Application of the Sea-Level Affecting Marshes Model (SLAMM 6) to Pinckney Island 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 plan for and potentially mitigate the effects of sea-level rise on the U.S. National Wildlife Refuge System (Refuge System), the U. S. Fish and Wildlife Service (FWS) uses a variety of analytical approaches, most notably the SLAMM model. FWS conducts some SLAMM analysis in-house and, more commonly, contracts the application of the SLAMM model. In most cases Refuge System SLAMM analyses are designed to assist in the development of comprehensive conservation plans (CCPs), land acquisition plans, habitat management plans, and other land and resource management plans.

This is the second application of SLAMM to Pinckney Island 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 applied input parameters on a broad spatial scale and did not consider eustatic sea-level rise greater than 1 m by 2100. This application considered a much smaller area and simulated eustatic SLR scenarios of 1.5 and 2 m by 2100.

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.

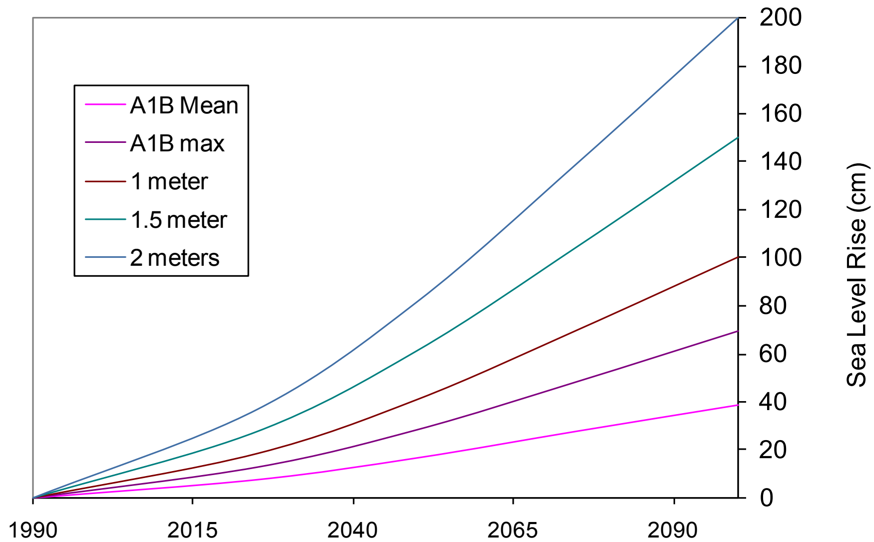


Figure 1. Summary of SLR scenarios utilized.

Data Sources and Methods

Wetland layer. Figure 2 shows the most recent available wetland layer obtained from National Wetlands Inventory (NWI) photos dated 1989 and 1999. Converting the NWI survey into 28 m x 28 m cells indicated that the approximately 4,050 acre Pinckney Island NWR (approved acquisition boundary including water) is composed of the following categories:

Land cover type		Area (acres)	Percentage (%)
	Regularly-flooded Marsh	1777	44
	Undeveloped Dry Land	1293	32
	Estuarine Open Water	710	18
	Estuarine Beach	95	2
	Irregularly-flooded Marsh	81	2
	Swamp	41	1
	Inland Open Water	19	< 1
	Developed Dry Land	16	< 1
	Transitional Salt Marsh	8	< 1
	Inland Fresh Marsh	5	< 1
	Tidal Swamp	3	< 1
	Total (incl. water)	**4047**	**100**

