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ASSESSING RANGE SHIFTS OF COASTAL SPECIES TO INFORM CONSERVATION IN A KEY CALIFORNIA BIOGEOGRAPHIC TRANSITION ZONE

Technical Documentation

A Capstone Project submitted in partial satisfaction of the requirements for the degree of
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The Capstone Project is required of all students in the Master of Environmental Data Science (MEDS) Program. The project is a six-month-long activity in which small groups of students contribute to data science practices, products or analyses that address a challenge or need related to a specific environmental issue. This MEDS Capstone Project Technical Documentation is authored by MEDS students and has been reviewed and approved by:

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ABSTRACT

Point Conception, located within the Dangermond Preserve, is one of California's most prominent ecological transition zones, marking a major boundary between northern and southern marine ecoregions. Its unique position at the intersection of two major currents creates a steep gradient in oceanographic and ecological conditions, acting as a natural barrier to the range expansions of many marine species. Rocky intertidal species are vulnerable to climate change-induced habitat changes, including ocean acidification, rising sea levels, changes in water temperature, and more frequent and intense storms. Species ranges are expected to shift in response to a changing climate; however, it is not known how biogeographic barriers, such as Point Conception, might affect or constrain such shifts. Currently, there is no comprehensive understanding of the ranges of intertidal species found in or near the Point Conception region. Using long-term ecological survey data from the MARINe network, this project located species range boundaries along the California coast and identified species with boundaries at or near Point Conception. Additionally, by incorporating current and projected environmental variables into a species distribution model, the project characterized potential species range shifts within the Point Conception region. In collaboration with The Nature Conservancy's Dangermond Preserve, an interactive dashboard was developed displaying current and possible future ranges of a variety of key intertidal species, which will be used both by conservation scientists and by donors and community members to understand the preserve's unique ecological significance. By improving data accessibility and visualization, the dashboard supports more effective conservation planning and environmental decision-making.

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1. EXECUTIVE SUMMARY

Background and Motivation

Point Conception, located within the Jack and Laura Dangermond Preserve, is one of California's most prominent ecological transition zones. It serves as a critical boundary between the state's northern and southern marine ecoregions, shaped by the convergence of two major ocean currents (Dawson, 2001; Doyle, 1985; Miller, 2023). This dynamic intersection creates a steep gradient in oceanographic and ecological conditions, forming a natural barrier that limits the range expansions of many marine species (Fredston-Hermann et al., 2018). A species' range, or the geographic area where it can survive and reproduce, is determined by a complex combination of environmental and physiological factors. When these conditions change, species may be forced to shift their ranges in order to persist. This process, known as a range shift, is especially relevant in the face of climate change, which is rapidly altering marine habitats. Rocky intertidal species are particularly susceptible to these changes, including ocean acidification, sea level rise, temperature fluctuations, and the increasing frequency and intensity of storms (Helmuth, 2006). Although it is well established that species ranges shift in response to climate stressors, the extent to which geographic features like Point Conception influence or impede these shifts remains uncertain (Bates et al., 2014).

The Jack and Laura Dangermond Preserve, acquired by The Nature Conservancy (TNC) in 2017, spans 24,460 acres along California's coastline. Managed by TNC, a nonprofit organization dedicated to environmental conservation, the Preserve encompasses a rich diversity of habitats and is home to more than 1,500 species of plants and animals (The Nature Conservancy, 2020). Point Conception, situated within the Preserve, represents one of the most significant marine biogeographical landmarks on the coast (Fredston-Hermann et al., 2018). Recognized as a vital migratory corridor, the Preserve plays a key role in TNC's conservation strategy to protect one of the last remaining stretches of undeveloped coastline in the state.

Problem Statement

California's coastal intertidal biodiversity is increasingly vulnerable to climate change impacts, yet conservation professionals have few tools to forecast these changes effectively. While there is a general understanding of species richness in California, there has yet to be an analysis of intertidal species ranges along the coastline and how they may change under different climate scenarios. Through our partnership with The Nature Conservancy, this project applies data science methodologies to analyze potential shifts in species ranges, serving as an early stepping stone towards understanding how intertidal communities may respond to climate change.

Objectives

This capstone project has been developed to enhance coastal conservation planning by analyzing intertidal species range shifts and presenting the findings through an interactive platform.

This project is broken into three main objectives:

1. Identify and map rocky shore species' range edges along California's coast,
2. Characterize and predict potential species range shifts occurring within the Point Conception region
3. Establish a ranking system to prioritize monitoring for coastal range expansions or retractions within the Dangermond Preserve.

Methods

To evaluate how rocky intertidal species ranges are shifting across California's coastline, we used long-term biodiversity data from the Multi-Agency Rocky Intertidal Network (MARINe) and environmental variables from the Bio-ORACLE database. We first divided the coast into 100 km segments and identified species' northern and southern range edges, focusing on those near Point Conception. Contemporary range shifts were assessed using five-year intervals from 2000–2024, applying cumulative distribution functions and generalized additive models (GAMs) to track movement of species' core ranges over time. Projected future shifts were modeled using species distribution models (SDMs) under a mid-range climate scenario (SSP 4.5) for the year 2050. Finally, we developed a range shift potential assessment to identify species most likely to experience range expansions or contractions at Point Conception, helping prioritize future monitoring efforts.

Deliverable

The culmination of this project is an interactive web application, the California Ranges of Intertidal Species Portal (CRISP), hosted by The Nature Conservancy on the Dangermond Geospatial Hub. CRISP integrates all analytical components into an accessible platform that allows users to explore maps of northern and southern species range edges along the California coastline. Users can interactively view the number and identity of species present in each coastal segment, examine results from the contemporary range shift analysis, and explore current and projected habitat suitability maps. The application also synthesizes findings across analyses to assign vulnerability scores to each species, helping inform monitoring priorities. CRISP supports The Nature Conservancy's conservation planning at the Dangermond Preserve and provides a scalable tool for managing intertidal biodiversity under climate change.

Results and Conclusions

By analyzing rocky shore species' range edges along California's coast, we identified several species with range edges in California, particularly around Point Conception. A total of 248 species were found to have a range edge within California, and 59 of these had either a northern or southern range edge near Point Conception. Of those 59 species, 23 had a southern range edge extending out of Point Conception, while 14 had a northern range edge extending into it. The remaining 22 species did not show a clear directional trend at their range boundaries.

When examining the results of the difference between current and projected future habitat suitability, the data suggest a coastwide decline in suitable habitat. On average, species are projected to experience a 28.7% reduction in modeled habitat suitability by mid-century.

This projected loss of suitable habitat highlights the urgent need for targeted conservation strategies. Species with declining habitat suitability, particularly those with range edges near Point Conception, may face increased vulnerability to climate change. These findings can inform proactive monitoring and management efforts, helping to prioritize regions and species most at risk and guide adaptive conservation planning along California’s dynamic coastline.

Executive Summary References:

Bates, A. E., Pecl, G. T., Frusher, S., & others. (2014). Defining and observing stages of climate-mediated range shifts in marine systems. *Global Environmental Change, 26*, 27–38. https://doi.org/10.1016/j.gloenvcha.2014.03.009

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The Nature Conservancy. (2020). The Jack and Laura Dangermond Preserve. *The Nature Conservancy.* https://www.nature.org/en-us/about-us/where-we-work/united-states/california/stories-in-california/dangermond-preserve/

2. APPROACH

The analysis proceeded in three phases. First, we identified the northernmost and southernmost observations for each species in the MARINE dataset to define their range edges, and selected species with a range edge within 100 km of Point Conception. Second, we analyzed temporal trends in species distributions using a normalized abundance model, which captured shifts in the central tendency of species' ranges from 2000 to 2024. Finally, we developed species distribution models (SDMs) for species with northern range edges near Point Conception, using presence–absence data from the MARINE dataset and environmental predictors from Bio-ORACLE. For each species, we constructed multiple SDMs using a suite of algorithms and synthesized them into an ensemble SDM (ESDM). These models were used to project future habitat suitability in 2050 under a moderate emissions scenario (SSP2-4.5). Results from all three phases were combined to generate a range shift potential assessment, which assigns a priority monitoring score for species most likely to undergo coastal range expansions or contractions within the Dangermond Preserve. These findings are presented in the CRISP Shiny dashboard hosted by The Nature Conservancy.

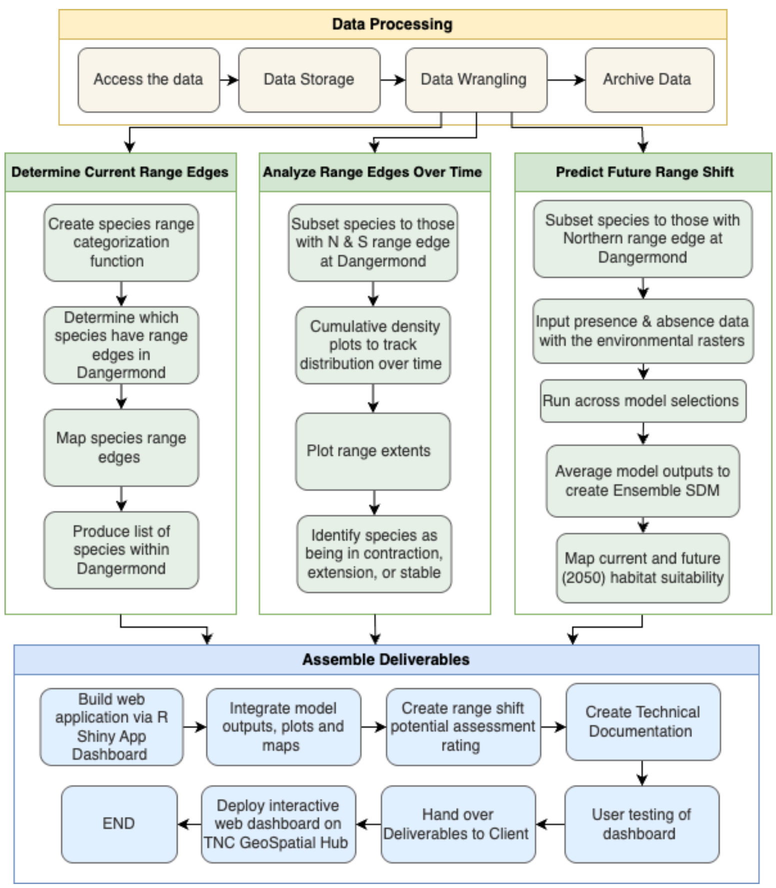

Figure 1. Workflow diagram illustrating the steps used to complete the project. The process begins with data processing, followed by a series of analytical steps: determining current range edges, analyzing changes in range edges over time, and predicting future range shifts. The final step involves compiling the results into a web application.

