Application of the Sea-Level Affecting Marshes Model (SLAMM 6) to Aransas NWR

U. S. Fish and Wildlife Service
National Wildlife Refuge System
Division of Natural Resources and Conservation Planning
Conservation Biology Program
4401 N. Fairfax Drive - MS 670
Arlington, VA 22203

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Jonathan S. Clough & Evan C. Larson, Warren Pinnacle Consulting, Inc.
PO Box 253, Warren VT, 05674
(802)-496-3476

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Introduction

Tidal marshes are among the most susceptible ecosystems to climate change, especially accelerated sea level rise (SLR). The Intergovernmental 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 is 50 to 140 cm. Rising sea levels may result in tidal marsh submergence (Moorhead and Brinson 1995) and habitat "migration" as salt marshes transgress landward and replace tidal freshwater and Irregularly Flooded 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 1 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 6) 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 specified interval for large 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 or can be specified to respond to feedbacks such as frequency of flooding.

SLAMM Version 6.0 was developed in 2008/2009 and is based on SLAMM 5. SLAMM 6.0 provides backwards compatibility to SLAMM 5, that is, SLAMM 5 results can be replicated in SLAMM 6. However, SLAMM 6 also provides several optional capabilities.

- Accretion Feedback Component: Feedbacks based on wetland elevation, distance to channel, and salinity may be specified. This feedback will be used in USFWS simulations, but only where adequate data exist for parameterization.
- Salinity Model: Multiple time-variable freshwater flows may be specified. Salinity is estimated and mapped at MLLW, MHHW, and MTL. Habitat switching may be specified as a function of salinity. This optional sub-model is not utilized in USFWS simulations.
- Integrated Elevation Analysis: SLAMM will summarize site-specific categorized elevation ranges for wetlands as derived from LiDAR data or other high-resolution data sets. This functionality is used in USFWS simulations to test the SLAMM conceptual model at each site. The causes of any discrepancies are then tracked down and reported on within the model application report.
- Flexible Elevation Ranges for land categories: If site-specific data indicate that wetland elevation ranges are outside of SLAMM defaults, a different range may be specified within the interface. In USFWS simulations, the use of values outside of SLAMM defaults is rarely utilized. If such a change is made, the change and the reason for it are fully documented within the model application reports.
- Many other graphic user interface and memory management improvements are also part of the new version including an updated *Technical Documentation*, and context sensitive help files.

For a thorough accounting of SLAMM model processes and the underlying assumptions and equations, please see the SLAMM 6.0 *Technical Documentation* (Clough, Park, Fuller, 2010). 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). Site-specific factors that increase or decrease model uncertainty may be covered in the *Discussion* section of this report.

Sea Level Rise Scenarios

SLAMM 6 was run using scenario A1B from the Special Report on Emissions Scenarios (SRES) – mean and maximum estimates. The A1 family of scenarios assumes that the future world includes rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. In particular, the A1B scenario assumes that energy sources will be balanced across all sources. Under the A1B scenario, the IPCC WGI Fourth Assessment Report (IPCC, 2007) suggests a likely range of 0.21 to 0.48 meters of sea level rise by 2090-2099 "excluding future rapid dynamical changes in ice flow." The A1B-mean scenario that was run as a part of this project falls near the middle of this estimated range, predicting 0.39 meters of global sea level rise by 2100. A1B-maximum predicts 0.69 meters of global SLR by 2100.

The latest 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 the 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 of 50 to 140 cm. This work was recently updated and the ranges were increased to 75 to 190 cm (Vermeer and Rahmstorf, 2009). Pfeffer et al. (2008) suggests that 2 meters by 2100 is at the upper end of plausible scenarios due to physical limitations on glaciological conditions. A recent US intergovernmental report states "Although no ice-sheet model is currently capable of capturing the glacier speedups in Antarctica or Greenland that have been observed over the last decade, including these processes in models will very likely show that IPCC AR4 projected sea level rises for the end of the 21st century are too low." (US Climate Change Science Program, 2008) A recent paper by Grinsted et al. (2009) states that "sea level 2090-2099 is projected to be 0.9 to 1.3 m for the A1B scenario…" Grinsted also states that there is a "low probability" that SLR will match the lower IPCC estimates.

To allow for flexibility when interpreting the results, SLAMM was also run assuming 1 meter, 1½ meters, and 2 meters of eustatic sea-level rise by the year 2100. The A1B- maximum scenario was scaled up to produce these bounding scenarios (Figure 1).

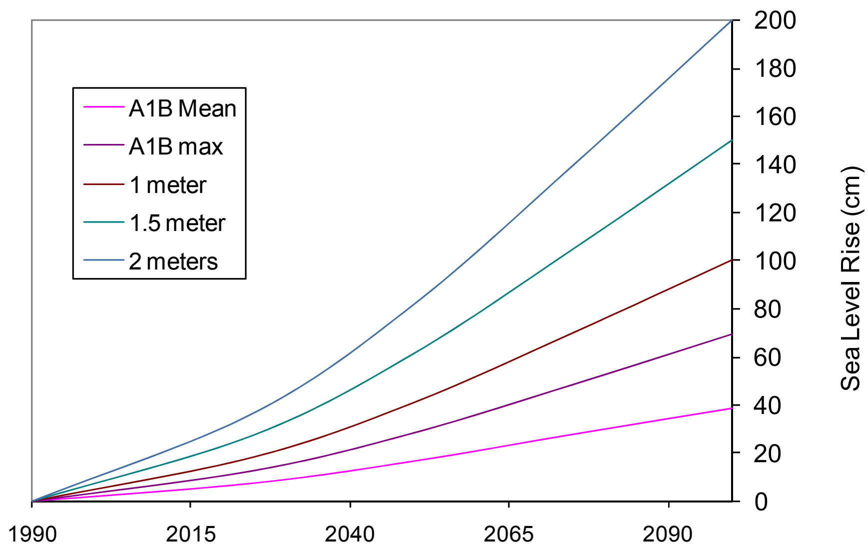


Figure 1: Summary of SLR scenarios utilized

Methods and Data Sources

The digital elevation map used in this simulation was derived from LiDAR data as supplied by NOAA with a timestamp of 2006 (Figure 1).

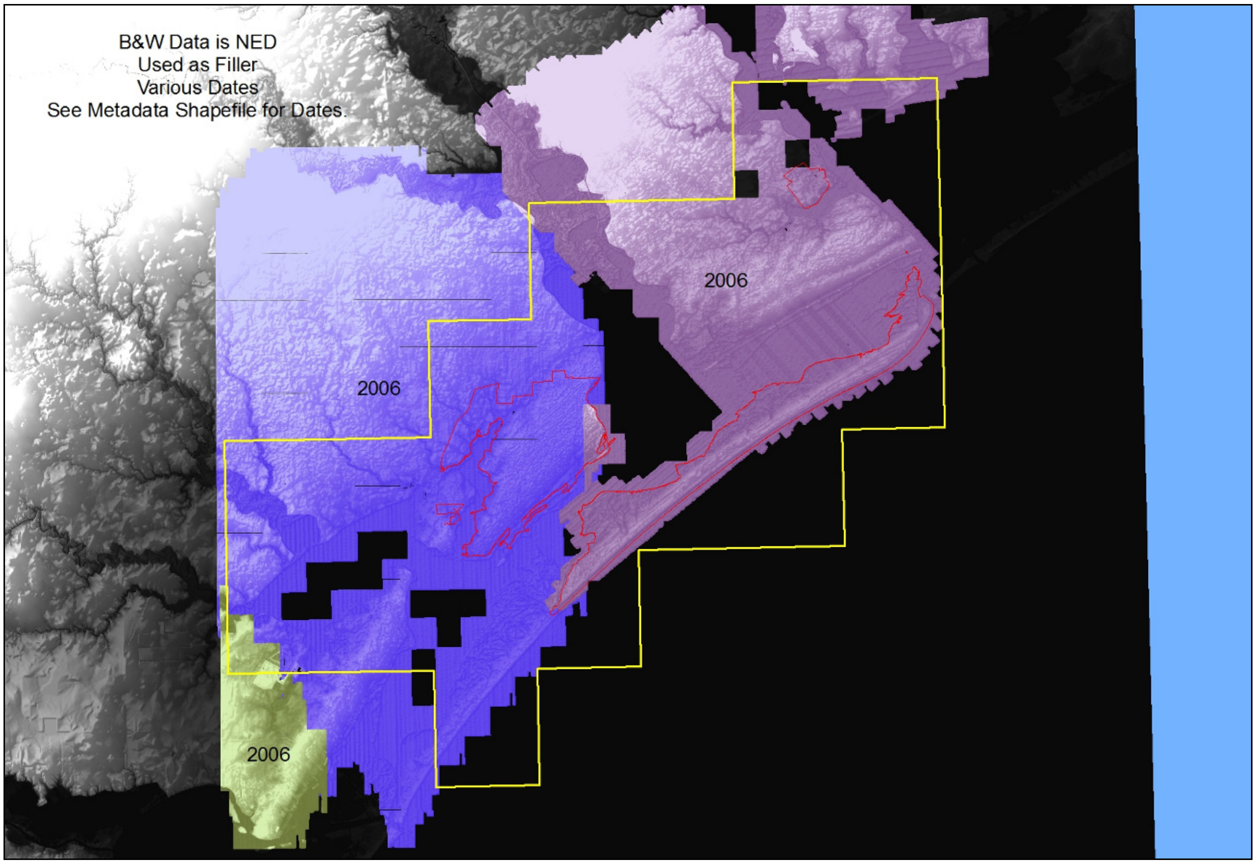


Figure 2: Shade-relief elevation map of refuge (red).

The wetlands layer for the study area was produced by the National Wetlands Inventory and was based on a 2009 photo date (Figure 2). Converting the NWI survey into 30 meter cells indicates that the approximately 116,891 acre refuge (approved acquisition boundary including water) is composed of the following categories (see next page):

	Undeveloped Dry Land	44.9%
	Inland Fresh Marsh	16.4%
	Estuarine Open Water	13.4%
	Regularly Flooded Marsh	10.6%
Open Ocean	Open Ocean	4.2%
	Irregularly Flooded Marsh	4.2%
	Estuarine Beach	2.7%
	Swamp	0.9%
	Inland Open Water	0.9%
	Ocean Beach	0.8%
	Tidal Flat	0.7%
	Developed Dry Land	0.2%
	Inland Shore	0.1%

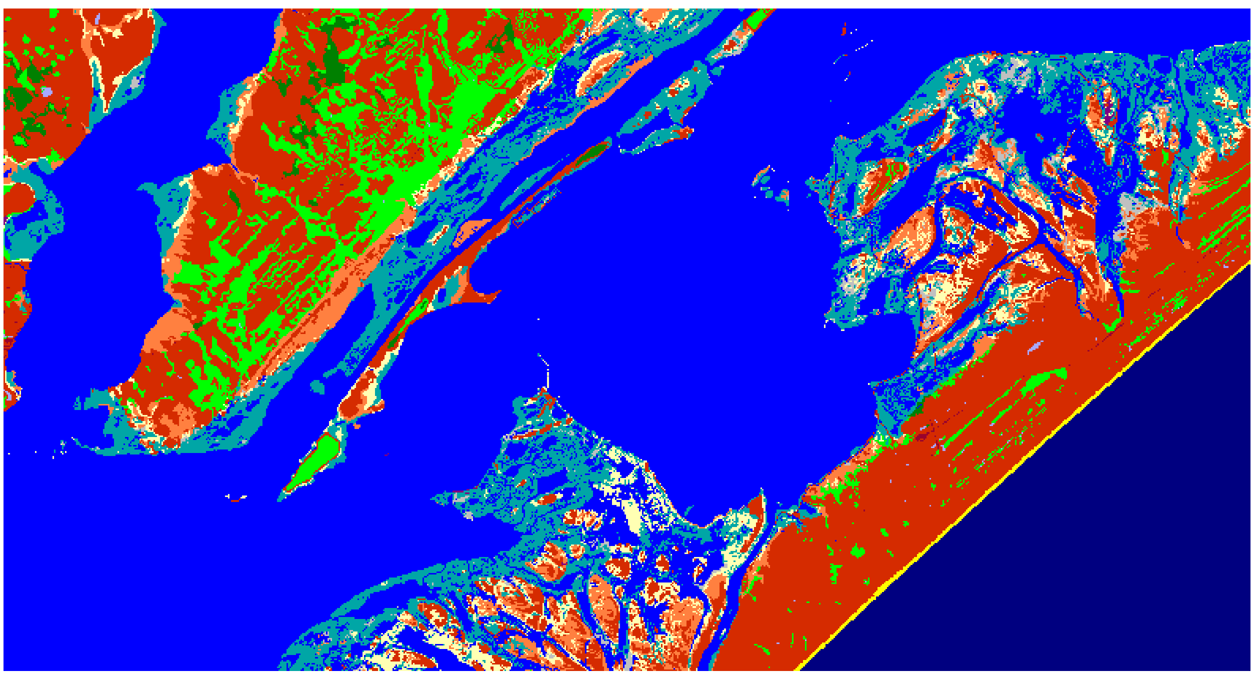


Figure 3: Portion of study area for Aransas NWR.

According to the National Wetland Inventory, there are many impounded wetlands within the study area. Within the Aransas National Wildlife Refuge, there is a significant diked area that straddles the Aransas and Tatton Units (Figure 3) as well as a large open water dike and inland fresh marsh dike within the Myrtle Unit (Figure 4). Outside of the refuge there are several diked and impounded swamp, open water and inland fresh marsh, particularly along the Intracoastal Waterway (Figure 5).

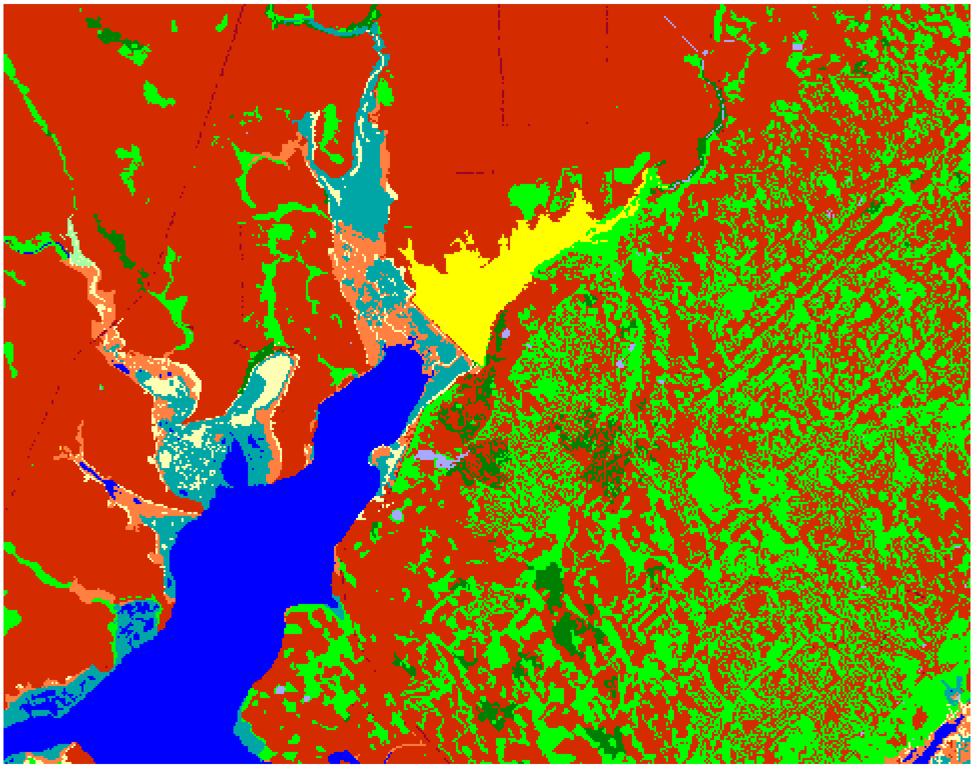


Figure 4: Diked area within the Aransas and Tatton Units.

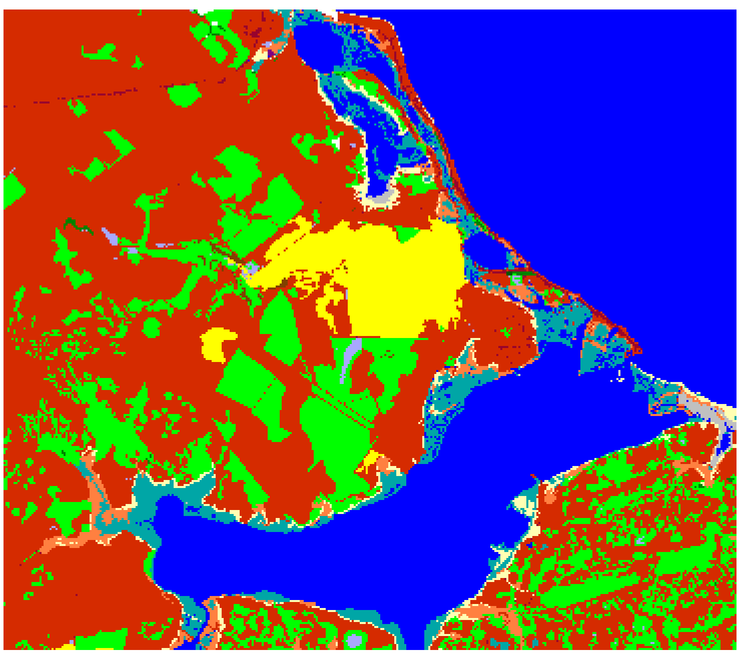


Figure 5: Diked area within the Myrtle Unit.

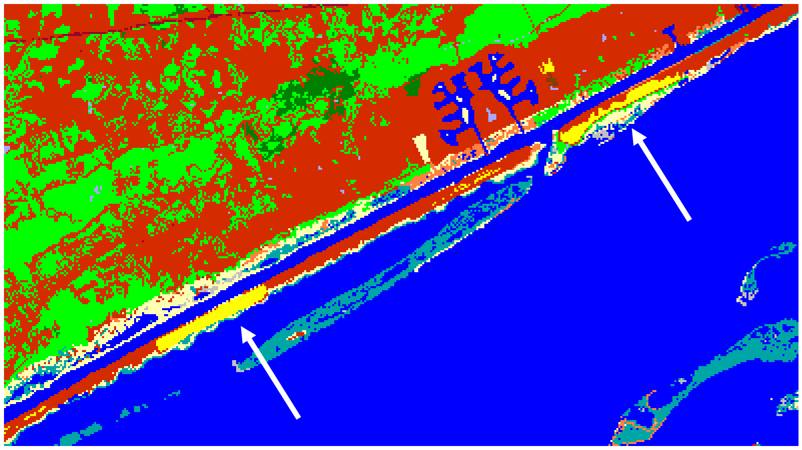


Figure 6: Example of dikes along Intracoastal Waterway.

The historic trend for sea-level rise in this area was estimated at 5.16 mm/year using the nearest NOAA gage with long-term SLR data (8774770, Rockport, TX). The rate of sea level rise for this refuge has been substantially higher than the global average for the last 100 years (approximately 1.7 mm/year, IPCC 2007a), and this difference is likely due to land subsidence. The differential between local and global rates of sea-level rise is projected to continue through the year 2100 within these model simulations.

A number of tide gages were used to determine tide range for this SLAMM application (Figure 6). Tides gathered range from 0.11 meters to 0.499 meters (8773963, North Matagorda, TX; 8773037, Seadrift, TX; 8774770, Rockport, TX; 8773259, Port Lavaca, TX; 8775270, Port Aransas, H. Caldwell Pier, TX; 8774513, Copano Bay, TX; 8773701, Port O'Connor, TX).

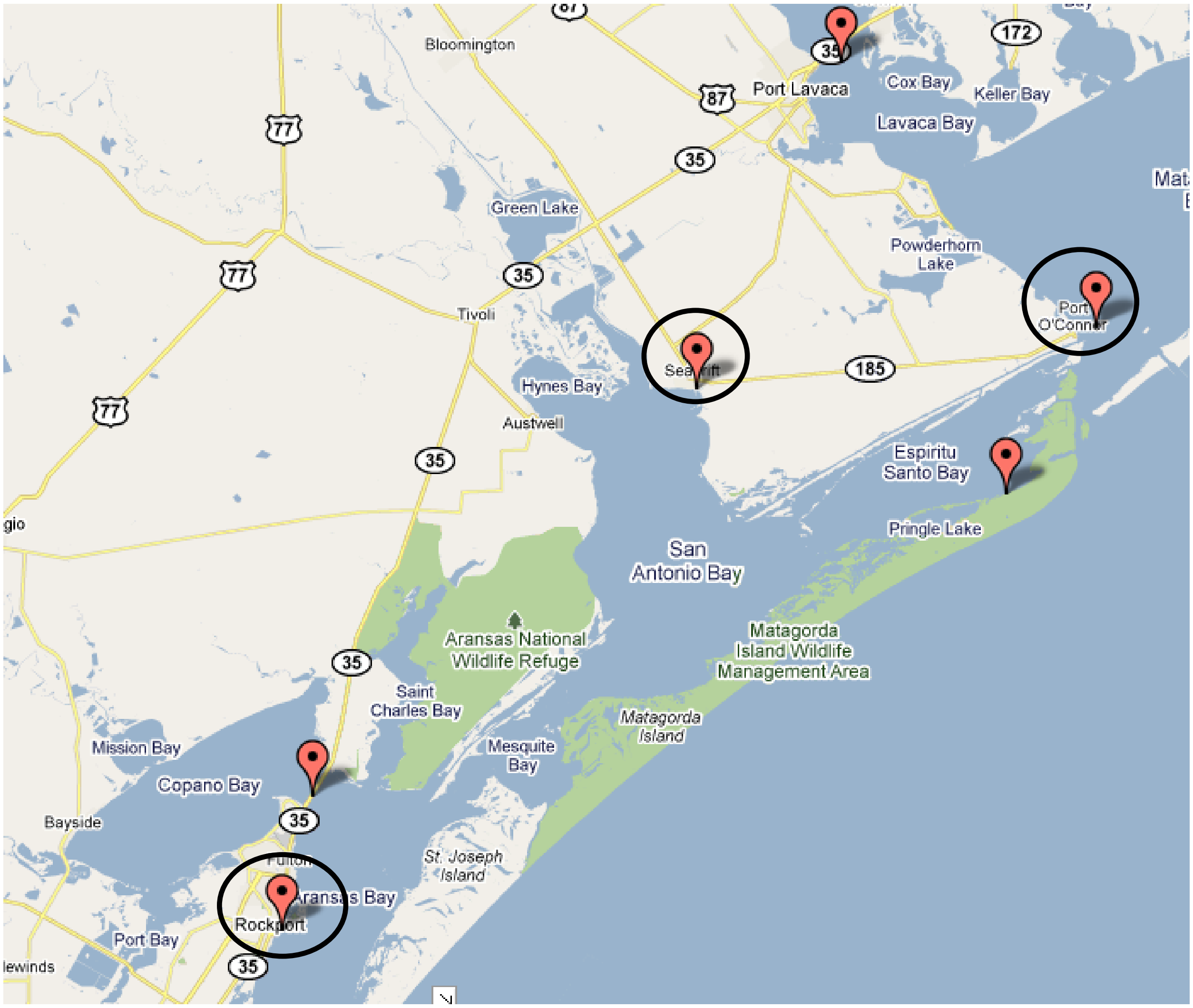


Figure 7: Location of NOAA tides gages used for Aransas NWR study area.
Circled gages were used within the "frequency of inundation" analysis

The elevation at which estuarine water is predicted to regularly inundate the land (the salt elevation) was estimated based on a frequency of inundation analysis using data from TCOON (Texas Coastal Ocean Observation Network) tide stations at Seadrift (031) and Port O'Connor (057) as well as from the Rockport NOAA gage (8774770, Rockport, TX). This procedure was done to more-precisely estimate the wet-land to dry-land elevation boundary and also to include the effects of wind tides within estimates of land inundation. The elevation of saline inundation is assumed to occur where water penetrates at least once every 30 days. Results from the NOAA Rockport gage and the Seadrift gage matched extremely closely (Figure 7). Based on this analysis, the model estimates that salt water regularly penetrates an elevation 0.36 meters above mean tide level (MTL) for areas west of Port O'Connor – which consists of the majority of the study site coast – and 0.48 meters above MTL to the east.

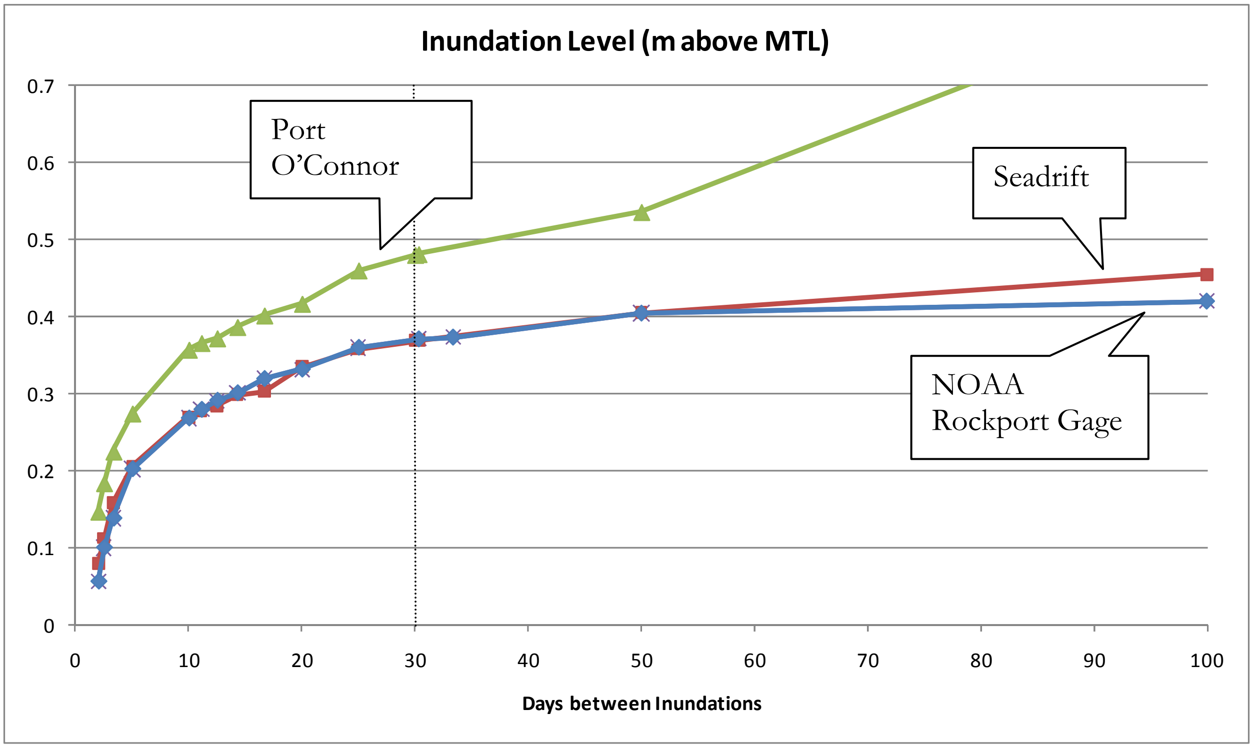


Figure 8: Frequency of inundation analyses from three tide gages within the study area.

Two sources of accretion data were considered when setting accretion rates for wetlands within the study area. Callaway, Patrick, and DeLaune (1997) reported average accretion rates of 4.4 mm/year with a standard deviation of 1.6 mm/year (from a transect taken east of the Aransas Unit, Figure 8). The measured rate within the National Wildlife Refuge itself was 4.8 mm/year though this transect was labeled as "incomplete." Because of this, the value of 4.4 mm/year was preferentially utilized though the model is unlikely to be too sensitive to this minor difference. Another study, (Feagin and Yeager, 2008) reported temporally variable accretion rates before and after growth faulting (7.8 mm/year before and 1.3 mm/year after faulting). A dynamic model of growth faulting and subsequent effects on accretion rates is outside the scope of this analysis. However, it is noted that the average of these two rates (4.55 mm/year) is close to the long-term accretion rate utilized within the modeling. Based upon the analysis above, accretion values for regularly flooded and irregularly flooded marshes were set to 4.4 mm/year.

Feagin and Yeager also found accretion rates in salt flats to be 3.3 mm/year. Salt-flats are grouped with estuarine beaches in the SLAMM simulation, and accretion rates may be underestimated in these locations.

The MTL to NAVD88 correction was derived using available data from NOAA gages. Behind the barrier island the correction was set to 0.339 meters, and the coastal value was set to 0.107 meters.

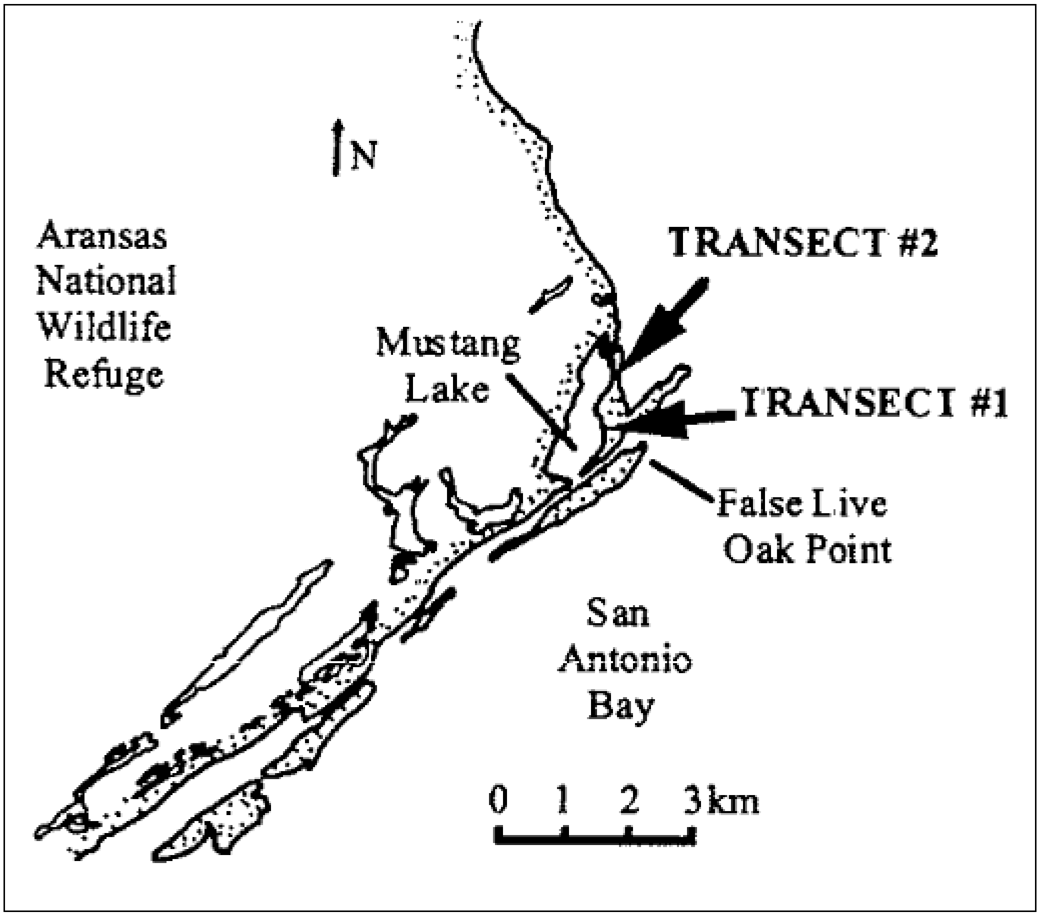


Figure 9: Location of accretion study (Callaway et al. 1997)

Modeled U.S. Fish and Wildlife Service refuge boundaries for Texas are based on Approved Acquisition Boundaries as published on the FWS National Wildlife Refuge Data and Metadata website. The cell-size used for this analysis was 30 meter by 30 meter cells. Note that the SLAMM model will track partial conversion of cells based on elevation and slope.

As part of this project, communication with several scientists and stakeholders was undertaken to try to gather the best possible sources for model data and parameters.