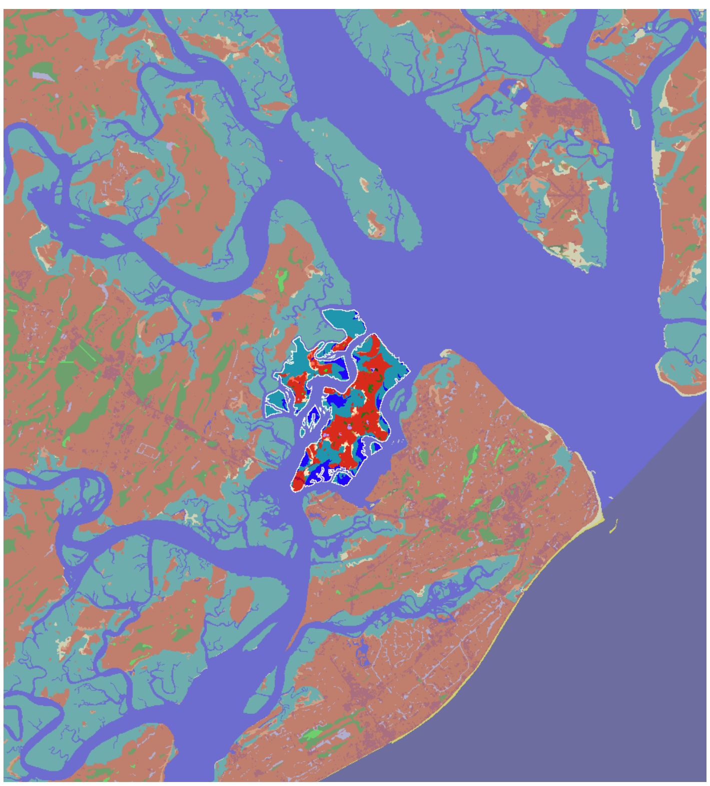


Figure 2. 1989/1999 NWI coverage of the study area. Refuge boundaries are indicated in white.

Input subsites and parameter summary. Based on different National Wetland Inventory photo dates, the study area was subdivided in the subsites illustrated in Figure 3.

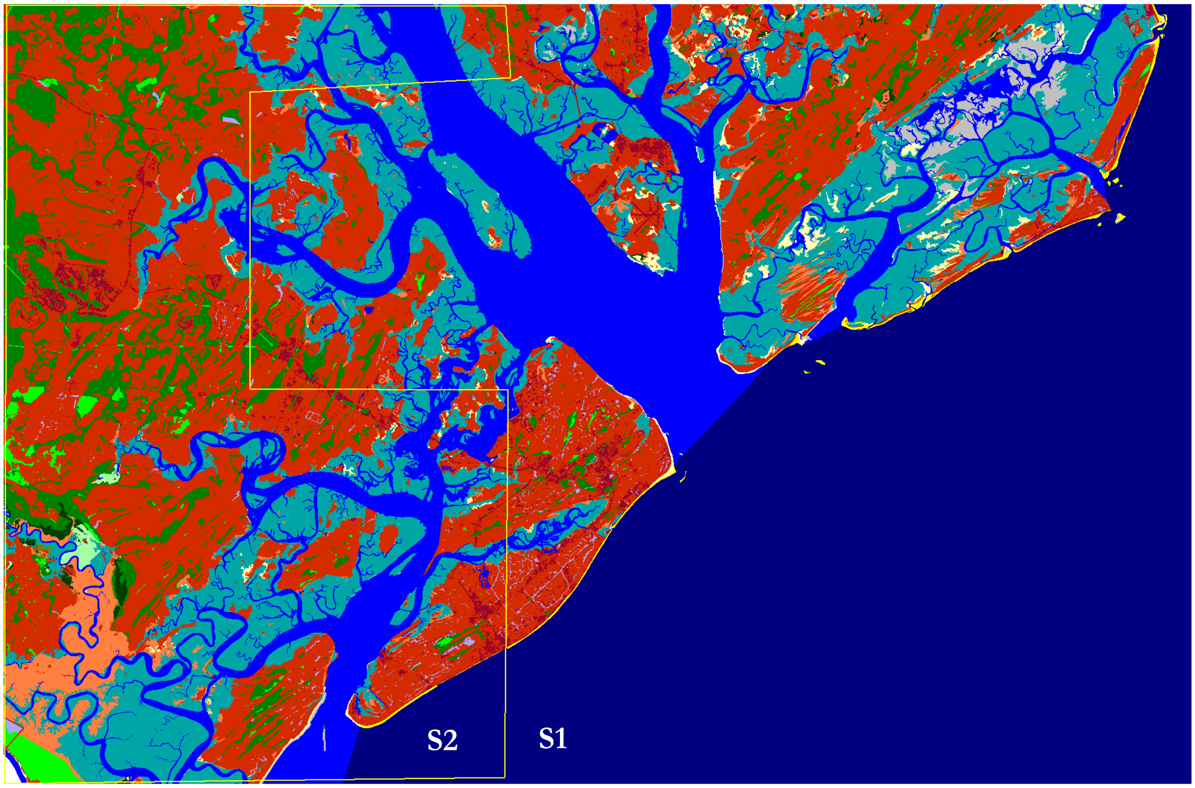


Figure 3. Input subsites for model application.

