Application of the Sea-Level Affecting Marshes Model (SLAMM 5.0) to Guadalupe-Nipomo Dunes NWR

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Introduction

Tidal marshes are among the most susceptible ecosystems to climate change, especially accelerated sea level rise (SLR). The International Panel on Climate Change (IPCC) Special Report on Emissions Scenarios (SRES) suggested that global sea level will increase by approximately 30 cm to 100 cm by 2100 (IPCC 2001). Rahmstorf (2007) suggests that this range may be too conservative and that the feasible range by 2100 could be 50 to 140 cm. Pfeffer et al. (2008) suggests that 200 cm by 2100 is at the upper end of plausible scenarios due to physical limitations on glaciological conditions. Rising sea level may result in tidal marsh submergence (Moorhead and Brinson 1995) and habitat migration as salt marshes transgress landward and replace tidal freshwater and brackish marsh (Park et al. 1991).

In an effort to address the potential effects of sea level rise on United States national wildlife refuges, the U. S. Fish and Wildlife Service contracted the application of the SLAMM model for most Region 4 refuges. This analysis is designed to assist in the production of comprehensive conservation plans (CCPs) for each refuge along with other long-term management plans.

Model Summary

Changes in tidal marsh area and habitat type in response to sea-level rise were modeled using the Sea Level Affecting Marshes Model (SLAMM 5.0) that accounts for the dominant processes involved in wetland conversion and shoreline modifications during long-term sea level rise (Park et al. 1989; www.warrenpinnacle.com/prof/SLAMM).

Successive versions of the model have been used to estimate the impacts of sea level rise on the coasts of the U.S. (Titus et al., 1991; Lee, J.K., R.A. Park, and P.W. Mausel. 1992; Park, R.A., J.K. Lee, and D. Canning 1993; Galbraith, H., R. Jones, R.A. Park, J.S. Clough, S. Herrod-Julius, B. Harrington, and G. Page. 2002; National Wildlife Federation et al., 2006; Glick, Clough, et al. 2007; Craft et al., 2009.

Within SLAMM, there are five primary processes that affect wetland fate under different scenarios of sea-level rise:

- **Inundation:** The rise of water levels and the salt boundary are tracked by reducing elevations of each cell as sea levels rise, thus keeping mean tide level (MTL) constant at zero. The effects on each cell are calculated based on the minimum elevation and slope of that cell.
- **Erosion:** Erosion is triggered based on a threshold of maximum fetch and the proximity of the marsh to estuarine water or open ocean. When these conditions are met, horizontal erosion occurs at a rate based on site-specific data.
- **Overwash:** Barrier islands of under 500 meters width are assumed to undergo overwash during each 25-year time-step due to storms. Beach migration and transport of sediments are calculated.
- **Saturation:** Coastal swamps and fresh marshes can migrate onto adjacent uplands as a response of the fresh water table to rising sea level close to the coast.

- **Accretion:** Sea level rise is offset by sedimentation and vertical accretion using average or site-specific values for each wetland category. Accretion rates may be spatially variable within a given model domain.

SLAMM Version 5.0 is the latest version of the SLAMM Model, developed in 2006/2007 and based on SLAMM 4.0. SLAMM 5.0 provides the following refinements:

- The capability to simulate fixed levels of sea-level rise by 2100 in case IPCC estimates of sea-level rise prove to be too conservative;
- Additional model categories such as "Inland Shore," "Irregularly Flooded (Brackish) Marsh," and "Tidal Swamp."
- *Optional.* In a defined estuary, salt marsh, brackish marsh, and tidal fresh marsh can migrate based on changes in salinity, using a simple though geographically-realistic salt wedge model. This optional model was not used when creating results for Guadalupe-Nipomo Dunes NWR.

Model results presented in this report were produced using SLAMM version 5.0.1 which was released in early 2008 based on only minor refinements to the original SLAMM 5.0 model. Specifically, the accretion rates for swamps were modified based on additional literature review. For a thorough accounting of SLAMM model processes and the underlying assumptions and equations, please see the SLAMM 5.0.1 technical documentation (Clough and Park, 2008). This document is available at http://warrenpinnacle.com/prof/SLAMM

All model results are subject to uncertainty due to limitations in input data, incomplete knowledge about factors that control the behavior of the system being modeled, and simplifications of the system (CREM 2008).

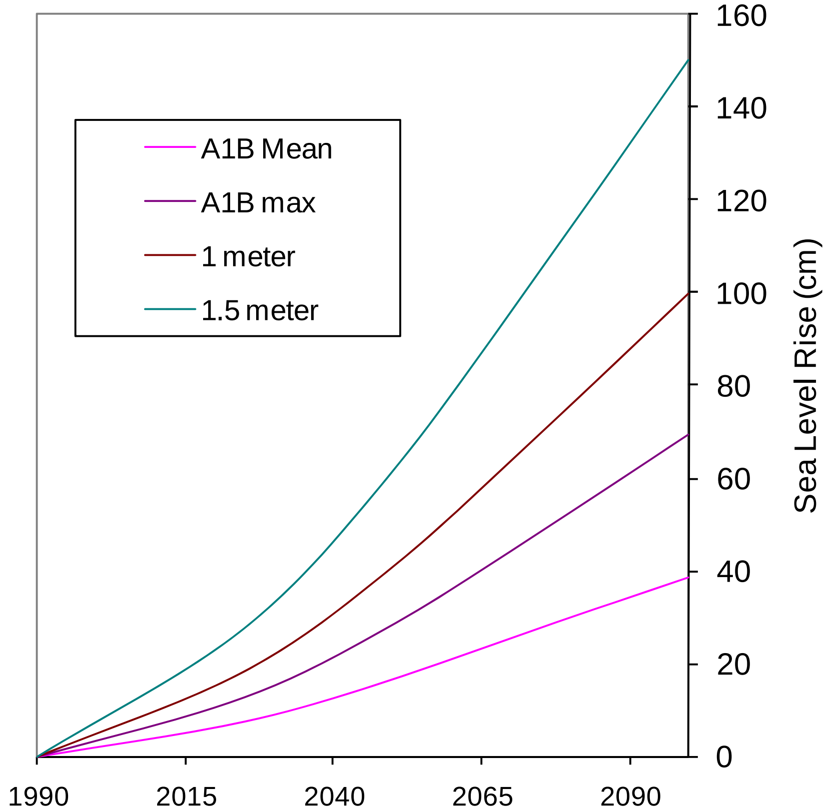
Sea-Level Rise Scenarios

The primary set of eustatic (global) sea level rise scenarios used within SLAMM was derived from the work of the Intergovernmental Panel on Climate Change (IPCC 2001). SLAMM 5 was run using the following IPCC and fixed-rate scenarios:

Scenario	Eustatic SLR by 2025 (cm)	Eustatic SLR by 2050 (cm)	Eustatic SLR by 2075 (cm)	Eustatic SLR by 2100 (cm)
A1B Mean	8	17	28	39
A1B Max	14	30	49	69
1 meter	13	28	48	100
1.5 meter	18	41	70	150

Recent literature (Chen et al., 2006, Monaghan et al., 2006) indicates that the eustatic rise in sea levels is progressing more rapidly than was previously assumed, perhaps due to dynamic changes in ice flow omitted within the IPCC report's calculations. A recent paper in the journal *Science* (Rahmstorf, 2007) suggests that, taking into account possible model error, a feasible range by 2100 might be 50 to 140 cm. To allow for flexibility when interpreting the results, SLAMM was also run assuming 1 meter, 1½ meters of eustatic sea-level rise by the year 2100. The A1B- maximum scenario was scaled up to produce these bounding scenarios (Figure 1).

Figure 1: Summary of SLR Scenarios Utilized



Methods and Data Sources

A limited set of LIDAR data was found for Guadalupe-Nipomo Dunes NWR; the elevation data used are based on a combination of the LIDAR and the National Elevation Dataset (NED).

NED data were derived from a 1956 survey illustrated within the USGS topographic map shown below (Fig. 2a) and the LIDAR data were derived based on 1998 flights (Fig. 2b). The contour intervals that resulted from the NED survey are forty feet with ten foot supplemental contours closest to sea-level. The process of creating a digital elevation map (DEM) from a contour map does attempt to interpolate between contour lines but there is considerable uncertainty in this process.

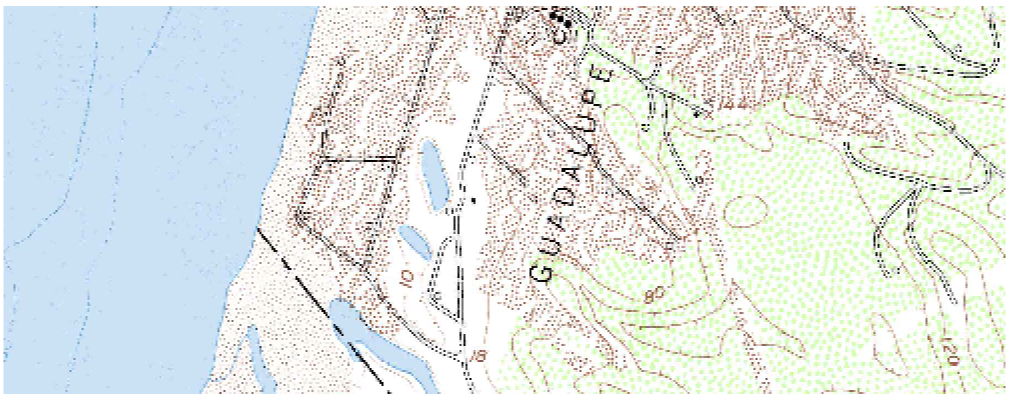


Figure 2a: Guadalupe-Nipomo Dunes Excerpt from USGS Map.

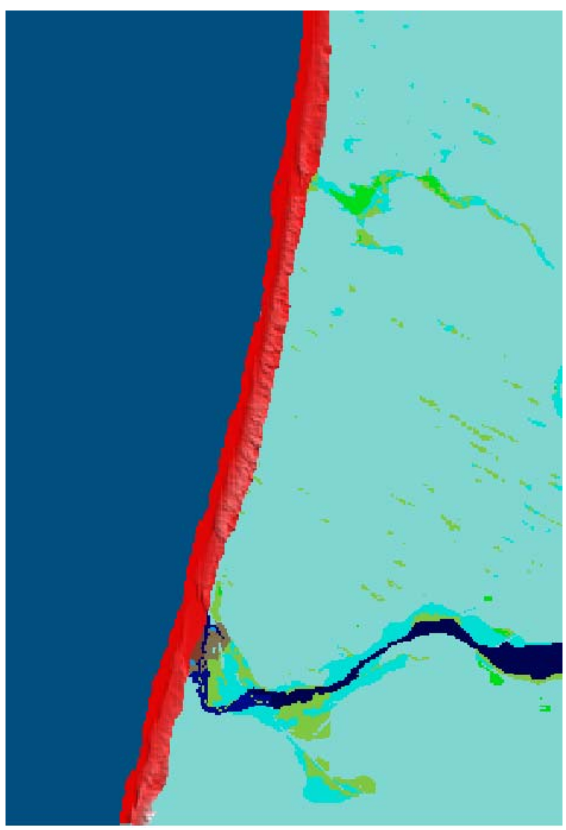


Figure 2b: Guadalupe-Nipomo Dunes LIDAR Coverage (in Red) Over NWI Map.

The National Wetlands Inventory for Guadalupe-Nipomo Dunes is based on a photo date of 2005. This survey, when converted to 30 meter cells, suggests that on that date, the approximately eight thousand five hundred acre refuge (approved acquisition boundary including water) was composed of the categories as shown below:

Dry Land	87.5%
Inland Fresh Marsh	5.6%
Swamp	2.4%
Inland Open Water	2.1%
Ocean Beach	1.6%
Estuarine Open Water	0.3%
Brackish Marsh	0.2%
Inland Shore	0.1%
Saltmarsh	0.1%

There are no dikes in the region of the Guadalupe-Nipomo Dunes NWR according to the National Wetlands Inventory and personal communication with the refuge manager.