- Jim Dick, the Regional Wetlands Coordinator for the Southwest Region of USFWS;
- Dan Alonso, the Project Leader of Aransas NWR;
- Beau Hardegree, biologist in the USFWS Coastal Program;
- James Rizzo of the Texas Coastal Ocean Observation Network;
- Carey Strobel, wildlife biologist at Aransas NWR.

These sources pointed us to important data resources and additional contacts which aided our modeling effort. Their contributions provided us with a new wetlands data layer, data sources for the spatial tide analysis, as well as additional accretion data and information about dike locations.

SUMMARY OF SLAMM INPUT PARAMETERS FOR ARANSAS NWR

Parameter	Global	SubSite 1	SubSite 2	SubSite 3
Description		Myrtle	Matagorda Unit	OceanSide
NWI Photo Date (YYYY)	2008	2008	2008	2008
DEM Date (YYYY)	2006	2006	2006	2006
Direction Offshore [n,s,e,w]	South	East	North	South
Historic Trend (mm/yr)	5.16	5.16	5.16	5.16
MTL-NAVD88 (m)	0.339	0.339	0.339	0.107
GT Great Diurnal Tide Range (m)	0.111	0.283	0.131	0.499
Salt Elev. (m above MTL)	0.36	0.48	0.36	0.332
Marsh Erosion (horz. m /yr)	0	0	0	0
Swamp Erosion (horz. m /yr)	0	0	0	0
T.Flat Erosion (horz. m /yr)	0	0	0	0
Reg. Flood Marsh Accr (mm/yr)	4.4	4.4	4.4	4.4
Irreg. Flood Marsh Accr (mm/yr)	4.4	4.4	4.4	4.4
Tidal Fresh Marsh Accr (mm/yr)	5.9	5.9	5.9	5.9
Beach Sed. Rate (mm/yr)	0.5	0.5	0.5	0.5
Freq. Overwash (years)	20	20	20	20
Use Elev Pre-processor [True,False]	FALSE	FALSE	FALSE	FALSE

Parameter	SubSite 4	SubSite 5	SubSite 6	SubSite 7
Description	Copano Bay	Copano Sub 1	Copano Sub 2	Copano Sub 3
NWI Photo Date (YYYY)	2008	2008	2008	2008
DEM Date (YYYY)	2006	2006	2006	2006
Direction Offshore [n,s,e,w]	South	South	North	South
Historic Trend (mm/yr)	5.16	5.16	5.16	5.16
MTL-NAVD88 (m)	0.339	0.339	0.339	0.339
GT Great Diurnal Tide Range (m)	0.117	0.117	0.117	0.117
Salt Elev. (m above MTL)	0.36	0.36	0.36	0.36
Marsh Erosion (horz. m /yr)	0	1	1.88	1.56
Swamp Erosion (horz. m /yr)	0	1	1.88	1.56
T.Flat Erosion (horz. m /yr)	0	1	1.88	1.56
Reg. Flood Marsh Accr (mm/yr)	4.4	4.4	4.4	4.4
Irreg. Flood Marsh Accr (mm/yr)	4.4	4.4	4.4	4.4
Tidal Fresh Marsh Accr (mm/yr)	5.9	5.9	5.9	5.9
Beach Sed. Rate (mm/yr)	0.5	0.5	0.5	0.5
Freq. Overwash (years)	20	20	20	20
Use Elev Pre-processor [True,False]	FALSE	FALSE	FALSE	FALSE

Parameter	SubSite 8	SubSite 9	SubSite 10	SubSite 11
Description	Copano Sub 4	Copano Sub 5	Copano Sub 6	Copano Sub 7
NWI Photo Date (YYYY)	2008	2008	2008	2008
DEM Date (YYYY)	2006	2006	2006	2006
Direction Offshore [n,s,e,w]	South	South	East	North
Historic Trend (mm/yr)	5.16	5.16	5.16	5.16
MTL-NAVD88 (m)	0.339	0.339	0.339	0.339
GT Great Diurnal Tide Range (m)	0.117	0.117	0.117	0.117
Salt Elev. (m above MTL)	0.36	0.36	0.36	0.36
Marsh Erosion (horz. m /yr)	2.29	1.68	1.07	1.68
Swamp Erosion (horz. m /yr)	2.29	1.68	1.07	1.68
T.Flat Erosion (horz. m /yr)	2.29	1.68	1.07	1.68
Reg. Flood Marsh Accr (mm/yr)	4.4	4.4	4.4	4.4
Irreg. Flood Marsh Accr (mm/yr)	4.4	4.4	4.4	4.4
Tidal Fresh Marsh Accr (mm/yr)	5.9	5.9	5.9	5.9
Beach Sed. Rate (mm/yr)	0.5	0.5	0.5	0.5
Freq. Overwash (years)	20	20	20	20
Use Elev Pre-processor [True,False]	FALSE	FALSE	FALSE	FALSE

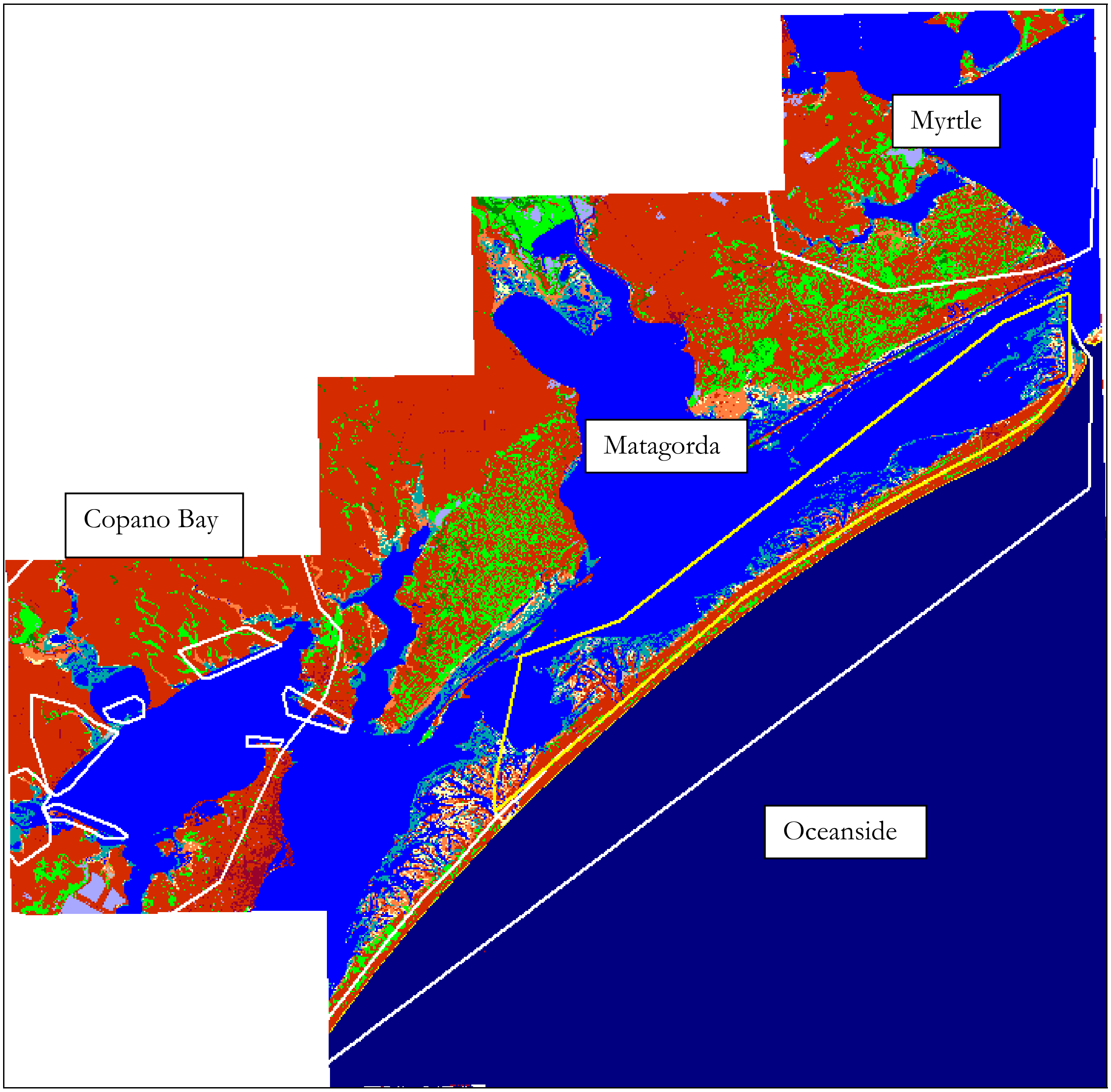


Figure 10: Input subsites for model application. More Copano Bay subsites below.

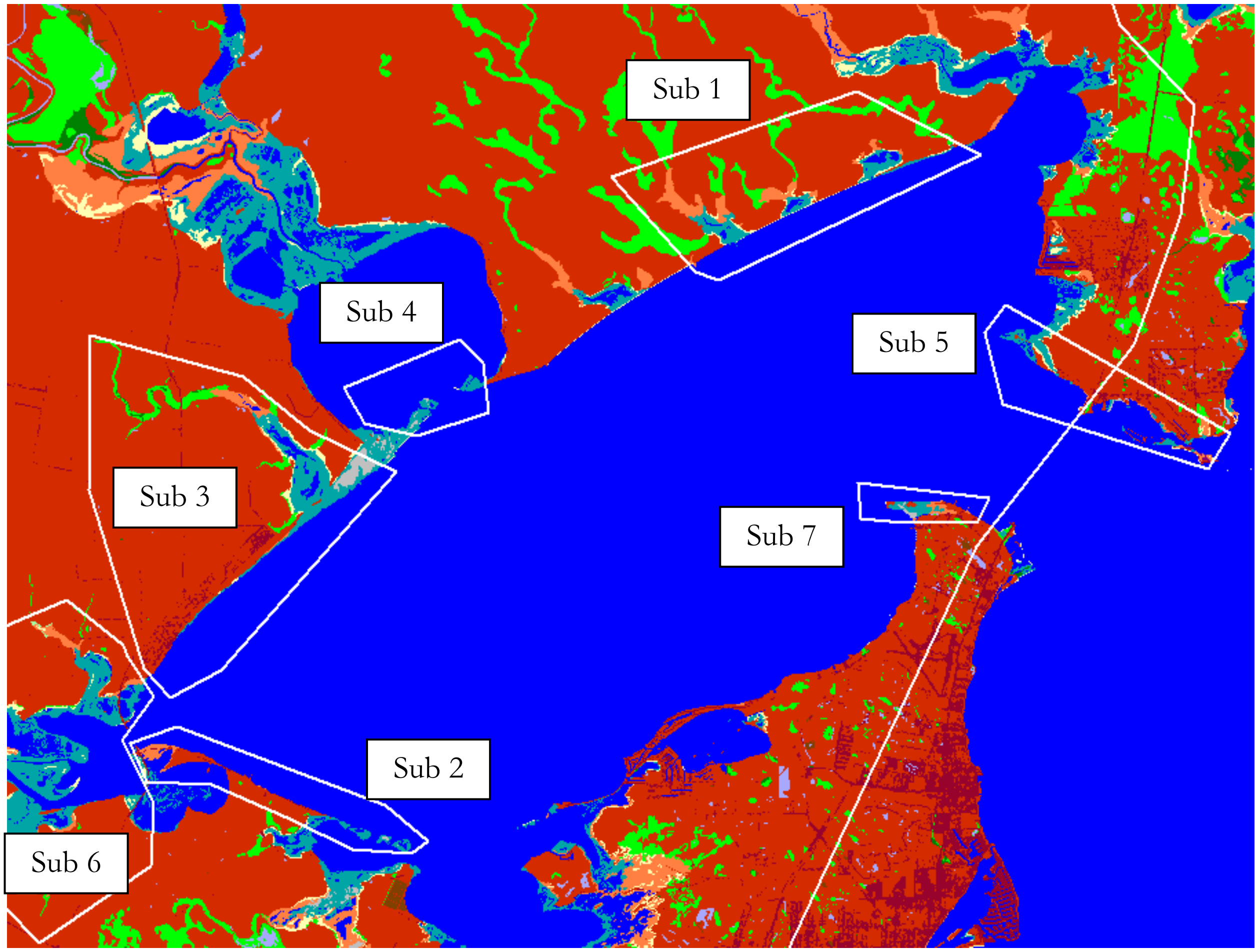


Figure 11: Close up of Copano Bay input subsites.

Results

Unlike most USFWS SLAMM analyses, in this study tables and maps of results are broken down for both in-refuge and the entire study area. Non-refuge areas, usually referred to as "contextual results", were closely evaluated as part of this analysis. A summary of those results start on page 47. Results presented here are for the USFWS national wildlife refuge only.

Aransas National Wildlife Refuge

Between 5% and 15% of undeveloped dry land – which makes up roughly half of the refuge – is predicted to be lost in sea-level rise scenarios of up to one meter by 2100. However, when sea-level rise increases to two meters by 2100, the dry-land loss approaches 56%. Inland fresh marsh is relatively unaffected until sea-level approaches and exceeds one meter by 2100. Up to 30% of this land-cover category is ultimately vulnerable to the effects of sea-level rise.

Refuge salt marshes show an interesting pattern in this analysis with up to 70% of regularly flooded marshes lost in scenarios of approximately one meter of SLR. However, in higher SLR scenarios, much of the dry lands on Matagorda Island and San Jose Island are predicted to convert to marshlands thus reducing overall category loss rates.

SLR by 2100 (m)	0.39	0.69	1	1.5	2
Undeveloped Dry Land	5%	9%	15%	38%	56%
Inland Fresh Marsh	0%	1%	4%	15%	29%
Regularly Flooded Marsh	35%	71%	68%	50%	8%
Irregularly Flooded Marsh	10%	47%	75%	94%	98%
Estuarine Beach	74%	91%	95%	97%	98%
Swamp	2%	3%	5%	10%	18%
Developed Dry Land	16%	22%	31%	63%	80%

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

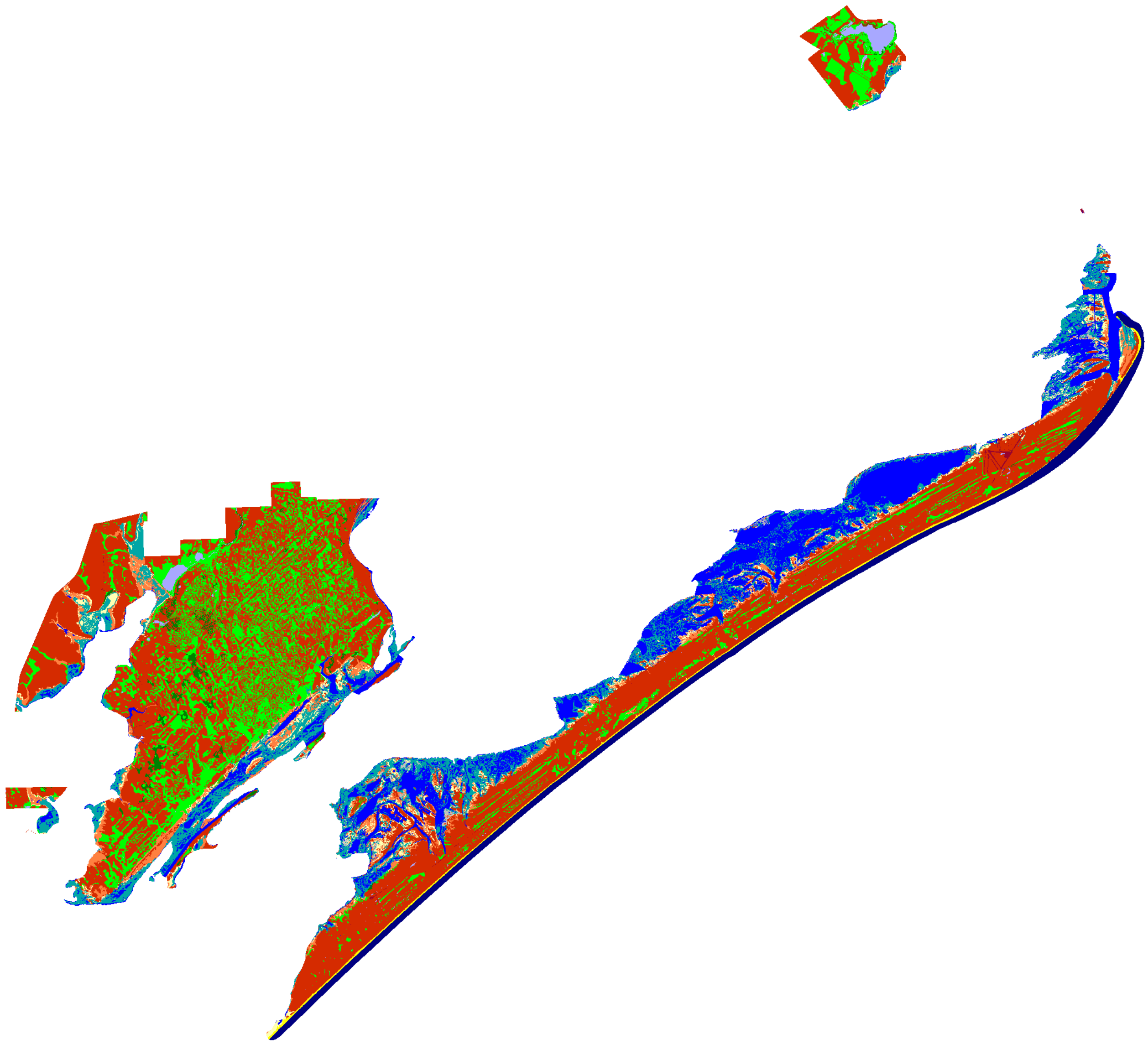
Maps of SLAMM input and output to follow will use the following legend:

Undeveloped Dry Land	
Inland Fresh Marsh	
Estuarine Open Water	
Regularly Flooded Marsh	
Open Ocean	
Irregularly Flooded Marsh	
Estuarine Beach	
Swamp	
Inland Open Water	
Ocean Beach	
Tidal Flat	
Developed Dry Land	
Inland Shore	
Mangrove	
Tidal Fresh Marsh	
Transitional Salt Marsh	

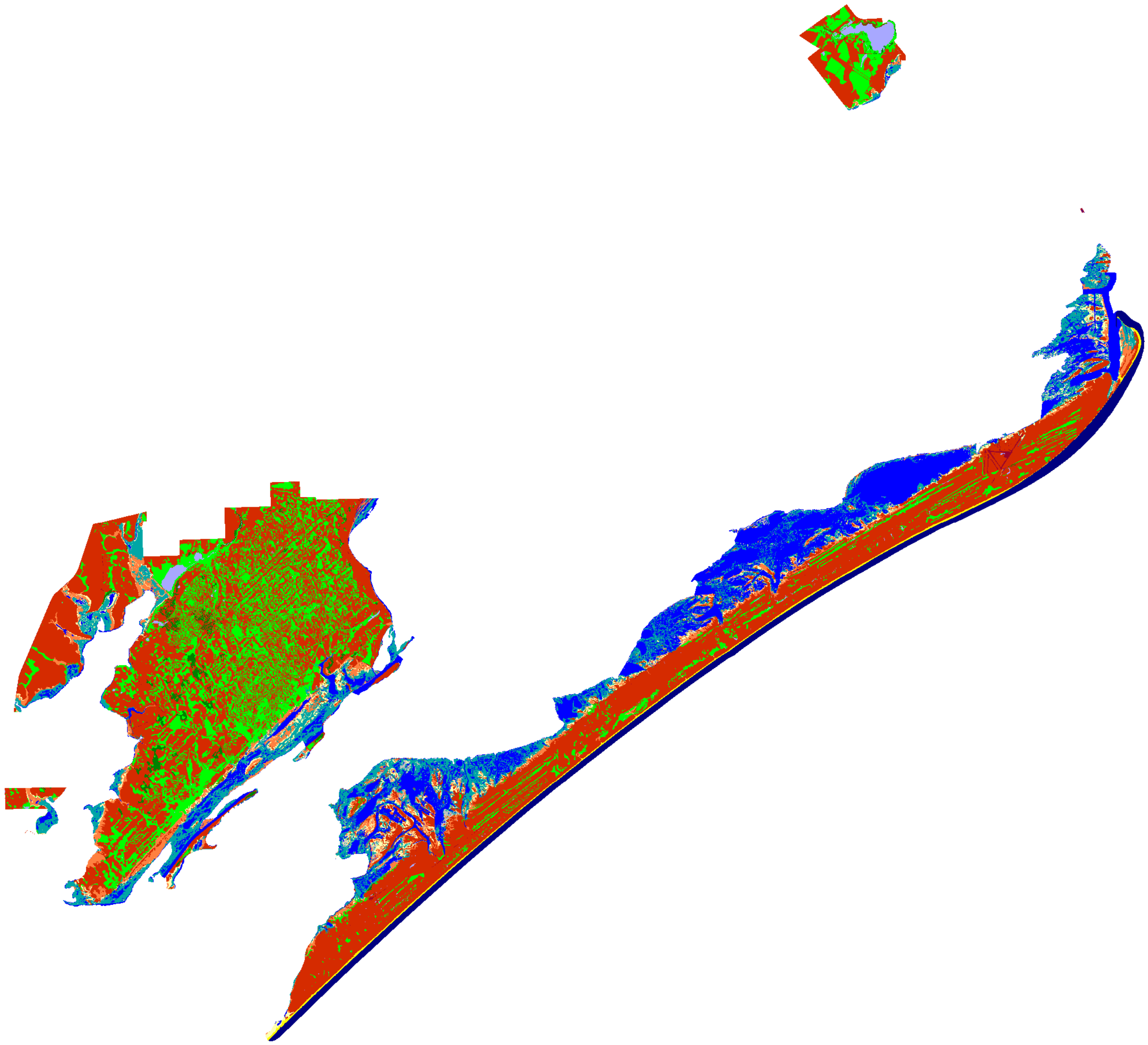
Aransas NWR
IPCC Scenario A1B-Mean, 0.39 M SLR Eustatic by 2100

Results in Acres

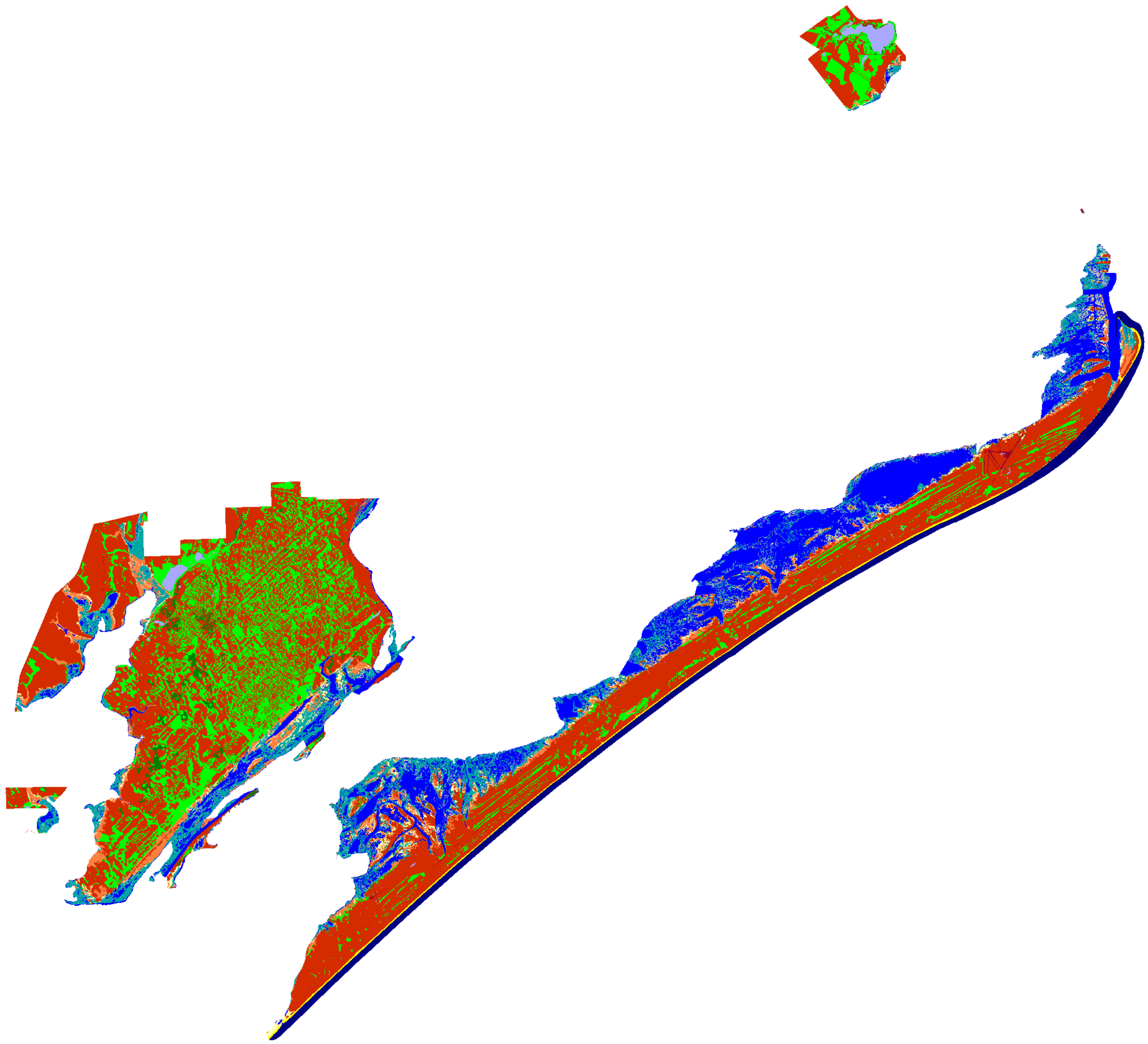
		Initial	2025	2050	2075	2100
	Undeveloped Dry Land	52499.9	52070.1	51668.0	50985.8	49966.3
	Inland Fresh Marsh	19191.0	19156.8	19148.6	19134.1	19117.8
	Estuarine Open Water	15656.5	16364.3	17127.8	19106.7	21500.7
	Regularly Flooded Marsh	12432.3	11842.7	11283.8	10052.6	8037.5
	Open Ocean	4904.5	4927.5	4941.8	4963.4	4993.4
	Irregularly Flooded Marsh	4904.5	4828.3	4786.0	4657.7	4427.7
	Estuarine Beach	3156.4	3036.7	2713.2	1730.3	820.8
	Swamp	1058.8	1055.7	1051.2	1046.3	1042.5
	Inland Open Water	1017.7	1017.2	1016.8	1013.4	1007.2
	Ocean Beach	910.7	907.0	900.3	890.3	876.2
	Tidal Flat	766.1	894.9	1083.1	1511.4	2497.2
	Developed Dry Land	254.4	242.6	234.9	223.0	212.9
	Inland Shore	76.5	76.5	76.3	75.5	74.3
	Mangrove	45.1	44.4	44.4	44.4	44.3
	Tidal Fresh Marsh	16.9	16.9	16.9	16.8	16.6
	Transitional Salt Marsh	0.0	409.8	798.4	1439.7	2255.8
	Total (incl. water)	**116891.4**	**116891.4**	**116891.4**	**116891.4**	**116891.4**



