Salinas River State Beach Dune Restoration Project

Final Restoration & Monitoring Report

July 2019

Central Coast Wetlands Group
at Moss Landing Marine Laboratories

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Project Partners

Central Coast Wetlands Group at Moss Landing Marine Laboratories

Coastal Conservation and Research, Inc.

California State Parks

Ecological Concerns Incorporated

Return of the Natives

Cypress Coast Fence

Point Blue

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Table of Contents

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EXECUTIVE SUMMARY

Project Description

In 2015, the State Coastal Conservancy funded the Salinas River State Beach Dune Restoration project through the Climate Ready Grant Program. Salinas River State Beach (SRSB) is located in Moss Landing in Monterey County, California

Although SRSB contains rare coastal dune habitat, the natural dune vegetation at SRSB has been disrupted by the introduction of iceplant (*Carpobrotus edulis*) and other invasive plants. Iceplant is an invasive species that impacts important physical and ecological dune functions. The degradation of foredune habitat by iceplant undermines the dune's capacity to act as a protective barrier to sea level rise (SLR). The SRSB dune system forms a continuous linear buffer between coastal storm flooding and the Moss Landing community, adjacent estuaries, and nearby low-lying agricultural land within the lower Salinas Valley. The degradation of foredune habitat by invasive iceplant leaves the dune system vulnerable to sea level rise induced erosion. Small breaches in the most vulnerable sections of the SRSB could allow ocean flooding of vast areas of the Salinas Valley.

The following project goals were identified in the Salinas River State Beach Dune Restoration and Management Plan (CCWG 2015), which was written during the planning phase of the project:

- Goal 1: Eradicate iceplant from foredune and mid-dunes
- Goal 2: Establish diverse native plant composition in SRSB dunes
- Goal 3: Enhance storm resilience of dune system
- Goal 4. Support California State Parks dune management efforts

The Central Coast Wetlands Group (CCWG) at Moss Landing Marine Laboratories, in partnership with California State Parks and Coastal Conservation and Research, have worked to restore (eradicate invasive iceplant and reestablish native plants) from approximately 20 acres of sensitive dune habitat in areas that have been identified as being vulnerable to sea level rise impacts. Iceplant was eradicated primarily through the use of hand spraying herbicide (2% dilution of Roundup) and hand pulling of iceplant in areas where special status plant species were present. Sprayed iceplant was left in place to act as mulch for native plants. Approximately 20,000 native plants were propagated, using seed sourced from the SRSB dune system, throughout the project period and planted during the 2016/2017 and 2017/2018 planting season. Additionally, seeds were hand broadcast and lightly raked in to dune areas with bare sand. Efforts to increase the structural integrity of the dunes included strategic planting placement and the use of drift wood and hay bales to help build dunes. Several trail upgrades were made that include updating or replacing fencing to help better delineate access ways and reduce wayward foot traffic through sensitive dune habitat. Interpretive signs were installed at two main access locations and along main dune trails to provide education about sea level rise, dune erosion, habitat restoration, and endangered species.

Vegetation Surveys

Vegetation surveys were used to characterize the vegetation community located at the site over the course of the restoration project, including percent cover of native and non-native vegetation and diversity of the plant community. CCWG performed vegetation surveys at the three restoration locations (Potrero, Molera, and Salinas River mouth) that comprise the restoration project area. Survey methods included point-intercept transects laid parallel to the beach (along the foredune and mid-dune) and perpendicular to the beach to determine percent cover, as well as quadrat transects laid parallel to the beach (along the foredune and mid-dune) to determine species richness. Survey results are as follows:

Eradication of Iceplant from Foredune and Mid-Dunes

In the foredune iceplant cover was reduced from 41% to 3% total cover. In the mid-dune, iceplant cover was reduced from 43% to 5% total cover. The perpendicular transects which cross the foredune and mid-dune showed a reduction in iceplant from 23% to less than 3% total cover.

Native Cover

In the foredune native cover stayed about the same, beginning at 7% and decreased to 6% total cover. In the mid-dune native cover increased from 29% to 32% cover. The perpendicular transects which cross the foredune and mid-dune showed a similar increase in native cover from 27% to 36% total cover.

Species Richness

Species richness for all three restoration areas (Potrero, Molera, and Salinas River) stayed about equal.

Dune Mapping

Dune mapping surveys were carried out to assess the geomorphologic characteristics and variability of the different habitats associated with the dunes with focus on the windward slope (the side of the dune facing the ocean), the foredune, and the transition with the adjacent beach habitats including runnel and beach berm. High-resolution (<~10cm) dune mapping was conducted before, during, and after project implementation using a combination of survey tools including differential GPS equipment, Terrestrial Laser Scanners (TLS), and Unmanned Aerial Vehicles (UAV). Sampling events occurred in 2015, in 2016, and 2018. Results show that over the 4 year period, while the dune habitats stayed relatively stable, the profile of the upper beach changed dramatically indicating both erosion and accretion of sand, as a result of wave energy at the time of the survey and local wave dynamics.

Much of the change that affected the foredune over the study period has occurred on the portions of the foredunes that were already steep, supporting the interpretation that dune erosion is enhanced where the upper beach has a more reflective (i.e. less dissipative) profile. It also suggests that the steepest dune faces are the one that are more subjected to geomorphological change both in terms of erosion but also accumulation of sand.

Study Plots

The intent of this restoration study was to investigate the effectiveness of different invasive species elimination and native planting strategies to increase native species cover and reduce/eliminate iceplant cover within an active restoration site. Study results will be used to will help to inform future restoration efforts.

The following hypotheses were tested:

- Degraded plant material of herbicide-sprayed iceplant provides a protective mulch layer over bare sand that helps native plant propagation and growth and reduces invasive weed establishment.
- Planting dunes with native plants at higher densities leads to greater cover.
- Planting dunes with greater numbers of species will increase native cover and diversity and reduce invasive species establishment.

Results suggest the following:

- Dead iceplant mulch helped increase cover of planted plants and lower iceplant recruitment but reduced natural native plant recruitment.
- Iceplant recruitment was shown to be higher in study plots where iceplant was removed completely
- Greater density of native planting led to greater native cover
- Greater native plant diversity within plots resulted in greater plant diversity, but not the highest native cover.

Sediment Study

High-resolution sediment grain size sampling was conducted in 2019 to help understand the effects of the dune restoration process on the composition of the sand and the effectiveness of using natural materials such as logs and hay bales to entrain sand and improve dune resilience. Sediments samples were collected at different locations for grain size analysis.

The grain size data collected for this study show that the sedimentologic characteristics of the sand can vary over very short distances and corresponding habitats located along the cross-section profile of the dunes have distinctive characteristics. The sand is less sorted in high-energy wave-dominated beach areas and finer and better sorted material exists in the foredune where wind-driven processes such as saltation (particles carried by wind bounce along the surface) dominate. Further, the particle size results document enhanced sand accretion in areas where natural structures such as hay bales and wood log were placed and demonstrate that these structures intercept the saltation load on the ocean side (finer sediments) and captures sand delivered during high-energy/high-surge events on the land side (coarser grain sizes).

Looking Forward

Lessons learned during this project that will help inform future dune restoration projects. Recommendations include:

- For large-scale projects, leave dead iceplant in place to act as mulch for native plants.
- Allow for enough time (project duration) to manage iceplant recruitment for several years after initial eradication effort.
- Conduct long-term vegetation and dune topography monitoring to better understand how restoration efforts (removal of iceplant, planting of natives, and strategic placement of natural materials) affects longer term dune erosion and accretion processes.
- Conduct high resolution studies to better understand sand accumulation processes using strategic placement of native pants and natural materials (such as logs, hay bales, and jute fencing)
- Establish standardized monitoring strategies for dune restoration projects:
    - Work with other dune restoration groups to standardize monitoring such as vegetation survey methods and dune topography survey methods.
    - Develop a Dune Rapid Assessment Method (DRAM) to create a cost-effective standardized monitoring strategy for dune restoration projects and ambient surveys.

1. PROJECT DESCRIPTION

Site Location

Salinas River State Beach (SRSB) comprises approximately 280 acres of beach and coastal dunes located in Northern Monterey County, California (Figure 1). SRSB is bordered by the Pacific Ocean to the west and the old Salinas River channel and agricultural fields to the east. SRSB extends northward to Sandholdt Road in Moss Landing and southward to the Salinas River mouth, wrapping around the Monterey Dunes colony in the lower half of the state beach. The most prominent feature of the state beach is the extensive sand dune system, which extends inland in some places for over 1000 feet and is 50–60 feet above sea level at the highest point.

The SRSB was classified as a State Beach by the California State Park and Recreation Commission in November 1962, to "protect and perpetuate the area's natural resource values and to provide beach-oriented recreation opportunities for the enlightenment, inspiration, and enjoyment of present and future generations (DPR 1987). The State Park and Recreation Commission resolution establishing the state beach specifically distinguishes the foredune and coastal scrub plant communities, the solitary sandy beach, the visual texture of the dunes and the expanse of Monterey Bay as the important elements. SRSB is also zoned as "scenic and natural resource recreation" in the North County Land Use Plan and "recreational" within the Monterey Bay National Marine Sanctuary.

SRSB contains rare coastal dune and coastal marsh which provide habitat for many species of wildlife and migratory birds, and which host numerous special status animal and plant communities. SRSB also contains two subunits classified as Natural Preserves: the Salinas River Dunes Natural Preserve and the Salinas River Mouth Natural Preserve. The natural dune vegetation at SRSB, however, has been disrupted by the introduction of iceplant (*Carpobrotus edulis*) and other invasive plants. Iceplant is an invasive species that has choked dune systems and impacted important physical and ecological dune functions. The degradation of foredune habitat by invasive species undermines the dune's capacity to act as a protective barrier to SLR. The SRSB dune system forms a continuous linear buffer between coastal storm flooding and the Moss Landing community and harbor, MPAs in the Moro Cojo and Elkhorn Sloughs, and the low-lying agricultural land within the Salinas Valley. The degradation of foredune habitat by invasive iceplant leaves the dune system vulnerable to sea level rise induced erosion. Small breaches in the most vulnerable sections of the SRSB dunes could allow ocean waters to flood vast areas of the lower Salinas Valley.

In 2015, the State Coastal Conservancy funded the Salinas River State Beach Dune Restoration project through the Climate Ready Grant Program. Since 2015, the Central Coast Wetlands Group (CCWG) has worked in partnership with California State Parks to restore 20 acres of sensitive dune habitat. The Project focuses on three areas within the dunes complex that have been identified as most vulnerable to sea level rise impacts (Figure 2).

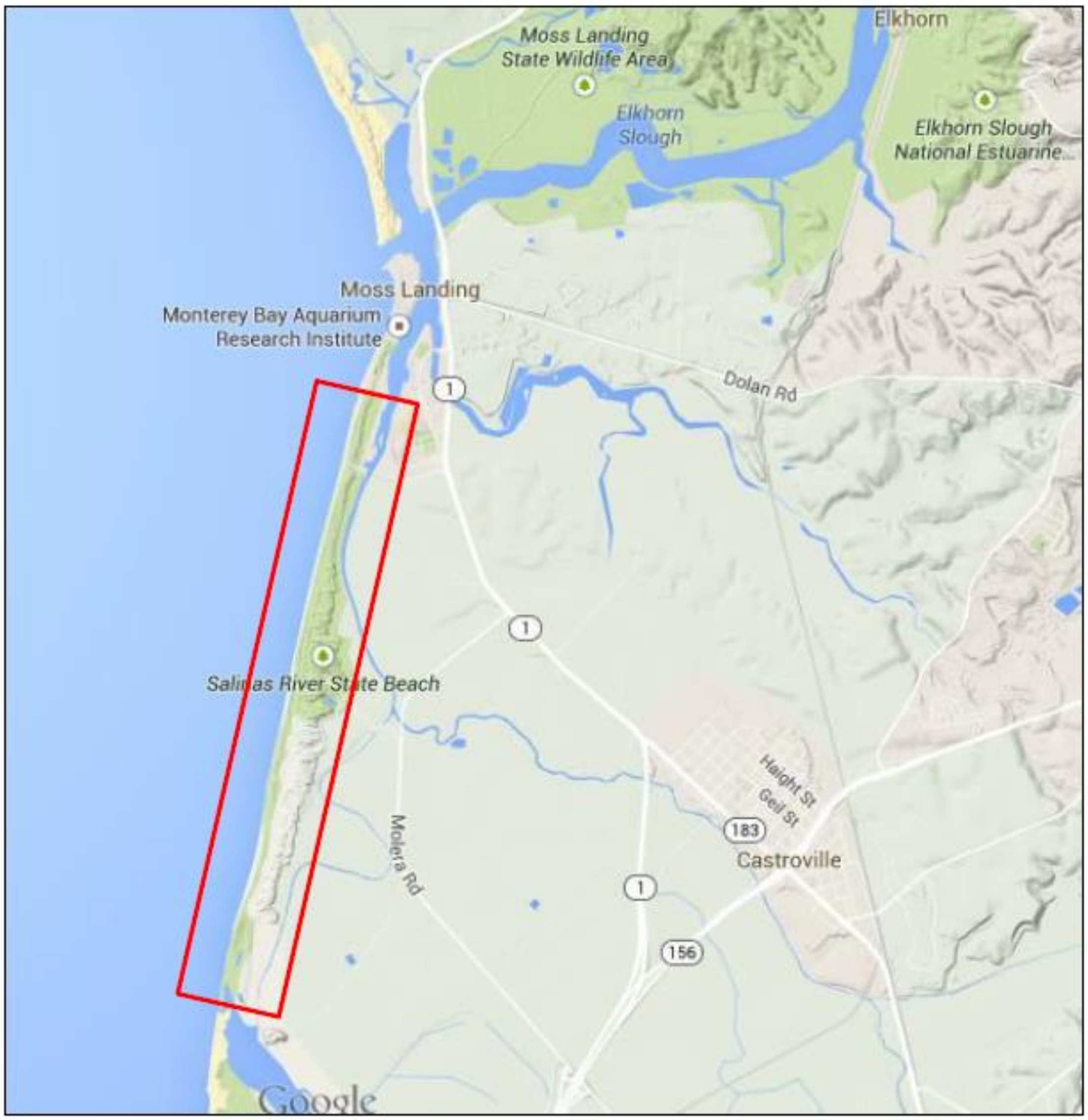

Figure 1. Salinas River State Beach Dune Restoration project vicinity map

Figure 2. Project areas targeted for invasive species removal and reestablishment of native dune vegetation. Left panel shows overview of all sites. Three right panels show closeup of individual restoration areas (Potrero, Molera, Salinas River).

Project Overview

The Central Coast Wetlands Group (CCWG) at Moss landing Marine Labs, in partnership with California State Parks and Coastal Conservation and Research, have worked to restore (eradicate invasive iceplant and reestablish native plants) 20 acres of sensitive dune habitat in areas that have been identified as vulnerable to sea level rise impacts. Iceplant was eradicated primarily through the use of hand spraying herbicide (2% dilution of Roundup). Hand spraying by certified contract professionals was determined to be less destructive to the dunes, the native plant and animals and any archeological resources than would large scale hand or automated removal of iceplant cover. Hand pulling of iceplant was conducted in areas where special status plant species are present. Sprayed iceplant was left in place to act as mulch for native plants. Iceplant was left to decompose for 4–9 months before native plants were planted within the mulch. Seeds were collected from native plants for propagation and hand broadcasting from the SRSB dunes complex to maintain local genetic diversity. Approximately 20,000 native plants were propagated throughout the project period and planted during the 2016/2017 and 2017/2018 planting season. Additionally, seeds were hand broadcast and lightly raked in to dune areas with bare sand. Efforts to increase the structural integrity of the dunes included strategic foredune planting of native dune grass and the use of drift wood and hay bales to enhance sand accretion of the dunes. Several trail upgrades were made including replacing fencing to better delineate and manage access ways and reduce wayward foot traffic through sensitive dune habitat. Interpretive signs were installed at two main access locations and along main dune trails to provide the public with information regarding sea level rise, dune erosion, habitat restoration, and endangered species conservation.