3. METHODS

3.1 Data

The intertidal species survey data, which form a key component of our analyses, come from the Multi-Agency Rocky Intertidal Network (MARINe) Biodiversity Survey dataset. This data set was designed to provide information on the structure and dynamics of rocky intertidal communities along the Pacific Coast of North America. The data, spanning the years 2000–2024, was accessed by our client, Dr. Erica Nielsen, through a formal data request. Prior to analysis, species not of concern and substrate elements were filtered out of the datasets.

The environmental variables used in the species distribution models were obtained from Bio-ORACLE, a global dataset of raster layers providing modelled geophysical, biotic, and environmental information for surface and benthic marine realms. These data have a spatial resolution of 0.05 degrees and are available in 10 decadal time steps from 2000 to 2100. Data files were accessed using the R package *'biooracler'*, and, following the advice of the client, five environmental variables were selected for model input: mixed layer depth, cloud cover, salinity, ocean temperature, and dissolved oxygen. The future projections used in the analysis included the target year 2050 and are based on the Shared Socioeconomic Pathway (SSP) 4.5 - a "middle-of-the-road" emissions scenario. The code to download this data and the specific file names can be found within this script on our project GitHub repository.

In addition, a series of spatial datasets were used to produce the maps featured on the project's web dashboard. These are further detailed in Table 1.

Table 1. Data Summary

Dataset Name	File Type	Source and Citation	Content	Use
MARINe biodiversity data	.csv, .xlsx	MARINe acquired via The Nature Conservancy and Dr. Erica Nielsen. (data request, early 2025) marine.ucsc.edu (2024). Coastal Biodiversity Surveys | MARINe. [online] Available at: /contact/data-request-form [Accessed 8 Jan. 2025].	Raw biodiversity data, including its own metadata tab, point contact data for transects, quadrats, and swaths. Metadata on species taxonomy.	Range edge categorization, range shift analysis, habitat suitability maps, Web dashboard
California Boundary	.csv, .shp, .dbf, .cpg, .prj, .shx	US Census Bureau TIGER/Line Shapefiles	Boundary of the California Coastline	Range edge map
Coastline Segments	.csv	Acquired via The Nature Conservancy and Dr. Erica Nielsen. (Created, early 2025)	100 km coastline segments of the California Coastline	Range edge map

Dataset Name	File Type	Source and Citation	Content	Use
Dangermond Preserve Simple Boundary	.csv, .shp, .dbf, .cpg, .prj, .shx	Dangermond Preserve Geospatial Hub	Boundary of the Jack and Laura Dangermond Preserve.	Range edge map
Environmental Rasters	.tif	Bio-ORACLE	Bathymetry and abiotic factor data	Habitat suitability maps

3.2 Range Edge Categorization

To analyze current species' ranges, we first divided the California coastline into segments. Starting from the Government Point MARINe site (1.72 km southeast of Point Conception), we iteratively measured 100 km north and south along the coastline, continuing until reaching the northern and southern borders of California. We then grouped marine sites within each segment. This was to account for any sampling inconsistencies within individual sites.

Each resulting segment was labeled based on distinctive geographic or ecological features. Two focal segments—100 km north and 100 km south of Point Conception—were identified as segments of interest, referred to as northern and southern Point Conception, respectively. These focal segments encompass 16 MARINe sites in total (7 northern, 9 southern); across the state, site counts per segment range from 2 to 12.

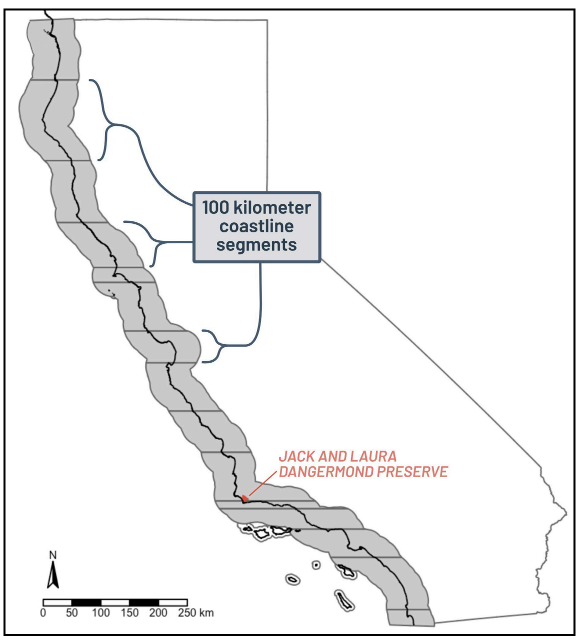

Figure 2. Map of California divided into 100-kilometer coastal segments, used to group intertidal sampling sites. This segmentation groups sampling sites to better account for variation in sampling year and was used in the range categorization analysis. The location of the Jack and Laura Dangermond Preserve is also highlighted in red.

Following guidance from our client, we defined a species' range edges as the northernmost and southernmost coastline segments where it has ever been observed in our dataset. A species was considered present at a MARINe site if it had been observed there at any point in time. The northern range edge was defined by the maximum latitude of observed presence, and the southern range edge by the minimum latitude. These range edge sites were then categorized into the previously defined coastline segments. Species with range edges falling within the northern or southern Point Conception segments are included in our Contemporary Range Shifts (Sec. 3.3) and Projected Range Shifts (Sec. 3.4).

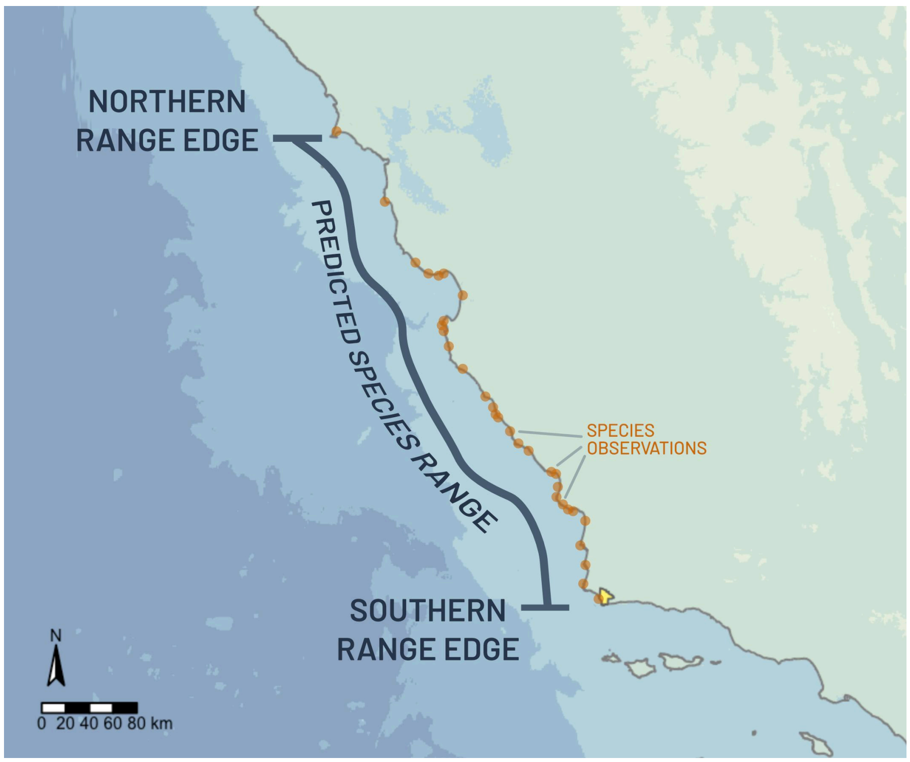

Figure 3. Diagram illustrating how a predicted species range is quantified along the coastline. The species range is defined by connecting the northernmost and southernmost observations, with each most northernmost and southernmost observations representing a range edge.

3.3 Contemporary Range Shifts

In the previous analysis, the absolute ranges were calculated for each species in the entire 25-year dataset. However, this next analysis looked at how species ranges change over time. Due to inconsistent annual site sampling, we modeled the species distribution in 5-year time chunks. We then took the "core range" by using the 95th and 5th percentiles from this distribution and identified them as the northern and southern boundaries, respectively. This was to remove any possible noise that could have arisen from rare observations outside this "core range". From these core range boundaries, we looked to see how the boundaries move over time.

3.3.1 Spatial Coastline Distributions

We employed a cumulative distribution function (CDF) approach to model species distributions along the California coastline. Because the coastline is not linear and trends east-west in places, we used distance along the coastline from the southern California border rather than latitude to track these ranges.

