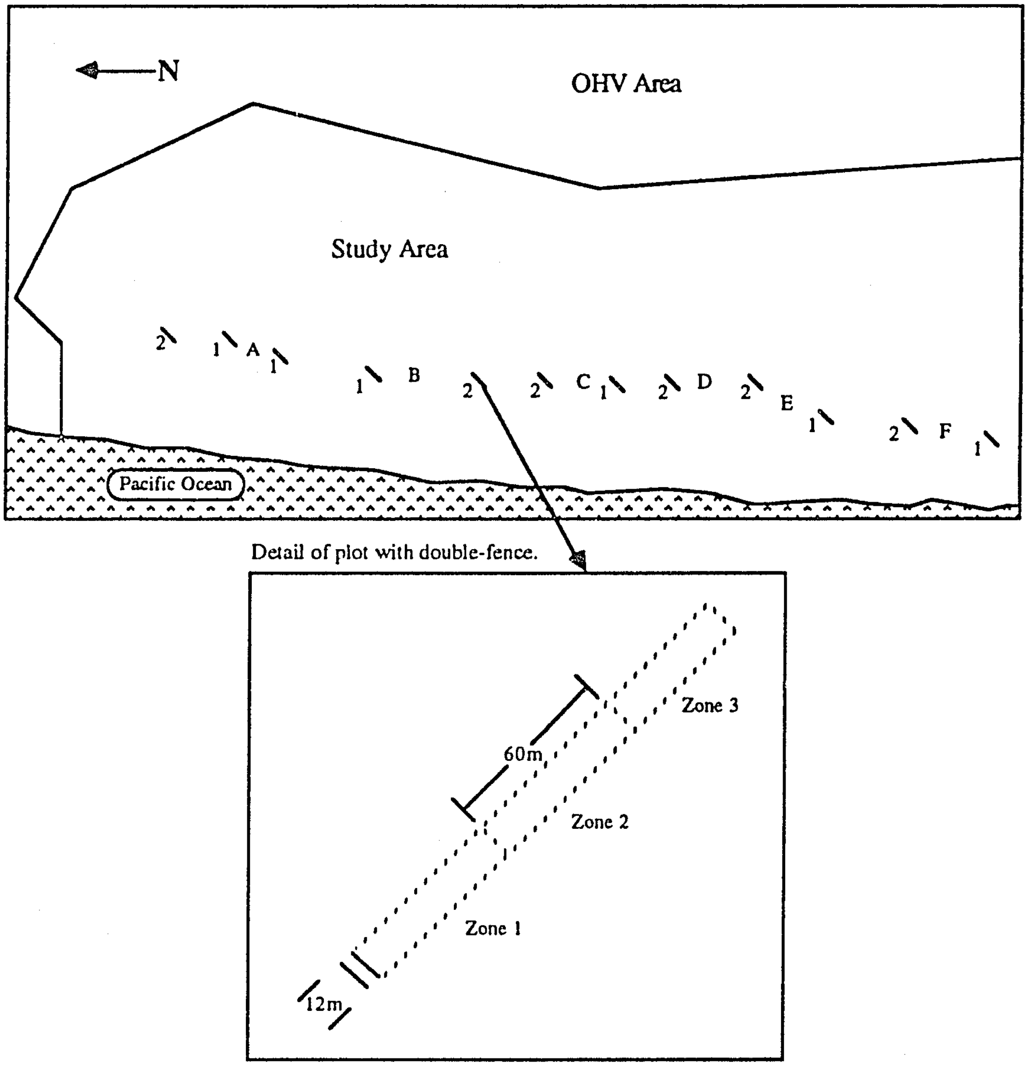

Figure 1. Arrangement of plots in the study area. 1=plot with single fence, 2=plot with double fence, and letters A-F=control plots (no fences). Plots are 12 m wide by 180 m long. Zones are 12 m wide by 60 m long.

Twenty individuals of each species were picked randomly in each fence treatment in each zone for each replicate, and their survival was monitored monthly for ten months. A total of 360 plants were selected and marked with colored thread tied around the plant and a numbered stake driven into the ground nearby. Many of the seedlings became buried by sand but did not die immediately. Those that had to be excavated to be counted were re-buried so as not to give them an advantage. Two-way Analysis of Variance (ANOVA) with repeated measures was used to test differences in the mean survival and mortality rate over a ten month period, time being the repeated measure. The main factors were fence treatment (double, single, or none) and distance behind the fences (Zone 1, 2, or 3). To avoid Type I error, alpha was set at 0.025.

Percent cover was used to evaluate ground cover composition. Measurements were made only for the top ten components of the ground cover. A visual estimate to the nearest two percent of percent cover for each ground cover element was recorded for each quadrat. Ground cover elements were evaluated individually using a three-way ANOVA, with main effects of time period, fence treatment and distance from the fences. Multivariate Analysis of Variance (MANOVA) using Wilks' Lambda was used to collectively evaluate the differences in habitat composition. Again, to avoid Type I error, alpha was set at 0.025.