The following project goals were established in the Salinas River State Beach Dune Restoration and Management Plan (CCWG 2015):

- Goal 1: Eradicate iceplant from foredune and mid-dunes
- Goal 2: Establish diverse native plant composition in SRSB dunes
- Goal 3: Enhance storm resilience of dune system
- Goal 4. Support California State Parks dune management efforts

Restoration Design

Iceplant Eradication

Herbicide Application

Iceplant was sprayed within the 20-acre target foredune and mid-dune area (Figure 2) in the early spring and fall and early winter of 2016. Spraying occurred approximately 4–9 months prior to revegetation efforts to allow enough time for the iceplant to decompose and allow for easier planting. In areas with a substantial cover of native species, iceplant was sprayed in late fall when the natives are dormant and germinating native seedlings are limited.

Crew members were trained to properly identify iceplant and native dune species and had proper certifications to use the spray application equipment. A 2% dilution of Roundup (2% glyphosate/1.5%

imazapyr mix + surfactant solution) with added tracer die was used. Iceplant was sprayed in linear swaths parallel to the shore by the field crew in a manner that limits dune trampling. Spraying was limited to still and dry days to prevent chemical drift from rain and wind. A second spot application was completed approximately 3–9 months after the initial application to areas where iceplant remained robust. The foredune areas were sprayed outside of the Snowy Plover nesting season (March–September) to ensure breeding plovers were not impacted. Sprayed iceplant was left in place to act as mulch for new native plants.

Hand-pulling

In many places, native species were intermixed with the iceplant and therefor care was taken to minimize drift or overspray of herbicides on native plants. No spraying occurred in areas where sand gilia and Monterey spineflower were present. Iceplant located in areas with sensitive plant species was hand pulled to protect the special status plants. After planting and seeding occur, herbicide spraying was limited to areas where overspray would not jeopardize native plants.

Other Non-Native Plant Eradication Efforts

European beach grass (Ammophila arenaria)

Ammophila sp. is present on the adjacent Monterey Dunes Colony property and had recruited to one area south of the Monterey Dunes Colony. Herbicide application staff with Ecological Concerns Incorporated treated the area with 2% glyphosate/1.5% imazapyr mix + surfactant solution during at least two application periods. Native dune grass was planted in place of the European populations after spraying ended.

Arundo donax

Arundo donax was present near the southern end of the focus area and efforts were made to eliminate the species from the river mouth area. The Arundo was cut by mechanical means and the cut stump was treated with a 50–100% solution of Roundup.

Native Seed Collection

Seed was collected each year for propagation and out planting during the fall/winter planting season. Restoration crew members collected seeds of native species (listed in Table 1) at the Salinas River State Beach dunes complex to ensure local genetic diversity was supported. To ensure maximum genetic diversity, seed was collected from un-restored sections of the nearby dunes, and from as many different plants of the same species as possible. No more than 10% of the produced seed was collected from any one plant.

Dune Grass Rhizome Collection

Native dune grass (*Leymus mollis*) planting is most successful using small plugs generated from segmenting adult plants. Local dune grass was collected in small numbers and planted in the greenhouse to generate an adult population from which to establish rhizome plugs for out planting.

Broadcast Seeding

A seed mix of native species was created (based on Table 1) for hand broadcasting. Broadcast seeding is an effective way to help revegetate unsanctioned pathways and other bare areas of the foredune. Broadcast seeding was done during the winter season. Seed was spread by hand onto the sand or within fully decomposed iceplant litter and raked lightly. Two seed mixes were created, representing the species diversity of the foredune and mid-dune areas.

Table 1. Seed collected at Salinas River State Beach for plant propagation and broadcast seeding within the project area.

Species	Common name
Abronia latifolia	yellow sand verbena
Abronia umbellata	pink sand verbena
Ambrosia chamissonis	beach bur
Armeria maritima	sea thrift
Artemisia pycnocephala	beach sagewort
Atriplex leucophylla	beach saltbush
Calystegia solanella	beach morning glory
Camissonia cheiranthifolia	beach primrose
Cardionema ramosissimum	sand mat
Castilleja latifolia	seaside painted cup
Chorizanthe pungens ssp. pungens	Monterey spineflower
Corethrogyne filaginifolia	California aster
Dudleya caespitosa	coast dudleya
Ericameria ericoides	mock heather
Eriogonum latifolium	coast buckwheat
Eriophyllum staechadifolium	lizard tail
Eschscholzia californica maritima	beach poppy
Extriplex californica	California salt bush
Gilia tenuiflora ssp. arenaria	sand gilia
Lathyrus littoralis	beach pea
Leymus mollis	American dune grass
Phacelia ramosissima	branching phacelia

Dune Plant Propagation

Species from the California State Parks approved plant list (Table 1) were collected within 1km of the project site. Quantities of individual plants of each species were grown and out planted in numbers to reestablish the expected diversity and density. The use of perlite soil amendment for seed propagation helped reduce soil compaction, and mimicked low water retention and high permeability found within the soil type of coastal dunes. Depending on the species, propagation began between winter and spring to allow for seedlings to grow large enough to be out planted in late fall (Nov/Dec) prior to first rains. Consistent watering, thinning to one seedling per cell, and the prevention of herbivory were all essential for the survival and health of the dune seedlings.

- From seed: Seeds were propagated in 3" deep trays with a mixture of perlite and top soil or potting soil. Once seedlings germinated, they were transplanted into 2" pots within a soil/sand mix and grown out.
- From plant material (rhizomes): *Leymus mollis* was propagated/divided from parent material/cuttings taken from approved locations within the project site. Cuttings were planted in 2" pots.

Native Species Out-planting Techniques

Iceplant Mulch and Native Planting

Decomposed iceplant material was left in place after the application of herbicide (approximately 6 months after initial application). The mulch/decomposed iceplant layer provides insulation from extreme soil temperature fluctuations, retains dune moisture, inhibits weed colonization and can enhance fog condensation (D'Antonio 1990[1], Magnoli et al. 2013[2]). Plants were planted within iceplant either by using a spade to cut through the dead iceplant, or by removing iceplant by hand, to clear a small area for the young plant to be installed. Plants were placed at distances of 6 to 18 inches apart, dependent on the species and expected width of a one-year-old plant.

Planting on Bare Sand

Some native plants were planted in foredune areas where no plants currently exist to help aid in the capture of sand. In these areas, plants were planted within small mounds (3" high) above the base elevation to reduce burial. Plant spacing in this area was determined in close consultation with State Parks and Point Blue to ensure that snowy plover breeding habitat was not negatively impacted by planting density.

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[1] Carla M. D'Antonio. 1990. Seed Production and Dispersal in the Non-Native, Invasive Succulent Carpobrotus edulis (Aizoaceae) in Coastal Strand Communities of Central California. Journal of Applied Ecology, Vol. 27, No. 2. pp. 693-702

[2] Magnoli, Susan M., Kleinhesselink, Andrew R., Cushman, J. Hall. 2013. Responses to invasion and invader removal differ between native and exotic plant groups in a coastal dune. Oecologia 173:1521–1530

Summary of Restoration Efforts

Goal 1: Eradicate Iceplant from Foredune and Mid-Dunes

Herbicide Application

Herbicide was applied to iceplant between October and February of years 2016, 2017, and 2018. During the late 2016 and early 2017 spraying season the herbicide application crew completed initial spraying at the Potrero and Molera project areas, and began applying herbicide to the Salinas River project area. Heavy rains during this time period limited opportunities for the crew to spray, as herbicide cannot be applied within 48 hours of rain. After the initial effort, approximately 20% the iceplant remained to be sprayed within the project area. Due to spring through fall access limitations, no additional spraying was possible in early 2017.

During Fall 2017 (the second year of spraying), ECI finished applying herbicide to the entire project site. They also went back through the project site and spot sprayed locations where iceplant wasn't dead or was resprouting. Further, ECI cut and applied herbicide to *Arundo donax* near the Salinas River Mouth and sprayed a patch of invasive European beachgrass (*Ammophila arenaria*) near the Potrero Rd access.

During Fall 2018, ECI spot sprayed areas where iceplant had not died during the first two years or areas where resprouting was occurring.

Left: the herbicide application crew and project manager discuss iceplant locations to focus on for spraying efforts. Right: CCR and CCWG staff conduct an iceplant pulling day to remove any newly sprouted iceplant.

Hand pulling

During the Fall of 2016 and Winter of 2017, the CCR restoration crew and CCWG staff began hand pulling iceplant throughout the project area in locations where iceplant was heavily mixed with native species. Each fall and winter through March 2019, the crew continued to hand-pull iceplant in areas where it was mixed with natives or in areas where small amounts of iceplant began to resprout.

Goal 2: Establish Diverse Native Plant Composition in SRSB Dunes

Out-planting

Between January 2017 and March 2019, approximately 20,000 plants were planted within the project area. Plant propagation and out-planting focused on species that were known to be common and easily established at the site, as well as species that were less common in order to increase diversity of the dune plant community. Table 2 below lists the species planted and numbers of each species out-planted during each season.

Table 2. SRSB plant species out-planted within project site

Species	Common name	Planting Season			Total
		2016/2017	*2017/2018*	*2018/2019*	
Abronia latifolia	yellow sand verbena	18	0	0	18
Abronia umbellata	pink sand verbena	18	0	0	18
Ambrosia chamissonis	beach bur	654	294	61	1,009
Armeria maritima	sea thrift	364	980	782	2,126
Artemisia pycnocephala	beach sagewort	2,036	588	560	3,184
Atriplex leucophylla	beach saltbush	1,056	294	354	1,704
Calystegia solanella	beach morning glory	17	0	0	17
Camissonia cheiranthifolia	beach primrose	1,552	147	19	1,718
Cardionema ramosissimum	sand mat	1,000	49	36	1,085
Castilleja latifolia	seaside painted cup	49	0	0	49
Corethrogyne filaginifolia	California aster	315	147	35	497
Dudleya caespitosa	coast dudleya	750	147	49	946
Ericameria ericoides	mock heather	1,086	441	87	1,614
Eriogonum latifolium	coast buckwheat	1,080	539	560	2,179
Eriophyllum staechadifolium	lizard tail	1,400	490	339	2,229
Eschscholzia californica maritima	beach poppy	0	74	269	343
Extriplex californica	California salt bush	16	49	16	81
Lathyrus littoralis	beach pea	0	98	66	164
Leymus mollis	American dune grass	475	550	115	1,140
Phacelia ramosissima	branching phacelia	17	0	0	17
		11,903	**4,887**	**3,348**	**20,138**

Native plants in cones, rose pots, and gallon containers are staged for planting into the dead iceplant.

Hand Broadcast Seeding

Distinct seed mixes were made for hand broadcasting on to the foredune and mid-dunes (Table 3) and hand broadcast during the late fall and early winter months.

Table 3. SRSB seed mixes

Location for seed mix	**Species in seed mix**
Foredune	*Ambrosia chamissonis, Armeria maritima, Artemisia pycnocephala, Atriplex leucophylla, Eriogonum latifolium, Eschscholzia californica maritima, Lathyrus littoralis*
Mid-dune	*Abronia umbellata, Armeria maritima, Artemisia pycnocephala, Calystegia solanella, Cardionema ramosissimum, Castilleja latifolia, Chorizanthe pungens ssp. pungens, Dudleya caespitosa, Ericameria ericoides, Eriogonum latifolium, Eriophyllum staechadifolium, Eschscholzia californica maritima, Gilia tenuiflora ssp. arenaria, Phacelia ramosissima*

Goal 3: Enhance Storm Resilience of Dune System

The project team worked to restore 20 acres of dune habitat through eradication of iceplant and establishment of native species (see Goal 1 and 2 above). The project also included strategic planting of dune grass on the foredune and installation of hay bales and drift wood in a few select locations along the foredune in order to help capture sand, build dunes, and increase dune face resiliency (Figure 3 and Figure 4).

Figure 3. Newly installed native dune grass helps capture sand in the foredune.

Figure 4. Installation of drift wood and hay bales along the foredune help capture sand and increase dune roughness. Left: Initial placement of hay bales and driftwood near the Potrero Rd beach access trail. Right: After a few months the hay bales slowly decompose while continuing to help capture sand and add to foredune roughness.

Goal 4. Support California State Parks Dune Management Efforts

Interpretive Signage

Interpretive and regulatory signs were installed in 2017 and 2018 at beach access trails and along back-dune trails. The interpretive signs highlight the important functions of dune systems, sea level rise impacts, and the dune restoration process. Two wayside signs (24"x36") were installed at the Potrero Rd beach access parking lot and two larger panels (32"x40") and a 3-sided wooden kiosk were installed at the Molera Rd parking lot. Ten "Please keep off the dunes" regulatory signs were installed along beach access trails and along the back dune "horse trail" (Figure 5).

Figure 5. Interpretive and regulatory signage installed at SRSB. Top left: Wayside interpretive signs at Potrero Rd beach access parking lot. Bottom left: Interpretive kiosk installed at Molera Rd beach access parking lot. Right: "Please stay on trails" signage installed along dune trails.

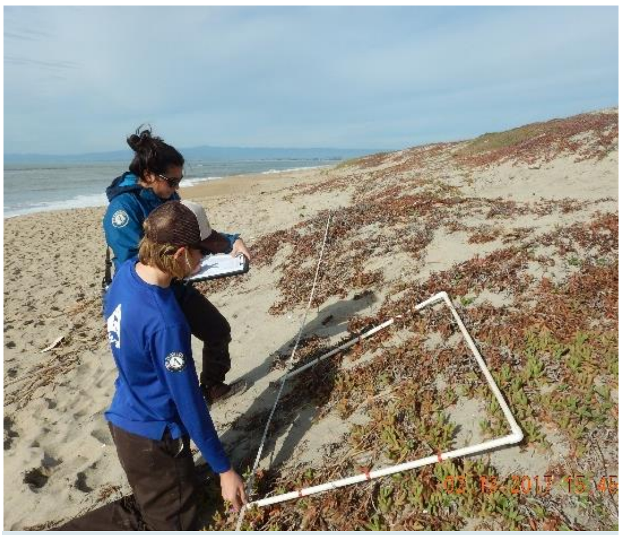
Fencing

Six hundred feet of no-climb fencing was installed along the Sandholdt Rd parking lot in 2017 and 2018. Fencing was designed with a 6 inch gap between the bottom of the fence and ground for small animals to easily pass through. This area was identified to be the priority for fence installation as it is where the dunes receive the most wayward foot traffic which disturbs dune topography and sensitive habitat (Figure 6).

Figure 6. New no-climb fencing was installed along the Sandholdt Rd parking lot to reduce wayward foot traffic through sensitive dune habitat

Monitoring

State Parks has limited resources to conduct biological monitoring at SRSB. As part of the project, the Central Coast Wetlands Group conducted vegetation surveys and high resolution dune mapping throughout the project period (2016-2019) in order to document restoration success and investiagte restoration best practices. Monitoring was also used to identfy areas where adaptive management was needed.



CCC Watershed Stewards assisting with a parallel quadrat vegetation transect along the foredune.

Dr. Ivano Aiello and students surveying the dunes with the terrestrial laser scanner.

