Application of the Sea-Level Affecting Marshes Model (SLAMM 6) to Tybee 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 (Park et al. 1991).

In an effort to address the potential effects of sea level rise on United States national wildlife refuge system, the U. S. Fish and Wildlife Service contracted the application of the SLAMM model for many coastal 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.

This is the second application of SLAMM to Tybee NWR. The first application in 2008 was extracted from a broader study, "Effects of Sea level Rise and Climate Variability on Ecosystem Services of Tidal Marshes, South Atlantic Coast," a Science to Achieve Results (STAR) grant awarded by the USEPA. The previous simulations did not include LiDAR-derived elevation data while the current application uses a bare-earth LiDAR elevation dataset.

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).

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 (m) 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 and 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 is used 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 (Council for Regulatory Environmental Modeling 2008). Site-specific factors that increase or decrease model uncertainty may be covered in the *Discussion* section of this report.

Sea Level Rise Scenarios

Some SLAMM 6 predictions are obtained using SLR estimates from the Special Report on Emissions Scenarios (SRES) published by the Intergovernmental Panel on Climate Change (IPCC). All IPCC scenarios describe futures that are generally more affluent than today and span a wide range of future levels of economic activity, with gross world product rising to 10 times today's values by 2100 in the lowest, to 26-fold in the highest scenarios (IPCC 2007). Among the IPCC families of scenarios, two approaches were used, one that made harmonized assumptions about global population, economic growth, and final energy use, and those with an alternative approach to quantification. This is important to keep in mind as not all of the IPCC scenarios share common assumptions regarding the driving forces of climate change.

In this model application, the A1B scenario mean and maximum predictions are applied. Important assumptions were made in this scenario: reduction in the dispersion of income levels across economies (i.e. economic convergence), capacity building, increased cultural and social interactions among nations, and a substantial reduction in regional differences in per capita income, primarily from the economic growth of nations with increasing income (Nakicenovic et al. 2000). In addition, 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. Given today's global economic and political climate, as well as environmental and ecological constraints, these may not be feasible assumptions for the future.

In particular, the A1B scenario assumes that energy sources will be balanced across all sources, with an increase in use of renewable energy sources coupled with a reduced reliance on fossil fuels (Nakicenovic et al. 2000). Given this A1B scenario, the IPCC WGI Fourth Assessment Report (IPCC 2007) suggests a likely range of 0.21 m to 0.48 m of SLR by 2090-2099 "excluding future rapid dynamical changes in ice flow."   The IPCC-produced A1B-mean scenario that was run as a part of this project falls near the middle of this estimated range, predicting 0.39 m of global SLR by 2100.   A1B-maximum predicts 0.69 m of global SLR by 2100. However, other scientists using the same set of economic growth scenarios have produced much higher estimates of SLR as discussed below.

Recent literature (Chen et al. 2006; Monaghan et al. 2006) indicates that eustatic sea level rise is progressing more rapidly than was previously assumed. This underestimation may be due to the dynamic changes in ice flow omitted within the IPCC report's calculations, and a consequence of overestimating the possibilities for future reductions in greenhouse gas emissions while concurrently striving for economic growth.

A recent paper in the journal *Science* (Rahmstorf 2007) suggests that, taking into account possible model error, a feasible range of 50 to 140 cm by 2100. 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 m 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 SLRs 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.

The variability of SLR predictions presented in the scientific literature illustrates the significant amount of uncertainty in estimating future SLR. Much of the uncertainty may be due to the unknown future of the drivers climate change, such as fossil fuel consumption and the scale of human enterprise. In order to account for these uncertainties, and to better reflect these uncertainties as well as recently published peer-reviewed measurements and projections of SLR as noted above, SLAMM was run not only assuming A1B-mean and A1B-maximum SLR scenarios, but also for 1 m, 1.5 m, and 2 m of eustatic SLR by the year 2100 as shown in Figure 1.
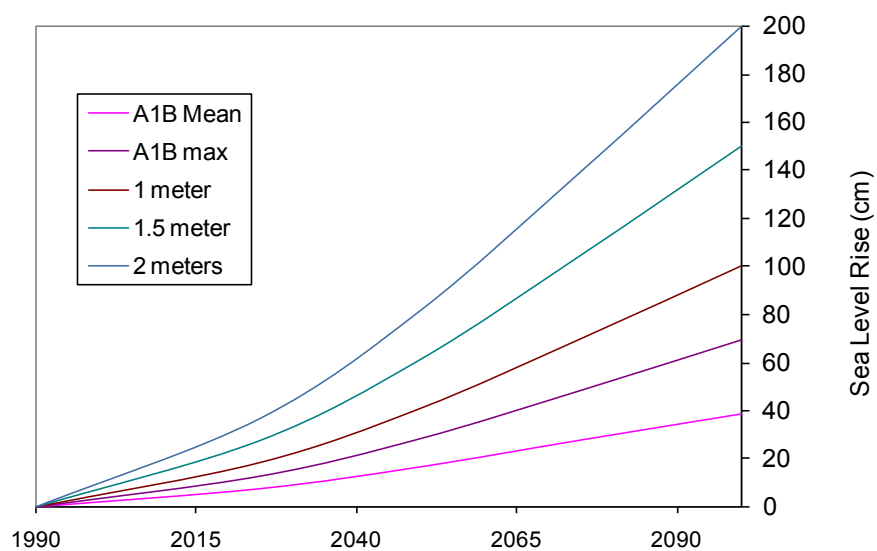
Figure 1. Summary of SLR scenarios utilized.

Data Sources and Methods

Wetland layer. Figure 2 shows the most recent available wetland layer obtained from a National Wetlands Inventory (NWI) photo dated 2006. Converting the NWI survey into 5 m x 5 m cells indicated that the approximately 680 acre Tybee NWR (approved acquisition boundary including water) is composed of the following categories:

	Land cover type	Area (acres)	Percentage (%)
	Undeveloped Dry Land	410	60
	Swamp	147	22
	Regularly-flooded Marsh	47	7
	Estuarine Beach	40	6
	Estuarine Open Water	18	3
	Inland Fresh Marsh	11	2
	Transitional Salt Marsh	3	< 1
	Irregularly-flooded Marsh	3	< 1
	Total (incl. water)	**678**	**100**
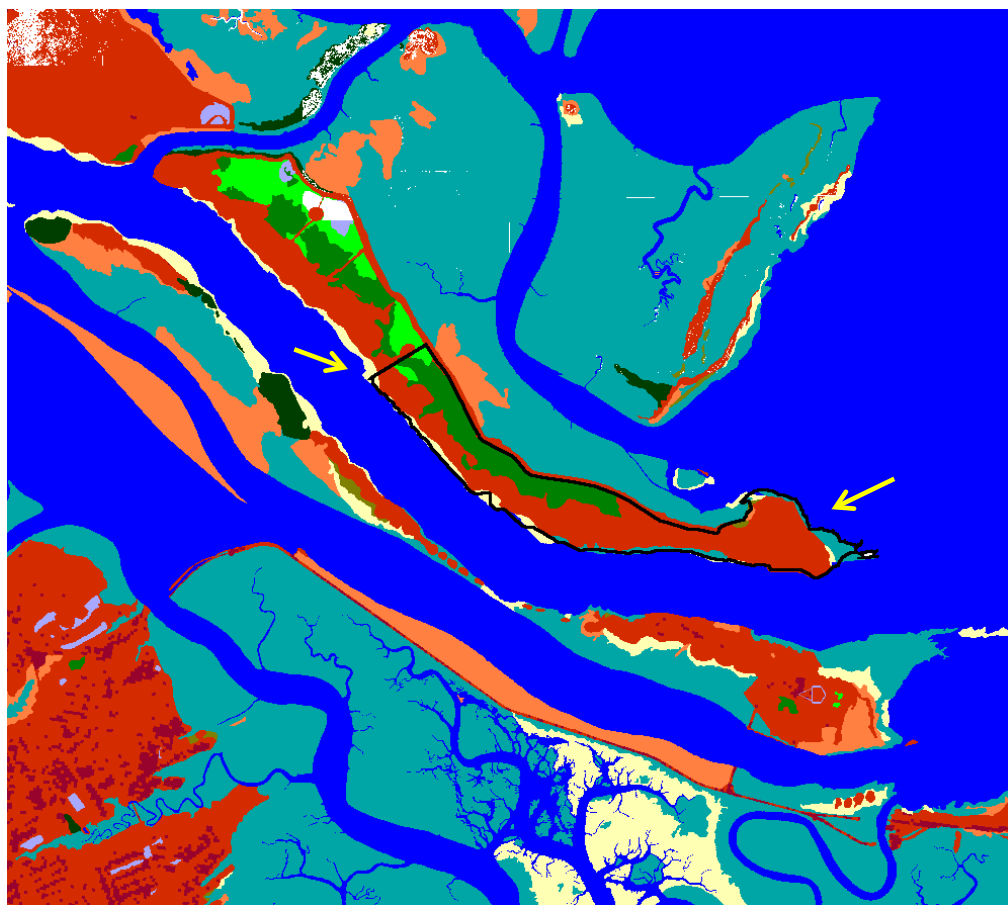
Figure 2. 2007 NWI coverage of the study area. Refuge boundaries are indicated in black.

Elevation Data. The layer covering the study area is a combination of the 2010 bare-earth Chatham County, Georgia LiDAR data and the 2007 bare-earth Jasper County, South Carolina for the northeast portion of the refuge, as shown in Figure 3. The Chatham County LiDAR layer was provided by the Savannah Area Geographic Information System. It is important to note that some patches within the Jasper County LiDAR layer did not have elevation data associated with them (cells were designated as "no-data"). These small patches were not modeled and the land-cover type within them was assumed to be persistent.
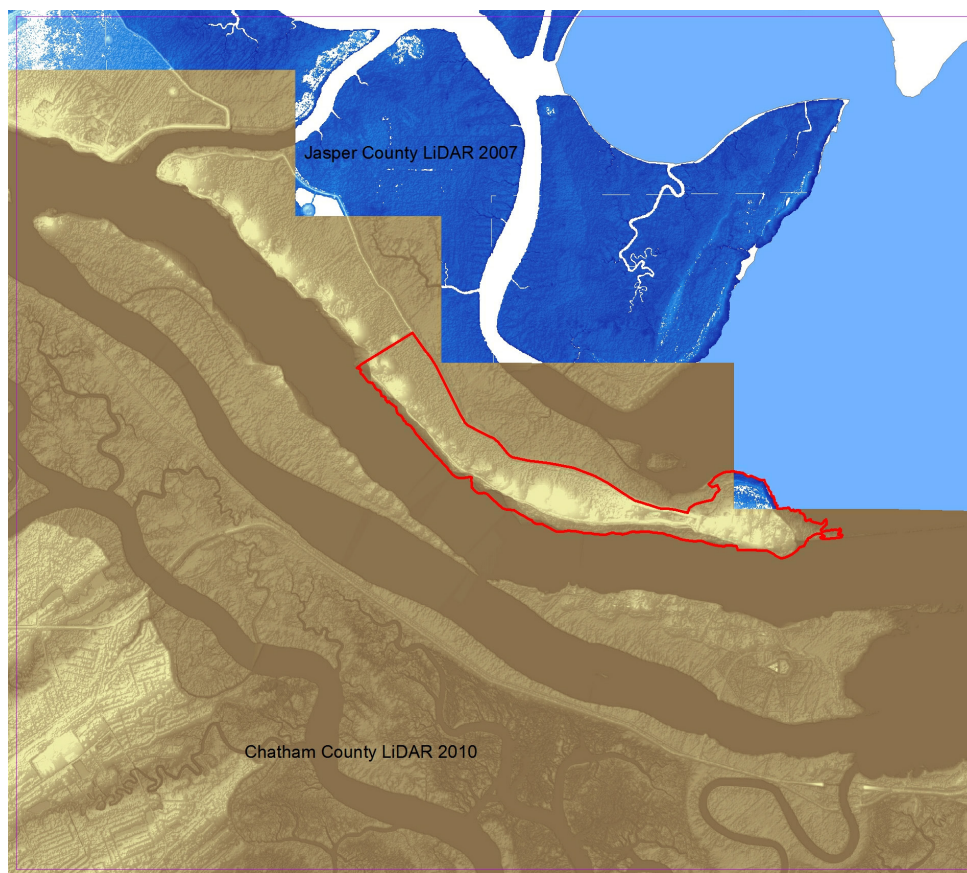
Figure 3. The coverage of the LiDAR data for the entire study area.

Dikes and Impoundments. According to the National Wetland Inventory, there are no areas protected by dikes within the refuge.

Model Timesteps. Model forecast data is output for years 2025, 2050, 2075 and 2100 with the initial condition date set to 2006, the most recent wetland data available.

Historic sea level rise rates. The Fort Pulaski, Georgia (#8670870) NOAA gauge is adjacent to Tybee Island NWR. The historic trend for relative sea level rise rates recorded at this station is 2.98 mm/yr., and this rate was applied to the entire study area. This rate is higher than the global (eustatic) SLR for the last 100 years (approximately 1.7 mm/yr.), perhaps indicating some subsidence in this area.
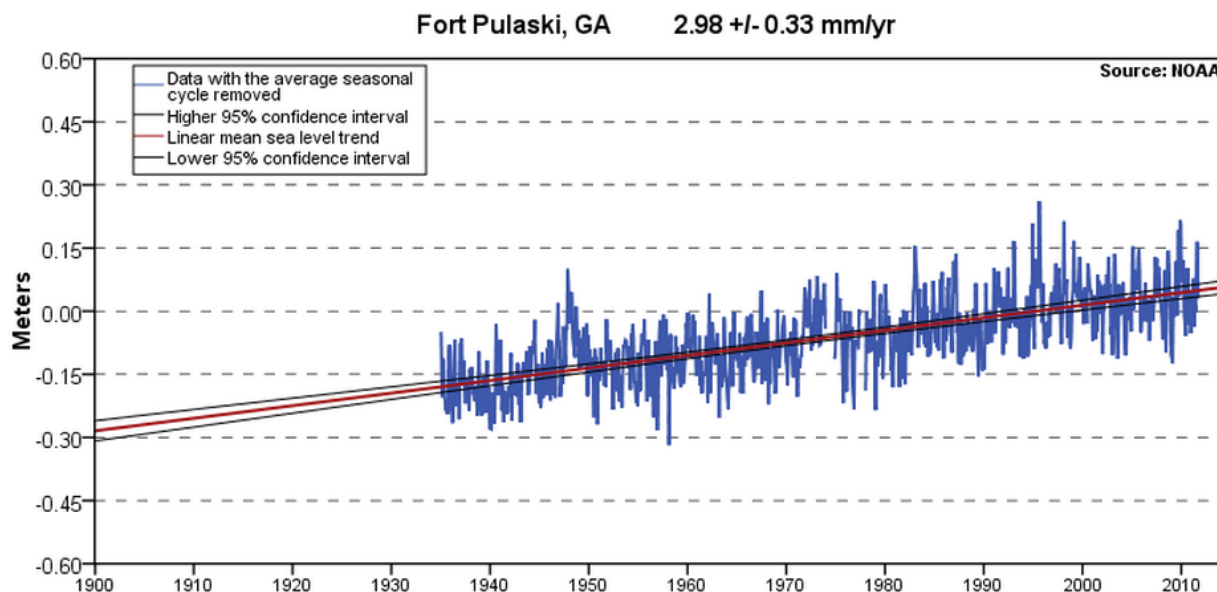
Figure 4. Historic Sea level trend at Fort Pulaski, GA.

Tide Ranges. The great diurnal range (GT) was applied using the data from the Fort Pulaski and Bloody Point, New River, SC (#8669801) NOAA gauge stations, which had GT measurements of 2.287 m and 2.238 m, respectively.

Salt elevation. This parameter within SLAMM designates the boundary between wet and dry lands or saline wetlands and fresh water wetlands. Based on regional data for this application, salt elevation was estimated at 1.5 Half Tide Units (HTU) for all input subsites, corresponding to 1.72 m above MTL within the majority of the refuge area.

Accretion rates. Regularly-flooded marsh was assigned an accretion rate of 1.9 mm/yr., irregularly-flooded marsh was assigned a rate of 4.3 mm/yr., and tidal fresh marsh was assigned an accretion rate of 4.8 mm/yr. based on measured rates of accretion in Georgia Marshes (Craft, personal communication). Tidal fresh and inland fresh marsh accretion rates were set to the SLAMM default value of 4 mm/yr.

Erosion rates. Horizontal erosion of marshes and swamps occurs only at the wetland-to-open-water interface and only when adequate open water (fetch) exists for wave setup. Due to lack of site-specific values, erosion rates were set to the SLAMM defaults. Tidal flat erosion was set to 0.2 m/yr., marshes were set to 2 m/yr., and a rate of 1 m/yr. was applied to swamps.

Elevation correction. MTL to NAVD88 corrections determined using NOAA's VDATUM software varied from 0.60 to 0.12 m. To account for this variability a spatially variable raster of corrections was applied.

Refuge boundaries. Modeled USFWS refuge boundaries for Georgia and South Carolina are based on Approved Acquisition Boundaries as published on the USFWS National Wildlife Refuge Data and Metadata website. The cell-size used for this analysis is 5 m.

Input subsites and parameter summary. Based on spatial variability of the tide ranges and different elevation datasets, the study area was subdivided in the subsites illustrated in Figure 5.
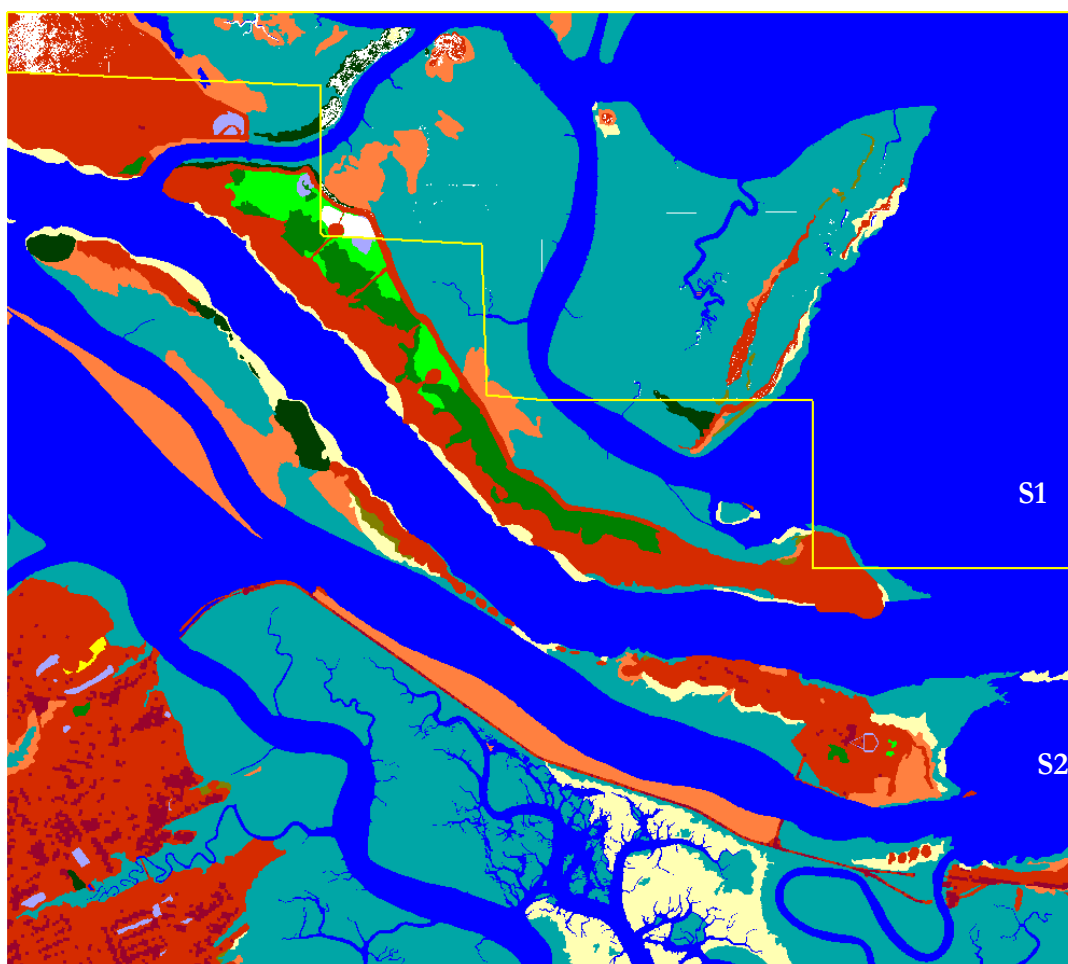
Figure 5. Input subsites for model application.

Table 1 summarizes all SLAMM input parameters for the input subsites. Values for parameters with no specific local information were kept at the model default value. The majority of the refuge lies within subsite 2. The connectivity module of SLAMM was used in this model application in order to ensure dry land only converts to wetland if there is an unimpeded path from open water to the dry land in question.

Table 1. Summary of SLAMM input parameters for Tybee NWR.

Parameter	S1	S2
NWI Photo Date (YYYY)	2006	2006
DEM Date (YYYY)	2007	2010
Direction Offshore [n,s,e,w]	East	East
Historic Trend (mm/yr.)	2.98	2.98
GT Great Diurnal Tide Range (m)	2.238	2.287
Salt Elev. (m above MTL)	1.68	1.72
Marsh Erosion (horz. m /yr.)	2	2
Swamp Erosion (horz. m /yr.)	1	1
T.Flat Erosion (horz. m /yr.)	0.2	0.2
Reg.-Flood Marsh Accr (mm/yr.)	1.9	1.9
Irreg.-Flood Marsh Accr (mm/yr.)	4.3	4.3
Tidal-Fresh Marsh Accr (mm/yr.)	4.8	4.8
Inland-Fresh Marsh Accr (mm/yr.)	4	4
Tidal Swamp Accr (mm/yr.)	1.1	1.1
Swamp Accretion (mm/yr.)	0.3	0.3
Beach Sed. Rate (mm/yr.)	0.5	0.5
Freq. Overwash (years)	25	25

Results

The initial land cover in acres and percentage losses by 2100 of each wetland type for different SLR scenario are presented in Table 2. Land-cover losses are calculated in comparison to the initial 2006 NWI wetland coverage and wetland categories are sorted by decreasing initial land cover excluding open water.

Simulation results suggest Tybee NWR will be relatively resilient to the effects of SLR at lower SLR scenarios. However, at 1.5 m of SLR by 2100 and above severe wetland losses are projected. Swamp, irregularly-flooded, and inland fresh marsh show minimal losses up to 1 m of SLR by 2100, while at 1.5 m and above the majority of these habitats are predicted to be lost. Undeveloped dry land and estuarine beach show consistent loses as SLR rates increase, culminating in maximum losses of 30% and 60%, respectively.