Because sites were not sampled annually, we were unable to estimate annual distributions. Instead, we divided the dataset into five-year intervals:

- 2000–2004
- 2005–2009
- 2010–2014
- 2015–2019
- 2020–2024

For each species within each interval, we implemented a normalization procedure:

- Our "density" variable was either the density per meter squared (from swath or quadrat collection methods) or percent cover (from the point contact collection method).
- If a site was sampled more than once in the interval, the mean density across years was calculated.
- Starting at the southernmost site, the mean densities were cumulatively summed to create a cumulative density distribution: at each site, the value represents the density at that site plus the summed densities at all sites further south.
- Cumulative densities were divided by the value at the northernmost site, creating a cumulative distribution function that ranges between zero and one.

The cumulative distribution is more easily modeled and visualized than the raw distribution of densities at each site. If the species has been moving northward over time, then we expect to see a directional translation of the cumulative distributions from one time period to the next.

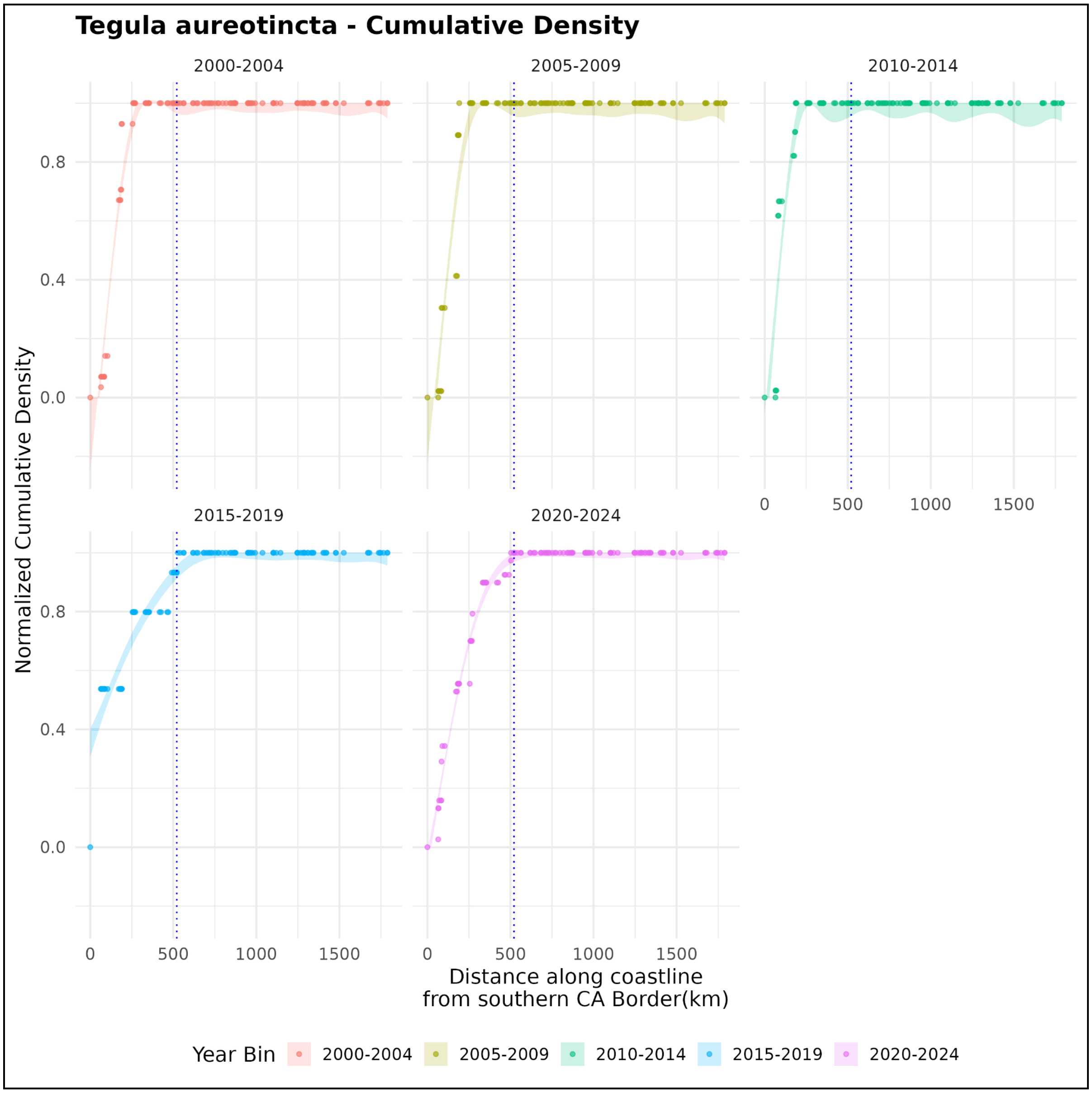

Figure 4: Example cumulative density plot for a species with a northern range edge at Point Conception. Density is normalized from 0 to 1 and increases stepwise with distance (in kilometers) along the California coastline, starting from the southern border.

3.3.2 Core Range Predictions

Each of the empirical CDFs was fit with a generalized additive model (GAM), which was used to approximate the locations of the 95th and 5th percentiles of species distribution along the California coastline. We define this as the species' core range. These percentiles serve as quantitative indicators of the northernmost and southernmost range edges, respectively, of the core range (in which most of the population is found). We then asked whether either of these had identifiable trends over time.

Species of particular ecological concern are identified using two criteria:

1. The northern edge has a northward-moving trend
2. The southern edge has a northward-moving trend

A linear model was run on all northern and southern range edges of species with a range edge within the Point Conception region (Results, Table 3). If a species was found to have a slope of at least 4 km/yr (one coastline segment over the 25 years), we classified these as northward-moving boundaries. This analytical approach helps identify whether an intertidal species' range has already shifted along the coastline, which informs our estimates of its potential risk of shifting in the future.

3.4 Projected Range Shifts

This analysis focused on intertidal species with a northern range edge located within the coastal segments nearest to Point Conception. These species were selected to evaluate how projected environmental changes may alter suitable habitat distribution. The goal was to model current habitat suitability using presence-absence data from the MARINe Coastal Biodiversity Survey and predict future suitability under a projected climate scenario (Shared Socioeconomic Pathway - 4.60). This approach indicates whether species may face a contraction, expansion, or change of suitable habitat, signaling potential range shifts. The model incorporates only environmental predictors and excludes factors such as physiology, behavior, dispersal, and species interactions, which have been shown to play an important roles in the viability of suitable habitat for intertidal species (Pinsky et al. 2020).

Environmental variables are sourced from the Bio-ORACLE database. Baseline conditions use mean values from 2000 to 2010, while future projections use averages from 2050 to 2060. Rasters were cropped to the California coastline with a 20-kilometer buffer to constrain predictions to areas relevant to intertidal species distributions.

Species distribution models (SDMs) were constructed using the R package '*SSDM*', which handles environmental data input, model fitting, and performance evaluation. An ensemble approach averages predictions from multiple model algorithms to improve accuracy. The models included in the ensemble are listed in Figure 5. The consensus method applied is a weighted average, with weights based on model accuracy.

Final outputs include continuous habitat suitability maps with values ranging from 0 to 1, representing relative habitat suitability across the study area for both the present day and 2050. A change detection map, with values ranging from -1 to 1, is produced by comparing baseline and future suitability, highlighting areas projected to become unsuitable over time.

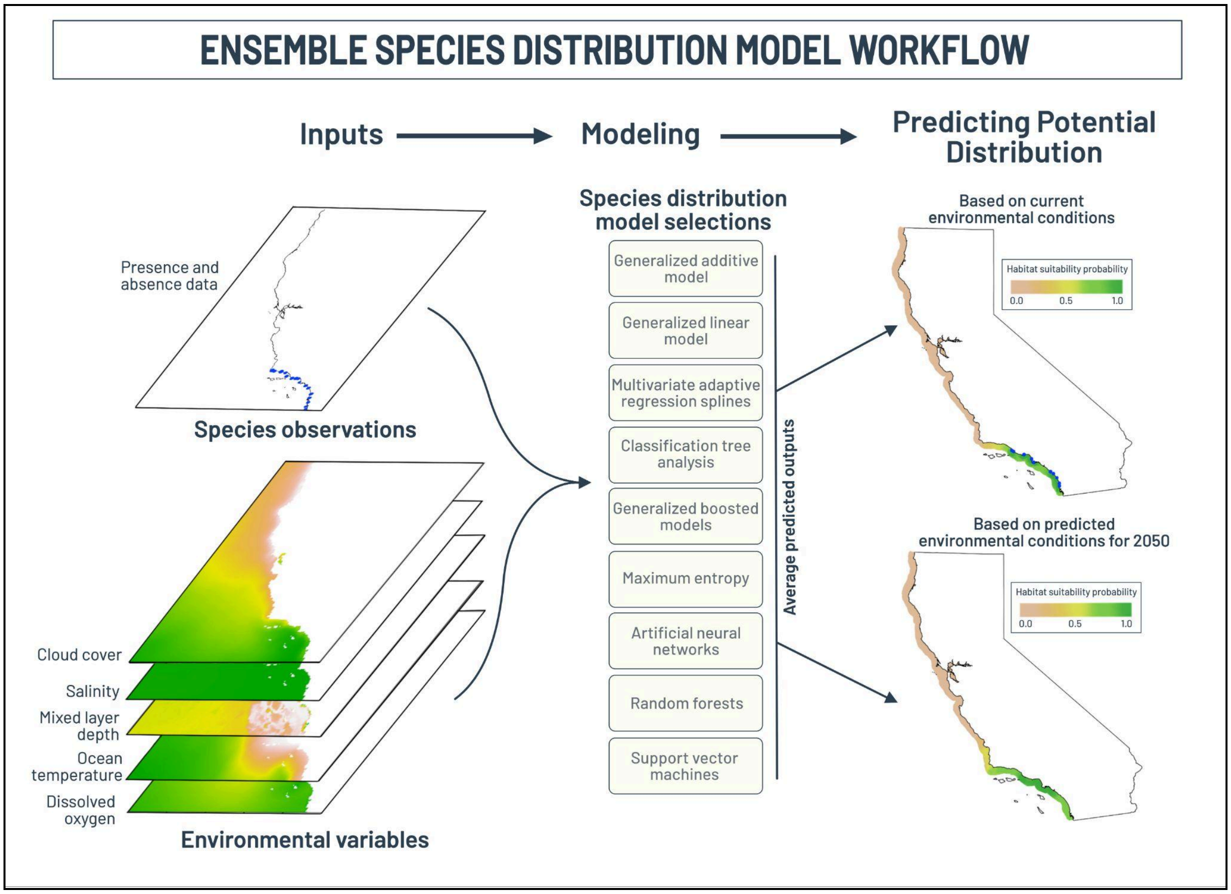

Figure 5. Workflow of the Ensemble Species Distribution Modeling (ESDM) approach. Presence-absence data from the MARINe Biodiversity dataset and environmental variables (cloud cover, salinity, mixed layer depth, ocean temperature, and dissolved oxygen) from Bio-ORACLE serve as model inputs. Seven modeling algorithms are used to generate individual species distribution models. The resulting outputs are averaged to produce ensemble habitat suitability maps under two scenarios: one based on historical/current environmental conditions and one projecting future habitat suitability under expected environmental changes.