2. VEGETATION MONITORING

Purpose

Vegetation surveys were used to characterize the vegetation community located within the restoration areas and to document changes over the course of the restoration project. Information collected during surveys included percent cover of native and non-native vegetation and plant species diversity. Presence of iceplant during monitoring was noted for spraying or hand removal. CCWG performed vegetation surveys at the three restoration areas (Potrero, Molera, and Salinas River mouth). The results of these surveys provide information on the success of restoration activities.

Methods

Vegetation transects were established throughout the project area in 2016 within areas scheduled for iceplant removal and native planting (Figure 7). Vegetation monitoring was conducted before project initiation (February 2016), twice a year (February and October) during restoration, and once post restoration (February 2019).

Two vegetation monitoring techniques were used during surveys:

1. The Point Intercept Method was used to estimate cover of specific species and to quantify native and non-native cover. The method noted species type, mulch or bare ground at regular intervals (i.e. intercepts) along the transect. Percent cover was estimated based on the number of noted occurrences of the species relative to the total number of points measured.

2. The quadrat method was used to determine species richness. This method tallied the unique species found within a 1-meter square quadrat placed at numerous locations along the transect length.

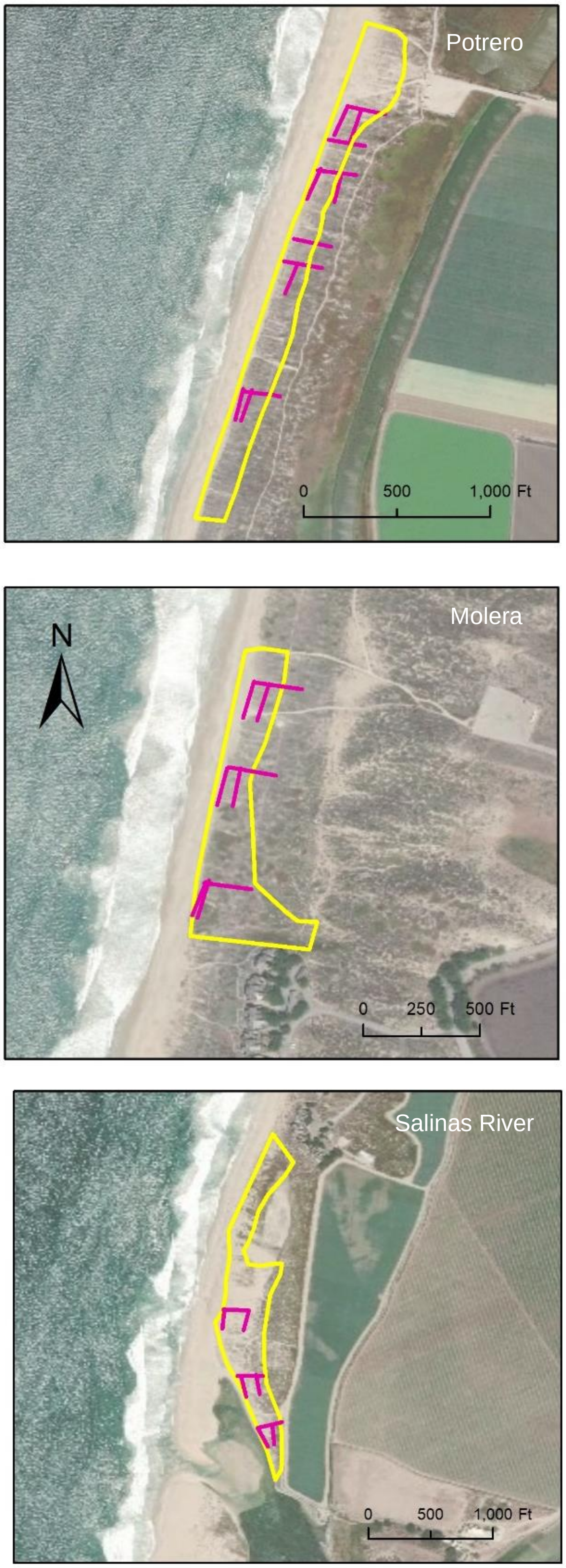


Figure 7. Vegetation Transect Locations

Specific survey efforts for this project are detailed below and shown in Figure 8.

Vegetation Monitoring included:

1. Point-intercept transects perpendicular to the coastline (percent cover): 50 m transect laid perpendicular to shore documenting plant species cover.

2. Point-intercept transects parallel to the coastline (percent cover): two 50 m transect laid parallel to shore, one along the foredune and one along the mid-dune, documenting plant species cover.

3. Parallel quadrat transects (species richness): Five randomly placed quadrats (1m^2) sampled within each 50-meter transects, one along the foredune and one along the mid-dune, to quantify the diversity on the site and to capture the presence of rare species.

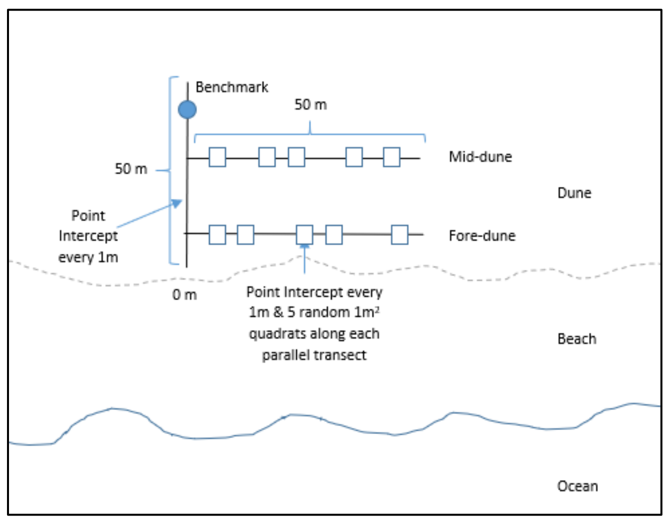


Figure 8. Vegetation Transect Layout

Sampling Schedule

Surveys were conducted twice a year, each year of the project (2016-2019). Surveys occurred outside of the plover nesting season. Fall surveys were conducted after September 30th and the "Spring" surveys were conducted before March 1st.

Results

Percent Cover

The following graphs show average native plant cover, iceplant cover, and other non-native cover for each type of vegetation transect (Perpendicular point-intercept, Parallel foredune point-intercept, and Parallel mid-dune point intercept) throughout the project period. Percent cover includes open sand areas of the dune system, not only the vegetation. Percent cover of abiotic features (bare sand, wrack, etc.) were calculated, but omitted from the graphs.

The perpendicular point-intercept transect surveys found that iceplant was reduced from 23% to 3% total cover. Native cover increased from 27% to 36% total cover, and was greatest at 47% in Spring 2018. The cover of other non-native species increased from 1.8% cover to 2.4% total cover (Figure 9).

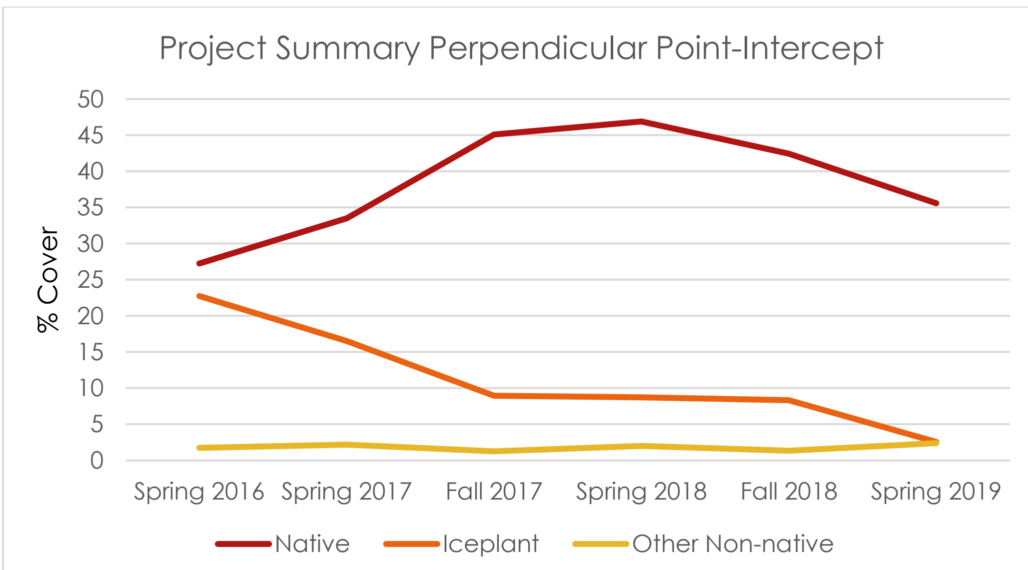


Figure 9. Average of point-intercept perpindicular vegetation trasnects for entire project area

In the foredune, iceplant was reduced from 41% to 3% total cover. Native cover decreased slightly from 7% to 6% total cover, but increased to 19% in Fall 2018. Other non-native species decreased from 5% to 2% cover (Figure 10).

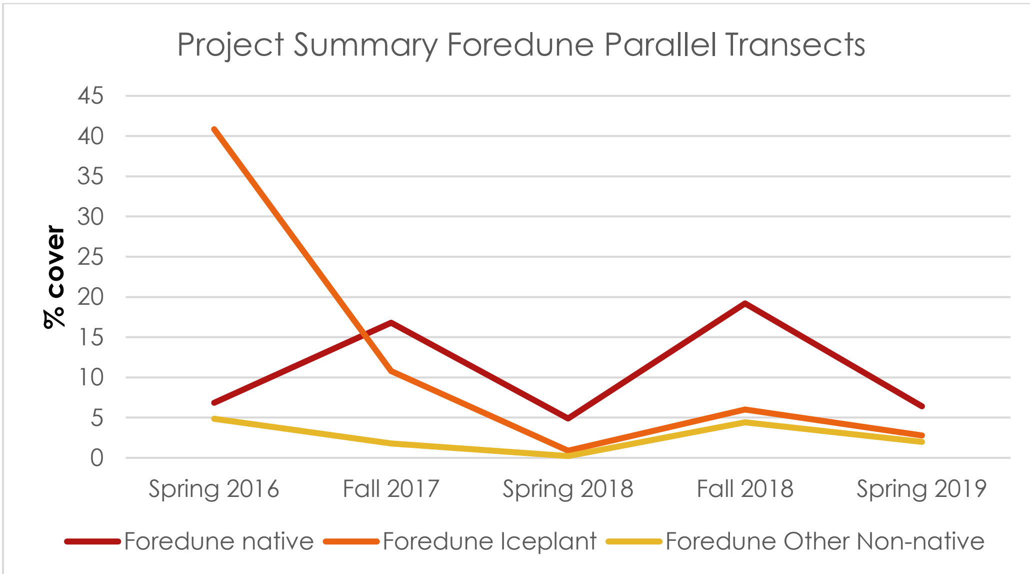


Figure 10. Average of foredune point-intercept parallel vegetation trasnects for entire project area

In the mid-dune, iceplant was reduced from 43% to 5% total cover. Native cover increased from 29% to 32% total cover, and was greatest at 46% in Fall 2018. Other non-native species cover increased slightly from .3% to 2% total cover (Figure 11).

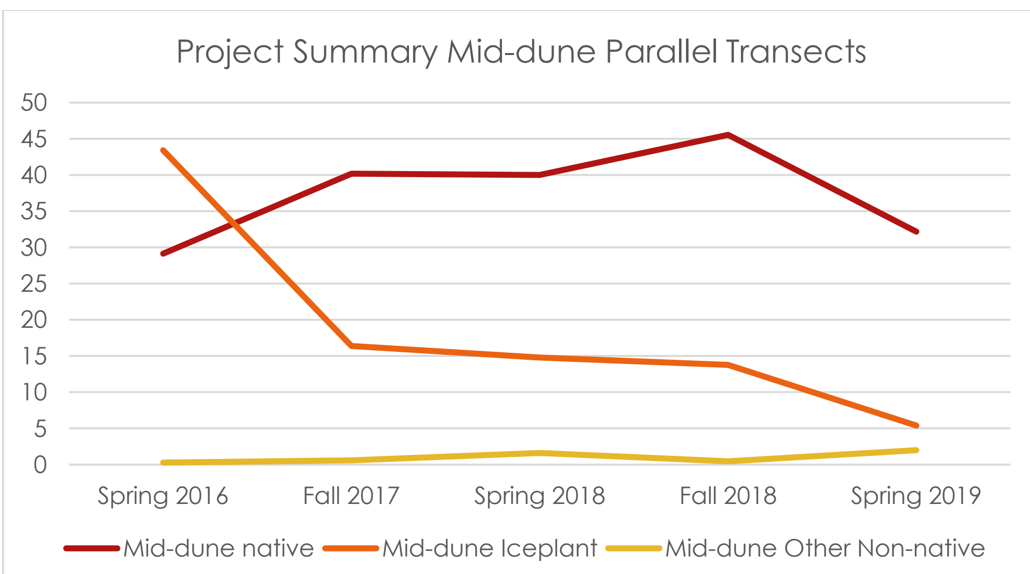


Figure 11. Average of mid-edune point-intercept parallel vegetation trasnects for entire project area

The foredune point intercept transects show that initial iceplant comprised a greater percent of cover than the native species (41% compared to 7%), whereas as in the mid-dune the cover of iceplant and native plants were more similar (43% and 29%). At the end of the project, iceplant cover in both the foredune and mid-dune was reduced to less than 5%, but native plant total cover did not change significantly.

Many of the individual transects document a similar trend of large decrease in iceplant cover and small increase in native cover. Some individual transects documented much higher increases in native cover (Figure 12).

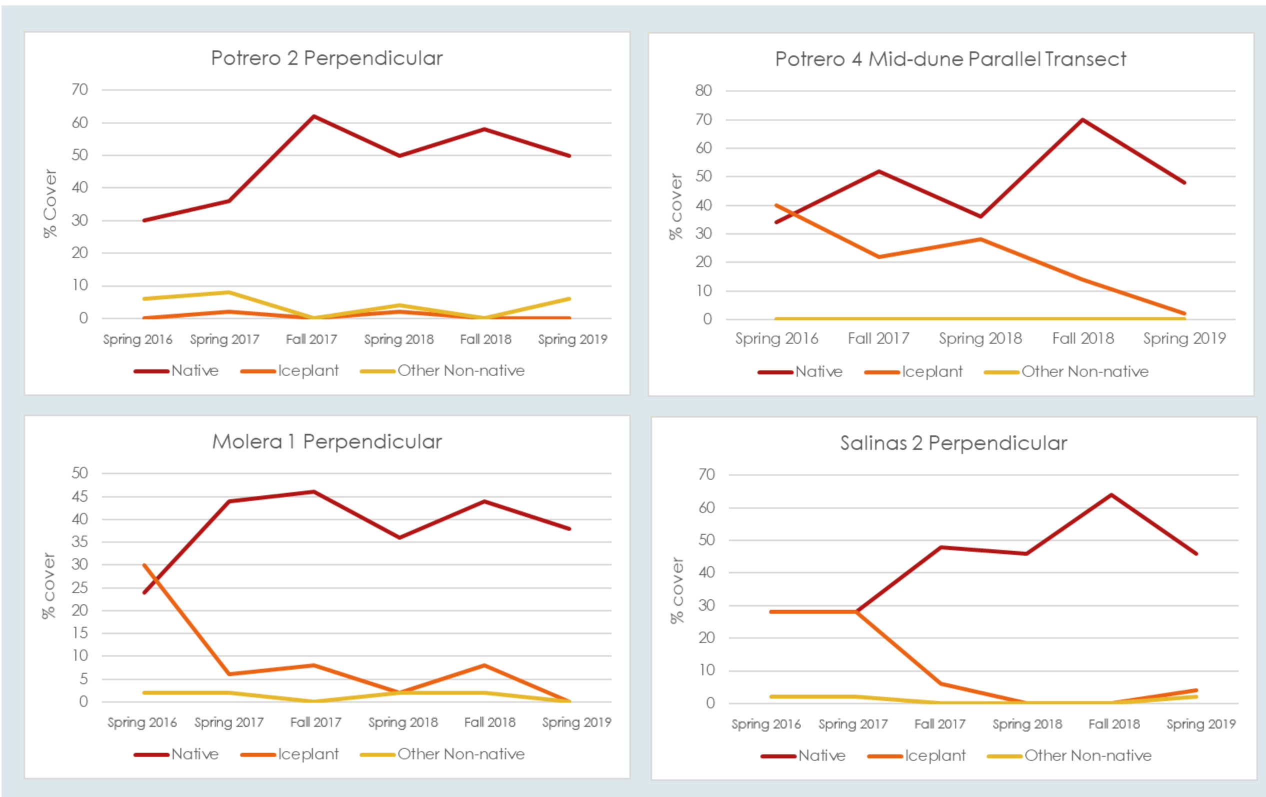


Figure 12. Changes in percent cover of native and non-native plant species along individual vegetation transect surveys over time.

