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

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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 (R. A. 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 many coastal 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. As noted above, this analysis is a summary of model runs produced by The Nature Conservancy through grant from the Gulf of Mexico Foundation, Inc., to support the Gulf of Mexico Alliance (Clough et al. 2011).

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 et al. 1992; Park et al. 1993; Galbraith et al. 2002; National Wildlife Federation & Florida Wildlife Federation 2006; Glick et al. 2007; Craft et al. 2009). The first phase of this work was completed using SLAMM 5, while the second phase simulations were run with SLAMM 6.

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 et al. 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

Forecast simulations used 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." (Clark 2009) 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).

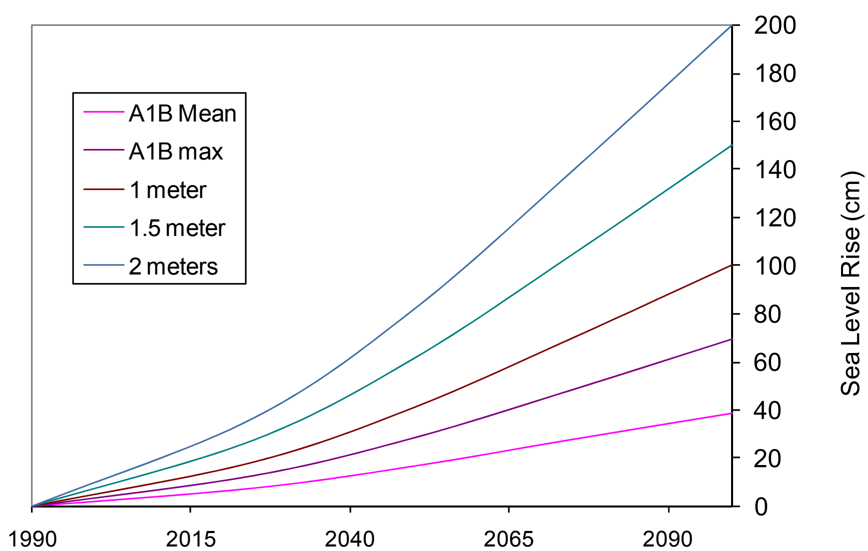


Figure 1: **Summary of SLR scenarios utilized**

Methods and Data Sources

The digital elevation map used in this simulation was derived from two LiDAR data sets:

- 2005 "Mississippi Merged" LiDAR Data (2005 LiDAR data merged with 2005 Post-Katrina LiDAR data to create a bare-earth product for flood plain mapping in coastal Mississippi). http://www.csc.noaa.gov/crs/tcm/ldartdat/metatemplate/ms2005_merge_template.html. As noted in the meta-data for this dataset, at least 95% of the positions have an error less than or equal to a root mean square error of 18.5 cm (if errors are normally distributed).
- Alabama/Louisiana/Mississippi Coastal Area Pre-Hurricane Katrina, 1/9-Arc Second LiDAR from the National Elevation Dataset (NED). NED metadata does not precisely define the flight date for these data.

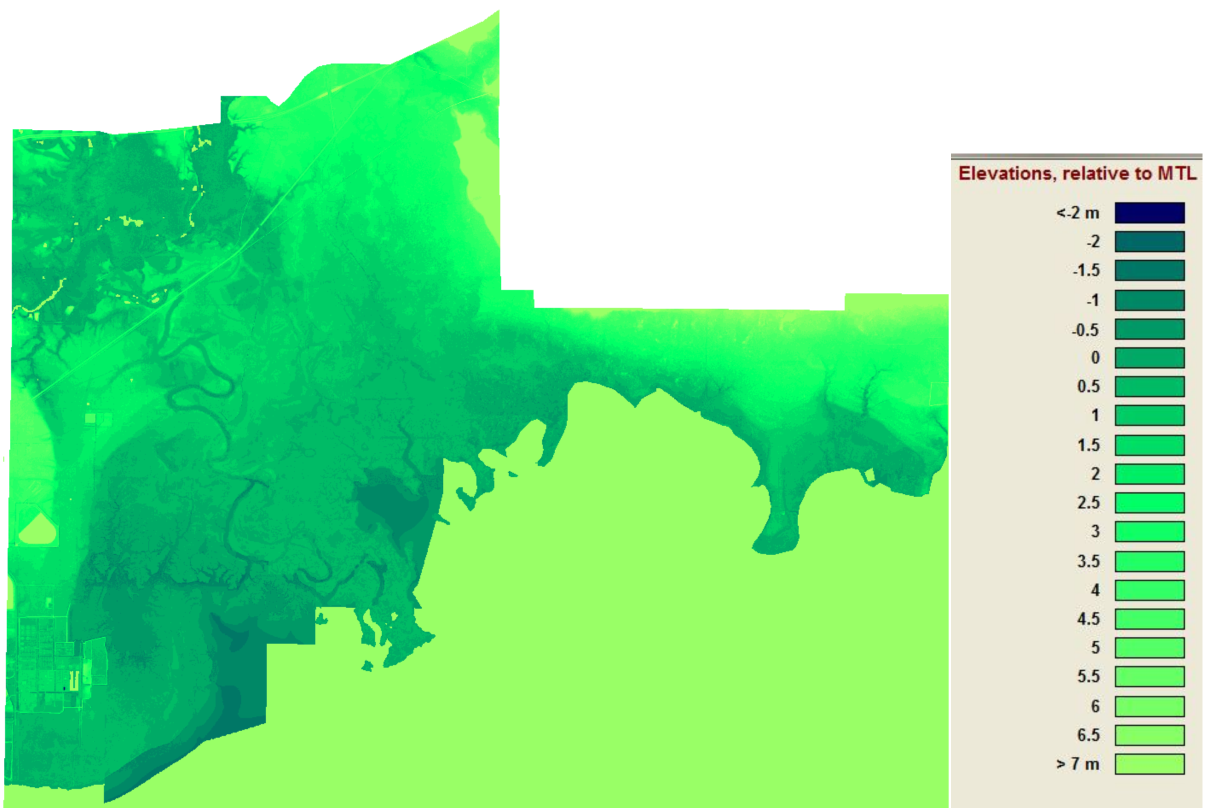


Figure 2. Shade-relief elevation map of refuge

The wetlands layer for the study area was produced by the National Wetlands Inventory and was based on a 2009 photo date (Figure 3). Converting the NWI survey into 10 meter cells indicated that the approximately 18228 acre refuge (approved acquisition boundary including water) is composed of the following categories:

		Acres	Percentage
	Swamp	6626.2	36.4%
	Irregularly Flooded Marsh	4627.9	25.4%
	Estuarine Open Water	2284.1	12.5%
	Inland Fresh Marsh	2229.5	12.2%
	Cypress Swamp	1531.1	8.4%
	Undeveloped Dry Land	495.9	2.7%
	Riverine Tidal	140.3	< 1%
	Developed Dry Land	114.8	< 1%
	Estuarine Beach	61.8	< 1%
	Tidal Fresh Marsh	59.5	< 1%
	Inland Open Water	29.5	< 1%
	Inland Shore	15.7	< 1%
	Tidal Swamp	11.8	< 1%
	Total (incl. water)	**18228.1**	100.0%

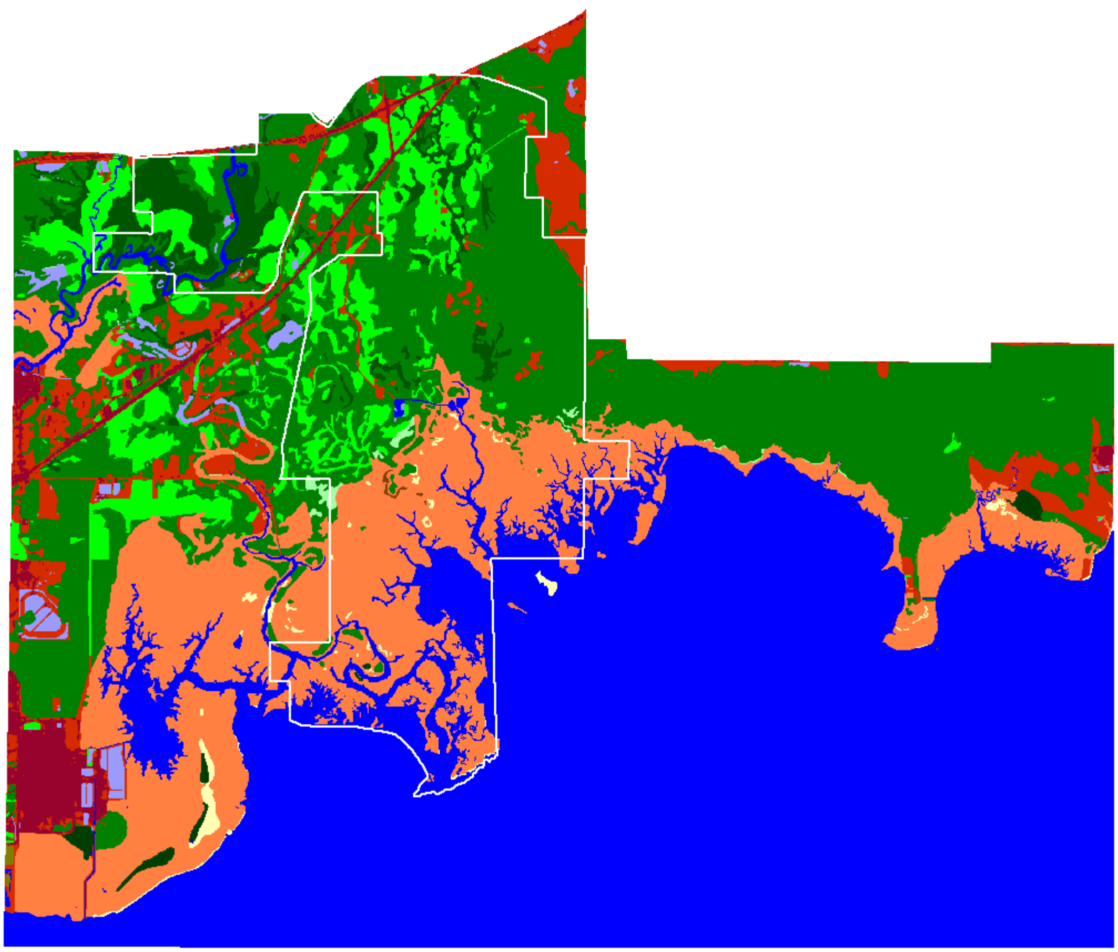


Figure 3. Portion of study area for Grand Bay NWR. White line indicates Refuge boundary

According to the National Wetland Inventory, there are no impounded or diked areas within Grand Bay NWR.

The historic trend for sea level rise was estimated at 2.98 mm/year using the value of the closest tide station (8735180, Dauphin Island, Alabama; Figure 6). This measured rate is higher than the global average for the last 100 years (approximately 1.5-2.0 mm/year) potentially reflecting local land subsidence at this site.

The great diurnal tide range at this site was estimated at 0.477 meters using local water level data. The 0.477 m value represents the average of seven years of data from four site-specific gages available from the Central Data Management Office of the National Estuarine Research Reserve System. This calculation conforms closely to the 19-year tidal epoch average from the two closest NOAA stations (8741196 Pascagoula Point MS, and 8741533 Pascagoula NOAA Lab, which average 0.470 meters).

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 local gage in Point Aux Chenes Bay. For this application, the salt boundary was defined as the elevation above which inundation is predicted less than once per thirty days. Based on this analysis SLAMM mean high water spring (MHWS) was set to 1.7 half-tide units, or 0.401 meters above MTL for this site. This matches the lower range of LiDAR data for the elevation ranges of non saline-inundated categories (e.g. dry land, inland fresh marsh, non-tidal swamp) fairly well.

Accretion rates in salt marshes were set to 3.9 mm/year, based on measurements taken by Callaway and coworkers in Biloxi, MS (1997). By averaging the accretion rates for the mid and high marsh from the Callaway and coworkers study, a value of 5 mm/yr was applied to irregularly-flooded marsh. A value for low marsh (e.g., regularly-flooded marsh) of 6.8 mm was determined through examination of Figure 5 in Callaway et al. (1997). Accretion feedbacks based on marsh elevation were not incorporated.

The MTL to NAVD88 correction was applied via input subsites, as shown in Figure 4, rather than a text raster input. This was deemed acceptable due to the low variability of the correction value.

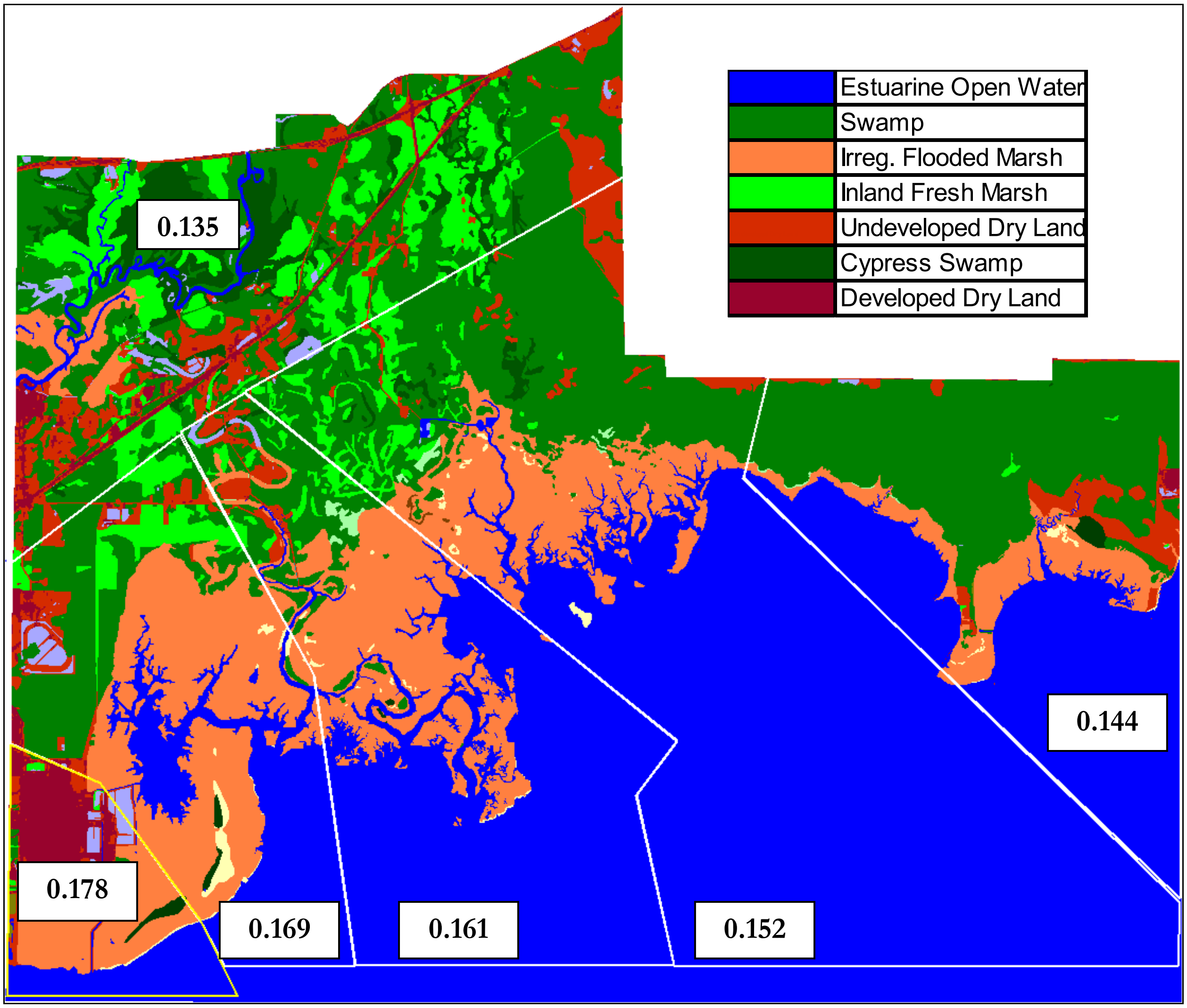


Figure 4. VDATUM corrections (m) used for model runs

Modeled U.S. Fish and Wildlife Service refuge boundaries for Mississippi and Alabama 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 10 meter by 10 meter cells. Note that the SLAMM model will track partial conversion of cells based on elevation and slope.

Table 1. Summary of SLAMM input parameters for Grand Bay NWR

Parameter	Value
NWI Photo Date	2009
DEM Date (YYYY)	2005
Direction Offshore [n,s,e,w]	South
Historic Trend (mm/yr)	2.98
MTL-NAVD88 (m)	Global = 0.135
GT Great Diurnal Tide Range (m)	0.477
Salt Elev. (m above MTL)	0.401
Marsh Erosion (horz. m /yr)	1.8
Swamp Erosion (horz. m /yr)	1
T.Flat Erosion (horz. m /yr)	0.5
Reg. Flood Marsh Accr (mm/yr)	6.8
Irreg. Flood Marsh Accr (mm/yr)	5
Tidal Fresh Marsh Accr (mm/yr)	5.9
Beach Sed. Rate (mm/yr)	0.5
Freq. Overwash (years)	25
Use Elev Pre-processor [True,False] -	False

Results

This simulation of the Grand Bay NWR was completed using a SLAMM model that was calibrated to historical data for a previous project (Clough et al. 2011). This calibrated model predicts that Grand Bay NWR will be severely impacted depending on the SLR scenario and wetland class. Table 5 presents the predicted loss of each wetland category by 2100 for each of the five SLR scenarios examined. At 1 meter of SLR by 2100, what some scientists consider to be the "most likely" scenario, 88% of refuge irregularly-flooded marsh and 31% of swamp is predicted to be lost. These wetland types comprise the majority of the refuge and are predicted to be lost at greater rates in the higher SLR scenarios.

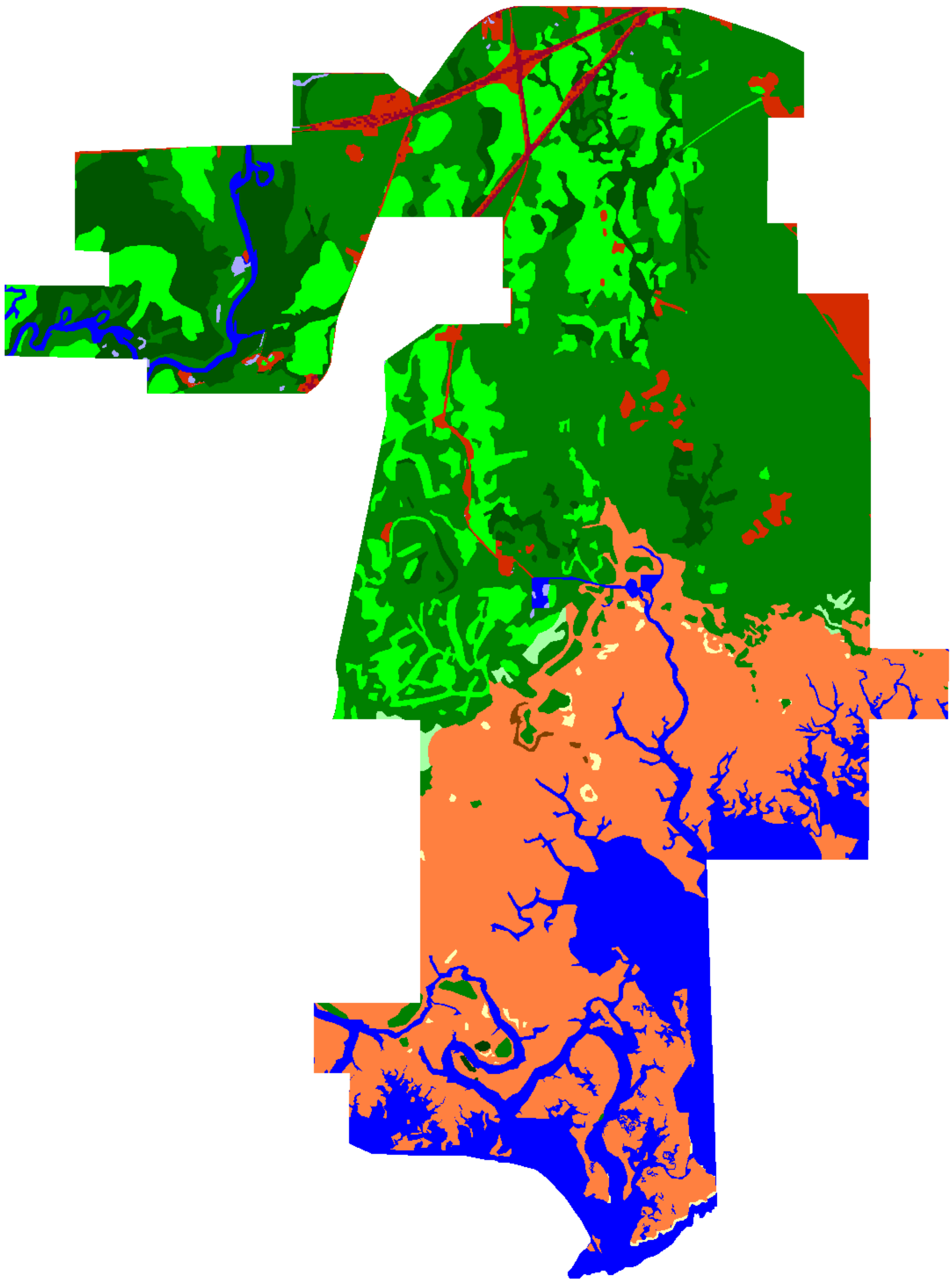
Table 2. Predicted Loss Rates of Land Categories by 2100 Given Simulated Scenarios of Eustatic Sea Level Rise

SLR by 2100 (m)	0.39	0.69	1	1.5	2
Swamp	11%	24%	38%	52%	61%
Irregularly Flooded Marsh	5%	21%	88%	99%	100%
Inland Fresh Marsh	1%	11%	22%	36%	46%
Undeveloped Dry Land	11%	14%	19%	34%	42%
Cypress Swamp	58%	63%	70%	73%	76%
Developed Dry Land	0%	0%	1%	1%	3%
Estuarine Beach	22%	83%	99%	100%	100%
Tidal Swamp	83%	98%	99%	99%	100%
Riverine Tidal	46%	51%	55%	58%	58%
Tidal Fresh Marsh	0%	8%	37%	99%	100%
Inland Shore	15%	69%	100%	100%	100%

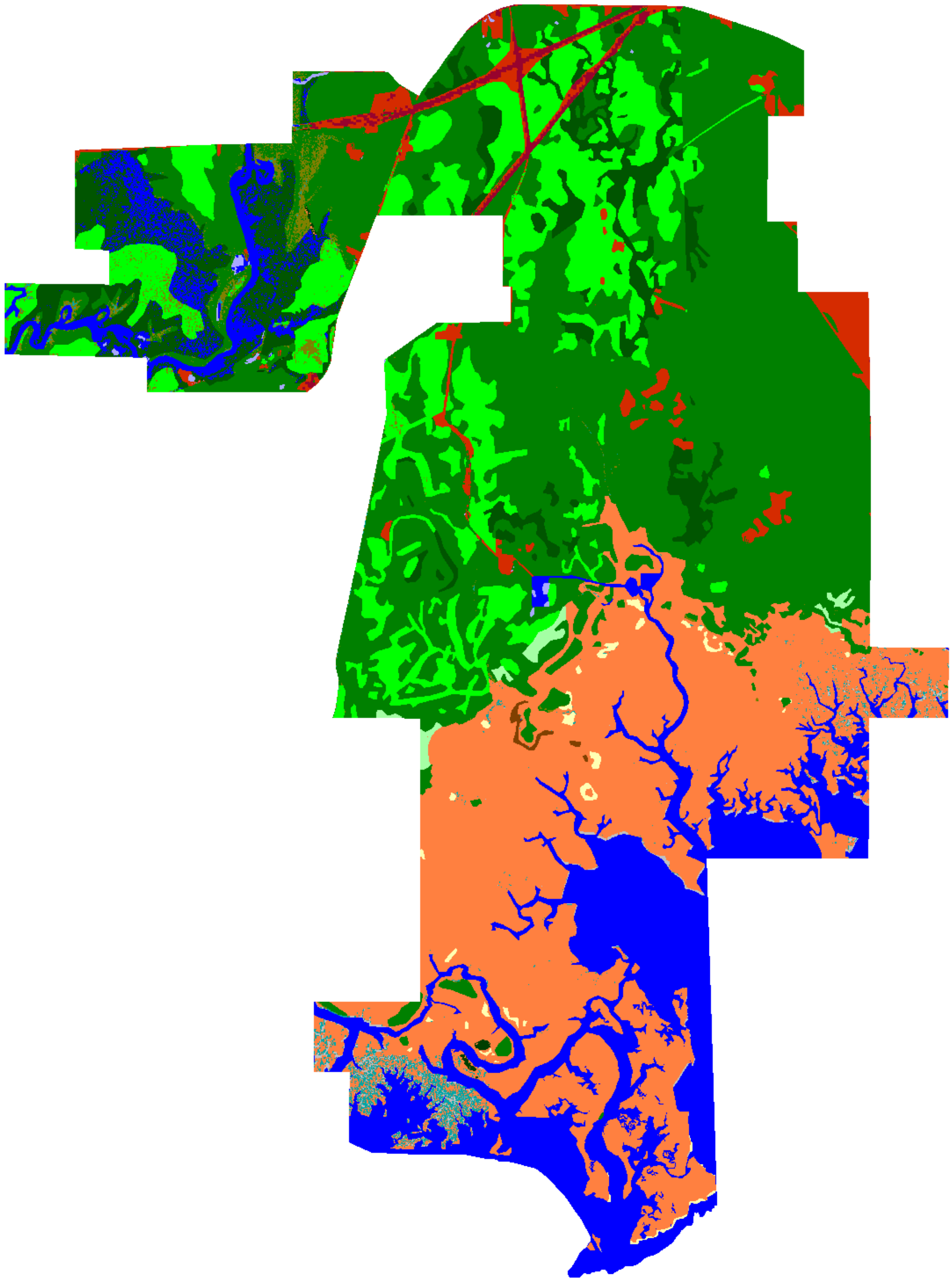
Grand Bay NWR
IPCC Scenario A1B-Mean, 0.39 M SLR Eustatic by 2100