3.5 Range shift potential assessment

To synthesize the previous analyses, a range shift potential assessment assigns a score based on two ecological processes, range expansions into and contractions out of the Point Conception region. Lower scores indicate higher priority for monitoring potential range shifts. This assessment will only be done on species identified as having a northern range edge in the Point Conception buffer.

The range shift potential assessment will be utilized by the Nature Conservancy to understand which species are of most concern to the current intertidal ecosystems of the Dangermond Preserve. With this list of species, the organization will be able to create species monitoring plans, inform future conservation efforts, and move to improve the health of Dangermond's rocky intertidal.

Table 2. Range shift potential assessment value system

Range expansions into Point Conception:	**Range contractions out of Point Conception:**
Northern Range Edge within Point Conception: +1 **(required)**	Southern Range Edge within Point Conception: +1 **(required)**
Northward trend in the species' core range northern boundary: +1	Northward trend in the species' core southern boundary: +1
Increased habitat suitability predicted at 2050 within Point Conception: +1	Decreased habitat suitability predicted at 2050 within Point Conception: +1

3.6 Interactive Web Application

The interactive web application was tested using the `*shinytest2*` R package, which allows for manual testing of the Shiny dashboard to enhance user engagement. This R package automated the testing of our Shiny app by simulating user interactions and verifying that the app's outputs were as expected. It integrated with `testthat` and employed a headless browser for reliable end-to-end testing.

Deployment / Hosting

The interactive web application is hosted on the Dangermond Preserve Geospatial Hub. It is designed to assist the client in conservation planning efforts and facilitate scientific communication. The client will be responsible for the maintenance of this web application, which will be detailed in our reproducible workflow framework for analyzing new static datasets.

RESULTS REPORT

Range Edge Categorization

By utilizing the methods under Range Edge Categorization, we have found a series of species with range edges in California and Point Conception. From the 396 species analyzed, 248 were found to have a range edge within California, while 59 were found to have a range edge within Point Conception. Those species are listed in Table 3. A map that colors the coastline segments by the number of range edges within each, separated by northern range edges and southern range edges (Figure 6), highlights the high number of range edges near Point Conception compared to the rest of the California coastline.

Table 3. List of species identified as having a northern range edge or southern range edge within the Point Conception coastal segments.

SOUTHERN RANGE EDGE			NORTHERN RANGE EDGE		
	SCIENTIFIC NAME	**COMMON NAME**		**SCIENTIFIC NAME**	**COMMON NAME**
1	*Acmaea mitra*	Whitecap limpet	1	*Acanthinucella paucilirata*	Checkered Unicorn
2	*Aglaophenia spp*	Hydroid species	2	*Acrosorium spp*	Genus of red algae
3	*Ahnfeltiopsis linearis*	Flattened Ahnfelts Seaweed	3	*Aplysia californica*	California Seahare
4	*Amphissa columbiana*	Wrinkled Amphissa	4	*Bugula neritina*	Brown Bryozoan
5	*Analipus japonicus*	Bottlebrush Seaweed	5	*Chondria arcuata*	Species of red algae
6	*Calliostoma annulatum*	Jeweled Top Snail	6	*Chondria dasyphylla*	Species of red algae
7	*Calliostoma canaliculatum*	Channeled Topsnail	7	*Dictyota coriacea*	Species of brown algae
8	*Calliostoma ligatum*	Blue-Ringed Top Snail	8	*Gastroclonium parvum*	Species of red algae
9	*Chone minuta*	Minute Feather-Duster	9	*Haminoea vesicula*	Blister Glassy-Bubble
10	*Cirolana spp/Gnorimosphaeroma oregonense*	Cirolana spp/ Oregon Pillbug	10	*Jania rosea*	Species of coralline algae
11	*Coryphella trilineata*	Three-lined Aeolid	11	*Laurencia spp*	Genus of red algae
12	*Cryptochiton stelleri*	Gumboot Chiton	12	*Macron lividus*	Livid Macron
13	*Cryptosiphonia woodii*	Bleached Brunette	13	*Nemalion elminthoides*	Sea Noodle
14	*Derbesia marina*	Silky thread weed	14	*Norrisia norrisii*	Norris's Topsnail
15	*Desmarestia ligulata*	Flattened Acid Kelp	15	*Opalia wroblewskyi**	Boreal Wentletrap
16	*Dilsea californica*	Species of algae	16	*Paraxanthias taylori*	Lumpy Rubble Crab
17	*Diodora aspera*	Rough Keyhold Limpet	17	*Pseudochama exogyra*	Reversed Chama
18	*Fucus spp*	Genus of brown algae	18	*Pseudomelatoma penicillata*	Doleful turrid
19	*Halichondria spp*	Genus of sea sponge	19	*Roperia poulsoni*	Poulson's Dwarf Triton
20	*Halosaccion glandiforme*	Sea Sacks	20	*Sargassum agardhianum*	Species of brown algae
21	*Halymenia/Schizymenia spp*	Genus of red algae	21	*Taonia lennebackerae*	Species of brown algae
22	*Haplogloia andersonii*	Species of brown algae	22	*Tegula aureotincta*	Gilded Tegula

SOUTHERN RANGE EDGE			NORTHERN RANGE EDGE		
23	*Henricia spp*	Genus of sea star	23	*Zonaria farlowii*	Banded Fanweed
24	*Laminaria setchellii*	Southern Stiff-striped Kelp			
25	*Laminaria sinclairii*	Dense-clumped Kelp			
26	*Lottia asmi*	Black Limpet			
27	*Neoptilota/Ptilota spp*	Genus of red algae			
28	*Neorhodomela larix*	Black Pine Seaweed			
29	*Neorhodomela oregona*	Species of red/brown algae			
30	*Onchidella carpenteri*	Leather Limpet			
31	*Opalia wroblewskyi**	Boreal Wentletrap			
32	*Pelvetiopsis arborescens/limitata*	Dwarf rockweed			
33	*Semibalanus cariosus*	Thatched Barnacle			
34	*Spirobranchus spinosus*	California Christmas Tree Worm			
35	*Styela montereyensis*	Long-stalked Sea Squirt			
36	*Tegula brunnea*	Brown Tegula			
37	*Ulothrix spp*	Genus of green algae			

* Species only found within Point Conception coastal segments along California Coast

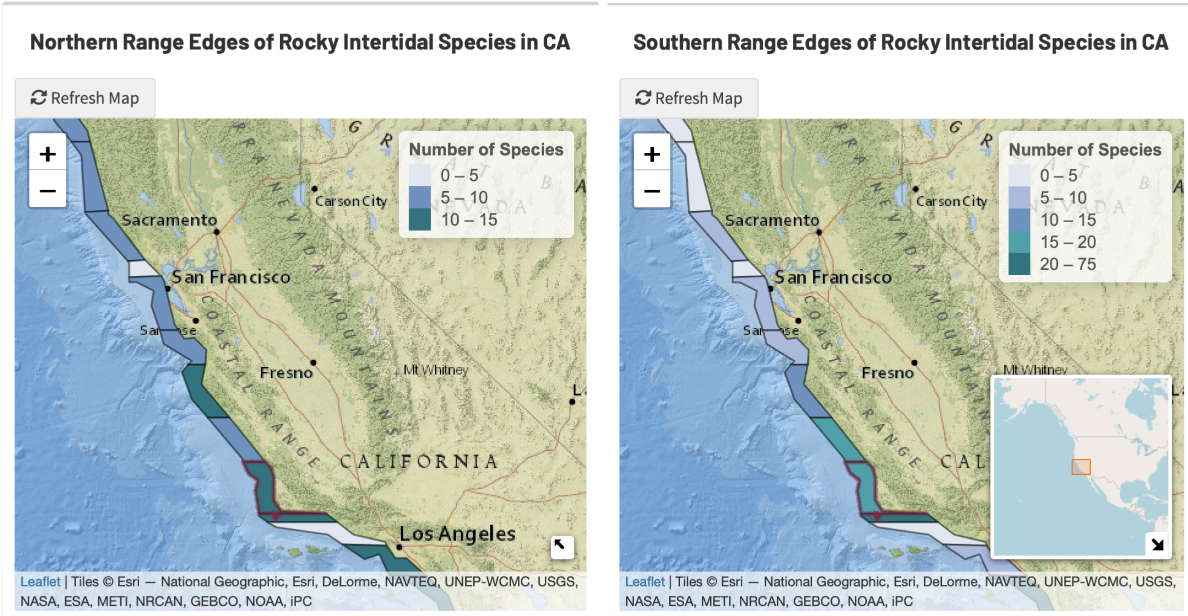

Figure 6: Rocky intertidal species' northern and southern range edges across the CA coastline, aggregating MARINe survey sites in 100 *km* coastal segments, highlighting Point Conception as a biodiversity hotspot.