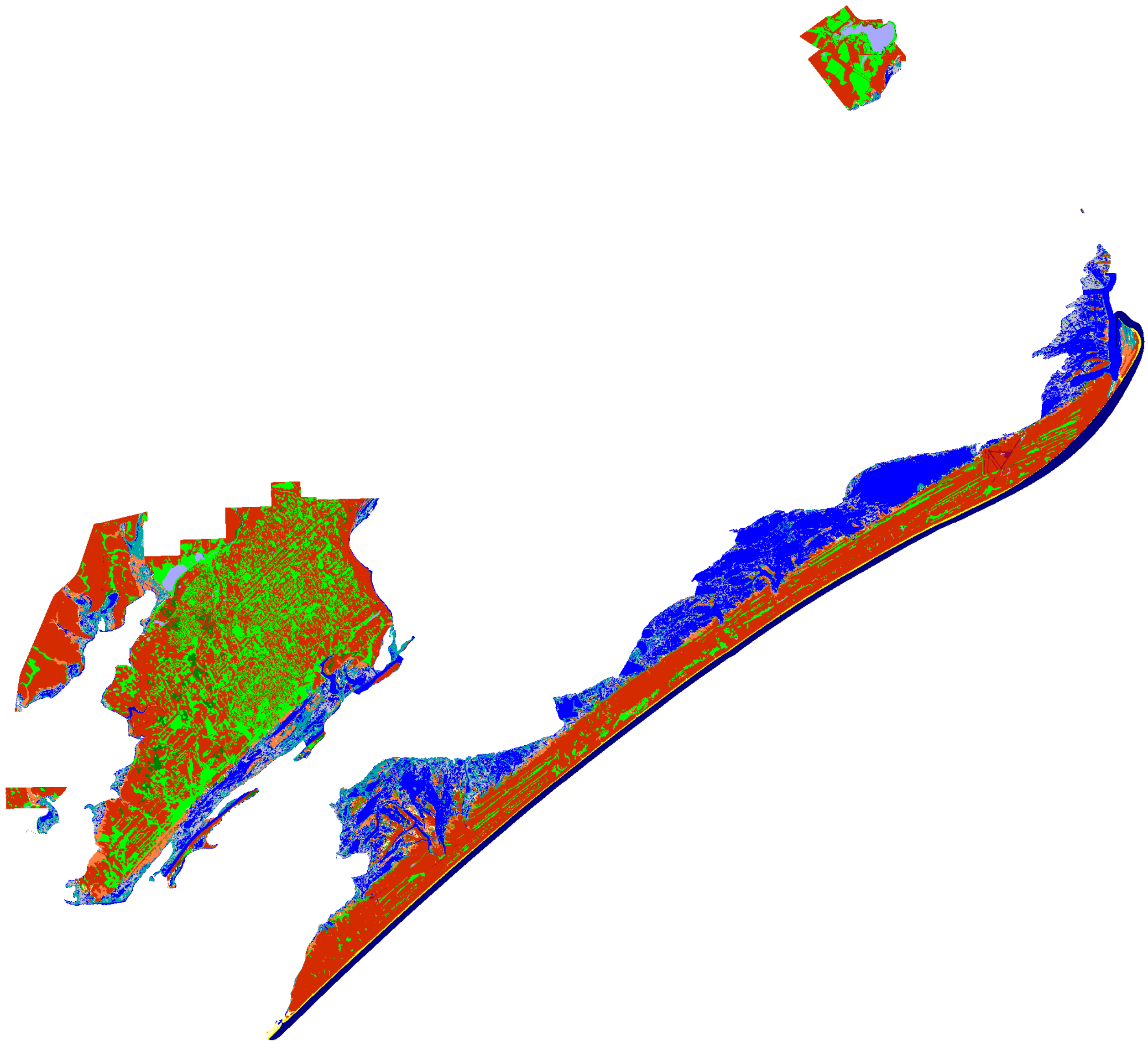
Aransas NWR, Initial Condition



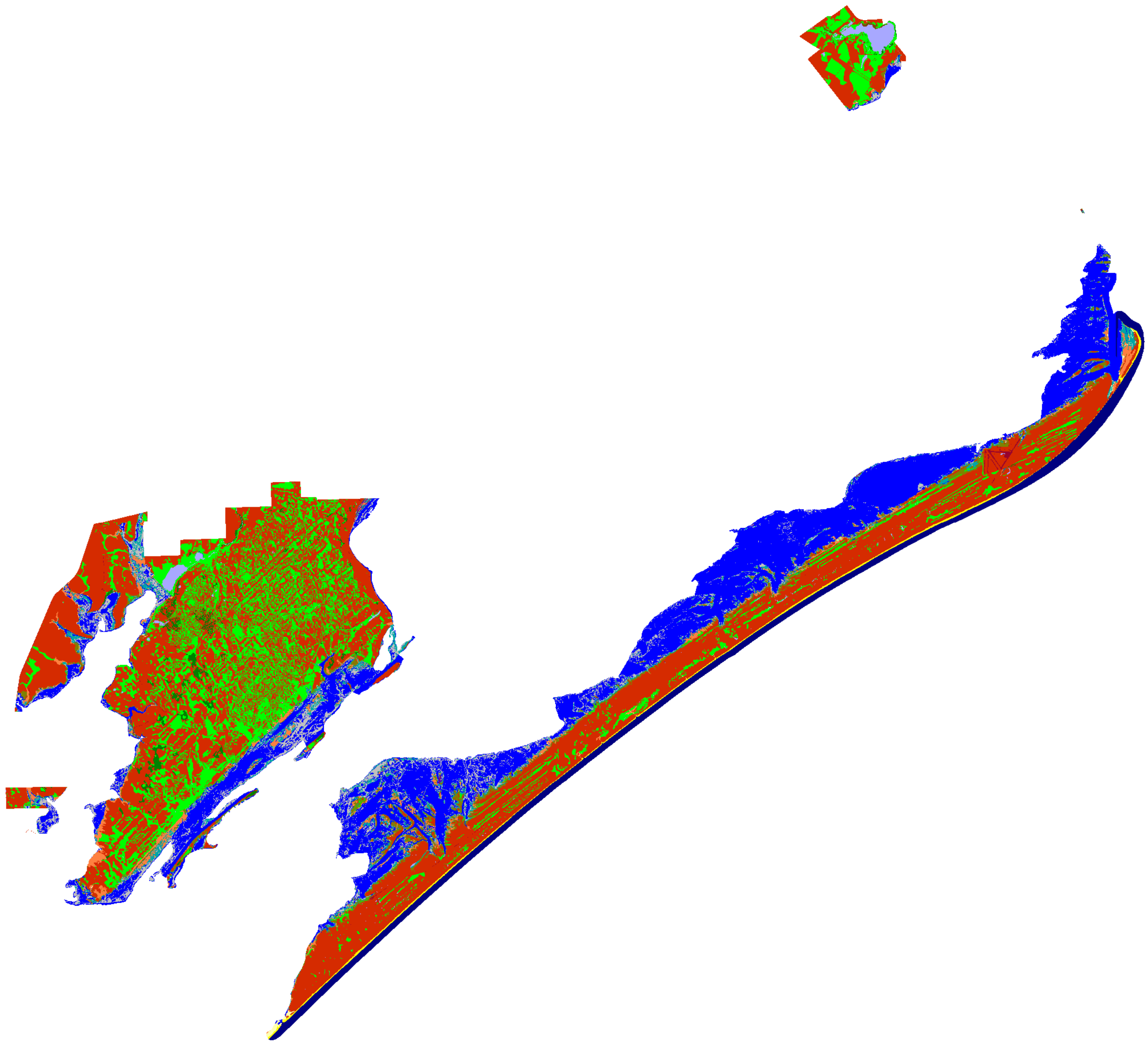
Aransas NWR, 2025, Scenario A1B Mean



Aransas NWR, 2050, Scenario A1B Mean



Aransas NWR, 2075, Scenario A1B Mean

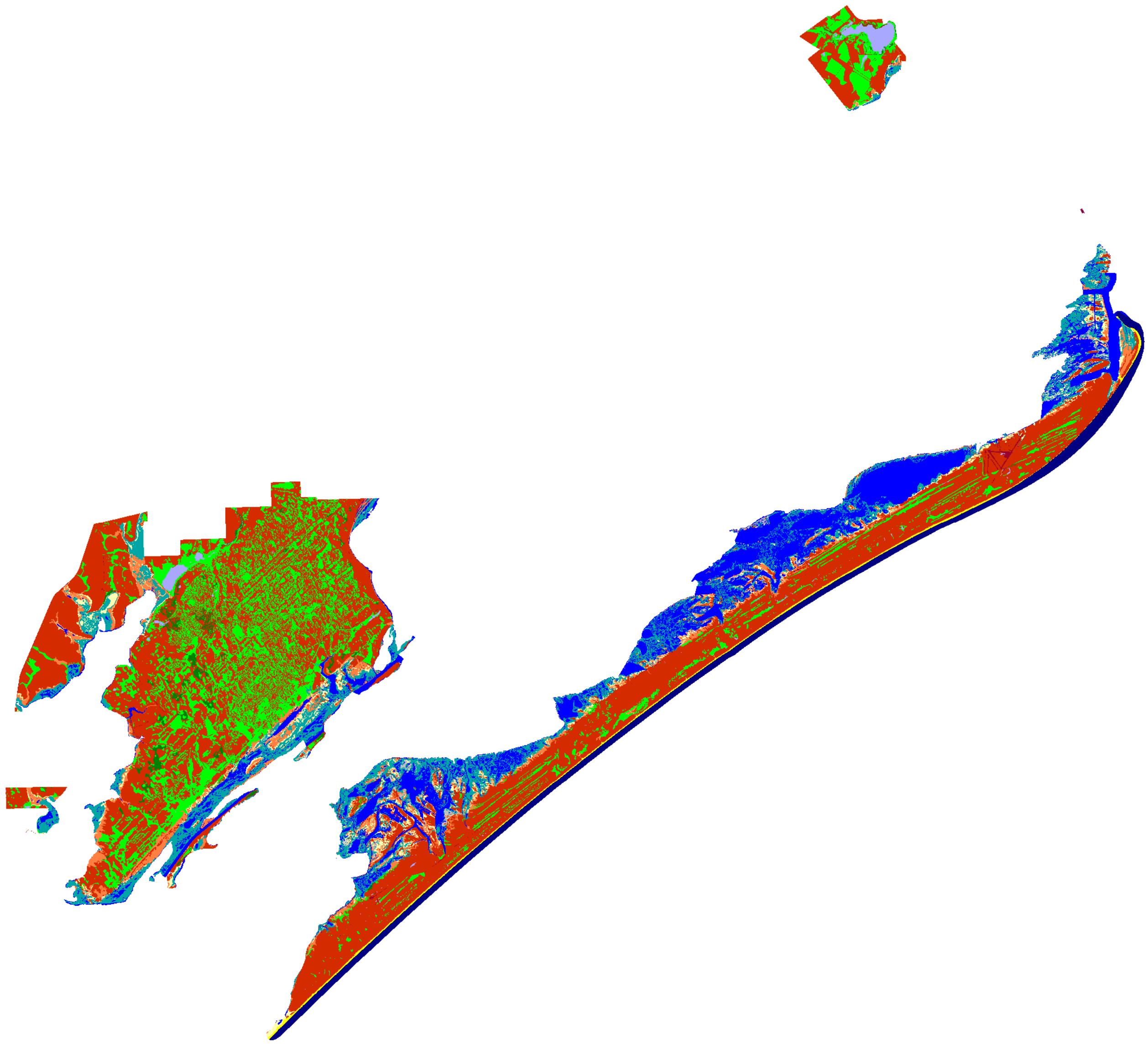


Aransas NWR, 2100, Scenario A1B Mean

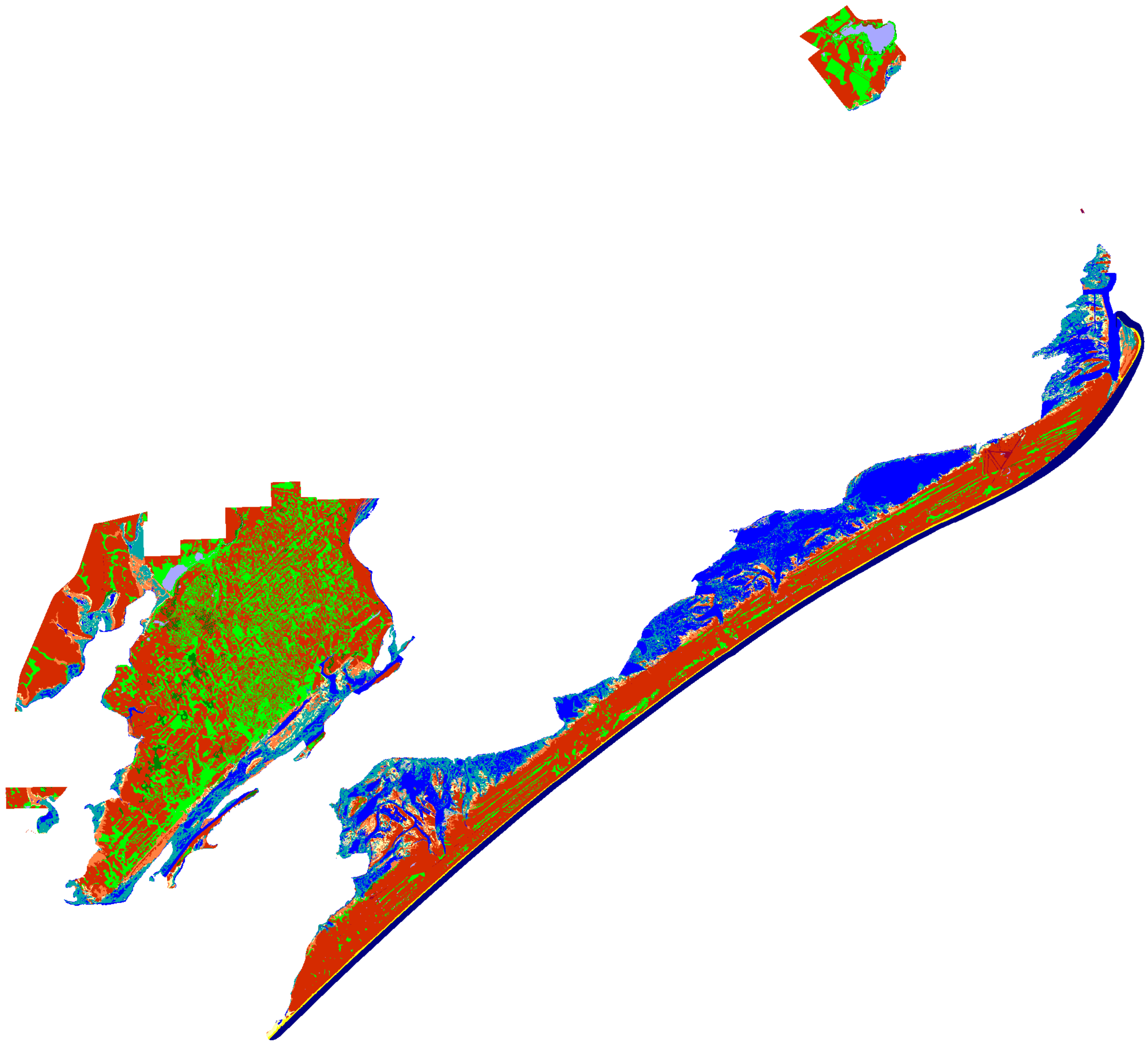
Aransas NWR
IPCC Scenario A1B-Max, 0.69 M SLR Eustatic by 2100

Results in Acres

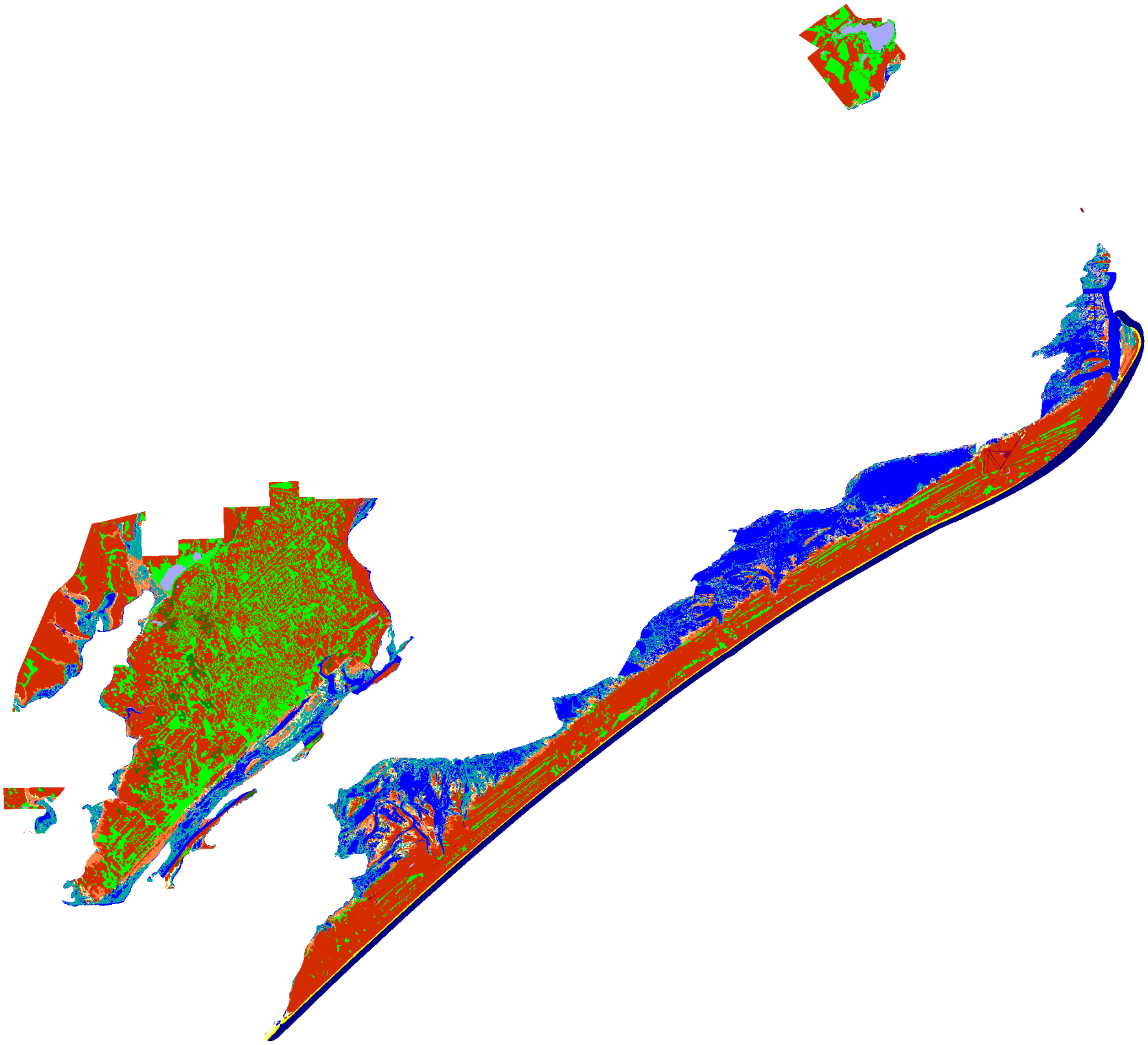
		Initial	2025	2050	2075	2100
	Undeveloped Dry Land	52499.9	52023.0	51382.8	50053.1	47982.8
	Inland Fresh Marsh	19191.0	19152.8	19126.3	19068.7	18944.8
	Estuarine Open Water	15656.5	16423.6	17993.2	21507.6	27526.6
	Regularly Flooded Marsh	12432.3	11687.0	10055.7	5843.2	3563.1
	Open Ocean	4904.5	4928.2	4948.0	4984.9	5054.8
	Irregularly Flooded Marsh	4904.5	4816.0	4654.0	3957.5	2610.4
	Estuarine Beach	3156.4	3003.7	2267.3	832.0	274.4
	Swamp	1058.8	1055.0	1048.6	1042.6	1031.5
	Inland Open Water	1017.7	1017.2	1015.2	1007.4	999.4
	Ocean Beach	910.7	906.3	894.2	869.1	820.3
	Tidal Flat	766.1	1046.6	2093.9	5467.4	4801.9
	Developed Dry Land	254.4	241.3	229.8	213.5	198.5
	Inland Shore	76.5	76.5	76.1	74.4	73.0
	Mangrove	45.1	44.4	44.2	44.1	42.0
	Tidal Fresh Marsh	16.9	16.9	16.7	15.1	11.8
	Transitional Salt Marsh	0.0	452.9	1045.3	1910.6	2956.0
	Total (incl. water)	**116891.4**	**116891.4**	**116891.4**	**116891.4**	**116891.4**



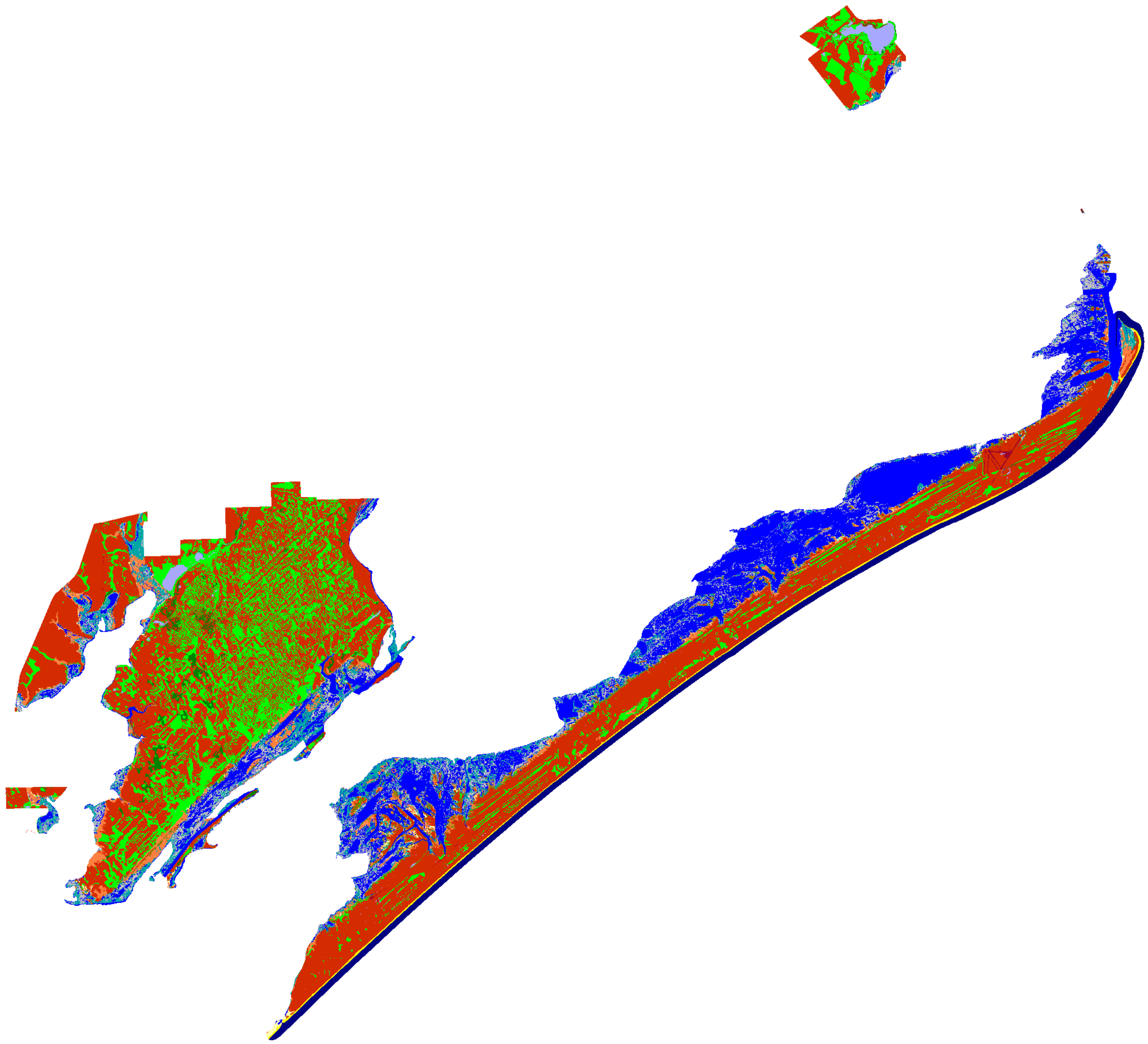
Aransas NWR, Initial Condition



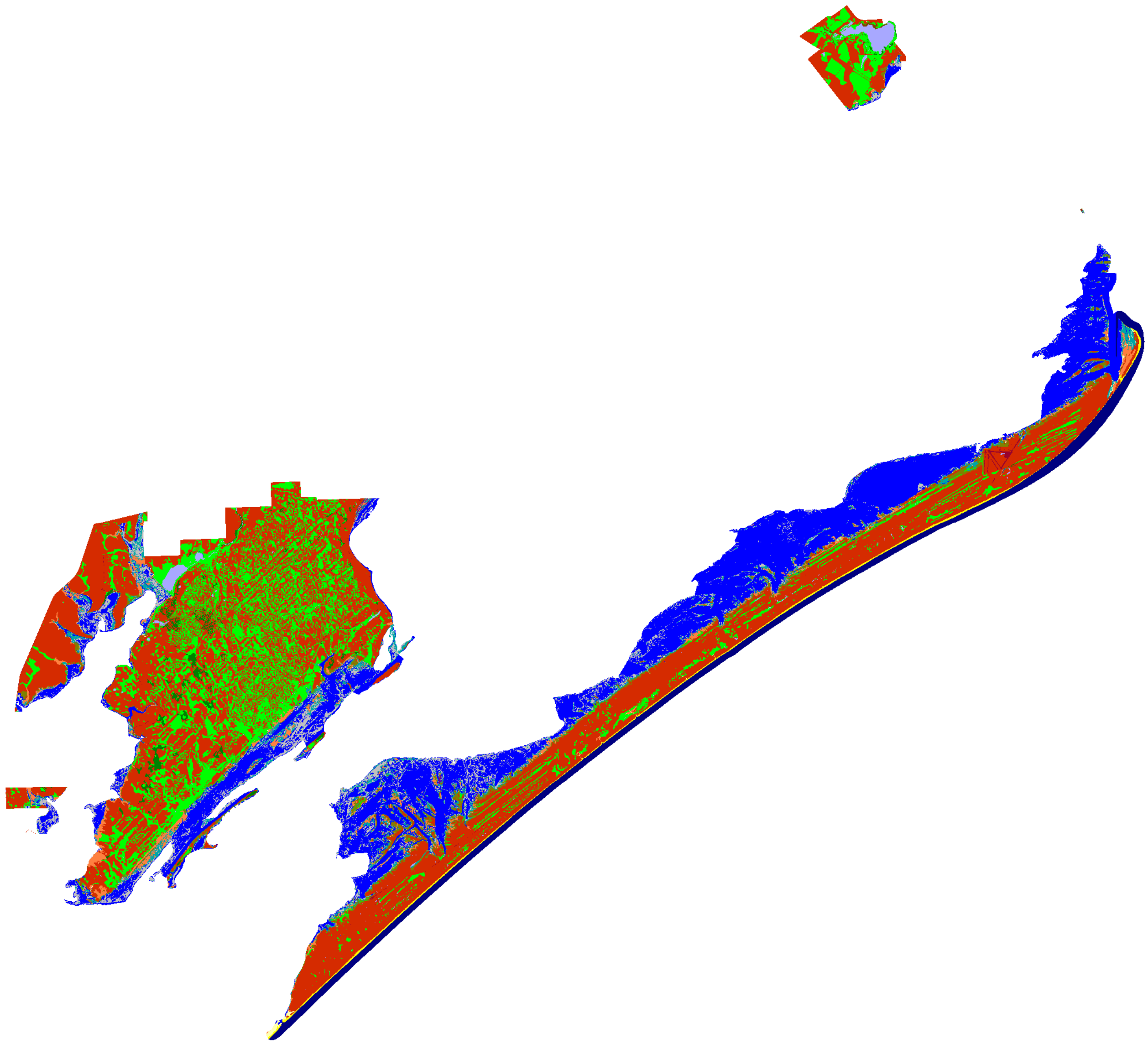
Aransas NWR, 2025, Scenario A1B Maximum



Aransas NWR, 2050, Scenario A1B Maximum



Aransas NWR, 2075, Scenario A1B Maximum

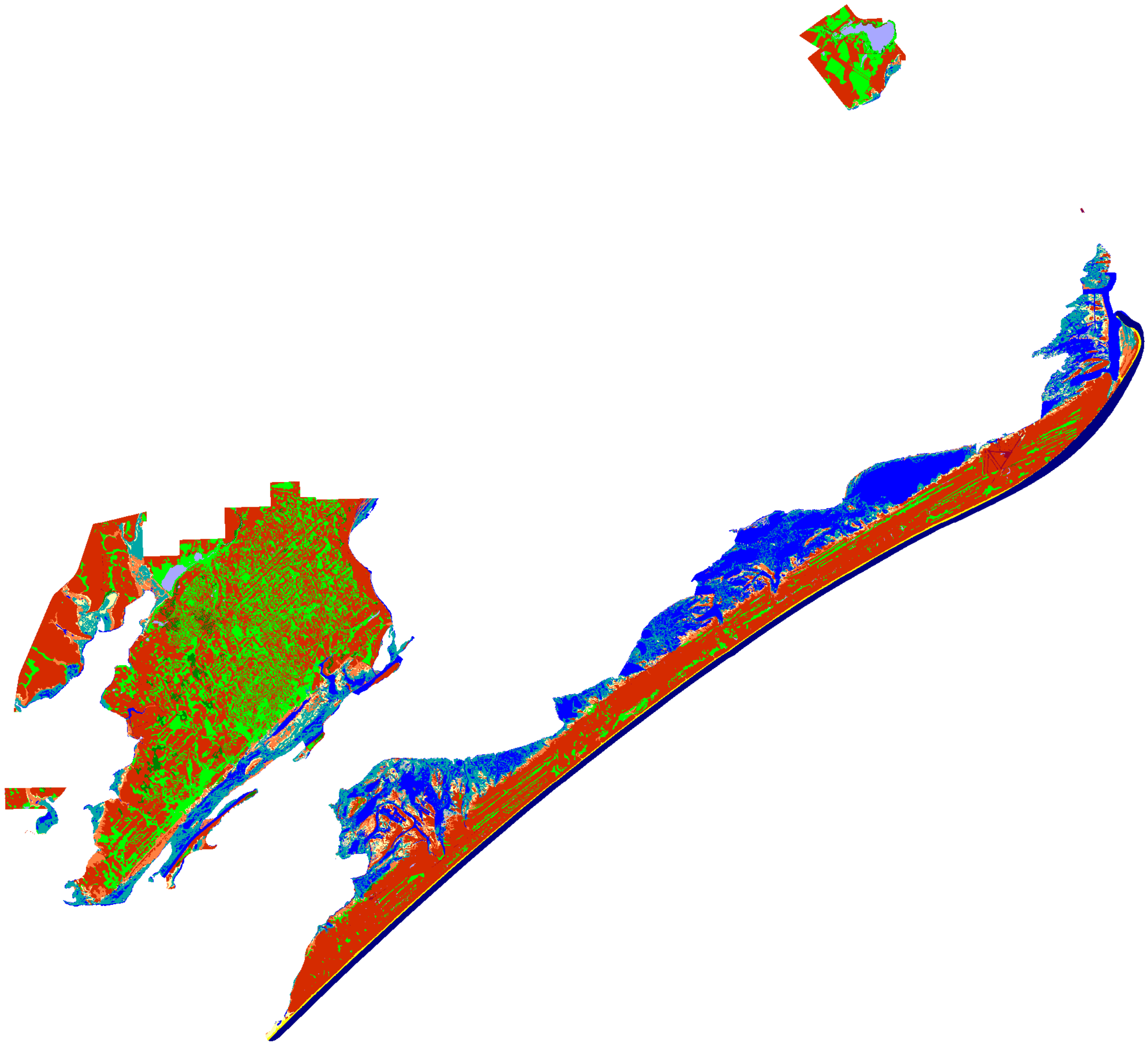


Aransas NWR, 2100, Scenario A1B Maximum

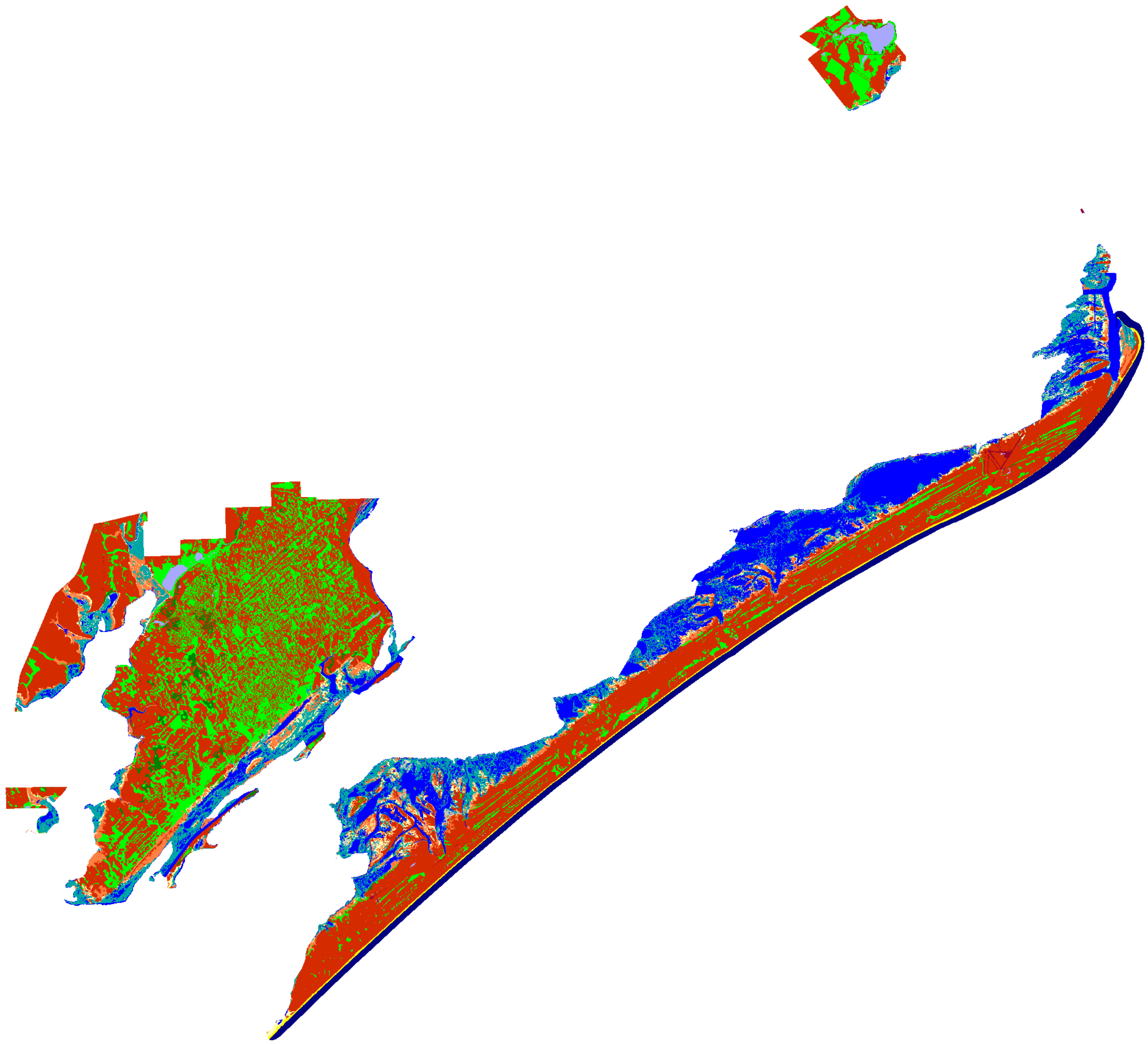
Aransas NWR
1 Meter Eustatic SLR by 2100