Results in Acres

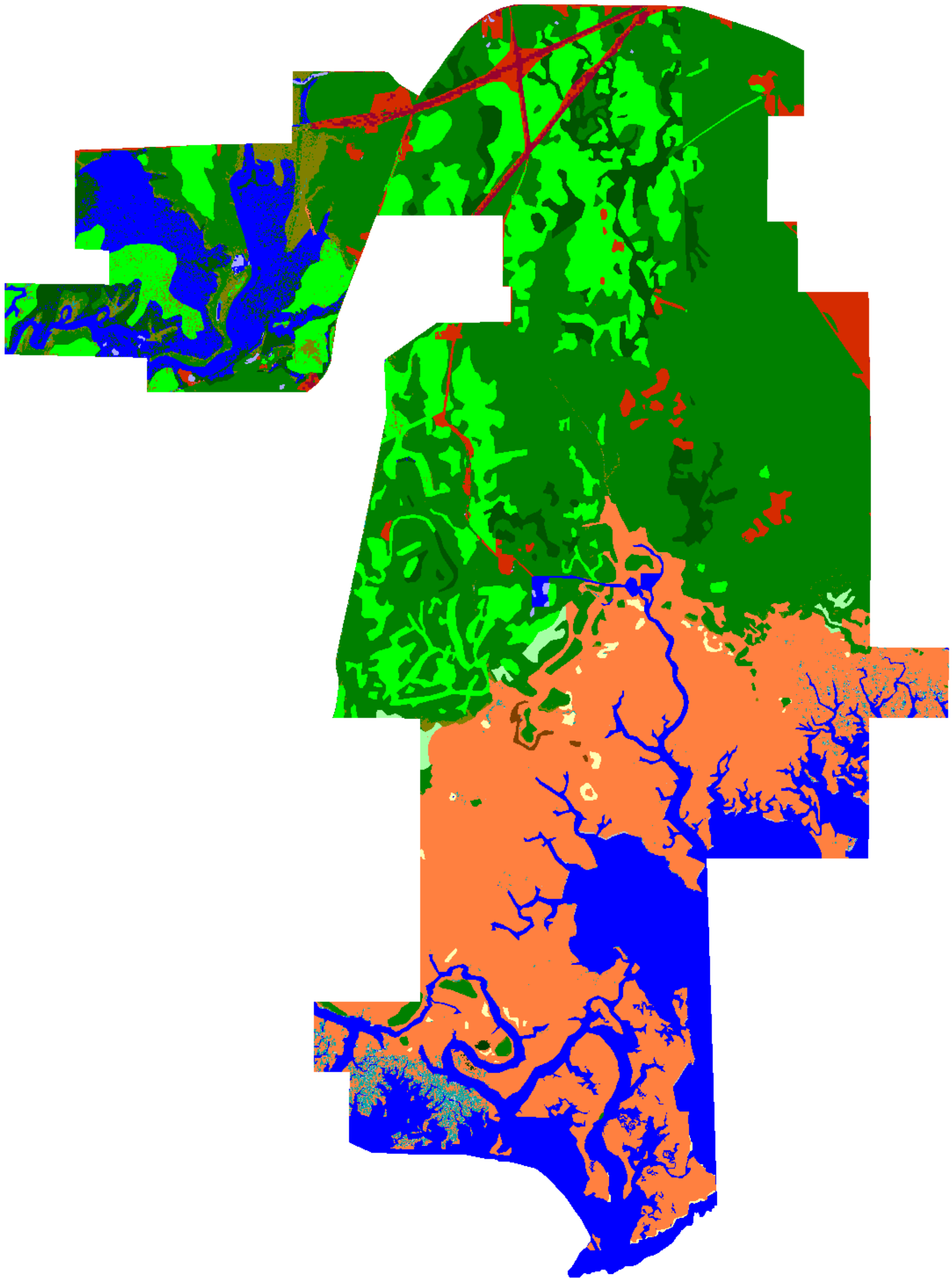
		Initial	2009	2025	2050	2075	2100
	Swamp	6626.2	6589.2	6547.8	6419.7	6245.0	5926.9
	Irregularly Flooded Marsh	4627.9	4438.7	4422.0	4425.7	4423.2	4402.1
	Estuarine Open Water	2284.1	2443.3	2624.0	3055.2	3269.9	3346.4
	Inland Fresh Marsh	2229.5	2190.7	2191.2	2193.7	2198.2	2203.5
	Cypress Swamp	1531.1	1380.1	1241.9	868.8	704.5	648.3
	Undeveloped Dry Land	495.9	471.8	463.1	456.8	450.4	442.0
	Riverine Tidal	140.3	132.3	107.6	93.5	81.7	75.8
	Developed Dry Land	114.8	114.7	114.7	114.6	114.4	114.3
	Estuarine Beach	61.8	61.8	60.1	57.5	54.6	48.4
	Tidal Fresh Marsh	59.5	59.4	59.4	59.4	59.4	59.4
	Inland Open Water	29.5	29.5	23.0	21.0	18.3	17.2
	Inland Shore	15.7	15.7	15.7	15.7	15.5	13.5
	Tidal Swamp	11.8	11.1	10.3	6.3	3.7	2.0
	Tidal Flat	0.0	0.0	73.3	35.5	8.3	18.0
	Regularly Flooded Marsh	0.0	190.1	137.4	136.0	137.6	147.8
	Transitional Salt Marsh	0.0	99.8	136.8	268.6	443.4	762.5
	Total (incl. water)	**18228.1**	**18228.1**	**18228.1**	**18228.1**	**18228.1**	**18228.1**



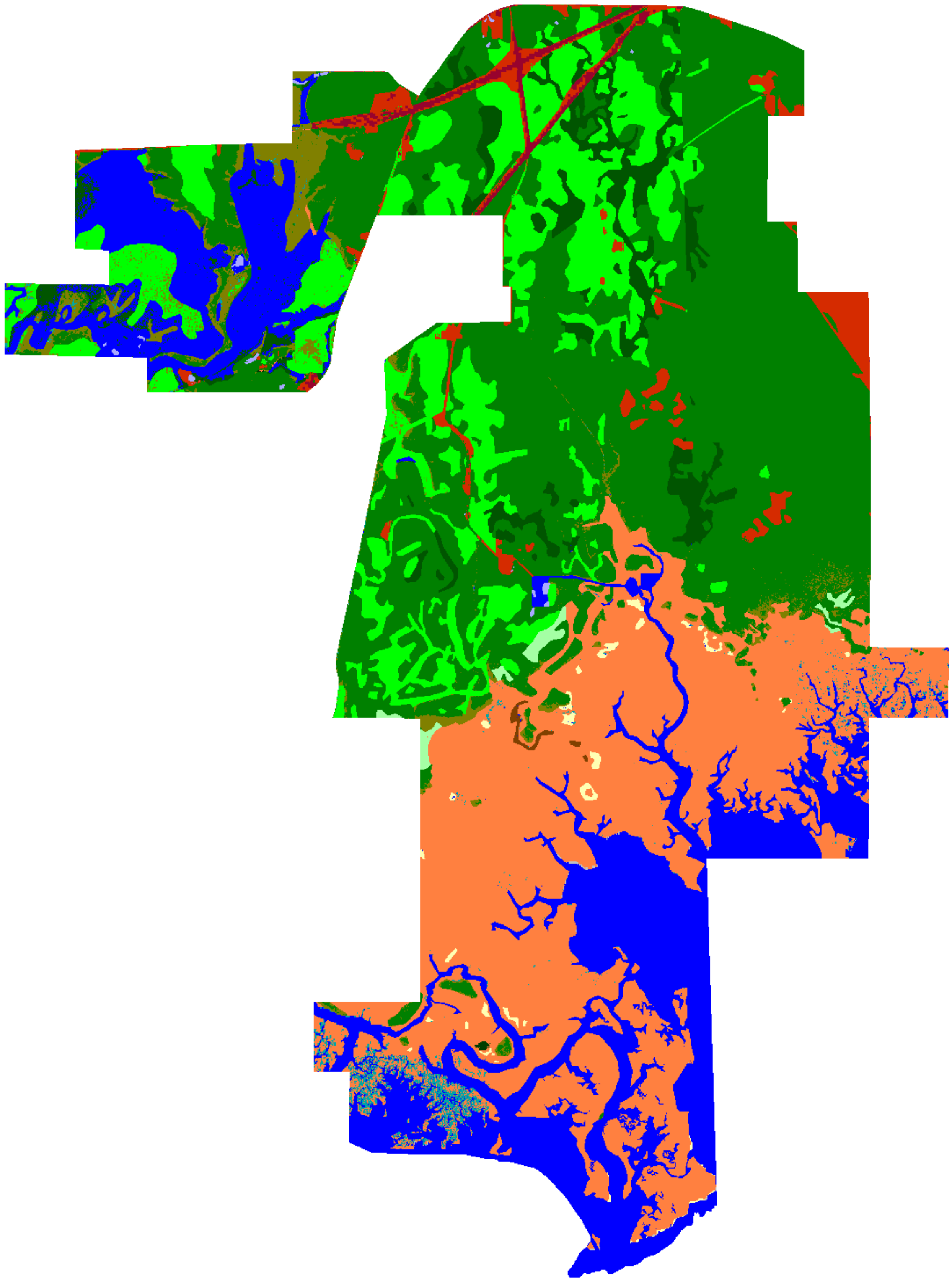
Grand Bay NWR, Initial Condition



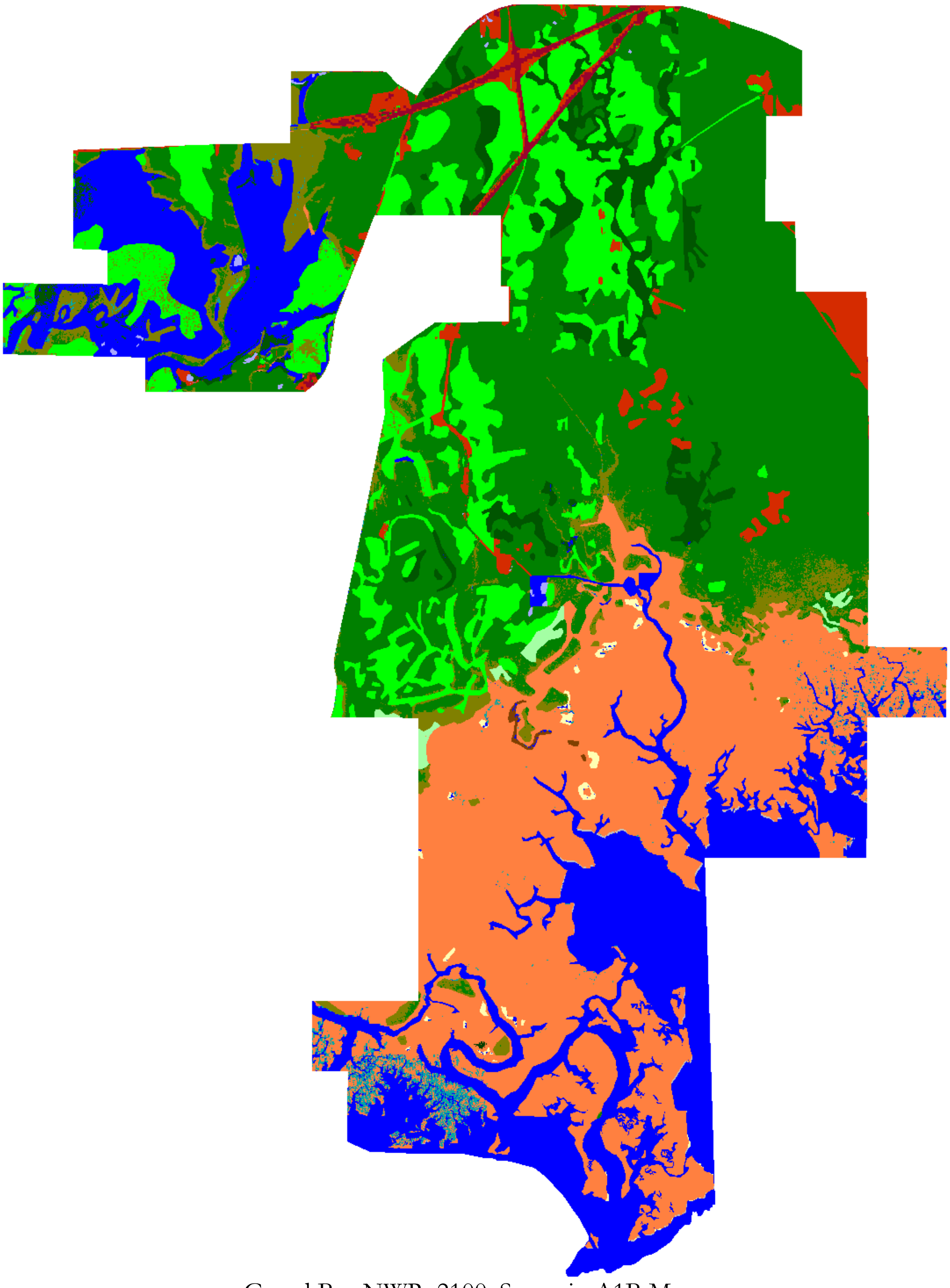
Grand Bay NWR, 2025, Scenario A1B Mean



Grand Bay NWR, 2050, Scenario A1B Mean



Grand Bay NWR, 2075, Scenario A1B Mean

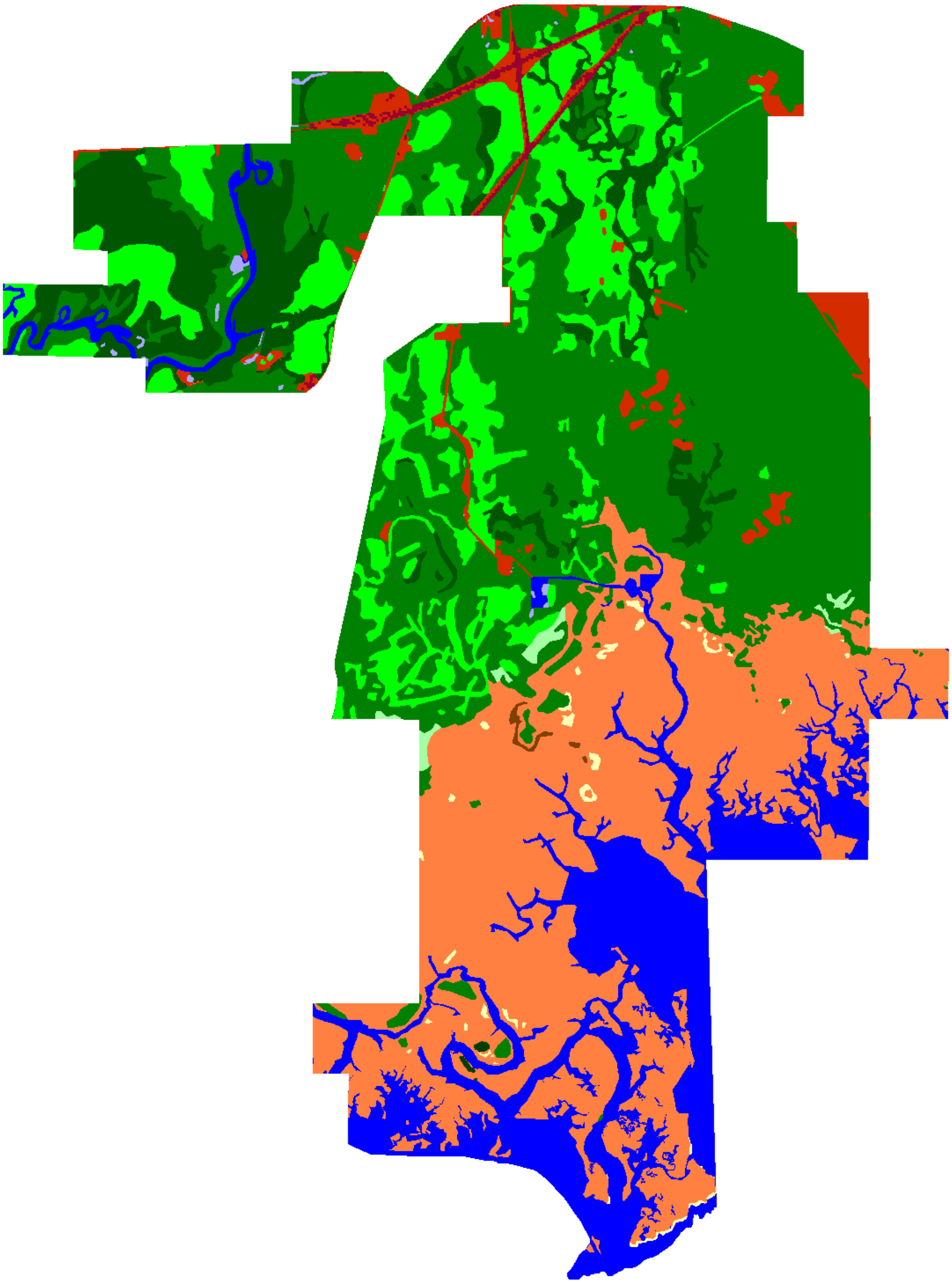


Grand Bay NWR, 2100, Scenario A1B Mean

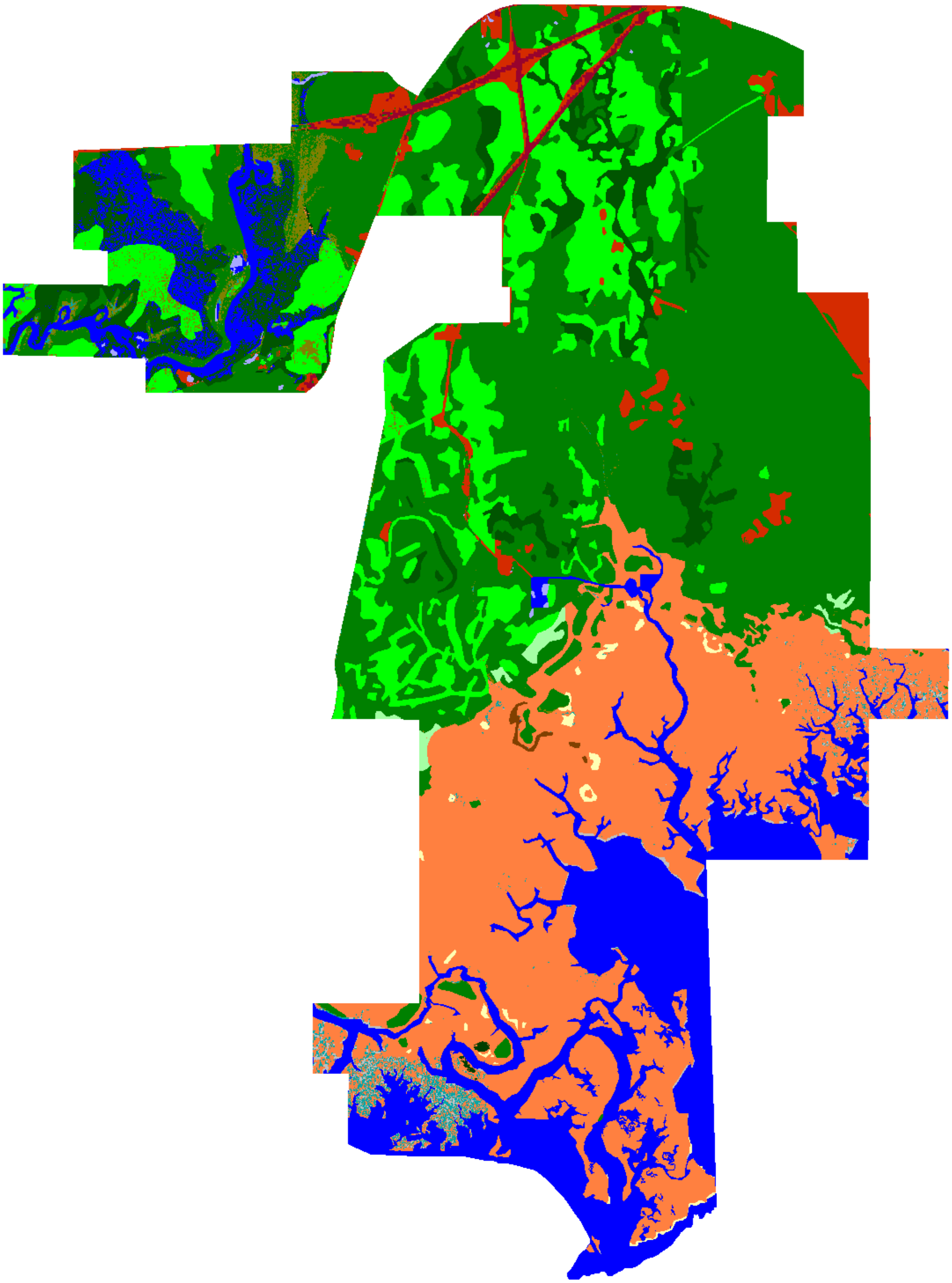
Grand Bay NWR
IPCC Scenario A1B-Max, 0.69 M SLR Eustatic by 2100

Results in Acres

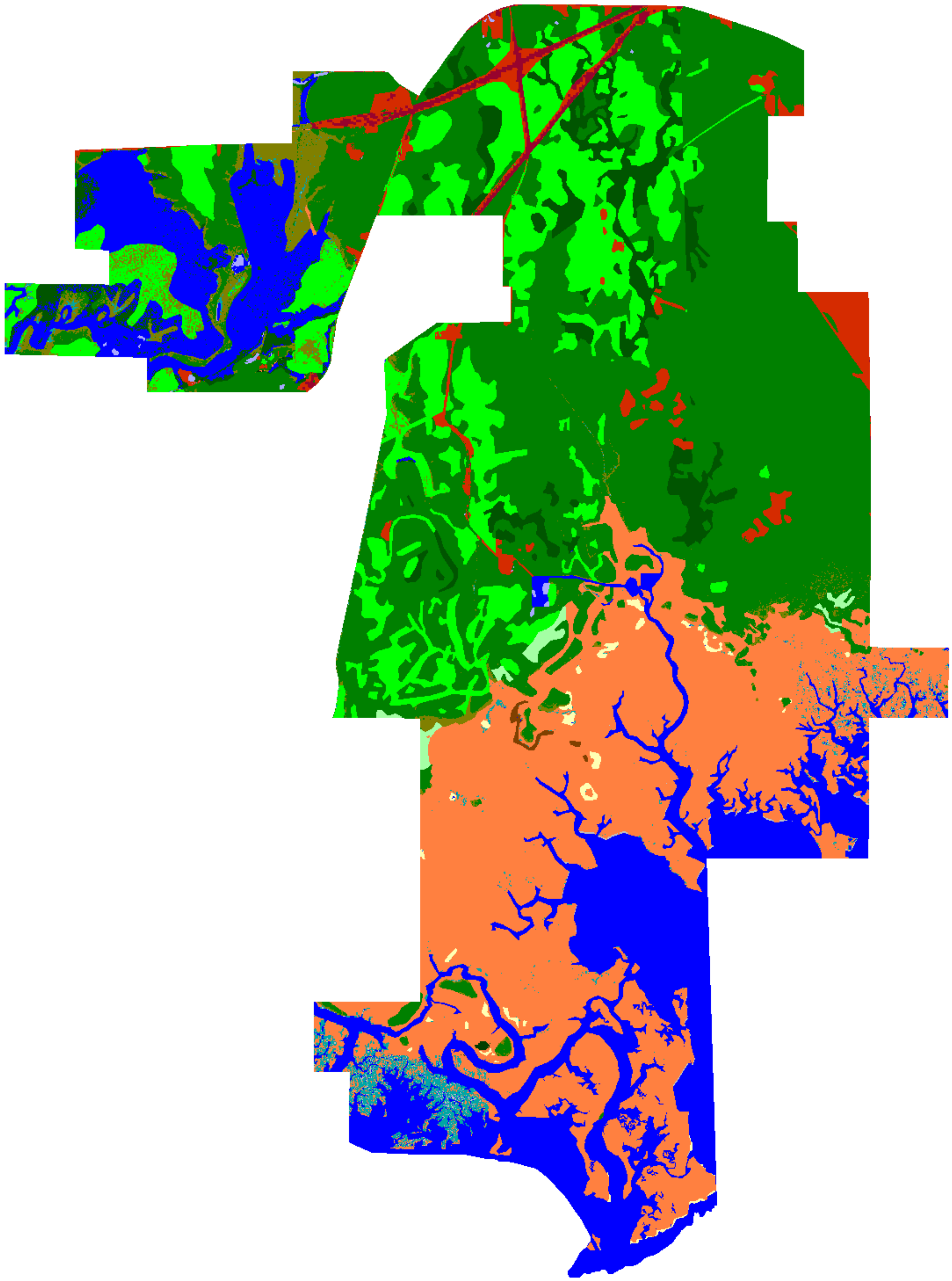
		Initial	2009	2025	2050	2075	2100
	Swamp	6626.2	6589.2	6521.7	6314.5	5781.4	5015.8
	Irregularly Flooded Marsh	4627.9	4438.7	4422.7	4352.3	4160.7	3648.3
	Estuarine Open Water	2284.1	2443.3	2715.9	3206.1	3386.3	3580.1
	Inland Fresh Marsh	2229.5	2190.7	2188.7	2161.9	2059.9	1986.9
	Cypress Swamp	1531.1	1380.1	1152.7	742.2	636.2	564.0
	Undeveloped Dry Land	495.9	471.8	462.9	455.7	447.5	424.0
	Riverine Tidal	140.3	132.3	105.7	87.3	75.6	68.2
	Developed Dry Land	114.8	114.7	114.7	114.5	114.3	114.2
	Estuarine Beach	61.8	61.8	60.1	57.2	44.8	10.7
	Tidal Fresh Marsh	59.5	59.4	59.4	59.2	56.5	54.7
	Inland Open Water	29.5	29.5	22.7	19.6	17.1	13.4
	Inland Shore	15.7	15.7	15.7	15.6	12.3	4.8
	Tidal Swamp	11.8	11.1	9.6	4.0	0.6	0.2
	Tidal Flat	0.0	0.0	81.6	36.9	44.3	184.0
	Regularly Flooded Marsh	0.0	190.1	131.5	209.2	639.3	1492.6
	Transitional Salt Marsh	0.0	99.8	162.5	391.8	751.3	1066.0
	Total (incl. water)	**18228.1**	**18228.1**	**18228.1**	**18228.1**	**18228.1**	**18228.1**