Species Richness

Using data collected during the quadrat surveys, species richness was calculated for each of the three restoration areas and is shown in Figure 13. Species richness did not change between the beginning and the end of the project. Diversity decreased after the initial spraying and iceplant removal and then increased during the second and third years of the project. The Potrero area had the greatest species richness, followed by the Salinas River mouth area, and then the Molera area.

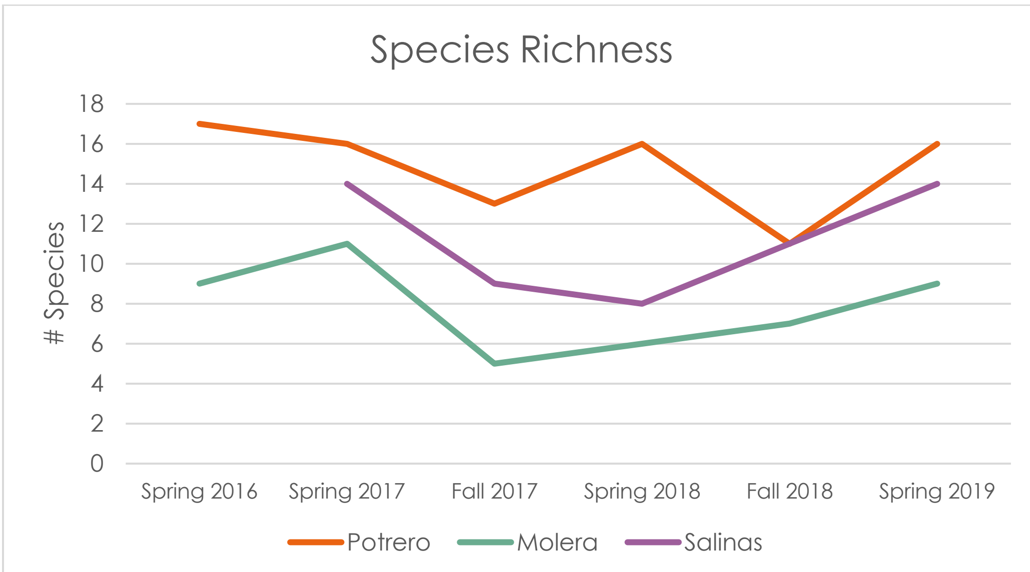


Figure 13. Species Richness within each Restoration Area (Potrero, Molera, Salinas River) over time.

Discussion & Conclusion

The vegetation surveys show a difference in the initial vegetation community in the foredune and mid-dune areas. In the foredune, iceplant cover was greater than cover of natives. The foredune also saw the most variability in vegetation cover, most likely due to seasonal differences in sand erosion and accretion and wave impacted foredunes. In contrast, the mid-dunes had similar cover of natives and iceplant, both greater than in the foredune.

Within the entire project area, iceplant in the foredune was reduced from 41% to 3% cover and iceplant in the mid-dune was reduced from 43% to 5% cover. On average, the percent cover of native vegetation did not change significantly, however in certain site-specific areas, where iceplant was reduced to almost 0%, native cover did increase (Figure 12). This may indicate that herbicide application had limited impact on native vegetation. The perpendicular transects which cross the foredune and mid-dune and extend slightly into the back dune show a lower initial percent cover of iceplant (23%) and higher native cover (27%) indicating that native cover is naturally more present than iceplant.

Seasonal difference of native plant cover was documented between the Spring and Fall surveys, with percent native cover highest in Fall and lower in Spring. Because Spring surveys were actually conducted in February and Fall surveys were conducted in October (due to limitation of accessing the study site during Western snowy plover breeding season: March-September), this seasonal variation in cover is most likely due to robust growth of the vegetation through Fall at and cold winter weather leading to plant senescence documented in the February surveys.

Other variability in percent cover of native plants may be attributed to differences in plant communities of the three restoration areas and inconsistencies in herbicide application (due to site specific constraints) between the three restoration areas. For example, Potrero was sprayed each year. Molera was partially sprayed the first year, and spraying was completed the 2nd year, with follow up spot spraying the 3rd year. Salinas was not sprayed during the first year, so initial iceplant removal did not occur at Salinas until Fall 2017, with only one year of follow up spot spraying.

Other studies have found that when iceplant is removed, invasive grasses become established. This did not occur within this study. Cover of non-natives other than iceplant did not increase during the project period. Non-natives noted during transects were primarily sea rocket and New Zealand spinach, neither of which are seen as invasive species of concern on the dunes.

The presence of European dune grass and *Arundo* were also significantly reduced within the treatment areas and the project team will work with State Parks to track regrowth and support future spraying of remnant populations. Similarly, iceplant was found to recruit through regrowth of sprayed plants and through seed dispersal by birds. When plants are small, removal and thus maintenance of iceplant free dune habitat, is simple. If plants are allowed to regrow into large patches, additional spraying is needed which has greater impacts on the dunes and costs to execute.

Therefore, the restoration team recommends (and will work with State Parks to establish) an annual dune walk, aimed at removing any small recruits of iceplant and noting any large patches that will require mechanical or chemical removal. Because iceplant growth is greatest during the summer growing season, the restoration team will discuss opportunities to complete mid and back dune removal activities during the summer/fall plover nesting season, when access to the foredune is restricted, to ensure iceplant growth is limited and thus can be removed by hand.

Additional Study: GIS Analysis of Vegetation Cover

A separate GIS analysis was carried out using the image classification toolset in ArcGIS to compare high resolution orthomosaic images from the UAV surveys (see section 3) in order to determine change in iceplant and native cover between the start of the project and the end of the project. Specifically, the interactive supervised classification tool was used that isolates the spectral signatures for iceplant, mock heather (one of the more dominant natives on the dunes), bare ground, and other (unidentified native plants, dead iceplant, etc.). However, live iceplant exhibits a wide range of colors that includes red, orange, and green making it particularly difficult to accurately classify the other vegetation types. The results of the analysis compare changes in vegetation at the unrestored area adjacent and the focus area within the restoration boundaries (Figure 14 and Figure 15). The data show that in the unrestored area iceplant increased between 2015 and 2018 and in the restored area, iceplant decreased between 2015 and 2018. Mock heather was shown to decrease at both sites, bare ground stayed about equal, and “other” increased at the restoration site, but stayed about equal at the control (unrestored) site. It can be assumed that the “other” category is comprised mostly of other native dune plants as well as the dead iceplant.

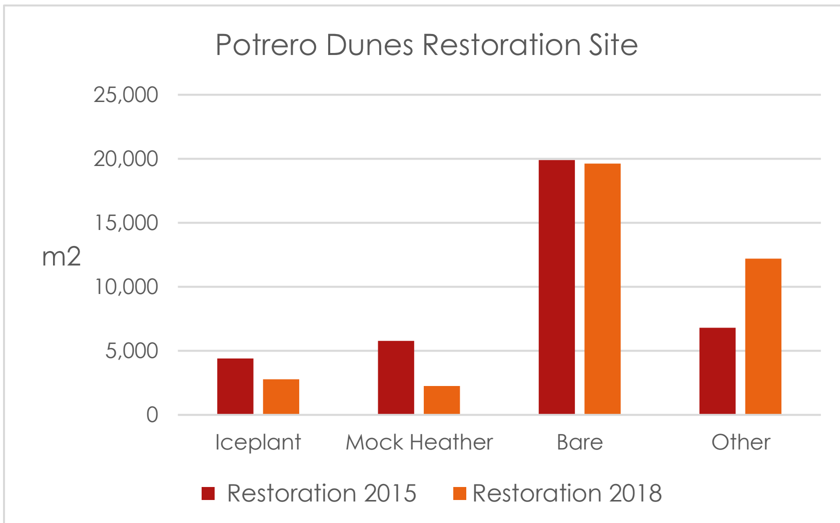


Figure 14. Results of the image classification GIS analysis for a restored section of the dunes within the project site near the Potrero Rd beach access trail.

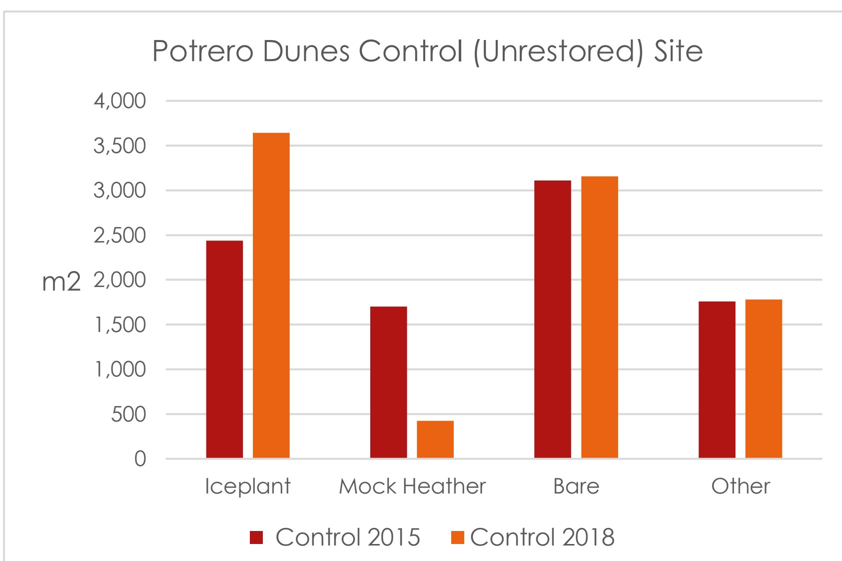


Figure 15. Results of the image classification GIS analysis for an unrestored section of the dunes adjacent to the project area.

3. DUNE MAPPING

Purpose

The surveys were carried out to assess the geomorphologic characteristics and variability of the different habitats associated with the dunes with focus on the windward slope (the side of the dune facing the ocean), the foredune and the transition with the adjacent beach habitats including runnel and beach berm. High-resolution (<~10cm) dune mapping was conducted before and after project implementation using a combination of survey tools including differential GPS equipment, Terrestrial Laser Scanners (TLS), and Unmanned Aerial Vehicles (UAV).

Methods

A beach/dune morphology baseline of the study area was created before project implementation. Digital Elevation Models (DEM) of the section of the beach between the mouth of the Salinas River and the head of the Monterey Canyon (at the mouth of the Moss Landing Harbor) and adjacent dunes were created based on the stereophotogrammetric analysis (~2cm resolution) of surveys conducted with an Unmanned Aerial Vehicle (UAV). For all UAV surveys a set of temporary Ground Control Points (GCPs) was created using a differential GPS with the GCPs being markers visible from the aerial photos. The GCPs were used for the stereophotogrammetric analysis of the UAV photos using the software Pix4D which resulted in the production of DEMs of the surveyed areas.

Terrestrial Laser Scanner (TLS)-based, beach/dune morphology baselines using a Trimble VX Spatial Station were combined with the aerial surveys to measure beach/volume change. This state-of-the-art spatial station is equipped with Direct Reflex (DR) technology, a direct drive system with robotic servo-mechanisms and a built-in digital camera. The instrument is operated via radio-link by a controller unit, it can acquire accurate (<3 mm), multiple (15 points/s) spatial data (point clouds), and the range of operation of the DR laser is 2 to 500 meters while on target mode (optical prism mounted on a survey rod) the acquisition can work as far as 2 km away.

The TLS surveys were conducted along the Potrero and Molera restoration area (Figure 16). The TLS survey areas cover a coast-parallel band of approximately 200m centered at the survey benchmark. For each survey area 2 stable benchmarks (physically a ~5 foot long rebar hammered in the ground) were determined using a differential GPS (horizontal and vertical accuracy ~2cm). The point cloud produced includes a cross-shore transect from the dune crest(s) to the beach (Figure 17). Scanning resolutions range between 10 and 50cm with approximately 10,000 single point measurements with a survey rod were combined to account for geomorphological features (e.g. slope of the foredune) not directly visible from the TLS or for areas covered by intense vegetation.

Post-processing of the TLS data was done with Real Works (software by Trimble). Post-processing operations include editing of the point clouds, merging of point clouds and survey points collected from different fore-sights, interpolation and contouring, creation of surface meshes, and photographic rendering of three-dimensional (3D) surface models. Real Works was also used for the analysis/parameterization of the surface scans (e.g. volumes, slope angles), to compare TLS and UAV data and for the serial scans to identify and quantify areas subjected to volume changes. The vertical datums of the beach and dunes were defined relative to the operational MHW elevation datum for the Monterey Bay area (MHW for the closest tidal station Monterey Harbor is 1.40m NADV88).

Sampling Schedule

Sampling events occurred during implementation (2016–2018). A baseline UAV survey covering the section of the beach between the mouth of the Salinas River and the head of the Monterey Canyon was carried out in October 2015. A second UAV survey which covered a similar extent as the October 2015 survey and with similar resolution was carried out in September 2016. Further UAV surveys were carried out in 2018 with focus on the Potrero section of Salinas River State Beach. TLS surveys were conducted throughout the duration of the project and occurred outside of the plover nesting season (March-October).

Figure 16. Overview map showing the location of the TLS surveys in the northern restoration areas (Potrero Rd. section) and central restoration sites (Molera Rd section).