Results in Acres

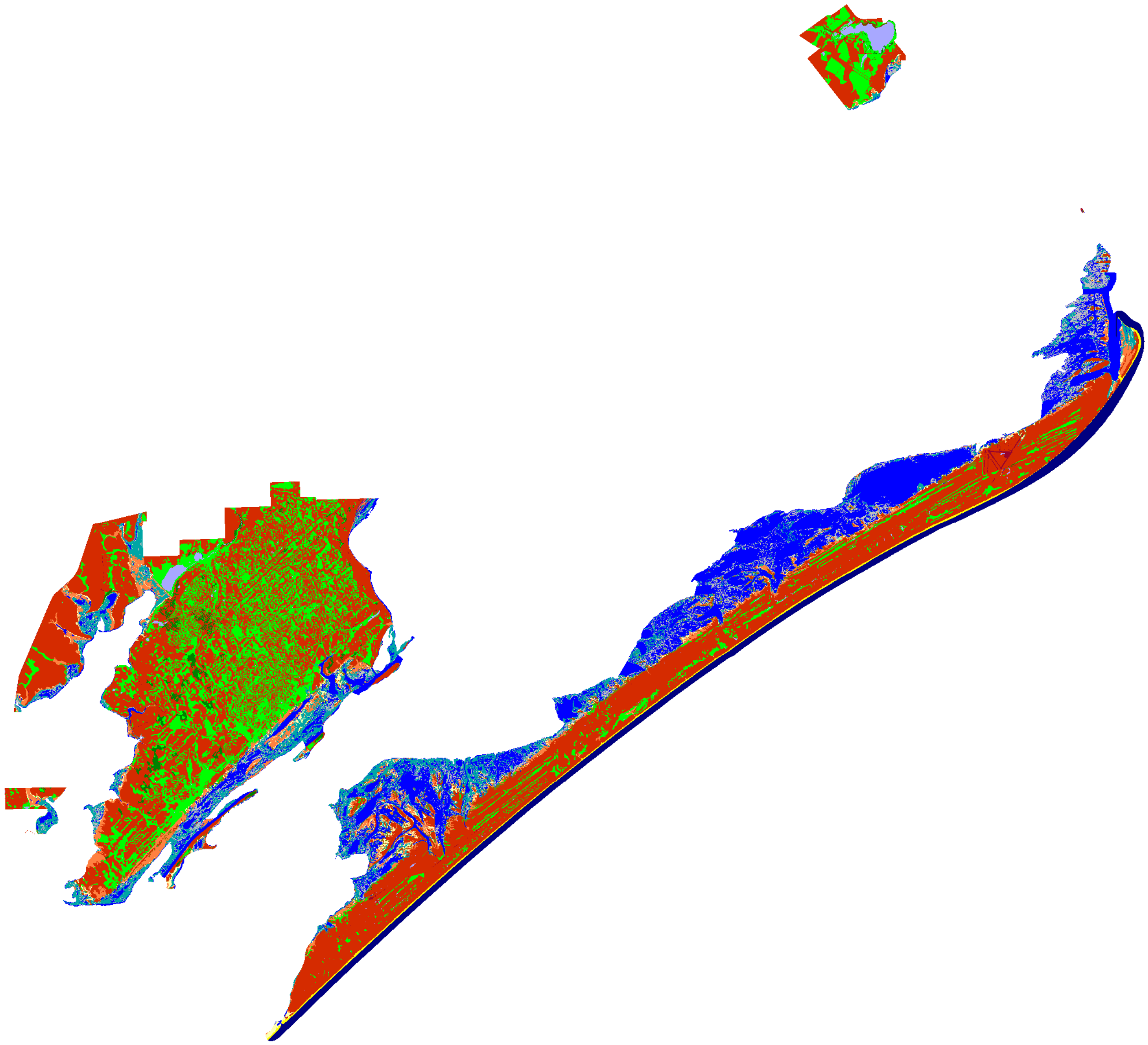
		Initial	2025	2050	2075	2100
	Undeveloped Dry Land	52499.9	51964.0	51003.3	48823.0	44395.9
	Inland Fresh Marsh	19191.0	19147.0	19093.2	18905.6	18451.6
	Estuarine Open Water	15656.5	16501.9	18909.3	24662.5	31677.1
	Regularly Flooded Marsh	12432.3	11480.3	7809.9	3950.1	4036.3
	Open Ocean	4904.5	4929.1	4992.0	5301.4	5881.2
	Irregularly Flooded Marsh	4904.5	4798.5	4380.2	2620.9	1213.4
	Estuarine Beach	3156.4	2958.2	1724.6	386.7	144.3
	Swamp	1058.8	1054.4	1045.9	1036.0	1006.6
	Inland Open Water	1017.7	1017.0	1013.7	1002.1	986.5
	Ocean Beach	910.7	905.4	850.3	558.6	126.9
	Tidal Flat	766.1	1250.5	4413.8	6760.7	3726.8
	Developed Dry Land	254.4	240.1	223.7	205.6	175.3
	Inland Shore	76.5	76.5	75.6	73.3	71.0
	Mangrove	45.1	44.3	44.1	39.9	29.2
	Tidal Fresh Marsh	16.9	16.8	15.7	10.7	6.1
	Transitional Salt Marsh	0.0	507.5	1296.1	2554.1	4963.1
	Total (incl. water)	**116891.4**	**116891.4**	**116891.4**	**116891.4**	**116891.4**



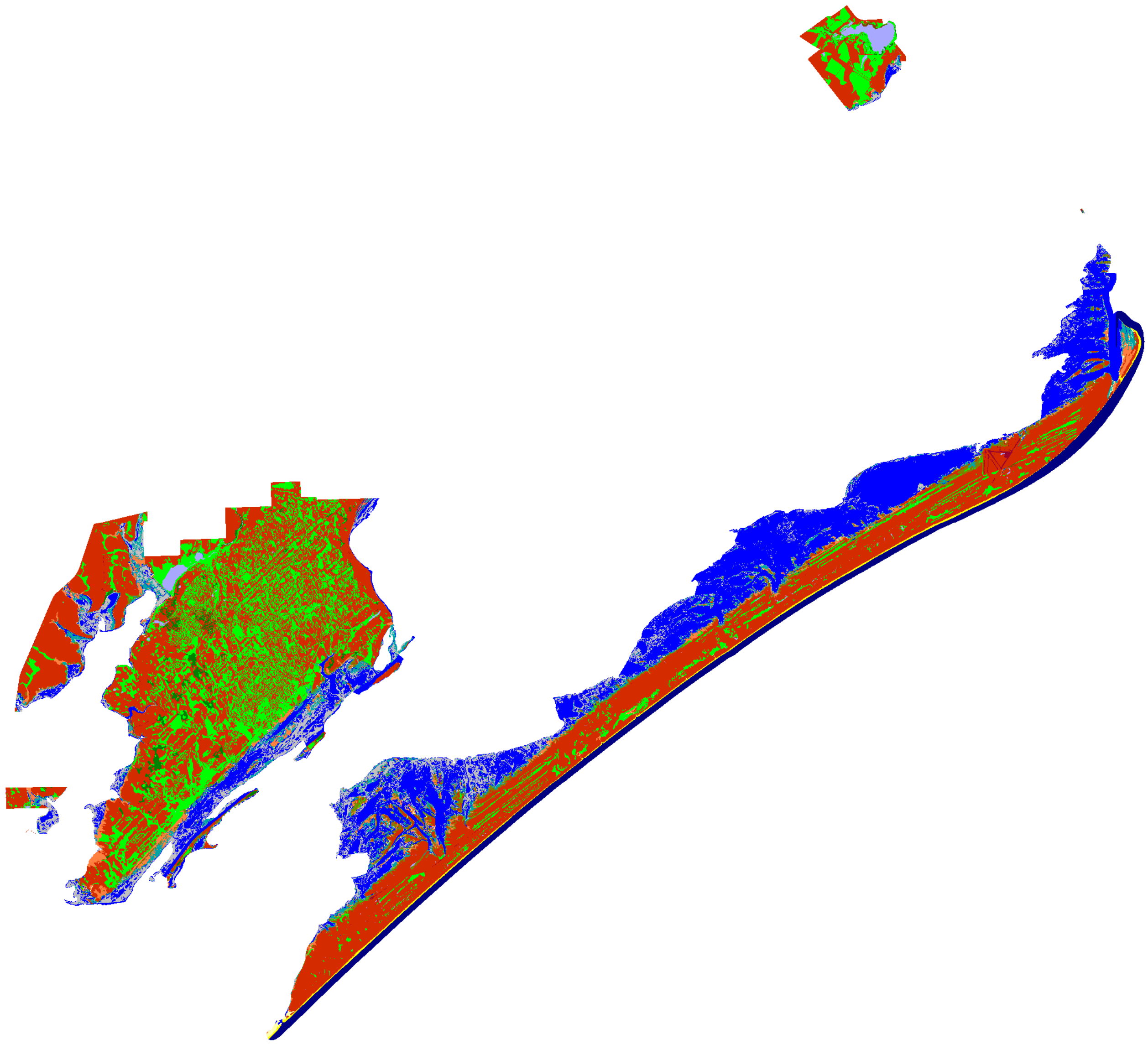
Aransas NWR, Initial Condition



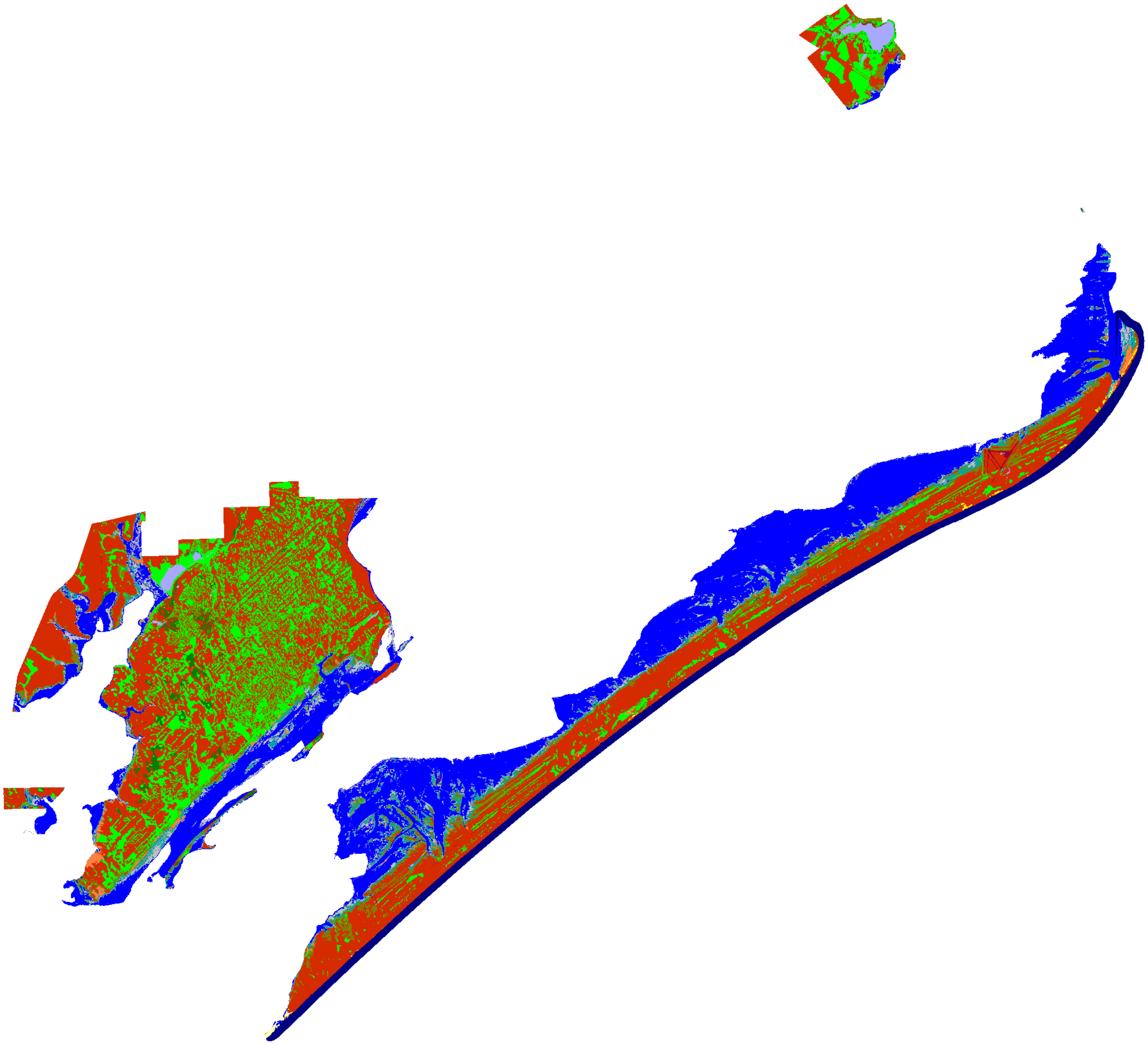
Aransas NWR, 2025, 1 Meter



Aransas NWR, 2050, 1 Meter



Aransas NWR, 2075, 1 Meter

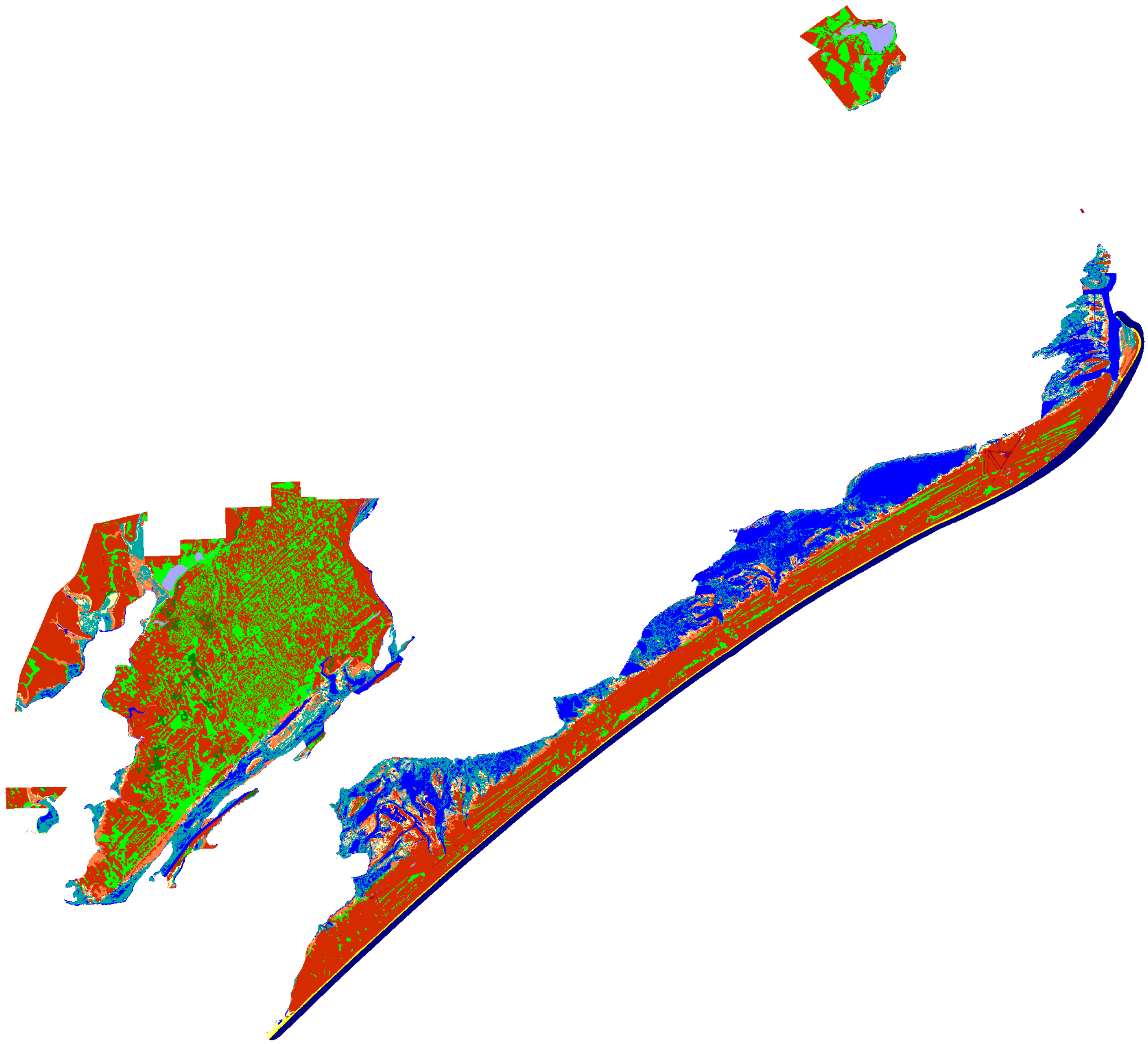


Aransas NWR, 2100, 1 Meter

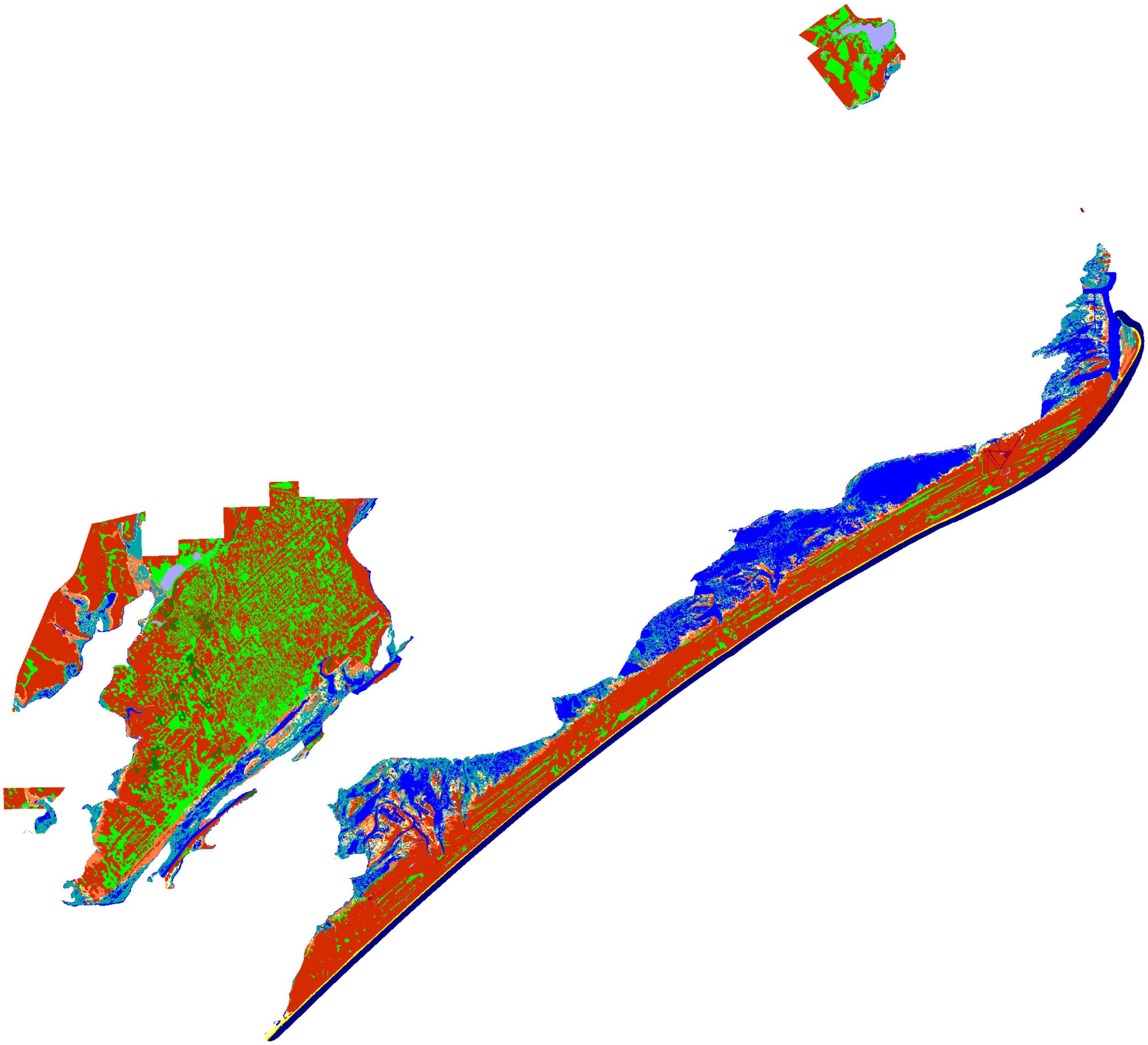
Aransas NWR
1.5 Meters Eustatic SLR by 2100

Results in Acres

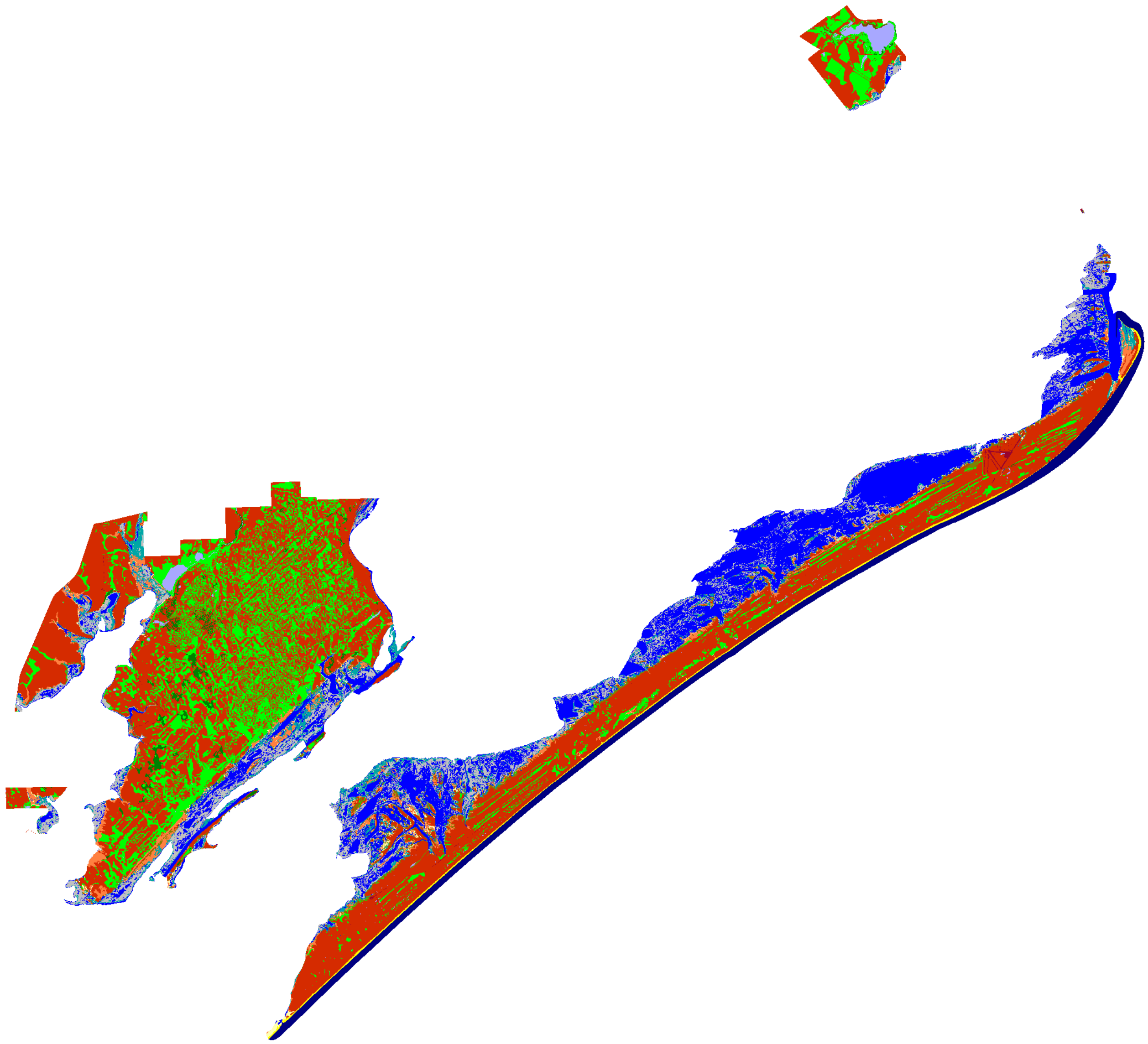
		Initial	2025	2050	2075	2100
	Undeveloped Dry Land	52499.9	51862.7	50234.0	45630.4	32591.0
	Inland Fresh Marsh	19191.0	19135.6	18985.9	18283.3	16289.5
	Estuarine Open Water	15656.5	16634.9	20301.0	29578.5	34065.5
	Regularly Flooded Marsh	12432.3	11039.9	4484.8	4305.9	6197.0
	Open Ocean	4904.5	4931.1	5338.7	5884.5	6315.6
	Irregularly Flooded Marsh	4904.5	4755.7	3405.5	1130.8	289.0
	Estuarine Beach	3156.4	2887.3	910.0	164.1	83.2
	Swamp	1058.8	1053.4	1043.2	1014.2	948.1
	Inland Open Water	1017.7	1017.0	1007.4	990.8	959.2
	Ocean Beach	910.7	903.4	507.5	38.3	1484.8
	Tidal Flat	766.1	1696.5	8507.4	4284.4	4257.3
	Developed Dry Land	254.4	238.1	215.2	181.2	93.5
	Inland Shore	76.5	76.4	74.5	72.6	5.6
	Mangrove	45.1	44.2	41.5	23.7	3.9
	Tidal Fresh Marsh	16.9	16.7	13.1	5.3	1.1
	Transitional Salt Marsh	0.0	598.4	1821.7	5303.5	13307.0
	Total (incl. water)	**116891.4**	**116891.4**	**116891.4**	**116891.4**	**116891.4**