Contemporary Range Shifts

We used the methods in Contemporary Range Shifts to analyze how the 59 species with range edges found within Point Conception trend over time. We found that 18 species have a southern range edge moving out of Point Conception, and 14 have a northern range edge moving into Point Conception. The other 27 species analyzed did not exhibit an overall trend at their northern or southern boundaries. An example of the output of this analysis in plot form is found in Figure 7.

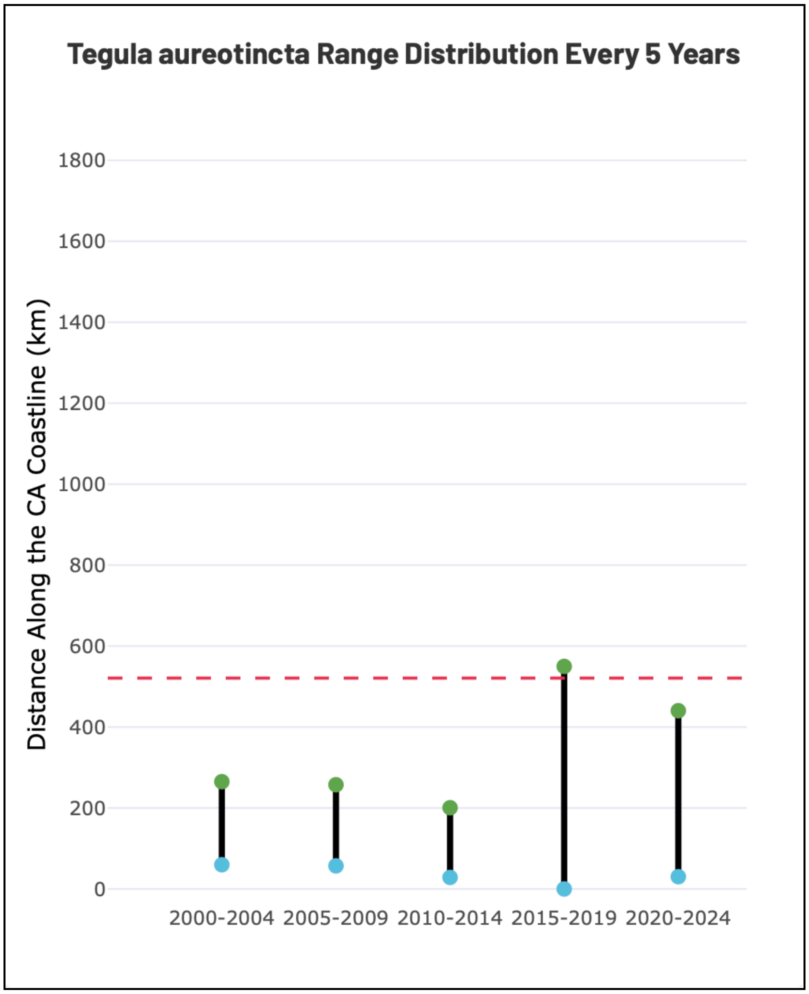

Figure 7: Example core range plot for *Tegula aureotincta,* a species with a northern range edge at Point Conception. Northern (green dot) and southern boundaries (blue dot) are represented by the 95th and 5th percentile eCDF approximation of the GAM models. The distance along the coast begins at the California-Mexico border (0 km), and the red dashed line represents Point Conception (520 km).

Table 4. List of species that were identified as having northward shifts in either range edge found in the Point Conception region.

NORTHWARD SHIFT					
Southern Range Edge			**Northern Range Edge**		
	SCIENTIFIC NAME	**COMMON NAME**		**SCIENTIFIC NAME**	**COMMON NAME**
1	*Ahnfeltiopsis linearis*	Flattened Ahnfelts Seaweed	1	*Aplysia californica*	California Seahare
2	*Calliostoma annulatum*	Jeweled Top Snail	2	*Bugula neritina*	Brown Bryozoan

NORTHWARD SHIFT					
Southern Range Edge			Northern Range Edge		
3	*Calliostoma canaliculatum*	Channeled Topsnail	3	*Chondria arcuata*	Species of red algae
4	*Cryptosiphonia woodii*	Bleached Brunette	4	*Chondria dasyphylla*	Species of red algae
5	*Derbesia marina*	Silky thread weed	5	*Gastroclonium parvum*	Species of red algae
6	*Dilsea californica*	Species of algae	6	*Haminoea vesicula*	Blister Glassy-Bubble
7	*Diodora aspera*	Rough Keyhold Limpet	7	*Jania rosea*	Species of coralline algae
8	*Fucus spp*	Genus of brown algae	8	*Nemalion elminthoides*	Sea Noodle
9	*Halosaccion glandiforme*	Sea Sacks	9	*Norrisia norrisii*	Norris's Topsnail
10	*Haplogloia andersonii*	Species of brown algae	10	*Paraxanthias taylori*	Lumpy Rubble Crab
11	*Neoptilota/Ptilota spp*	Genus of red algae	11	*Pseudochama exogyra*	Reversed Chama
12	*Neorhodomela oregona*	Species of red/brown algae	12	*Roperia poulsoni*	Poulson's Dwarf Triton
13	*Onchidella carpenteri*	Leather Limpet	13	*Taonia lennebackerae*	Species of brown algae
14	*Pelvetiopsis arborescens/limitata*	Dwarf rockweed	14	*Tegula aureotincta*	Gilded Tegula
15	*Semibalanus cariosus*	Thatched Barnacle			
16	*Spirobranchus spinosus*	California Christmas Tree Worm			
17	*Styela montereyensis*	Long-stalked Sea Squirt			
18	*Ulothrix spp*	Genus of green algae			

Although statistical tests were not applied to linear model results, GAM and CDF modeling incorporated rigorous ecological validation procedures to ensure outputs aligned with rocky intertidal ecosystem dynamics.

Projected Range Shifts

Of the 59 species identified as having a northern or southern range edge near Point Conception, 53 were included in the habitat suitability modeling. Six species were excluded due to insufficient observation data. For each of the 53 species, a baseline suitability map (2000–2024) and a future suitability map (2050–2060) were generated (see Figure 8 for an example).

To assess changes in habitat suitability, a change detection map was created by subtracting baseline values from future projections. Negative values indicate areas currently modeled as suitable that are projected to become unsuitable, while positive values represent areas expected to gain suitability under future conditions. Overall, the results suggest a coastwide decline in suitable habitat, with species experiencing an average reduction of 28.7% in modeled habitat suitability by mid-century.

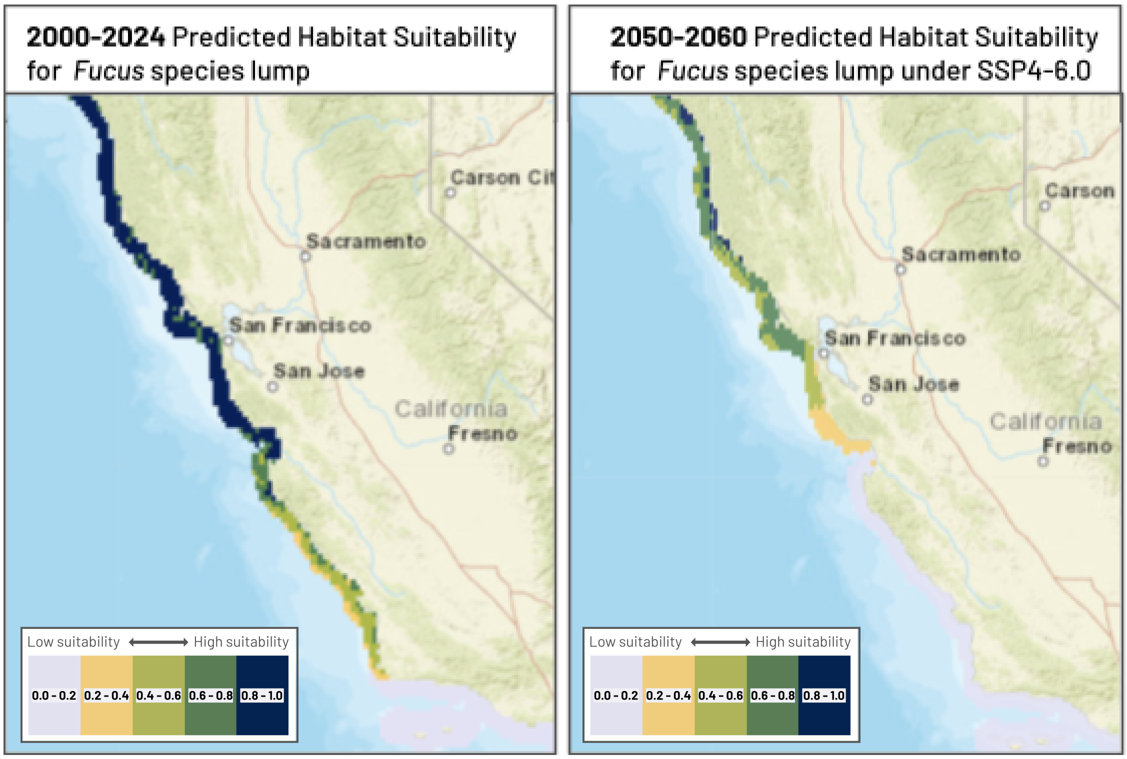

Figure 8: Habitat suitability maps of *Fucus* species along the California coast comparing historic conditions (2000–2024) to future projected conditions (2050, SSP4-6.0 scenario). Values range from 0.0 to 1.0, where low values indicate predicted unsuitable habitat, while higher values indicate predicted high-quality habitat. Compared to the 2000-2024 suitability, the future projected suitability under the Shared Socioeconomic Pathway 4-6.0 displays a notable northward shift in high-quality habitat.