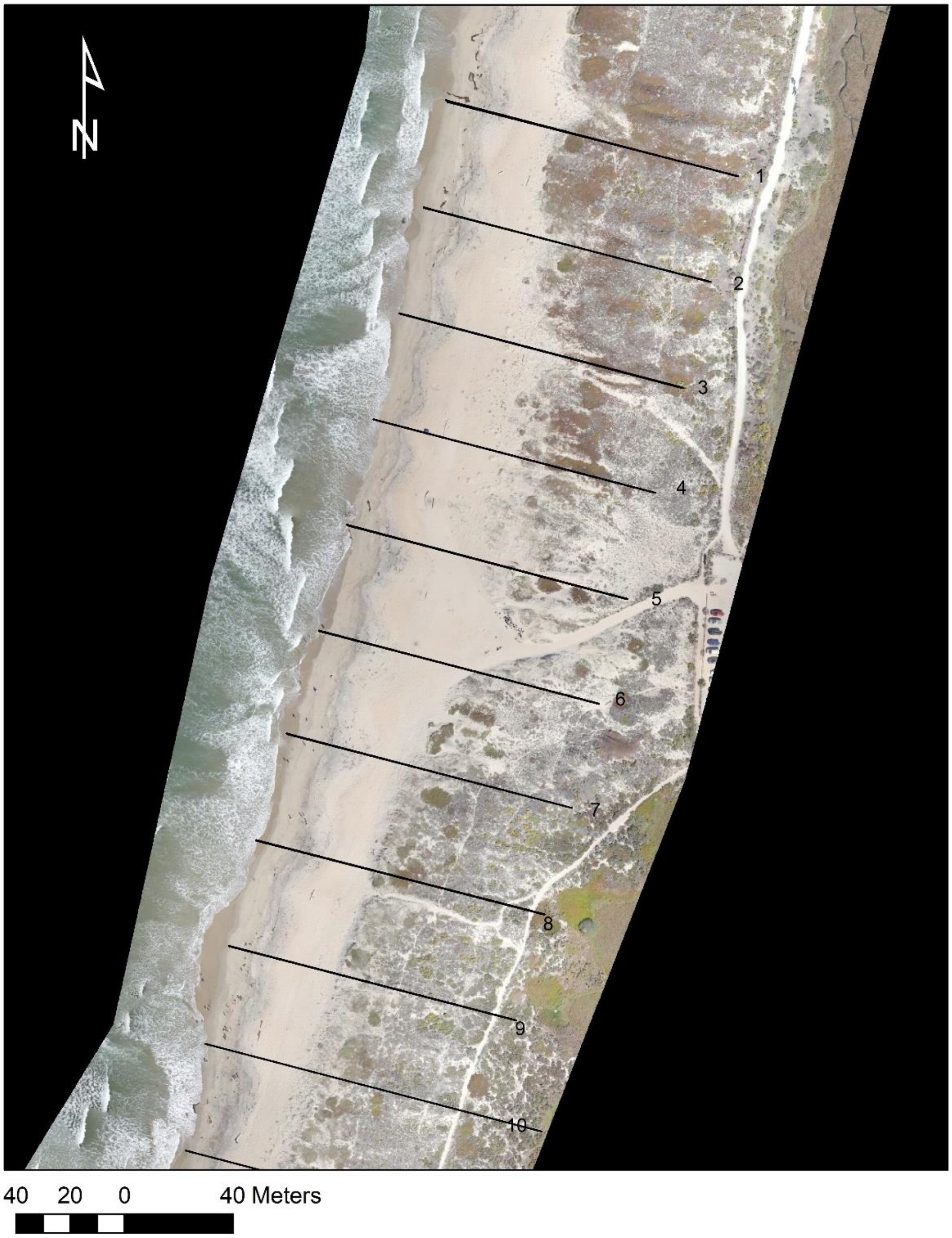


Figure 17. Imagery from UAV survey (2016). The lines represent the locations of cross sections used to assess topographic change for both unrestored areas and restored areas at the Potrero restoration site.

Results and Discussion

The surveys conducted in the Fall of 2015 and 2016 provide a baseline of the 'natural' change prior to dune restoration (Figure 18A, B and C). Although the time series provided by the survey is relatively short, it covers a period characterized by both 'normal' and El Niño conditions (the 2016-2017 El Niño). Overall, the surveys show that there is little major topographic change between surveys with the exception of a few areas of accretion in the dune area (up to 1m) that are mainly located in the northern restoration area south of the Potrero Rd. entrance. Erosion (up to >5m) was detected in the inner beach (runnel) of the central and southern restoration areas and in the region that links the upper beach with the foredune (see discussion below).

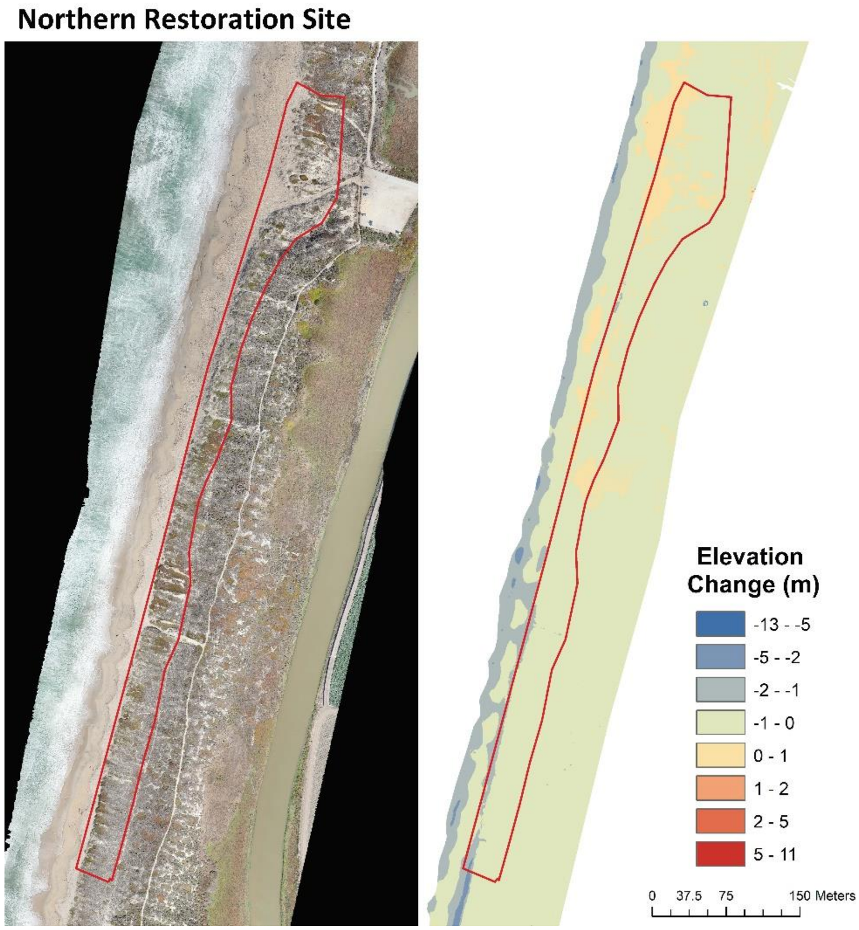


Figure 18A. Digital elevation models (DEMS) and aerial photographs of the UAV surveys. The maps on the right show elevation change in meters calculated by subtracting the 2015 from the 2016 surveys for the northern (Potrero) sites.

Central Restoration Site

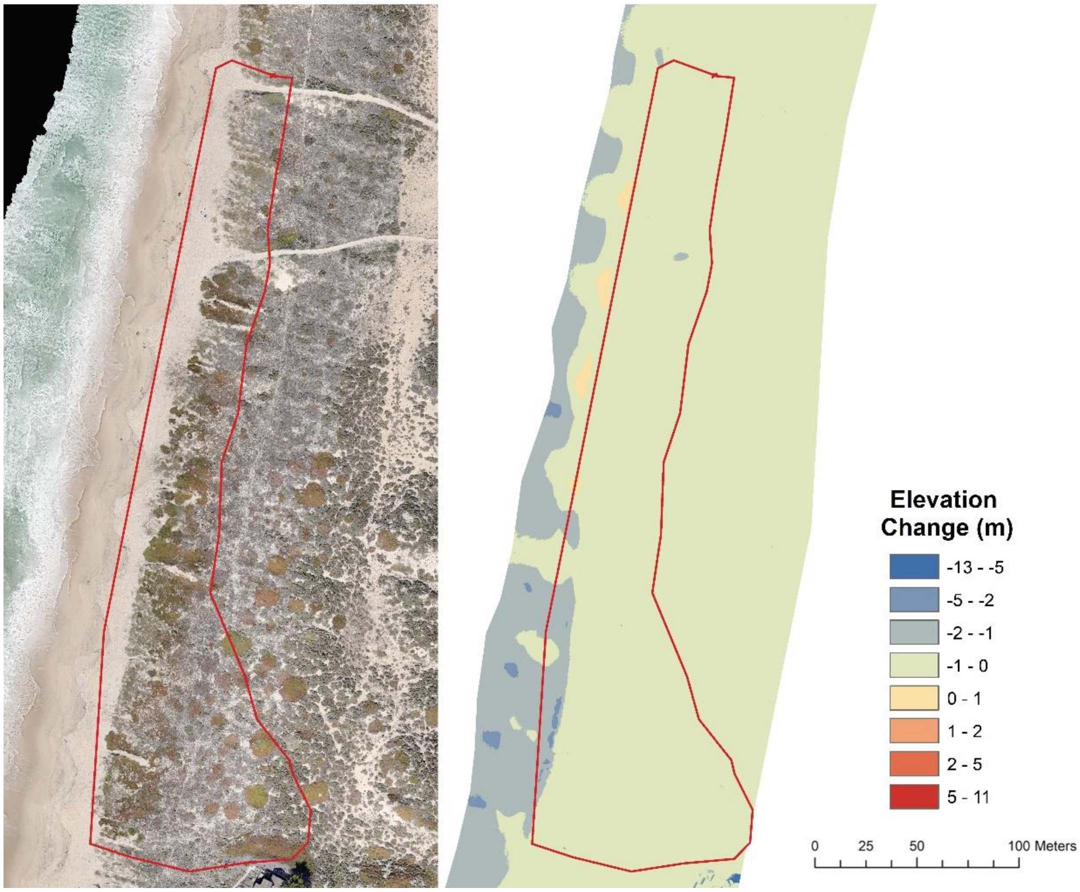


Figure 18B. Digital elevation models (DEMS) and aerial photographs of the UAV surveys. The maps on the right show elevation change in meters calculated by subtracting the 2015 from the 2016 surveys for the central (Molera) sites.

Figure 18C. Digital elevation models (DEMS) and aerial photographs of the UAV surveys. The maps on the right show elevation change in meters calculated by subtracting the 2015 from the 2016 surveys for the southern (Salinas River) sites.

Examples of survey comparisons between the initial (2015) baseline survey and the UAV-TLS surveys carried out in 2018 after restoration are shown as beach to dune cross-sections (see Figure 17 for section locations and Figure 19 for the cross-sections). The examples are from the northern restoration area and each plot shows the cross-sectional topographic profile (~120m) of the 2015 (blue), 2016 (red) and 2018 (green) surveys and, from left to right, include the upper beach, the foredune, and the dune crest area. Sections 1, 2 and 3 (Figure 19A) are just outside of the restored area while sections 6, 8 and 9 are within the restored area (Figure 19B). The most obvious and expected change between the surveys that span a 4 year period is that while the dune habitats are relatively stable the upper beach changes dramatically as a result of both wave energy at the time of the survey and local wave dynamics. Small changes in elevation (~±30cm) between surveys in the dune habitats do not necessarily reflect changes in topography, but can be explained by both the vertical error between surveys which can be estimated in ±10cm, and differences in the distribution and height of the vegetation which is particularly abundant in the crest areas.

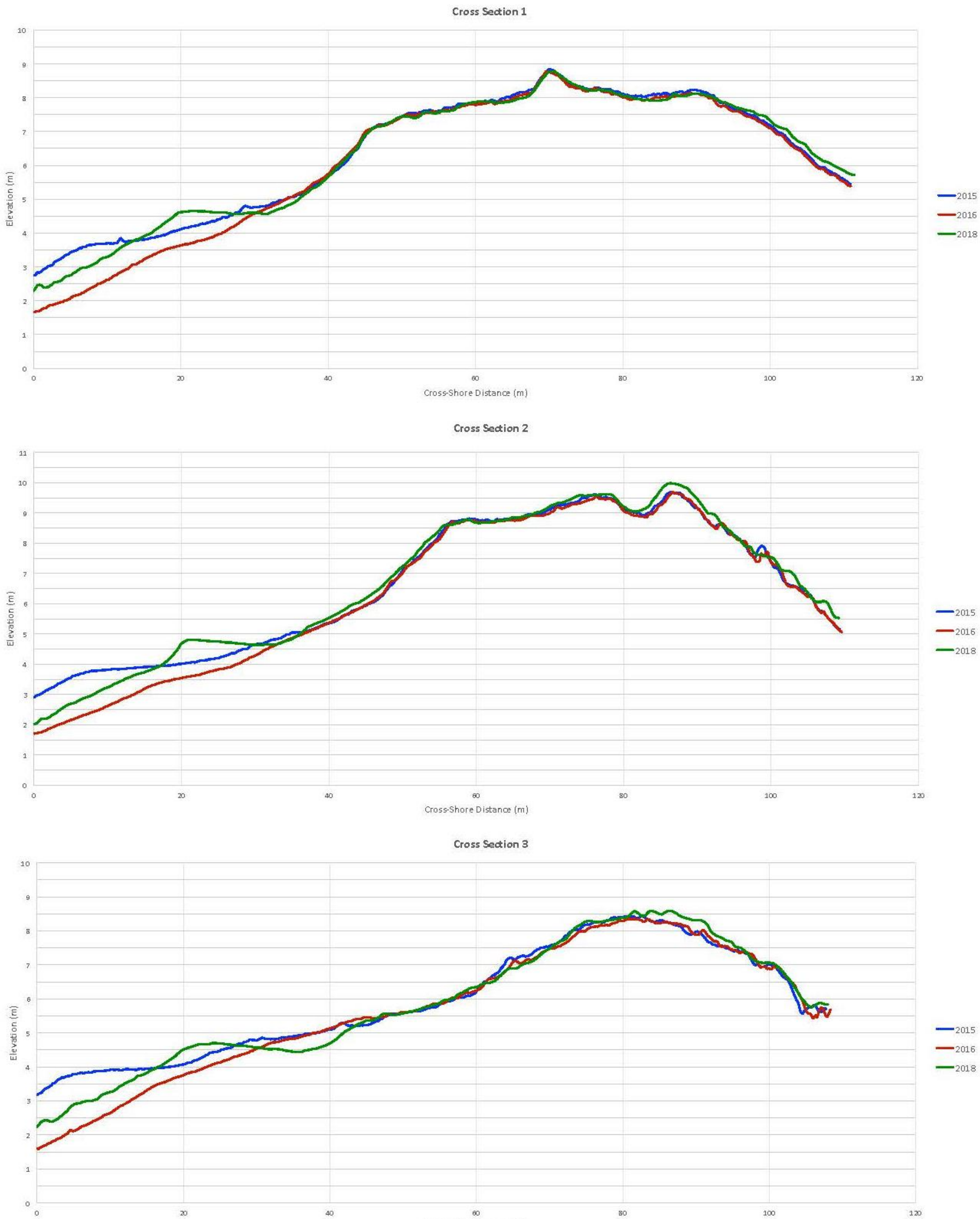


Figure 19A. Typical cross sections of the northern area outside the restoration area. Each plot shows the cross sectional topographic profile (~120m) of the 2015 (blue), 2016 (red) and 2018 (green) surveys and, from left to right, include the upper beach, the foredune, and the dune crest area.