Elevation Data. At this time there no LiDAR data available for Beaufort County, SC. There are plans for a possible collection of LiDAR-based elevation data for this area in 2013. Due to the lack of high-resolution elevation data, the National Elevation Dataset (NED) was used for elevation data. The contour intervals of these data were 5 to 10 meters which resulted in poorly characterized wetland elevations. As a consequence of this lack of vertical accuracy, the SLAMM elevation pre-processor was used for the entire site. This module assigns elevations for wetlands as a function of the local tide range (Clough et al. 2010). This process causes additional uncertainty in model results as covered in the *Discussion* section below.

Dikes and Impoundments. According to the National Wetland Inventory there is one small area of the refuge that is protected by dikes. The location of this impounded area is shown in yellow in Figure 3.

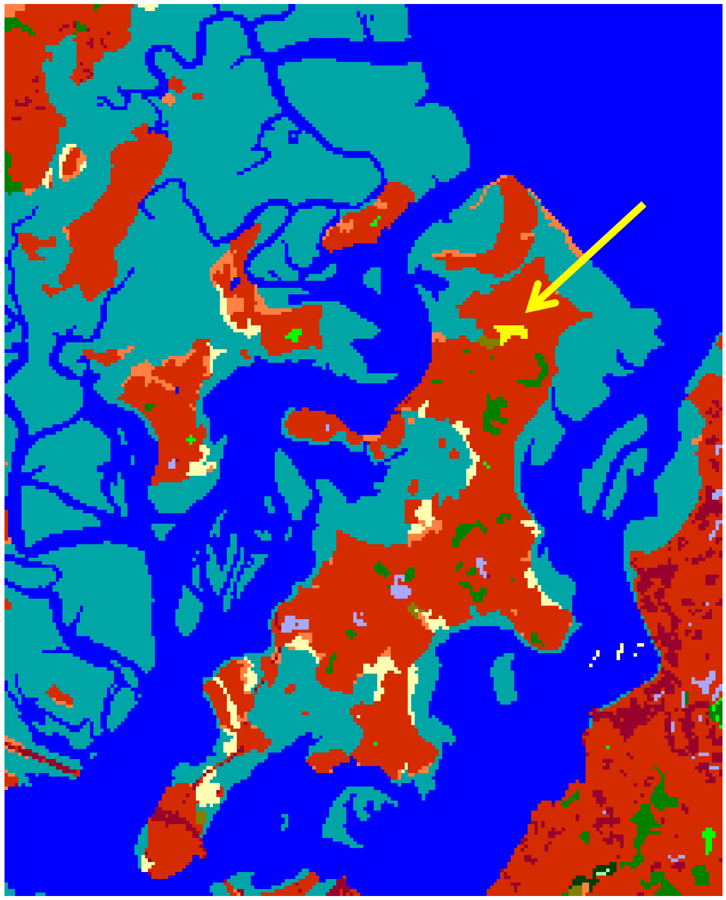


Figure 4. Location of dikes in Pinckney Island NWR (shown in yellow).

Model Timesteps. Model forecast data is output for years 2025, 2050, 2075 and 2100 with the initial condition date set to 1999, the most recent wetland data available.

Historic sea-level rise rates. The refuge is located between the Fort Pulaski, GA (#8670870) and Charleston, SC (#8665530) NOAA gauge stations. The average historic trend for relative sea-level rise rates recorded at these two stations is 3.07 mm/yr. (period of record shown in Figure 4). This rate is higher than the global (eustatic) SLR for the last 100 years (approximately 1.7 mm/yr.), which may indicate some subsidence in this area.

