BREN SCHOOL OF ENVIRONMENTAL SCIENCE & MANAGEMENT
UNIVERSITY OF CALIFORNIA, SANTA BARBARA

IMPACT OF SEA LEVEL RISE ON PLANT SPECIES:

A THREAT ASSESSMENT FOR THE CENTRAL CALIFORNIA COAST

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The Group Project is required of all students in the Master's of Environmental Science and Management (MESM) Program. It is a three-quarter activity in which small groups of students conduct focused, interdisciplinary research on the scientific, management, and policy dimensions of a specific environmental issue. This Final Group Project Report is authored by MESM students and has been reviewed and approved by:

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Abstract

Sea level rise poses a threat to the survival of rare plant species along the central California coast. While global sea level has been steadily increasing for at least 20,000 years, this trend has accelerated in the last 15 to 20 years in response to climate change. The State of California projects that by the end of the 21st century, the Pacific Ocean will rise by 1.4 meters. Although rare coastal plant species will be increasingly exposed to sea level rise, most research has focused on the impact to urban infrastructure. To address this information gap, we developed for the U.S. Fish and Wildlife Service a method of quantifying the exposure of coastal plant species to sea level rise. Our results suggest that a range of species occupying coastal wetlands, dunes, and bluffs will be threatened. As a supplementary analysis, we considered the additive impact of climate change by modeling future suitable habitat. In conclusion, on the central California coastline, a hotspot of biodiversity, sea level rise could factor into the extinction of rare plant species. The U.S. Fish and Wildlife Service can draw on these results in assessing the impact of sea level rise on plants that are listed under the Endangered Species Act, as well as on unlisted but rare species. Ultimately, this project will help land managers to identify species in need of protection and take appropriate actions to increase their resiliency to climate change.

I. Executive Summary

Introduction

Sea level rise (SLR) poses a threat to the survival of rare plant species along the central California coast. While global mean sea level has been steadily increasing for at least 20,000 years, this trend has accelerated in the last 15 to 20 years in response to climate change. The mechanistic causes of accelerated SLR are thermal expansion of the oceans and the melting of polar ice sheets. Projecting into the future, the State of California estimates that the Pacific Ocean will rise 1.4 meters by 2100.

As coastal plant species are increasingly exposed to SLR, they must adapt by moving to safer ground. Sedentary plants, however, are highly susceptible to fast changes in sea level, relative to mobile animal species. Adaptive migration can be difficult for rare plant species with small populations, which may be constrained by low dispersal ability, genetic diversity, and available habitat. As an additional pressure, many migrating plant populations will be squeezed on the inland side by urban development. Finally, climate change is likely to cause dramatic shifts in suitable habitat.

Despite these concerns, the threat of SLR to plant species has received relatively little attention. The U.S. Fish and Wildlife Service (USFWS) is interested in filling this information gap as part of its Strategic Plan for Responding to Accelerating Climate Change. In particular, USFWS would like to evaluate the impact of SLR in listing decisions and recovery plans for threatened and endangered species. By assessing the impact of SLR, the agency can better comply with its mission under the Endangered Species Act of 1973 to protect vulnerable species from extinction.

This Master's Group Project meets our client's need by quantifying the exposure of coastal plant species to SLR. We also undertook a supplementary analysis of current and future suitable habitat for a highly exposed plant species.

Methods and Results

We assessed the exposure of plant species to three physical processes that are exacerbated by SLR: inundation, flooding, and erosion. Inundation is the submergence of low-lying land at least once per day. Flooding during storm events occurs less frequently than inundation but can extend much farther inland. Erosion is a wearing away of land through the removal of dune or cliffs along the shoreline. SLR will increase the inland extent of all three processes, which could submerge plant populations or reduce their available habitat.

These SLR-related threats were projected into the future by the Pacific Institute, using the A2 emissions scenario from the Intergovernmental Panel on Climate Change (IPCC). This scenario assumes a 1.4-meter rise in sea level by 2100, a figure which is widely used by the State of California for climate-change planning purposes. The threats data allowed us to look at the effects of SLR across three time horizons: 2025, 2050, and 2100.

We overlaid future projections of these threats with the populations of a select group of plant species. For in-depth analysis, we chose nine rare plant species that represent a diverse range of life histories, habitats, elevation, level of endemism, and listing status within the Tri-County Area (San Luis Obispo, Santa Barbara, Ventura). To identify larger trends, we expanded our scope to 88 coastal species in the Tri-County Area. Location information about populations was derived from the California Natural Diversity Database (CNDDB). Overlaying the location data for species on top of the threat data, we could analyze the potential threat for each occurrence in the Tri-County region.

Our results suggest that a range of species occupying coastal wetlands, dunes, and bluffs will be threatened. From our in-depth analysis, we found that four of the nine species were exposed to at least one of the SLR-related threats. These plants were *Castilleja ambigua* ssp. *insalutata, Chloropyron maritimum* spp. *maritimum, Cirsium scariosum* var. *loncholepis,* and *Dithyrea maritima*. Interestingly, flooding poses the greatest threat to our species, while cliff erosion demonstrated the least threat. In the broader analysis of 88 species, we found that the level of threat decreased as elevation increased.

After quantifying the exposure of our species of interest to SLR, we undertook a secondary analysis to examine the plants' exposure to climate change. Using Maximum Entropy (MaxEnt), a species distribution model, we estimated the area of suitable habitat to which a species could move in the future. MaxEnt is a statistical model that uses the location data of species in concert with environmental and climatic data to infer the potential current and future spatial niche of a species. This is a widely used and generally robust species distribution model that can offer insight as to where the species may occur currently and in the future.

We chose to run MaxEnt on one of our species, *C. maritimum*, which was shown to be extensively threatened by SLR. In addition to location data, we used several environmental inputs: mean diurnal range, annual precipitation, growing degree days above 5^{o}C, aridity index, soil pH, and available water-holding capacity. To project future suitable habitat, we used two downscaled general circulation models (GCM) under the IPCC's A2 emissions scenario: the NOAA Geophysical Fluid Dynamics Laboratory (GFDL) and the Parallel Climate Model (PCM). The GFDL climate model predicts a hotter and drier California, while the PCM climate model predicts a warmer and wetter California.

We identified a substantial amount of future suitable habitat for *C. maritimum*, although the amount of area found varied between the two climate projections of the GCMs. Compared to the species' current range, the GFDL model predicted an overall growth (252% increase) while the PCM model predicted a reduction (7% decrease) in suitable habitat. When we overlaid SLR-related threats on top of each future habitat projection, we found that SLR reduced habitat by roughly 10-40% depending on the scenario.

Our findings show that there is great uncertainty as to the effect of climate change and SLR's interaction with one another, and their compound impact over suitable habitat is both extremely localized and spatially heterogeneous. Nonetheless, USFWS can use this information to shape management practices that are better informed by the potentially wide-ranging impact that SLR and climate change will have on the viability of already rare and threatened species.

Discussion

Our results demonstrate that there is a significant negative correlation between the elevation of coastal plant species and exposure to SLR-related threats. We identified rare species at low elevations that are highly exposed to SLR. This suggests that other rare species found at lower elevations may also be at risk. Furthermore, our in-depth analysis of nine species was corroborated by the larger analysis of 88 species, in that the proportion of species projected to be exposed to SLR remained approximately the same.

As SLR impacts coastal plant species, climate change may also substantially shift the location of species' suitable habitat. This represents an added environment stress to which species must adapt. The relative impact of SLR could vary substantially depending on future habitat predictions.

Implications

Our results may help USFWS to argue for the listing of rare species under the Endangered Species Act, enabling greater protection for such at-risk species. For instance, two of the four affected species in our in-depth analysis, *D. maritima* and *C. ambigua*, are not currently listed. Furthermore, information from this project can inform USFWS in the evaluation of 5-year reviews of listed species and recovery plans. In addition, the agency may use the threats analysis output from our model to avoid future mitigation, transplanting, and other resource-intensive management efforts in the areas identified as SLR threat zones.

The specific effects of climate-related stressors on microhabitats and individual organisms are still highly uncertain, as are the expected responses that will result from implementing adaptation strategies. More work is needed to evaluate the feasibility of options, better define the cost-effectiveness, and provide additional guidance for management.

II. Objectives

The overarching goal of this project was to provide the U.S. Fish and Wildlife Service (USFWS) with a systematic framework for assessing the exposure of sensitive coastal plant species to SLR.

This goal was achieved by:

1. Quantifying the exposure of rare, threatened, and endangered coastal plant species to SLR in the Tri-County Area of San Luis Obispo, Santa Barbara, and Ventura Counties. Exposure to SLR includes the direct effect of greater inundation, as well as the related effects of increased cliff and dune erosion, and flood events (See Appendix I for definitions).

2. Identifying plant species that could be exposed to SLR by 2025, 2050, and 2100.

3. Locating future suitable habitat for species with populations that are exposed to SLR.

4. Developing methods for objectives 1 through 3 that are easily adaptable for future use by USFWS.

5. Identifying knowledge gaps with regard to SLR, coastal plant species, and management options.

III. Project Deliverables

1. Maps of SLR-related threats overlaid with species occurrences will be provided confidentially to the client, upon request. Confidentiality is necessary to protect proprietary information and vulnerable species.

2. Quantitative estimates for each species of exposure to SLR:
    - Total percentage by area of all occurrences affected by each SLR-related threat at time horizons of 2025, 2050, and 2100.
    - Fraction of occurrences affected by each SLR-related threat at each time horizon.

3. Case study of current and future suitable habitat for one highly exposed species.

4. Methodologies and models used to assess species' exposure to SLR and suitable habitat, including both mapping in GIS and analysis.

5. Recommendations for future research to reduce existing knowledge gaps.

IV. Importance of Research

This project breaks new ground in the analysis of SLR as a threat to coastal plant species. Most recent studies, by contrast, have examined only the impact of SLR on human infrastructure. While USFWS has anticipated SLR as a potential threat to flora listed under the Endangered Species Act (ESA), this is the first quantitative and spatial assessment of the impact on species along the central California coast. Furthermore, our analysis suggests that currently unlisted yet rare species may require listing because of vulnerability to SLR. On a policy level, this project helps USFWS to account for the effects of climate change in listing decisions and recovery plans, in accordance with the agency's Strategic Plan for Responding to Accelerating Climate Change from 2010. More fundamentally, USFWS will be better equipped in its mission to save valuable species from extinction and to preserve biodiversity. Our methodology is also valuable for its adaptability; as estimates of sea level change over time, updated projections of SLR-related threats can be inserted into our GIS models. The results of these models provide quantitative evidence that could induce USFWS to argue for the listing of rare species under the ESA, or the relisting of threatened species as endangered.

Beyond assessing the threat of sea level rise, this project will provide USFWS with a framework for predicting the additive impact of climate change on coastal plant species. It is possible that climatic shifts will outpace the ability of species to adapt by migration. To address this problem, we will provide a model to predict suitable habitat under future climatic conditions and SLR. This tool will guide management actions to ensure that coastal species keep pace with shifting habitat under climate change and SLR.

Our research will also have a broad impact on stakeholders beyond USFWS because of the agency's outreach efforts to local land managers in the Tri-County Area. Since USFWS itself manages little land along the central California coast, it must collaborate with and guide the actions of other governmental agencies and nonprofit land trusts that manage coastal habitats. These managers will now be able to plan for the effects of SLR on sensitive species. In addition, our research may potentially drive the collection of field data that assesses vulnerability. As a more general benefit, this project highlights the need for land managers to think more broadly than solely protecting current populations. To preserve rare species in a dynamic environment, it is imperative to account for temporal and spatial shifts in the distribution of suitable habitat.

V. Literature Review

<u>Overview</u>

This section will first provide background on SLR, including its causes and recent trends. Second, we will discuss several physical processes that are intensified by SLR – inundation, flooding, and erosion – and their general effects on coastal plant species. Third, we will explore how suitable habitat modeling can account for the effects of climate change as well as SLR. Finally, we will explain how our project fits into the context of vulnerability assessment.

<u>Sea Level Rise</u>

Global climate change due to anthropogenic emissions of greenhouse gases (GHGs) will have persistent effects on physical processes upon which plant species depend. These effects include increases in mean temperature, global sea level, and extreme storm events, as well as changes in precipitation patterns.

Global sea level, defined as the mean height of the Earth's oceans, has been rising at an accelerating rate since the late 19th century (IPCC, 2007). Prior to this trend, global sea level was stable for two to three millennia (IPCC, 2007). Over the last 60 to 70 years, however, global sea level has increased 1.7 ± 0.3 mm/year, according to tidal gauge measurements (Nicholls and Cazenave, 2010; IPCC, 2007). More recent data recorded between 1993 and 2009 reveal a significantly higher increase in mean sea level of 3.3 ± 0.4 mm/year (Nicholls and Cazenave, 2010). This acceleration indicates an increase in external forcing from anthropogenic GHGs (IPCC, 2007; Nicholls and Cazenave, 2010; Overpeck et al., 2006).

There are two mechanisms by which anthropogenic climate change is accelerating SLR. First, increasing temperatures in polar regions are melting the ice sheets of Greenland and Antarctica (Nicholls and Cazenave, 2010). This phenomenon may result in irreversible SLR. In addition, it is estimated that thermal expansion caused by the overall warming of the oceans has contributed to approximately 25% of SLR since 1960 and 50% from 1993 to 2003 (IPCC, 2007; Nicholls and Cazenave, 2010). It is worth noting that through these processes, it can take decades or centuries for global sea level to reach equilibrium with near-surface temperatures (Nicholls et al., 1995).

During the 21st century, the trend of SLR is expected to persist and possibly accelerate further. The IPCC's Fourth Assessment Report projected 0.2-0.5 meters of SLR by 2100, under the A1F1 emissions scenario; the latter assumes continued intensive fossil-fuel consumption resulting in atmospheric carbon dioxide concentrations of 1000 ppm by 2100 (IPCC, 2007). However, more recent research has shown that even this high-end estimate may significantly underestimate future SLR. A study that was commissioned for the State of California projects that, under the medium-high A2 emissions scenario, mean sea level will rise 1.4 meters by 2100 (Cayan et al., 2009). This projection relies on historical evidence to assume that sea level rises as a function of global average air temperature near the Earth's surface (Rahmstorf, 2007). In addition, the authors adjusted for the effects of dams on freshwater input to oceans.

Nonetheless, the exact magnitude of future SLR is very uncertain, especially with regard to freshwater input from melting ice sheets (Nicholls and Cazenave, 2010). Neither the IPCC projections nor Cayan et al.'s (2009) explicitly account for the melting of ice sheets because of the complexity of the process. Historical records indicate that melting ice sheets have contributed significantly more to SLR than is being observed today, with a peak contribution of about 1 meter per century (Overpeck et al., 2006).

Furthermore, there is an unknown threshold in the melting of ice sheets, beyond which SLR could reach historic levels that are 4-6 meters higher than today (Overpeck et al., 2006). In fact, accelerated melting of ice sheets has recently been observed in Greenland and Antarctica (Nicholls and Cazenave, 2010). Thus, current projections of SLR could prove too conservative. As sea level models incorporate this evidence, projections of SLR could increase Even if the anthropogenic forcings were reduced, the coupled trends of melting ice and SLR could persist for centuries before reaching equilibrium, meaning SLR would continue even with conservative fossil fuel use (Overpeck et al., 2006).

On a local or regional level, natural factors could also modify SLR. Variation in tides, atmospheric pressure, wind and tectonics all affect local sea levels (Ryan and Noble, 2007). Sea level has declined in regions with upward tectonic movement, while subsidence in other areas has exacerbated anthropogenic SLR (Nicholls and Cazenave, 2010). Global weather patterns can also significantly affect local sea levels. For example, El Niño Southern Oscillation (ENSO) events along the California coast have generally increased local sea level (Ryan and Noble, 2007). Furthermore, it has been proposed that anthropogenic GHG forcings may increase the likelihood of El Niño events (Yeh et al., 2009), although these effects may be too weak for detection above natural El Nino variability (McPhaden et al., 2011).

In summary, uncertainty and spatial variation make it difficult to project SLR by the end of the century. Projections by the IPCC may significantly underestimate the contribution of ice-sheet melting (Rignot et al., 2011). The dynamic nature of SLR, especially in localized areas, further complicates the ability to project future increases.

Inundation

The most direct impact of SLR on coastal areas is an increase in tidal inundation. As sea level rises along the California coast, the Pacific Ocean will encroach on sites that were not historically inundated. This effect is significant because an increase in inundation would have a major impact on key coastal habitats that contain rare and listed species.

Coastal wetlands, especially, as well as dry lands at the interface of river deltas and shores, will be lost to inundation as SLR accelerates (Titus, 1990). Both habitats collect sediment to stay just above sea level. If SLR accelerates, some of these lands will be lost to permanent or more regular inundation. Lowlands and deltas may be more susceptible to an increase in inundation, since the effect depends on local geomorphology. For example, coastal bluffs and cliffs may be less vulnerable to direct inundation because they typically range in elevation from 0 to 70 meters above sea level (Titus, 1990).

An increase in inundation would not only cause habitat loss, but would also test the tolerance of plant species to waterlogging and salinity. Inundation causes waterlogging of the soils and submergence for plant species, which are abiotic stresses that influence species composition and productivity in numerous plant communities (Jackson and Colmer, 2005). While most coastal plant species can tolerate a couple of days of inundation, long periods of inundation can cause severe injury or death to some species.

Models of inundation depend on several factors. Most important is the elevation of high tide, which we will describe in depth in our methods section. The factor of SLR adds to this tidal elevation, resulting in a greater inland extent of inundation. Another factor is the slope of coastal areas – the lower the slope, the greater the loss of land to inundation (Nicholls et al., 1995).

Inundation is also limited by the rate at which sedimentation can keep up with SLR. Coastal wetlands, for example, can accrete vertically due to biomass/sediment input and keep pace with slow rates of SLR (Nicholls et al., 1995). This rate of accretion can increase with the rate of sea level rise up to some limiting value, above which SLR will exceed marsh accretion (Nicholls et al., 1995). Inundation and wetland loss only occurs above this threshold rate of SLR (Nicholls et al., 1995). This limiting rate of marsh accretion depends on a range of factors and is poorly defined on a site-by-site basis (Nicholls et al., 1995).

Ideally, inundation modeling would account for the impacts on wetlands as a habitat. However, wetland losses comprise a complex sequence of processes involving reduced wetland productivity and ultimate death of the individual plants (Nicholls et al., 1995). Given the reconnaissance level of analysis that would be needed to explore this complexity, a simple modeling approach is required to predict the impact of inundation in response to SLR (Nicholls et al., 1995).

Flooding

In addition to increasing inundation, SLR will also intensify the flooding associated with extreme storm events. Coastal flooding during storm events occurs as a result of both marine and fluvial forcings. While modeling complex fluvial interactions with marine forcings was beyond the scope of this project, inputs from rivers and streams could increase the inland extent of flooding.

The marine input to coastal flooding is partially influenced by storm surge, which is the abnormal rise in water level during a storm event, above the baseline of predicted astronomical tide (Salmun et al., 2011). In terms of magnitude, storm surge is influenced by several factors: tides, wind stress, atmospheric pressure, wave height, transport of water by waves and swell, and coastline configuration and bathymetry (Salmun et al., 2011).

SLR will increase the impact of storm surge by raising the baseline elevation from which the ocean rises during extreme weather. Even a small increase in sea level would substantial increase the extent of coastal flooding from storm surge (Leatherman, 1984; Cayan et al., 2008a). In general, SLR is expected to alter storm surge levels in proportion to the amount of rise for any given GHG emissions scenario.

By intensifying storm surge, SLR is likely to increase the frequency of extreme flood events, resulting in more catastrophic damage to coastal areas (Leatherman, 1984). Therefore, areas that are not regularly flooded may experience catastrophic flooding under SLR. Small increments of SLR can greatly increase the frequency of flood events (Cayan et al., 2008a). In the San Francisco Bay, for example, assuming a 30 cm/century rate of SLR, Cayan et al. (2008a) projected that the frequency of extreme events above its historical 99.99 percentile would be 17 events per year from 2070 to 2099. However, a 60 cm/century rate of SLR, the frequency of extreme events is projected to increase by 235 per year between 2070 and 2099 (Cayan et al., 2008a).

When storm surge interacts with the shoreline, extensive modification can occur. The amount of damage depends largely upon surge elevation and penetration. The inland extent of storm surge can be estimated by flood frequency curves from the Army Corps of Engineers, as well as the National Weather Service's SLOSH simulation computer model. However, the most widely used mapping of coastal flood zones is FEMA's Coastal Flood Insurance Study (FIS) (FEMA, 2005).

Even though storm surge is an important component of coastal flooding, FEMA's FIS does not attempt to model storm surge or even flooding; instead, FEMA uses historic data on the extent of flooding and extrapolates this data to estimate 100-year flood zones. The 100-year flood is defined as a flood extent that has a 1% chance of being equaled or exceeded in a given year (FEMA, 2005). This flood extent can be used as a proxy for the inland extent of the worst storm surge predicted to affect the coast (Leatherman, 1984).

In addition, it is acceptable to rely on FEMA's flood maps in place of more complex storm surge modeling on the West Coast because storm surge plays a much smaller role in coastal flooding as compared to the East and Gulf Coasts. The largest measured storm surge on the West Coast was approximately 1 meter in Washington State, whereas on the East Coast storm surge during a hurricane can exceed 30 feet (FEMA, 2005).

Nonetheless, storm surge in the Tri-County Area can still pose a threat to threatened and endangered plants. For these species, a single storm event could destroy entire populations (USFWS Status Review, 2009b). For example, coastal flooding during the winter of 2005 caused the failure of an outplanted population of *Astragalus pycnostachyus* var. *lanosissimus* in Ormond Beach, Ventura County (Jensen, 2007). In another instance, a severe storm event that deposited beach cobble on a coastal bluff in the Tri-County Area drastically reduced a population of the federally endangered *Potentilla hickmanii* (USFWS Status Review, 2009a). In addition, storm surge can alter coastal habitats by introducing saline water into sensitive areas; salt spray can damage individual plants, thereby changing the potential species composition, (Ridden and Adams, 2010).

<u>Erosion</u>

Even without accounting for SLR, coastal zones are inherently dynamic environments with a background rate of natural erosion of the coastline (Leatherman, 1984). Along the Tri-County coastline, erosion primarily affects dunes and cliffs. Erosion of both cliffs and dunes reduces the available habitat for coastal plant communities (Feagin et al., 2005).

It is important to clarify the distinction between inundation and erosion. While both phenomena cause land loss (Nicholls et al., 1995), erosion represents the physical removal of soil and sediment by wave action; by contrast, inundation is the permanent submergence of low-lying land at least once per day due to a rise in sea level (Nicholls et al., 1995).

Dune or beach erosion is defined as the permanent loss of sand; it typically depends on the dune's exposure to weathering processes, local wave climate, surge levels, sediment composition, and beach slope (van Rijn, 2011). Cliff erosion applies to sea cliffs and bluffs. Several factors determine the rate of cliff erosion: wave undercutting, rain wash and accompanying groundwater seepage, rip-currents hollowing out embayments in the fronting beach, and rock structures such as bedding and joints (Komar and Shih, 1993). Erosion can be increased by extreme storm-wave conditions and water-level variations due to tides and phenomena such as El Niños, which would increase tidal elevations (Komar et al., 1999).

By classifying the coastline by geomorphology, the primary land loss mechanisms can be defined and an appropriate land loss model can be selected and applied (Nicholls et al., 1995). Exposed sandy coasts and erodible cliffs, steep rocky coasts, and sheltered low-lying coasts will all experience varying erosion responses because of their different geomorphology (Nicholls et al., 1995).

Along the Tri-County coastline, SLR is already exacerbating erosion beyond the natural background rate (Leatherman, 1984). In fact, SLR has been identified as the principal forcing function in shoreline retreat along sandy coasts worldwide; significantly more retreat results from erosion than passive inundation (Ashton et al., 2011). For seaside cliffs, retreat is largely a function of the rate of SLR and the total elevation change of sea level (Ashton et al., 2011).

Elevated erosion rates under sea level rise are expected to impair the community composition of coastal habitats (Feagin et al., 2005), resulting in lower biodiversity. In the Tri-County Area, these coastal habitats house many threatened and endangered plant species (CNDDB, 2011). Thus, to accurately assess the threat of SLR to sensitive coastal plant species, it is important to model the effects of SLR on erosion.

There are two common approaches to modeling the effect of SLR on shoreline erosion. Both methods make a fundamental simplifying assumption that SLR is the only cause of shoreline change (Nicholls et al., 1995). One method, Bruun Rule, depends on the concept of total water level (TWL) in relation to erosion (Leatherman, 1984). TWL is defined as the sum of the height of measured tides plus wave run-up on the beach. Factors that influence TWL include mean sea level, tides, waves, wave run-up, storm surge, and El Nino. According to the Bruun Rule, the profile of the shoreline will remain the same even as erosion occurs because TWL remains constant. However, as sea level rises, the coastline must recede at a greater pace to reach equilibrium. We describe the mechanism of coastal erosion, based on the Bruun Rule, in greater detail in our methods section.