Table 2. Predicted loss rates of land categories by 2100 given simulated scenarios of eustatic SLR at Tybee NWR. *Negative values indicate gains.*

	Land cover change by 2100 for different SLR scenarios (%)				
	0.39 m	0.69 m	1 m	1.5 m	2 m
Undeveloped Dry Land	11%	14%	16%	24%	30%
Swamp	0%	0%	0%	83%	93%
Regularly-flooded Marsh	6%	7%	-28%	-38%	-305%
Estuarine Beach	20%	21%	24%	43%	64%
Inland Fresh Marsh	0%	0%	0%	90%	95%
Irregularly-flooded Marsh	0%	0%	9%	88%	100%

Wetland losses are coupled with gains in regularly-flooded and transitional salt marsh, open water, and tidal flat. Table 3 presents the acreage gains for each of these categories.

Table 3. Predicted land cover gains by 2100 given simulated scenarios of eustatic SLR at Tybee NWR. *Negative values indicate losses.*

	Initial	Land cover change by 2100 for different SLR scenarios (Acres)				
		0.39 m	0.69 m	1 m	1.5 m	2 m
Regularly Flooded Marsh	47	-3	-3	13	18	143
Estuarine Open Water	18	13	14	17	29	46
Inland Fresh Marsh	11	0	0	0	-9	-10
Transitional Salt Marsh	3	38	44	28	168	56

IPCC Scenario A1B-Mean, 0.39 m SLR eustatic by 2100

Results in Acres

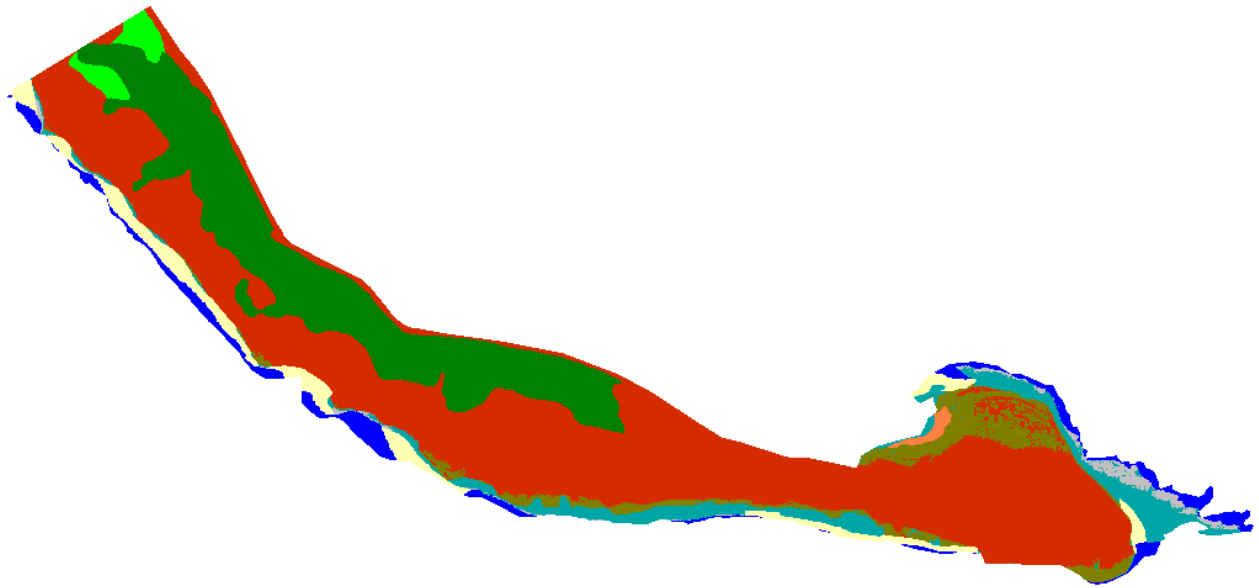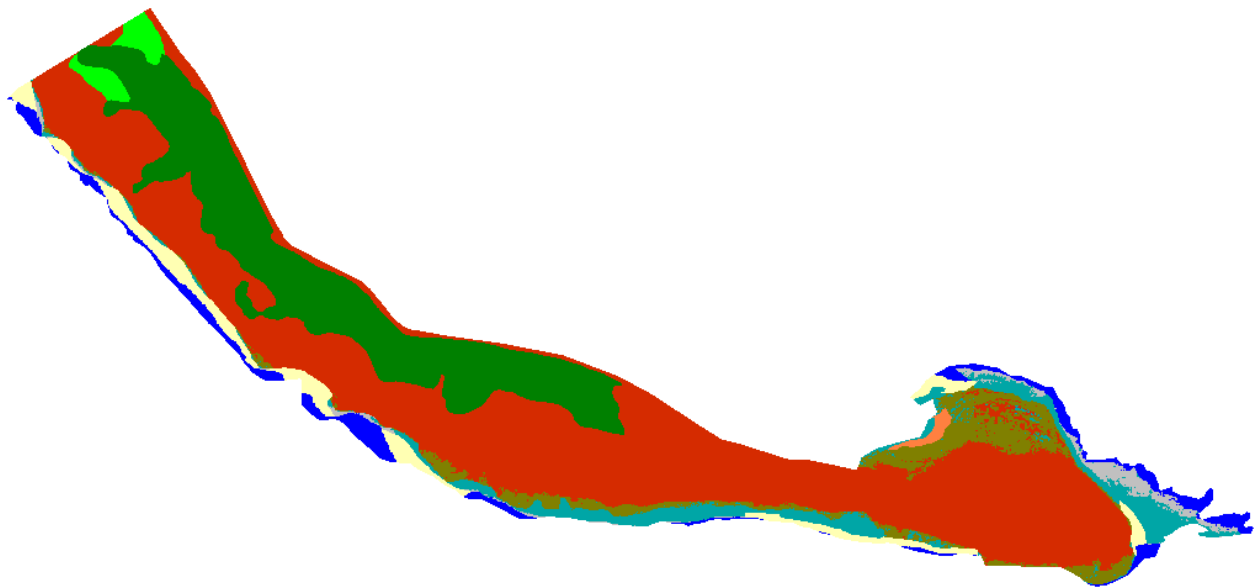|		Initial	2025	2050	2075	2100
	Undeveloped Dry Land	410	383	376	369	363
	Swamp	147	147	147	147	147
	Regularly Flooded Marsh	47	50	47	46	44
	Estuarine Beach	40	40	39	33	32
	Estuarine Open Water	18	19	20	28	30
	Inland Fresh Marsh	11	11	11	11	11
	Transitional Salt Marsh	3	23	29	36	41
	Irregularly Flooded Marsh	3	3	3	3	3
	Tidal Flat	0	5	7	7	7
	Total (incl. water)	**678**	**678**	**678**	**678**	**678**
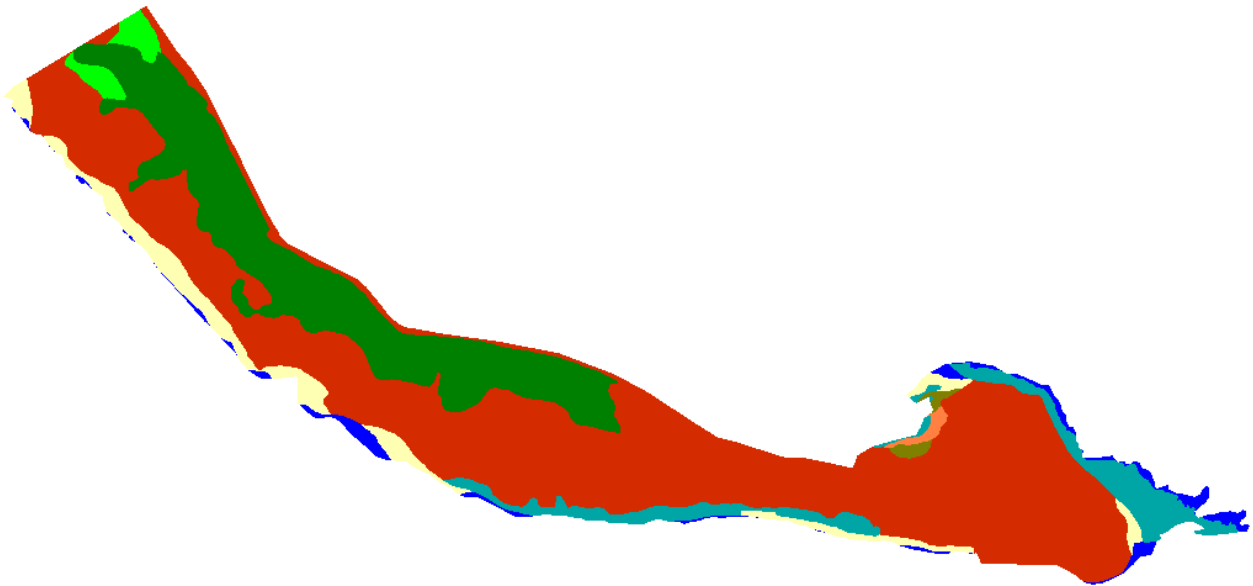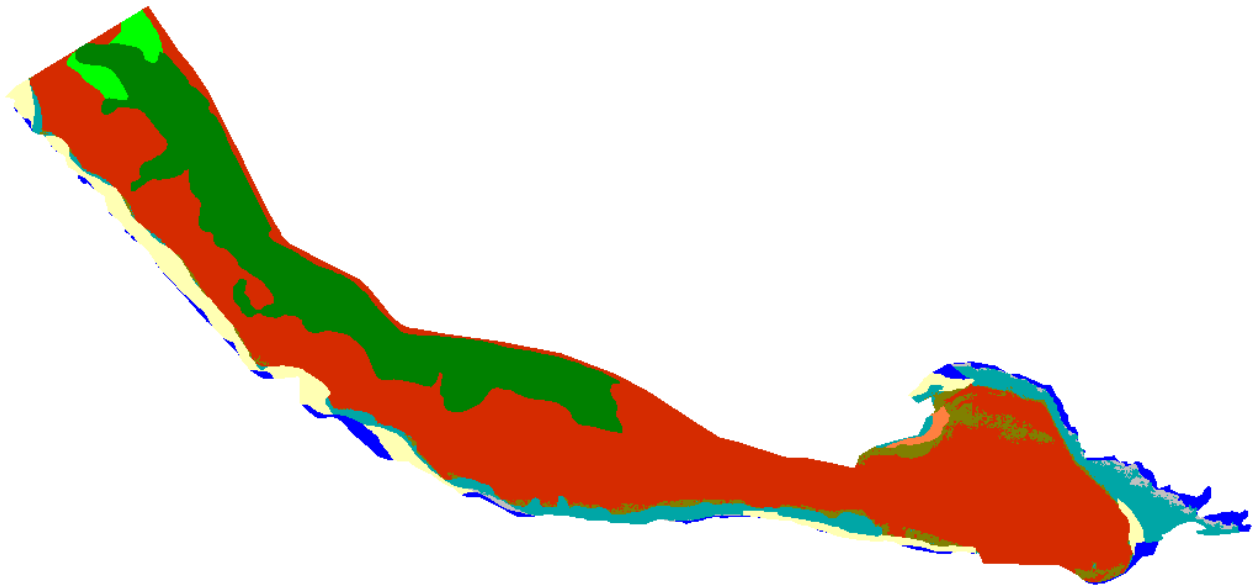
Tybee NWR, Initial Condition.
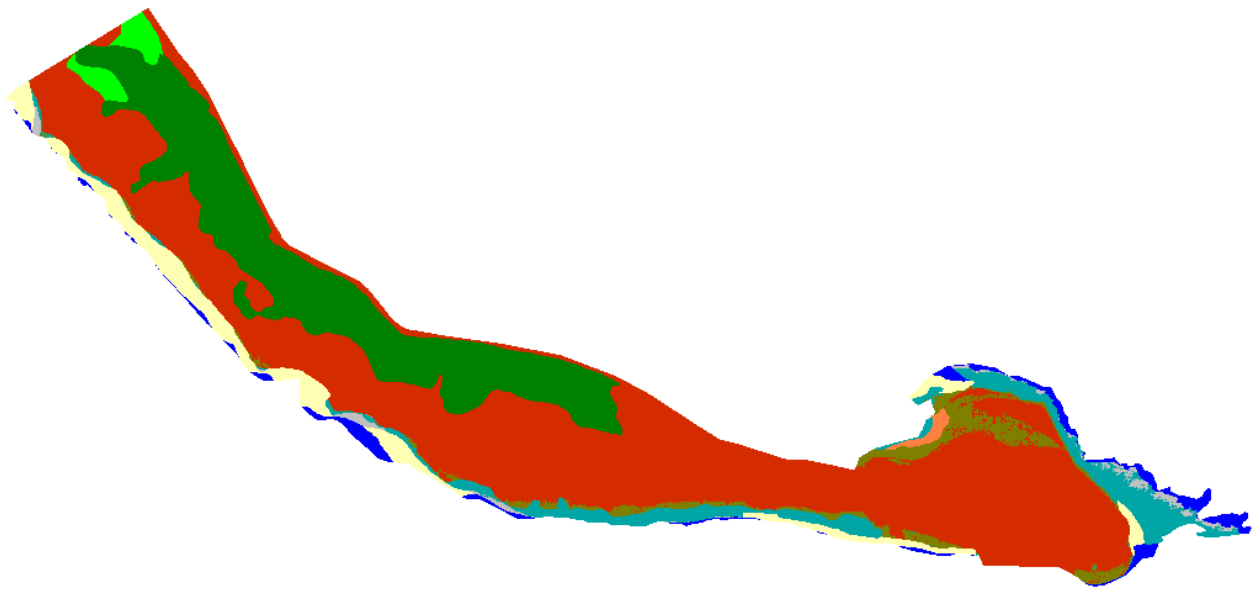
Tybee NWR, 2025, Scenario A1B Mean, 0.39 m SLR by 2100.
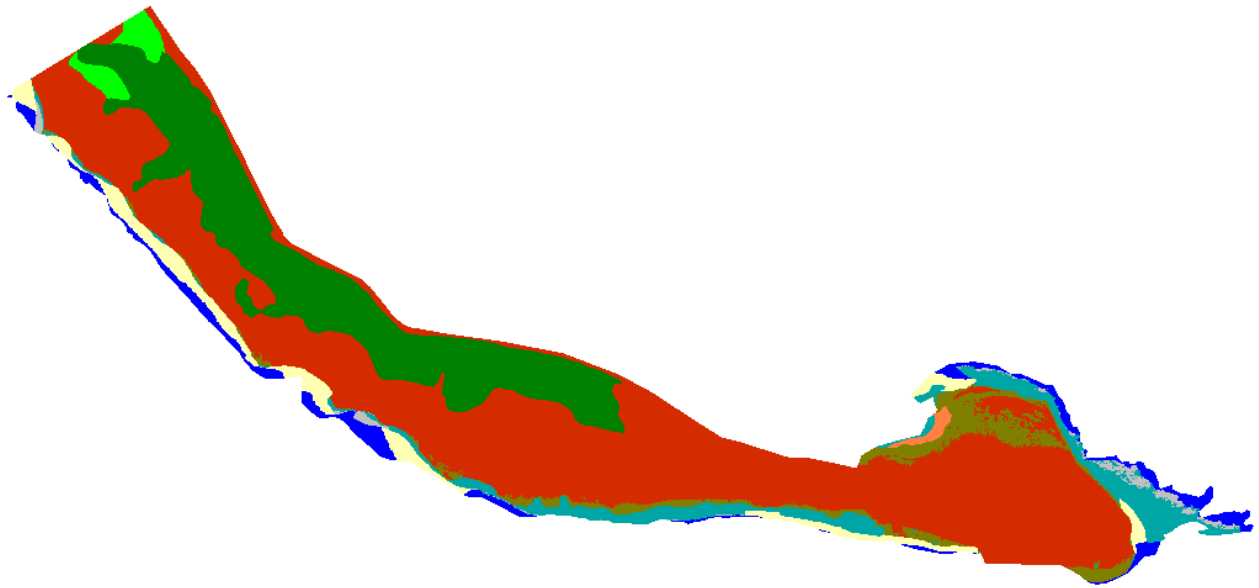
Tybee NWR, 2050, Scenario A1B Mean, 0.39 m SLR by 2100.
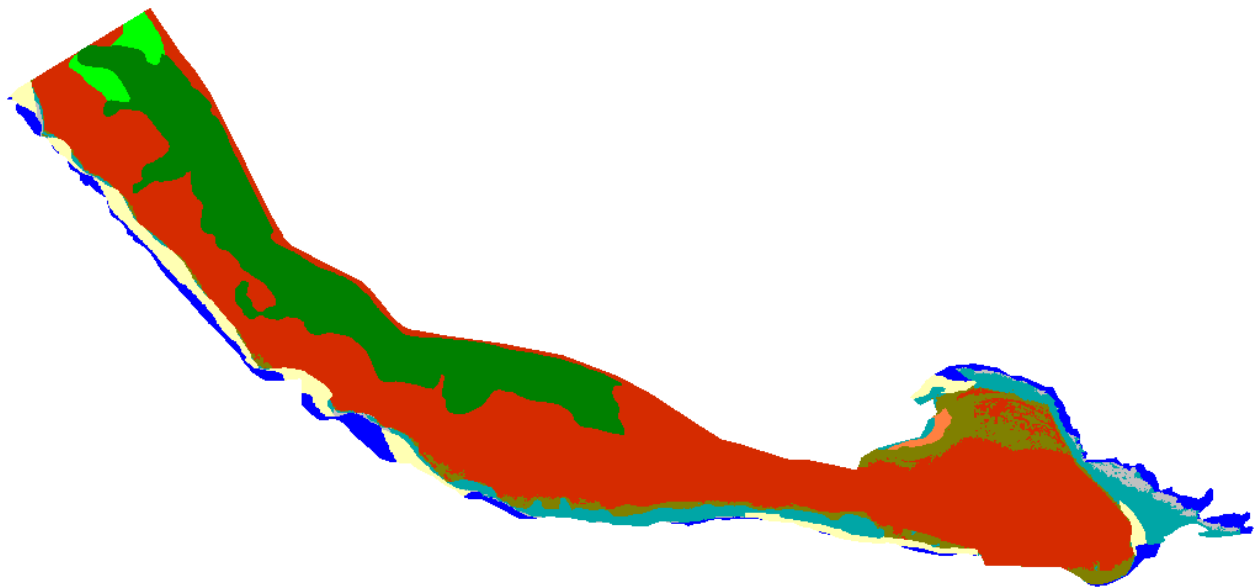
Tybee NWR, 2075, Scenario A1B Mean, 0.39 m SLR by 2100.

Tybee NWR, 2100, Scenario A1B Mean, 0.39 m SLR by 2100.

IPCC Scenario A1B-Max, 0.69 m SLR eustatic by 2100

Results in Acres

		Initial	2025	2050	2075	2100
	Undeveloped Dry Land	410	381	371	361	352
	Swamp	147	147	147	147	147
	Regularly Flooded Marsh	47	50	46	44	44
	Estuarine Beach	40	40	33	32	32
	Estuarine Open Water	18	19	27	30	32
	Inland Fresh Marsh	11	11	11	11	11
	Transitional Salt Marsh	3	24	33	41	47
	Irregularly Flooded Marsh	3	3	3	3	3
	Tidal Flat	0	5	8	9	12
	Total (incl. water)	**678**	**678**	**678**	**678**	**678**
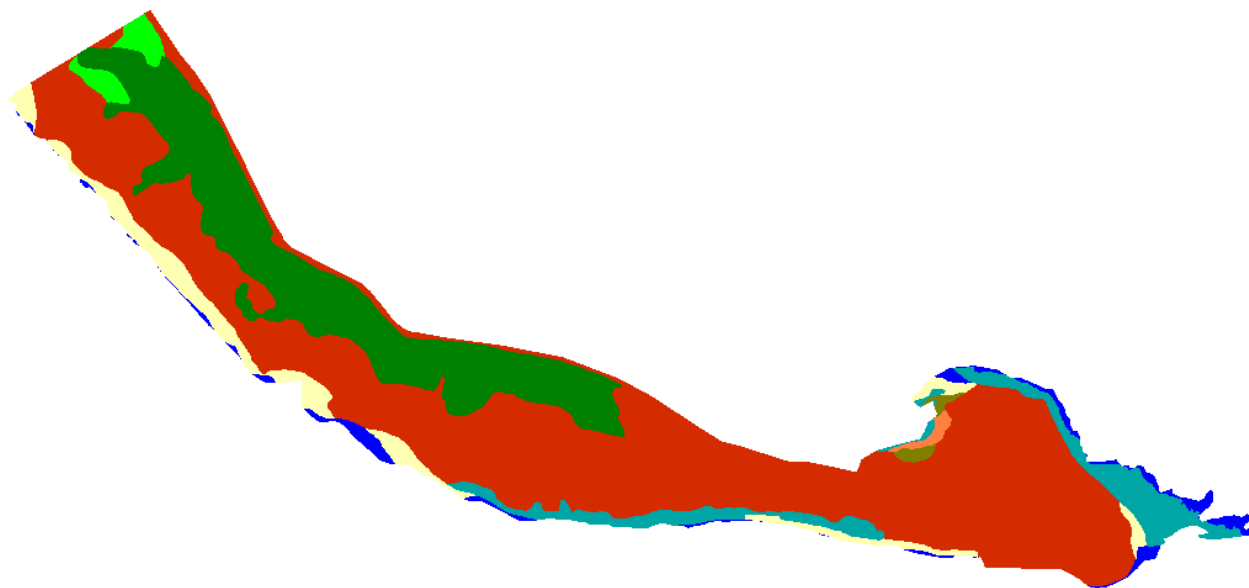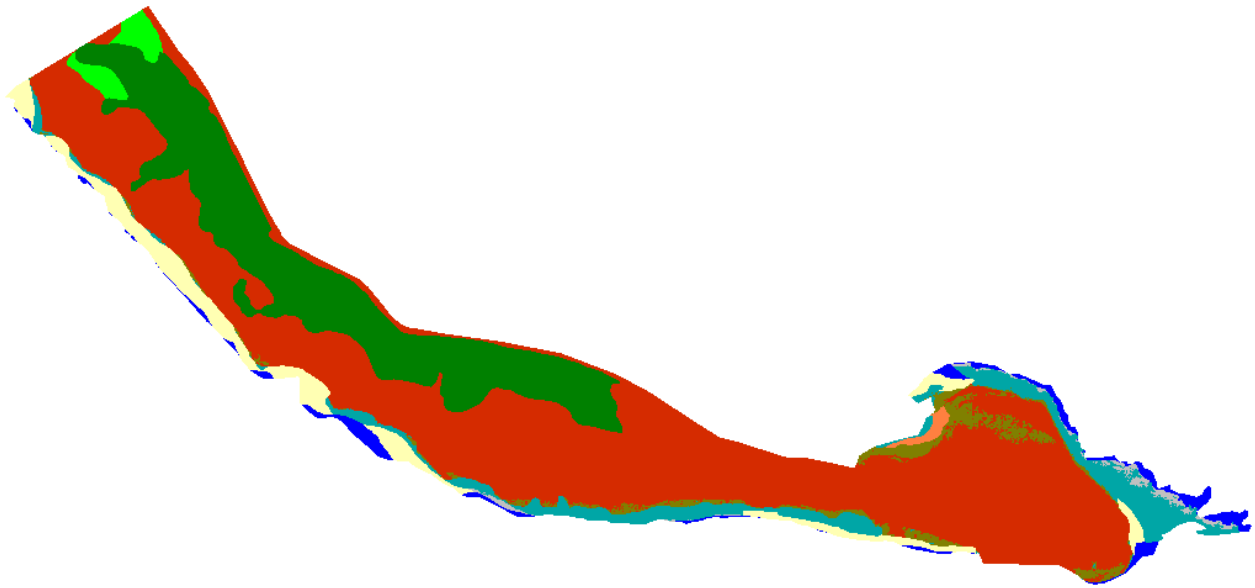
Tybee NWR, Initial Condition.
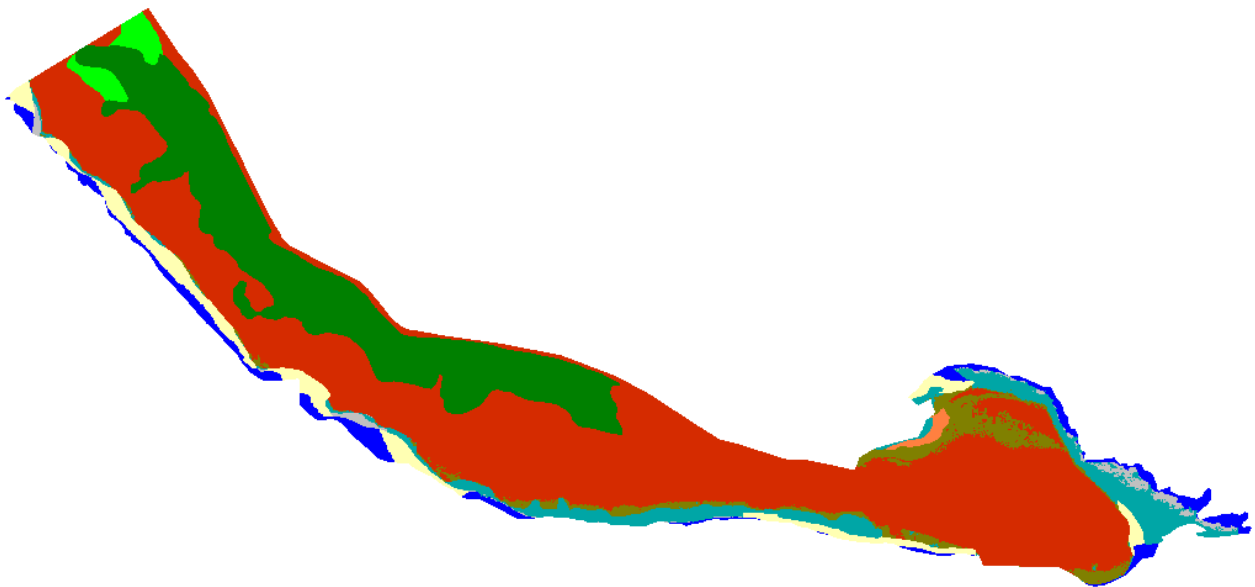
Tybee NWR, 2025, Scenario A1B Maximum, 0.69 m SLR by 2100.

