NOAA Technical Memorandum
NOS MEMD 14

DUNE VEGETATION REESTABLISHMENT AT TIJUANA ESTUARY

Lisa F. Wood and Joy. B. Zedler

Pacific Estuarine Research Laboratory, Biology Department,
San Diego State University, San Diego, CA 92182-0057

Washington, D.C.

August 1987

UNITED STATES DEPARTMENT OF COMMERCE / National Oceanic and Atmospheric Administration / National Ocean Service

NOAA TECHNICAL MEMORANDA

National Ocean Service Series

Marine and Estuarine Management Division

The National Ocean Service, through its Office of Ocean and Coastal Resource Management, conducts natural resource management related research in its National Marine Sanctuaries and National Estuarine Reserve Research System to provide data and information for natural resource managers and researchers. The National Ocean Service also conducts research on and monitoring of site-specific marine and estuarine resources to assess the impacts of human activities in its Sanctuaries and Research Reserves and provides the leadership and expertise at the Federal level required to identify compatible and potentially conflicting multiple uses of marine and estuarine resources while enhancing resource management decisionmaking policies.

The NOAA Technical Memoranda NOS MEMD subseries facilitates rapid distribution of material that may be preliminary in nature and may be published in other referreed journals at a later date.

MEMD 1 M.M. Littler, D.S. Littler and B.E. Lapointe. 1986. Baseline Studies of Herbivory and Eutrophication on Dominant Reef Communities of Looe Key National Marine Sanctuary.

MEMD 2 M.M. Croom and N. Stone, Eds. 1987. Current Research Topics in the Marine Environment.

MEMD 3 C.E. Birkeland, R.H. Randall, R.C. Wass, B. Smith, and S. Wilkens. 1987. Biological Resource Assessment of the Fagatele Bay National Marine Sanctuary

MEMD 4 H. Huber. 1987. Reproduction in Northern Sea Lions on Southeast Farallon Island, 1973-1985.

MEMD 5 J.A. Bohnsack, D.E. Harper, D.B. McClellan, D.L. Sutherland, and M.W. White. 1987. Resource Survey of Fishes within Looe Key National Marine Sanctuary.

MEMD 6 S.G. Allen, D.G. Ainley, L. Fancher, and D. Shuford. 1987. Movement Patterns of Harbor Seals (Phoca vitulina) from the Drakes Estero Population, California, 1985-86.

MEMD 7 S.G. Allen. 1987. Pinniped Assessment in Point Reyes, California, 1983 to 1984.

MEMD 8 G.H. Han, R.W. Calvert, J.O. Blanton. 1987. Current Velocity Measurements at Gray's Reef National Marine Sanctuary.

MEMD 9 B.E. Lapointe and N.P. Smith. 1987. A Preliminary Investigation of Upwelling as a Source of Nutrients to Looe Key National Marine Sanctuary.

MEMD 10 C.S. Nordby. 1987. Monitoring of Fishes and Invertebrates at Tijuana Estuary.

MEMD 11 R.T. Heath. 1987. Phosphorus Dynamics in the Old Woman Creek National Estuarine Research Reserve - A Preliminary Investigation.

MEMD 12 A.J.C. Woods. 1987. Fluvial Erosion, Sedimentation, and Hydraulic Geometry in the Contributing Watershed of Old Woman Creek National Estuarine Research Reserve.

MEMD 13 D.G. Ainley, L.B. Spear, J.F. Penniman, C.S. Strong, and I. Gaffney. 1987. Foraging Ecology of Seabirds in the Gulf of the Farallones.

MEMD 14 L.F. Wood and J.B. Zedler. 1987. Dune Vegetation Reestablishment at Tijuana Estuary: Interactions Between the Exotic Annual, Cakile maritima, and the Native Perennial, Abronia maritima.

National Marine Sanctuary Program
Marine and Estuarine Management Division
Office of Ocean and Coastal Resource Management
National Ocean Service
National Oceanic and Atmospheric Administration
U.S. Department of Commerce

NOTICE

REPORT TO
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
U.S. DEPARTMENT OF COMMERCE

NOAA TECHNICAL MEMORANDA SERIES NOS/MEMD

Dune Vegetation Reestablishment at Tijuana Estuary

Lisa F. Wood and Joy B. Zedler

August 1987

U.S. DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
NATIONAL OCEAN SERVICE
OFFICE OF OCEAN AND COASTAL RESOURCE MANAGEMENT
MARINE AND ESTUARINE MANAGEMENT DIVISION
WASHINGTON, D.C.

REPORT TO
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
U.S. DEPARTMENT OF COMMERCE

NOAA TECHNICAL MEMORANDA SERIES NOS/MEMD

Dune Vegetation Reestablishment at Tijuana Estuary

Lisa F. Wood and Joy B. Zedler

Pacific Estuarine Research Laboratory, Biology Department,
San Diego State University, San Diego, CA 92182-0057

This work is the result of research sponsored by the U.S.
Department of Commerce, National Oceanic and Atmospheric
Administration, National Ocean Service, Office of Ocean and
Coastal Resource Management, Marine and Estuarine Management Division
Under Grant Number NA-86-AA-D-CZ016

NOTE TO READERS

On April 7, 1987, the Congress of the United States amended Section 315 of the Coastal Zone Management Act to establish the National Estuarine Reserve Research System (P.L. 99-272). Formerly known as the National Estuarine Sanctuary Program, each national estuarine sanctuary established prior to this date was automatically made part of the new system and designated a national estuarine research reserve. The new System emphasizes the research value of each site since they are areas representative of estuarine ecosystems that are suitable for long-term research and contribute to the biogeographical and typological balance of the System.

TABLE OF CONTENTS

LIST OF TABLES

ABSTRACT

Comparisons of dune vegetation at the disturbed strand at Tijuana Estuary with less disturbed sites in Baja California show that the exotic annual, *Cakile maritima*, is dominant and the native perennial, *Abronia maritima* is rare only in disturbed sites. In experiments at Tijuana Estuary, California, *Abronia maritima* was negatively affected by *Cakile maritima* Pots were planted with 3 densities of *Abronia* seedlings, *Cakile* seedlings, or both (5X replication). In the presence of *Cakile*, *Abronia* seedlings were smaller than in monocultures of equal density. On the other hand, *Cakile* seedlings were no more affected by the presence of *Abronia* than they were by the presence of other *Cakile* seedlings at the same density. *Cakile* has great invasion potential and inhibits *Abronia* seedling establishment. *Cakile* does not stabilize the substrate as well as *Abronia* and so disturbances have a more severe impact in *Cakile*-dominated areas. Disturbances that are severe enough to destroy entire *Abronia* mats favor *Cakile* invasion and the restriction of *Abronia* recruitment. These findings help explain the decline in *Abronia* abundance at Tijuana Estuary that has occurred over the past 50 years.

INTRODUCTION

Background. A native to the shores of the Mediterranean Sea, Cakile maritima Scop. was first reported in California in the mid 1930's (Rose, 1936). It was introduced near San Francisco and quickly spread north to British Columbia and south to Cedros Island, Baja, California (Barbour, 1970), 28° latitude (Macdonald and Barbour,1974). It arrived in the San Diego area sometime between 1936 and 1964 (Purer, 1936; Chapman, 1964). Although it has a broad distribution, it is restricted to a narrow band of coastal strand throughout its range (Barbour, 1970).

Few studies have been done on the effects of exotics on the native strand plant community. Cakile edentula, a congener from the east coast of the United States, was introduced to the west coast in the 1800's (Barbour, 1970). It was well established when C. maritima arrived in the 1930's (Chapman, 1964, Barbour, 1970). According to Barbour, C. maritima has "largely replaced" this congener (Barbour, 1970). The effects of another exotic, Carpobrotus edule, have been studied at Morro Bay, California. Over the ten-year period from 1969 to 1979 this aggressive exotic expanded into areas previously dominated by native plants, altering the community structure of the area (Williams and Williams, 1984).

