

UC Santa Barbara

Reports

Title

Outplanting Field Experiment for *Lupinus nipomensis* at Black Lake Ecological Area

Permalink

<https://escholarship.org/uc/item/99c5418t>

Authors

Nolan, Madeline
Luong, Justin

Publication Date

2016-09-01

Data Availability

The data associated with this publication are available upon request.

Copyright Information

This work is made available under the terms of a Creative Commons Attribution-ShareAlike License, available at <https://creativecommons.org/licenses/by-sa/4.0/>

UC SANTA BARBARA



**Outplanting Field Experiment of *Lupinus nipomensis*
At Black Lake Ecological Area**

September 2016

Madeline Nolan *Ecology, Evolution and Marine Biology PhD Student*

Justin Luong *Research Affiliate*

Lisa Stratton *Director of Ecosystem Restoration*



**OUTPLANTING FIELD EXPERIMENT FOR *LUPINUS NIPOMENSIS* AT BLACK LAKE
ECOLOGICAL AREA, LAND CONSERVANCY OF SAN LUIS OBISPO COUNTY**

**Prepared by: Cheadle Center for Biodiversity and Ecological Restoration; Justin
Luong, Madeline Nolan**

**Prepared for: U.S. Fish and Wildlife Service
Ventura, California
Cooperative Agreement Award #F12AC00683
Project Officer: Connie Rutherford**

September 2016

Introduction

Restoration of coastal dune ecosystems in California will, in part, be dependent on the successful reestablishment of endemic species that have been extirpated from protected dune reserves due to anthropogenic and climate change stressors. While the historic extent of coastal dune ecosystems in California is unknown, habitat conversion is thought to have reduced and left the remaining habitat both highly fragmented and degraded (Van der Maarel & Usher, 1997). Unfortunately, global climate change is predicted to further decrease suitable habitat area (Doukakis, 2005; Hapke et al., 2006) which could potentially lead to the extirpation of rare and threatened species that are endemic to coastal dune ecosystems (Doody, 2005; Schwartz et al., 2006). One characteristic which makes the restoration of coastal dune ecosystem particularly important, is their endemic plant biodiversity (Pardini et al 2015), with dune ecosystems in southern California hosting a number of endangered species such as *Cirsium rhizophyllum*, *Dithyrea maritima*, and *Delphinium parryi ssp. blochmaniae*. The loss of even a small amount of habitat can have a large impact on endangered plant species (Tzatzanis et al., 2003) because these species have restricted home ranges with specific and often unknown habitat preferences (McLeod et al., 2001). Therefore, one way to conserve endangered plants that are threatened by habitat conversion is to reestablish extirpated populations into protected areas by translocating individuals from extant populations into the new areas (Maunder 1992; Fenu et al 2016). However, these reintroductions are often fraught with difficulties and only a small proportion lead to the successful establishment of a population (Godefroid et al 2011). While reintroduction failure is thought to be predominately due to unsuitable restoration sites or environmental factors, (Godefroid et al 2011), a number of failures are due to the poor understanding of the habitat preference of the species of interest (Falk et al., 1996; Fiedler, 1991). One common problem noted in a number of studies on the restoration of endangered species, was the importance of microsite suitability for establishment success (Kollmann et al 2008; Vargas et al 2013; Dunwiddie and Martin 2016). Regardless of the ultimate cause, the failure of the majority of reintroduction highlights the difficulty in assessing whether a habitat is suitable for the target species (Berg 1996; Davy 2002).

In this paper, we describe a study on the translocation and reestablishment of *Lupinus nipomensis*, a federally endangered species endemic to California coastal dunes. *L. nipomensis* is a critically endangered (Clark, 2000) annual herb found in the Guadalupe-Nipomo Dune complex. Currently, it is estimated that the population size ranges from 100-1800 individuals a year, with a consistent loss in individuals over the past five years (Hall, Land Conservancy of San Luis Obispo, personal communication, 2014). Currently, *L. nipomensis* is confined to a nine geographically isolated populations that are located on privately owned land. Therefore, to better protect this species from habitat conversion and climate change, United States Fish and Wildlife Service (USFWS) has prioritized this species for reestablishment into a protected preserve. A number of potentially suitable sites have been identified (CCBER, unpublished data, 2015) which include Guadalupe Dunes National Wildlife Refuge (protected and managed by USFWS) and Black Lake Ecological Area (protected and managed by the Land Conservancy of San Luis Obispo). For this project, we choose to focus on the Black Lake Ecological

Area because it has a significantly reduced population of the invasive *Ehrharta calycina*. We were interested in understanding how abiotic characteristics (such as aspect and topography) and biotic interactions (such as herbivory) influence the establishment and growth of *L. nipomensis*. We predicted that plants would have decreased growth and reproduction when planted in areas that were highly exposed and not protected from herbivory. Furthermore, we predicted that scarification and increased time spent in the soil would increase germination rates. The results of this research will help practitioners choose appropriate microsite conditions in which to reestablish populations of *Lupinus nipomensis* on protected lands.

Methods

Species Description

Lupinus nipomensis is a federally endangered annual species of lupine that is endemic to California. It is a small herb in the Fabaceae family, found in 2mi² extent along the Central California Coast in the Guadalupe-Nipomo Dune Complex (Wilken, 2009). However, it is thought that the actual area of occupancy is a much smaller area than the range suggests, with individuals having preference for specific microsites within the range (Hall, LCSLO, personal communication). It grows as a basal rosette reaching 1-2 dm in height with somewhat succulent leaves and stems that store water for reproduction (Sholars, 2016). Historically, *L. nipomensis* was observed most often in the back dunes although it could occasionally be found in the inter-dunes. Currently, the loss of coastal back dune habitat because of land use conversion for human development is further limiting the range of *L. nipomensis* (Skinner & Pavalik, 1994). Moreover, *L. nipomensis* is facing increased competition from the noxious invasive weed, *Ehrharta calycina*, which has similar habitat preferences to *L. nipomensis* (Bossard et al., 2000; Hall, personal communication 2014). This is problematic for *L. nipomensis* and other native species in the area because it has been shown that native species are often outcompeted by exotic species, such as *Ehrharta calycina* (D'Antonio & Vitousek, 1992; Baird, 1977). Currently, *L. nipomensis* is restricted to nine geographically isolated populations that have a fluctuating total population that ranges from 100-1800 individuals in any given year. Since 2000, it has been listed as an endangered species and conservation efforts have been ongoing (Clark, 2000).

Seed Source

Seeds in this experiment were collected from the plants grown at the Cheadle Center for Biodiversity and Ecological Restoration (CCBER) native plant nursery grown in 2012. Those plants grown at the CCBER nursery were derived from wild *L. nipomensis* populations on the Nipomo Mesa by the Santa Barbara Botanical Garden in 2005.