Tybee NWR, 2050, Scenario A1B Maximum, 0.69 m SLR by 2100.

Tybee NWR, 2075, Scenario A1B Maximum, 0.69 m SLR by 2100.

Tybee NWR, 2100, Scenario A1B Maximum, 0.69 m SLR by 2100.

1 m eustatic SLR by 2100

Results in Acres

		Initial	2025	2050	2075	2100
	Undeveloped Dry Land	410	379	366	354	343
	Swamp	147	147	147	147	147
	Regularly Flooded Marsh	47	50	46	46	60
	Estuarine Beach	40	40	32	32	30
	Estuarine Open Water	18	19	28	31	35
	Inland Fresh Marsh	11	11	11	11	11
	Transitional Salt Marsh	3	25	36	43	32
	Irregularly Flooded Marsh	3	3	3	3	2
	Tidal Flat	0	5	10	12	18
	Total (incl. water)	**678**	**678**	**678**	**678**	**678**
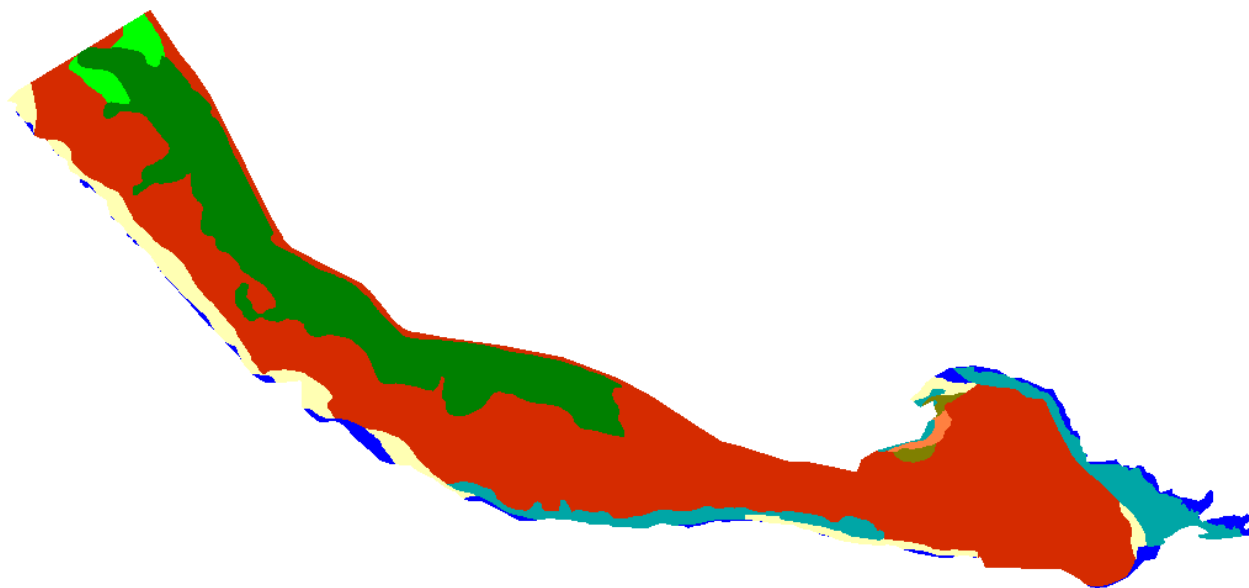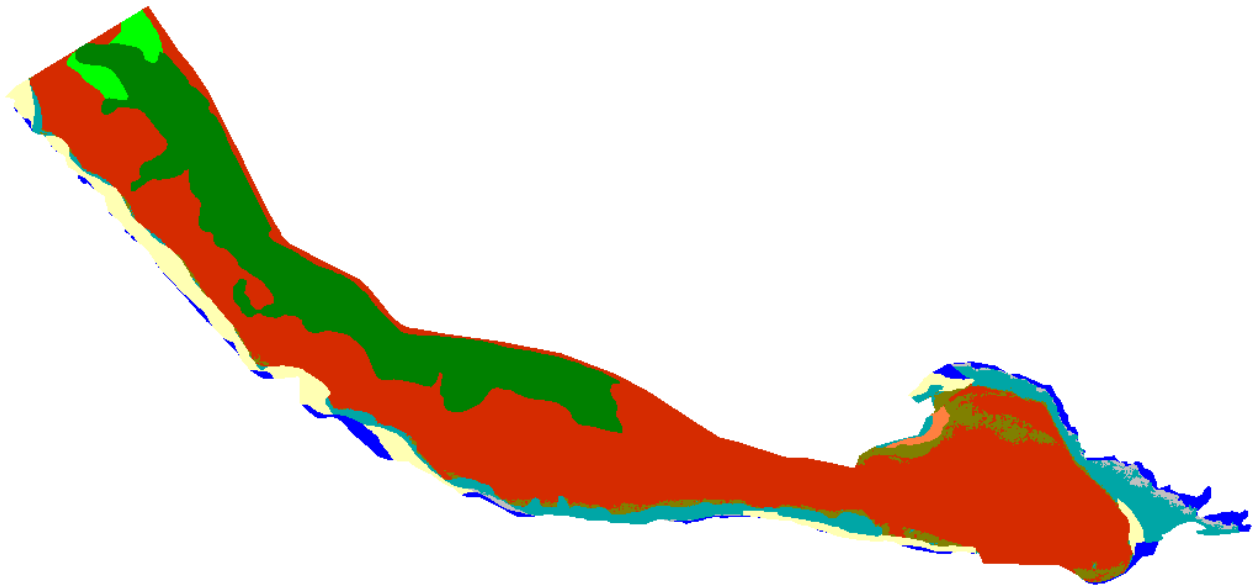
Tybee NWR, Initial Condition.
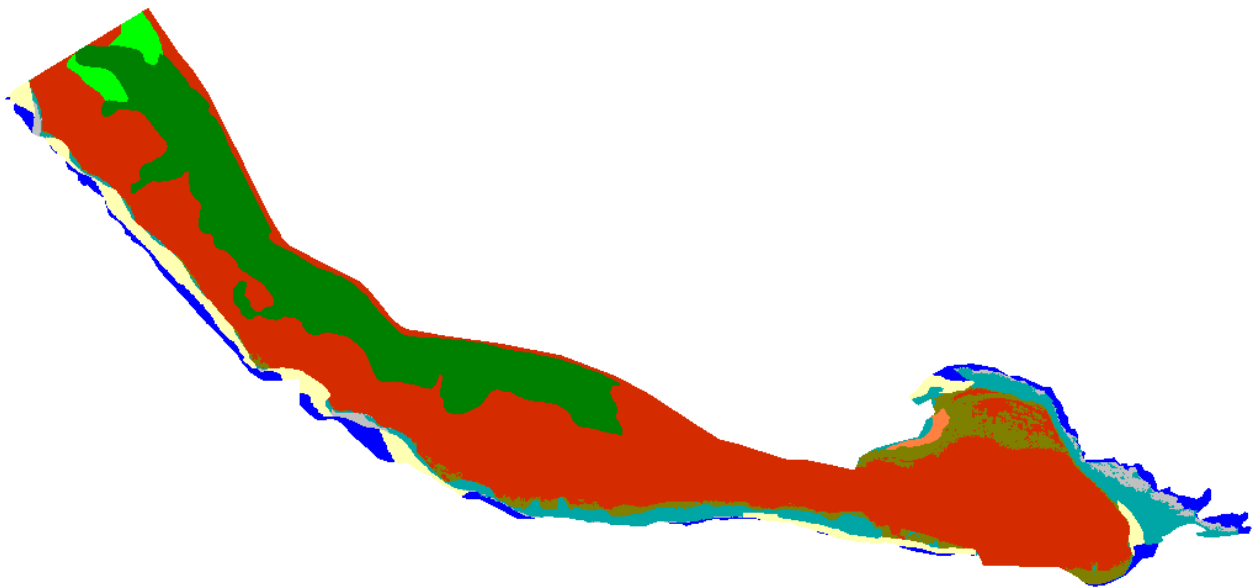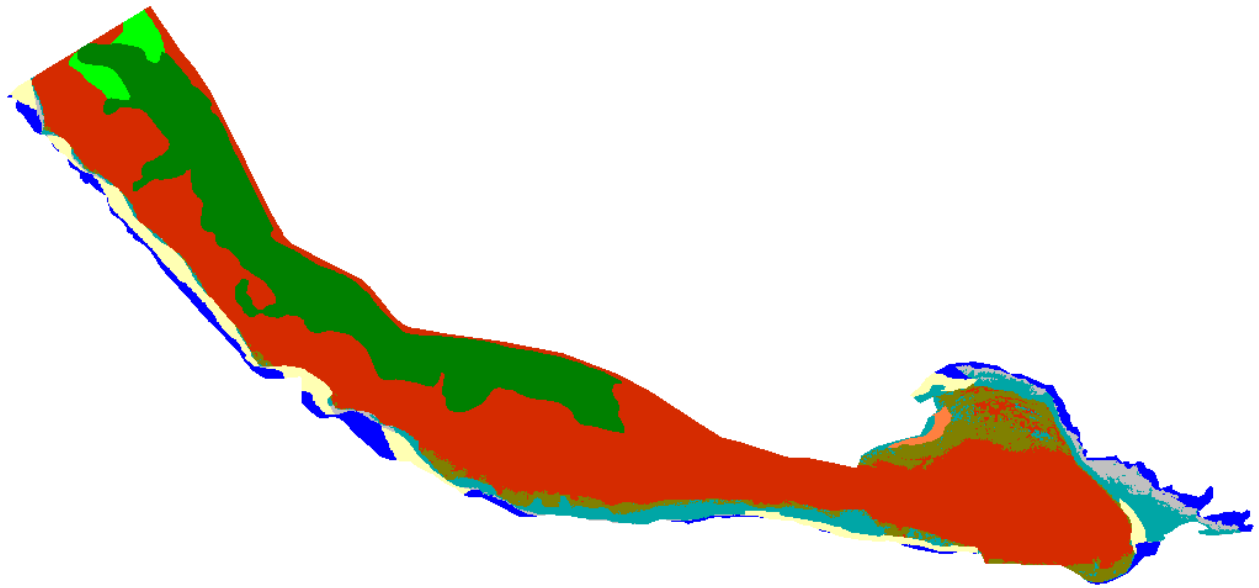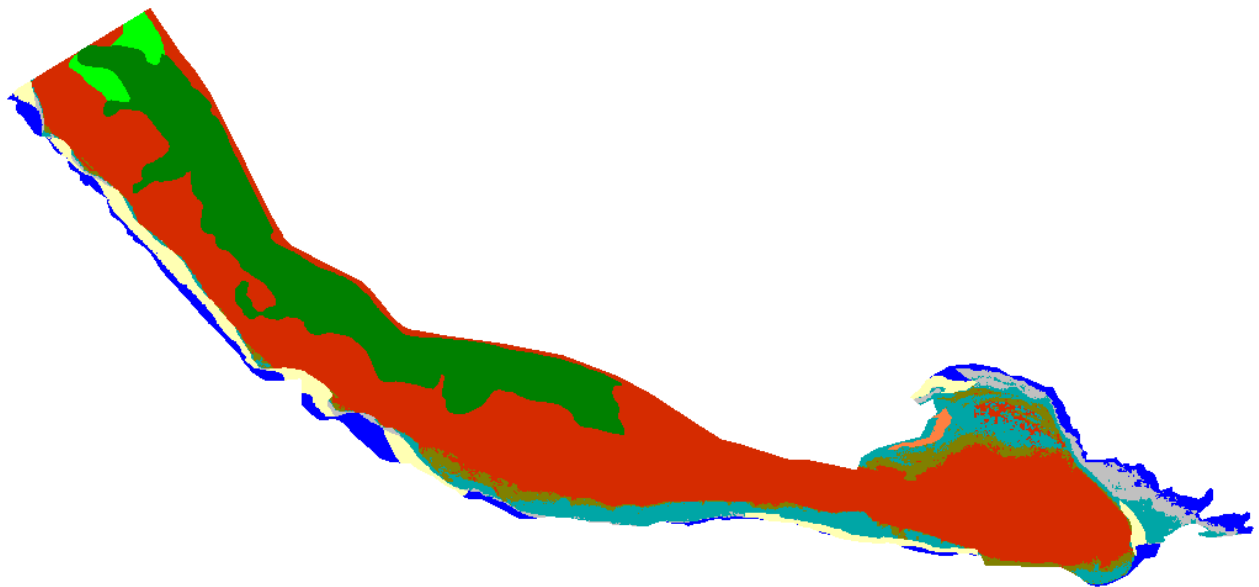
Tybee NWR, 2025, 1 m SLR by 2100.

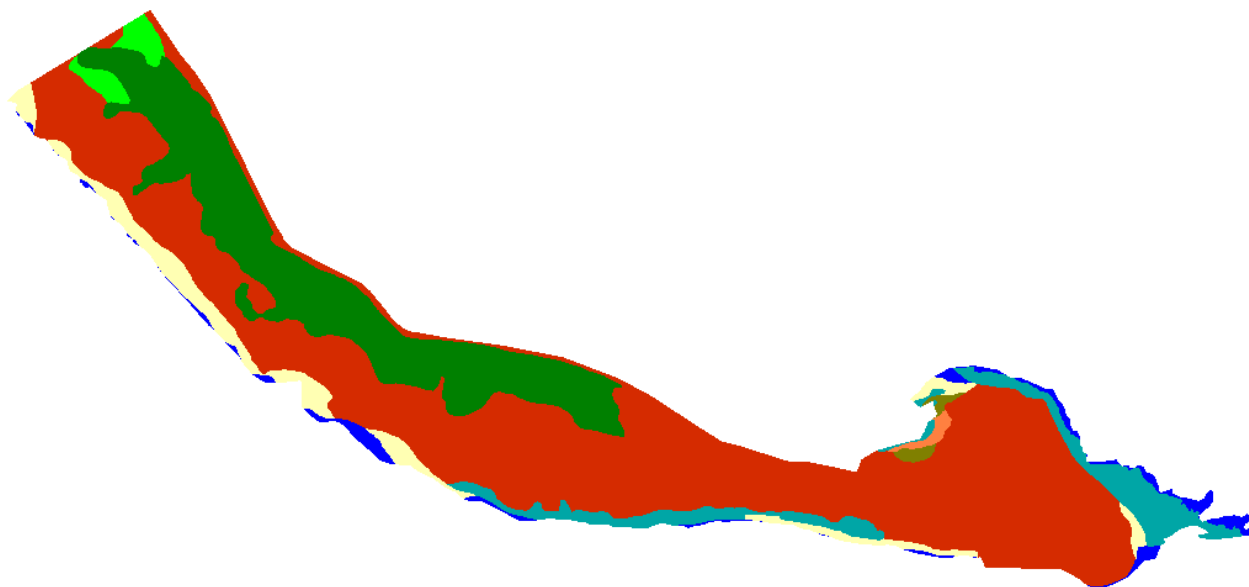Tybee NWR, 2050, 1 m SLR by 2100.

Tybee NWR, 2075, 1 m SLR by 2100.

Tybee NWR, 2100, 1 m SLR by 2100.