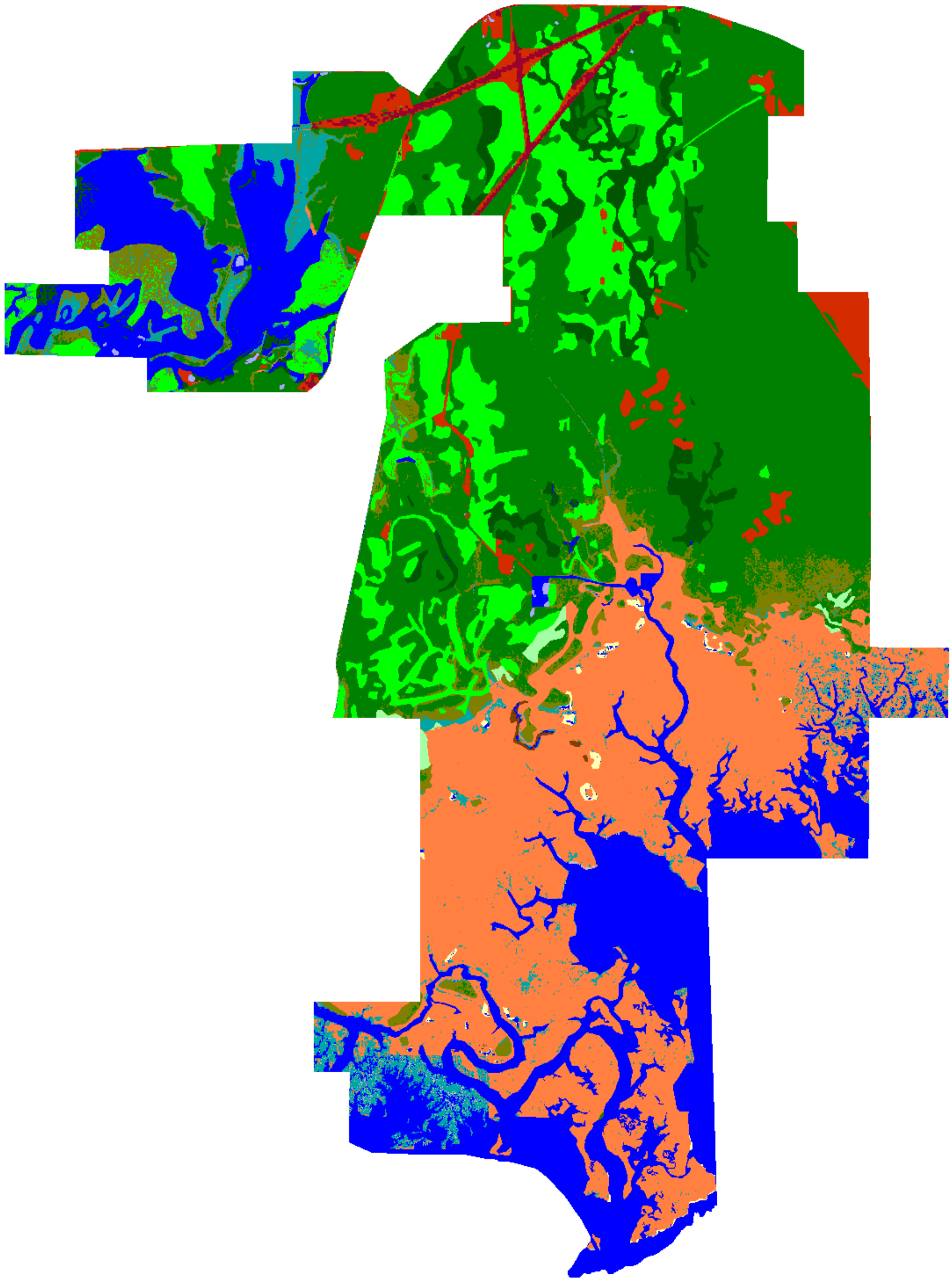
Grand Bay NWR, Initial Condition



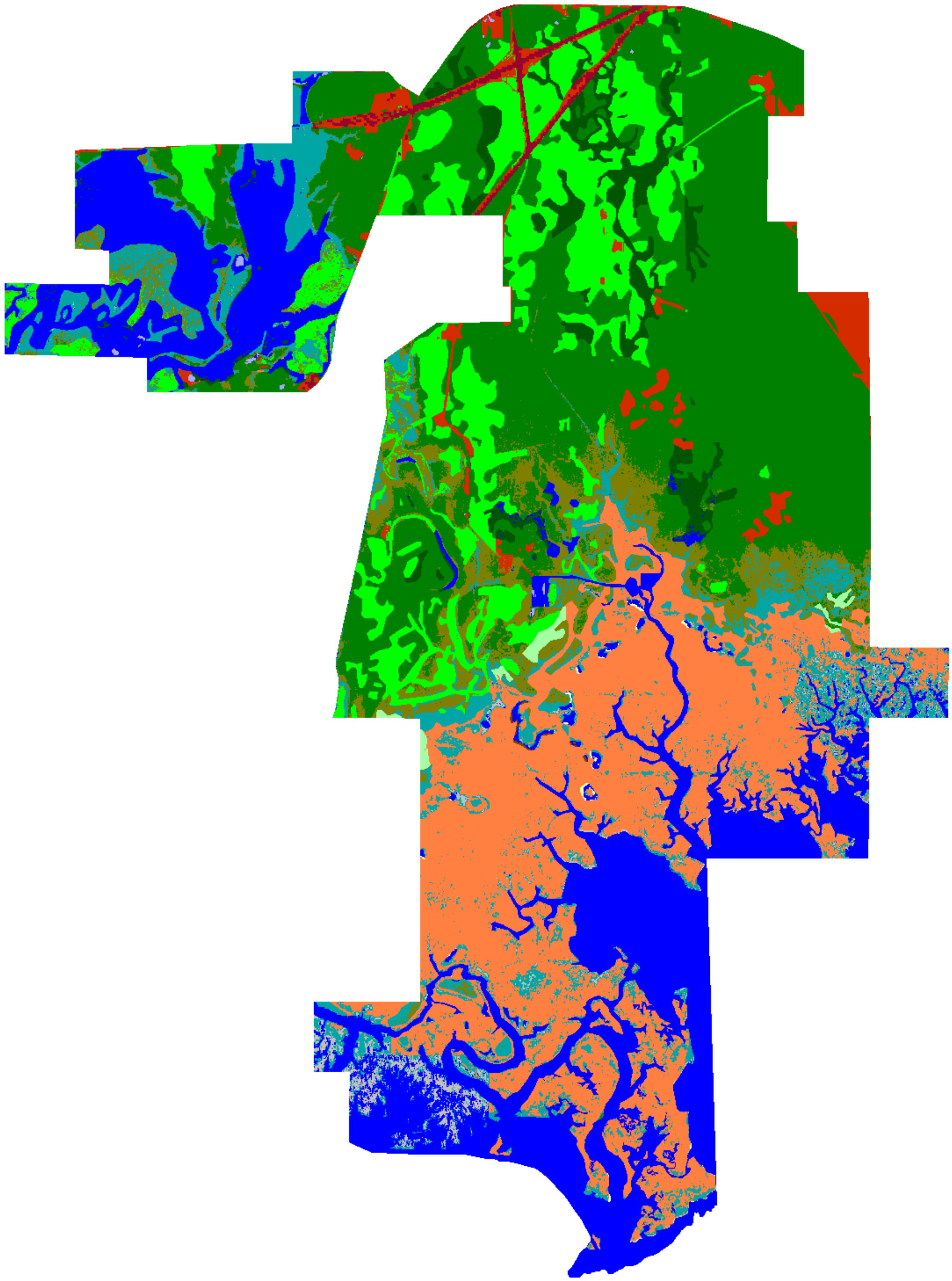
Grand Bay NWR, 2025, Scenario A1B Maximum



Grand Bay NWR, 2050, Scenario A1B Maximum



Grand Bay NWR, 2075, Scenario A1B Maximum

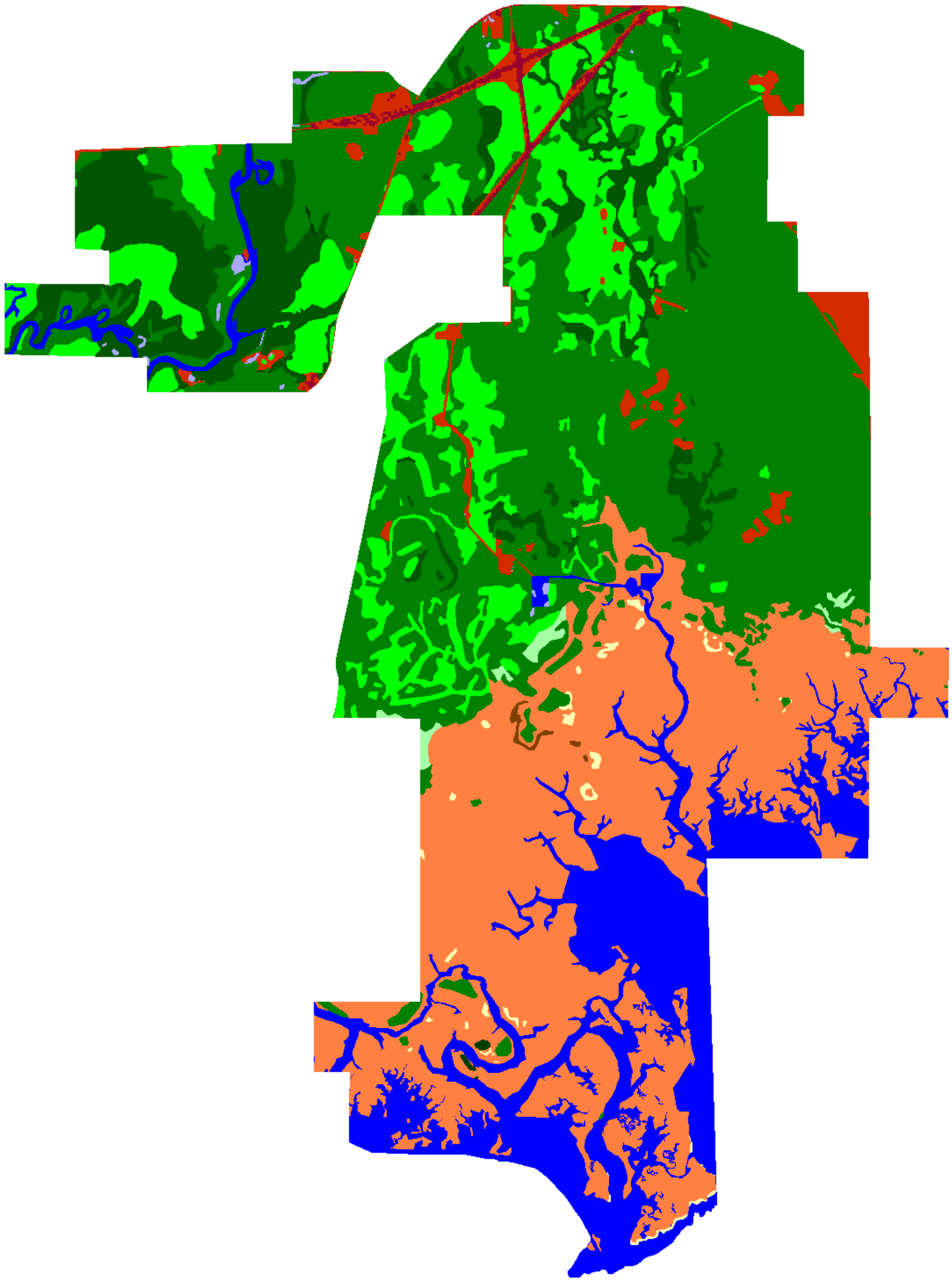


Grand Bay NWR, 2100, Scenario A1B Maximum

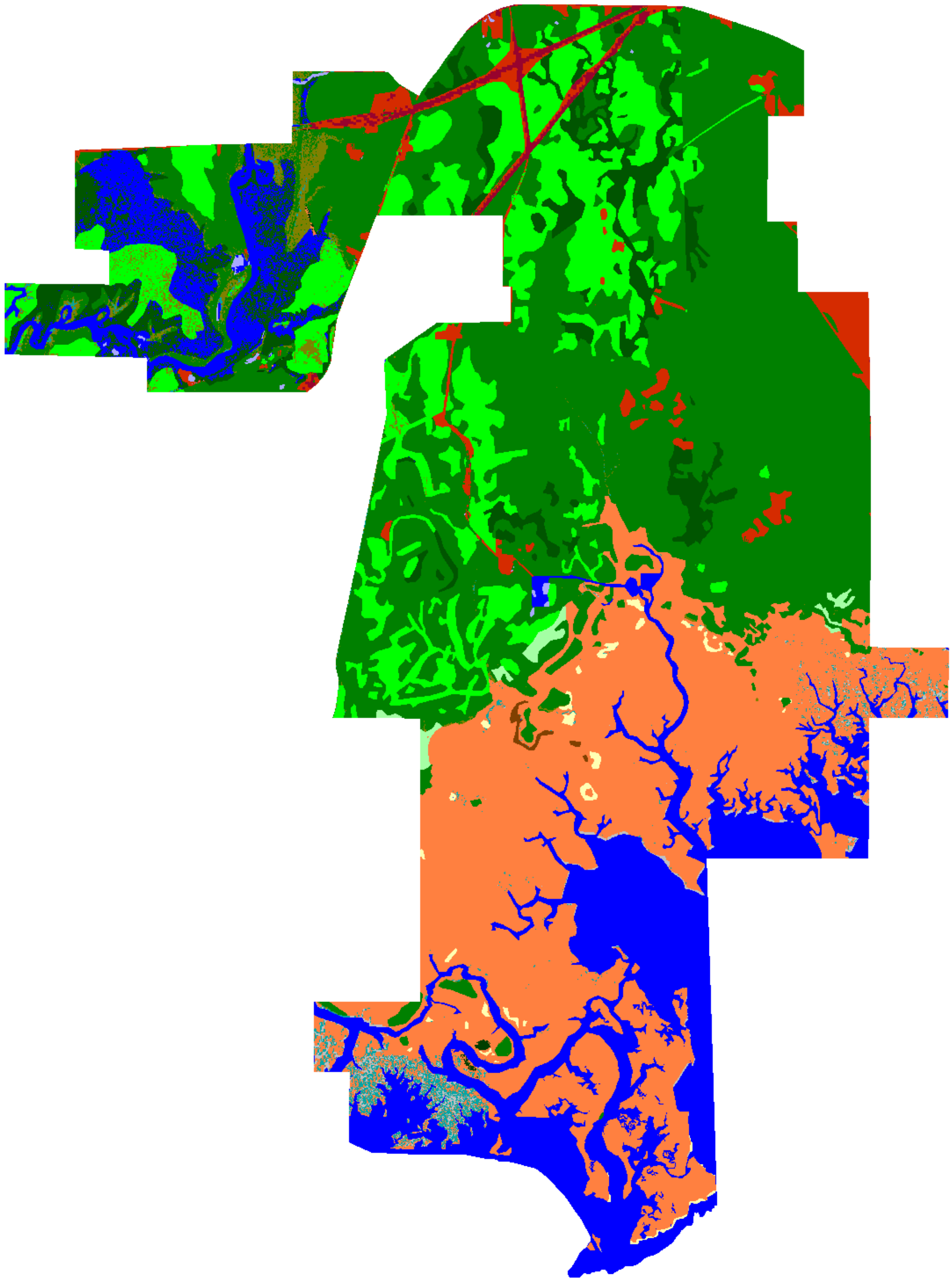
Grand Bay NWR
1 Meter Eustatic SLR by 2100

Results in Acres

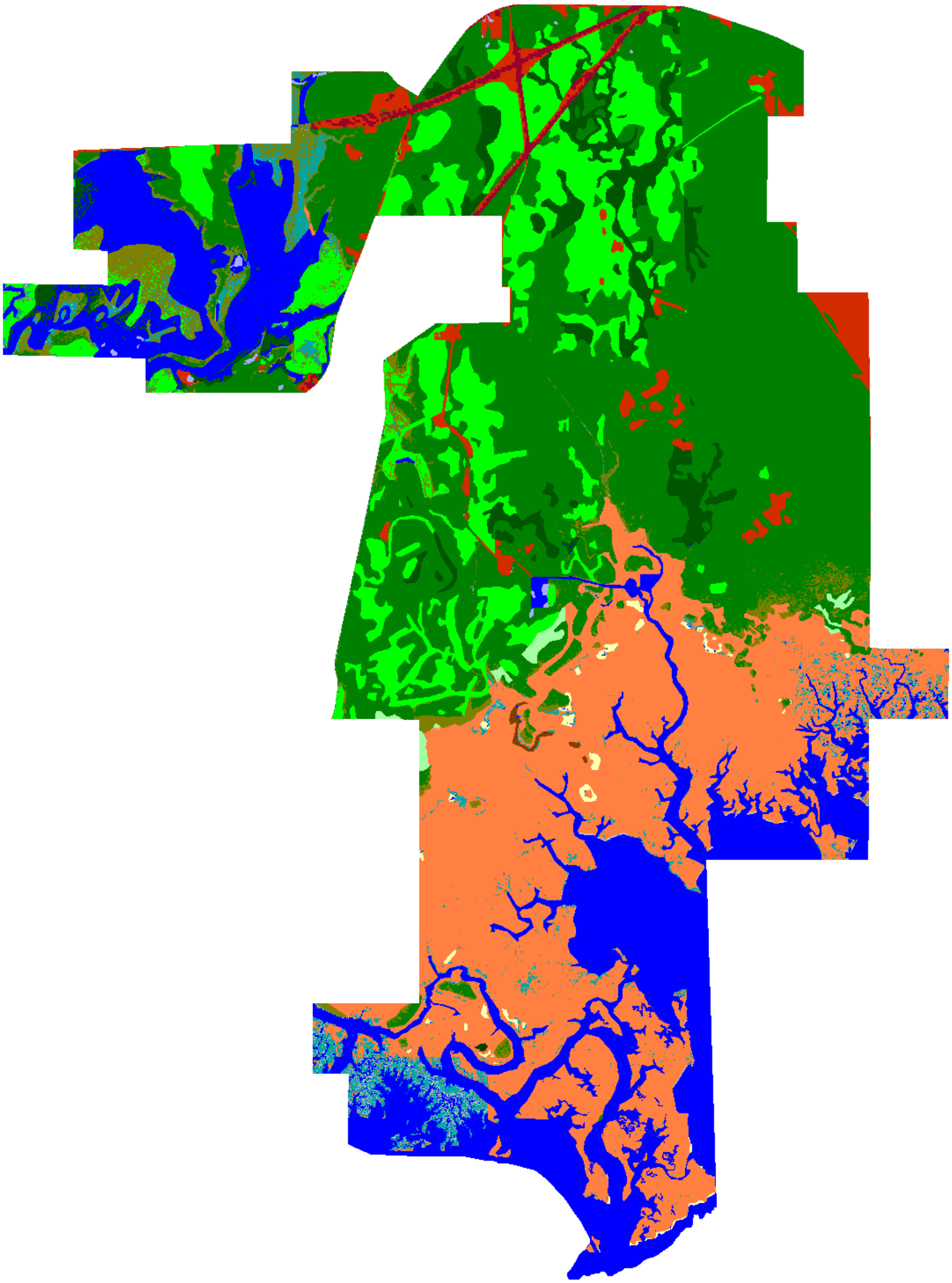
		Initial	2009	2025	2050	2075	2100
	Swamp	6626.2	6589.2	6493.1	6153.3	5175.4	4093.1
	Irregularly Flooded Marsh	4627.9	4438.7	4394.8	4194.0	3141.6	541.5
	Estuarine Open Water	2284.1	2443.3	2814.1	3310.3	3586.6	4106.4
	Inland Fresh Marsh	2229.5	2190.7	2176.4	2047.4	1917.8	1749.7
	Cypress Swamp	1531.1	1380.1	1057.6	678.2	584.3	465.1
	Undeveloped Dry Land	495.9	471.8	462.6	454.8	440.2	401.3
	Riverine Tidal	140.3	132.3	103.6	83.5	69.4	63.1
	Developed Dry Land	114.8	114.7	114.6	114.4	114.3	114.1
	Estuarine Beach	61.8	61.8	60.1	56.0	17.2	0.9
	Tidal Fresh Marsh	59.5	59.4	59.3	56.1	52.8	37.3
	Inland Open Water	29.5	29.5	22.2	18.7	15.3	9.0
	Inland Shore	15.7	15.7	15.7	15.3	6.3	0.1
	Tidal Swamp	11.8	11.1	8.5	2.8	0.3	0.1
	Tidal Flat	0.0	0.0	92.8	75.7	258.5	1495.0
	Regularly Flooded Marsh	0.0	190.1	152.8	427.0	1725.3	3861.8
	Transitional Salt Marsh	0.0	99.8	199.8	540.6	1122.8	1289.5
	Total (incl. water)	**18228.1**	**18228.1**	**18228.1**	**18228.1**	**18228.1**	**18228.1**



