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Dune restoration at Sunset State Beach in Northern California

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**DUNE RESTORATION AT SUNSET STATE BEACH
IN NORTHERN CALIFORNIA**

**A Thesis
Presented to
The Faculty of the Department of Environmental Studies
San Jose State University**

**In Partial Fulfillment
Of the Requirements for the Degree
Master of Science**

**By Eryn Leigh Caster
December 2001**

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ABSTRACT

DUNE RESTORATION AT SUNSET STATE BEACH IN NORTHERN CALIFORNIA

By Eryn L. Caster

Coastal sand dune environments in northern California are subject to degradation as a result of development, uncontrolled pedestrian access, and agriculture. Ecological restoration is becoming increasingly important in efforts to preserve this unique environment. This research gathered and analyzed data from a coastal sand dune restoration project at Sunset State Beach, in Watsonville, California to determine the relationship of the restoration site to a relatively undisturbed reference site. The study site is a seven-acre blowout area that has been revegetated with native plants propagated from genetic stock taken from within the park. A seven-acre control site adjacent to the restoration site was used for comparison. Data were gathered on several parameters including; soil seed bank, soil nutrients, density, species diversity, frequency, and coverage parameters. This study found that there was a statistically significant difference among the parameters measured on the restoration site and the reference site.

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Introduction

Coastal sand dune systems are dynamic and fragile. The use of coastal dunes for residential, agricultural, and industrial purposes has destroyed much of the native coastal dune habitat in California. In addition, uncontrolled visitor foot traffic over the sand dunes has caused some damage to plant communities (Gray, G. 1996). The survival of the coastal sand dune ecosystem and many of the species associated depends on effective preservation, restoration, and management of the ecosystem. The purpose of this study is to gather data on the current status and progress of a restored dune site in order to prepare recommendations for meeting the management objectives at Sunset State Beach in Watsonville, California.

Ecological restoration is growing as a viable approach to preserve coastal dune ecology. As the dune environment becomes more disturbed due to increased use by humans, restoring it will become increasingly important for ethical, scientific, aesthetic, and recreation purposes. Dune restoration will provide increased recreational opportunities including landscape painting, photography, bird watching, and just relaxing with a picnic. Native plant walks, talks about endangered species, and interpretive programs about the dune environment's plant and animal communities are important to the public's appreciation of the coast and will increase awareness of the need for

protection. Coastal sand dunes provide habitat for threatened and endangered species in California (Appendix 1); in order to ensure survival of those species, it is important that they have the habitat necessary for their survival. Stabilizing the shifting sand is not enough to ensure the survival of those species. The habitat must be protected and restored to ecological conditions that support the indigenous biotic community and natural ecosystem processes. By understanding the factors that result in successful restoration of coastal sand dune environments, we can preserve and better protect endangered populations of both plants and animals.

Currently, data on the performance of coastal sand dune restoration projects are lacking, especially in terms of achieving ecosystem integrity and meeting stated objectives. Since current projects often use past projects as models, it is important to determine the performance of past projects (Moss 1996). If these past projects have not met their goals, it is important to determine why in order to improve upon the restoration techniques employed. This research will provide the necessary data to determine if the stated management objectives for the Sunset State Beach restoration site have been met and will produce recommendations for monitoring which can be beneficial to future projects. Recommendations will be based on examples of remaining habitat as models

for restoration site performance. In addition, the monitoring methods outlined in this project may be used to evaluate the success of other dune restoration projects.

This study evaluated the restored area by measuring baseline parameters including: soil nutrient levels, the number and type of seeds in the soil seed bank, species diversity, density, composition, and frequency. This research addressed several questions: (1) Was the restoration effort successful in meeting the goals for dune stabilization and the native species establishment set for the site? (2) How closely does the restoration site mimic the vegetation composition and soil characteristics of a reference site? (3) Is a long term monitoring plan necessary? (4) What recommendations for future Pacific coast dune restoration can be drawn from Sunset State Beach restoration effort?

Sunset State Beach is located in the south end of Santa Cruz County, 5 miles west of Watsonville, California. Much of the area inland from the ocean is dominated by sand dunes. The coastal sand dune environment is very fragile. Wind and wave action is constantly shifting the sand. The flora of the dune ecosystem has evolved to cope with the constant environmental change; the dune plants are able to withstand shifting sand, desiccation, wind, and sea spray. Undisturbed, the coastal sand dune vegetation stabilizes

the sand and provides habitat for wildlife. Unfortunately, much of the original dune area has been disturbed, and in an effort to restore the unique habitat, it has been revegetated.

In assessing this restoration site, permanent quadrates were established. The number and types of plants that occur on the restoration site and on the reference site were recorded within quadrats. Within each quadrat, for each plant, the foliage diameter was measured in centimeters. The data were used to calculate cover, density, diversity, and frequency. Data in a subset of quadrates was gathered on the soil seed bank and soil nutrients.

There are many parameters that can be used to assess the success of restored plant communities. The methods chosen for this study were adequate to determine if the restoration project met the stated management goals and to provide a basis for future monitoring. The permanent quadrats allow the project manager to return to the same spot in future years and collect data at different times thereby providing useful information about the changes in the plant populations and physical characteristics over time.

This Master's thesis research focused on the restoration of one Pacific Coastal dune site, however, the results can be used to devise and implement effective monitoring plans for other dune areas along the central coast of California. There are numerous sites around the Monterey Bay that require native dune restoration, and this project will provide useful

and effective monitoring recommendations that can be used by managers implementing these projects. This research will also provide baseline data that can be used to set target criteria in future dune restoration projects. The lack of data from reference sites on ecological structures and functions is a major problem in restoration. This thesis will provide some of this important data for northern California dune habitats. Private organizations seeking to determine if mitigation projects are successful will also find the results of this project useful. Also, managers of dune restoration projects, especially the State Department of Parks and Recreation and the Fort Ord redevelopment committee, can use the methods outlined in this project to set up effective monitoring plans.

Objectives

This research evaluated a set of site parameters at the Sunset State Beach dune restoration site 12 years after the implementation of a 7-acre restoration project. The conditions at the restoration site were compared to a reference site in order to address these four questions: (1) To what extent does the restored area at Sunset State Beach have the same species composition as the undisturbed area? (2) Is there a statistically significant difference in seed bank composition between the two sites? (3) Is there a statistically significant difference between the average percent cover between the restoration site and the reference site? (4) Is there a statistically significant difference between the nitrogen, phosphorous, organic carbon, organic matter, and pH on the restored area, the reference site, and in the greenhouse? Qualitative comparisons were made between the literature on dune plant communities and the restoration site. The State Park goals for the restoration project are compared to the current site conditions to assess progress toward State Park management goals. Finally, these data are used to make recommendations to further the site goals and to help in planning and executing new dune restoration projects.

Related Research

General Description of Coastal Sand Dune Ecosystems

The coastal dunes along the Northern California coast are composed of a series of parallel ridges that form perpendicular to the prevailing winds. The dunes extend south from Bodega Bay to the northern end of Monterey County. The dune field system in the Monterey Bay region is the largest in California, covering approximately 40 square miles (California Coastal Commission 1987). The climate is characterized by cool wet winters with warm and dry summers and average temperature ranges between 45-65 °F throughout the year. The mean annual precipitation along the coast averages 18 inches (SCDPR 1990). Common dune plant species include yellow bush lupine, *Lupinus arboreus*, yellow and pink sand verbena, *Abronia spp.*, beach pea, *Lathyrus littoralis*, yarrow, *Achillea millefolium*, and beach sagewort, *Artemisia pycnocephala*. Two common invasive non-native species that occur on the coastal dunes include ice plant, *Carpobrotus spp.* and European dune grass, *Ammophila arenaria*. Dune erosion is increased by coastal development and the building of sea walls and other protective structures that disrupt natural recycling of sand to the beaches. Off-road vehicles, foot traffic, and horses can damage native dune vegetation, loosening the sand, leaving the dunes vulnerable to erosion.

Coastal sand dunes are composed of nearly pure sand with few clay particles to retain moisture and nutrient ions. Typically, the soil is low in nitrogen and phosphorous, and there is no rich black color from decomposing organic matter (Barbour 1973). Dune soils are composed mainly of quartz and carbonate, and a small amount of heavy mineral may be present. Soil drainage and permeability are rapid, leading to leaching of calcium carbonate and other nutrients (Packham 1997).

Differences in soil moisture content and salinity are important in determining the different species composition along topographic gradients. Fluctuations of these two factors may be responsible for year-to-year changes in the occurrence of short lived dune species (Oloff, Huisman, and Van Tooren 1993). Oloff, Huisman, and Van Tooren (1993) found that nitrogen was an important limiting factor in aboveground biomass production of dune vegetation.

Vegetation plays a key role in determining the shape of sand dunes and the amount of sand transported in a dune system. Vegetation acts as a baffle, absorbing wind energy and determining the shape of dune. Dune vegetation is uniquely adapted to deal with high salt concentrations and wind (Viles and Spencer 1995). Plants that live in areas of high wind have reduced evaporating surfaces on their leaves and stems, including thick fleshy leaves or the replacement of functional leaves by fleshy green stems (Munz 1964).

Adaptations to high salt concentration include deep hardy root systems and low sprawling shoots. For example, *Abronia latifolia*, yellow sand verbena, grows in mats along the foredunes. Many dune plants have developed physiological adaptations to high salt concentrations and low nutrient levels. For example *Atriplex patula* var. *hastata*, saltbush, has evolved cells for salt excretion on its stem and leaves (California Coastal Commission 1987).

Coastal Dune Succession and Vegetation Communities

Woodhouse (1982) identified three vegetation zones of succession for coastal sand dunes: the pioneer zone, the scrub or intermediate zone, and the forest zone. The pioneer zone is found on the upper beach and foredunes and is characterized by recent or continuing sand movement. Vegetation is limited to a few species of grasses, forbs, and sedges. A majority of these pioneer species act as dune stabilizers and dune builders, including *Lupinus ssp.* and *Ericameria ericoides*. The scrub or intermediate zone is immediately behind the pioneer zone where ridges, plains, and swales characterize the topography. This zone is considered a progression in ecological succession toward a mature forest community. In the scrub intermediate zone, sand movement decreases, soil development begins, and plant diversity increases compared to the pioneer community.

Additional plant species in this community include *Ambrosia sp.* (beach bur), *Artemisia pycnocephala* (beach sagewort), and *Abronia sp.* (sand verbena). Many plants within this zone cannot withstand sand burial and the thin open ground cover is less resistant to wind erosion. The forest zone forms on dunes only after substantial soil development. The vegetation varies from thick shrubs and vines to coniferous and hardwood forests.