1.5 m eustatic SLR by
2100

Results in Acres

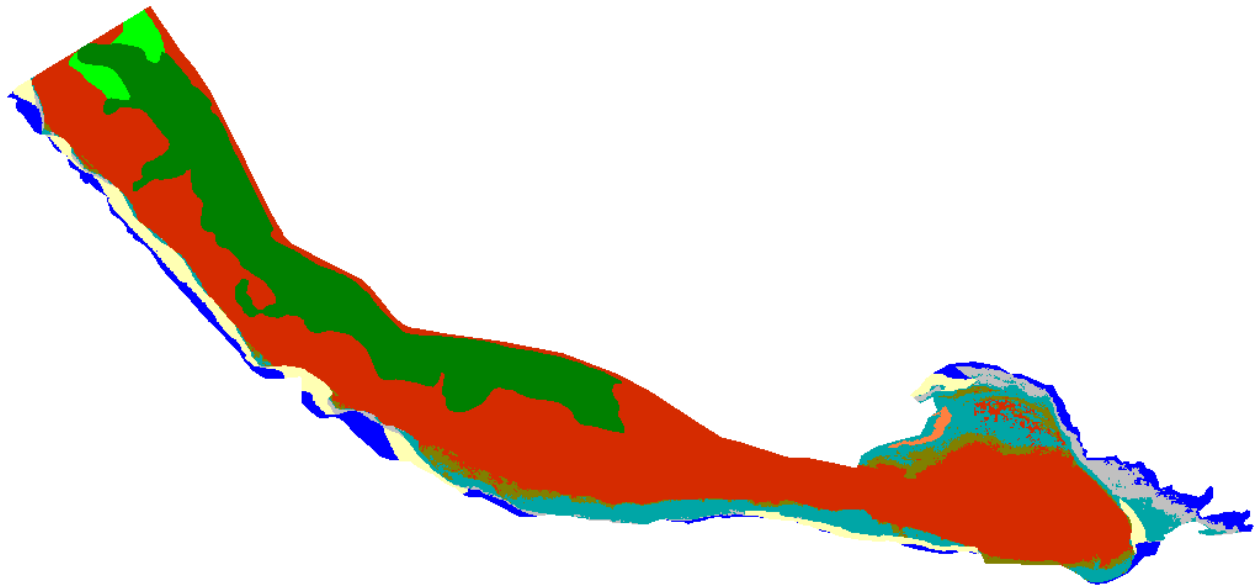|		Initial	2025	2050	2075	2100
	Undeveloped Dry Land	410	376	360	344	311
	Swamp	147	147	147	147	25
	Regularly Flooded Marsh	47	49	46	64	65
	Estuarine Beach	40	39	32	31	23
	Estuarine Open Water	18	20	28	34	47
	Inland Fresh Marsh	11	11	11	11	1
	Transitional Salt Marsh	3	28	39	27	171
	Irregularly Flooded Marsh	3	3	3	2	0
	Tidal Flat	0	6	12	19	35
	Total (incl. water)	**678**	**678**	**678**	**678**	**678**
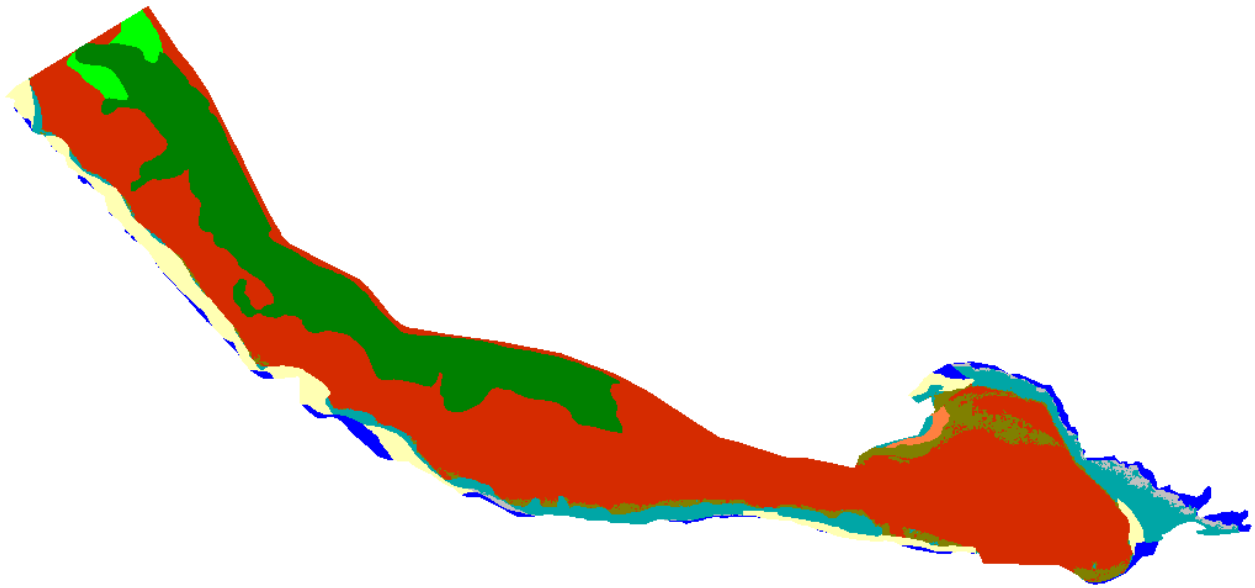
Tybee NWR, Initial Condition.
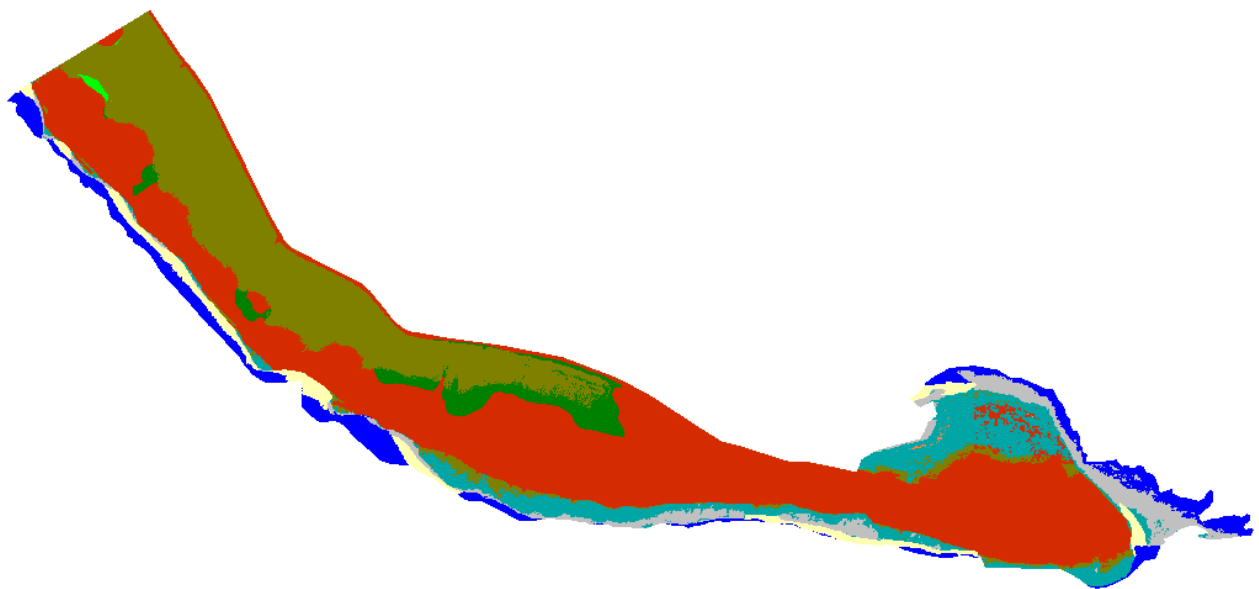
Tybee NWR, 2025, 1.5 m SLR by 2100.
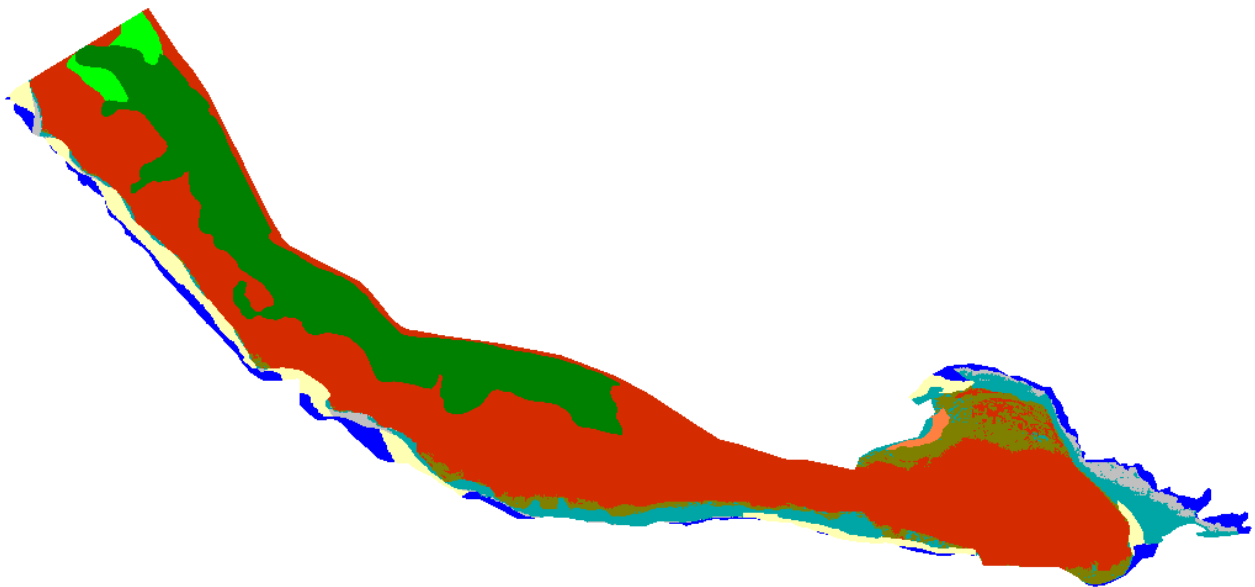
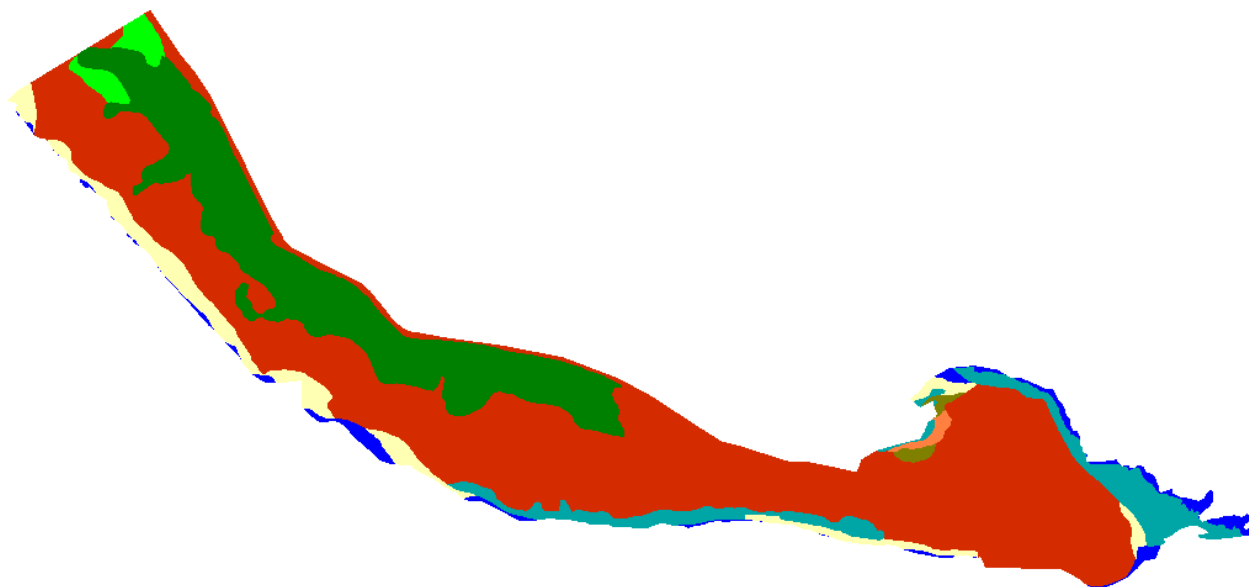Tybee NWR, 2050, 1.5 m SLR by 2100.

Tybee NWR, 2075, 1.5 m SLR by 2100.

Tybee NWR, 2100, 1.5 m SLR by 2100.

2 m eustatic SLR by 2100

Results in Acres

|		Initial	2025	2050	2075	2100
	Undeveloped Dry Land	410	374	354	318	287
	Swamp	147	147	147	33	10
	Regularly Flooded Marsh	47	49	52	63	190
	Estuarine Beach	40	33	32	26	15
	Estuarine Open Water	18	26	29	41	64
	Inland Fresh Marsh	11	11	11	1	1
	Transitional Salt Marsh	3	29	36	162	59
	Irregularly Flooded Marsh	3	3	3	1	0
	Tidal Flat	0	6	16	32	52
	Total (incl. water)	**678**	**678**	**678**	**678**	**678**
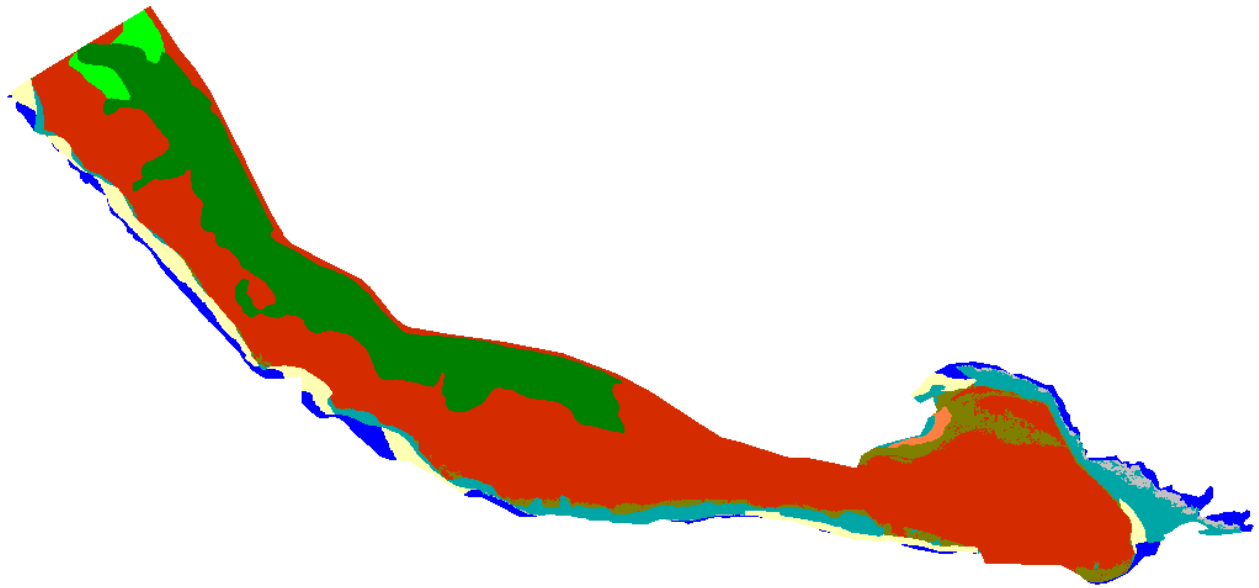
Tybee NWR, Initial Condition.

Tybee NWR, 2025, 2 m SLR by 2100.
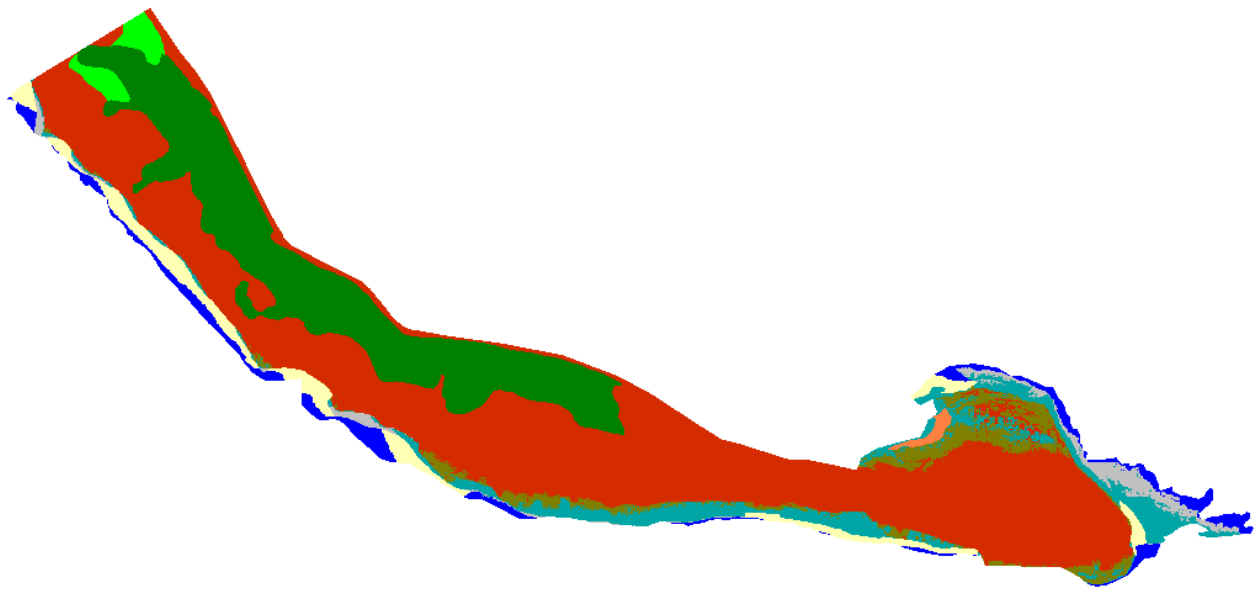
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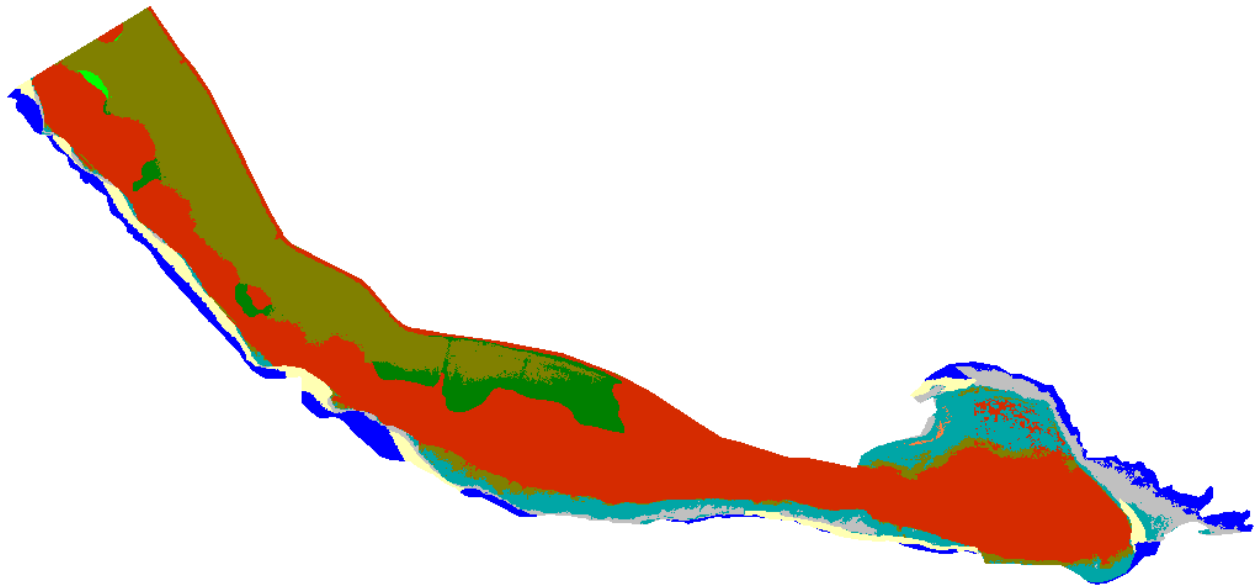
Tybee NWR, 2075, 2 m SLR by 2100.
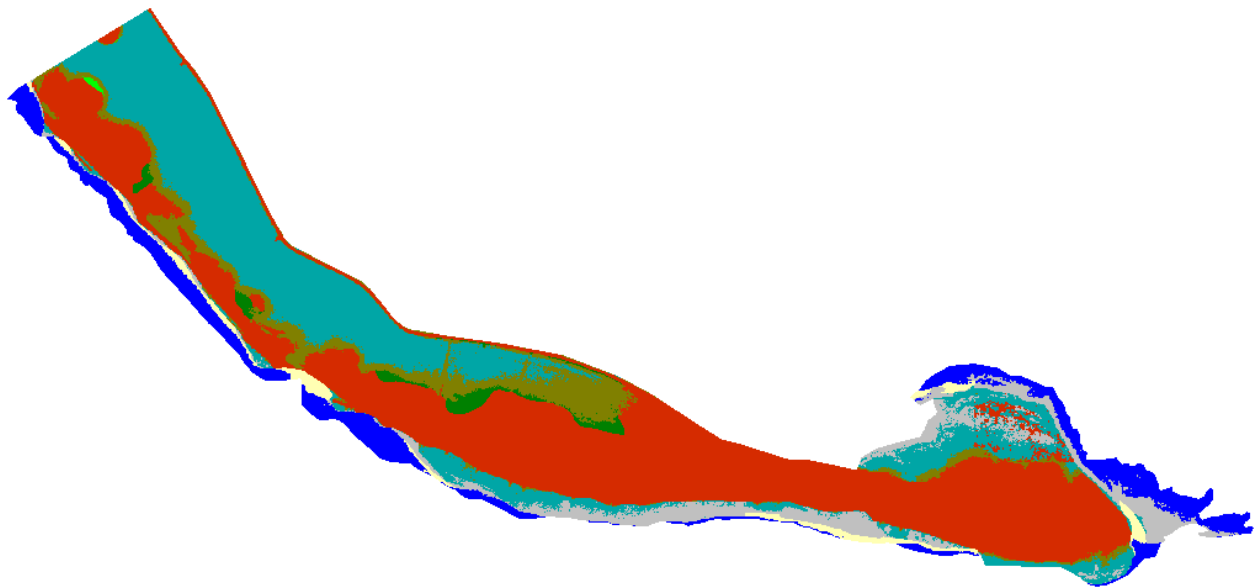
Tybee NWR, 2100, 2 m SLR by 2100.

Discussion

Tybee NWR is composed primarily of dry land. SLAMM projections indicate that losses of dry land will occur predominantly in the eastern half of the refuge that borders open ocean, while the upstream portions of the refuge appear more resilient to SLR until scenarios reach 1.5 meters or greater. These results may be attributed to the lower elevations in the section of refuge that borders the open ocean, especially in the north. Upstream portions of the refuge are predicted to experience less loss at the lower SLR scenarios examined due in large part to the higher elevations of these areas.

One important caveat is the lack of elevation data for some cells in the eastern part of the refuge, as shown in Figure 6. These areas are not modeled and therefore are not lost even though adjacent cells convert to wetlands. This leads to a minor lack of precision in the dry-land loss and marsh gain statistics.
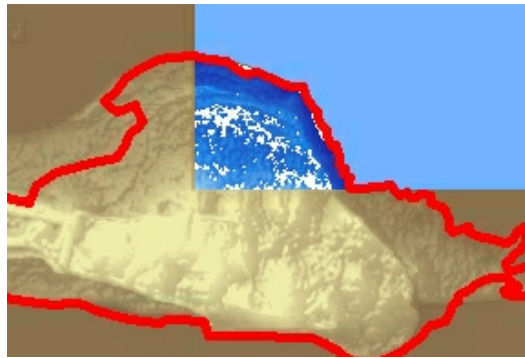

Figure 6. Missing elevation data in 2007 Jasper Co. LiDAR, shown as white pixels on blue background.

The previous SLAMM application to Tybee NWR predicted more wetland loss than these updated simulations. The main difference between the two projects is the use of 2010 LiDAR data for the majority of the refuge area in the current model application. The use of LiDAR is a significant improvement in the input data and leads to a more accurate description of wetland elevations.

While model and data updates improve the SLAMM projections reported here, input layers, parameter inputs, sea level rise scenarios and the conceptual model have uncertainties and errors that should keep in mind when interpreting these results. The variability, confidence, and sensitivity of the results should be studied as a function of these uncertainties to provide a range of possible outcomes and their likelihood that could better assist the decision making process and management plans. In addition, uncertainty in future sea-level rise is important to keep in mind when interpreting these results. Much of this uncertainty is due to assumptions made regarding the drivers of climate change in projecting SLR rates. Future levels of economic activity, fuel type, and fuel consumption are unknown and estimates of these driving variables are speculative. To account for these uncertainties, results presented here investigated effects for a wide range of possible sea level rise scenarios, from a more conservative rise (0.39 m by 2100) to a more accelerated process (2 m by 2100).