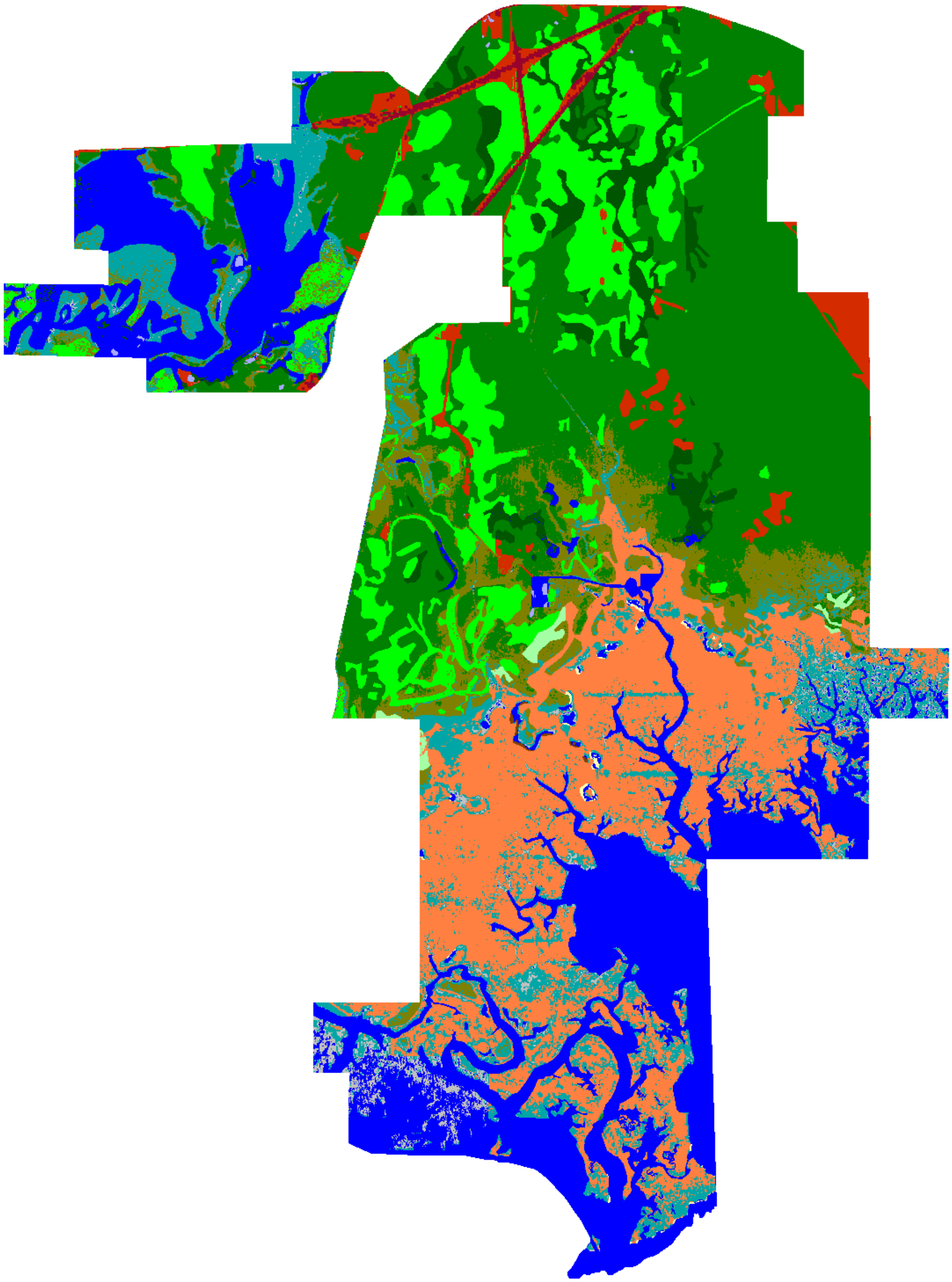
Grand Bay NWR, Initial Condition



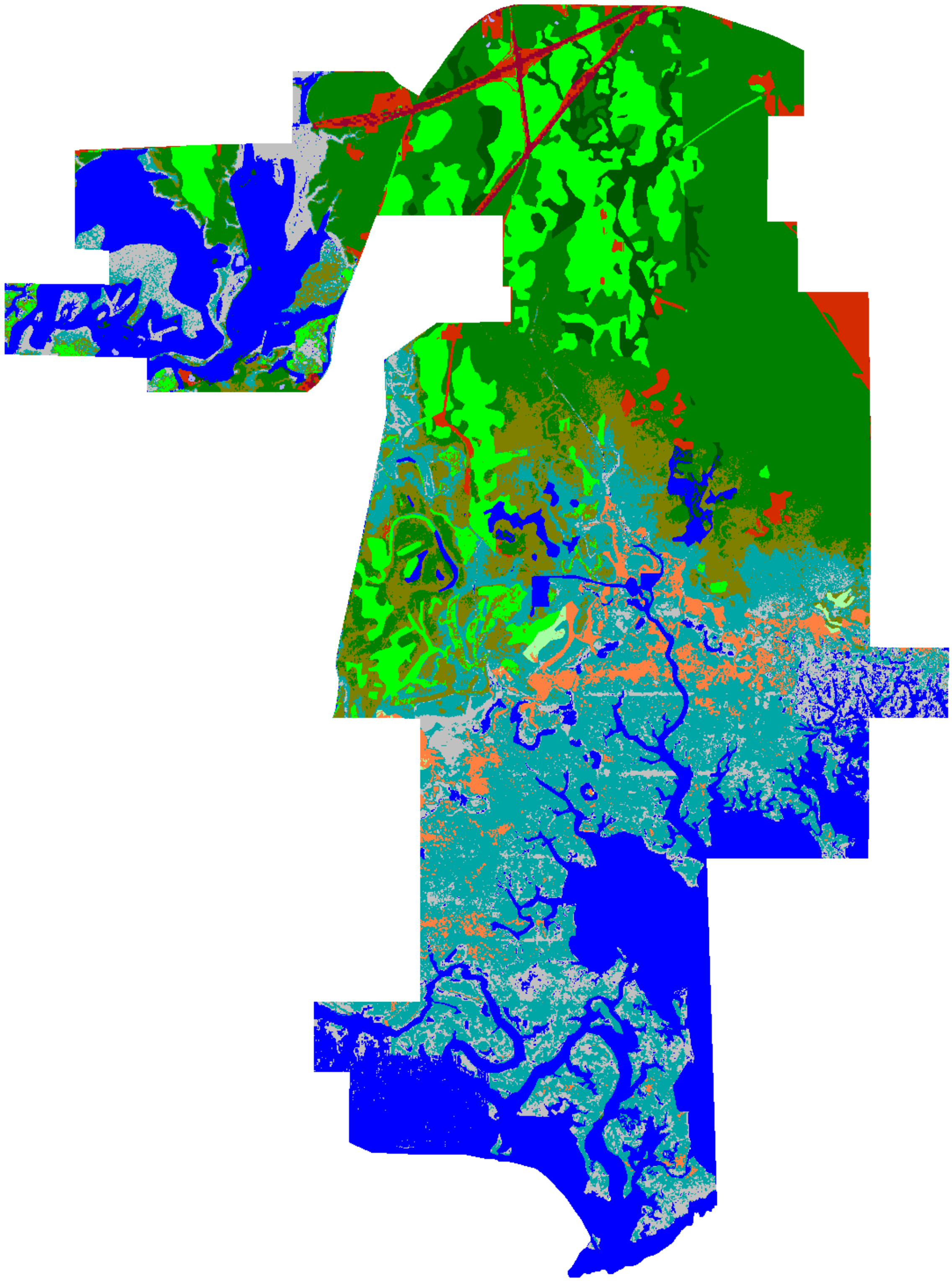
Grand Bay NWR, 2025, 1 Meter



Grand Bay NWR, 2050, 1 Meter



Grand Bay NWR, 2075, 1 Meter

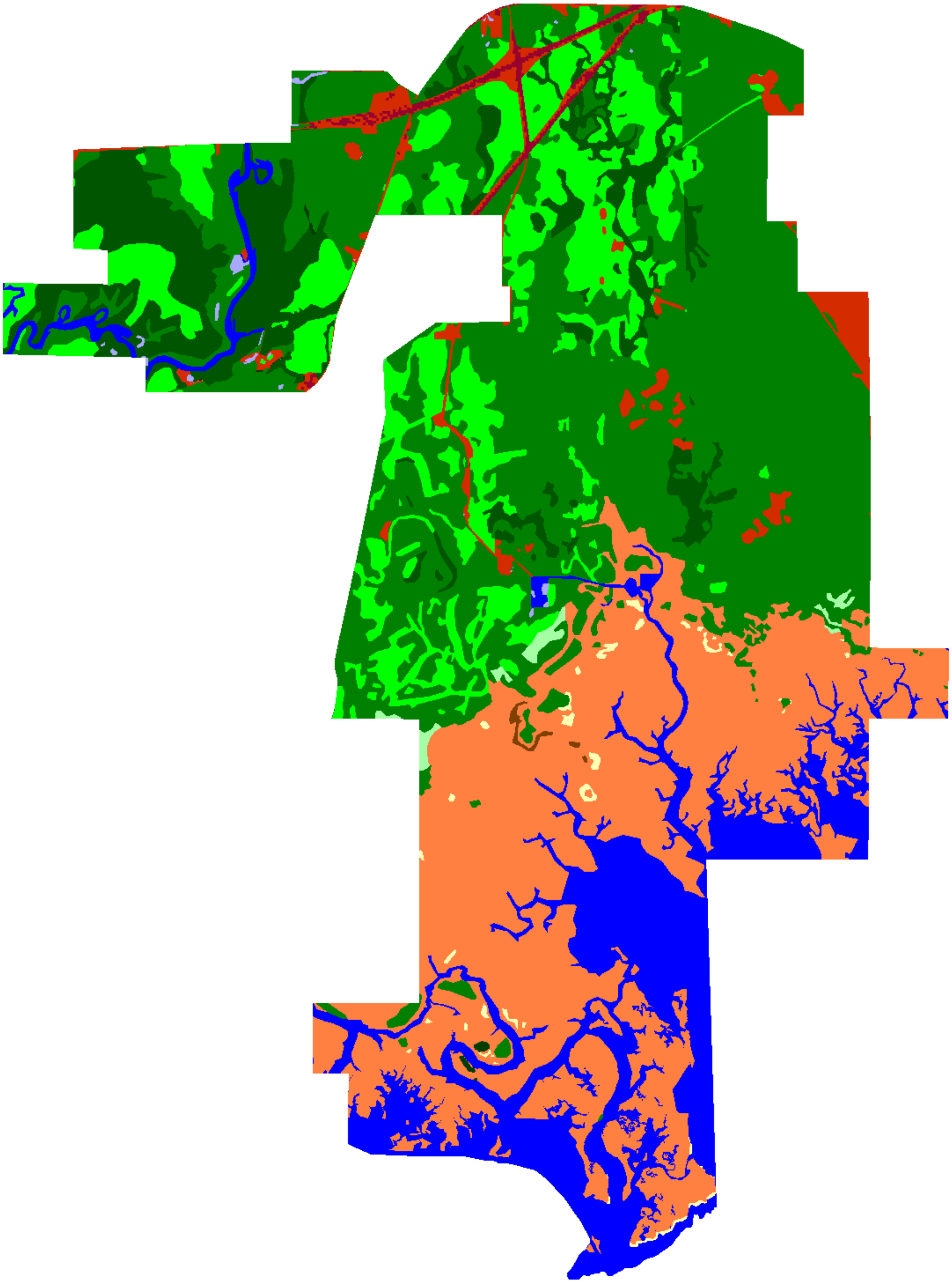


Grand Bay NWR, 2100, 1 Meter

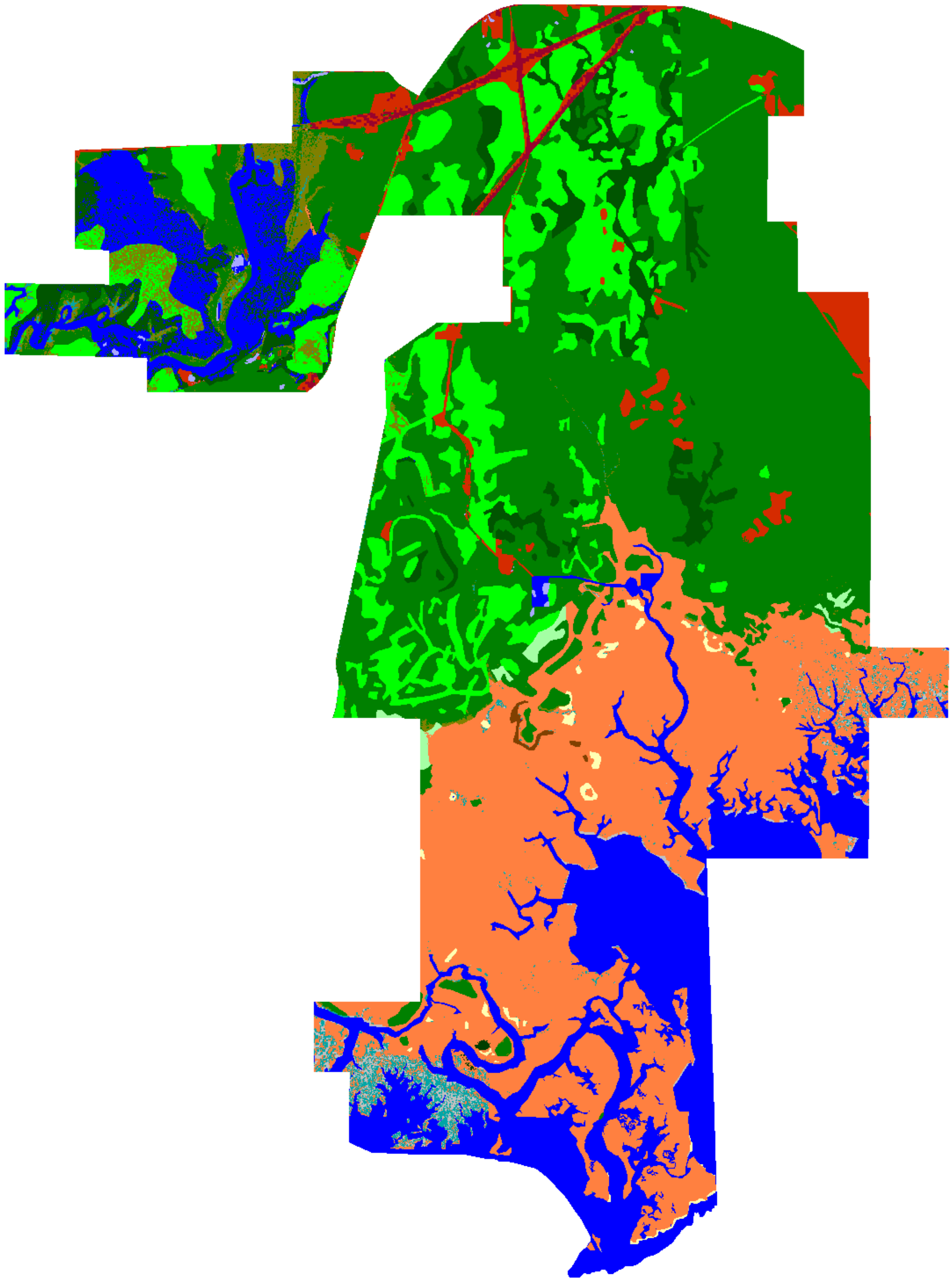
Grand Bay NWR
1.5 Meters Eustatic SLR by 2100

Results in Acres

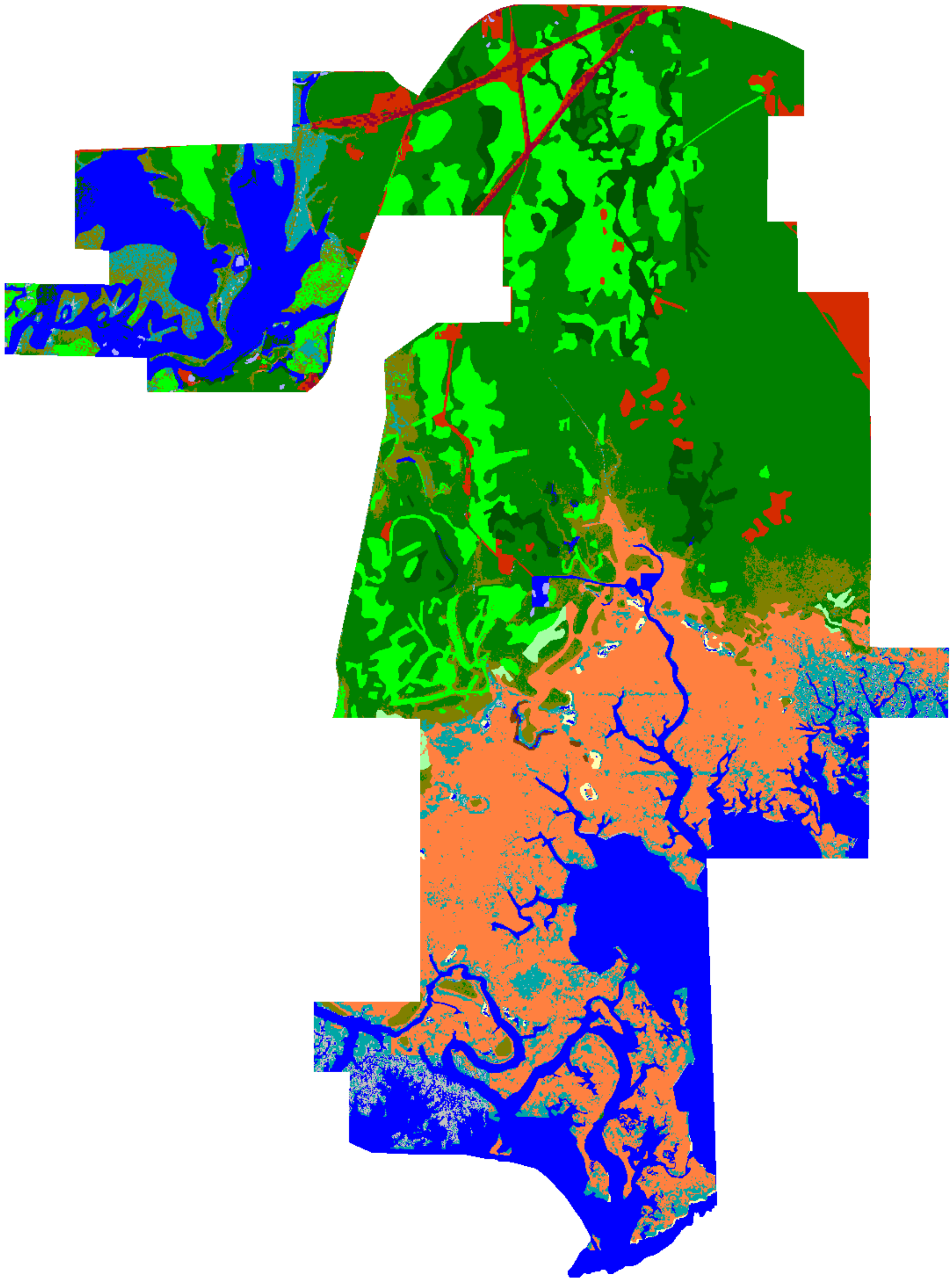
		Initial	2009	2025	2050	2075	2100
	Swamp	6626.2	6589.2	6445.0	5697.8	4183.1	3160.3
	Irregularly Flooded Marsh	4627.9	4438.7	4344.2	3495.9	205.1	27.9
	Estuarine Open Water	2284.1	2443.3	2951.3	3414.9	3907.0	5180.4
	Inland Fresh Marsh	2229.5	2190.7	2120.2	1924.6	1638.4	1420.4
	Cypress Swamp	1531.1	1380.1	925.2	630.0	471.7	415.5
	Undeveloped Dry Land	495.9	471.8	461.9	452.9	414.0	328.7
	Riverine Tidal	140.3	132.3	100.6	78.3	64.8	59.3
	Developed Dry Land	114.8	114.7	114.6	114.3	114.1	113.5
	Estuarine Beach	61.8	61.8	60.0	43.5	1.3	0.1
	Tidal Fresh Marsh	59.5	59.4	58.5	53.4	23.3	0.9
	Inland Open Water	29.5	29.5	21.8	17.3	11.1	7.6
	Inland Shore	15.7	15.7	15.7	11.6	0.1	0.0
	Tidal Swamp	11.8	11.1	6.5	0.4	0.1	0.1
	Tidal Flat	0.0	0.0	117.1	177.3	1082.7	4147.0
	Regularly Flooded Marsh	0.0	190.1	189.9	1163.7	4271.1	2039.8
	Transitional Salt Marsh	0.0	99.8	295.5	952.2	1840.1	1326.6
	Total (incl. water)	**18228.1**	**18228.1**	**18228.1**	**18228.1**	**18228.1**	**18228.1**



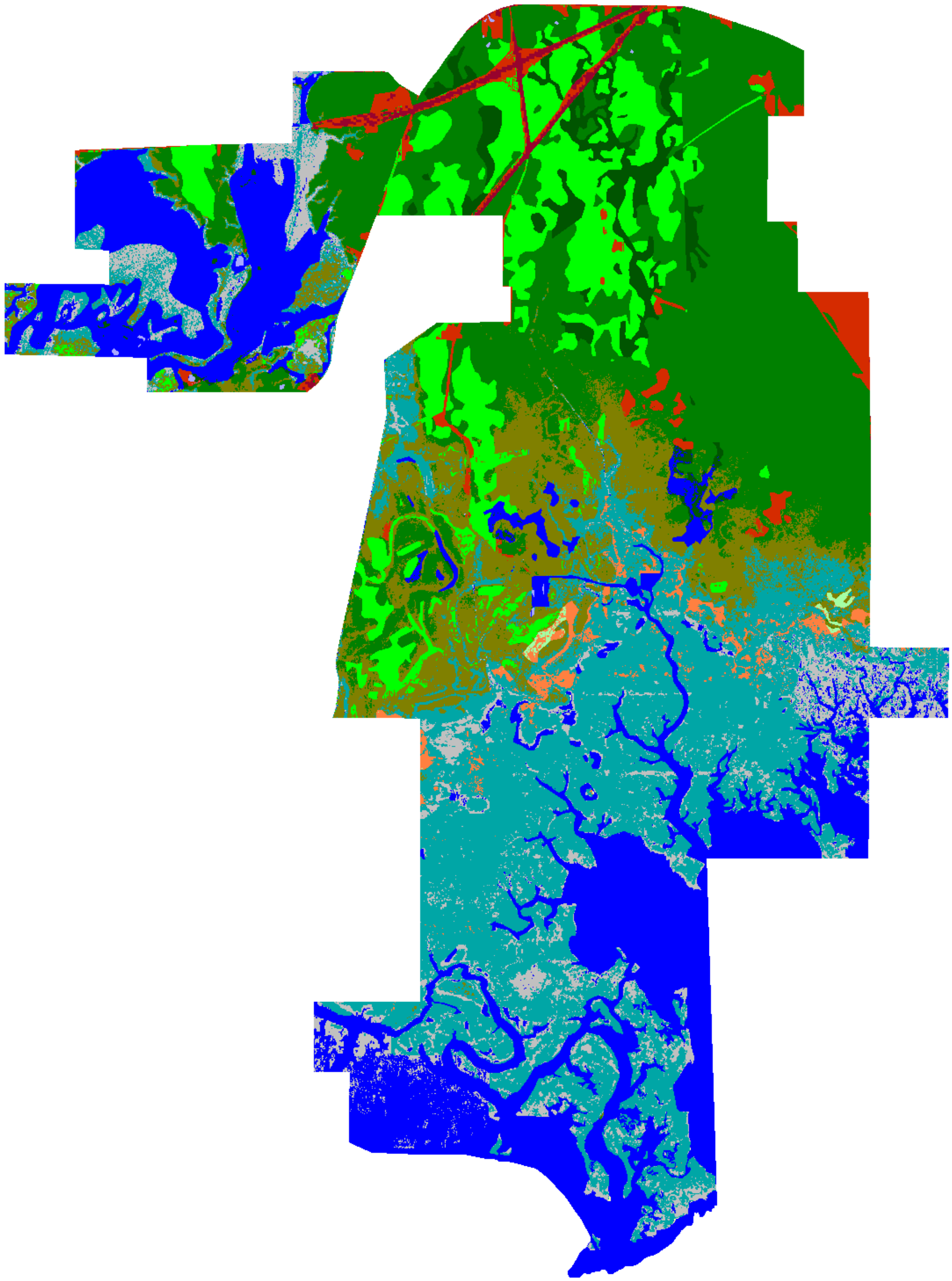
Grand Bay NWR, Initial Condition



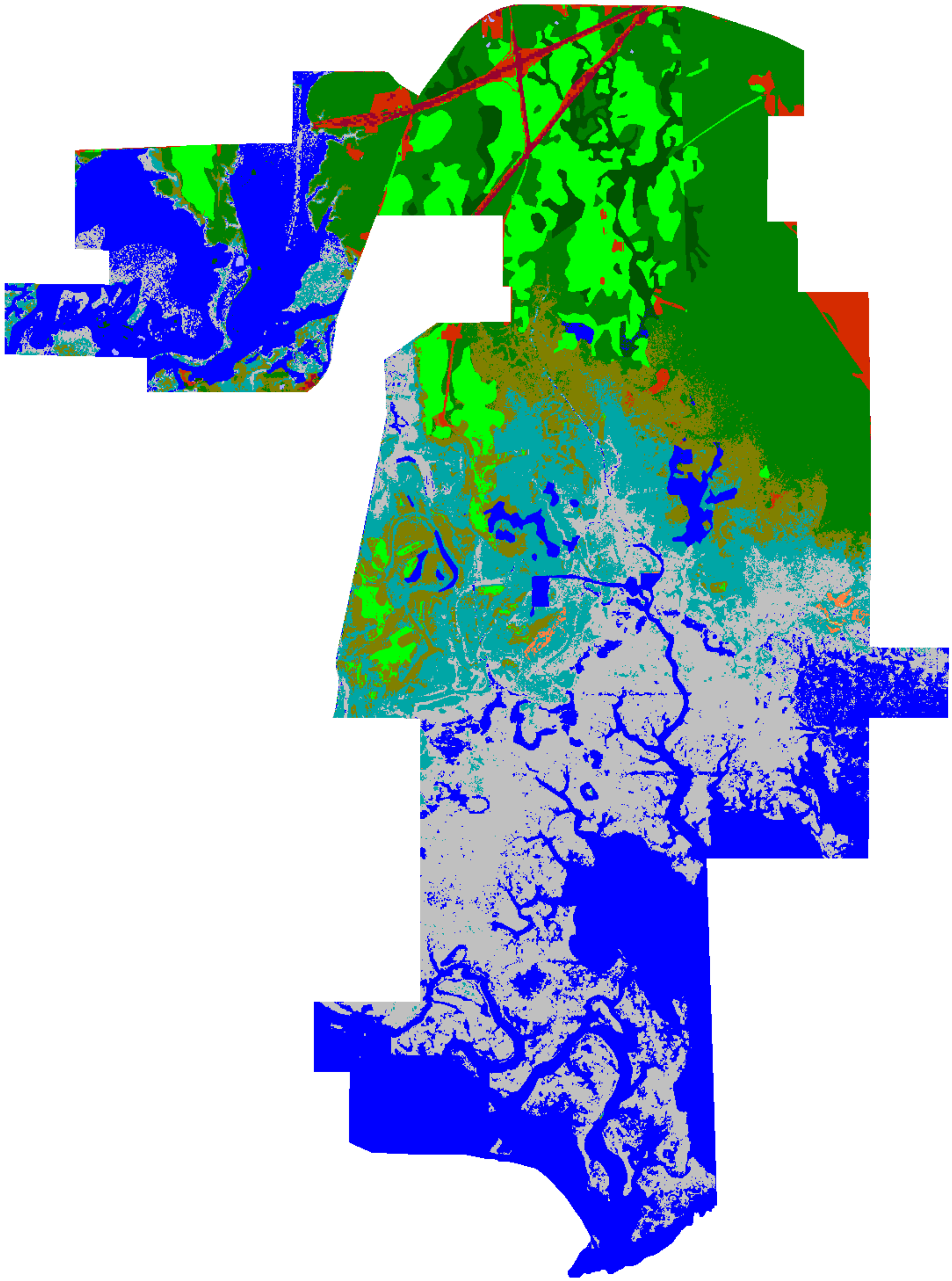
Grand Bay NWR, 2025, 1.5 Meters



Grand Bay NWR, 2050, 1.5 Meters



Grand Bay NWR, 2075, 1.5 Meters

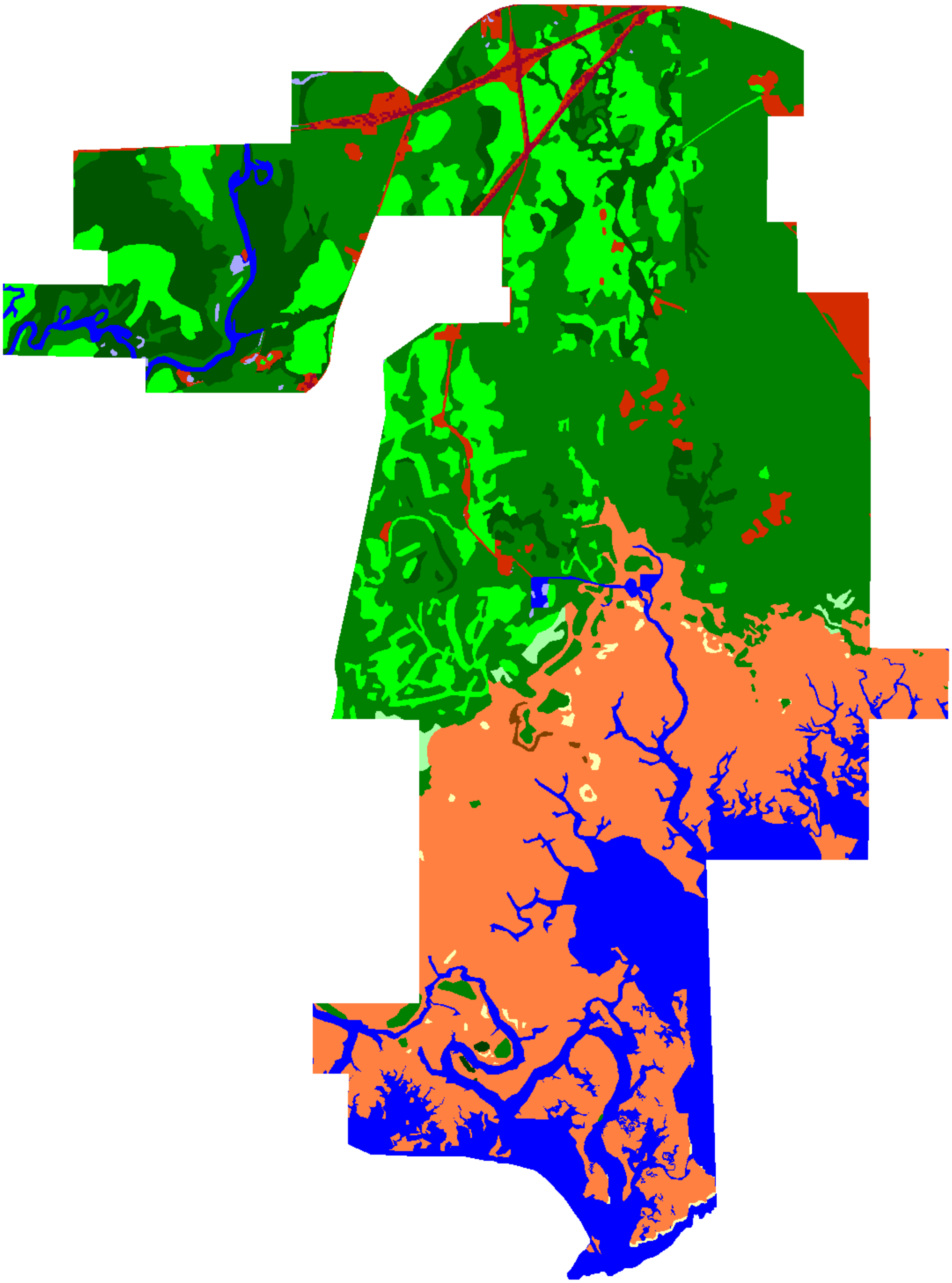


Grand Bay NWR, 2100, 1.5 Meters

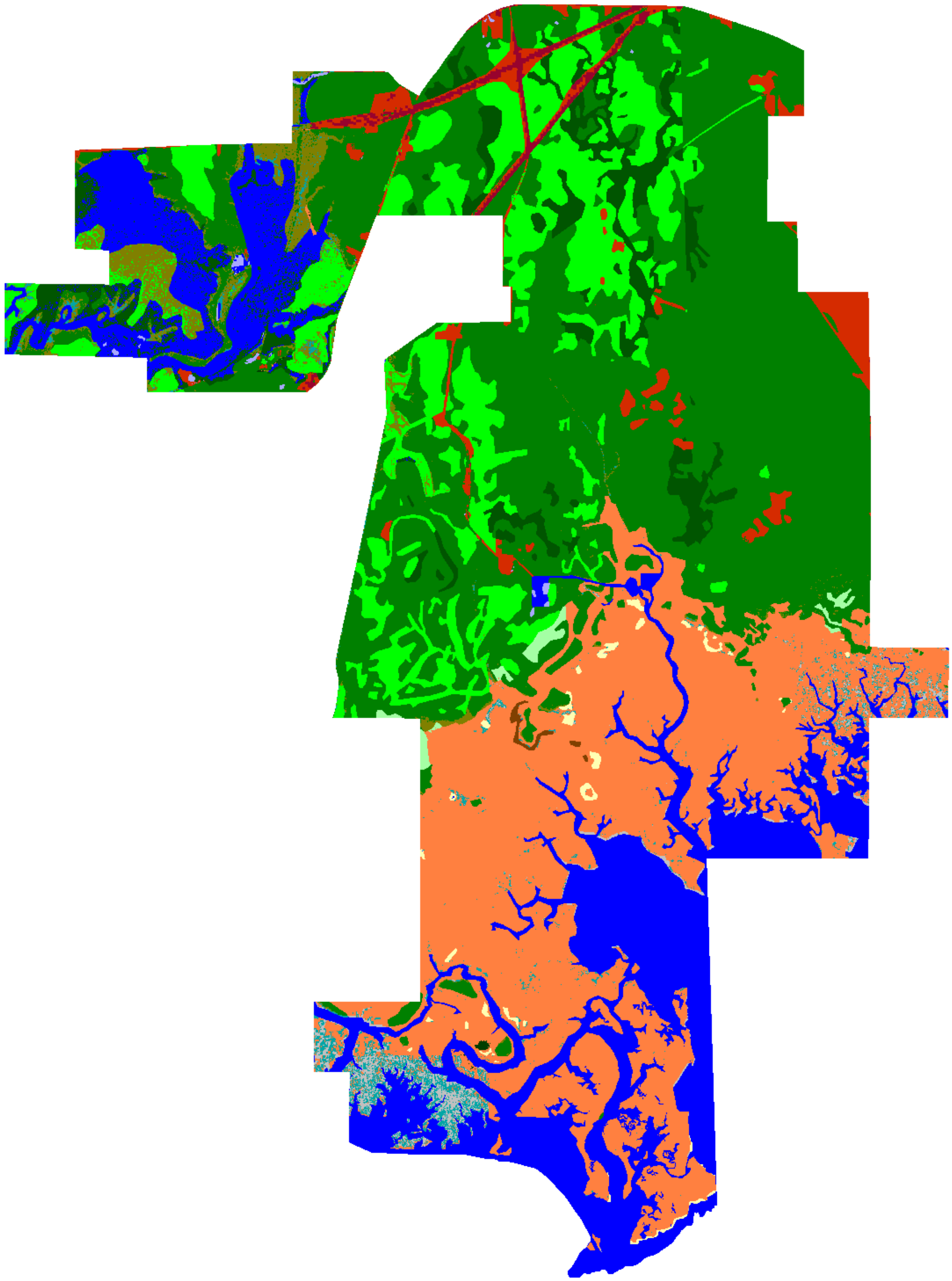
Grand Bay NWR
2 Meters Eustatic SLR by 2100