A similar vegetation change has occurred on the strand in the San Diego area. Prior to the introduction of C. maritima, Abronia maritima Nutt. ex Wats. was the most common plant on the seaward side of the strand at Tijuana Estuary and nearby Silver Strand (Harwood, 1931; Purer, 1936). Since the 1930's A. maritima has decreased in abundance and now has a limited and patchy distribution in the San Diego area. Farther south along the coast, at San Quintin, Baja California, C. maritima has a limited distribution. These seldom-disturbed dunes are still dominated by A. maritima. The purpose of this study is to investigate the role of the exotic C. maritima on the coastal strand of Southern California.

Importance. Strand systems are dynamic, living buffers vital to the protection and stability of the coastline. The energy from ocean winds and waves is dissipated along the length of the strand. Plants play a key role in the buffering capacity of the strand by stabilizing the sandy substrate. Any object extending above the ground can reduce the wind velocity below that necessary to carry sand (Barbour, 1985). Species vary in the amount of sand they accumulate and also in their ability to hold sand once it has been deposited (Barbour, 1985, Wiedeman, 1984). Good sand stabilizers form hummocks, which in turn promote the formation of dunes. Plants that are not good sand stabilizers may also accrete sand in hummocks, but these are temporary in nature and do not promote the formation of dunes (Wiedeman, 1984). A. maritima is a good sand stabilizer (Weideman, 1984, Fink, 1987, Johnson, 1978). C. maritima, however, has very poor sand holding properties because it has upright branches; it has few surface roots; and it normally dies and blows away in the winter, when the strongest onshore winds and highest waves occur. Therefore, a shift from an A. maritima-dominated system to a C. maritima-dominated system is a shift from a more stable to a less stable strandline.

Dunes and hummocks stabilized by plants help buffer inland areas from storm winds and ocean waves (Tinley, 1985). However, when a storm hits an area with severely disturbed vegetative cover, or with poor sand-holding properties, large amounts of sand can be displaced. The resulting landward migration of the coastline and disturbances to inland areas can have catastrophic consequences. For example, in January of 1983 a high tide coincided with a winter storm (Cayan and Flick, 1985). Because trampling had reduced the vegetative cover at Tijuana Estuary (Jorgensen, pers. comm., 1985), and much of the remaining cover was C. maritima (Chapman, 1964), the strand had not developed hummocks or dunes and was not adequately covered with stabilizing plants. Waves washed over the strand and deposited sand in the channels of the estuary. The resulting loss of tidal prism reduced the scouring effect of daily tides on the mouth of the estuary. The mouth became closed, depriving Tijuana Estuary (Figure 1) of ocean flushing (Zedler and Nordby, 1986).

As a result of the 1983 washover, an extensive dune restoration project (Figure 2) was initiated on the coastline south of the estuary mouth. The purpose of the project was to return sand to its prewashover location and to forestall the migration of the strandline. Landward migration of this strandline at Tijuana Estuary has been approximately 2.5 meters per year for the past ten years (Williams and Swanson, 1987). In the fall of1986, over 3,000 cubic meters of sand were bulldozed from the landward side of the strand to the seaward side. The sand was piled into hummocks measuring approximately 4 m across the base and 2 m in height. In the winter of 1987, approximately 2,000 plants were planted on the hummocks. Native dune plants with good sand stabilizing abilities, such as Abronia maritima (Wiedeman, 1984; Orme, 1973), or æsthetic and cultural values such as Oenothera cheiranthifolia (Raven, 1982), were used in the revegetation effort. Several hundred meters of plastic sand fencing were installed parallel to the coastline (Mendelsohn, et. al., 1983) in an effort to trap sand and prevent trampling until plants could establish. In addition to the plantings on the hummocks, vegetative cover has developed from the aggressive invasion of C. maritima.

Purpose. The purpose of this study was to investigate the role of C. maritima on the strand south of the Tijuana Estuary mouth. The plant community at Tijuana Estuary was compared with that of two less disturbed locations at San Quintin, Baja California (Figure 3). The percent cover of C. maritima on the bulldozer-created hummocks (restored areas of strand) was compared with the percent cover of C. maritima on areas that were left undisturbed (Figure 2). The effect of C. maritima on the growth and establishment of the former dominant, A. maritima, and the nature of the interaction was investigated.

Study Site. The study was performed on the strand at Tijuana Estuary, a National Estuarine Research Reserve (Figure 1), located just north of the United States-Mexico border, latitude 32°34' north, longitude 117°07' west. The climate of the region is dry Mediterranean (Wiedeman,1983), with a temperature range of from 5-21°C and, on average, 20 cm of rain each year. The amount and timing of precipitation are subject to much variation.

The strand slopes gently upward, leveling off and then sloping downward to the banks of the estuarine channels, which mark the landward boundary of the strand. Small hummocks are present where stabilizing perennials have caused sand accretion and also where bulldozers left mounds. This type of configuration is called a "sand plain" type dune system (Wiedeman, 1983) or "hummock dunes" (Tinley, 1985). It is difficult to differentiate the beach from the sand plain. Therefore, the more general term, "strand", meaning beach and/or dune, vegetated and unvegetated, will be used (Barbour, 1985). The strand is highly disturbed, receiving high levels of pedestrian, equestrian, and vehicular traffic. In addition, most of the strand was subjected to bulldozing during the dune restoration.

Manipulative experiments were performed at the Pacific Estuarine Research Laboratory (PERL), located approximately 3 km east of the strand (Figure 1).

Comparisons were made between the strand at Tijuana Estuary and two dune systems near San Quintin, Baja California (Figure 3). At the first site, a small, remote beach on the coastal side of San Quintin Bay, the dune system was approximately 9 meters tall and 100 meters across (from the seaward edge to the edge of the estuary). These dunes were virtually undisturbed. The second site, Playa San Ramon, was located on a long beach and dune system. The dunes were approximately 8 meters tall and 64 meters across.

Although this site was much less disturbed than the strand at Tijuana Estuary, there was ample evidence of human activity, primarily roads and trails made by off road vehicles.

Subjects of Study. A. maritima is a perennial plant that grows in low dense mats (Purer, 1934), usually on the seaward side of the strand (Purer, 1936b, Johnson, 1978, Barbour, 1976). It is found in coastal strand areas from latitude 35^o to latitude 23^o (Figure 3)(Macdonald and Barbour, 1974). Mats range in size from 0.5 m to 5 m or more in diameter (Wiedeman, 1983, Johnson, 1978). Each mat produces several propagules (achenes) each year.

C. maritima is an annual plant that grows in loose clumps from a few cm to 1 m in diameter, and up to 0.5 m in height. It is found both on the seaward and on the landward side of the strand from 28^o to 54^o latitude (Macdonald and Barbour, 1974). C. maritima plants produce a very large number of propagules which are attached to branches in pairs. Each pair consists of two types of fruit: an indehiscent silicle, firmly attached to the branches of the parent plant, and a dehiscent silicle, which detaches from the indehiscent silicle when the plant dies and begins to dry. Individuals typically germinate in the spring and die in the fall, but they may be found germinating after rain at any time of the year. Under favorable conditions, they may persist for more than one growing season (Barbour, 1985, Cunniff, 1984).

METHODS

Plant Composition at Tijuana Estuary. The strand vegetation south of the mouth at Tijuana Estuary was characterized at two sites during the months of November and December, 1984 (Figure 2). At each of the two sites, five transects were established perpendicular to the coast at random points. The transects started at the first occurrence of dune vegetation and terminated after 100 meters or at the first occurrence of saturated soil, whichever came first. Measurements were made using the line intercept method (Cox, 1985). Within 10-meter intervals along each transect, cover, frequency of occurrence, and total coverage were calculated. An importance value (the average of the relative cover and relative frequency) was calculated.