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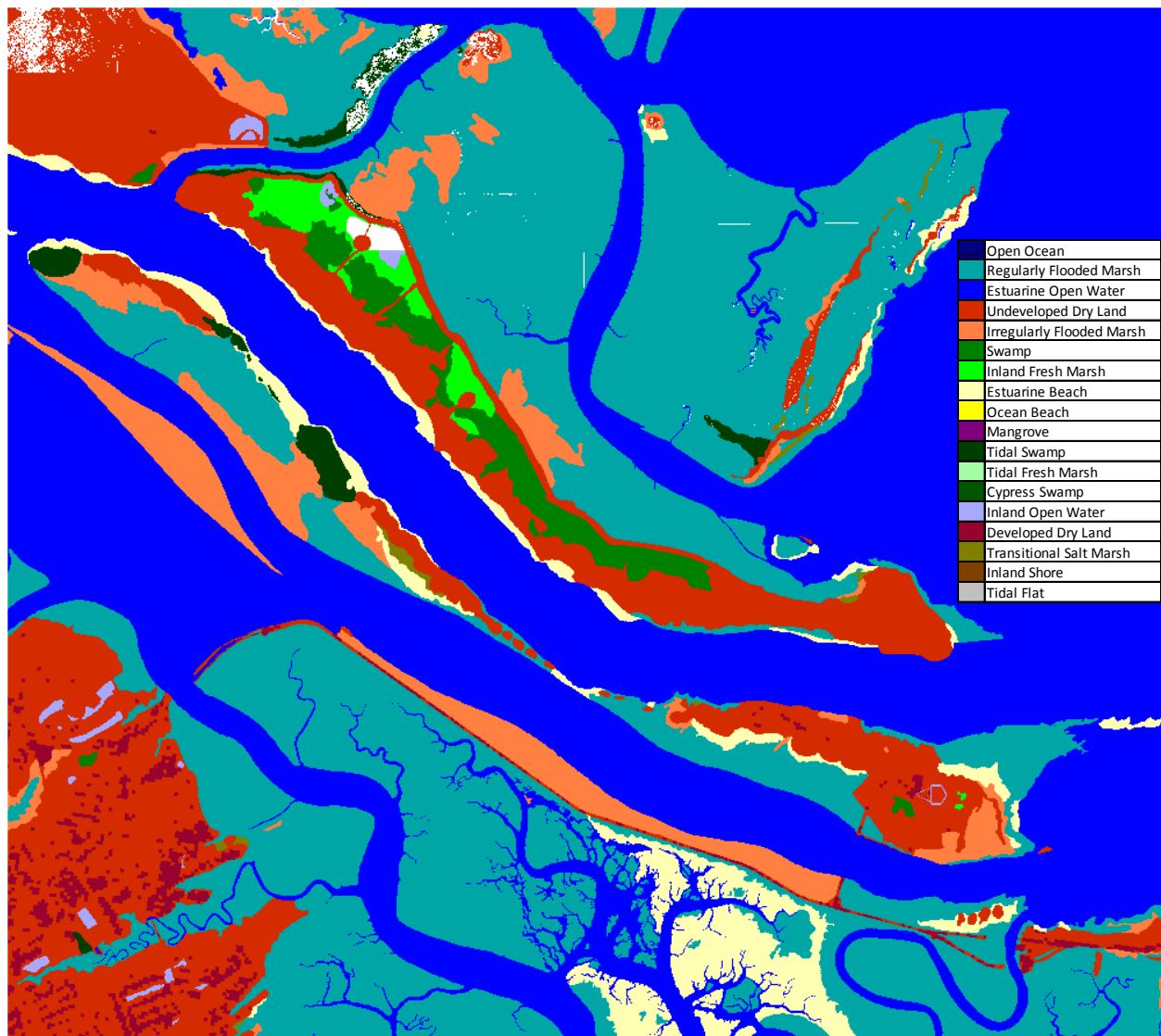
Appendix A: Contextual Results

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. Therefore, an area larger than the boundaries of the USFWS refuge was modeled. Maps of these results are presented here with the following caveats:
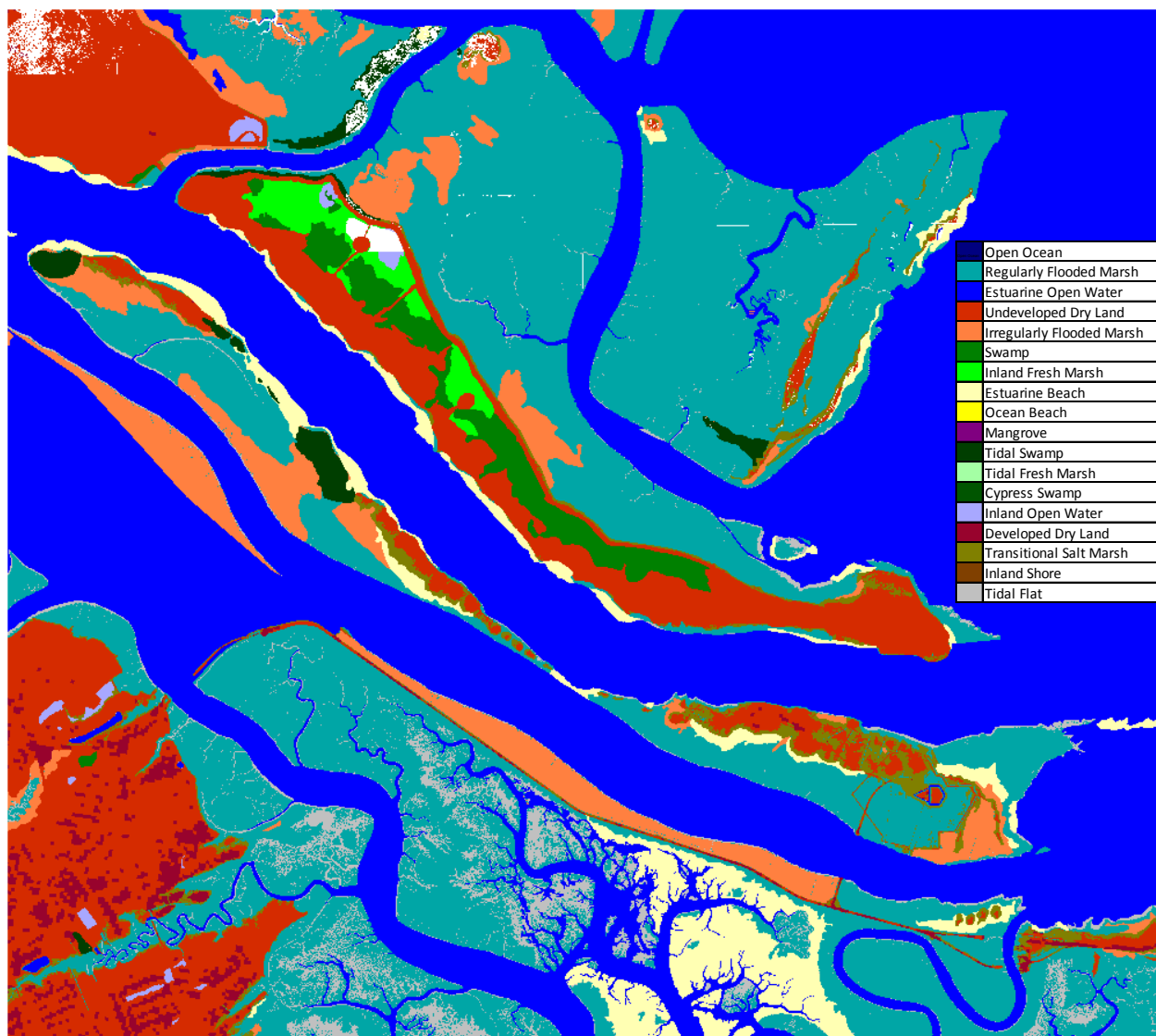
- Results were critically examined within USFWS refuges but not closely examined for the larger region.
- Site-specific parameters for the model were derived for USFWS refuges whenever possible and may not be regionally applicable.
- Especially in areas where dikes are present, an effort was made to assess the probable location and effects of dikes for USFWS refuges, but this effort was not made for surrounding areas.
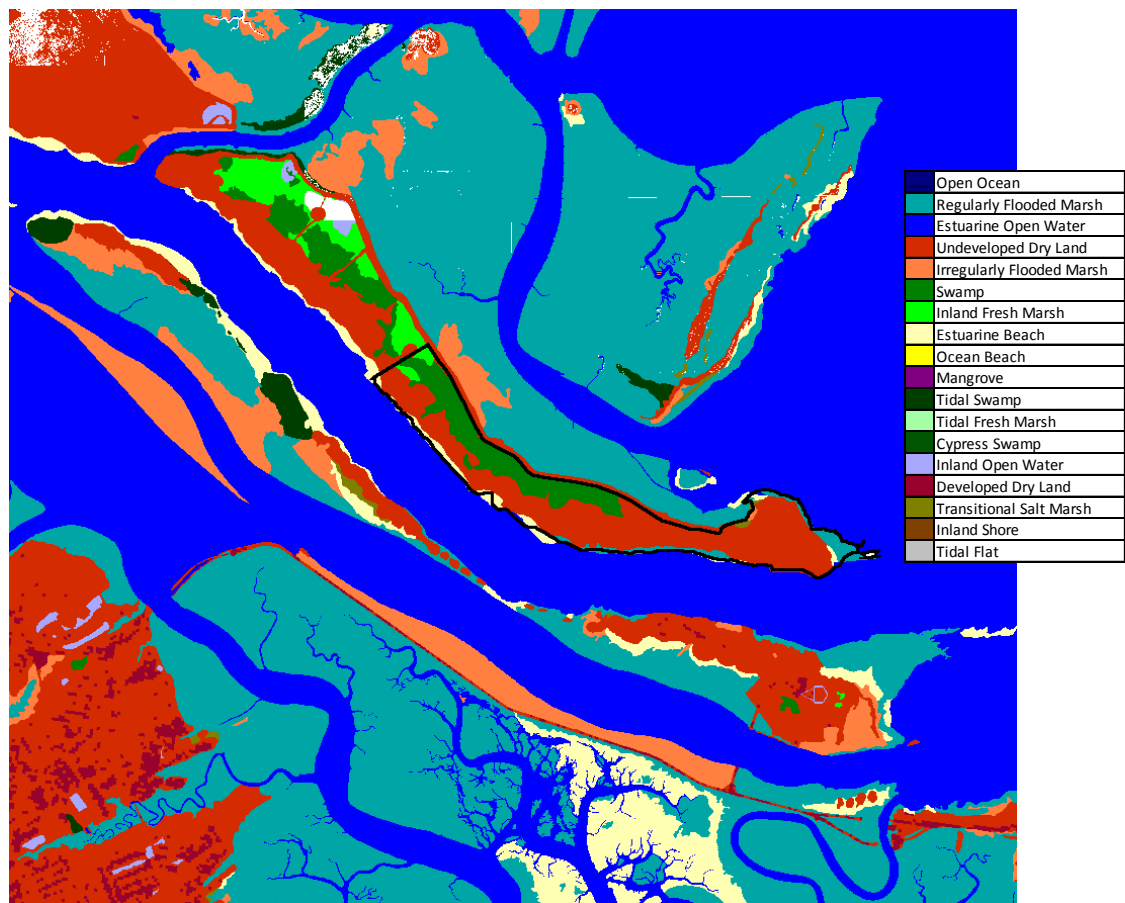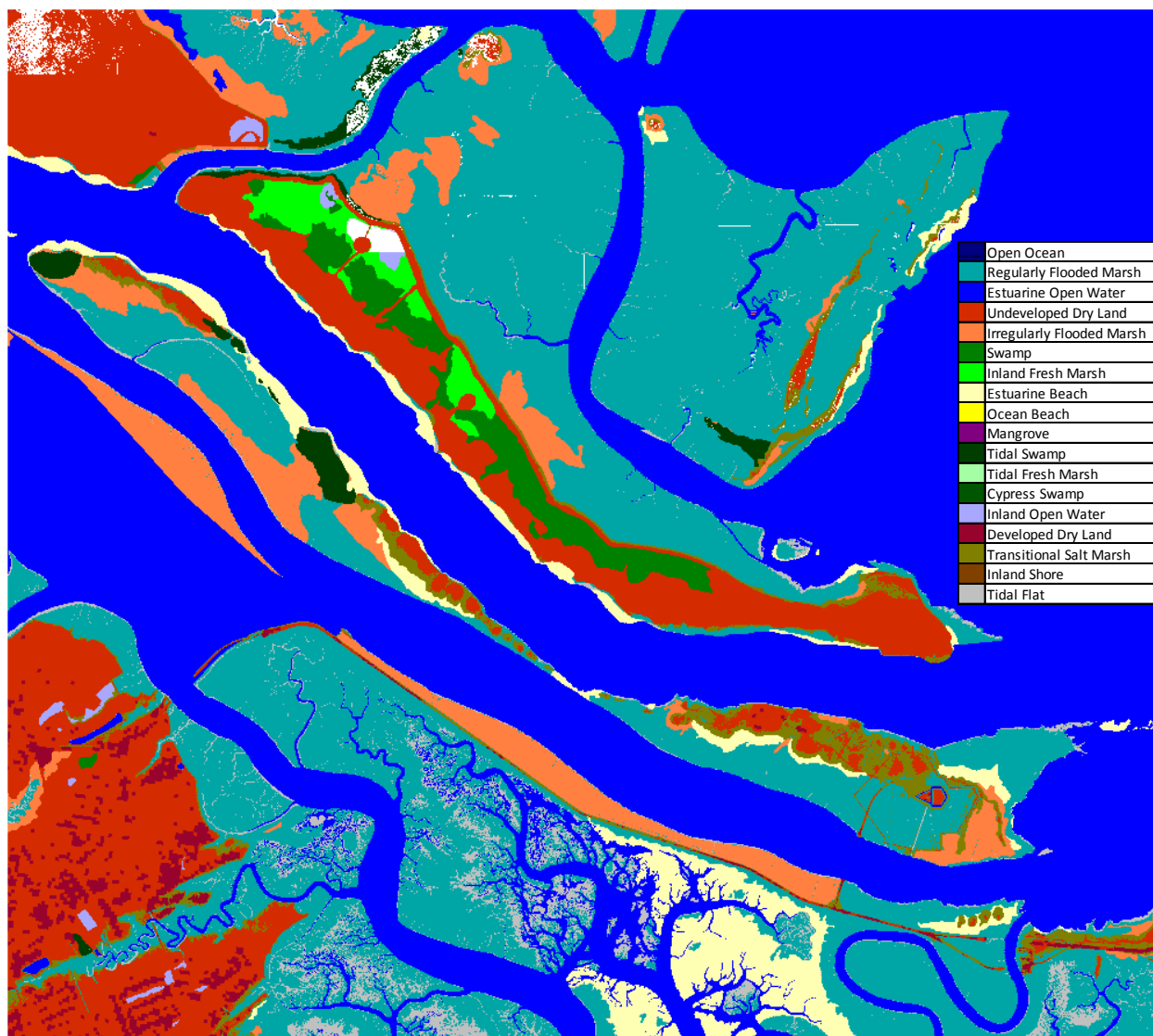

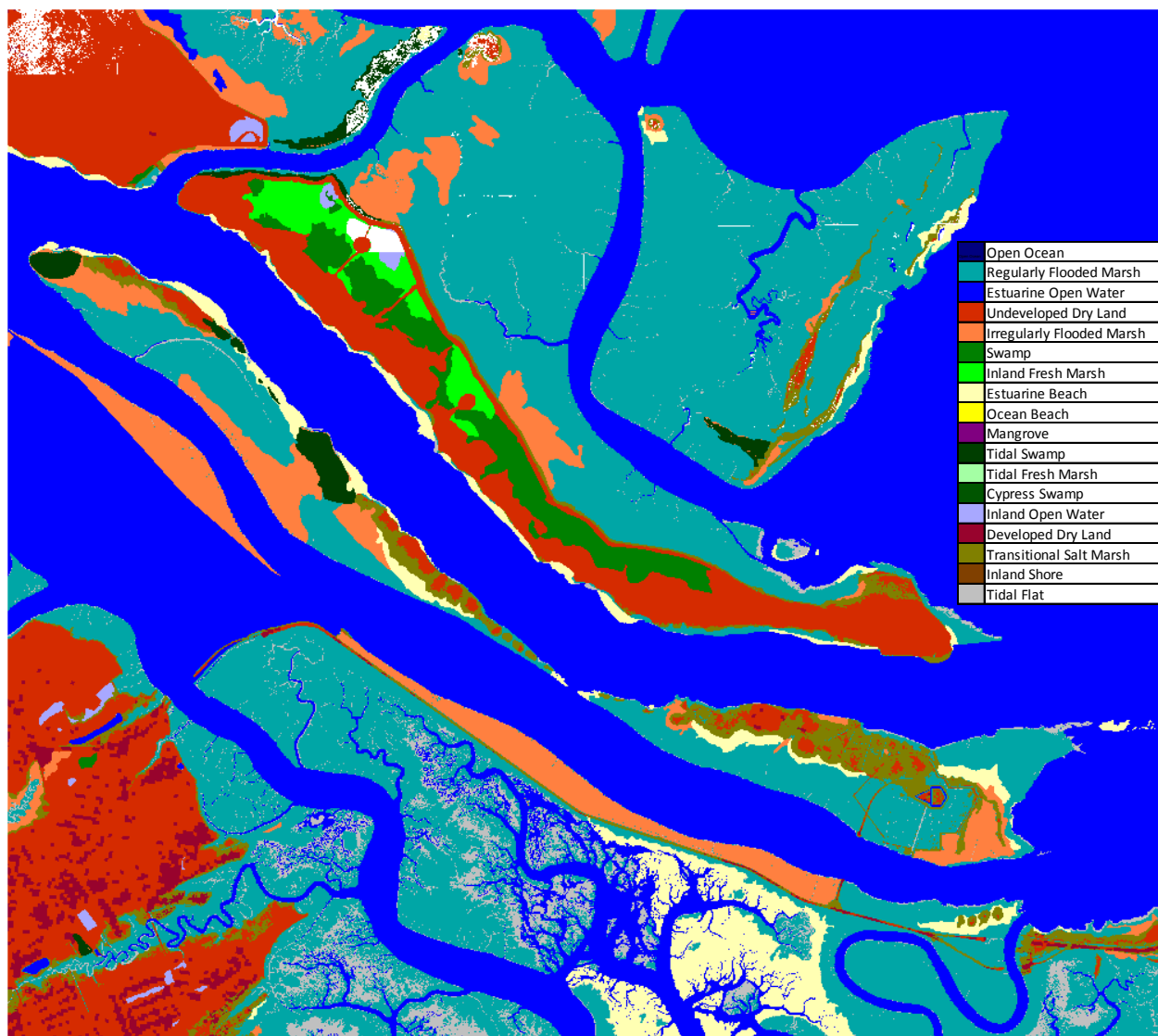Tybee National Wildlife Refuge within simulation context (white).
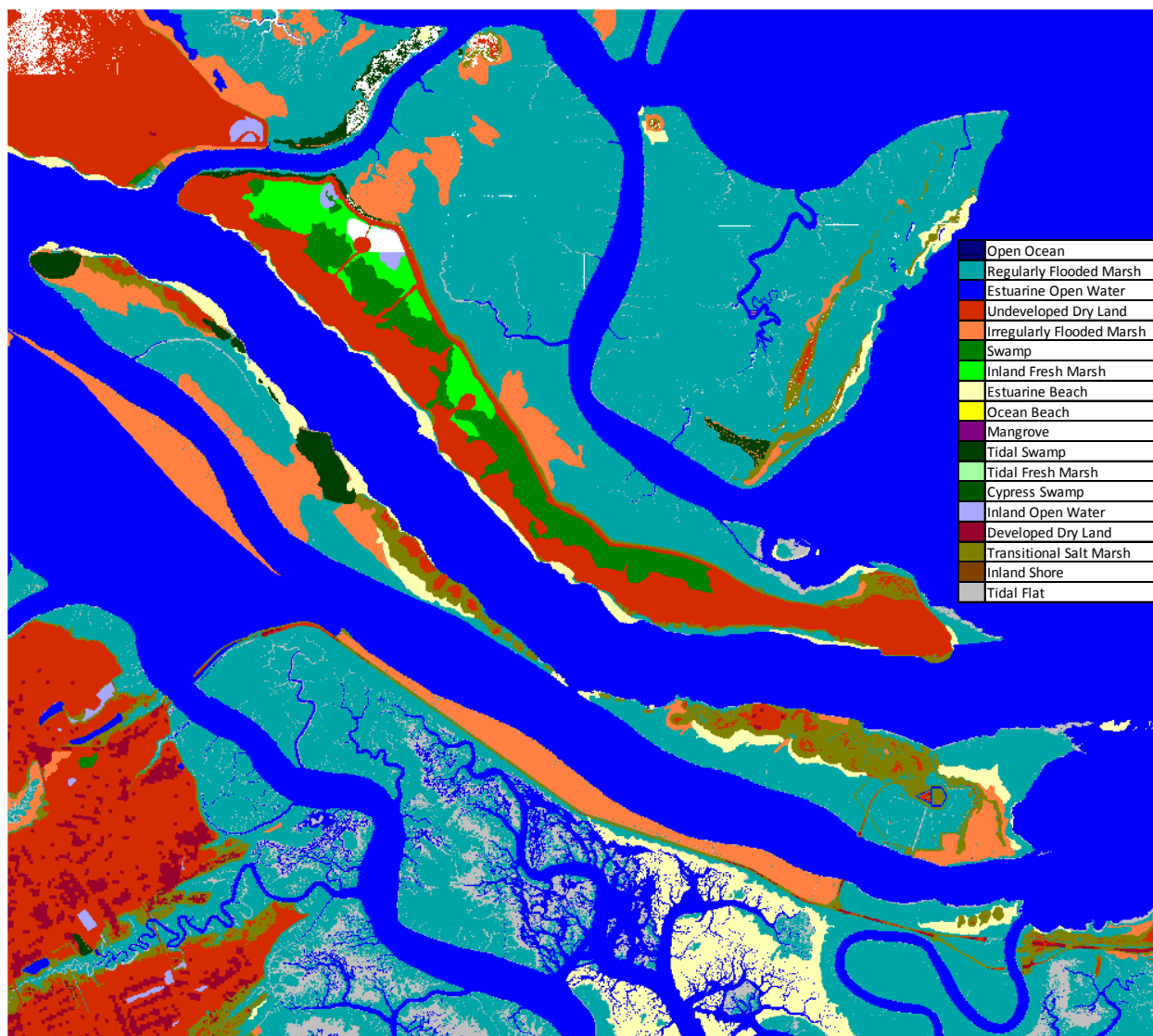
Tybee NWR, Initial Condition.

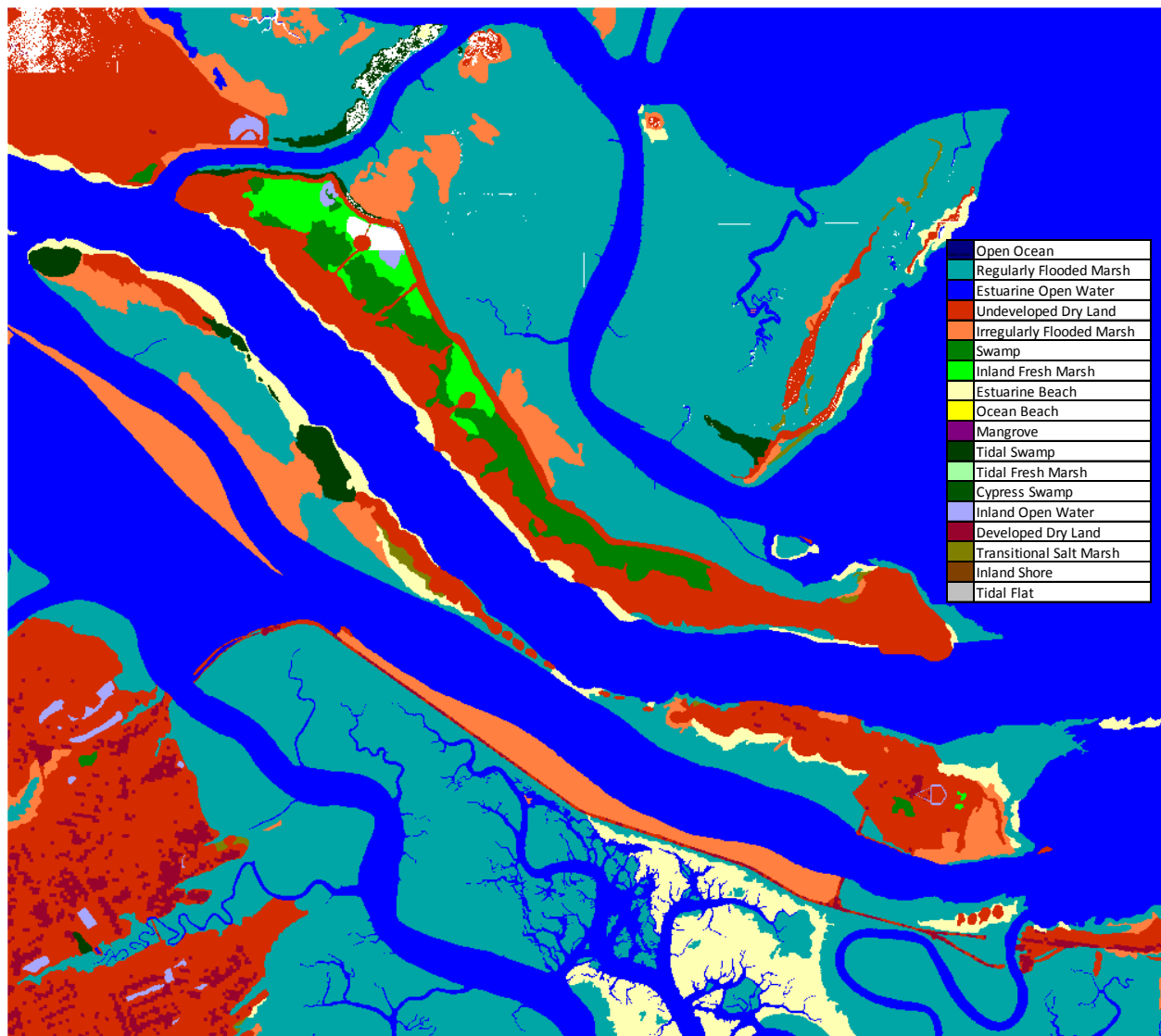Tybee NWR, 2025, Scenario A1B Mean, 0.39 m SLR by 2100.