Another method of modeling the effect of SLR on erosion uses historical trends to identify the rate of retreat. This approach, while less sophisticated than the Bruun Rule, is more realistic; it involves the empirical determination of new shorelines using trend lines (Leatherman, 1984). Shoreline response is based on the historical trend with respect to the local sea level changes during a given time period (Leatherman, 1984). The first step is to quantify the historic shift in shorelines. The second step is to establish a change per year relationship for different shoreline types and wave exposures using the historical rate of local SLR (Leatherman, 1984). This rate can then be projected into the future.

<u>Suitable Habitat</u>

The threat of sea level rise to coastal plant species will not occur in isolation; rather, as plant species are exposed to the effects of SLR in the 21st century, they will simultaneously be exposed to the emerging and related threat of climate change.

California's climate is projected to change within the next hundred years in the form of increasing temperature and varying precipitation (Hayhoe et al., 2004). Climatic factors are known to be important drivers of species ranges (Woodward and Williams, 1987). For example, it has been shown that for many species, annual minimum temperature can limit plant distribution by exceeding the species' threshold for survival (Woodward, 1987). Climate change could alter the current distribution of a species by shrinking or shifting its climatic envelope. If species cannot adapt to new climatic conditions, or migrate at the same rate of changing climate, the species could go extinct (Davis and Shaw, 2001). Due to the dynamic nature of climate, any analysis of future suitable habitat must account for changes in temperature and precipitation over time.

It is possible to examine the additional effect of climate change on coastal plants through species distribution models (SDMs). These models can project either current or future suitable habitat for a species, based on location and environmental data (Elith and Leathwick, 2009; Hijmans and Graham, 2006). Suitable habitat is the physical space that a species can occupy, based on the relationship between current species distribution and a set of corresponding environmental variables. These variables capture the most important dimensions of the ecological niche for species' ability to survive and reproduce (Polechova and Storch, 2008).

There are a wide variety of SDMs that predict suitable habitat. Common SDMs include BIOCLIM, DOMAIN, GARP, GLM, and GAM (Elith et al., 2006; Wisz et al., 2008). One SDM in particular, Maximum Entropy (MaxEnt), has frequently been applied to predict the effect of climate change on species distribution (Hijmans and Graham, 2006; Fitzpatrick et al., 2008; Loarie et al., 2008). MaxEnt represents the a highly regarded program for modeling shifts in climate space, due to its high performance capability, user-friendly interface, and various modeling options (Hijmans and Graham, 2006; Phillips et al., 2006; Fitzpatrick et al., 2008; Elith et al., 2006).

Like other SDMs, MaxEnt uses environmental variables with current, known occurrences to approximate species distributions (Gogol-Prokurat, 2011). MaxEnt achieves this by finding the most uniform spread of the species' spatial data in relation to the constraints imposed by the available environmental data of the region (Phillips et al., 2006).

Furthermore, MaxEnt has been widely used to model the distributions of rare species (Gogol-Prokurat, 2011). MaxEnt has consistently demonstrated the highest predictive performance for species with very small sample sizes, compared with other SDMs (Hernandez et al., 2006; Wisz et al., 2008). For example, a MaxEnt analysis was recently conducted to identify suitable habitat for four rare plant species endemic to the Sierra Nevada foothills of California (Gogol-Prokurat, 2011).

In addition, while many SDMs require both presence and absence data to confirm relationships between environmental variables and location data, MaxEnt is adept at processing presence-only location data (Phillips et al., 2006). This difference is important because rare and endangered species often have presence-only data. MaxEnt performs relatively well with presence-only data because it uses the background environmental data for the entire study region as pseudo-absence data (Phillips et al., 2006).

MaxEnt has two other advantages. For example, MaxEnt can integrate downscaled climate data from general circulation models (GCMs) to predict shifts in species distribution under climate change (Sork et al., 2010; Hoagland et al., 2011). Finally, while it is a challenge to identify suitable habitat at a resolution high enough for specialist plants, MaxEnt has successfully been applied at grain sizes of 25-250 meters (Gogol-Prokurat, 2011).

Despite the relatively large advantages MaxEnt offers for modeling rare species, it is important to note a few limitations of the model. As with any SDM, MaxEnt is based on a number of critical assumptions. First, MaxEnt does not account for certain inter-specific interactions, such as dependence on pollinators, competition with invasives, herbivory, (Fitzpatrick et al., 2008). MaxEnt assumes that such variables do not affect the distribution of suitable habitat. Second, phenotypic elasticity is not considered (Hoagland et al., 2011).

MaxEnt also assumes that the current distribution of a species encompasses its entire climatic range; however, it is possible that climate is not what limits a species to its current distribution, in which case the climatic tolerance could be broader. Finally, there is a high level of uncertainty about which environmental inputs are appropriate for certain plant species because of the lack of knowledge about their habitat requirements.

Given that SLR and climate change are both likely to affect the future distribution of rare coastal plant species, it would be interesting to model their combined effects. To the best of our knowledge, however, this analysis has not been performed.

Vulnerability

To this point, we have described environmental changes to which coastal plant species are being exposed in the 21st century. Exposure to SLR and climate change, however, is one component of a broader vulnerability analysis. The vulnerability of a system also depends on its sensitivity to environmental change, as well as its adaptive capacity or resiliency (IPCC, 2007; Fussel and Klein, 2006). Sensitivity is the degree to which a system is affected by external change, while adaptive capacity is the system's ability to adapt and respond to that change (IPCC, 2007).

For lack of sufficient species-specific data, we were not able to analyze the sensitivity or adaptive capacity of coastal plant species. It is still worth noting that two species with approximately the same exposure to SLR could be affected differently based on their individual sensitivities and adaptive capacities. For example, a species that is highly sensitive to salinity could be at greater risk. Moreover, the species in this study are inherently sensitive to SLR and climate change because of their rarity; sensitivity depends largely on the population size and total number of populations (Young et al., 2010).

Additionally, competition with opportunistic, invasive species can increase the sensitivity of native species to climate change. Examinations of the ecological effects of climate change have also focused on the increased potential for invasive species, pests, and disease to shift distributions and afflict endemic populations (Parmesan, 2006). Sensitivity can also depend on the following factors: abundance of propagules, the temporal scale at which successful establishment occurs, dependence on specific disturbance regimes, confinement to rare soil types or geologic features, specificity to pollinators, and genetic factors, among others (Young et al., 2010). These inherent factors may be especially important for rare and endangered species.

The vulnerability of plant species also depends on their adaptive capacity or resilience to environmental change. Human infrastructure can serve as a major constraint on adaptive capacity. For example, while marshes are moving inland in response to SLR, their migration can be squeezed between a rising sea and urban infrastructure such as roads and buildings on the inland side (The National Academies, 2009).

Dispersal ability can place another constraint on resilience. While dispersal ability can buffer climate impacts, endemic flora with limited dispersal may experience contraction in their current ranges (Loarie et al., 2008). In fact, physical or geographic constraints on dispersal can leave species with no refuge under climate change (The National Academies, 2009). If climate change imposes rapid environmental changes over ecosystems with little flexibility for species to respond, an increased rate of species extinction could result (Walther et al., 2002; Thomas et al., 2004).

Furthermore, climate change could shrink the amount of suitable habitat to which species could migrate. It is worth noting that plant species differ broadly in dispersal ability and physiological tolerance to temperature change, photo-period, and moisture, species responses will be unique resulting in changes to community composition (Parmesan, 2006).

VI. Methodology for Analyzing SLR

A. Overview

Species Selection Process and Data: We selected an initial set of 9 species on the basis of several criteria, including rarity, elevation of occurrence, and habitat type. We obtained location data for these species mostly from the California Department of Fish and Game's California Natural Diversity Database (CNDDB), as well as from local land managers. Location data were used to create a spatial representation of each species' range within the Tri-County Area. We used GIS layers for each species of concern to perform statistical analyses that will determine the percentage of each species' current distribution that will be altered or completely inundated based on our model's parameters.

Threats Modeling: We projected onto the Tri-County coastline the future threats of inundation, extreme flood events, and erosion, based on the IPCC's (2007) A2 scenario for sea level rise in 2025, 2050, and 2100. Based on high-resolution spatial projections of each threat, we used ESRI's ArcMap to assess the exposure of each species to SLR-related threats along the Tri-County coastline.

Model Builder: To make our threats analysis process transferable to the U.S. Fish and Wildlife Service, we created a set of models in ArcGIS that automates the process.

Suitable Habitat Process: As a case study on the additive effect of climate change, we performed a MaxEnt analysis to identify current and future suitable habitat for one species that was projected to be exposed to SLR. We evaluated suitable habitat based on six environmental parameters. This analysis provided quantitative data on areas where management actions such as outplanting may be pursued.

B. Species Selection Process and Data

Using the CalFlora Plant Database (CalFlora), we initially generated a list of rare species in the Tri-County Area that occurred at low enough elevations (0-30 meters) to potentially be exposed to SLR. This search resulted in 30 species. We further winnowed the list by choosing a representative sample of the following characteristics:

- Common coastal habitats in the Tri-County Area
- Plant families
- Current and historic ranges
- Endemicity
- Listing status

Thus, we derived a list of nine species that represent 6 different families; 6 habitats including coastal marshes (fresh and brackish), coastal dunes, scrub, coastal bluffs, and meadows and grasslands; a mix of annuals and perennials; a mix of herbs, succulents, woody and deciduous shrubs; a suitable variety of elevation ranges; and a mix of state and federally listed species, as well as unlisted but rare species (Table 1). Then we checked with CNDDB and consulted with experts at the USFWS office in Ventura to ensure that we had not omitted any significant species that should be included.

Table 1: Species matrix

	Scientific Name	Common Name	Family	Habitat Type
1	*Arenaria paludicola*	marsh sandwort	Caryophyllaceae	Marshes and Swamps
2	*Astragalus pycnostachyus* var. *lanosissimus*	Ventura marsh milkvetch	Fabaceae	Coastal Salt Marsh
3	*Castilleja ambigua* ssp. *insalutata*	Johnny nip	Orobanchaceae	Wetland Riparian
4	*Chloropyron maritimum* ssp. *maritimum*	salt marsh bird's beak	Orobanchaceae	Coastal Salt Marsh, Coastal Dunes
5	*Cirsium scariosum* var. *loncholepis*	La Graciosa thistle	Asteraceae	Coastal Dunes, Brackish Marshes, Riparian Scrub
6	*Dithyrea maritima*	beach shieldpod	Brassicaceae	Coastal Dunes and Bluffs
7	*Lupinus nipomensis*	Nipomo Mesa lupine	Fabaceae	Coastal Dunes
8	*Nasturtium gambelii*	Gambel's watercress	Brassicaceae	Marshes and Swamps
9	*Sanicula maritima*	adobe sanicle	Apiaceae	Meadows, Grassland

It is important to note that our risk assessment can be applied for coastal species anywhere, although this project's scope was limited to the Tri-County Area. In addition, while the Channel Islands are part of Santa Barbara County, we excluded them because the processes of inundation, flooding, and erosion are far more complex than on the mainland. Nonetheless, we assumed that erosion on the Channel Islands will be minimal because their coastline is largely solid bedrock.

Location Data

We obtained location data for our selected species from the California Department of Fish and Game's *California Natural Diversity Database* (CNDDB), along with additional information on *C. maritimum* from Martin Ruane (Naval Base Ventura County). Each occurrence in CNDDB serves as a proxy for a population; technically, an occurrence is a cluster of individuals within ¼ mile of one another and separated by at least that distance from other occurrences. USFWS provided us with occurrences from CNDDB as GIS layers in polygon form. We chose to use polygon instead of point data for occurrences because it enables an analysis of the percent area affected by SLR.

We improved the accuracy of location data by removing all occurrences recorded before 1970. These earlier occurrences, which have not been corroborated recently, were assumed to be extirpated. Thus, we assumed that occurrences recorded after 1970 are still extant. In addition, we deleted polygons greater than 4 km in diameter, on the assumption that they were large because of location uncertainty.

We extracted data on species polygons (herein referred to as occurrences) from the database in order to overlay them onto the modeled SLR scenarios described below. Two versions of the occurrence layer were incorporated into the GIS model: the first includes all occurrences from CNDDB, while the second layer contains only those occurrences presumed extant, removing those labeled extirpated or possibly extirpated, as well as any occurrences greater than 4km in diameter. In both versions, we added two new occurrences of *C. maritimum* and additional area for existing occurrences based on observations from Martin Ruane (Naval Base Ventura County). This correction was limited to Pt. Mugu.

Due to incomplete and uncertain data on the number of individuals present within each occurrence, we assumed that populations were distributed evenly across occurrences. Thus, we included occurrences regardless of the number of individuals or clusters of populations known to be extant within them. We did not have enough detailed data to perform an analysis on the abundance or density of plants; however, we used the area affected to determine to relative threat to each occurrence.

Elevation Data

We extracted elevation data from the USGS seamless server in the form of 1/3 arc-second National Elevation Dataset (NED). This dataset has a horizontal resolution of approximately 10 meters and an average vertical accuracy of +/- 7m. This 7m accuracy is the average for the entire contiguous United States, although more recent calculations of the vertical accuracy have suggested that the average is likely closer to 2.44m. The data from PWI uses a combination of this NED and coastal LIDAR data, so its accuracy is likely higher than 2.44m.

California County Data

To define the spatial extent of our analysis, we downloaded county-level data for the State of California from the USGS seamless server. This data was in the form of polygons for the shape of each county.

Datum and Projection

We standardized our GIS analysis by using the California (Teale) Albers (Meters) projection, based on the North American Datum of 1983.

<u>C. Threats Modeling</u>

Introduction

To identify the exposure of our species to a range of threats exacerbated by SLR – inundation, flooding, and dune and cliff erosion – we projected the spatial extent of each threat for the time horizons of 2025, 2050, and 2100. We used ESRI's ArcGIS software to overlay high-resolution models of SLR-related threats on species occurrences in the Tri-County Area.

In projecting the threats, we made extensive use of data from outside sources. The Pacific Institute (PI) hired the consulting firm Philip Williams & Associates, Ltd. (PWA) to model SLR-related threats for the time horizons of 2025, 2050, and 2100. While PI provided the 2100 models, we acquired additional data from PWA. PI submitted these data to state agencies in California, including the California Energy Commission, California Department of Transportation, and the Ocean Protection Council, to quantify the effect of SLR on coastal communities, infrastructure, and ecosystems. Henceforth, we will attribute the above threats data to PWA.

Inundation Modeling

To project inundation in the Tri-County Area, we used GIS layers from PWA for the baseline year of 2000 and the future time horizon of 2100. For the baseline layer, PWA represented the maximum extent of inundation as the mean higher high water mark superimposed over the National Elevation Database. Mean higher high water refers to the higher of two high tides per 24-hour tidal cycle, averaged over a year (See Figure 1). PWA used mean higher high water because it most accurately reflects the coastal elevation inundated by tidal forces on a daily basis. In Figure 1, mean sea level is represented by the zero line.

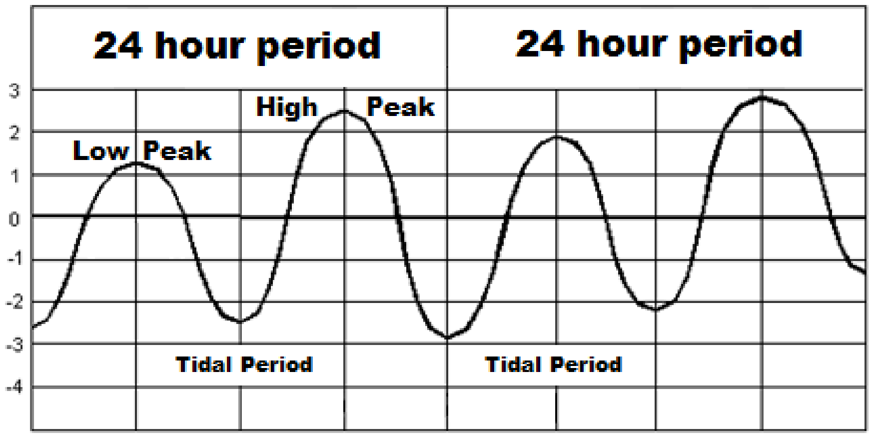

Figure 1: Representation of high and low tides over two day period. There are two high and two low tides in a 24 hour period where one is higher than the other. The average extent of these higher tides is the value used to estimate the mean higher high water level.

To estimate the mean higher high water mark, as the baseline inundation layer, PWA obtained tidal data between the mid-1980s and 2000 from 12 NOAA tide stations located throughout the California Coast. Relative sea heights were obtained for the higher of each day's two high tides for each tide station. Mean high tide elevation was calculated for each station for the roughly 16-year study period.

The mean high tide elevation from each station was then interpolated to the entire coast to produce the inundation extent for 2000. To interpolate, PWA used the mean inundation elevation and the NED to create a maximum inundation extent. This elevation does not account for storm surge or sediment accretion. The latter could counterbalance the effects of inundation in coastal marshes; however, this process was beyond the scope of our project. To model inundation in 2100, PWA created a layer that increased the 2000 inundation elevation by 1.4 meters, accounting for SLR.

We applied PWA's baseline inundation layer to our time horizon of 2025 and adopted their 2100 layer for the same year. While the extent of inundation is expected to increase between 2000 and 2025, we assumed that this change was minimal enough to justify using the baseline layer as a low-end estimate for the intermediate time horizon. We did not create a layer for 2050 because none was available from PWA and there was no defensible means of interpolating between the baseline and 2100 inundation layers. Finally, we limited the scope of PI's layers to the Tri-County Area. The inundation layer for 2100 created by PWA can be seen in Figure 2.

Figure 2: Inundation extent for 2100. The blue hatched area represents the area that will be submerged daily by the ocean every day. The area shown is a sample area from Ventura/Oxnard.

Flood Modeling

Along with inundation, we also modeled coastal flooding events along the Tri-County coastline for 2025, 2050, and 2100. We used the flood layer created by PWA for 2100 and projected our own flood extents for the earlier time horizons.

PWA's process for creating the 2100 flood layer relied heavily on FEMA 100-year flood maps. Since FEMA largely creates flood maps for urbanized areas, PWA interpolated flood extents from existing maps for those areas lacking published flood zones. The initial FEMA flood maps were created in the 1980's and therefore needed to be updated to include current sea level elevations for 2000. To complete this step, PWA used the calculated mean higher high water elevation used for the inundation modeling and then rounded to the nearest foot to create an updated flood elevation.

To estimate flood elevations in areas lacking formal FEMA flood maps, PWA estimated flood elevation using the published data for nearby areas while also taking into account wave exposure. Wave exposure incorporates the contour of the coast, shore orientation, profile steepness, general increase in wave intensity with increasing latitude, and professional knowledge (Heberger et al., 2009). Additionally, PWA used Euclidean allocation analysis to fill in gaps between existing flood maps (Figure 3). Euclidean allocation creates a flood elevation for points along the coast where there is no data (ESRI 2011). This is done by assigning a value to a location along the coast based on the closest known flood elevation and filling in this line from known elevation to known elevation.

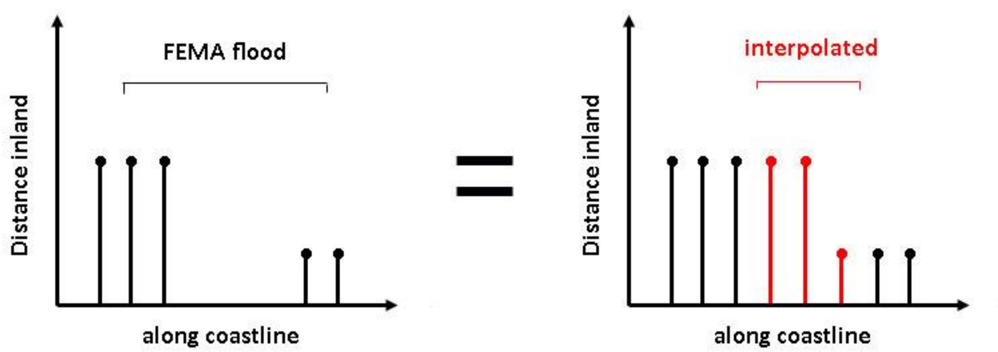

Figure 3: The Euclidian allocation method was used to interpolate the areas along the coastline where there was no FEMA data available to estimate flood extent.

Projecting the flood zone's extent into 2100, PI modified the current flood elevations by adding 1.4 meters to account for projected SLR.

In order to complete a full threat analysis over the three time horizons, we created flood extents for both 2025 and 2050. Lacking elevation data at a scale refined enough to replicate the process completed by PWA, we chose to use a more qualitative approach to estimate the intermediate time horizons. Initially, we downloaded 1/3 arc-second USGS National Elevation Dataset (NED) raster files for the Tri-County region.

After acquiring the Tri-County NED, the next step in the analysis was to determine the base flood elevation for the 2100 flood layer. To determine the 2100 base flood elevation (BFE), both the 2100 flood layer from PWA and USGS NED were used to estimate the BFE for 2100. PWA's 2100 flood layer does not follow elevation contours, so a single elevation estimate for the entire coast does not accurately reflect flooding extents, especially in low-lying areas where flooding has a more dramatic effect.

In order to account for the variations in flood elevations, we created a low-land flooding factor, which represents a maximum elevation beyond the 2100 BFE that will be exposed to flooding. The difference between the BFE and the low-land flooding elevation was used to adjust our estimates for flood extent in 2025 and 2050 (Figure 4).

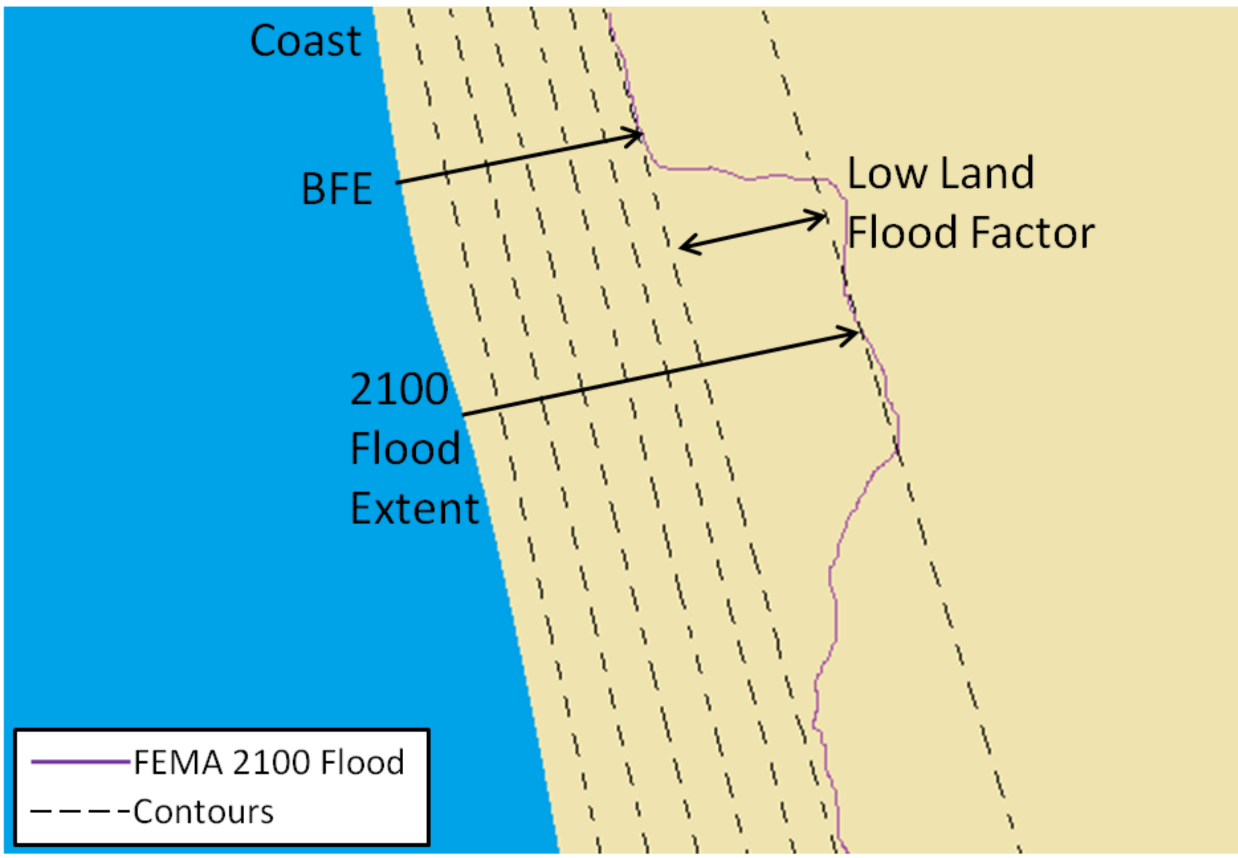

Figure 4: Process for estimating coastal flooding using the low-land flooding factor. Contour lines were used to estimate the average base flood level and the farthest inland extant flood level from the FEMA 2100 flood estimate. These were used to estimate the low-land flooding factor.