Results in Acres

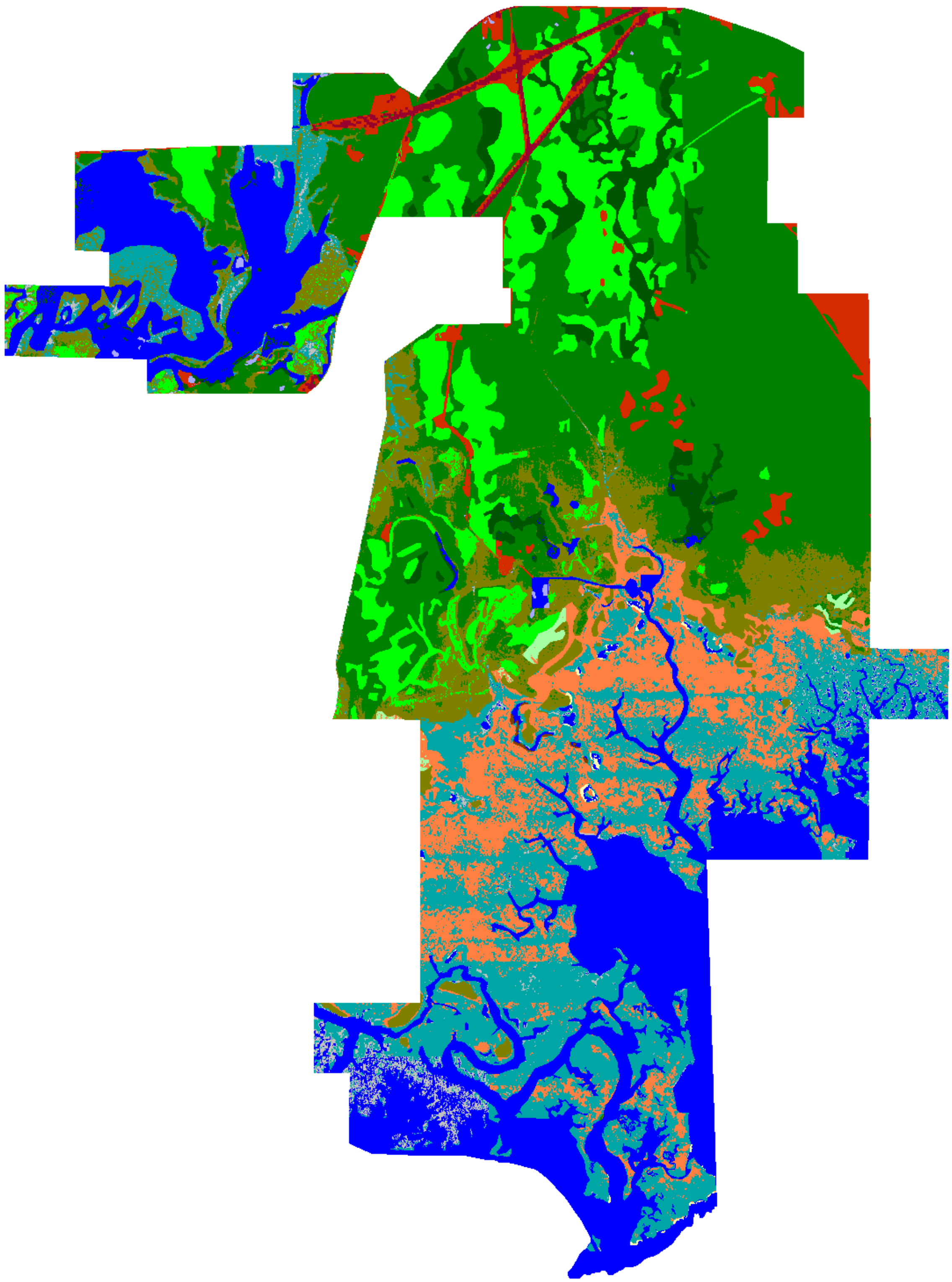
		Initial	2009	2025	2050	2075	2100
	Swamp	6626.2	6589.2	6397.5	5187.1	3432.8	2616.2
	Irregularly Flooded Marsh	4627.9	4438.7	4284.8	1664.9	49.2	2.0
	Estuarine Open Water	2284.1	2443.3	3048.0	3536.8	4105.8	7114.7
	Inland Fresh Marsh	2229.5	2190.7	2068.3	1787.4	1443.0	1207.1
	Cypress Swamp	1531.1	1380.1	833.5	585.7	431.4	359.9
	Undeveloped Dry Land	495.9	471.8	461.3	448.2	364.7	287.5
	Riverine Tidal	140.3	132.3	97.6	74.0	62.2	58.9
	Developed Dry Land	114.8	114.7	114.5	114.3	113.9	111.8
	Estuarine Beach	61.8	61.8	60.0	18.9	0.2	0.0
	Tidal Fresh Marsh	59.5	59.4	57.0	42.5	1.9	0.0
	Inland Open Water	29.5	29.5	21.3	16.5	7.9	6.9
	Inland Shore	15.7	15.7	15.7	6.6	0.0	0.0
	Tidal Swamp	11.8	11.1	4.8	0.3	0.1	0.0
	Tidal Flat	0.0	0.0	152.1	224.3	2871.4	3099.5
	Regularly Flooded Marsh	0.0	190.1	234.4	3016.1	3161.2	2231.7
	Transitional Salt Marsh	0.0	99.8	377.2	1504.8	2182.6	1131.8
	Total (incl. water)	**18228.1**	**18228.1**	**18228.1**	**18228.1**	**18228.1**	**18228.1**



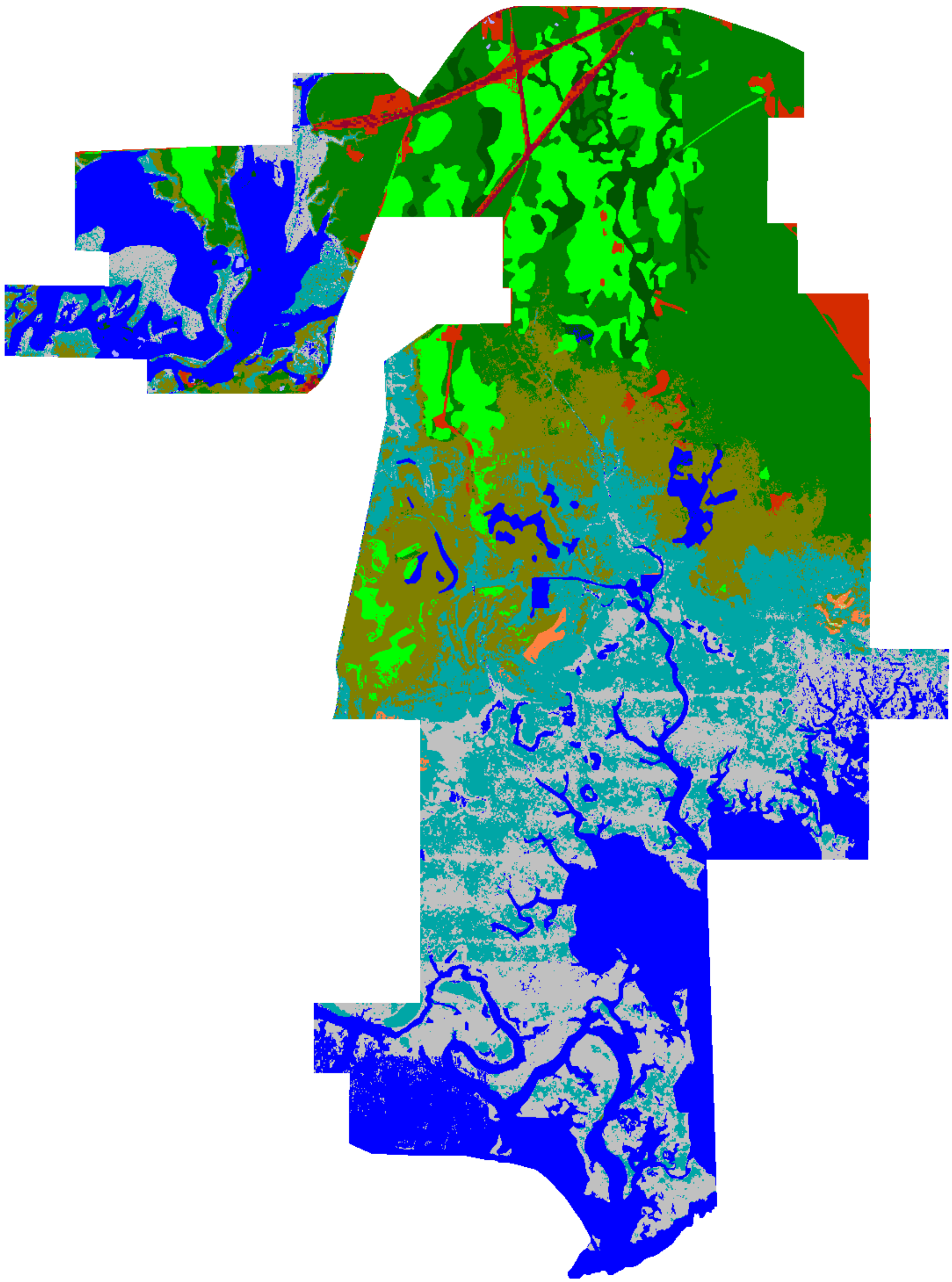
Grand Bay NWR, Initial Condition



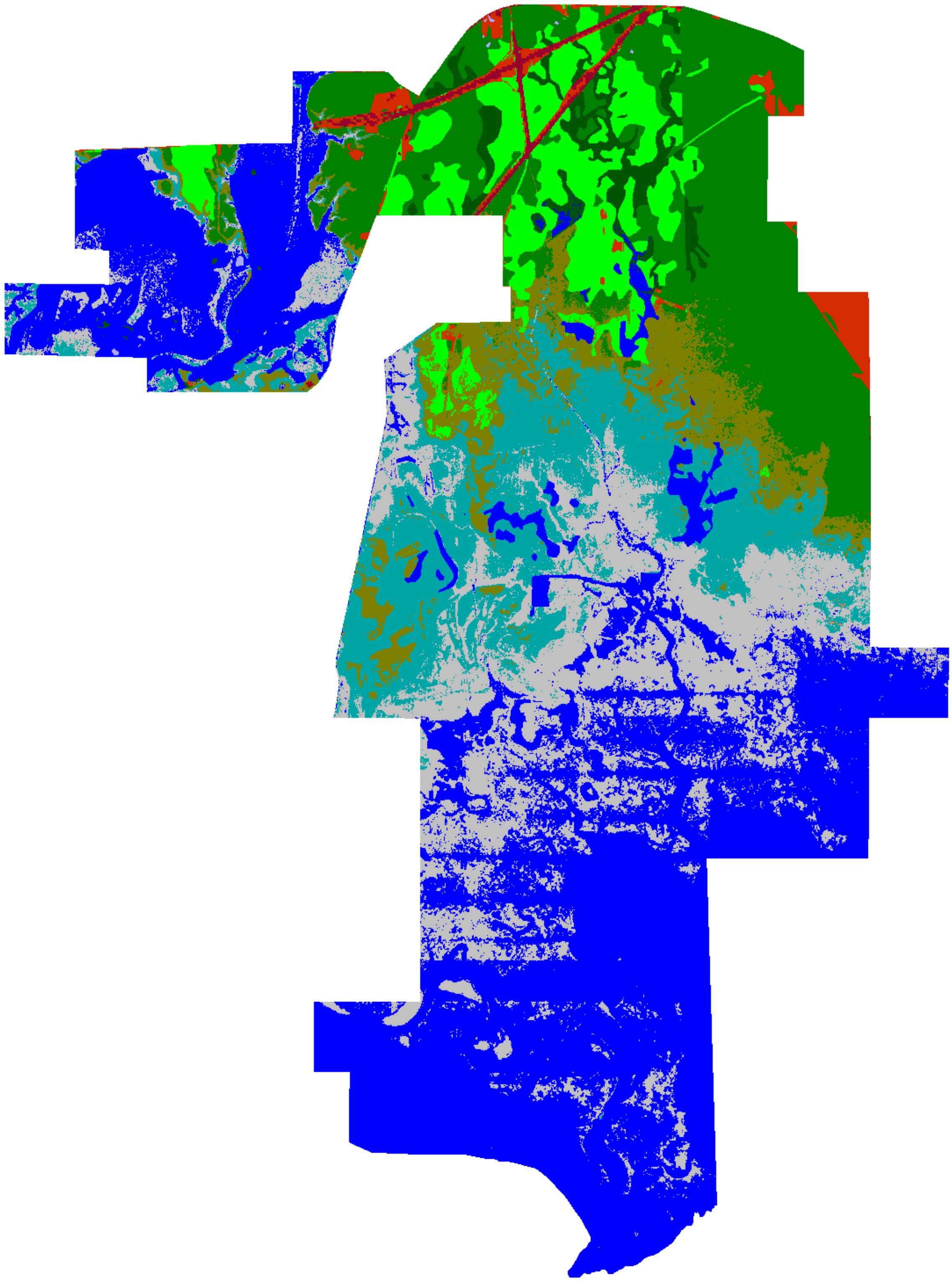
Grand Bay NWR, 2025, 2 Meters



Grand Bay NWR, 2050, 2 Meters



Grand Bay NWR, 2075, 2 Meters



Grand Bay NWR, 2100, 2 Meters

Discussion

Model results for Grand Bay NWR indicate that it is vulnerable to sea level rise under more extreme SLR scenarios. When rates of sea-level rise exceed measured accretion rates for irregularly-flooded marsh in this region, marshes are predicted to sustain considerable losses.

Not surprisingly, model sensitivity analysis suggests that model predictions are quite sensitive to model inputs of accretion rates in the refuge (Clough et al. 2011). Local accretion data were not available for this site, and accretion values were estimated using data from Biloxi MS (Clough et al. 2011). Local data regarding accretion rates within the refuge itself could provide better predictions of marsh losses in the future.

On the other hand, elevation data were based on high-vertical-resolution LiDAR data for the entire refuge, reducing model uncertainty considerably. An elevation uncertainty analysis found minimal variations in model predictions on the basis of elevation-data uncertainty (Clough et al. 2011).

Swamp and irregularly-flooded marsh make up more than 61% of the NWR. SLAMM simulations suggest irregularly-flooded marsh in the Grand Bay NWR to be highly impacted by SLR above 1 m by 2100. Swamp lands, which are further inland from the open water, are predicted to be more resilient to SLR than irregularly-flooded marsh. Cypress swamp makes up approximately 8% of the refuge and is predicted by SLAMM to be impacted by even the lowest SLR scenario (0.39 m by 2100), with 58% loss of this wetland type by 2100.

The area surrounding Grand Bay was studied in a previous SLAMM analysis funded by The Nature Conservancy (Clough et al. 2011). Maps of results for the larger study area are presented in the "contextual maps" below.

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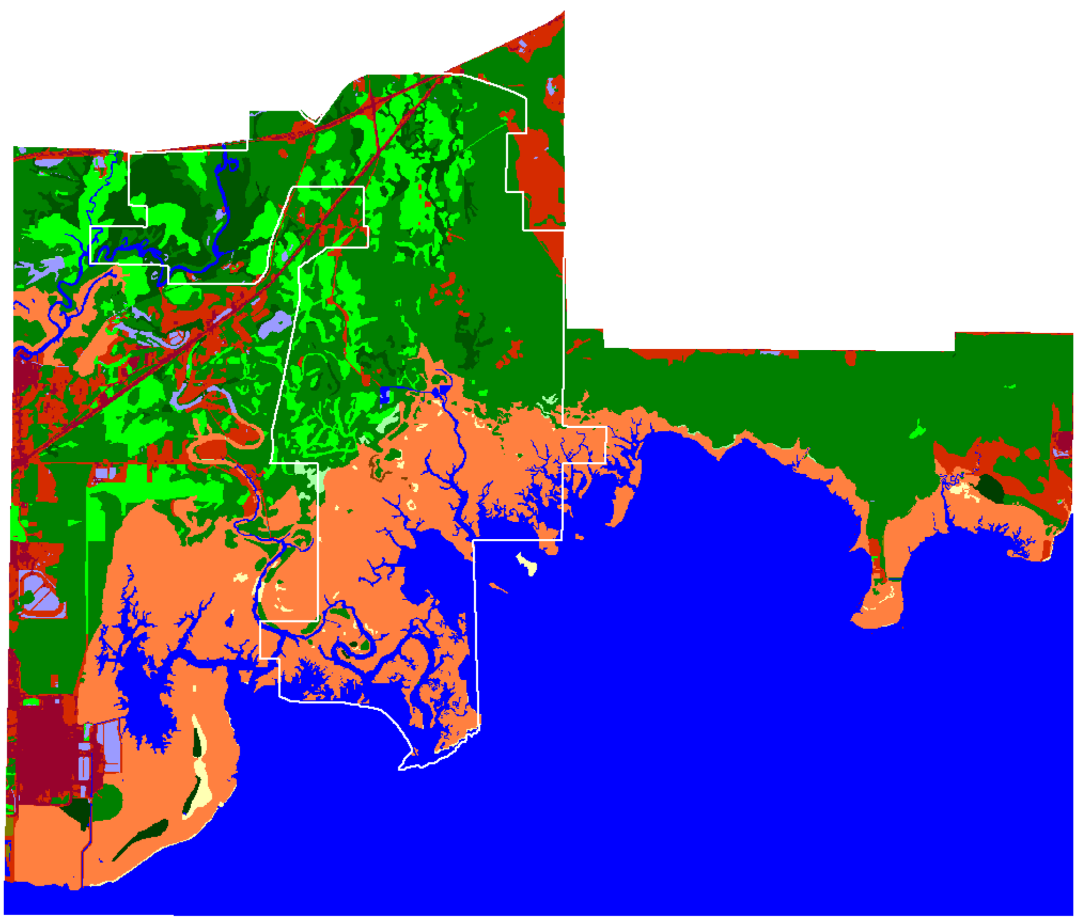
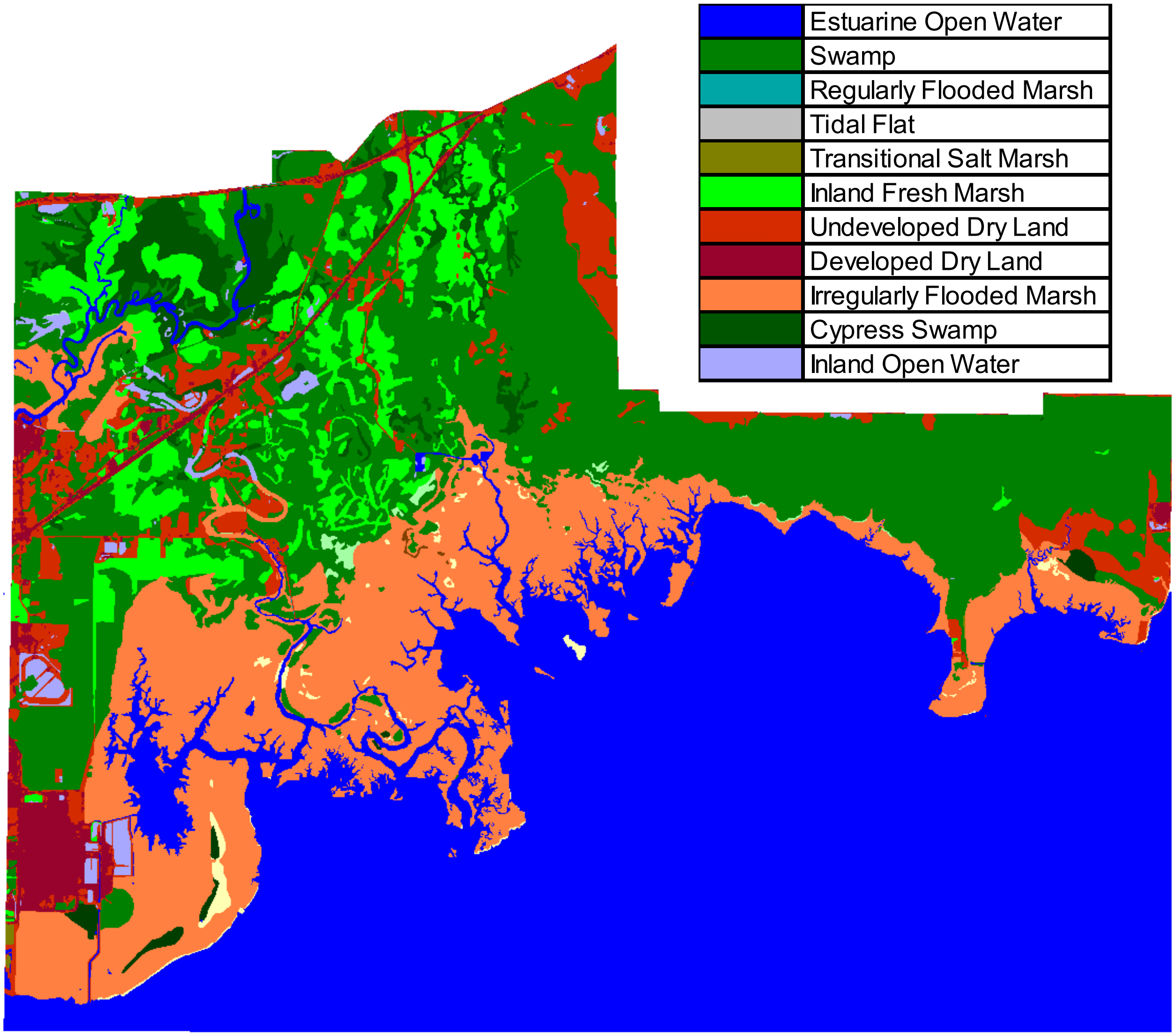
Appendix A: Contextual Results

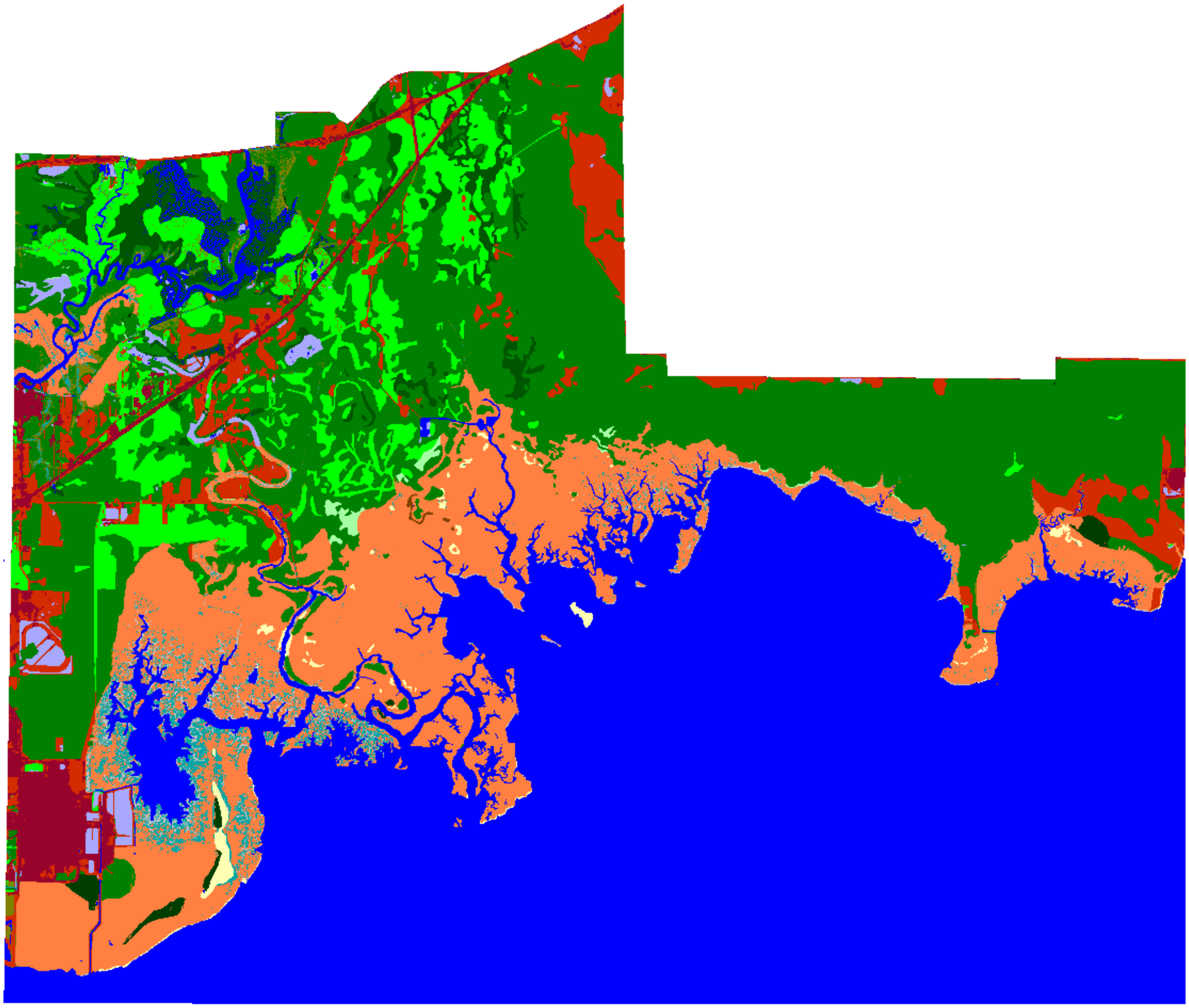
The SLAMM model does take into account the context of the surrounding lands or open water when calculating effects. For example, erosion rates are calculated based on the maximum fetch (wave action) which is estimated by assessing contiguous open water to a given marsh cell. Another example is that inundated 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. A full analysis of this study are was funded by the Sea-Level Rise and Conservation Project of The Nature Conservancy who also provided GIS processing in support of these analyses. Funding for this project of The Nature Conservancy was provided through a grant from the Gulf of Mexico Foundation, Inc., to support the Gulf of Mexico Alliance.



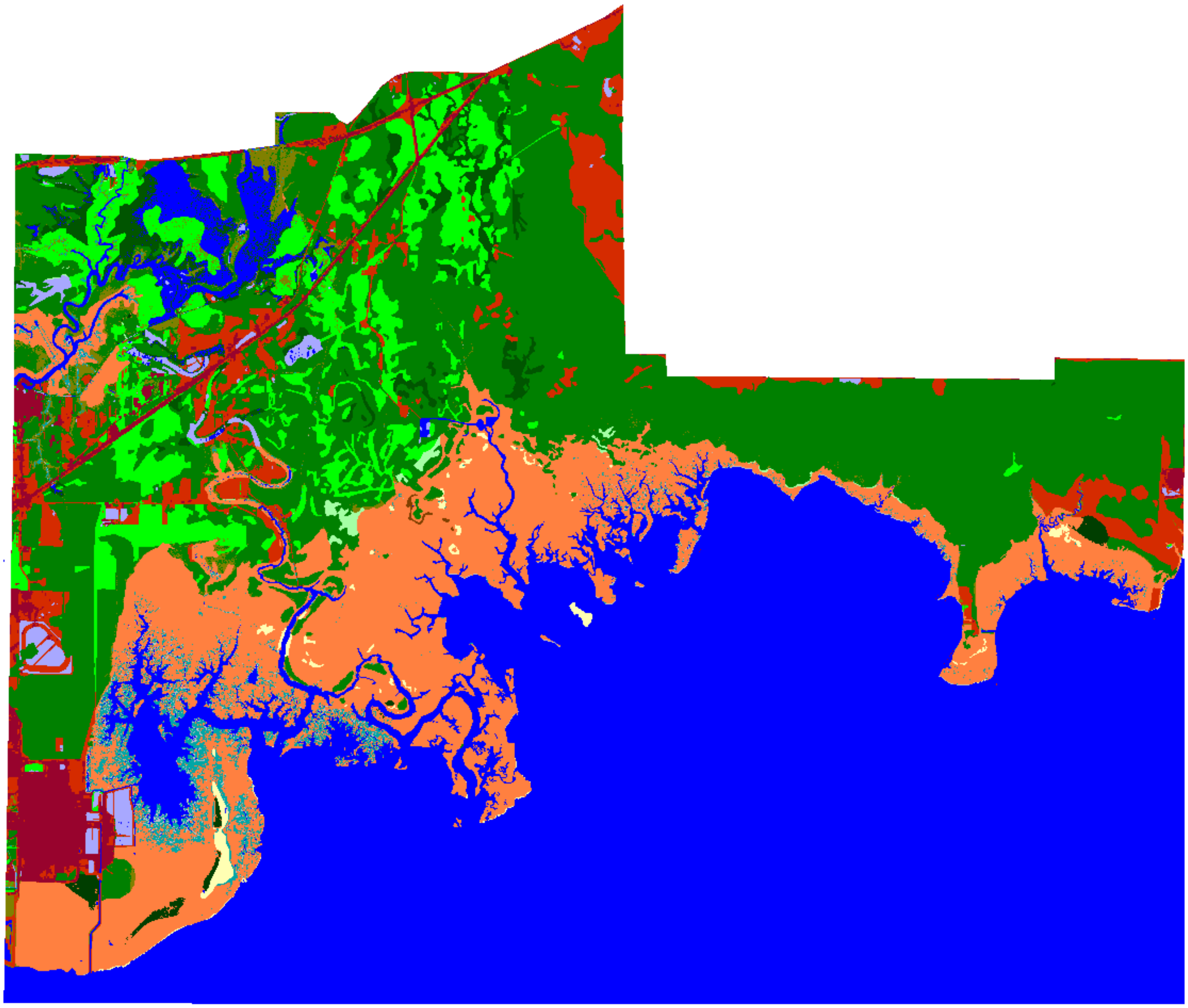
Grand Bay National Wildlife Refuge within simulation context (outlined in white).



