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# Determining the influence of *Lupinus arboreus* and the recruitment of non native species in the Lanphere Dunes

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## Abstract

The sand dunes of the Pacific Northwest are dynamic and house diverse dune mat communities. Introduction of non native species into dune mat communities change soil characteristics of dunes, such as the case of yellow bush lupine (*Lupinus arboreus*). Lupine establishment provides ideal conditions for other non natives to invade. These impacts have been observed within the Lanphere Dunes Unit of the Humboldt Bay Wildlife Refuge in Arcata, California. The United States Fish and Wildlife Service (USFWS) plans to test lupine eradication methods in a one acre parcel within Lanphere. This study aims to collect baseline data for that parcel, focusing on the effects of lupine on native dune mat. We determined the number of lupine individuals within the site, the species composition compared to two reference sites, and soil organic matter content within the project area. The large amount of lupine was correlated with the high cover of annual grasses. In contrast, the uninvaded area had the highest cover of dune mat and open sand, representing a healthy dune ecosystem. Soil samples showed that the non native species contributed to the increased organic matter content within the soil. This study provides insight into the impacts of lupine on a dune community.

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## Introduction

Invasive species are known for negatively impacting ecosystems by outcompeting natives and altering species composition (Corbin & D'antonio, 2012). The removal of these invasive species can restore biodiversity and abiotic processes of the ecosystem (Pickart, 2013). Some invasive species can be found in dune communities of the Pacific Northwest. These sand dunes are a dynamic, wind shaped ecosystem that house a unique community called dune mat. The dune mat is comprised of diverse and ecologically important plant species which serve as a food source and habitat for wildlife, from solitary bees to brush rabbits (Pickart & Sawyer, 1998). Invasion of non natives, such as yellow bush lupine (*Lupinus arboreus*), have affected the dune mat community since their introduction (Pickart et al., 1998). Yellow bush lupine, like all other species in the legume family (Fabaceae), are nitrogen fixers. Lupines add nitrogen into the sand, making it available and hospitable to other non natives such as rattlesnake grass (*Briza maxima*), ripgut brome (*Bromus diandrus*), and iceplant (*Carpobrotus* sp.; Pickart et al., 1998). For example, *Briza maxima* was found to have 50% greater root biomass and 90% greater shoot biomass when in the presence of lupine (Maron & Connors, 1996). Additionally, with the increase of nitrogen in the soil, native vegetation growth may be stunted, primarily in initial stages (Bardgett & Wardle, 2010). Essentially, the presence of yellow bush lupine has the ability to prevent establishment of important native species, including threatened and endangered dune mat species. Excess nitrogen also provides more forage value, which is important for deer species, creating a negative impact on certain dune mat natives (Sanz et al., 2011).

The increase in non natives species also changes the soil characteristics of dunes (Konlechner, 2015). Dunes are naturally deficient in nutrients due to the poor nutrient retention of sand. As

the non natives die, they add more organic matter into the soil than if they were absent. The addition of organic matter and nitrogen converts the sand into a nutrient rich soil which can recruit more non natives, completely changing the species composition of the dune mat (Corbin & D'antonio, 2012). Ultimately, this leads to changes in plant community composition within the dune mat communities.

