# Application of the Sea-Level Affecting Marshes Model (SLAMM 6) to Cedar Island NWR

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August 18, 2010

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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.

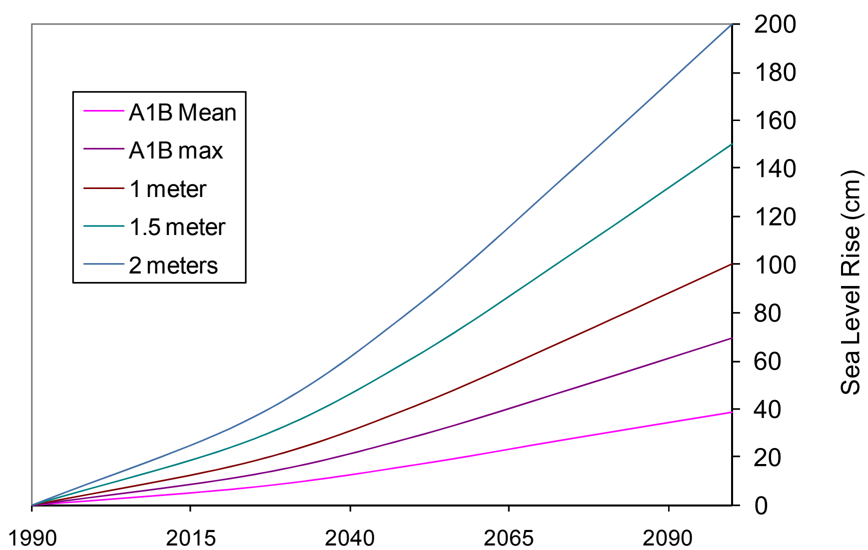
## *Sea Level Rise Scenarios*

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 National Elevation Dataset (NED) with a timestamp of 2003 (Figure 1). The northwest most portion of the study area apparently did not have LiDAR flown (elevations were all zero) so wetland elevations were estimated using the SLAMM pre-processor. The fringe of tidal flats at the north of the study area also did not have elevation data and were estimated in this manner as well.

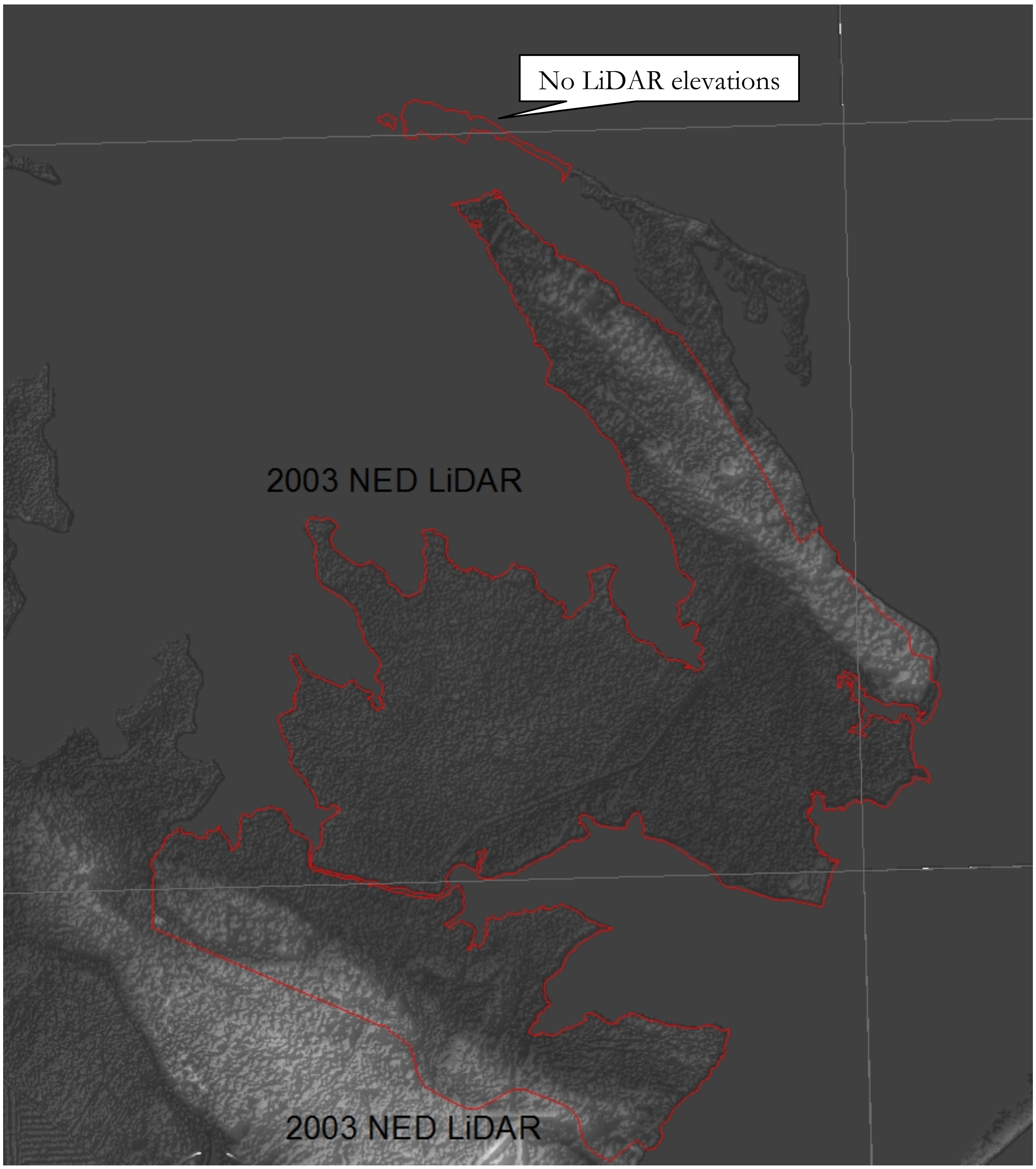



**Figure 1:** Shade-relief elevation map of refuge (red).

The wetlands layer for the study area was produced by the National Wetlands Inventory and was based on a 2008 photo date (Figure 2). Converting the NWI survey into 10 meter cells indicates that the approximately seventeen thousand acre refuge (approved acquisition boundary including water) is composed of the following categories (excluding categories below 1%):

| | | |
|---|---|---|
| | Regularly Flooded Marsh | 57.7% |
| | Swamp | 25.7% |
| | Irregularly Flooded Marsh | 8.5% |
| | Estuarine Open Water | 2.2% |
| | Undeveloped Dry Land | 1.6% |
| | Tidal Swamp | 1.3% |
| | Estuarine Beach | 1.1% |

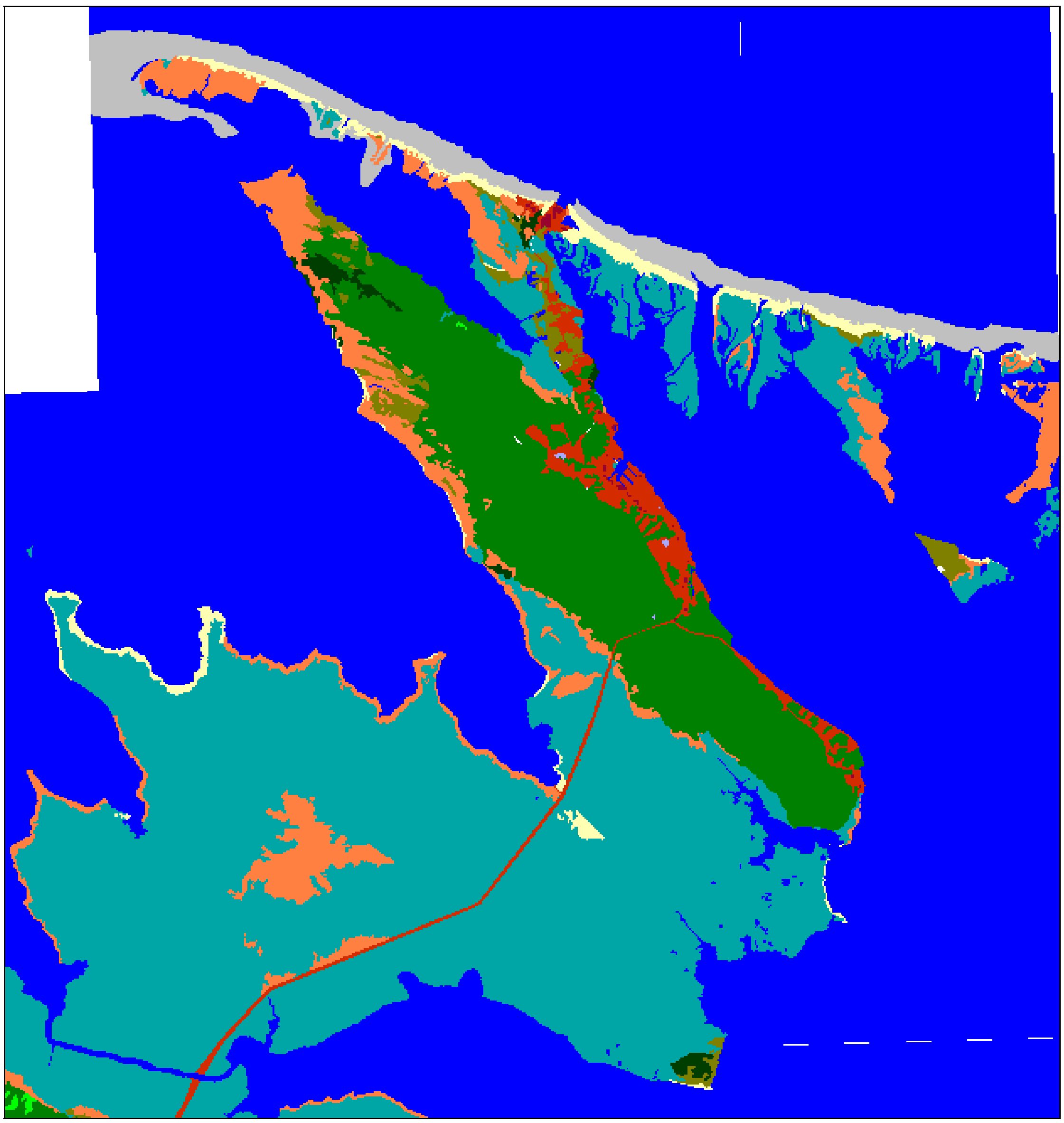


**Figure 2:** Cedar Island NWR wetlands layer.

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

The historic trend for sea level rise was estimated at 2.57 mm/year using the value of the nearest NOAA gage with SLR data (8656483, Beaufort, NC). The rate of sea level rise for this refuge has apparently been slightly higher that the global average for the last 100 years (approximately 1.7 mm/year, IPCC 2007a).

Two tide range values were used for this site (Figure 3). The tide value (great diurnal range or GT) used for the north and west of the refuge was estimated at 0.127 meters using the more northern of NOAA tide gage (8655151, Cedar Island, NC). The tide value used for the eastern shore of the refuge was estimated at 0.227 using the NOAA tide gage located to the east (8655875, Sea Level, NC) (see Input Parameter Table and Figure 5).

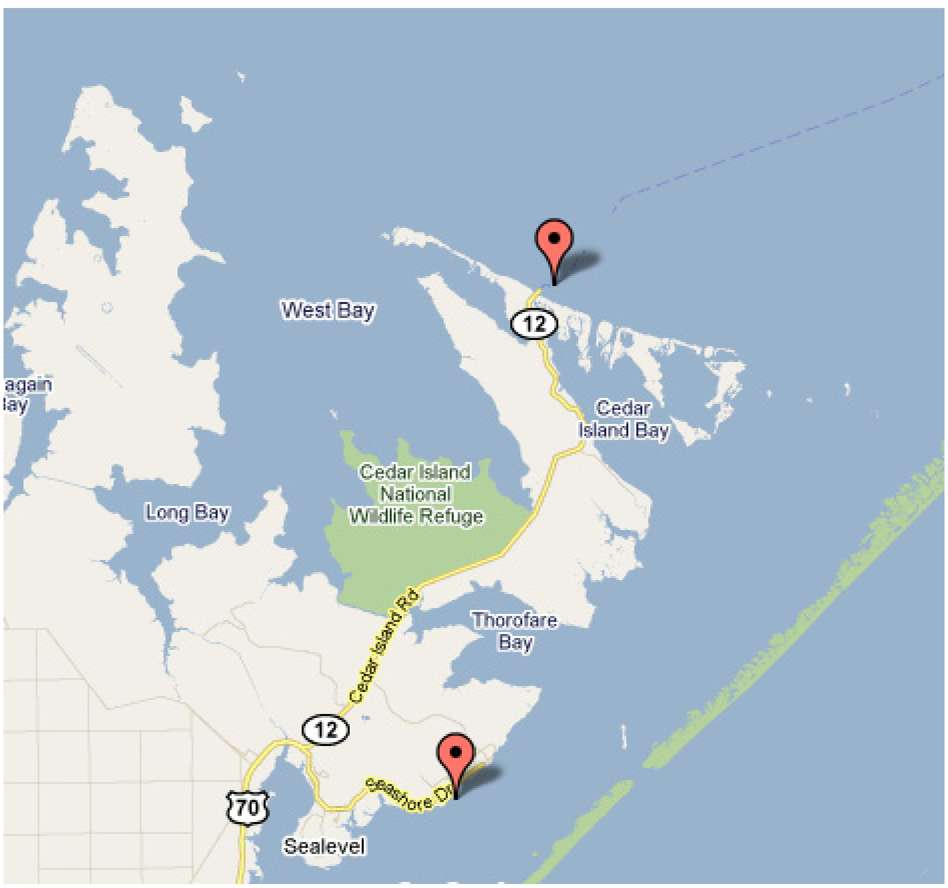



**Figure 3:** Location of NOAA tides gages used in refuge model application.

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 from the Sea Level, NC gage (8655875) (Figure 4). This procedure was done to include the effects of wind tides within estimates of land inundation, especially important at this site because lunar tides are extremely low in magnitude. The regularly flooded inundation level was assumed to occur where water penetrates at least once every 30 days, or approximately 290% of MHHW. A discussion with Kevin Keeler of Cedar Island Refuge confirmed that wind tide impact is important in the strip of irregularly flooded marsh that borders the regularly flooded marsh.

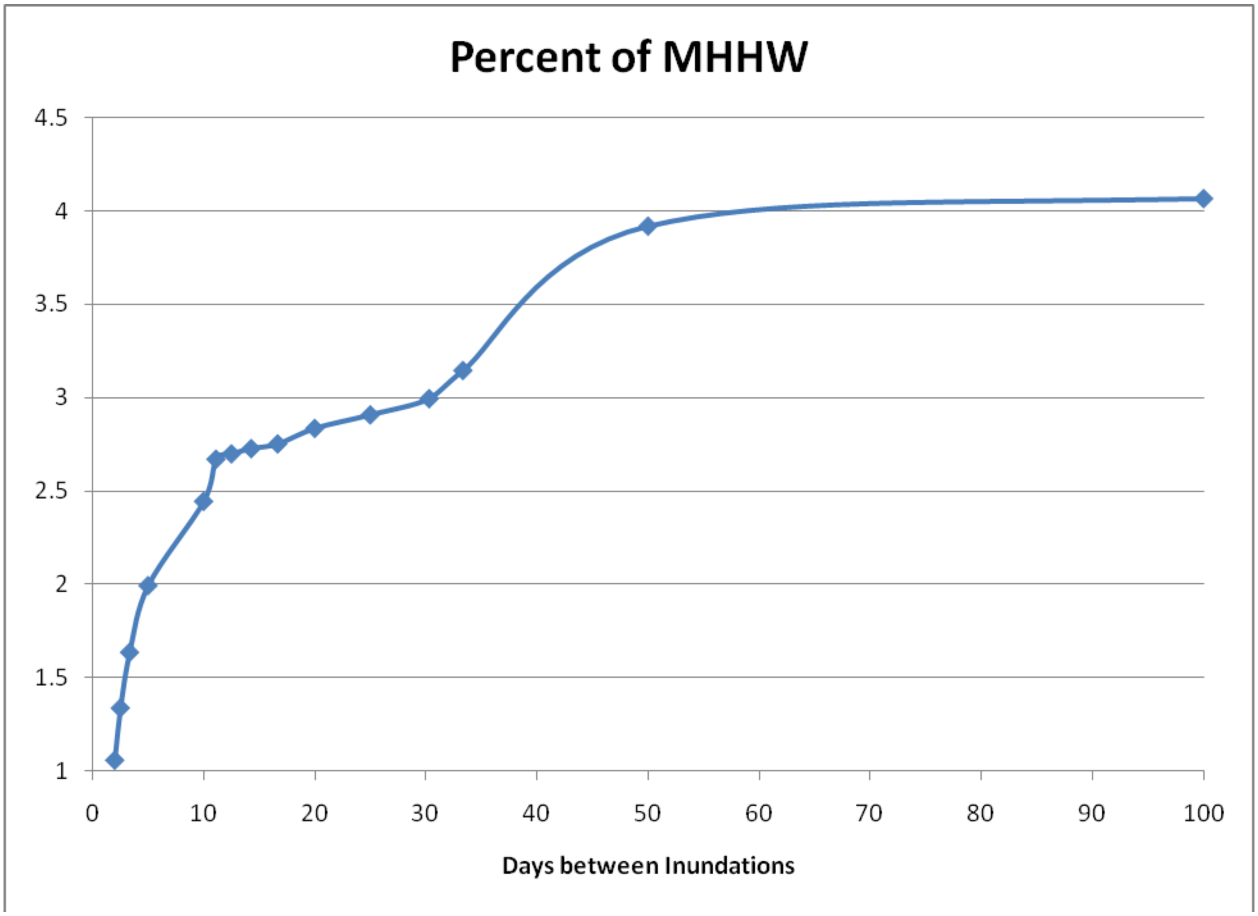



**Figure 4:** Percent inundation analysis.

Both regularly flooded and irregularly flooded marshes were parameterized using data directly measured on Cedar Island, with accretion rates set to 3.7 mm/year (Cahoon 1995). Tidal fresh marsh accretion values were set to 5.9 mm/year based upon an average of fresh marsh accretion rates within the region (Reed 2008, n=8)

The MTL to NAVD88 correction was derived using the NOAA VDATUM product. We used an elevation correction value of 0.018 meters for this study area.

Modeled U.S. Fish and Wildlife Service refuge boundaries for North Carolina 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.

Assumed upper elevation boundaries for regularly flooded, irregularly flooded, estuarine beach and tidal flat were also refined based on local LiDAR data to improve elevation pre-processing in the small non-LiDAR area in the northwest of the study area (subsite 2 in Figure 5).

## SUMMARY OF SLAMM INPUT PARAMETERS FOR CEDAR ISLAND NWR

| Parameter | Global | SubSite 1 | SubSite 2 |
|---|---|---|---|
| Description | Global | SubSite 1 | No LiDAR |
| NWI Photo Date (YYYY) | 2008 | 2008 | 2008 |
| DEM Date (YYYY) | 2003 | 2003 | 2003 |
| Direction Offshore [n,s,e,w] | North | East | North |
| Historic Trend (mm/yr) | 2.57 | 2.57 | 2.57 |
| MTL-NAVD88 (m) | -0.04 | -0.1 | -0.04 |
| GT Great Diurnal Tide Range (m) | 0.127 | 0.22 | 0.127 |
| Salt Elev. (m above MTL) | 0.18 | 0.32 | 0.18 |
| Marsh Erosion (horz. m /yr) | 1.8 | 1.8 | 1.8 |
| Swamp Erosion (horz. m /yr) | 1 | 1 | 1 |
| T.Flat Erosion (horz. m /yr) | 0.5 | 0.5 | 0.5 |
| Reg. Flood Marsh Accr (mm/yr) | 3.7 | 3.7 | 3.7 |
| Irreg. Flood Marsh Accr (mm/yr) | 3.7 | 3.7 | 3.7 |
| Tidal Fresh Marsh Accr (mm/yr) | 5.9 | 5.9 | 5.9 |
| Beach Sed. Rate (mm/yr) | 0.5 | 0.5 | 0.5 |
| Freq. Overwash (years) | 10 | 10 | 10 |
| Use Elev Pre-processor [True,False] | FALSE | FALSE | TRUE |

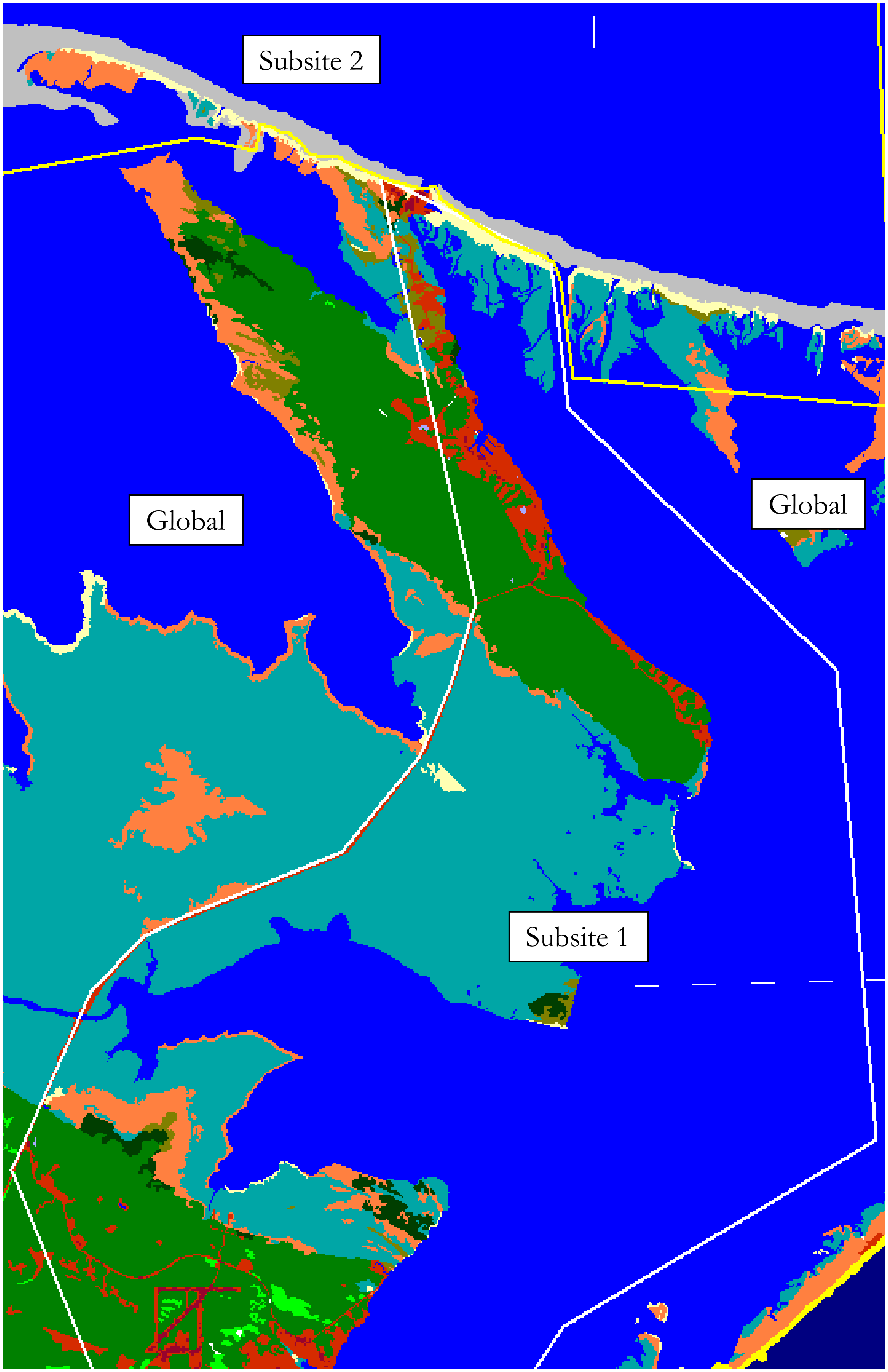



**Figure 5:** Input subsites for model application.

# Results

SLAMM predicts that Cedar Island NWR will be impacted by sea level rise inundation effects. While many the land categories fare well in the most conservative scenario, more extreme scenarios present the refuge with significant challenges. Between 24% and 88% of the refuge's regularly flooded marsh (which comprises a majority of the refuge) is predicted to be lost in scenarios of 0.69 meters and above. Between 16% and 63% of refuge swamp is predicted to be lost in the same range of scenarios. Between one third and two thirds of dry land is also predicted to be lost.

| Eustatic SLR by 2100 (m) | 0.39 | 0.69 | 1 | 1.5 | 2 |
|---|---|---|---|---|---|
| Regularly Flooded Marsh | 1% | 24% | 65% | 87% | 88% |
| Swamp | 4% | 16% | 26% | 43% | 63% |
| Irregularly Flooded Marsh | 0% | 22% | 61% | 94% | 98% |
| Undeveloped Dry Land | 31% | 37% | 43% | 50% | 64% |
| Tidal Swamp | 35% | 54% | 73% | 95% | 100% |
| Estuarine Beach | 32% | 63% | 89% | 100% | 100% |