The historic trend for sea level rise was estimated at 0.79 mm/year using the value from the closest station (9412110, Port San Luis California). This measured rate is roughly half the global average for the last 100 years (approximately 1.5 mm/year).

The tide range at this site was estimated at 1.64 meters using the average of the two closest NOAA oceanic gages (9411406, Oil Platform Harvest, CA; 9412110, Port San Luis, CA). The USGS topographical map for this region suggests an approximate tidal range of four feet (1.22 meters).

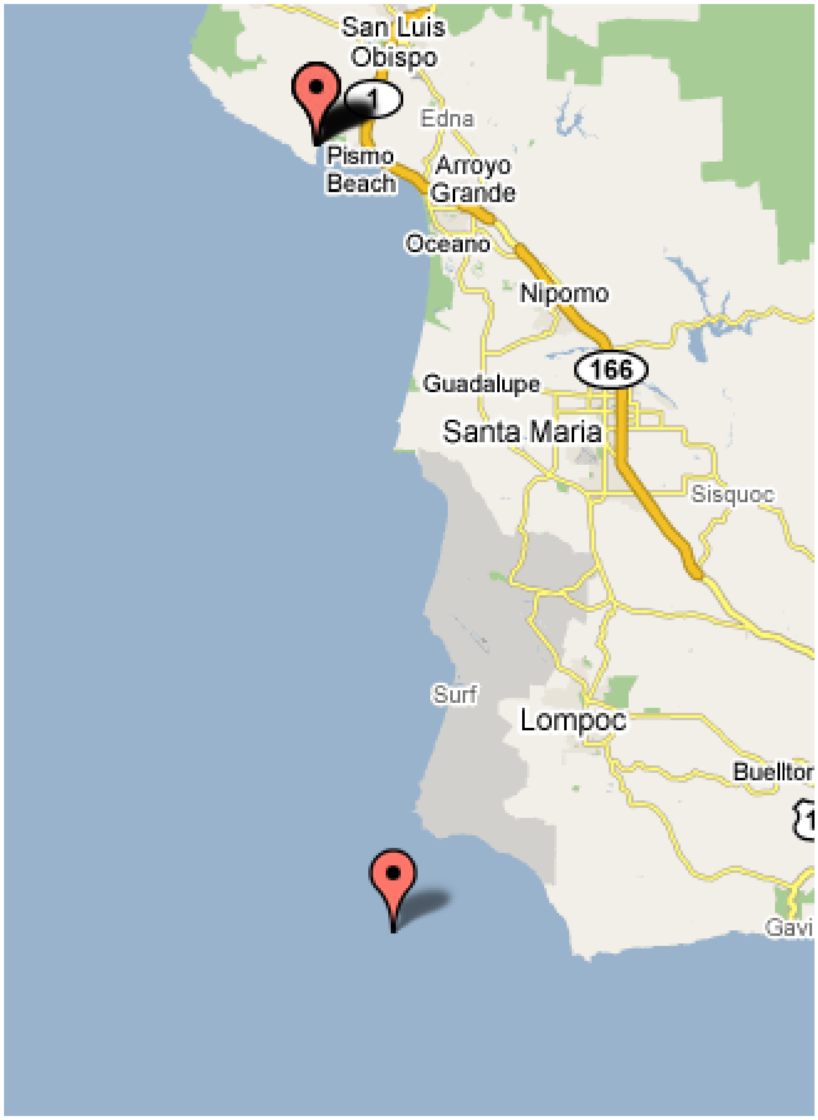


Figure 3: NOAA Gages Relevant to the Study Area.

Accretion rates in all marshes were set to 9.5 mm/year, though there is little salt marsh so this parameter is less sensitive for this site. 9.5 mm/year is the mean of a range of accretion values measured in Tijuana Slough, CA (Weis, D.A. et. al. 2001). Based on the publications that we tracked down, accretion rates in California tend to be somewhat higher than those nationwide (Weis. et. al. 2001; Patrick, 1990; Grismer et al, 2004; Reed, 2002).

Modeled U.S. Fish and Wildlife Service refuge boundaries are based on Approved Acquisition Boundaries as published on the FWS "National Wildlife Refuge Data and Metadata" website, and are current as of October 2008 according to Valerie Howard, Realty Cartographer for Region 8.

The cell-size used for this analysis was 30 meter by 30 meter cells. However, the SLAMM model does track partial conversion of cells based on elevation and slope.

SUMMARY OF SLAMM INPUT PARAMETERS FOR GUADALUPE-NIPOMO DUNES

Description	Guadelupe Nipomo Dunes
DEM Source Date (yyyy)	1956
NWI_photo_date (yyyy)	2005
Direction_OffShore (N|S|E|W)	W
Historic_trend (mm/yr)	0.79
NAVD88_correction (MTL-NAVD88 in meters)	0.839
Water Depth (m below MLW- N/A)	2
TideRangeOcean (meters: MHHW-MLLW)	1.64
TideRangeInland (meters)	1.64
Mean High Water Spring (m above MTL)	1.091
MHSW Inland (m above MTL)	1.091
Marsh Erosion (horz meters/year)	1.8
Swamp Erosion (horz meters/year)	1
TFlat Erosion (horz meters/year) [from 0.5]	0.5
Salt marsh vertical accretion (mm/yr) Final	9.5
Brackish March vert. accretion (mm/yr) Final	9.5
Tidal Fresh vertical accretion (mm/yr) Final	9.5
Beach/T.Flat Sedimentation Rate (mm/yr)	0.5
Frequency of Large Storms (yr/washover)	25
Use Elevation Preprocessor for Wetlands	TRUE *

* Because LIDAR data produce a much more accurate DEM, only the elevations of wetlands lying outside of the LIDAR data were overwritten as a function of the local tidal range using the SLAMM elevation pre-processor.

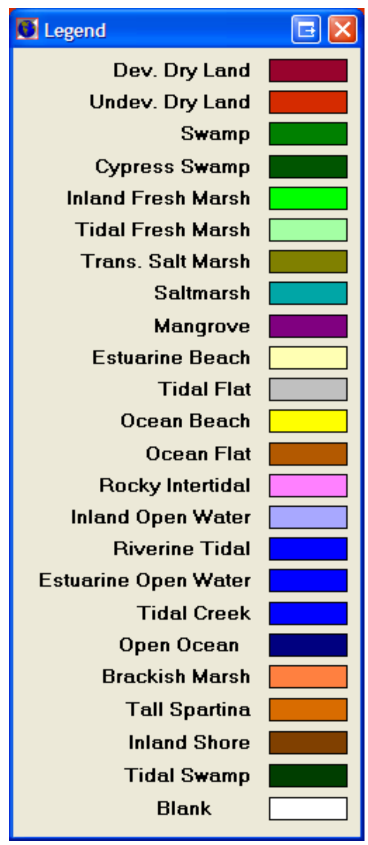
Results

Dry land, fresh marsh, and swamp, the three most common land covers in this refuge, are predicted to be resilient to sea level rise, even under the 1.5 meter scenario. The oceanic beach fringe to the west of the refuge is subject to more effects, losing a minimum of 38% of its mass due to erosion and inundation. The small fringes of brackish marsh and fresh marsh at the south of the refuge are predicted to be more vulnerable.

SLR by 2100 (m)	0.39	0.69	1	1.5
Dry Land	0%	0%	1%	1%
Inland Fresh Marsh	0%	0%	0%	1%
Swamp	3%	3%	4%	4%
Ocean Beach	38%	46%	52%	100%
Brackish Marsh	20%	29%	30%	78%
Inland Shore	0%	0%	0%	0%
Saltmarsh	71%	71%	67%	-70%

Predicted Loss Rates of Land Categories by 2100 Given Simulated Scenarios of Eustatic Sea Level Rise

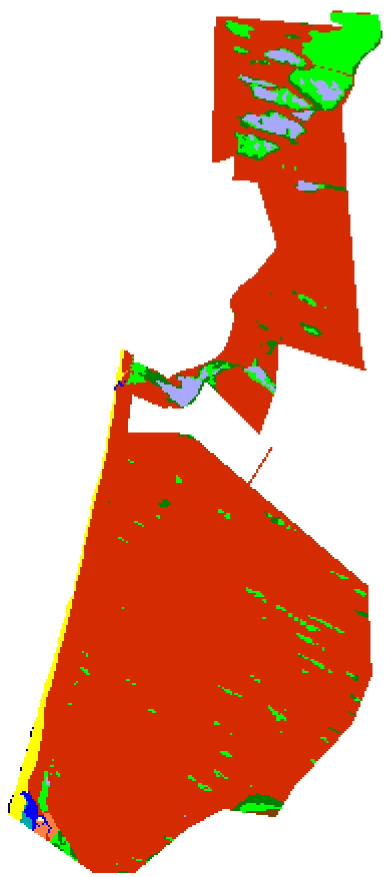
Maps of SLAMM input and output to follow will use the following legend:



Guadalupe
IPCC Scenario A1B-Mean, 0.39 M SLR Eustatic by 2100

Results in Acres

	Initial	2025	2050	2075	2100
Dry Land	7456.4	7430.4	7428.8	7427.5	7426.2
Inland Fresh Marsh	479.3	480.4	480.6	480.7	480.7
Swamp	203.7	202.2	201.2	199.9	198.4
Inland Open Water	180.1	180.1	180.1	178.8	178.6
Ocean Beach	135.2	133.8	110.6	89.4	84.0
Estuarine Open Water	22.5	22.4	25.3	28.6	30.0
Brackish Marsh	19.8	17.8	17.3	16.7	15.8
Inland Shore	8.5	8.5	8.5	8.5	8.5
Saltmarsh	7.8	5.3	3.9	3.3	2.2
Open Ocean	3.3	29.8	54.4	77.7	84.4
Estuarine Beach	1.3	1.1	0.8	0.6	0.4
Tidal Flat	0.0	5.8	5.8	5.1	6.9
Trans. Salt Marsh	0.0	0.2	0.6	1.2	1.8
Total (incl. water)	**8517.9**	**8517.9**	**8517.9**	**8517.9**	**8517.9**