Area Description

The Black Lake Ecological Area is located in a back dune ecosystem near Nipomo, CA in San Luis Obispo County (Figure 1). The climate is a typical Mediterranean climate with wet, cool winters, characterized by large, sporadic rain events, and dry, hot summers. However, the summer months are not as dry as a typical

Mediterranean climate due to the presence of occasional fog events (Fayram & Fyre, 2014). Back dunes are the oldest part of a dune complex where plant establishment over time has increased dune stability. They are characterized by low relief, 25 m or less, sinuous dune ridges, and tend to accumulate the highest plant diversity through time (Buckley, 1979; Miller et al., 2010).

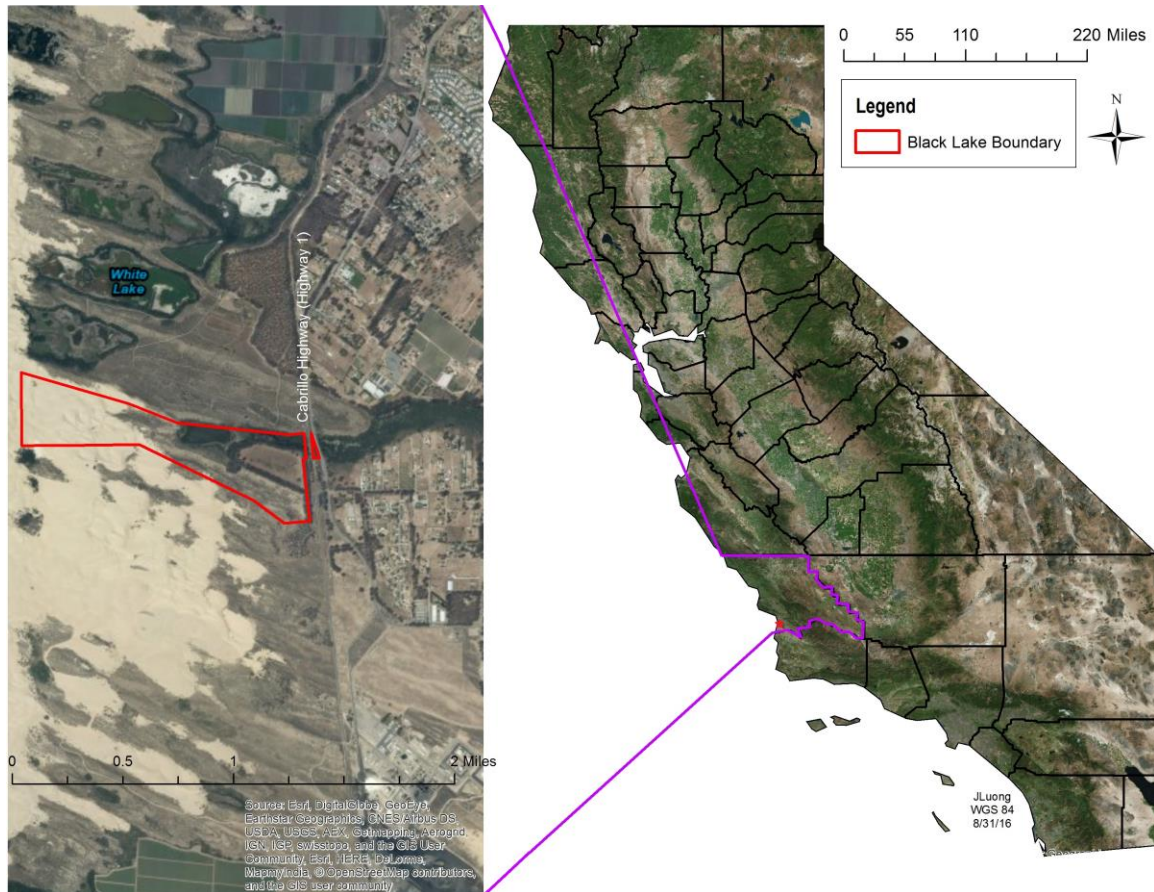


Figure 1 Black Lake Ecological Area. Panel A) the boundaries of the reserve which is abuts Cabrillo Highway to the east and is surrounded by residential development, recreational areas, and agricultural land. Panel; to the north is a OHV recreational dune park and to the west lies younger parts of the dune complex and ocean B) Blake Lake Ecological Area is located in San Luis Obispo County in central California along the coast.

Black Lake Ecological Area is defined by three distinct habitat types that can be found adjacent to the experimental area. There is a large wooded area interspersed by exotic annual grasses and native forbs, a stabilized dune area dominated by native dune vegetation, such as *Eriogonum parviflorum*, *Croton californicus*, *Mucronea californica* and *Ericameria ericoides*, and a 7 acre freshwater lake with accompanying wetland vegetation such as *Salix lasiolepis*, *Schenoplectus californicus*, and *Juncus patens*. The experiment took place in the stabilized dune area. The soil profile of the dune area is typical of dune ecosystems with fine sand (125-250 μm) from 0 – 18 meters in the profile and no hydric soils (Soil Survey Staff, 2016). On a finer scale, we found that the texture (through particle size analysis) was sandy loam, the average pH was 6.12, average

electroconductivity was 31.13, average soil organic matter was 3.27 grams/100gram of soil, average percent nitrogen was 0.0402 and the average percent carbon was 0.7005. While the area is largely unmanaged, there is an on-going effort to control the exotic veldt grass, *E. calycina*, population through graminoid specific herbicide, Fusilade DX (fluazifop-p-butyl). To minimize the effects of herbicide on the growth and reproduction of plants in the experiment, herbicide was restricted to areas at least 50 feet from the experimental plots.

Experimental Treatments

We investigated the strength of a number of variables that could influence the establishment, growth and reproduction of *L. nipomensis*. We manipulated the aspect (north facing, south facing, no aspect), topography (gentle slope, steep slope, swale, road), and exposure to herbivory (2 x 4 inch caging, ¼ inch caging, no caging) in a factorial design combined with a scarification treatment.

Aspect & Topography Treatment

To determine if *L. nipomensis* is influenced by small scale differences in environmental variables (i.e. microhabitats) across the dune complex, we manipulated both the slope and aspect of the experimental plot because it is known that some lupine species are sensitive to water and light availability (Braatne & Bliss, 1999). In conjunction, it has been shown by Bennie et al. (2006) that varying slopes and aspects can cause variation in exposure. There were 4 topography treatments (steep slopes, gentle slopes, swales, and ridges) and 3 different aspect treatments (north facing, south facing, and no aspect). We crossed the different aspect treatments with the topography treatments for a total of five different treatments: steep south facing, steep north facing, swale no aspect, ridge no aspect, and gentle south facing. We could not include a north facing gentle slope because one did not exist within the experimental area.