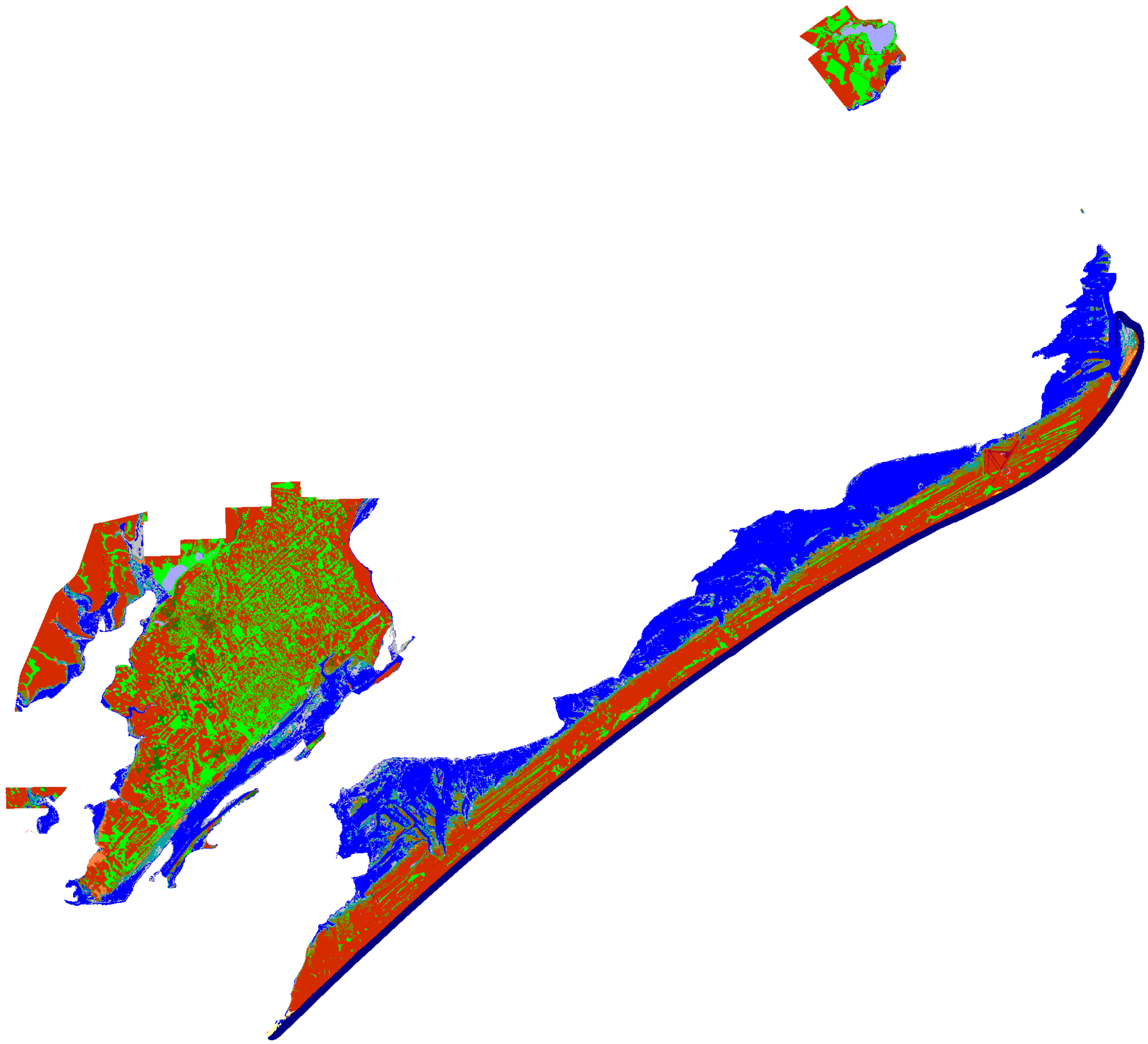
Aransas NWR, Initial Condition



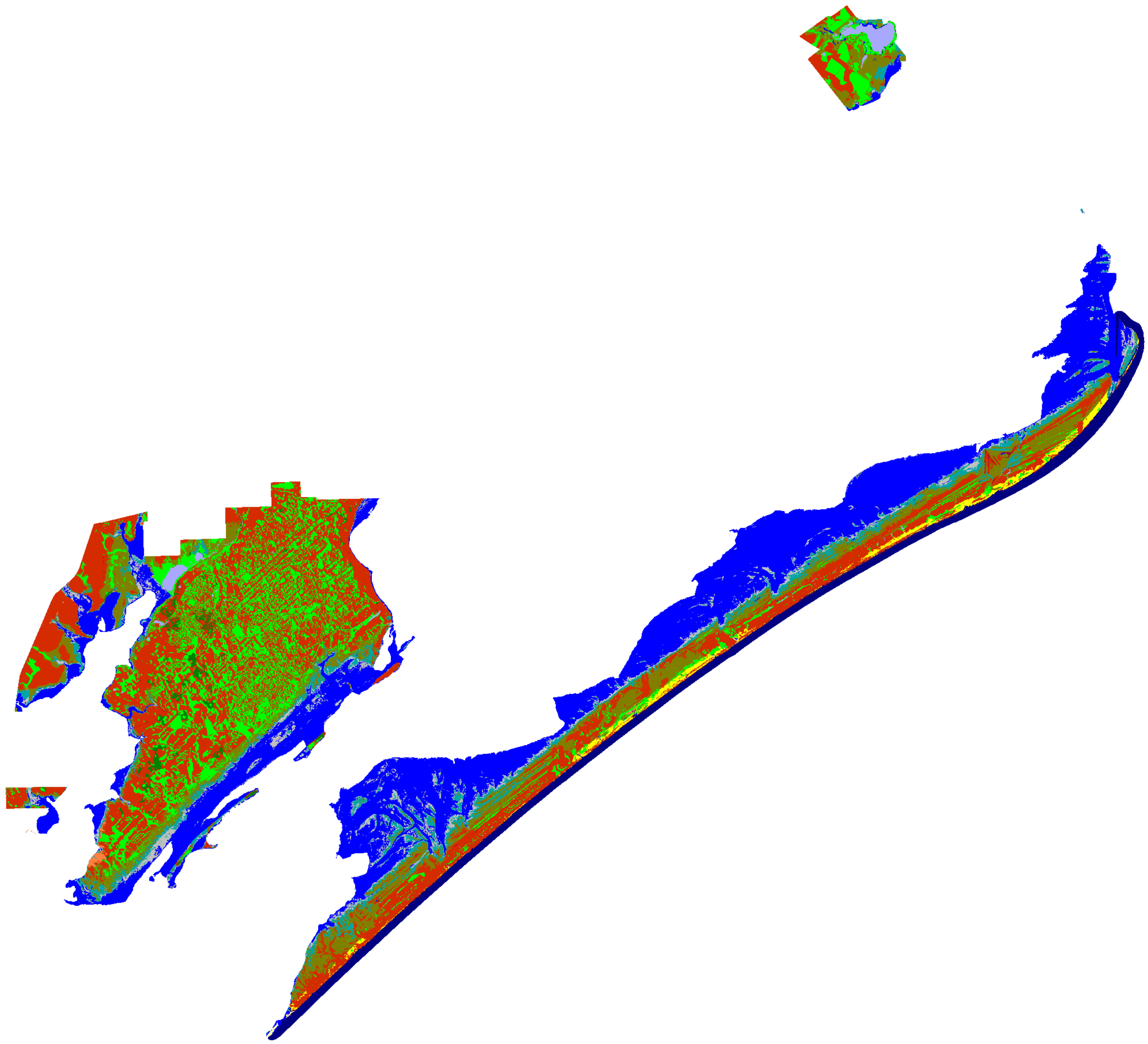
Aransas NWR, 2025, 1.5 Meters



Aransas NWR, 2050, 1.5 Meters



Aransas NWR, 2075, 1.5 Meters

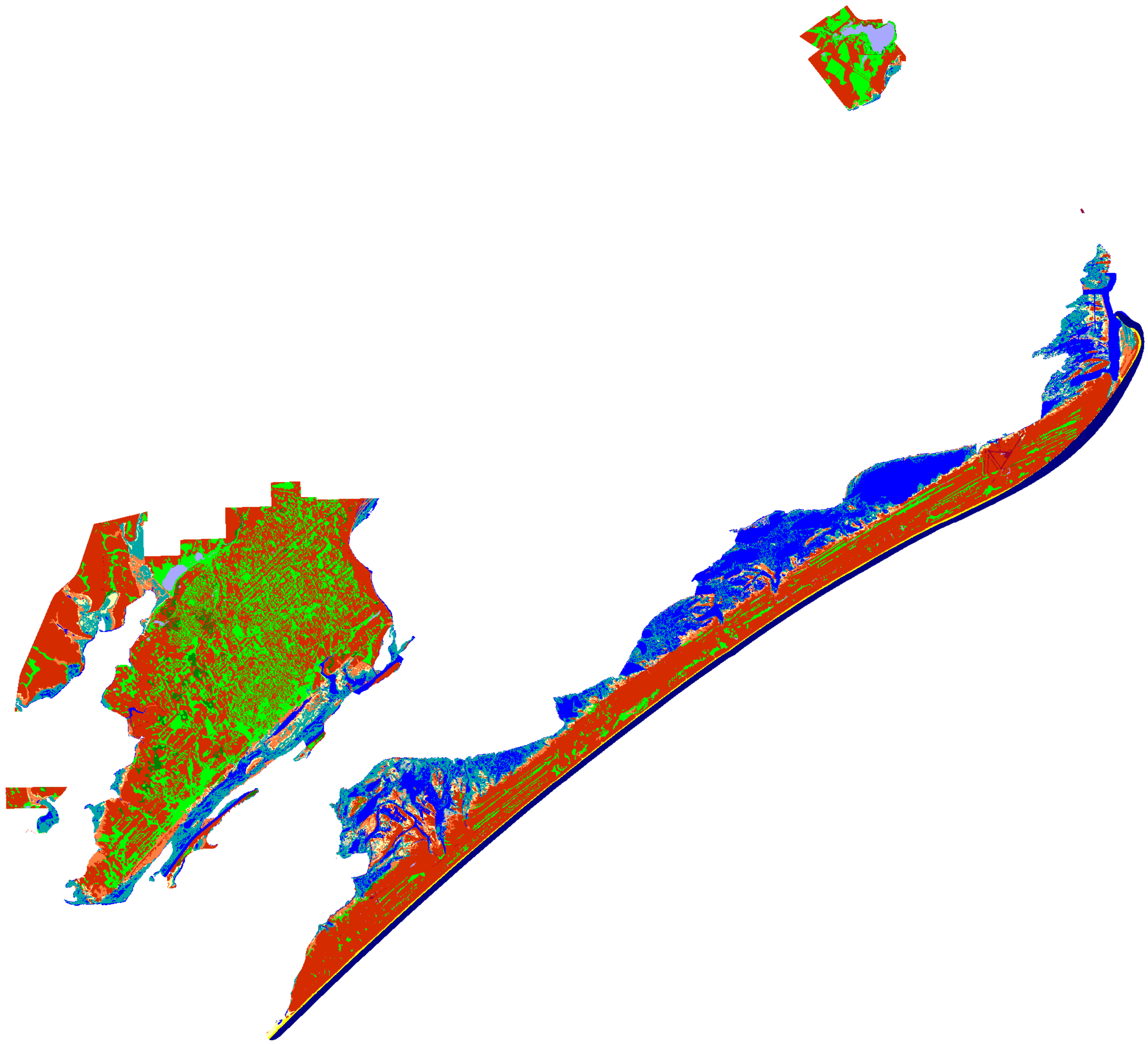


Aransas NWR, 2100, 1.5 Meters

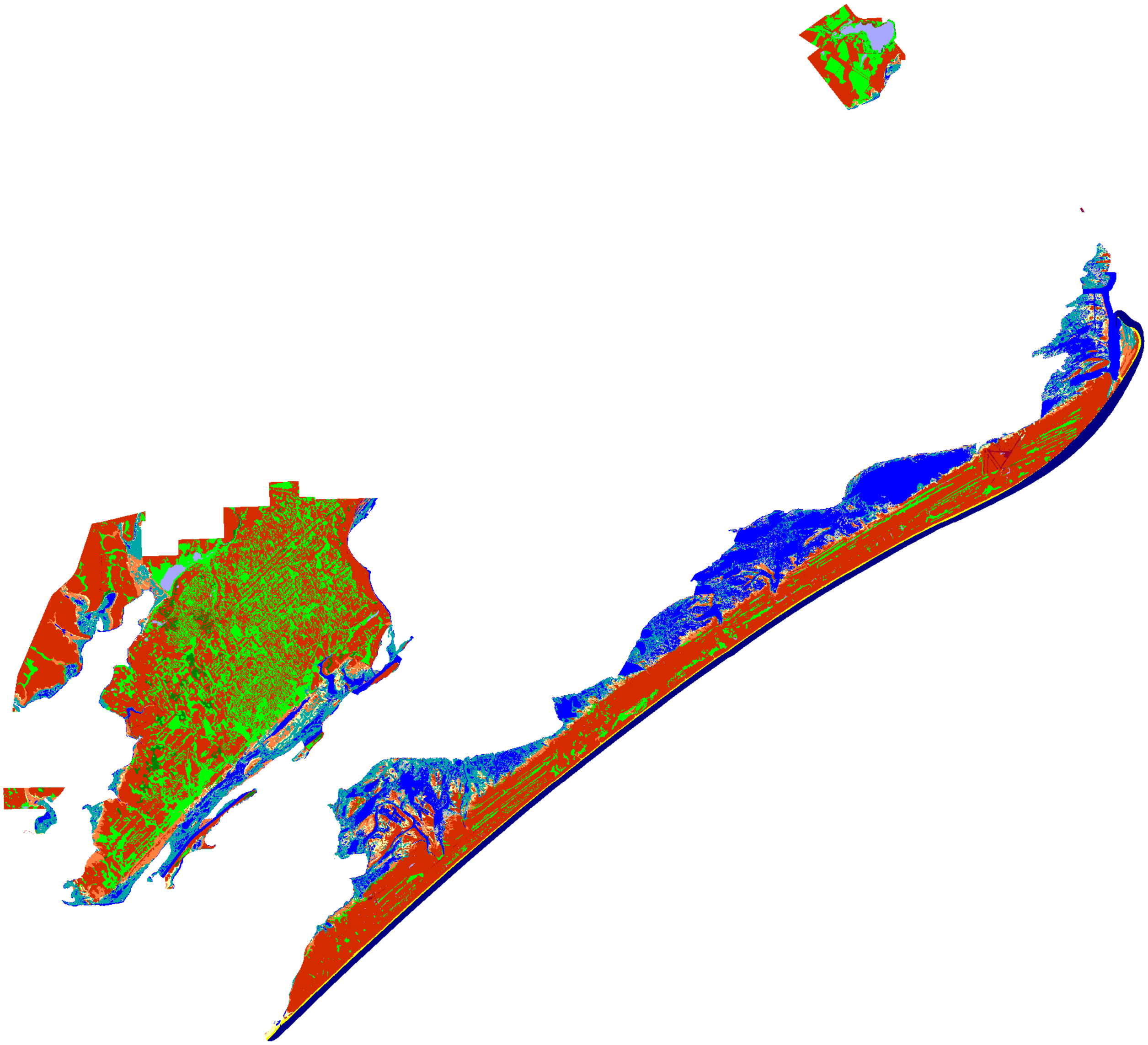
Aransas NWR
2 Meters Eustatic SLR by 2100

Results in Acres

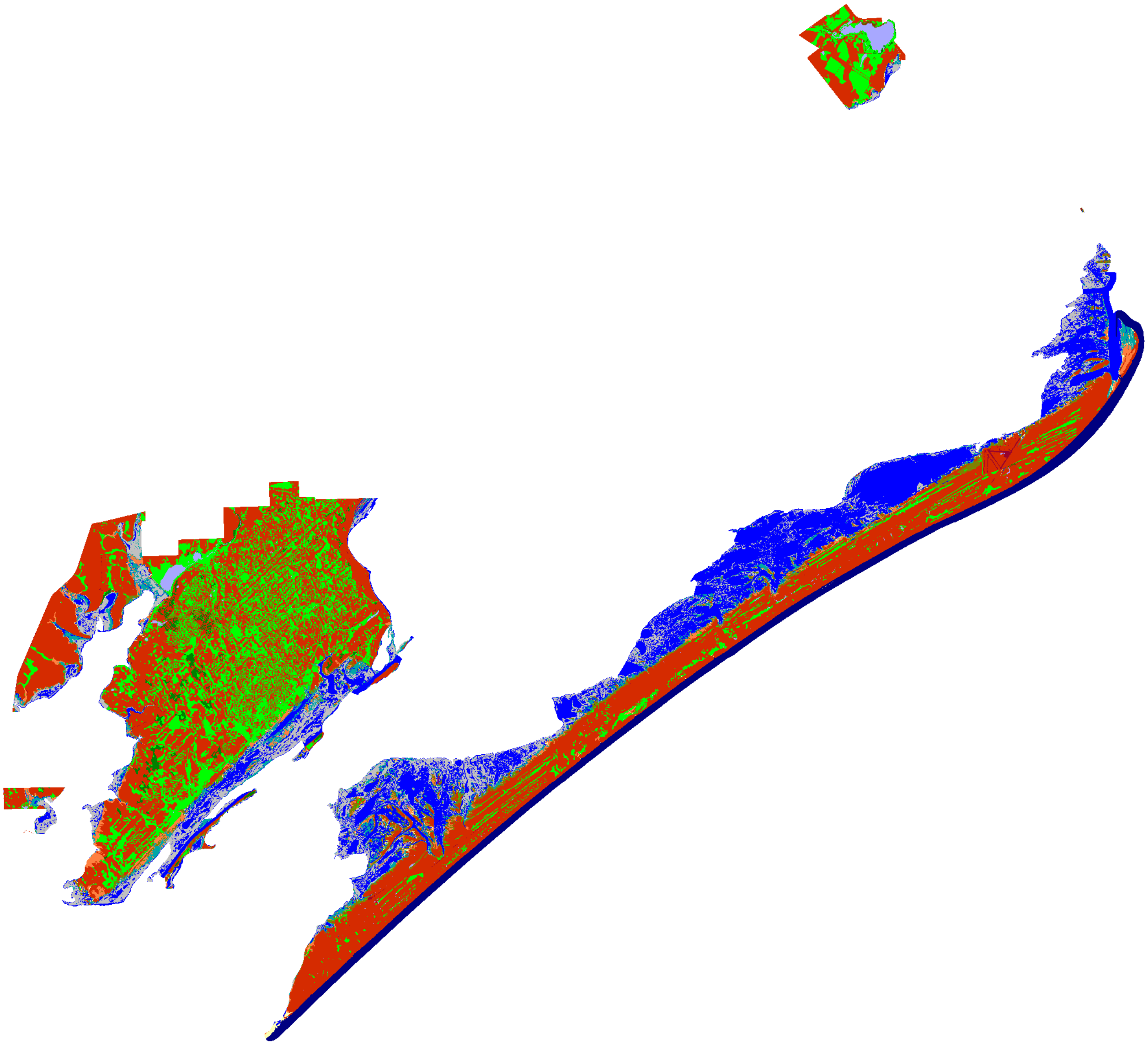
		Initial	2025	2050	2075	2100
	Undeveloped Dry Land	52499.9	51748.3	49230.5	39451.9	22921.8
	Inland Fresh Marsh	19191.0	19122.4	18788.4	16859.0	13553.2
	Estuarine Open Water	15656.5	16821.0	21497.7	31617.1	35543.0
	Regularly Flooded Marsh	12432.3	10411.6	3817.9	4859.1	11396.7
	Open Ocean	4904.5	4934.5	5670.6	6026.6	7616.1
	Irregularly Flooded Marsh	4904.5	4685.5	2313.6	419.7	104.3
	Estuarine Beach	3156.4	2786.0	473.3	108.0	68.7
	Swamp	1058.8	1052.0	1037.6	974.3	865.3
	Inland Open Water	1017.7	1016.6	1002.8	981.0	908.9
	Ocean Beach	910.7	900.1	176.2	591.5	1735.6
	Tidal Flat	766.1	2345.7	9672.6	3744.1	4847.4
	Developed Dry Land	254.4	236.4	208.4	147.4	50.7
	Inland Shore	76.5	76.3	73.9	36.1	1.8
	Mangrove	45.1	44.2	34.3	5.5	1.1
	Tidal Fresh Marsh	16.9	16.5	8.3	1.8	0.1
	Transitional Salt Marsh	0.0	694.3	2885.5	11068.3	17276.5
	Total (incl. water)	**116891.4**	**116891.4**	**116891.4**	**116891.4**	**116891.4**



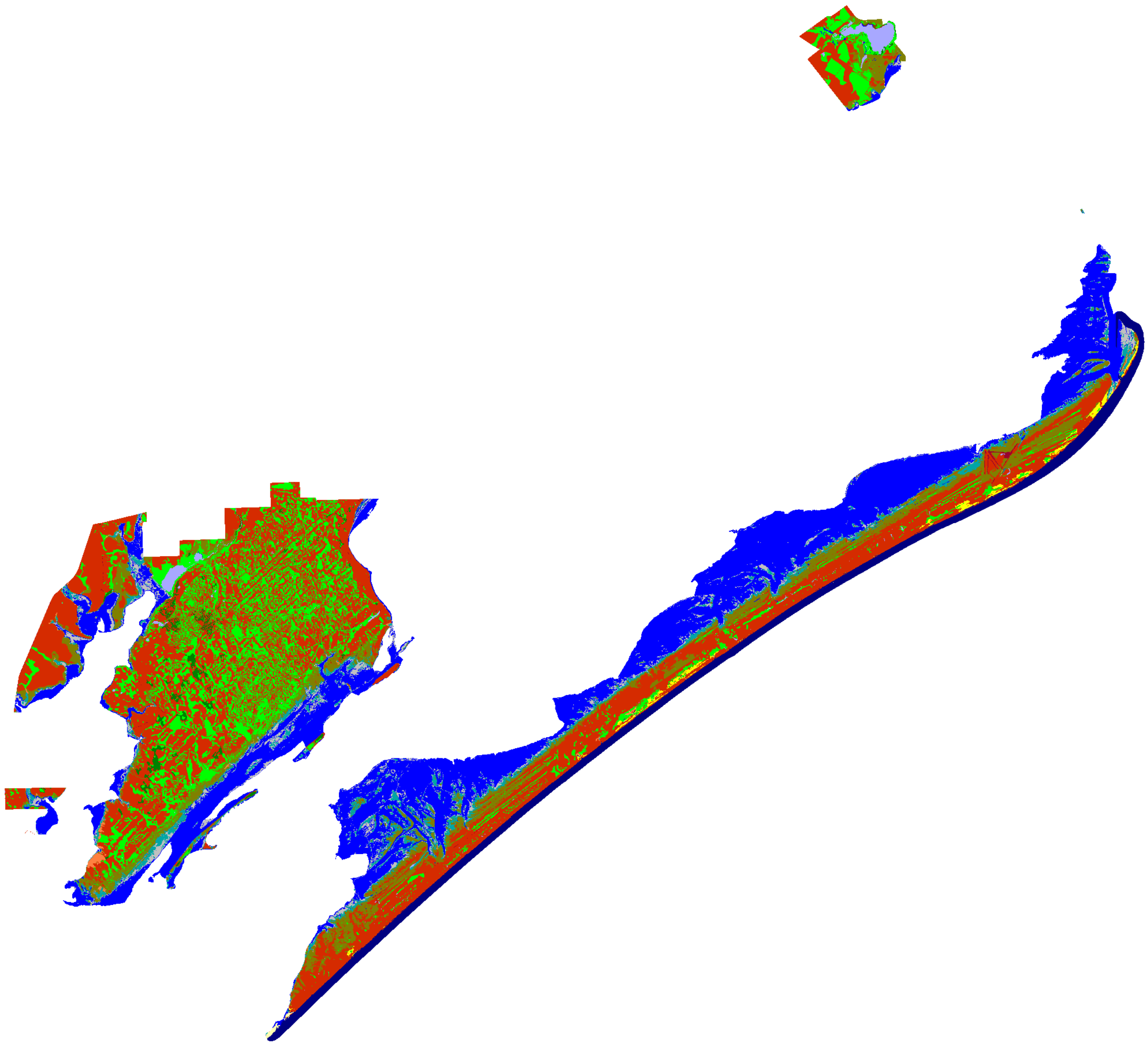
Aransas NWR, Initial Condition



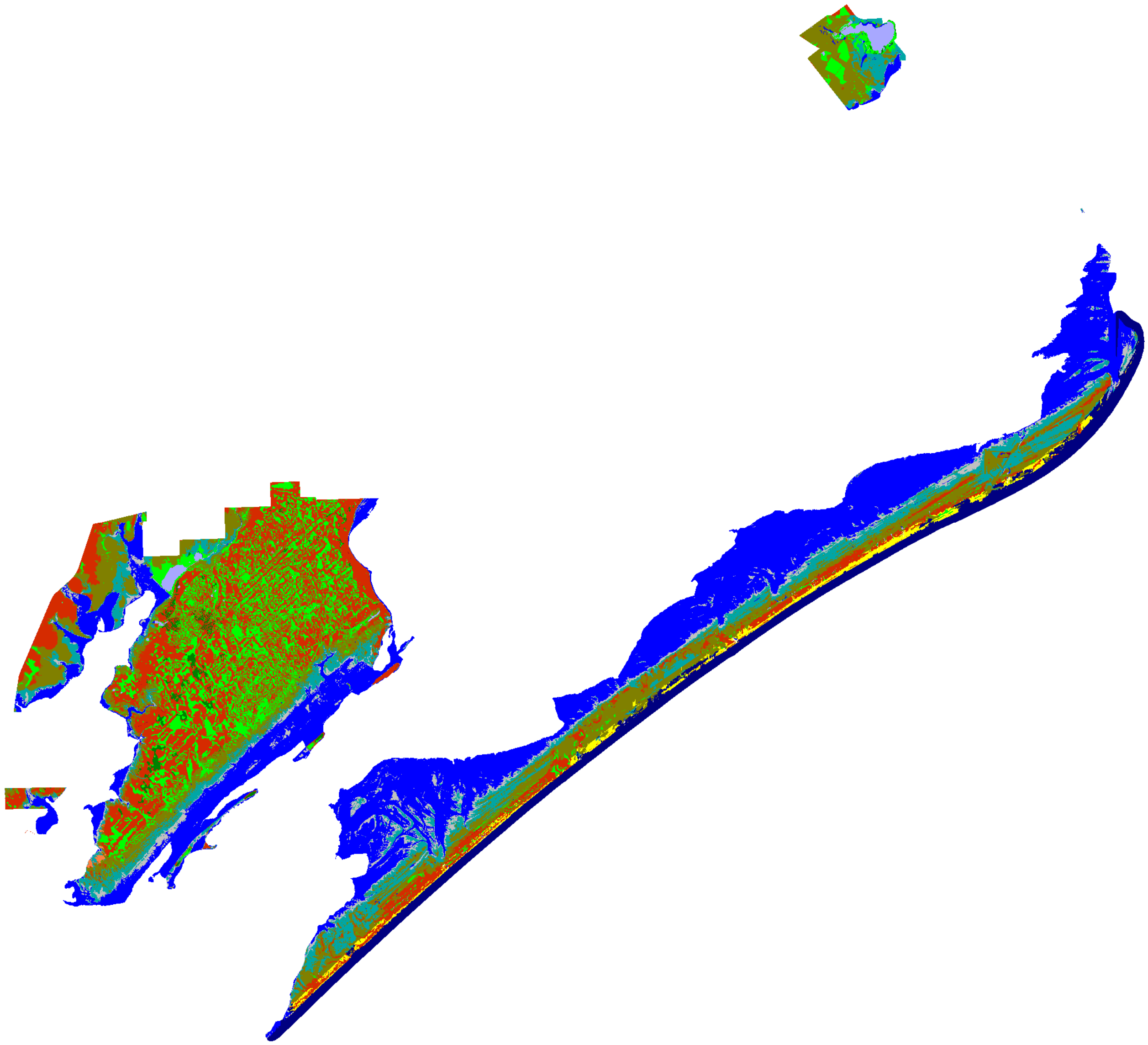
Aransas NWR, 2025, 2 Meters



Aransas NWR, 2050, 2 Meters



Aransas NWR, 2075, 2 Meters



Aransas NWR, 2100, 2 Meters

Greater Aransas Study Area

SLAMM predicts that the greater Aransas study area will experience similar patterns of wetland losses as the refuge itself. Dry lands for the larger study area have higher average elevations; therefore loss rates are predicted to be roughly half of that predicted within the refuge itself. However, wetland migration to dry lands is predicted to be more extensive when the larger study area is considered.

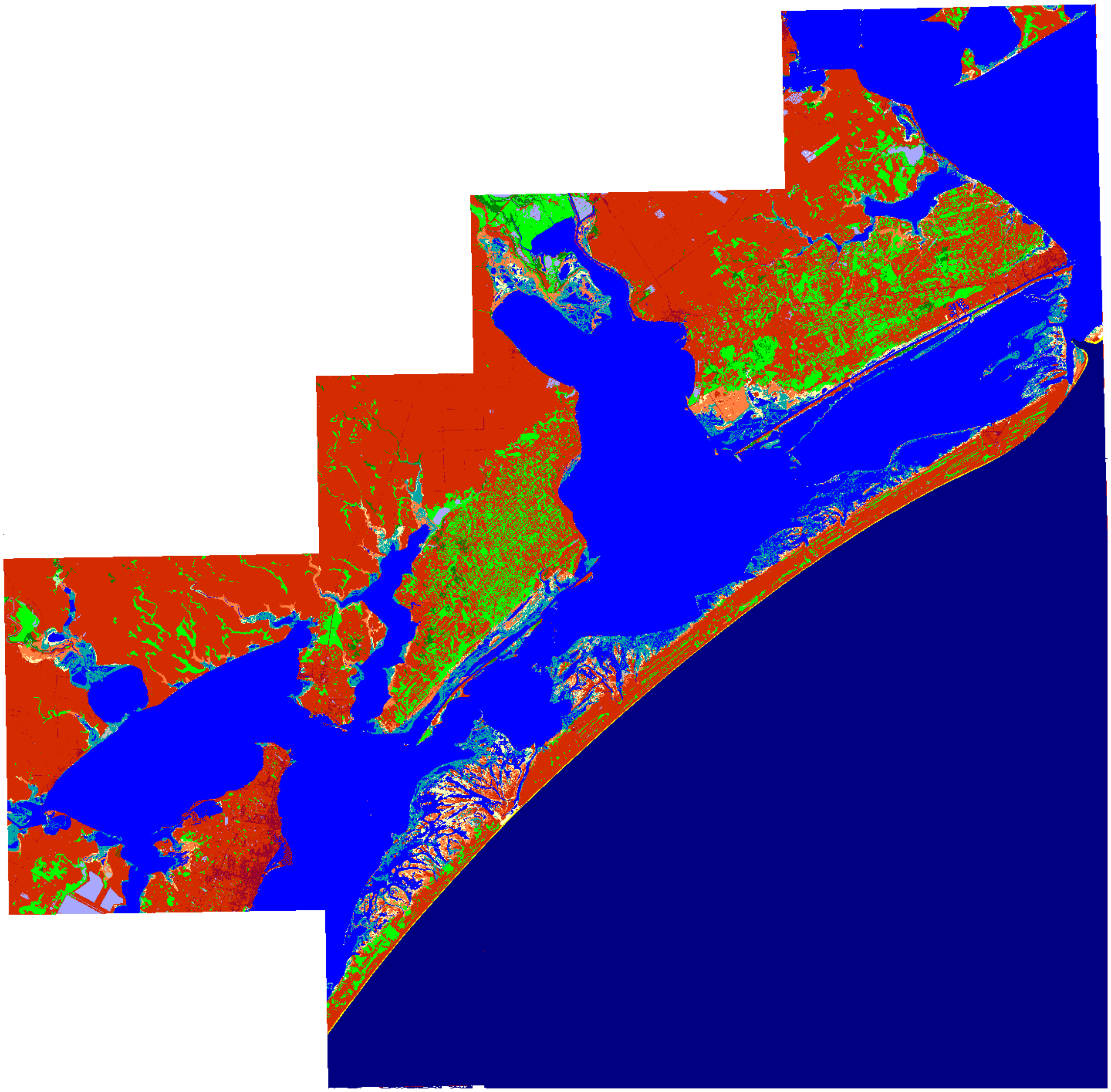
SLR by 2100 (m)	**0.39**	**0.69**	**1**	**1.5**	**2**
Undeveloped Dry Land	3%	5%	9%	17%	27%
Inland Fresh Marsh	1%	4%	10%	23%	37%
Regularly Flooded Marsh	30%	59%	46%	20%	-13%
Irregularly Flooded Marsh	10%	37%	67%	92%	96%
Estuarine Beach	70%	88%	94%	96%	97%
Developed Dry Land	9%	14%	18%	28%	39%
Swamp	18%	27%	35%	43%	50%

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

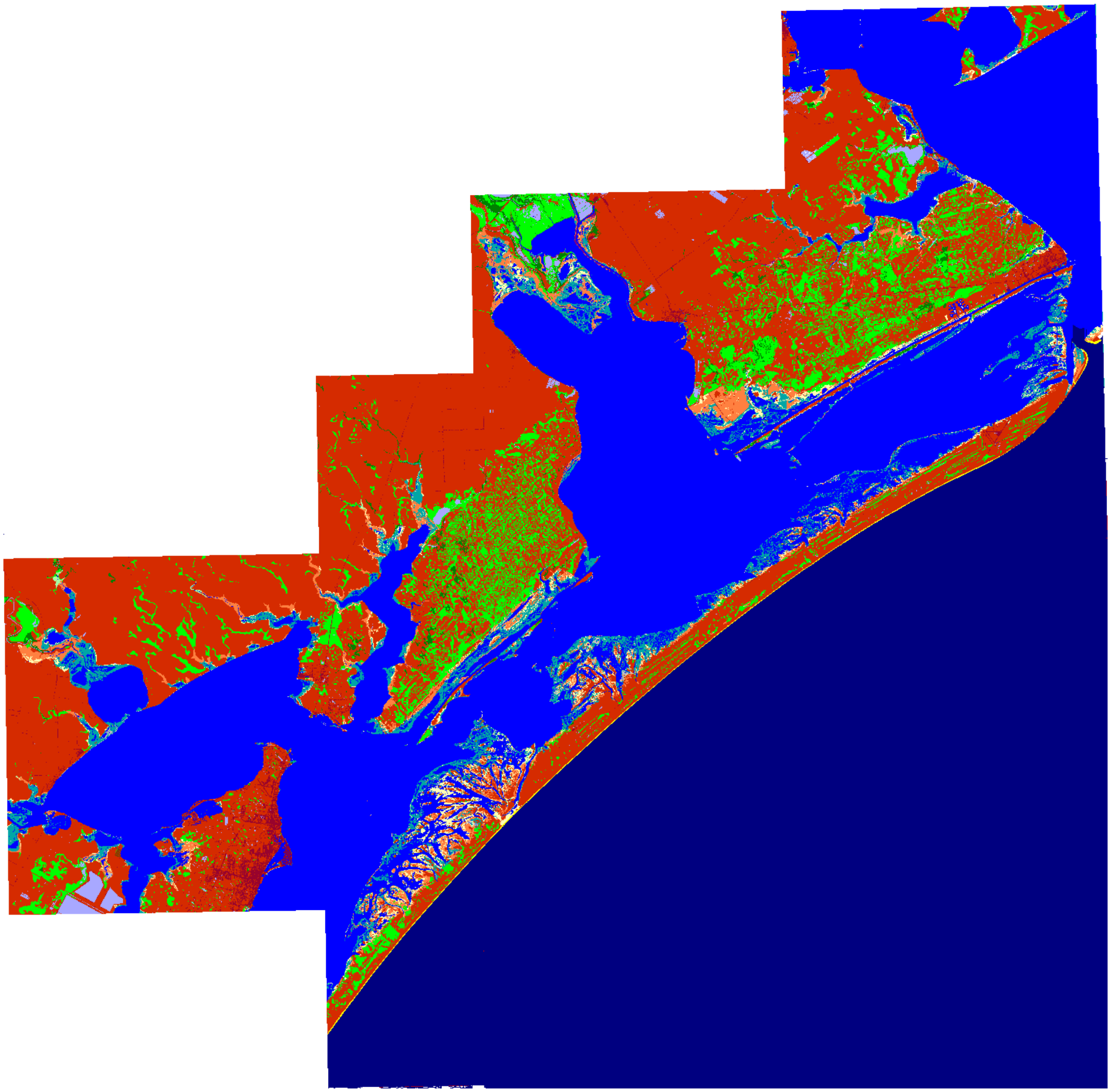
Aransas Context
IPCC Scenario A1B-Mean, 0.39 M SLR Eustatic by 2100