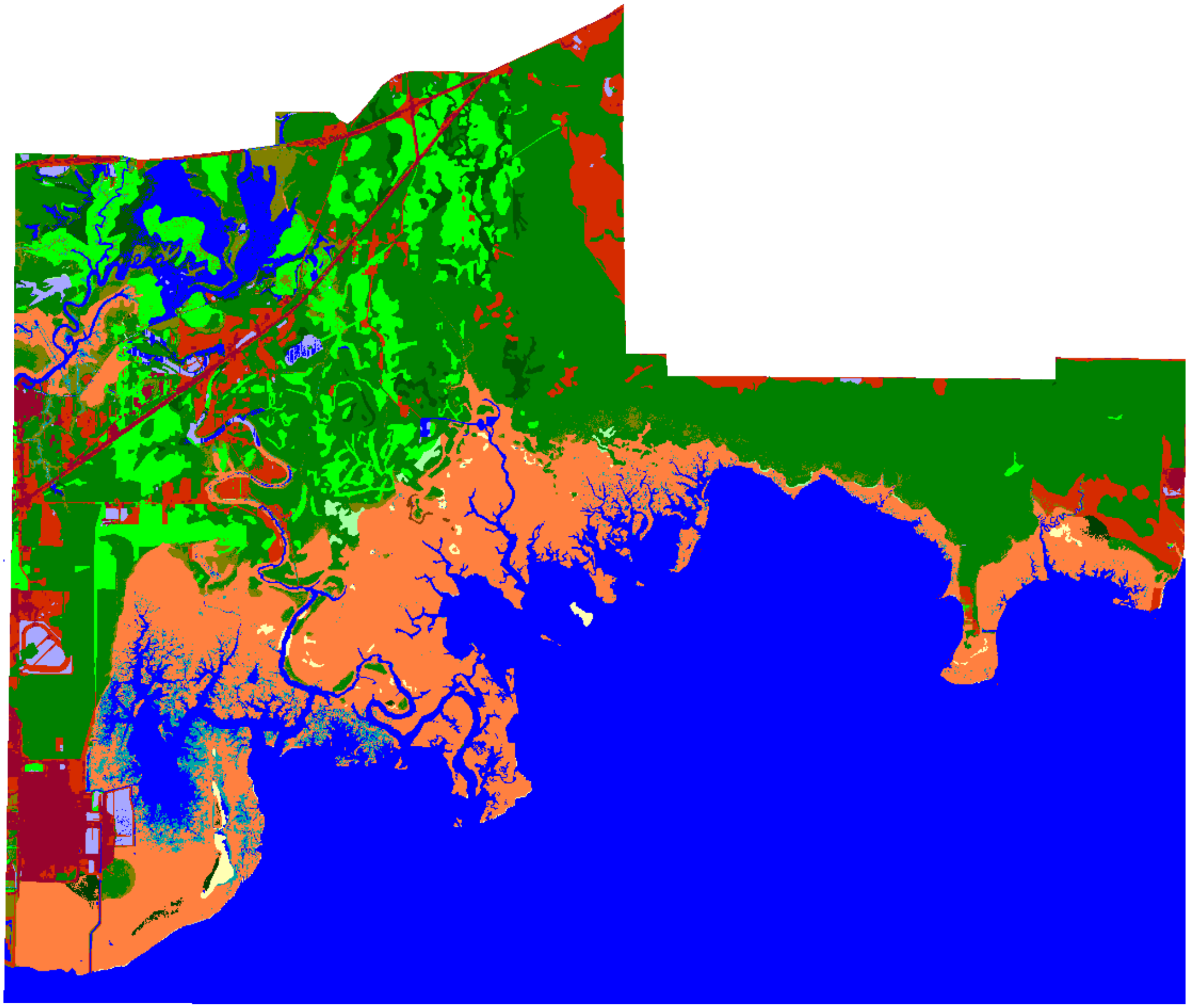
Grand Bay Context, Initial Condition



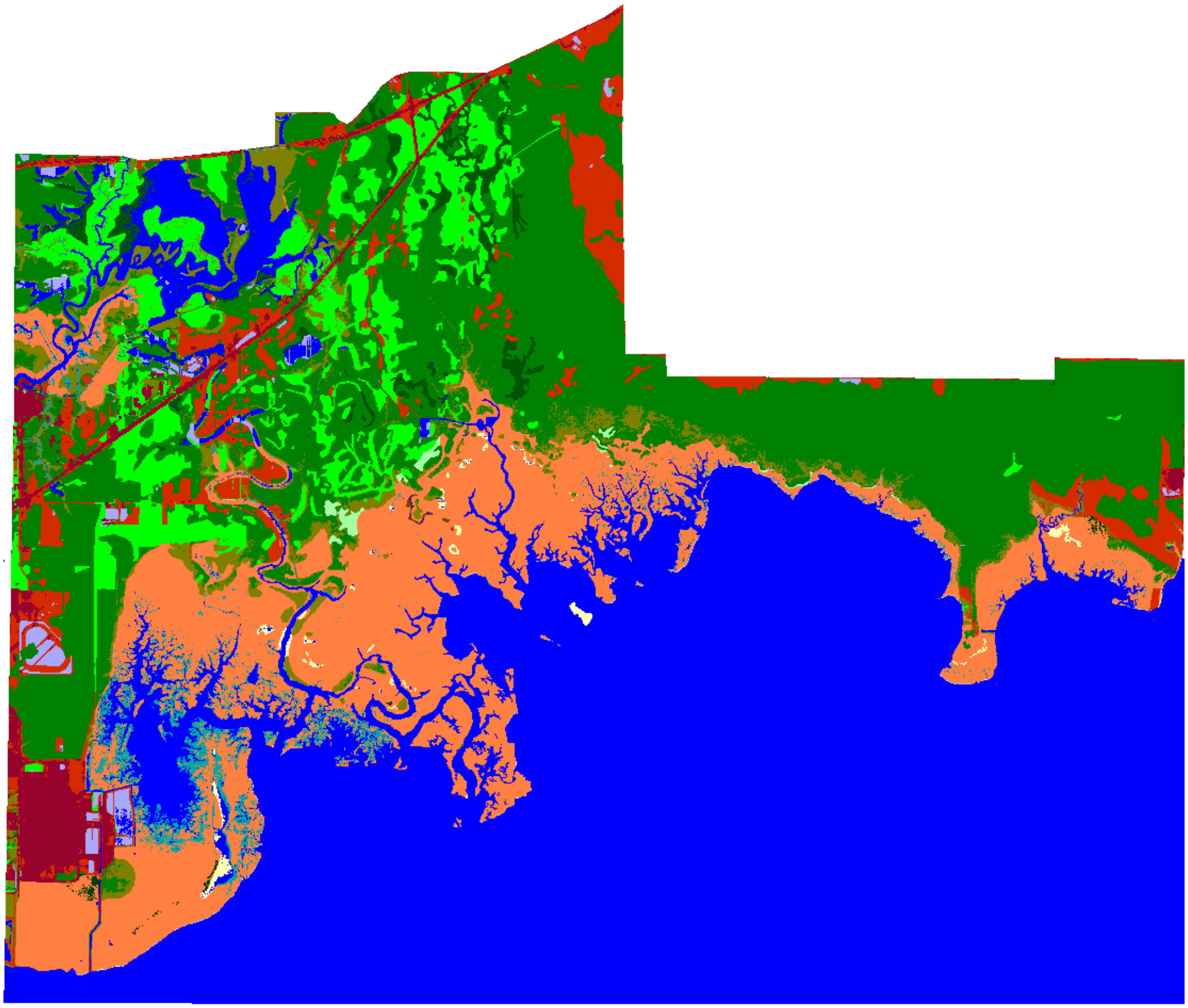
Grand Bay Context, 2025, Scenario A1B Mean



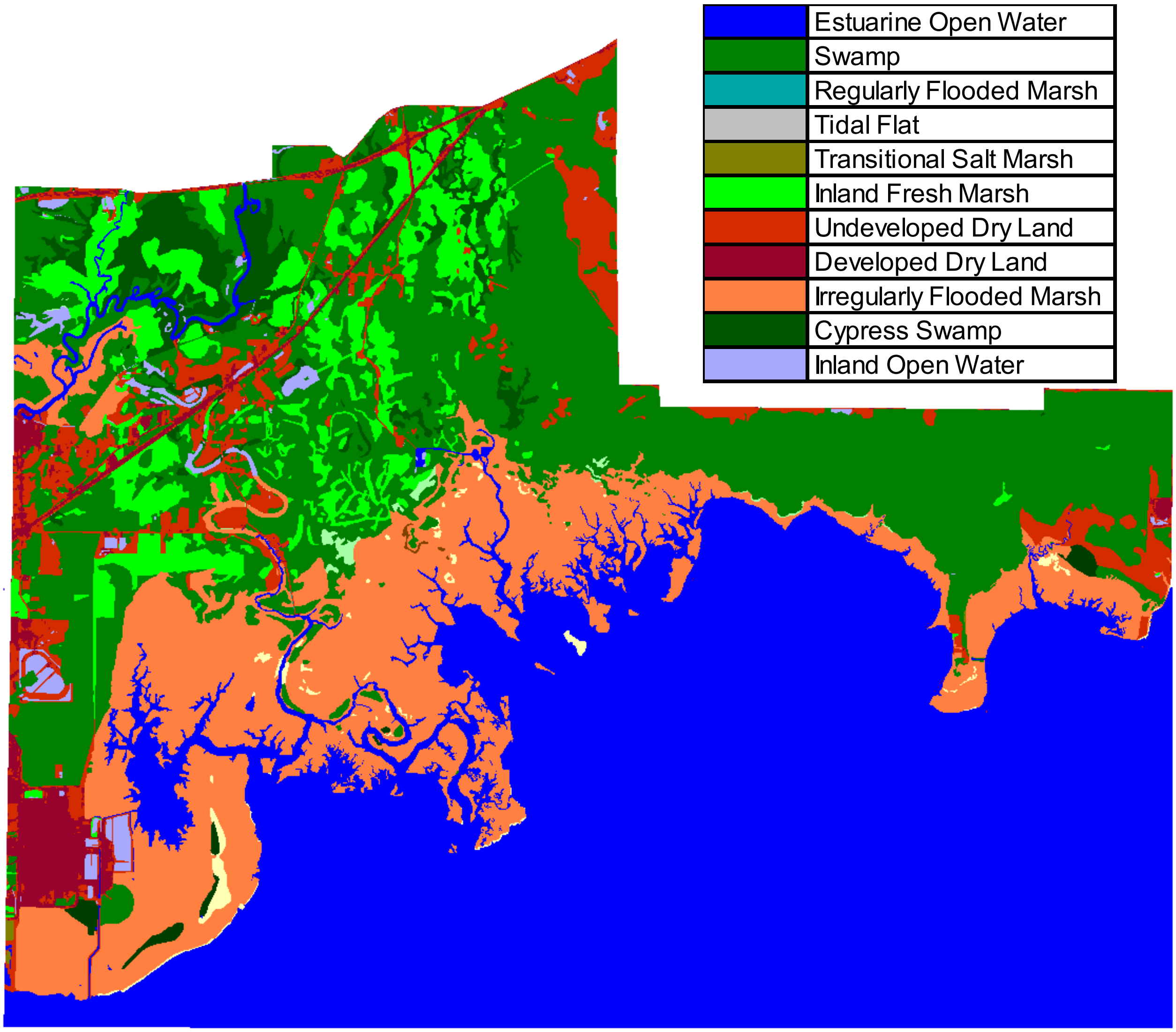
Grand Bay Context, 2050, Scenario A1B Mean



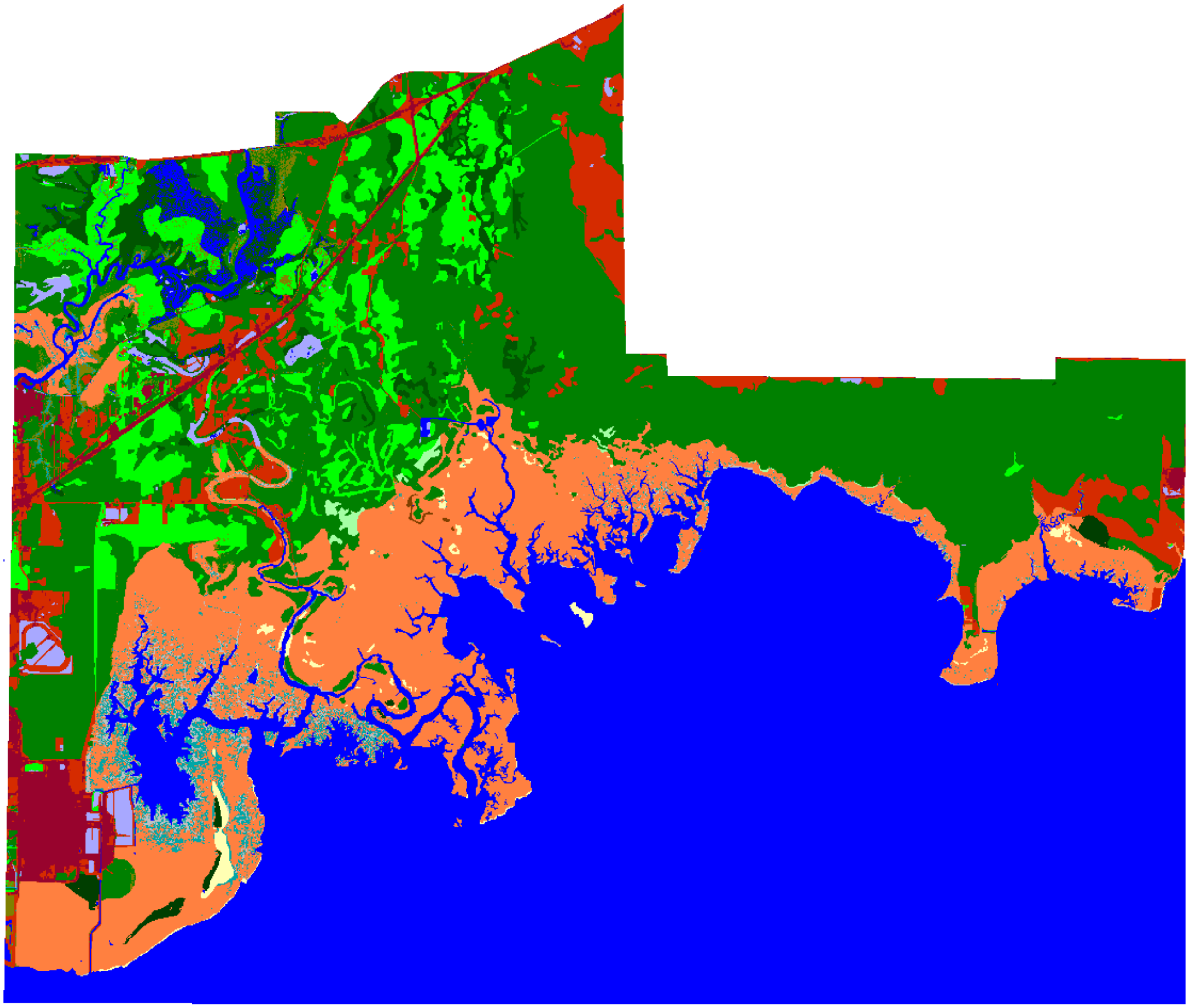
Grand Bay Context, 2075, Scenario A1B Mean



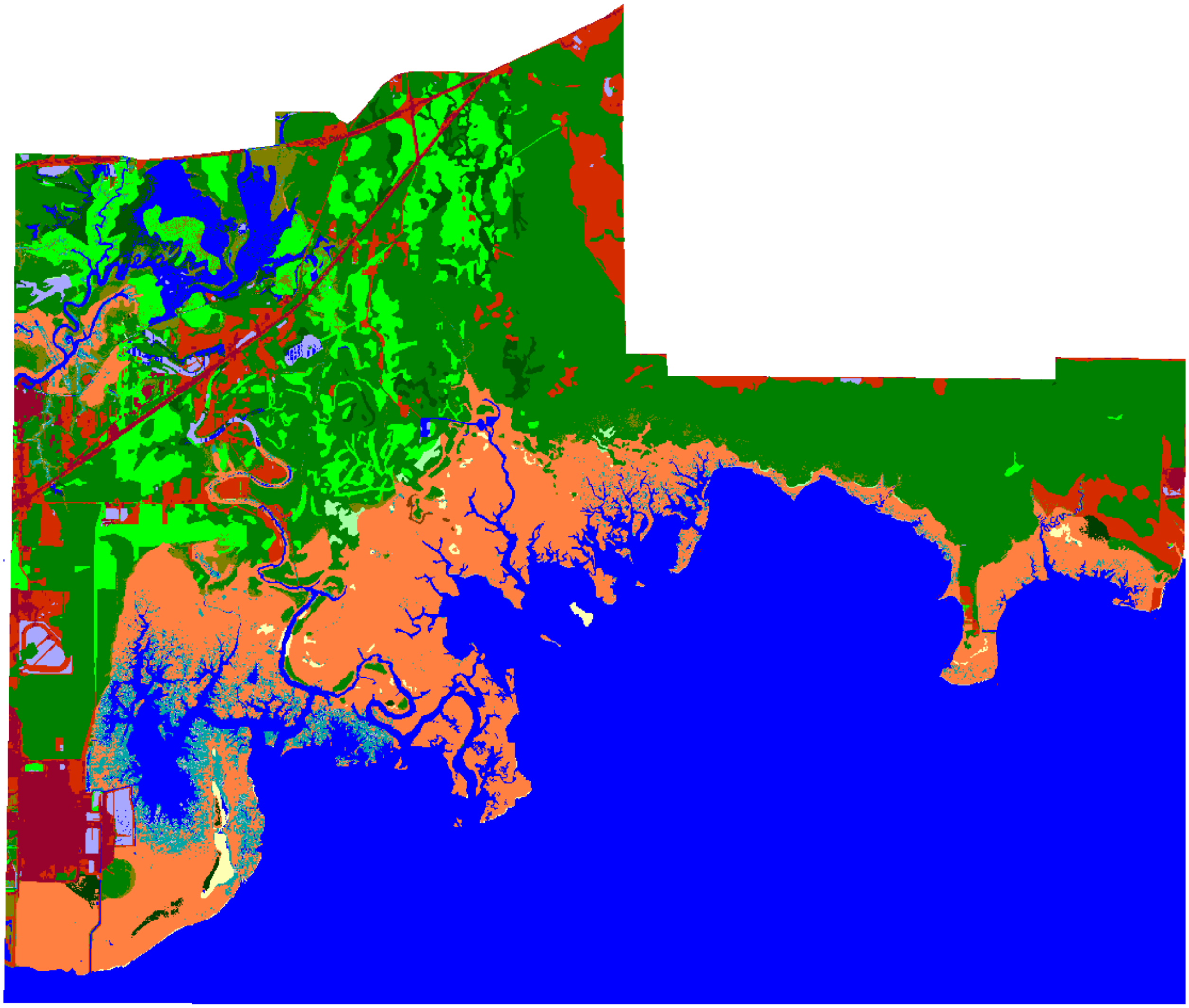
Grand Bay Context, 2100, Scenario A1B Mean



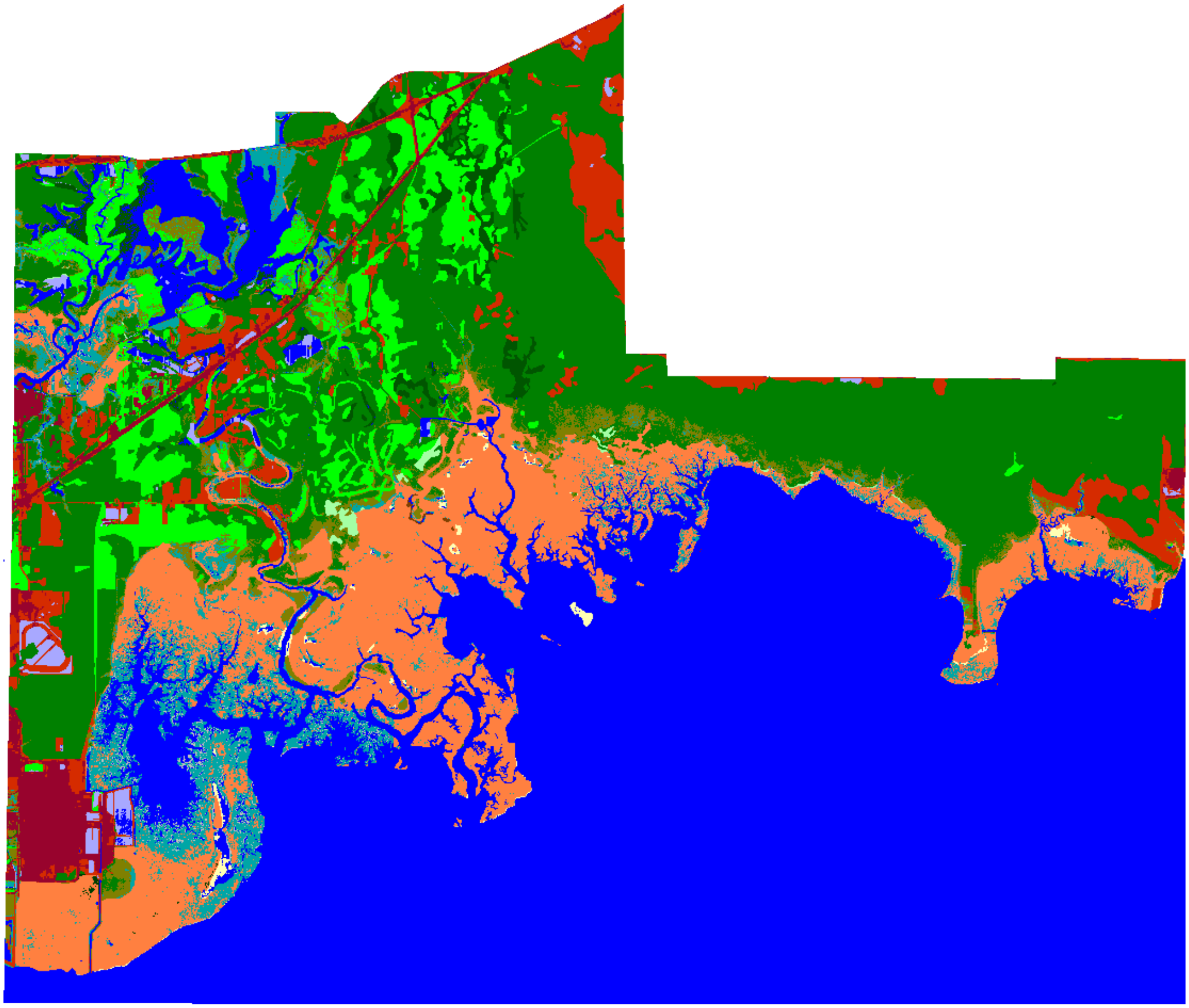
Grand Bay Context, Initial Condition



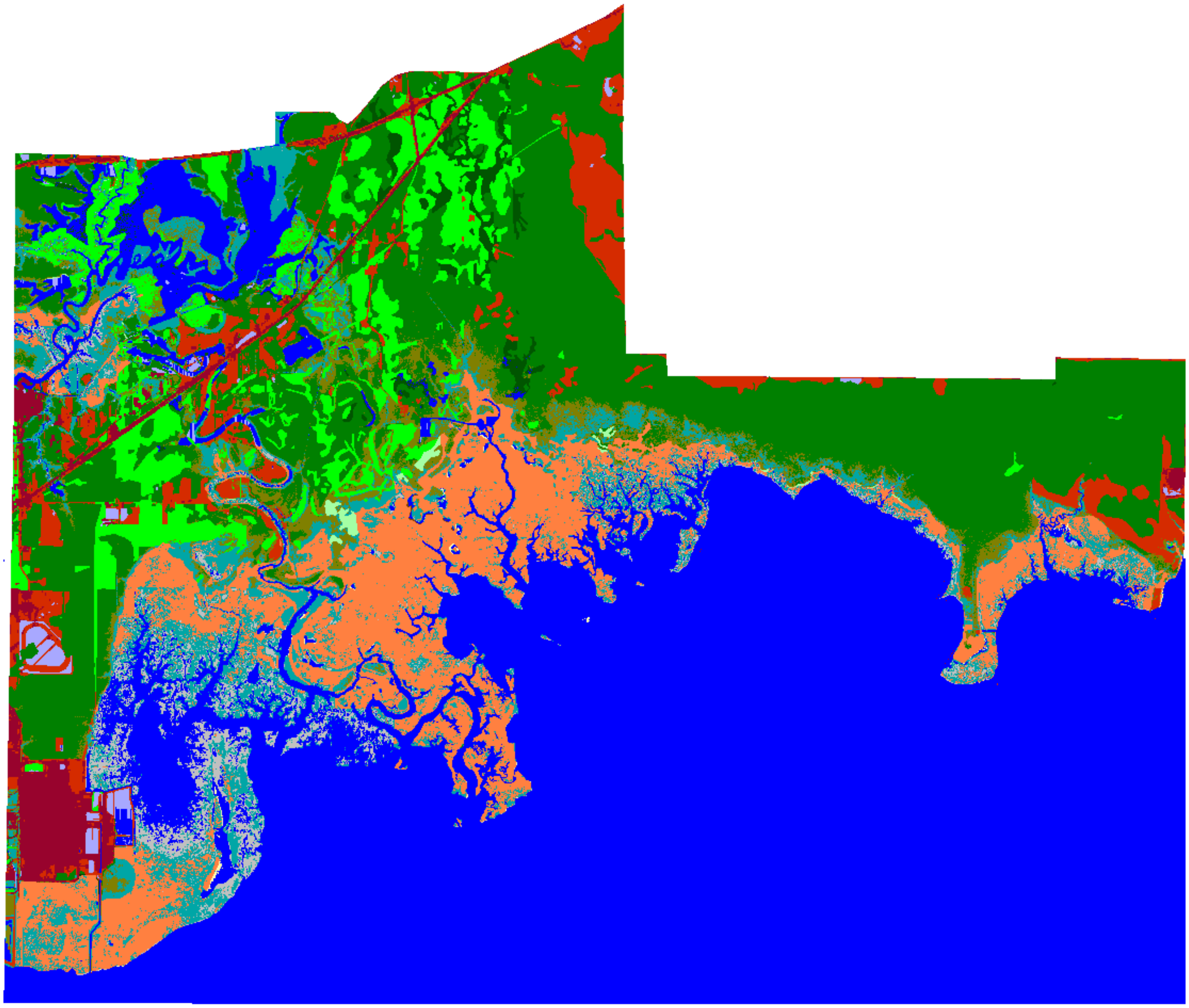
Grand Bay Context, 2025, Scenario A1B Maximum