Caging Treatment

There was clear evidence of deer herbivory throughout the site with deer scat, broken twigs, and leaf damage frequently seen. The presence of elevated levels of herbivory is a common problem in restoration efforts (Rausher & Feeny, 1980). When excessive, herbivory can lead to a reduction in seedling survival and consequently, population persistence (Salihi & Norton, 1987). To determine if herbivory was negatively impacting the ability of *L. nipomensis* to naturally recruit and propagate in the area, we had two different caging treatments and a control to test for the effects of different sized herbivores. The caging treatments differed in the size of the top screen. The first treatment was a 1/4 in² mesh size (small cage) which would block most herbivores except small insects and arthropods. The second treatment was a 2x4 in² mesh top (large cage) which would only prevent deer herbivory but allow rodents, bird, and insects through (Figure 2). All cages were fully enclosed and built to be 90cm in diameter and 60cm tall. The sides of the cages were created with 0.25 in² mesh hardware cloth wrapped around rebar. All caging treatments with 0.25in² hardware cloth were dug down 7.5cm deep in order to prevent animals from accessing loose openings at the base of the cage. The control treatment only had rebar present at the four corners.

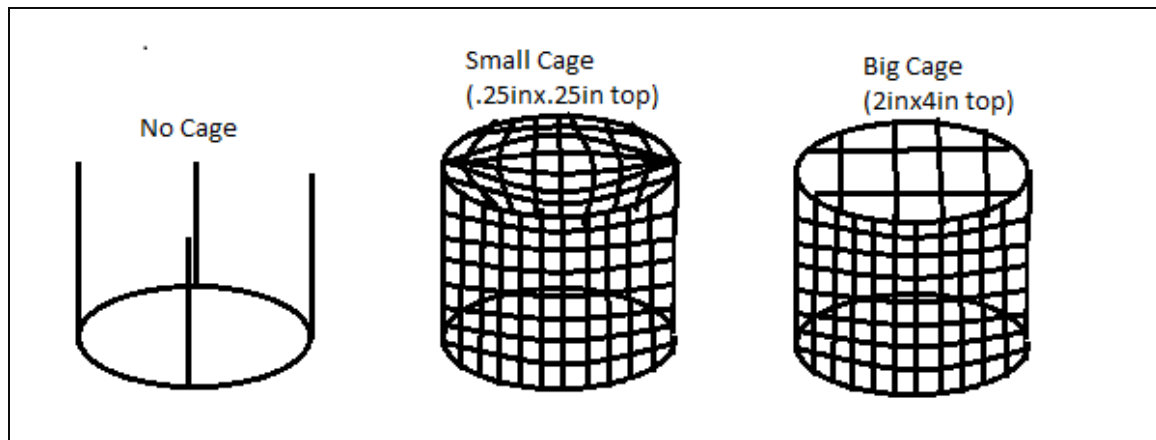


Figure 2 Sketches of the caging treatments design. No Cage consists of just 4 rebar posts, outlining a circle. The small cage consists of the same skeleton with 0.25in² hardware cloth wrapping the rebar with the same 0.25in² hardware cloth as a top. The big cage differs from the small cage only by its larger mesh on the top (2in x 4in top).

Scarification Treatment

While there have been no studies on the effect of scarification on *L. nipomensis* itself, it is known that other species of lupine have hard seed coats that require scarification to promote germination (Hughes, 1915). Prior to sowing the seeds in the field, we scarified half the seeds by running the wide-edge of the seeds across 400 grit sandpaper one time. The operculum was avoided during the scarification process. Within each plot, 40 *L. nipomensis* seeds were sown. Each plot was divided into two semi-circles in a north-south orientation and the seeds were split evenly between the division, one side receiving seeds that were scarified and the other receiving seeds that were not scarified. Seeds were sown in a grid of individual depressions approximately 5 mm deep and covered in a thin layer of sand.

Experimental Design

At each of the 4 topographical sites described above, we haphazardly replicated each caging treatment three times for a total of 9 plots in each topographical site (per year; Figure 3). Prior to sowing, all eucalyptus litter and the noxious weeds, *Ehrharta calycina* and *Conicosia pugioniformis* were removed from within all plot areas. In addition, all *E. calycina* and *C. pugioniformis* were removed if they occurred within 5 meters of any plot. No irrigation was provided during the experiment.

The first sowing of seeds took place on December 18, 2014. In December of 2015, three additional caging replicates were placed in the steep, swale and gentle topography treatments and an additional set of cages were placed on the north facing steep slope. These additional cages were sowed with seeds in the same manner as described above. A total of 1440 seeds were sown each growing season.

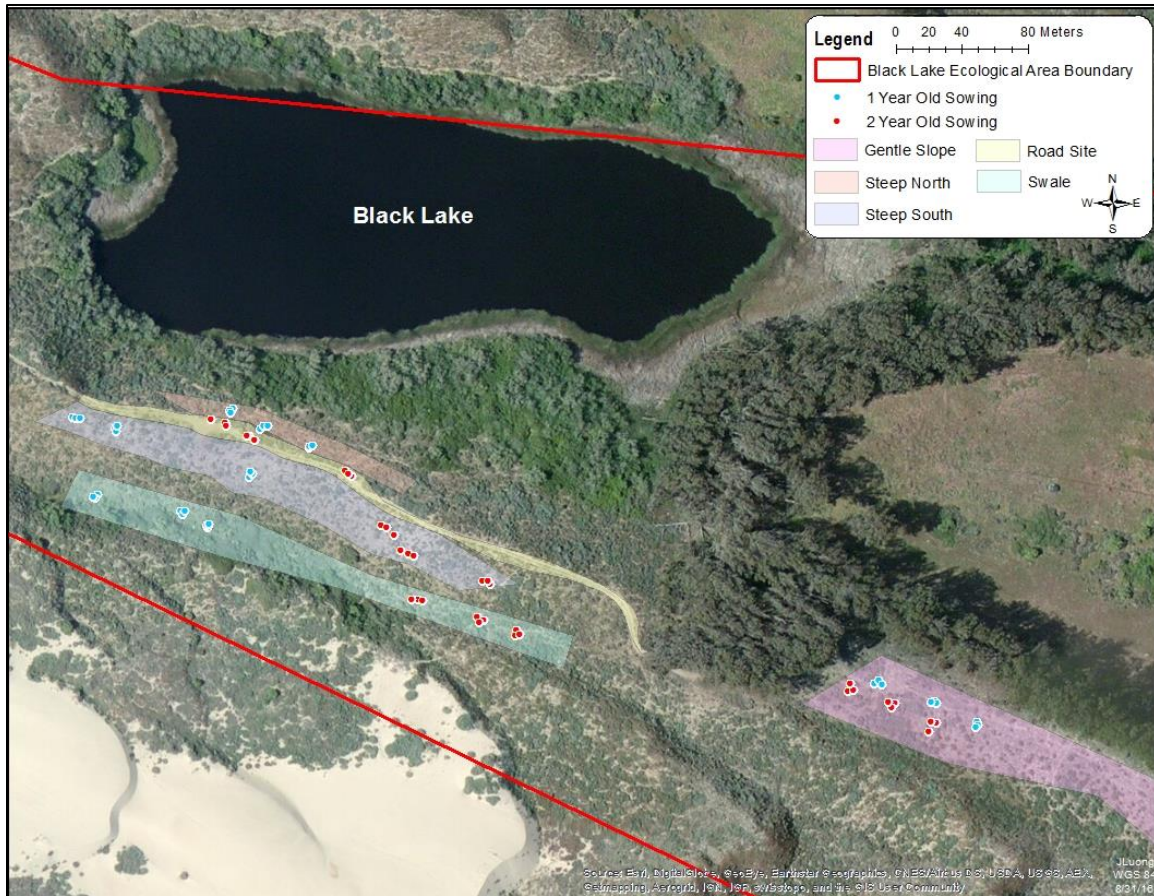


Figure 3 Black Lake Ecological Area study site. Within the image, topographies are delineated and the age and location of sowings of seeds are displayed.