Individual plant counts were used to evaluate species abundance. The number of individuals of each species was counted in each quadrat. Seedlings were included in the survey. Each species was evaluated individually using a three-way ANOVA, with main effects of time period, fence treatment, and distance from the fences. A MANOVA using Wilk's Lambda was used to collectively evaluate the differences in species abundance. To avoid Type I error, alpha was set at 0.025.

RESULTS

The fences had no measurable effect on the survival of the *C. cheiranthifolia* or the *A. chamissonis* (Tables 1 and 2). The non-significant interaction between Fence and Zone indicates distance from the fence is independent of the fence treatment in relation to survival. The minimum detectable difference between the survivor means for *C. cheiranthifolia* was 0.514 individuals per month, while the minimum detectable difference for *A. chamissonis* was 0.573 individuals per month. The insignificant main fence effect further indicates that fence treatment had no effect on plant survival. The lack of an interaction between fence and time shows no difference in rate of mortality between treatments. The minimum detectable difference between the survivor means of *C. cheiranthifolia* for the main effect was 0.614 individuals per month, while the minimum detectable difference between the survivor means for *A. chamissonis* for the main effect was 0.685 individuals per month.

Distance from the fences (zone) did have an effect on both overall survival and rate of mortality for both species. For both *C. cheiranthifolia* and *A. chamissonis*, the significant main Zone effect from the two way ANOVA indicates that there is a difference in plant survival over the three zones

Table 1. Two-way Repeated Measures Analysis of Variance for survival of *Camissonia cheiranthifolia*. Time is the repeated measure. Fence and Zone are treatments. Part A. ANOVA table. Part B. Multivariate *a priori* comparisons.

A. Two-Way Repeated Measures ANOVA table

Source	DF	MS	F	P
Between Subjects				
Fence	2	0.026	0.017	0.983
Zone	2	30.845	19.787	<0.001
Fence*Zone	4	1.895	1.215	0.318
Error	45	1.559		
Within Subjects				
Time	9	4.560	56.139	<0.001
Time*Fence	18	0.019	0.229	1.000
Time*Zone	18	0.338	4.167	<0.001
Time*Fence*Zone	36	0.083	1.017	0.445
Error	405	0.081		

B. Multivariate *a priori* comparisons

Effect	DF	Wilks' Lambda	F	P
Zone 1 vs. 2 & 3	10, 36	0.420	4.963	<0.001
Zone 2 vs. 3	10, 36	0.670	1.776	0.101

Table 2. Two-way Repeated Measures Analysis of Variance for survival of *Ambrosia chamissonis.* Time is the repeated measure. Fence and Zone are treatments. Part A. ANOVA table. Part B. Multivariate *a priori* comparisons.

A. Two-Way Repeated Measures ANOVA table

Source	DF	MS	F	P
Between Subjects				
Fence	2	2.037	1.098	0.342
Zone	2	12.824	6.914	0.002
Fence*Zone	4	0.413	0.223	0.924
Error	45	1.855		
Within Subjects				
Time	9	7.624	94.301	<0.001
Time*Fence	18	0.032	0.390	0.989
Time*Zone	18	0.237	2.931	<0.001
Time*Fence*Zone	36	0.034	0.415	0.999
Error	405	0.081		

B. Multivariate *a priori* comparisons

Effect	DF	Wilks' Lambda	F	P
Zone 1 vs. 2 & 3	10, 36	0.502	3.574	0.002
Zone 2 vs. 3	10, 36	0.847	0.651	0.760

(Fig. 2). The *a priori* comparisons show that, for both species, survival in Zone 1 is significantly lower than in Zones 2 and 3. The significant interaction between Zone and Time shows that rate of survival also differs over the three zones (Tables 1 and 2). The rate of survival in Zone 3 is greater than in the other two zones.

Ninety-nine percent of the ground cover in the study area can be characterized by nine categories. The top nine categories of ground cover composition (in descending order of importance) were: Bare ground (76%), *Cakile maritima* (6.7%), Straw (5.3%), *Carpobrotus chilensis* (3.0%), *Camissonia cheiranthifolia* (2.9%), *Abronia maritima* (2.5%), *Ambrosia chamissonis* (2.2%), *Malacothrix incana* (0.2%), and *Atriplex leucophylla* (0.1%).

The MANOVA indicated that fences had little or no effect on the overall ground cover composition (Table 3). Neither the main Fence effect nor the Fence*Zone interaction was significant. When the ground cover composition elements were evaluated independently, only *C. chilensis* (P=0.006) showed a significant univariate effect. The *a priori* comparison showed that percent cover of *C. chilensis* for the single fence treatment was greater (5.7%, P=0.005) than for the double fence treatment (1.7%). The *a priori* comparison showed that percent cover of *C. chilensis* was greater (P=0.018) in Zone 1 (4.7%) than in Zone 2 (1.6%), and in Zone 3 (2.6%).