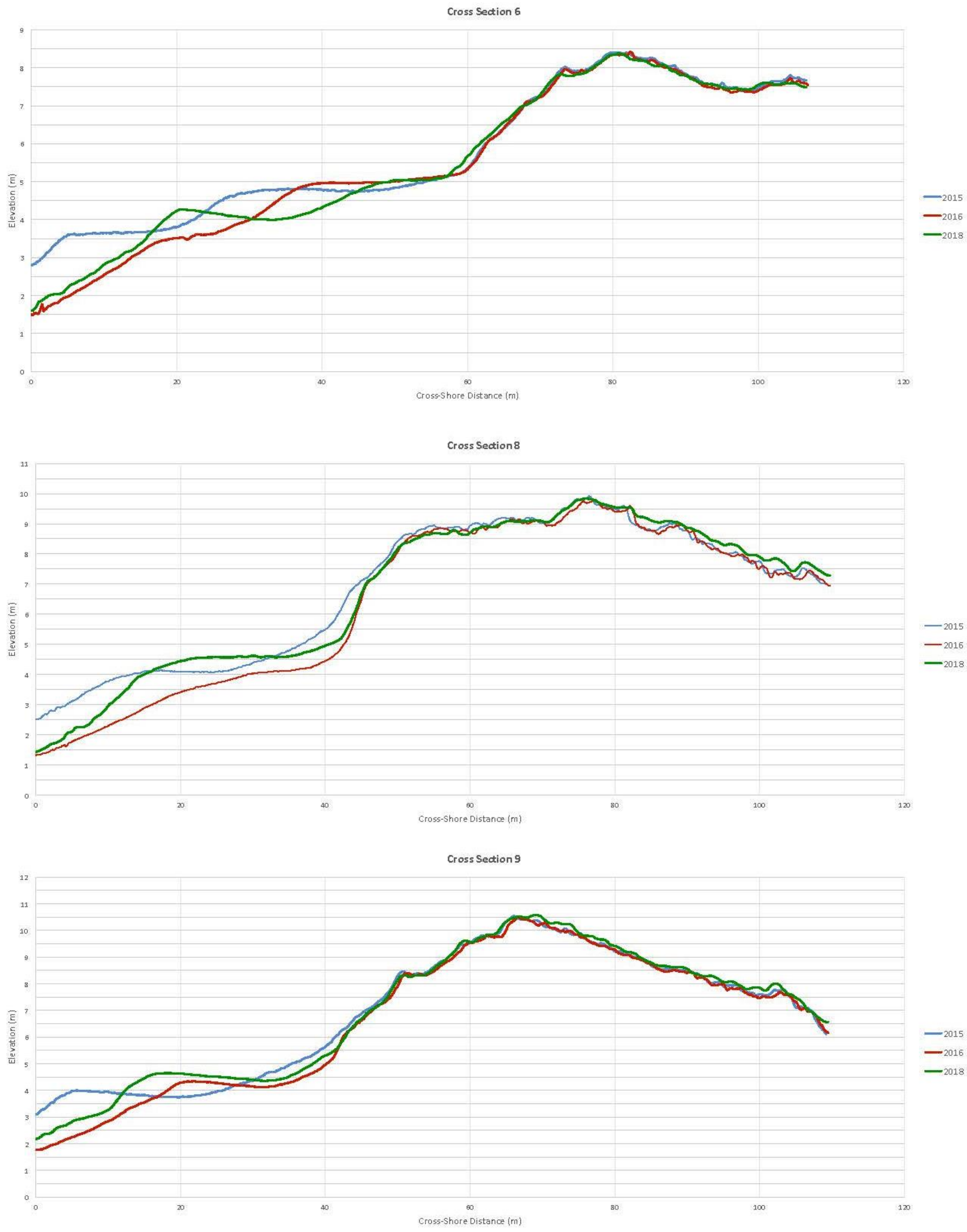


Figure 19B. Typical cross sections of the northern area inside the restoration area. Each plot shows the cross sectional topographic profile (~120m) of the 2015 (blue), 2016 (red) and 2018 (green) surveys and, from left to right, include the upper beach, the foredune, and the dune crest area.

The area that links the foredune to the upper beach is particularly critical for the resilience of the dune because it has a buttressing effect on the foredune and protects it from wave erosion during high-energy high-surge events. Also, erosion of the foredune can increase the steepness of the slope and might cause catastrophic mass failures which might affect the stability of the inner part of the dune. The surveys of the restored area (Figure 19B) show that this key habitat was subjected to erosion and mass failures in 2016 with vertical loss of sand of up to 3m (e.g. at around 40m distance in sections 8 and 9 in Figure 19B). The follow up surveys in 2018, after restoration, show that the areas that were subjected to erosion recovered some of the lost sediments in 2018. It is worth noting that much of the change that affected the foredune over the study period has occurred on the portions of the foredunes that were already steep (e.g. cf. Figure 19A and 19B), supporting the interpretation that dune erosion is enhanced where the upper beach has a more reflective (i.e. less dissipative profile). It also suggests that the steepest dune faces are the one that are more subjected to geomorphological change both in terms of erosion but also accumulation of sand.

The dune mapping that occurred during the project period only picked up seasonal changes in topography (i.e. erosion due to winter storms, and accretion during summer months). Long-term dune topography data collection is needed to be able to better understand how restoration efforts (removal of iceplant, planting of natives, and strategic placement of natural materials) affects longer term dune erosion and accretion processes. However, the results of the study do provide high resolution base line maps and data for future work and help us better understand the shorter-term variation in dune topography throughout the seasons.

This survey helps to document the temporal variability in sand supply and the movement of sand through the system over time. As restoration continues, we will continue to document seasonal fluctuations in sand supply and wave induced erosion as well as long term changes in dune elevation and morphology. Future surveys can also be used to test how restoration activities help to reduce storm impacts to the dune system. Additional observations and local sediment accretion studies will provide additional information on sand movement and restoration effects.

4. RESTORATION STUDY PLOTS

Purpose

There is limited information on restoration best practices for large scale coastal dune restoration projects. The intent of this restoration study was to investigate success of different invasive species elimination and native planting strategies within an active restoration site, with the aim to gather information that will help to inform future restoration efforts both at Salinas River State Beach as well as at other project sites.

The following hypotheses were tested as part of this project:

Hypothesis 1: Degraded plant material of herbicide sprayed iceplant provides a protective mulch layer over bare sand that helps native plant propagation and growth and reduces invasive weed establishment.

Hypothesis 2: Planting dunes at high densities leads to greater initial cover of native plants

Hypothesis 3: Planting dunes with greater numbers of species will increase success of restoration efforts

Methods

Three study plots were established within large monoculture areas of sprayed/dead iceplant (>50m2) in February of 2017 at each of the three restoration areas (Potrero, Molera, Salinas River) after the initial herbicide application effort. Within each study plot, six experimental planting treatment plots were established, which are outlined below in Table 4.

Table 4. Planting treatments within study plots

Treatment Letter	Description of Treatment	Species & Quantity Planted
A	Dead iceplant left in place (Mulch), Average density plants	2 x Sagewort, 1x Mock Heather
B	Dead iceplant left in place (Mulch), Double density plants (Figure 20)	4 x Sagewort, 2x Mock Heather
C	Dead iceplant left in place (Mulch), double density plants, double species	2 x Sagewort, 1x Mock Heather, 2x Buckwheat, 1x Dudelya
D	Dead iceplant removed (No Mulch), average density plants	2 x Sagewort, 1x Mock Heather
E	Dead iceplant removed (No Mulch), double density plants	4 x Sagewort, 2x Mock Heather
F	Dead iceplant removed (No Mulch), double density plants, double species	2 x Sagewort, 1x Mock Heather, 2x Buckwheat, 1x Dudelya
Control-1	Dead iceplant left in place (Mulch)	none
Control-2	Dead iceplant removed (No Mulch)	none

Each of the six treatments was replicated three times within each of the three study sites, resulting in 54 total treatment study plots (nine total replicates of each planting treatment).

Two times a year (February and October) between February 2017 and February 2019, plant community measurements, including % cover of native species, % cover of live iceplant, % cover of dead iceplant, % cover of other non-native species, % cover of bare sand, and native species diversity, were taken within each of the 54, two-meter diameter treatment plots

Figure 20. Example of Treatment Plot B. The photo shows the native sagewort planted within the dead iceplant mulch layer.

Results

Native Cover

Treatment F (double diversity) resulted in the best cover of native species (44%) as well as the largest increase in percent of native cover (42%) by the end of the study period (Figure 21 and Figure 22). With the exception of Treatment F, the treatments planted with double plant density (Treatment B and E) resulted in better native cover than the other planting treatments. All treatment except double diversity showed that with dead iceplant left in place (mulch) allowed for a slightly greater increase in cover than their treatment counter parts in which the dead iceplant was removed (no mulch).

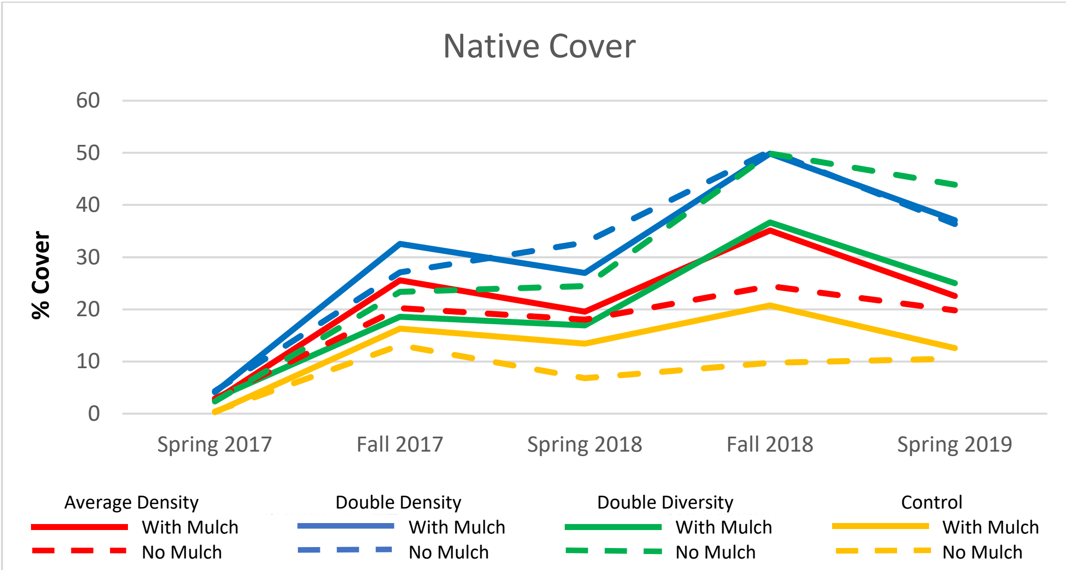


Figure 21. Average percent total cover of natives for each treatment throughout study period (2017-2019). Same colored lines are the same planting treatment. Solid vs dashed lines show whether iceplant was left in place to act as mulch (solid)or removed completely from the plot (dashed).

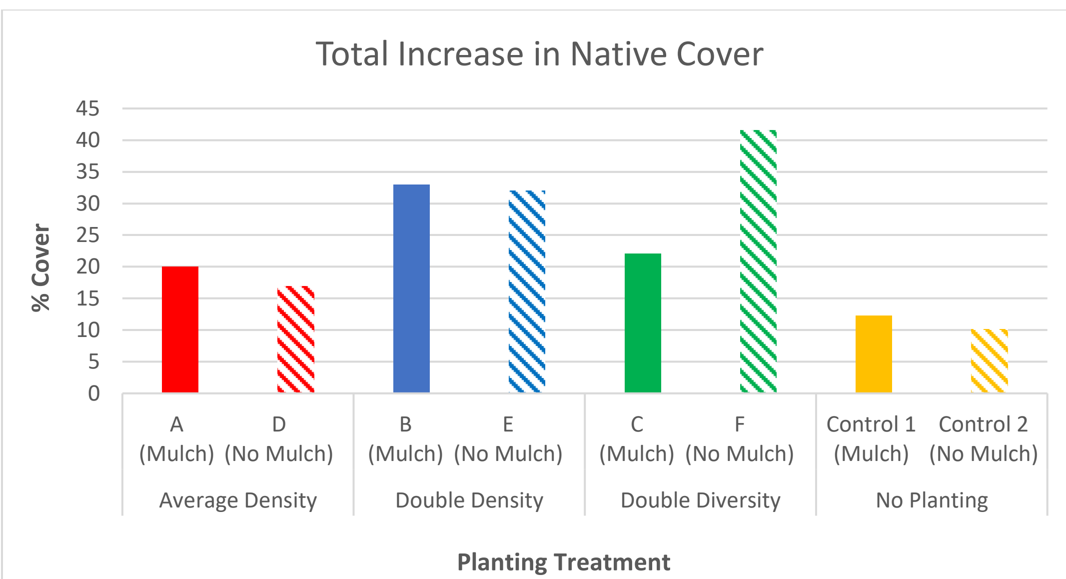


Figure 22. Average change in percent native cover for each treatment throughout study period (2017-2019)

Iceplant Cover

Treatment D (average density of plants with iceplant removed) had the largest recruitment (7% cover) of new iceplant during the study period. All the treatments in which dead iceplant was removed (no mulch) had larger increases in iceplant recruitment compared to their treatment counterparts, which had dead iceplant left in place (mulch). Treatment B and D (double density of plants) had the least amount of iceplant recruitment during the study period (0%) (Figure 23 and Figure 24).

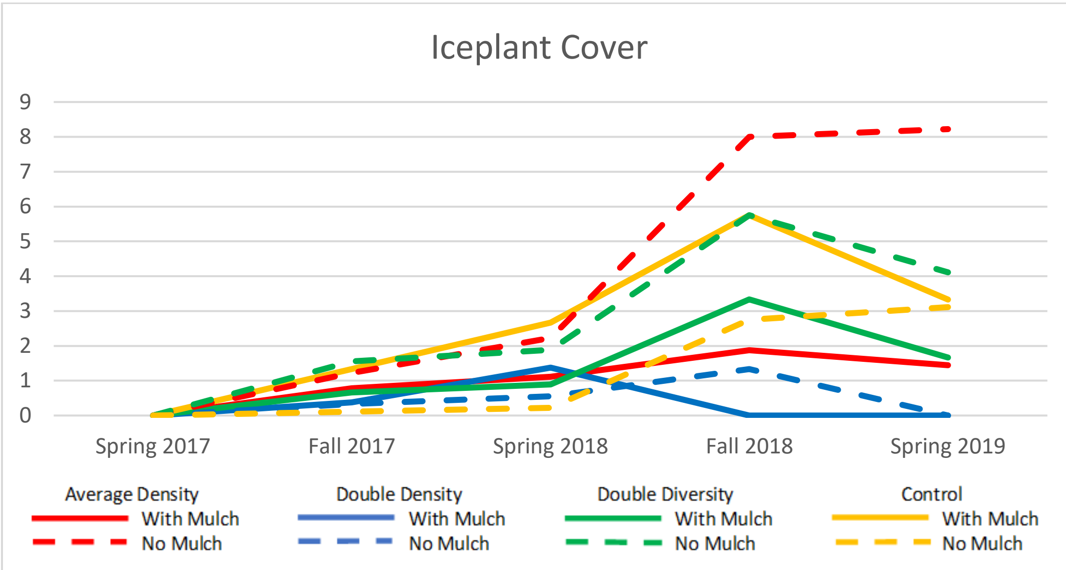


Figure 23. Average percent total cover of iceplant for each treatment throughout study period (2017-2019. Same colored lines are the same planting treatment. Solid vs dashed lines show whether iceplant was left in place to act as mulch (solid) or removed completely from the plot (dashed).

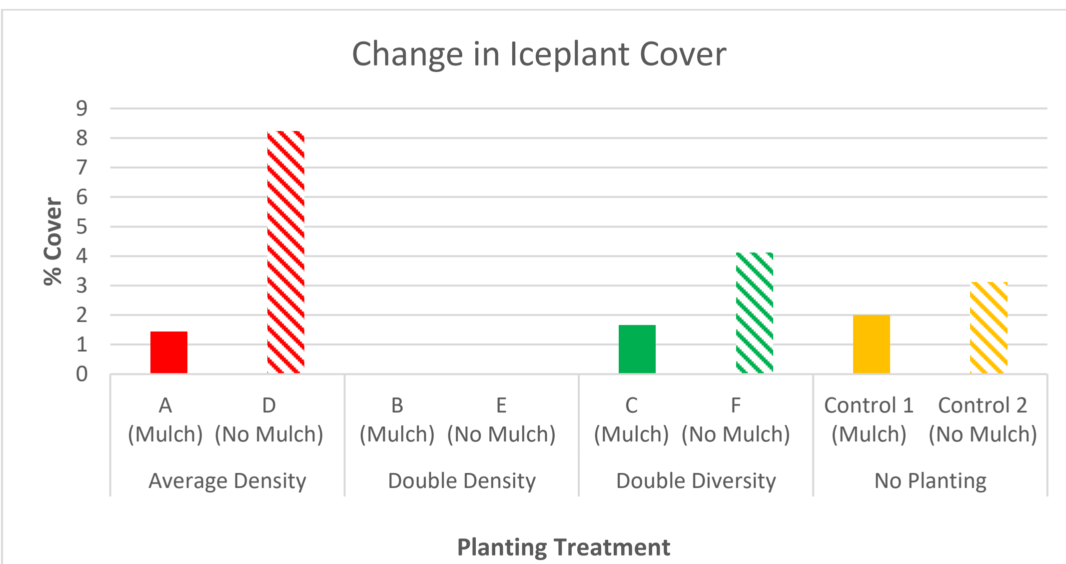


Figure 24. Average change in percent iceplant cover for each treatment throughout study period (2017-2019)

Native Plant Diversity

All treatments (except Treatment D) that had dead iceplant removed (no mulch) returned a greater plant diversity at the end of the study than their treatment counterparts in which dead iceplant was left in place (mulch). Double diversity treatments (C and F) resulted in greater average number of species than the other planting treatments (Figure 25).