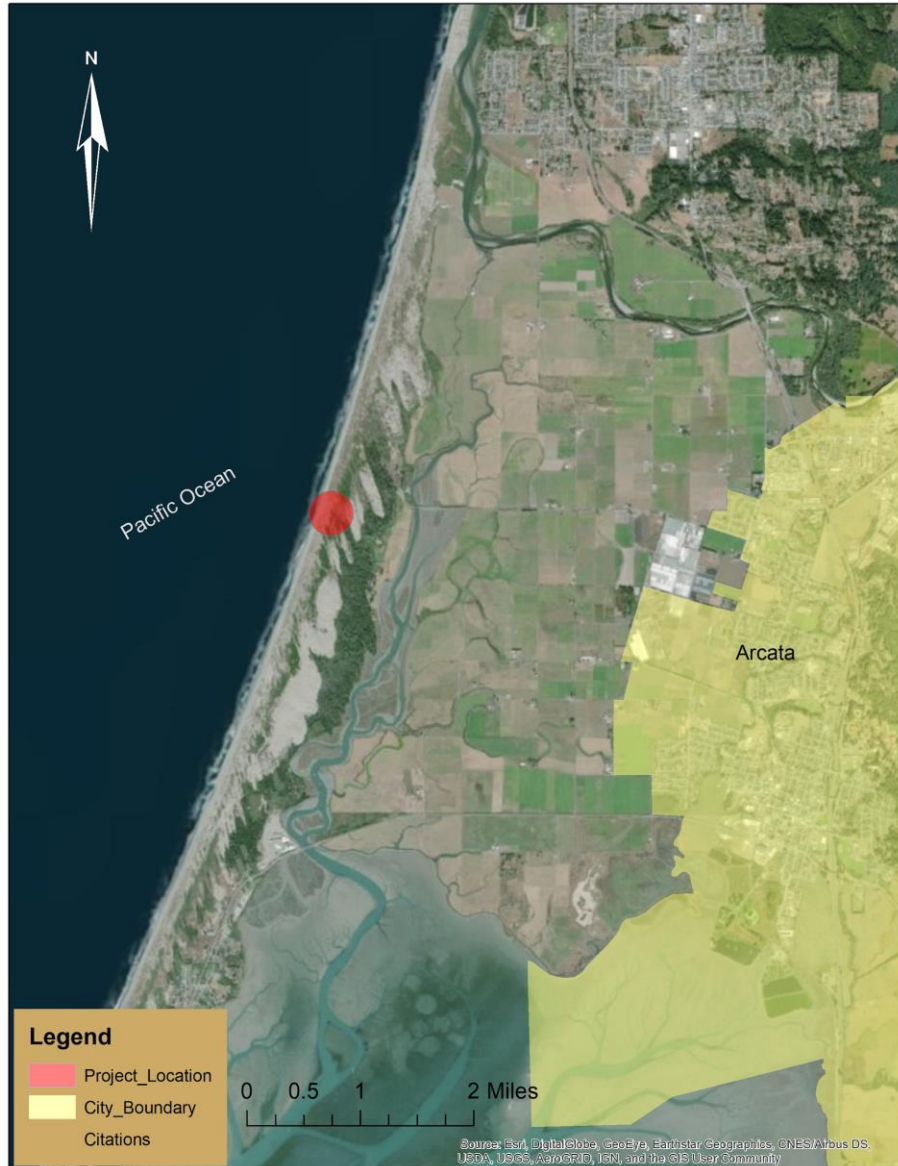
It is also important to consider the legacies of biotic and soil characteristics the lupine leave, even after they are removed. Some non native species can impact the surrounding area for up to five years even after removal (Corbin & D'antonio, 2012). Locations of lupine germination, growth, and death provide ideal conditions for introduced annual plants to create a new, less diverse community (Maron & Jefferies, 1996). However, once lupine are no longer an influence, native species have a better chance of survival due to an increase in available area and resources (Pickart et al., 1998; Maron & Jefferies, 1999). The main priority of lupine management would be to focus on preventing its original establishment, therefore inhibiting the future recruitment of other invasives (Konlechner et al., 2015).

Similar impacts have been observed within the Lanphere Dunes located in Arcata, California. The Lanphere Dunes is a unit of the Humboldt Bay National Wildlife Refuge Complex managed by the United States Fish and Wildlife Service (USFWS; Figure 1). The USFWS serves to preserve natural coastal habitats and protect native species and are concerned with the invasion of yellow bush lupine in the Lanphere Dunes. Lupine has been observed to create a habitat for non natives to invade (Maron & Connors, 1996). These non natives have become competitors to

the native dune mat species. Lupine has altered soil characteristics to create favorable conditions for other invasive grass species which may outcompete natives (Pickart et al., 1998).

The USFWS plans to experiment with different lupine eradication methods. The lupine will be removed manually and two different treatments will be tested on the non native annual grasses and iceplant. One treatment will include herbicide alone and the other flaming alone.