Cooper (1922) described succession in the Monterey Bay region as progressing from a pioneer community to dune scrub, then to chaparral, and finally to an oak or pine woodland. Cooper described the pioneer community as including *Abronia latifolia*, *A. umbellata*, *Artemisia pycnocephala*, *Erigonum latifolium*, and *Poa douglasii*. He states that the dune scrub community is dominated by *Ericameria ericoides*, with *Eriogonum parvifolium*, *Eriophyllum staechadifolium*, and *Lupinus chamissonis* as important associates. The chaparral stage is largely composed of *Arctostaphylos sp.* and *Ceanothus sp.* The mature community contains an overstory of *Pinus radiata* and *Quercus agrifolia*, with *Pinus* being the dominant overstory on the Monterey Peninsula.

Barbour and Major (1990) describe the species composition occurring most commonly on open dune area as *Abronia latifolia* and *Ambrosia chamissonis*. They list the dune scrub species occurring on stabilized dunes, in order of dominance, as follows: *Lupinus arboreus*, *L. chamissionis*, *Rhumnus californica*, *Baccharis pilularis*, and

Ericameria ericoides. All these species range in height from 1-2 meters. Sub-shrubs were identified as *Artemisia pycnocephala* and *Eriophyllum staechadifolium*.

McBride and Stone (1976) conducted a study to determine the sequence of successional stages of vegetation occurring on the sand dunes of Monterey, California. They calculated total cover, identified the dominant species, and characterized soil development. This study identified two successional sequences controlled by the topographic position on the dunes. One route occurs on the ridges and slopes, the other in the swales. The sequence of succession was closely paralleled by the degree of soil development. The total plant cover increased through the first three stages of succession in all topographic positions. The successional sequence for the slopes and ridges included: 1) bare sand, 2) *Artemisia* –*Ericameria* stage, 3) *Ericameria*-*Baccharis* stage 4) *Baccharis*-*Rhus* stage, 5) *Pinus* stage, a *Pinus*-*Quercus* stage or a *Quercus* stage and a 6) *Quercus* dominated mature community.

Vegetation at Sunset Beach

Four major vegetation communities exist at Sunset State Beach representing 3 stages in the successional sequence for slopes and ridges: coastal woodland/forest with an estimated coverage of 20%, coastal scrub with an estimated coverage of 56%, coastal

strand with an estimated coverage of 9%, and fresh water marsh with an estimated coverage of 15% (SCDPR 1990).

The coastal woodland/forest is dominated by three tree species: the non-native eucalyptus (*Eucalyptus globulus*), and the native Monterey pine (*Pinus radiata*), and Monterey cypress (*Cupressus macrocarpa*). Dominant understory species include coyote brush (*Baccharis pilularis*), seaside woolly sunflower (*Eriophyllum staechadifolium*), and sea fig (*Carpobrotus sp.*).

The coastal strand vegetation occurs near the beach and is dominated by non-native European dune grass (*Ammophila arenaria*). Native species that occur in this habitat include the beach bur (*Ambrosia chamissionis*) and sand verbena (*Abronia umbellata*) (SCDPR 1990).

The coastal scrub community occurs on the stabilized sand dunes between the ocean beach and the upland coastal terrace. Dominant species include: mock heather (*Ericameria ericoides*), bush lupine (*Lupinus arboreus*), sea fig (*Carpobrotus sp.*), and beach sagewort (*Artemisia pycnocephala*) (SCDPR 1990).

Sunset Beach supports a large number of non-native invaders that have displaced natives. The plant list for Sunset State Beach shows that 38% of the species in the park are non-native (Appendix 2). Two of the major competitors are *Ammophila arenaria*

(European dune grass) and *Carpobrotus sp.* These non-natives have altered the composition of the dune community, in some cases outcompeting native plant species for space. *Ammophila* will extend new shoots when it is partially buried by sand; the new shoots trap more sand crowding out native species, changing the structure of the dune plant community (California Coastal Commission, 1987).

A rare native species that requires protection is *Chorizanthe pungens* (Monterey spine flower), an endemic plant that is listed by the federal government as threatened. The spine flower thrives on open sand and disturbed habitat and, interestingly, is growing well along the edges of the park trails that connect the different camp ground loops (Teare 1995).

Agricultural and residential development surrounding Sunset have had a direct impact on the dune ecosystem. Management practices on the surrounding agricultural lands, including the use of pesticides and fertilizers, affect the quality of air and ground water within the park. The construction of rock walls near the residential developments, which are adjacent to Sunset State Beach, affect the movement of sand to the dunes and may increase coastal beach erosion (SCDPR 1990). With continued development, the remaining natural ecosystems have become increasingly important as representative of the natural conditions of the area (Figure 1). Several areas at Sunset State Beach are

Figure 1 Aerial Photograph of Sunset State Beach
California Department of Parks and Recreation. 1986.

excellent patches of the indigenous beach and dune environment exhibiting mobile dunes, beach berms, intertidal, and subtidal areas.

Animal Life

The diversity and complexity of coastal dune plant communities support a variety of animal life. Habitats at Sunset State Beach that provide important habitat for bird species include a fresh water lagoon, a popular feeding and resting spot for migrating birds. The endangered snowy plover and brown pelican rest and forage at Sunset State Beach (Bloome 1996).

The coastal scrub community represents a dense mosaic of vegetation, and a herbaceous understory provides habitat for many mammals, reptiles, and birds. Some of these species are the dusky footed wood rat (*Neotoma fuscipes*), deer mice (*Peromyscus sp.*) California vole (*Microtus californicus*), brush rabbit (*Sylvilagus sp*), song sparrows, northern alligator lizard (*Gerrhonotus coeruleus*), western fence lizard (*Sceloporus occidentalis*), and Pacific gopher snake (*Pituophis melanoleucus catenifer*) (SCDPR 1990).

The California Department of Fish and Game's Natural Diversity Data Base (NDDDB) lists coastal freshwater marsh and the dune scrub as sensitive plant communities

(Natural Heritage Division California Department of Fish and Game 1996). The NDDDB also provides information on threatened and endangered plants and animals within the park. Several endangered plant and animal species occur at Sunset State Beach (Appendix 1). One species that receives special management effort is the snowy plover, a threatened shore bird that breeds on the beach. California Department of Parks and Recreation staff and volunteers place wire mesh cages over nests containing eggs in an attempt to prevent damage to the eggs and to protect young chicks from fox predation (Bloome 1996).

Background on Restoration

According to Cairns (1991), "Restoration means recreating both the structural and functional attributes of a damaged ecosystem." However, before a restoration effort can begin, the restorationist needs to understand the basic ecological components and processes of the community and understand why there is a need for restoration. Bradshaw (1987) states, "Restoration requires that we understand not only the nature of the ecosystem itself, but also the nature of the damage and how to repair it." Anyone who desires to restore anything will soon realize that they need to know something about

the object, the nature of its parts, how it was constructed, and how the whole system works (Bradshaw 1987).

It is impossible to know all of the factors that comprise and influence a natural community, therefore restorationists must choose to reinstate those structures and processes that best move a site toward a functioning community. Based on the goals of a project and the implementation methods, restorationists must choose the monitoring parameters that best measure the progress of the site toward ecological functioning within economic and time constraints. Time and cost constraints require that: 1) restoration projects must be oriented toward a defined goal; 2) management recommendations should be based on the results of targeted monitoring; 3) efforts that are out of scope with the defined goal should be avoided (Palmer 1987).

Ecological recovery should involve the re-establishment of the ecosystem to some "pre-disturbance" condition or "original" condition. Parameters targeted typically include the original species composition, original frequency of species present in the community, original cover and height of species, original species pattern, and the original interrelations of plants and animals in the community. "Original" is often defined as "compared with corresponding natural, undamaged area", or reference site (Hylgaard

1980-81). The recovery of damaged ecosystems is associated strongly with re-establishment of natural successional processes (McIntosh 1980).

Ewel (1997) has defined five criteria by which to judge the success of ecosystem restoration: sustainability, invasibility, productivity, nutrient retention, and biotic interaction. In order for restoration to be successful the ecosystem must be sustainable, capable of perpetuating itself without being managed by people. The restored ecosystem should resist invasions by new species. A restored community should have productivity equal to the original community. Net ecosystem productivity measures many processes including photosynthesis, respiration, herbivory, and death; therefore, it is useful in measuring community performance. If the restored community loses greater amounts of nutrients than the original community, it will be unsustainable in the long run, experiencing declines in productivity and invasions by new species. Biotic interactions lead to the reconstruction of the whole community. If a restored community is missing an essential microbes, a key pollinator, or a specific link in the food chain the ecosystem will not function like the original.

Unfortunately, many factors constrain restoration and reproducing the pre-disturbance condition frequently is not possible (Cairns 1989, 1991). For example, there is often a lack of information on the pre-disturbance condition of the system. Information

such as habitat size, surrounding habitat types, and original species composition may not be available (Cairns 1989). Restorationists must do their best to determine this information from historical sources, aerial photos, and measurements from model sites.

Reference sites are necessary for the comparison of the restored area with a corresponding undamaged area. Reference or model sites are critical to planning and evaluating restoration projects. Measurements of the ecological structures and functions or the natural ecosystem taken at reference sites can be used to provide target criteria for the restoration site. These target criteria therefore determine what parameters will be monitored.

Bradshaw (1987) uses a simplified 2-dimensional graph that provides ecological perspectives on restoration practices. The graph (Figure 2) also illustrates the different forms that restoration of degraded lands make take. Ecosystem development can be shown in two dimensions, structure and function. In natural succession, there is an increase in both dimensions. Restoration is designed to move a degraded site onto a natural trajectory that will eventually take the site back to a fully functioning ecosystem. Many factors may constrain full recovery and may take the site off this idealized trajectory.

Figure 2. Bradshaw's Graph of Ecosystem Development

A. D. Bradshaw, The reclamation of derelict land and the ecology of ecosystems, In Restoration Ecology. 1987

Once the restoration effort is planned and implemented, restorationists assess whether the system: 1) Is on or near the expected restoration trajectory, and 2) Is meeting the goals set for the restoration. To assess the progress of a restoration project, long term monitoring is necessary (Viles and Spencer 1995). For species, "monitoring is a quantitative assessment of the status of a population over time..." (Pavlik and Barbour 1988). Palmer (1987) defines rare plant monitoring as : "The acquisition and analysis of quantitative data that document the condition of the population or community over time. The goal of such documentation may include detecting changes at a site or testing the effects of a management treatment."

Management requires knowledge of the population status, that is whether it is growing, declining, or stable, under natural conditions (Pavlik and Barbour 1988). Successful monitoring requires that efforts be both efficient and accurate (Palmer 1987). If monitoring is to contribute significantly to our understanding of restoration and ultimately to effective management, it must yield a predictive understanding of population structure and function (Davy and Jefferies 1981).