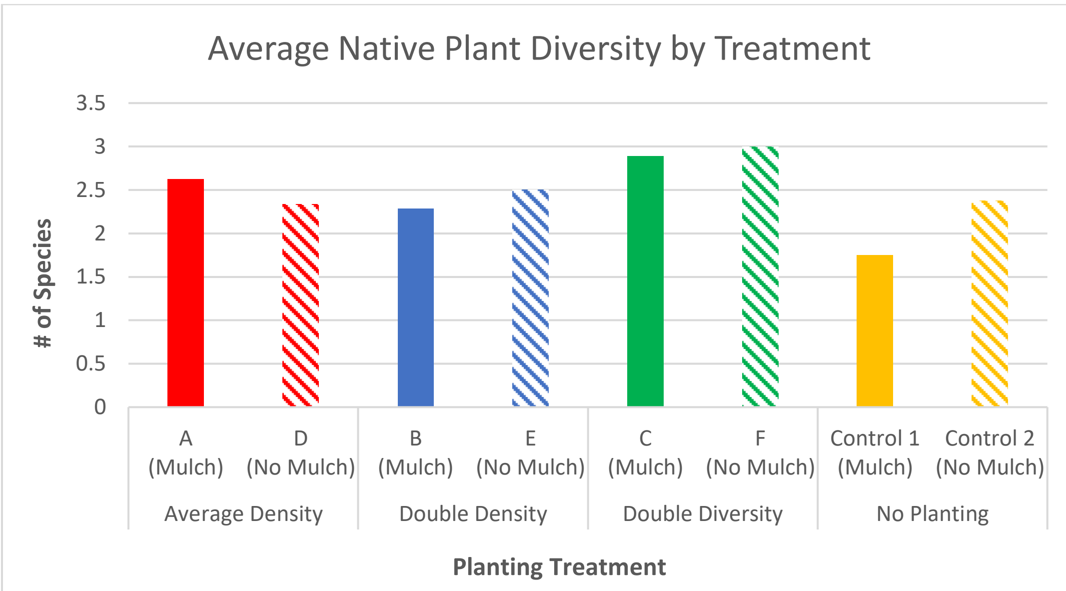


Figure 25. Average number of native plant species for each treatment at the end of the study (February 2019)

Discussion and Conclusion

The hypotheses that were tested resulted in the following outcomes:

Hypothesis 1: *Degraded plant material of herbicide sprayed Iceplant provides a protective mulch layer over bare sand that helps native plant propagation and growth and reduces invasive weed establishment.*

Degraded iceplant left in place to act as mulch keeps recruitment of iceplant minimal, but does not necessarily help native plant growth.

Hypothesis 2: *Planting dunes at high densities leads to greater cover of native plants.*

Double density planting treatment resulted in greater cover (33%) than the average density planting treatment (20%) and the control (12%), which were not planted.

Hypothesis 3: *Planting dunes with greater numbers of species will increase native cover and reduce invasive species establishment.*

In treatments with mulch this was not true. Double diversity treatment (C) had similar cover to the average density and diversity plot (A). Treatments that had iceplant removed exhibited a greater plant diversity at the end of the project, with Treatment F (double planting diversity) showing the greatest average number of species between all the study plots. However, many of the plants noted in the treatment plots without mulch were not species planted as part of the study, but species that naturally recruited (verbena, beach burr, beach pea, beach primrose). These results indicate that removing dead iceplant allows for greater recruitment of native species from the seed bank, which may lead to greater native cover than solely planting natives. Greater diversity treatment plots did not reduce invasive species establishment.

Iceplant mulch reduces iceplant recruitment but also reduces native plant recruitment from seed. Future restoration efforts will need to compare the benefits of reduced recruitment of invasive iceplant with the costs of propagating and planting native species, needed to support native plant recruitment. Mulch was found to reduce natural recruitment from available seed bank. If funding for planting of native species is not available and restoration work is limited to the elimination of iceplant, removing mulch in some areas within the sprayed dunes may increase natural recruitment that can benefit the entire dunes.

Seasonal differences can be seen between fall and spring surveys, with percent native cover peaking in Fall and decreasing in Spring (Figure 21). Because Spring surveys were conducted in February before annual growth and Fall surveys were conducted in October, seasonal percent cover variability is most likely showing the annual growth of vegetation before winter colder weather sets in and plants senesce.

Percent cover results of this study (higher cover in double density, similar diversity in all planted plots) might have been different if other more robust species were chosen. Sagewort is a very robust species and had greater survivorship than some of the other plants chosen. Furthermore, some of the species chosen for the double diversity plots don't lead to high percent cover (e.g. *dudelya*).

This study helps demonstrate that, although iceplant was almost completely eliminated from the restoration area, iceplant management is necessary for several years after initial eradication effort to keep iceplant from recruiting rapidly through seed or vegetative regrowth of areas where spraying did not completely kill the plant.

Key Findings

- Greater diversity plots had the greatest plant diversity (but not the greatest cover).
- Greater density plots led to greatest cover.
- Mulch helped restoration efforts (greater cover and lower iceplant) but did reduce native plant natural recruitment.
- Native planting increases native cover significantly and reduces iceplant recruitment.

5. SAND CAPTURE STUDY

Purpose

The following section focuses on the high-resolution sampling that was specifically aimed at understanding the effects of the dune restoration process on the composition of the sand and the effectiveness of using natural materials such as logs and hay bales to entrain sand and improve dune resilience.

Methods

In early 2019, sediment samples were collected from the dunes and adjacent beach habitats, specifically next to natural materials such as logs and hay bales that were installed at the Potrero restoration site in early 2018. Reference sediment samples from the different section of the beaches (e.g. swash zone, berm, runnel) and dune (e.g. foredune, dune crest) were also collected for reference (Figure 1).

Sampling was conducted using standard beach sediment sampling procedures that include the removal of the upper ~1 cm of the sediment (often the surface is also 'contaminated' with plant material and other non-mineral components).

The grain size analyses were carried out with a Beckman Coulter LS 12 30 LPSA (the instrument uses a 5 mW laser diode with a wavelength of 750 nm). Laser diffraction particle-size measurement is based on the Fraunhofer and Mie theories of light scattering whereby spherical particles of a given size diffract light at a specific angle, with the angle increasing with decreasing particle size. Prior to measurement, the samples were air dried and then the sediment was split using the "coning and quartering method" in order to obtain the necessary amount of sample, which was tested by repeat runs. The samples were analyzed between 0.4µm and 2000µm using the LS 12 30 dry module which feeds the instrument using a vacuum pump. All the statistical parameters reported were obtained using arithmetic statistics.

Results and Discussion

The results are compared with the composition of sediment samples collected from the 'natural' beach and dune habitats (see 'Reference Samples' below).

Reference Samples

Control samples were collected over a cross sectional area that includes the beach berm, the runnel (the back of the berm) and the foredune to assess the 'natural' variability of grain sizes across these habitats (Figure 26 and Table 5). The samples have clearly distinct grain size characteristics which reflect the different transporting media (water vs. air) and the energy of the environment. The coarsest samples are from the beach berm which is a sedimentary bar created by sediment accumulation during up-wash (sample BERM). The mode of particles settled in such a high energy environment is coarser (mode ~825µm) and the sand less sorted (286µm) than samples collected from the runnel (RUN). The samples from the foredune (FD-1 & 2) are much finer (mode ~ 360µm) and better sorted than the samples from both the berm (BERM) and the runnel (RUN) indicating a dominance of wind-related transportation processes such as bed-load traction and saltation. Interestingly, the samples from the runnel (RUN) has characteristics of both the BERM and the FD samples indicating a mixed wave- and wind-origin. The latter suggests that the inland portion of the beach which is critical in that it characterizes the transition between the beach and the foredune is affected and controlled by both wave action (e.g. during high-energy events) and wind transport.

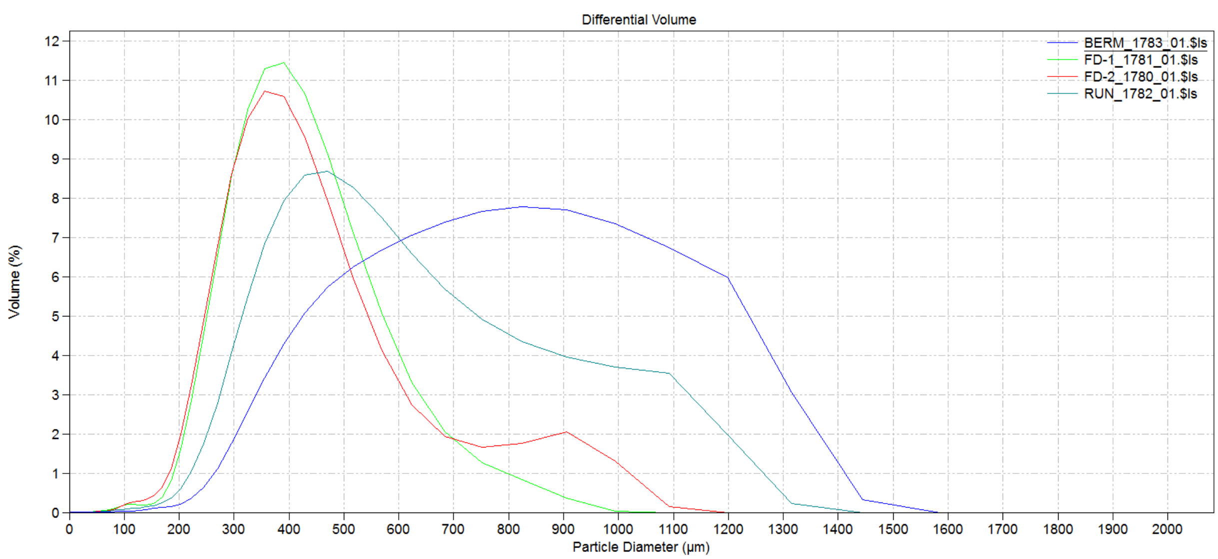


Figure 26. Frequency plots with the results of the grain size analysis for the reference samples: BERM (blue) = sample from the beach berm; RUN (light blue) = sample form the runnel (between dune and berm); FD-1 & FD-2 (green and red) = samples from the foredune

Table 5. Reference Samples

Site	Mean (µm)	S.D. (µm)	C.V. (%)
BERM	717	286	39.9%
RUN	556	243	43.7%
FD-1	395	135	34.1%
FD-2	408	172	42.3%

Hay Bales and Logs Samples

Sampling was also done on and next to different hay bales and wood logs that were installed on the foredune in 2017 as part of the restoration process. The grain size analyses indicate that even at small spatial scales (a few tens of cm) there is a significant grain size variability in relation to structures used for restoration such as the hay bales and wood logs. The grain size variability suggests that these structures do interact with the different transporting media that act on the beach and dune and hence with the flow of sand. For instance, when sand is transported (or eroded) to the back of the beach (e.g. runnel area) or the foredune by waves during high-energy, high-surge events, it will have grain size characteristics similar to the sand present in the lower part of the beach (e.g. BERM sample in Figure 1). Sand can be also carried by the wind, mainly through a combination of traction (essentially rolling on the surface without suspension in air) and saltation (bouncing along the surface with some suspension in the air) processes, to the back of the beach and, obviously, to the dune. The sand subjected to this type of transportation process will be better sorted and finer and have characteristics similar to the dune sample (FD) in Figure 26.

The results of our sediment sampling from selected structures in the northern (Potrero Rd section) restoration area offer evidence of both mechanism of transportation and of the efficacy of sand entrainment by the structures:

Example 1: A sample that was collected from the front of hay bale #2 (Figure 27) has mean size (494µm) and mode (430µm) that are similar to the dune sample (FD in Figure 14), while the sample in the back of the hay bale (closer to the dune face) is coarser grained (mean=560; mode=518µm) and is more similar to the sample collected from the runnel (RUN in Figure 26). The grain size suggests that a different transportation mechanism for the sample from the front of the hay bale facing the (mainly wind) vs. the one in the back (mainly wave transport).

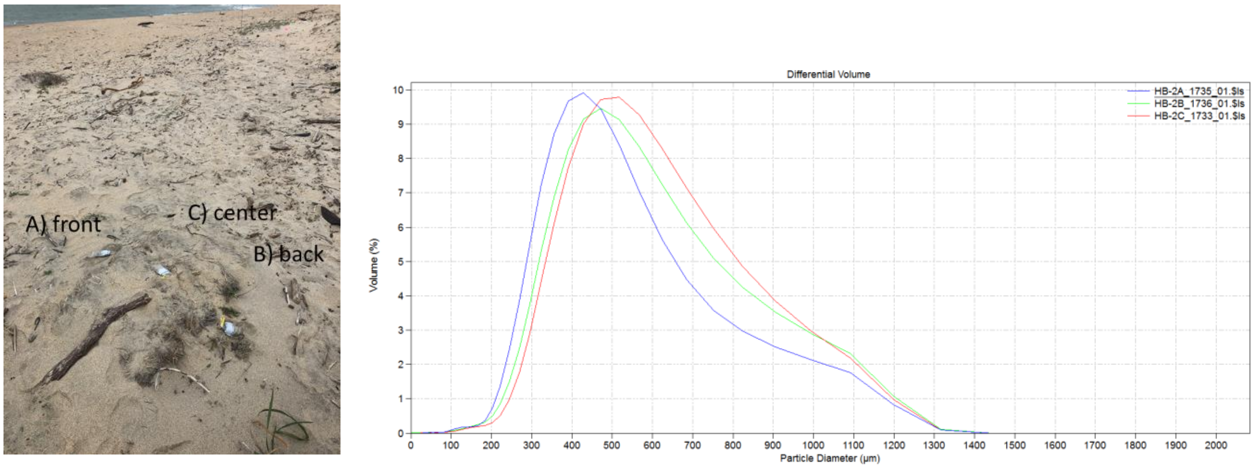


Figure 27. Results of the grain size analysis for hay bale#2. The Figure includes a photograph showing the location of the grain size samples in relation to the ocean (upper left) and the dune (lower right). A frequency plot of the grain sizes is also included.

Example 2: Samples collected from the front of wood log #1 (Figure 28) show grain size variability with the one located on the ocean side having smaller mean size (466µm), and one in the back closer to the dune having coarser grain size (mean=507µm). Both samples have similar modes (~429µm) and are similar to the sample from the foredune (FD; Figure 26) suggesting that transport was mainly by wind.