Experimental Procedure and Monitoring

Plots were monitored every two weeks starting after the second sowing of *L. nipomensis* (see above). All new germinants were marked with a unique identification number and each individual was measured for growth and reproductive success. The growth of each individual was measured by counting the number of true leaves, measuring the natural height of the plant from the soil level to the tallest point on the plant, and measuring the diameter over the widest part of the plant. Reproduction was assessed for each individual by counting the number of flower clusters and seed pods. Herbivory was measured using a 5-point scale with 0 = no herbivory, 1 = only leaflets affected, 2 = one whole leaf affected, 3 = multiple whole leaves affected, 4 = entire plant affected, 5 = dodder (*Cuscuta sp.*) parasitism. Lastly, percent cover of each plot was noted. *E. calycina* and *C. pugioniflormis* were removed after percent cover estimates if they occurred within plots.

Data Analysis

R Studio was used for all statistical analyses (R Development Core Team, 2007). An analysis of variance (ANOVA) was used to determine if there were significant interactions between aspect, topography, and herbivory on the growth rate or reproduction of *L. nipomensis*. These were followed by a Tukey's honestly significant

difference test (TukeyHSD). Student's T-test was used to determine the difference in growth and reproduction of *L. nipomensis* in paired treatments (i.e. to compare the two types of topography that had no aspect).

Results

Seed Production and Growth Rate

A total of 343 individuals germinated in all plots with 39 individuals successfully reproducing and producing seed. All other individuals died before they could reproduce. The majority died from desiccation (156), with other individuals dying from being buried (6), being washed out (3), herbivory (1), natural senescence (37) or undeterminable causes (140). Across all germinated individuals, the average growth rate was 0.118 ± 0.01 leaves/day, which ranged from -0.2 to 1.919 leaves/day. For plants that successfully reproduced, the average number of seed pods was 3.94 ± 0.323 pods per individual plant. However, the number of pods produced varied greatly between individuals, ranging from 2 to 249 pods on a single individual. Across all individuals that produced seed pods, there was a significant positive correlation between the growth rate and seed pod production of *L. nipomensis* ($R^2=0.5548$; Figure 4).

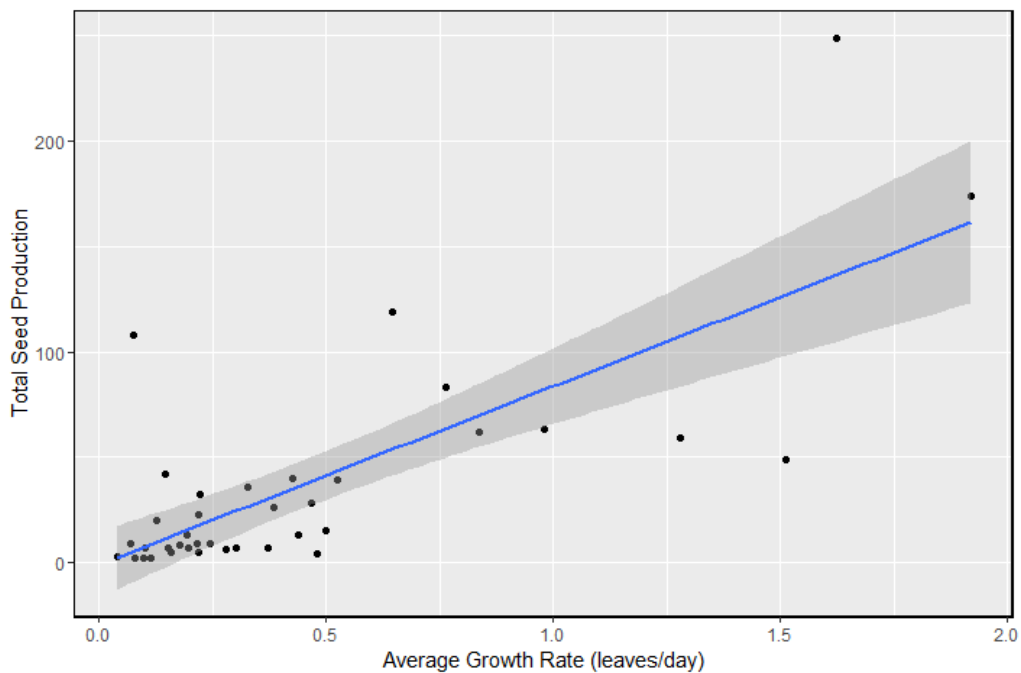


Figure 4 Correlation between average growth rate and total seed production ($R^2=0.5548$). This shows a direct relationship which implies any variable that would increase growth would increase seed production and any variable that would decrease growth would decrease seed production. The shaded area represents a 95% confidence interval and the regression follows the equation: $y = 0.201 + 0.00669x$.

Effect of Topography and Aspect

We found that topography had a significant effect on the growth of *L. nipomensis* ($F=3.559$, $p=0.0211$). The growth rate of *L. nipomensis* was similar across all topographies except the ridge, where individuals that grew on the ridge had a greater growth rate, 0.236 leaves/day, then those grown on the steep slope, 0.0925 leaves/day

($p=0.02582$). Topography had no significant effect on the seed production of *L. nipomensis* ($F=1.647$, $p=0.178$; Figure 5).

Aspect also had a significant effect on the growth of *L. nipomensis* ($F=3.621$, $p=0.0278$), but not on the production of seed ($F=0.518$, $p=0.596$). The *L. nipomensis* grown on plots with no aspect had a growth rate of 0.168 leaves/day, which was greater than both the south-facing (0.109 leaves/day, $p=0.0832$) and the north-facing plots (0.0748 leaves/day, $p=0.03381$). There was no significant difference between the growth rate of individuals grown in north facing and south facing plots ($p=0.6168$; Figure 5).