Results in Acres

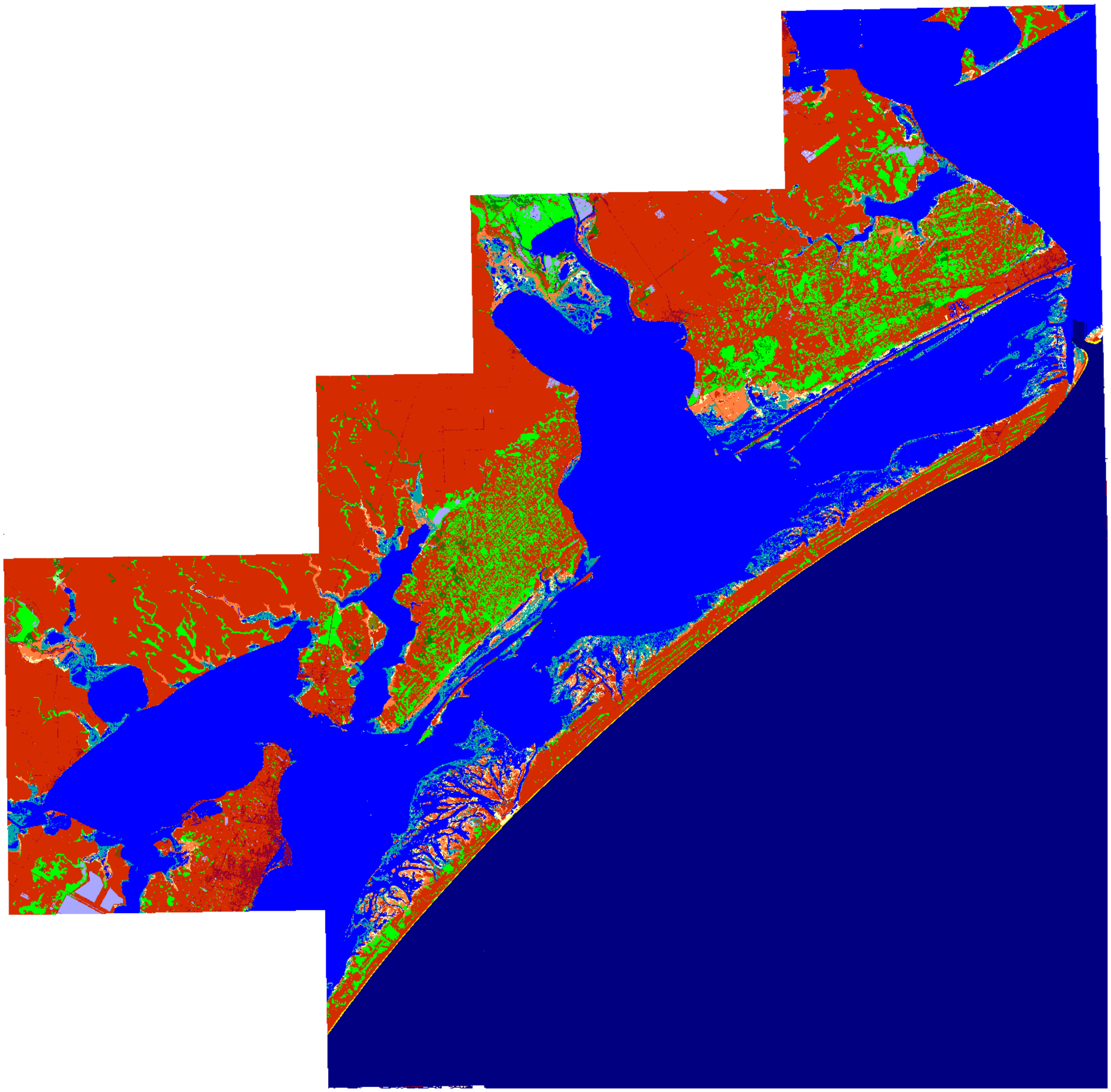
		Initial	2025	2050	2075	2100
	Open Ocean	499966.3	500238.3	500391.7	500564.8	500767.3
	Estuarine Open Water	337324.3	339776.7	342634.2	347838.7	354108.9
	Undeveloped Dry Land	283220.3	281830.1	280528.1	278473.1	275183.5
	Inland Fresh Marsh	59411.7	59297.1	59254.6	59193.5	59059.2
	Regularly Flooded Marsh	32212.4	30609.8	29187.1	26676.3	22416.5
	Irregularly Flooded Marsh	18037.5	17782.3	17610.4	17112.6	16322.2
	Estuarine Beach	11657.7	10873.8	9057.7	6151.6	3482.9
	Inland Open Water	6416.7	6409.8	6389.8	6334.7	6272.2
	Developed Dry Land	6304.4	6254.5	6157.3	5992.9	5745.1
	Swamp	5039.9	4968.8	4739.2	4496.7	4145.3
	Tidal Flat	1662.6	2015.1	2619.6	3712.7	5924.4
	Ocean Beach	1345.0	1323.4	1302.4	1276.2	1238.3
	Inland Shore	518.0	502.4	486.8	455.8	428.5
	Mangrove	419.9	406.4	406.4	406.2	403.1
	Tidal Fresh Marsh	195.3	190.3	189.2	186.2	182.3
	Riverine Tidal	57.2	44.3	38.9	34.7	23.4
	Tidal Swamp	8.7	8.2	7.6	6.8	6.4
	Cypress Swamp	1.3	1.3	1.3	1.3	1.2
	Transitional Salt Marsh	0.4	1266.9	2797.2	4884.7	8088.8
	Total (incl. water)	**1263799.5**	**1263799.5**	**1263799.5**	**1263799.5**	**1263799.5**



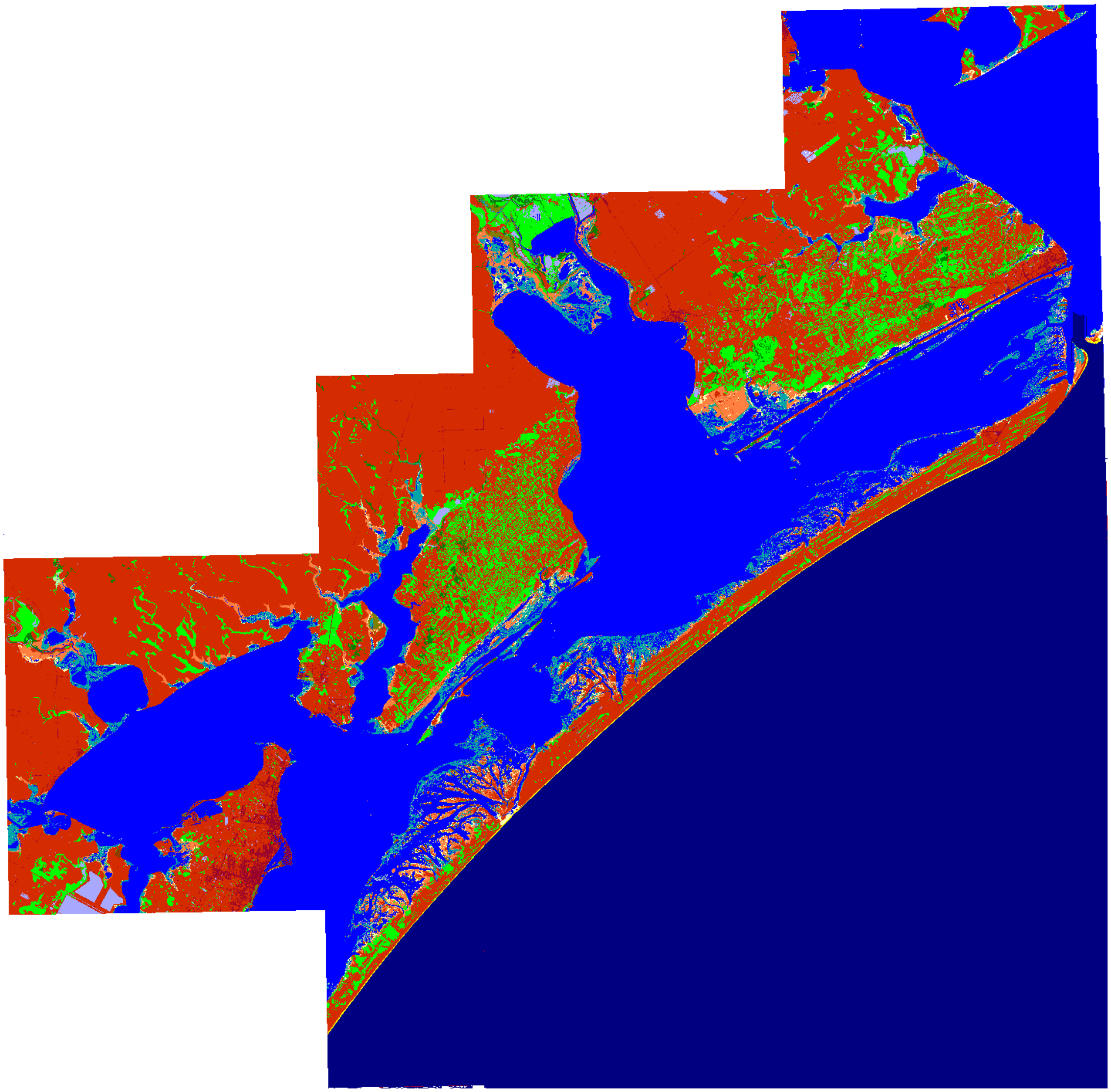
Greater Aransas, Initial Condition



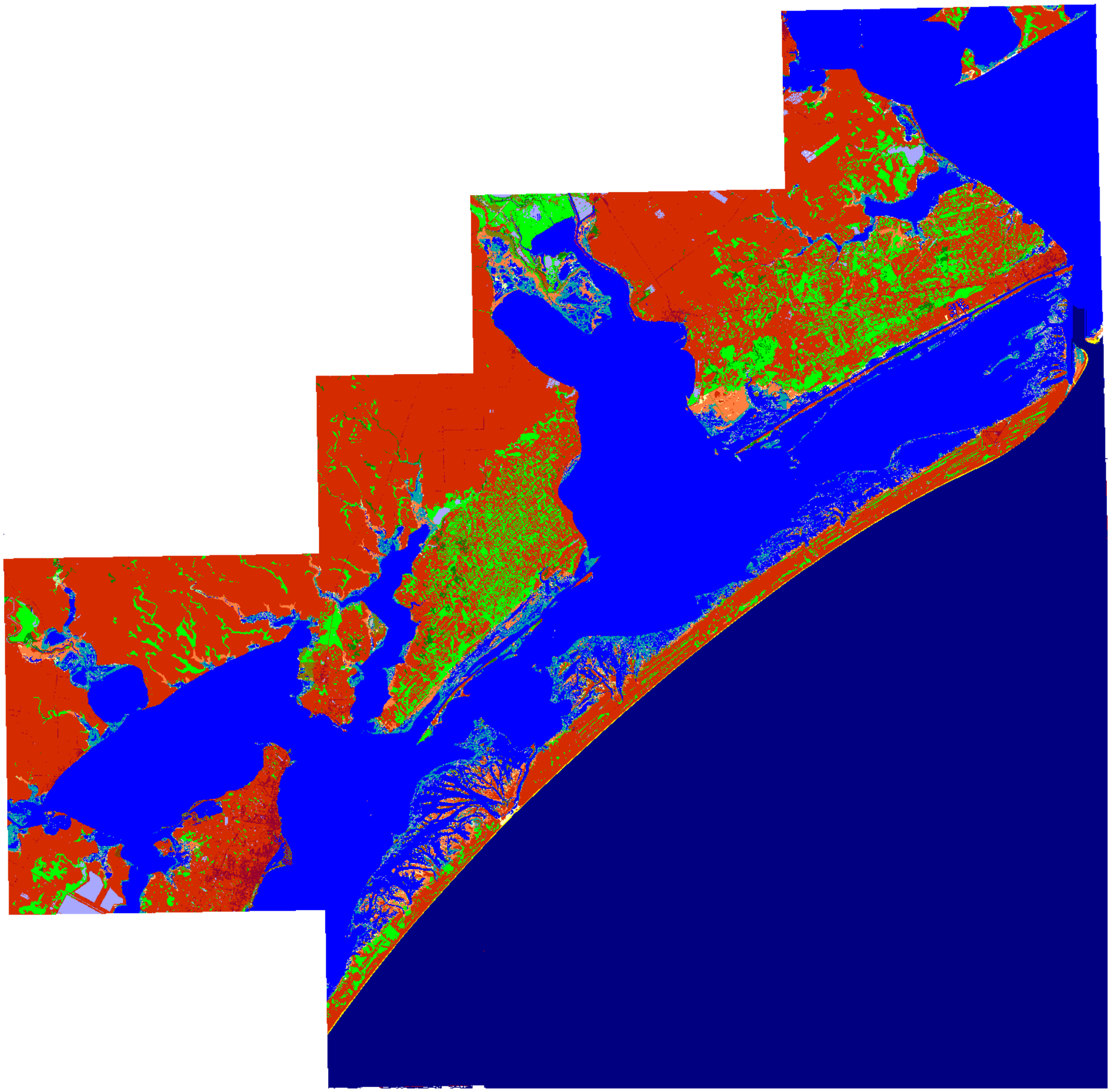
Greater Aransas, 2025, Scenario A1B Mean



Greater Aransas, 2050, Scenario A1B Mean



Greater Aransas, 2075, Scenario A1B Mean

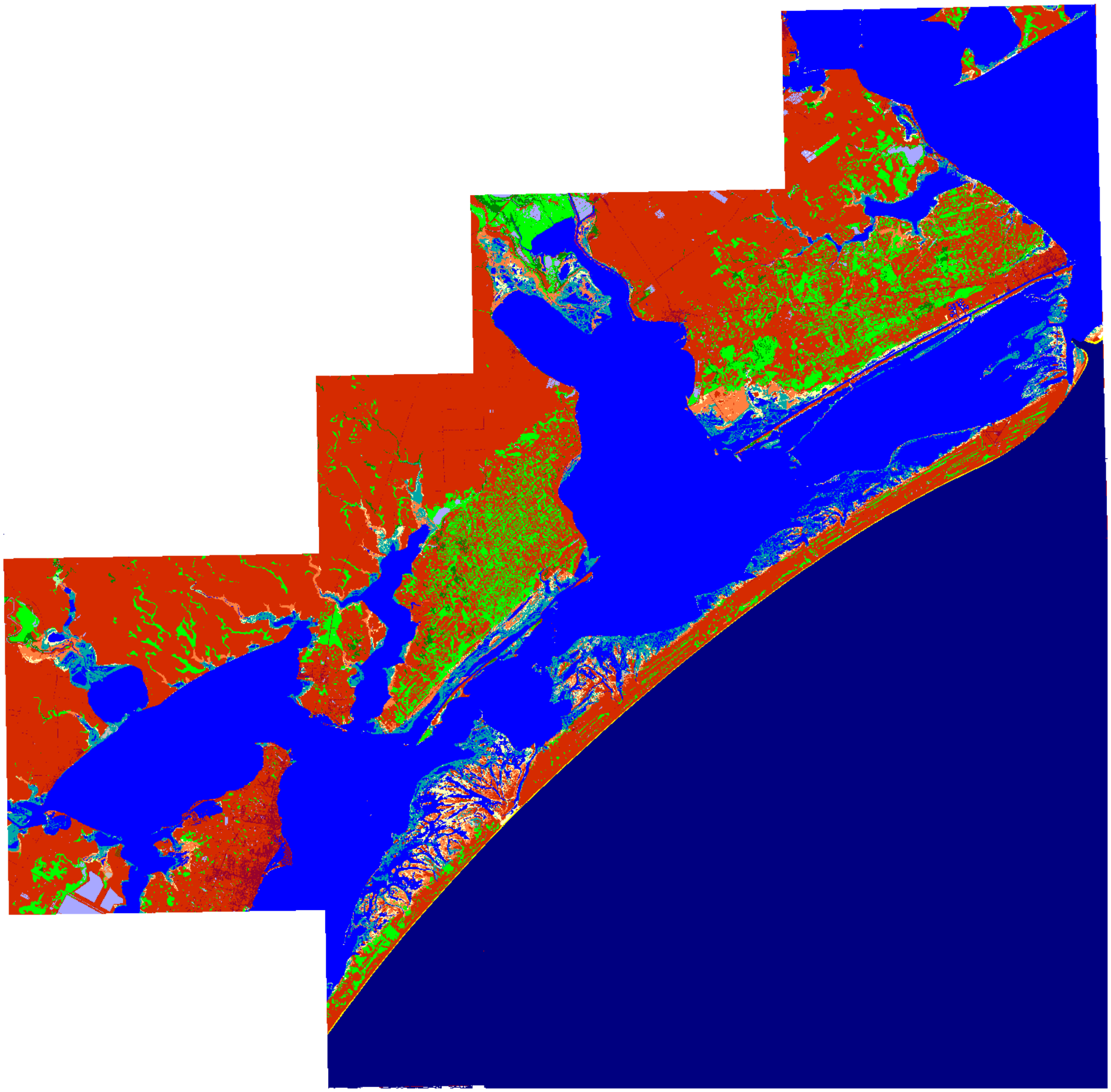


Greater Aransas, 2100, Scenario A1B Mean

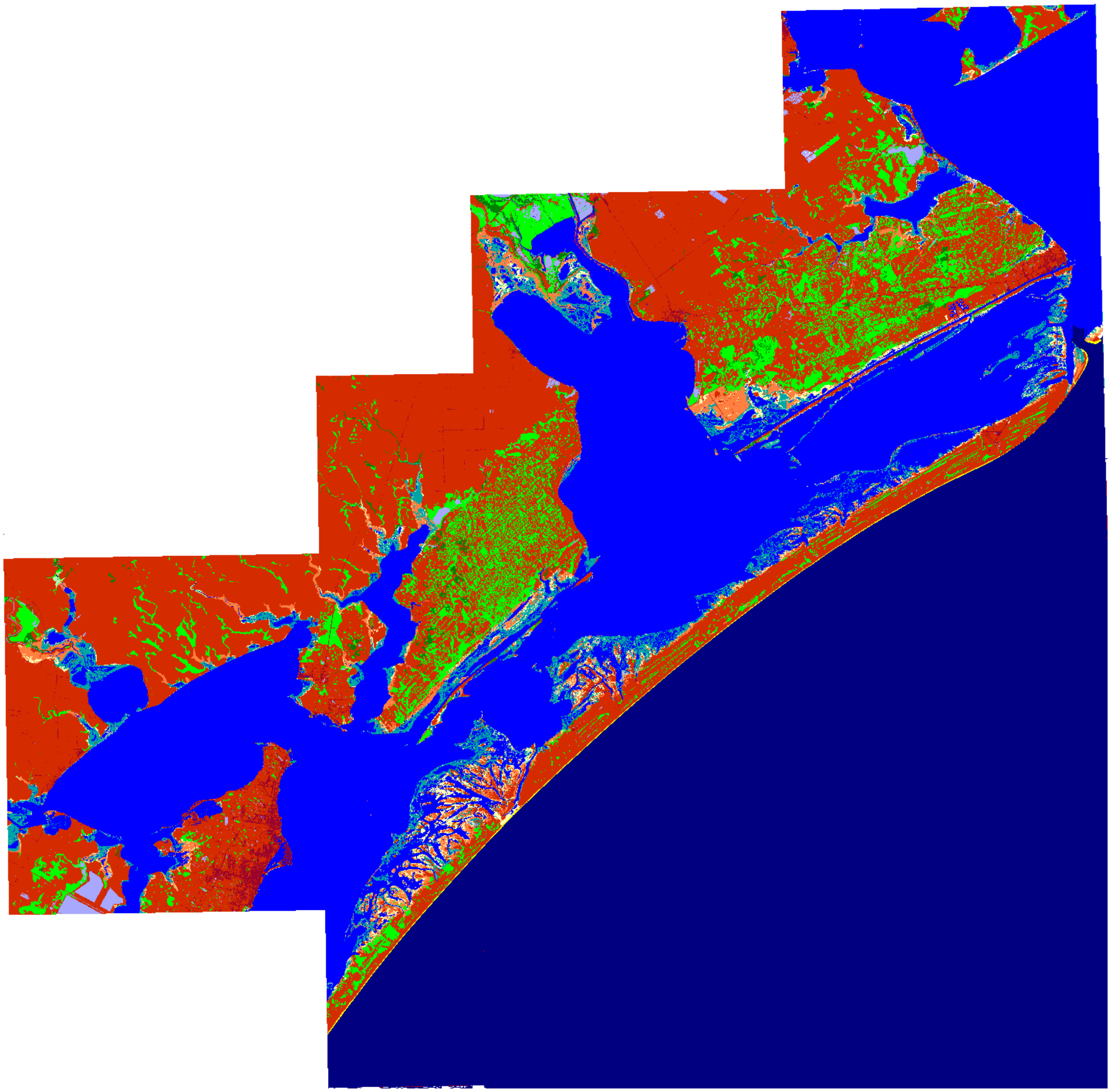
Aransas Context
IPCC Scenario A1B-Max, 0.69 M SLR Eustatic by 2100

Results in Acres

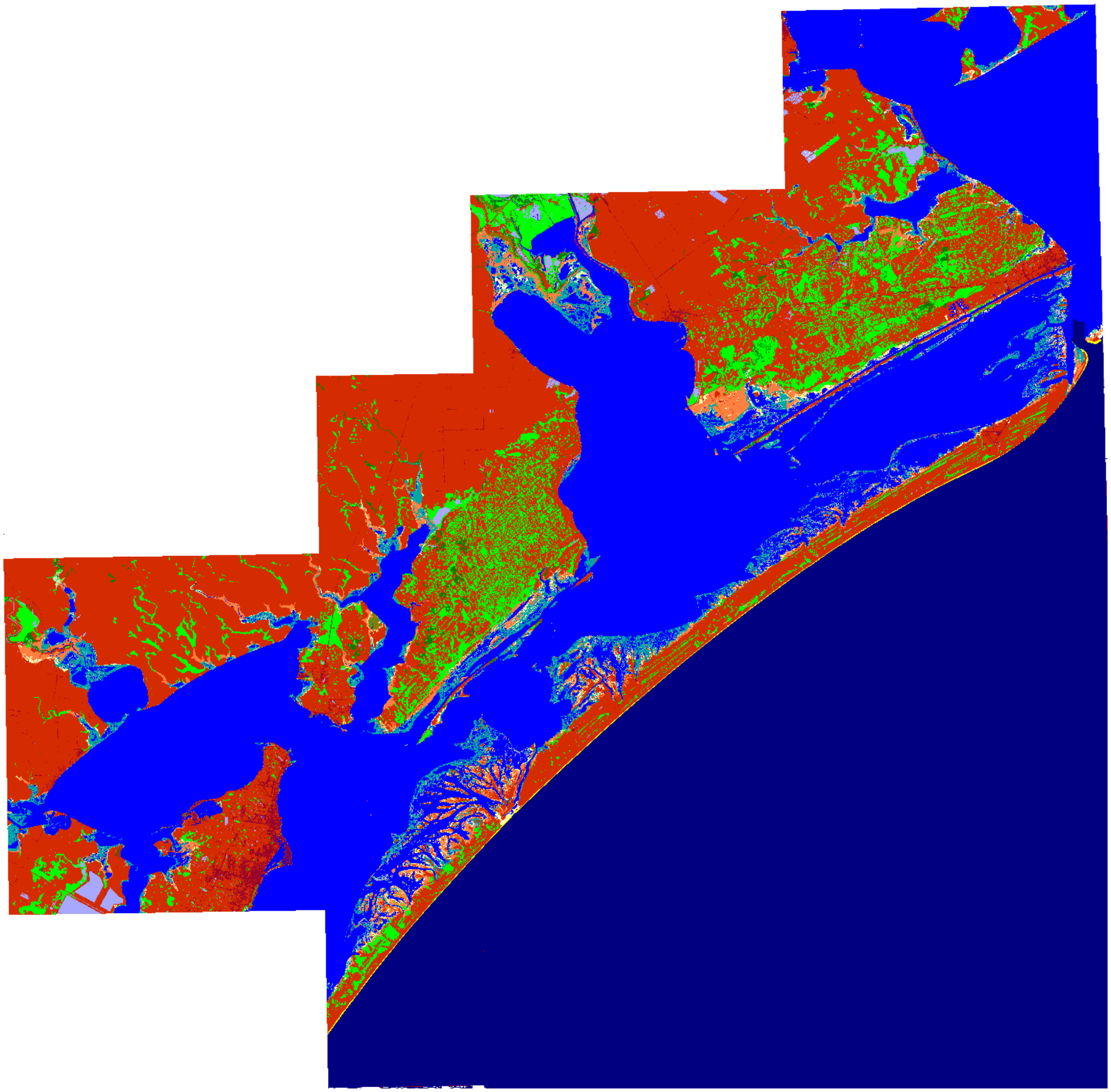
		Initial	2025	2050	2075	2100
	Open Ocean	499966.3	500240.5	500415.5	500636.6	500934.7
	Estuarine Open Water	337324.3	340033.9	344856.7	354105.3	369471.4
	Undeveloped Dry Land	283220.3	281642.4	279659.4	275367.4	268587.0
	Inland Fresh Marsh	59411.7	59285.4	59150.7	58678.3	57324.5
	Regularly Flooded Marsh	32212.4	30262.7	26707.3	17923.2	13314.2
	Irregularly Flooded Marsh	18037.5	17733.8	17112.6	14953.8	11428.5
	Estuarine Beach	11657.7	10693.4	7698.2	3519.7	1348.6
	Inland Open Water	6416.7	6405.4	6368.7	6283.3	6052.2
	Developed Dry Land	6304.4	6248.3	6086.5	5766.6	5437.8
	Swamp	5039.9	4959.9	4636.9	4145.1	3692.5
	Tidal Flat	1662.6	2383.1	5038.9	12917.9	12585.7
	Ocean Beach	1345.0	1321.3	1279.0	1218.7	1080.4
	Inland Shore	518.0	500.4	474.3	431.4	383.6
	Mangrove	419.9	406.2	398.3	381.7	362.9
	Tidal Fresh Marsh	195.3	189.4	182.9	165.8	140.1
	Riverine Tidal	57.2	44.0	37.4	27.8	9.6
	Tidal Swamp	8.7	8.0	7.1	6.4	4.6
	Cypress Swamp	1.3	1.3	1.3	1.2	0.4
	Transitional Salt Marsh	0.4	1440.0	3687.9	7269.1	11640.9
	Total (incl. water)	**1263799.5**	**1263799.5**	**1263799.5**	**1263799.5**	**1263799.5**



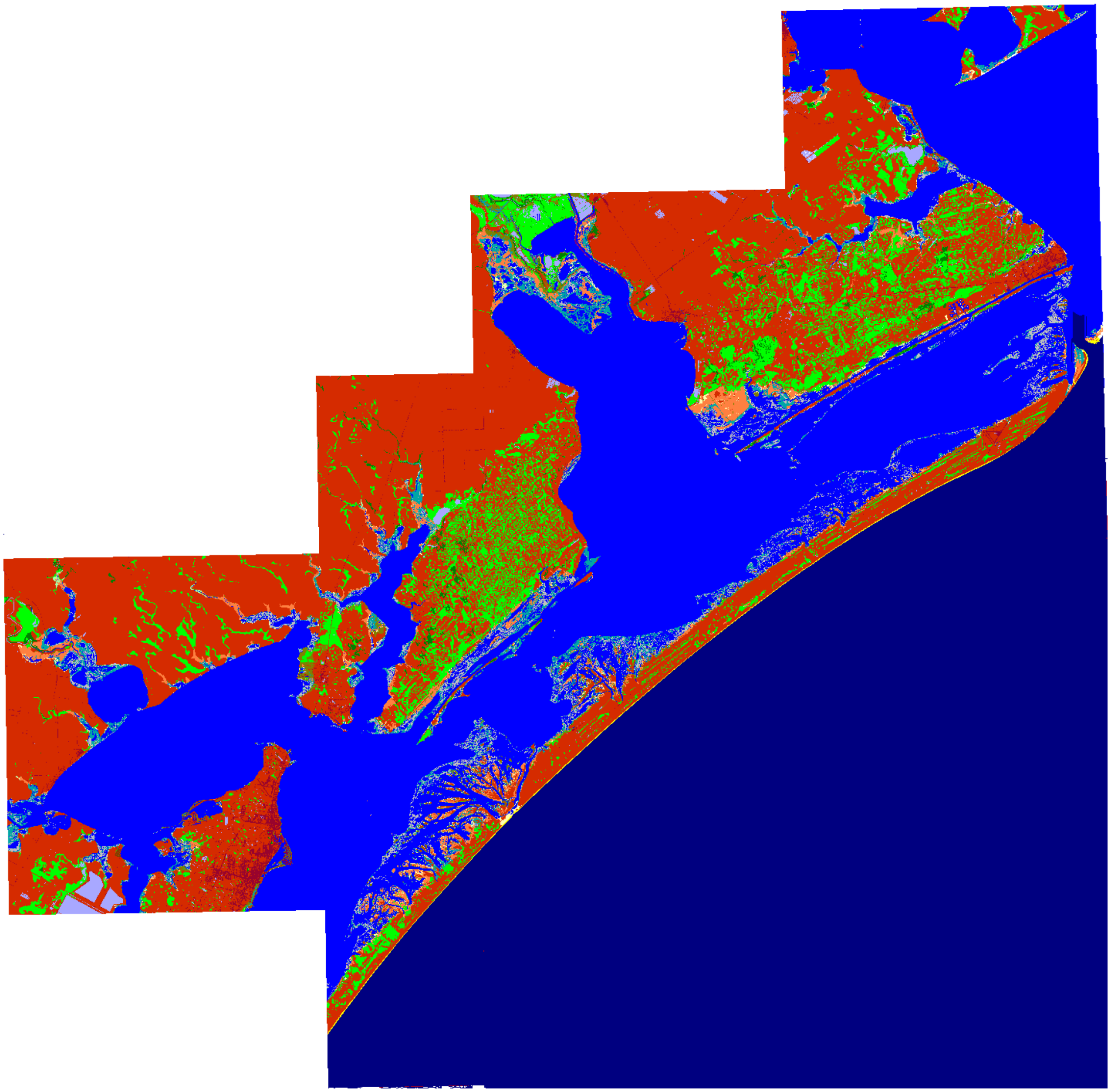
Greater Aransas, Initial Condition



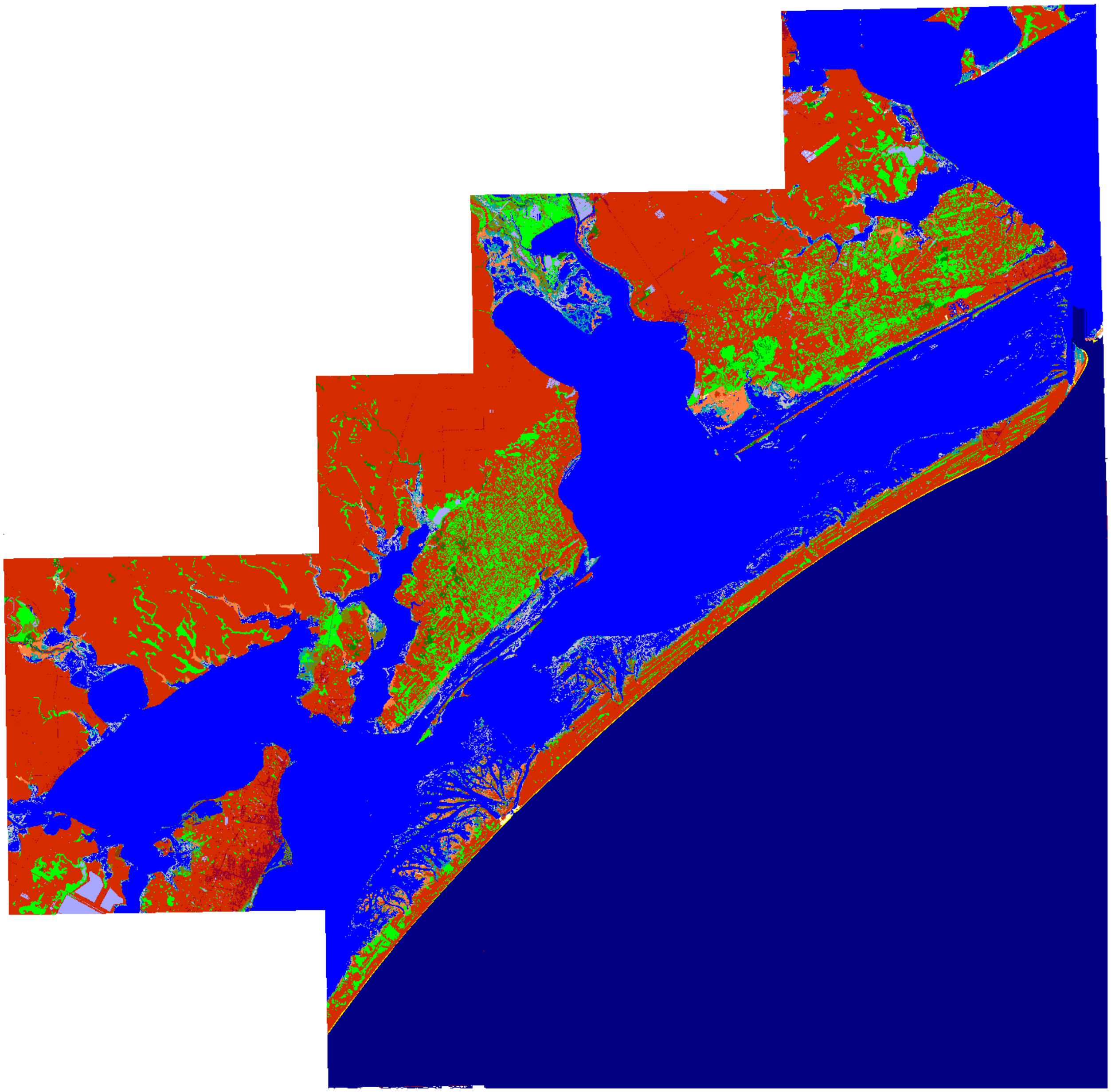
Greater Aransas, 2025, Scenario A1B Maximum