On the other hand, the MANOVA showed that Ground Cover composition changed with distance from the foredunes as a function of Time (Fig. 3a and 3b). Evaluation of ground cover categories showed a significant

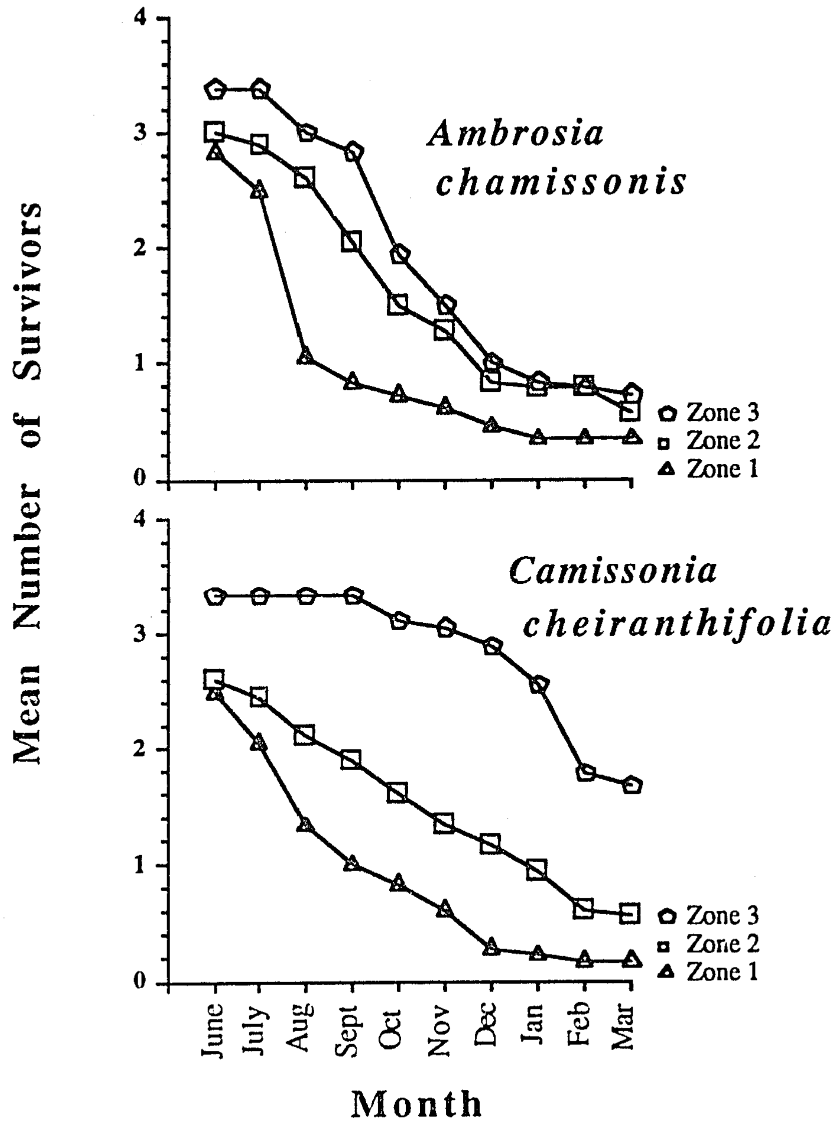

Figure 2. Mean number of survivors of *Ambrosia chamissonis* and *Camissonia cheiranthifolia* over time.

Table 3. Three-way Multivariate Analysis of Variance for percent ground cover. Variables were Arcsine transformed prior to analysis. Period, Fence, and Zone are treatments.

Effect	DF	Wilks' Lambda	F	P
Period	30, 925	0.497	8.298	<0.001
Fence	20, 630	0.922	1.311	0.164
Zone	20, 630	0.517	12.305	<0.001
Period*Fence	60, 1655	0.831	0.990	0.498
Period*Zone	60, 1655	0.664	2.246	<0.001
Fence*Zone	40, 1196	0.868	1.134	0.263
Period*Fence*Zone	120, 2459	0.666	1.103	0.215

univariate effect for Bare ground (P<0.001), *C. maritima* (P=0.006), and Straw (P<0.001).

The three-way MANOVA showed that both fences and distance from the foredunes had an effect on species abundance (Table 4). The interaction between Period and Zone indicated that there was a significant change in overall abundance among zones that was dependent on time (Fig. 4). The evaluations for each species showed that there was a significant univariate effect in the abundance of *Camissonia* (P<0.001), *Ambrosia* (P=0.002), and *Cakile* (P<0.001).