Guadalupe NWR, Initial Condition

Guadalupe NWR, 2025, Scenario A1B Mean

Guadalupe NWR, 2050, Scenario A1B Mean

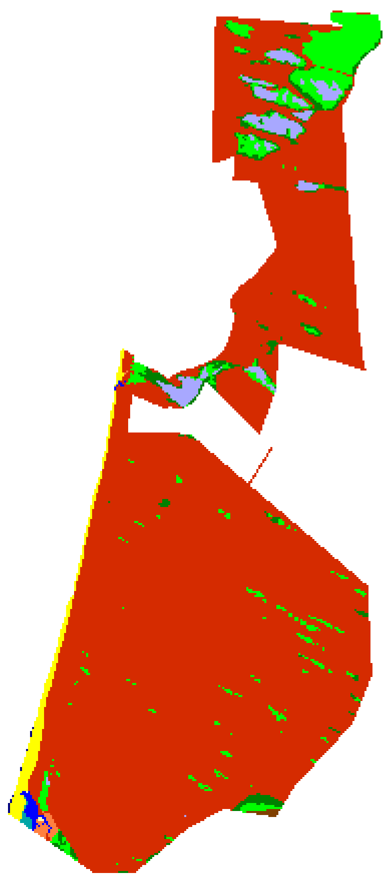
Guadalupe NWR, 2075, Scenario A1B Mean

Guadalupe NWR, 2100, Scenario A1B Mean

Guadalupe
IPCC Scenario A1B-Max, 0.69 M SLR Eustatic by 2100

Results in Acres

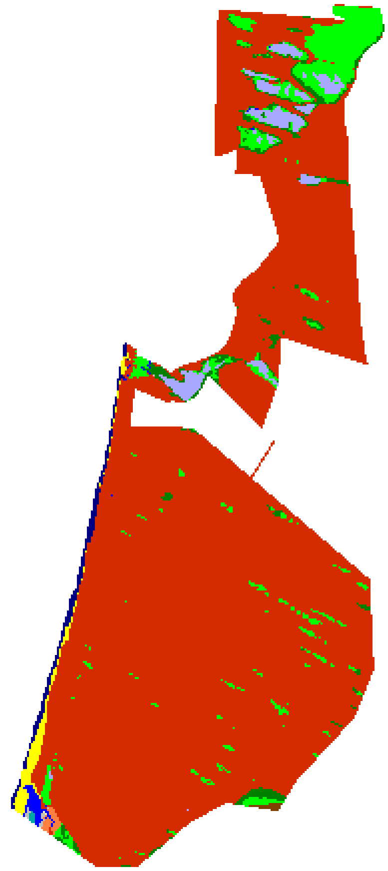
	Initial	2025	2050	2075	2100
Dry Land	7456.4	7429.8	7427.6	7424.6	7421.6
Inland Fresh Marsh	479.3	480.4	480.6	480.7	480.8
Swamp	203.7	202.0	200.6	198.5	196.7
Inland Open Water	180.1	180.1	178.8	178.6	178.4
Ocean Beach	135.2	127.6	89.2	79.3	73.2
Estuarine Open Water	22.5	22.4	26.2	28.6	30.5
Brackish Marsh	19.8	17.8	17.1	15.6	14.0
Inland Shore	8.5	8.5	8.5	8.5	8.5
Saltmarsh	7.8	5.3	3.9	3.3	2.2
Open Ocean	3.3	36.6	77.4	90.8	99.5
Estuarine Beach	1.3	1.1	0.7	0.4	0.0
Tidal Flat	0.0	5.8	6.1	6.6	8.9
Trans. Salt Marsh	0.0	0.4	1.3	2.6	3.8
Total (incl. water)	**8517.9**	**8517.9**	**8517.9**	**8517.9**	**8517.9**



Guadalupe NWR, Initial Condition

Guadalupe NWR, 2025, Scenario A1B Maximum

Guadalupe NWR, 2050, Scenario A1B Maximum



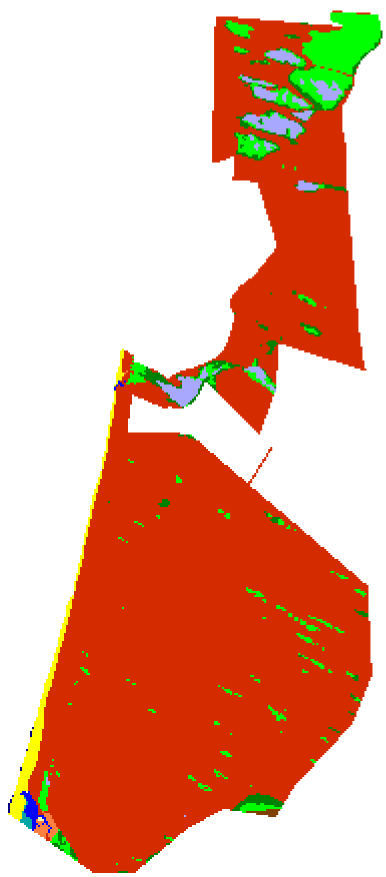
Guadalupe NWR, 2075, Scenario A1B Maximum

Guadalupe NWR, 2100, Scenario A1B Maximum

Guadalupe
1 Meter Eustatic SLR by 2100

Results in Acres

	Initial	2025	2050	2075	2100
Dry Land	7456.4	7429.2	7426.2	7421.7	7417.2
Inland Fresh Marsh	479.3	480.4	480.6	480.7	480.8
Swamp	203.7	201.8	199.9	197.6	196.5
Inland Open Water	180.1	180.1	178.6	178.4	177.5
Ocean Beach	135.2	119.6	80.5	70.6	65.4
Estuarine Open Water	22.5	22.5	26.5	29.1	31.8
Brackish Marsh	19.8	17.8	16.7	14.7	13.8
Inland Shore	8.5	8.5	8.5	8.5	8.5
Saltmarsh	7.8	5.3	3.9	3.3	2.5
Open Ocean	3.3	45.2	87.4	102.1	111.2
Estuarine Beach	1.3	1.0	0.6	0.0	0.0
Tidal Flat	0.0	5.9	6.6	7.6	8.7
Trans. Salt Marsh	0.0	0.6	2.0	3.8	4.0
Total (incl. water)	**8517.9**	**8517.9**	**8517.9**	**8517.9**	**8517.9**

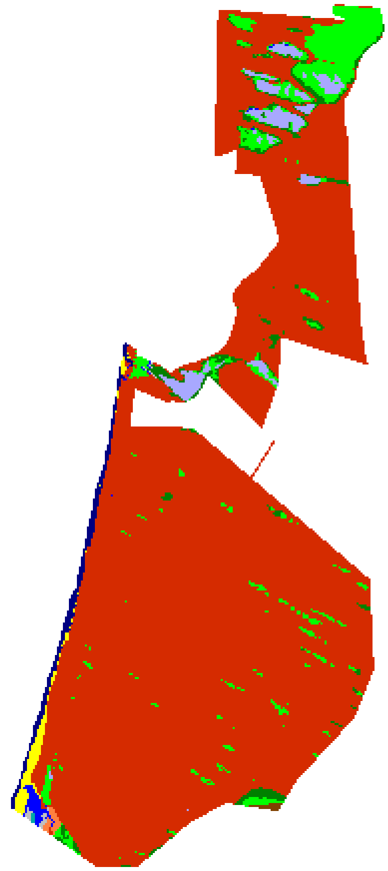


Guadalupe NWR, Initial Condition

Guadalupe NWR, 2025, 1 meter

Guadalupe NWR, 2050, 1 meter

Guadalupe NWR, 2075, 1 meter

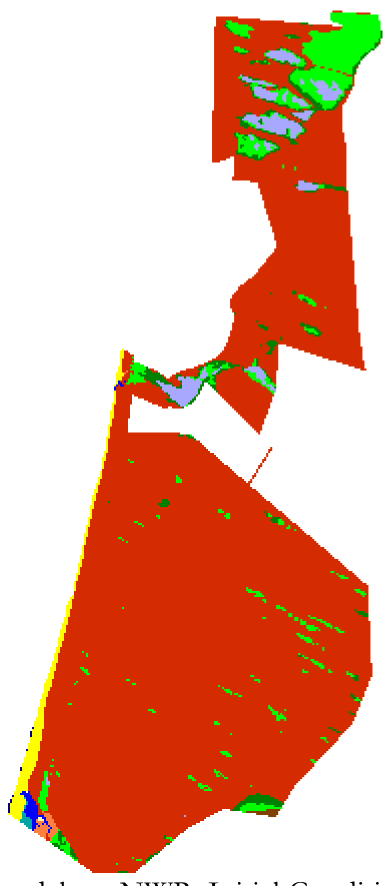


Guadalupe NWR, 2100, 1 meter

Guadalupe
1.5 Meters Eustatic SLR by 2100

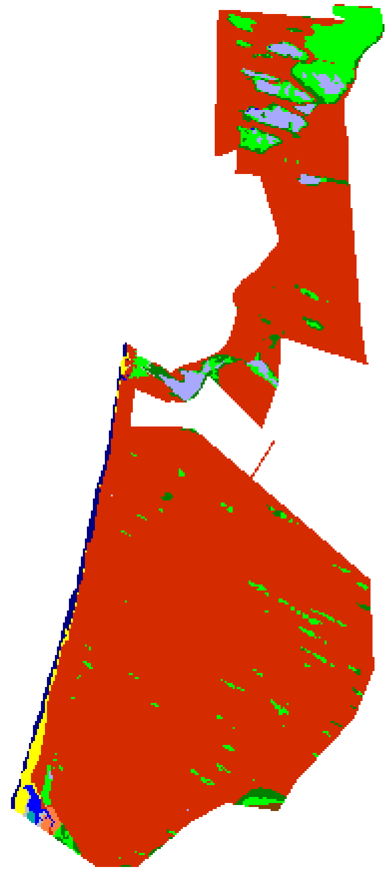
Results in Acres

	Initial	2025	2050	2075	2100
Dry Land	7456.4	7428.4	7423.5	7416.7	7407.6
Inland Fresh Marsh	479.3	480.4	480.2	477.7	473.6
Swamp	203.7	201.5	198.6	197.2	195.9
Inland Open Water	180.1	180.1	178.6	177.5	168.8
Ocean Beach	135.2	101.2	67.7	0.1	0.3
Estuarine Open Water	22.5	22.5	25.9	30.5	33.6
Brackish Marsh	19.8	17.8	16.1	10.6	4.4
Inland Shore	8.5	8.5	8.5	8.5	8.5
Saltmarsh	7.8	5.3	4.1	9.3	13.2
Open Ocean	3.3	64.3	103.4	177.1	192.4
Estuarine Beach	1.3	0.9	0.2	0.0	0.0
Tidal Flat	0.0	6.0	7.5	7.3	12.2
Trans. Salt Marsh	0.0	0.9	3.7	5.6	7.5
Total (incl. water)	**8517.9**	**8517.9**	**8517.9**	**8517.9**	**8517.9**



Guadalupe NWR, Initial Condition

Guadalupe NWR, 2025, 1.5 meter



Guadalupe NWR, 2050, 1.5 meter

Guadalupe NWR, 2075, 1.5 meter

Guadalupe NWR, 2100, 1.5 meter

Discussion:

The high elevation of dry land and fresh marsh for this site suggests that the majority of this wildlife refuge is not subject to the pressures of increased sea level rise. However, the small fringe of ocean beach to the west of this refuge is predicted to have significant effects under all scenarios. This prediction is all-the-more salient because this portion of the refuge is based on high quality elevation data (LIDAR).

The small fringes of saltmarsh and brackish marsh to the south of the refuge are also predicted to be vulnerable.

As noted above, the elevation data for this site utilize both LIDAR and NED data. The LIDAR covers only about 370 meters in from the ocean, and therefore only the western-most fraction of the NWR is LIDAR elevation, the rest being NED.