Equation:

Flood elevation = 2000 BFE + SLR elevation + low-land flood elevation

We also determined the BFE for 2000 using the method described above. The final step in our process was to add the low-land flood factor and projected SLR for each intermediate time horizon to the estimated 2000 BFE, in order to create flooding elevations for 2025 and 2050 (See equation above). The SLR elevation for the intermediate time horizons uses the updated A2 SLR projections created by Cayan et al. (2009) from which the 2025 and 2050 SLR projections were extracted. The 2100 flood extent can be seen in Figure 5. In order to ensure that the flood extent for the intermediate time horizons did not extend beyond the 2100 extent or fall below the 2000 extent, we adjusted the calculated extents for 2025 and 2050. First, we merged the intermediate flood layers with the 2000 flood extent to ensure that they did not fall below the 2000 flood extent. We then clipped the merged layers based on the 2100 layer, so that the intermediate extents did not exceed the 2100 flood extent created by PWA.

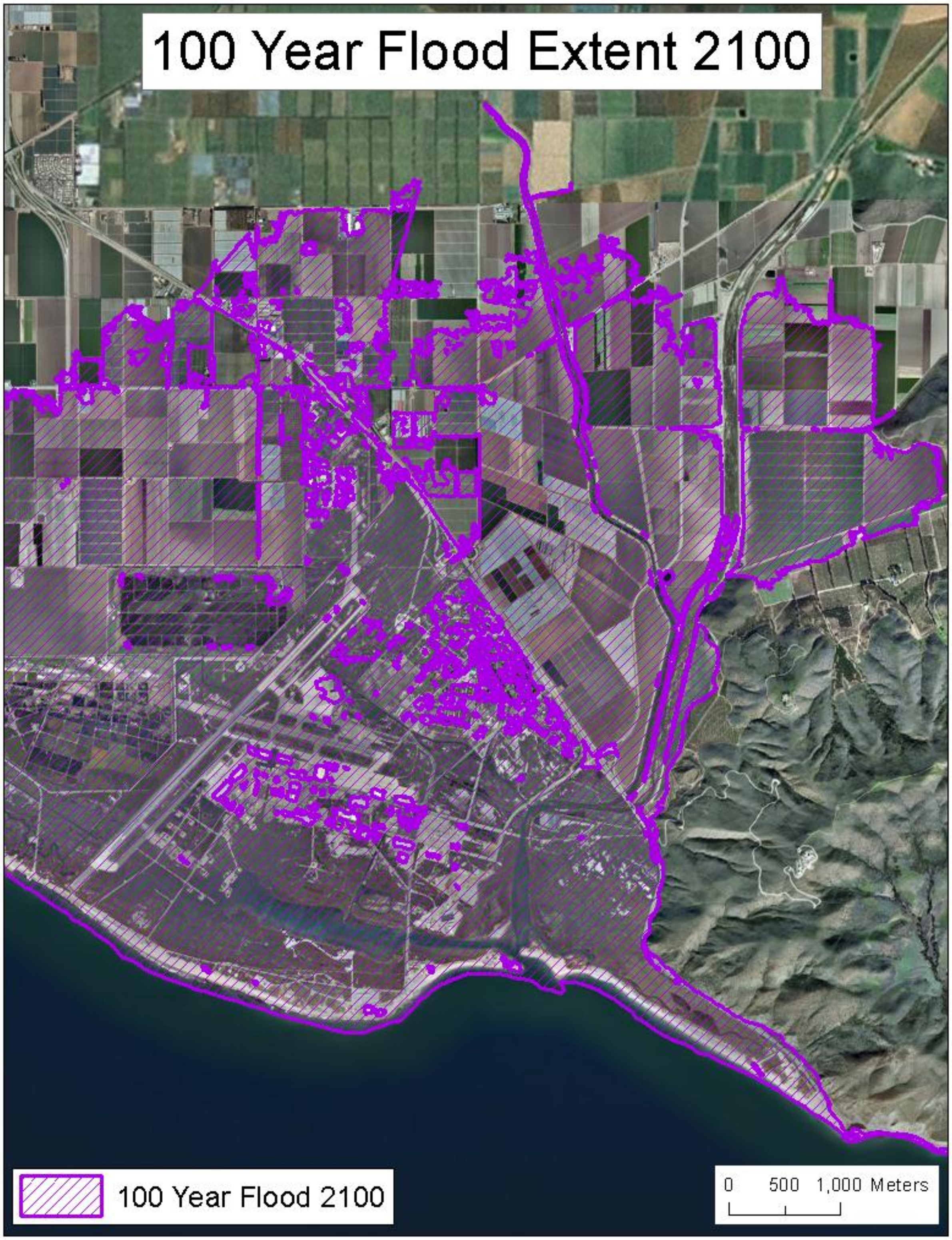

Figure 5: Flood extent for 2100. The purple hatched areas represent the extent of area that has a 1%

chance of being flooded in any year. The small polygons within this area that are not hatched are areas of higher elevation that will not be submerged.

Erosion Modeling

Along with inundation and flooding, we utilized PWA's models of coastal erosion for 2025, 2050, and 2100.

To project future erosion rates, PWA added the effects of SLR to natural background erosion rates; SLR was determined based on Cayan et al.'s updated A2 scenario (2009). SLR alters erosion rates by raising the total water level (TWL). Total water level is defined as the sum of the height of measured tides plus wave run-up. Factors that influence TWL include mean sea level, tides, waves, wave run-up, storm surge, and El Nino (Heberger et al., 2009). Wave run-up refers to the measured wave run-up onto the beach minus deepwater waves, based on an equation from Stockdon et al. (2006). Measured wave run-up is based on relationships between wave height, wave period, and beach slope.

PWA estimated TWL by accounting for measured tides and wave run-up (Cayan et al., 2009). They then segmented the coast into 500-meter blocks to account for variations in both toe elevation and changes in TWL along the coast. For each block, PWA compared the toe elevation with the TWL elevation; when TWL elevation exceeded the toe elevation, an erosion response was elicited. This model assumed no input from extreme flooding events.

Both cliff and dune shorelines took into account historic trends in shoreline change based on data from USGS National Shoreline Change Assessment. The measured erosion response is dependent on the backshore type, geology, failure mechanism, and shoreline change. The nature of the erosion response differs between dunes and cliffs.

Dune Erosion Modeling

PWA's dune erosion modeling was largely based on the following information from Komar et al. (1999). In that paper, an analysis of potential foredune erosion is based on assessments of extreme measured tides (the highest of which occur during El Niño winters), plus the run-up of waves on beaches during extreme storms (Komar et al., 1999). The foredune is the point at which a dune meets the beach. The assessments of extreme measured tides and wave run-up are combined to evaluate the TWLs for 2025 through 2100, which are then compared with the elevation of the toe of the foredunes (Komar et al., 1999).

Two approaches are employed to estimate the resulting dune erosion. A simple geometric model calculates maximum possible dune retreat. Process-based models, such as SBEACH and COSMOS, are then applied to obtain more reasonable estimates that account for the time lag of erosion behind the causative process (Komar et al., 1999). These models account for mean sea level and TWL (Komar et al., 1999).

In PWA's model, dune erosion only occurred where TWL exceeded the elevation of the toe of the dune. In order to determine the toe elevation, PWA divided the coast into 4,096 geologic units based on similar characteristics and then broke these units into 500-meter segments. The backshore was calculated for each segment. Using TWL, PWA then created percent exceedance curves for each 500-meter segment based on individual toe and slope elevations. TWL exceedance curves were used to run the dune erosion model, which included changes in TWL from SLR combined with shoreface slope, historic shoreline trends (from USGS), and impacts from 100-year storm events. Then, PWA predicted future toe locations from 1998 LIDAR data using projected exceedance curves for each 500-meter segment. Finally, PWA calculated the retreat distance for dunes using a shoreface profile slope from a 10-meter contour to the backbeach elevation. PWA found that there was a shift from accretion to erosion sometime between 2050 and 2100, which is indicative of the time lag associated with SLR effects.

Since PWA provided us with dune erosion estimates for 2025, 2050, and 2100, we did not need to manipulate these data.

Cliff Erosion Modeling

One of the most problematic aspects in modeling cliff erosion is the cliff itself – stratified layers consisting of non-uniform materials have different densities and therefore the rates of erosion differ (Komar and Shih, 1993). These factors are important in determining whether cliff retreat takes the form of abrupt large-scale landsliding or the more continuous failure of small portions of the cliff face (Komar and Shih, 1993).

The interaction of water and tectonic processes are also complex. In some locations, waves play an active role in directly cutting away the base of the cliff (Komar and Shih, 1993); elsewhere, retreat may be influenced by groundwater seepage and direct rainwash, with oceanic waves acting only to remove the accumulated talus at the base of the cliff (Komar and Shih, 1993). In addition, tectonic-induced spatial variability alters cliff retreat rates throughout the coast (Komar and Shih, 1993).

There is considerable spatial variability in the rates of cliff retreat, including a coast-wide pattern that is likely due to tectonic activity causing differential uplift rates (Komar and Shih, 1993). Similarly there are marked differences in the nature of the erosion processes depending on the composition and stratigraphy of the bluff (Komar and Shih, 1993).

The degree of cliff erosion, however, is often based on qualitative assessments (Komar and Shih, 1993). Direct evidence is provided by the degree of vegetative cover, the quantity of accumulated talus fronting the cliff, and the occurrence or absence of wave attack in recent years (Komar and Shih, 1993). There is a great deal of local variability (spatial and temporal) in erosion rates that can only be explained by other factors. These include: the overall ability of the fronting beach to act as a buffer between the waves and cliffs, beach processes such as run-up and erosion within rip-current embayments, and the composition and structure of the cliff material (Komar and Shih, 1993).

Aerial photographs are commonly used, as by Komar and Shih (1993), to obtain quantitative measurements of long-term cliff recession rates, but they have only been partially successful. Another factor that makes it difficult to use aerial photographs to measure cliff recession is mass movement of the cliff itself (Komar and Shih, 1993). Calculation of reliable historical recession rates is fundamental to predicting future trends even without SLR. Historical trends may be extrapolated to produce estimates of future retreat by assuming that typical behavior is contained within the record of cliff scars from historical erosion (Bray and Hooke, 1997).

Simple predictive models including a modification of the Bruun Rule are developed and applied to estimate cliff sensitivity to SLR (Bray and Hooke, 1997. According to the Bruun Rule, SLR should result in a shift in the position and elevation of an equilibrium profile that otherwise remains constant (Bray and Hooke, 1997).

In response to the changes in first-order factors such as sea level, cliffs will not adjust instantaneously (Bray and Hooke, 1997). There will be almost certainly lags in their responses. Projections of recession therefore should be treated as maxima and should not occur in full until after 2050, when lags have worked through the system (Bray and Hooke, 1997).

Since cliff erosion is an extremely complicated process, PWA simplified the analysis by excluding the terrestrial mass wasting processes that are discussed above. Thus, PWA assumed that only marine processes would elicit an erosion response. As with the dune erosion model, PWA used exceedance curves to estimate the erosion response when TWL exceeds the base of the cliff. PWA prorated erosion rates every 10 years rather than continuously modeling erosion, since the latter tends to occur episodically. On top of this, PWA added two standard deviations to the erosion estimate to account for the exclusion of mass wasting from the model (Revell, PWA, personal communication).

Since PWA provided us with cliff erosion data for 2025, 2050, and 2100, no additional manipulation on our part was necessary.

D. Threats Analysis

In order to analyze the threat of SLR to each species, we collected data from CNDDB on each occurrence for each species. This data was combined with PWA's threat layers, which we limited to the Tri-County Area. In addition, we only analyzed the threat to extant occurrences.

The first step was to calculate the area of each occurrence. Then, we overlaid the occurrences with each threat layer to find those that would be threatened by SLR. We calculated the area of overlap with each occurrence to find the percent area threatened, as well as the number of occurrences threatened. This process is depicted below in Figure 6. In this figure, we show occurrences of hypothetical species because our actual species are too sensitive for their exact locations to be published.

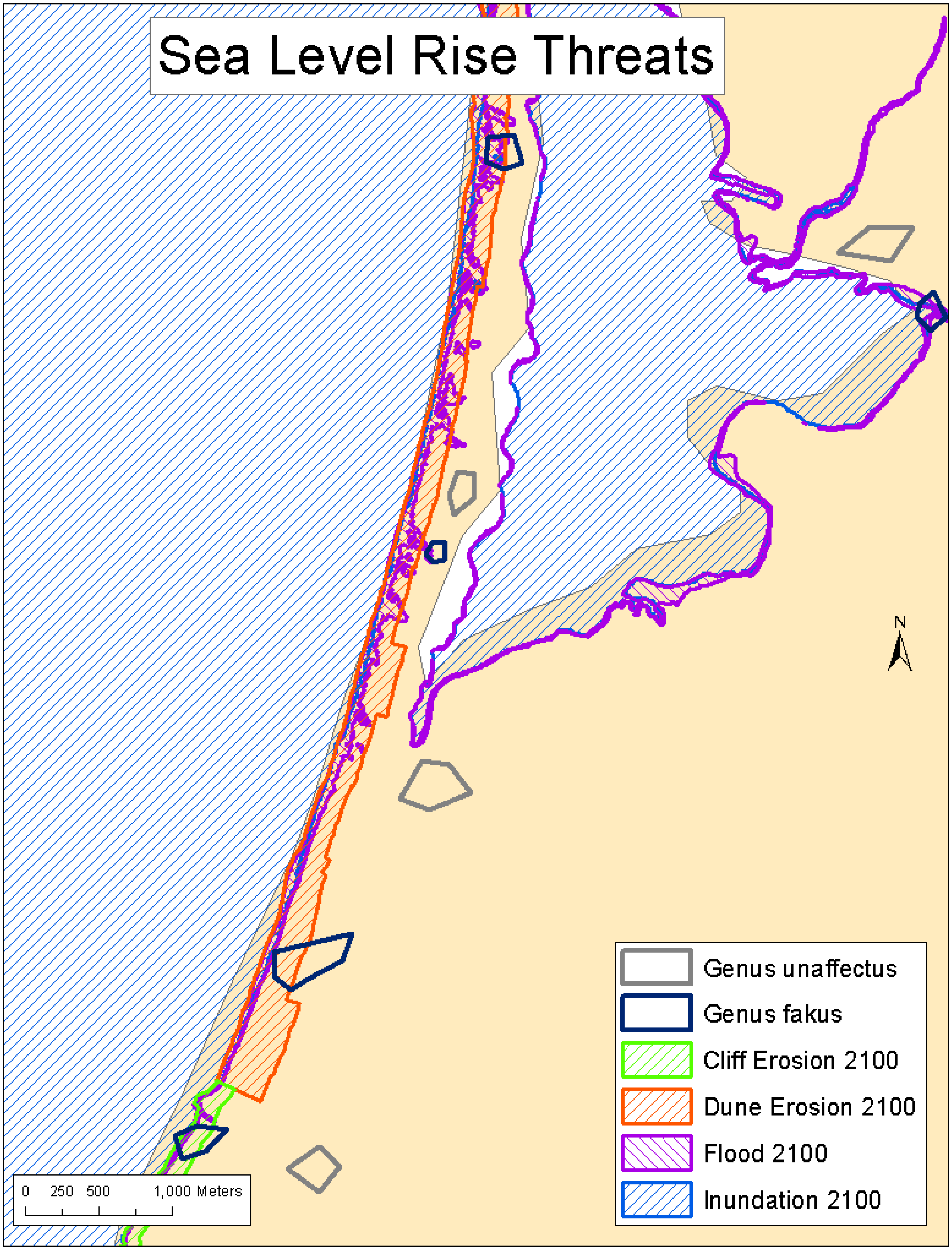
Sea Level Rise Threats
Genus unaffectus
Genus fakus
Cliff Erosion 2100
Dune Erosion 2100
Flood 2100
Inundation 2100
0 250 500 1,000 Meters
N

Figure 6: Overlay of all threats with sample species occurrences. This is a sample area from Morro Bay that shows the extent of inundation, flooding, and dune and cliff erosion by 2100 compared with two sample species, one that is affected (genus fakus) and one that is unaffected (genus unaffectus)

The metrics of percent area affected and number of occurrences affected are each appropriate in different respects. For example, a species can simultaneously have few occurrences affected even as a high percentage of its area is affected. Conversely, it is possible for all of a species' occurrences to be affected while the percent area affected may be very small. These metrics represent the most detailed information available that is consistently measured for rare plant species. The alternative would be to collect less detailed binary information on the presence or absence of threat to each species as a whole.

Combined Threats Analysis

At this stage, we determined the combined effect of all threats on each species, eliminating overlap and possible interactions among threats. Lacking the means to weight the relative impact of each threat, we simply identified where any threat might occur. While the threat of flooding is the most spatially extensive, we had no information to weigh its relative impact.

In modeling all future threats, we assumed that the current occurrences of species will stay in the same locations. This is a reasonable assumption because plants are unlikely to migrate substantial distances within our time-scale.

Extirpated Analysis

We also compared the relative threat of SLR for presumed extant occurrences to presumed extirpated occurrences. To do this, we ran the *Threats Analysis* (above) for the extirpated occurrences to identify the extent for these threats.

Extended Species Analysis

To identify patterns in threats, we selected a set of species from CNDDB within the Tri-County Area for which at least one occurrence was found below 100 meters. This resulted in a list of 132 species, of which only 88 were limited to the Tri-County Area, excluding the Channel Islands. For these 88 species, we ran the Threat Analysis (above) and graphed them against elevation to determine a possible correlation.

Model Builder

We created a Model Builder model that utilized tools in GIS to automate the *Threat Analysis*. We validated the outputs of the model by comparing the output with a manual run of the *Threat Analysis*. The model was divided into two sets of processes. The first model output creates a layer showing the overlap of threat and occurrences (Figure 7). The second model uses the output of the first model to calculate the area of each threat for each species (Figure 8).

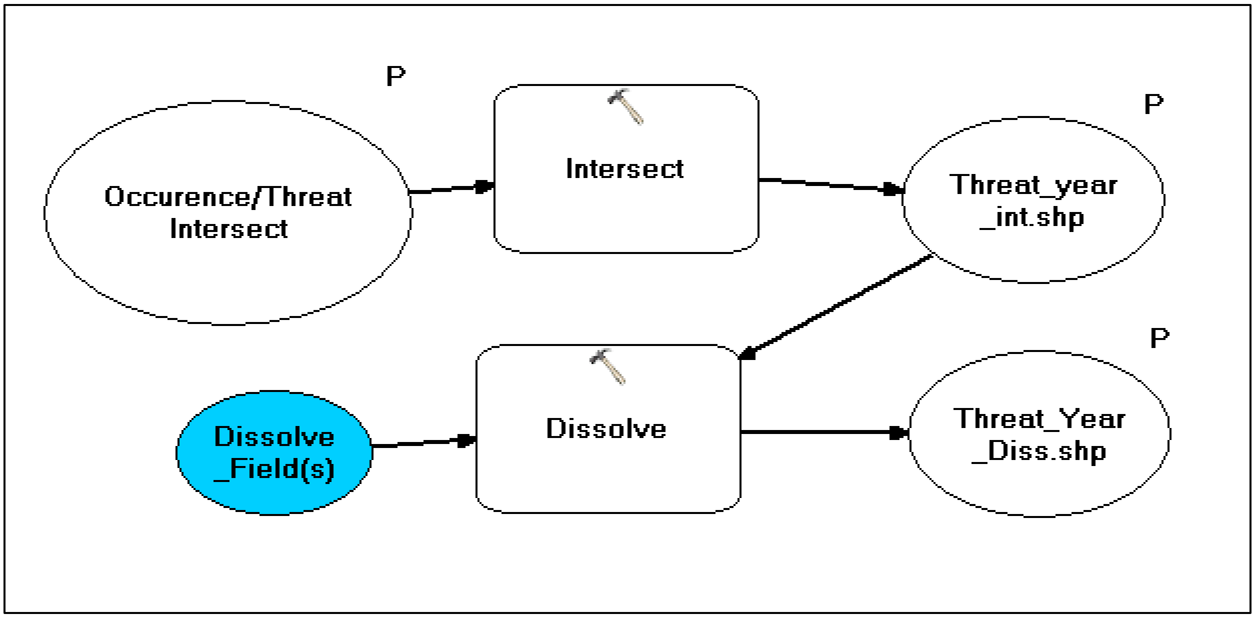

Figure 7: Model 1. This shows the first set of processes used with the model to overlay the occurrences with the threats.

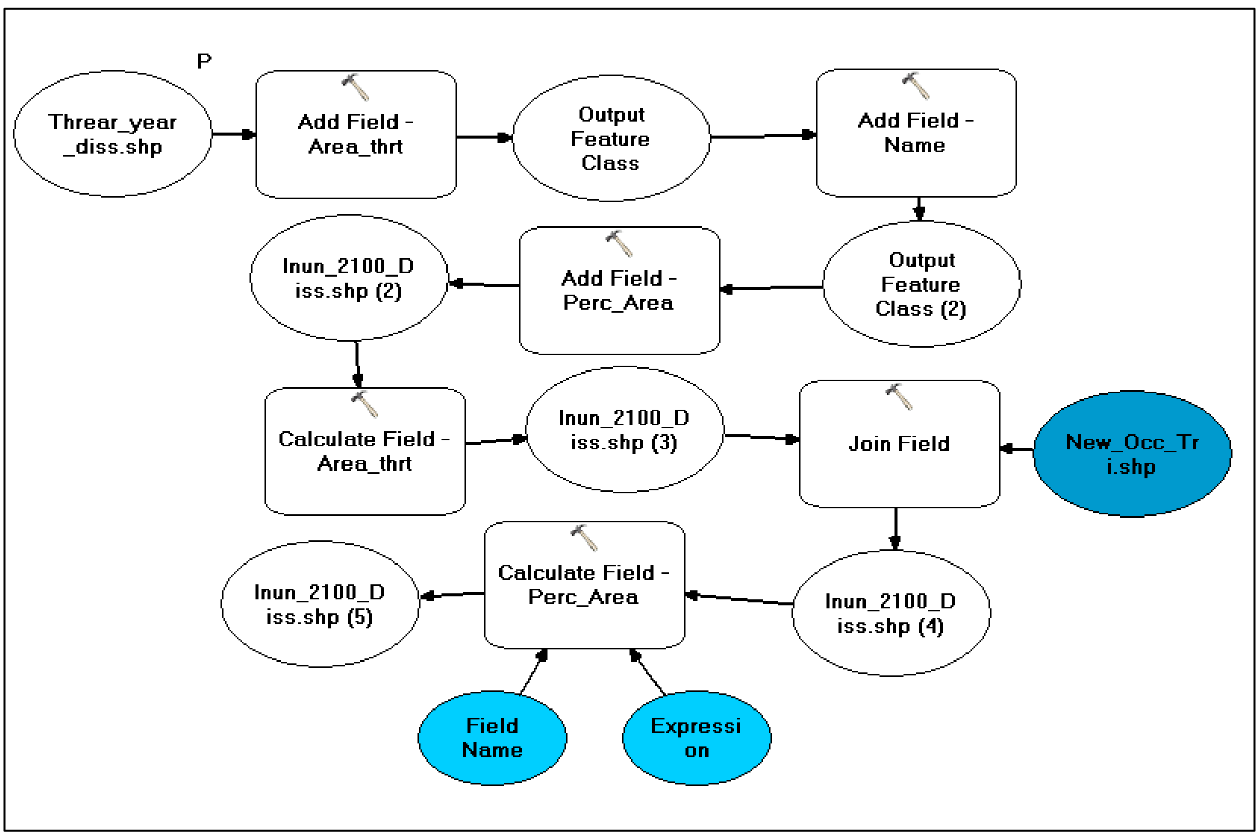

Figure 8: Model 2. This shows the second set of processes used to calculate the extent to which the threats intersected with the species occurrences.

VII. Results of SLR Analysis

<u>Analysis of SLR-Related Threats</u>

Exposure of Extant Occurrences to Each Threat

Inundation

Inundation proved to be an important threat to several of the nine species that we analyzed. When excluding occurrences that are presumed to be extirpated, four species were affected by inundation. The estimated loss in area due to inundation ranged from 0.3% to 65% for the different species, with the average loss at 19% of the known area occupied by each species.

On the level of individual species, *C. maritimum* was most threatened by inundation, with 65% of its total area affected by 2100 (Figure 9). The next most exposed species, *D. maritima*, was never affected at more than 10% of its area. Furthermore, the areas of *C. ambigua* and *C. scariosum* affected by inundation were less than 1% of their total area. It is also noteworthy that *C. scariosum* is only affected by 2100, not by the earlier time horizons.