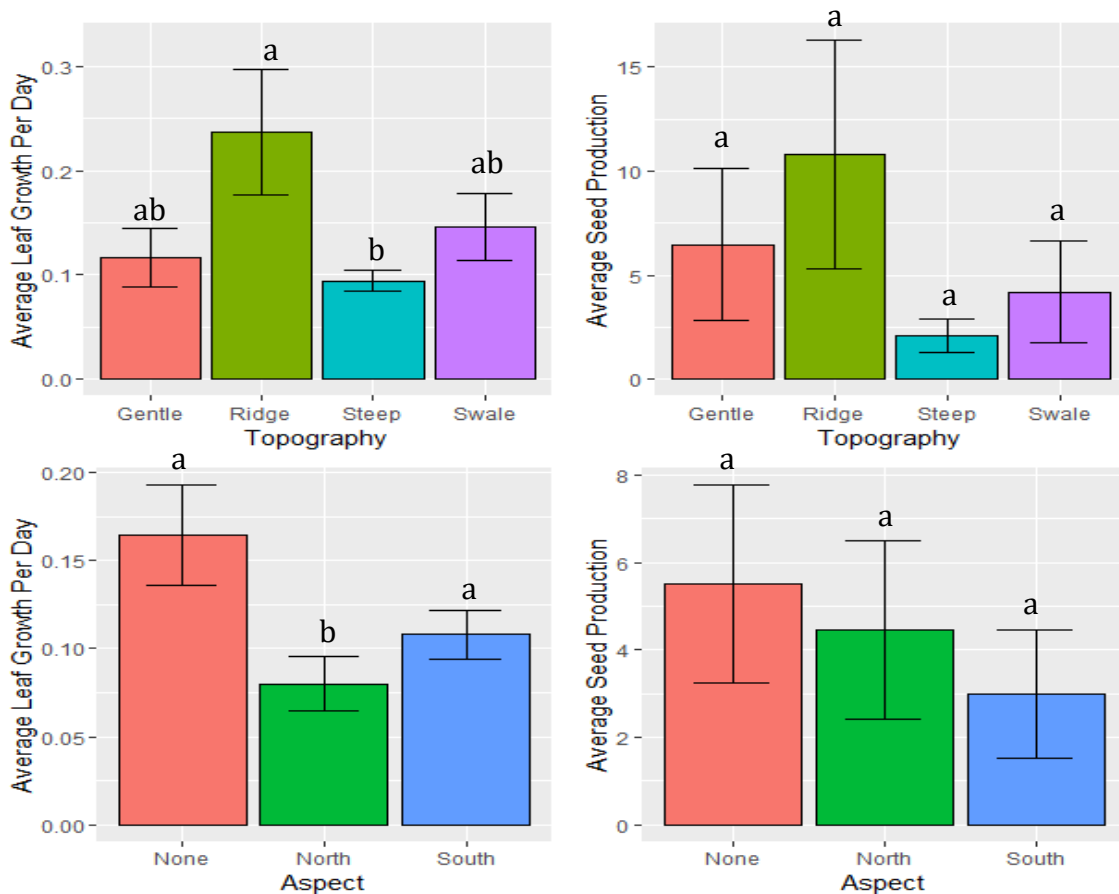


Figure 5 The effect of topography (top row) and aspect (bottom row) on growth rates and seed production. There is a significant difference in productivity between the road and steep slope. Aspect only affects growth rate and the north-facing aspect had the lowest productivity. Aspect did not significantly affect seed production.

Effect of Caging

The type of caging treatment had no effect on the growth and seed production of *L. nipomensis* ($F=1.222$, $p=0.296$).

Effect of Herbivory

Plants that experienced different levels of herbivory also experienced differences in growth ($F=24.05$, $p=1.44e^{-6}$; Figure 6). We found that *L. nipomensis* that experienced class 5 herbivory (parasitism from *Cuscata*) grew on average 0.366 ± 0.538 leaves/day more than *L. nipomensis* experiencing any other herbivory class with the exception of

class 4 ($p_{5/0} = 0$, $p_{5/1} = 1.784e^{-4}$, $p_{5/2} = 5e^{-7}$, $p_{5/3} = 1.393e^{-3}$). In that case *L. nipomensis* grew 0.626 ± 0.321 more leaves/day when experiencing class 5 herbivory ($p=2e^{-7}$). Plants that experienced class 4 herbivory grew 0.218 ± 0.0267 fewer leaves/day than those that experienced class 1 ($p=0.0293$) and class 3 herbivory ($p=5.630e^{-3}$). Furthermore, it was observed that class 3 herbivory grew about 0.170 more leaves/day compared to those that experienced no herbivory ($p=6.35e^{-5}$) and those that experienced class 2 herbivory ($p=0.0144$). Finally, it was also determined that *L. nipomensis* that experienced class 1 herbivory grew 0.128 more leaves/day versus those that experienced no herbivory ($p=1.954e^{-3}$). The same trend was observed between max herbivory and total seed production as well with the exception of the class 5 difference with class 3 and class 1 ($F=8.626$, $p=1.02e^{-7}$).

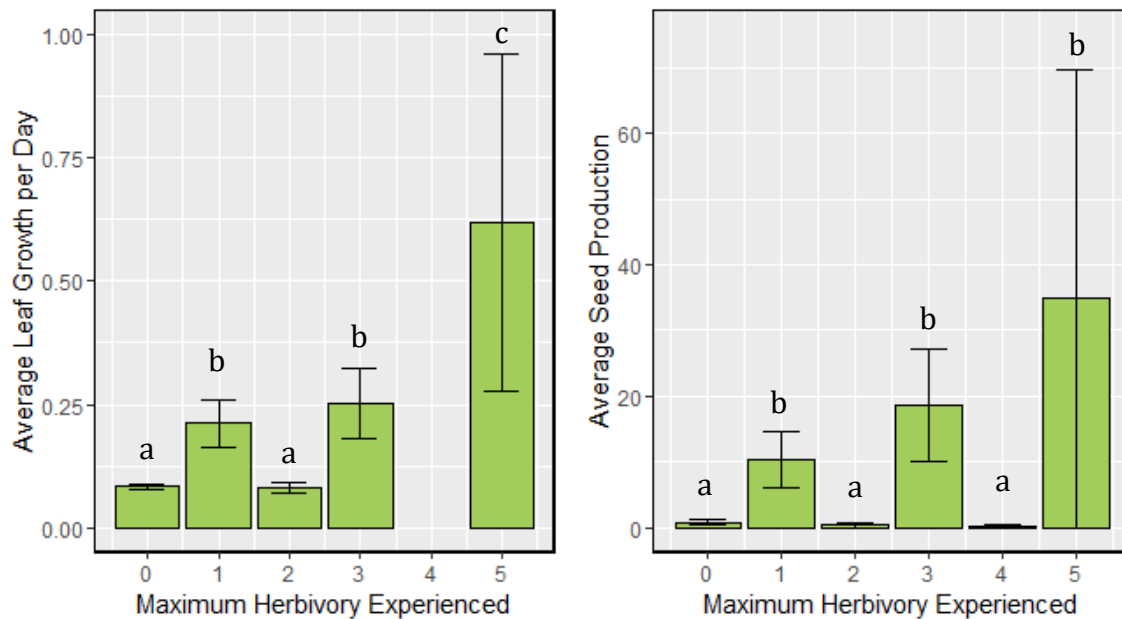


Figure 6 The effect of herbivory on the growth rate and total seed production of *L. nipomensis* was significant; Parasitism (class 5) on *L. nipomensis* had more of a beneficial effect than any other herbivory class including no herbivory. Very little or moderate herbivory can also have a beneficial effect on the productivity of *L. nipomensis*.