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

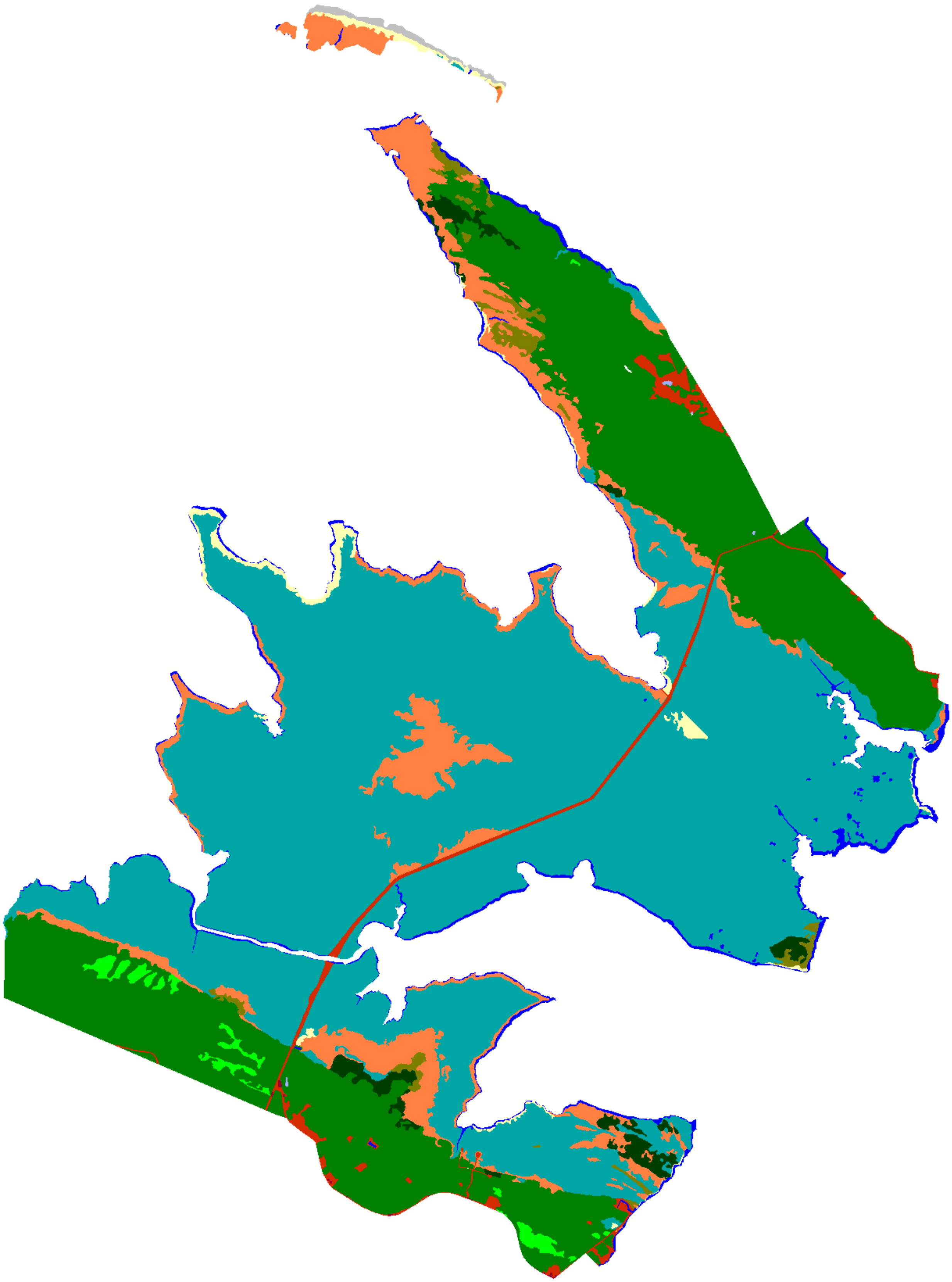
Maps of SLAMM input and output to follow will use the following legend:

| | |
|---|---|
| Undeveloped Dry Land | |
| Swamp | |
| Tidal Swamp | |
| Tidal Fresh Marsh | |
| Riverine Tidal | |
| Inland Open Water | |
| Inland Fresh Marsh | |
| Cypress Swamp | |
| Irregularly Flooded Marsh | |
| Estuarine Open Water | |
| Regularly Flooded Marsh | |
| Transitional Salt Marsh | |
| Tidal Flat | |

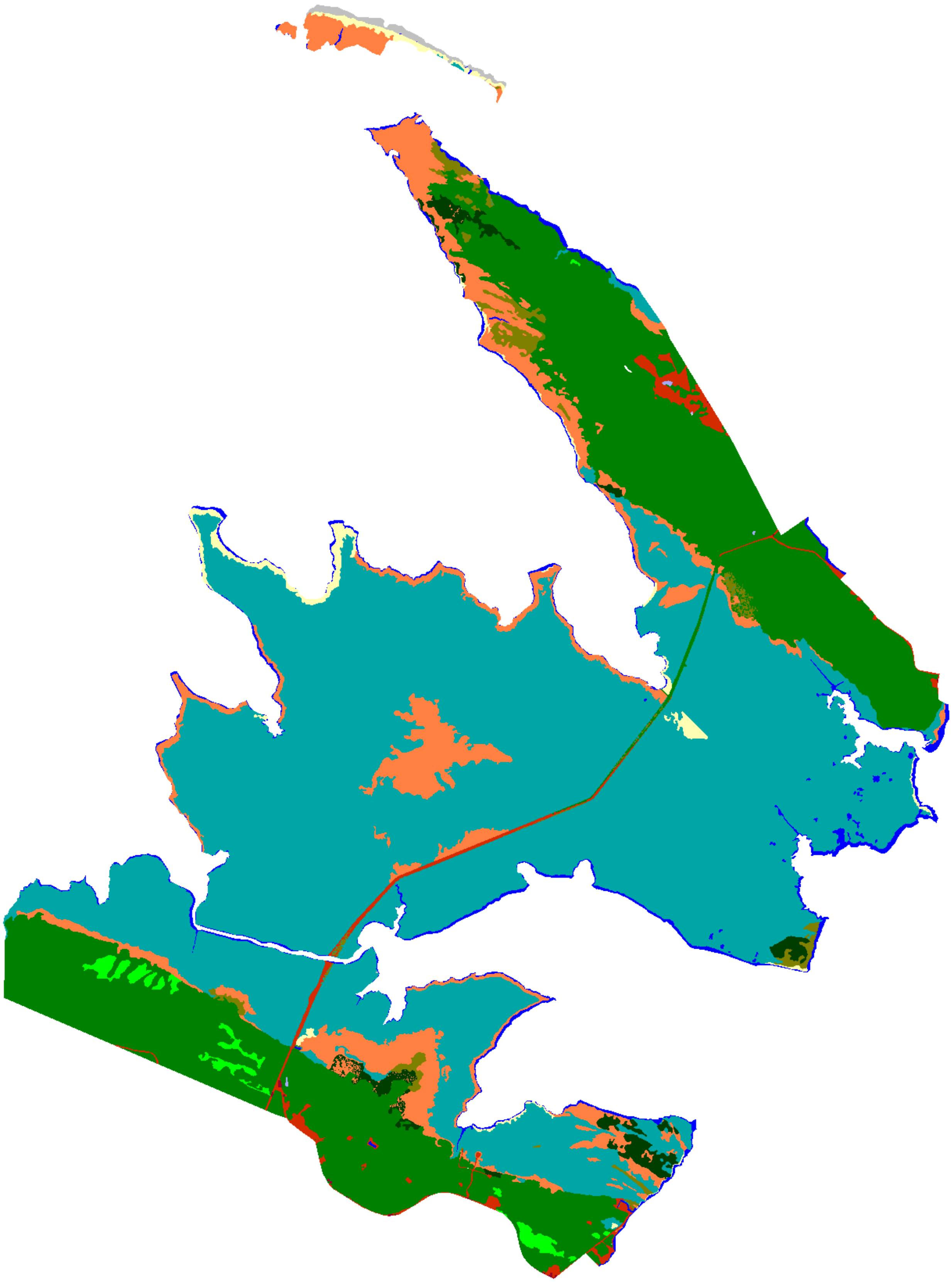
Cedar Island NWR
IPCC Scenario A1B-Mean, 0.39 M SLR Eustatic by 2100

Results in Acres

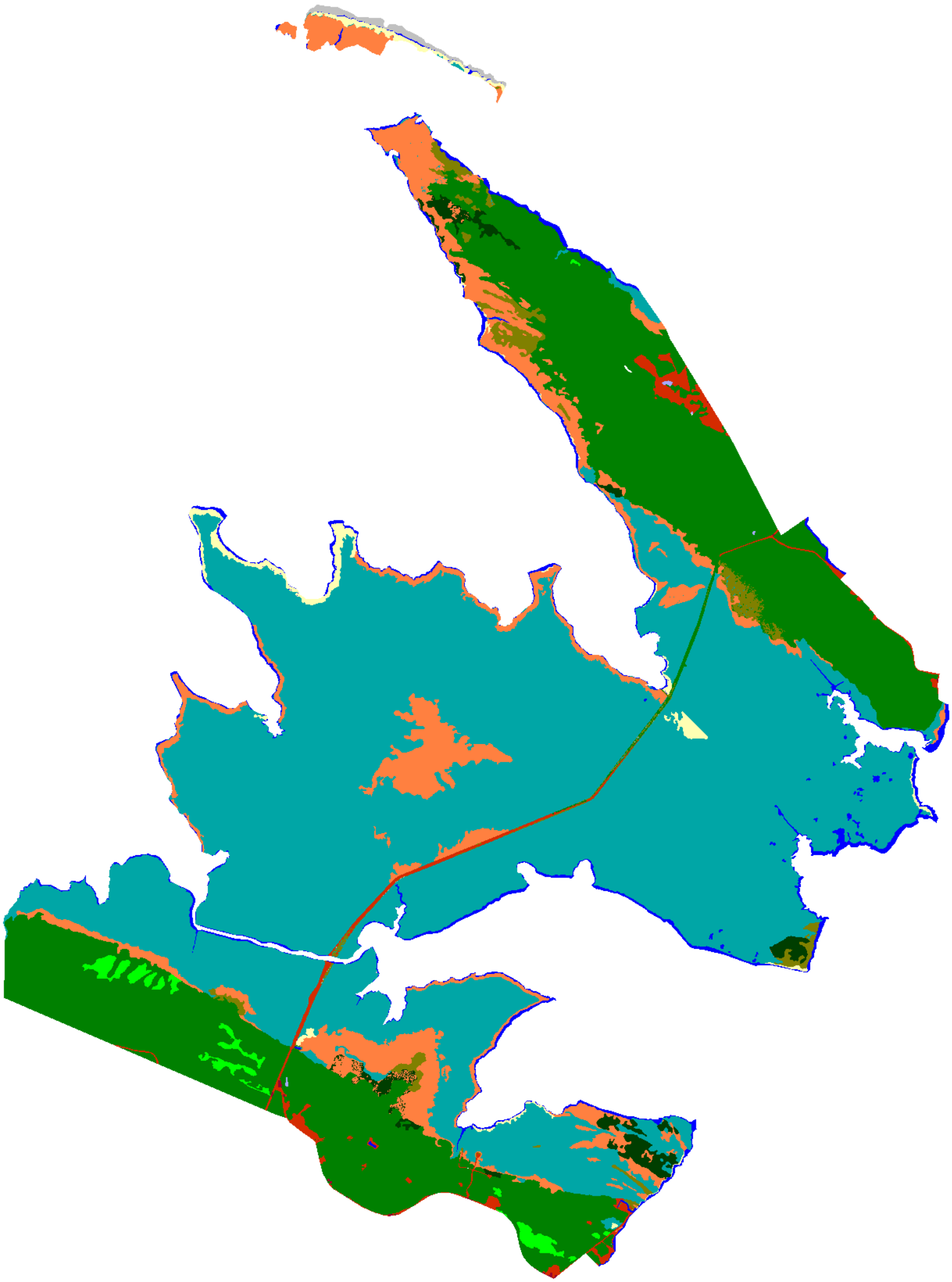
| | | Initial | 2025 | 2050 | 2075 | 2100 |
|---|---|---|---|---|---|---|
| | Regularly Flooded Marsh | 9722.2 | 9725.2 | 9734.3 | 9714.6 | 9667.7 |
| | Swamp | 4333.4 | 4353.1 | 4318.3 | 4258.0 | 4175.3 |
| | Irregularly Flooded Marsh | 1429.8 | 1432.7 | 1438.2 | 1439.8 | 1436.1 |
| | Estuarine Open Water | 373.8 | 383.3 | 405.4 | 439.1 | 505.4 |
| | Undeveloped Dry Land | 273.8 | 221.0 | 214.7 | 202.3 | 190.0 |
| | Tidal Swamp | 214.1 | 196.6 | 179.4 | 157.3 | 139.5 |
| | Estuarine Beach | 181.1 | 177.9 | 165.0 | 140.7 | 122.5 |
| | Transitional Salt Marsh | 153.6 | 183.4 | 222.5 | 285.0 | 342.9 |
| | Inland Fresh Marsh | 112.3 | 112.3 | 112.3 | 112.3 | 112.3 |
| | Tidal Flat | 43.9 | 52.6 | 47.9 | 88.9 | 146.4 |
| | Developed Dry Land | 4.5 | 4.5 | 4.5 | 4.5 | 4.5 |
| | Inland Open Water | 2.9 | 2.9 | 2.9 | 2.9 | 2.9 |
| | **Total (incl. water)** | **16845.5** | **16845.5** | **16845.5** | **16845.5** | **16845.5** |



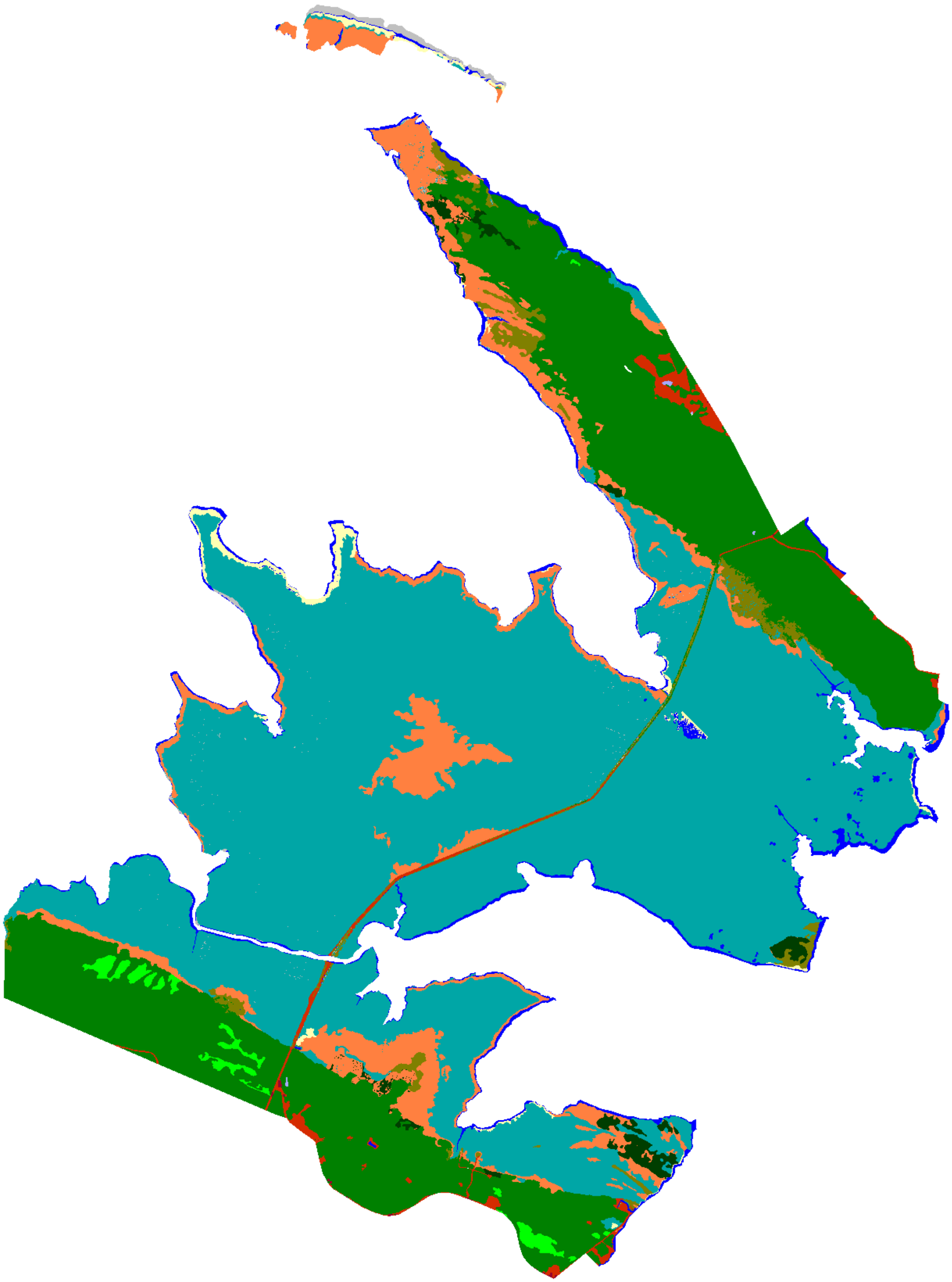
Cedar Island NWR, Initial Condition



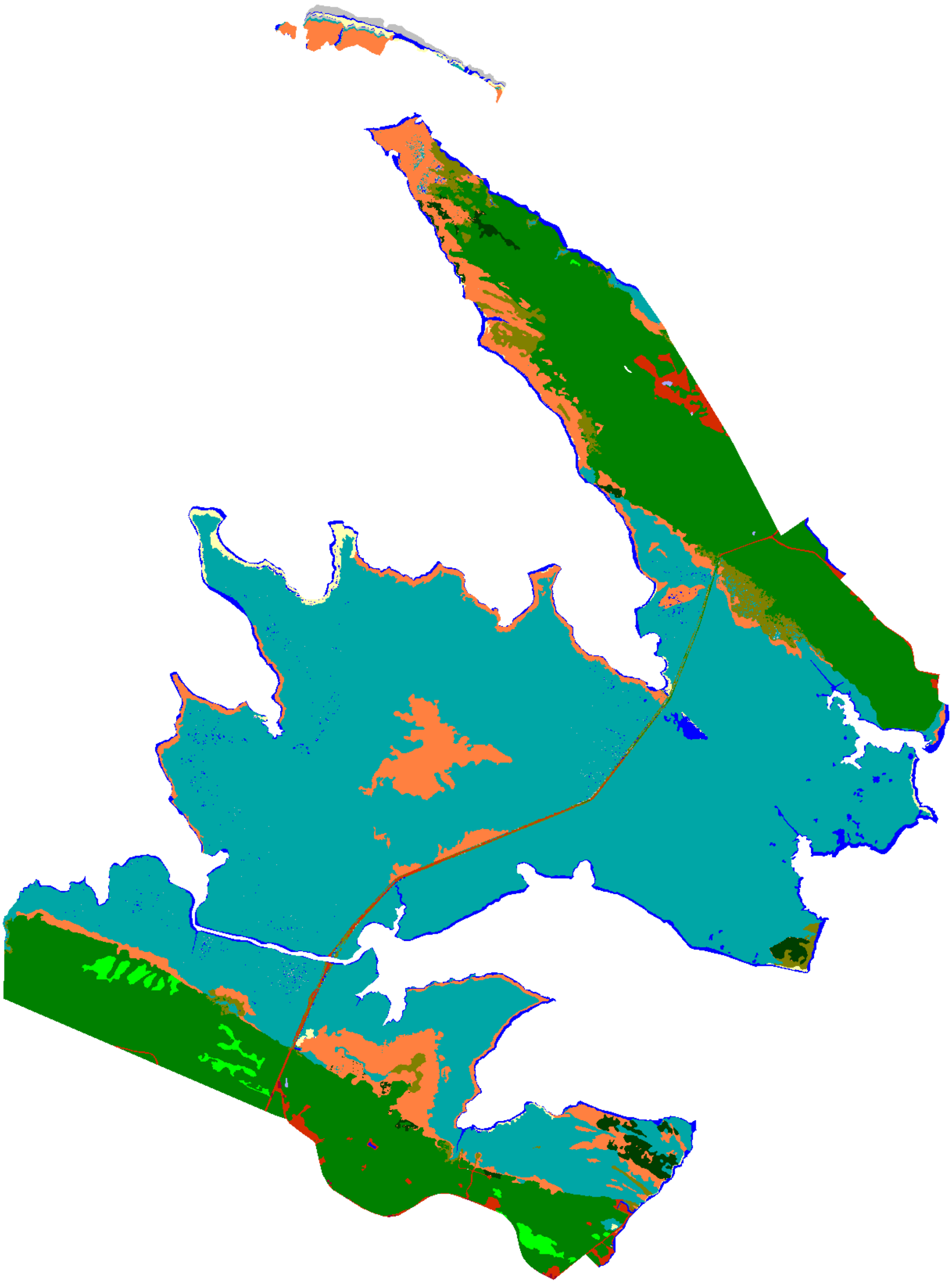
Cedar Island NWR, 2025, Scenario A1B Mean