Methods for Monitoring Plant Populations

When monitoring plant populations, a variety of techniques should be used in conjunction with each other. Integrated monitoring studies that contribute data toward a complete understanding of the biology of rare species are most useful as a basis for conservation management, "Permanent quadrat studies and survey techniques have been successfully used together, in large measure overcoming the deficiencies of scale in the former and the lack of perspective in the latter" (Davy and Jefferies 1981).

There are a wide variety of methods for monitoring plant populations and many techniques can be directly applied to monitoring restoration projects. The data that are generated can be used to evaluate the progress of the restoration project and can be used to change the current management practices, if necessary.

A valuable parameter for monitoring dune restoration projects is soil seed bank analysis, quantifying the density and type of seeds in the soil. This parameter can provide useful data of the past species composition of an area (Glass 1988, Hutchings 1986, Harper 1977). The role of seed banks is becoming increasingly important in understanding changes in populations and communities (Glass 1988). Data from seed bank analysis can be used to determine which species are present in the soil compared to which species are actually growing (Pavlik and Barbour 1988). Understanding the seed

bank may prove useful in efforts to maintain floristic diversity within a community (Glass 1988).

It is important to determine not only the density and diversity of plants at a study site, but to also evaluate the health and potential for reproductive success among individuals of plant population. Analysis of seed samples illustrates differences in reproductive output among different populations of plants and may also indicate the presence of seed predators. The reproductive output of a plant is an indicator of how well the plant is doing in its natural environment (Pavlik and Barbour 1988).

Plants should be surveyed for canopy volume, which is deduced from measurements of plant length, width, and height. The number of inflorescences per plant, the number of developed and aborted fruit, and the number of flowers per inflorescence should also be sampled. These values can be used to calculate the mean number of seed containing fruits per individual (Pavlik and Barbour 1988).

Soil type is one of the factors that directly controls plant species distribution and performance (Ball 1986). A plant that grows in a certain type of soil is adapted to the mineral and nutrient content of that soil (Campbell 1993). When taking a plant from one area and transplanting it to another, there may be differences in the soil nutrients and minerals that may effect plant survival and reproduction. It is important to determine if

the variation in soil nutrients between areas is having an effect on the establishment and reproductive success of plants on the restoration site.

One method of preparing plants for the restoration site is to compare the nutrient composition in the soil from which the plants were taken with that of the soil on the restoration site. For example, if plants are grown in a greenhouse it is important to understand the differences between greenhouse conditions and the restoration site. Kachi and Hirose (1983) found that there was a difference in the limiting nutrients between the greenhouse soil and the soil of the sand dunes in which the plants were established. In the greenhouse, phosphorous was the soil nutrient that limited plant growth; on the study site, soil nitrogen was the limiting nutrient. Application of fertilizer can help plants make the transition from greenhouse soil to sand dunes. Soil nutrient assessment can also establish changes in soil nutrients over time. Nitrate can be leached quickly out of dune soil, primarily because of the low water holding capacity of sand. Changes in soil nutrients over time may explain changes in reproductive success or species composition. Olff, Huisman, and Van Tooren (1993) found that nitrogen was an important limiting factor in aboveground biomass production of dune vegetation.

"Permanent quadrats have been the backbone of long-term studies of vegetation change" (Goldsmith, Harrison, and Morton 1986). By sampling vegetation in successive

years through the use of quadrats, it is possible to produce a diagram which shows the degree of vegetation type change over the long-term.

If rare plants are a part of the restoration, specific methods may be used to monitor them. Palmer (1987), identifies 3 methods used to monitor rare plant populations: (1) inventory studies, (2) survey studies, (3) demographic studies. An inventory is a simple count of plants in a population repeated at intervals, usually yearly. This is a way of monitoring population size from year to year. A survey study uses a repeatable sampling methods to make estimates about the community or population parameters. Also, a survey can be used to obtain more data on an entire population, in addition to an inventory, such as the number of plants that reproduce in a year. Demographic studies involve marking and mapping every plant in the sample in order to follow the fates of individual plants.

Unfortunately, there is a lack of monitoring data from dune restoration projects, in general. Specifically, the dune restoration project at Sunset State Beach began in 1985, and data on the establishment success, growth rate, or reproductive success of transplanted seedlings had not been regularly collected or documented (Gray, G. 1996).

Description of the Existing Site

Location

Sunset State Beach is located in the south end of Santa Cruz County, five miles west of Watsonville, California, and it is one of the 10 state-owned beaches located along Monterey Bay (Figure 3). Sunset State Beach is approximately 13 miles south of Santa Cruz, within three miles of State Highway 1. The park is spread between two USGS quads: Watsonville West and Moss Landing (Figures 4 and 5). Sunset State Beach, approximately 305 acres in size, is bounded by the Pacific Ocean to the west, the Pajaro River to the south and Sunset Beach Road to the north.

Figure 3. Location map of State owned beaches in the Monterey Bay Region.
California Department of Parks and Recreation, Sunset State Beach general plan,
1990.

Figure 4. Watsonville West Topographic Map with Sunset State Beach designated above the Pajaro River. USGS 1954.

Figure 5. Moss Landing Topographic Map. USGS 1954.

Park Description

In the Monterey region, the immediate inland area from the ocean is dominated by sand dunes, a fragile environment in which wind and wave action constantly shifting the sand. The southwest facing topography of Sunset State Beach consists of extensive sand dunes ranging in elevation from 200 feet in the northern section of the Park to 40 feet in the southern section. Wind erosion causes sand deposition east of the beach resulting in a change in dune configuration.

The beach itself provides many recreational opportunities including fishing, surfing, boogie boarding, beach combing, sun bathing, kite flying, and bird watching. The Park also has camping facilities for recreational vehicles, touring bicyclists, and tent campers. There are several interpretive programs that are offered at the Park including Jr. Rangers, nighttime campfires, and nature walks. A unique feature of the Park is the glider port where model plane enthusiasts launch and fly their airplanes.

As stated earlier, there are four dominant plant communities found in the park: coastal woodland forest, riparian, coastal strand, and the coastal scrub community. The coastal scrub community has been degraded by human activity and, therefore, has been the focus of restoration work by the State Park personnel. However, there are also patches of relatively intact coastal scrub. This thesis research focused on a comparison

between an intact coastal scrub community and a coastal scrub restoration project at Sunset State Beach.

Need for Restoration

The Department's management policy for the coastal sand dunes at Sunset State Beach is as follows:

Human activities within the dunes shall be regulated to prevent destruction of the natural dune environment. Hiking, horseback riding, model plane gliding, and other recreational uses shall be restricted to designated areas and routes. Destabilized areas within the dunes shall be revegetated. The highest priority for dune stabilization and revegetation in this area will be where continued erosion threatens recreational facilities. In order to maintain the genetic integrity and diversity of California native plants, revegetation efforts shall utilize native plants from local populations (SCDPR 1990).

A variety of management problems at Sunset State Beach have degraded natural habitats. Overuse by visitors has been a problem since the creation of the park in 1931 (Gray, G. 1996). Heavy recreational use, including surfing, swimming, surf fishing, volleyball, model plane gliding, and camping has lowered the quality of the dune habitat in some areas, of the park. The coastal areas of Santa Cruz County are major recreational destinations in California. Sunset State Beach averaged more than 390,000 visitors annually in 1980. Camping within the park accounted for 37% of the visitors (SCDPR

1990). Uncontrolled pedestrian traffic from the camp ground to the beach has disturbed native vegetation and destabilized sand dunes allowing the sand to shift, in some cases covering vegetation and causing dune blowouts. In an effort to stop the shifting sand and stabilize the dunes, ice plant, an invasive non-native species, was planted in 1976 (Gray, G. 1996). The ice plant has altered the native community structure, as well as the distribution of native species, and is competing with native species. Currently, there is an ice plant removal program in place.

This research is focused on the coastal dune restoration project that began in 1984/85. The goals for the project were to: 1) Stabilize the shifting sand at the restoration site, 2) Revegetate the site with native species, 3) Increase numbers of the endangered Monterey spine flower, *Chorizanthe pungens* var. *pungens*.

Dune restoration was required to repair habitat damaged by uncontrolled pedestrian traffic from the park's campground over the sand dunes. The pedestrian traffic removed the vegetation and weakened the dunes resulting in a "blowout". A blowout occurs when an area of vegetation is lost or destroyed, and the sand is free to blow away. To repair the damage and restore the native community, the California Department of Parks and Recreation initiated a revegetation and dune stabilization effort in 1985. As part of the stabilization program, the sand dunes were fenced off restricting pedestrian

access. A sand ladder series was put in place between the fenced-off dunes. The sand ladders consist of logs wired together providing a path over the dunes and they are designed to limit uncontrolled pedestrian foot traffic. To begin the revegetation project, a native plant nursery was established, in order to propagate seedlings from the genetic stock of plants within the park. Seed was collected and seedlings were grown in a greenhouse at the park. A monitoring plan was outlined, however, no ongoing monitoring has taken place (Gray, G. 1990). In addition, an exotic plant removal project was undertaken. Ten acres of ice plant were to be removed and eventually replanted with native vegetation.

Dune Restoration and Stabilization Methods

To meet the Department's management policy for Sunset State Beach, the dunes needed to be stabilized in the seven-acre blowout area before the revegetation effort could begin. There are several methods for stabilizing sand dunes including putting crimped or tackified straw into the sand, placing polypropylene netting over the straw, hydromulching, or using a stabilizing emulsion such as kelp. Straw crimped into sand is effective and economical, and this was the method chosen for stabilizing the dunes at Sunset (SCDPR 1985).

Straw was applied at the rate of 6,000 pounds per acre. The straw was spread over the sand and then crimped, or in some cases, rolled into the sand. The straw was crimped with a "Finn" crimper, which forces a blunt straight notched disk into the sand, pulled by a tractor. Rolling is accomplished by a specially designed roller that is either pulled behind a tractor or moved up and down steep slopes with a winch (SCDPR 1985).

After the straw was spread, native seed, ammonium phosphate fertilizer and a stabilizing agent were applied to the blowout area. The seed was collected from plants within the Park. Application of the seed varied from 5-20 pounds per acre (Table 1). The fertilizer used was a slow release fertilizer applied at a rate of 500 pounds per acre. All applications were done with hydroseeding equipment. As a contingency measure, 20,000 plants were grown from native seed in a nursery for later planting, if broadcast seeds did not grow (SCDPR 1985).

Table 1. Composition of seed mix

Species name	% in seed mixture
<i>Artemisia pycnocephala</i> (Beach Sagewort)	17
<i>Eriophyllum staechadifolium</i> (Lizard Tail)	22
<i>Ericameria ericoides</i> (Mock Heather)	42
<i>Lotus scoparius</i> (Deerweed)	4
<i>Lupinus arboreus</i> (Bush Lupine)	15

Revegetation

Seeds collected from sources within the park and surrounding areas were propagated in a greenhouse located at the park. A total of ten different species were propagated and over 14,000 seedlings were planted on the restoration site (Table 2). The plants were taken from the greenhouse to the field and planted in the winter after at least two inches of rain to eliminate the need for an irrigation system. In the spring, more seed was collected and the cycle was begun again (Teare 1995).