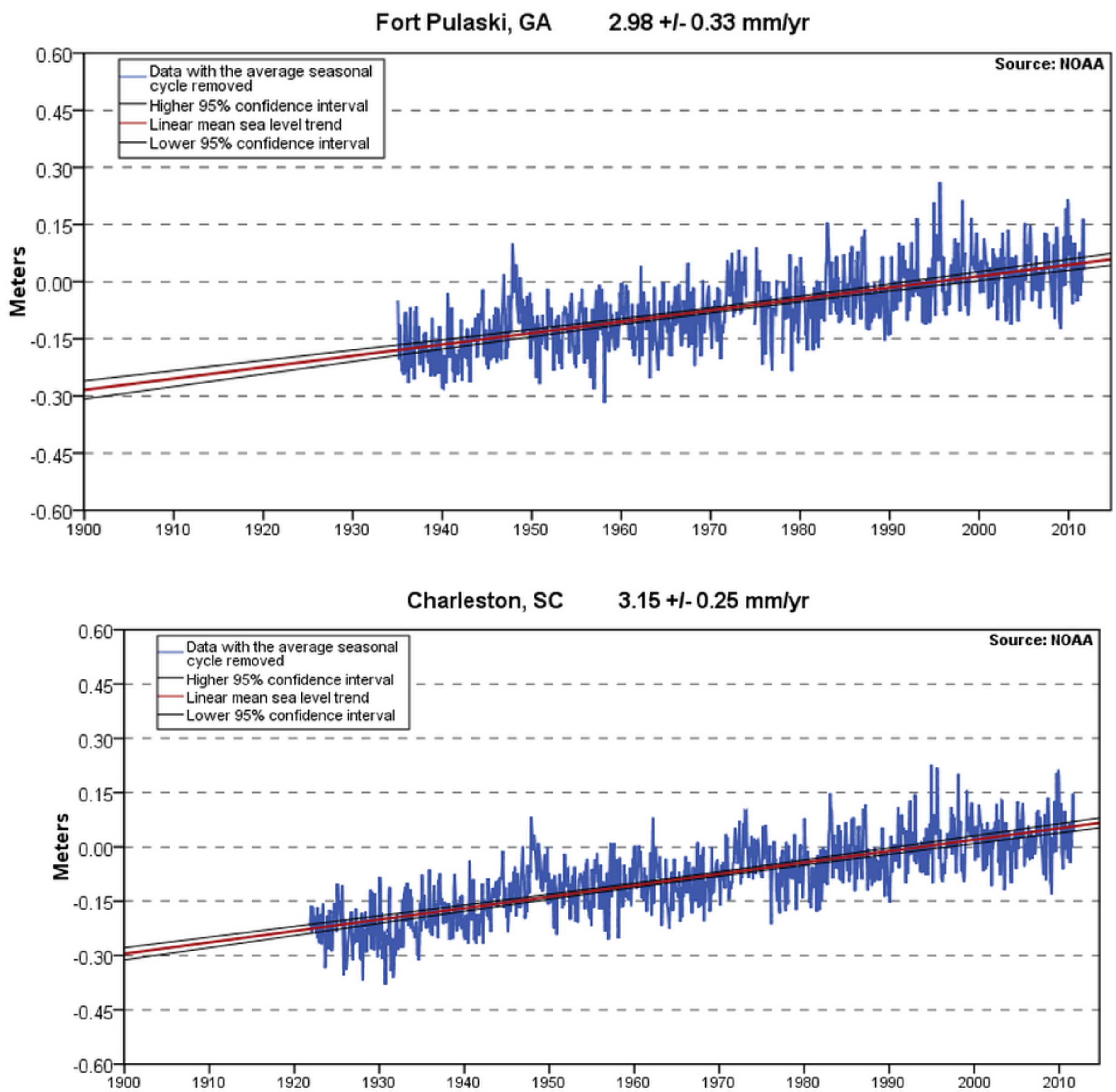


Figure 5. Historic sea-level trends at Fort Pulaski, GA and Charleston, SC.

Tide Ranges. The great diurnal range (GT) was applied using the average of the data collected at NOAA gauge stations surrounding Pinckney Island NWR. This resulted in the application of a GT of 2.3 m. The stations used to determine this value are shown in Table 1.

Table 1. NOAA tide gauges used to assign the Great Diurnal Tide Range (GT).