Cedar Island NWR, 2050, Scenario A1B Mean



Cedar Island NWR, 2075, Scenario A1B Mean

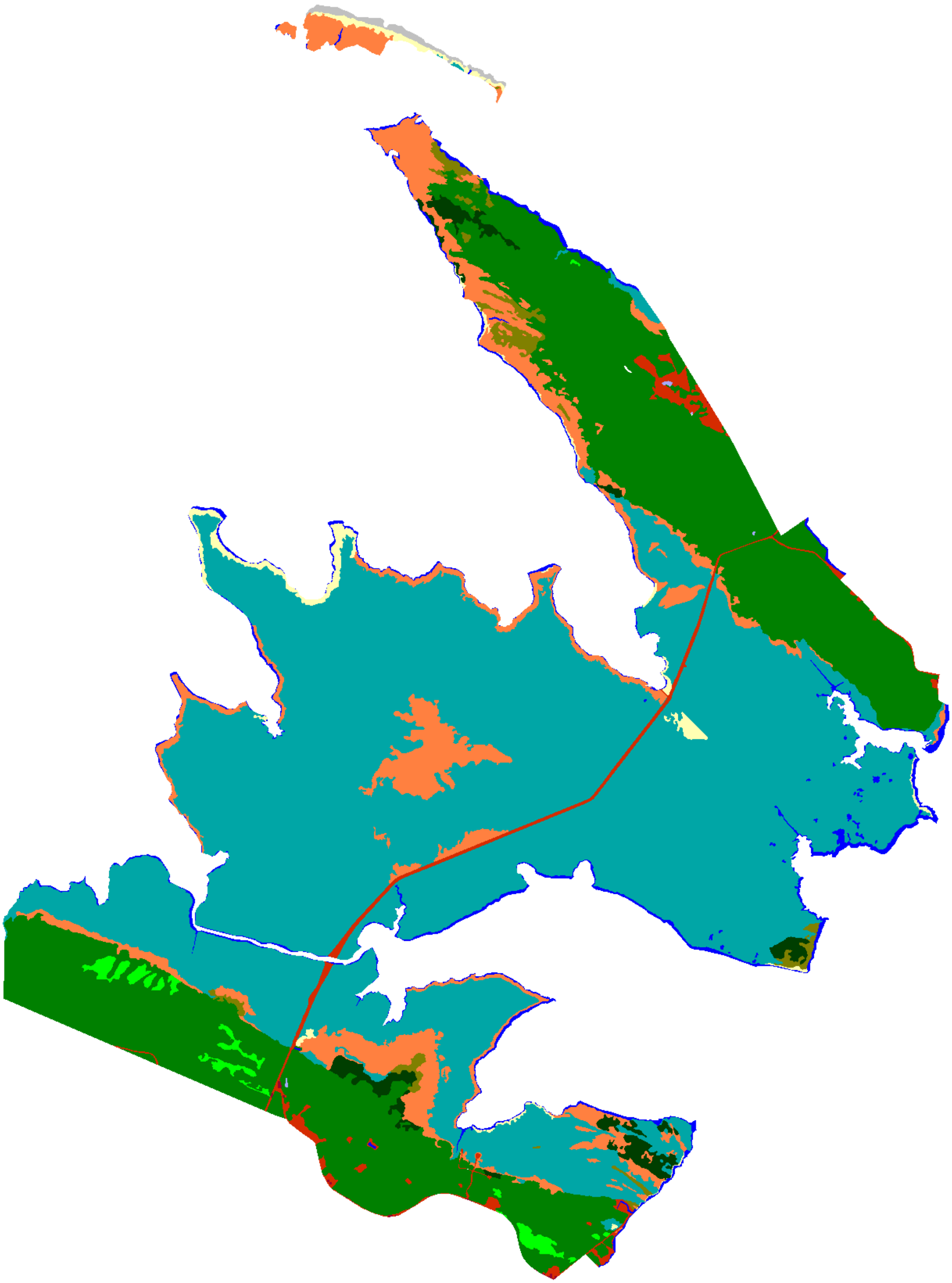


Cedar Island NWR, 2100, Scenario A1B Mean

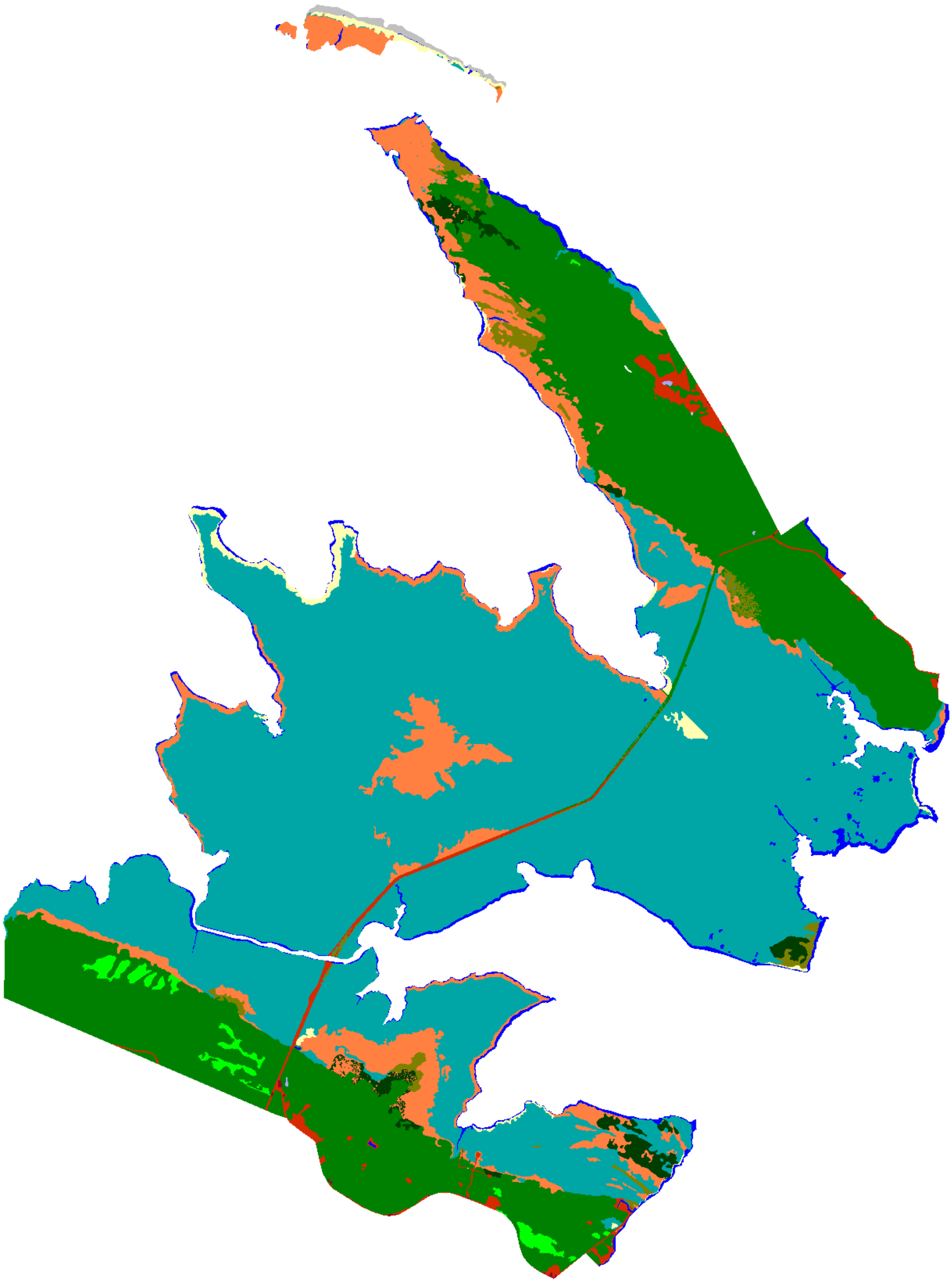
Cedar Island NWR
IPCC Scenario A1B-Max, 0.69 M SLR Eustatic by 2100

Results in Acres

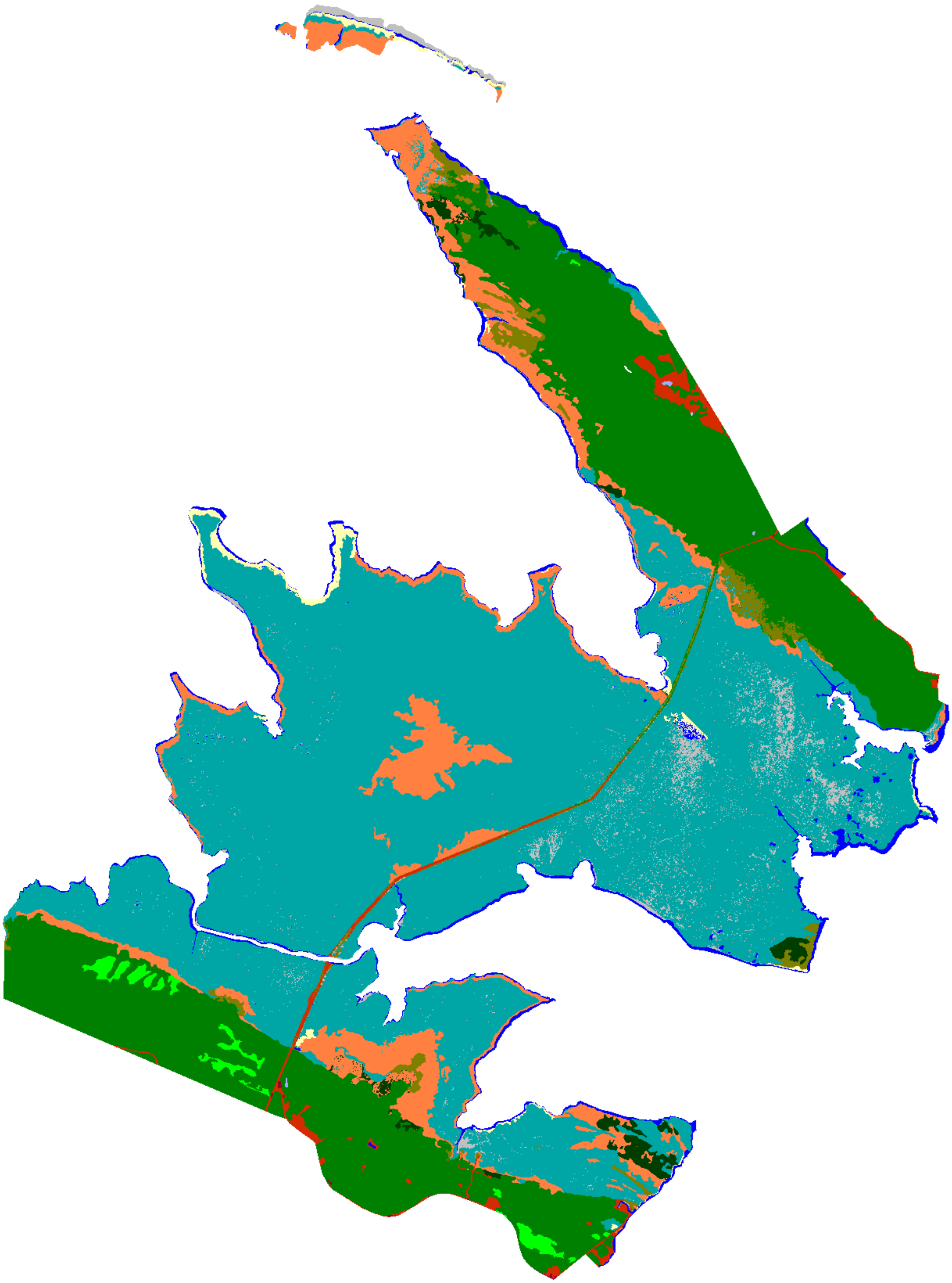
| | | Initial | 2025 | 2050 | 2075 | 2100 |
|---|---|---|---|---|---|---|
| | Regularly Flooded Marsh | 9722.2 | 9734.2 | 9516.5 | 8630.3 | 7359.8 |
| | Swamp | 4333.4 | 4341.0 | 4268.0 | 4061.7 | 3655.1 |
| | Irregularly Flooded Marsh | 1429.8 | 1423.6 | 1408.1 | 1325.3 | 1117.5 |
| | Estuarine Open Water | 373.8 | 388.4 | 435.5 | 750.7 | 1913.1 |
| | Undeveloped Dry Land | 273.8 | 219.5 | 205.1 | 186.8 | 173.2 |
| | Tidal Swamp | 214.1 | 191.7 | 160.2 | 128.6 | 98.5 |
| | Estuarine Beach | 181.1 | 176.0 | 148.1 | 113.3 | 66.8 |
| | Transitional Salt Marsh | 153.6 | 195.0 | 270.0 | 395.4 | 574.0 |
| | Inland Fresh Marsh | 112.3 | 112.3 | 112.3 | 112.3 | 112.2 |
| | Tidal Flat | 43.9 | 56.4 | 314.3 | 1133.7 | 1767.8 |
| | Developed Dry Land | 4.5 | 4.5 | 4.5 | 4.5 | 4.5 |
| | Inland Open Water | 2.9 | 2.9 | 2.9 | 2.9 | 2.9 |
| | **Total (incl. water)** | **16845.5** | **16845.5** | **16845.5** | **16845.5** | **16845.5** |



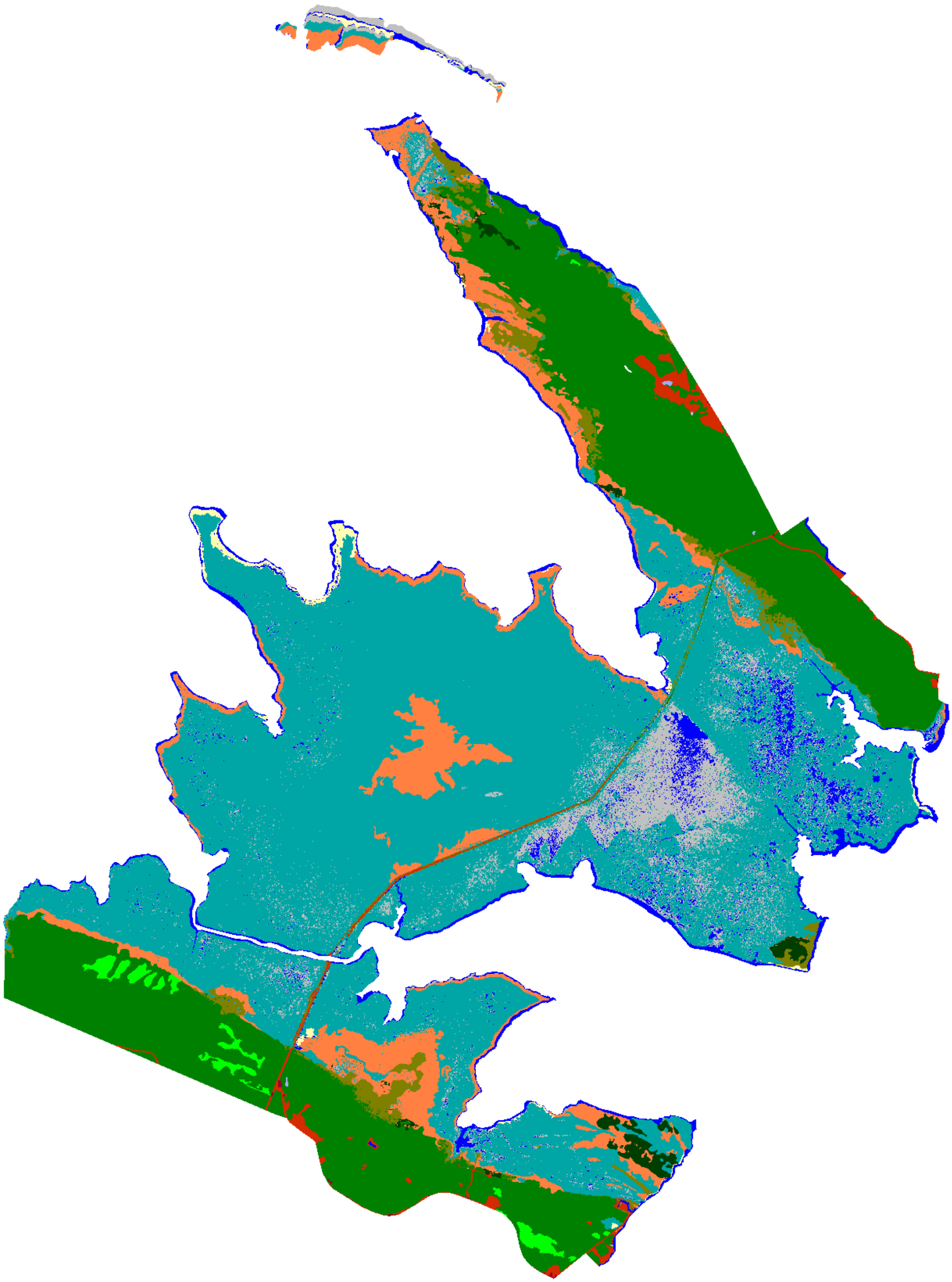
Cedar Island NWR, Initial Condition



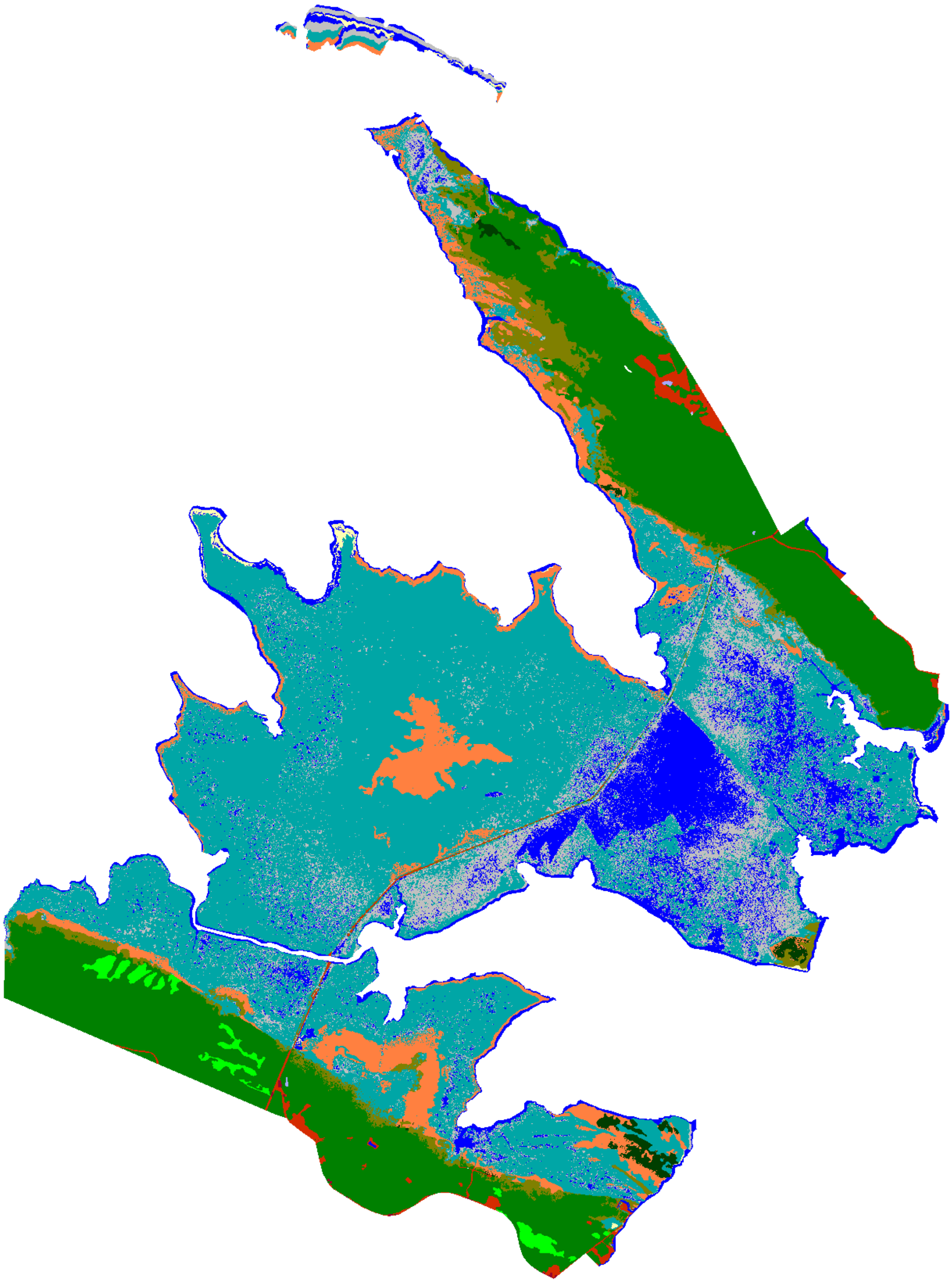
Cedar Island NWR, 2025, Scenario A1B Maximum



Cedar Island NWR, 2050, Scenario A1B Maximum



Cedar Island NWR, 2075, Scenario A1B Maximum

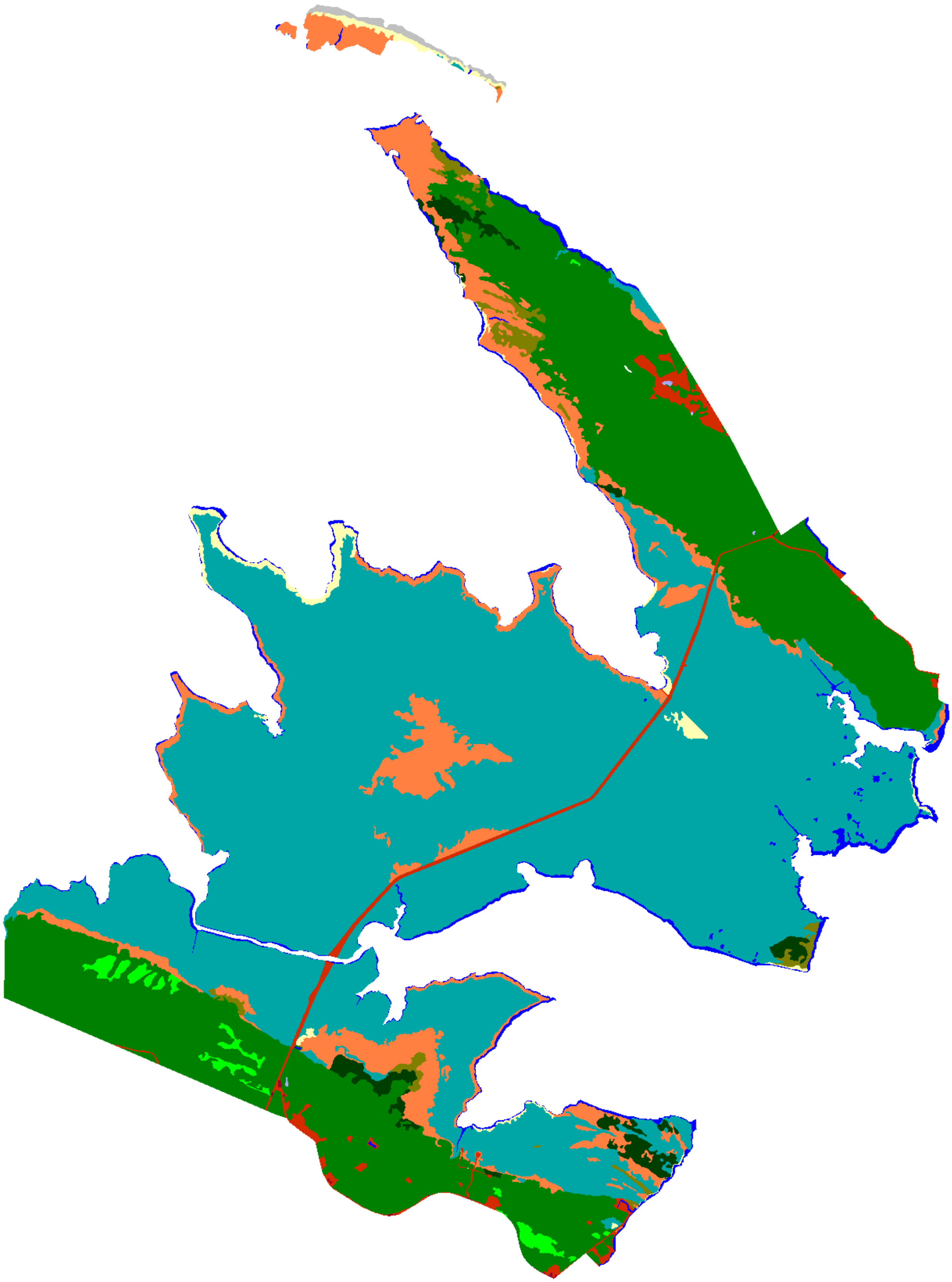


Cedar Island NWR, 2100, Scenario A1B Maximum

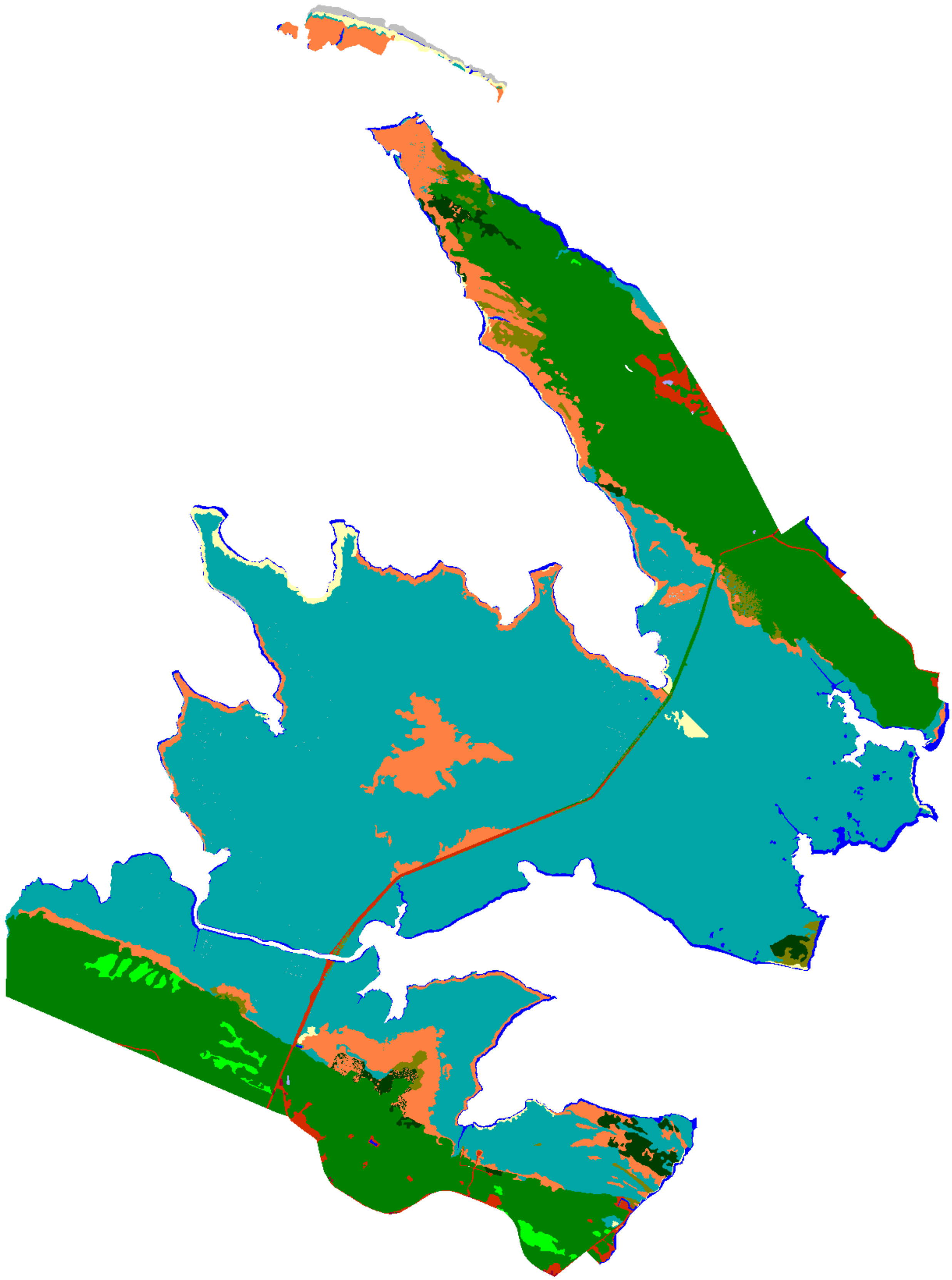
Cedar Island NWR
1 Meter Eustatic SLR by 2100