Experimental restoration on fully lupine invaded, or "lupinized", plots have occurred recently on a smaller scale, making this the first relatively large area to test these methods (A. Pickart, personal communication, November 26, 2018). The focus of this study is to collect baseline data for the one acre plot where the USFWS is conducting their experimental removal methods (Figure 2) and determine the effects of the lupine on the dune mat species composition and the soil. There are three objectives of this study. The first objective is to count and map the lupine individuals within the project area. Our second objective is to determine the effects of yellow bush lupine on the dune mat communities by gathering species composition and soil samples of the site. Finally, our third objective is to determine reference conditions for the project area by gathering species composition of an uninvaded site and a "lupinized" site.



*Figure 1. General location of the project area within the Lanphere Dunes in relation to the City of Arcata.*



*Figure 2. Location of the project area in relation to Humboldt County, CA.*



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## Methods

### Study Area

The project area lies on the North Coast of California in Humboldt County, an area commonly known for its rich biodiversity. This region has a mean annual temperature of 53° Fahrenheit and experiences an average of 49.5 inches of precipitation per year (NOAA, 2005). The project site is within the Lanphere Dunes, which is a unit of the Humboldt Bay National Wildlife Refuge in California. The refuge was originally Wiyot territory before the land was acquired by William and Hortense Lanphere (USFWS, 2017). The Lanphere brothers then gave the land to The Nature Conservancy, who later gave it to the USFWS. The goals of this refuge are to prevent and remove invasives, conserve pristine habitat for native flora (Appendix A) and fauna, and overall improve the natural processes of the area (A. Pickart, personal communication, September 27, 2018).

Yellow bush lupine became a focus for eradication after its initial invasion from a northern neighboring property where it was planted in the 1960s (USFWS, 2017). Restoration at the Lanphere Dunes began in 1978 with the first ever "lupine bash", an annual event to remove yellow bush lupine, started by the California Native Plant Society (USFWS, 2017). In the 1990s, experimental removal of invasive European beachgrass (*Ammophila arenaria*) began, as well as the first large-scale restoration project (A. Pickart, personal communication, November 26, 2018). Forty years later, eradication projects have continued and have facilitated the recovery of ecological processes (A. Pickart, personal communication, September 27, 2018). The USFWS has decided to test spraying versus flaming restoration techniques as a way to eradicate other

invasives in a new parcel that they have acquired. These invasives include the yellow bush lupine and annual grasses which compete with native dune mat species. Baseline monitoring could help determine the effects of yellow bush lupine and the recruitment of other invasives due to altered soil properties. The project area was about an acre in size off an unmarked trail, just north of the property's established "Drifting Sands" trail.

### Mapping Lupine Locations

We walked the project area in order to census the yellow bush lupine population. We made sure that we walked close enough to one another to account for all lupine individuals. It was important to take great caution while walking through the area as to not disturb present native species. In order to accurately determine the locations of each individual lupine, we used a Trimble Juno GPS unit to map and flag each individual so we would not take multiple locations of the same lupine. The point was taken at the main root of the plant, which was useful for mapping larger shrubs. Dead individuals were not counted. If an individual appeared dead, but still had living vegetation, it was counted in the census. We included young and mature lupine. After all the lupine points were taken we transferred the points on to ArcMap and created a map that showed their locations in the project area.

### Estimating Species Composition

In ArcMap we used the "Create Fishnet" tool to divide the project area into a 25 by 7 grid with 175 points. Then we used the "Select by Location" tool to derive sampling locations that lie within the project boundary. From this we received 128 locations for species composition (Appendix B). Points that were directly on the boundary were excluded from sampling. At the project area we navigated to each sampling location using the Juno GPS unit. Using a 0.5 m by

0.5 m point frame with 25 points we estimated the cover canopy for each species within the point frame using ocular estimation (each square was considered 4 percent of the entire quadrat). An agreement on percentage cover of each category was made among us 3 individuals to ensure the most accurate representation of the plot.