Plant Composition at San Quintin Bay and Playa San Ramon. Strand vegetation in Baja California was characterized at two locations, San Quintin Bay and Playa San Ramon (Figure 3). At each site a single, 2-m wide transect was established from the base of the foredune to the edge of the estuary. Within contiguous 2-m square quadrats along each transect, each species encountered was recorded and the percent cover of A. maritima was estimated using cover classes.

Cover Measurements. In order to test the hypothesis that C. maritima preferentially germinates and establishes in disturbed areas, percent cover was measured on the hummocks created by bulldozers, and on unbulldozed areas south of the mouth of Tijuana Estuary (Figure 2). Three random points along a line parallel to the surf zone were chosen in the bulldozed area and three were chosen in the unbulldozed area. A transect line perpendicular to the surf zone was established at each of these six points. A 0.1-meter-square quadrat was placed at each of ten points chosen at random along each of the transect lines. The percent cover of each species within the quadrat was estimated and recorded to the nearest 5%. The relative cover was calculated from the absolute cover.

Artificial Dune Experiment, Germination. In order to test the hypothesis that C. maritima directly affects A. maritima , a pot experiment was performed at PERL (Figure 1). All C. maritima fruits were collected from the strand at Tijuana Estuary. A. maritima fruits were in short supply at Tijuana Estuary and so were also collected from Silver Strand State Park. Anthocarps were removed from the seeds, which were stored in plastic vials at room temperature until they were planted on March 15, 1986.

Both species produce long roots within days of germinating. Long tubes, 2 cm in diameter and 17-cm long, were made from butcher paper to accommodate these roots. The tubes were filled with sand from the strand at Tijuana Estuary. Ten tubes were placed in each of 60 1-gallon pots. The sand was well watered and planted with one seed per tube. Each gallon pot contained tubes of only one species. In all there were 340 C. maritima seeds, and 260 A. maritima seeds planted in the tubes. The pots were arranged in a randomized block design on one shelf of the greenhouse. Temperature and relative humidity measurements were made in the greenhouse on three successive days at 11:00 AM and 1:00 PM. The temperature on the shelf of the greenhouse was from 8 to 10^{o}C above ambient, and the relative humidity was 5 to 6% above ambient. The seeds were watered with tap water every 1 to 3 days until most of the seeds had germinated (30 days).

Artificial Dune Experiment, Growth. Forty-five 7.5-cm diameter polyvinyl chloride pipes were cut into 1.5-meter lengths, buried to ground level in an artificial dune (a mound of dirt covered with a thin layer of sand), and filled with sand collected from the strand at Tijuana Estuary. Five replicates of nine treatments were arranged in a randomized block design. The treatments included: three densities of C. maritima (2, 4, and 6 plants per pipe) grown in monocultures; three densities of A. maritima (2, 4, and 6 plants per pipe) grown in monocultures; and three densities of mixed culture (1 A. maritima and 1 C. maritima, 1 A. maritima and 3 C. maritima, and 1 A. maritima and 5 C. maritima per pipe).

The pipes were well watered with tap water and seedlings from the tubes in the greenhouse were removed from their butcher paper and transplanted into the pipes according to the planting scheme above. The plants were watered with tap water approximately every three days. Soon after the seedlings were transplanted, rabbit herbivory was noticed on A. maritima. It was eliminated by constructing an aviary wire fence around the artificial dune.

After 61 days, the 1.5-m pots were excavated. The roots were washed, and separated by plant. The above- and below-ground portions of each plant were bagged separately, dried in ovens at 30°C for approximately 2 days (to constant weight) and weighed to the nearest 0.01gram.

Artificial Dune Experiment, Statistical Methods. Comparisons of root, shoot, and total plant weights were made for each species. All tests for significance used the 0.05 rejection level.

The biomass data for the roots, shoots, and total plants of A. maritima were analyzed for density and competition effects using a two-way analysis of variance (ANOVA). This analysis was performed with BioMedical Computer Programs (Dixon, 1987). A test for normality was run on 2D and a test for equality of variance test on 7D. All three data sets were nonnormal and had unequal variances according to Levene's test. Therefore all three were log transformed. The log-transformed data were normal and the variances were equal according to the test criteria.

The data on the weight of C. maritima at the lowest density were analyzed with a one way ANOVA by competition (with and without A. maritima) using BMDP. These data were normal and had equal variances and so they were not log transformed. The root to shoot ratio was normal, but had unequal variances, so a Welch Brown-Forsythe test was performed (variances were not assumed to be equal).

Monitoring of *A. maritima*. The effects of C. maritima on the growth of established A. maritima mats were investigated by monitoring the growth of 6 large, well established mats. The mats were monitored for 8 months, from July, 1986, to March, 1987. They were located at the very south end of the strand (Figure 2) and were chosen because of their accessibility. Every 2-3 months the longest diameter and its perpendicular of each mat were measured and recorded. General notes were taken on the condition of the plant or group of plants and its neighbors. The two diameter values were averaged and used with the equation for the area of a circle to estimate the area of each mat.

Soil Analysis. In order to determine if soil nitrogen and phosphorus might be limiting, some of the sand collected for the experiments was analyzed for total Kjeldahl nitrogen and total phosphorus using a selenium copper catalyst (Page, 1982). The method was modified for a block digester and the digest was analyzed on a Technicon Autoanalyzer (industrial method 329-74W/B).

Fertilizer Experiment. A second competition experiment was performed to examine the role of nutrients in the interaction between C. maritima and A. maritima. Thirty-six 10-cm diameter, 0.6-meter-long plastic pipes were filled with sand collected from the strand at Tijuana Estuary. The sand was leached of nutrients by washing each pipe with a flow of deionized water for approximately 20 minutes per pipe. The pipes were buried to ground level in the substrate at PERL and a fence of aviary wire was constructed around them. An excess of fruits was planted on May 5, 1986. After germination, the seedlings were thinned to obtain six density and competition treatments: monocultures (no competition) of C. maritima at two densities (2 and 4 plants per pot); monocultures (no competition) of A. maritima at two densities (2 and 4 plants per pot); mixed cultures (competition) at two densities (1 A. maritima and 1 C. maritima, and 1 A. maritima and 3 C. maritima).

In addition to the six density and competition treatments, half of the pots were watered with tap water, and the other half with a standard Van de Elst fertilizer solution (Table 1). In all there were 12 different treatments, each replicated three times. Each treatment was represented once in each of three contiguous areas. Treatments were randomized within the areas.

The plants were given water or water and fertilizer every 2 to 3 days for 26 days. They were then excavated and harvested. Roots and shoots were bagged by species and by pot and were dried and weighed as above.

Table 1. Composition of Van de Elst nutrient solutions (weights per liter of water).

Chemical	High nitrogen	Standard nitrogen	No nitrogen
KCl	--	--	1.04 g
K_2SO_4	--	--	0.61 g
KNO_3	14.0 g	1.4 g	--
$(NH_4)_2SO_4$	4.6 g	0.46 g	--
$Ca(H_2PO_4)_2 \cdot H_2O$	0.7 g	0.7 g	0.7 g
$MgSO_4 \cdot 7H_2O$	0.7 g	0.7 g	0.7 g
trace elements*	1.0 ml	1.0 ml	1.0 ml
FeEDTA	0.4 ml	0.4 ml	0.4 ml

*Composition of trace elements solution per liter H_2O

Chemical	grams
KCl	3.728
H_3BO3	1.546
$MnSO_4 \cdot H_2O$	0.845
$ZnSO_4 \cdot 7H_2O$	0.575
$CuSO_4 \cdot 5H_2O$	0.125
$H_2MoO_4 \cdot H_2O$	0.018

Fertilizer Experiment. Statistical Analysis. Comparisons of root, shoot, and total biomass were made for each species. All tests for significance used the 0.05 rejection level. These data were analyzed for normality with BMDP as above and were nonnormal until they had been log transformed. Statview, version .99, was used on a MacIntosh computer to perform a three-way ANOVA comparing density, competition, and fertilizer treatments on all three of these data sets.