Results in Acres

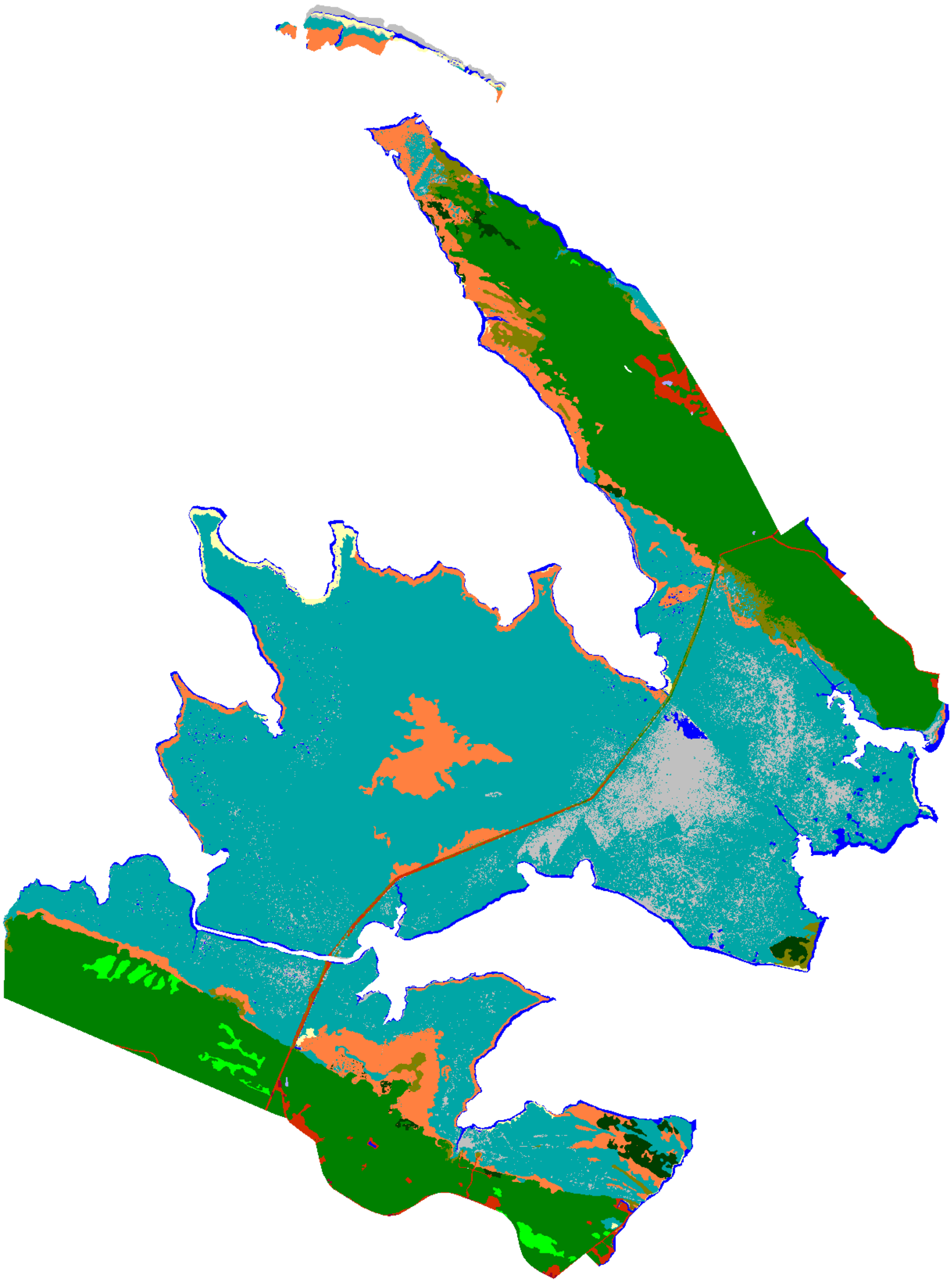
| | | Initial | 2025 | 2050 | 2075 | 2100 |
|---|---|---|---|---|---|---|
| | Regularly Flooded Marsh | 9722.2 | 9726.1 | 8851.1 | 6819.7 | 3385.9 |
| | Swamp | 4333.4 | 4331.2 | 4224.3 | 3717.4 | 3193.0 |
| | Irregularly Flooded Marsh | 1429.8 | 1415.3 | 1352.3 | 1037.9 | 554.4 |
| | Estuarine Open Water | 373.8 | 393.3 | 481.3 | 1573.6 | 4290.8 |
| | Undeveloped Dry Land | 273.8 | 217.5 | 196.3 | 175.8 | 154.9 |
| | Tidal Swamp | 214.1 | 186.2 | 142.9 | 101.1 | 58.5 |
| | Estuarine Beach | 181.1 | 173.2 | 129.9 | 74.7 | 19.9 |
| | Transitional Salt Marsh | 153.6 | 204.3 | 291.4 | 651.7 | 608.3 |
| | Inland Fresh Marsh | 112.3 | 112.3 | 112.3 | 112.1 | 111.0 |
| | Tidal Flat | 43.9 | 78.7 | 1056.2 | 2573.9 | 4461.3 |
| | Developed Dry Land | 4.5 | 4.5 | 4.5 | 4.5 | 4.5 |
| | Inland Open Water | 2.9 | 2.9 | 2.9 | 2.9 | 2.9 |
| | **Total (incl. water)** | **16845.5** | **16845.5** | **16845.5** | **16845.5** | **16845.5** |



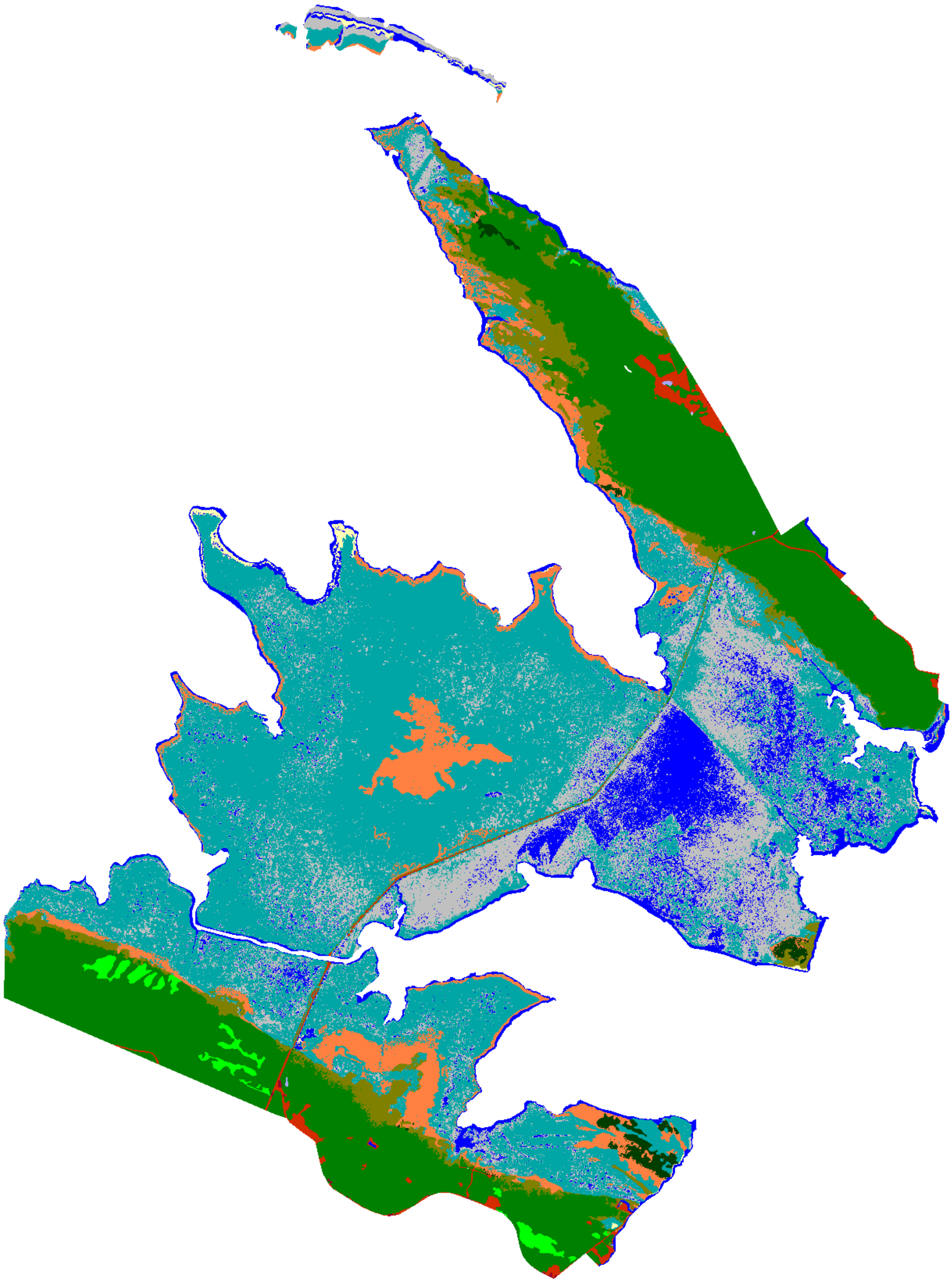
Cedar Island NWR, Initial Condition



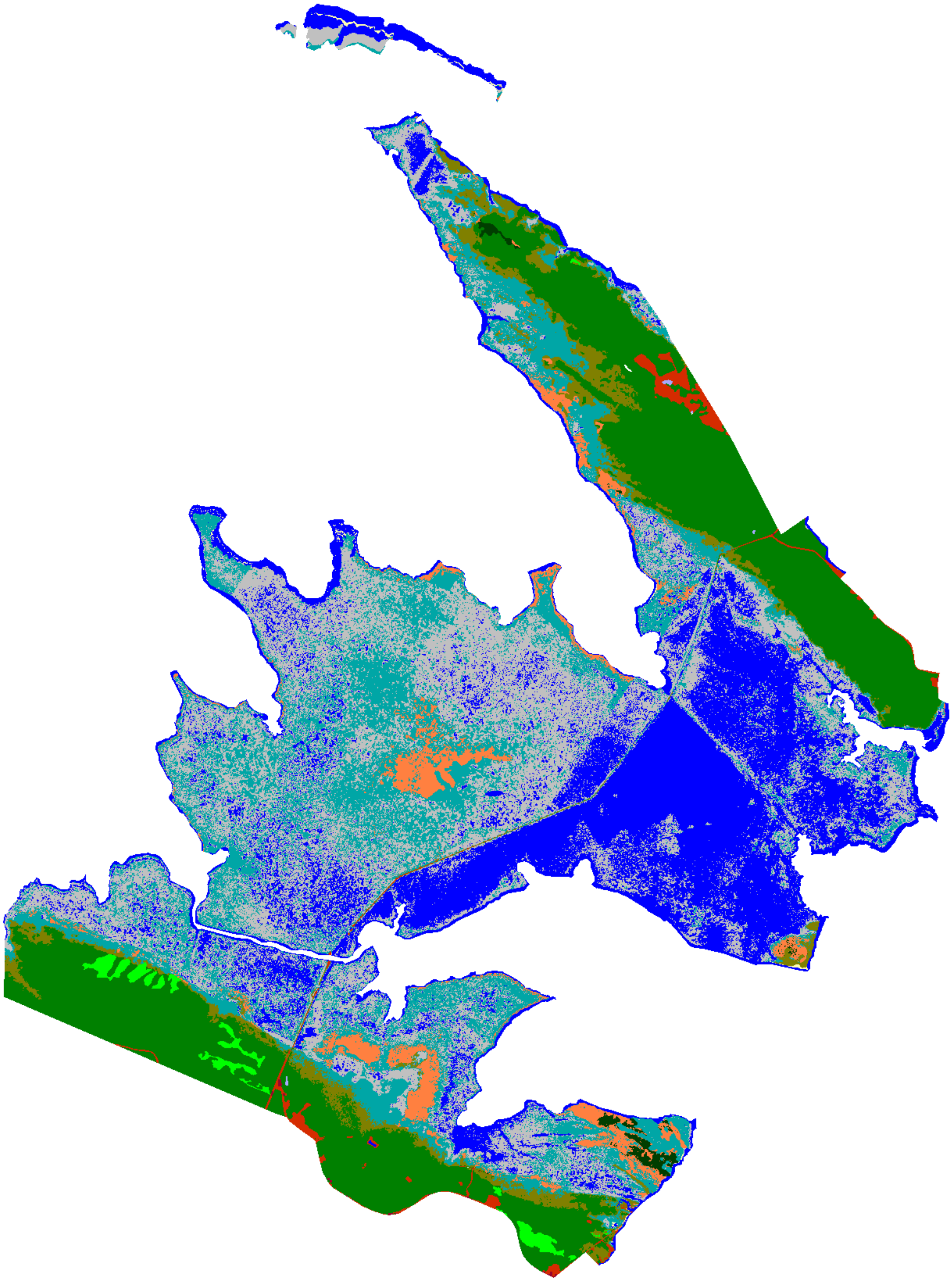
Cedar Island NWR, 2025, 1 meter



Cedar Island NWR, 2050, 1 meter



Cedar Island NWR, 2075, 1 meter

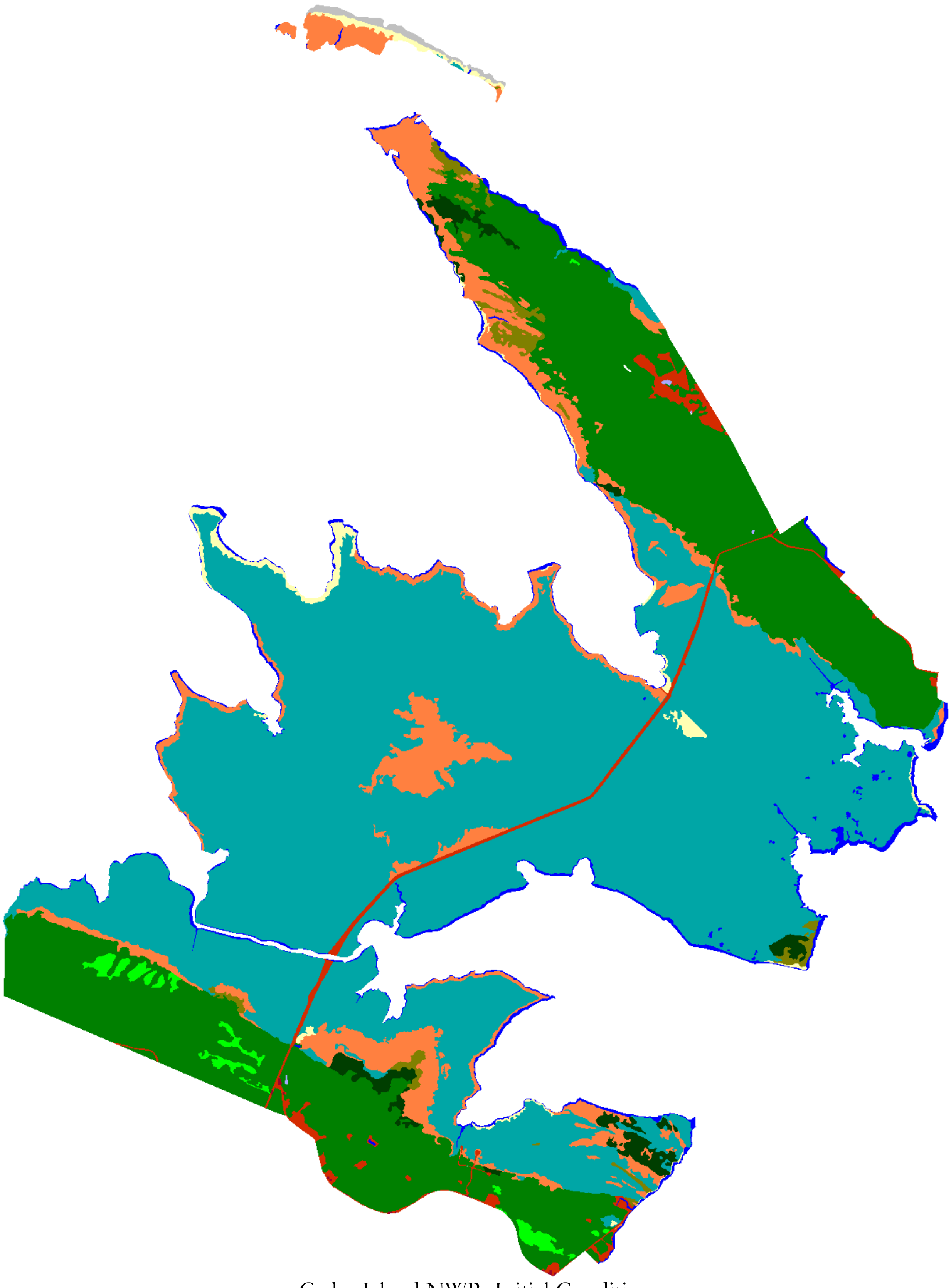


Cedar Island NWR, 2100, 1 meter

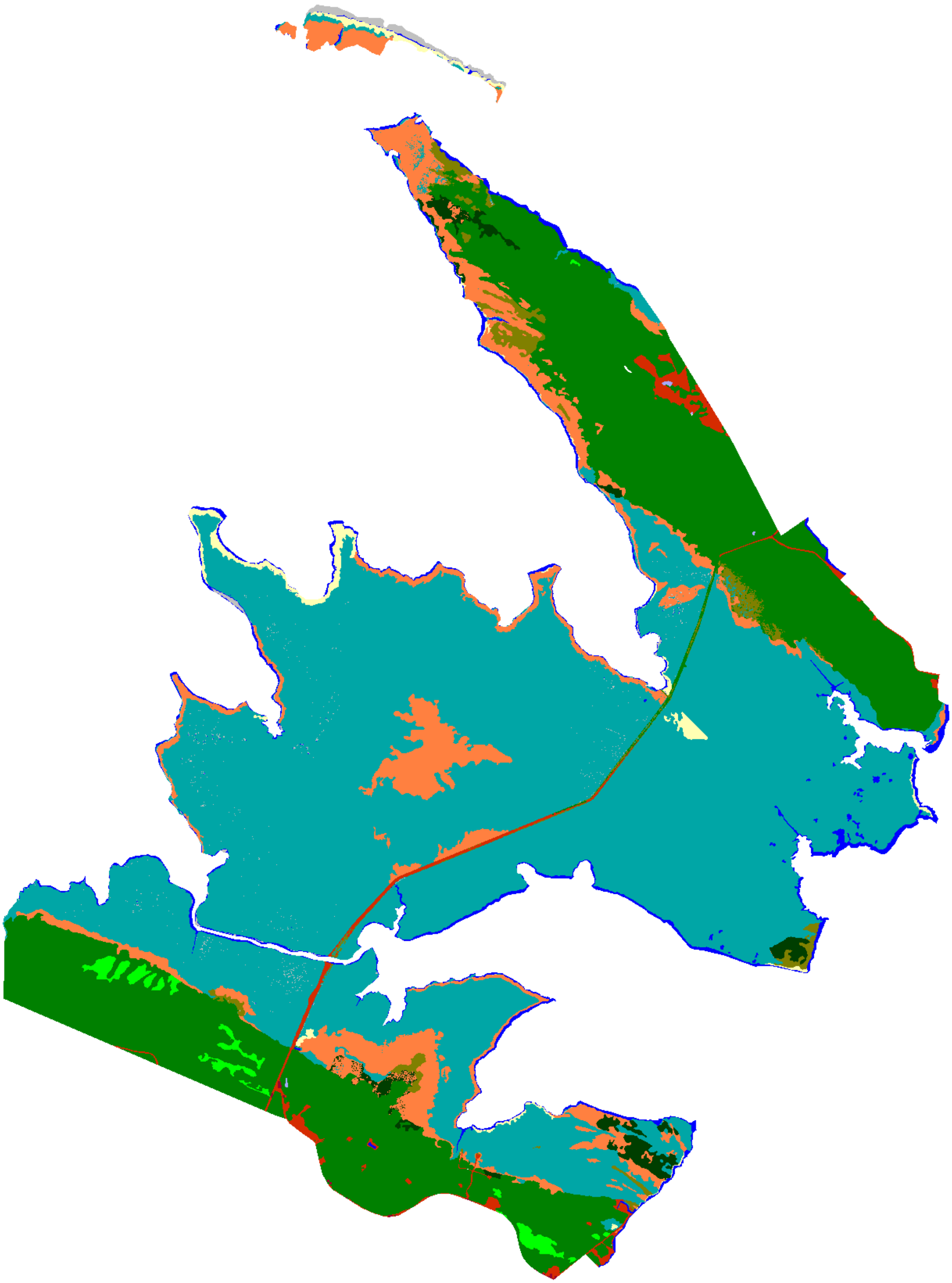
Cedar Island NWR
1.5 Meters Eustatic SLR by 2100

Results in Acres

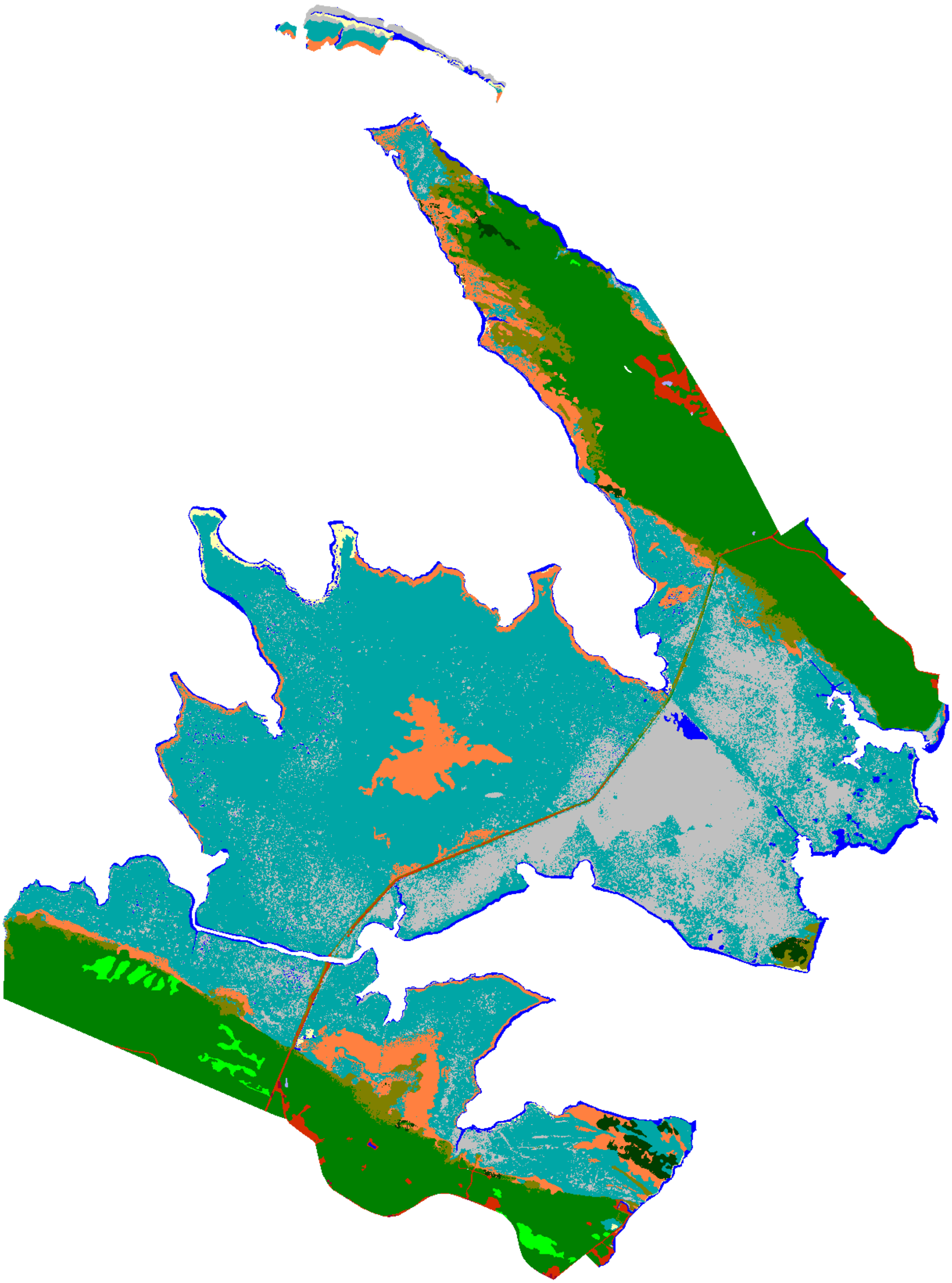
| | | Initial | 2025 | 2050 | 2075 | 2100 |
|---|---|---|---|---|---|---|
| | Regularly Flooded Marsh | 9722.2 | 9671.4 | 7455.6 | 2481.7 | 1226.9 |
| | Swamp | 4333.4 | 4311.9 | 3925.4 | 3216.2 | 2459.4 |
| | Irregularly Flooded Marsh | 1429.8 | 1400.3 | 1162.1 | 450.4 | 86.3 |
| | Estuarine Open Water | 373.8 | 403.2 | 598.8 | 3347.1 | 9624.1 |
| | Undeveloped Dry Land | 273.8 | 214.7 | 184.8 | 156.4 | 136.7 |
| | Tidal Swamp | 214.1 | 176.6 | 120.3 | 57.6 | 10.5 |
| | Estuarine Beach | 181.1 | 165.4 | 105.3 | 21.9 | 0.8 |
| | Transitional Salt Marsh | 153.6 | 220.8 | 549.6 | 786.6 | 785.8 |
| | Inland Fresh Marsh | 112.3 | 112.3 | 112.2 | 110.2 | 105.6 |
| | Tidal Flat | 43.9 | 161.4 | 2623.9 | 6210.0 | 2402.4 |
| | Developed Dry Land | 4.5 | 4.5 | 4.5 | 4.5 | 4.4 |
| | Inland Open Water | 2.9 | 2.9 | 2.9 | 2.9 | 2.6 |
| | **Total (incl. water)** | **16845.5** | **16845.5** | **16845.5** | **16845.5** | **16845.5** |