Table 2. Origin of seed stock

Species name	Seed source	Number planted on site
<i>Eriophyllum staechadifolium</i> Lizard tail	Soledad prison	information unknown
<i>Ericameria ericoides</i> Mock Heather	Soledad prison	information unknown
<i>Lupinus arboreus</i> Bush Lupine	Soledad prison	information unknown
<i>Artemisia pycnocephala</i> Beach Sagewort	Soledad prison	information unknown
Total		12240
<i>Eriophyllum staechadifolium</i> Lizard Tail	Napa CCC	1200
<i>Eriophyllum staechadifolium</i> Lizard Tail	Ano Nuevo	500
<i>Chorizanthe pungens</i> Spine Flower	Shade house	300
<i>Cirsium occidentale</i> Cobweb Thistle	Shade house	200
<i>Chlorogalum pomeridianum</i> Soap Plant	Shade house	40
<i>Oenothera cheiranthiaefolia</i> Beach Primrose	Shade house	50
<i>Erysimum latrinose</i> Coast Wall Flower	Shade house	50
<i>Dudleya farinosa</i> Live Forever	Shade house	0
<i>Ericameria ericoides</i> Mock Heather	Shade house	40
<i>Lupinus arboreus</i> Bush Lupine	Shade house	50
Grand Total		14,670

An important feature of the restoration work was protecting the new plants from *Spermophilus beecheyi*, the California ground squirrel. This rodent eats the roots and shoots of the newly transplanted seedlings and can destroy or limit the success of restoration plantings. To combat this problem a two step abatement program was instituted. Each plant seedling was protected from rodent herbivory with a small cage constructed of chicken wire. The cages were 10 inches high and 6 to 10 inches in diameter. The second step was squirrel eradication. Bait stations were placed near active burrows and baited with diphacione treated grain, a poison (Ferreira 1989). The removal program was temporarily successful in reducing the number of ground squirrels, however, the squirrel population eventually returned to a high level, then leveled out (Ferreira 1989).

Restricting Human Access

Sand dunes have been greatly impacted by human use. Development causes the entire loss of dune systems and dunes suffer degradation due to human pedestrian and vehicle traffic. Uncontrolled pedestrian traffic is a serious impact to the ecosystem leading to dune 'blowouts', the complete loss of vegetation allowing free sand movement. Once a blowout has occurred, the steady movement of sand makes natural

revegetation very difficult. However, some restoration or revegetation methods can be undertaken to stabilize the dunes and restore native vegetation.

At Sunset State Beach, pedestrian traffic between the campground, parking area, and the beach had destroyed some of the vegetation and reduced the value of the remaining habitat. The seven-acre blowout site was fenced off to keep pedestrian traffic from further destabilizing the dune and upsetting newly sprouted plants. The perimeter of the project was fenced with 2-inch by 4-inch wire mesh with 4-foot by 4-foot posts spaced 8 feet apart. A 2-inch by 6-inch top rail was constructed (SCDPR 1985). Signs were posted along the fence explaining the native plant rehabilitation.

Methods

The methods employed in this research were designed to address these four null hypotheses: (1) The restored area at Sunset State Beach has the same species composition as the reference area, (2) There is no statistically significant difference in seed bank composition between the two sites, (3) There is no statistically significant difference between the average percent cover between the restoration site and the reference site, (4) There is no statistically significant difference between the nitrogen, phosphorous, organic carbon, organic matter, and pH on the restored area, the undisturbed area, and in the greenhouse. Also, data were collected to make qualitative comparisons between the literature on dune communities and the process of the restoration site.

This study employed standard methods for sampling vegetation including quadrats to assess cover, density, and frequency of species occurrence (Barry 1996; Goldsmith, Harrison, and Morton 1986; Bonham 1989; Brower, Zar, and von Ende 1990), a soil seed bank analysis (Pavlik and Barbour 1988; Hutchings 1986), and a soil nutrient assessment for nitrogen, phosphorus, and pH (Kachi and Hirose 1983). Samples of the soil, the soil seed bank, and the placement of quadrates were taken randomly throughout the restoration and reference areas. Each area is approximately seven acres. Thirty quadrat samples, ten soil samples, and ten samples for seed bank analysis were

taken from the reference site and the same number from restoration site. Samples were collected in the spring of 1995.

Parameters measured in each quadrat included percent cover, species composition, species density, and frequency (Haynes 1982). All of these measurements can give insight into the health of the plant population. These data, gathered over time, can provide information about the trend of the plant community, the individual plant species within the community, and the successional state of the site.

A soil seed bank analysis was performed on samples from ten quadrates on the restoration and ten quadrates on the reference site. After sifting through the soil with a mesh sieve, the contents of the sieve were analyzed under a dissecting microscope at 2x or 4x to determine if seeds were present in the samples. Forceps were used to separate the content of the sieve. Once the seeds were found they were identified.

Location of Study Site

The study site (Figure 6) is located at Sunset State Beach in Watsonville, California. The park is comprised mostly of coastal sand dunes. In 1985 a dune restoration and revegetation project began. A seven-acre blowout site was restored using broadcast seeding and plants propagated from stock taken from within the park. The

revegetation project was completed in 1987 and baseline data were gathered on two occasions between January 1986 and April 1987. No monitoring has taken place since the baseline information was gathered. The reference (Figure 7) site is a seven-acre site that has not experienced a blowout: the dune vegetation is relatively undisturbed and no revegetation efforts have occurred on the site. The elevation and topography of the restoration and reference sites are similar. This comparison is suitable because the restored area and the undisturbed area are located within the same park and have the same geologic history, similar soil types, experience the same weather conditions, and have genetically similar plants. These factors reduce the possibility of variation in the results, caused by differences between sites.

Figure 6. Photographs of the Restoration site

Photographs by the author

Figure 7. Photographs of the Reference site

Photographs by the author

Study design and data collection

The study employed random sampling designs on both the reference and revegetated areas. To determine density, species composition, species diversity, and coverage on each site 30 4 x 4-meter quadrats were placed randomly by pre-selecting random coordinates (Brower, Zar, von Ende 1990; Bonham 1989). Ten of those were permanent while the other twenty will not be fixed at each site. In each quadrat, the number of species was counted, abundance of each plant species was determined and the foliage diameter of individuals was measured. The same methods were used to gather data on the rare plant species.

Ten permanent quadrats were established throughout both the restoration and reference areas by setting 1x1x12 inch iron stakes and marking the corners of the quadrates with wooden stakes to facilitate relocation during the study (Barry 1996). Quadrats were marked on base maps of Sunset State Beach. UTM coordinates for each quadrat were recorded using a GPS. Within each quadrat, these parameters were measured: soil seed bank, soil pH, nitrogen, phosphorous, organic matter, organic carbon, and cover.

The soil seed bank was estimated as follows. A 1-liter plastic container was pressed into the sand at random locations within each of the 10 permanent plots (Pavlik

and Barbour 1988). The sand was put into a jar and the seeds were separated using a medium-course mesh soil sieve. The seeds were identified by visual inspection. Those seeds that cannot be identified visually were grown in the greenhouse at Sunset State Beach in soil from the sample area.

The soil was tested for pH and phosphorus in the reference site, the restoration site, and from the greenhouse where seedlings were propagated. Nitrogen, organic matter, and organic carbon were tested at the restoration site and the reference site. Soil nutrient and pH testing were performed by Soil Control Lab in Watsonville, California. Samples were collected randomly from the study area to comprise the total volume of 1 cup of soil per sample. Samples were collected in Zip-Lock bags and delivered to the testing facility the same morning they were taken.

Data Analysis

Microsoft Excel was used to conduct statistical analyses. Calculations performed include the relative frequency of each species, total coverage per quadrat, and average total cover of each species. The mean number of species for the restoration and reference sites was calculated with the standard deviation. t-Tests were performed on the means from the soil nutrient analysis to determine if there was significant difference between the

restoration site and the reference site. t-tests were also preformed on the mean number of species per plot and the average percent cover to determine if there is significant difference between the restoration site and the reference site.

Limitations

The timing of the seed bank analysis may have an effect on the results of the analysis. The seed bank should be tested for more than one year to get an accurate picture of the species in the soil. This will help account for seasonal, climatic, and life history variations. This study spanned only a few months. This study did not construct a full lifetable, but gathered baseline data that can be used in future evaluation of the restoration project and for design of new restoration projects. Due to cost constraints, the number of soil samples taken were limited to 22, ten in the restoration site, ten in the reference site, and two from the greenhouse soil. Gathering soil from several plant root-zones within the study and control area will provide preliminary information on soil composition throughout the area, but will not provide the quantitative data needed to gain a full understanding of the nutrient composition of the sites. Also, the restoration site was only compared to one reference site. Use of three or more reference sites is recommended to give a better idea of the natural variation in the parameters measured.

Results

Soil seed bank

Only three species of seeds were identified at the restoration site: *Artemisia pycnocephala*, *Ghaphalium stramineum*, and *Lotus scoparius* (Table 3). The average number of seeds per plot is shown in figure 8. The total number of seeds counted is given in table 3. Three species were also identified at the reference site: *Artemisia pycnocephala*, *Ghaphalium stramineum*, and *Erysimum ammophilum*. A t- Test ($\alpha=0.05$) was performed comparing the means for the number of *Artemisia pycnocephala* seeds and *Ghaphalium stramineum* seeds at the restoration and reference sites. The analysis did not show significant differences between the means of the samples from the two sites.