RESULTS

Plant Composition at Tijuana Estuary. C. maritima was the most common plant at both sites at Tijuana Estuary. A. maritima was present only at site 1 and was much less important than C. maritima at that site.

At site 1, plant coverage accounted for 10.7% of the 5 10-m transects; bare sandy areas accounted for the rest. Dead C. maritima was the most important plant in the transect, followed by live C. maritima, Ambrosia chamissonis ssp bipinnatesecta, A. maritima, and live and dead Distichlis spicata (Table 2).

At site 2, located near the equestrian trail, plant coverage accounted for 45.4% of the 5 23-m transects, and bare sandy areas accounted for the rest. Again, dead C. maritima was the most important plant, followed by D. spicata, Carpobrotus edulis, Frankenia grandifolia, and live C. maritima (Table 2). A. maritima did not occur at this location.

Table 2. Relative Cover, Relative Freauency, and Importance Value for Sites 1 and 2 on the Strand at Tijuana Estuary.

SITE 1

SPECIES	COVER	FREQUENCY	IMPORTANCE
C. maritima (live)	0.63	7	8.4
C. maritima (dead)	10.19	47	80.1
A. chamissonis	0.94	3	6.3
A. maritima	0.71	1	3.5
D. spicata (live)	0.00	1	0.8
D. spicata (dead)	0.01	1	0.9

SITE 2

SPECIES	COVER	FREQUENCY	IMPORTANCE
C. maritima (live)	0.08	1	2.2
C. maritima (dead)	11.03	16	54.2
D. spicata	6.58	7	27.9
C. edulis	1.30	3	8.4
F. grandifolia	1.67	2	7.5

Plant Composition at San Quintin Bay and Playa San Ramon. In contrast to the strand at Tijuana Estuary, C. maritima was present but extremely rare at both sites in Baja California. It occurred once within a transect at Playa San Ramon, but was found only on the edges of the San Quintin dune system, and not within a transect. Percent cover of C. maritima in both transects in Baja was 0.

Total plant coverage, at least on the foredune, was due to A. maritima coverage. A. maritima cover was higher in the first 30 meters at San Quintin Bay (29.3%) than in the first 30 meters at Playa San Ramon (24.7%). Both values are intermediate between the values for total plant coverage at the two sites at Tijuana Estuary (10.7 and 45.4%).

A. maritima was dominant at both Baja California sites, although it was more abundant at San Quintin Bay, the less disturbed site (Table 3). A. maritima had a higher percent cover in the first 40 meters of dunes at San Quintin Bay (27.3%) than at Playa San Ramon (19.5%). However, the percent cover of A. maritima dropped on the leeward side of both dune systems.

Table 3. Percent cover of A. maritima, and total number of species present at Playa San Ramon and San Quintin Bay, Baja, California.

Site	% cover in the first 40 m	Total % cover of A. maritima	Total number of species
San Quintin Bay	27.3%	14.2%	28
Playa San Ramon	19.5%	13.7%	13

Cover Measurements. C. maritima was much more common on the bulldozed hummocks (site B) than it was in flat areas that had been left undisturbed (site A; Table 4). The differences in cover between the areas were significant according to a chi square test ($p<.05$).

Table 4. Percent cover of C. maritima within 30 0.1-m^2 quadrats along three transects in an unbulldozed area and in a bulldozed area at Tijuana Estuary.

TRANSECT NUMBER	C. maritima OCCURRENCE		AVERAGE % COVER	
	UNBULLDOZED (SITE A)	BULLDOZED (SITE B)	UNBULLDOZED (SITE A)	BULLDOZED (SITE B)
1	2	6	1	26
2	0	9	0	35
3	4	7	3	17

Artificial Dune Experiment. Growth. The A. maritima dry weight data were analyzed for an effect due to density and for an effect due to the presence of C. maritima (competition effect). Figures 4 (root biomass mean), 5 (shoot biomass mean), and 6 (total plant biomass mean) show that A. maritima grew larger in the absence of C. maritima. This trend was significant according to the ANOVA (Table 5). There was no interaction between terms.

Table 5. Analysis of competition and density treatments on A. maritima data from the artificial dune experiment showing degrees of freedom, F-values, and tail probabilities.

ANOVA BY COMPETITION AND DENSITY

DATA SET	SOURCE	DEGREES OF FREEDOM	F VALUE	TAIL PROBABILITY
LOG (SHOOT)	COMPETITION	1	26.85	0.0000
	DENSITY	2	1.71	0.2029
	INTERACTION	2	1.20	0.3202
	ERROR	23		
LOG (ROOT)	COMPETITION	1	16.05	0.0006
	DENSITY	2	2.35	0.1182
	INTERACTION	2	1.06	0.3638
	ERROR	23		
LOG (TOTAL)	COMPETITION	1	25.95	0.0000
	DENSITY	2	2.03	0.1543
	INTERACTION	2	1.05	0.3677
	ERROR	23		

According to a Welch Brown-Forsythe ANOVA (variances were not assumed to be equal) the root/shoot ratio of A. maritima was not significantly affected by the different density treatments, nor by the presence of C. maritima (Table 6).

Table 6. Welch Brown-Forsythe ANOVA by density and competition on A. maritima root/shoot ratios.

DATA SET	SOURCE	F-VALUE	TAIL PROBABILITY
LOG(ROOT/SHOOT)	COMPETITION	0.22	0.6490
	DENSITY	0.66	0.5290
	INTERACTION	1.99	0.1713

To test for an effect of the presence of A. maritima on the weight of C. maritima, a one-way ANOVA was performed on C. maritima dry weight data. Data from C. maritima pots with a density of two, and from pots with both species and a density of two were analyzed. No significant ($p<.05$) competitive effect was detected. The root/shoot ratio data was normal, but had unequal variances, so a Welch Brown-Forsythe test was performed. No significant competitive effect was detected (Table 7).

Table 7. ANOVA table for C. maritima data from the artificial dune experiment.

DATA SET	SOURCE	DF	F-VALUE	TAIL PROBABILITY
SHOOT	COMPETITION	1	0.64	0.4484
	ERROR	8		
ROOT	COMPETITION	1	0.87	0.3780
	ERROR	8		
TOTAL	COMPETITION	1	0.66	0.4399
	ERROR	8		
RATIO	WELCH BROWN-FORSYTHE		2.32	0.176

Monitoring of *A. maritima*. A. maritima mat size was not closely correlated with the presence of C. maritima. Mat 1 (Figure 7) grew more than the other mats from July to January (1,415%) and had little C. maritima around it, but mat 4 also grew very well (211%) even though there was much C. maritima around it. Initial size or distance from the ocean might be better predictors of amount of mat growth. All mats grew by 105 to 1,415% from July, 1986 to January, 1987. In January growth slowed, and from January 10 to March 20, all plants decreased in size (Figure 7).

Soil Analysis. The soil was very low in nitrogen and had a low level of phosphorus. The soil samples tested contained on average 0.013 mgN/g soil and 0.022 mgP/g soil compared with 0.7 mgN/g soil and 0.01 mgP/g soil required for good soil (Wiedeman, 1984).

Fertilizer Experiment. In order to determine the effect of nutrients on the interaction between A. maritima and C. maritima, a three-way ANOVA was performed on the A. maritima dry weight data from the fertilizer experiment (competition, density, and fertilizer treatments). The shoot and total biomass means were significantly lower ($p<.05$) for plants receiving the competition treatment (Figure 8). The root biomass mean showed the same trend (Figure 8), but the differences were not significant ($p=.08$). The root/shoot ratio did not show a strong trend with regard to the competition treatment ($p=.30$).

The shoot, root, and total weight data sets all showed that the plants tended to grow larger in the presence of fertilizer (Figure 8). This trend was significant ($p<.05$) only for the root weight data. In the root/shoot ratio data, there was a significant interaction between density and fertilizer treatments. This interaction was the only significant interaction which occurred between factors.