The significant multivariate main Fence effect showed that there was a significant change in overall abundance among fence treatments (Fig. 5). The individual species evaluations showed a significant change in abundance for *Carpobrotus* (P=0.023), *Ambrosia* (P=0.001), and *Cakile* (P=0.024). The *a priori* comparison showed that abundance of *C. chilensis* decreased from 0.192 individuals per quadrat in the single fence treatment to 0.083 individuals per quadrat in the double fence treatment (P=0.011), abundance of *A. chamissonis* increased from 0.408 individuals per quadrat in the single fence treatment to 1.008 individuals per quadrat in the double fence treatment (P=0.001), and abundance of *C. maritima* increased from 22.175 individuals per quadrat in the single fence treatment to 37.658 individuals per quadrat in the double fence treatment (P=0.007). When the data were analyzed including only mature plants (i.e. excluding seedling counts), *Cakile maritima* no longer showed a significant difference between fences (P=0.174). *Ambrosia chamissonis* and *Carpobrotus chilensis* still showed a significant difference between the fences.

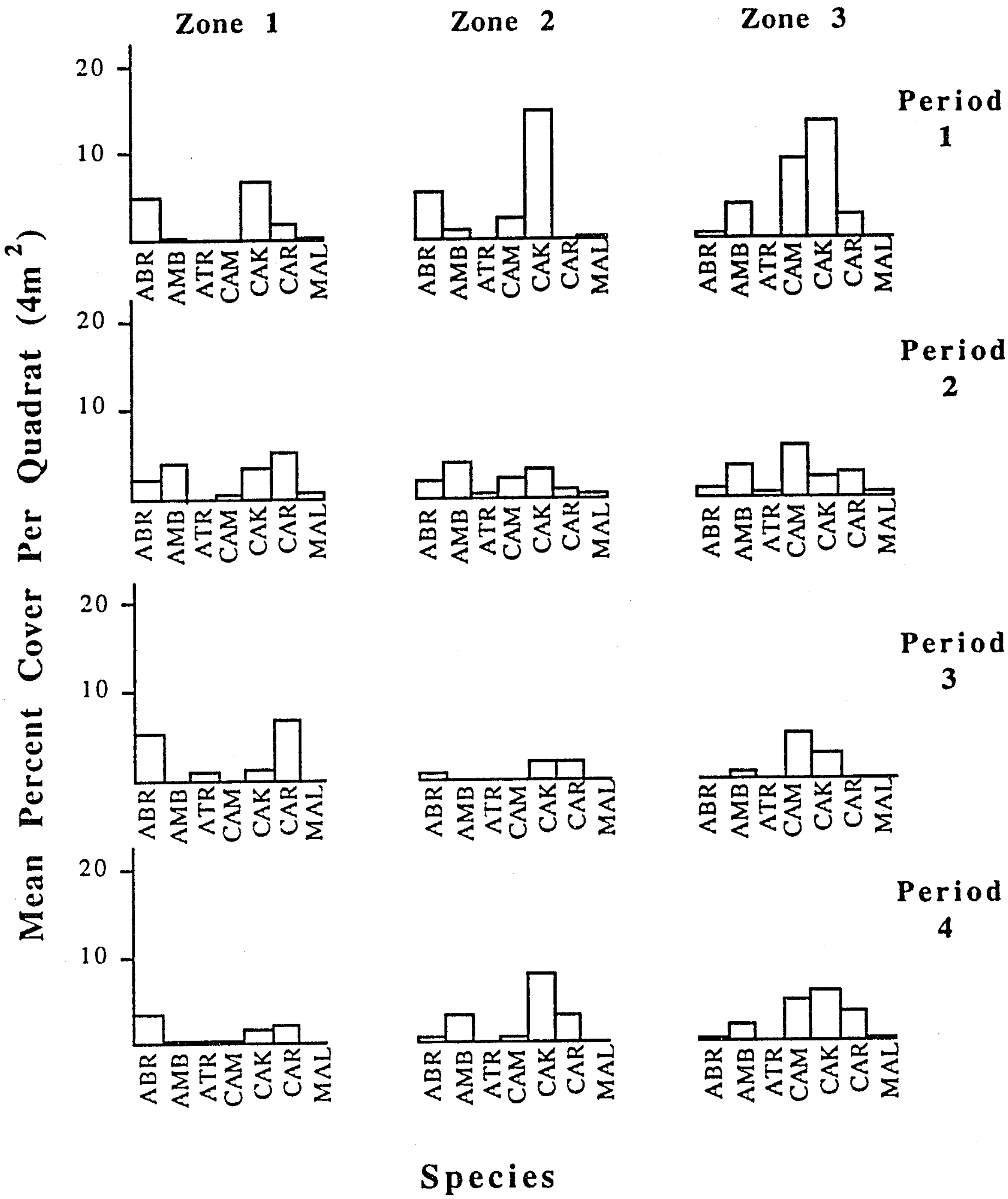

Figure 3a. Multivariate Period*Zone interaction. Mean percent cover per quadrat for *Abronia latifolia* (ABR), *Ambrosia chamissonis* (AMB), *Atriplex leucophylla* (ATR), *Camissonia cheiranthifolia* (CAM), *Cakile maritima* (CAK), *Carpobrotus chilensis* (CAR), and *Malacothrix incana* (MAL).