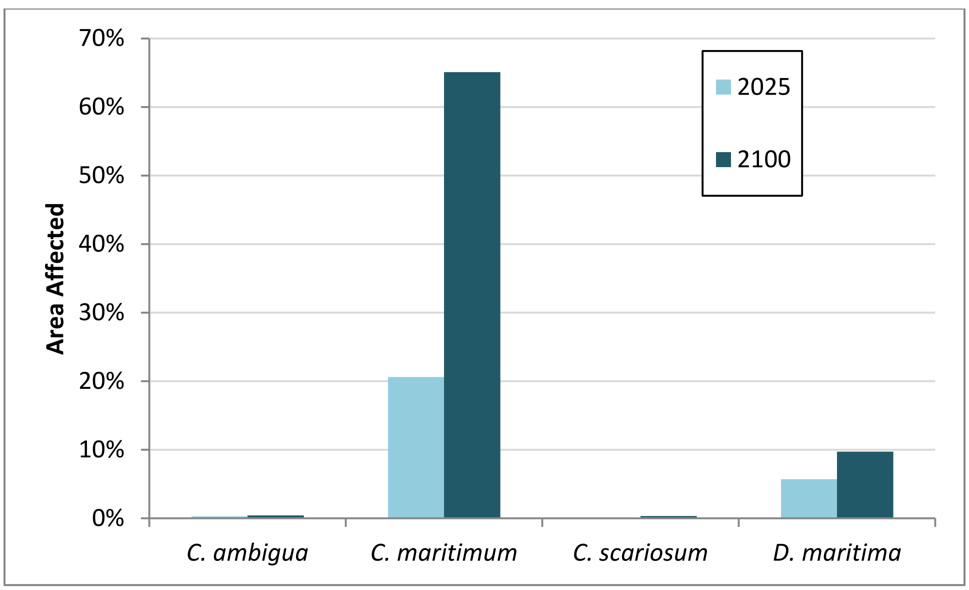

Figure 9: Percent area of presumed extant occurrences covered by regular inundation. *C. maritimum* experiences the highest level of threat with 20% of its area threatened by 2025 and 65% threatened by 2100. *C. ambigua* and *C. scariosum* are minimally threatened.

Flooding

As with the inundation results, our flood model projected that four out of nine species would be affected by any time horizon. In fact, the same four species that were affected by inundation – *C. ambigua, C. maritimum, C. scariosum,* and *D. maritima* – are also affected by extreme flood events. For these species, the percent area projected to be affected ranged from 3% to 86%, with the average area estimated to be affected was 33%.

The most worrisome results are for *C. maritimum*, for which 85% of its total area is affected as early as 2025 (Figure 10). *C. scariosum* and *D. maritima* are affected almost equally, with 20-25% of their total areas flooded by 2100. The least affected species, *C. ambigua*, is projected to have minimal impact from flooding.

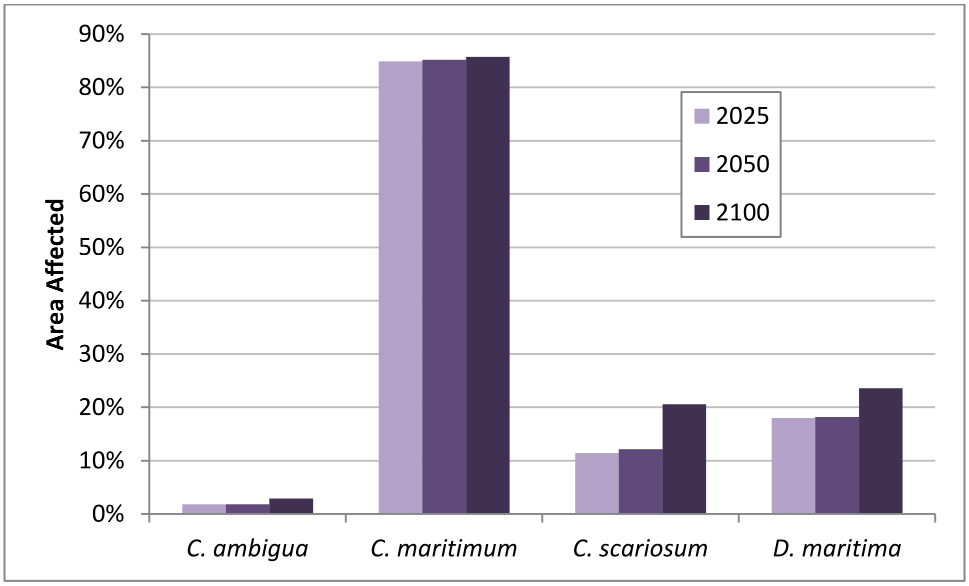

Figure 10: Percent area of presumed extant occurrences likely impacted by flooding. *C. maritimum* is threatened by 85% as early as 2025. The other three species are threatened to less than 25% of the area.

Dune Erosion

Our model predicted that dune erosion would affect only three out of nine species. In contrast to the inundation and flooding results, *C. ambigua* is not threatened by dune erosion; *C. maritimum, C. scariosum, and D. maritima* are affected. For these three species, the area projected to be affected ranged from 0.8% to 40% of their total area. The average area predicted to be affected in some way by dune erosion was 14%. Exposure to dune erosion means either total loss of the dune or a shift in its land mass.

Our model indicates that *D. maritima* is the species most threatened by dune erosion, with almost 40% of its total area eroded by 2100 (Figure 11). Furthermore, *D. maritima* is threatened by dune erosion as early as 2025, with greater than 30% of its total area exposed. The other two affected species (*C. maritimum* and *C. scariosum*) are projected to experience minimal impact.

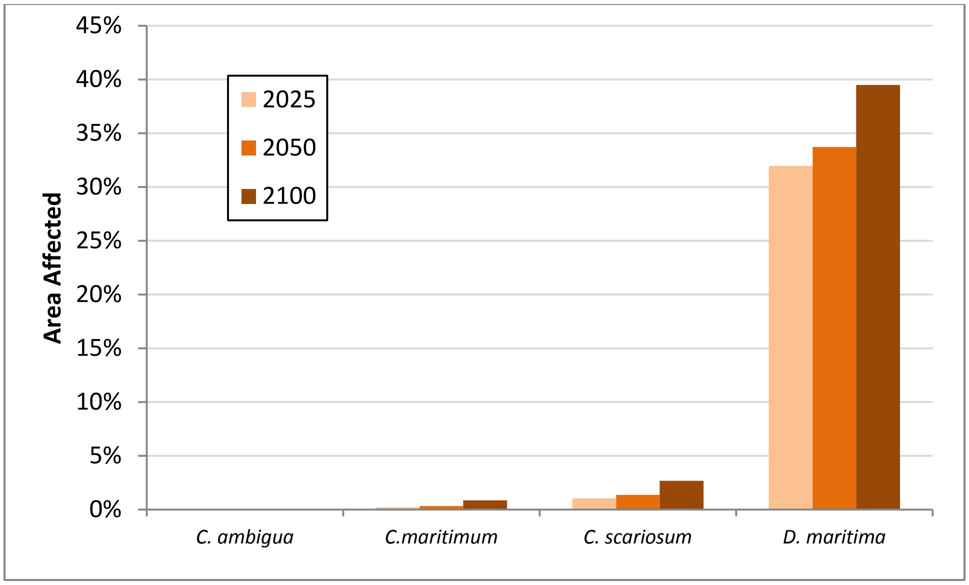

Figure 11: Percent area of presumed extant occurrences affected by dune erosion. Dune erosion only seriously threatens *D.maritima* at 35% of its area by 2025 and almost 40% by 2100.

Cliff Erosion

Cliff erosion proved to be a negligible threat to our set of nine coastal species. Only one species was affected – *D. maritima* – and the effect was on less than 0.15% of its total area (Figure 12). Considering dune and cliff erosion, this species is by far the most affected.

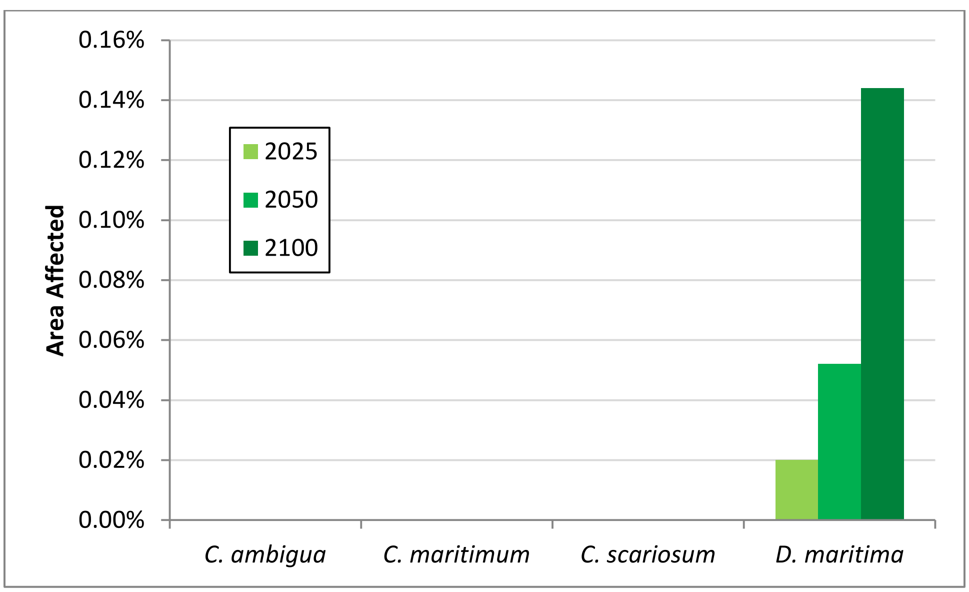

Figure 12: Percent area of presumed extant occurrences affected by cliff erosion. Cliff erosion only threatens *D. maritima* as the other three species affected by sea level rise are not cliff species.

Combined Threats

When examining the combined effect of the four threats related to SLR, four out of the nine species are affected to some extent by at least one threat. The percent area predicted to be affected by some SLR-related threat ranged from 3% to 92%, with an average predicted area of 42%.

The species most significantly threatened by sea level rise is projected to be *C. maritimum* (Figure 13). These threats to *C. maritimum* are immediate, as 85% of its total area is threatened by SLR as early as 2025. Moreover, the overall impact of SLR on *D. maritima* also increased dramatically between 2025 and 2100, to nearly 50% of its total area. A third species, *C. scariosum*, is projected to have less than 25% of its area affected by SLR by 2100. Of the four species affected, *C. ambigua* is the least concerning because less than 5% of its total area is threatened by 2100.

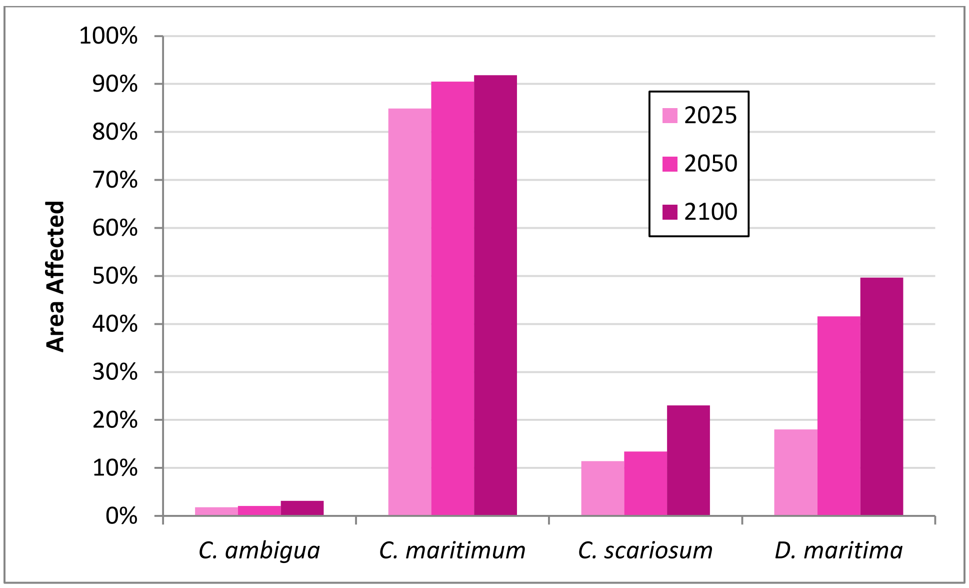

Figure 13: Percent area of presumed extant occurrences exposed to any SLR-related threat. *C. maritimum* and *D. maritima* are the most threatened of our sample of 9 species. *C. ambigua* is minimally threatened.

Species-Specific Results

C. maritimum (Salt marsh bird's beak):

The total area projected to be lost to SLR-related threats is 1.6 km^2, which represents 92% of the known presumed extant area. As can be seen in Figure 14, a majority of every single extant occurrence is threatened by SLR. This figure shows the area of each occurrence that will be exposed to any SLR-related threat, relative to each occurrence's total area.

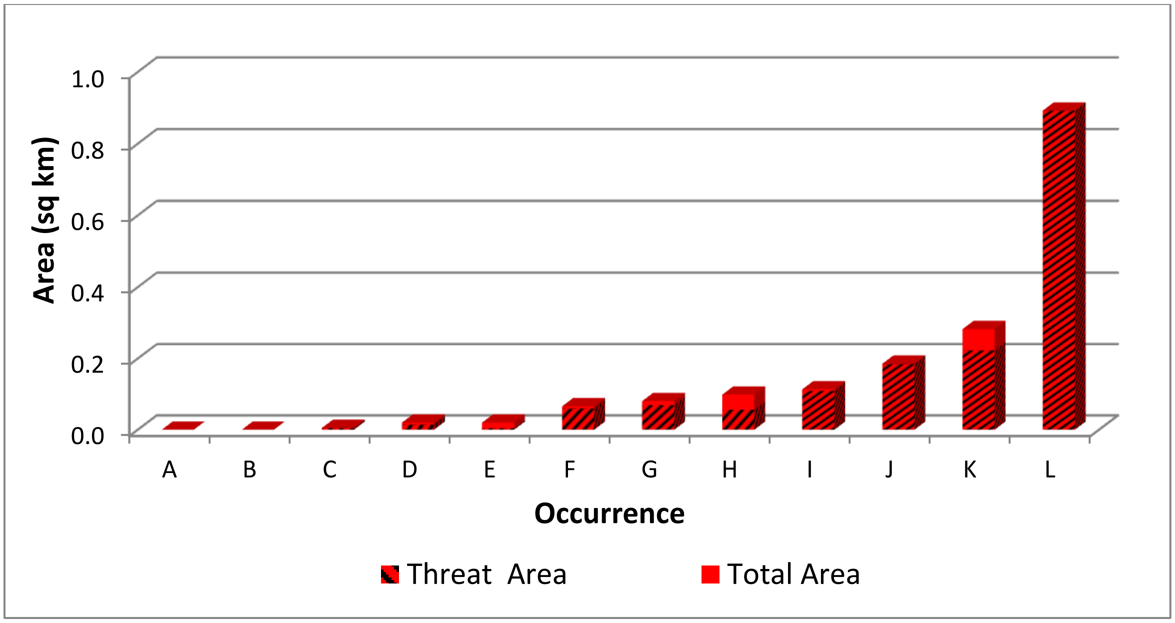

Figure 14: Relative threat to each occurrence for *C. maritimum* from all threats combined. The red columns represent the area of each occurrence for *C.* maritimum and the hatched red area represents the area that intersects with the sea level rise threats by 2100.

D. maritima (Beach shieldpod):

The total area predicted to be lost to SLR threats is 0.7 km^2, which represents 50% of the known presumed extant area. Only three occurrences are unthreatened (Figure 15). For most of the occurrences that are threatened, a majority of the area is at risk.

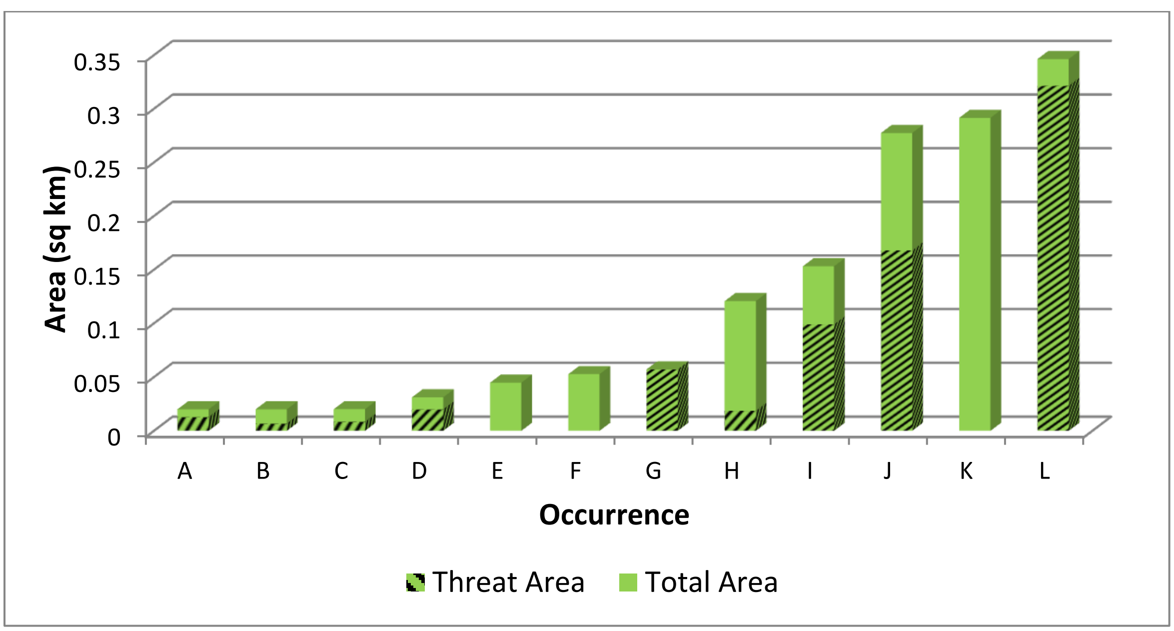

Figure 15: Relative threat to each occurrence for *D. maritima* from all threats combined. The green represents that area of each occurrence for *D. maritima* and the hatched green area represents the species area that intersects with the sea level rise threats.

C. scariosum (La Graciosa thistle):

The total area projected to be lost to SLR-related threats is 0.5 km^2, which represents almost 25% of the presumed extant area. SLR is not projected to impact a sizable fraction of current known occurrences given that only two occurrences are threatened, and only to a relatively small fraction of the total area (Figure 16). Nonetheless, *C. scariosum*'s largest occurrence may experience a sizable threat; but it is worth noting that this occurrence is relatively very large, so both the occurrence and its threatened area may not be entirely accurate.

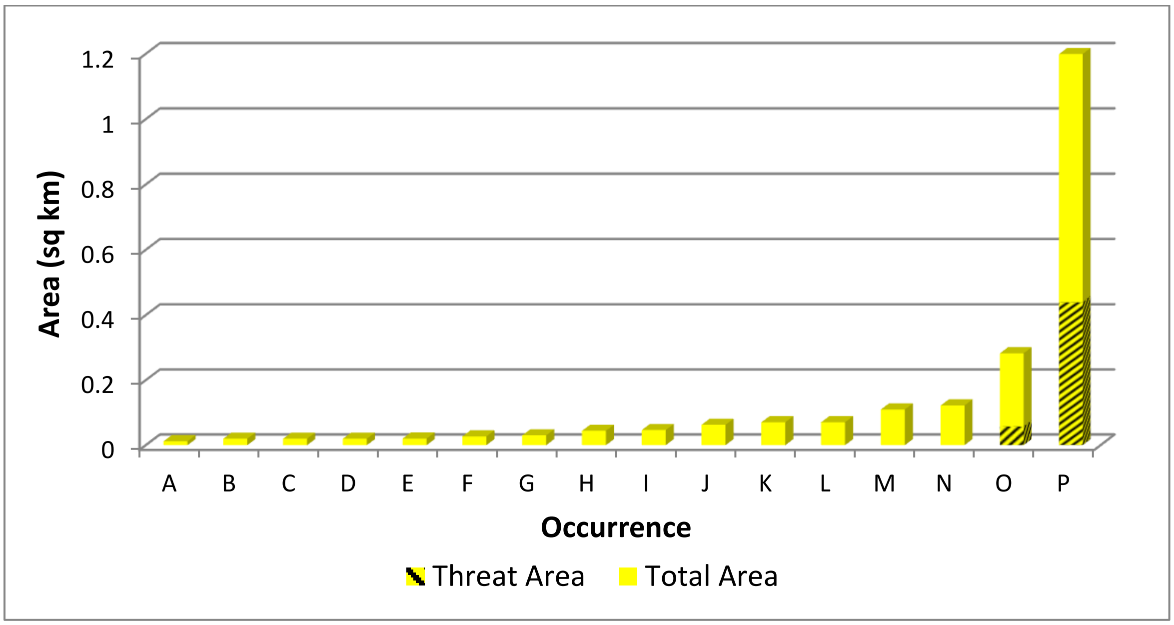

Figure 16: Relative threat to each occurrence for *C. scariosum* from all threats combined. The yellow bars represent the occurrence areas for *C. scariosum* and the hatched yellow areas are the areas where sea level rise intersects with the species.

C. ambigua (Johnny Nip):

The total area projected to be lost to SLR-related threats is 0.06 km^2, which represents only 3% of the known presumed extant area. Combined, each threat affects all of the occurrences, but only to a very small extent (Figure 17). Given the disparity in the threat area and the threat to occurrences, our model does not provide any guidance on the true relative threat. If our model underestimates sea level rise threats, then greater than 3% of the area is likely to be lost.

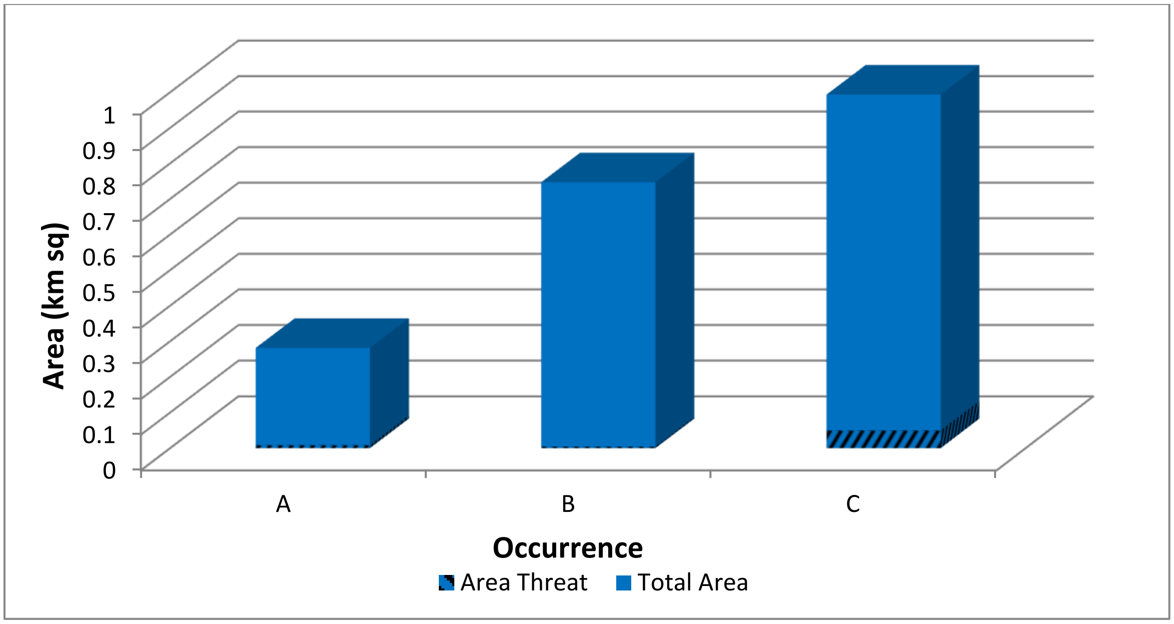

Figure 17: Relative threat to each occurrence for *C. ambigua* from all threats combined. The blue bars represent the occurrence area for *C. ambigua* and the blue hatched areas represent the intersection of the sea level rise threats with the species.

Comprehensive Threat Results

We created bubble graphs showing the percent area threatened for our four species against the number of occurrences unaffected for each species. The bubble graphs are designed such that the highest threat is indicated by top-right quadrant. The x-axis is the percent area threatened, so that the greater the area threatened, the more concern there is for that species. The bar graph data from Figures 9 – 13 are now shown on the x-axis. The y-axis is flipped, showing occurrences unaffected, so that the top of the axis indicates greater concern. If the shape is at the bottom left of the graph, it means that the species is not threatened.

In the bubble graphs, the relative size of the shape indicates percent of occurrences threatened, so that the larger the shape, the greater the threat. The four shapes indicate the different species threatened by SLR in our model. The colors indicate the three time horizons.

For inundation, we can see that the *C. maritimum* is most threatened for each time horizon (Figure 18). *C. scariosum* is not threatened until 2100, and most occurrences are unthreatened at that. For *C. ambigua*, most occurrences are threatened but only to a small extent.