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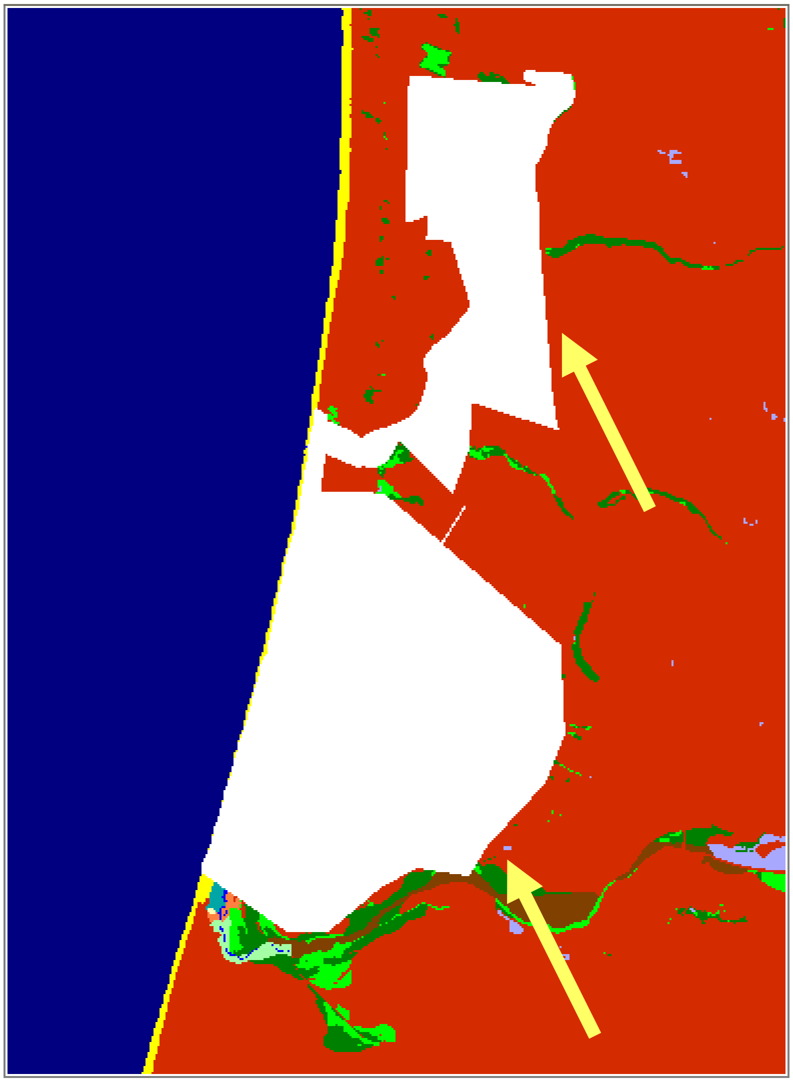
Appendix A: Contextual Results

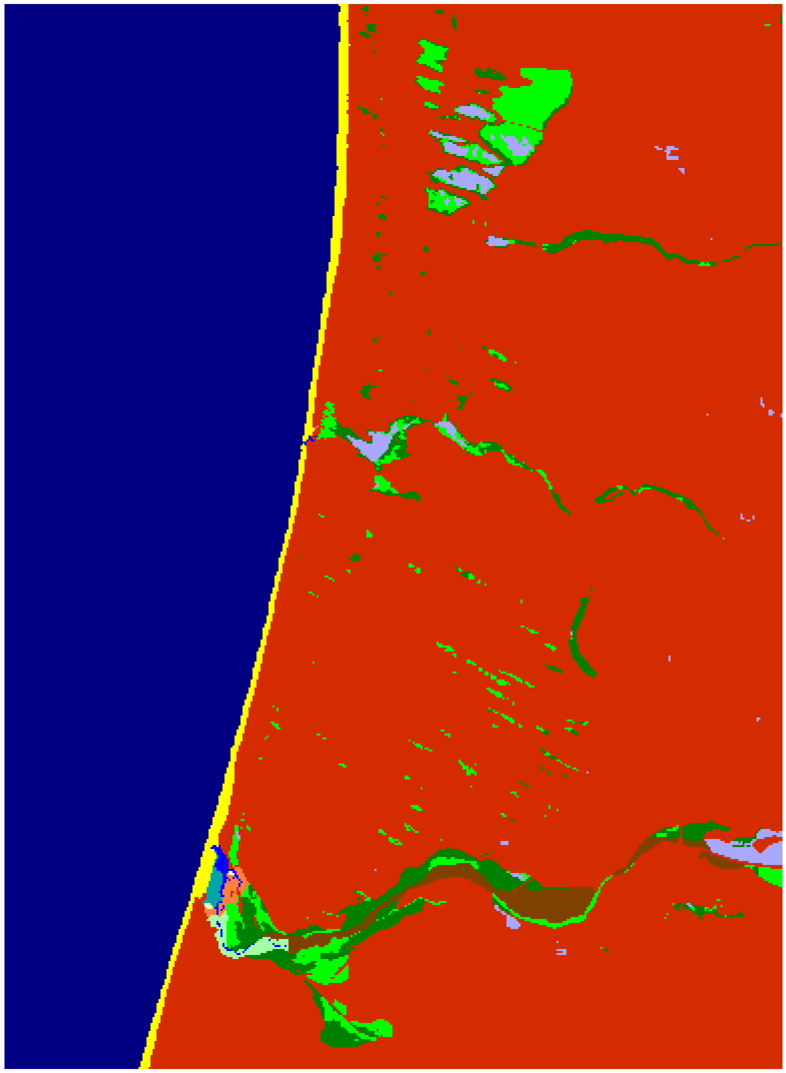
The SLAMM model does take into account the context of the surrounding lands or open water when calculating effects. For example, erosion rates are calculated based on the maximum fetch (wave action) which is estimated by assessing contiguous open water to a given marsh cell. Another example is that inundated dry lands will convert to marshes or ocean beach depending on their proximity to open ocean.

For this reason, an area larger than the boundaries of the USFWS refuge was modeled. These results maps are presented here with the following caveats:

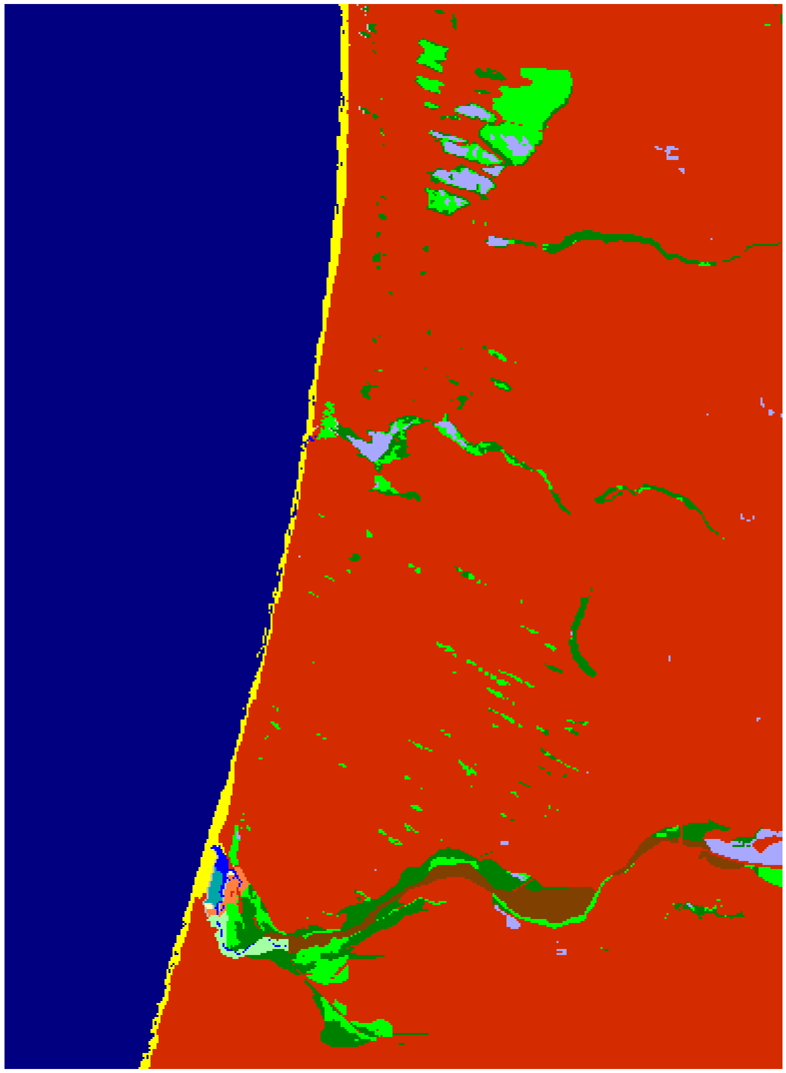
- Results were closely examined (quality assurance) within USFWS refuges but not closely examined for the larger region.
- Site-specific parameters for the model were derived for USFWS refuges whenever possible and may not be regionally applicable.
- Especially in areas where dikes are present, an effort was made to assess the probable location and effects of dikes for USFWS refuges, but this effort was not made for surrounding areas.



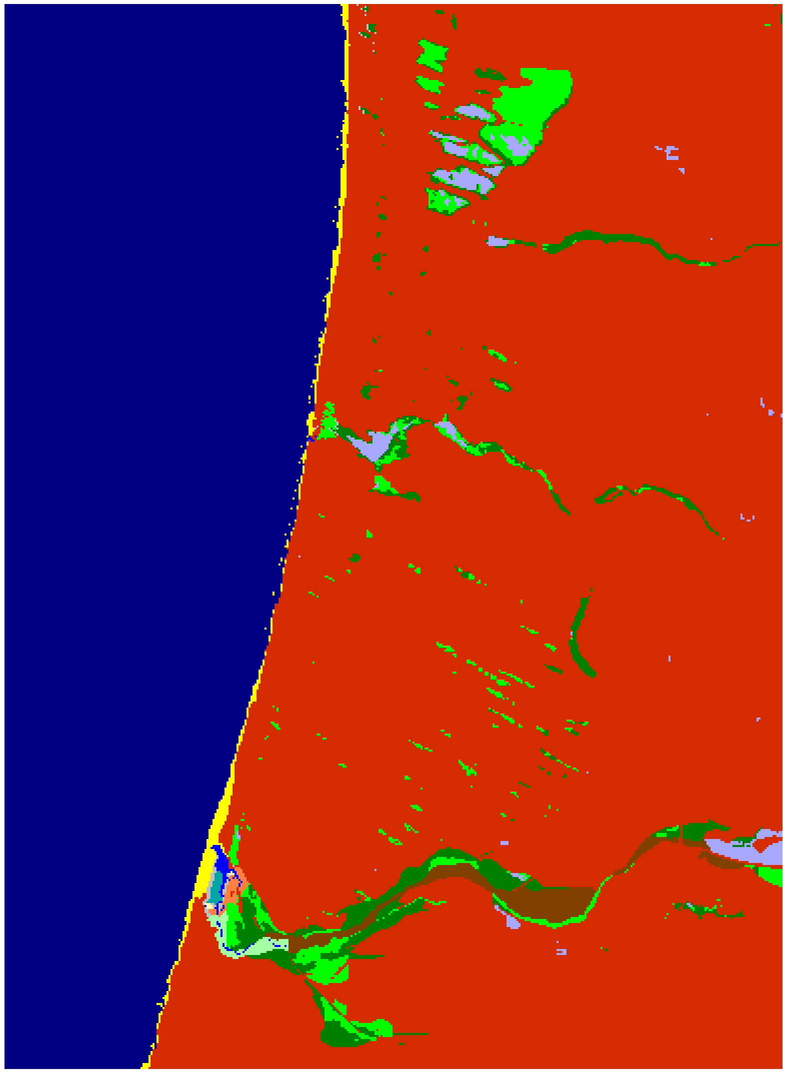
Location of Guadalupe-Nipomo Dunes National Wildlife Refuge (white areas) within simulation context



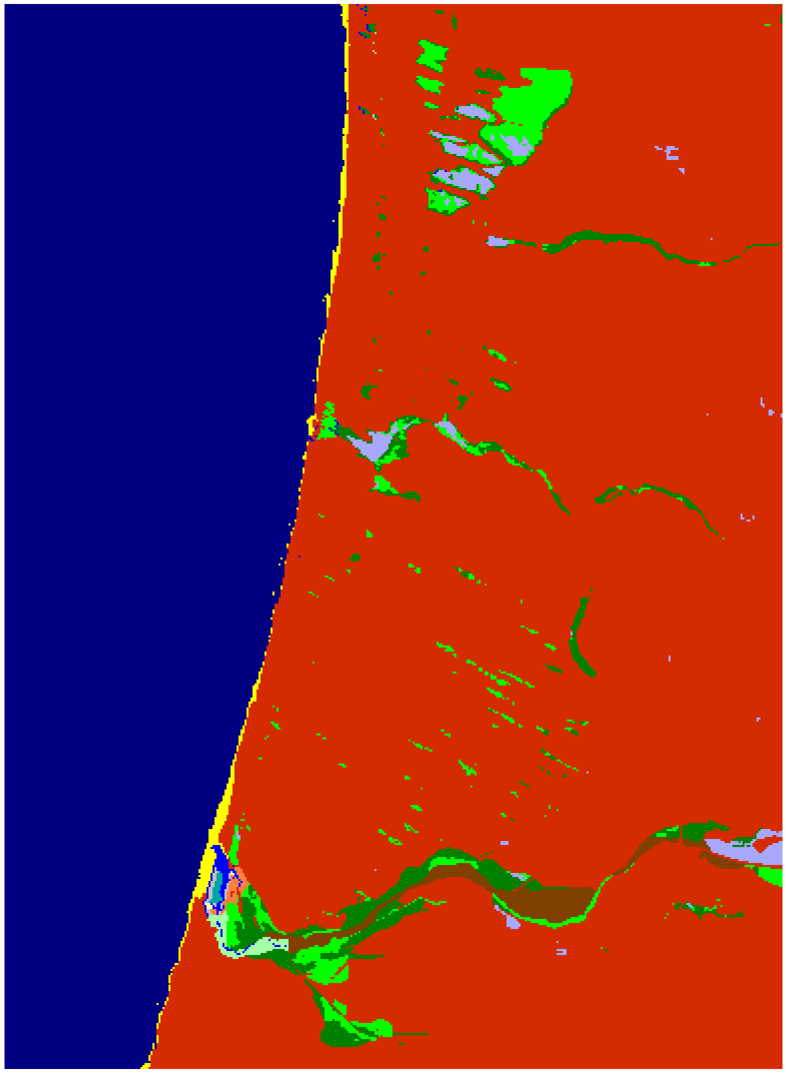
Guadalupe-Nipomo Dunes Context, Initial Condition