We also sampled species composition in two control areas: an uninvaded by yellow bush lupine area and a fully invaded area. This approach for sampling the uninvaded site and fully "lupinized" was different from the project area since there were no established areas for the control plots. The uninvaded site was far enough away from the "Silver Bee" trail so it would not land in the sampling plot. The "lupinized" plot was off trail, north of the project area with a large population of yellow bush lupine. We used the spoke method to derive our sampling locations. From the center point we drew out five 50 meter transects that were  $72^\circ$  apart from each other (Appendix C). At each transect we determined two sampling locations using a random number generator ([randomnumbergenerator.com](http://randomnumbergenerator.com)), for a total of ten quadrat samples within each location. We chose numbers between five and 50, leaving a five meter buffer around the center point. The determination of species composition was approached in the same manner as the project area.

We only sampled locations that included at least one percent cover of one of the specified vegetation types or open sand (Appendix D). We recorded canopy cover of species that were alive during the 2018 growing season, including annual grasses that had already completed their life cycle and senesced, in addition to all living perennial vegetation within the plots. If there was dead lupine vegetation within the quadrat but living vegetation on that individual, then it was

counted as part of the composition. In the case of the "lupinized" site, dead lupine was still part of composition due to the small sampling size.

## Soil Sampling

We took soil samples at the project site for each vegetation type and open sand. Only one sample was taken for each category totaling 8 samples. The soil sample collected was at a depth of 20 centimeters at a location that best represented the vegetation type. We chose to weigh each sample to 5 grams and weighed each crucible before burning. We weighed each soil sample and crucible to the nearest 0.01 gram. We burned each sample (loss of ignition) in a furnace at 100°C (212°F) for 24 hours. We weighed each sample again and subtracted the difference to find the organic matter (OM) percent in each sample taken.

## Data Analysis

To analyze the species composition, we used Excel to calculate the average for each of the vegetation types and open sand's percent cover from each quadrat to determine the percent cover for the entire project area.

To analyze the soil, we calculated the mean OM content from each vegetation type and open sand using the following equation:

$$\frac{\text{Oven dry samples} - \text{Burned samples}}{\text{Oven dry samples}} \times 100.$$

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## Results

### Mapping Lupine Locations

We mapped a total of 587 lupine individuals within the project area (Figure 3). There were large groups of lupine in and near dune hollows, creating a clumped distribution throughout the project area.



*Figure 3 shows the locations of all the lupine individuals within the project area.*

## Estimating Species Composition

We sampled 115 locations out of the original 128 locations. Locations that we did not sample, did not contain any of the vegetation types or open sands within the quadrat (Appendix B). The locations that we did sample contained at least one of the vegetation types and open sands.

Our results showed that the fully invaded lupine site had the greatest percentage of lupine, *B. maxima*, *B. diandrus*, annual grasses, and scrub (Figures 4-6, Appendix E). There was a lower percent cover of dune mat and open sand within the "lupinized" site than the uninvaded site and the project area (Appendix G). The uninvaded site had the highest percent cover of dune mat and open sand, and the least annual grasses. The highest percentage of *B. maxima* and *B. diandrus* were shown in the fully invaded site compared to the project area; while the two grass species were absent in the uninvaded lupine site (Appendix F).