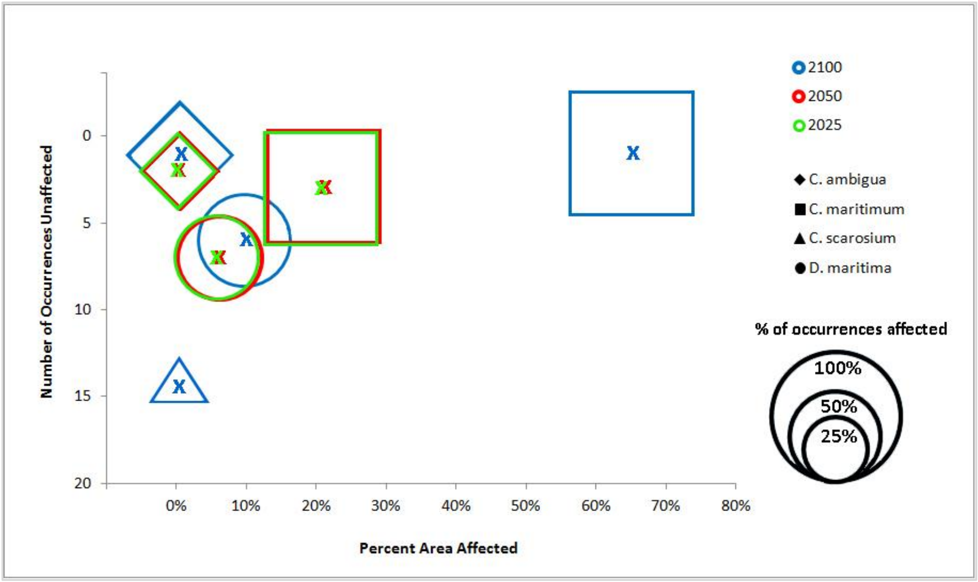

Figure 18: Inundation threat to affected species for all time horizons. The x-axis represents the percent area affected, the y-axis represents the number of occurrences unaffected, the colors represent the time horizons, the shapes represent the different species, and the size of the shape represents the extent to which the occurrences are threatened. So the larger the shape and the closer to the top right side of the graph the more threatened the species. This graph shows that *C. maritimum* is most threatened by inundation. *C. ambigua* is only threatened in the sense that all of its occurrences are affected by sea level rise, though the percent area threatened is minimal.

For flooding, *C. maritimum* is significantly threatened as early as 2025 (Figure 19). For *C. ambigua*, none of the occurrences are unaffected. In other words, most of the occurrences for *C.* ambigua in 2025 and 2050, and all in 2100 are threatened. However, the percent area threatened is small for all three time horizons. The species *C. scariosum* and *D. maritima* are least threatened.

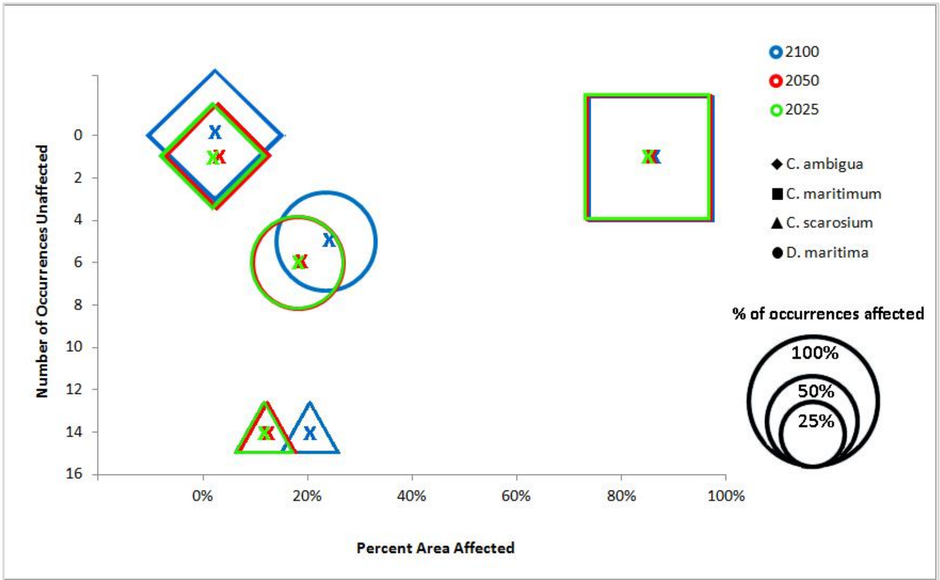

Figure 19: Flood threat to affected species for all time horizons. This graph shows that *C. ambigua* is threatened as early as 2025 by flooding. While each occurrence of *C. ambigua* is threatened, its percent area threatened is minimal. *C. scariosum* and *D. maritima* are less threatened.

Only three species are threatened by dune erosion, and of these, only the *D. maritima* is highly threatened, as can be seen by its location in the top right corner (Figure 20). The other two species, *C. maritimum* and *C. scariosum*, are minimally threatened.

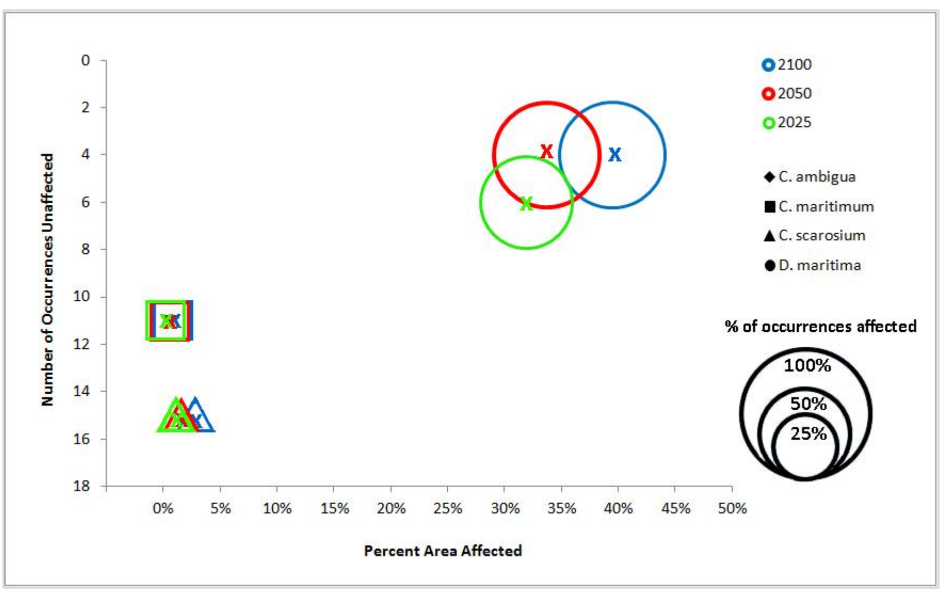

Figure 20: Dune erosion for affected species for all time horizons. Only three species are threatened by dune erosion. *D. maritima* is most threatened. *C. ambigua* and *C. scariosum* are minimally threatened. *C. maritimum* is not threatened by dune erosion.

Only one species is threatened by cliff erosion: *D. maritima* (Figure 21). While it may appear to be somewhat threatened in regards to percent area affected in 2100, given the scale of the graph, it is not seriously threatened by cliff erosion.

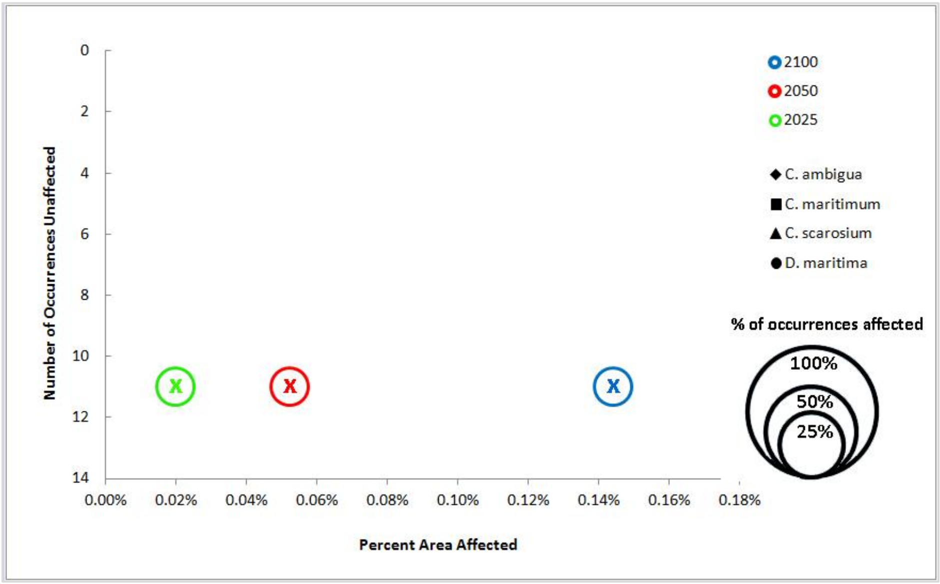

Figure 21: Cliff erosion threat to affected species for all time horizons. Only *D. maritima* is threatened by cliff erosion and it is only minimally threatened, both in area and number of occurrences.

For all threats combined, *C. maritimum* (top right) is most threatened, followed by *D. maritima* (middle) and *C. ambigua* (top left), while *C. scariosum* (bottom left) is least threatened (Figure 22).

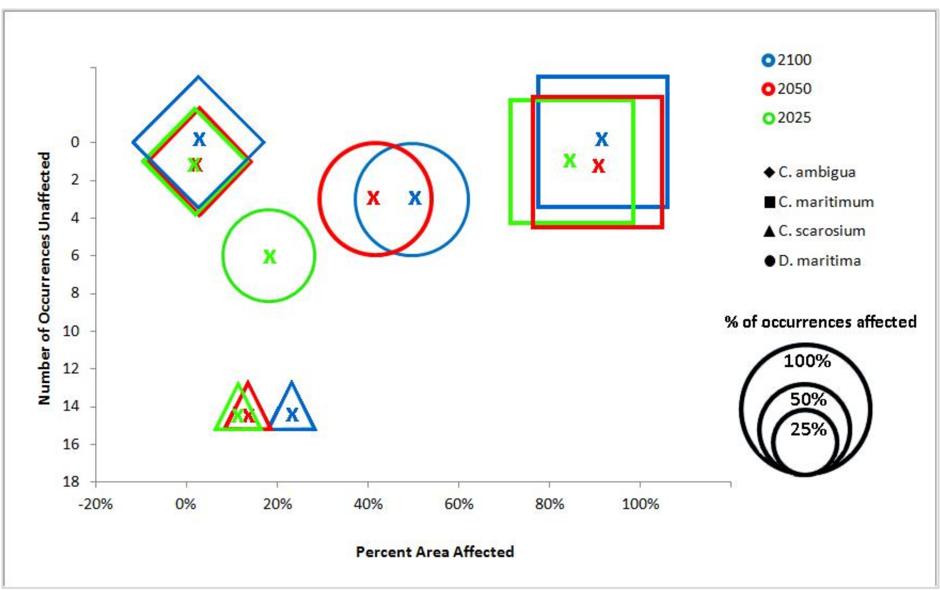

Figure 22: All threats combined to affected species for all time horizons. This shows the combination of all threats on each species. *C. maritimum* is the most threatened species.

Comparison of Threat Extent to Extant and Extirpated Occurrences

For the species with extant occurrences threatened (*C. maritimum*, *C. scariosum*, and *D. maritima*), there is a slight bias toward extinction of extant sites as a result of SLR. This is because on average, the threat to extirpated sites is lower than extant sites (Figure 23). For the fourth species that has extant occurrences threatened, *C. ambigua*, there is no threat from SLR to the extirpated occurrences (Figure 23). This tells us that the threat from SLR is probably relative insignificant for this species.

There is a set of species for which all potentially threatened occurrences have already been extirpated (*A. paludicola*, *A. pycnostachyus*, and *N. gambelii*) (Figure 23). This suggests that for some species, either coastal development was the cause of extirpation or SLR has already impacted these species. There are two species that are not threatened at all, whether by extant or extirpated occurrences (*L. nipomensis* and *S. maritima*) (Figure 23).

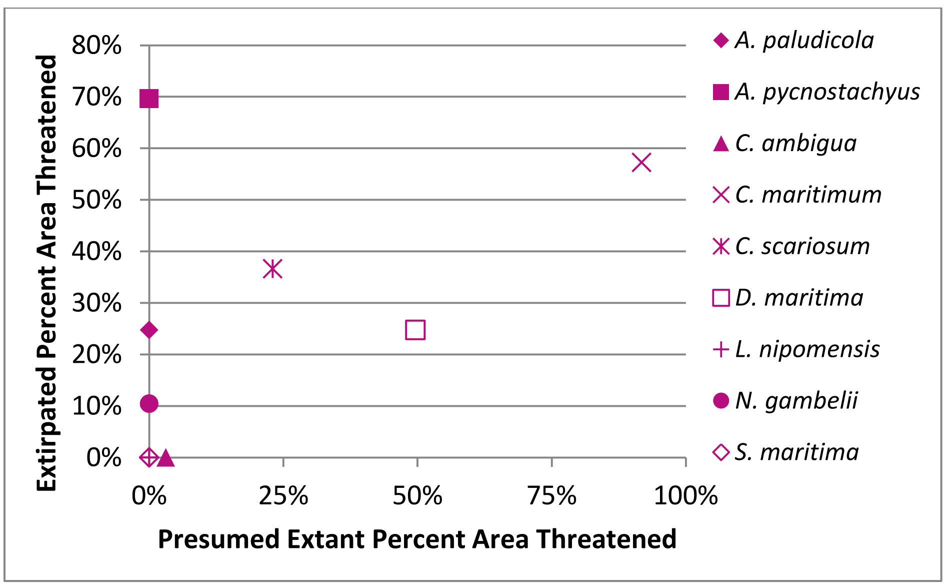

Figure 23: Comparison of threat to extant and extirpated occurrences for all threats combined. This graph shows that most of the species presumed extant occurrences that are not threatened by sea level rise are threatened when looking at the extirpated occurrences. For the species where the presumed extant occurrences are threatened, most also have extirpated occurrences that are threatened by sea level rise.

This pattern (above) generally holds when we look at each SLR threat individually (Figure 24). The percent area for extant occurrences increases more rapidly than for extirpated occurrences for inundation and dune erosion. This means that the presumed extant occurrences are more likely to be threatened by inundation and dune erosion than the presumed extirpated occurrences. Flooding is less biased towards extirpation of extant occurrences than extirpated occurrences. According to our data, cliff erosion is a negligible threat to our set of nine species including both extant and extirpated occurrences.

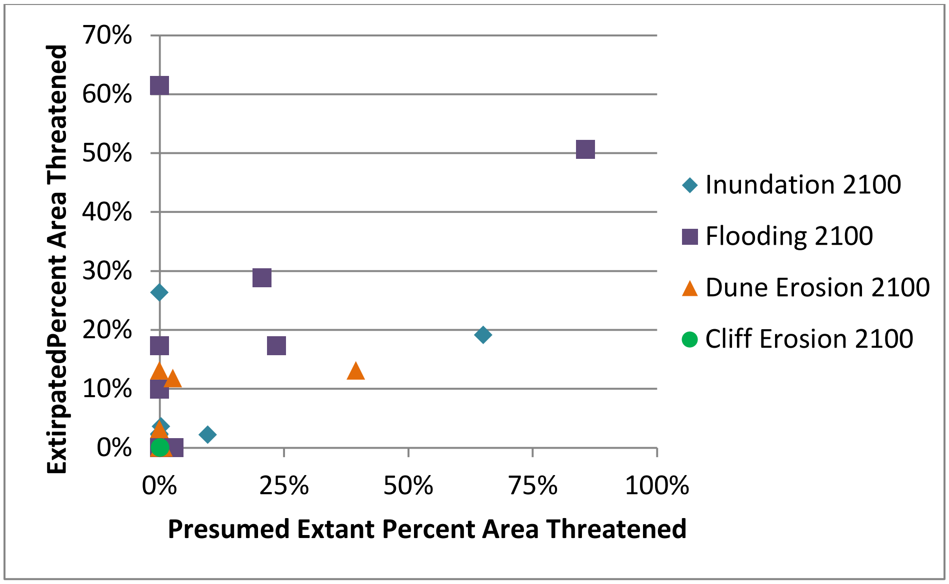

Figure 24: Comparison of exposure of extant and extirpated occurrences to each SLR threat. This graph shows that flooding is somewhat more likely to occur on extirpated occurrences than inundation and dune erosion (which are more likely to occur on presumed extant occurrences).

Trend Identification for 88 Species

The output of the logistic regression on all 88 species indicates that the probability of threat significantly correlates with the average elevation for each species. All threats show a negative trend where the odds ratio decreases with increasing elevation. The slope of the logistic regression varies for each threat.

The threat of inundation significantly correlates with species' elevations ($p = 2.51 \times 10^{-14}$) (Figure 25-A). The odds ratio decreases by 11.4% with every meter increase in elevation. This tells us that beyond approximately 30 meters in elevation, there is no threat of exposure to inundation.

The threat of flooding significantly correlates with species' elevations ($p = 0.04225$) (Figure 25-B). The odds ratio decreases by 8.2% with every meter increase in elevation. This tells us that beyond approximately 50 meters in elevation, there is no threat of exposure to flooding. This also fits well with the inundation results, which indicates that the threat of flooding by 2100 likely covers an additional 20 meters in elevation beyond inundation.

The threat of dune erosion significantly correlates with species' elevations ($p = 0.0022$) (Figure 25-C). The odds ratio decreases by 5.2% for every meter increase in elevation. This tells us that beyond approximately 55 meters in elevation, there is no threat of exposure to dune erosion. It is somewhat surprising that the maximum threat elevation for dune erosion is actually greater than it is for flooding. This appears to be because there are a handful of outliers that are at higher elevations (40 – 60 meters) and threatened by dune erosion. Without these, the probability curve would presumably be shifted to lower elevations. This may be a result of how we measured elevation for each occurrence.

The threat of cliff erosion significantly correlates with species' elevations (p = 0.0016) (Figure 25-D). The odds ratio decreases by 2% for every meter increase in elevation. This tells us that beyond approximately 150 meters in elevation, there is no threat of exposure to cliff erosion. There are a handful of outliers that influence the slope of this logistic regression analysis, which results in an overestimate of the probability of exposure at higher elevations. Like with dune erosion, this is likely because of how we measured the elevation of each occurrence.

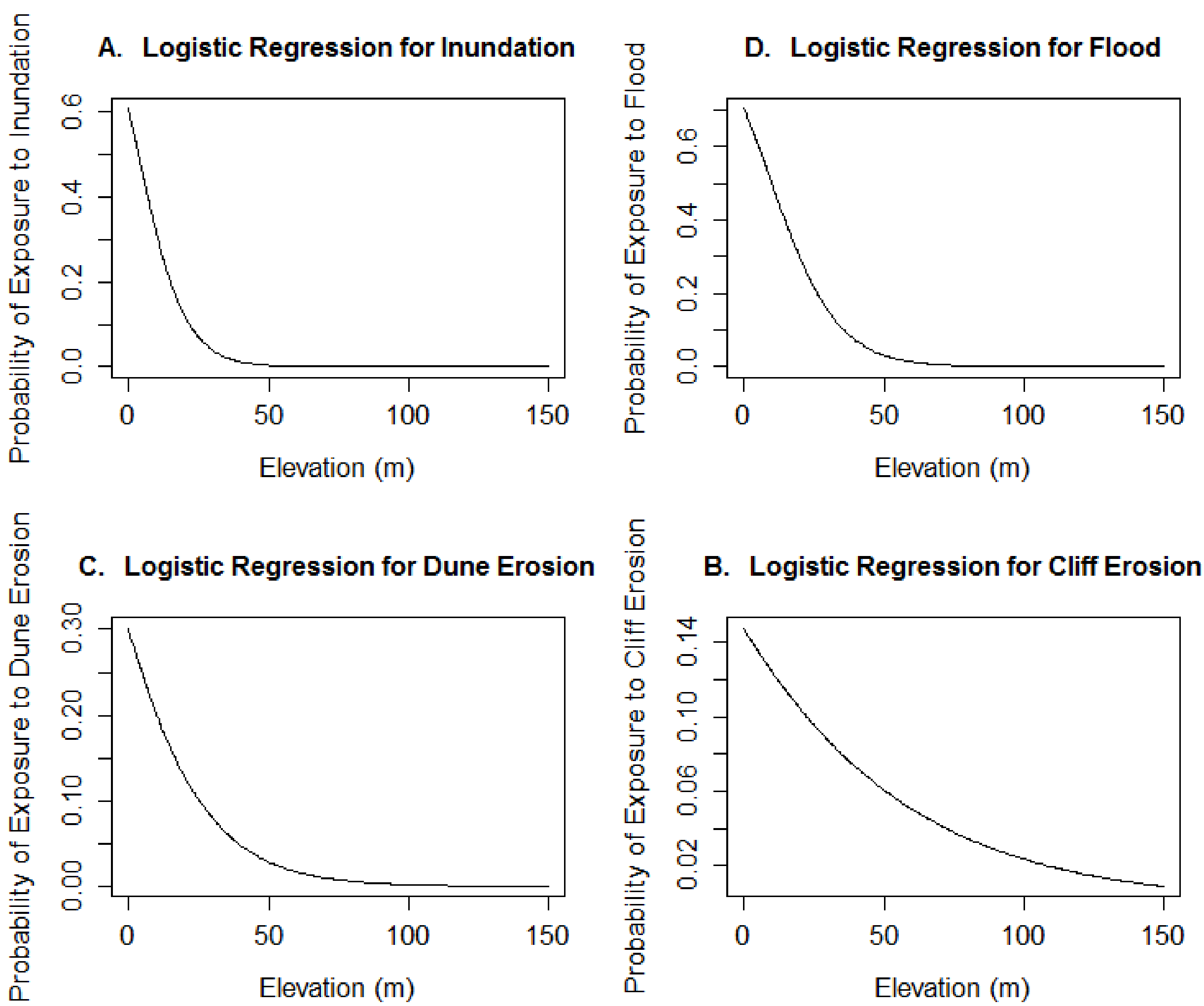

Figure 25: Logistic regression output. This shows that the inundation and flooding have a higher probability of occurring for species at lower elevations than dune and cliff erosion. This also shows that the probability of threat from inundation is negligible beyond 30m, for flooding beyond 50m, for dune erosion beyond 65m, and for cliff erosion there is still a small probability of threat at up to 15m.

The table below shows the statistical output of the logistic regression graphed above (Figure 25).

Table 2: Logistic regression statistics

	Estimate	St Error	Z value	P Value
Elevation by Inundation	-0.121	0.0159	-7.622	2.51e-14
Elevation by Flooding	-0.086	0.0094	-9.135	2e-16
Elevation by Dune Erosion	-0.054	0.0089	-6.000	1.97e-09
Elevation by Cliff Erosion	-0.020	0.0047	-4.150	3.33e-05

VIII. Methodology for Suitable Habitat Analysis

Overview

After generating the results of our SLR threat analysis, we conducted a supplementary analysis to consider the additive effect of climate change on coastal plant species. For this additional analysis, we selected as a case study the species that was most exposed to SLR in our initial set of nine species – *C. maritimum* spp. *maritimum*. We examined the effect of climate change on *C. maritimum* by modeling its future suitable habitat in MaxEnt, based on its current location data and six environmental variables. We then compared the projected distributions of current and future suitable habitat. After modeling in MaxEnt, we quantified how the interaction between SLR and shifts in climate will affect the total amount of suitable habitat in the Tri-County Area that will be available to the species in the future.

Location Data

We used 27 georeferenced, presence-only occurrence records of the species. In order to make strong predictions for the relationships between location data and environmental variables, MaxEnt must account for the entire range of a species. Thus, we included extirpated occurrences, as well occurrences located outside of the Tri-County Area and across California. Expanding the set of occurrences to the entire state had the added benefit of increasing our model's statistical validity, since *C. maritimum* has only 12 occurrences in the Tri-County Area.

Environmental Data

In addition to location data, we used environmental variables to build the MaxEnt model. The environmental inputs were in the form of ASCII raster grids with consistent cell size resolutions. We formatted the grids and location data to have the same geographic bounds and spatial projection (North American Datum 1983 Albers).

We chose 6 environmental inputs consisting of 4 bioclimatic and 2 edaphic variables:

• Mean Diurnal Range	(Mean(period max-min))
• Annual Precipitation	(mm)
• Growing Degree Days Above 5^{o}C	(cum. Temp.)
• Aridity Index	(X100)
• Soil pH	
• Available Water Holding Capacity	

We obtained environmental variables for the current time frame from the Parameter-elevation Regressions on Independent Slopes Model (PRISM) Climate Group at Oregon State University.

We chose these variables because they represent general climatic trends and seasonality, which are considered relevant to the physiological function of plants (Woodward, 1987). Mean diurnal range represents the temperature seasonality of a region. It is defined as the difference between each month's maximum and minimum temperatures, averaged over a year. Annual precipitation, defined as the sum of all monthly precipitation estimates, is an important factor in plant survival. Growing degree-days refers to the heat threshold required for plants to thrive and mature (Grigorieva et al., 2010). This variable is the average of the minimum temperature and maximum temperature for a day subtracted by 5^{o}C, then summed across a year. This value is the theoretical threshold below which plants cannot grow.

The aridity index was calculated by United Nations Environment Program (Middleton and Thomas, 1992) and is an indicator of the degree of dryness of a climate within a given area. It is calculated by dividing the annual precipitation by the potential evapotranspiration. While our model also includes annual precipitation, the aridity index accounts for the relationship between precipitation and transpiration related to plant physiology.

Soil pH and available water-holding capacity are two important non-climatic variables that affect the physiological function of plants. Both variables describe the biochemical environment of the vadose zone, from which plants draw water and nutrients essential to their survival.