Greater Aransas, 2050, Scenario A1B Maximum



Greater Aransas, 2075, Scenario A1B Maximum

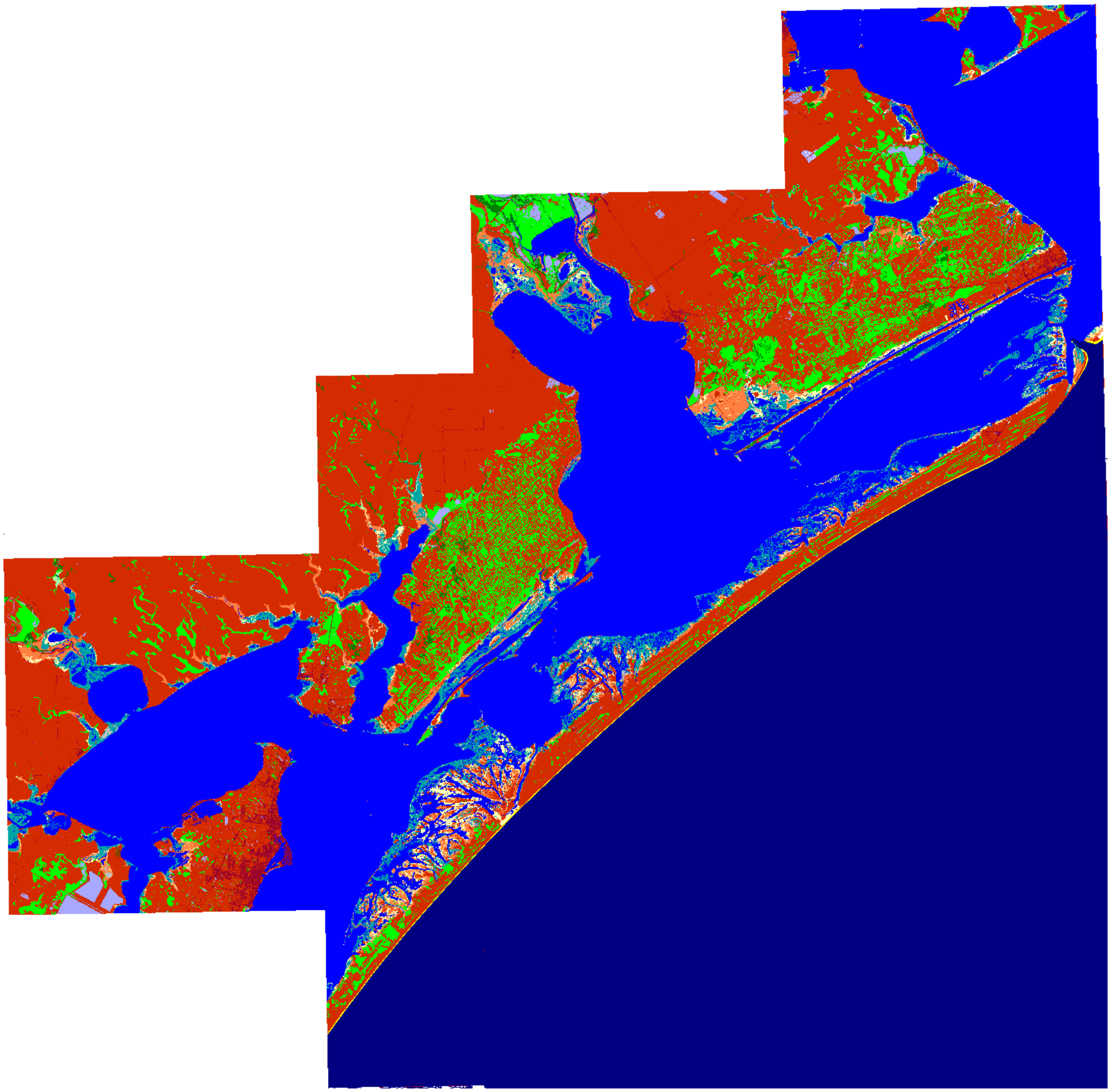


Greater Aransas, 2100, Scenario A1B Maximum

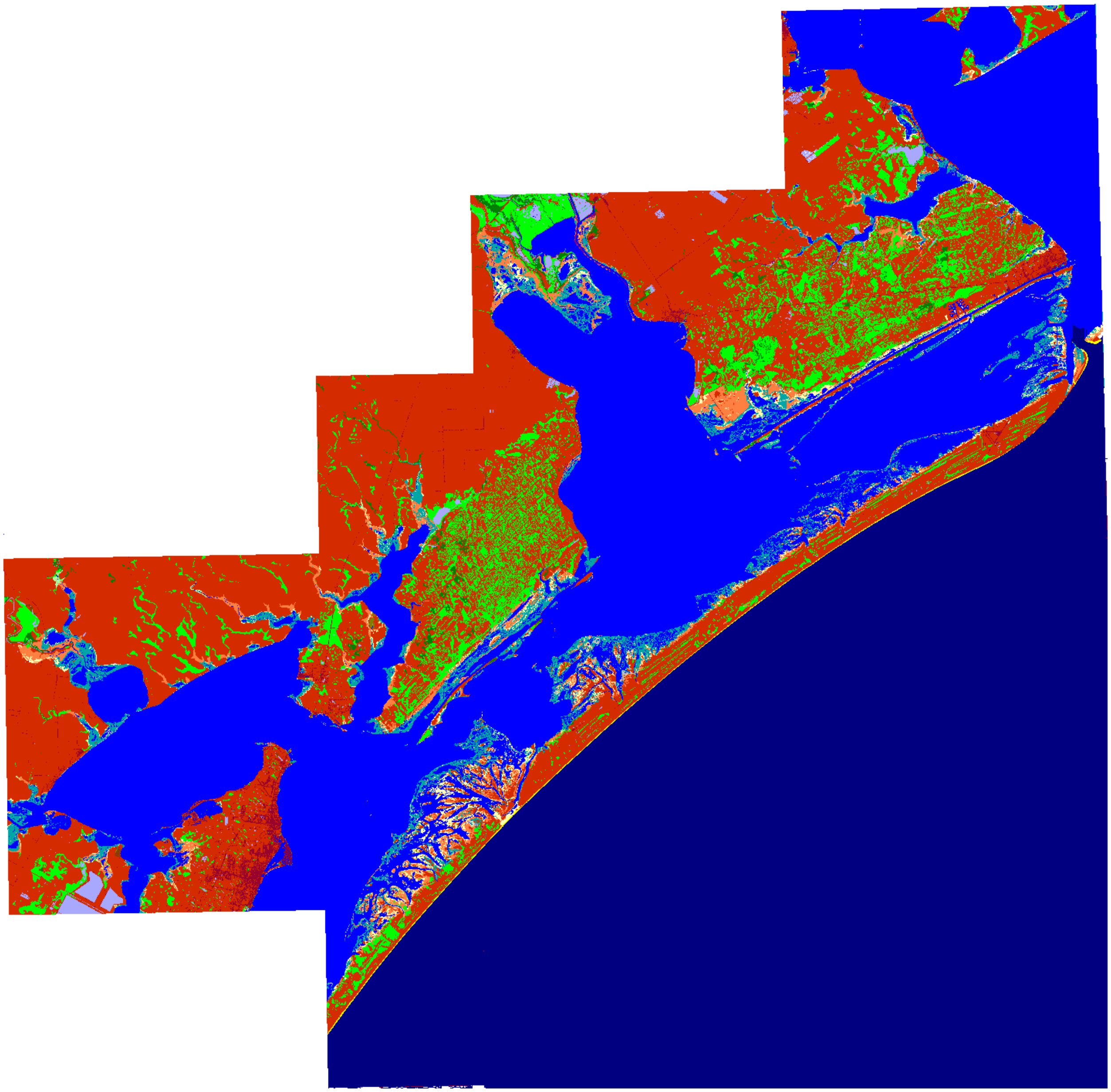
Aransas Context
1 Meter Eustatic SLR by 2100

Results in Acres

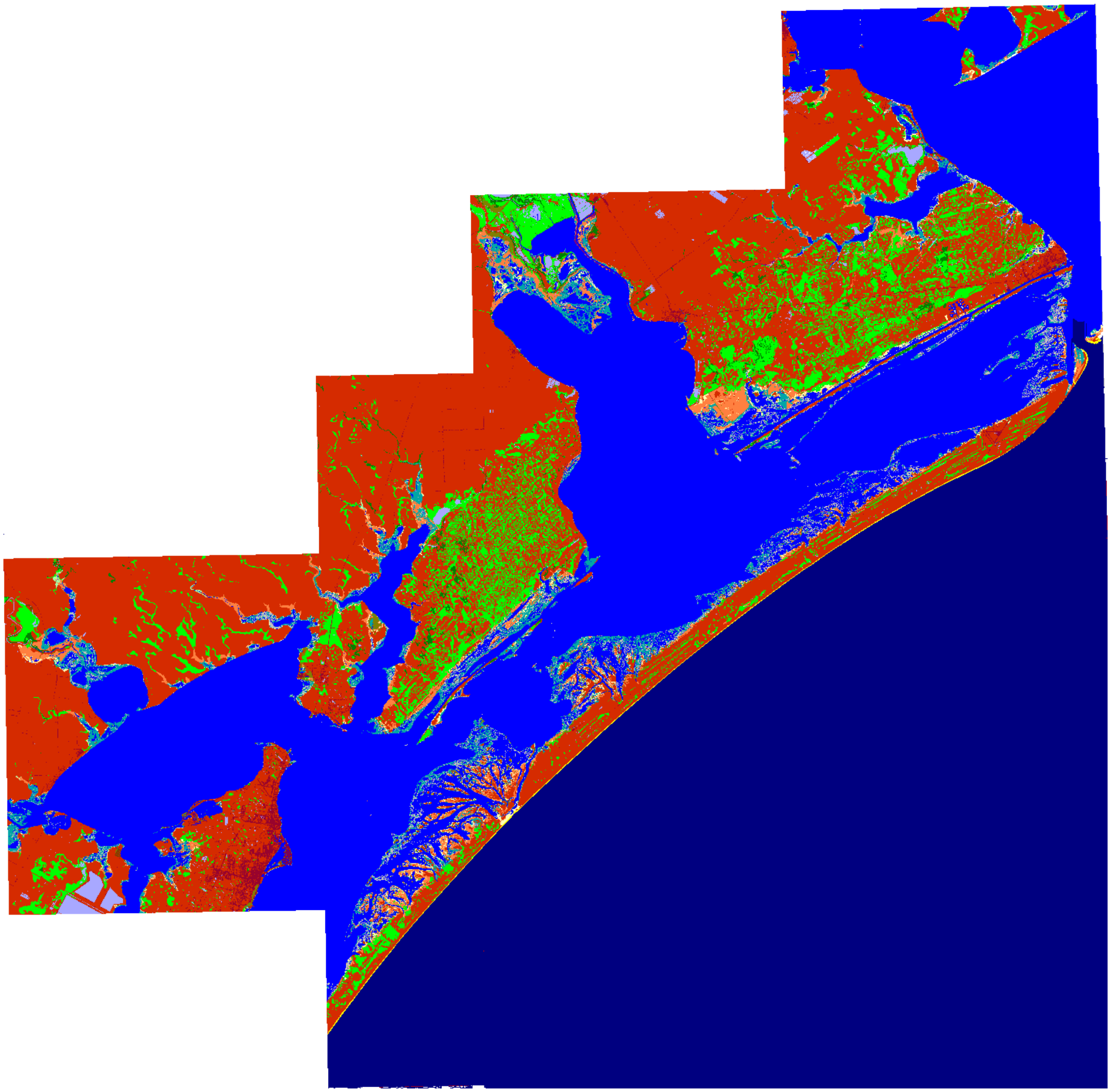
		Initial	2025	2050	2075	2100
	Open Ocean	499966.3	500243.5	500498.2	501114.5	502027.8
	Estuarine Open Water	337324.3	340359.7	347332.5	361935.2	380494.5
	Undeveloped Dry Land	283220.3	281470.6	278529.0	271449.8	258846.5
	Inland Fresh Marsh	59411.7	59264.9	58948.9	56978.2	53531.6
	Regularly Flooded Marsh	32212.4	29815.0	22282.7	14078.1	17415.9
	Irregularly Flooded Marsh	18037.5	17662.8	16184.8	11466.7	5949.4
	Estuarine Beach	11657.7	10456.8	6136.5	1862.6	675.5
	Inland Open Water	6416.7	6404.9	6348.9	6223.9	5830.1
	Developed Dry Land	6304.4	6241.2	6002.4	5554.1	5163.1
	Swamp	5039.9	4947.3	4487.3	3867.5	3286.9
	Tidal Flat	1662.6	2869.0	10094.3	16903.5	12175.6
	Ocean Beach	1345.0	1318.3	1205.7	751.0	135.9
	Inland Shore	518.0	499.2	457.6	402.4	320.0
	Mangrove	419.9	402.8	384.1	351.6	302.9
	Tidal Fresh Marsh	195.3	188.0	172.1	131.9	74.4
	Riverine Tidal	57.2	43.6	36.0	21.6	7.3
	Tidal Swamp	8.7	7.9	6.7	5.2	0.7
	Cypress Swamp	1.3	1.3	1.3	0.8	0.0
	Transitional Salt Marsh	0.4	1602.6	4690.5	10700.8	17561.5
	Total (incl. water)	**1263799.5**	**1263799.5**	**1263799.5**	**1263799.5**	**1263799.5**



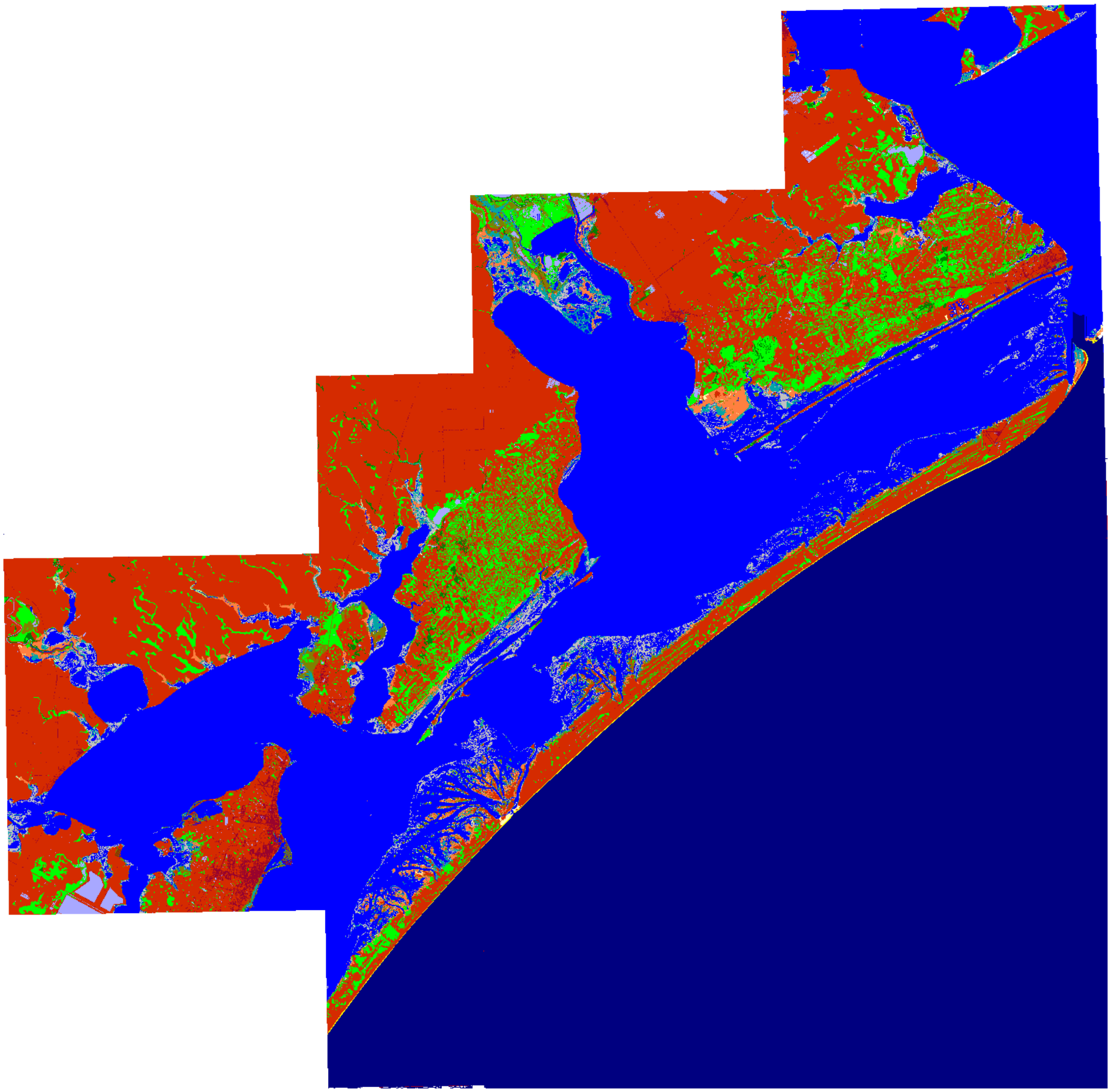
Greater Aransas, Initial Condition



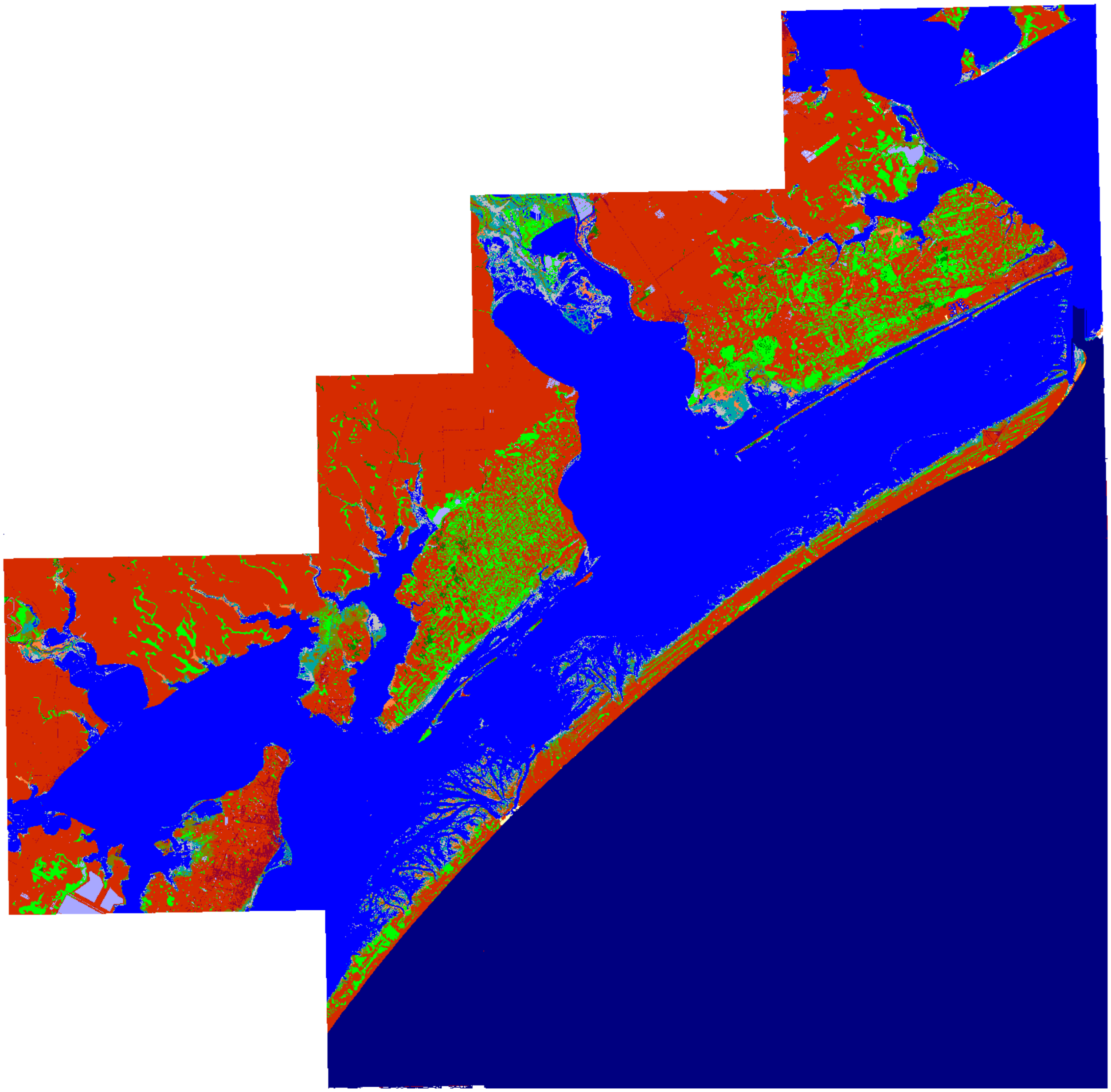
Greater Aransas, 2025, 1 Meter



Greater Aransas, 2050, 1 Meter



Greater Aransas, 2075, 1 Meter

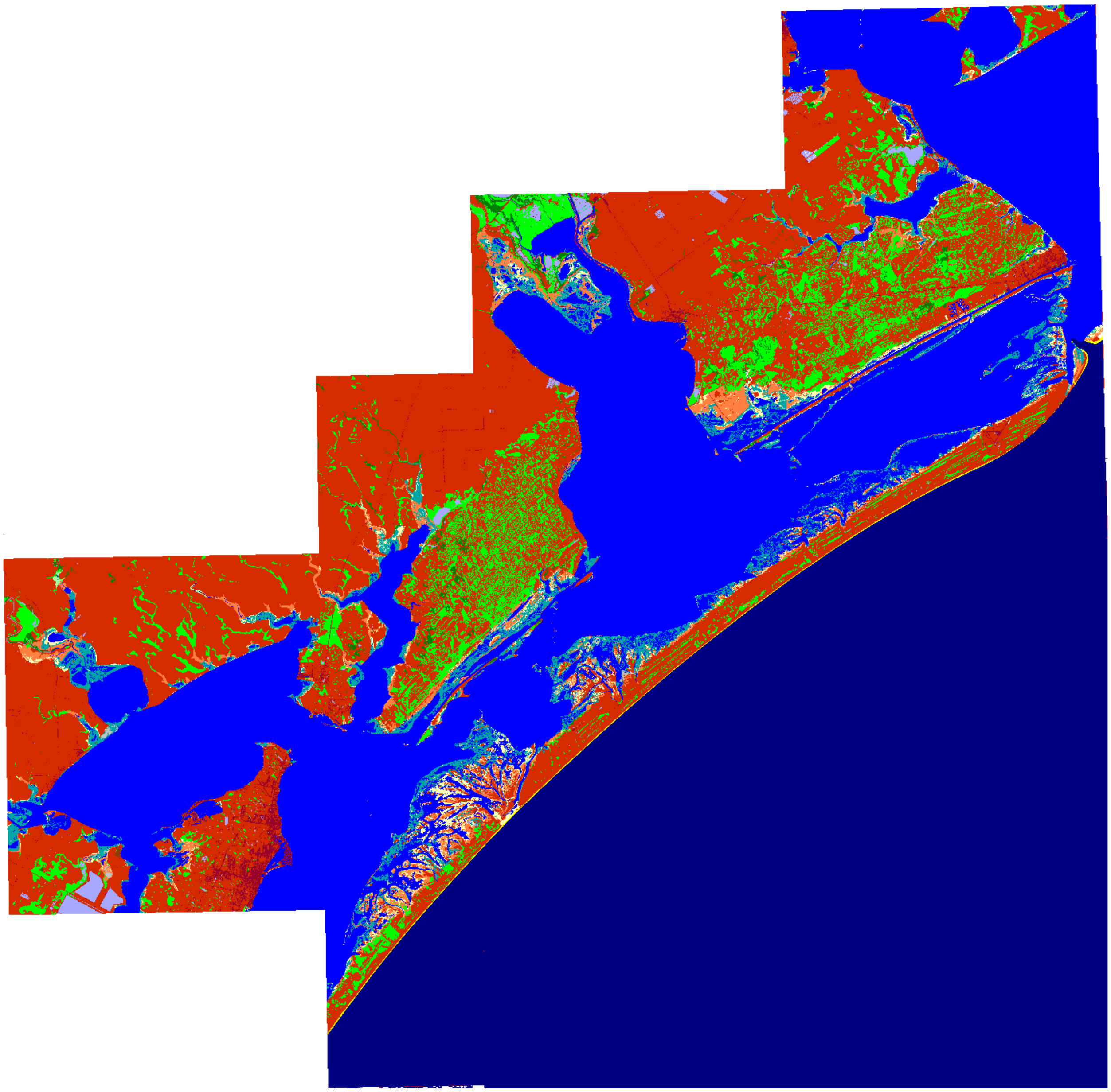


Greater Aransas, 2100, 1 Meter

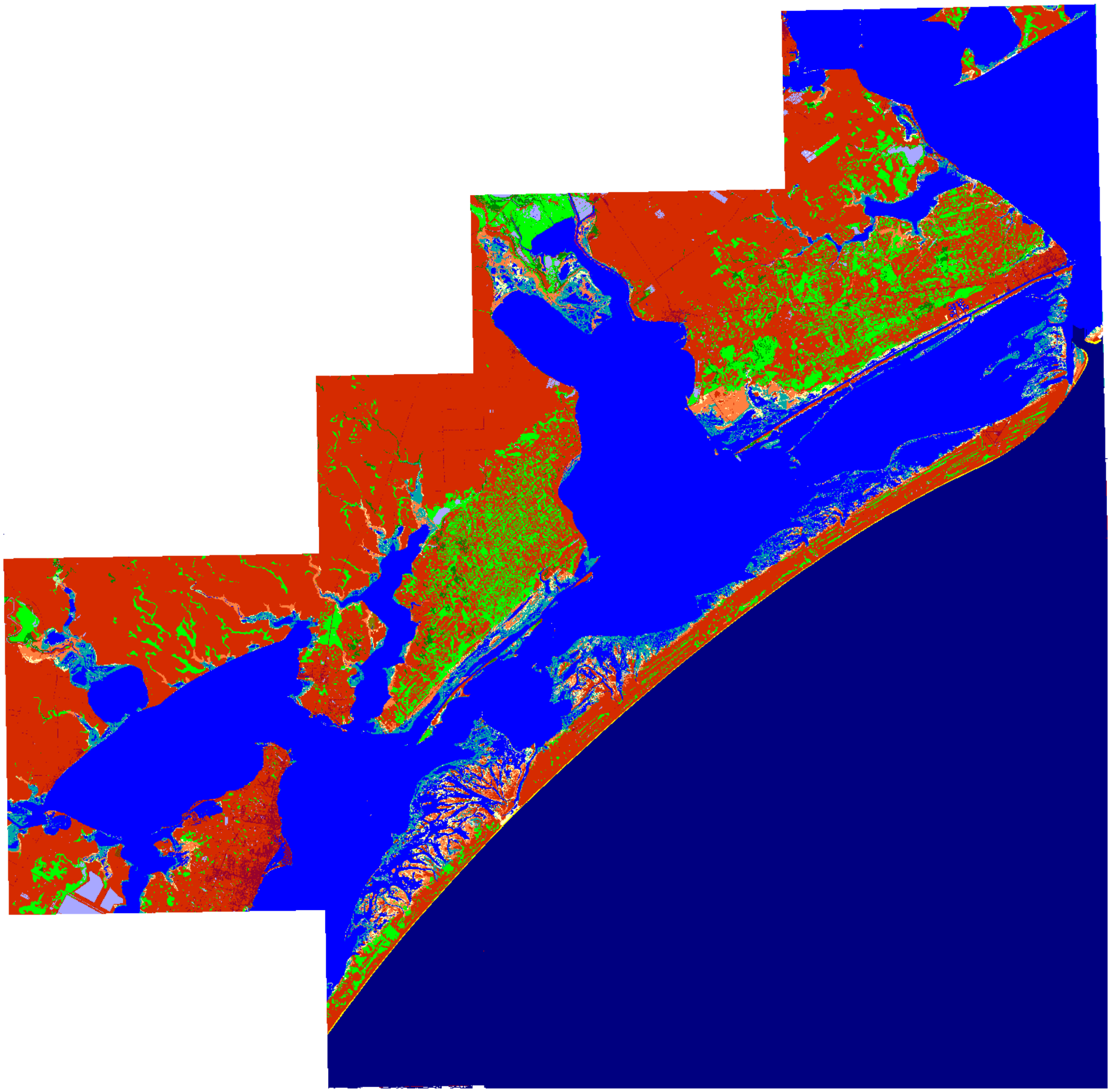
Aransas Context
1.5 Meters Eustatic SLR by 2100

Results in Acres

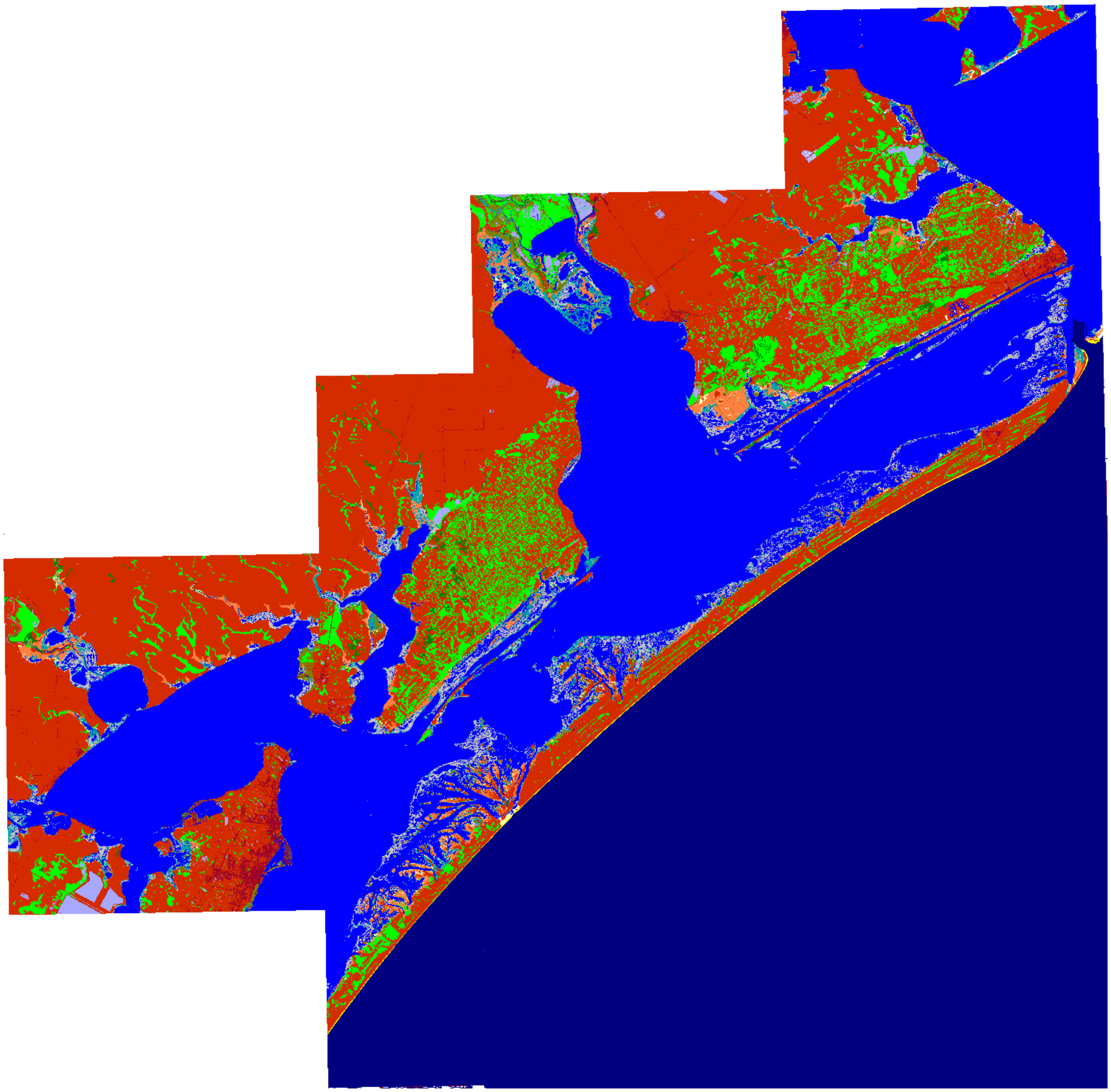
		Initial	2025	2050	2075	2100
	Open Ocean	499966.3	500250.2	501007.6	501900.7	502517.6
	Estuarine Open Water	337324.3	341012.8	351248.8	374505.7	388665.9
	Undeveloped Dry Land	283220.3	281148.7	275996.6	262040.4	234432.0
	Inland Fresh Marsh	59411.7	59222.5	58073.6	52699.8	45572.4
	Regularly Flooded Marsh	32212.4	28875.8	15036.5	17135.6	25652.5
	Irregularly Flooded Marsh	18037.5	17495.0	13557.4	5565.0	1448.6
	Estuarine Beach	11657.7	9964.6	3775.8	788.9	410.0
	Inland Open Water	6416.7	6403.6	6313.5	6001.3	5636.8
	Developed Dry Land	6304.4	6222.9	5833.0	5251.6	4558.6
	Swamp	5039.9	4810.0	4189.7	3400.0	2870.0
	Tidal Flat	1662.6	3925.2	19760.1	13222.5	16174.1
	Ocean Beach	1345.0	1311.6	713.4	38.7	1539.1
	Inland Shore	518.0	494.8	436.8	340.7	200.9
	Mangrove	419.9	397.7	359.8	284.2	217.8
	Tidal Fresh Marsh	195.3	184.8	147.2	62.5	27.5
	Riverine Tidal	57.2	43.4	31.8	8.9	2.2
	Tidal Swamp	8.7	7.8	6.4	1.4	0.0
	Cypress Swamp	1.3	1.3	1.3	0.0	0.0
	Transitional Salt Marsh	0.4	2026.7	7310.1	20551.5	33873.7
	Total (incl. water)	**1263799.5**	**1263799.5**	**1263799.5**	**1263799.5**	**1263799.5**