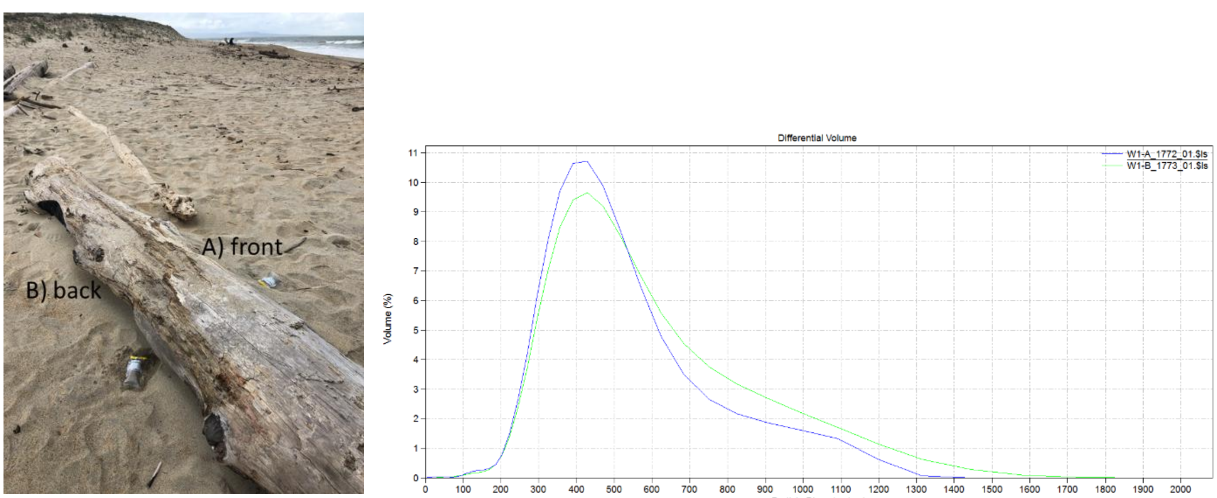
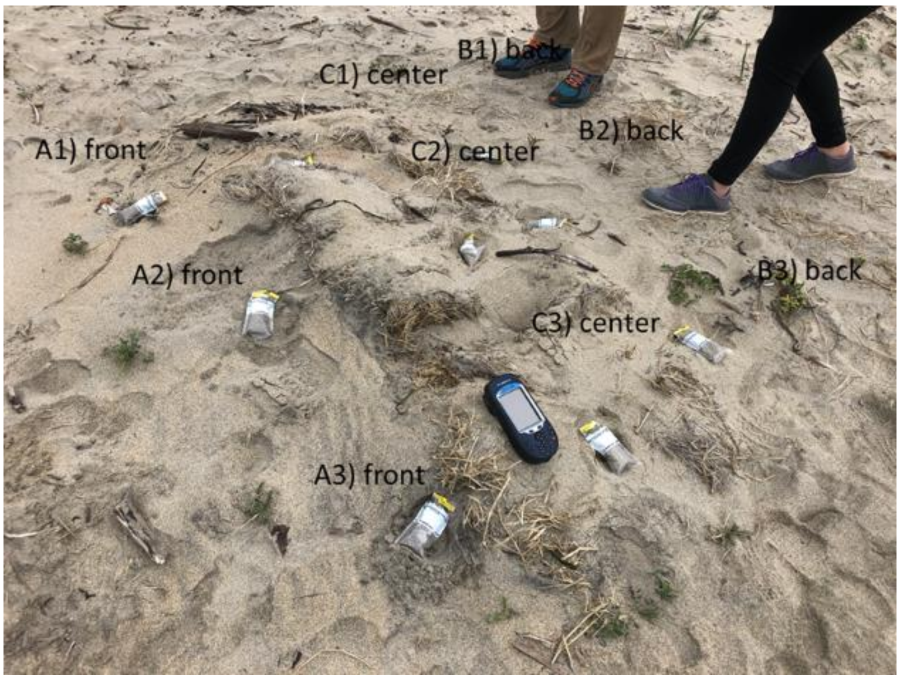


Figure 28. Results of the grain size analysis for wood log#2. The Figure includes a photograph showing the location of the grain size samples in relation to the beach (upper right) and the dune (lower left). A frequency plot of the grain sizes is also included. Note that the sample from the front of the log (blue) has a smaller grain size than the sample from the back (green) (see text for discussion)

Example 3: The grain size analysis for hay bale #3 (Figure 29) show sedimentologic variability at local scales (hay bale #3 was the closest to the foredune amongst the sampled structures). In general, the grain size characteristics of the samples from hay bale #3 are a mixture between berm and foredune and there is variability in grain sizes amongst the samples collected from the different sides of the hay bale. For instance, A1 is from a coarse patch (mean size=563µm) and the sample resemble the runnel sample (RUN; Figure 1) while A3 is much finer (mean=427µm) and it comes from a darker patch that is more similar to the foredune samples (FD; Figure 26).



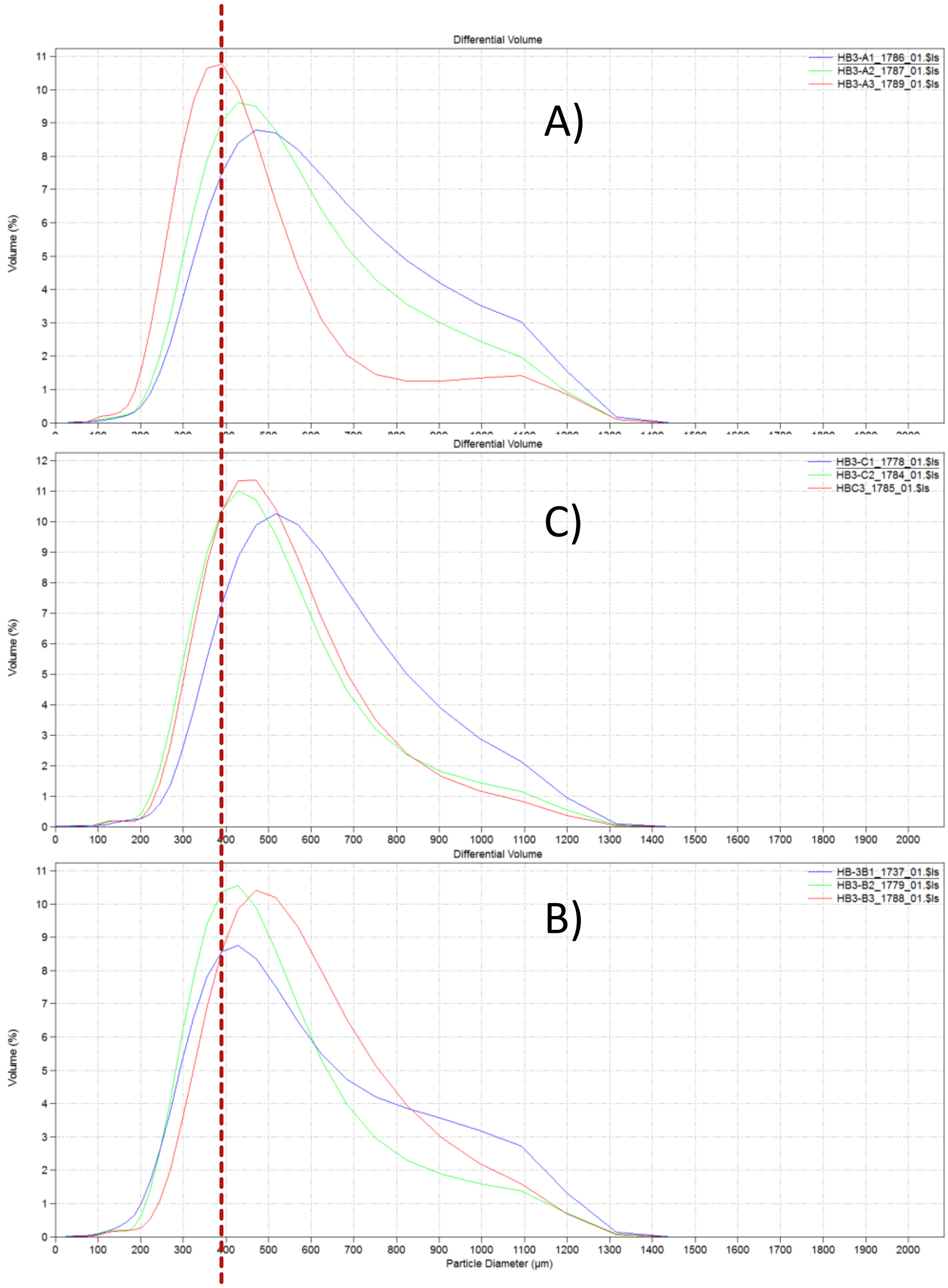
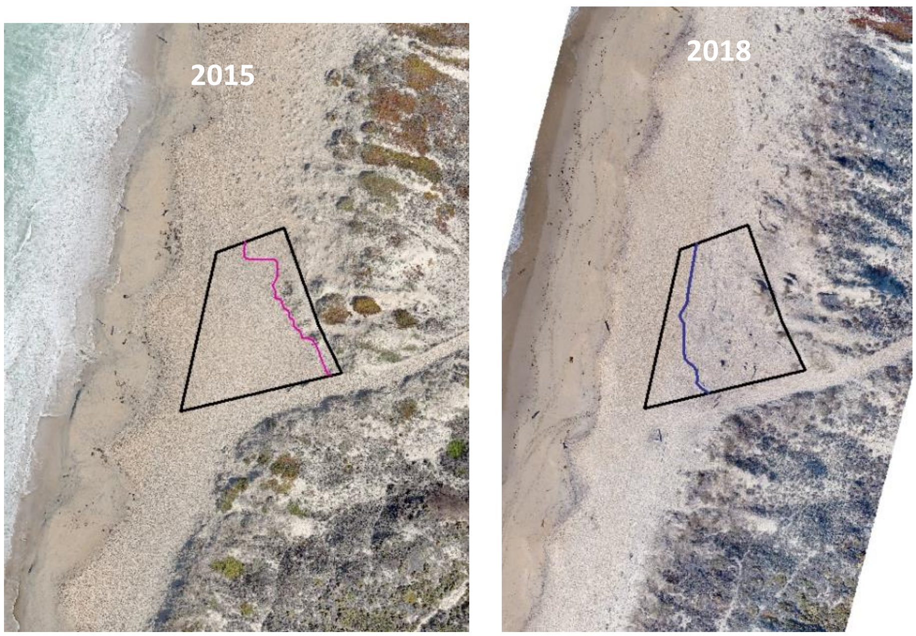


Figure 29. Results of the grain size analysis for hay bale #3. The Figure includes a photograph showing the location of the grain size samples in relation to the ocean (left) and the dune (right).

Additional Study: Change in Foredune

Using high resolution images from the UAV surveys (see section 3), a GIS analysis was conducted to determine how the location of the foredune may have changed between 2015 and 2018, within a focus area of the project. This change was determined by comparing the location of foredune vegetation (an indicator of the toe of the foredune) in 2015 to the location in 2018 in the area where the hay bales and logs were installed (in 2017). The purpose of the hay bales and logs, as discussed previously, is to aid in the capture of sand which to rebuild the foredune in a high traffic area. It will also help to eliminate an unnecessary portion of the beach access trail which acts as a potential storm wave runup path. Results from this analysis are shown in Figure 30. The foredune vegetation moved seaward and the increase in rugosity of the beach between 2015 and 2018 is apparent. This may suggest that the hay bales and logs in this focus area are capturing additional sand and helping to rebuild the dune in this high traffic area. It should be noted that ropes were also installed around this area during winter 2018 which helped reduce foot traffic and may have allowed native plants a better chance to recolonize.



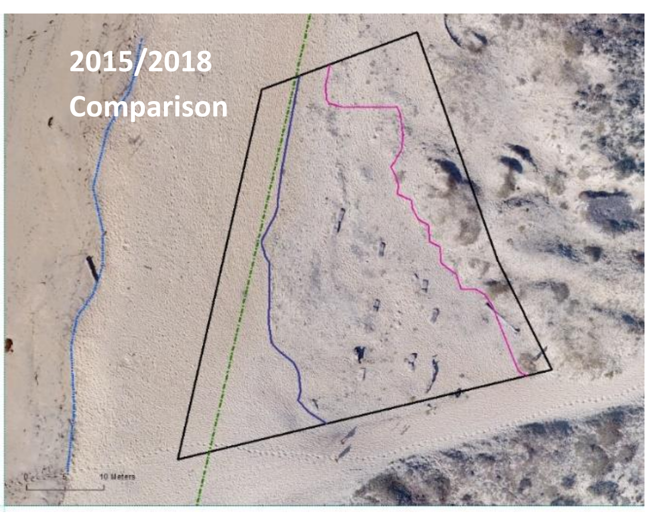


Figure 30. Foredune comparison between 2015 (top left) and 2018 (top right). The bottom image shows both the 2015 and 2018 seaward edges of the foredune vegetation on top of the 2018 aerial imagery.

6. LOOKING FORWARD

One of the goals of this project was to complete studies that could inform future dune restoration work, specifically to increase dune resiliency to rising sea levels. The following are some key lessons learned from this project as well as recommendations for future efforts.

- Iceplant eradication method: For large scale dune restoration projects using herbicide rather than hand pulling is the most efficient and cost-effective means to help eradicate iceplant. Data from our study shows that leaving dead iceplant in place as mulch, rather than removing it, leads to less recruitment of live iceplant.

- Iceplant management: Ongoing efforts to eradicate iceplant (both spraying and hand pulling) may be needed for the first few years of a restoration project. Our study showed that sites that had less follow up herbicide application had higher reestablishment of iceplant.

- Native plant reestablishment: If natural seed bank is known to be abundant, then not as much effort needs to be put into propagation and out-planting of natives. However, if leaving dead iceplant in place, then this will also reduce recruitment of some native species from seed. Projects must take into account individual site conditions to determine the most effective native plant establishment method. Clearing small areas of mulch may support native plant recruitment.

- Dune Resiliency and Restoration: Dune erosion is enhanced where the upper beach has a more reflective profile (i.e. less dissipative profile). These steep dune faces are subjected to greater geomorphological change through erosion and accumulation of sand. This supports the idea that reducing foredune steepness by removing iceplant and planting natives to create a more gradual foredune slope helps create a more resilient dune face to storm waves and erosion. Additionally, adding structural features such as hay bales and large wood, aids in sand accumulation, helping to reduce foredune face steepness and enhance dune resilience.

- Managing traffic and realigning pathways to limit wave runup is effective at reestablishing natural foredune habitat.

- Seed dispersal may be more effective than large scale plant propagation efforts. Native planting may support greater species diversity or help reestablish priority areas of dunes (foredune). Planting of native dune grass was effective and increased roughness of foredune areas.

- Native plant propagation can increase the diversity of plants and may best be used to increase rare species.

- Dune topography mapping: Using UAV high resolution DEMS and TLS surveys is an effective way to map dune topography over time. However, dune topography monitoring that occurs only during a project period (typically 3-5 years) will most likely only pick up seasonal changes in topography (i.e erosion due to winter storms). Long-term dune topography data collection is needed to be able to better understand how restoration efforts (removal of iceplant, planting of natives, and strategic placement of natural materials) affects longer term dune erosion and accretion processes.

- Expand foredune sand accumulation study: An expanded study on foredune sand accumulation processes using strategic placement of native plants and natural materials (such as logs, hay bales, and jute fencing) is recommended. Initial findings suggest that short term dune building is enhanced by these structures.

- Establish standardized monitoring strategies for dune restoration projects: Work with other dune restoration groups to standardize monitoring such as vegetation survey methods and dune topography survey methods. Work with partners to develop a Dune Rapid Assessment Method (DRAM) to create a cost-effective standardized monitoring strategy for dune restoration projects and ambient surveys.