In addition current values for our environmental inputs, we accounted for future projections of these inputs. Thus, we obtained projections of the six variables detailed above from general circulation models (GCMs) under the IPCC A2 emissions scenario. Due to the large variability in long-range climatic predictions for 2100, we chose two GCMs that predicted different future scenarios for California: the NOAA Geophysical Fluid Dynamics Laboratory Model (GFDL) and the Parallel Climate Model (PCM). The GFDL climate model predicts a hotter and drier California, while the PCM climate model predicts a warmer and wetter state (Cayan et al., 2008b). We obtained downscaled environmental data from the two GCMs at a grid size of 90-meter resolution. The time horizon for this data is centered on 2085, representing an end-of-century, 30-year average (Flint and Flint, 2012). For our purposes, we refer to this time horizon simply as 2100.

After inputting the location data and current environmental variables, we calibrated the MaxEnt model. We used the default value settings suggested by Philips et al. (2006). We retained 33% of the occurrence records at random in order to evaluate the model (testing). The rest of the occurrence records were used to build the MaxEnt model (training). We set the number of replicates to 10. To eliminate possible sources of bias in selecting test samples, we selected "crossvalidate" under the setting of Replicate Run-type. This cross-validation is especially important for running MaxEnt with small numbers of occurrence records, since small test samples naturally increase the likelihood of choosing a test sample that is not distributed evenly across all of the occurrence points.

Model Validation

After inputting our current and future data, we ran the model and tested the goodness-of-fit from our results based on the testing samples that we set aside. To evaluate model performance, we had MaxEnt draw a receiver operating characteristic (ROC) curve based upon two terms, sensitivity and specificity, that describe how well the model predicts presence or absence of suitable habitat. Sensitivity indicates how well the model predicts presence, while specificity indicates how well the model predicts absence.

We measured the quality of the model's performance by calculating the area underneath the ROC curve (referred to as the AUC) (Philips et al., 2006). The AUC produced a single number between 0 and 1, in which a higher AUC indicates a better model fit. Our model's average AUC among the ten replicates was 0.978 and the standard deviation was 0.041, indicating that the projected distribution of *C. maritimum* ssp. *maritimum* is relatively well described by our environmental inputs.

Manipulating Presence/Absence Data

MaxEnt produces a continuous map of the probability of species presence in which each cell contained within the map corresponds to a presence probability between 0 and 1. As probability increases, the likelihood that the area is suitable for the species is higher, according to the model. For our purposes, we converted the probability of species presence into binary presence/absence maps, in order to compare current and future suitable habitat projections and how the SLR threats will overlap with these projections.

Converting continuous values into binary presence/absence entailed adopting an optimal probability threshold. Probabilities that fell below this threshold indicated the absence of suitable habitat, whereas probabilities that fell above the threshold indicated presence of suitable habitat. Traditionally, the threshold probability between presence and absence has been set at 0.5 (Li et al., 1997). Recent evidence, however, has suggested that minimizing the difference threshold between sensitivity and specificity was found to be a more accurate predictor of species presence (Jimenez-Valverde and Lobo, 2007).

To set our probability threshold, we minimized the threshold between sensitivity and specificity by averaging values of the "Equal test sensitivity and specificity logistic threshold" column from the table, maxentresults.csv output. We found the average probability to be 0.39.

Inclusion of SLR Threats

After calculating the probability threshold, we created binary presence/absence maps in GIS in the form of polygons. Maps were created for present-day projections using the PRISM GCM MaxEnt output, as well as for two versions of 2100 using the GFDL and PCM outputs. We manually classified the presence and absence categories into two ranges: all cells below 0.39 indicated species absence, while cells between 0.39 and 1 indicated species presence. The same threshold level was used to visualize the results for each current and future MaxEnt output. Within each binary presence/absence map, we calculated the area of presence data (all cells between 0.39-1) in GIS to compare the relative gain or loss in habitat between the current and future scenarios.

To gain a more comprehensive view of how both climate change and SLR will affect suitable habitat, we quantified the relative impact of SLR on suitable habitat. For the PRISM model's binary presence/absence map, we overlaid a combined threat layer which represented the extent of inundation, flooding, as well as cliff and dune erosion for 2025. For the 2100 scenarios, combined threat layers projected for 2100 were overlaid onto MaxEnt's GFDL and PCM outputs. This analysis was performed only for the Tri-County Area, because the extents of the threats layers were limited to this region. Areas of intersection between suitable habitat and the threats zone represented areas that were no longer suitable habitat for the species. For each of the scenarios, these areas were calculated as a percent decrease in the total amount of suitable habitat found.

IX. Results of Suitable Habitat Analysis

MaxEnt's output provides presence probability maps which indicate future suitable habitat (Figure 26). Shown below is the MaxEnt output for *C. maritimum*. We only ran MaxEnt for this species as it was most threatened under our SLR analysis.

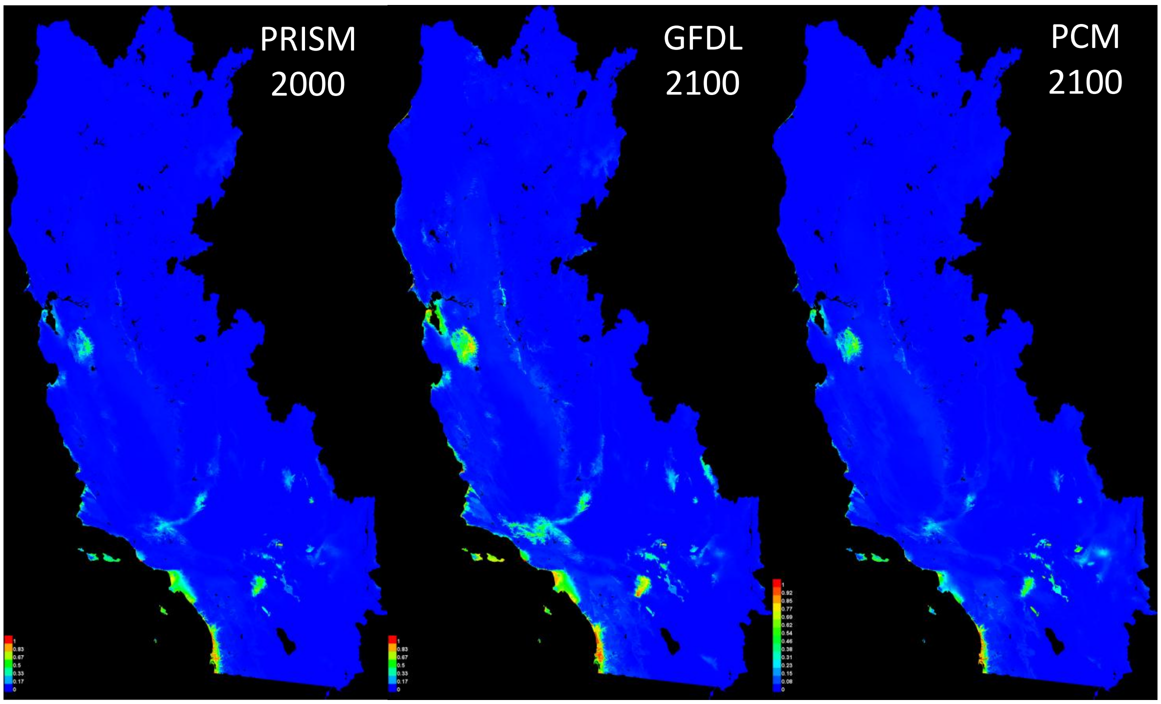

Figure 26: Spatial distribution of suitable habitat predicted by MaxEnt simulations. The red/yellow/green areas represent suitable habitat and the blue areas represent unsuitable habitat for the present day and the two 2100 climate models for *C. maritimum*.

Blue hues indicate a low probability of presence (0-0.25). Green and yellow hues indicate a medium presence probability (0.25-0.85). Red and orange hues indicate a high presence probability (0.80-1).

<u>Current Suitable Habitat Results</u>

The presence-probability map illustrating *C. maritimum's* current projected range (Figure 26 - PRISM 2000) depicted most suitable habitat to be located along the coast. Areas with the highest probabilities of occurrence directly abutted the shore, with decreasing probabilities of presence extending inland of those high probability areas. Areas with the largest concentrations of presence probabilities above the optimal threshold (0.39) were found predominantly in Southern California. More specifically, areas indicating presence that extended the farthest inland from the shore were located near Southern Los Angeles, Huntington Beach, and San Diego. However, with the exception of San Diego, these areas generally did not have the highest probability levels. Areas with the highest probability of presence (above 0.70), were found at Port Hueneme, the Channel Islands, and Del Mar and Mission Bay region shorelines of San Diego county. The only region found to have a high range of presence probability north of these regions was Morro Bay.

Several patches of suitable habitat were also found in inland regions far from the coastline. These regions are less likely to provide realistic, suitable habitat for the species due to known habitat characteristics that *C. maritimum* requires, notably marshland habitat.

Future Suitable Habitat

The GFDL model predicts a notable increase in the total amount of suitable habitat available to *C. maritimum* in 2100 (Figure 26 – GFDL 2100). This increase in future suitable habitat built outward from the regions identified as current suitable habitat in the PRISM model. Overall, areas that formerly represented mid-range presence probabilities in the PRISM scenario increase to higher probabilities by 2100. Morro Bay, Port Hueneme, and the shores of Del Mar and Mission Bay in San Diego County increased their presence-probabilities to 1.0, indicating a 100% prediction of suitable habitat. The shores of Vandenberg Air Force Base, South Los Angeles, Huntington Beach, and the Channel Islands, which previously contained presence probabilities between 0.20 and 0.50, increased to probabilities of over 0.80. New patches of suitable habitat with presence probabilities exceeding 0.80 were also found in the San Francisco Bay area, Point Reyes, and Bodega Bay.

The PCM model, however, predicts a slight decrease in the total amount of suitable habitat available to *C. maritimum* in 2100 (Figure 26 – PCM 2100). Regions previously identified as having concentrated presence-probabilities in the PRISM model shrank in overall size and extent inland. Port Hueneme and the shores of Del Mar and Mission Bay in San Diego County are the only regions that experience presence-probabilities above 0.80. The shores of Point Reyes, the San Francisco Bay area, Morro Bay, Vandenberg Air Force Base, South Los Angeles, Huntington Beach, and the Channel Islands, previously identified as highly suitable in the GFDL projections, decreased to lower presence probabilities between 0.40 and 0.77. In addition, the PCM predicts that large valley regions located directly inland of the coast will increase their presence probabilities from predictions of 0.0 at present to 0.08 by 2100, although this finding of inland habitat may be unrealistic.

Quantified Area of Total Suitable Habitat

In addition to providing a spatial representation of the distribution of suitable habitat that C. maritimum is predicted to have in the future, the total area of suitable habitat for each scenario was also calculated based on presence above the optimal threshold of 0.39. Figure 27 shows the total amount of suitable habitat predicted for C. maritimum within the entire state of California for each emissions scenario: PRISM (present-day), GFDL (2100), and PCM (2100). For the PRISM model, MaxEnt predicted a total area of 2,842km^2 as suitable habitat. This amount increased to a total of 7,170km^2 in the GFDL model simulation, representing a 252% increase in total area predicted for 2100, compared to the predicted present-day area. By contrast, the PCM model predicted a total area of 2,630km^2 by 2100, decreasing the amount of suitable habitat predicted by the PRISM model by 7%.

However it is important to note that despite the large difference in predicted suitable habitat from the two future climate projections, the suitable habitat does not seem to be shifting far away from the projected current suitable habitat of *C. maritimum*. This indicates that there will be some level of suitable habitat remaining in these areas for the species in the future. It is merely a matter of expansion or contraction of suitable habitat around current suitable habitat depending on the climate projection used.

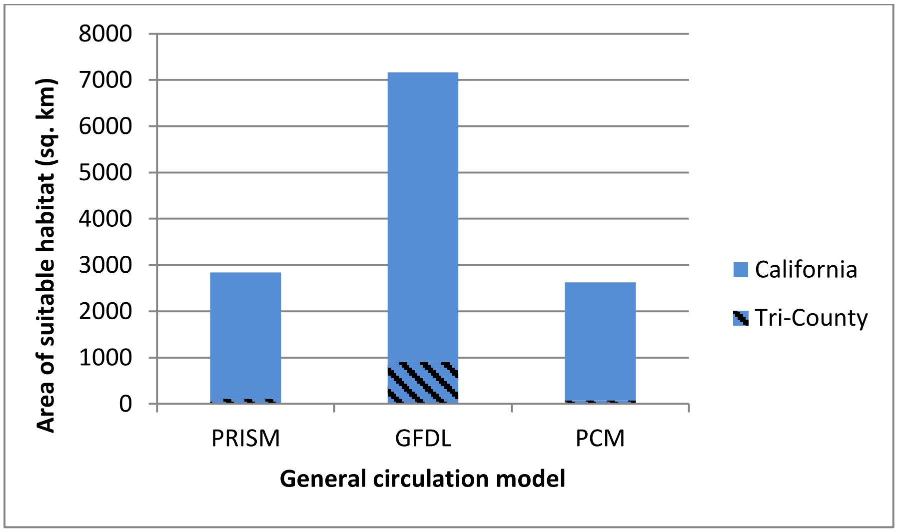

Figure 27: Area of suitable habitat predicted by MaxEnt simulations. This graph shows the total area predicted for the species within California (blue bars) and the extent of this area located within the Tri-County area (blue-hatched).

Figure 28 shows the MaxEnt output when converted to binary presence/absence map using an optimal threshold of 0.39. The colored areas represent suitable habitat for the three scenarios.

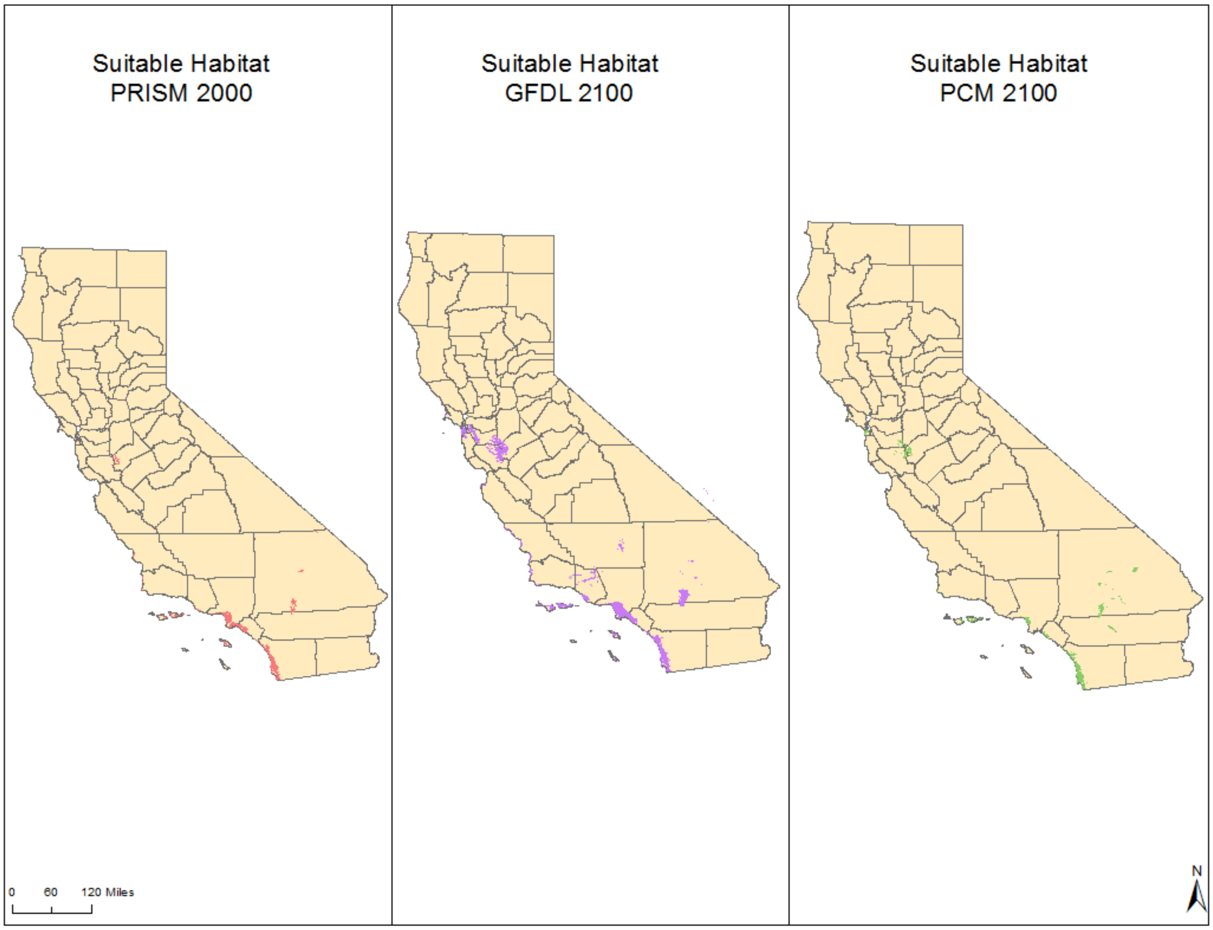

Figure 28: Presence of suitable habitat above threshold of 0.39 probability. The red areas on each map represent this suitable habitat for *C. maritimum*.

In order to link the MaxEnt suitable habitat simulations to our earlier SLR threats analysis, the total area of suitable habitat found within the Tri-County Area was calculated and overlaid with a combined SLR threats layer. In Figure 29, the percentage of suitable habitat in California that falls within the Tri-County Area is depicted by the lighter-hued portions of the larger pies. The pies to the right represent suitable habitat inside the Tri-County Area. Darker-hued portions of the latter pies indicate the proportionate effect of SLR on suitable habitat.

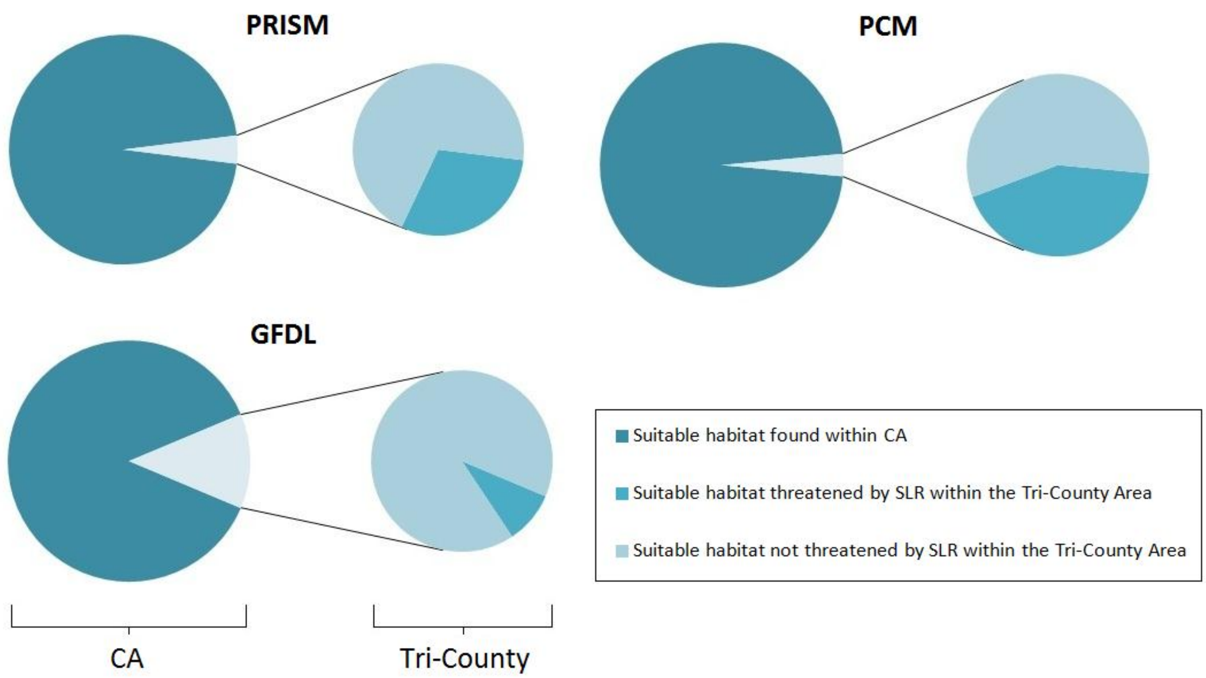

Figure 29: Relative suitable habitat for California and the Tri-County Area in relation to SLR threats. The larger circles represent the suitable habitat found in California, the lighter blue within this circle represents the suitable habitat found in the Tri-County area (also shown in the smaller circles). The lighter blue within these smaller circles represents the area within the Tri-County that is also threatened by sea level rise for the *C. maritimum*.

For the PRISM present-day model (Figure 29 – PRISM), MaxEnt predicted a total area of 2,842km^2 as suitable habitat for *C. maritimum* within the entire state of California. Approximately 3.96% of that area, or 113km^2, was located within the Tri-County Area. Of this 113km^2 of suitable habitat within the Tri-County Area, 30.1% (33.9km^2) was found to be threatened by inundation, flooding, and cliff and dune erosion projected for 2025.

For the GFDL 2100 model (Figure 29 – GFDL), MaxEnt predicted a total area of 7,170km^2 as suitable habitat for *C. maritimum* within the entire state of California. Approximately 12.7% of that area, or 907km^2, was located within the Tri-County Area. Of this 907km^2 of suitable habitat within the Tri-County Area, 9.3% (84.5km^2) was found to be threatened by SLR threats projected for 2100.

For the PCM 2100 model (Figure 29 – PCM), MaxEnt predicted a total area of 2,630km^2 as suitable habitat for *C. maritimum* within the entire state of California. Approximately 2.95% of that area, or 77.6km^2, was located within the Tri-County Area. Of this 77.6km^2 of suitable habitat within the Tri-County Area, 42.8% (33.2km^2) was found to be threatened by SLR threats projected for 2100.

X. Discussion

Using the most recent projection of SLR-related threats to the Tri-County Area for 2100, we have identified areas where rare and endangered species could be at risk from inundation, flooding, cliff and dune erosion. Species found at very low elevations are extremely likely to be exposed to SLR. However, there is still a small possibility that plants found at higher elevations will be exposed to some SLR-related threats, specifically cliff erosion.

Out of our initial set of nine species, *C. maritimum* has the lowest average elevation, and it was the most threatened species. *C. ambigua* had the second lowest average elevation, and all of its occurrences were affected. By contrast, *L. nipomensis*, *S. maritima*, and *N. gambelii* have the highest average elevation and are not affected by any threat. This confirms the largest trend identified in the analysis of 88 species.

On a preliminary level, there may be a relationship between the extent to which a threat affects a species and the species' general habitat. For example, dune species are more likely to be threatened by dune erosion. However, we cannot conclusively identify trends based on available data. Even within a set of species of similar habitat and elevation, there are variations in the severity of the threat. These variations may be based on species-specific characteristics that were beyond the scope of this project. There may be other possible factors influencing a species' probability of exposure, such as proximity to the coastline; however, our research did not investigate these potential relationships.

Based on our research, it is clear that certain species in the Tri-County Area, such as *C. maritimum*, will be extremely threatened by SLR. Therefore, these species may face a high extinction risk without active management to improve their resilience.

It is worth noting that our results likely underestimate the exposure of coastal plant species to SLR, given that SLR projections are likely to increase in the near future. Recent findings of accelerated melting of polar ice sheets suggest that our assumption of 1.4 meters of SLR by 2100 is a conservative estimate (Nicholls and Cazenave, 2010). If projections of SLR were to increase, then plants found at higher elevations could be at greater risk. There is, however, significant uncertainty in future SLR based on the wide variety of recent projections.

As SLR impacts coastal plant species, climate change may also substantially shift the location of species' suitable habitat. This represents an added environment stress to which species must adapt. The relative impact of SLR could vary substantially depending on future habitat predictions. If future habitat is predicted to shrink, SLR will be a larger threat on what area is left.

Nonetheless, there is a high degree of uncertainty as to how climate change will shift habitat. Our two future scenarios feature opposing projections for the suitable habitat of our case study species— one of growth in suitable habitat, and the other of contraction. In a plausible worst case scenario, the combination of SLR and climate change could seriously contract suitable habitat. While we found no substantial shifts in suitable habitat for our case study, other species may experience variable shifts in suitable habitat as well as contractions or expansions of future suitable habitat.

There are other predictors for future suitable habitat that may influence a species' likelihood of survival. Even when climate and soil may be suitable, other factors such as inter-specific interactions and land use changes could prevent species from surviving in ostensibly suitable habitat.

In spite of the above uncertainties, our research opens a new direction for analyzing the impacts of SLR and climate change on coastal plant species. This is an important first step in assessing these emerging threats on the West Coast. SLR has not been considered in conjunction with rare plant management in California. Therefore, our research provides the USFWS with information for improved planning and management of coastal plant species.

Additionally, these results may help the USFWS argue for their listing, ensuring more protection for at-risk species. In addition to supporting listing for these species, USFWS may use the threats analysis output from our model to avoid future mitigation, transplanting, and other resource-intensive management efforts in the areas identified as sea level rise threat zones.

XI. Implications

Our research was a first attempt at modeling SLR and climate change and its potential effect on coastal plant species. As such, there are a number of possible improvements that could be made to improve the accuracy and scope of our research.