Table 3. Total number of seeds found

<u>Species</u>	<i>Artemisia pycnocephala</i> Beach sagewort	<i>Ghaphalium stramineum</i> Pearly everlasting	<i>Lotus Scoparius</i> Deerweed	<i>Erysimum ammophilum</i> Coast wallflower
<u>Restoration site</u>	39	19	2	0
<u>Reference site</u>	22	16	0	4

Figure 8. Average number of seeds found per plot

Plant Species Diversity and Cover

For each site, measurements were taken in 30 quadrats to determine the species diversity per plot, the total number of plants per quadrat, and foliage diameter. Figure 9 shows the total number of different species found overall on the restoration site and the reference sites. Nineteen species were recorded on the restoration site, with *Artemisia*

pycnocephala, *Ghaphalium stramineum*, and *Camissonia cheiranthifolia* occurring most frequently. On the restoration site twenty-one percent of the species, (four species) were non-native invaders (Table 4). The reference site contained 28 different species with *Ericameria ericoides*, *Artemisia pycnocephala*, *Pteridium aquilinum*, *Dudleya farinosa*, and *Erysimum ammophilum* occurring most frequently, on half or more of the plots. Seventeen percent of the species (five species) on the reference site were non-native (Table 5). Both the restoration site and the reference site contained two rare plant species, *Erysimum ammophilum* (Monterey Bay wallflower) and *Chorizanthe pungens* var. *pungens* (Monterey spine flower). An average of 5.0 (sd=0.25) species per plot occurred on the restoration site, while an average of 6.7 species per plot (sd=0.12) occurred on the reference site. A t-Test showed there was significant difference between the average number of species per plot at each site (Figure 10)(t-value=2.1, $\alpha=0.05$)

Figure 9. Total number of different species identified at each site

Figure 10. Average number of species per plot

Table 4. Restoration site species frequency

Species	# of plots found out of 30	Frequency of occurrence (% of plots)
<i>Artemisia pycnocephala</i> Beach sagewort	29	0.96
<i>Gnaphalium stramineum</i> Pearly everlasting	22	0.73
<i>Camissonia cheiranthifolia</i> Beach evening primrose	19	0.63
<i>Lotus scoparius</i> Deerweed	14	0.46
<i>Eriophyllum staechadifolium</i> Lizard tail	12	0.4
<i>Ericameria ericoides</i> Mock heather	10	0.33
<i>Erysimum ammodendrum</i> Monterey Bay wall flower **	8	0.26
<i>Chorizanthe pungens</i> var. <i>pungens</i> Monterey spine flower **	7	0.23
<i>Lupinus arboreus</i> Yellow bush lupine	4	0.13
<i>Gnaphalium ramosissimum</i> Pink everlasting	4	0.13
<i>Carpobrotus edulis</i> Hottentot fig ice plant *	4	0.13
<i>Baccharis pilularis</i> Coyote bush	4	0.13
<i>Carpobrotus chilensis</i> Sea fig ice plant *	3	0.1
<i>Lupinus chamissonis</i> Blue-flowered dune lupine	2	0.06
<i>Dudleya farinosa</i> Live forever	2	0.06
<i>Cyrtanthus intermedia</i> White forget-me-not	2	0.06
<i>Chenopodium ambrosioides</i> Mexican tea	1	0.03
<i>Cakile maritima</i> Sea rocket *	1	0.03
<i>Ammophila arenaria</i> European dune grass *	1	0.03

* = Non-native species

** = Threatened Species

Table 5. Reference site species frequency

Species	# of plots found out of 30	Frequency of occurrence (% of plots)
<i>Ericameria ericoides</i> Mock heather	28	0.93
<i>Artemisia pycnocephala</i> Beach sagewort	17	0.56
<i>Pteridium aquilinum</i> Bracken fern	16	0.53
<i>Dudleya farinosa</i> Live forever	16	0.53
<i>Erysimum ammophilum</i> Monterey Bay wall flower **	15	0.5
<i>Gnaphalium stramineum</i> Pearly everlasting	14	0.46
<i>Eriophyllum staechadifolium</i> Lizard tail	14	0.46
<i>Lotus scoparius</i> Deerweed	11	0.36
<i>Baccharis pilularis</i> Coyote bush	9	0.3
<i>Anagallis arvensis</i> Scarlet pimpernel *	7	0.23
<i>Achillea millefolium</i> Coast yarrow	7	0.23
<i>Cirsium occidentale</i> Cobweb thistle	6	0.2
<i>Gnaphalium ramosissimum</i> Pink everlasting	5	0.16
<i>Chorizanthe pungens</i> var. <i>pungens</i> Monterey spine flower **	5	0.16
<i>Chenopodium ambrosioides</i> Mexican tea	5	0.16
<i>Cyrphantha intermedia</i> White forget-me-not	4	0.13
<i>Carpobrotus edulis</i> Hottentot fig ice plant	4	0.13
<i>Marah</i> sp. Wild cucumber	3	0.1
<i>Abronia latifolia</i> Yellow sand verben	3	0.1
<i>Toxicodendron diversilobum</i> Poison oak	2	0.06
<i>Solanum douglassii</i> Douglas' nightshade	2	0.06
<i>Rumex acetosella</i> Sheep sorrel *	2	0.06
<i>Lupinus arboreus</i> Yellow bush lupine	2	0.06
<i>Camissonia cheiranthifolia</i> Beach evening primrose	2	0.06
<i>Lupinus chamissonis</i> Blue-flowered dune lupine	1	0.03
<i>Lathyrus littoralis</i> Beach pea	1	0.03
<i>Carpobrotus chilensis</i> sea fig ice plant *	1	0.03
<i>Cakile maritima</i> Sea rocket *	1	0.03
<i>Ammophila arenaria</i> European dune grass *	0	0

* = Non-native species

** = Threatened species

Percent total cover in each plot at the reference site plots averaged 83.6 %, while the restoration site averaged 30.7% cover. There was a significant difference between these average cover estimates (Figure 11) (t -value = 10.19, $\alpha=0.05$). On the restoration site, three species, *Artemisia pycnocephala*, *Eriophyllum staechadifolium*, and *Baccharis pilularis* comprised 69.2% of the average total cover, while 17 species made up the remaining 30.8 % of the total cover (Figure 12). On the reference site three species: *Ericameria ericoides*, *Artemisia pycnocephala*, and *Baccharis pilularis* made up 78.5% of the average total cover. The remaining 26 species made up the final 21.5 % of the average total cover (Figure 13).

Figure 11. Average percent cover

Figure 12. Restoration site relative cover

Figure 13. Reference site relative cover

Abundance

The restoration site contained a total of 3,722 plants, while the reference site contained 1,902 plants total. On the restoration site, *Artemisia pycnocephala* was the most numerous species, followed by *Ghaphalium stramineum*, *Camissonia cheiranthifolia*, and *Lotus scoparius* (Table 6). On the reference, site *Chorizanthe pungens* occurred in the greatest number followed by *Dudleya farinosa*, *Artemisia pycnocephala*, and *Erysimum ammophilum* (Table 7).

There was a significant difference in the average foliage diameter of several species between the sites. For example, the restoration site *Artemisia pycnocephala* occurs 1,034 time, with an average foliage diameter of 33.92 cm (Table 6). On the reference site *Artemisia pycnocephala* occurs 190 times with the average foliage diameter of 64.93 cm (Table 7). Also dominant on the restoration site is *Ghaphalium stramineum* occurring 972 times with an average foliage diameter of 9.0 cm. On the reference site *Ghaphalium stramineum* occurs 148 times, with an average foliage diameter of 28.3 cm. On the restoration site *Chorizanthe pungens* var. *pungens* occurred 636 times, with an average foliage diameter of 1.9 cm., while on the reference site it occurred 201 times with a foliage diameter of 1.9 cm. *Chorizanthe pungens* var. *pungens* was the most abundant plant on the reference site and the third most abundant of the restoration site.

Table 6. Restoration site abundance

Species	total # plants	Ave foliage diameter cm
<i>Artemisia pycnocephala</i> Beach sagewort	1,034	33.9
<i>Gnaphalium stramineum</i> Pearly everlasting	972	9.0
<i>Chorizanthe pungens</i> var. <i>pungens</i> Monterey spine flower	636	1.9
<i>Camissonia cheiranthifolia</i> - Beach evening primrose	635	4.0
<i>Erysimum ammodendrum</i> Coast(MB) wall flower	127	8.0
<i>Lotus scoparius</i> Deerweed	119	28.6
<i>Cyrtanthus intermedia</i> White forget-me-not	65	1.2
<i>Eriophyllum staechadifolium</i> Lizard tail	42	80.6
<i>Ericameria ericoides</i> Mock heather	21	55.1
<i>Lupinus chamissonis</i> Blue-flowered dune lupine	13	120.7
<i>Dudleya farinosa</i> Live forever	11	7.8
<i>Baccharis pilularis</i> Coyote bush	9	64.2
<i>Lupinus arboreus</i> Yellow bush lupine	8	14.5
<i>Ammophila arenaria</i> European dune grass	8	41.1
<i>Carpobrotus edulis</i> Hottentot fig ice plant	7	155.6
<i>Gnaphalium ramosissimum</i> Pink everlasting	6	8.2
<i>Carpobrotus chilensis</i> Sea fig ice plant	4	147.6
<i>Chenopodium ambrosioides</i> Mexican tea	2	56.1
<i>Cakile maritima</i> Sea rocket	2	37.5

Table 7. Reference site abundance

Species	total # plants	Ave. foliage diameter cm
<i>Chorizanthe pungens</i> var. <i>pungens</i> Monterey spine flower	201	1.9
<i>Dudleya farinosa</i> Live forever	193	14.0
<i>Artemisia pycnocephala</i> Beach sagewort	190	64.9
<i>Erysimum ammodendrum</i> Coast(MB) wall flower	163	6.2
<i>Cypripedium intermedia</i> White forget-me-not	163	1.4
<i>Gnaphalium stramineum</i> Pearly everlasting	148	28.3
<i>Ericameria ericoides</i> Mock heather	142	117.4
<i>Achillea millefolium</i> Coast yarrow	133	6.3
<i>Pteridium aquilinum</i> Bracken fern	129	44.6
<i>Rumex acetosella</i> Sheep sorrel	80	5.8
<i>Anagallis arvensis</i> Scarlet pimpernel	73	11.0
<i>Camissonia cheiranthifolia</i> Beach evening primrose	63	5.6
<i>Baccharis pilularis</i> Coyote bush	39	112.5
<i>Cirsium occidentale</i> Cobweb thistle	32	19.4
<i>Eriophyllum staechadifolium</i> Lizard tail	31	98.1
<i>Lotus scoparius</i> Deerweed	28	41.61
<i>Gnaphalium ramosissimum</i> Pink everlasting	25	11.9
<i>Abronia latifolia</i> Yellow sand verbena	21	7.4
<i>Chenopodium ambrosioides</i> Mexican tea	9	79.1
<i>Cakile maritima</i> Sea rocket	8	3.7
<i>Marah</i> sp. Wild cucumber	7	32.1
<i>Lathyrus littoralis</i> Beach pea	6	6.2
<i>Carpobrotus edulis</i> Hottentot fig ice plant	6	134.5
<i>Lupinus arboreus</i> Yellow bush lupine	4	18.6
<i>Toxicodendron diversilobum</i> Poison oak	3	83.7
<i>Solanum douglassii</i> Douglas' nightshade	2	31.0
<i>Lupinus chamissonis</i> Blue-flowered dune lupine	1	60.0
<i>Carpobrotus chilensis</i> sea fig ice plant	1	150.0
<i>Ammophila arenaria</i> European dune grass	0	0

Soil Data

Information on soil nutrients was calculated from 10 soil samples collected at the restoration site and 10 collected at the reference site. The soil organic carbon at the restoration site was 0.22 %, while the reference site contained 3.2 % organic carbon. A t-Test showed there was significant difference between the two sites for organic carbon also (t-value = 108.5, $\alpha=0.05$) (Figure 14). The restoration site contained 0.38% organic matter while the reference site contained 5.5 % organic matter. A t-Test analysis showed there was significant difference between the sites (t-value = 190.6, $\alpha=0.05$) (Figure 15).