NOAA Station #	Station Name	GT (m)
8670870	Fort Pulaski, GA	2.3
8669801	Bloody Point, New River, SC	2.2
8669691	Daufuskie Landing, New River, SC	2.3
8669601	Pine Island, Ramshorn Creek, SC	2.4
8669338	Broad Creek, SC	2.5
8669133	Skull Creek South, SC	2.4
8668918	Ribaut Island, Skull Creek, SC	2.3
8668482	Baileys Landing, Okatee River, SC	2.7
8668223	Broad River Bridge, SC	2.4
8668092	Battery Creek, SC	2.5
8667999	Beaufort, SC	2.4
8668155	Distant Island Creek, Upper End, SC	2.2
8668601	Station Creek, SC	2.3
8668498	Fripps Inlet, SC	2.0
8668227	Johnsons Creek, Harbor Island, SC	2.0
8668146	Harbor River Bridge, St. Helena Sound, SC	2.0
	Average	**2.3**

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 1.73 m above mean tide level (MTL).

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 were determined from data collected at NOAA tide gauges. Like the GT parameter, the average value for the study area, -0.087 m, was applied.

Refuge boundaries. Modeled USFWS refuge boundaries for 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 28 m.

Table 2 summarizes all SLAMM input parameters for the input subsites. Values for parameters with no specific local information were kept at the model default value.

Table 2. Summary of SLAMM input parameters for Pinckney Island NWR.

Description	**S1/S2**
NWI Photo Date (YYYY)	1989/1999
DEM Date (YYYY)	1957
Direction Offshore [n,s,e,w]	East
Historic Trend (mm/yr)	3.07
MTL-NAVD88 (m)	-0.087
GT Great Diurnal Tide Range (m)	2.3
Salt Elev. (m above MTL)	1.73
Marsh Erosion (horz. m /yr)	2
Swamp Erosion (horz. m /yr)	1
T.Flat Erosion (horz. m /yr)	0.2
Reg.-Flood Marsh Accr (mm/yr)	1.9
Irreg.-Flood Marsh Accr (mm/yr)	4.3
Tidal-Fresh Marsh Accr (mm/yr)	4.8
Inland-Fresh Marsh Accr (mm/yr)	4
Mangrove Accr (mm/yr)	7
Tidal Swamp Accr (mm/yr)	1.1
Swamp Accretion (mm/yr)	0.3
Beach Sed. Rate (mm/yr)	0.5
Use Elev Pre-processor [True,False]	TRUE

Results

The initial land cover in acres and percentage losses by 2100 for each wetland type are presented in Table 3. Land-cover losses are calculated in comparison to the initial 1989/1999 NWI wetland coverage and wetland categories are sorted by decreasing initial land cover.

Simulation results suggest Pinckney Island NWR will be widely affected by accelerated SLR. Regularly-flooded marsh is currently the dominant wetland habitat type in the refuge. Losses of regularly-flooded marsh by 2100 are predicted to increase with increasing SLR, with the maximum observed loss occurring at 1 m of SLR by 2100. At higher rates of SLR, less total loss of regularly-flooded marsh is predicted since the loss of existing marsh is compensated by gains from the inundation of dry land and irregularly-flooded marsh. This phenomenon is illustrated in the maps in this section.

Dry-land habitat currently makes up 32 % of the refuge. At SLR scenarios of 1 m by 2100 and higher, more than 80% of this habitat type is predicted to be lost. Under the 2 m by 2100 scenario, nearly all dry land is predicted to be lost by 2100. Small amounts of beach, swamp, irregularly-flooded, and fresh marsh habitats currently occur in the refuge. However, at rates of SLR of 1.5 m by 2100 and greater, these wetland types are predicted to be completely lost.

Table 3. Predicted loss rates of land categories by 2100 given simulated scenarios of eustatic SLR at Pinckney Island NWR. *Negative values indicate gains.*

	Initial (acres)	Land cover change by 2100 for different SLR scenarios (%)				
		0.39 m	0.69 m	1 m	1.5 m	2 m
Regularly-flooded Marsh	1777.5	38%	74%	81%	75%	32%
Undeveloped Dry Land	1293.3	15%	28%	83%	96%	99%
Estuarine Beach	94.9	14%	25%	37%	57%	75%
Irregularly-flooded Marsh	81.2	13%	38%	65%	99%	100%
Swamp	40.7	3%	10%	40%	94%	100%
Developed Dry Land	15.9	8%	11%	85%	99%	100%
Inland Fresh Marsh	4.8	3%	21%	54%	96%	100%

Wetland losses are coupled with gains in estuarine open water, transitional salt marsh, and tidal flat. Table 4 presents the acreage gains for each of these categories.