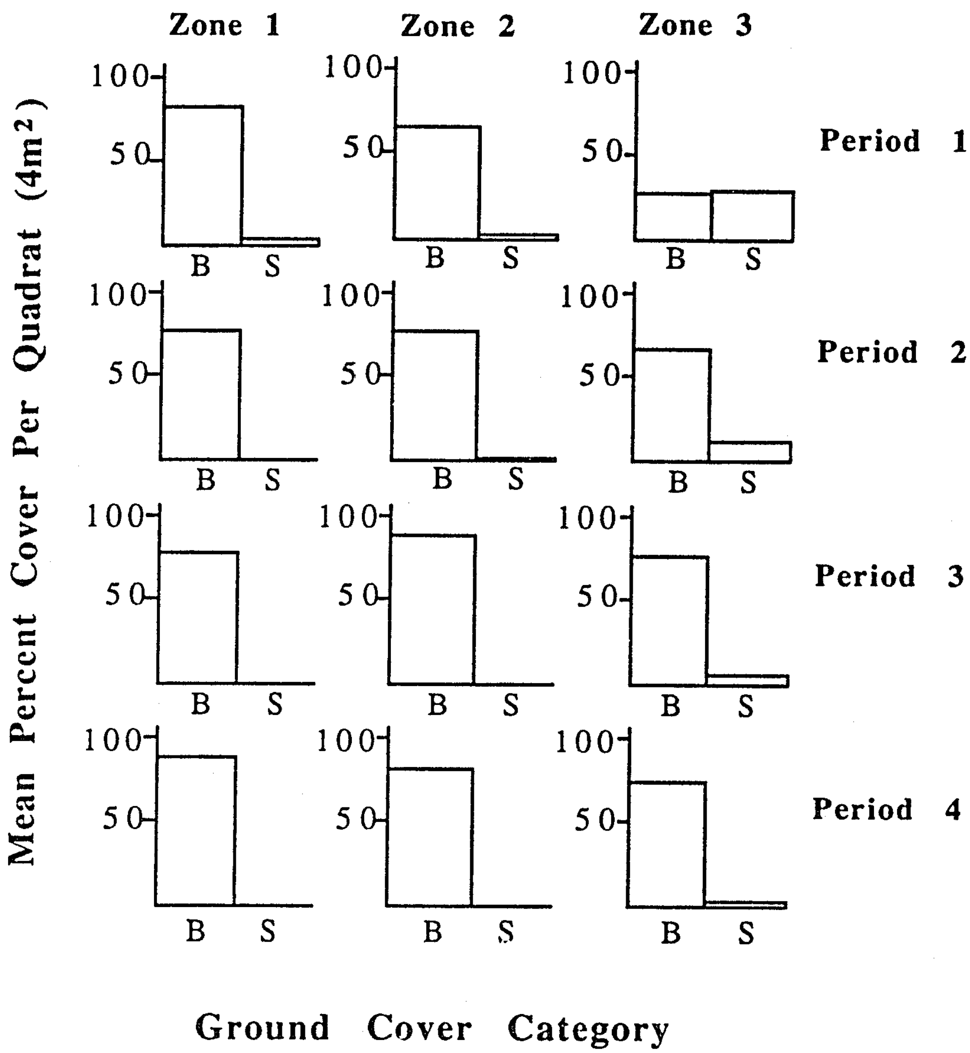

Figure 3b. Multivariate Period*Zone interaction. Mean percent cover per quadrat for Bare Ground (B) and Straw (S).

Table 4. Three-way Multivariate Analysis of Variance for abundance. Part A. ANOVA table. Part B. Multivarate *a priori* comparisons.

A. Three-Way MANOVA table for Abundance

Effect	DF	Wilks' Lambda	F	P
Period	18, 902	0.612	9.492	<0.001
Fence	12, 638	0.896	3.014	<0.001
Zone	12, 638	0.516	20.844	<0.001
Period*Fence	36, 1403	0.853	1.438	0.046
Period*Zone	36, 1403	0.75	2.645	<0.001
Fence*Zone	24, 1114	0.947	0.728	0.826
Period*Fence*Zone	72, 1741	0.775	1.157	0.176

B. Multivariate *a priori* comparisons

Effect	DF	Wilks' Lambda	F	P
Fence 0 vs. 1 & 2	6, 319	0.986	0.746	0.613
Fence 1 vs. 2	6, 319	0.908	5.378	<0.001