Figure 14. Soil Organic Carbon

Figure 15. Soil organic matter

Nitrogen and phosphorous were also tested at both sites. The restoration site contained an average of 8.6 mg/Kg and the reference site contained an average of 11.7 mg/Kg of phosphorous. The t-Test showed no significant difference between the sites for this nutrient, however the t-value was 0.1 away from showing significance (t-value = 1.60, $\alpha = 0.05$). Two soil samples were taken from the greenhouse for comparison to the actual conditions when the plants were transplanted. A t-Test showed there was significant

difference between the phosphorous levels in the greenhouse soil and both the restoration (t-value = 40.0, $\alpha=0.05$) and reference site (value = 39.0, $\alpha=0.05$) (Figure 16). The average total available nitrogen for the restoration site was 1.86 lbs./acre and for the reference site 9.5 lbs./acre. The t-Test analysis showed a significant difference between the two sites (t-value =4.5, $\alpha=0.05$) (Figure 17).

Figure 16. Soil phosphorous

Figure 17. Soil nitrogen

The pH was also tested at the sites and in the greenhouse, where seedlings were started. The average pH for the restoration site was 6.44, for the reference site 5.97 and for the green house it was 7.0 (Figure 18). Performing t-Tests showed there was a significant difference between the restoration site and the reference sites, and the greenhouse and both the restoration site and the reference site (t-value = 4.8, $\alpha=0.05$).

Figure 18. Average soil pH

The composition of the soil from the restoration site, reference site, and the green house was measured. The restoration site contained a higher percentage of sand sized particles than the reference site, although this difference was not significant (Figure 19).

Figure 19. Soil composition

Discussion

Seed Bank

The soil seed bank was measured to determine the potential reproductive success of the dune plants, but the seed bank from both the Sunset State Beach restored and reference sites was almost non-existent. But, as some researchers have found, seed banks in California dune communities can naturally be zero. For example, data by Pavlik and Barbour (1988) show there can be great range in the number of seeds in dune seed banks. They analyzed the seed bank for two plant species from the dune community in Eureka, California and found the soil seed bank for *Swallenia* contained 2-24 seeds/m² and for *Astragalus* 7-200 seeds/m². Seed numbers may be low due to poor productivity and good germination rate, or the presence of seed predators.

There are a variety of possibilities for the low number of seeds found in this study including seed death and decay, predation, burial by moving sand, and dispersal out of the study area by wind. Another factor affecting the number of seeds found may be the timing of the sample collection. The seed bank samples were collected on April 14 1997, well after most dune species have set seed. If a species has just dropped seeds, there is a much higher chance of finding the seeds from that species.

Seed predation may have significantly contributed to the low diversity and density of seeds found. *Peromyscus sp.*, *Spermophilus sp.*, and a variety of birds are common at the study site. Also, there is the possibility of predation by ants. Pavlik and Barbour (1988) found a seed predation rate of 10-15% per night by insects and small mammals giving an estimated half-life of 4-7 days assuming all seeds are eaten.

In some areas on the restoration site, sand moved between 6-8 inches during the 15-week course of this study. In that time, it is possible for seeds to become deeply buried. Despite these findings it seems as though the species are reproducing successfully. The restoration site has a high number of individual plants, although they have a low average foliage diameter. The reference site has a high percent cover with higher average foliage diameters.

Species Cover and Abundance

Results showed a significant difference in the percent cover between the restoration and the reference site. Cover at the restoration site may be limited by the absence of soil microbes and fungus that play a key role in soil formation and nutrient accumulation (Daubenmire 1968). Alternately, the cover may have been different due to a difference in successional stage between the two sites (Table 8). The restoration site

contained an average of 19% cover by *Artemisia pycnocephala* and *Ericameria ericoides* combined, dominated by *Artemisia*. This composition is similar to similar to McBride and Stone's (1976) successional stage two for ridges and slopes. *Ericameria ericoides* combined with *Baccharis* at the restoration site to produce a total cover of 5%.

Ericameria, as occurs in McBride and Stone's successional stage three, dominated this association. On the reference site, the average total cover comprised of *Artemisia* and *Ericameria* was 31%, dominated by *Ericameria ericoides*. The average total cover of *Ericameria* combined with *Baccharis* was 39%, dominated by *Ericameria ericoides*. The restoration site is similar to McBride and Stone's (1976) stage two, while the reference site is most similar to stage three. These results show that the restoration site is still in an early successional stage, but appears to be proceeding on an appropriate dune successional trajectory.

Table 8. Comparison of restoration and reference sites to McBride and Stone's data on dune succession in the Monterey Bay region

	Restoration site	McBride and Stone's Successional Stage 2	Reference site	McBride and Stone's Successional Stage 3
Average % cover of dominant species	<i>Artemisia pycnocephala</i> (16.0) <i>Ericameria erioides</i> (3.0)	<i>Artemisia pycnocephala</i> (7.31) <i>Ericameria erioides</i> (3.28)	<i>Baccharis pilularis</i> (10.0) <i>Ericameria erioides</i> (29.0)	<i>Baccharis pilularis</i> (11.4) <i>Ericameria erioides</i> (15.68)
Total % cover	30.7	12.9	83.6	43.4
# of species	19	16	28	21
pH	6.44	6.6	5.97	6.0
% Silt & Clay	1.7	10.9	4.4	11.6

Of the five species present in the seed mix (Table 1) that was applied to the restoration site, *Artemisia pycnocephala* and *Eriophyllum staechadifolium* made up 39% of the seed mix that was applied to the restoration site. Now, they comprise 59% of the plants present on the restoration site. The exact number of seedlings for each of these two species planted on site is unknown. This again is consistent with McBride and Stone's succession stage two in which *Artemisia* and *Ericameria* are dominant. If monitoring continues over the next several years, the data may show a change in species composition shifting toward successional stage three the *Ericameria-Baccharis* stage.

The study by McBride and Stone (1976), conducted on the western edge of the Monterey Peninsula, found the *Artemisia-Ericameria* successional stage on the slopes and ridges had an average total cover of 12.9 % with a height of 0.3m. *Artemisia pycnocephala* dominated the pioneer stage. The *Artemisia-Ericameria* stage was succeeded by the *Ericameria-Baccharis* stage, which had an average total cover of 43.5% with an average height of 0.4m. In this stage *Ericameria ericoides* was dominant. In the *Baccharis-Rhus* stage, where the two initial routes converged, the average total cover was 110.2%. This successional stage was dominated by *Baccharis pilularis*. The high cover resulted from considerable overlap among species. After this stage, the succession sequence was controlled by the presence of trees, which became established in the *Baccharis-Rhus* stage. In the *Pinus-Quercus* stage the average total cover was 92.3%. McBride and Stone found that, within the *Artemisia-Ericameria* stage, a total of 16 different species occurred, in the *Ericameria-Baccharis* stage 21 different species occurred, with some overlap between the successional stages. In the *Baccharis-Rhus* stage, 17 species occurred.

The restoration site contained 19 different species, 18 of which are also found on the reference site. The one species that is unique to the restoration site is the non-native *Ammophila arenaria*, European dune grass. The reference site contained a total of 28

different species, a significantly greater number than the restoration site. Although the restoration site had fewer species, there were more individual plants than on the reference site. The greater number of plants at the restoration site may be due to the fact that the plants are smaller and compete less for light or may be due to the young age of the site. The lack of a large canopy of shrubs at the restoration site, to block out sunlight, has allowed more plants to germinate.

The average foliage diameter of dominant species on the restoration site was less than that of the reference site. The small diameter, thus the low cover, may be explained by the low amounts of nitrogen, phosphorous, and organic matter found on the restoration site. Kachi and Hirose (1983) found that the amount of nitrogen and phosphorous in the sand affect growth of *Oenothera erythrosepala* in dune sand. Olff, Huisman, and van Tooren (1993) found that the nitrogen content of the soil was tightly correlated with the soil organic matter, that is, the more organic matter, the higher the nitrogen concentration. They concluded that nitrogen was an important limiting nutrient. They also found that nitrogen, which limits productivity, is nearly absent from dune soil during the early stages of succession. An accumulation of soil nitrogen was accompanied by an increase in biomass. They concluded that nutrient accumulation is linked to vegetation development. The findings of this study were in accord with Olff, Huisman, and van

Tooren (1993), as nitrogen levels at the restoration site were significantly lower than the reference site.

Moving sand may have a tremendous effect upon vegetation. Plants low in stature are often covered by sand and destroyed. Many plants are killed without being completely covered due to a reduced amount of oxygen to their roots. Sand particles blown by the wind are highly abrasive and may cause severe damage to small seedlings. In addition, high temperatures on bare sand can increase transpiration and respiration rates (Daubenmire 1968).

Soil Nutrients

As discussed above, researchers have found that soil nutrients are important indicators of vegetation condition and successional stage, and this study also found nitrogen linked to successional stage. There was a significant difference between the amount of soil nitrogen in the restoration site and the reference site. There was also a significant difference in the amounts of organic nitrogen and carbon between the sites. Lower percent cover on the restoration site may be linked to lower amounts of soil nutrients and organic matter.

Until dunes become stabilized, the rate of soil development is very slow because low vegetation cover results in greater leaching of soil nutrients (Chapman 1976). Levels of major nutrients, most notably nitrogen, phosphorous, and potassium limit many sand dune systems. The ability of dune soils to retain water and mineral nutrients increases as the soil organic matter content increases (Packham 1997). Packham found that organic carbon was very low in foredunes and slacks (0.52 mg/g in dry soil), but was substantially higher, 12.8 mg/g in dry soil where scrub developed and in old well-vegetated slacks. Total nitrogen was also very low (0.11 mg/g for dry soil) in the foredune and main dune while the total nitrogen levels increased to 2.15 mg/g in dry soil in the dune scrub. Organic matter expressed as organic carbon increased as succession progressed (McBride and Stone 1976).

As plant cover increases, sandy soils become stabilized. Organic matter falls to the surface and enriches the soil as well as improving water holding capacity (Barbour et al. 1973). In order for *Quercus agrifolia* or *Pinus radiata*, the dominant tree species of the mature community, to become established, the moisture holding capacity of the soil must reach a certain level. Successional progression towards the mature stage is correlated with soil development. Chemical weathering, enhanced by the presence of vegetation, increased as succession progressed. As a result, the percentage of silt and

clay sized particles increased (McBride and Stone 1976). The particle size of the soil present on the restoration site showed the soil was composed mainly of sand, 98.8 %, with only 1.2 % silt and clay. The reference site was composed of 95 % sand, and 5.0 % silt and clay.