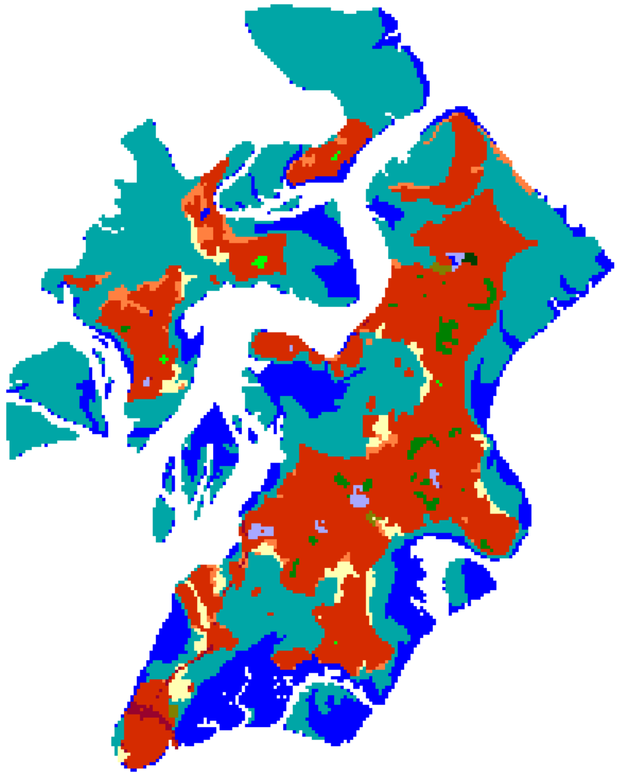
Table 4. Predicted land cover gains by 2100 given simulated scenarios of eustatic SLR at Pinckney Island NWR.

	Initial acres	Land cover gain by 2100 for different SLR scenarios (acres)				
		0.39 m	**0.69 m**	**1 m**	**1.5 m**	**2 m**
Estuarine Open Water	710	90	113	134	830	1634
Transitional Salt Marsh	8	201	365	999	873	71
Tidal Flat	0	608	1270	1515	1073	374

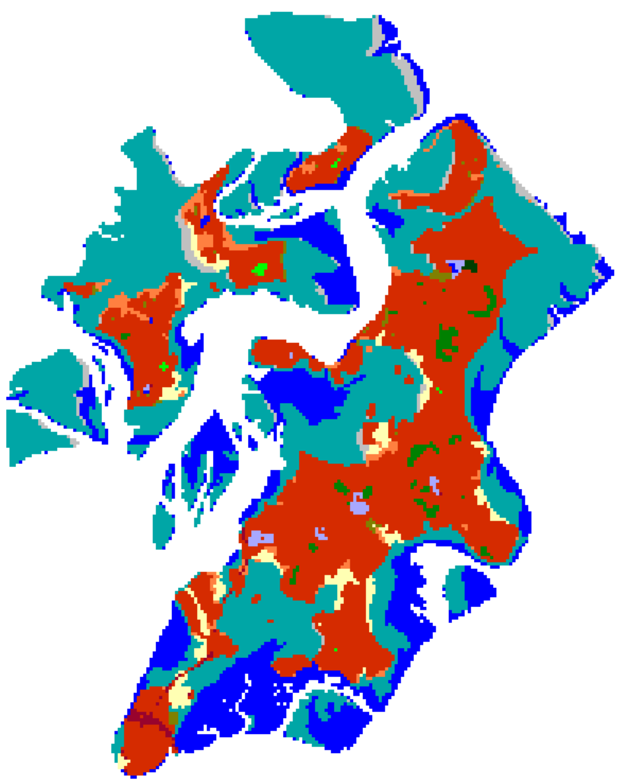
IPCC Scenario A1B-Mean, 0.39 m SLR eustatic by 2100