Priority Monitoring Assessment

To calculate the list of species for monitoring priority, we used the range shift potential assessment value system from Table 1 in the methods section. Of the 37 species tested for range contractions, we found that 11 species met all three criteria, giving them a “High” priority value. 21 of the species met two out of the three criteria, while 5 species met only the one required contraction criteria, a range edge in Point Conception, earning each a “Moderate” and “Low” priority ranking, respectively.

Of the 23 species tested for range contractions, we found that 12 species met all three criteria, giving them a “High” priority ranking. 8 of the species met two out of the three criteria, while 3 species met only the one required expansion criterion, a northern range edge in Point Conception, earning each a “Moderate” and “Low” priority ranking, respectively. Below are the full species lists and their final ranking.

Table 5. List of species identified as having range-contraction priority monitoring status within the Dangermond Preserve.

RANGE CONTRACTIONS			
	SCIENTIFIC NAME	**COMMON NAME**	**PRIORITY**
1	*Acmaea mitra*	Whitecap limpet	Moderate
2	*Aglaophenia spp*	Hydroid species	Low
3	*Ahnfeltiopsis linearis*	Flattened Ahnfelts Seaweed	High
4	*Amphissa columbiana*	Wrinkled Amphissa	Moderate
5	*Analipus japonicus*	Bottlebrush Seaweed	Moderate
6	*Calliostoma annulatum*	Jeweled Top Snail	Moderate
7	*Calliostoma canaliculatum*	Channeled Topsnail	Moderate
8	*Calliostoma ligatum*	Blue-Ringed Top Snail	Moderate
9	*Chone minuta*	Minute Feather-Duster	Moderate
10	*Cirolana spp/Gnorimosphaeroma oregonense*	Cirolana spp/ Oregon Pillbug	Low
11	*Coryphella trilineata*	Three-lined Aeolid	Low
12	*Cryptochiton stelleri*	Gumboot Chiton	Moderate
13	*Cryptosiphonia woodii*	Bleached Brunette	High
14	*Derbesia marina*	Silky thread weed	High
15	*Desmarestia ligulata*	Flattened Acid Kelp	Moderate
16	*Dilsea californica*	Species of algae	High
17	*Diodora aspera*	Rough Keyhold Limpet	Moderate
18	*Fucus spp*	Genus of brown algae	High
19	*Halichondria spp*	Genus of sea sponge	Moderate

RANGE CONTRACTIONS			
20	*Halosaccion glandiforme*	Sea Sacks	High
21	*Halymenia/Schizymenia spp*	Genus of red algae	Low
22	*Haplogloia andersonii*	Species of brown algae	High
23	*Henricia spp*	Genus of sea star	Moderate
24	*Laminaria setchellii*	Southern Stiff-striped Kelp	Moderate
25	*Laminaria sinclairii*	Dense-clumped Kelp	Moderate
26	*Lottia asmi*	Black Limpet	Moderate
27	*Neoptilota/Ptilota spp*	Genus of red algae	Moderate
28	*Neorhodomela larix*	Black Pine Seaweed	Moderate
29	*Neorhodomela oregona*	Species of red/brown algae	High
30	*Onchidella carpenteri*	Leather Limpet	High
31	*Opalia wroblewskyi**	Boreal Wentletrap	Low
32	*Pelvetiopsis arborescens/limitata*	Dwarf rockweed	Moderate
33	*Semibalanus cariosus*	Thatched Barnacle	High
34	*Spirobranchus spinosus*	California Christmas Tree Worm	Moderate
35	*Styela montereyensis*	Long-stalked Sea Squirt	Moderate
36	*Tegula brunnea*	Brown Tegula	Moderate
37	*Ulothrix spp*	Genus of green algae	High

Table 6. List of species identified as having range-expansion priority monitoring status within the Dangermond Preserve.

RANGE EXPANSIONS			
	SCIENTIFIC NAME	**COMMON NAME**	**PRIORITY**
1	*Acanthinucella paucilirata*	Checkered Unicorn	Low

RANGE EXPANSIONS			
2	*Acrosorium spp*	Genus of red algae	Moderate
3	*Aplysia californica*	California Seahare	Moderate
4	*Bugula neritina*	Brown Bryozoan	High
5	*Chondria arcuata*	Species of red algae	High
6	*Chondria dasyphylla*	Species of red algae	High
7	*Dictyota coriacea*	Species of brown algae	Moderate
8	*Gastroclonium parvum*	Species of red algae	High
9	*Haminoea vesicula*	Blister Glassy-Bubble	High
10	*Jania rosea*	Species of coralline algae	High
11	*Laurencia spp*	Genus of red algae	Moderate
12	*Macron lividus*	Livid Macron	Moderate
13	*Nemalion elminthoides*	Sea Noodle	High
14	*Norrisia norrisii*	Norris's Topsnail	High
15	*Opalia wroblewskyi**	Boreal Wentletrap	Low
16	*Paraxanthias taylori*	Lumpy Rubble Crab	Moderate
17	*Pseudochama exogyra*	Reversed Chama	High
18	*Pseudomelatoma penicillata*	Doleful turrid	High
19	*Roperia poulsoni*	Poulson's Dwarf Triton	High
20	*Sargassum agardhianum*	Species of brown algae	Moderate
21	*Taonia lennebackerae*	Species of brown algae	High
22	*Tegula aureotincta*	Gilded Tegula	High
23	*Zonaria farlowii*	Banded Fanweed	Moderate

* Species only found within Point Conception coastal segments along California Coast

According to our results, the species groups recommended for high-priority range expansion monitoring are *Bugula neritina*, *Chondria arcuata*, *Chondria dasyphylla*, *Gastroclonium parvum*, *Haminoea vesicula*, *Jania rosea*, *Nemalion elminthoides*, *Norrisia norrisii*, *Pseudochama exogyra*, *Roperia poulsoni*, *Taonia lennebackerae*, and *Tegula aureotincta*.

Similarly, species groups recommended for high-priority range contraction monitoring are *Ahnfeltiopsis linearis*, *Cryptosiphonia woodii*, *Derbesia marina*, *Dilsea californica*, *Fucus spp*, *Halosaccion glandiforme*, *Haplogloia andersonii*, *Neorhodomela oregona*, *Onchidella carpenteri*, *Semibalanus cariosus*, and *Ulothrix spp*.

The implementation of these recommendations requires careful consideration of the methodological limitations and associated uncertainties detailed above. We foresee this as a stepping stone for conservation leaders to employ their biological expertise in making monitoring decisions.

PRODUCT DESCRIPTION

Welcome to the California Range of Intertidal Species Portal (CRISP) dashboard. The interactive web application is a comprehensive priority monitoring assessment of rocky intertidal species, with range edges near Point Conception, at risk of suitable habitat loss due to changing environmental conditions. The assessment compiles analyses of their habitat ranges, contemporary range shifts over time, and projected habitat suitability utilizing MARINe coastal biodiversity survey data. The application is hosted on The Nature Conservancy's (TNC) Geospatial Hub and is intended to be primarily utilized by internal staff and partners, who may implement the product for priority monitoring, grant proposals, and public education purposes. It addresses the need for open-source, reproducible science that is user-friendly and accessible to a broad audience. Overall, the application provides a foundational framework for further analyses to investigate the ecological and biological factors that influence rocky intertidal species near the Jack and Laura Dangermond Preserve.

The analyses hosted on CRISP are organized chronologically into separate tabs that collectively form the priority monitoring assessment. Each tab offers a unique lens into further understanding the project's scope:

- **Home:** An introduction to the dashboard, including navigation tips and a brief overview of the project.
- **Background:** Context on species range shifts and the importance of the Point Conception biogeographic boundary.

- **Range Edges:** Explore how the northern and southern boundaries (range edges) of intertidal species are identified across the California coastline.
- **Contemporary Range Shifts:** Analyze how species' core ranges have shifted from 2000 to 2024, focusing on species whose range edges are near Point Conception.
- **Projected Shifts:** Visualize habitat suitability under both current and future climate scenarios to assess potential range changes.
- **Priority Monitoring Assessment:** Identify species that are most likely to undergo range expansions or contractions.
- **Data and Limitations:** Learn about the data sources, methods, and key assumptions behind the analysis, as well as known limitations.
- **Acknowledgements:** Credits to the project team, collaborators, and data providers.

The following sections describe the visualizations and results that can be explored through each analysis found on CRISP.

Range Edges

Two interactive Leaflet maps of California's coastline divide and group MARINe survey sites into 100-kilometer coastal segments, illustrating the number of rocky intertidal species with northern and southern range edges in each segment. A color gradient legend is utilized to indicate the number of species with range edges in each segment, highlighting Point Conception as a biodiversity hotspot. Next to each map, an interactive data table displays the scientific name, common name, range edge latitude, and an image of each rocky intertidal species that reaches the limit of its geographic range when a specific coastal segment is selected. At the bottom, a static map zoomed in on the Northern and Southern Point Conception coastal segments is accompanied by key takeaways from the analysis about the intertidal species or species groups residing near the biogeographic barrier (Fig. 9).