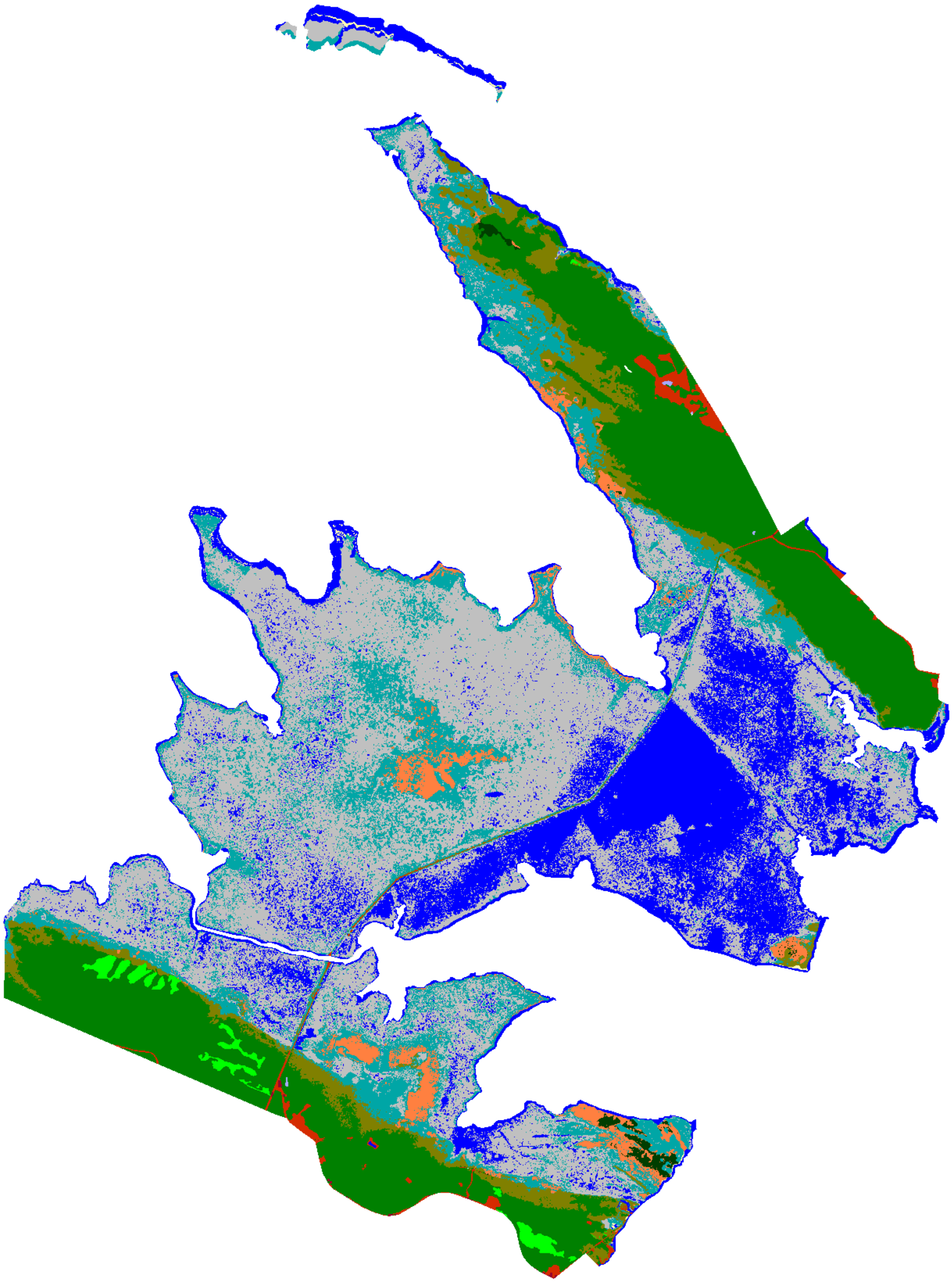
Cedar Island NWR, Initial Condition



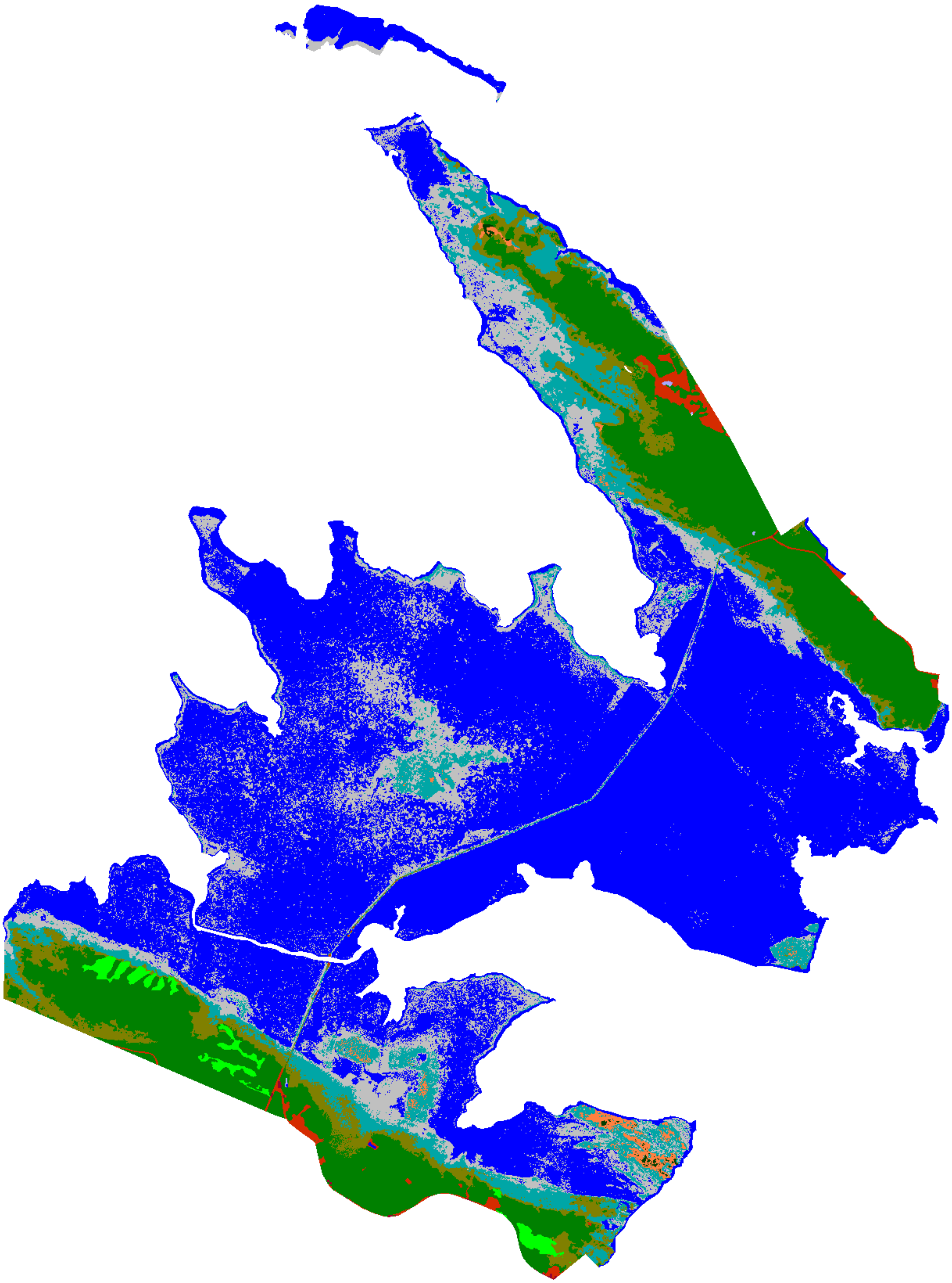
Cedar Island NWR, 2025, 1.5 meter



Cedar Island NWR, 2050, 1.5 meter



Cedar Island NWR, 2075, 1.5 meter

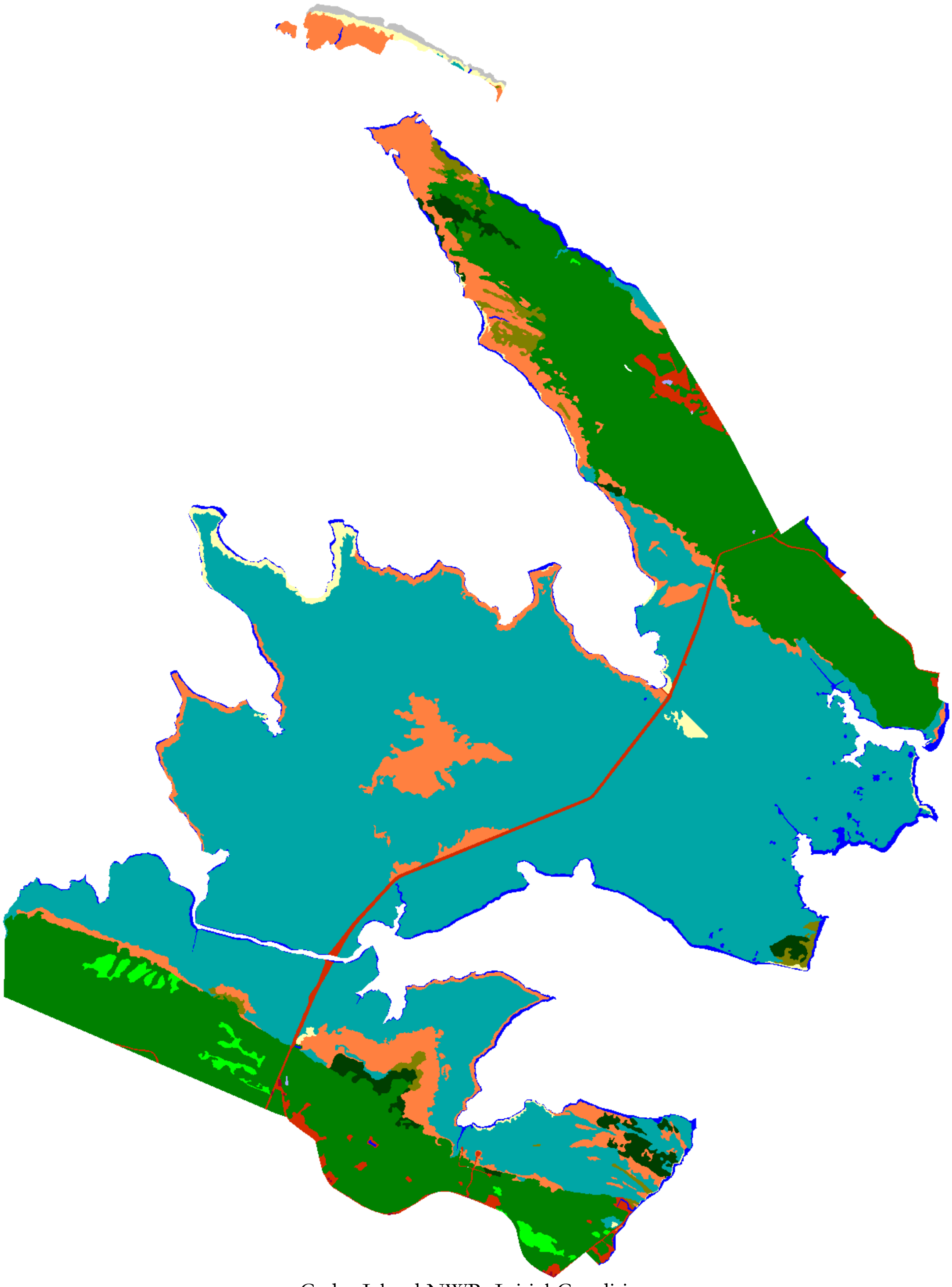


Cedar Island NWR, 2100, 1.5 meter

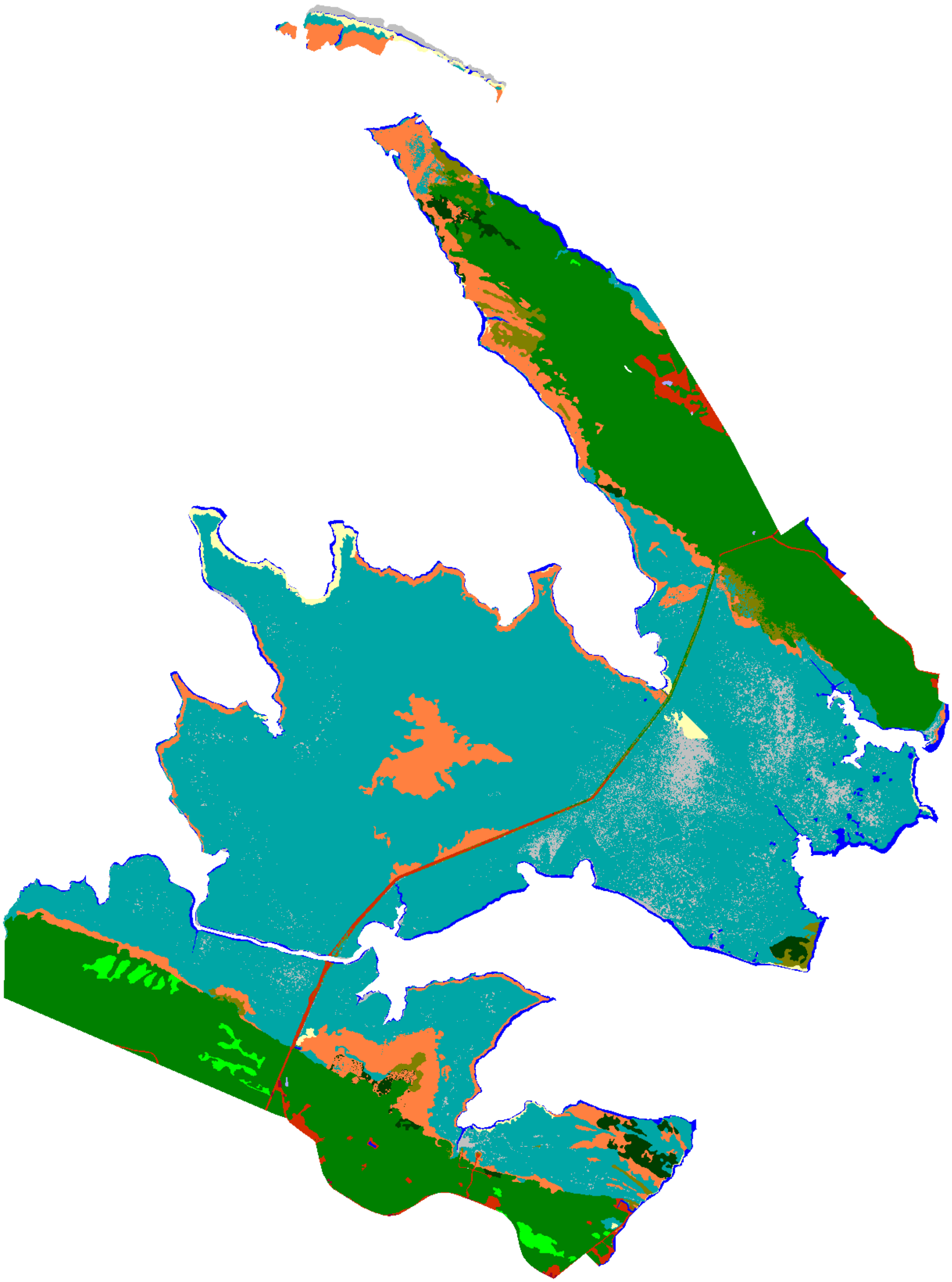
Cedar Island NWR
2 Meters Eustatic SLR by 2100

Results in Acres

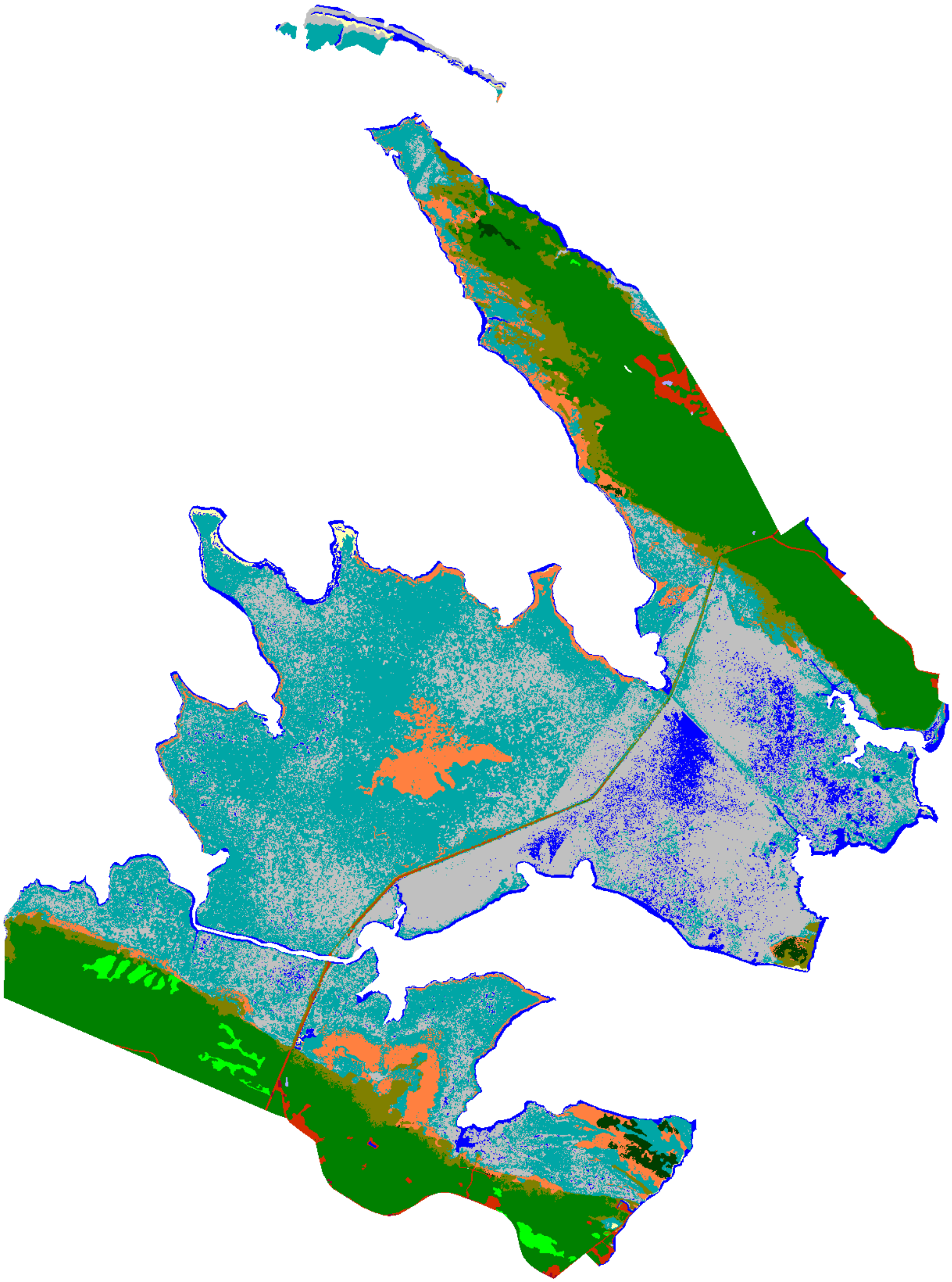
| | | Initial | 2025 | 2050 | 2075 | 2100 |
|---|---|---|---|---|---|---|
| | Regularly Flooded Marsh | 9722.2 | 9316.8 | 5508.0 | 1571.0 | 1155.4 |
| | Swamp | 4333.4 | 4290.2 | 3697.6 | 2734.1 | 1594.3 |
| | Irregularly Flooded Marsh | 1429.8 | 1379.9 | 864.4 | 145.2 | 24.2 |
| | Estuarine Open Water | 373.8 | 409.3 | 1043.2 | 5691.3 | 11140.6 |
| | Undeveloped Dry Land | 273.8 | 211.3 | 175.6 | 143.0 | 97.9 |
| | Tidal Swamp | 214.1 | 166.9 | 97.0 | 23.1 | 0.0 |
| | Estuarine Beach | 181.1 | 161.0 | 71.6 | 4.9 | 0.1 |
| | Transitional Salt Marsh | 153.6 | 239.1 | 732.7 | 1011.5 | 1195.7 |
| | Inland Fresh Marsh | 112.3 | 112.3 | 111.8 | 105.9 | 95.2 |
| | Tidal Flat | 43.9 | 551.3 | 4536.2 | 5408.0 | 1536.4 |
| | Developed Dry Land | 4.5 | 4.5 | 4.5 | 4.4 | 4.2 |
| | Inland Open Water | 2.9 | 2.9 | 2.9 | 2.9 | 1.5 |
| | **Total (incl. water)** | **16845.5** | **16845.5** | **16845.5** | **16845.5** | **16845.5** |