DISCUSSION

Coastal strand systems are dynamic by nature (Nichols, 1920; Martin, 1959; Wagner, 1964). Sand deposited along the beach is blown across the strand, frequently burying existing vegetation (Davies, 1977; Barbour 1985). Strand plants can survive in this shifting substrate, and some actually require burial for maximal growth (Eldred and Maun, 1982). A. maritima can grow up through as much as 18 cm of sand deposited over the course of a month (Johnson, 1978). Although all coastal strand plants are adapted to natural disturbances originating in the physical environment, some are quite vulnerable to the effects of exotic plants, trampling, and other anthropogenic disturbances.

A. maritima has declined in abundance at Tijuana Estuary over the past fifty years, while C. maritima has invaded and become the dominant species, suggesting that A. maritima is negatively affected by the presence of the exotic, C. maritima. Comparison of Tijuana Estuary with two relatively undisturbed dunes in Baja California supports this hypothesis. Of the sites characterized, Tijuana Estuary had high cover of C. maritima , Playa San Ramon had several occurrences, and at San Quintin Bay only seven individuals were located. The abundance of A. maritima was negatively correlated with both disturbance levels and with the abundance of C. maritima.

The artificial dune experiment was performed to test the hypothesis that C. maritima seedlings directly inhibit the establishment of A. maritima seedlings. The A. maritima data from the artificial dune experiment showed that the presence of C. maritima seedlings had a significant effect on the size of A. maritima seedlings. This retardation of growth could reduce levels of establishment in the field, providing a partial explanation for the observed negative correlation between A. maritima and C. maritima cover.

However, A. maritima distribution is easily disturbed. Observations of A. maritima on the strand at Tijuana Estuary indicate that it is vulnerable to trampling. Branches snap off easily under foot and with a single pass of a vehicle. Mortality due to trampling may have hastened the reduction of A. maritima cover at disturbed sites. The distribution of A. maritima is most likely a function of both factors: disturbance levels and the presence of C. maritima.

The cause of the inhibitory effect of C. maritima on A. maritima is still unclear. Nutrient levels were low on the strand at Tijuana Estuary, but no significant interaction was detected between competition and fertilizer treatments in the fertilizer study. Competition for nutrients may be a factor in seedling establishment, but a more sensitive experiment may be needed to detect it. Alternatively, other resources, such as water, may be limiting to seedlings. The glucocynalates present in C. maritima could exert an allelopathic effect on A. maritima seedlings. Rabbits may accentuate the interaction between the plants. They were commonly observed feeding on A. maritima, but never on C. maritima. All of the rabbit herbivory seen at the beginning of the artificial dune experiment was on A. maritima. In order to develop specific management practices designed to encourage A. maritima and discourage C. maritima, more experimentation into the nature of the interaction between these plants is needed.

Adult A. maritima plants are probably not affected by C. maritima. During the A. maritima mat monitoring process, there were no visible effects of C. maritima. Other factors such as proximity to the ocean or mat age may prove to be more important.

The level of C. maritima present at the three sites was positively correlated with the level of disturbance. Only a few individuals of C. maritima could be found around the edges of the dune at San Quintin Bay, despite the fact that the reported range of C. maritima extends much farther south to Cedros Island. This could be due to the introduction of appropriate microsites, or to the elimination of potential competitors, or other factors.

A. maritima has little effect on the distribution of C. maritima. The C. maritima data from the artificial dune experiment showed no response to competition with A. maritima. The presence of A. maritima on the strand at Tijuana Estuary did not prevent the invasion of C. maritima in the 1930's. Furthermore, a bulldozed site at Tijuana Estuary had more than twice the cover of C. maritima than an unbulldozed site, even with no A. maritima present. Thus, the establishment of C. maritima is facilitated by anthropogenic disturbances, but is little affected by the presence of A. maritima.

CONCLUSIONS

C. maritima is an aggressive exotic that does very well in disturbed areas. Anthropogenic disturbances, such as trampling and the introduction this exotic plant, are factors in the decline of the native, A. maritima, at Tijuana Estuary. A manipulative experiment found a significant competitive interaction between the two species, but the nature of the interaction is still unknown. A fertilizer experiment designed to determine the mechanism of the interaction was inconclusive. A. maritima distribution is probably more limited by disturbance levels than by the presence of C. maritima. Observations were made on the effects of trampling A. maritima mats. Stems were broken and a reduction in the size of the mat resulted.

IMPLICATIONS FOR MANAGEMENT

Because anthropogenic disturbances promote the exotic, C. maritima, and discourage the native, A. maritima, the most stable dunes can develop where anthropogenic disturbances are kept to a minimum. In areas already dominated by C. maritima, it is even more important to minimize disturbances. Fencing is a step in the right direction. An awareness of the importance of strand communities is needed to assure the cooperation of the public in dune restoration projects. The visitor's center at Tijuana Estuary should provide information and displays on coastal strand systems. A better understanding of the biological interactions on the strand and the cooperation of the public will help insure that the dunes become stabilized and revegetated by native plants.

Because C. maritima is a poor sand stabilizer, physical disturbances have a greater effect in areas which are dominated by it than in areas which are protected by A. maritima. According to the cover measurements taken at Tijuana Estuary, C. maritima seedlings preferentially germinate in disturbed areas, whereas according to the characterization studies and the historical perspective, A. maritima germination is inhibited by high disturbance levels. An A. maritima seedling which germinates in an area dominated by C. maritima is subjected to direct inhibition (due to competition or some other mechanism) and also to indirect inhibition (due to greater disturbance levels associated with C. maritima-dominated areas). Thus, C. maritima aggressively invades disturbed areas, then prevents the subsequent establishment of A. maritima through direct inhibition and by failing to buffer disturbances to the substrate.

The data on species diversity at Tijuana Estuary, San Quintin Bay, and Playa San Ramon indicate that C. maritima may have a similar relationship with other native species. In general, species diversity is negatively correlated with the level of C. maritima present and positively correlated with the level of A. maritima present. The strand at Tijuana Estuary is dominated by C. maritima and exhibits a paucity of species. Either through direct inhibition or by amplifying the effects of disturbance, C. maritima may be excluding certain species from this area entirely. Clearly this is only one of several explanations for the observed species distribution. More studies on the effects of the exotic, C. maritima, on native species are needed in order to gain a more complete understanding of its role in the biological community.

In addition to its effect on strand stability and on native plants, C. maritima may also have an adverse impact on the insect community. It has been suggested that bare areas on the dune are an essential resource to several substrate-dwelling species (Weideman, 1984). At Tijuana Estuary, the percent cover of the dominant, C. maritima, on the bulldozer-created hummocks was 75%, whereas at the two sites dominated by A. maritima, the maximum cover recorded on the foredune was much lower. In areas with a high percent cover, C. maritima may have a negative impact on dune insects requiring open space. Additional studies into the significance of open space to strand insect communities are important, not only for determining the effect of C. maritima on the community, but also for a better understanding of the strand system as a whole.

Although coastal strand systems in Southern California play a crucial role in the stability of the coastline, they have not been extensively studied (Barbour, 1985; Cunniff, 1984). The community structure of the strand affects its buffering capacity. C. maritima-dominated systems are far less stable than A. maritima-dominated systems. C. maritima invades disturbed areas readily and produces a very high percent cover in a short period of time, and thus it appears to be a good species for short term stabilization. However, even in the short term C. maritima may not be a valuable plant for stabilization. An extensive cover of C. maritima was present on several bulldozer-created hummocks which were totally blown away on February 6 during a Santa Ana wind. The presence of C. maritima seemed to have no stabilizing effect on these hummocks in particular and on the strand in general. Furthermore, in the long term, it discourages the establishment of A. maritima, and possibly other native plants, which have good stabilizing properties.

BIBLIOGRAPHY

Barbour, Michael G., 1970. Germination and early growth of the strand plant Cakile maritima. Bulletin of the Torrey Botanical Club. vol. 97, no.1, pp 13-21.

Barbour, Michael G., 1970a. Seedling ecology of Cakile in California. Bulletin of the Torrey Botanical Club. vol. 97, no. 5, pp 280-289.