There are two different sets of implications for our research. The first is specific to our client, USFWS, and recommends some broad management strategies. The second is improvements to the data we used and models we developed.

<u>Management Recommendations</u>

SLR in 5-Year Reviews

USFWS currently evaluates the status of listed species in their Five Year Reviews, using a "Five Factor Analysis". The two most significant factors for our purposes are sources of habitat loss (Factor A) and limited regulatory protection (Factor D). Climate change has been incorporated into Factor A for some species, although it is not systematically considered. As such, we would recommend that SLR be considered in the Five Year Reviews under Factor A. Our model provides some quantifiable data that can be included in these Five Year Reviews beyond qualitative assessments of possible effects.

Active Management

There two types of active management to reduce the exposure of plant species to SLR: in-situ practices and assisted migration. In-situ practices are valuable because they can prevent localized impacts. As an example, the system of oceanside culverts around the Point Mugu can be managed to attenuate localized SLR, thus reducing the exposure of *C. maritimum* populations (Martin Ruane, Naval Base Ventura County, personal communication).

Other in-situ protection options include hard engineering structure such as building breakwaters or sea walls. These options may protect specific areas from storm surge and other marine forcings. However, they should be approached with caution as they can cause accelerated erosion downdrift of the structures. Hard structures are destructive to shoreline processes and habitats such as intertidal zones and wetlands (NOAA, 2007).

Another in-situ option is to minimize sources of habitat degradation, such as anthropogenic stressors and invasive species. Improving ecosystem health, either by limiting human impacts or removing invasive species, helps to bolster the resilience of the habitat, which improves the probability of survival for individual species. For example, a recent assessment of outplanting sites for *A. pycnostachyus* highlighted at least two sites in Los Angeles County that would require the removal of iceplant, an invasive species, as part of site preparation (Jensen, 2007).

Assisted migration, either within the known historic range or beyond, is one option for reducing the threat of SLR to plant species and building resilience. Combining our SLR model with the projected suitable habitat provides managers with some indication of where species could survive and not be threatened by SLR. Unfortunately, assisted migration tends to have fairly low success rates due to a lack of understanding of each plant's ecological requirements (Florentine and Westbrooke, 2004; Faheslt, 2007). Lastly, USFWS may use the threats analysis output from our model to avoid future mitigation, transplanting, and other resource-intensive management efforts in the areas identified as SLR threat zones.

Modeling Recommendations

There are a number of limitations to the SLR and MaxEnt models that we used. As such, the following recommendations should be considered to improve model output.

Improved Species Data

Future analyses should take steps to ensure data accuracy for species occurrences. Much of the data in CNDDB is out of date and as such is not particularly accurate. For example, we were able to gather extremely accurate GPS spatial locations from Martin Ruane (Point Mugu Naval Base). Using current, ground-truthed species data, such as the above, would add confidence when analyzing the overlap between species occurrences and threats. Data should also be collected on the number of individuals or populations within an occurrence in a more systematic way.

SLR Modeling

We only used one emissions scenario to project SLR. It is important to model multiple emissions scenarios to get a better feel for the range of possible effects on coastal species. Emissions scenarios should also be updated as new data on SLR and climate change become available. It is likely that this will be necessary in light of recent acceleration in the melting of polar ice sheets. Without accounting for these changes, estimates of species' exposure to SLR will lose accuracy over time.

By accounting for fluvial and terrestrial forcings in the flood and erosion models, we would increase the robustness of the SLR threats analysis. Terrestrial flooding plays a large role in the rate of cliff erosion (Quigley, 1976). Currently, a study in Ventura County involving David Revell from Philip Williams and Associates, is attempting to account for terrestrial forcing in addition to marine forcings on both flooding and erosion. Accounting for this additional threat would aid in determining flood and erosion threats to plant species.

Our model only considers the effect of erosion on cliffs and dunes but not its differential effects on habitat types. A differential analysis would more accurately account for the variety of geological processes across habitats. For example, the Sea Level Affecting Marshes Model (SLAMM) looks specifically at the effects of SLR on marsh habitat (Clough, 2010). This type of in-depth will give a more detailed picture of the degree of threat that each species faces.

It would also be worthwhile to model the effect of saltwater intrusion on coastal aquifers. As inundation increases, salt water will contaminate freshwater stores on which plant species depend. In California, saltwater intrusion into aquifers is already occurring and will be accelerated by SLR (Heberger et al., 2009). Furthermore, the potential effects of lower water tables from human consumption will further exacerbate saltwater intrusion. Finally, it is worth taking into account each species' dependence on groundwater, effects SLR on saltwater intrusion, and water table heights.

Along with modeling exposure, it would be useful improve knowledge of the sensitivities of coastal plant species to SLR and climate change. This information would enable a full-fledged vulnerability assessment for individual species. One common tool, NatureServe's Climate Change Vulnerability Index, integrates factors that influence both exposure and species-specific sensitivity (Young et al., 2010).

MaxEnt Modeling

In general, we recommend that MaxEnt modeling be applied to any species that our analysis finds to be exposed to SLR-related threats. Second, we recommend efforts to increase the number of location records for species. While MaxEnt generally performs well with small numbers of location data, larger sample sizes would strengthen the statistical relationships made between species location and environmental data in MaxEnt, resulting in stronger predictions of suitable habitat. This can be achieved by GPS tracking of individuals within populations rather than using less precise occurrence data. Given that occurrences in CNDDB generally encompass an unknown number of individuals, marking the specific location of individuals can increase the sample size for better modeling.

Another method widely used by species distribution modeling of rare species is to incorporate location data from herbarium specimens. Although these individuals have long been extirpated, MaxEnt can still use historical location records as proxies of past climate preferences. Therefore, this herbarium database is a valid means of increasing sample sizes.

Lastly, the selection of the best environmental inputs for modeling is largely a species-specific question. For most rare species, it is relatively unknown which climatic and edaphic variables are most important for predicting suitable habitat. We recommend conducting preliminary model runs in MaxEnt to explore a wider variety of environmental variables. We also recommend conducting a correlation matrix on environmental variables to eliminate those that may be correlated. This is important because correlation among environmental variables may confound MaxEnt's evaluation of which variables contributed the most to the predictions of suitable habitat.

We are currently conducting subsequent MaxEnt simulations on a number of species identified to be severely exposed to sea level rise and will vary the environmental variables to better predict suitable habitat. We hope to publish our findings in a reputable journal in the near future.

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XIII. Appendices

Appendix I: Definitions

Occurrences – Polygons where species have been found. An occurrence is not necessarily a population; it can contain one individual plant or an entire population of plants, or a grouping of ramets. The area of the occurrence may be based on the age of the observation and the accuracy of the measurement.

Inundation – In the model, inundation indicates regular submergence rather than permanent submergence, accounting for tidal fluctuations. This is why inundation is sometimes referred to as mean higher high water mark in this paper.

Sea Level Rise – This phenomenon is an increase in the surface level of the oceans, which exacerbates four separate threats: inundation, cliff erosion, dune erosion, and periodic flooding.

Exposure – The intersection between species' occurrences with any physical process intensified by sea level rise.

Suitable Habitat – Suitable habitat is the physical space that a species can occupy, based on the relationship between current species distribution and a set of corresponding environmental variables.

Dune Erosion – This type of coastal erosion is a measure of shoreline retreat of dunes and beaches, incorporating accelerated historic erosion rates and impact of erosion from 100-year storms.

Cliff Erosion – This type of coastal erosion is a measure of accelerated historic erosion rates of sea cliffs and bluffs, incorporating a time-series of total water level (TWL) exceedances of the backshore.

100-Year Flood – The 100-year flood is a flood extent that has a 1% chance of being equaled or exceeded in a given year (FEMA, 2005).

Total water level (TWL) – TWL is the sum of the height of measured tides plus wave run-up on the beach.

Appendix II: Species Information

1. *Arenaria paludicola*

2011 California Native Plant Society

Arenaria paludicola, common name Marsh Sandwort. This is a perennial herb of the Caryophyllaceae family. It is native to California and Washington State, although at present only one population is thought to exist in the Black Lake Canyon area of Oso Flaco Lake in San Luis Obispo County. There have recently been reports of populations on Nipomo Mesa, though this is currently unconfirmed. It tends to prefer freshwater wetlands, freshwater marshes, or wetland-riparian habitats, though not necessarily coastal areas. It is often an emergent plant, growing along the edges of permanent, slow-moving streams and in freshwater marshes close to the ocean. Historically, it has been found at elevations ranging from 0 to 450 m in sandy soils that are constantly saturated with freshwater, and in conjunction with Gambel's water cress. It is capable of self-pollination but the seed set is most likely enhanced by insect visitation. It is listed both federally and with the State of California as endangered. It is extremely fragile and easily ripped from its environment through physical disturbances, such as storm surge (Mike Walgren , CA parks, personal communication).

The U.S. Fish and Wildlife Service is required to review the status of each federally listed species every five years (Section 4(c)(2) of the Endangered Species Act of 1973). These five-year reviews evaluate whether a federally listed species should be delisted, reclassified from endangered to threatened, reclassified from threatened to endangered, or if the species' classification should not change. The purpose of a five-year review is to ensure that listed species have the appropriate level of protection under the Act and to identify immediate threats to the species. The Marsh Sandwort was assigned a priority recovery number of 5 in the USFWS 5-year Review in 2008 for threatened and endangered species recovery. Presumed threats include: decline in suitable habitat (both quantity and quality), increased development, erosion, sedimentation, non-native invasive plants, lack of genetic diversity, sporadic inundation of stable wetland habitats, eutrophication from increased nutrient levels, groundwater pumping, conversion to agriculture, adverse effects from biostimulation, stochastic extirpation/extinction events due to small population size, and isolation of the remaining wild population. The loss of freshwater habitat is the most significant threat.

Arenaria paludicola reproduces asexually, and is generally found in marshes and other perennially mesic stream and creek habitat where riparian vegetation occurs. The species historically occurred along the Washington and California state coastlines, within boggy regions of freshwater marshes and swamps below 170 meters in elevation. Extirpated from its historic site at Black Lake Canyon in spite of re-introduction efforts during the 1990's, the only wild extant population is located at Oso Flaco Lake. One extant introduced population is located at Sweet Springs Marsh in Morro Bay. Montane populations located at 2500 meters in elevation were found in southern Mexico and Guatemala, although these populations may no longer be extant.

Population extinctions have occurred due to anthropogenic perturbations to habitat. At the Black Lake Canyon site, hydrologic changes have been made through the construction of two golf courses and the expansion of a nursery production facility. Subsurface recharge has decreased due to groundwater pumping and the presence of Eucalyptus trees throughout the canyon, and surface flows have increased carrying elevated concentrations of herbicides, pesticides, and fertilizers. Consequently, growth of *A. paludicola's* competitors and decline in the quality of marsh habitat is ongoing at both the Black Lake Canyon and Oso Flaco Lake sites.

The FWS has identified the species' continued threats in its 5-Year Review Five Factor Analysis. Loss of habitat to development via increased sedimentation, changes in hydrologic regime, and conversion of marshland to grass and shrub dominated communities is one of the most significant continued threats to *A. paludicola*. The encroaching extent of urbanization has limited the species' ability to colonize adjacent land to existing habitat. Eucalyptus pose a unique threat to the species because they increase shading, reduce local water availability, and may introduce organic matter to the vadose zone that could inhibit *A. paludicola's* growth. Herbivory and random extinction events due to *A. paludicola's* small population size compose the species' other threats. Published in 2008, the Five Factor Analysis does not account for any possible threat that sea level rise, or more generally climate change, may pose to the species.

2. *Astragalus pycnostachyus var. lanosissimus*

2007 Nicolas Jensen

Astragalus pycnostachyus var. lanosissimus, common name Ventura Marsh Milkvetch. This is a short-lived perennial herb of the Fabaceae family. It is native and endemic to California and only one population is presumed extant in Ventura County. It is found in a coastal marsh habitat, specifically low-elevation dune-swale areas where freshwater levels are high enough to reach roots and transitional wetland areas. It is thought to require a fairly shallow freshwater aquifer in back-dune habitats (Jennie Marek, USFWS, personal communication; CNPS Rare Plant Inventory). It is thought that the species may occur in habitats similar to the related, Northern Brine Milkvetch which is located in areas which have deep bay salt marshes with pickleweed or in areas south of Drakes Bay in coastal wetland such as Drakes Esterio, or Point Reyes. However, plants in higher salinity areas tend to have lower survivorship than plants in lower salinity areas, suggesting that the Ventura Marsh Milkvetch does not tolerate high salinity levels in the same way (Jennie Marek, USFWS, personal communication). This translates to poor survivorship in areas inundated by high-tides or coastal marshes (Dieter Wilken, Santa Barbara Botanical Garden, personal communication). As a result, Marsh Milkvetch may be sensitive to sea spray. There have been observed instances of damage and plant ranges retreating from the marsh which could be attributed to salt burn, but this supposition has not been completely proven (Mary Meyer, CDFG, personal communication)

The plant is an early successional plant and needs low competition (Mary Meyer, CDFG, personal communication). It is self-compatible, meaning that it can reproduce with itself but requires pollination by relatively large bees to set seed CNPS Rare Plant Inventory). Seeds appear to be adapted to persist in the soil for decades and are known to germinate when exposed to suitable habitat (Jennie Marek, USFWS, personal communication). Historically, it has been found at elevations ranging from 0 to 60 m. A collection record from 1910 from Ventura indicated the species existed at an elevation of 200ft (Mary Meyer, CDFG, personal communication). However, the historical habitat is not fully understood and the plant's temperature range is currently unknown (Jennie Marek, USFWS, personal communication). Given its reliance on transitional wetland habitat, it is hypothesized that individual Milkvetch occurrences might shift over time within larger meta-populations as wetlands shift. Observed planted populations suggest that the plant does not tolerate flooding for more than 10 days (Mary Meyer, CDFG, personal communication). However, temporary inundation could actually distribute seeds to suitable habitat (Jennie Marek, USFWS, personal communication). Along with this, increased precipitation would likely aid in seed dispersal and thus increase the population; decreased precipitation could decrease ground water levels which would decrease suitable habitat areas (Jennie Marek, USFWS, personal communication).

The Milkvetch is listed on both federally and state registers as endangered. The Fish and Wildlife 5-year review for the Milkvetch was completed recently in 2010 and the priority recovery number assigned to this plant is 6C. There have been several outplanting attempts by the USFWS, with widely varying success (ranging from complete failure to survival of half of the transplants) in its known historic range in Ventura County, the Carpinteria Salt Marsh Reserve, and Coal Oil Point. Presumed threats include: habitat loss from urbanization, stochastic extinction, and competition from invasive species, inundation, and saltwater intrusion.

Thought to be extinct, *Astragalus pycnostachyus var. lanosissimus* was rediscovered in 1997 in a degraded coastal dune system in Oxnard within an area of less than six acres. At this site, referred to as its site of natural occurrence, the population has been recorded to fluctuate between ~30-300 individuals over a 12-year period due to local precipitation patterns, climate variations, and recent management activities. Since its rediscovery in the late '90s, reintroduction efforts have been attempted at three locations within the species' historical range in Ventura, and two locations outside of its historical range in Santa Barbara County. At Ormund Beach, rabbit herbivory, salinity, and heavy rains in 2005 inundated the population and killed off all introduced individuals. At Mandalay State Beach, shallow dune swales were deemed too dry caused by individuals' inability to access the groundwater table, although six individuals currently remain. At McGrath State Beach, heavy rains and elevated water level conditions killed off the original introduced individuals. The high flows, however, transported seeds to more suitable habitat with sufficient space and pollinators, and 17 individuals currently remain (as of 2009). At Carpentaria Salt Marsh Reserve, an introduced population was planted in a transitional zone from salt marsh to delta scrub in silty loam soils overlaying clay strata. Individuals placed in lower salinity portions persisted, while those in higher salinity portions died. At Coal Oil Point Reserve, 32 individuals have been documented.

From numerous outplanting efforts, it's been deduced that *A. pycnostachyus* favors low-elevation coastal dune swales with access to freshwater via relatively high groundwater table levels. Habitat typically features well-drained sandy, clayey soils with limited salt accumulation. The species depends upon select bee and butterfly species for pollination. Salinity, availability of low-competition growing sites, herbivory by small mammals, and distance to the perched water table seem to influence survival. *A. pycnostachyus* tends to occur as meta-populations across a landscape; the species forms small colonies where habitat is temporarily suitable at different micro-habitat sites.

The FWS has identified the species' continued threats in its 5-Year Review Five Factor Analysis. Much of *A. pycnostachyus'* historic habitat has been altered or completely destroyed. At its site of natural occurrence, a soil remediation product currently taking place has removed all of the vegetation surrounding *A. pycnostachyus.* Irrigation has been installed to help the population survive, although it's uncertain if or to what extent the hydrology of the site has been permanently altered. The effects of widespread soil damage and changes in site hydrology may be compounded by the species' small population size, which has made individuals more vulnerable to stochastic events, competition with invasive species, increased nutrient loading from adjacent urban land uses, and potential impacts of recreation. Additionally, *A. pycnostachyus* is prone to aphid outbreaks and sooty fungus infestations. Seed predation by beetles and weevils, and physical damage by gophers, rabbits, and meadow voles have been identified as threats. However, the magnitude of impact of these natural threats varies with climate and site location. Climate change has been identified as a threat, although the impact it will have in combination with other factors such as small population size is unknown. All extant populations occur in relatively restricted areas for migration due to surrounding land uses. Thus, barring potential efforts to armor coastal developments against sea level rise that may protect the species, outplanting appears to be the most realistic management option for *A. pycnostachyus.*

3. *Castilleja ambigua ssp. insalutata*

2005 Bob Huettmann

Castilleja ambigua ssp. insalutata, common name Johnny Nip or Ambiguous Indian Paint Brush. It is an annual herb of the Orobanchaceae family. It belongs to a genus that is characteristic of plant communities across western North America, including dozens of species in the Western United States and North America. Castillejas are hemiparasitic, meaning that they are partly dependent on the roots of nearby plants for sustenance. While the species *Castilleja ambigua* is found along the West Coast of North America, this subspecies is endemic to California. It occurs on grassy meadows on coastal bluffs high above the ocean and headlands at elevations from 0 to 135 m (Mike Walgren, CA Parks, personal communication). The southernmost populations occur near Piedras Blancas (San Luis Obispo County), where there are other rare coastal bluff species on land managed by BLM. Many have looked for this species at Arroyo de la Cruz without success. It is believed that the populations around Pt. Joe and Pacific Grove in Monterey County no longer exist. According to a conversation with Mark Egger, "this is not surprising given the development that has occurred there".

This paintbrush is not recorded as being endangered at either the federal or state levels; however, it is on the California Native Plant Society's watch list for plants with limited distribution. There are 4 current observations that appear limited in distribution as they are located only within San Luis Obispo and Monterey Counties. No 5-year review has been completed to date. Likely threats include invasive species (specifically the ice plant), development, grazing, and erosion of beach bluff habitat (Dieter Wilken, Santa Barbara Botanical Gardens, personal communication). It may also be sensitive to salt water intrusion. It is thought that the best form of protection would be contiguous replacement of habitat as opposed to smaller transplant areas that are more spread out (Mike Walgren, CA Parks, personal communication).

No formal assessments of threats have been completed for this species in the form of a 5-Year Review.

4. *Chloropyron maritimum ssp. maritimum*

Bob Sloan 2009

Chloropyron maritimum ssp. maritimum, common name Salt Marsh Birds' Beak. This is an annual forb/herb of the Orobanchaceae family. Its historical range is from Baja Mexico to San Luis Obispo County. It is a hemi-parasitic plant that taps into the roots of co-occurring species (usually high tidal marsh species). Due to its dependence on the host plant, its geographic and ecological distribution is limited by the distribution of the host plant. The plant is generally a poor competitor and does better if it is not choked by other species (Mary Meyer, CDFG, personal communication). It is extremely sensitive to physical disturbance (Mike Walgren, CA Parks, personal communication). It is found from 0 to 30 meters elevation in clay and silt soils. The plant tends to be affiliated with locations that have a freshwater influence as freshwater floats above sea water. However, the plant sequesters the salt and extrudes salt outside of itself. (Mary Meyer, CDFG, personal communication). The subspecies has some tolerance to salinity, since it can grow in the full tidal zone as well. In spite of this, it seems to have a very narrow niche, since all observed locations are in patches and bands across the landscape.

Seeds generally germinate during winter rainfall when salinity is low and bloom in the summer, though they can also germinate in bare ground. It is suspected that tidal debris and sedimentation can sometimes be beneficial to germination (Mary Meyer, CDFG, personal communication). Pollination is a point of vulnerability for at least one population of bird's beak. Normally, the subspecies depends on pollination by ground-nesting bees, which nest in salt pans that are vulnerable to submergence under sea level rise (SLR) at Point Mugu (Martin Ruane, Naval Base Ventura County, personal communication). The salt pans at Point Mugu will be lost to SLR in a squeeze between encroaching wetlands and the Pacific Coast Highway. Pollination probably depends on insects (Dieter Wilken, Santa Barbara Botanical Garden, personal communication). Bird's Beak is an obligate outcrosser (meaning that one plant cannot reproduce with itself) with pollinators such as bees and flies which nest upland, and therefore it is thought that the plant needs to be near high upland areas close to marsh areas so that pollinators can function properly for the Bird's Beak (Dieter Wilken, Santa Barbara Botanical Garden, personal communication). In a "case study" on the dependence of pollinators, Richard Zembal "threw out" 100 seeds at Seal Beach and found that the seeds germinated and matured but could not reproduce for lack of pollinators (Martin Ruane, Naval Base Ventura County, personal communication). This indicates a strong dependence on insect pollinators that were clearly not present at Seal Beach.

It is suspected that the plant does not grow well in areas of high splash zone, generally they do better in protected areas. For example, a project meant to improve tidal flow into the marsh area resulted in the bird's beak no longer growing in that area. It is thought likely that high tide marsh plants tend to be more affected by high tide (Martin Ruane, Naval Base Ventura County, personal communication). The Point Mugu population is protected by a series of culverts that would “mute the effect of sea level rise,” while populations at Carpinteria salt marsh and the Tijuana estuary are more exposed to tidal influence (Martin Ruane, Naval Base Ventura County, personal communication). In other words, these culverts will “dampen effects of the tidal prism.” There is a possibility of adjusting the culverts at Point Mugu to manage the population.

There are a few known populations in the Tri-County Area: Carpinteria in Santa Barbara County, Morro Bay in San Luis Obispo County, Naval Base Ventura County at Point Mugu, and Ormond Beach in Ventura County. There is also a somewhat successful transplant population at McGrath State Beach in Oxnard. There are at least 3 subpopulations in Morro Bay, which is the northern-most known population. Occurrences are found along coastline in salt marshes, usually in the upper ecotonal edge or the marsh with the surrounding habitat and as far south as San Diego County and Mexico. This plant seems to do best in coastal salt marshes, probably because it’s hemiparasitic with host species in that habitat, but it’s rare throughout its range, and certainly would be impacted by sea level rise. At Point Mugu State Park, bird’s beak grows in a “bathtub ring” around the salt marsh (Martin Ruane, Naval Base Ventura County, personal communication). This habitat specificity might have more to do with dependence on host plants that grow in the upper ecotonal edge than on physical aversion to salinity or inundation (Martin Ruane, Naval Base Ventura County, personal communication). The population varies significantly across time as a result of rainfall variations at Point Mugu (Martin Ruane, Naval Base Ventura County, personal communication). The population dwindles to almost nothing during dry years and comes back during wet years. Timing of rainfall might also matter.

It is listed as federally and state endangered. The 5-year review was completed in 2009 and the recovery priority number assigned to it is 6. Threats include: trampling, invasive species, habitat shifting from climate change, and stochastic events. At Point Mugu, there is potential for migration to the “main central basin” below the Santa Monica Mountains, as SLR restores this area. For the plant to adapt to rising sea levels, assisted migration might be needed to help the plants move inland without forcibly transplanting individuals or seeds.

Chloropyron maritimum ssp. maritimum is a parasitic or opportunistically parasitic halophyte whose geographic and ecological distribution may be limited to host plants: saltgrass (*Distichlis spicata*), annual beardgrass (*Polypogon monspeliensis*), pickleweed (*Salicornia virginica*), fleshy jaumea (*Jaumea carnosa*), sunflower (*Helianthus annuus*), and more species that are yet undocumented. It is commonly found in coastal and inland salt marshes at upper elevation, where dry conditions persist throughout the summer months. Thus, the species’ orientation within marshland is very specific in terms of salinity, favoring habitat overlying tidal flows. Seed germination is associated with low salinity conditions tempered by an influx of freshwater (as rainfall). A 1987 study showed that normal salinity conditions ranged from 0-10ppt at the time of seed germination, and 10-20ppt at the end of the growing season. In lab and field studies, prolonged inundation inhibited seed germination so the species is not recognized as having a high tolerance for submergence. The species depends on various bee species for pollination. Dispersal occurs via tides; seeds float for up to 50 days before depositing at the debris line. To date, reintroduction attempts have had limited success in promoting self-sustaining populations within the historical range of the species.