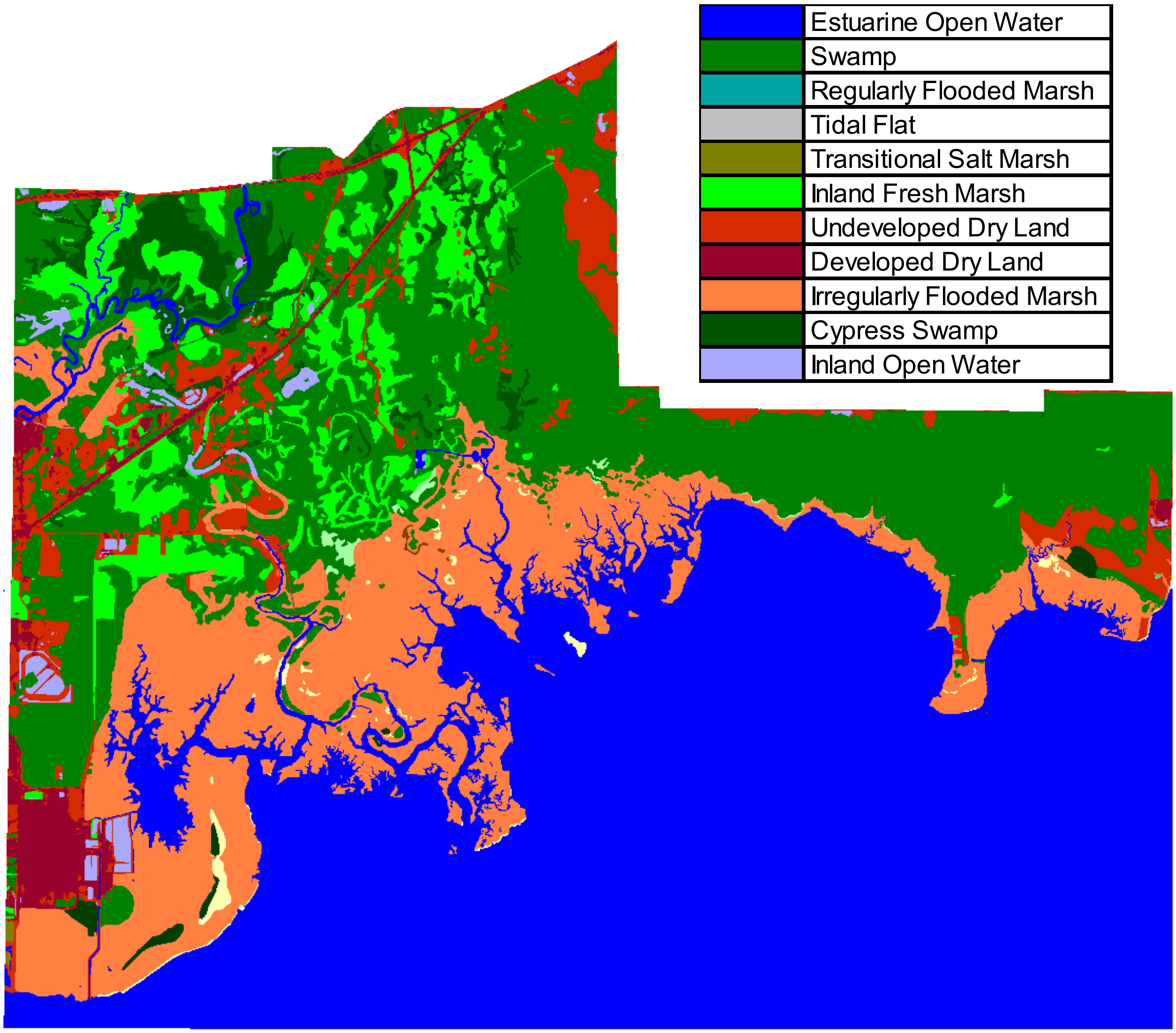
Grand Bay Context, 2050, Scenario A1B Maximum



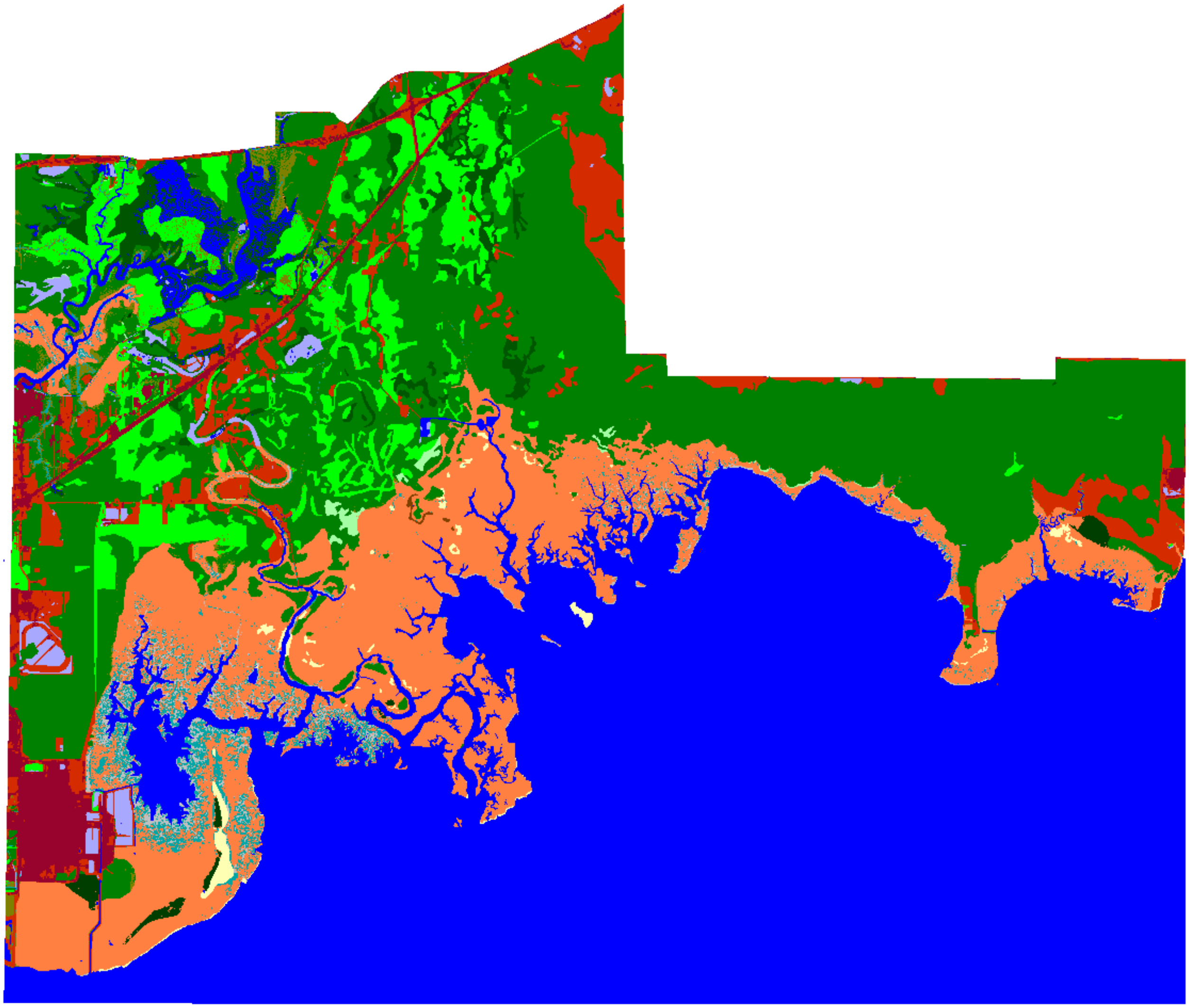
Grand Bay Context, 2075, Scenario A1B Maximum



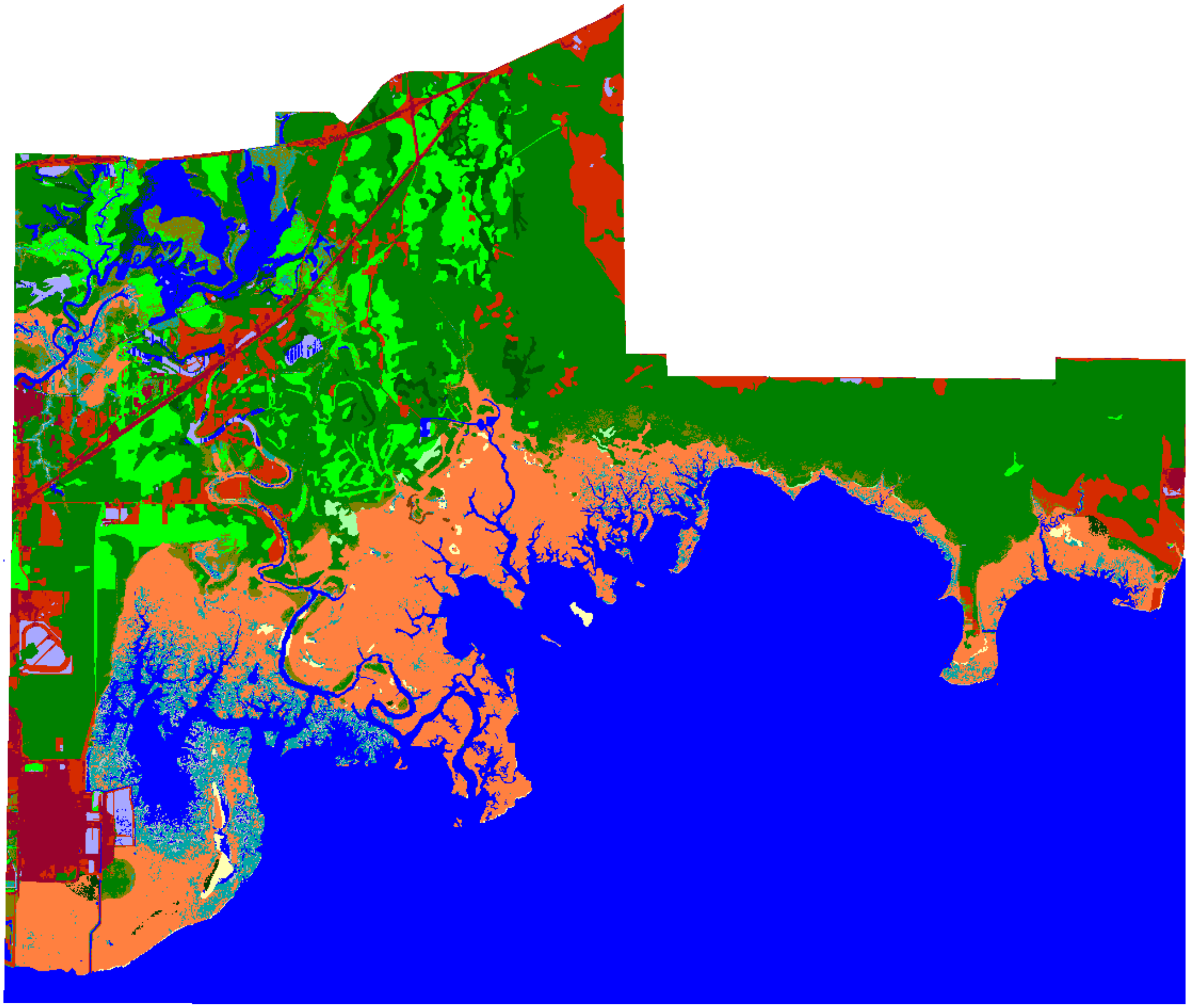
Grand Bay Context, 2100, Scenario A1B Maximum



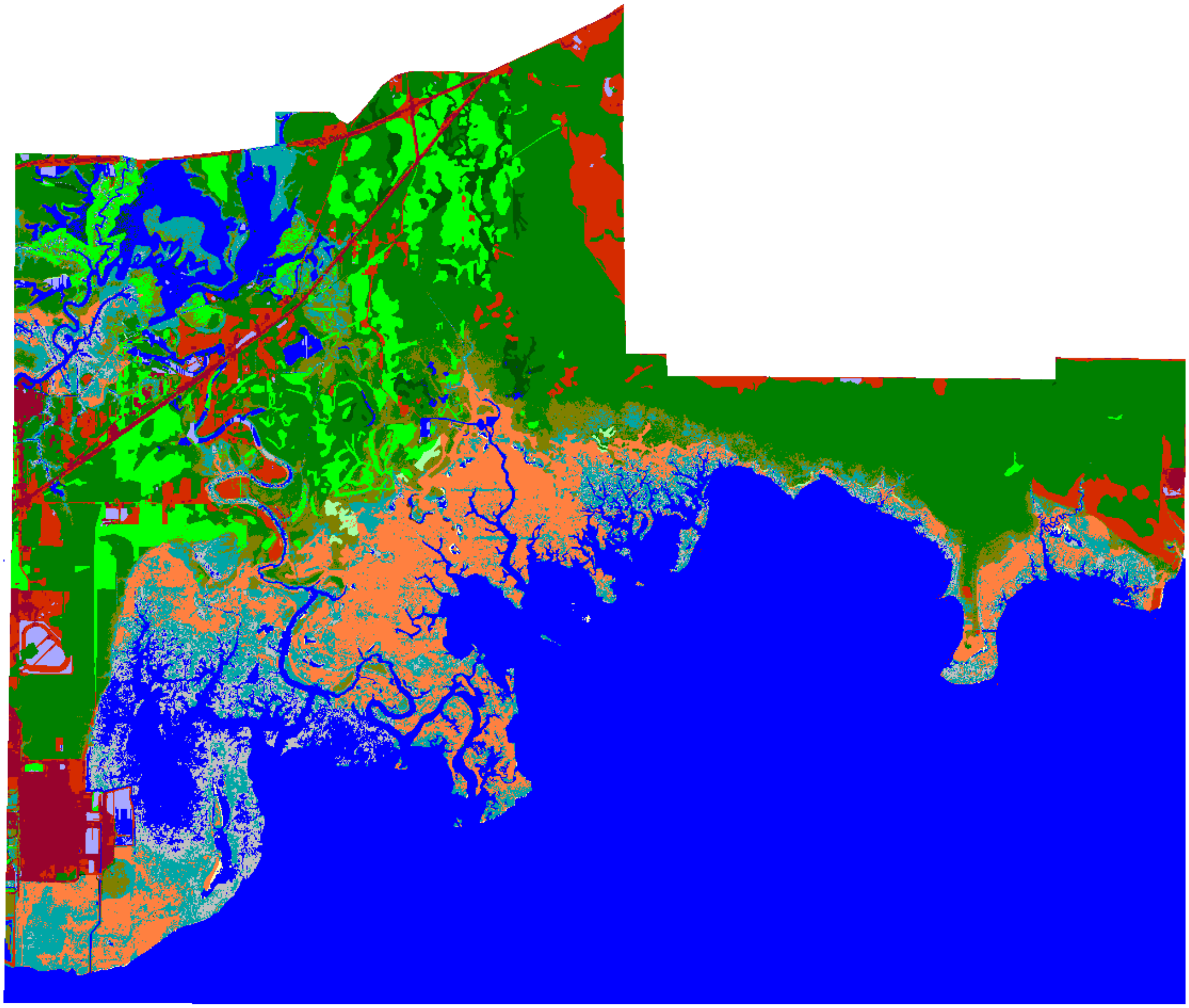
Grand Bay Context, Initial Condition



Grand Bay Context, 2025, 1 meter



Grand Bay Context, 2050, 1 meter



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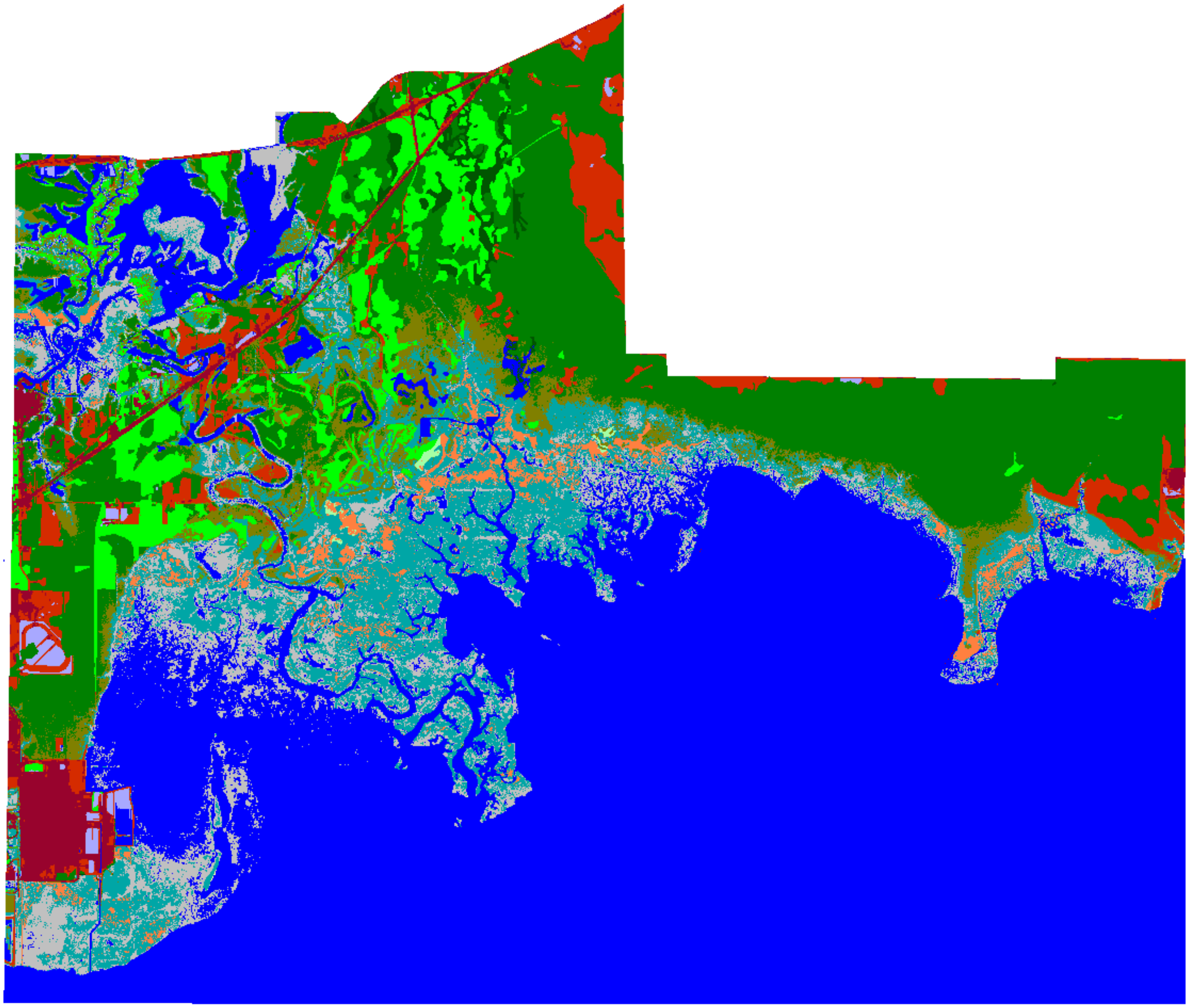
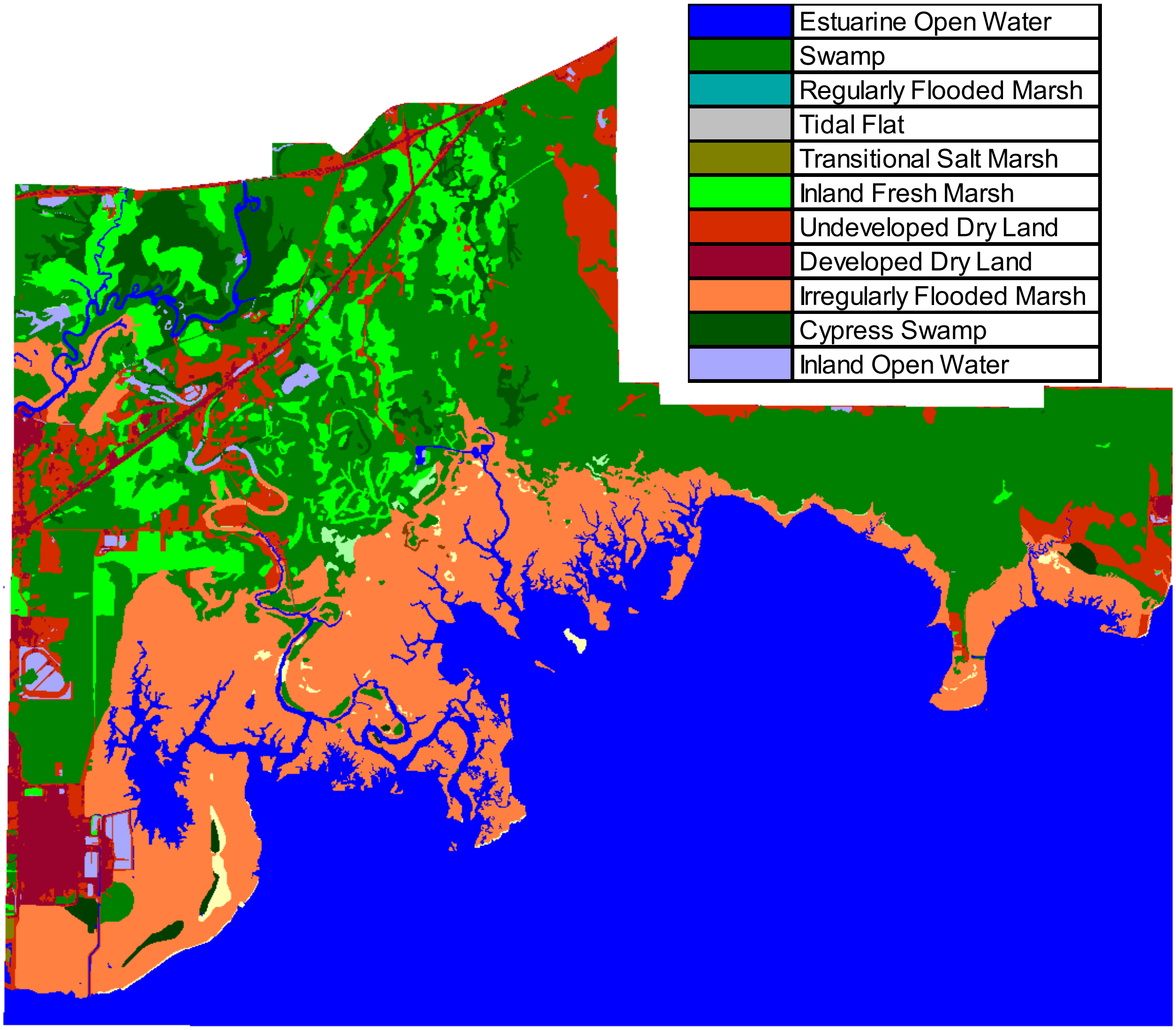
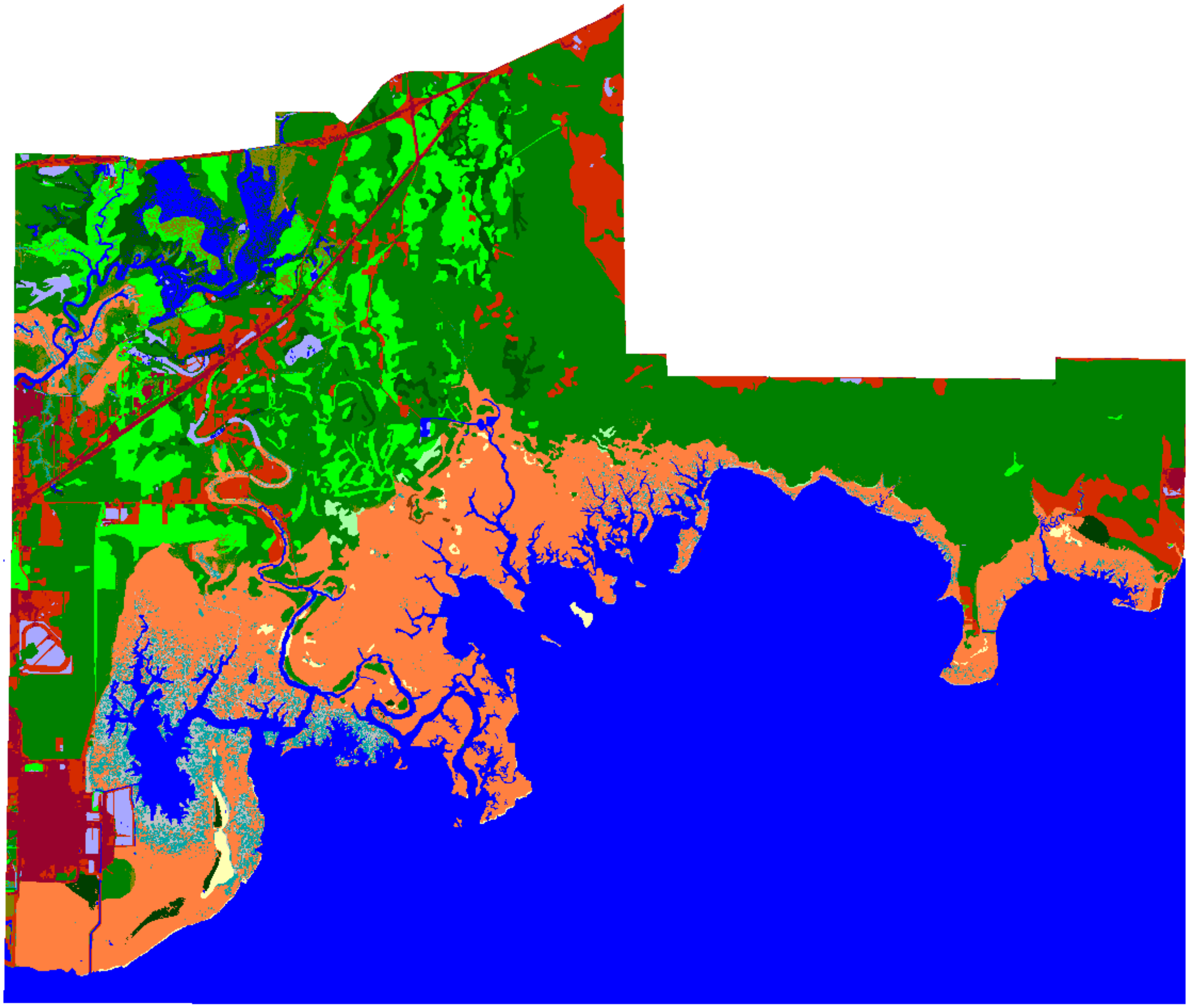