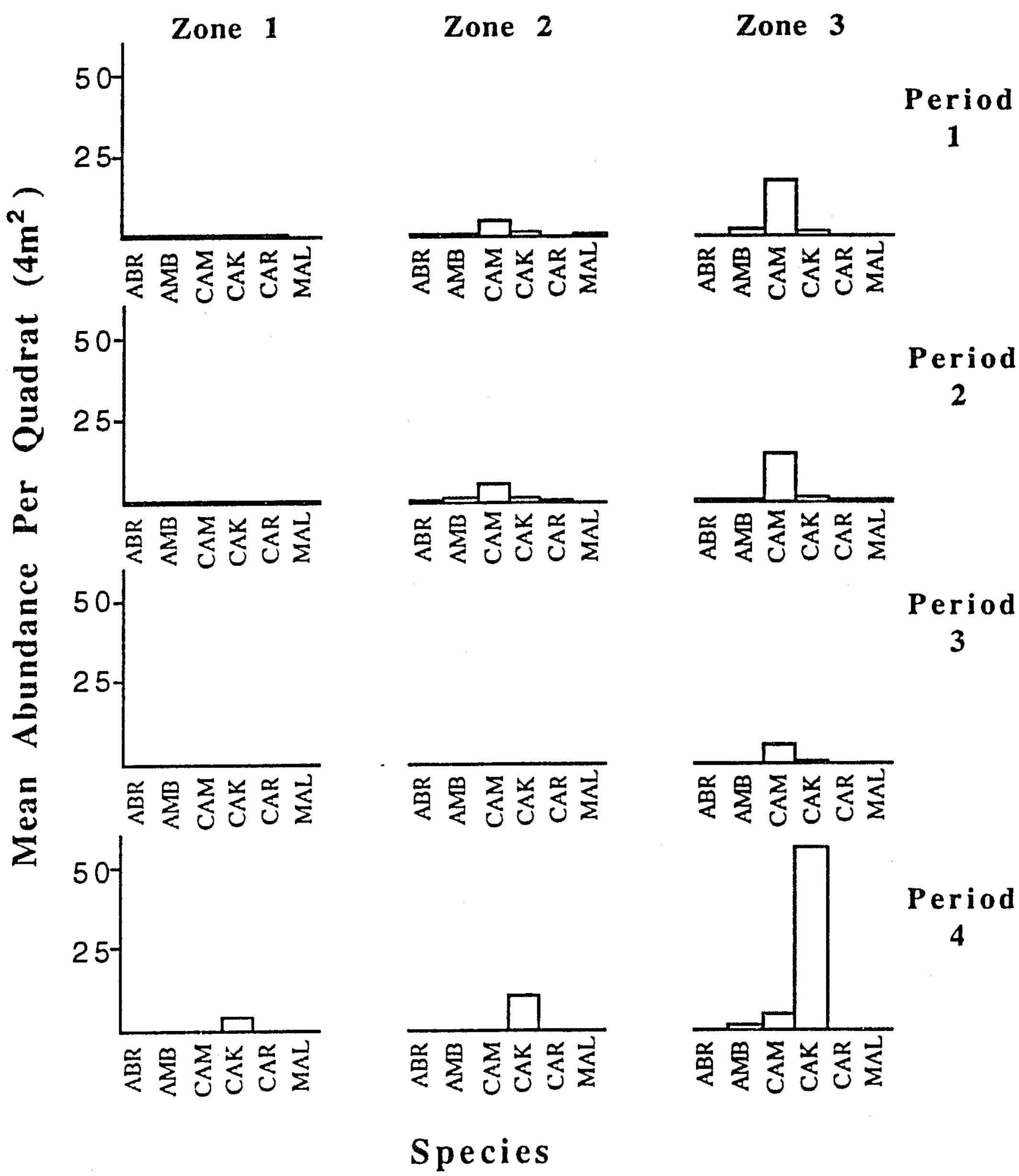

Figure 4. Multivariate Period*Zone interaction. Mean abundance per quadrat of *Abronia latifolia* (ABR), *Ambrosia chamissonis* (AMB), *Camissonia cheiranthifolia* (CAM), *Cakile maritima* (CAK), *Carpobrotus chilensis* (CAR), and *Malacothrix incana* (MAL).