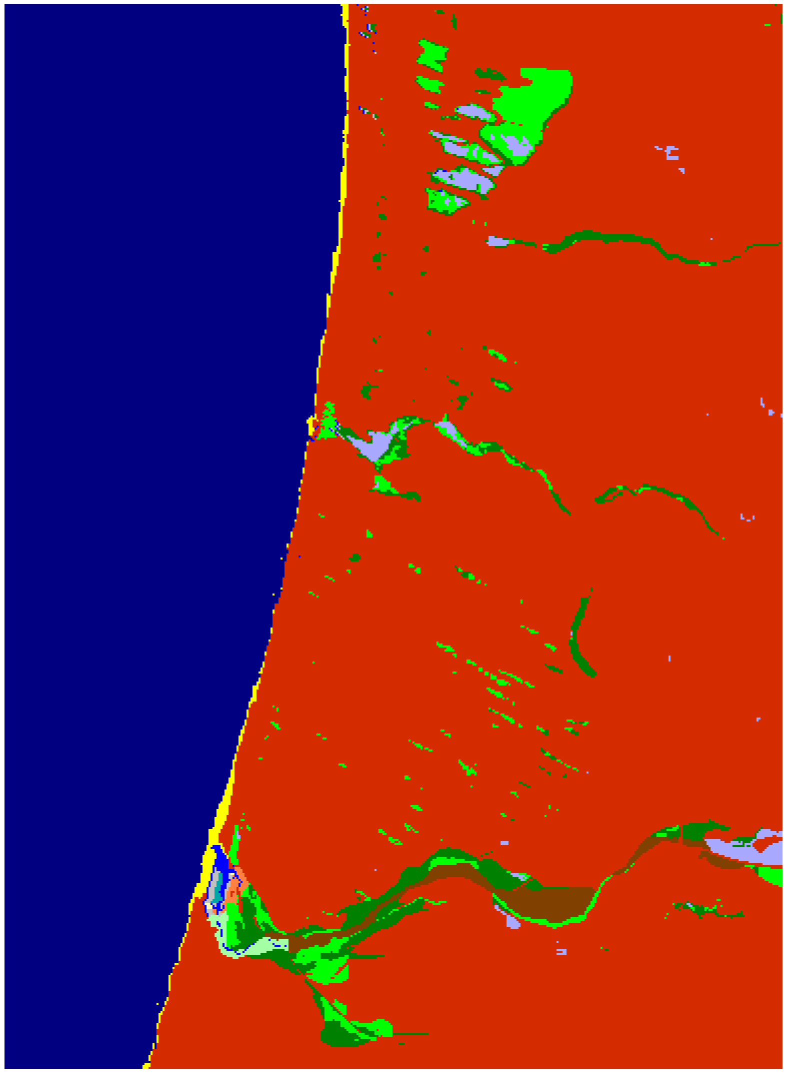


Guadalupe-Nipomo Dunes Context, 2025, Scenario A1B Mean

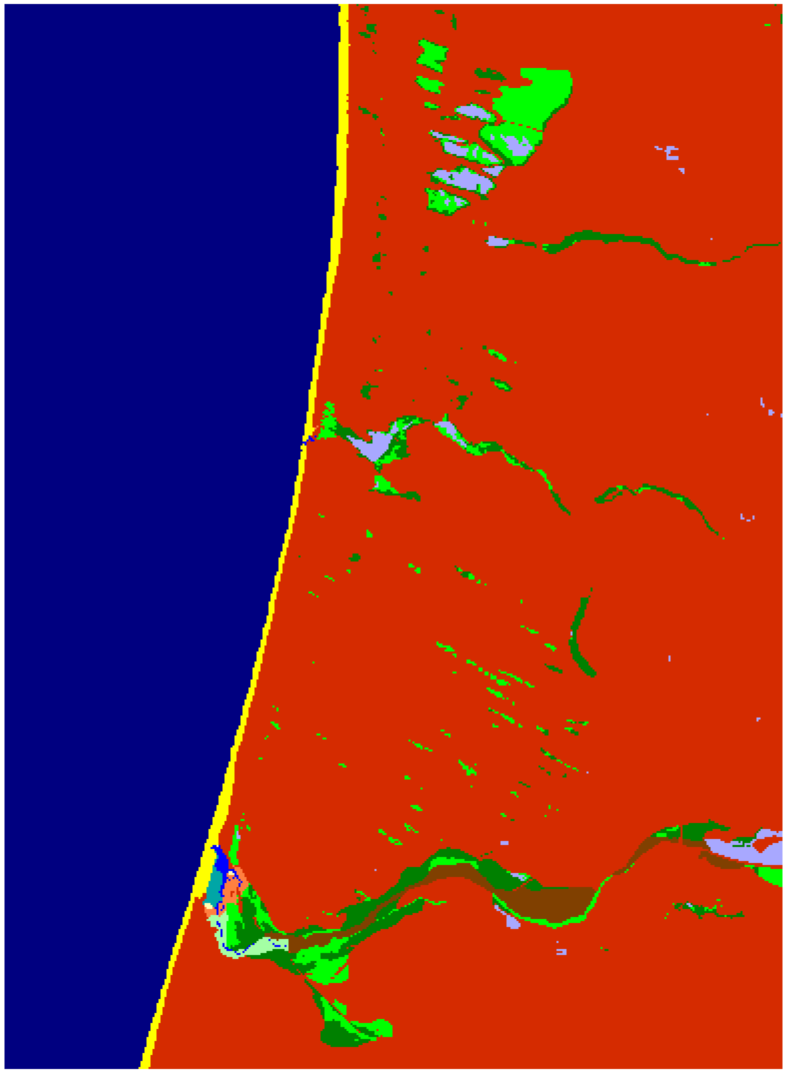


Guadalupe-Nipomo Dunes Context, 2050, Scenario A1B Mean

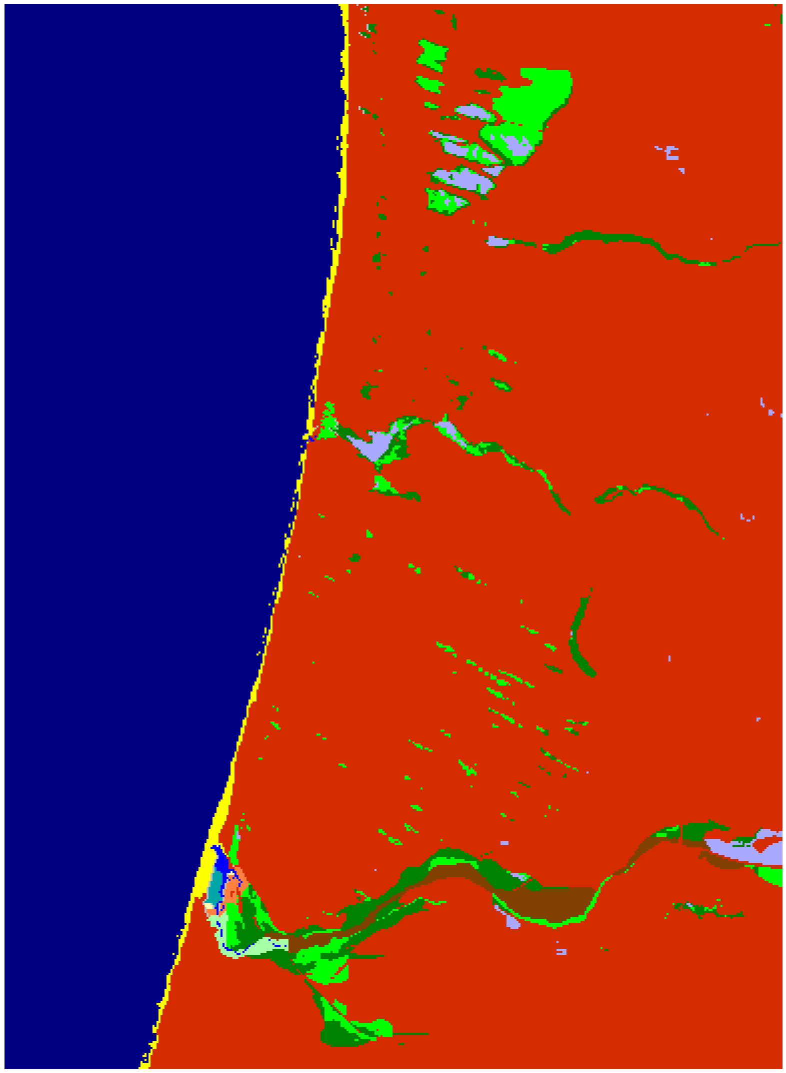

Guadalupe-Nipomo Dunes Context, 2075, Scenario A1B Mean



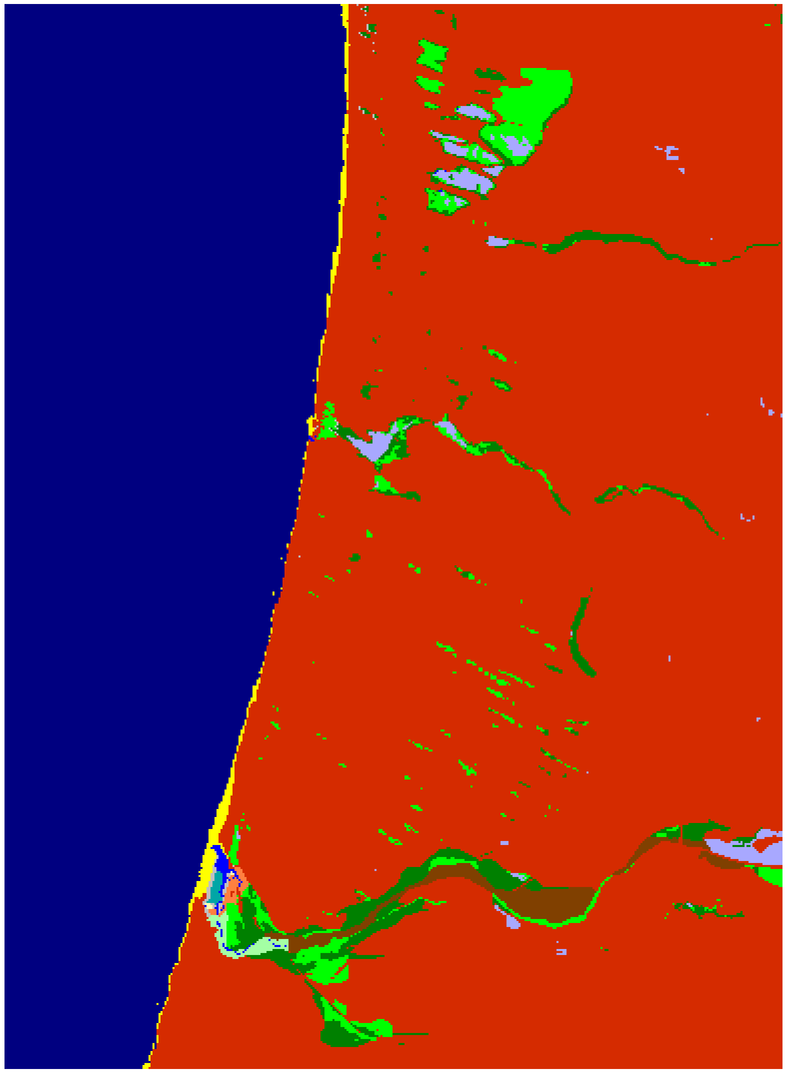
Guadalupe-Nipomo Dunes Context, 2100, Scenario A1B Mean