The FWS has identified the species' continued threats in its 5-Year Review Five Factor Analysis. Habitat loss for *C. maritimum* has historically been due to the filling in or clearing of salt marsh for development, as well as the diversion of freshwater from habitat that has rendered portions of the species' historic range unsuitable. The California Coastal Act and Federal Clean Water Act have since effectively stopped further habitat loss from development, with the exception of the Tijuana River estuary where proposed wastewater effluent may threaten *C. maritimum* habitat within the Tijuana River watershed in Baja. Off-highway vehicles and erosion from storm drain runoff have been identified as minor threats, although management practices are currently in place to both impacts. Insect herbivory, specifically by the salt marsh snout moth (*Lipographis fenestrella*), has been cited as a threat, although the magnitude of impact on populations is unknown.

Global climate change has been identified as a significant range-wide threat to the species. *C. maritimum* has a narrow vertical distribution within wetlands between 5.6ft (1.7) and 7.9ft (2.4m) above mean lower low water. Although the impact of incremental sea level rise on *C. maritimum* and associated host plants is unknown, the FWS anticipates that the species will move inland or upwards in elevation in response to tidal flow encroachment. Because the physiography of site locations varies with each occurrence, the ability of populations to migrate at the same pace of changes in estuarine hydrology will depend upon the suitability of adjacent habitat. The Sea Level Affecting Marshes Model (SLAMM) is recommended within the 5-year review to identify the species' most vulnerable occurrences. Changes in distributions of invasive species, pollinators, and host plants due to warmer, dryer conditions as a result of regional climate change have also been recognized as potential threats to the species. To date, the interaction of these threats has not been described or assessed.

5. *Cirsium scariosum var. loncholepis*

Chris Winchell 2011

Cirsium scariosum var. loncholepis, common name La Graciosa thistle. This is a short-lived perennial herb of the Asteraceae family. It is native to California, ranging from San Luis Obispo to San Diego Counties. There are 7 extant populations with 11 known occurrences in Guadalupe near Santa Maria in Santa Barbara County and southern Callender Dune Lake area in San Luis Obispo County. There were thought to be some individuals at Vandenberg Air Force Base, but it was misidentified and later turned out to be a different species. It prefers coastal dunes, brackish marshes, and riparian scrub. Historically, it was found in mesic sites in two dune complexes with medium moisture in back dune and coastal wetlands. A mesic habitat is one with moderate or well-balanced supply of moisture including mesic forests, temperate hardwood forests, or dry-mesic prairie. It has been found as far as 16 miles inland and at elevation ranges of 4 to 220 meters above sea level. It is likely pollinated by insects, is self-compatible so that individuals can reproduce with themselves, and the fruits are probably dispersed by birds and not wind (Dieter Wilkins, Santa Barbara Botanical Garden, personal communication). It is listed as "endangered" by the Federal Government and as "threatened" by the State of California. The 5-year review was completed in 2011 with a recovery priority number of 2. Likely threats include erosion of dunes, decreased habitat quality, stochastic events, specifically weather related events, due to lack of connectivity between populations. Its range is a relatively safe distance from the ocean since no individuals have been found below 4 meters above sea level, with suitable, surrounding habitat to which it can migrate. The concern however, is that the small number of individuals within each occurrence suggests that assisted migration or outplanting will be necessary (Mike Walgren, CA Parks, personal communication).

Cirsium scariosum var. loncholepis is a coastal wetland species found in San Luis Obispo and Santa Barbara counties. Blooming once and dying (aka a monocarpic perennial), its flowering heads produce ~163-473 seeds each which disperse by wind. The species has historically been limited to the Santa Maria Basin, an ecosystem dominated by moderate to strong northwesterly winds year-round. These winds create the parallel ridge-and-swale terrain that *C. scariosum* depends on for survival. Its historic habitat has been altered widely by changes in land use, via the conversion of wetlands and dune sheets to agricultural fields as well as more subtle changes within the basin that have caused the hydrologic regime to shift.

The FWS has identified the species' continued threats in its 5-Year Review Five Factor Analysis. *C. scariosum* faces continued threats of habitat fragmentation and changes in species composition and vegetative structure due to urban and agricultural development. Specifically, petroleum extraction has removed 1/3 of known populations. Continued habitat modifications from energy-related activities threaten the species. Mismanagement of watersheds where *C. scariosum* occurs has increased growth of the species' competitors through excessive nutrient loading. Lower groundwater table levels in the Guadalupe Dunes region have also further threatened the species' ability to survive. Other significant threats include vandalism, herbivory and trampling by cattle, and compromised genetics due to existing populations' small sizes.

The biggest threat relative to others for this species is its need for habitat connectivity in order for populations to persist. Altered hydrologic regimes within habitat between existing populations have increased the loss of connectivity between populations, especially of natural riparian drainages. As a species that disperses over long-distances and tends to exist in metapopulations, *C. scariosum* depends on suitable habitat for intermediate, transitory linkage populations in order to persist successfully. Climate change has been identified as a threat insofar as sea level rise will cause dune erosion to occur. If projections of a 2m rise by 2100 are actuated, coastal dune habitat in San Luis Obispo is expected to decrease either by 1.4 square miles.

6. *Dithyrea maritima*

California Native Plant Society 1984

Dithyrea maritima, common name Beach Shield Pod, is a rhizomatous perennial forb/herb of the Brassicaceae family. A forb is an herbaceous flowering plant that is not a graminoid (grasses, sedges, and rushes). It is native to California and Baja California. It is found in coastal strand and coastal sage scrub areas and in Southern California and the Channel Islands it appears to prefer coastal dunes. It is most commonly found in swales adjacent to both fore-dunes and back-dunes and is typically found in the same habitat as *Cirsium scariosum* and *Senecio Blochmaniae* (Dieter Wilken, Santa Barbara Botanical Garden, personal communication).

It has been seen once at Vandenberg Air Force Base (Dieter Wilken, Santa Barbara Botanical Garden, personal communication). It is found at elevations ranging from 0 to 50 meters above mean sea level. It is not currently listed on Federal endangered plant lists; however it is on the endangered species list for California. There are currently 21 populations that are thought to be extant, though not all are located within the Tri-County Area. It is self-incompatible, so it cannot reproduce with itself, and a number of the populations are clonal, meaning that the individuals are ramets that are genetically identical to one another (Dieter Wilken, Santa Barbara Botanical Garden, personal communication). There is no 5-year review; however it is directly referred to in other species' recovery plans. Likely threats include: habitat loss, foot trampling, and dune erosion. As it tends to grow on ocean-facing slopes, it may be susceptible to increased storm surge (Mike Walgren, CA Parks, personal communication).

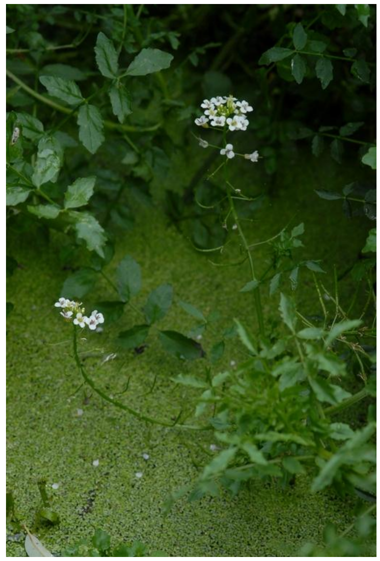
No formal assessments of threats have been completed for this species in the form of a 5-Year Review.

7. *Lupinus nipomensis*

Dieter Wilken 2005

Lupinus nipomensis, common name Nipomo mesa lupine. This is an annual herb of the Fabaceae family. It is native and endemic to California. The remaining range is very small; there is only 1 known population that is made up of a series of small colonies covering less than one square mile on the Guadalupe Dunes near the southwest edge of Nipomo Mesa in San Luis Obispo County. It is found in coastal dunes with fine-grained, sandy soils in sparsely vegetated, stabilized dune communities close to the coast. It is thought to prefer back dunes and sand flats just south of Oceano (Dieter Wilken, Santa Barbara Botanical Garden, personal communication). Historically it has been found at elevations ranging from 10 to 50 meters above sea level. It is self-compatible and self-pollinating (Dieter Wilken, Santa Barbara Botanical Garden, personal communication). It is listed by both the federal and state governments as “endangered. “ The 5-year review was completed in 2009 and the recovery priority number assigned to is 5. The primary threats to survival and recovery are competition from veldt grass, selective herbivory by pocket gophers, stochastic extirpation events of individual colonies, and possibly beach erosion of fore-dunes.

8. *Nasturtium gambelii*



Chris Winchell 2010

Nasturtium gambelii, formerly known as *Rorippa gambelii*, common name Gambel's yellowcress or watercress, is a perennial rhizomatous flowering herb of the Brassicaceae family. It is native to California with three extant populations; total population estimates are fewer than 300 individual plants. Current populations are found in (i) Oso Flaco Lake (genetically compromised and introgressed with another species) and (ii) Black Lake Canyon (Black Lake Canyon probably extirpated, in San Luis Obispo County and (iii) the Guadalupe-Nipomo Dunes and coastal land on Vandenberg Air Force Base (likely a hybrid and probably declining) in Santa Barbara County; though the historical range included Los Angeles, Orange, San Diego, and San Bernardino Counties. There is some possibility that the species also exists in some form in Mexico and Guatemala. It co-occurs with marsh sandwort. It grows in fresh and brackish marsh habitats, such as lakesides and marshes. It is often located in wetlands with floating mats of vegetation where it climbs over tullies and cattails (Mary Meyer, CDFG, personal communication). It is aquatic or semi-aquatic, sometimes floating on standing water or sprawling over wet ground. Its historical elevation range is from 5 to 330 meters above sea level, and is found in sandy and saturated soils with high organic content.

It is listed by the federal government as endangered and with the state of California as threatened. The 5-year review was completed in 2009 and the recovery priority number assigned to the species was 5. Probable threats include: loss and degradation of habitat due to development and urbanization, adverse effects from biostimulation, eutrophication, and sedimentation, inadequacy of existing regulatory mechanisms, non-native species, and stochastic extirpation/extinction, and genetic swamping from closely related species. The Vandenberg Air Force Base population is most significantly threatened by lowering water tables, whereas the Little Oso Flaco Lake occurrence is threatened by other species of water cress, sea level rise, and salinity increases (Dieter Wilken, Santa Barbara Botanical Garden, personal communication). Suggested possible management options include transplanting, reducing threats from invasive species, continued research, a captive breeding program, and seed banking.

USFWS has identified the species' continued threats in its 5-Year Review Five Factor Analysis. *Nasturtium gambelii* is faced with high extinction risks by virtue of its small population size. Only one remaining wild population of the species is known where genetically distinct individuals exist. Typically favoring coastal marshes and other perennially wet areas with riparian vegetation, the species' historic range consists of Black Lake Canyon, Oso Flaco Lake, and Little Oso Flaco Lake. Populations that previously inhabited this area are now presumed extirpated, in large part due to the presence of *N. officinale* (common name white or common watercress), a non-native invasive species that has largely outcompeted and hybridized with *N. gambelii*. Genetic swamping poses the most significant threat to the species, in addition to other changes to the species' habitat. These threats include altered hydrologic regime, habitat modification at the Oso Flaco Lake site where dune and sand encroachment have taken place, and lack of a permanent water source. Increased development just adjacent to *N. gambelii's* habitat has increased the species' competition with non-native species, exacerbated by nutrient-loading in the form of storm runoff. All of these factors equate to greater risk of extinction from stochastic events.

The extent to which *N. gambelii* could be affected by climate change was addressed in the 5-year review with uncertainty. Sea level rise specifically was identified as a threat insofar that coastal dune habitat in San Luis Obispo County is expected to decrease either through erosion or inundation by 1.4 square miles by 2100, if projections of a 2m rise are actuated. The report acknowledges that such a loss in historic *N. gambelii* habitat range would cause a loss of individual plants and seed banks.

9. *Sanicula maritima*

Dieter Wilken 2005

Sanicula maritima, common name Adobe Sanicle or Adobe Snakeroot. This is a perennial herb of the Apiaceae family. It is native and endemic to California. Its historic range included the Central Coast and the San Francisco Bay area. However today only 1 population is currently known to exist comprised of approximately 14 or 15 individuals. It was once seen near Jade Cover in Monterey County and there may still be viable populations on protected lands in Monterey County (Andrew Molera, State Park, personal communication). However, within the Tri-County Area, there is only 1 known population. The adobe snakeroot is polygamous, meaning that is has staminate and bisexual plants (Dieter Wilken, Santa Barbara Botanical Garden, personal communication). It grows in coastal, grassy, open wet meadows and ravines with an elevation range of 30 to 240 meters above sea level. It is not listed by the federal government, but it is on the rare species list for California. There is no 5-year review. The most probable threat to this species is salt water intrusion, although erosion, collapse of cliffs, and inbreeding depression are also possible (Dieter Wilken, Santa Barbara Botanical Garden, personal communication).

Appendix III: GIS Processes

Inundation Process

1. Create copy of base layer inundation layer and rename it "2050 inundation." This is the primary layer we will be working with.
    a. Load additional base layer and 2100 inundation layers along with the named 2050 layer.
2. Set the selectable layer only to 2050.
3. Use the editor toolbar to turn on editing, select the 2050 layer as the feature
    a) Zoom into a scale where the spatial distinction between 2050 and 2100 are easily distinguishable.
    b) Use the select tool to select groups of vertices, that when deleted will create a new line decreasing the distance between it and 2100 layer. Make sure the line does over extend into the 2100 layer or undercut the 2000 layer.
    c) Move along the polygon continuing the previous step.
    a. The preference in creating this line is towards selecting points nearer to the base inundation than the 2100 inundation.

Flooding Process

1. Download 1/3 arc-second national elevation dataset (NED) raster files from the USGS seamless server for the three counties of interest (Ventura, Santa Barbara and San Luis Obispo).
    a. Mosaic county-wide raster files into a single file for the Tri-County region
2. Use raster dataset tool "Mosaic to New Raster" to merge the three separate raster files into a single seamless dataset.
3. Project new Tri-County raster file from North American Datum 1983 to California Albers (Teale) so that the flood layers and raster dataset are in the same projection.
4. Add the base (current) FEMA flood feature, estimated 2100 flood feature and Tri-County raster file into a new instance of ArcMap.
5. Since the FEMA flood maps have estimated storm surge it is not possible to simply extract cells from the raster based on a specific elevation. In order to determine what elevation should act as the baseline (flood without storm surge) elevation for the current FEMA flood, use the following steps:
    a. Open the properties dialogue box for the Tri-County raster file and select the symbology tab.
    b. Select to show as "Classified"
    c. Click the classify button to choose the number of classes and cut-off values
        i. Specify 2 classes
        ii. Choose the cut-off value for the first of the two classes to be something that you believe might be close to the non-storm surge elevation for the current FEMA flood layer (ex. 3 meters). Click ok to bring you back to the symbology tab.
        iii. Choose colors that make the two classes easily distinguishable (ex. Blue/Red)
        iv. Click ok and you will see the delineation based on the elevation values you selected.
        v. Zoom into various parts of the map to determine if the estimated elevation closely approximated the non-storm surge flood elevation

vi. As needed, adjust the class value (increase or decrease elevation estimate so that in most areas of the map the delineation of elevations closely approximates the flood extent of the current FEMA flood layer).
vii. The elevation value will never perfectly match the current flood layer, especially in estuaries/wetlands where storm surge will have the greatest effect.
viii. Note the elevation determined to be the best approximation of the base flood elevation for the current FEMA flood, this will be used as the base flood elevation in the equation above.

6. In order to determine the storm surge factor, steps a-c, from section 5 above should be repeated. However, this time the instead of the current FEAM flood layer, determine the base elevation for the estimated 2100 flood layer. Note the base flood elevation for this step, it will be used in the storm surge factor calculation.
7. Next, repeat the previous step estimating the storm surge elevation again using the 2100 flood layer. This will be done, by manipulating the classified elevations so that the delineation between the two classes best approximates the areas inundated by extreme flooding. In this case, it is best to look at areas such as wetlands or estuaries where the estimated storm surge factor is most noticeable. Again, the delineation will never be exact, but use the elevation the best estimate that does not significantly overestimate the storm surge for any given area. Note this elevation.
8. Subtract the estimated 2100 base elevation from the estimated 2100 storm surge elevation. The result of this calculation yields the estimated storm surge factor for the equation above.
9. Determine the estimated increase in sea level for the year of interest from IPCC 2007 report A2 scenario. (until updated)
10. Use the values calculated in steps 5-c-viii, 8, and 9 to calculate the flood elevation for the year of interest.
11. Use spatial analyst extraction tool "Extract by Attribute" to create a new raster file based on the equation, *[Value] <= (calculated flood elevation).* The new file now contains only those cells that are at elevations at or below the calculated flood elevation with sea level rise.
12. Use Spatial Analyst Math tool "Int" tool. This tool takes the floating point elevation values and converts them to integers, for example, 1.6 becomes 1. This step is necessary because floating point values cannot be converted into vector (points, lines, polygons) data.
13. Ideally the next step would convert the file from step 12 directly to polygon features, however, there were errors in the processing so a new method was developed. Instead, use the *Conversion->From Raster->Raster to polyline* tool to convert the flood elevation data from a raster to a set of polylines.
14. Use the *Data Management->Features->Feature to Polygon* tool to convert the polyline feature to a polygon.
15. Use the *Data Management->Generalization->Dissolve* to dissolve the separate polygons into one continuous feature. (Do not select any fields to dissolve on)
16. Use the *Data Management->General->Merge* tool to merge the polygon layer from step 15 with the current FEAM flood layer. This step ensures that the future flood layer does not have lower elevations than the base flood layer, which is possible given the error contained in the flood estimation process.
17. Use the *Analysis Tools->Extract->Clip* tool where the input is the layer from step 16 and the 2100 flood layer is the clip layer. This ensures the new flood layer does not exceed the maximum extent of the 2100 layer.

Threats Analysis Process

The steps for running the threats model:

1. Open GIS map
2. Data management – right click add fields to the original species layer (to add multiple fields click batch)
    a. Add area_m (field type is double)
    b. Calculate area using calculate geometry
3. Intersect the polygon layer with each threat: analysis tools – overlay – intersect
    a. Select the polygon and the threat layer, name threat_int
        i. Everything else is left as preset
4. Data management – generalization – dissolve
    a. Input is intersect layer
    b. Dissolve by EO_ID
5. Data management – right click add fields (to add multiple fields click batch)
    a. Add area of threat
    b. Calculate area using calculate geometry
6. Join on dissolved, from table
    a. 1 is EO_ID
    b. 2 is species layer
    c. 3 is EO_ID
    d. Keep all records (auto index is ok)
7. Calculate total area of threat using field geometry
    a. Summarize threat area by species (select sum)
    b. Save as dBASE table
8. Open attribute table for original species occurrence layer
    a. Right click on species name field, go to summarize
        i. Select area field and click sum (area of all occurrences of each species)
    b. Save as dbf (and put .dbf after name)

Outside of GIS, in excel or other statistical software:

1. Import data on area of threat for each species, total area for each species, and number of occurrences for each species.
    a. Calculate percent area affected and percent of occurrences affected

Model Builder Model

Model 1 Process

1. Open “IntersectDissolve” Model
2. Add threat layer and occurrence polygon to Occurrence/Threat Intersect
3. Specify the location and file name in “Threat_year_diss.shp” text box as “the threat”_”the year”_”diss”. This will be the output of the model.
4. Specify the location and file name in “Threat_year_int.shp” text box as “the threat”_”the year”_”int”.
5. Click “Ok”

Model 2 Process

1. Open “Add_calc_field” Model
2. Add “Threat_year_diss.shp” from Model 1 to text box.
3. Click “Ok”

To analyze multiple species or multiple threats at one time, the “Batch” process can be used.

Batch Process for Model 1

1. Right click on “IntersectDissolve” Model and select “Batch”
2. Add inputs and output file names for each threat and species according to directions above.

Batch Process for Model 2

1. Right click on “Add_calc_Field” Model and select “Batch”
2. Add “Threat_year_diss.shp” to model input, add all “threat_year_diss.shp” files from Batch Process for Model 1 into separate rows.

Appendix IV: Data from SLR Threats Analysis

Table 3: Data on 9 species for detailed analysis.

Species Name	Total Area (m^2)	Number of Extant Occurrences
A. paludicola	26,931.67	2
A. pycnostachyus	22,338.39	1
C. ambigua	2,021,920	3
C. maritimum	1,764,295	12
C. scariosum	2,159,364	16
D. maritima	1,434,770	12
L. nipomensis	480,136.1	6
N. gambelii	20,105.74	1
S. maritima	1,341,273	11

Table 4: Area and occurrences threatened for extant occurrences of 9 species.

		Area Threatened (m^2)			Occurrences Threatened		
Threat	**Species**	**2025**	**2050**	**2100**	**2025**	**2050**	**2100**
Inundation	*C. ambigua*	5,642.4	5,767.1	8,284.1	1	1	2
	C. maritimum	363,547.5	371,326.0	1,148,346.7	9	9	11
	C. scariosum	0.0	0.0	7,105.1	0	0	2
	D. maritima	81,782.2	89,104.1	139,627.2	5	5	6
Flooding	*C. ambigua*	37,215.9	37,215.8	58,390.9	2	2	3
	C. maritimum	1,497,526.3	1,502,196.1	1,512,148.2	11	11	11
	C. scariosum	246,049.1	262,569.0	443,993.3	2	2	2
	D. maritima	258,987.7	261,399.7	337,738.9	6	6	7
Dune Erosion	*C. ambigua*	0.0	0.0	0.0	0	0	0
	C. maritimum	3,544.5	5,500.8	15,026.5	1	1	1
	C. scariosum	22,511.0	29,541.7	57,953.1	1	1	1
	D. maritima	458,266.6	483,591.7	566,565.5	6	8	8
Cliff Erosion	*C. ambigua*	0.0	0.0	0.0	0	0	0
	C. maritimum	0.0	0.0	0.0	0	0	0
	C. scariosum	0.0	0.0	0.0	0	0	0
	D. maritima	286.2	748.2	2,066.3	1	1	1
All Threats	*C. ambigua*	37,215.8	42,086.0	63,315.1	2	2	3
	C. maritimum	1,497,526.3	1,596,748.5	1,620,327.7	11	12	12
	C. scariosum	246,049.1	289,600.4	498,129.3	2	2	2
	D. maritima	258,987.6	596,237.6	712,144.9	6	9	9

Table 5: Data on 9 species for detailed analysis, extirpated occurrences only. See section on Comparison of Threat Extent to Extant and Extirpated Occurrences for more information.

Species	Total Area (m^2)	Number of Occurrences
A. paludicola	5,273,923.4	9
A. pycnostachyus	2,238,490.7	2
C. ambigua	6,044,136.3	2
C. maritimum	15,802,757.0	3
C. scariosum	4,168,825.1	1
D. maritima	1,130,890.9	1
L. nipomensis	16,448,474.3	8
S. maritima	0	0

Table 6: Area and occurrences threatened for extirpated occurrences of 9 species.

Threat	Species	Area Threatened 2025	2050	2100	Occurrences Threatened 2025	2050	2100
Inundation	*A. paludicola*	26,850.4	-	91,557.1	1	-	1
	A. pycnostachyus	382,234.6	-	588,662.9	1	-	2
	C. maritimum	755,221.7	-	1,154,926.8	2	-	2
	C. scariosum	36,074.9	-	89,839.7	1	-	1
	D. maritima	26,850.4	-	91,557.1	1	-	1
	N. gambelii	68,993.5	-	187,261.7	1	-	1
Flooding	*A. paludicola*	445,535.3	605,129.0	722,430.4	1	1	1
	A. pycnostachyus	1,322,841.8	1,339,738.0	1,376,266.7	2	2	2
	C. maritimum	2,669,374.1	2,753,588.4	3,061,153.5	2	2	2
	C. scariosum	603,391.0	637,147.4	718,980.3	1	1	1
	D. maritima	445,535.3	605,129.0	722,430.4	1	1	1
	N. gambelii	830,002.5	898,294.3	1,579,487.0	2	2	2
Dune Erosion	*A. paludicola*	345,771.1	384,986.7	545,027.3	1	1	1
	A. pycnostachyus	0	0	0	0	0	0
	C. maritimum	0	0	0	0	0	0
	C. scariosum	183,645.6	206,150.1	293,502.9	1	1	1
	D. maritima	345,771.1	384,986.7	545,027.3	1	1	1
	N. gambelii	152,898.2	172,255.9	252,651.4	1	1	1
Cliff Erosion	*A. paludicola*	0	0	0	0	0	0
	A. pycnostachyus	0	0	0	0	0	0
	C. maritimum	0	0	0	0	0	0
	C. scariosum	0	0	0	0	0	0
	D. maritima	0	0	0	0	0	0
	N. gambelii	0	0	0	0	0	0
All	*A. paludicola*	-	-	1,032,774.9	-	-	1
	A. pycnostachyus	-	-	1,558,904.1	-	-	2
	C. maritimum	-	-	3,458,763.8	-	-	2
	C. scariosum	-	-	914,351.3	-	-	1
	D. maritima	-	-	1,032,774.9	-	-	1
	N. gambelii	-	-	1,665,958.0	-	-	2

** Castilleja, Lupinus, and Sanicula experienced no threat from SLR for any extirpated occurrences.