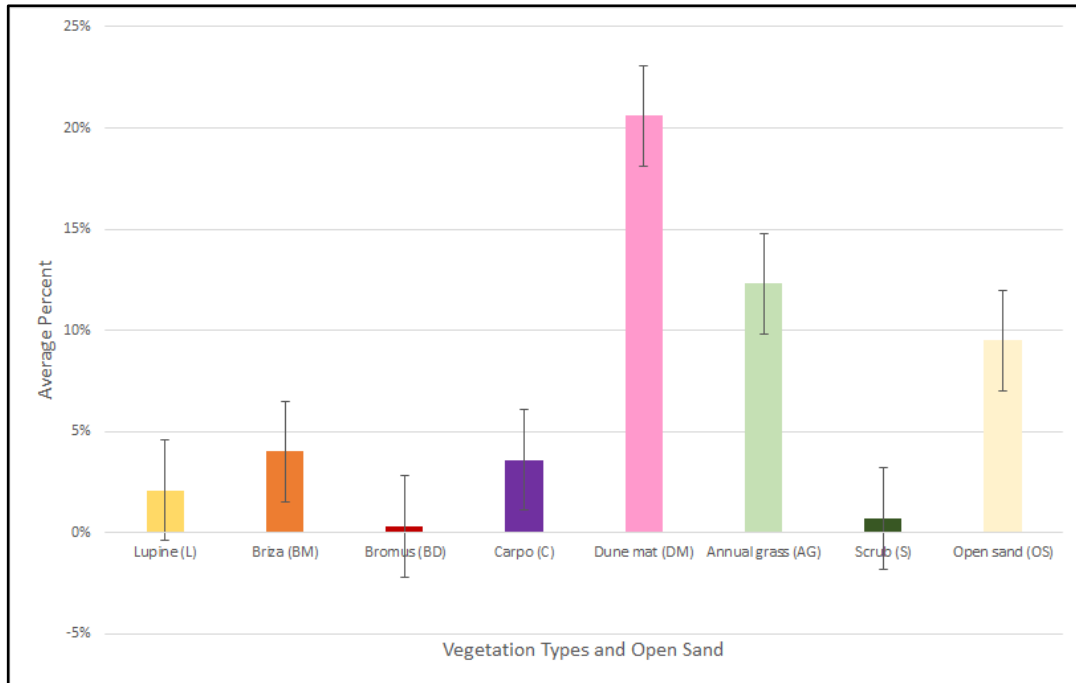


Figure 4. Average percent cover for each vegetation type and open sand (Lupine, Briza maxima, Bromus diandrus, Carpobrotus sp. [Carpo], Dune mat, Annual grasses, Scrub, and Open sand) within the project area.

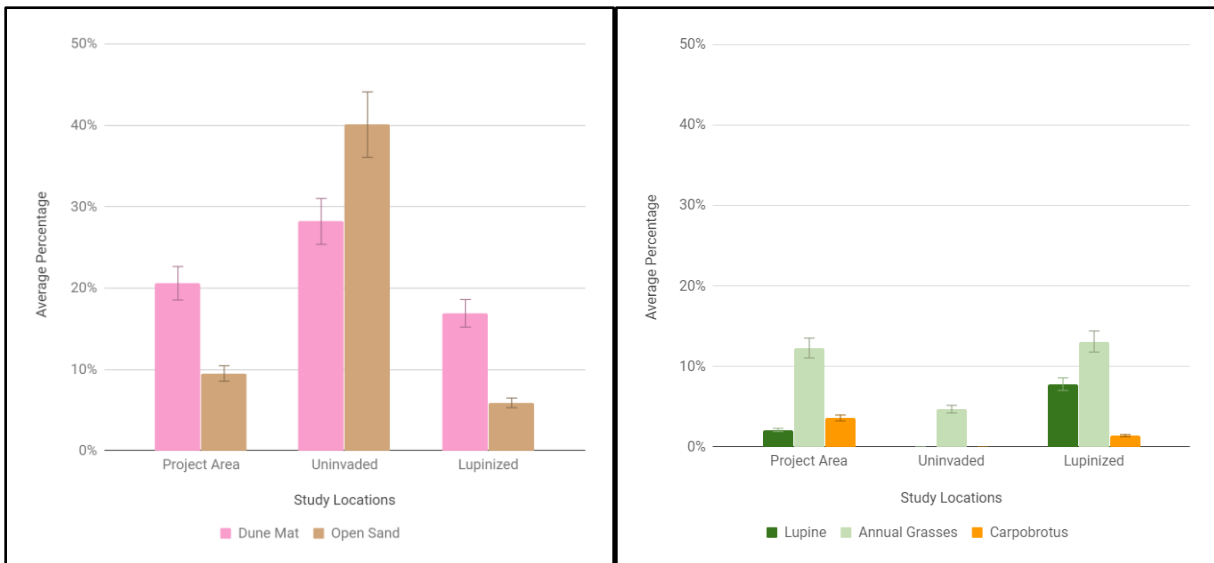


Figure 5 (left). Average percent cover of Dune Mat and Open Sand among the three study locations. Figure 6 (right). Average percent cover of Lupine, combined annual grasses (B. maxima, B. diandrus, and other annual grasses), and Carpobrotus sp. among the three locations.