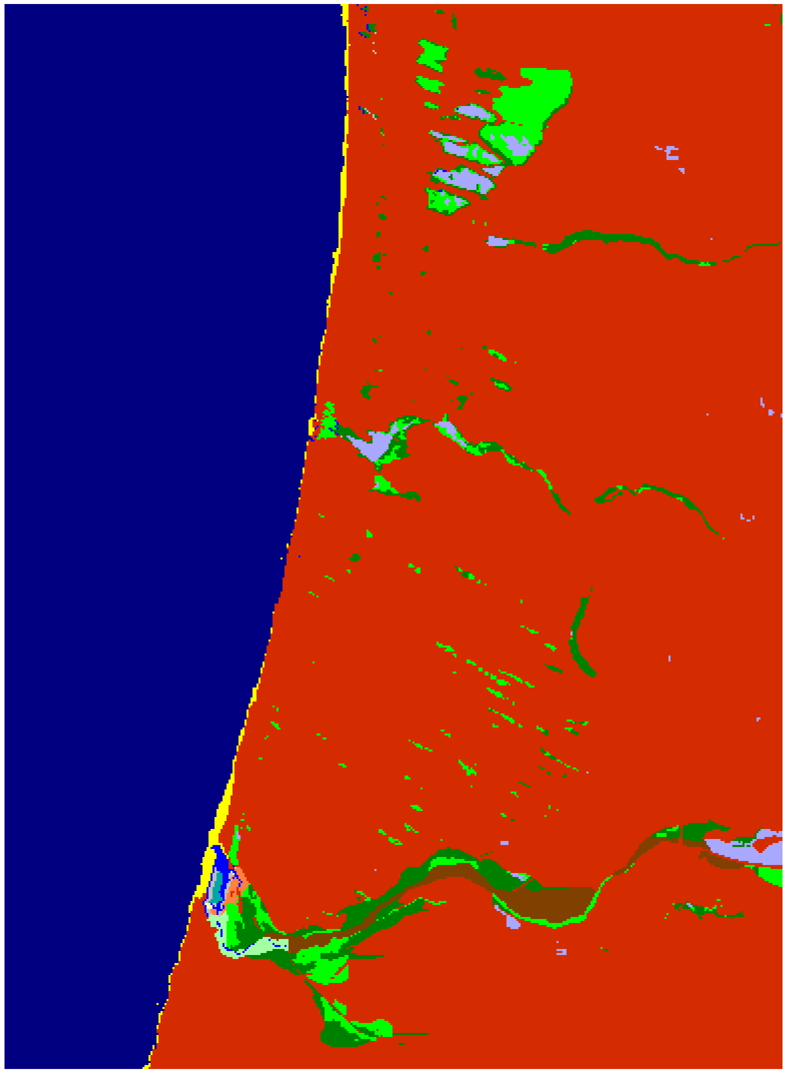
Guadalupe-Nipomo Dunes Context, Initial Condition



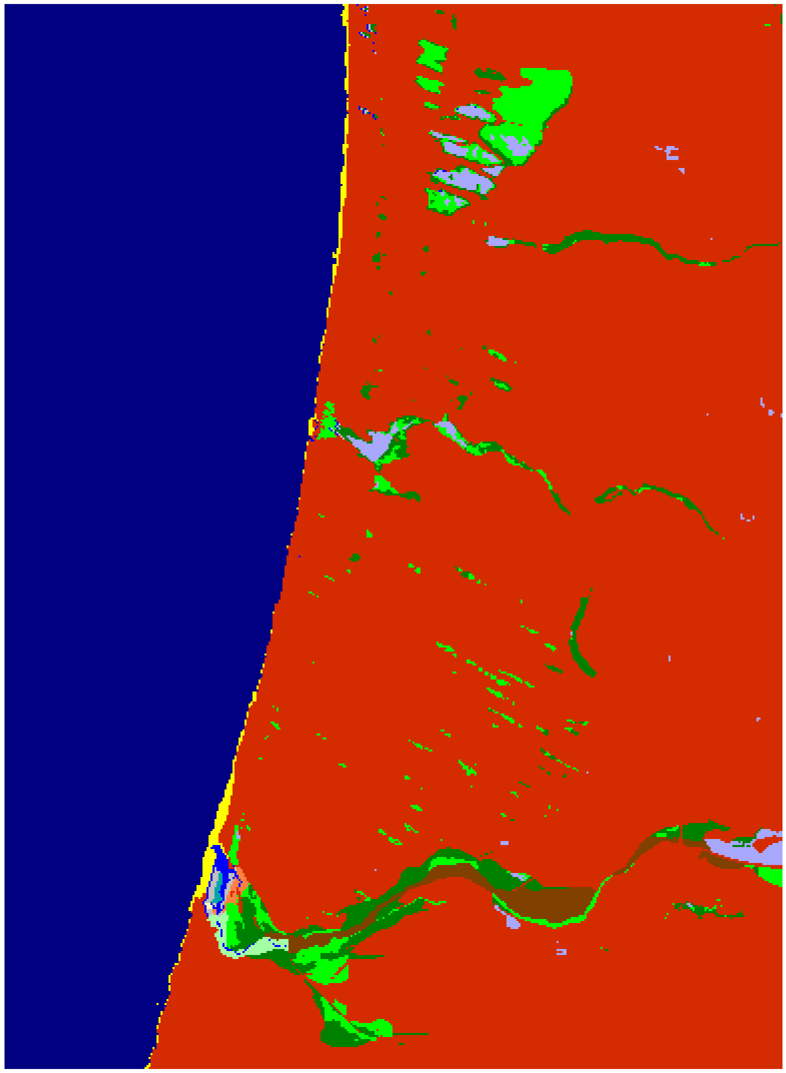
Guadalupe-Nipomo Dunes Context, 2025, Scenario A1B Maximum



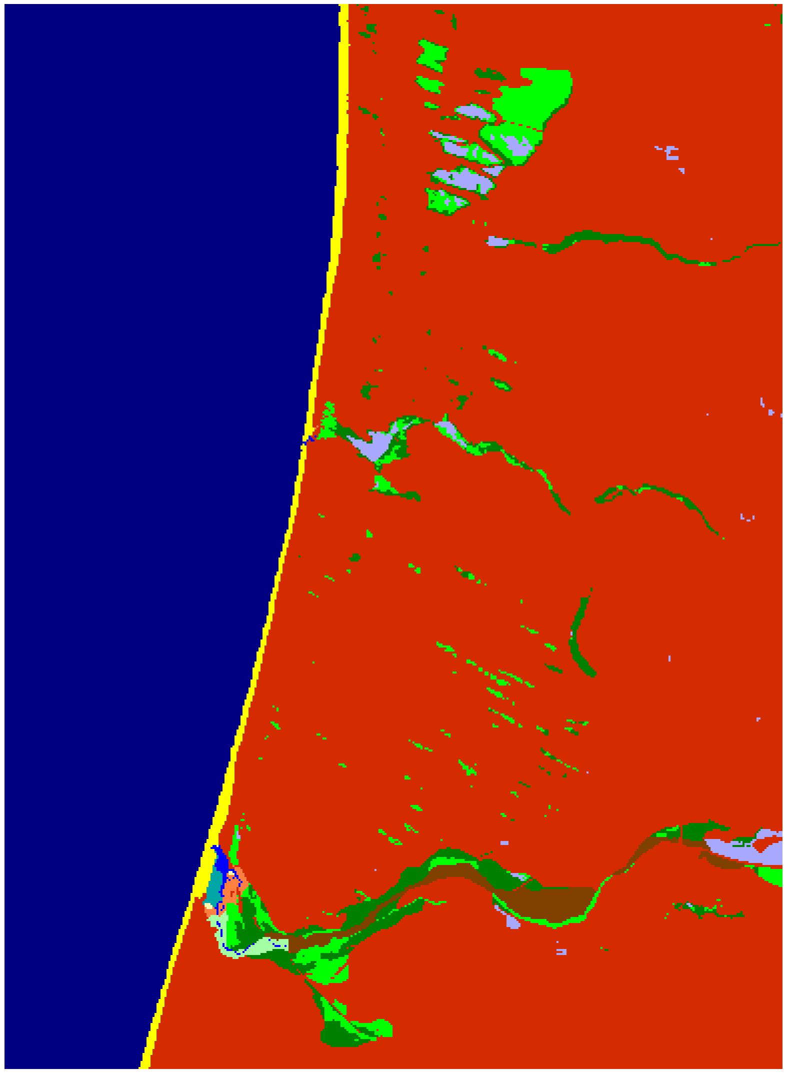
Guadalupe-Nipomo Dunes Context, 2050, Scenario A1B Maximum