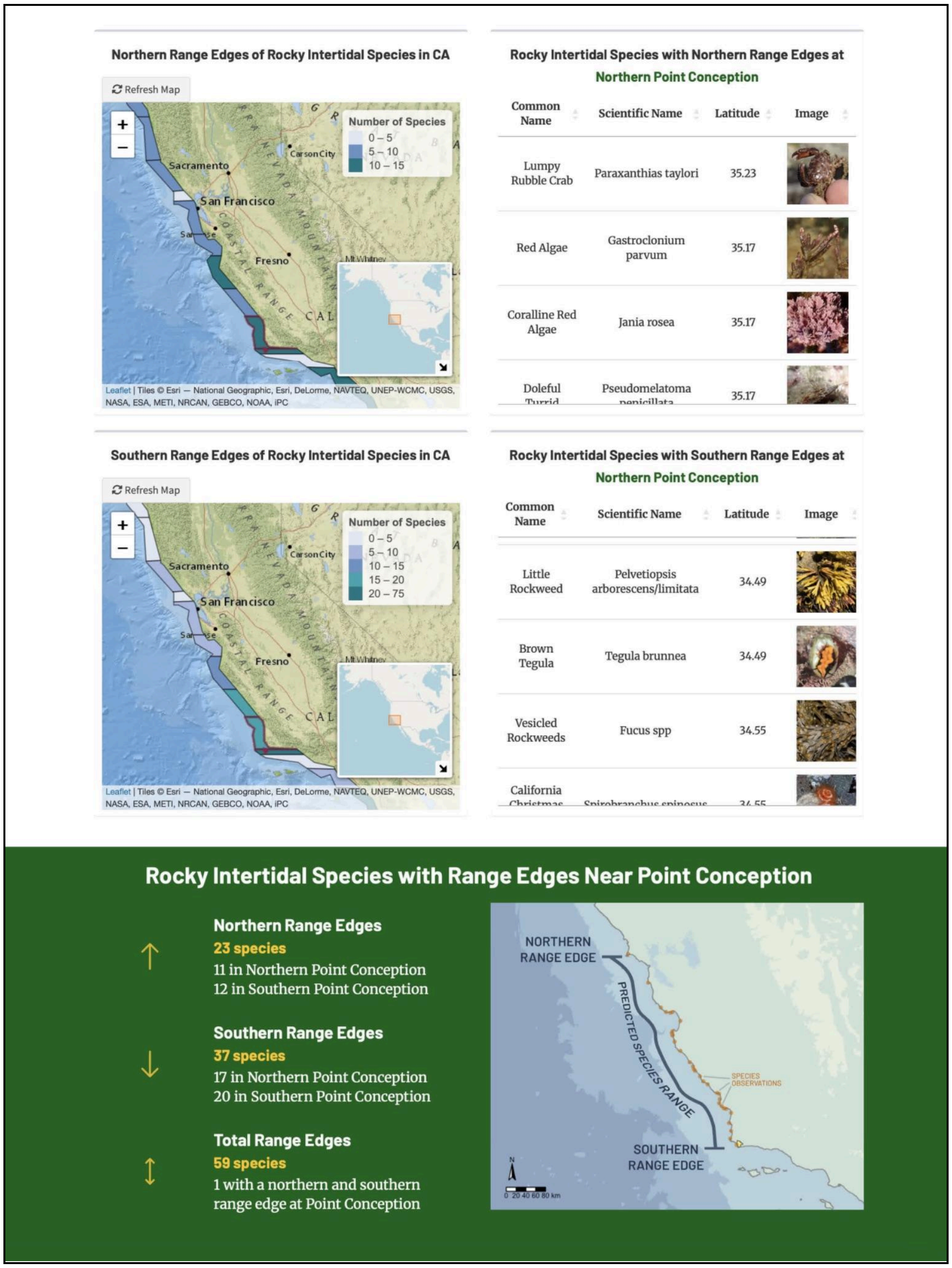

Figure 9: A portion of the material found on the 'Range Edges' tab of CRISP. It includes maps of areas along the California coast and a list of intertidal species that have a range edge within that coastal segment. It also contains summary statistics for range edges near Point Conception.

Contemporary Range Shifts

At the top, a dropdown widget enables users to select one of the 59 species or species groups previously defined as having range edges at Northern and Southern Point Conception. Below, an image of the selected species is displayed alongside a diagram of the analysis for visual context. The analysis showcases a range extent plot that illustrates the contemporary range shift of the selected species or species group every five years, highlighting Point Conception with a horizontal red dashed line. The plot functions as a dumbbell chart, depicting the movement of the northern and southern boundaries in kilometers along the California coastline. For geographic context, users hover over the y-axis of the plot to reveal coastal landmarks every 200 kilometers, as well as a reference map of the California coast that indicates distances from the southern border. At the bottom, a summary presents key takeaways from the analysis regarding the intertidal species or species groups that reside near the biogeographic barrier (Fig. 10).

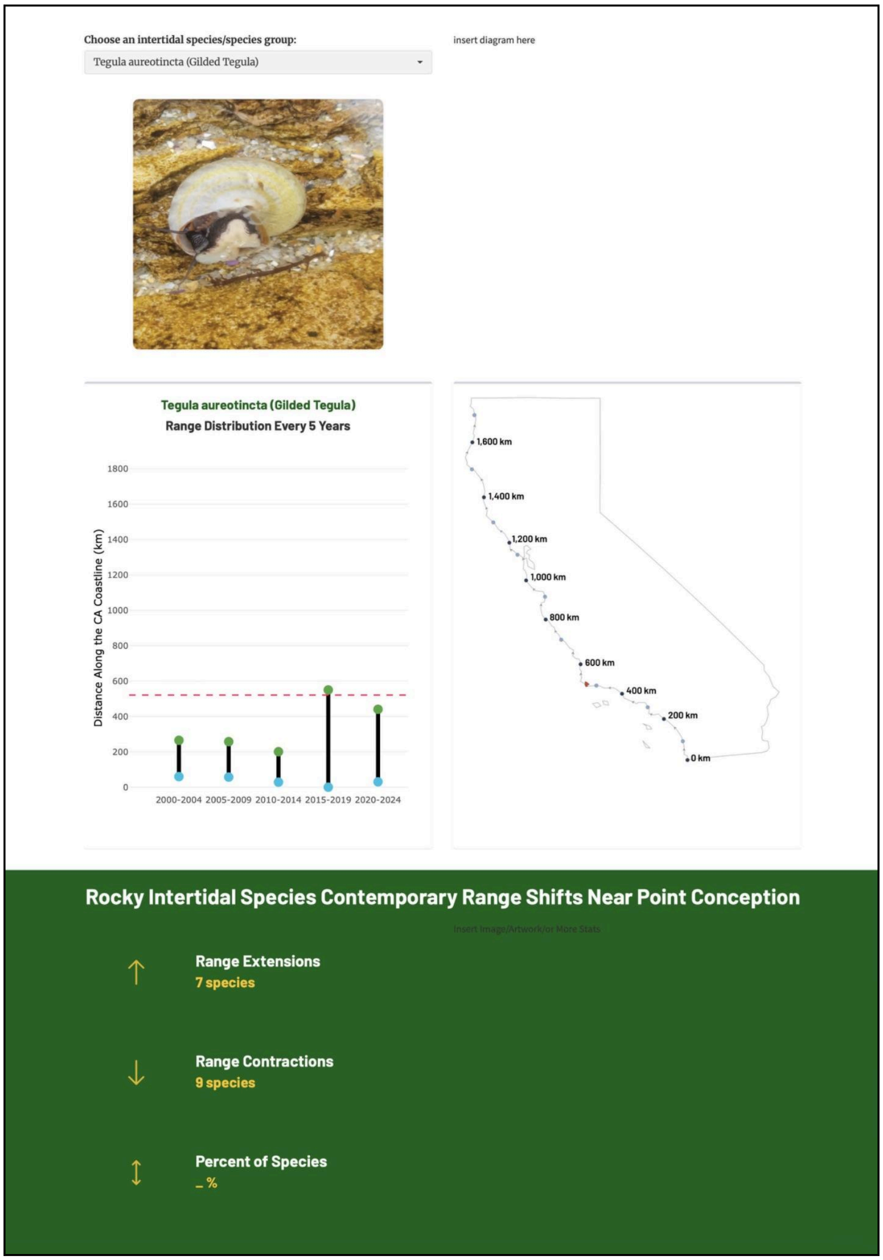

Figure 10: A portion of the material found on the 'Contemporary Range Shifts' tab of CRISP. It contains a drop-down menu to select an intertidal species, and then a plot is generated that displays its core range from 2000 to 2024, divided into 5-year bins.

Projected Range Shifts

At the top, a dropdown widget enables users to select one of the 59 species or species groups previously defined as having range edges at Northern and Southern Point Conception. Below, an image of the selected species is displayed alongside the habitat change detection map. This map is a product of the current and projected habitat suitability rasters, emphasizing areas along the coast where habitat is either gained or lost for the selected species or species group. Further down, users can view the current habitat suitability based on existing environmental conditions, utilizing raster data sourced from Bio-ORACLE and biodiversity coastal surveys. It also presents the projected habitat suitability for the year 2050 under a moderate climate scenario (SSP2-4.5), applying an ensemble model approach. A color gradient legend illustrates the differences in measurements, effectively highlighting potential shifts in suitable habitat for rocky intertidal species. At the bottom, a summary presents key takeaways from the analysis regarding the intertidal species or species groups that reside near the biogeographic barrier (Fig. 11).