Barbour, Michael G., 1985. Marine beach and dune communities; IN: Physiological Ecology of North American Plant Communities; B. F. Chabot and H. A. Mooney, editors, Chapman and Hall, New York.

Barbour, Michael G., T. DeJong, and A. F. Johnson, 1976. Synecology of beach vegetation along the Pacific Coast of the United States of America: a first approximation. Journal of Biogeography. 3:55-69.

Cayan, D. R. and R. E. Flick, 1985. Extreme sea levels in San Diego, California: winter 1982-1983. Scripps Institute of Oceanography Rference Series No. 85-3. Shore Process Laboratory, La Jolla, California.

Chapman, V. G., 1964. Coastal Vegetation. The MacMillan Company. New York.

Cox, George W., 1985. Laboratory Manual of General Ecology. Wm. C. Brown Publishers, Iowa.

Cunniff, S. E., 1984. Vegetation patterning on a Southern California barrier beach. M.S. Thesis. University of California at Los Angeles.

Davies, J. L., 1977. Geographical Variation in Coastal Development. Longman, New York.

Dixon, W. J., Editor, 1985. BMDP Statistical Software. University of California Press, Berkeley.

Eldred, R. A. and M. A. Maun, 1982. A multivariate approach to the problem of declining vigor of Ammophila. Canadian Journal of Botany, 60:137-180.

Harwood, R. O., 1931. The Tia Juana Estuaries and the Plant and Animal Life in them. An unpublished report.

Mendelsohn, A., J. W. Jordan, G. Talbot, and J. Starkovich, 1983. Dune building and vegetative stabilization in a sand deficient barrier island environment. Proceedings of the Third Symposium on Coastal Ocean Management ASCE, San Diego.

Orme, Antony R.,1973. Coastal dune systems of Northwest Baja California, Mexico. Technical Report 0-73-1.

Purer, Edith, 1934. Foliar differences in eight dune ond chaparral species. Ecology 15:197-203.

Purer, Edith, 1936. Studies of certain coastal sand dune plants of Southern California. Ecological Mongraphs 12:81-111.

Purer, Edith, 1936a. Plants of Silver Strand Beach State Park, San Diego County. Science Press Printing Company, Pennsylvania.

Raven, P., 1982. The importance of preserving species. A statement presented to the House subcommittee on the Endangered Species Act, February 22.

Rose, L. S., 1936. An unreported species of Cakile in California. Leaflets Western Botany. 1:224.

Wiedeman, A. M., 1984. The ecology of Pacific North West coastal sand dunes: A community profile. US Fish and Wildlife Service. WS/OBS-84/04, 130pp.

Williams, W. T., and J. A. Williams, 1984. Ten years of vegetation change on the coastal stand at Morro Bay, California. Bulletin of the Torrey Botanical Club. vol. 111, no. 2, pp145-152.

Zedler, J.B. and C. S. Nordby, 1986. The ecology of Tijuana Estuary: an estuarine profile. US Fish and Wildlife Biological Report. 85(7.5). 104pp.

Figure 1. Map of Tijuana River National Estuarine Research Reserve.

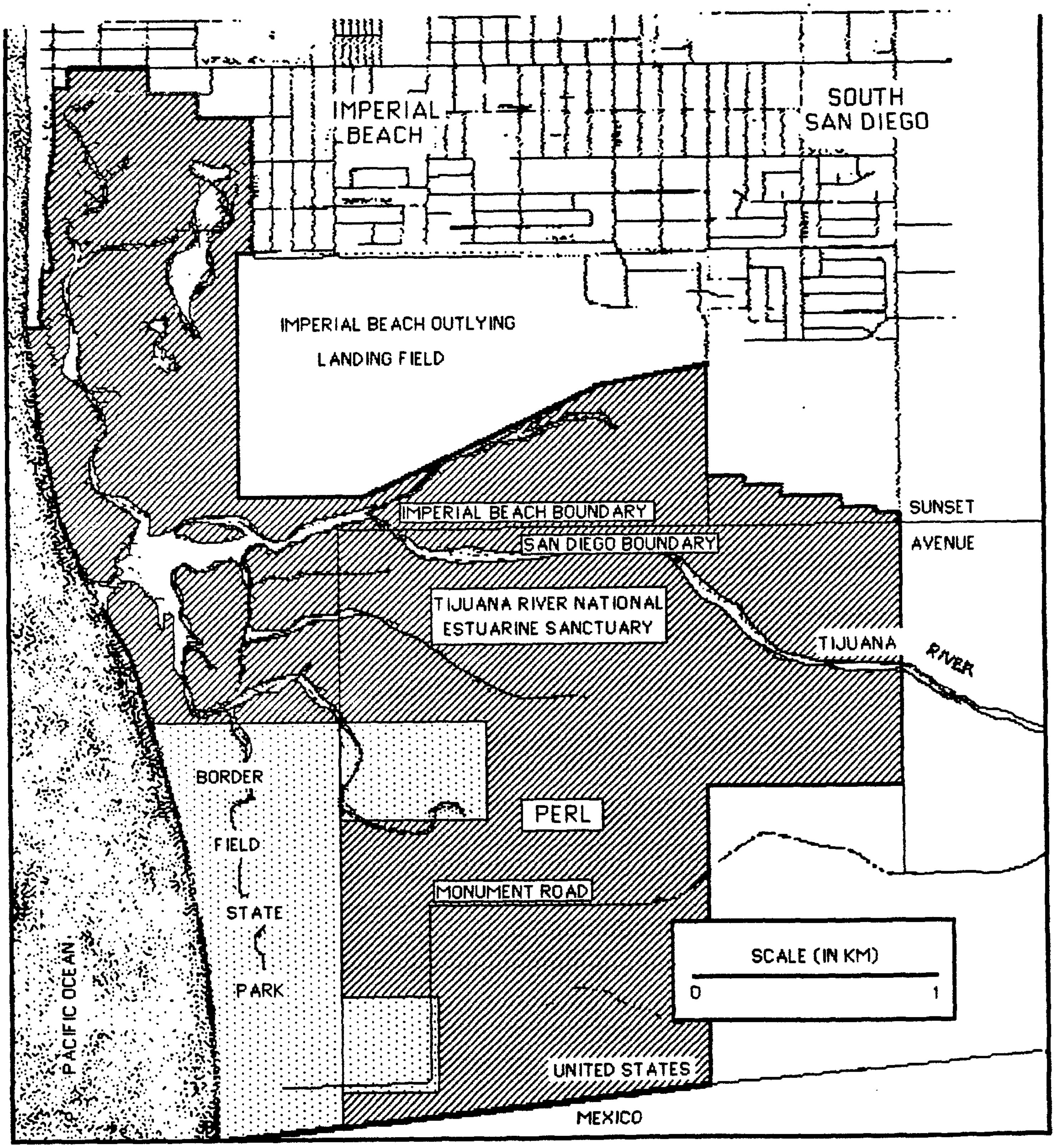

Figure 2. Map of the strand south of the Tijuana River mouth.