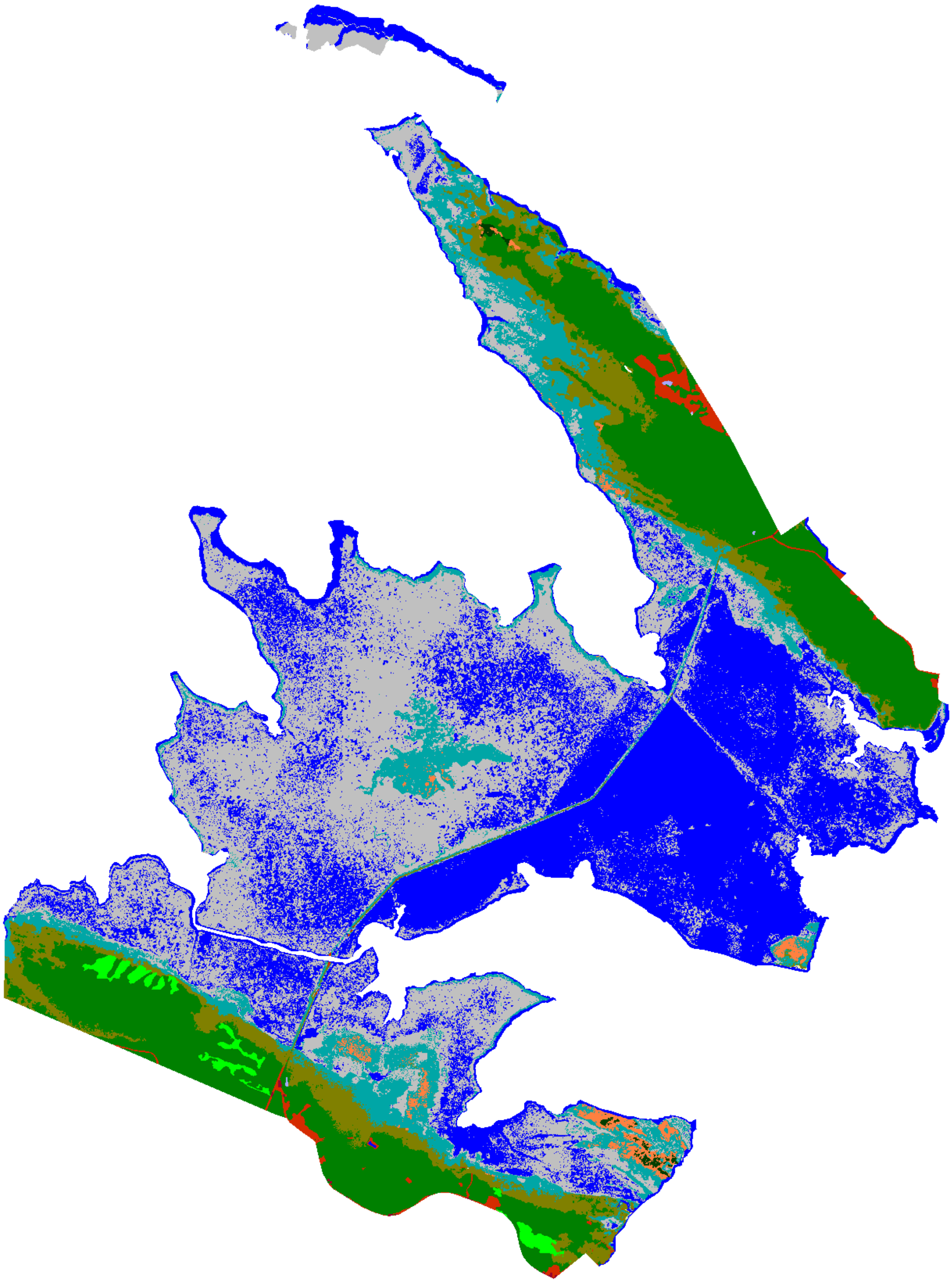
Cedar Island NWR, Initial Condition



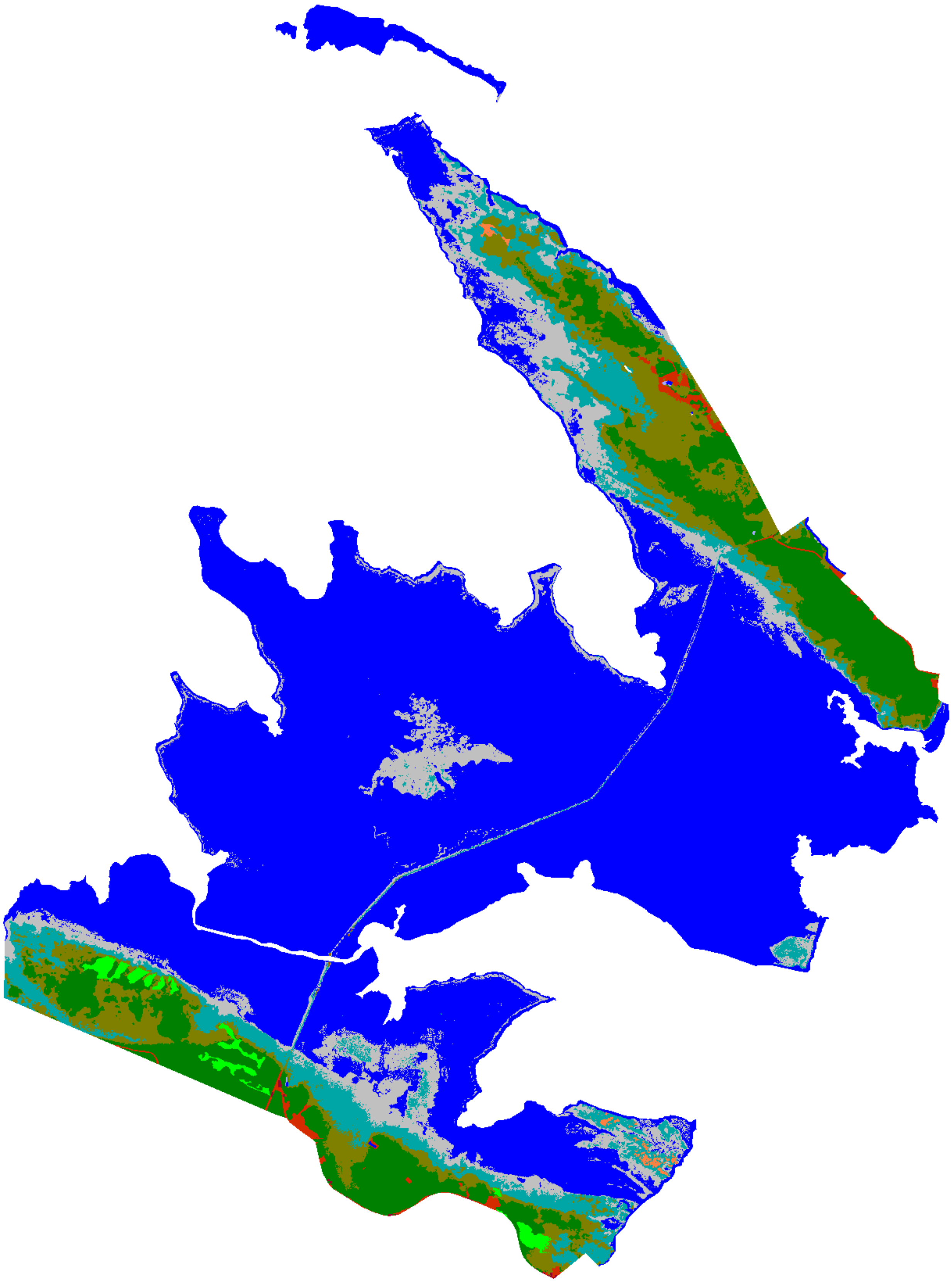
Cedar Island NWR, 2025, 2 meters



Cedar Island NWR, 2050, 2 meters



Cedar Island NWR, 2075, 2 meters



Cedar Island NWR, 2100, 2 meters

# Discussion

Cedar Island National Wildlife Refuge is located within a microtidal regime and is comprised mainly of low-lying regularly-flooded marsh. According to the LiDAR-based DEM used in the model (Figure 1), regularly flooded marsh east and south of Cedar Island Road is located at lower elevations than that lying north and west. Refuge manager Michael Hoff noted that wind tide impact is greatest from the northwest, creating fringes of irregularly flooded marsh and possibly increasing the overall sedimentation of the regularly flooded marsh in the northwest. This is likely related to the higher elevations in the northwest that improve marsh resiliency in these locations.

The recent date of the land cover data (2008 NWI) and the high vertical-resolution LiDAR DEM, reduce model uncertainty overall. Some uncertainty is introduced into the model, however by the frequency of inundation analysis, which is based on only 6 months of verified tidal data. The extent of wetland loss in the northern most reaches of the refuge is also uncertain, as these areas were not covered by LiDAR elevation data.

While model accretion data are based on site-specific data, they do not account for potential changes in marsh accretion as a function of sea-level rise. This model assumed constant accretion rates over the course of the simulation based on historical measurements. While SLAMM 6.0 has the capability to model feedbacks between cell inundation frequency and accretion rates, insufficient data were available at this site to define this relationship. Future model runs for this site can potentially evaluate the importance of this potential feedback as part of a model sensitivity or uncertainty analysis.

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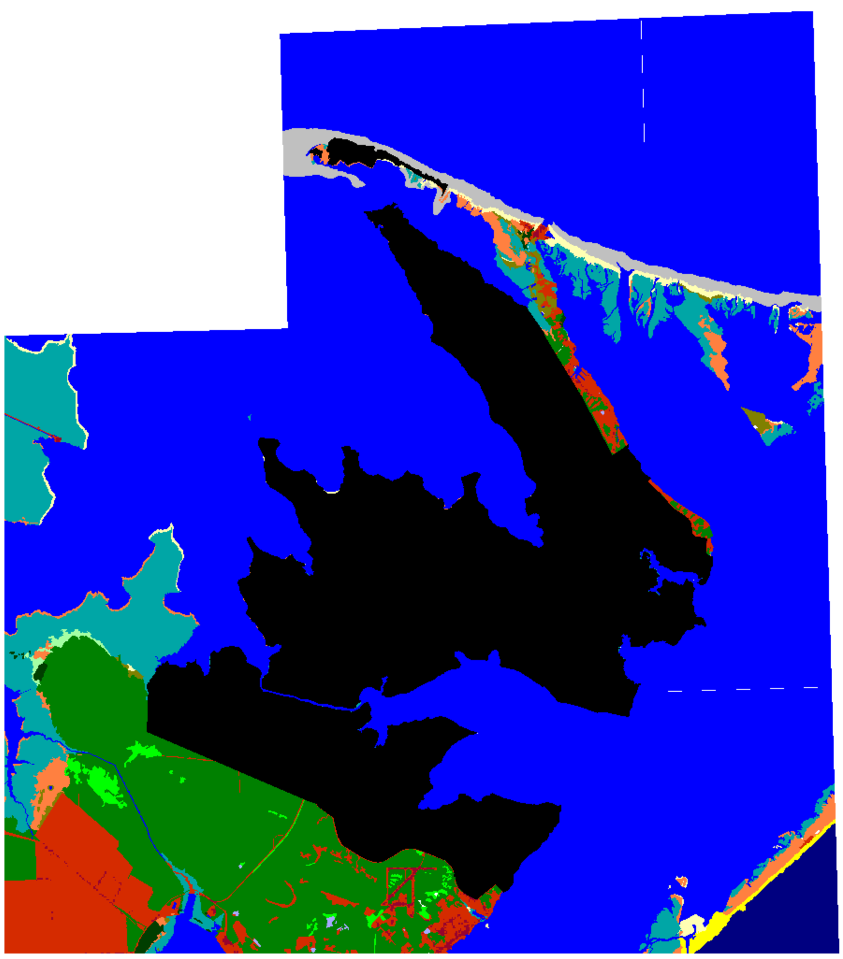
# Appendix A: Contextual Results

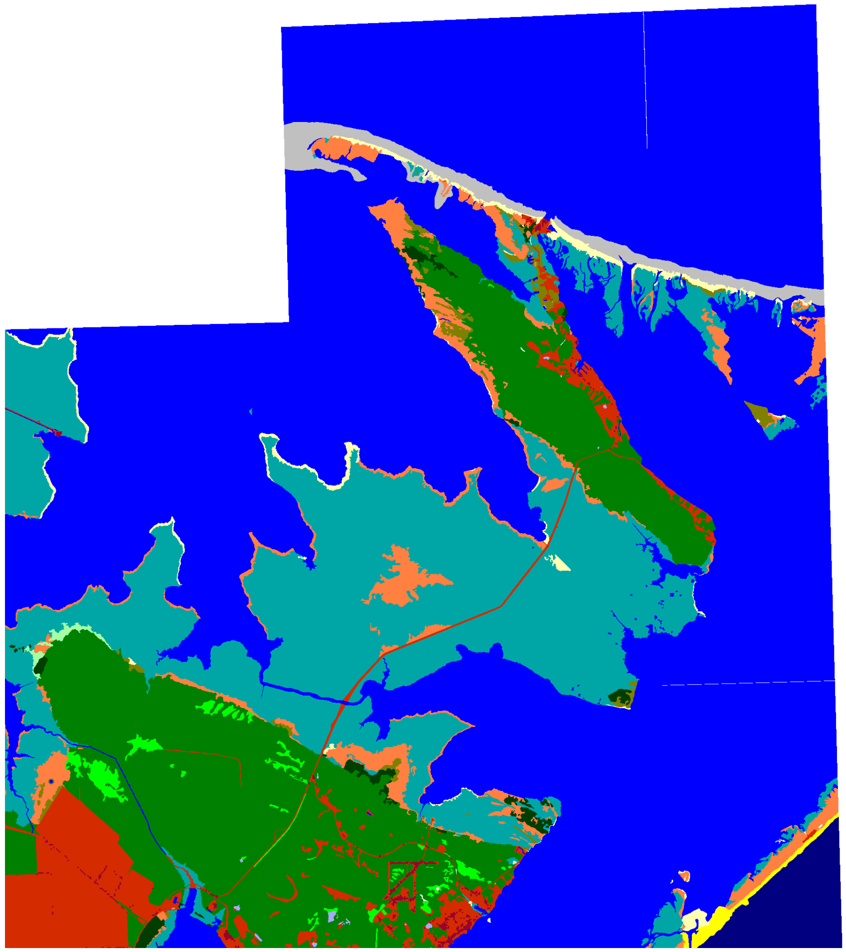
The SLAMM model does take into account the context of the surrounding lands or open water when calculating effects. For example, erosion rates are calculated based on the maximum fetch (wave action) which is estimated by assessing contiguous open water to a given marsh cell. Another example is that inundated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

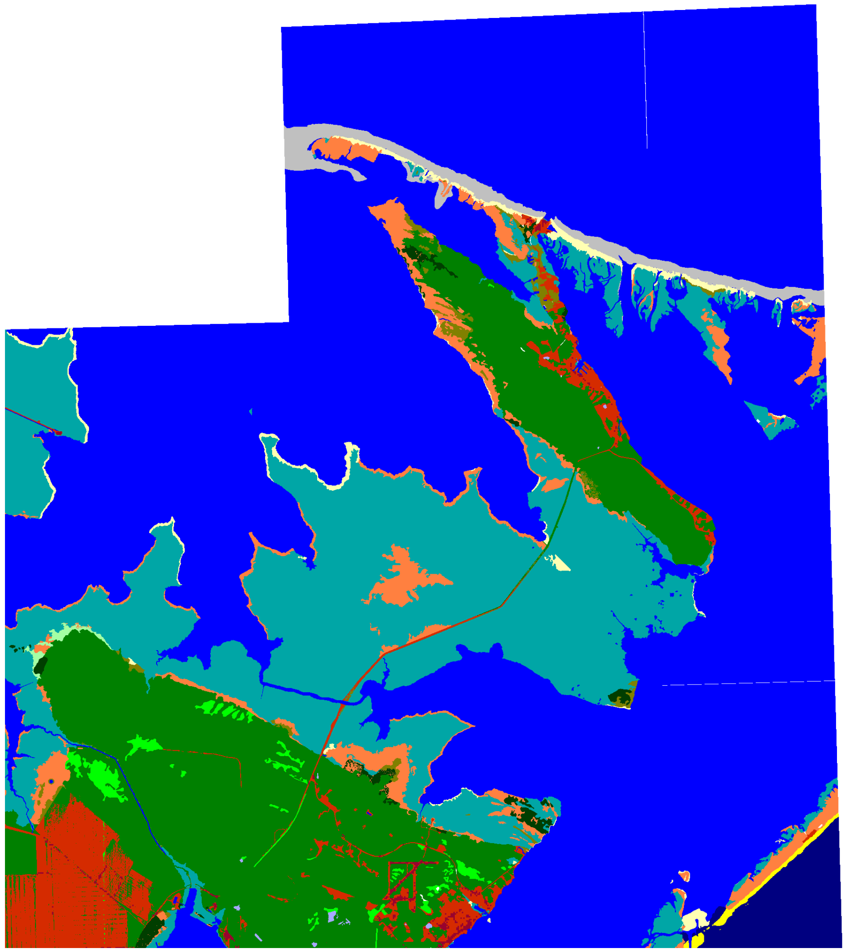
- Results were closely examined (quality assurance) within USFWS refuges but not closely examined for the larger region.
- Site-specific parameters for the model were derived for USFWS refuges whenever possible and may not be regionally applicable.
- Especially in areas where dikes are present, an effort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

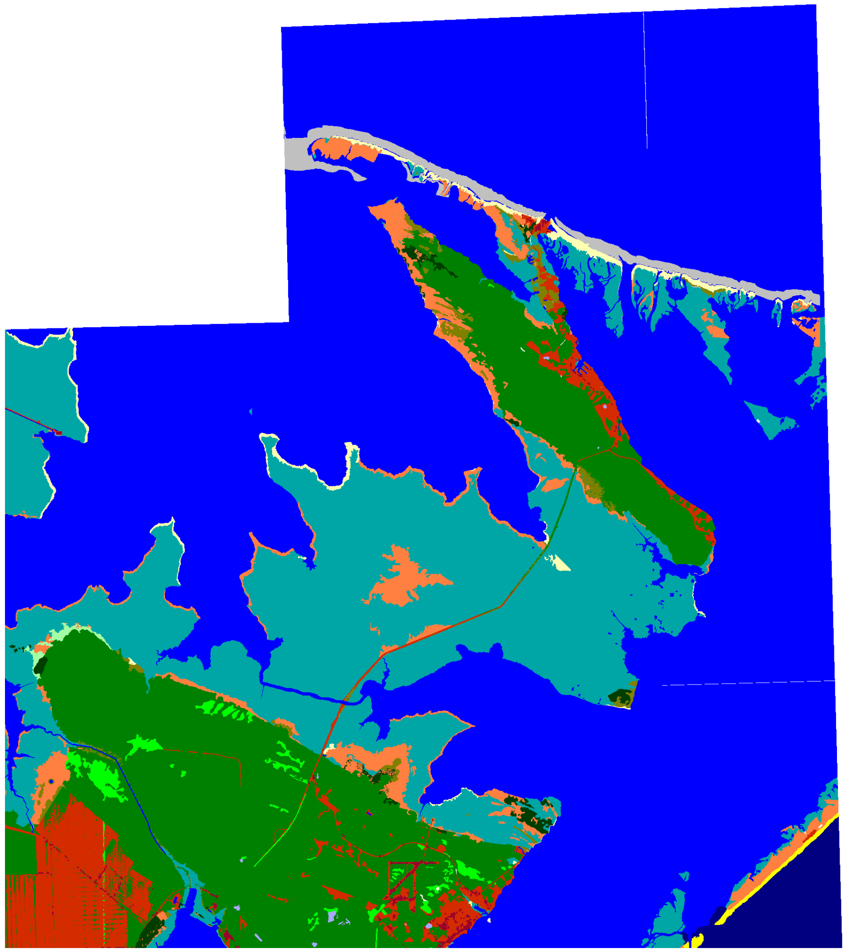


Cedar Island National Wildlife Refuge within simulation context (black).

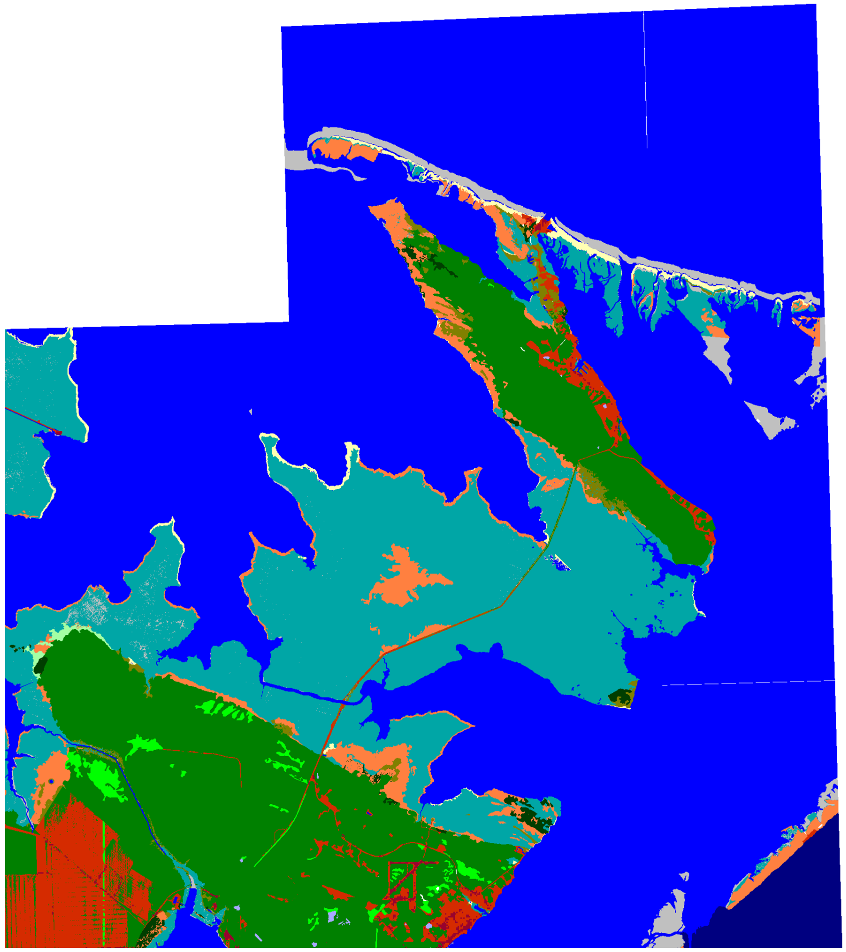


Cedar Island Context, Initial Condition

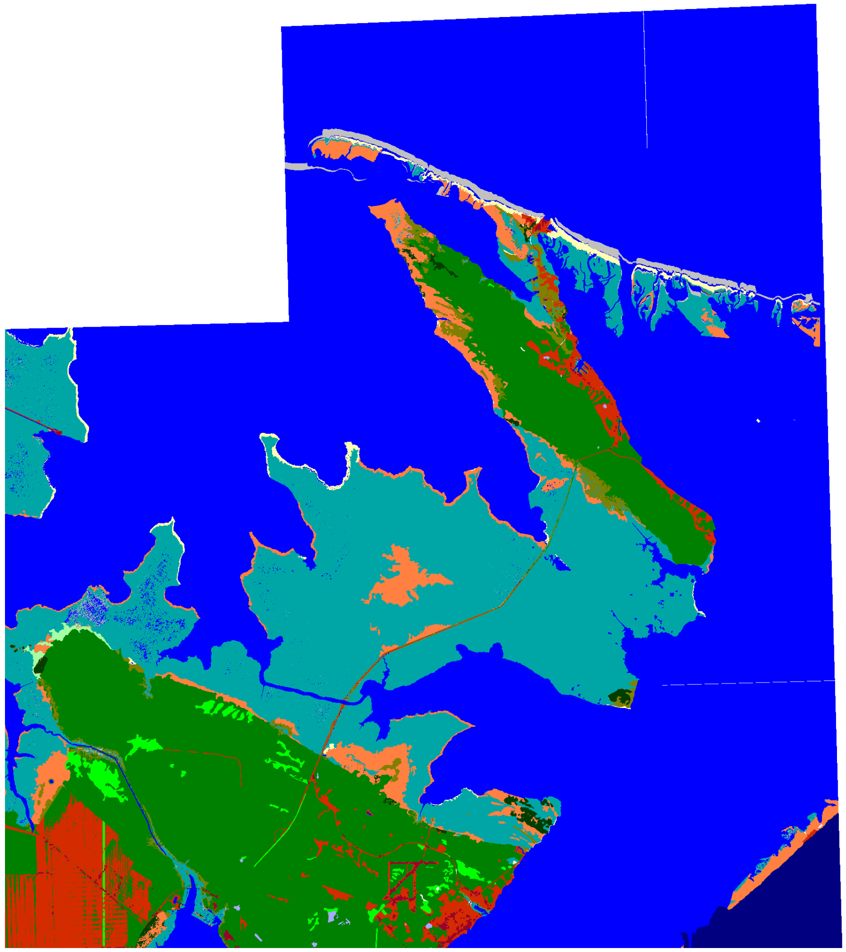

Cedar Island Context, 2025, Scenario A1B Mean



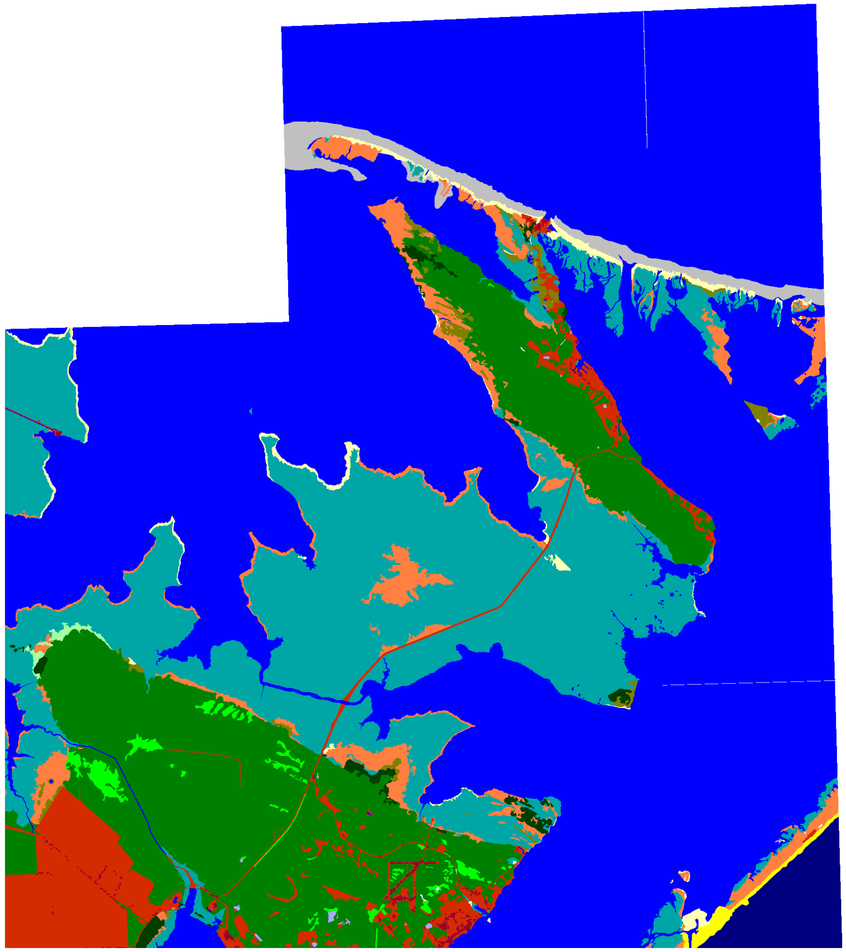
Cedar Island Context, 2050, Scenario A1B Mean