Development and accumulation of humus allows microbiota to become active and aids in the development of soil. Microorganisms, bacteria, and fungi promote aggregation of sand that increased water holding ability and increases the nutrient status of the soil (Daubenmire 1968). Sand from early stages in succession has been found to contain few ureolytic microorganisms, and as a result, urea hydrolysis may be limited in these soils. Skiba and Wainwright (1984) found that 1/3 of the urea added to sand and not colonized by microorganisms was undegraded after 6 weeks. Urease activity and urea hydrolysis increased with increasing vegetation cover and organic matter content, but decreasing pH.

McBride and Stone (1976) found that as the amount of organic matter increased in the soil, the pH decreased. The pH of the soil decreased with each successional stage until the *Baccharis-Rhus* stage, reaching a pH of 5.3. The pH of the restoration site was 6.44 and the reference site pH was 5.97. This correlates with the amount of organic matter present on the site. The restoration site had a lower percentage of organic matter,

0.38 %, while the reference site had a much higher percentage, 5.5 %. Both these parameters further confirm the early successional condition of the restoration site as compared to the reference site.

Evaluation of Restoration Progress

The objectives of the dune restoration project at Sunset State Beach were not clearly documented when the project began. There could be a variety of management objectives for any one site depending on the management plan. Possible objectives of the project include: replace non-native species with native species; manage to increase species diversity; manage for revegetation and increased cover; manage for species of interest or endangered species, especially *Chorizanthe*; maintain the ecological processes and the communities of the pre-disturbance condition.

Comparing the data from the restoration site to these possible management objectives is difficult because of the lack of clearly stated objectives prior to the beginning of the restoration effort. The restoration site contained three evasive non-native species *Ammophila arenaria*, European dune grass, and two species of *Carpobrotus*, ice plant. At the time of this study the objective of exotic plant removal has not been met, however when the revegetation effort was in progress the non-natives had

been removed. There is a difference in the species diversity between the sites. The restoration site contains 9 fewer species than the reference site, but one of those species contained in the restoration site is *Ammophila*. Without data on the species diversity of the restoration site before the revegetation project began, it is not possible to determine if the species diversity has increased since the project began. Using the reference site as a model of a 'natural' site, the objective of restoring the restoration site to a 'natural' state is not yet complete, but the site is progressing on a successional trajectory that appears directed toward a healthy mature dune system. A visual inspection of Aerial photographs from 1986 shows the site to be almost completely void of vegetation (Figure 1).

Comparing the percent cover of the restoration to the reference site shows the objective of restoring the restoration site to the average percent cover of the model site has not yet been met. Since the restoration site is in an early successional phase, this is to be expected. McBride and Stone (1976) found that successional stage 2 had 12.9% cover.

The sunset State Beach restoration site has 19% cover, comparing favorably to McBride and Stone's findings. Originally 300 *Chorizanthe pungens* seedlings were planted on the restoration site. At the time of this study, the number had increased to 636. The objective of managing to increase endangered species is progressing well. Using the

reference site as a model, the restoration site has not been restored to the conditions of the reference site, but it does appear to be a healthy stage two successional community.

Based on the literature, the restoration site and the reference site are at different successional stages. The restoration site is similar to McBride and Stone's successional stage two, while the reference site is representative of stage three. The dominant species are similar between the sites. On the restoration site beach sagewort, pearly everlasting, Monterey spine flower, and beach primrose are dominant. On the reference site, Monterey spine flower, beach sagewort, coast wallflower, and pearly everlasting are dominant.

A stated goal of the Sunset State Beach project was to revegetate the blow out area with native species that were genetically similar to those in the park (Gray, K 1985). There were no quantitative parameters for success, such as the expected area coverage by a specific date, and there were no data gathered before the revegetation project began to establish the baseline percent cover, species composition, or diversity. This lack of original baseline data makes determining the success of the project difficult. When baseline or historical data are not available to evaluate the progress of a site, reference sites often provide the standards.

From the results of this study the restoration site is not similar in species composition, percent cover, diversity, and soil nutrients to the reference site. The restoration site is dominated by a high number of individual plants with low average foliage diameter resulting in a low percentage cover. The reference site contains a higher number of plant species, with fewer individuals, but a larger average foliage diameter, resulting in a much higher percent cover.

In this thesis, the reference site provided the target criteria for determining the restoration site progress. Native plant species are present on the restoration site in higher numbers than on the reference site, but there are fewer species present on the restoration site than on the reference site. The restoration site contains 3 non-native species, while the reference site contains 2 non-native species. The restoration site has a much lower percent cover than the reference site. Using the reference site as a model, the restoration site has some distance to progress before it can be considered restored to conditions matching the reference site.

Table 9. Summary of parameters measured for the restoration and the reference site

Parameters measured	Restoration site	Reference site
Total # of individual plants	3,722	1,902
Number of species total	19	28
Number of <i>Chorizanthe pungens</i>	636	201
Number of exotic invaders	3	2
Species in seed bank	3	3
Total # of seeds found	60	42
Average % cover	30.7	83.6
Average soil nitrogen	1.86	9.5
Average soil phosphorous mg/Kg	8.6	11.75
Average % soil organic carbon	0.22	3.2
Average % soil organic matter	0.38	5.5
Average soil pH	6.44	5.97
Soil Composition % clay & silt	1.1	5.0
Soil Composition- % sand	98.9	95

Recommendations

Monitoring of the restoration site should be done yearly, revisiting the permanent quadrates in the spring so the data will be comparable to the baseline data gathered in this study. A GPS unit can be used with a metal detector to relocate the permanent plots established in this study. Data should be gathered on the soil nutrients, total number of plants, the percent cover, and the species composition and density found within each of the permanent plots, and within additional non-permanent plots. The methods for gathering the plant and soil data are easily replicated using this study as a guide. The results can be compared to the baseline data presented in this study to monitor change over time. The results of the continued monitoring can be used to determine if the goals and objectives of the management plan are being met.

When the project began, the goal was to stabilize the restoration site with native plant species, reducing further dune blowouts in areas where recreational use was threatened. This study found that while the restoration site has a large number of plants, it does not have the average percent foliage cover of the reference site. Two goals might be to increase the percent cover and increase the species diversity with native plant species. In order to achieve the mature community described by Cooper (1922), Barbour and Major (1990), and McBride and Stone (1976), the restoration site will need to remain

undisturbed by recreational uses, allowing the soil to build up nutrients that are necessary to support a the diversity of plants that will lead to the pine and oak forest. Another goal should be to increase the habitat for the endangered *Chorizanthe pungens* (Monterey spine flower), which requires bare sand.

It is the mission of California Department of Parks and Recreation to manage for the extraordinary biodiversity, to protect natural and cultural resources, and provide opportunities for high quality recreation within the parks. These restoration goals may compete to some extent with the mission of the State Park system to manage for high quality outdoor recreation. However, several management strategies can be applied to this site to protect the restoration effort while allowing visitors. To reduce pedestrian damage, the restoration site must remain fenced off and the sand ladders must remain in good repair, as they provide access to the beach from the campground without impacting the site. Public education, through interpretive talks, displays, and signs should be used to increase the public's understanding of the importance of staying on the sand ladders and out of restricted areas.

The propagation of seedlings from genetic stock taken from within the park should continue. Continued planting of the seedlings will increase the percent plant cover the site and can increase species diversity. In addition to continued planting on the

restoration site, fertilizer rich in nitrogen and phosphorous could be applied as well to boost growth and move the site quickly along its successional trajectory. The most effective fertilizer application methods and amounts should be studied with on-site experiments. Experiments could be conducted to determine the effects of fertilizer application of both nitrogen and phosphorous on density, diversity, and percent cover.

Managing for the Monterey spine flower is in direct opposition to increasing the cover and the diversity of the restoration site. The Monterey spine flower needs bare sand, while increasing cover will reduce the amount of bare sand available for the spine flower. A monitoring plan for the Monterey spine flower should be put in place with clear recommendations for increasing the bare sand available for the flower if its numbers begin to decrease on the restoration site.

For successful restoration projects clear goals must be stated and the parameters of success must be linked to these goals. If the success criteria are not met, then the management strategies should be modified to meet the goals. Changes might include increasing the number of plants planted, changing the season the plants are planted, changing the composition of the species, or changing the amount of fertilizer applied. Monitoring the restoration project each year will provide information to evaluate the site's progress and will provide data to assist in site management.

For this site, parameters of success should be agreed upon by managers of Sunset State Beach State Park keeping in mind the competing goals. Based on the data gathered, the following recommendations will assist restoration of the study site in its progress toward the mature community: 1) Exotic plant removal should continue, with the goal of eliminating all ice plant and European dune grass, 2) Native plants that have been grown from seed stock taken from within the park should replace the exotic species, 3) To increase the percent cover, fertilizer should be used on the restoration site regularly, 4) The site needs to be monitored yearly with data gathered on percent cover, species diversity and density, 5) The soil should be tested for nitrogen, phosphorous, and organic matter and organic carbon, 6) The soil should be tested for the presence of soil microbes and fungi, 7) A monitoring program for the Monterey spine flower should be put in place. Based on the results of the soil tests, adjustment can be made on the amount of fertilizer applied to the site. In addition, two more reference sites should be added to provide more information on the natural range of variability of the ecosystem.

Appendix 1

Threatened and Endangered Species of Sunset State Beach

Species	Status
Western Snowy Plover <i>Charadrius alexandrinus nivosus</i>	Federal: Threatened State: None
Robust Spine Flower <i>Chorizanthe robusta</i> var. <i>robusta</i>	Federal: Endangered State: None
Monterey Spine Flower <i>Chorizanthe pungens</i> var. <i>pungens</i>	Federal: Threatened State: None

Federal Category 1 and Category 2= Candidate for Federal Listing

Source: Compiled from Natural Diversity Database (1996). California Department of Fish and Game.