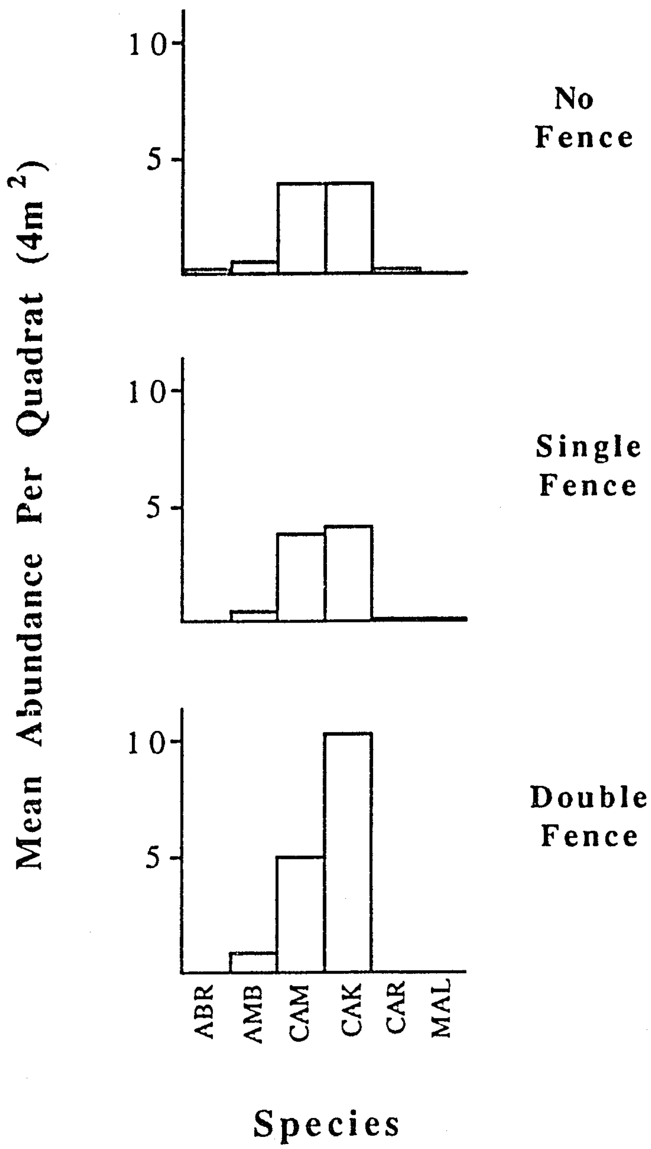

Figure 5. Multivariate main fence effect. Mean abundance per quadrat of *Abronia latifolia* (ABR), *Ambrosia chamissonis* (AMB), *Camissonia cheiranthifolia* (CAM), *Cakile maritima* (CAK), *Carpobrotus chilensis* (CAR), and *Malacothrix incana* (MAL).

DISCUSSION

Three measurements were used in this study to evaluate the effects of sand fences and distance from foredunes on revegetation success. The first two measurements, survival and percent cover, were not affected by fences but they were affected by distance from the foredunes. The third measurement, numerical abundance, was affected by both fences and distance from the foredunes. As percent cover expresses the area covered by a particular species, it is a more valuable measurement than is numerical abundance when considering sand stabilization. Numerical abundance, on the other hand, is expressed in number of individuals per unit area, and thus can seem inflated if the individual plants are small. This is especially true if seedlings are counted.

Generally, the presence or absence of fences did not alter percent cover of ground cover components or survival of *Ambrosia chamissonis* and *Camissonia cheiranthifolia*, and had a minimum impact on numerical abundance. Only three species were affected in the numerical abundance survey, and two of those may have nothing to do with fences. One, *Cakile maritima*, is significant only if seedlings are counted. For the other, *Carpobrotus chilensis*, both percent cover and numerical abundance were greater in the single fenced area. However, plants were already in place before the fences were established, so this effect may be a coincidence.

Fences may be useful for managing certain species. The abundance of two species was consistently greater behind the double fences. Examination of aerial photographs did not show differences in the accretion of sand at the different fence configurations so this phenomenon remains unexplained. To determine the significance of the double fence versus the single fence further investigation into the rate and volume of sand movement, along with more plant measurements would be necessary.

There is evidence that fences do affect species composition in relation to numerical abundance, but the precise relationship is not clear. The analysis shows a shift in overall species composition over all the fence configurations, but there is no discernible trend in the means. The fence treatments also may have had an effect on seedling recruitment for species such as *A. chamissonis* and *Cakile maritima*. Time of year may also affect the relative success of fences.

While fences did not have an effect on survival or percent cover and had minimal effect on numerical abundance, distance from the foredune remnants did have a strong effect on all three. The overall survival of *C. cheiranthifolia* and *A. chamissonis* increased as distance from the foredunes increased. Likewise, the mortality rate for both species decreased with distance but did not drop to zero. Throughout the study, sand steadily covered the study area, burying plants and eventually killing them. Weller (1989) found that distance from Lake Michigan significantly affected the emergence of *Lithospermum carolinense* seedlings because of greater sand deposition near the lake. The first two zones in this study may experience a similar situation.

However, many of the seedlings became buried by sand but did not die immediately. Those that were buried tended to become extremely etiolated. *A.*

chamissonis seemed to survive longer than *C. cheiranthifolia* in this state. Zhang and Maun (1990) found that seedlings of *Agropyron psammophilum* died when buried in sand to 100% of their height. Maun and Lapierre (1984, 1986) found that population density of *Ammophila breviligulata* decreased with greater burial depth in sand. Seedling emergence was greatly reduced at burial depth of 80 cm and the population was eradicated at 100 cm. They also found that emergence rate and survival of four dune species decreased with increased burial depth.