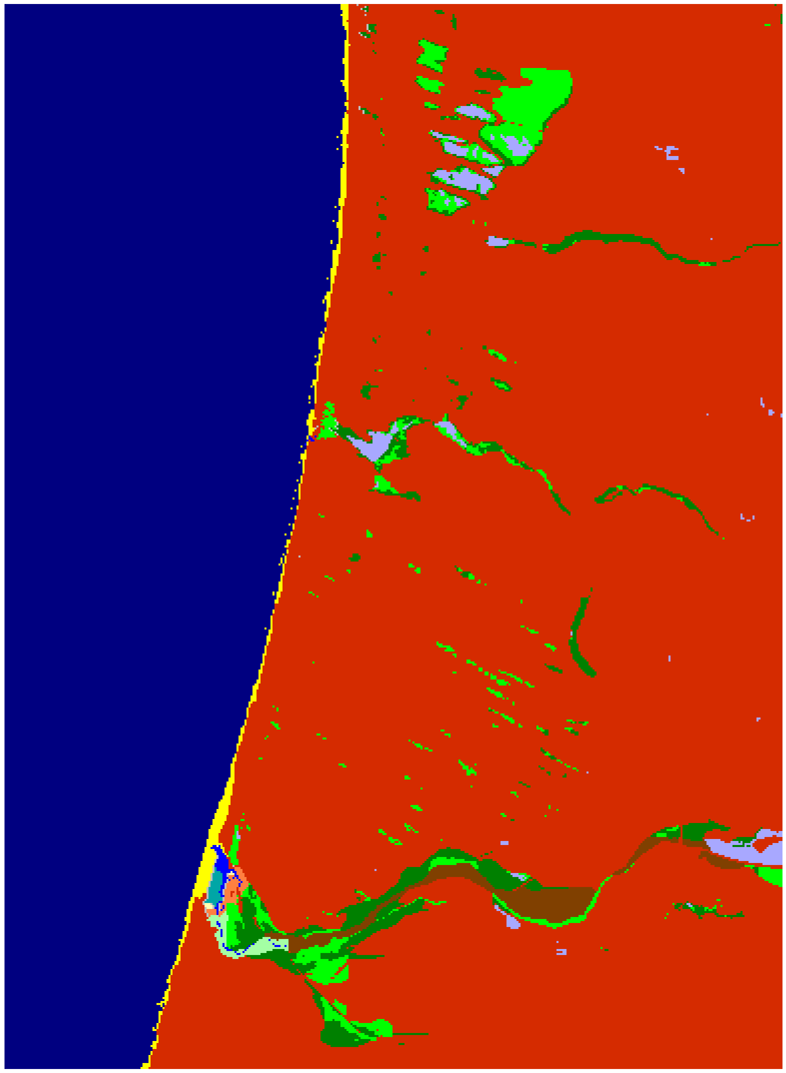


Guadalupe-Nipomo Dunes Context, 2075, Scenario A1B Maximum

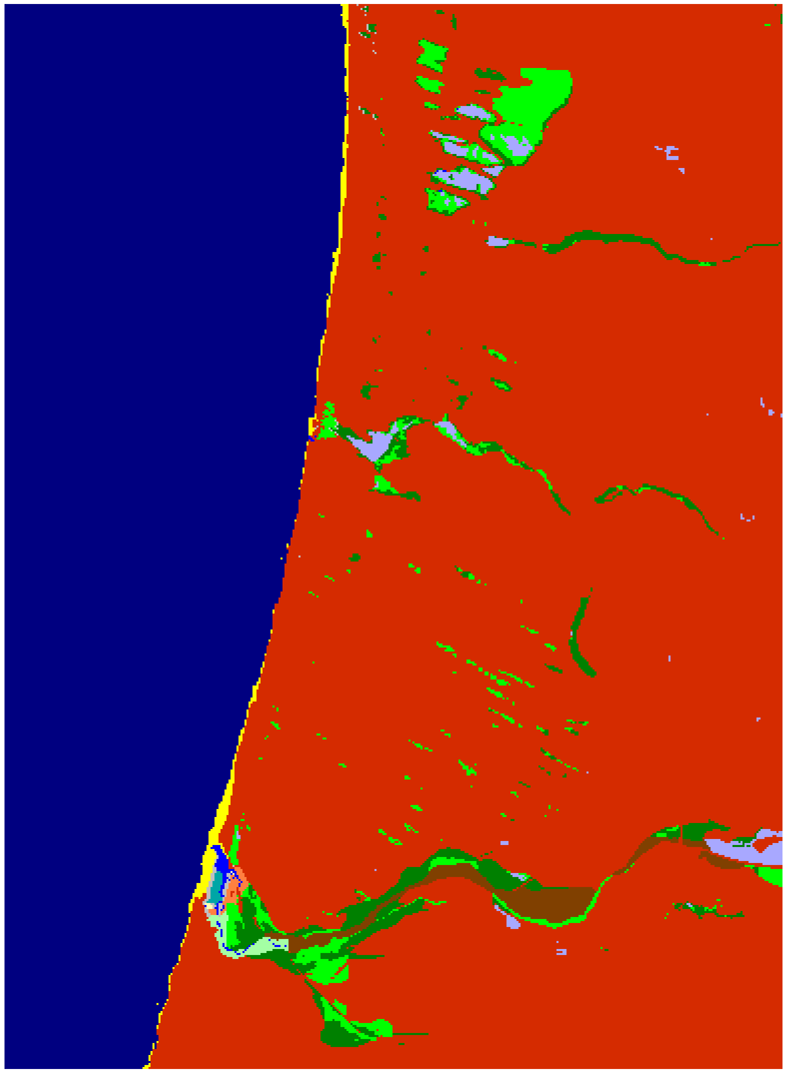


Guadalupe-Nipomo Dunes Context, 2100, Scenario A1B Maximum

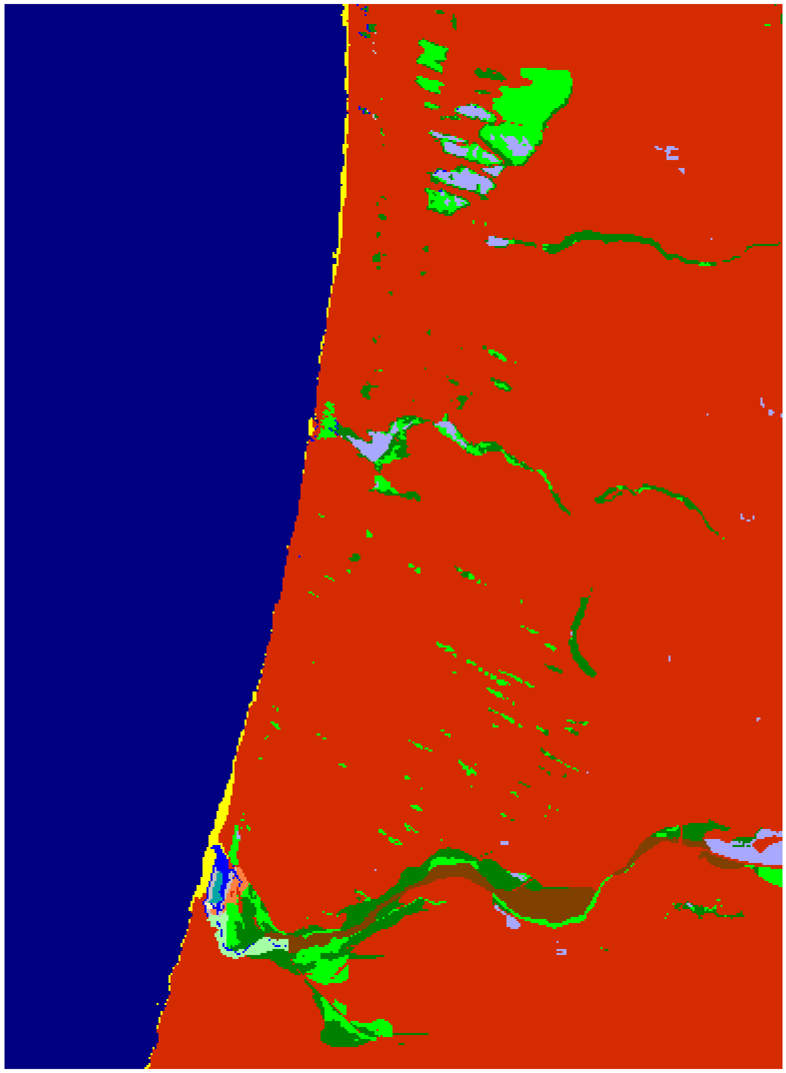

Guadalupe-Nipomo Dunes Context, Initial Condition



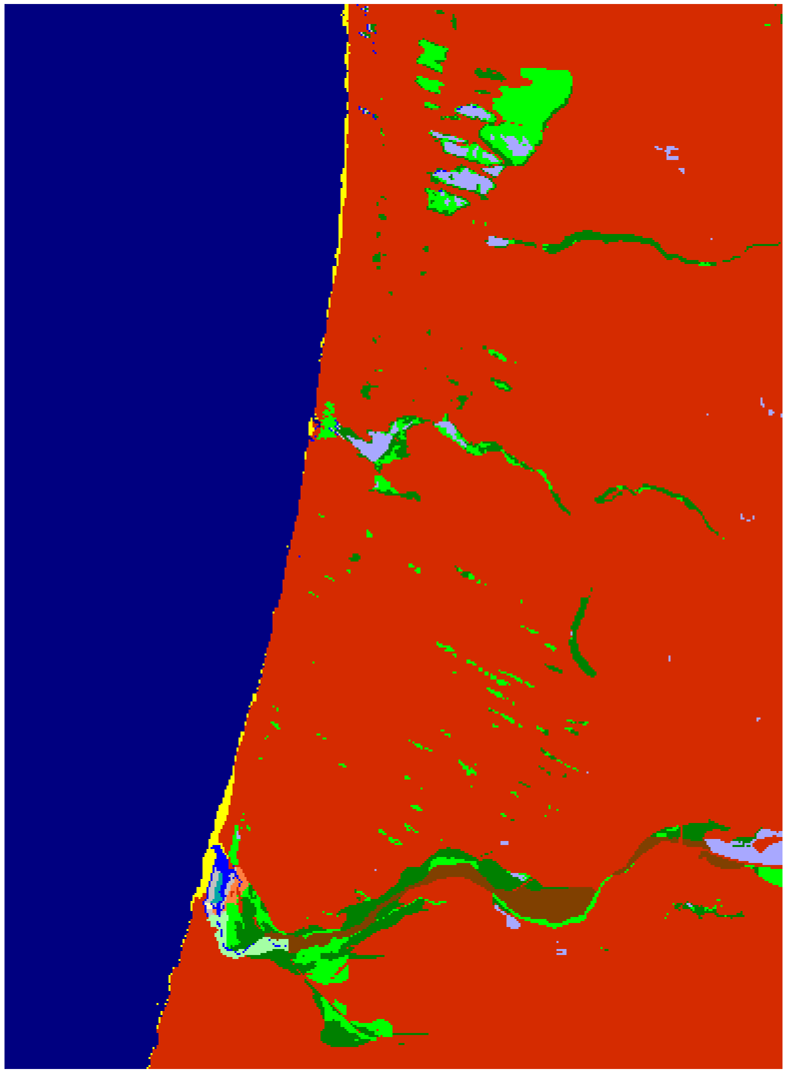
Guadalupe-Nipomo Dunes Context, 2025, 1 meter



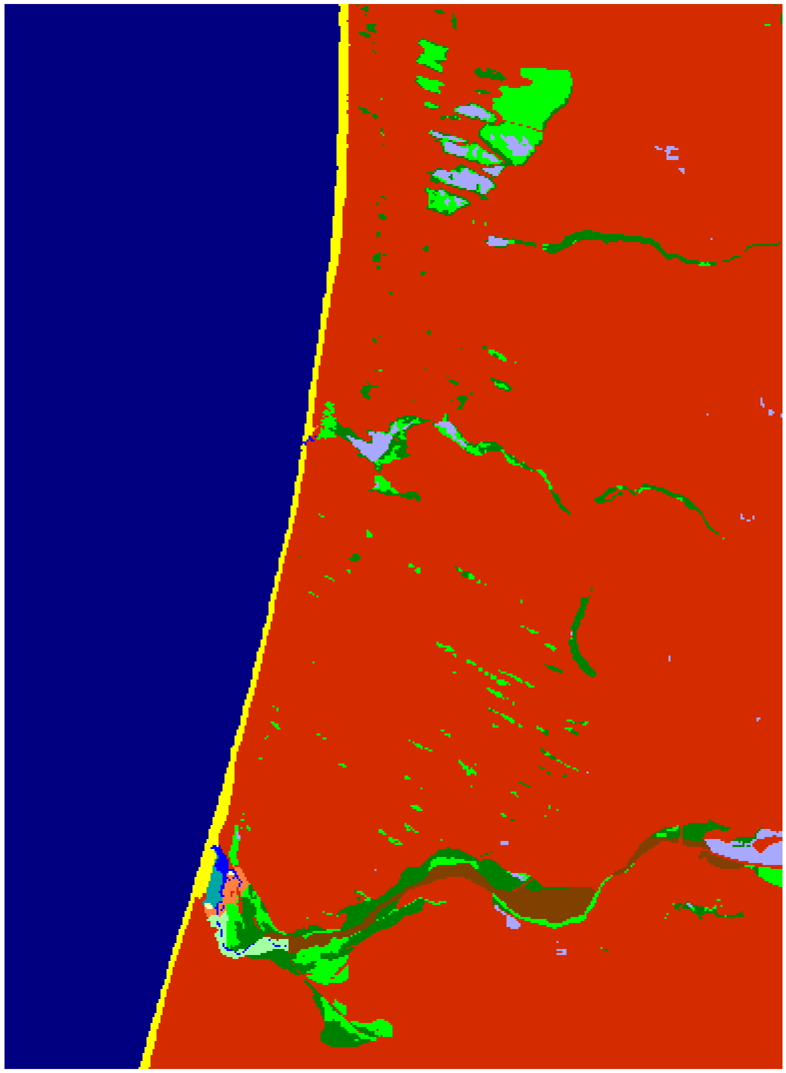
Guadalupe-Nipomo Dunes Context, 2050, 1 meter