Effect of Time

Overall, we determined there was a positive correlation between the number of months seeds were in the ground and the germination rate ($t=3.464$, $p=0.008304$; Figure 7). Furthermore, there was a suggested effect on germination dictated by number of months on the gentle slope, where seeds that had been sowed one month prior to the 2015-2016 rain season were 339% more likely to germinate than those who had sown 13 months prior to the 2015-2016 rain season ($t=2.96$, $p=0.0853$). Furthermore, we were able to find a significant effect of year on the steep slope, where seeds that had been in the ground for one month were 959% more likely to germinate than those that had been in the ground for 13 months ($t=4.69$, $p=0.04041$). No effect was observed in the swale or ridge.

There was a significant effect of year on the growth rate of *L. nipomensis* ($t=-3.15$, $p=0.002343$). Seeds that had been in the ground for 13 months had an average growth of 0.145 leaves/day greater than those that had only been in for just the season.

There was also a significant difference in seed production ($t=-2.35$, $p=0.0216$), with *L. nipomensis* that had been sown the previous year averaging 10.755 seeds more than individuals that were sown the same year as the data collection.

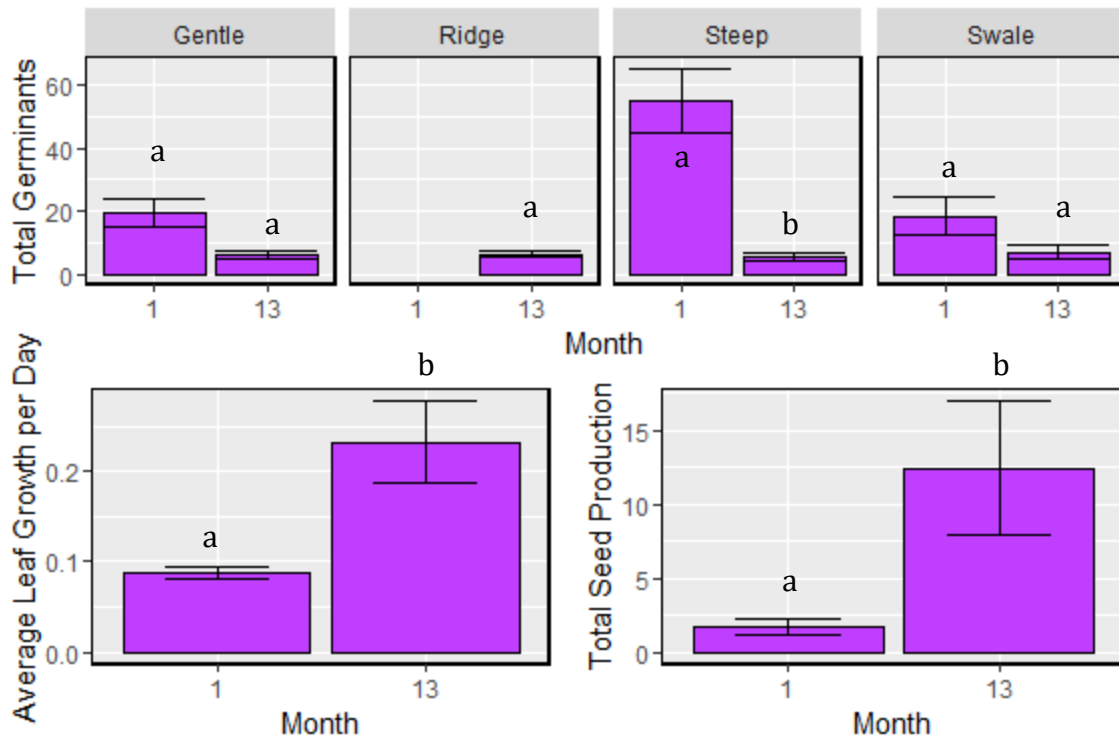


Figure 7 The effect of time on germination, growth and seed production. There was a temporal effect of sowing on germination, growth rate and seed production. Seeds sown the previous year (2014) germinated better, grew significantly more and produced more seeds than those sowed the same year (2015).

We found that scarification has a significant effect on percent germination ($F = 11.93$, $p = 0.000871$) where scarified seeds were 15.3% more likely to germinate than unscarified seeds. When examining the interaction of scarification with the time, we also found a significant effect ($F = 19.11$, $p = 3.56e^{-5}$). We found that scarification in seeds sown 1 month prior to monitoring were 26.5% more likely to germinate than those that were scarified and sown 13 months prior to monitoring ($p = 1.3e^{-6}$). We also found that scarified seeds sown 1 month prior monitoring were 25.0% more likely to germinate than those unscarified and sown 1 month prior ($p = 2.8e^{-6}$). Furthermore, we found that scarified seeds sown 1 month prior to monitoring were 20.7% more likely to germinate than unscarified seeds sown 13 months prior ($p = 6.04e^{-5}$). We found that there was no effect between unscarified seeds sown 13 months prior to monitoring and scarified seeds sown 13 months prior ($p = 0.699$) or compared to unscarified seeds sown the month prior ($p = 0.841$). Additionally, we found that unscarified seeds sown 1 month prior to monitoring did not differ in germination from those scarified and sown 13 months prior ($p = 0.994$).

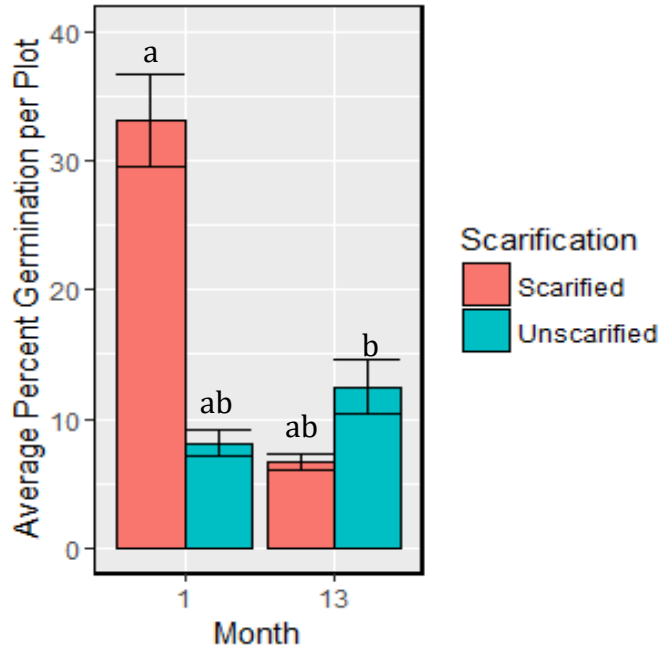


Figure 8 Average Percent Germination separated by month sown. Scarification treatment