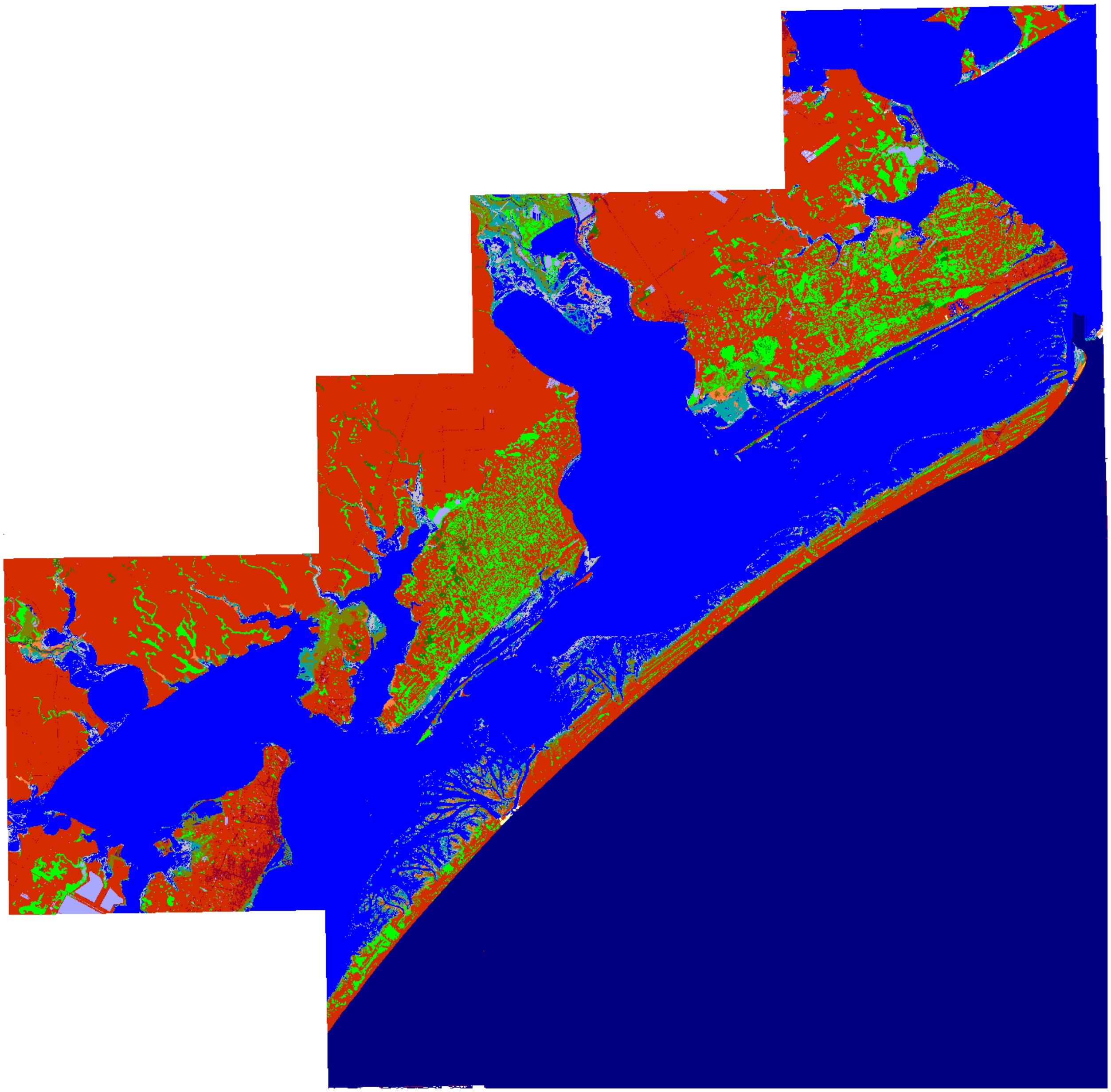
Greater Aransas, Initial Condition



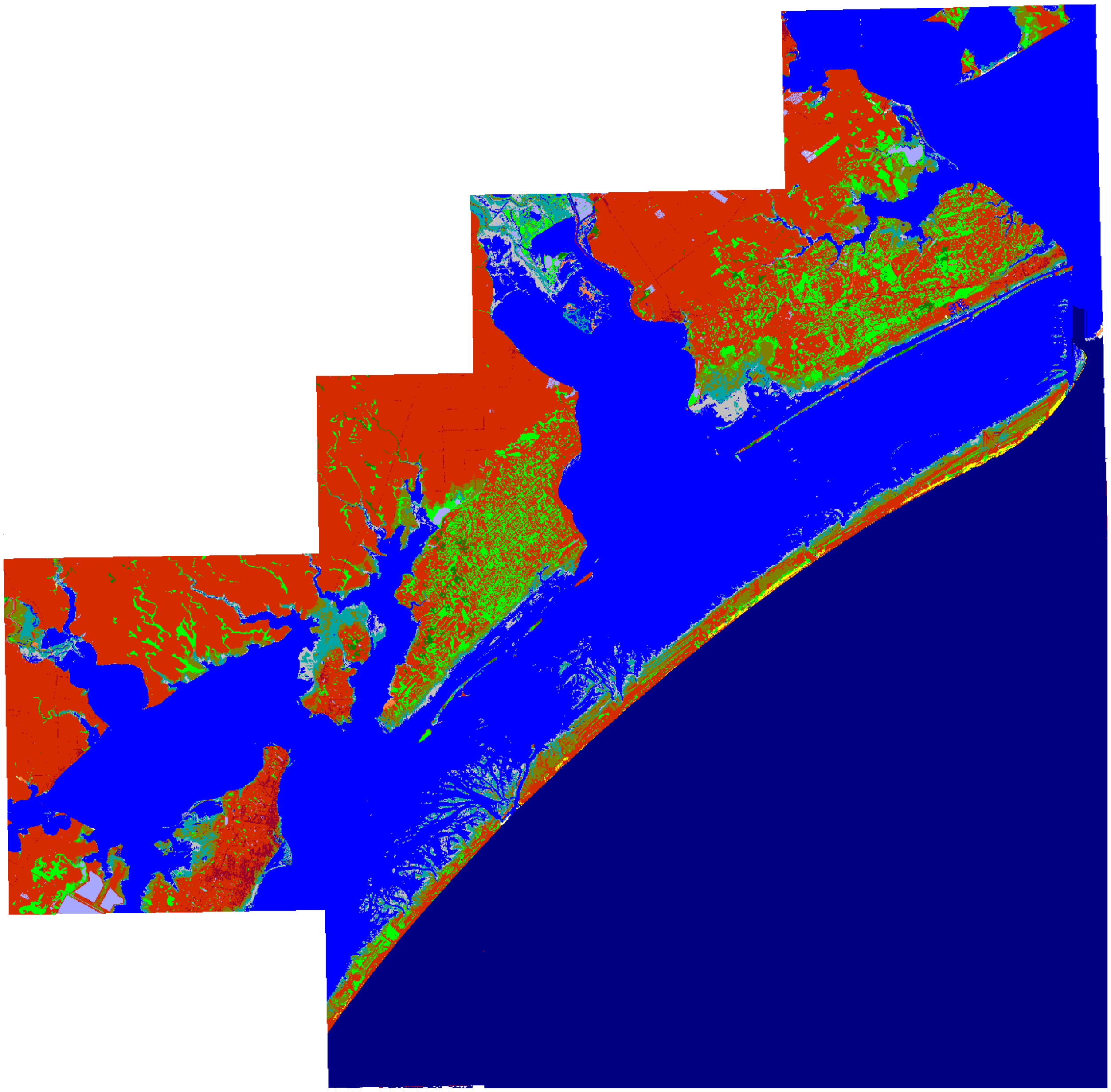
Greater Aransas, 2025, 1.5 Meters



Greater Aransas, 2050, 1.5 Meters



Greater Aransas, 2075, 1.5 Meters

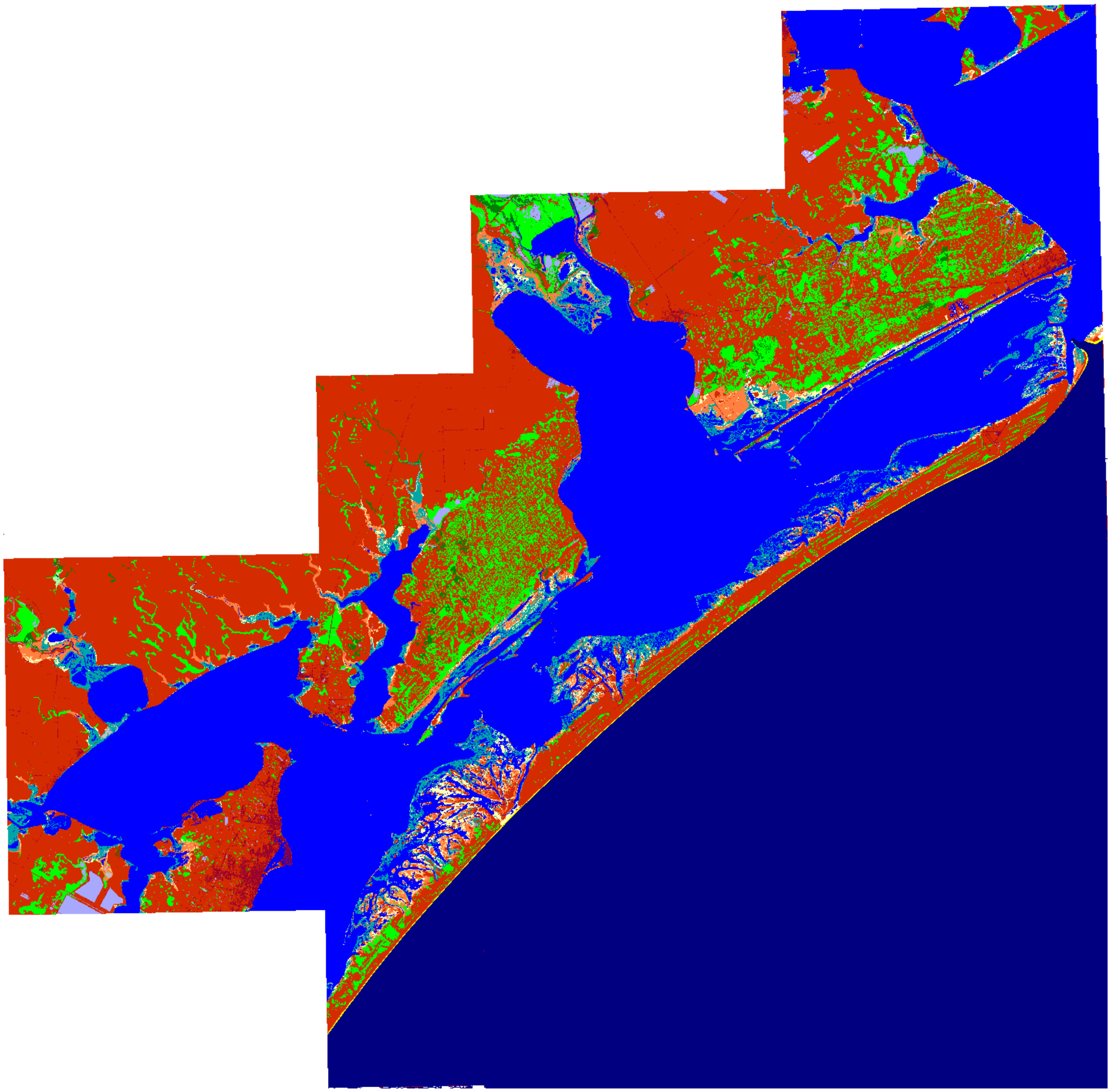


Greater Aransas, 2100, 1.5 Meters

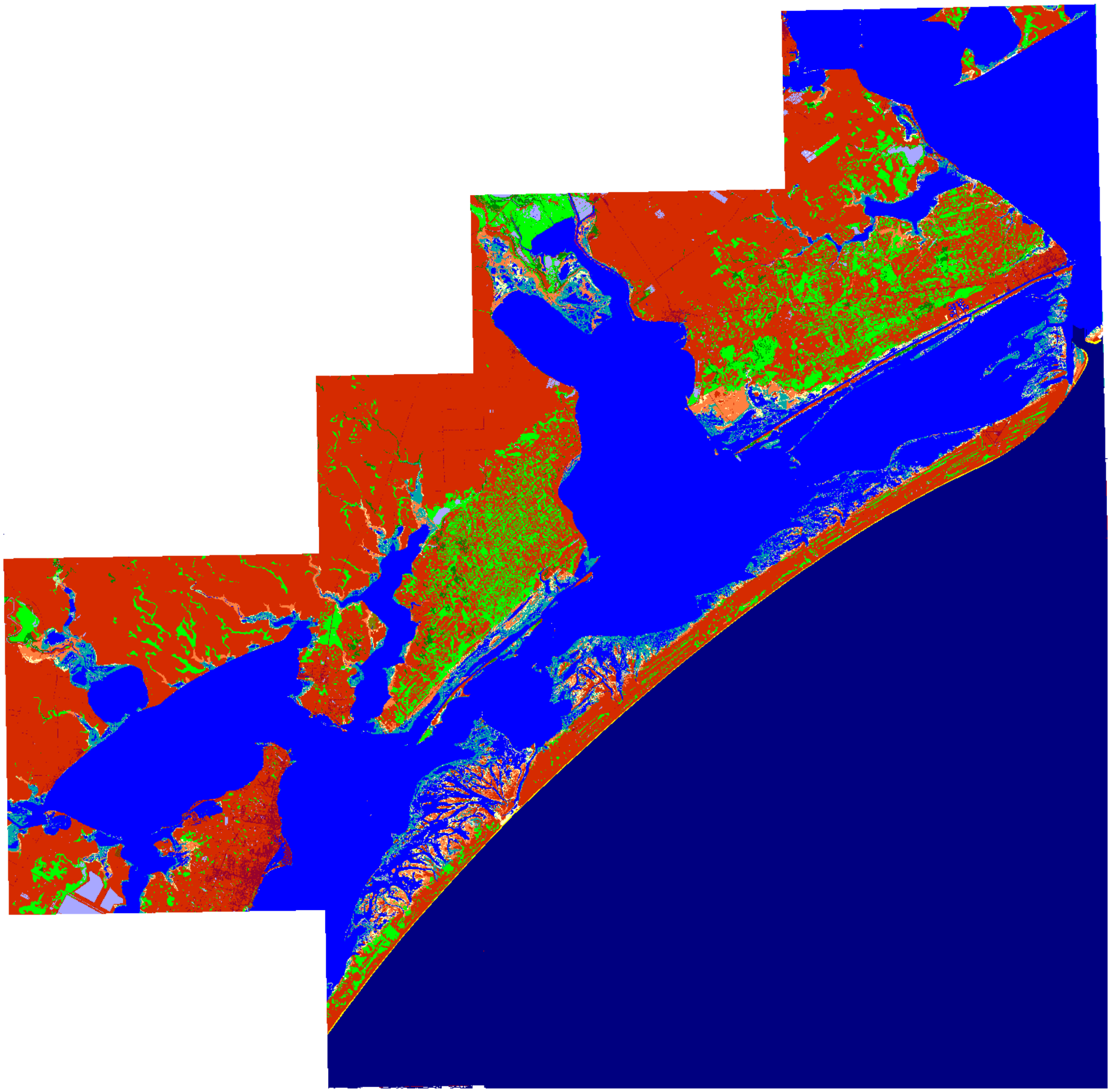
Aransas Context
2 Meters Eustatic SLR by 2100

Results in Acres

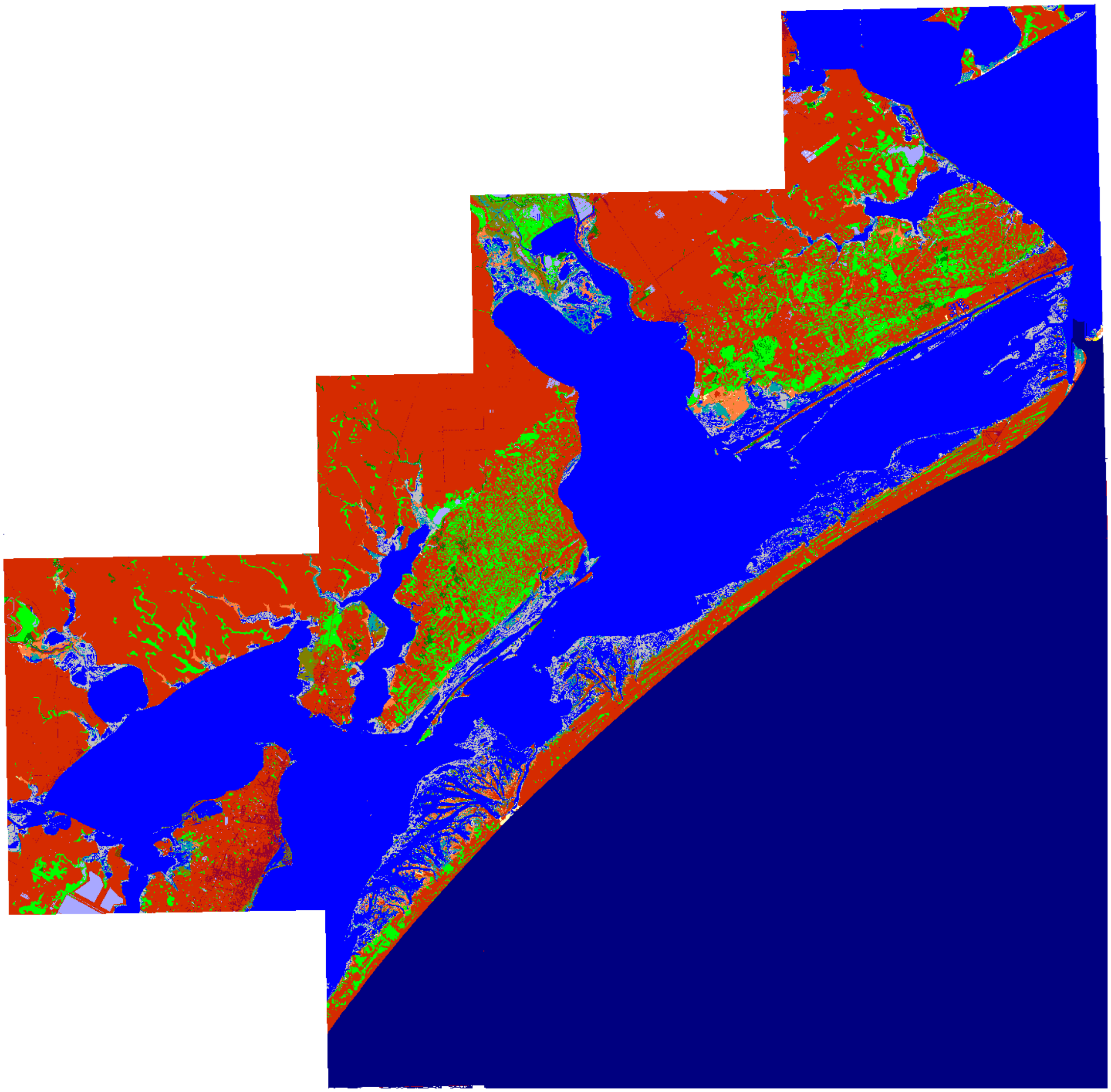
		Initial	2025	2050	2075	2100
	Open Ocean	499966.3	500261.5	501471.2	502068.4	503934.3
	Estuarine Open Water	337324.3	341790.8	354649.7	380277.4	393467.8
	Undeveloped Dry Land	283220.3	280793.5	272746.4	248196.6	205507.2
	Inland Fresh Marsh	59411.7	59154.6	56235.3	47445.3	37678.1
	Regularly Flooded Marsh	32212.4	27627.3	13511.2	21802.2	36300.6
	Irregularly Flooded Marsh	18037.5	17233.2	10526.5	2160.9	681.8
	Estuarine Beach	11657.7	9367.1	2211.1	497.7	342.4
	Inland Open Water	6416.7	6402.1	6270.4	5830.7	5458.7
	Developed Dry Land	6304.4	6177.7	5616.0	4905.4	3869.7
	Swamp	5039.9	4768.3	3920.1	3011.0	2517.4
	Tidal Flat	1662.6	5389.2	23219.6	12427.8	21015.4
	Ocean Beach	1345.0	1300.3	254.6	591.9	2145.2
	Inland Shore	518.0	490.9	411.9	251.0	173.5
	Mangrove	419.9	391.7	325.8	227.5	168.7
	Tidal Fresh Marsh	195.3	180.9	111.1	31.8	17.9
	Riverine Tidal	57.2	42.9	29.4	5.8	0.9
	Tidal Swamp	8.7	7.6	5.4	0.0	0.0
	Cypress Swamp	1.3	1.3	1.0	0.0	0.0
	Transitional Salt Marsh	0.4	2418.5	12283.1	34068.1	50519.9
	Total (incl. water)	**1263799.5**	**1263799.5**	**1263799.5**	**1263799.5**	**1263799.5**



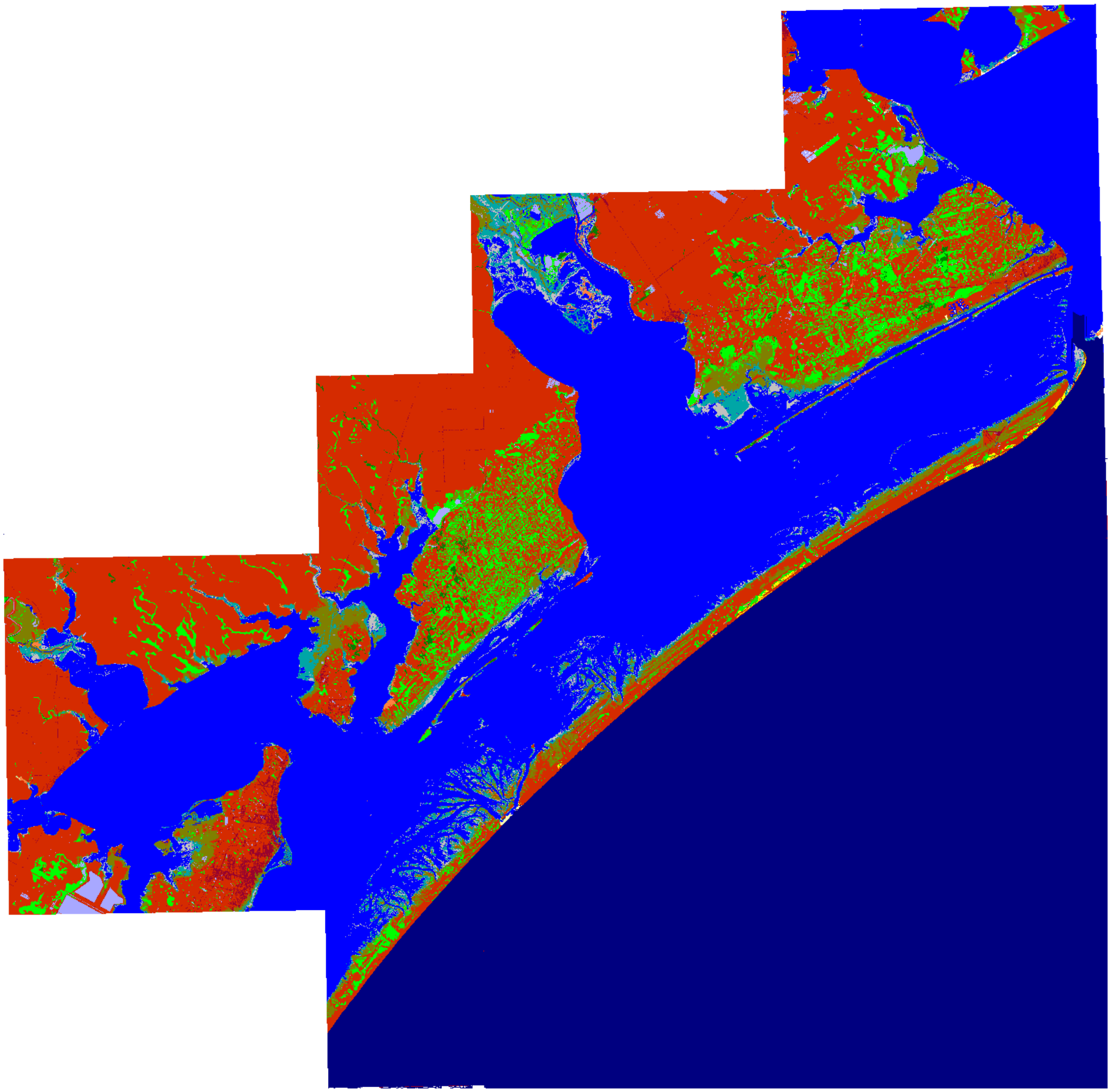
Greater Aransas, Initial Condition



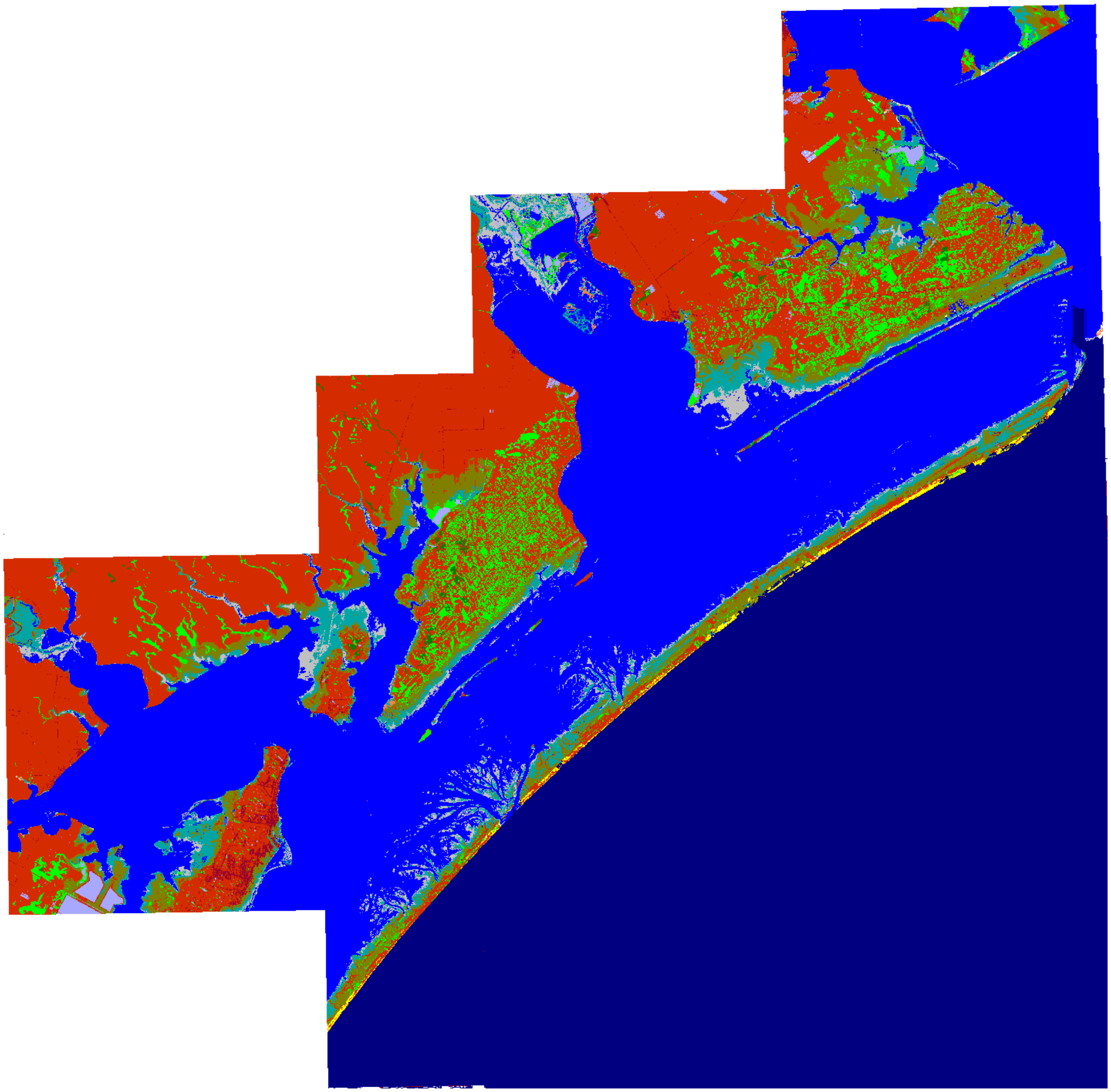
Greater Aransas, 2025, 2 Meters



Greater Aransas, 2050, 2 Meters



Greater Aransas, 2075, 2 Meters



Greater Aransas, 2100, 2 Meters

Discussion

Aransas National Wildlife Refuge is predicted to show more severe effects of sea-level rise than other areas because of its historically-high relative sea-level rise, likely due to land subsidence. Sea-level rise is predicted to continue to be differentially higher in this location than it is worldwide.

Within the refuge itself, inundation in the Matagorda Unit is predicted to be most extreme, with regularly-flooded, irregularly flooded and beach converting to water, and dry land converting to swamp and regularly flooded marsh. In the Aransas Unit, land loss occurs mainly along the Intracoastal Waterway, which is lined by regularly and irregularly flooded marshes. Loss in the Myrtle Unit is predicted to be minimal since most of the land is diked. The Tatton and Lamar Units – both small properties populated by few dikes and many marshes – are also predicted to be heavily impacted by sea level rise.

Up-to-date national wildlife inventory data and site-wide LiDAR data assist in reducing model uncertainty overall. LiDAR for this site is estimated to have a vertical root mean square error of 18.5 centimeters for bare ground (NOAA Digital Coast) but vertical errors may be higher within marshlands.

One of the largest areas of uncertainty within these predictions is the model's estimation of marsh accretion rates. There are multiple sources of accretion data within the study area that show significant spatial and temporal variability. Using a single accretion value site-wide for regularly and irregularly flooded marsh introduces uncertainty into model results.

In addition, within this simulation, accretion rates were held temporally constant. Vertical marsh accretion rates may react to an increase in sea level rise due to more frequent inundation and higher sediment concentrations within water. This could potentially lead to some additional marsh resilience. Insufficient data were available to define a relationship between marsh elevation, sea-level rise, and accretion rates at this time. Future model runs for this site could potentially evaluate the importance of this potential feedback as part of a model sensitivity or uncertainty analysis.

As noted above, the SLAMM model does not have a unique land-cover category for non-vegetated salt flats and these categories are grouped in with estuarine beach in this analysis. This could lead to an underestimation of accretion rates in salt flats.

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