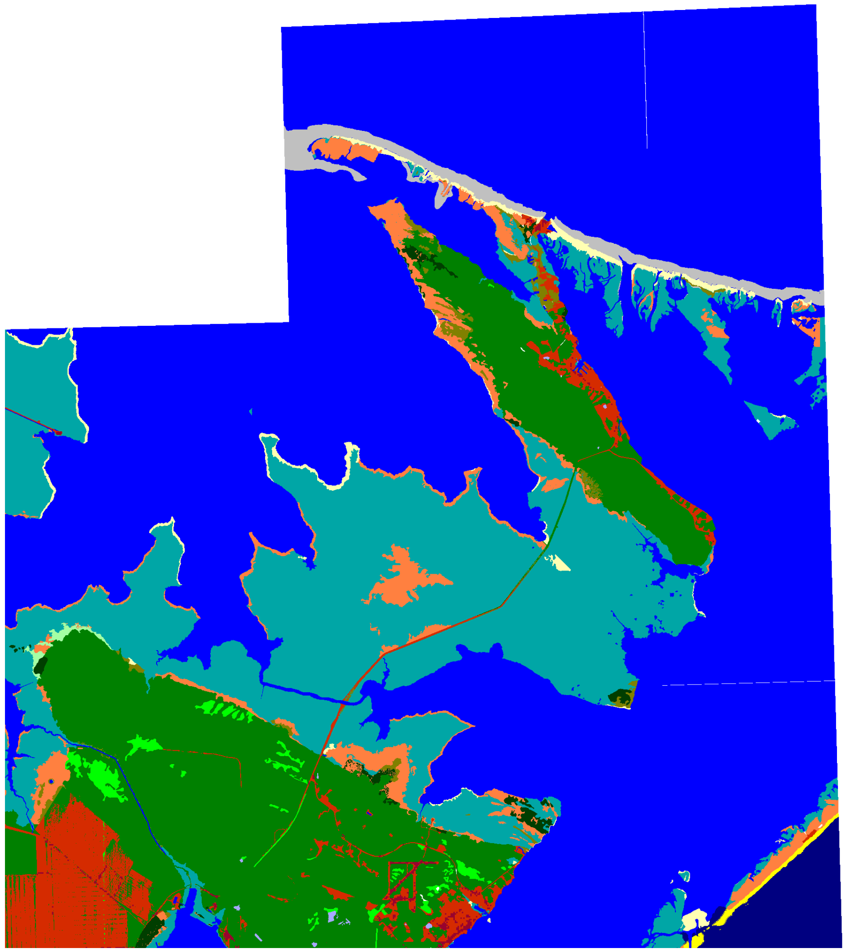
Cedar Island Context, 2075, Scenario A1B Mean



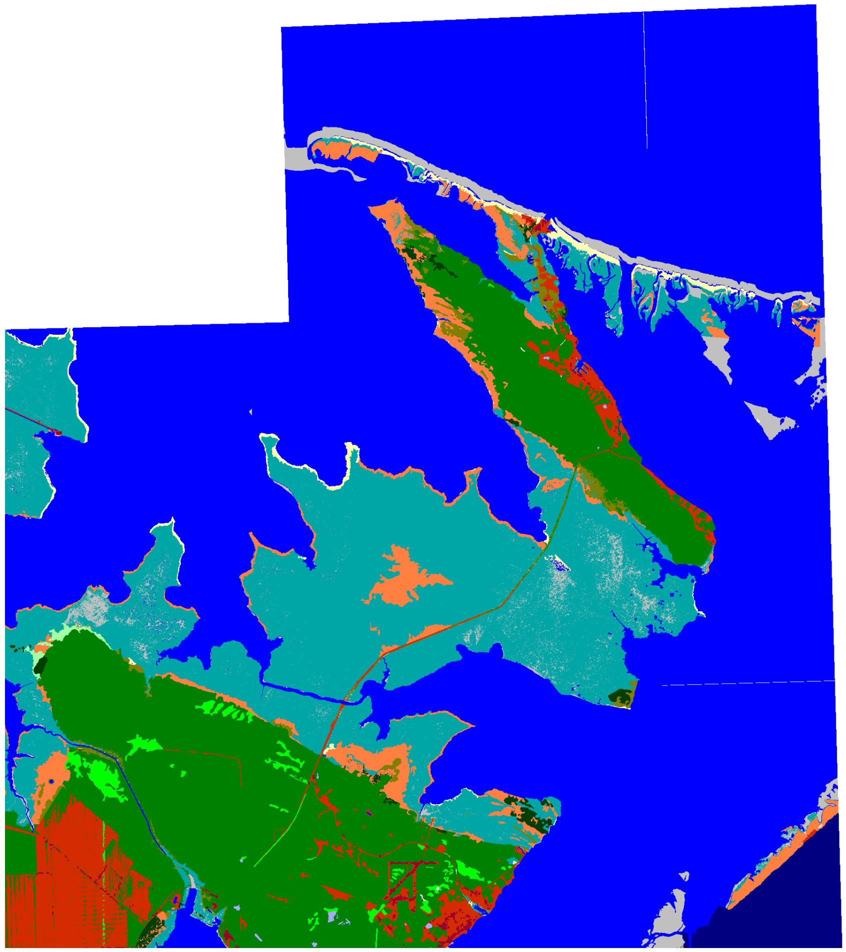
Cedar Island Context, 2100, Scenario A1B Mean