Discussion

Our study is the first to assess the importance of microsite factors for the growth cycle of the endangered plant *L. nipomensis*. Our results suggest that *L. nipomensis* requires specific microsite conditions in order to maximize its growth and establishment. The growth rate and reproduction of *L. nipomensis* was highest in plots that had no aspect and minimal herbivory present (Figure 5, 6). Additionally, we found that the growth rate and reproduction of *L. nipomensis* was maximized when seeds were in the ground for at least 13 months (vs. one month) regardless of scarification treatment (Figure 7, 8). Pardini et al. (2015) found that *Lupinus tidedromii*, another endangered sand lupine in Northern California had a preference for less stabilized sites and perhaps this is a preference of *L. nipomensis* for less stabilized habitat in terms of sand movement, as ridges generally lose sand while sand is continually being deposited in swales from ridges and slopes. Furthermore, we found that caging had no significant effect on herbivory protection even with a further analysis using an ANOVA comparing individual cage types against herbivory. In terms of herbivory, we found that there was a lack of mammal herbivory in a majority of our plots. Regardless, we found evidence of herbivory on individuals of *L. nipomensis*, which we believe was caused by arthropods as the damage was random, dispersed and capable of penetrating a 0.25in² mesh caging treatment. Studies have shown that arthropod herbivory is quite common among species in the genus *Lupinus* (Bishop et al., 2005). We found that not all herbivory classes had a negative effect on growth (Figure 6). If herbivory was light to moderate, individuals could respond with compensatory growth, an accelerated period of growth following period of slow development or cell loss, in order to mediate for loss of tissue (McNaughton, 1983; Belsky, 1986). In terms of pre-treatment, we found scarification of

seeds had a significant effect on average percent germination per plot unless coupled with duration of seed in the soil (Figure 8). When coupled with time in soil, scarification was only important when sown that season to improve germination rates. These results implicate that scarification is not necessary in an outplanting project with management lasting longer than one year which aligns with the common paradigm that Lupines, that have a tough seed coat, are naturally weathered by dune processes and do not require scarification to germinate the following year (Davidson & Barbour, 1977). Interestingly, we found that seeds sown 13 months prior had a greater growth and reproductive rates than those sown 1 month prior, which we believe is due to the fact that the seeds sown 13 months prior got an early start with light rains. These patterns for growth in *L. nipomensis* were found to hold true for reproductive success and seed production as well (Figure 1).

Restoration efforts should focus on selecting appropriate microsite conditions coupled with ongoing monitoring efforts to determine the persistence of the newly established populations to improve reestablishment success (Dunwiddie & Martin, 2016; Godefroid et al., 2011). Practitioners can use field surveys to determine optimal sites for restoration of *L. nipomensis* as it was found that they reach maximum fecundity in ridges and swales. For example, a ridge or swale on a back dune within areas of potentially historic occurrence (perhaps at the Guadalupe-Nipomo Dunes National Wildlife Refuge) with no particular aspect would be ideal for an outplanting effort. However, once *L. nipomensis* is established in these new sites, we recommend annual monitoring of both the population of *L. nipomensis* as well as the small mammal abundance. In addition to a population density output, annual surveys of the population should also include an estimate of the average size of individuals. Since we found a positive relationship between growth rates and seed production (Figure 1) these two metrics together would give practitioners a good approximation of the reproductive output of the population.

Despite our experiment demonstrating a clear benefit to choosing microsite, it is also important for future studies to conduct surveys of existing conditions of *L. nipomensis* in order to determine if their surveys corroborate our results on aspect and topography. Moreover, we do not know whether the lack of mammal herbivory was due to mammals not consuming *L. nipomensis* due to lack of preference or due to low densities in the experimental area which could be disentangled by a mammal survey. While we hypothesize that arthropods are the most problematic herbivore, it would be important to determine whether the herbivory seen in this experiment is a generalist or a specialist. If the arthropod was a specialist, it may be even more important to study their interactions and how their relationship may be a necessity (Pavlik et al. 1993; Cropper & Calder, 1990). Furthermore, we did not quantify seed herbivory which has been shown to be significant in other rare plant introductions (Pardini et al. 2015), so we do not know if the 2429 individuals which did not germinate over the two year span of the project are due to abiotic or biotic factors. Additionally, edaphic features were not thoroughly analyzed which could prove to be useful to determine why *L. nipomensis* is particularly sensitive to aspect (Rezaei & Gilkes, 2005; Godefroid et al., 2011). Furthermore, it is important to remember that our experiment is a short term study. This experimental area should be monitored at least annually for at least eight more years as translocation efforts cannot be accurately assessed prior to ten years of establishment (Holl, 2006). Finally, expanding the outplanting efforts to a larger area with similar micro-topographies, in a

larger context of habitats would be a potentially interesting study for *Lupinus nipomensis*, as it has been distinguished that rare plants can be pushed to the limit of their extent and their extant populations are not always their ideal habitat (Godefroid et al., 2011).

Conclusions

Our study is one of few that highlights the importance of understanding specific microsite factors that may affect the success of a rare plant reintroduction effort (Godefroid, 2011; Dunwiddie & Martin, 2016). Comprehension of the habitat preferences of *L. nipomensis* allows practitioners to focus restoration efforts in areas that are most likely to lead to the successful reestablishment of a population. Successful relocation efforts are imperative, as *L. nipomensis* is steadily declining with a severely limited population (Land Conservancy of San Luis Obispo, unpublished data). With the loss of these sensitive endemic species, we also face a particular challenge in protecting the ecosystems they inhabit. Although our results are specific to *L. nipomensis*, our careful consideration of microsite conditions that would affect reintroduction efforts should be utilized broadly. With an uncertain future, it is most to understand the mechanisms behind reintroduction efforts if we are to preserve the rich endemic diversity found in coastal dune ecosystems.

REFERENCES

- Baird, A.M.** 1977. Regeneration after fire in King's Park, Perth, Western Australia. *Journal of Royal Society of Western Australia*, 60: 1-22
- Belsky, A.J.** 1986. Does Herbivory Benefit Plants? A Review of the Evidence. *The American Naturalist*, 127(6): 870-892.
- Bennie, J., Hill, M.O., Baxter, R., Huntley, B.** 2006. Influence of slope and aspect on long-term vegetation change in British chalk grasslands. *Journal of Ecology*, 94: 355–368. doi:10.1111/j.1365-2745.2006.01104.x
- Bishop, J.G., Fagan, W.F., Schade, J.D., Crisafulli, C.M.** 2005. Causes and Consequences of Herbivory on Prairie Lupine (*Lupinus lepidus*) in Early Primary Succession. In: Ecological Responses to the 1980 Eruption of Mount St. Helens: 151-161.
- Bossard, C.C., Randall, J.M., Hoshovsky, M.C.** (2000). Invasive plants of California's Wildlands. Berkeley: University of California Press.
- Braatne, J., & Bliss, L.** (1999). Comparative Physiological Ecology of Lupines Colonizing Early Successional Habitats on Mount St. Helens. *Ecology*, 80(3): 891-907.
- Buckler, W.R.** 1979. Dune type inventory and barrier dune classification study of Michigan's Lake Michigan shore. *Geological Survey Division, Michigan Dept. of Natural Resources* (23).
- Clark, J.R.** 2000. Endangered and Threatened Wildlife and Plants; Final Rule for Endangered Status for Four Plants from South Central Coastal California. United States Fish and Wildlife Service. <<http://ecos.fws.gov/docs/federal_register/fr3546.pdf>>
- County of Santa Barbara.** 2015. Webpage. County of Santa Barbara Public Works: Arroyo Grande Sensor (739).
- Cropper, S. C., & Calder, D. M.** 1990. The floral biology of *Thelymitra epipactoides* (Orchidaceae), and the implications of pollination by deceit on the survival of this rare orchid. *Plant Systematics and Evolution*, 170(1-2), 11-27.
- D'Antonio, C., & Vitousek, P.** 1992. Biological Invasions by Exotic Grasses, the Grass/Fire Cycle, and Global Change. *Annual Review of Ecology and Systematics*, 23: 63-87.
- Davidson, E.D. & Barbour, M.G.** 1977. Germination, Establishment, and Demography of Coastal Bush Lupine (*Lupinus arboreous*) at Bodega Head, California. *Ecology* 58:592-600