## Soil Sampling

We found that soil beneath *B. maxima* had the highest percent OM (Table 1). The sample from *L. arboreus* had the second largest amount of OM. Our annual grass sample showed more OM than *B. diandrus*, but less than *L. arboreus*. Open sand had the least amount of OM compared to other vegetation types and open sands.

*Table 1 shows soil organic matter percentages for each vegetation type and open sand.*

Vegetation Type and Open Sand	Organic Matter
<i>B. maxima</i>	0.423%
<i>L. arboreus</i>	0.297%
Annual grasses	0.268%
Scrub	0.264%
<i>B. diandrus</i>	0.255%
Dune mat	0.242
<i>Carpobrotus</i> sp.	0.201%
Open sand	0.048%



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## Discussion

Our study showed that the project area contained a large number of lupine individuals. These lupine were able to thrive in the windy and salty conditions by establishing themselves in the back dunes where the wind and spray is less harsh. Because lupine are nitrogen fixers, they change soil structure and composition and allow other non native species to establish in places where they would not normally be found, which was shown in our study.

The "lupinized" area showed a higher amount of annual grasses, specifically *B. maxima*, and a lower amount of dune mat than the other two sites. The addition of nitrogen tends to improve the nutritive quality of *B. maxima* (Sanz et al., 2011). Our results showed that the presence of lupine had affected the presence of annual grasses and dune mat. This suggests that lupine is a facilitator for the recruitment of annual grasses such as *B. maxima* into the dune ecosystem.

The presence of lupine appeared to limit the ability for natives to exist in the understory (Wozniak, 2000). We saw that lupine commonly had annual grasses in the understory. This shows that some dune mat was able to survive near lupine yet this was uncommon. This supports the statement that lupine commonly creates ideal conditions for non natives to grow and thrive (Maron & Jefferies, 1999).

Our study also found that the highest invasive species cover was found in the fully "lupinized" area compared to the project area and the uninvaded site (Appendix F). The project area had a similar total percentage of invasives to the fully "lupinized" area. This was likely caused by the

high percentage of lupine found within the two sites. Non native percent cover was higher where there was a high cover of lupine. These invasives are of most concern as they inhibit native vegetation establishment due to increased nutrients within the soil (Pickart, 1998). In contrast, the highest percent of open sand and dune mat was found in the uninvaded project area (Appendix G). This is most representative of a healthy dune community as the lack of non natives allow for the sand to continue to shift.

We collected soil samples to determine if lupine, as well as other non native species, incorporate more OM to the soil than if they were absent. Our *Briza maxima* sample had the highest amount of OM, even compared to our lupine sample. The *Bromus diandrus* and other annual grass samples also showed higher OM content compared to the other vegetation types and open sands. Lupine recruits annual grass species which contribute to the increased OM content in the soil. We only sampled the soil once for each vegetation type and open sand within the project area, so the percent OM of each group may not be well represented.

More soil samples should be taken to increase the confidence of this study. Particularly, collecting soil samples within the control sites would be beneficial for data interpretation among the three different locations. Overall, a larger sample size would provide more accurate results. In regards to estimating species composition, consistent sampling procedures will provide stronger results. We used the spoke method on the control sites but predetermined locations for the project area, which may have skewed the accuracy of comparison. We sampled 10 plots within each of the two control sites, whereas we sampled 115 plots within the project area. Consistency in our methods for sampling could improve overall results and interpretation.

It is important to understand the effects of invasives, such as lupine and annual grasses, and consider their ability to alter dune habitats. These non native species leave behind legacies that can last for several years, even after their removal (Corbin & D'antonio, 2012). The lupine legacies facilitate competition between annual grasses and natives. Once these annual grasses are removed, dune mat species may recover (A. Pickart, personal communication, November 26, 2018). A better understanding of the specific legacies that can be left behind can lead to more beneficial and dynamic restoration goals to be used in the future.

This study provides insight into the impacts of nitrogen fixing lupine on a nutrient poor dune community. Though this study is focused on the dunes of northwestern California, similar ideas would apply in areas that have experienced similar impacts. Deducing the causes of these impacts can assist land managers in determining the best management and restoration practices to prevent future degradation and alterations.