Appendix 2

VASCULAR PLANTS OF SUNSET STATE BEACH

Aizoaceae - Fig-Marigold Family

2,3	<i>Carpobrotus chilensis</i> (Molina) N.E. Br.	sea fig, ice plant
2,3	<i>Carpobrotus edulis</i> (L.) N.E. Br.	hottentot fig, ice plant
3	<i>Tetragonia tetragonioides</i> (Pallas) Kuntze	New Zealand spinach

Anacardiaceae - Sumac Family

	<i>Toxicodendron diversilobum</i>
(Torrey & A. Gray) E. Greene | poison oak |
|--|---|------------|

Apiaceae - Carrot Family

3	<i>Conium maculatum</i> L.	poison hemlock
	<i>Sanicula crassicaulis</i> DC.	snake root

Apocynaceae - Dogbane Family

	<i>Apocynum cannabinum</i> L.	Indian hemp
3	<i>Vinca major</i> L.	periwinkle

Araceae - Arum Family

3	<i>Zantedeschia aethiopica</i> (L.) Sprengel	calla lily

Araliaceae - Ginseng Family

3	<i>Hedera helix</i> L.	English ivy

Asteraceae - Sunflower Family

	<i>Achillea millefolium</i> L.	yarrow
	<i>Ambrosia chamissonis</i> (Less.) E. Greene	beach bur, silver beachweed
	<i>Artemisia pycnocephala</i> DC.	beach sagewort
	<i>Baccharis pilularis</i> DC.	coyote brush
3	<i>Centaurea melitensis</i> L.	star thistle, tocalote
3	<i>Centaurea solstitialis</i> L.	yellow star thistle
	<i>Cirsium occidentale</i> (Nutt.) Jepson	cobweb thistle
3	<i>Cirsium vulgare</i> (Savi) Ten.	bull thistle
	<i>Conyza canadensis</i> (L.) Cronq.	horseweed
	<i>Ericameria ericoides</i> (Less.) Jepson	mock heather, golden bush
	<i>Erigeron glaucus</i> Ker-Gawler	seaside daisy
	<i>Eriophyllum staechadifolium</i> Lagasca	lizard tail,
seaside woolly sunflower
4	<i>Gnaphalium bicolor</i> Bioletti	Bioletti's cudweed
	<i>Gnaphalium ramosissimum</i> Nutt.	pink everlasting
	<i>Gnaphalium stramineum</i> Kunth	cotton-barting plant
	<i>Grindelia latifolia</i> Kellogg	coastal gum plant
	<i>Grindelia stricta</i> DC.	gum plant
	<i>Heterotheca grandiflora</i> Nutt.	telegraph weed, camphor weed
3	<i>Hypochaeris glabra</i> L.	smooth cat's-ear
	<i>Madia sativa</i> Molina	coast tarweed
3	<i>Senecio mikanioides</i> Walp.	German ivy
3	<i>Senecio vulgaris</i> L.	common groundsel, butterweed

3	<i>Sonchus oleraceus</i> L.	common sow thistle
3	<i>Taraxacum officinale</i> Wigg.	common dandelion
Boraginaceae - Borage Family		
	<i>Amsinckia spectabilis</i> Fischer & C. Meyer	fiddleneck
	<i>Cryptantha intermedia</i> (A. Gray) E. Greene	white forget-me-not
Brassicaceae - Mustard Family		
3	<i>Cakile maritima</i> Scop.	sea rocket
1	<i>Erysimum ammophilum</i> A.A. Heller	Monterey Bay wallflower
3	<i>Hirschfeldia incana</i> (L.) Lagr.-Fossat	short-pod mustard
3	<i>Raphanus sativus</i> L.	wild radish
Caprifoliaceae - Honeysuckle Family		
	<i>Sambucus mexicana</i> C. Presl	blue elderberry
Caryophyllaceae - Pink Family		
3	<i>Stellaria media</i> (L.) Villars	common chickweed
Chenopodiaceae - Goosefoot Family		
	<i>Chenopodium ambrosioides</i> L.	Mexican tea
	<i>Salicornia subterminalis</i> Parish	pickleweed
Convolvulaceae - Morning-glory Family		
	<i>Convolvulus</i> sp.	morning-glory
Crassulaceae - Stonecrop Family		
1	<i>Dudleya farinosa</i> (Lindley) Britton & Rose	live forever
Cucurbitaceae - Gourd Family		
	<i>Brandegea bigelovii</i> (S. Watson) Cogn.	Brandegea
Cupressaceae - Cypress Family		
	<i>Cupressus macrocarpa</i> Gordon	Monterey cypress
Cyperaceae - Sedge Family		
	<i>Cyperus eragrostis</i> Lam.	nutsedge
Dennstaedtiaceae - Bracken Fern Family		
	<i>Pteridium aquilinum</i> (L.) Kuhn	bracken fern
	var. <i>pubescens</i> (L.) Underw.	
Equisetaceae - Horsetail Family		
	<i>Equisetum</i> sp.	horsetail
Euphorbiaceae - Spurge Family		
3	<i>Euphorbia peplus</i> L.	petty spurge
Fabaceae - Legume Family		
1	<i>Lathyrus littoralis</i> (Nutt.) Endl.	beach pea
	<i>Lotus scoparius</i> (Nutt.) Otley	deerweed, California broom
1	<i>Lupinus arboreus</i> Sims	yellow bush lupine
1	<i>Lupinus chamissonis</i> Eschsch.	blue-flowered dune lupine
3	<i>Trifolium incarnatum</i> L.	crimson clover
Fagaceae - Oak Family		
	<i>Quercus agrifolia</i> Nee	coast live oak
Hippocastanaceae - Buckeye Family		
1	<i>Aesculus californica</i> (Spach) Nutt.	California buckeye

Hydrophyllaceae - Waterleaf Family	
Phacelia ramosissima <i>Lehm.</i>	branched phacelia
var. montereyensis <i>Munz</i>	
Iridaceae - Iris Family	
Iris douglasiana <i>Herbert</i>	Douglas' iris
Juncaceae - Rush Family	
Juncus balticus <i>Willd.</i>	wire rush
Lamiaceae - Mint Family	
Satureja douglasii (<i>Benth</i>) <i>Briq.</i>	yerba buena
Lemnaceae - Duckweed Family	
Lemna sp.	duckweed
Liliaceae - Lily Family	
Chlorogalum pomeridianum (<i>DC.</i>) <i>Kunth</i>	soap plant, amole
Malvaceae - Mallow Family	
3 Lavatera arborea <i>L.</i>	tree-mallow
Lavatera assurgentiflora <i>Kellogg</i>	island mallow, malva rosa
3 Malva parviflora <i>L.</i>	cheeseweed
Myrtaceae - Myrtle Family	
3 Eucalyptus globulus <i>Labill.</i>	blue gum
Nyctaginaceae - Four O'clock Family	
Abronia latifolia <i>Eschsch.</i>	yellow sand verbena
Abronia umbellata <i>Lam.</i>	pink sand verbena
Onagraceae - Evening Primrose Family	
Camissonia cheiranthifolia (<i>Sprngel</i>) <i>Raim</i>	beach evening primrose
Epilobium brachycarpum <i>C. Presl</i>	panicked willow herb
Oenothera villosa <i>Thunb.</i>	Hooker's evening primrose
ssp. strigosa (<i>Rydb.</i>) <i>W. Dietr. & Raven</i>	
Oxalidaceae - Oxalis Family	
3 Oxalis sp.	yellow wood sorrel
Papaveraceae - Poppy Family	
Eschscholzia californica <i>Cham.</i>	California poppy
Pinaceae - Pine Family	
Pinus muricata <i>D. Don</i>	Bishop pine
Pinus radiata <i>D. Don</i>	Monterey pine
Plantaginaceae - Plantain Family	
3 Plantago lanceolata <i>L.</i>	English plantain
Plumbaginaceae - Leadwort Family	
Armeria maritima (<i>Miller</i>) <i>Willd.</i>	sea thrift
ssp. californica (<i>Boiss.</i>) <i>Pors.</i>	
Poaceae - Grass Family	
2,3 Ammophila arenaria (<i>L.</i>) <i>Link</i>	European dunegrass
3 Avena fatua (<i>L.</i>)	wild oat
3 Briza maxima <i>L.</i>	rattlesnake grass
2,3 Cortaderia selloana (<i>Schultes</i>) <i>Asch & Graebner</i>	pampas grass
3 Cynosurus echinatus <i>L.</i>	hedgehog dogtail grass

	<i>Distichlis spicata</i> (L.) E. Greene	saltgrass
	<i>Festuca</i> sp.	fescue
	<i>Hordeum jubatum</i> L.	foxtail barley
3	<i>Hordeum murinum</i> L.	foxtail barley
	ssp. <i>leporinum</i> (Link) Arcang.	
3	<i>Lolium multiflorum</i> Lam.	Italian ryegrass
	<i>Poa douglasii</i> Nees	sand dune bluegrass
3	<i>Polypogon maritimus</i> Willd.	Mediterranean beard grass
3	<i>Polypogon monspeliensis</i> (L.) Desf.	annual beard grass
Polemoniaceae - Phlox Family		
	<i>Navarretia squarrosa</i> (Eschsch.) Hook. & Arn.	skunkweed
Polygonaceae - Buckwheat Family		
4	<i>Chorizanthe pungens</i> Benth. var. <i>pungens</i>	Monterey spineflower
4	<i>Chorizanthe robusta</i> C. Parry	robust spineflower
	<i>Eriogonum latifolium</i> Smith	coast buckwheat
	<i>Polygonum amphibium</i> L.	swamp knotweed
3	<i>Polygonum arenastrum</i> Boreau	common knotweed
3	<i>Rumex acetosella</i> L.	sheep sorrel
3	<i>Rumex conglomeratus</i> Murray	dock
3	<i>Rumex crispus</i> L.	curly dock
3	<i>Rumex pulcher</i> L.	fiddle dock
Portulacaceae - Purslane Family		
	<i>Claytonia perfoliata</i> Willd.	miner's lettuce
Primulaceae - Primrose Family		
3	<i>Anagallis arvensis</i> L.	scarlet pimpernel
Rhamnaceae - Buckthorn Family		
	<i>Rhamnus californica</i> Eschsch.	California coffeeberry
Rosaceae - Rose Family		
	<i>Fragaria chiloensis</i> (L.) Duchesne	beach strawberry
3	<i>Malus sylvestris</i> Miller	apple
	<i>Rosa californica</i> Cham. & Schltdl.	California rose
	<i>Rubus ursinus</i> Cham. & Schltdl.	California blackberry
Salicaceae - Willow Family		
	<i>Salix</i> sp.	willow
Scrophulariaceae - Figwort Family		
	<i>Castilleja latifolia</i> Hook. & Arn.	Monterey Indian paintbrush
3	<i>Digitalis purpurea</i> L.	foxglove
	<i>Linaria canadensis</i> (L.) Dum.-Cours.	blue toadflax
	<i>Mimulus aurantiacus</i> Curtis	sticky monkey flower
Solanaceae - Nightshade Family		
	<i>Solanum douglasii</i> Dunal	Douglas' nightshade
Typhaceae - Cattail Family		
	<i>Typha latifolia</i> L.	broad-leaved cattail
Urticaceae - Nettle Family		
	<i>Urtica dioica</i> L. ssp. <i>holosericea</i> (Nutt.) Thorne	hoary nettle

Plant list from California Department of Parks and Recreation, compiled by Kathy Teare

VASCULAR PLANTS OF SUNSET STATE BEACH

TAXA NOMENCLATURE

The Jepson Manual, Higher Plants of California, 1993.

- SYMBOLS:**
- 1 - Collected seed for cultivation
 - 2 - Control measures taken
 - 3 - Exotic species, taxa not considered native to California
 - 4 - Rare plant

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