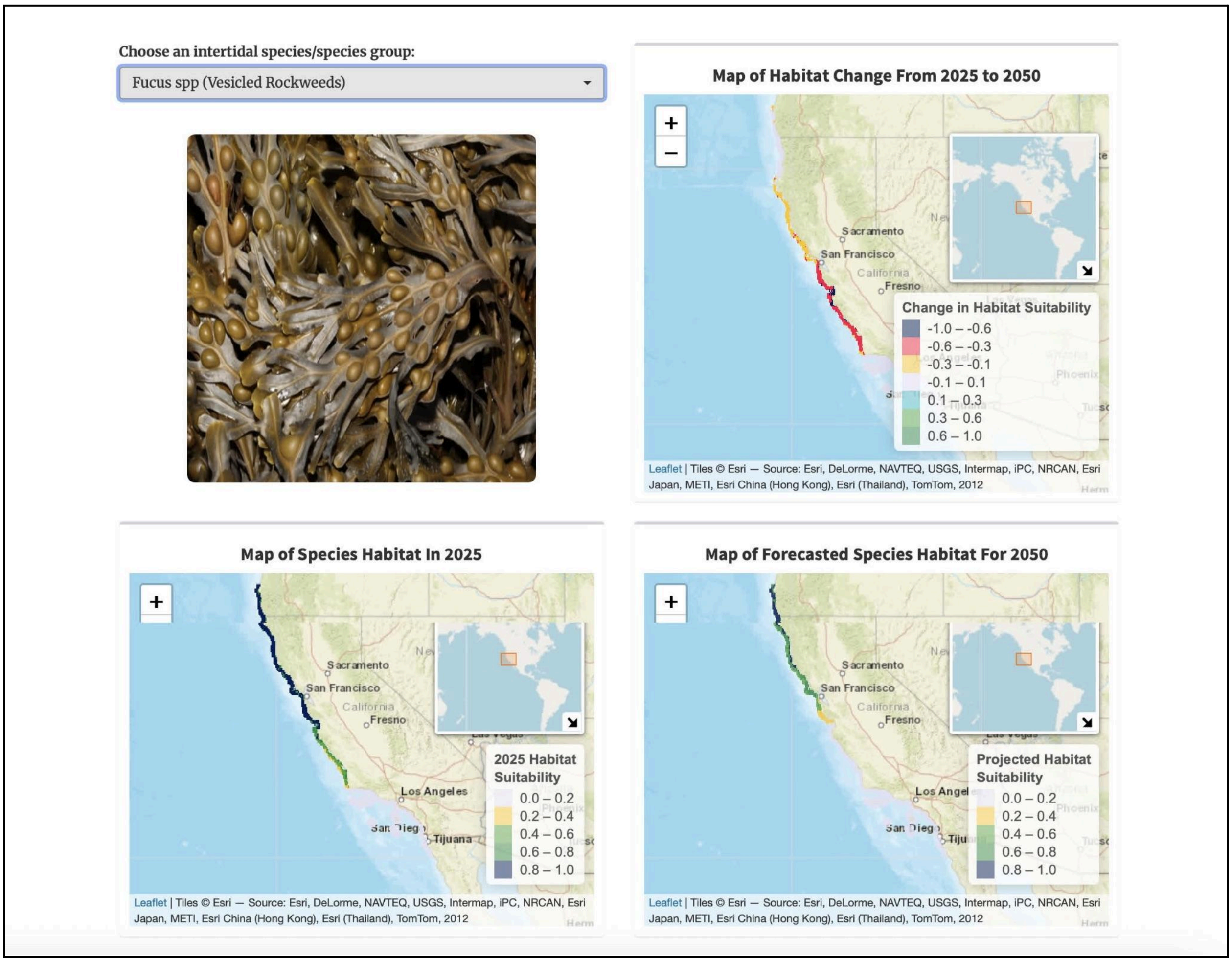

Figure 11: A portion of the material found on the 'Projected Range Shifts' tab of CRISP. It contains a drop-down menu to select a species, which then displays habitat suitability maps for the species along the California coast.

Priority Monitoring Assessment

A picker widget allows users to select a monitoring priority level, based on an additive assessment of the three previous analyses for both species that experience a range extension or contraction. An interactive data table updates accordingly, displaying the species name, common name, cumulative score, and an image associated with the selected priority level. Higher scores indicate a higher monitoring priority. At the bottom, a summary presents key takeaways from the analysis regarding the intertidal species or species groups that reside near the biogeographic barrier (Fig. 12).

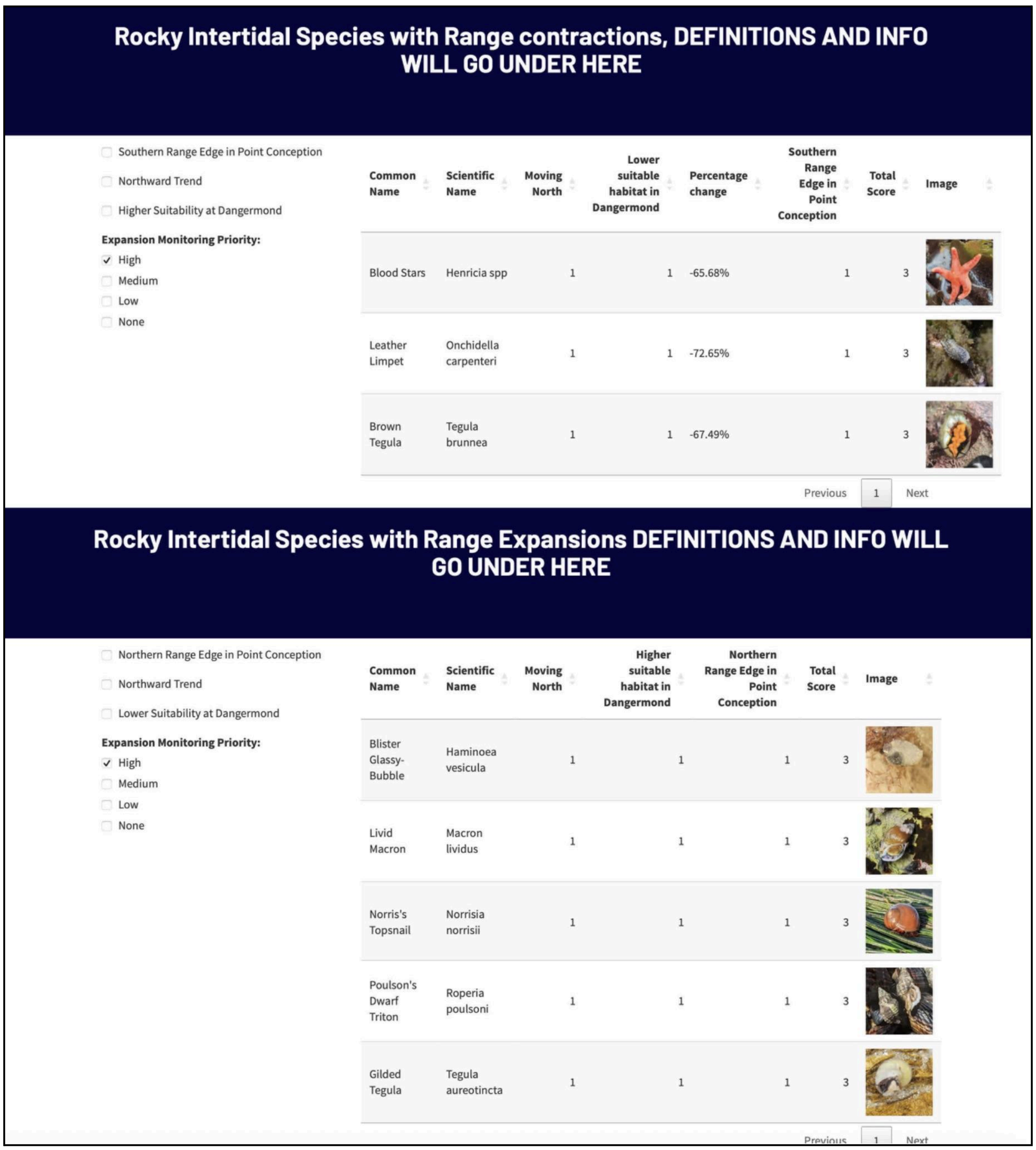

Figure 12: A portion of the material found on the `Priority Monitoring Assessment' tab of CRISP. For each species, a score is assigned to determine the risk of expansion of the species range into the Dangermond Preserve, or contraction of the range out of the Dangermond Preserve

Performance and Limitations

The data used for the dashboard analyses are static, covering the period from 2000 to 2024. No future updates or maintenance for the dataset are planned; however, the dashboard is intended to serve as a framework that can be adapted and applied to data from 2025 onward. To optimize performance and minimize computation time, habitat suitability models will be pre-run and uploaded as raster images layered on top of a Leaflet map.

ARCHIVE ACCESS

All data, models, and finalized products were delivered to the client in a shared Box folder. One data folder will live on the coastal_species_analysis repository in our GitHub, under "archive_data/CA_coastal_buffer_modeling". A formal Dryad archive of our habitat suitability rasters exists for ease of access (Sibley et.a;, 2025). The following is a summary of the archived items:

Data

TNC Box data folder (Raw and Processed)

- Raw
    - Coastline shape files
    - Dangermond shapefiles
    - California state shapefiles
    - Coastline 100km segment locations
    - Bio-ORACLE rasters
    - MARINe biodiversity abundance data
- Processed
    - Species with Point Conception Range edges
    - Marine Sites Categorization Identification
    - Species Range Categorization
    - Species Monitoring Priority List

DRYAD

- Habitat Suitability Rasters

All data is publicly available through their respective sources. The MARINe datasets are publicly available, but there must be a specified request to the MARINe network to access the data. While the other tabs are personal to the requester, the "Type of information you are looking for" tab must have specific wording to access the same data used for this project. For this section, one must ask for Coastal Biodiversity Survey data for all species in the entire MARINe extent. Our processed suitability rasters are available on DRYAD for any individual or organization to quickly reproduce our process, though they can easily reproduce the rasters themselves following our code.

Code

All code lives in two GitHub repositories: *coastal_species_analysis* (range analysis & modeling) and *dashboard* (Interactive Web Dashboard) under the *coastalconservation* GitHub organization. A Readme.md will be included in each repository to guide the reader through the workflow. A text file with a list of all R packages and software versions used in each repository will be included. It will be in a file named *session_info.txt* within each repository.

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