In the ground cover study, all three zones exhibited significant differences in ground cover components. *Abronia maritima*, *Carpobrotus chilensis* and *Cakile maritima* were nearly equally represented in Zone 1, but in Zone 2 *C. maritima* was dominant. Both *A. maritima* and *C. chilensis* are perennial plants characteristic of foredunes. *Cakile maritima* is an opportunistic introduced annual that has naturalized on the Pacific coast (Barbour and Rodman, 1970). Whether or not *C. chilensis* is native is questionable (Breckon and Barbour, 1974), but it is prominent on the dunes in the study area. *Camissonia cheiranthifolia* and straw are more important in Zone 3. *Camissonia cheiranthifolia* is a native perennial that probably could not withstand burial in the first two zones. Straw mulch was spread over the entire study area but, like the *C. cheiranthifolia*, was buried by sand in the first two zones. Bare ground, or area not covered by plants or straw, was the dominant feature, especially in Zone 1.

The implications of this work are that sand fences are not useful in enhancing revegetation in active sand dunes, but that distance from the foredune remnants should be emphasized instead. However, seedling recruitment should also be investigated. Future revegetation efforts should concentrate in the region of Zone 3 of this study, or approximately 120 m away from the foredune remnants. The optimum distance may be closer than 120 m, but the data were collected at the end of a five year drought, and mortality may have been higher than it would have been during a "normal" rainfall year. Monitoring should include a winter through fall sequence (this study did not) to determine what kind of seedling mortality can be expected seasonally.

The use of sand fences should not be entirely ruled-out. Only one type of sand fence was used in this study, and a different design may be more successful. Bijker (1978) reviewed work by various authors regarding the effectiveness of sand fences. Jensen (1954) found that fence porosity affected the degree of shelter afforded at different distances from the fence, and a porosity of 35% to 50% gave the best results. Phillips (1974) stated that fences with 36% porosity would show maximum sand deposition. Savage (1963) used slat fencing and brush fencing in single and double configuration and found that 25% porosity was more effective than 50% porosity, and brush fencing worked better than slat fencing. Castro's work (1971) suggested that a fence with 30% porosity would produce no reverse (wind) flow and a (wind) velocity of zero at a distance equal to about four times the height of the fence.

A different mix of species may be more successful in the future. *Atriplex leucophylla* is a tough perennial that grows closest to the ocean of all the species in the study area and builds small hillocks of sand. In the words of Cooper (1936), *Atriplex leucophylla* is the "...most aggressive of the foredune builders in its advance toward the sea..." *Abronia maritima* and *A. latifolia* are also important vigorous foredune builders. According to Cooper (1936), among those species important in a secondary capacity of surface binding rather than dune-forming are: *Fragaria chiloensis*, *Calystegia soldanella*, *Ambrosia chamissonis*, and *Camissonia cheiranthifolia* (although its sand-binding potential is questionable, it certainly is vigorous in the study area). *Ambrosia chamissonis* seems particularly well-suited to the unstable environment in the foredunes because of its tendency to become etiolated when buried by sand.

Plants with a clonal habit may be more successful in revegetation than others. These plants are known to translocate nutrients from mother ramets to daughter ramets. Hartnett and Bazzaz (1983) found that young ramets of *Solidago canadensis* were dependent on the parental ramet during emergence and establishment, but became independent later. Friedman and Alpert (1991) found translocation of nutrients between ramets of *Fragaria chiloensis* under conditions of limited resources. One drawback to the use of clonal plants at Pismo Dunes is that under severely limiting conditions, such as occur in unstable dune environments, the parental ramets stop the nutrient supply to the daughter ramets. However, these connections may be re-established when more favorable conditions resume (Friedman and Alpert 1991).

Investigations into the presence of mycorrhizal plant associations and the possibility of inoculating the dunes with spores of endomycorrhizal fungi should not be overlooked. Endomycorrhizae, especially vesicular-arbuscular mycorrhizae (VAM), may play a very important role in dune-building and stabilization of active dunes (Koske and Polson, 1984). VAM are thought to improve the mineral nutrition of their higher plant associates by making otherwise insoluble minerals (especially phosphorous) available to them (Jehne and Thompson, 1981; Nicolson, 1967). VAM are also capable of binding sand grains to the roots of plants, forming aggregates that are not as susceptible to erosion as loose sand (Jehne and Thompson, 1981; Sutton and Sheppard, 1976).

Building and stabilizing sand dunes is a lengthy process, especially if allowed to occur naturally. Keen and Shane (1990) reported that the length of time to destabilize dunes near Lake Ann, Minnesota, was tens to hundreds of years, while the length of time for those same dunes to stabilize was hundreds to thousands of years. Therefore, it is critical to revegetate and stabilize disturbed dunes. Revegetation may be expedited by using appropriate species planted at approximately 120 m from the foredune remnants, possibly using fences, and exploiting plant-mycorrhizae associations.

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