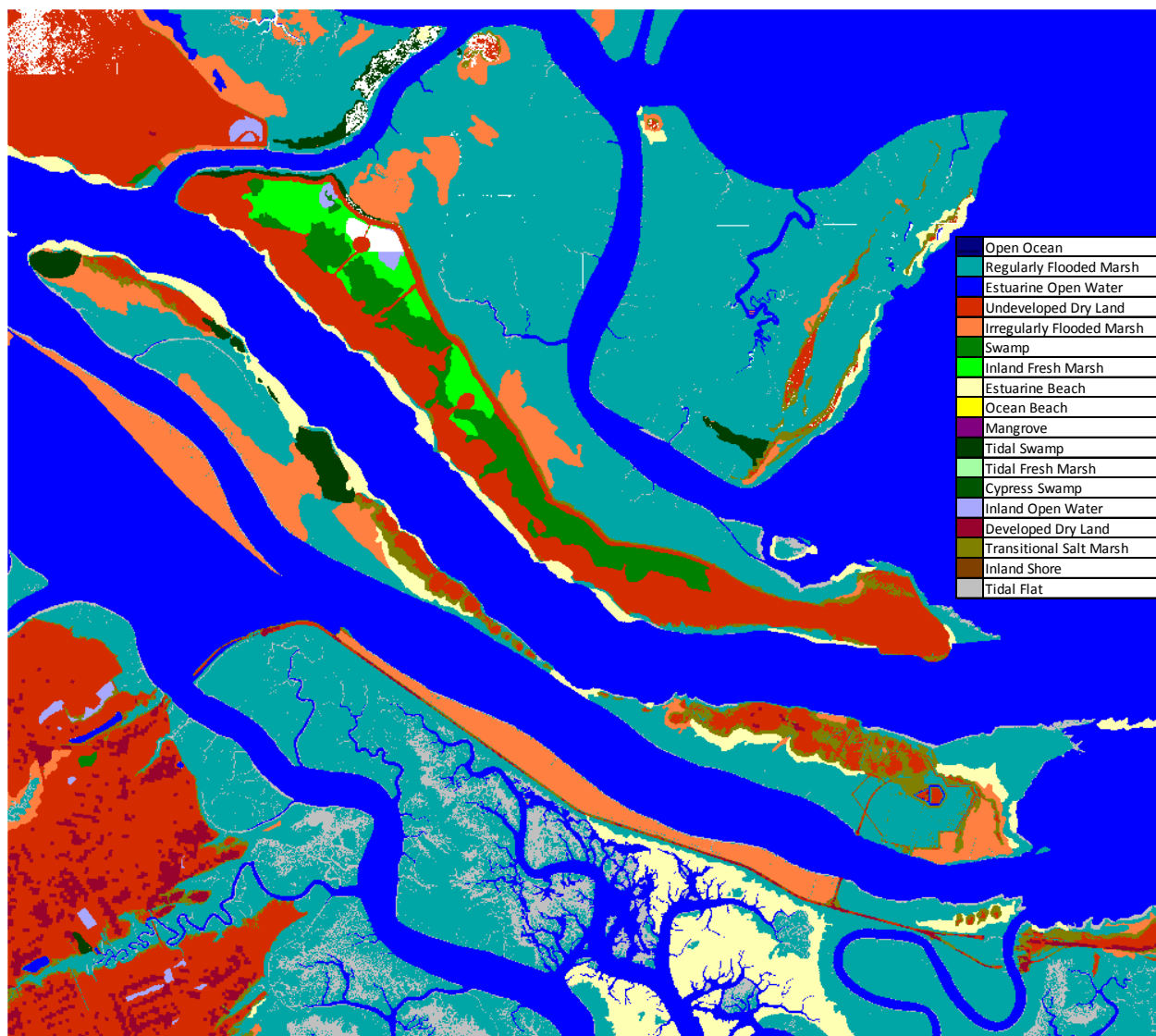|	
■	Open Ocean
■	Regularly Flooded Marsh
■	Estuarine Open Water
■	Undeveloped Dry Land
■	Irregularly Flooded Marsh
■	Swamp
■	Inland Fresh Marsh
■	Estuarine Beach
■	Ocean Beach
■	Mangrove
■	Tidal Swamp
■	Tidal Fresh Marsh
■	Cypress Swamp
■	Inland Open Water
■	Developed Dry Land
■	Transitional Salt Marsh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

Tybee NWR, 2050, Scenario A1B Mean, 0.39 m SLR by 2100.

Tybee NWR, 2075, Scenario A1B Mean, 0.39 m SLR by 2100.

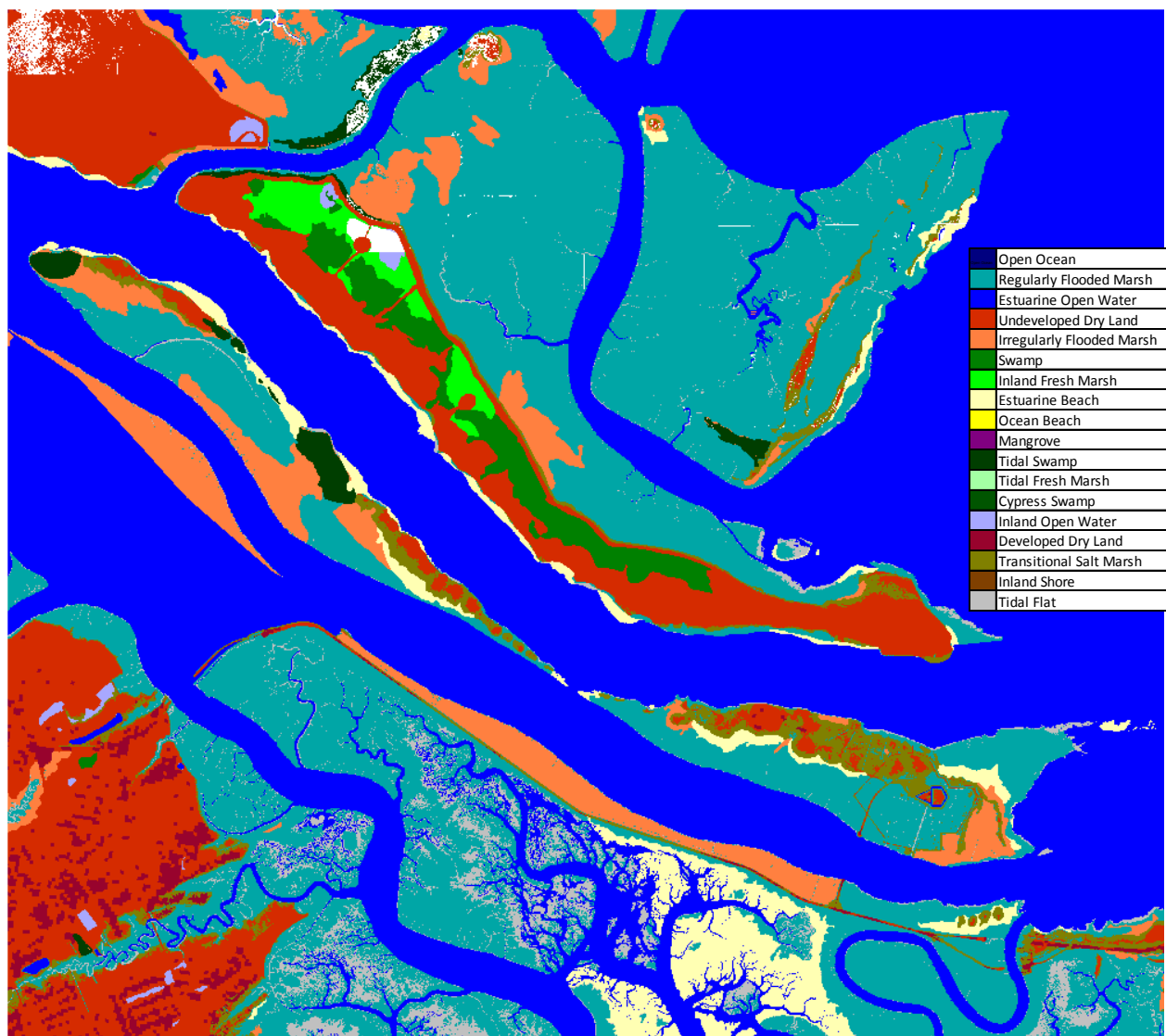|	
■	Open Ocean
■	Regularly Flooded Marsh
■	Estuarine Open Water
■	Undeveloped Dry Land
■	Irregularly Flooded Marsh
■	Swamp
■	Inland Fresh Marsh
■	Estuarine Beach
■	Ocean Beach
■	Mangrove
■	Tidal Swamp
■	Tidal Fresh Marsh
■	Cypress Swamp
■	Inland Open Water
■	Developed Dry Land
■	Transitional Salt Marsh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

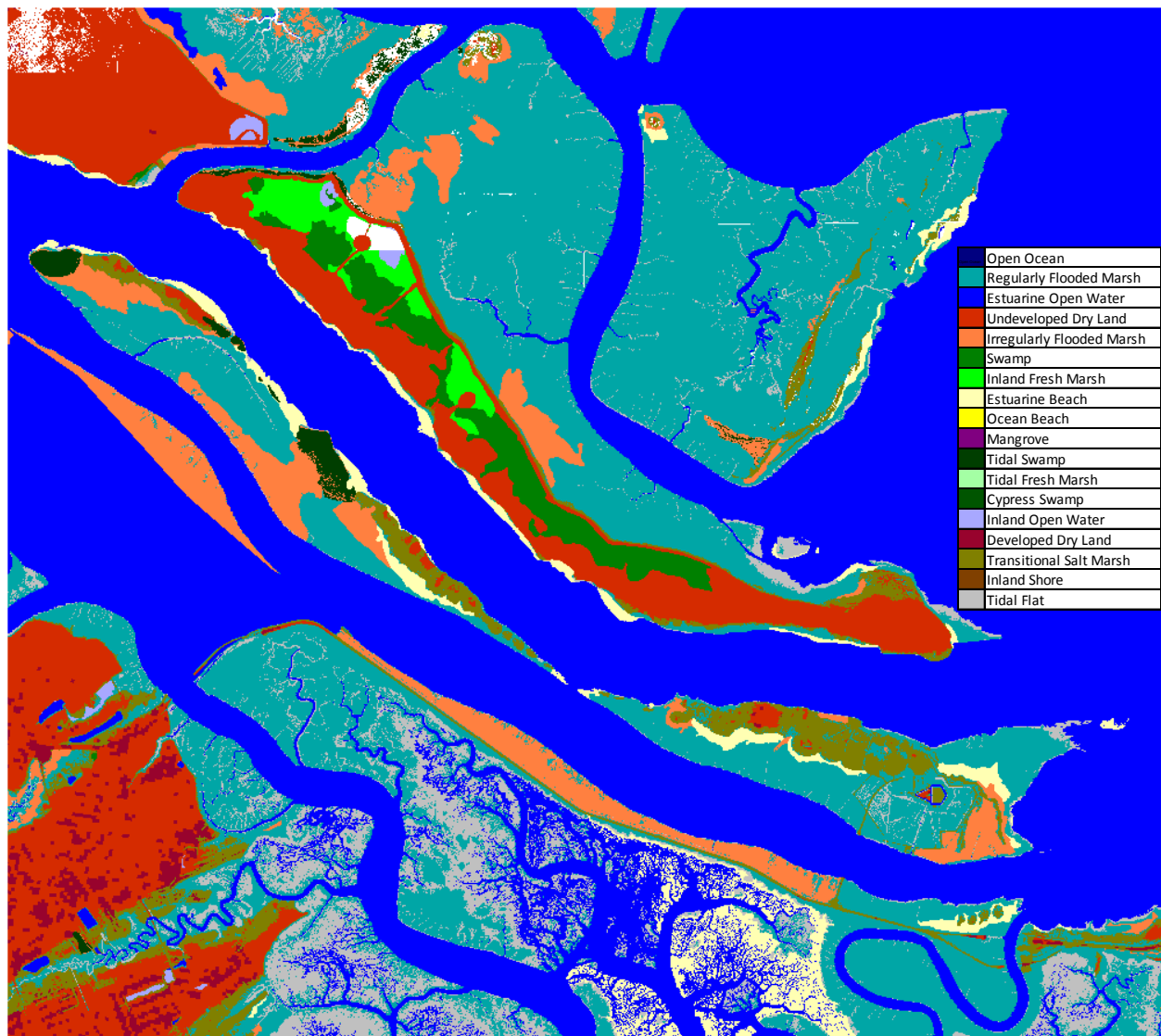Tybee NWR, 2100, Scenario A1B Mean, 0.39 m SLR by 2100.

Tybee NWR, Initial Condition.
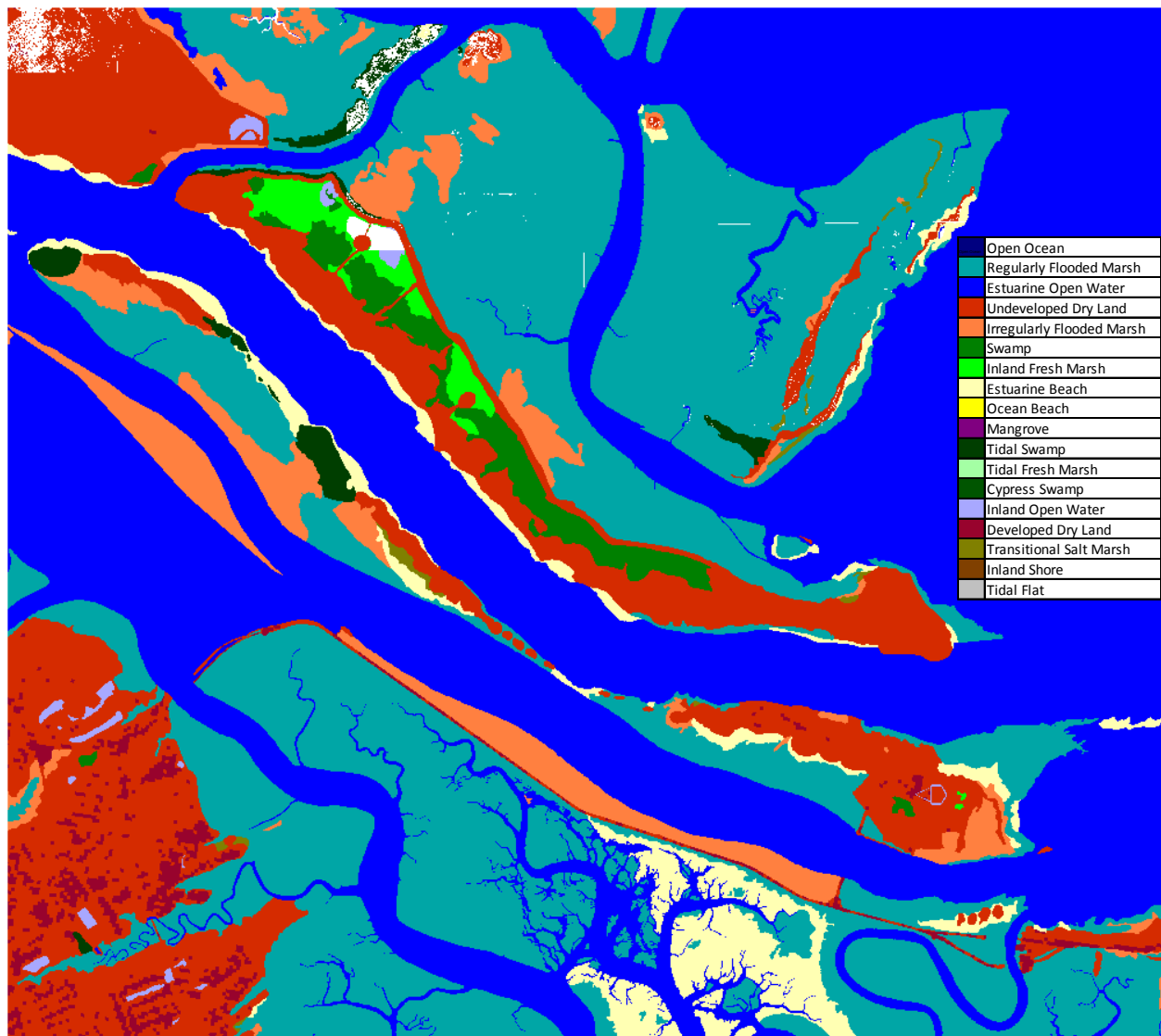
Tybee NWR, 2025, Scenario A1B Maximum, 0.69 m SLR by 2100.
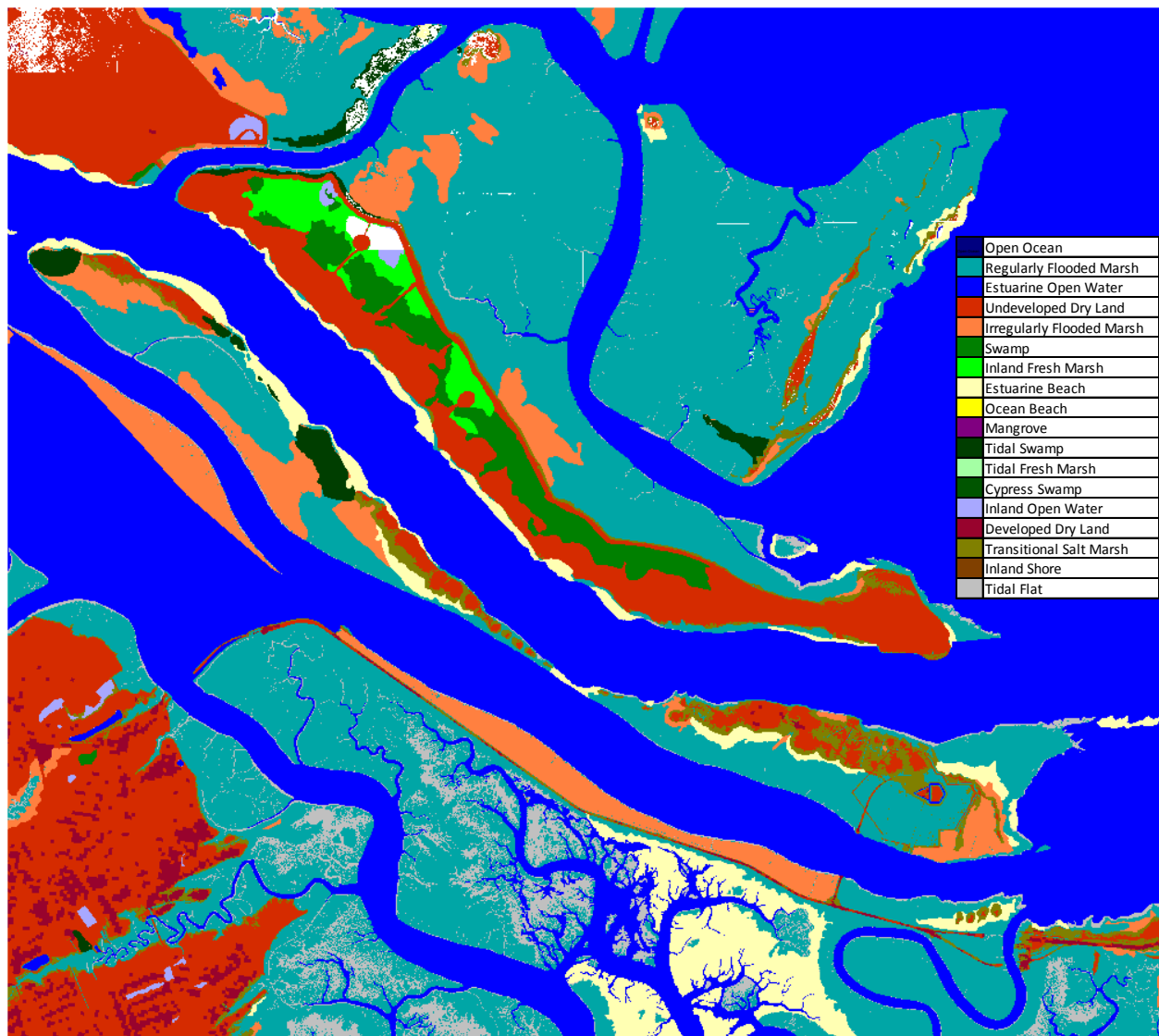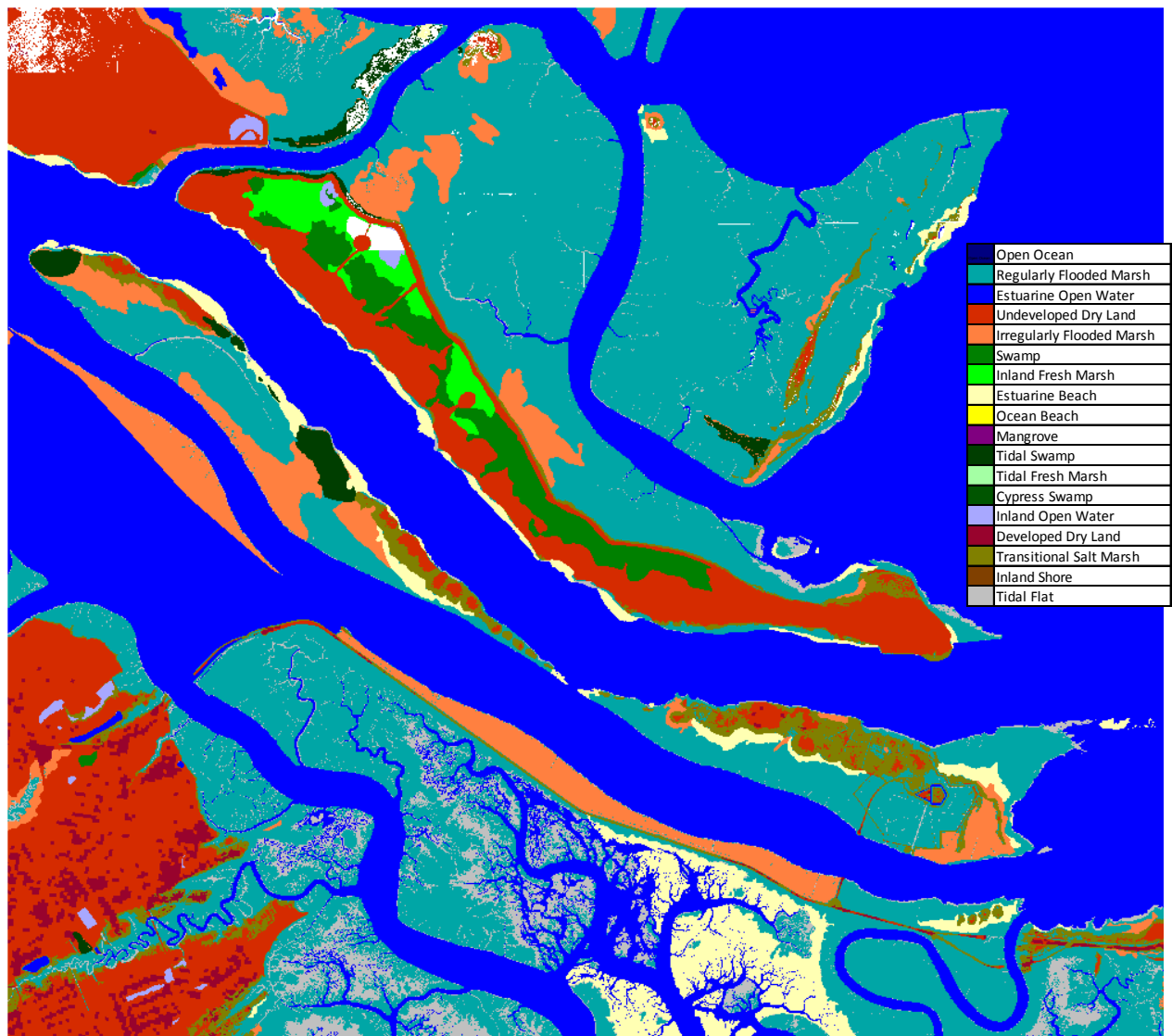
Tybee NWR, 2050, Scenario A1B Maximum, 0.69 m SLR by 2100.