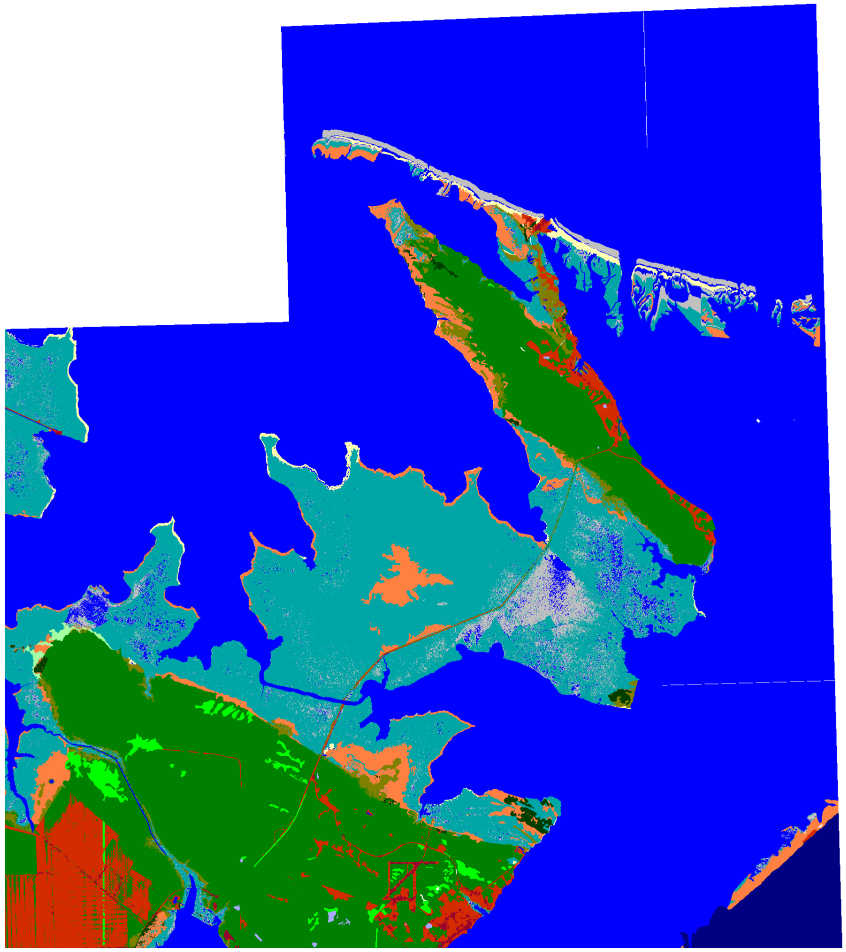


Cedar Island Context, Initial Condition

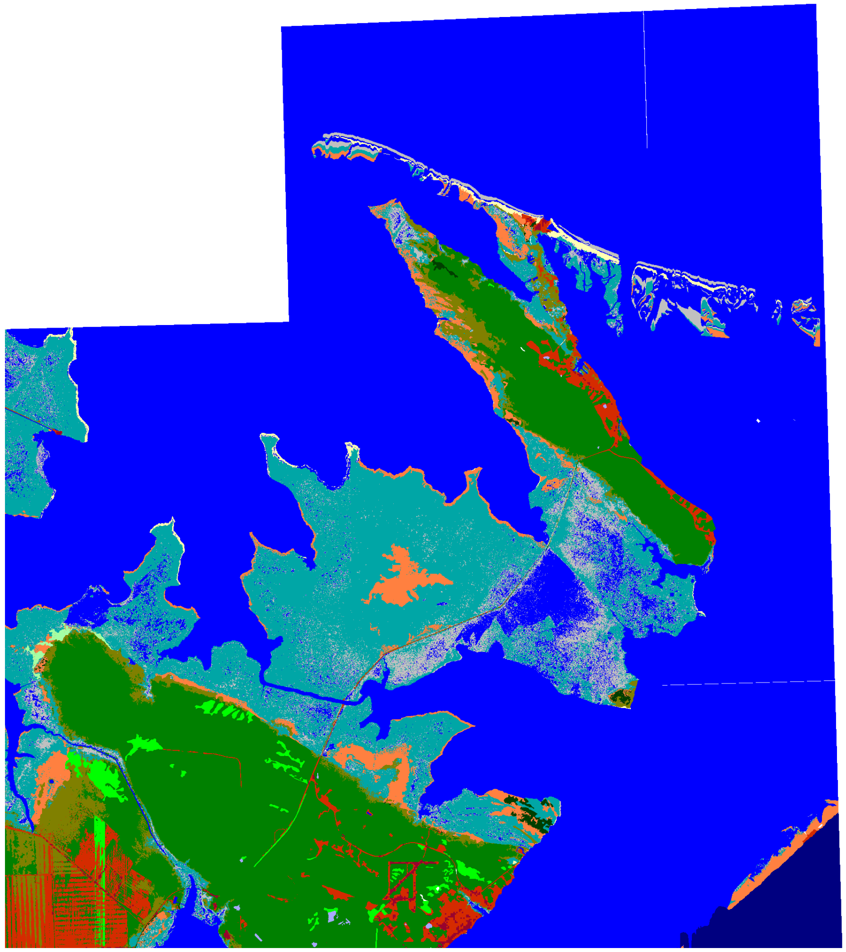


Cedar Island Context, 2025, Scenario A1B Maximum

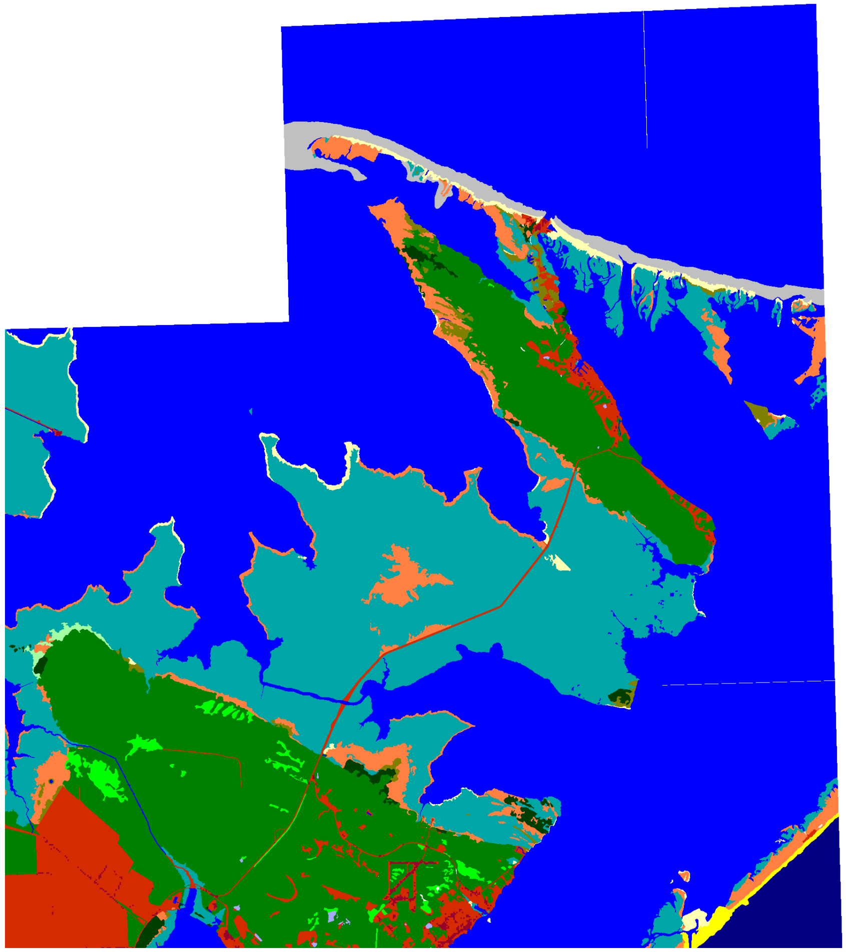

Cedar Island Context, 2050, Scenario A1B Maximum

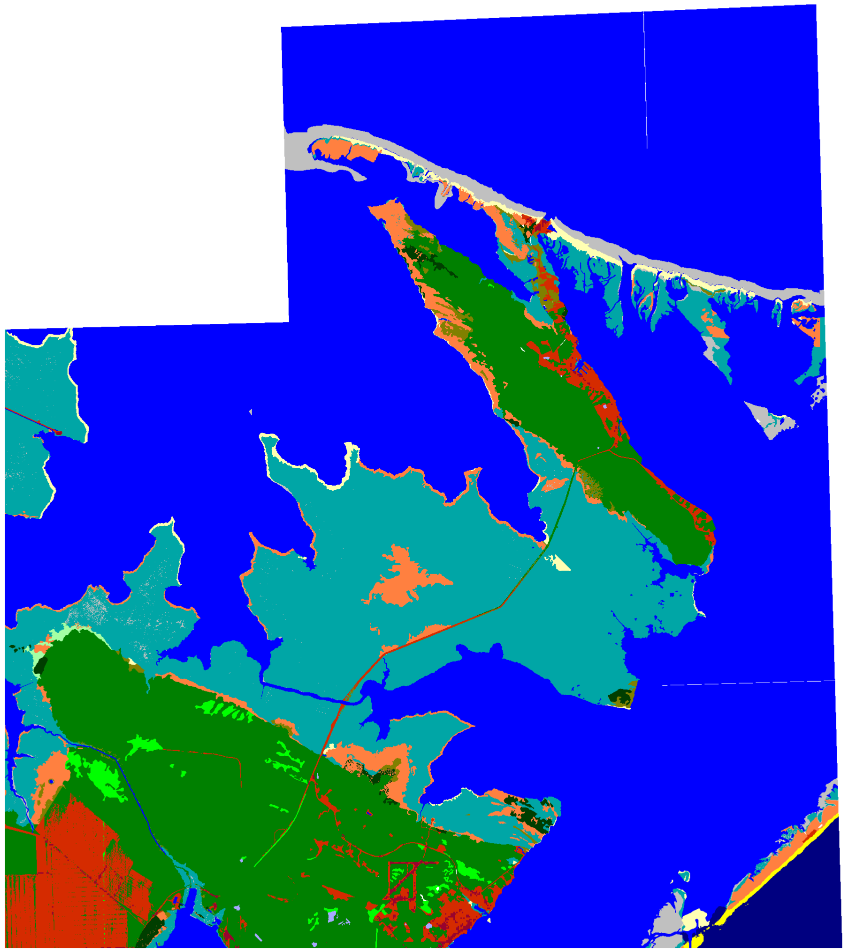


Cedar Island Context, 2075, Scenario A1B Maximum

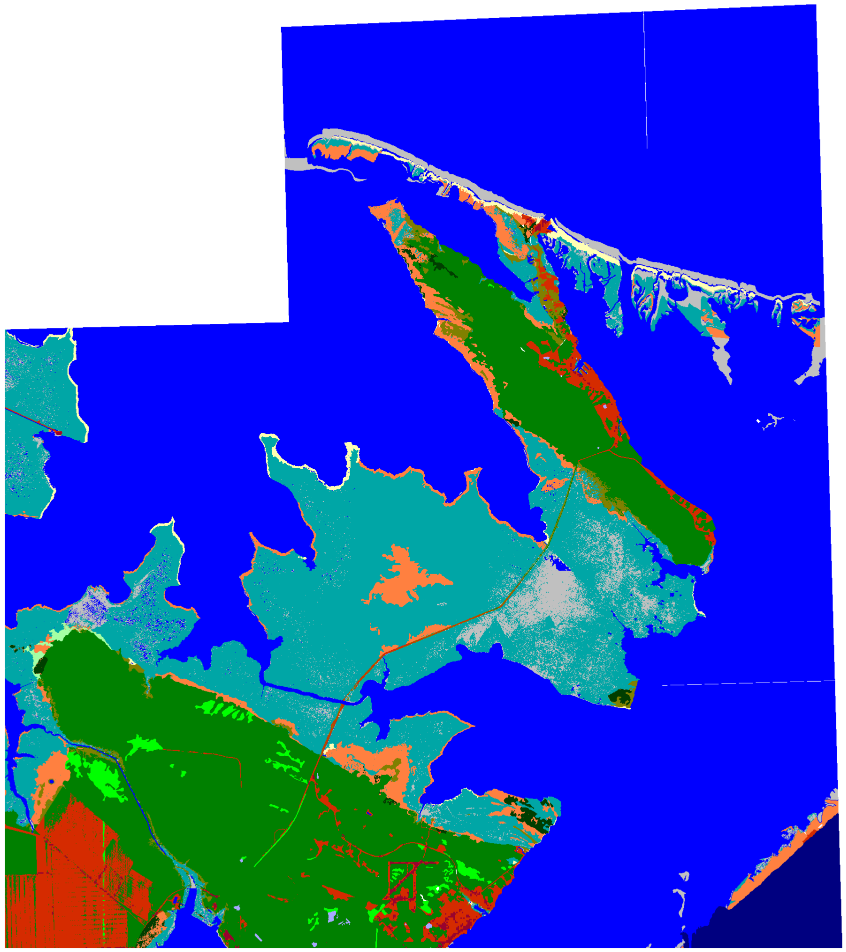


Cedar Island Context, 2100, Scenario A1B Maximum

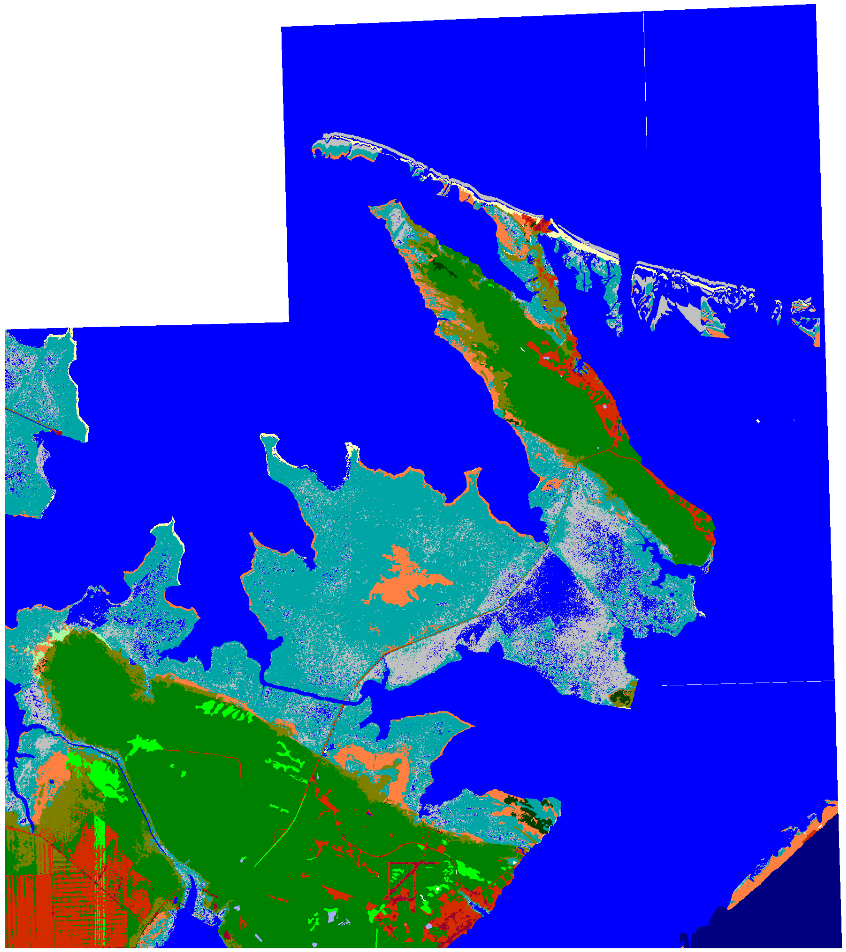

Cedar Island Context, Initial Condition



Cedar Island Context, 2025, 1 meter



Cedar Island Context, 2050, 1 meter



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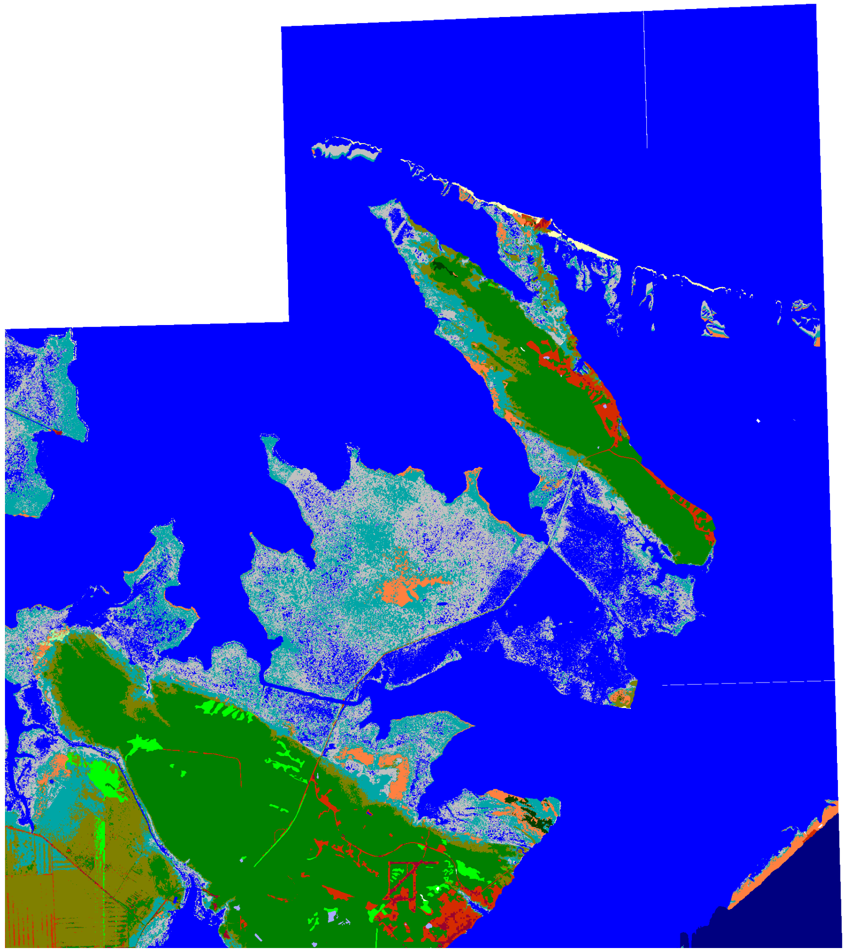
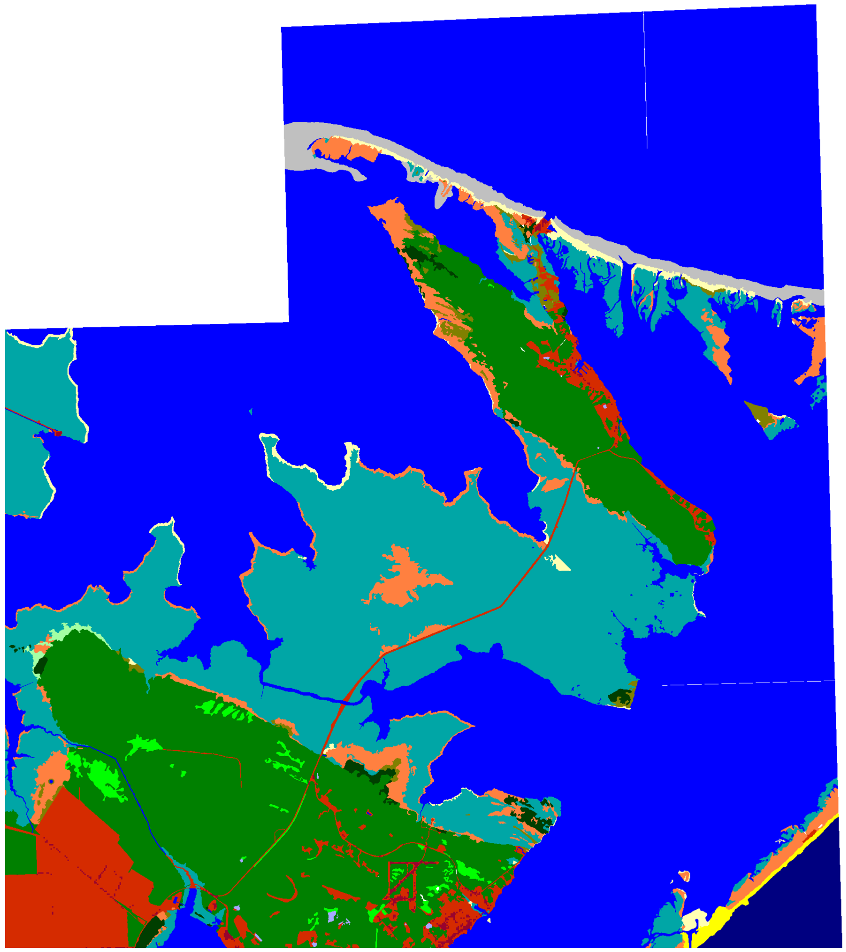
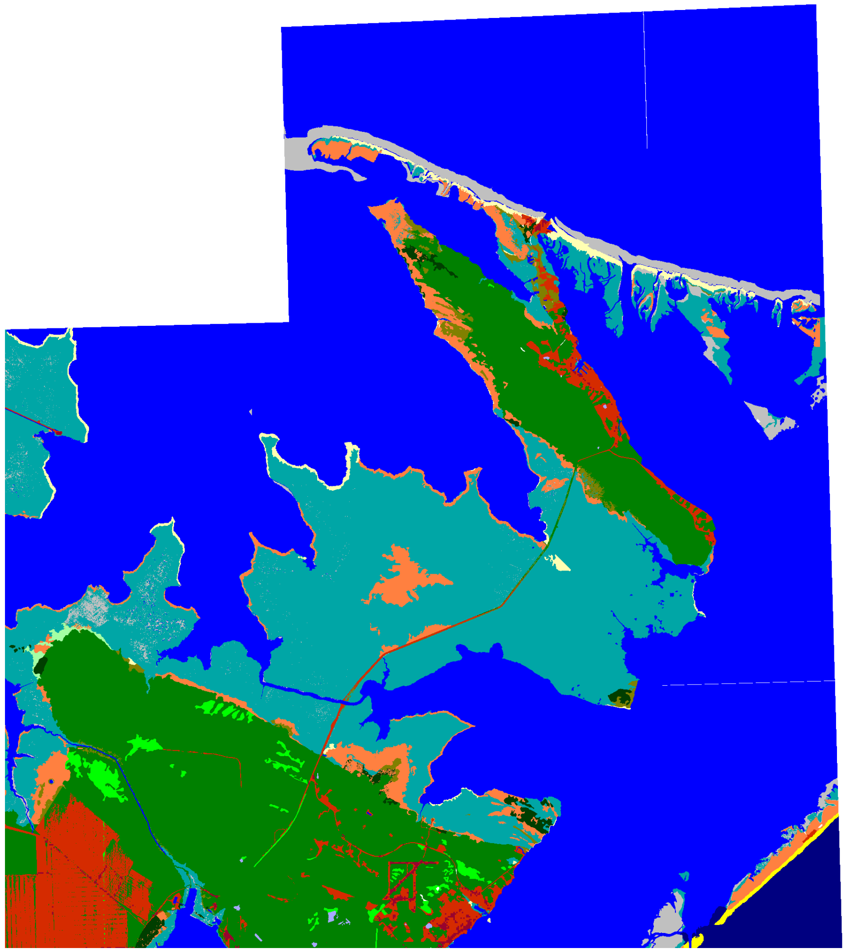


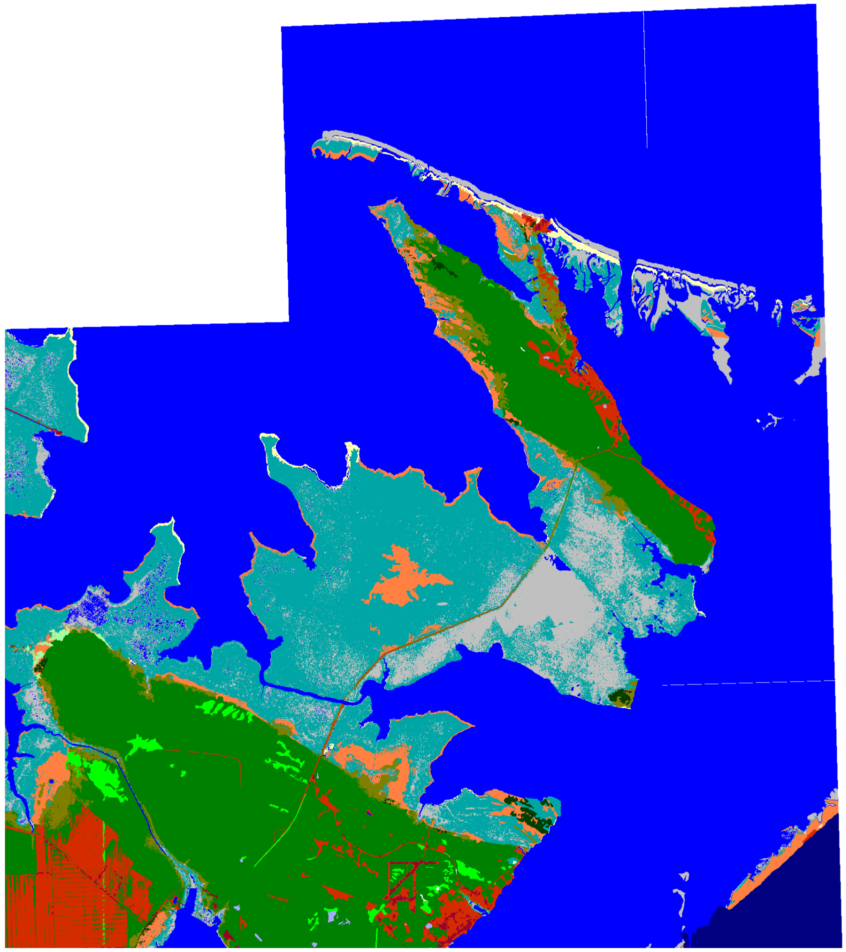
Cedar Island Context, 2100, 1 meter



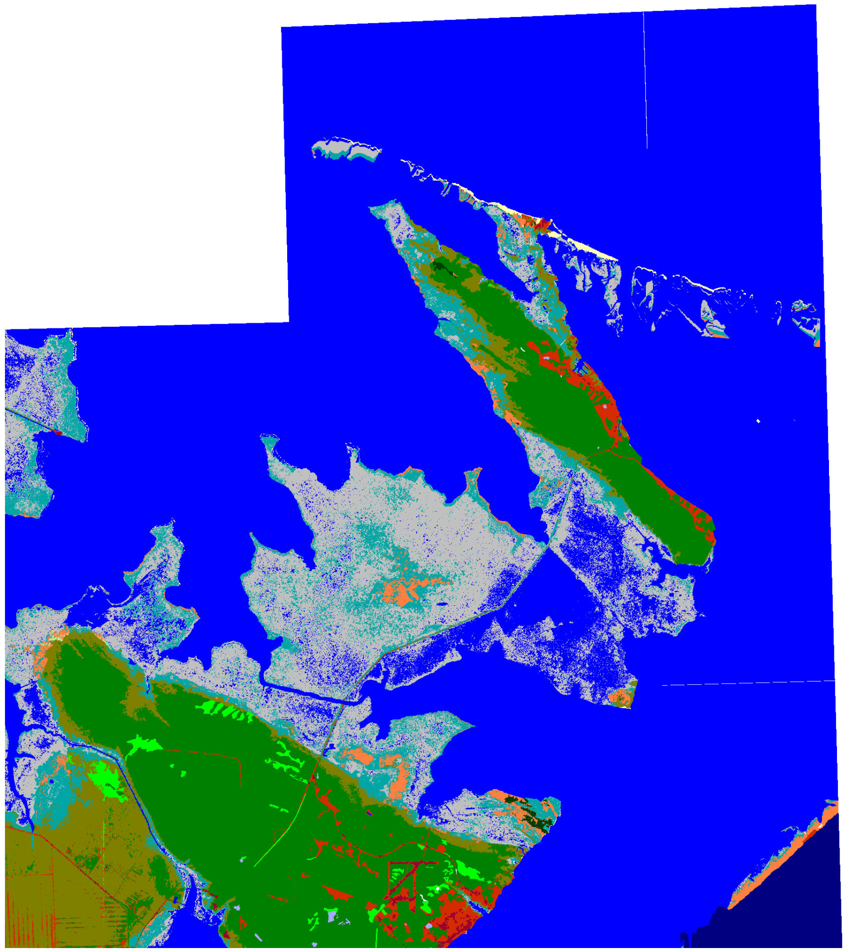
Cedar Island Context, Initial Condition



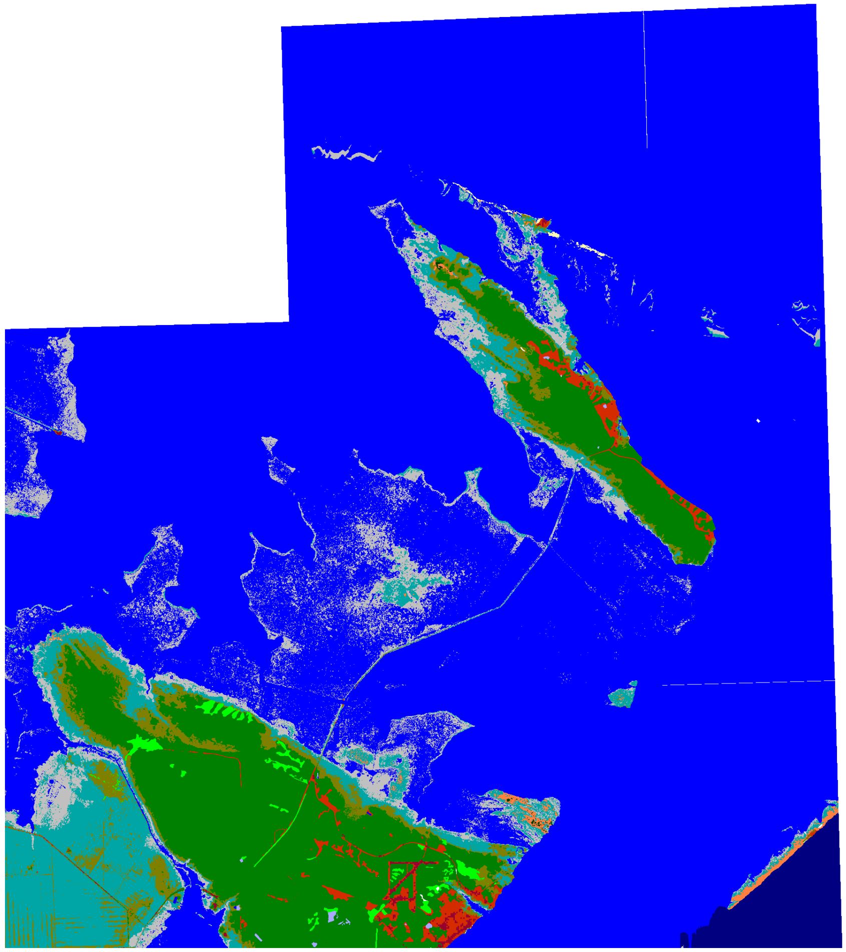
Cedar Island Context, 2025, 1.5 meter



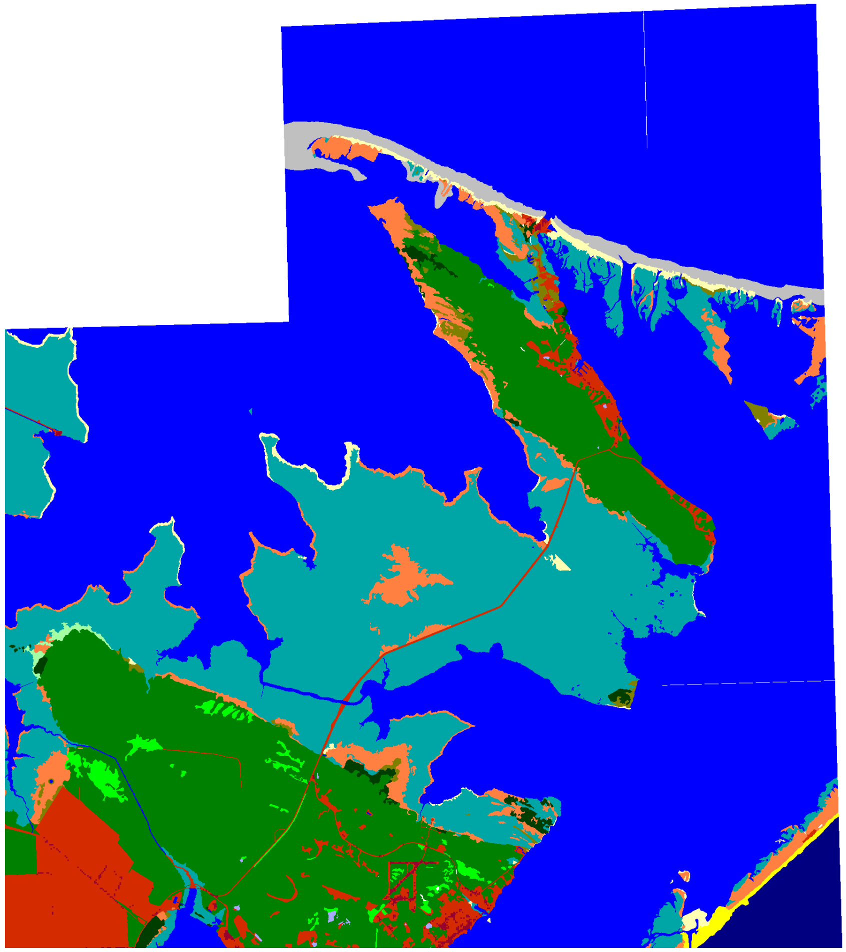
Cedar Island Context, 2050, 1.5 meter



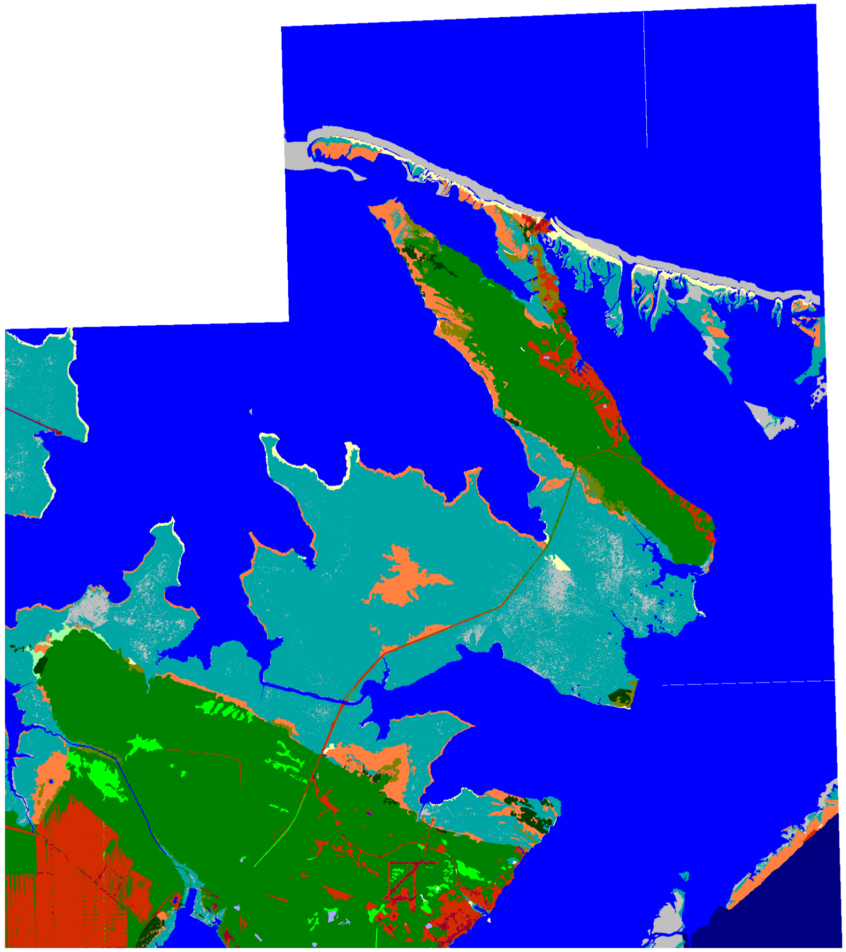
Cedar Island Context, 2075, 1.5 meter

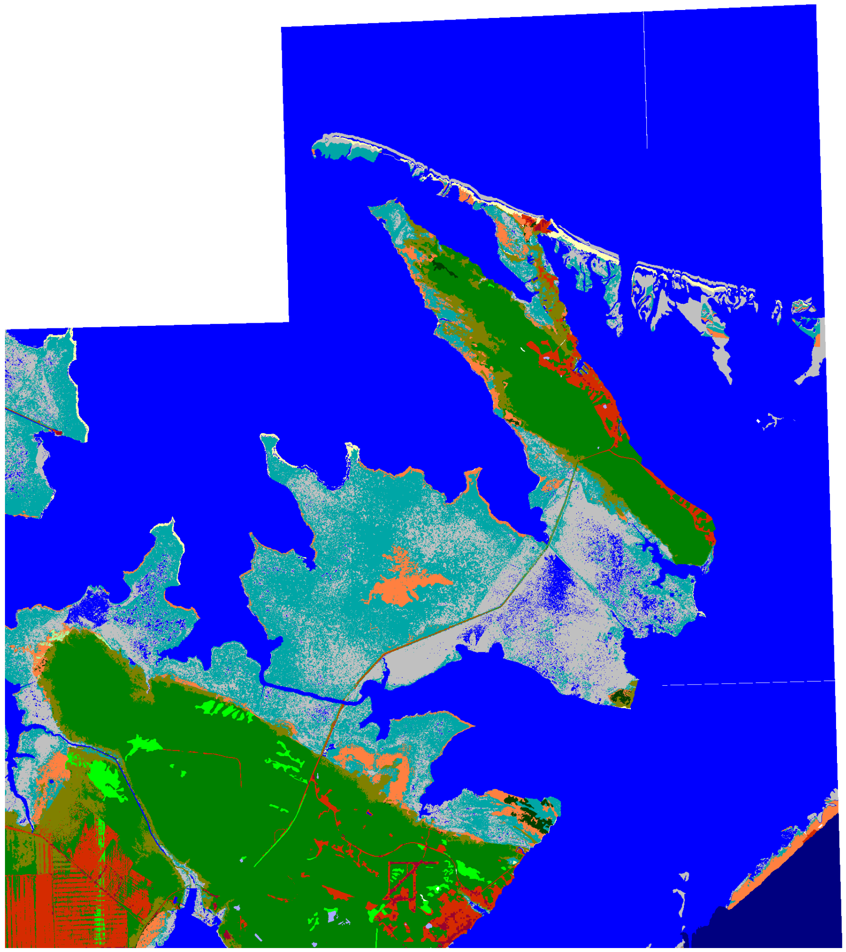


Cedar Island Context, 2100, 1.5 meter

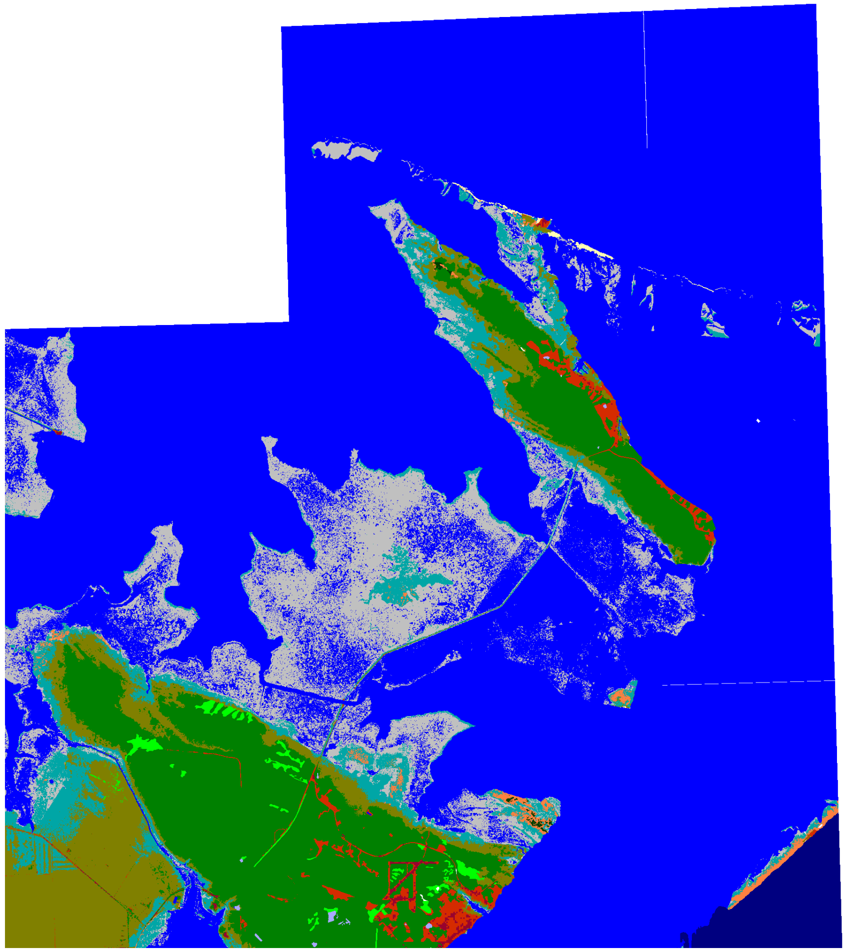


Cedar Island Context, Initial Condition

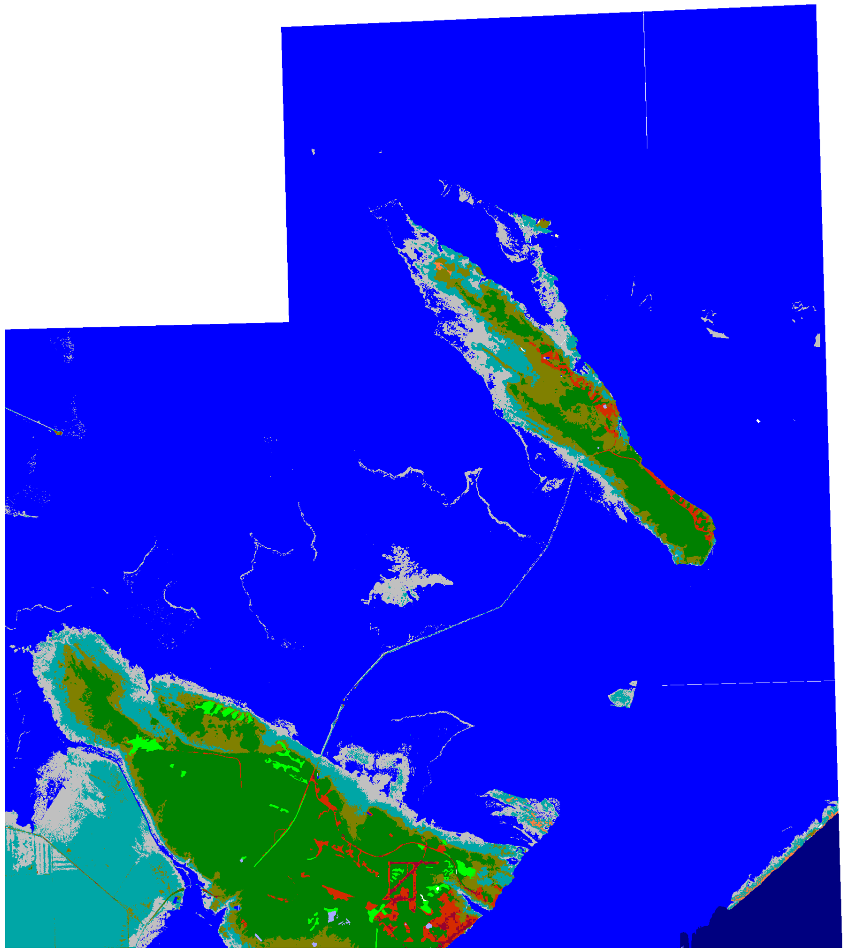

Cedar Island Context, 2025, 2 meter



Cedar Island Context, 2050, 2 meter



Cedar Island Context, 2075, 2 meter


Cedar Island Context, 2100, 2 meter