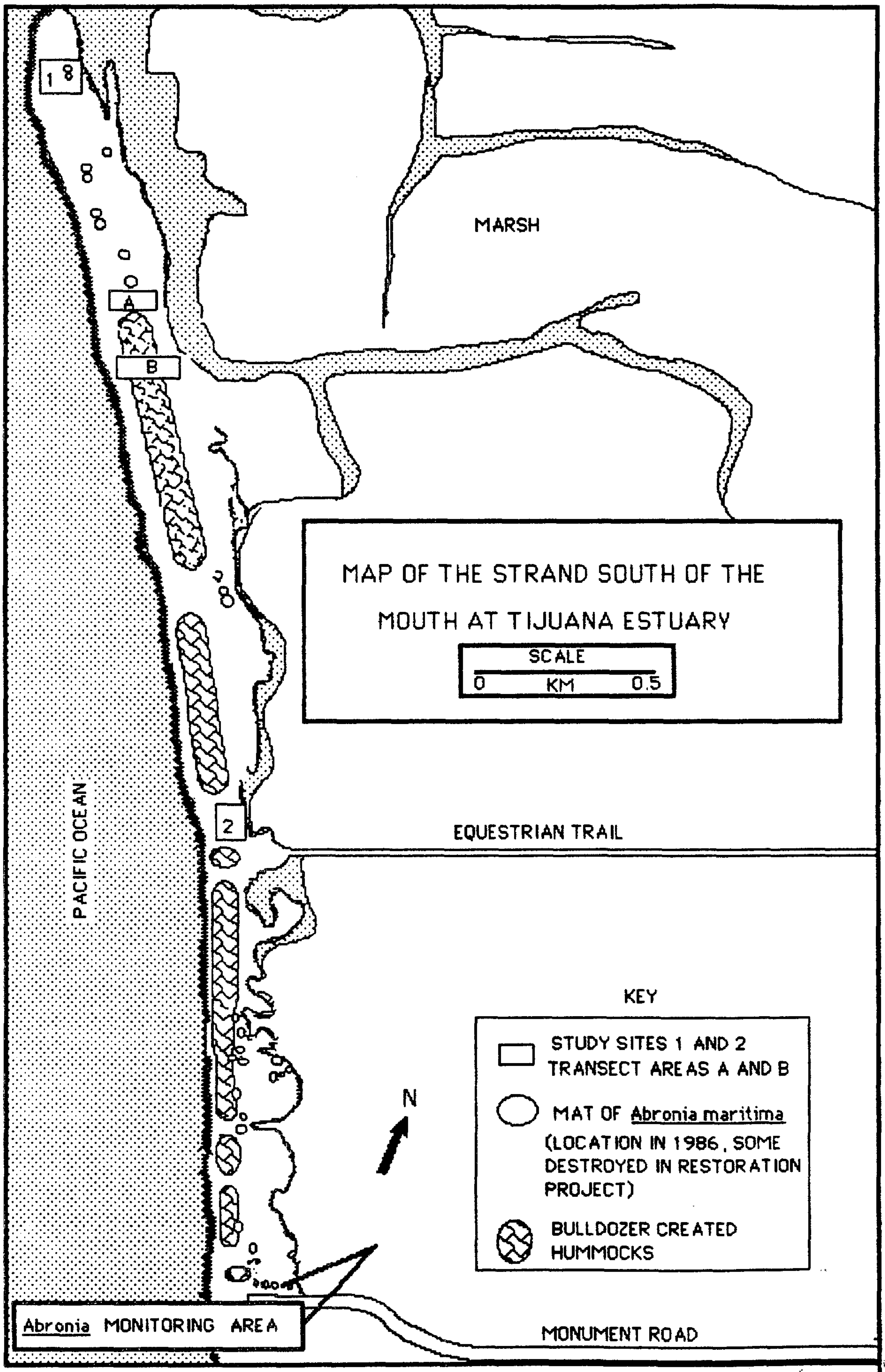

Figure 3. Geographic range of *Abronia maritima*

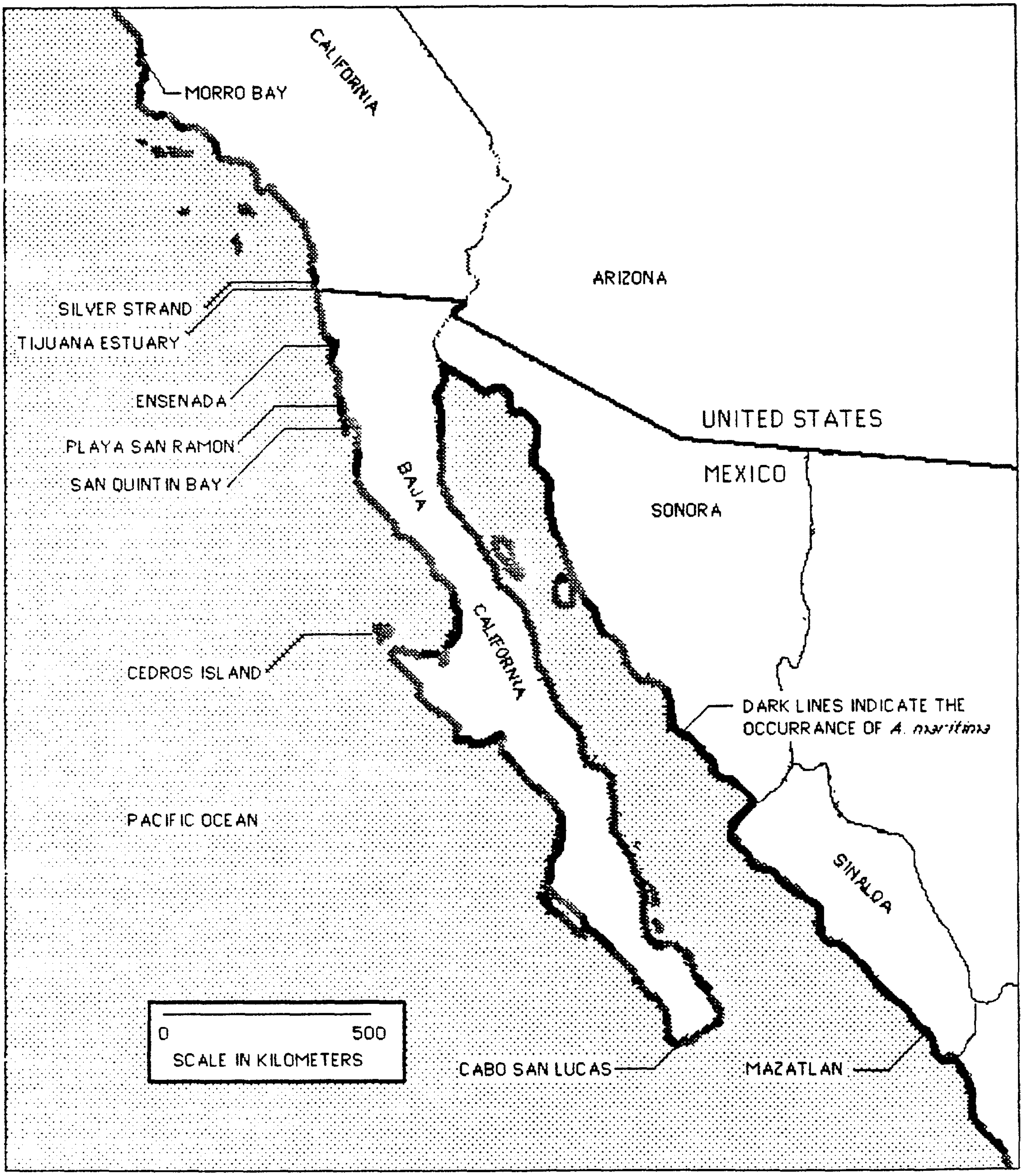

Figure 4. Root biomass (mean weight per plant, n=5). Ratios represent the number of *Abronia* and the number of *Cakile* plants present in each pipe. Bars are + 1 standard error.