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

Tybee NWR, 2075, Scenario A1B Maximum, 0.69 m SLR by 2100.
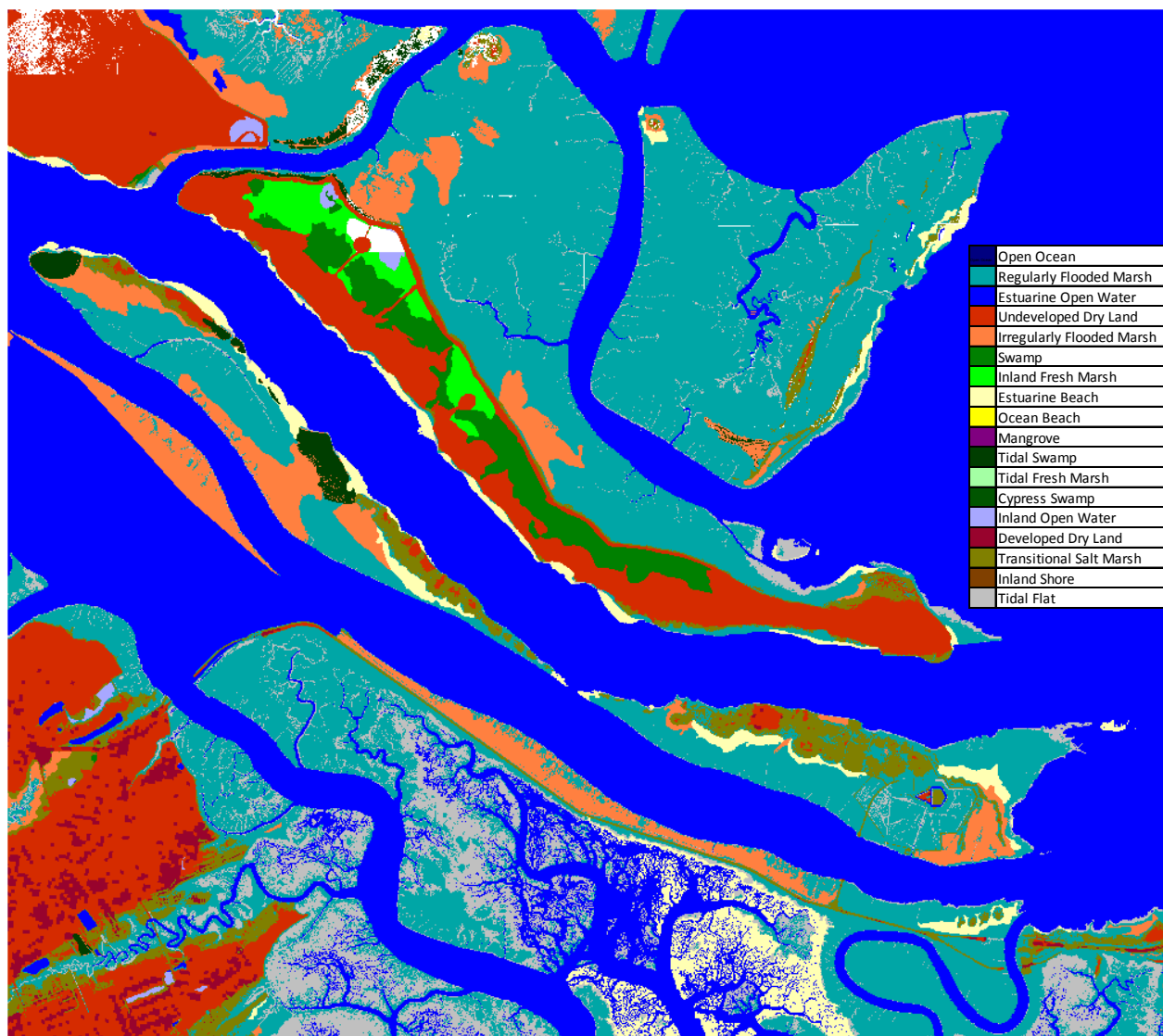
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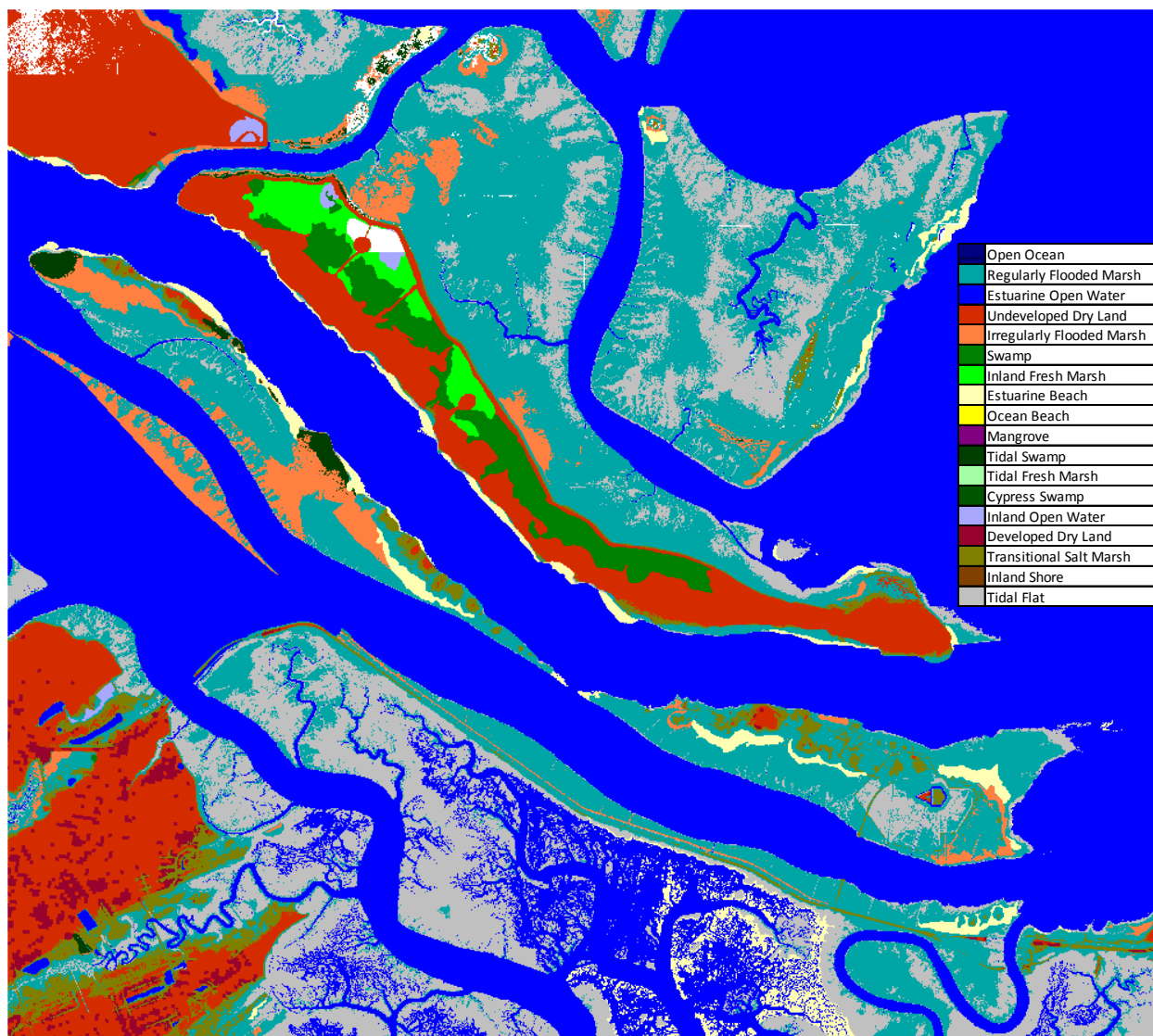
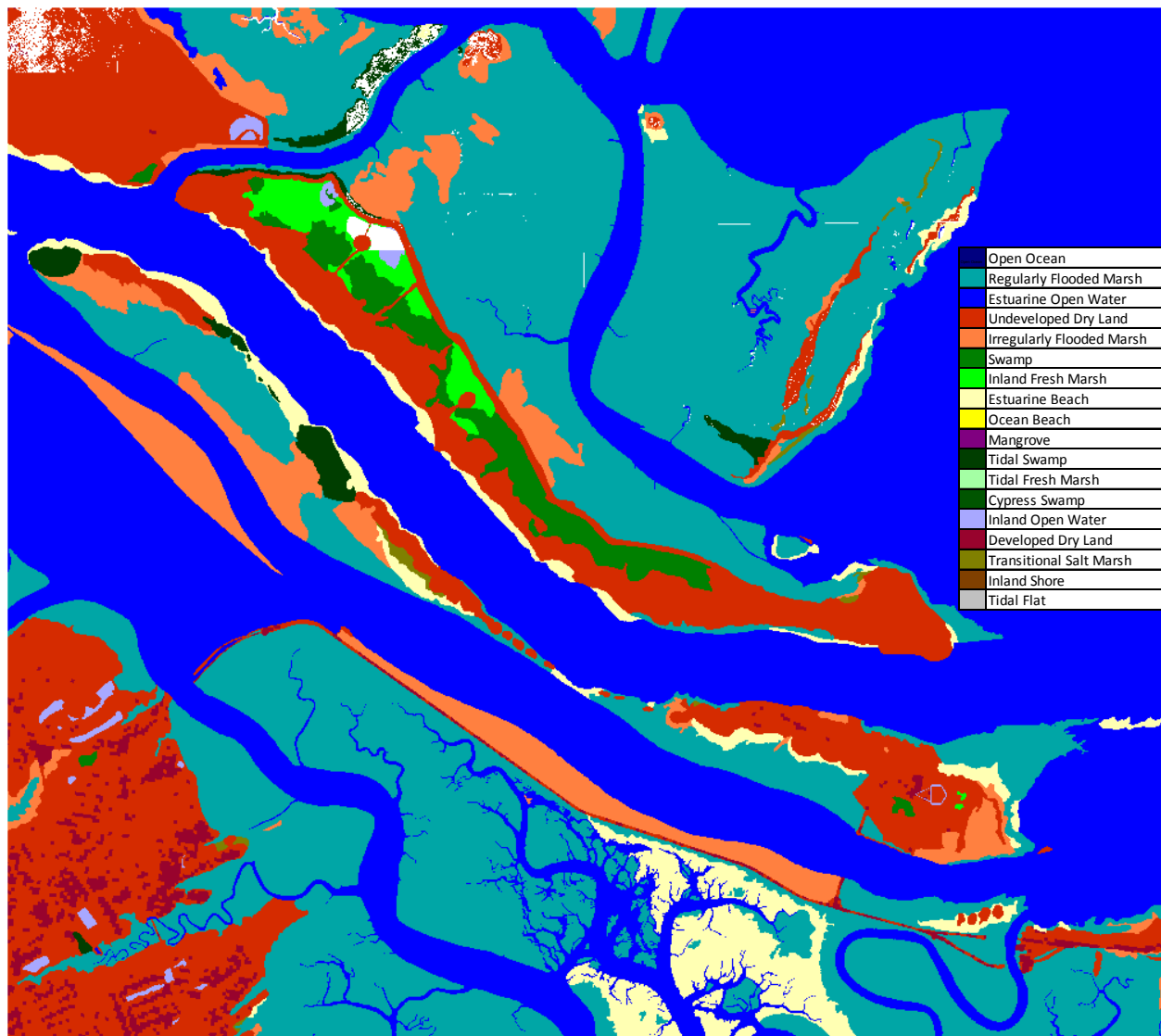Tybee NWR, Initial Condition.

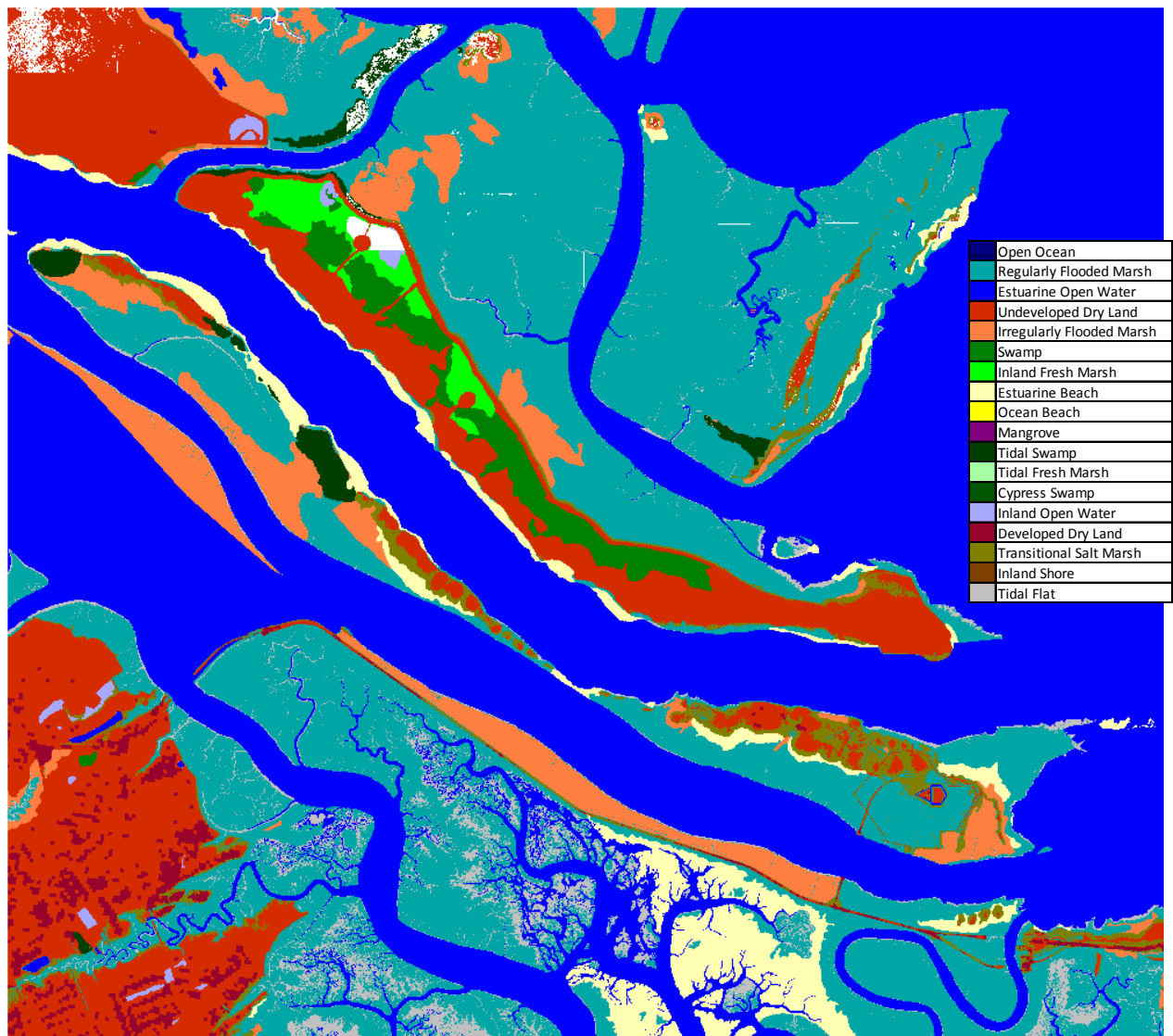Tybee NWR, 2025, 1 m SLR by 2100.

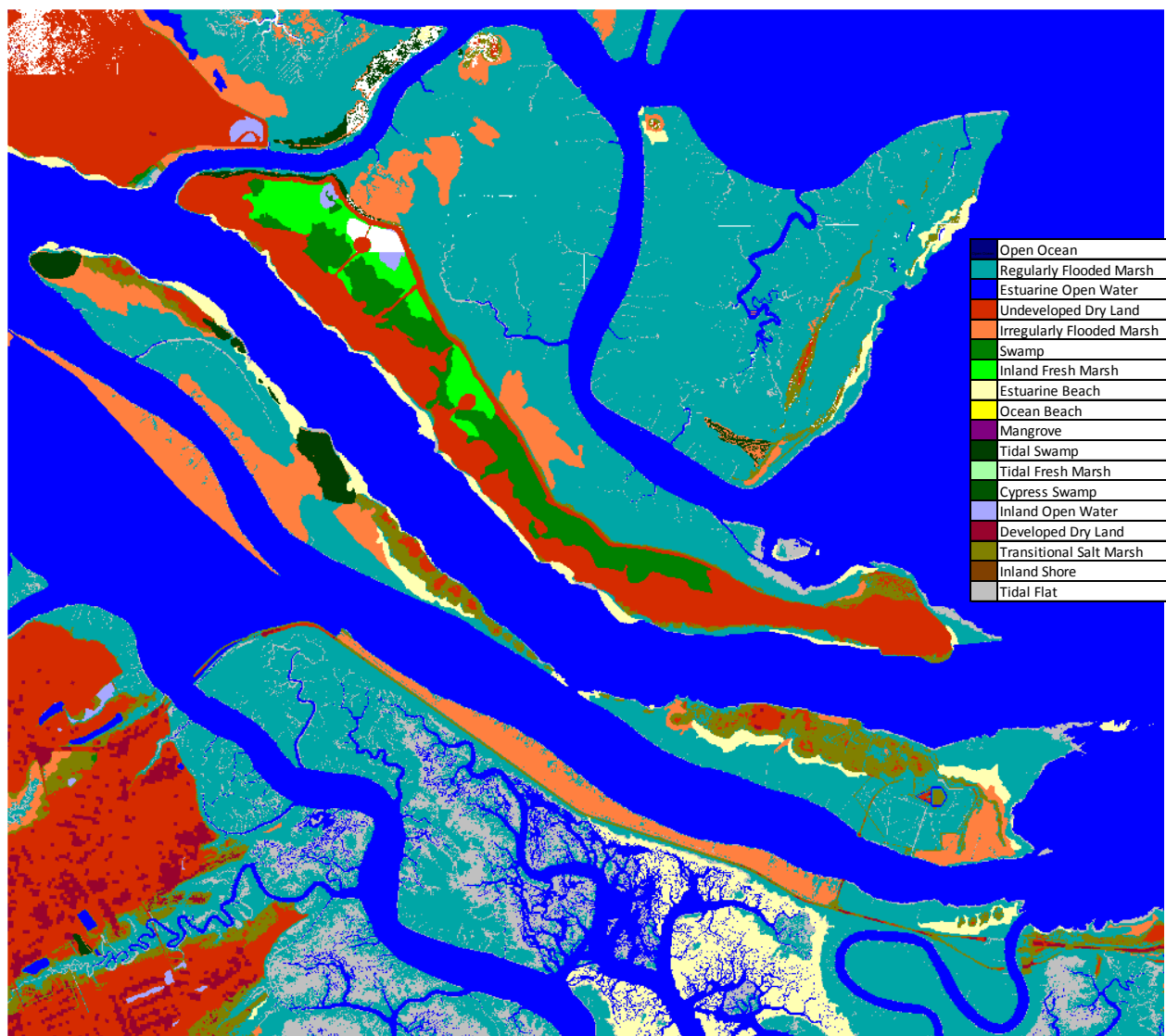Tybee NWR, 2050, 1 m SLR by 2100.