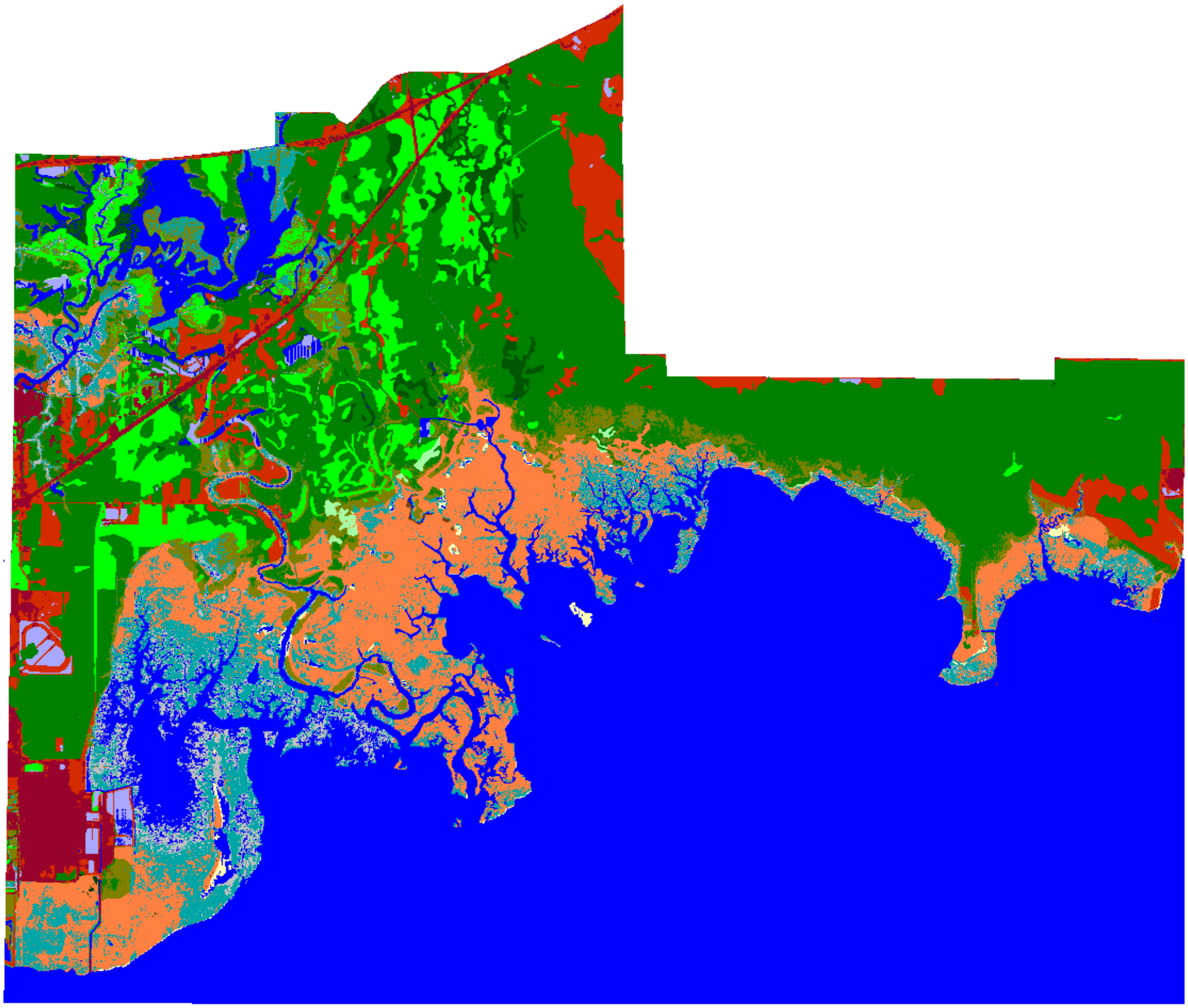
Grand Bay Context, 2100, 1 meter



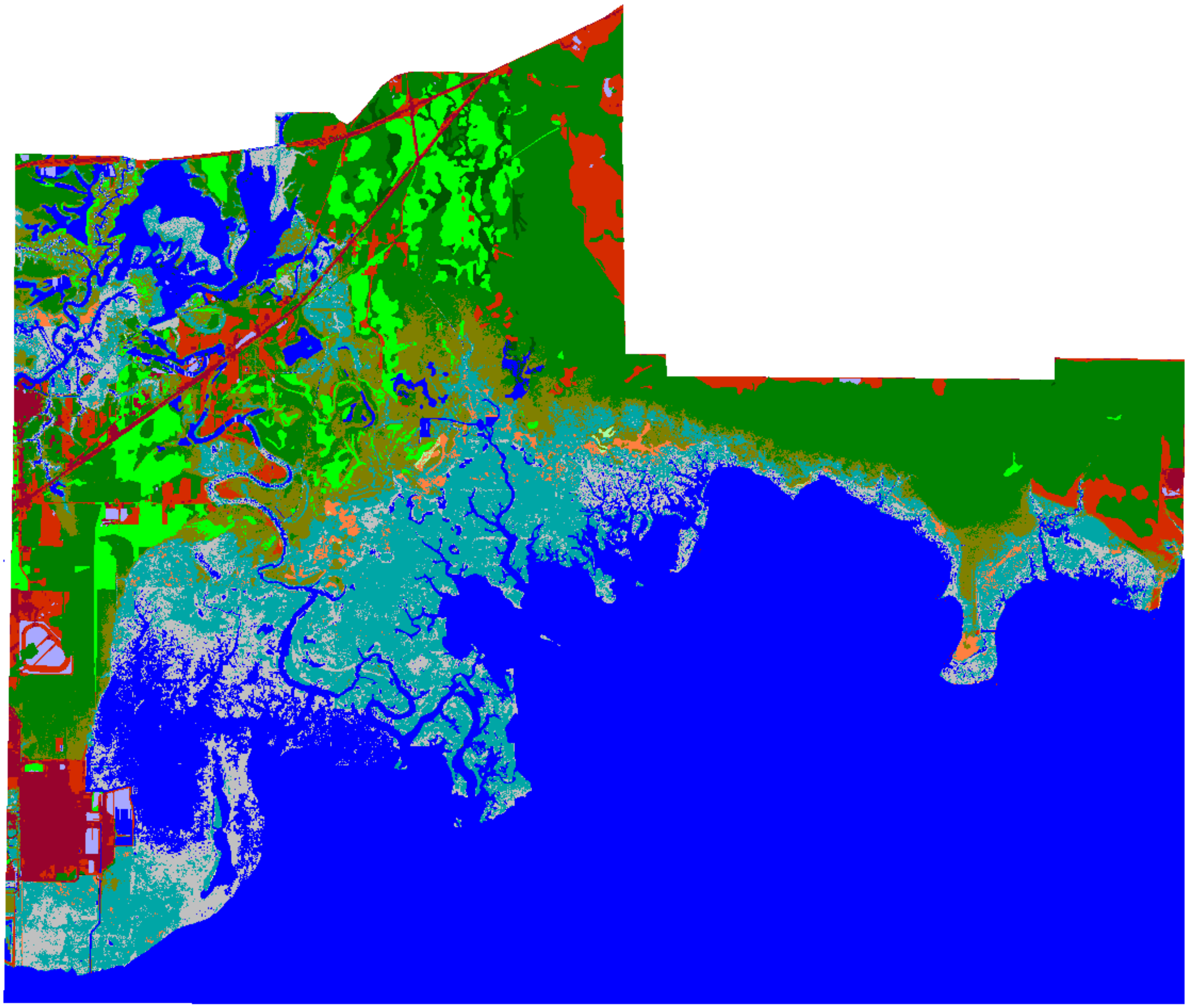
Grand Bay Context, Initial Condition



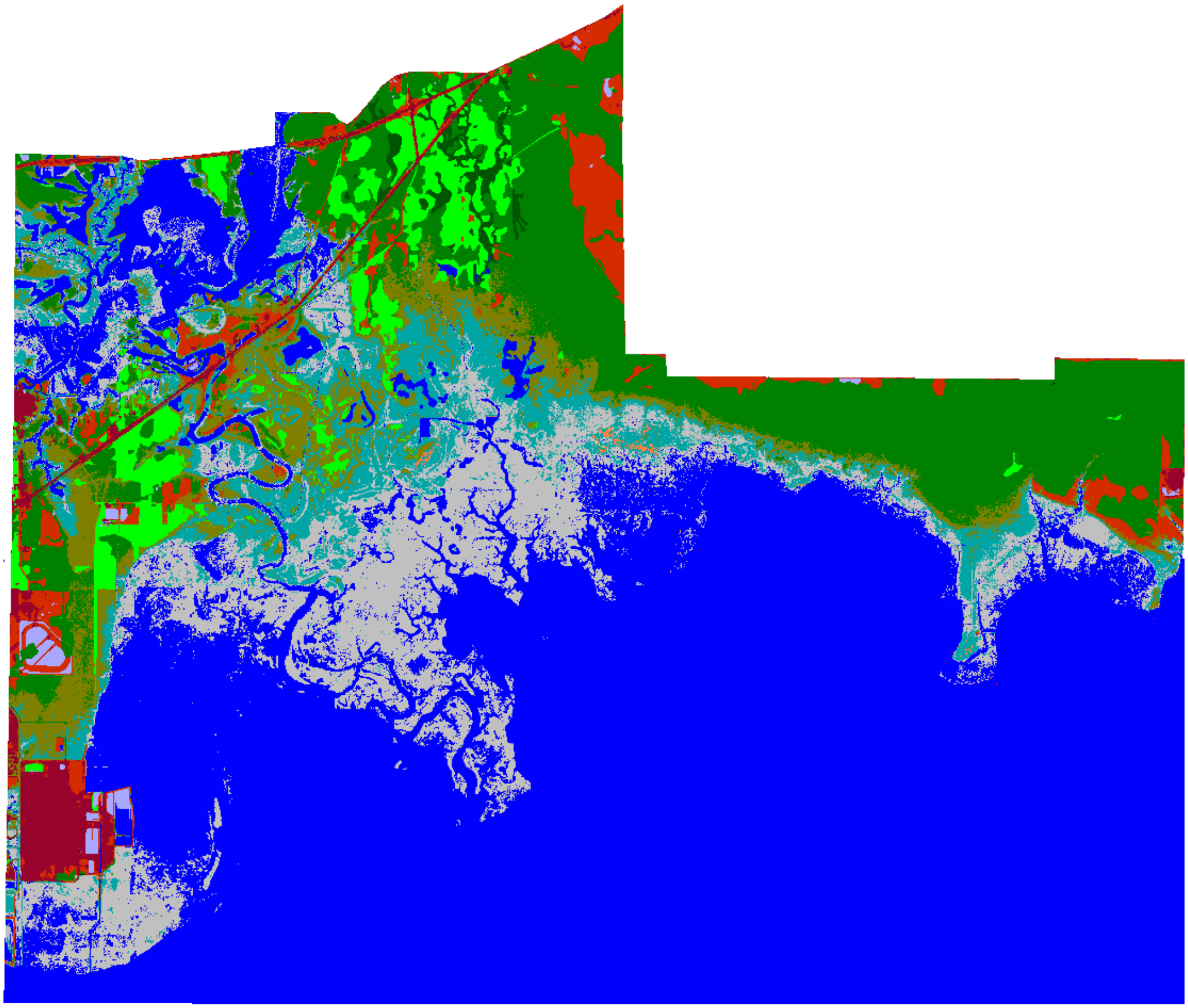
Grand Bay Context, 2025, 1.5 meter



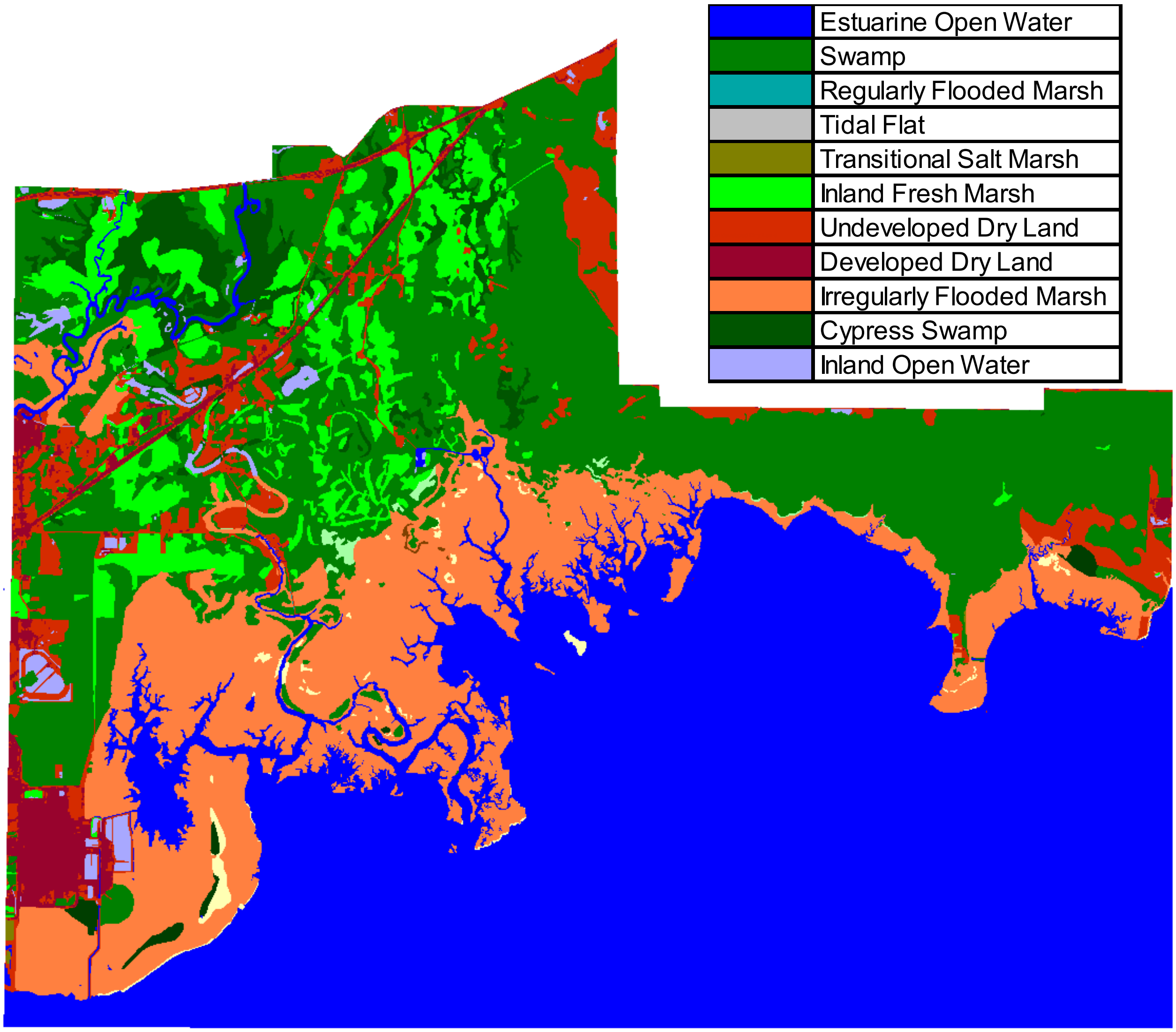
Grand Bay Context, 2050, 1.5 meter



Grand Bay Context, 2075, 1.5 meter



Grand Bay Context, 2100, 1.5 meter



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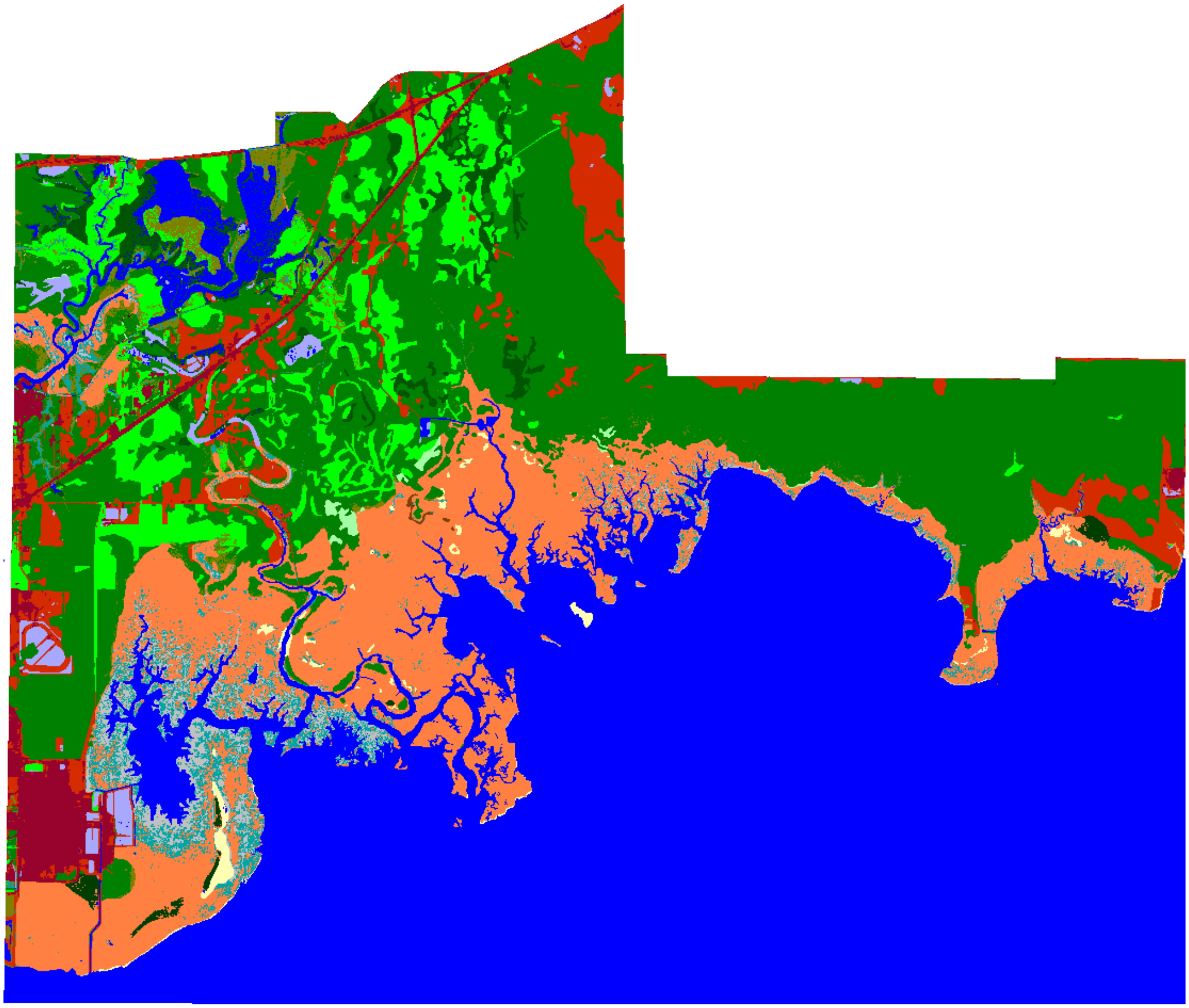
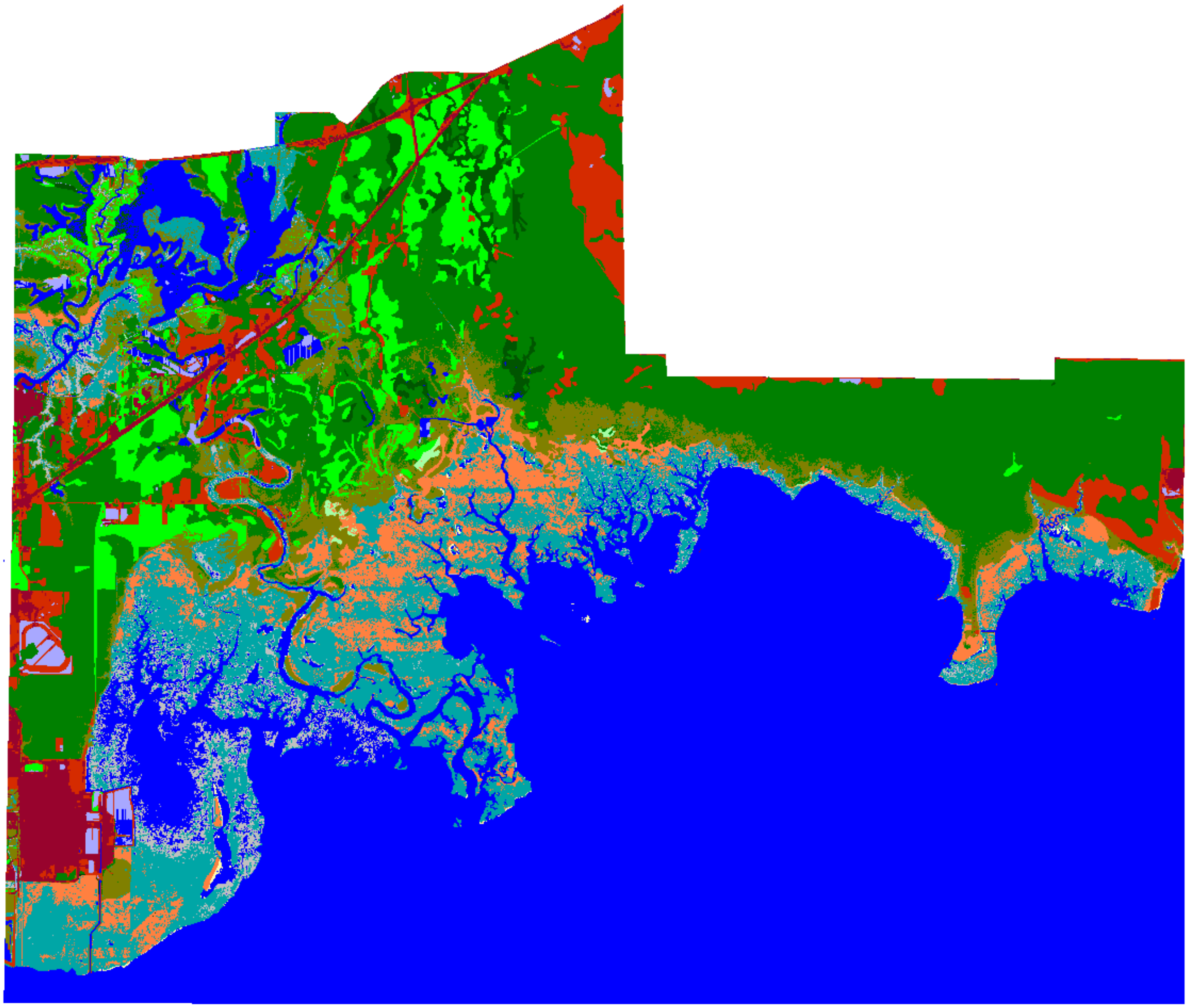


Grand Bay Context, 2025, 2 meter



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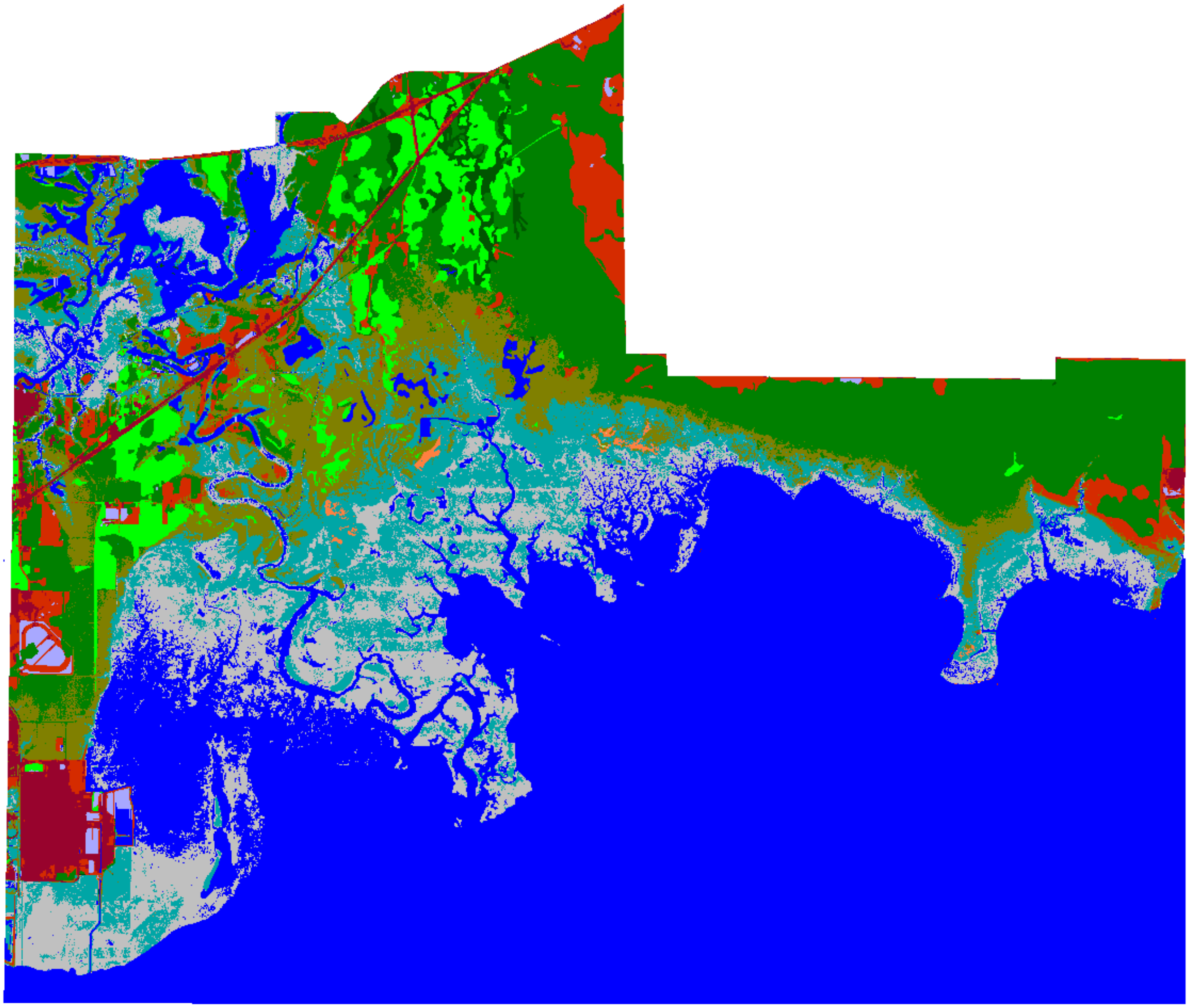
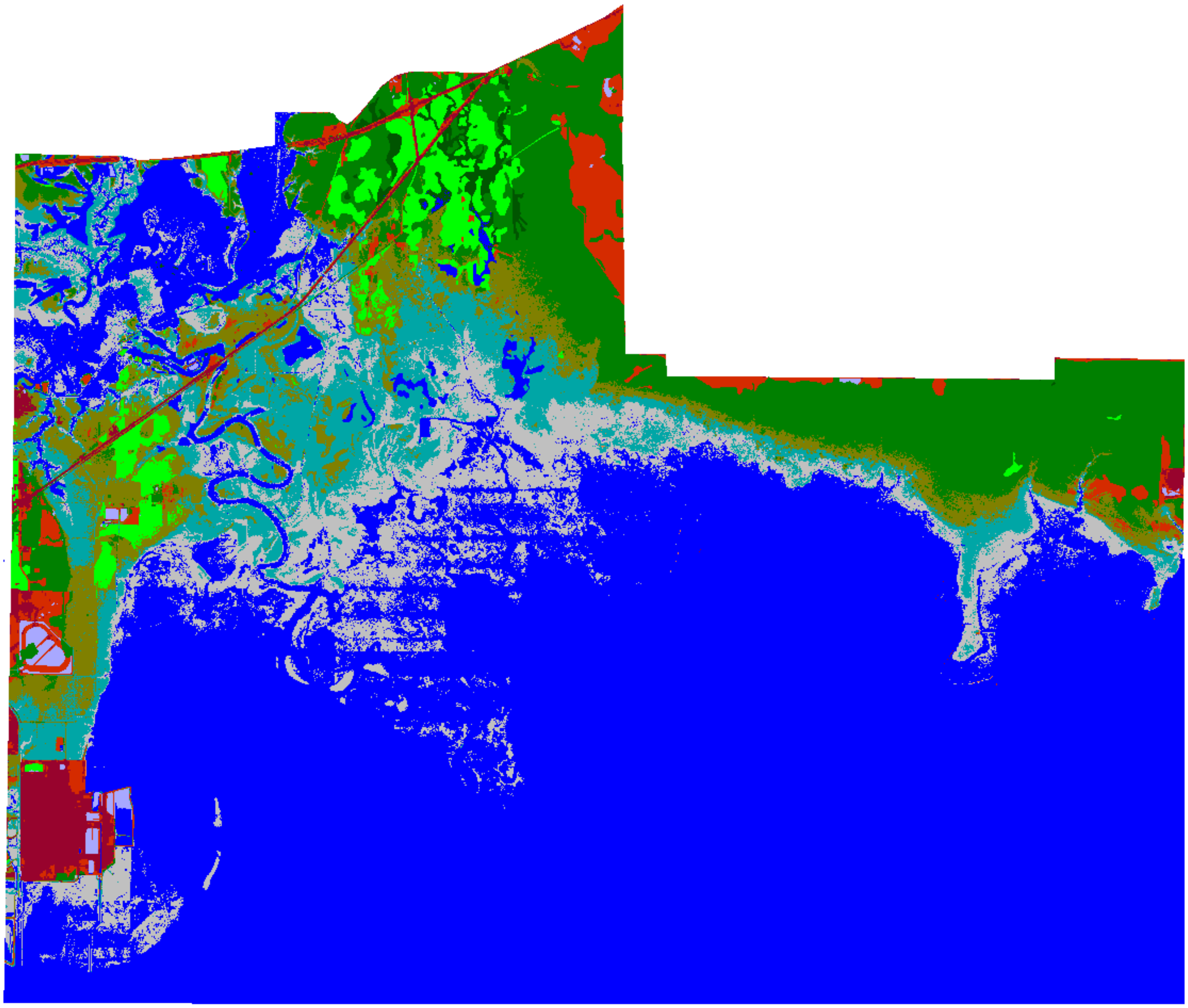


Grand Bay Context, 2075, 2 meter



Grand Bay Context, 2100, 2 meter