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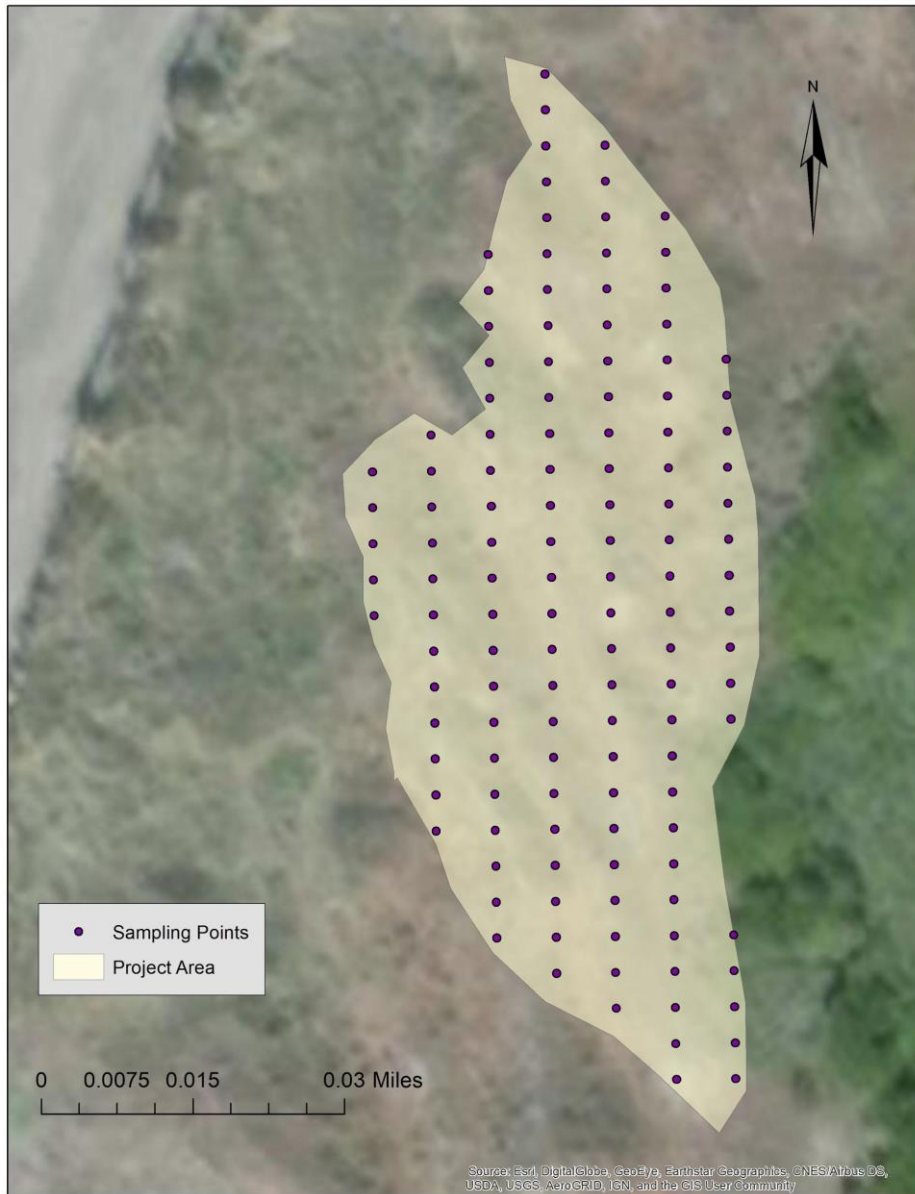
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## Appendix