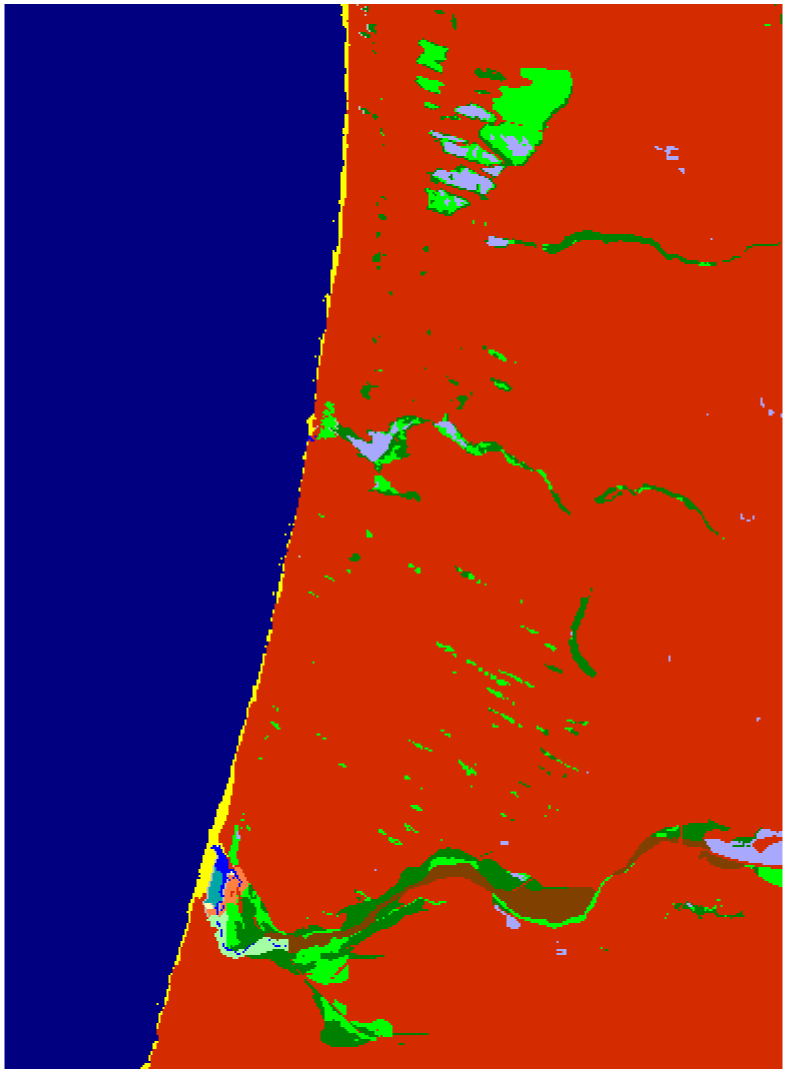
Guadalupe-Nipomo Dunes Context, 2075, 1 meter



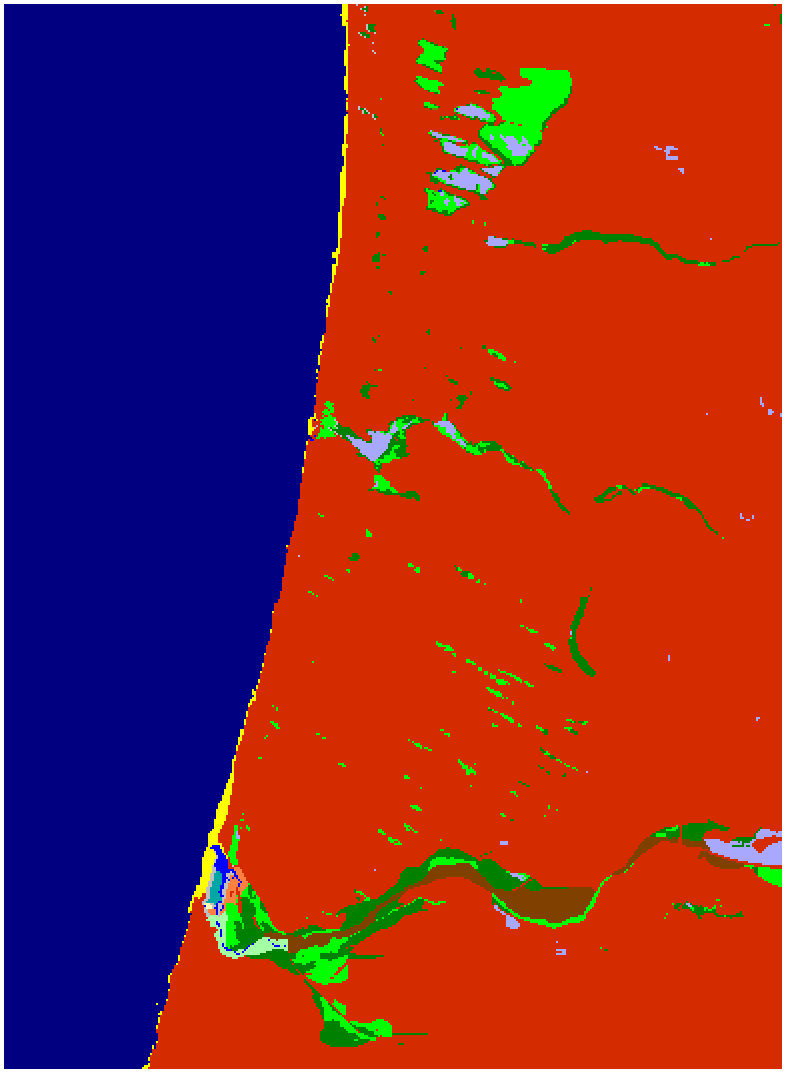
Guadalupe-Nipomo Dunes Context, 2100, 1 meter



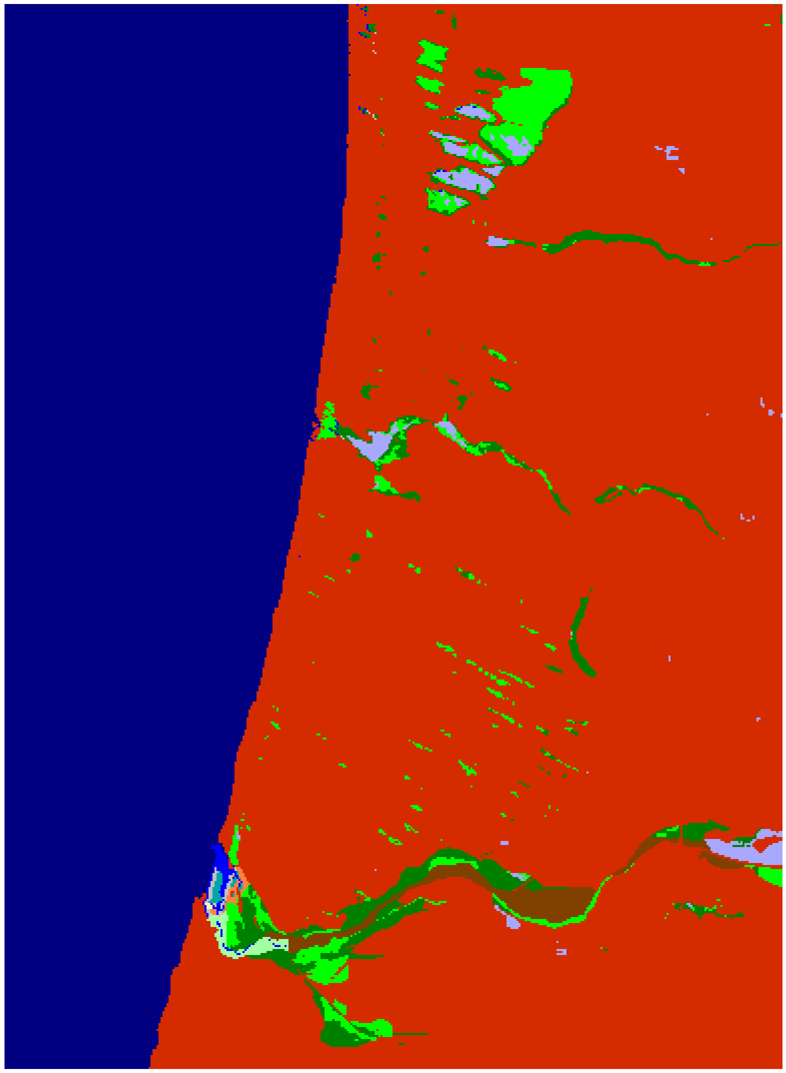
Guadalupe-Nipomo Dunes Context, Initial Condition



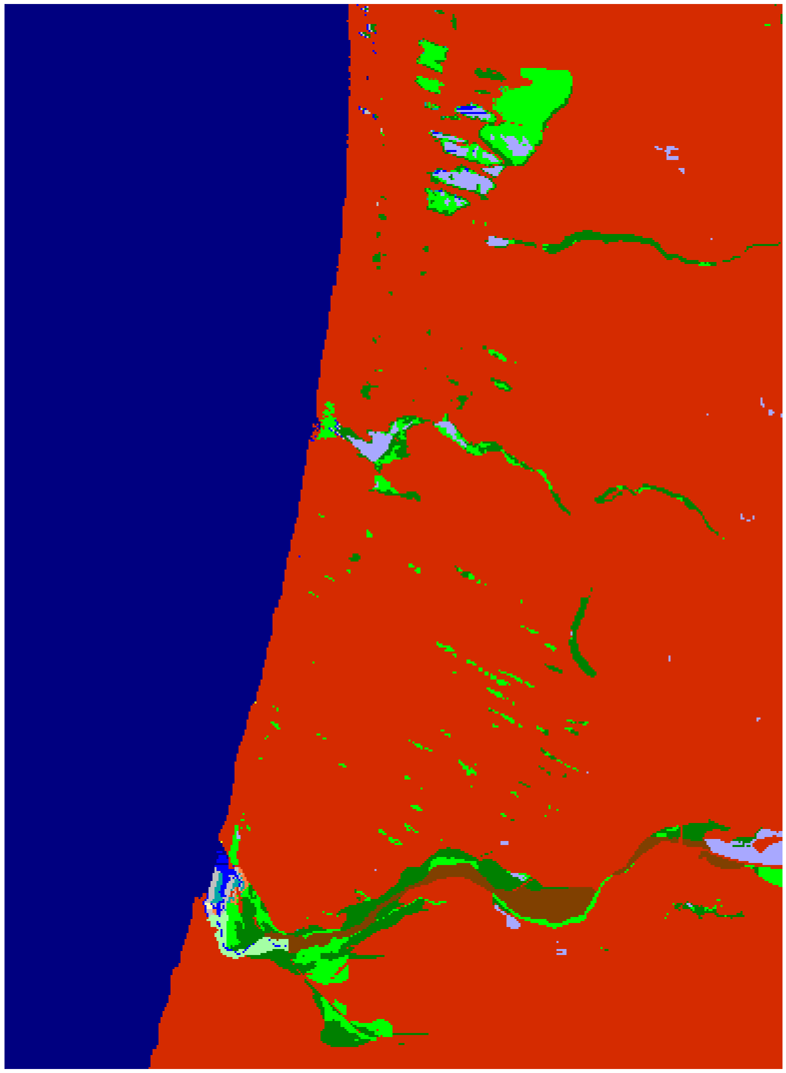
Guadalupe-Nipomo Dunes Context, 2025, 1.5 meter



Guadalupe NWR, 2050, 1.5 meter



Guadalupe-Nipomo Dunes Context, 2075, 1.5 meter



Guadalupe-Nipomo Dunes Context, 2100, 1.5 meter