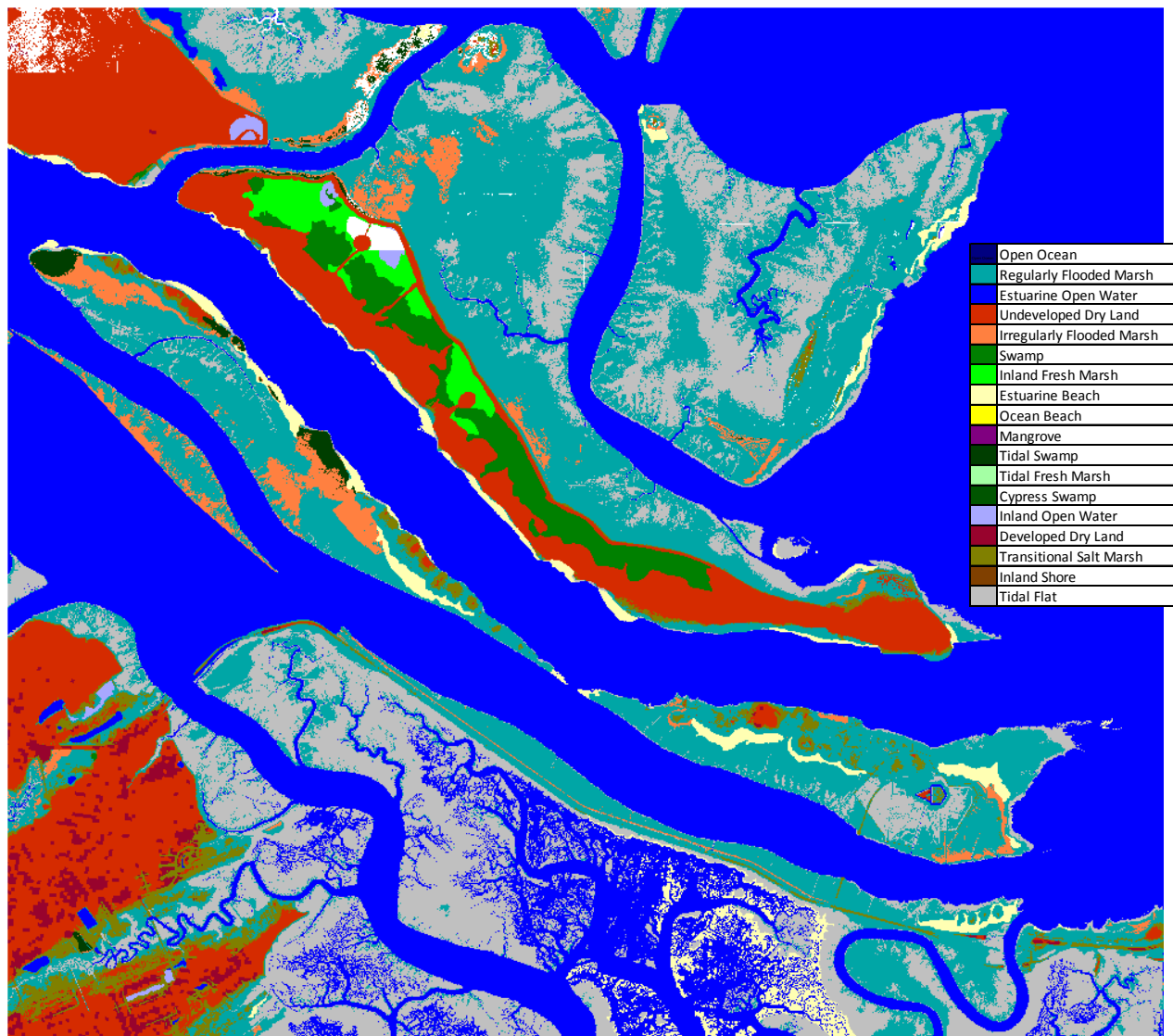Tybee NWR, 2075, 1 m SLR by 2100.

Tybee NWR, 2100, 1 m SLR by 2100.

Tybee NWR, Initial Condition.

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

Tybee NWR, 2025, 1.5 m SLR by 2100.

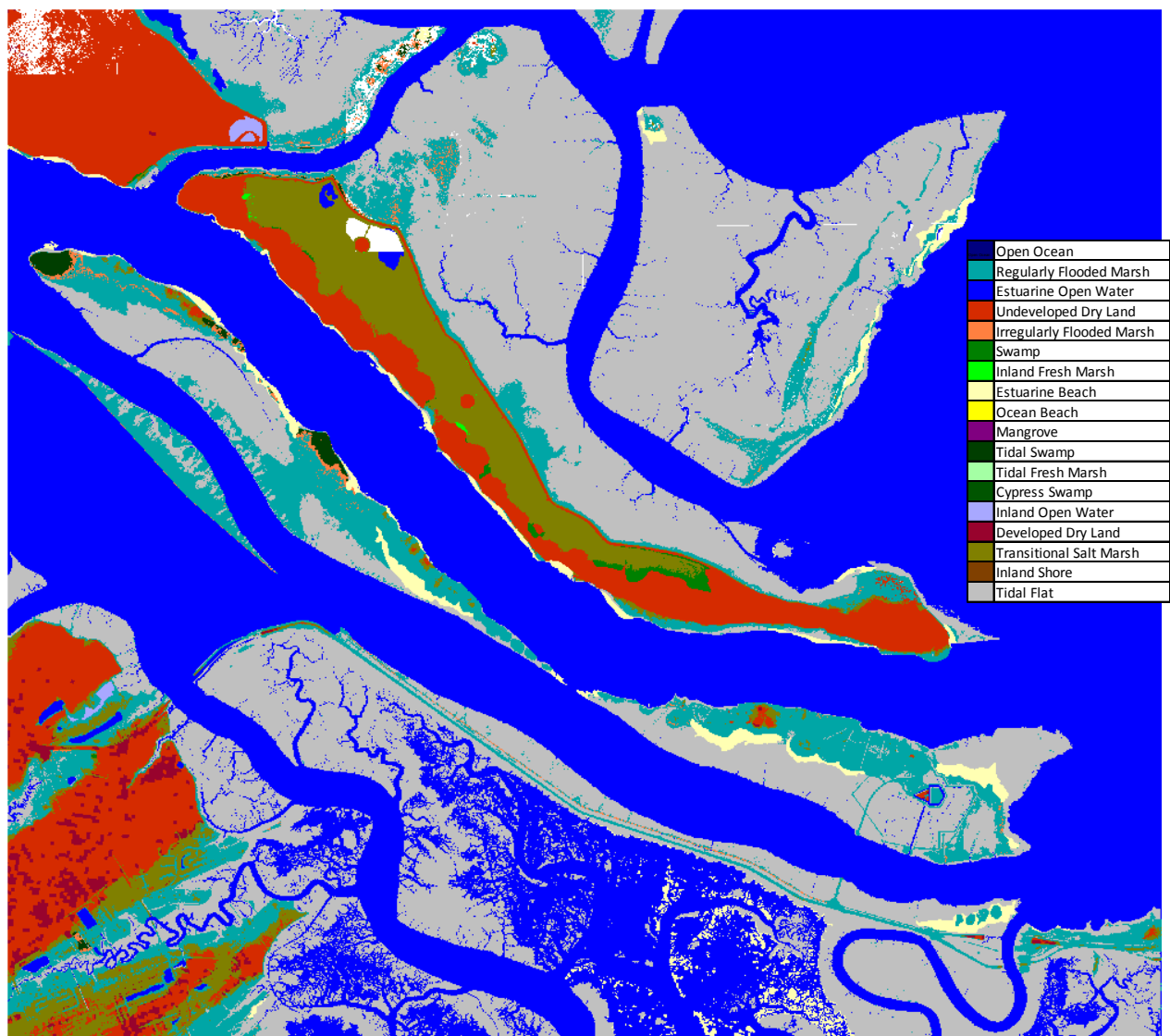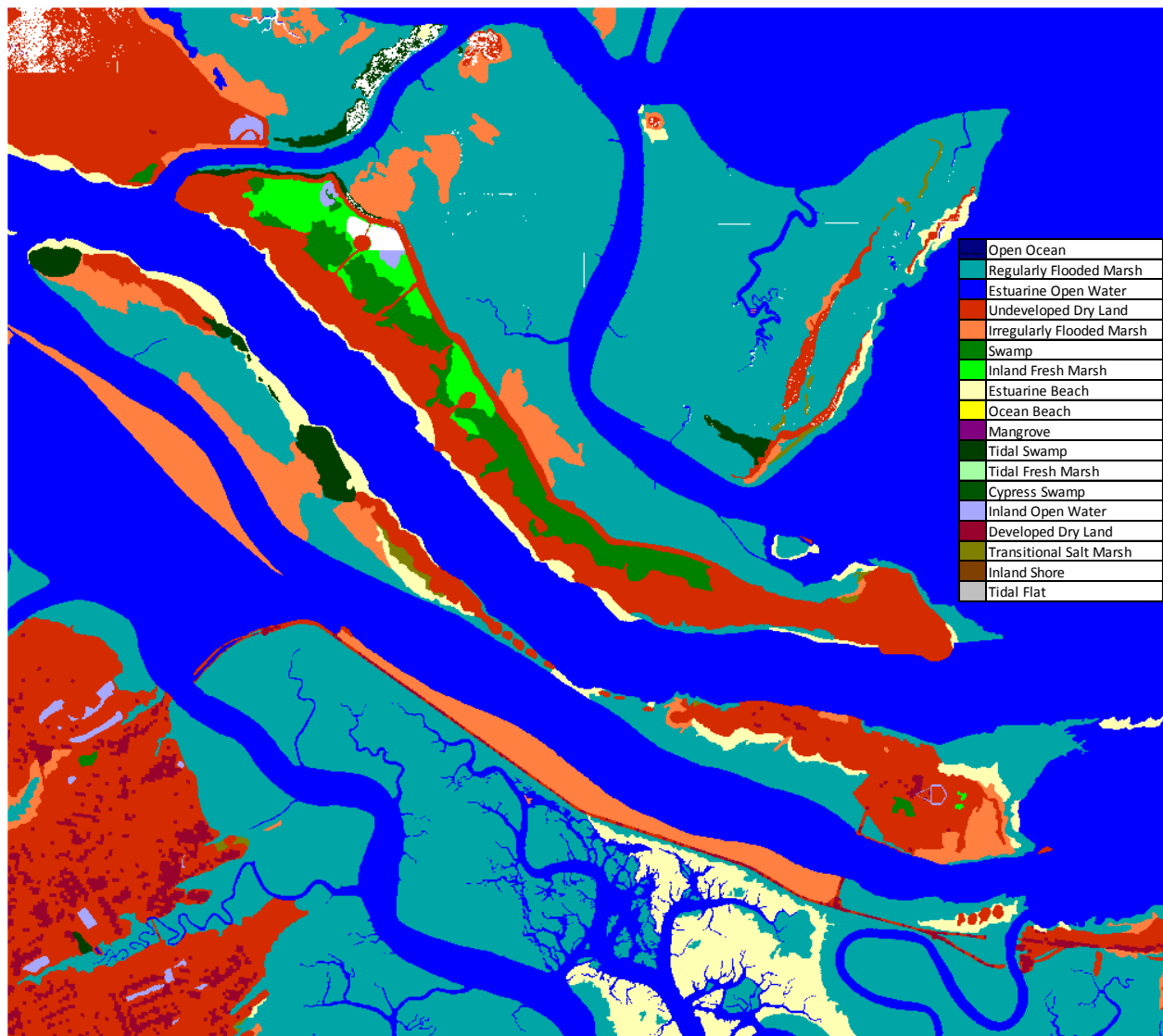| | Open Ocean |
	Regularly Flooded Marsh
	Estuarine Open Water
	Undeveloped Dry Land
	Irregularly Flooded Marsh
	Swamp
	Inland Fresh Marsh
	Estuarine Beach
	Ocean Beach
	Mangrove
	Tidal Swamp
	Tidal Fresh Marsh
	Cypress Swamp
	Inland Open Water
	Developed Dry Land
	Transitional Salt Marsh
	Inland Shore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

Tybee NWR, 2050, 1.5 m SLR by 2100.

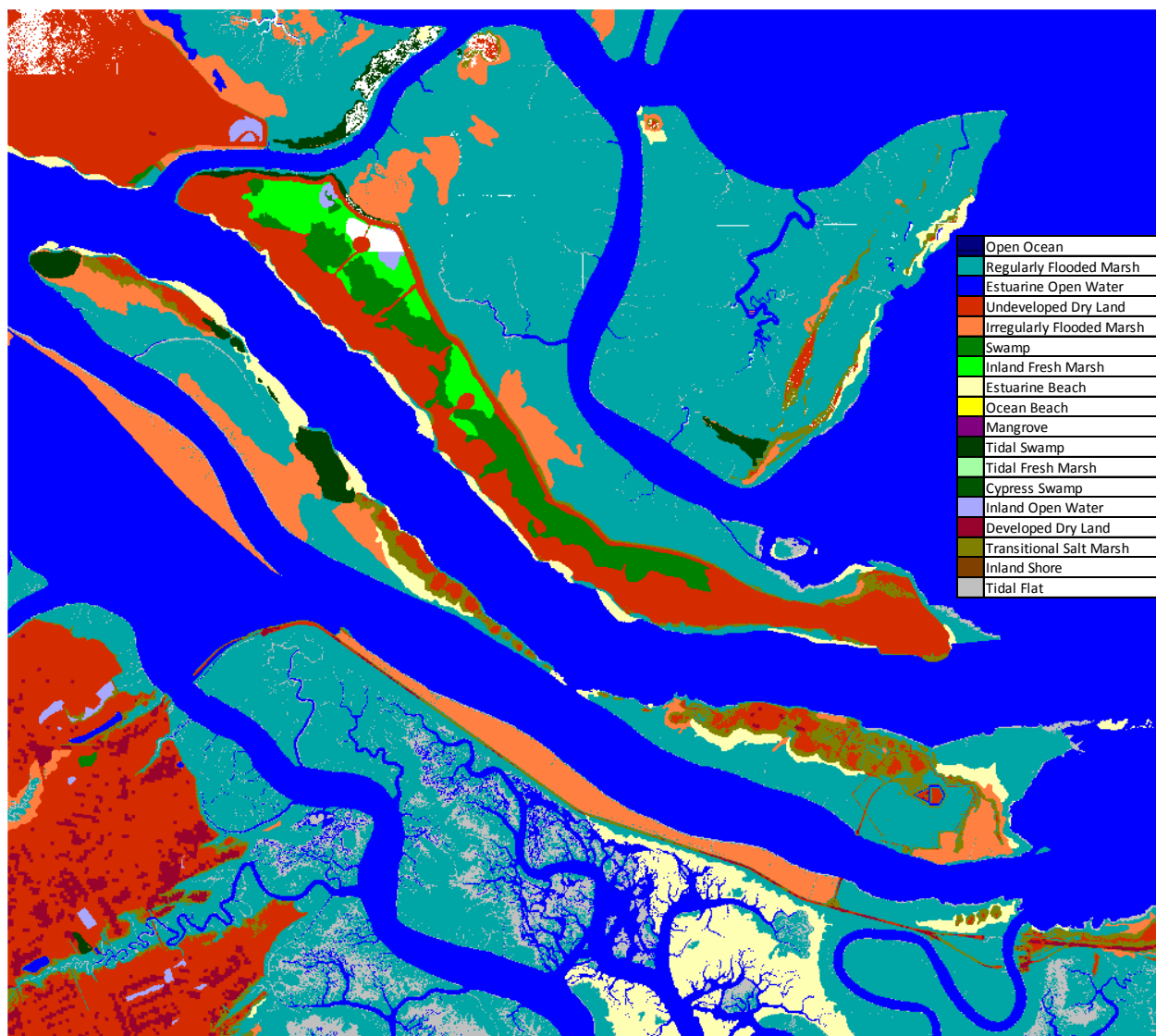Tybee NWR, 2075, 1.5 m SLR by 2100.

Tybee NWR, 2100, 1.5 m SLR by 2100.

Tybee NWR, Initial Condition.

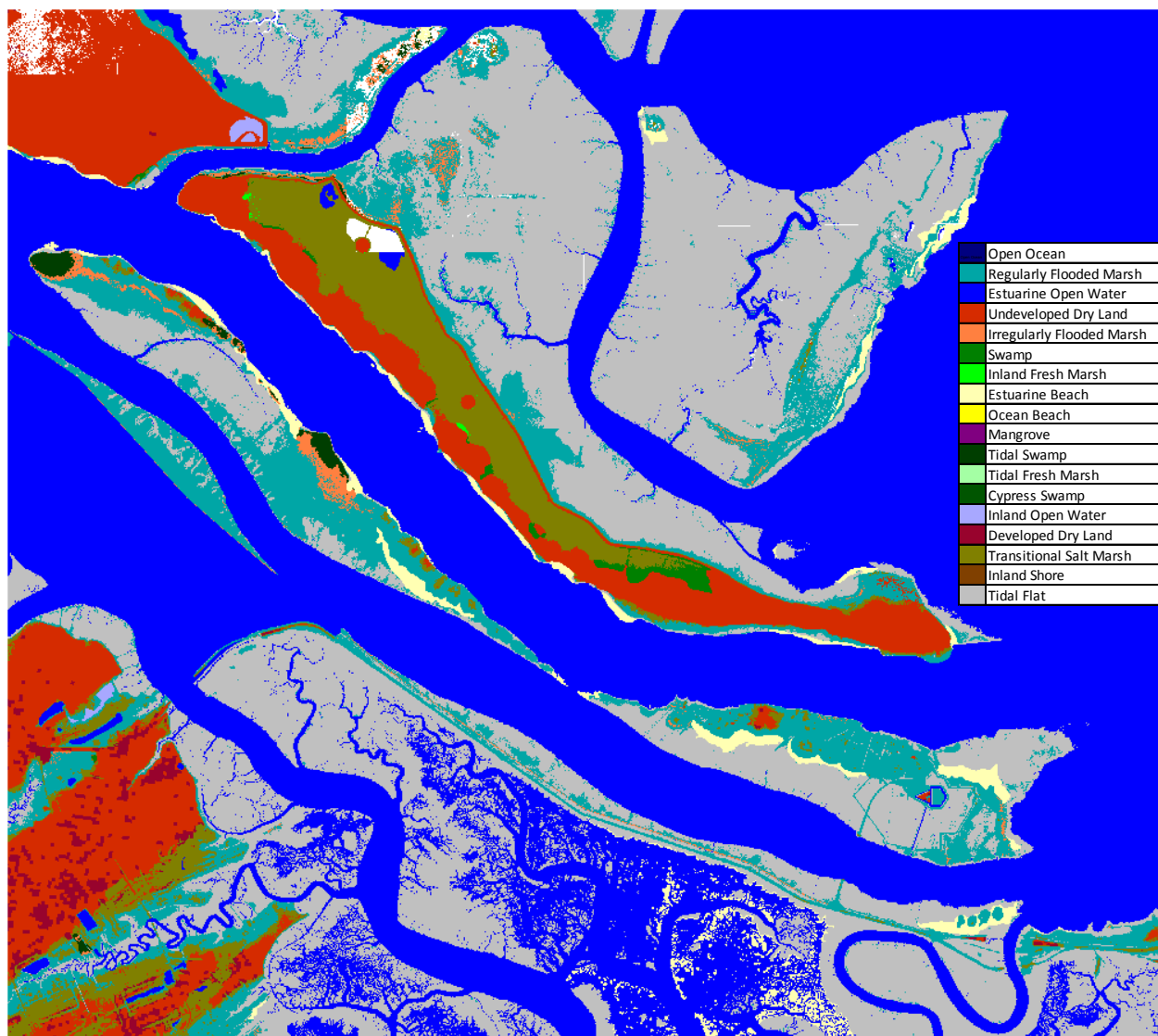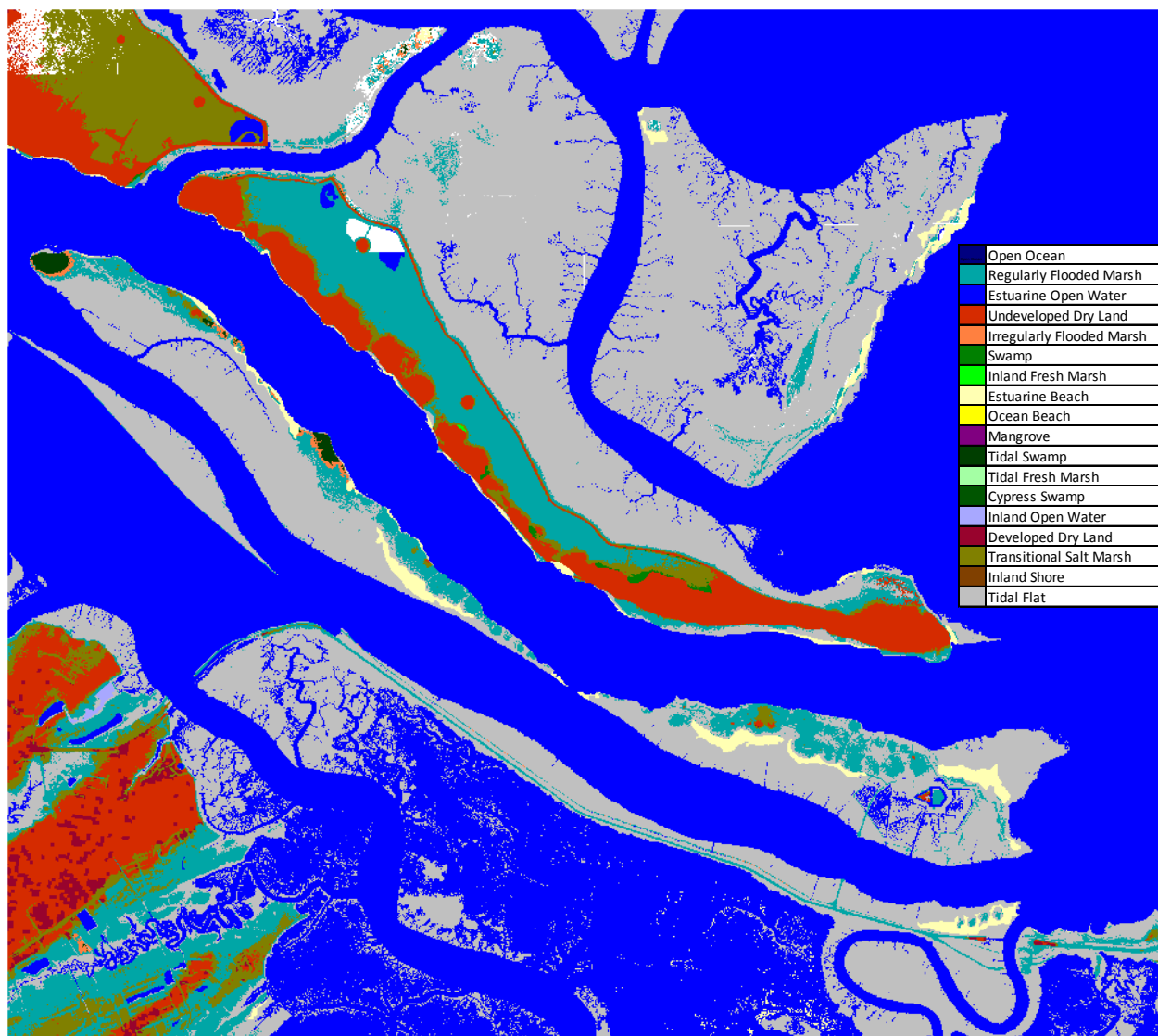|	
■	Open Ocean
■	Regularly Flooded Marsh
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■	Inland Fresh Marsh
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■	Mangrove
■	Tidal Swamp
■	Tidal Fresh Marsh
■	Cypress Swamp
■	Inland Open Water
■	Developed Dry Land
■	Transitional Salt Marsh
■	Inland Shore
■	Tidal Flat

Tybee NWR, 2025, 2 m SLR by 2100.

Tybee NWR, 2050, 2 m SLR by 2100.

Tybee NWR, 2075, 2 m SLR by 2100.

Tybee NWR, 2100, 2 m SLR by 2100.