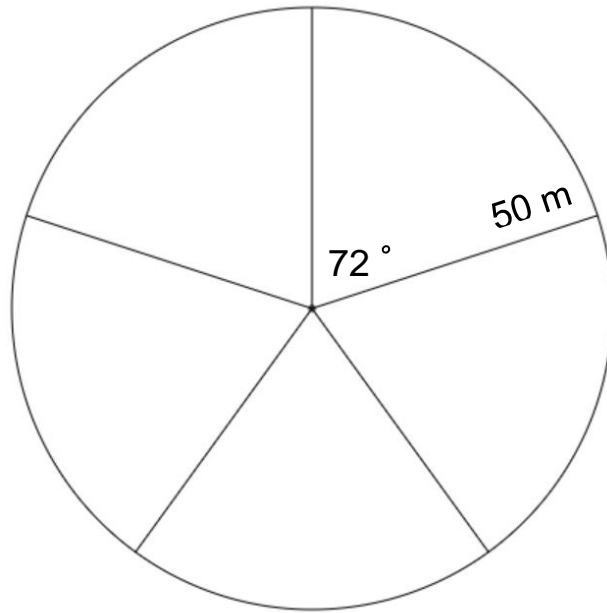
### Tables & Figures

Appendix A. Table of common dune mat species within the Lanphere Dunes, including their common names.

<b>Plant species</b>	<b>Common name</b>
<i>Abronia latifolia</i>	Yellow sand verbena
<i>Achillea millefolium</i>	Common yarrow
<i>Armeria maritima ssp. californica</i>	California sea-pink
<i>Artemisia pycnocephala</i>	Coastal sagewort
<i>Elymus mollis ssp. mollis</i>	Dune wild-rye
<i>Eriogonum latifolia</i>	Beach buckwheat
<i>Erysimum menziesii</i>	Menzies' wallflower
<i>Fragaria chiloensis</i>	Beach strawberry
<i>Polygonum paronychia</i>	Beach knotweed
<i>Solidago spathulata</i>	Dune goldenrod



Appendix B. Map of the 128 sampling points within the project area derived from ArcMap.



Appendix C. Diagram of how we sampled species composition within the two control sites

Appendix D. Table of vegetation types and open sand used to sample at the project area and the two control areas.

<b>Vegetation type and open sand</b>	<b>Abbreviation</b>	<b>Example species/botanical names</b>
Dune mat	DM	California sea-pink ( <i>Armeria maritima ssp. californica</i> ), Beach buckwheat ( <i>Eriogonum latifolium</i> ), Dune goldenrod ( <i>Solidago spathulata</i> )
Yellow bush lupine	L	<i>Lupinus arboreus</i>
Rattlesnake grass	BM	<i>Briza maxima</i>
Ripgut brome	BD	<i>Bromus diandrus</i>
Annual grasses	AG	Silver hairgrass ( <i>Aira caryophyllea</i> ), Yellow hairgrass ( <i>Aira praecox</i> ), Red fescue ( <i>Festuca rubra</i> )
Iceplant	C	<i>Carpobrotus edulis</i> , <i>C. chilensis</i>
Scrub	S	Coyote brush ( <i>Baccharis pilularis</i> )
Open sand	OS	N/A



Appendix E. Table of the average percent composition for each species in relation to the three separate sites.

	Project Area	Uninvaded Site	Fully Invaded Site
<i>L. arboreus</i>	2.1	0	7.8
<i>B. maxima</i>	4	0	6.2
<i>B. diandrus</i>	0.3	0	1.4
<i>Carpobrotus</i> sp.	3.6	0	0.6
Dune mat	20.6	28.2	16.9
Annual Grasses	12.3	4.7	13.1
Scrub	0.7	0	3.5
Open Sand	9.5	40.1	5.9

Appendix F. Table of the total percentage of invasive and introduced species of the three sites.

	Project Area	Uninvaded Site	Fully Invaded Site
<i>L. arboreus</i>	2.1	0	7.8
<i>B. maxima</i>	4	0	6.2
<i>B. diandrus</i>	0.3	0	1.4
<i>Carpobrotus</i> sp.	3.6	0	0.6
Annual Grasses	12.3	4.7	13.1
TOTAL	22.3	4.7	29.1

Appendix G. Table of total percentage of dune mat and open sand of the three sites.

	Project Area	Uninvaded Site	Fully Invaded Site
Dune Mat	20.6	28.2	16.9
Open Sand	9.5	40.1	5.9
TOTAL	30.1	68.3	22.8