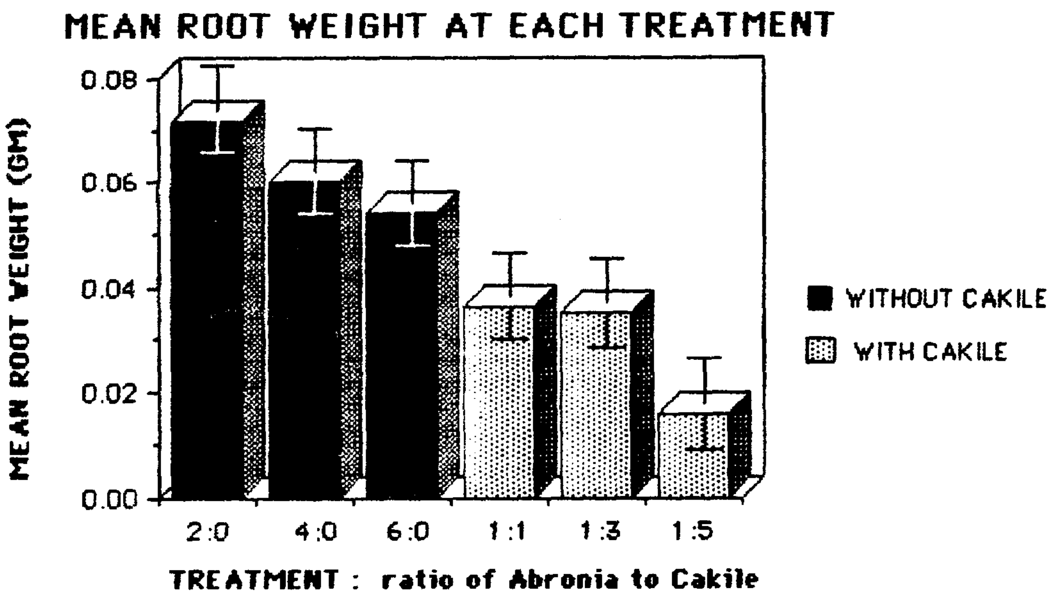

Figure 5. Shoot biomass (mean weight per plant, n=5). Ratios and bars as in Figure 4.

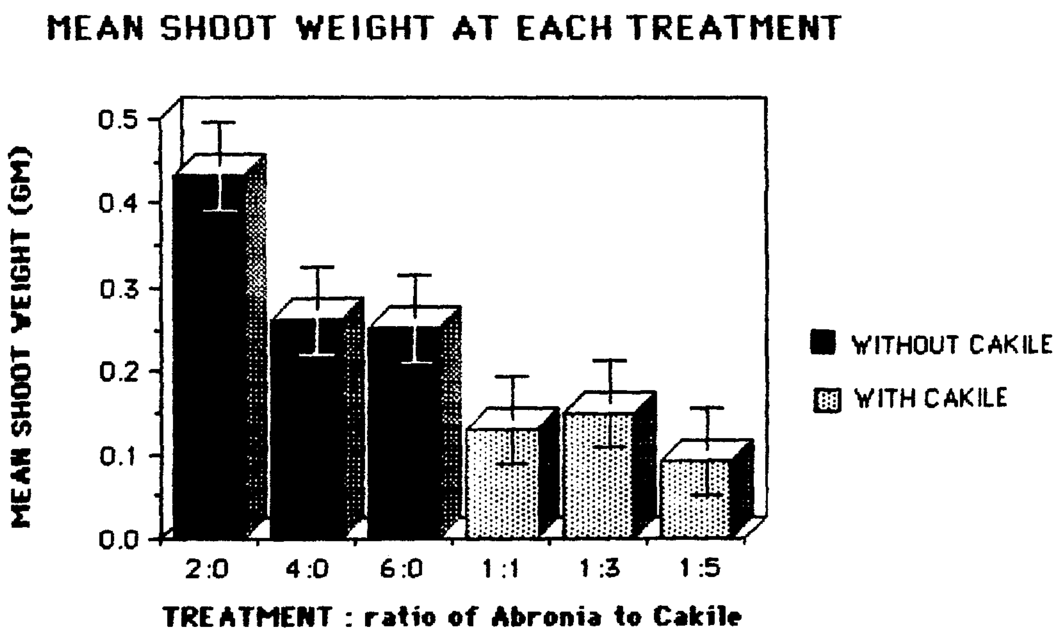

Figure 6. Total plant biomass (mean weight per plant, n=5). Ratios and bars as in Figure 4.

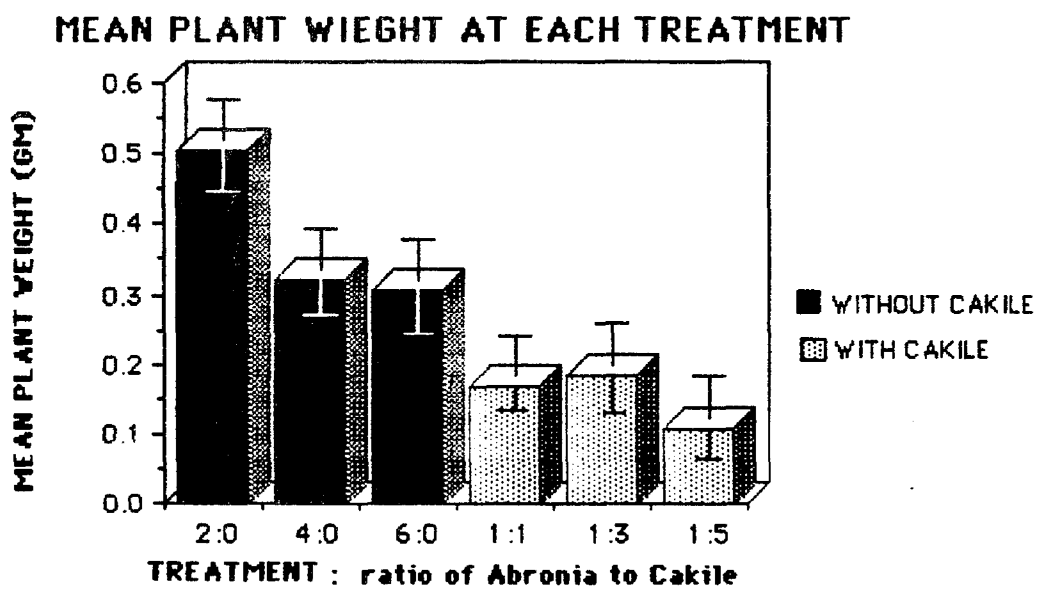

Figure 7. *Abronia* mat growth: Six individual mats of *Abronia* measured over an eight-month period.

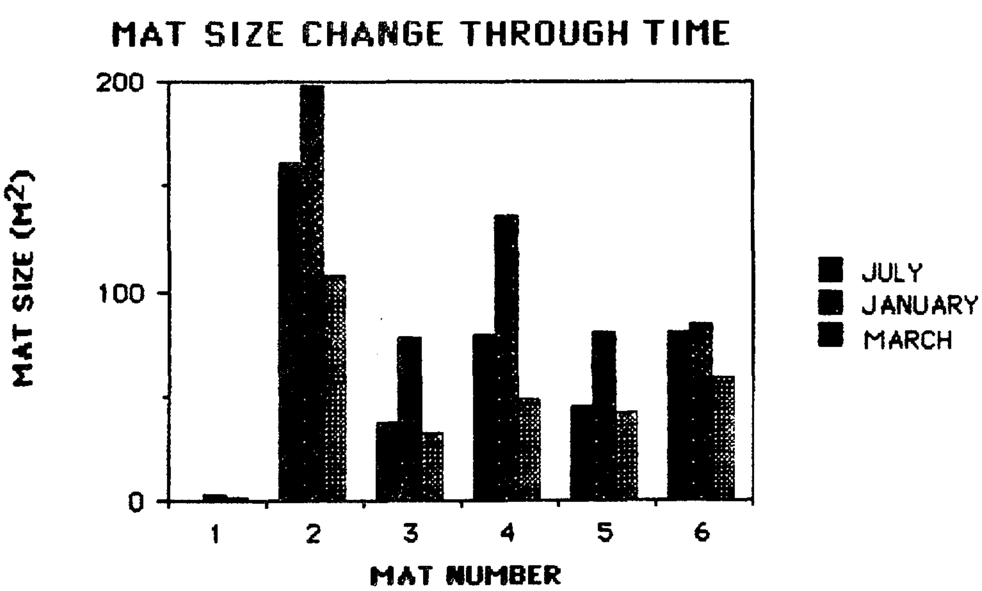

Figure 8. Biomass data from the fertilizer experiment (mean weight per plant, n=[illegible]). Ratios and bars as in Figure 4