- Davy, A.**, 2002. Establishment and manipulation of plant populations and communities in terrestrial systems. In: Perrow, M.R., Davy, A.J. (Eds.), *Handbook of Ecological Restoration. Principles of Restoration*, vol. 1. Cambridge University Press, Cambridge, pp. 223–241.
- Doody JP.** 2005. Shoreline management—conservation, management or restoration? In: Herrier J-L, Mees J, Salman A, Seys J, Van Nieuwenhuyse H, Dobbelaere I (eds) *Proceedings ‘Dunes and Estuaries 2005’—International Conference on Nature Restoration Practices in European Coastal Habitats*. Koksijde, Belgium, pp 407–419
- Doukakis, Efstratios.** 2005. Coastal Vulnerability and Risk Parameters. *European Waters* 12: 3-7.
- Dunwiddie, P.W., Martin, R.A.** 2016. Microsites Matter: Improving the Success of Rare Species Reintroductions. *PLoS ONE* 11(3): e0150417.
- Falk, D.A., Millar, C.I., Olwell, M.** 1996. Restoring diversity: strategies for reintroduction of endangered plants. *Island Press*, Washington, D.C.
- Fayram, T., Frye J.** 2014. Santa Barbara County Hydrology Report. Santa Barbara County.
- Fiedler, P.L.** 1991. Mitigation-related transplantation, relocation and reintroduction projects involving endangered and threatened and rare plant species in California. Report FG-8611. California Department of Fish and Game, Sacramento.
- Godefroid, S., Piazza, C., Rossi, Buord, S., Stevens, A., Aguraiuja, R., Cowell, C., Weekly, C.W., Vogg, G., Iriondo, J.M., Johnson, I., Dixon, B., Gordon, D., Magnanon, S., Valentin, B., Bjureke, K., Koopman, R., Vicens, M., Virevaire, M., Vanderborght, T.** 2011. How successful are plant species reintroductions? *Biological Conservation*, 144: 672-682.
- Groves, R.H., di Castri K.J.** 1991. *Biogeography of Mediterranean Invasions*. Cambridge University Press, Cambridge.
- Hall, J.** 2014. In person communication. San Luis Obispo Land Conservancy.
- Hapke, C. J., Reid, D., Richmond, B. M., Ruggiero, P., & List, J.** (2006). National assessment of shoreline change Part 3: Historical shoreline change and associated coastal land loss along sandy shorelines of the California Coast. *US Geological Survey Open File Report, 1219*, 27.
- Holl, KD, Hayes GF.** 2006. Challenges to Introducing and Managing Disturbance Regimes for *Holocarpha macradenia*, an Endangered Annual Grassland Forb. *Conservation Biology*, 20(4):1121-1131.
- Hughes, H.D.** 1915. Making legumes grow. *Farm and Fireside* 38 (19) : 7.
- McLeod, M., Jones K., Jones G., Hammond N, Cunningham, E.C., Beigle G, Beigle J.** Dune Mother’s Wildflower Guide. Dunes of Coastal San Luis Obispo & Santa Barbara Counties, California. California Native Plant Society, Sacramento, California.
- Miller, T.E., Gornish E.S., Buckley, H.L.** 2010. Climate and coastal dune vegetation: disturbance, recovery, and succession. *Plant ecology*, 206: 97-104.
- Pardini, E.A., Vickstrom, K.E., Knight, T.M.** 2015. Early Successional Microhabitats Allow the Persistence of Endangered Plants in Coastal Sand Dunes. *PLoS ONE* 10(4): e0119567.
- Pavlik, B. M., Ferguson, N., Nelson, M.** 1993. Assessing limitations on the growth of endangered plant populations, II. Seed production and seed bank dynamics of *Erysimum capitatum ssp. angustatum* and *Oenothera deltooides ssp. howellii*. *Biological conservation*, 65(3), 267-278.
- R Development Core Team.** 2007. R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. <www.R-project.org>
- Rausher, M.D., Feeny P.P.** 1980. Herbivory, plant density, and plant reproductive success: the effects of *Battus philenor* on *Aristolochia reticulata*. *Ecology*, 61:905-917.
- Rutherford, C.** 2015. In person communication. United States Fish & Wildlife, Ventura, California.
- Salihi, D., Norton, B.** 1987. Survival of Perennial Grass Seedlings Under Intensive Grazing in Semi-Arid Rangelands. *Journal of Applied Ecology*, 24(1): 145-151.
- Skinner, M.W., Pavlik B.M.** California Native Plant Society's inventory of rare and endangered vascular plants of California. California Native Plant Society, 1994.
- Sholars Teresa.** 2016. *Lupinus nipomensis*, in Jepson Flora Project (eds.) *Jepson eFlora*, <http://ucjeps.berkeley.edu/cgi-bin/get_IJM.pl?tid=31836>, accessed on August 26, 2016.
- Soil Survey Staff, Natural Resources Conservation Service (NCRS)**, United States Department of Agriculture. Web Soil Survey. Available online at <http://websoilsurvey.nrcs.usda.gov/>. Accessed [8/8/16].
- Tzatzanis M, Wrבka T, Sauberer N .** 2003 Landscape and vegetation responses to human impact in sandy coasts of Western Crete, Greece. *Journal for Nature Conservation* 11:187–195.

- Van der Maarel E, Usher MB.** 1997 Recreational use of dry coastal ecosystems. In: van der Maarel E (ed) Dry coastal ecosystems: general aspects, ecosystems of the world, vol. 2. Elsevier, Amsterdam, pp 519–529
- Wilken, D.** 2009. *Lupinus nipomensis* 5 Year Review: Summary and Evaluation. United States Fish and Wildlife Service. <https://ecos.fws.gov/docs/five_year_review/doc3219.pdf>