Results in Acres

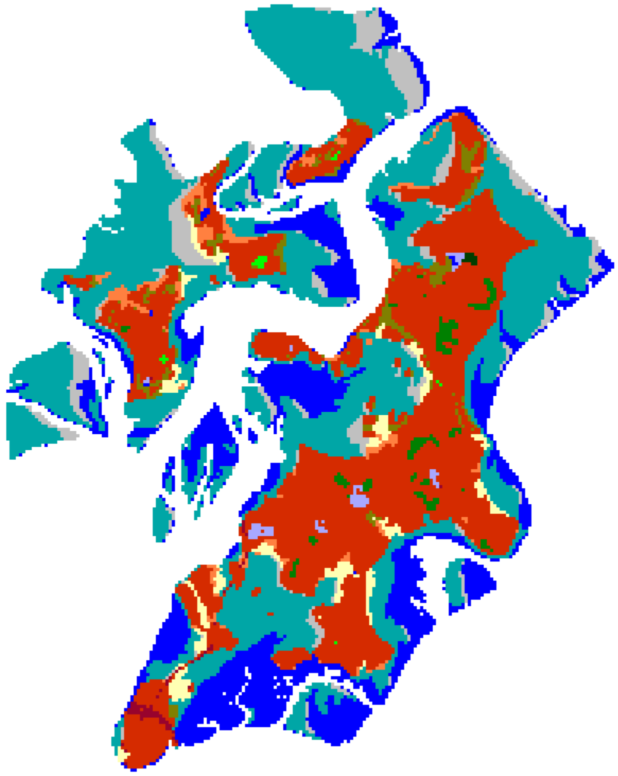
		Initial	**2025**	**2050**	**2075**	**2100**
	Regularly-flooded Marsh	1777	1683	1529	1316	1105
	Undeveloped Dry Land	1293	1268	1215	1156	1094
	Estuarine Open Water	710	729	749	774	799
	Estuarine Beach	95	93	90	86	82
	Irregularly-flooded Marsh	81	74	74	73	71
	Swamp	41	41	41	40	40
	Inland Open Water	19	18	18	18	18
	Developed Dry Land	16	15	15	15	15
	Transitional Salt Marsh	8	33	87	146	209
	Inland Fresh Marsh	5	5	5	5	5
	Tidal Swamp	3	3	3	3	3
	Tidal Flat	0	85	222	416	608
	Total (incl. water)	**4047**	**4047**	**4047**	**4047**	**4047**



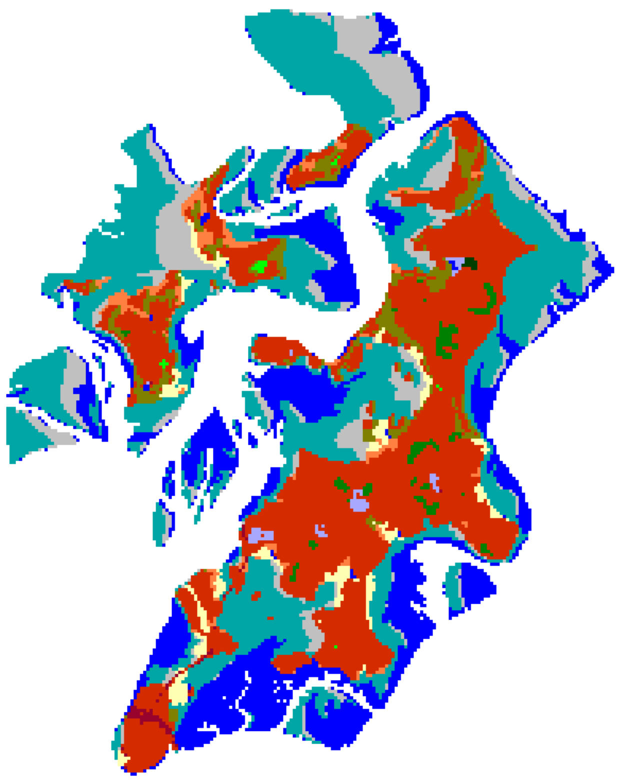
Pinckney Island NWR, Initial Condition.



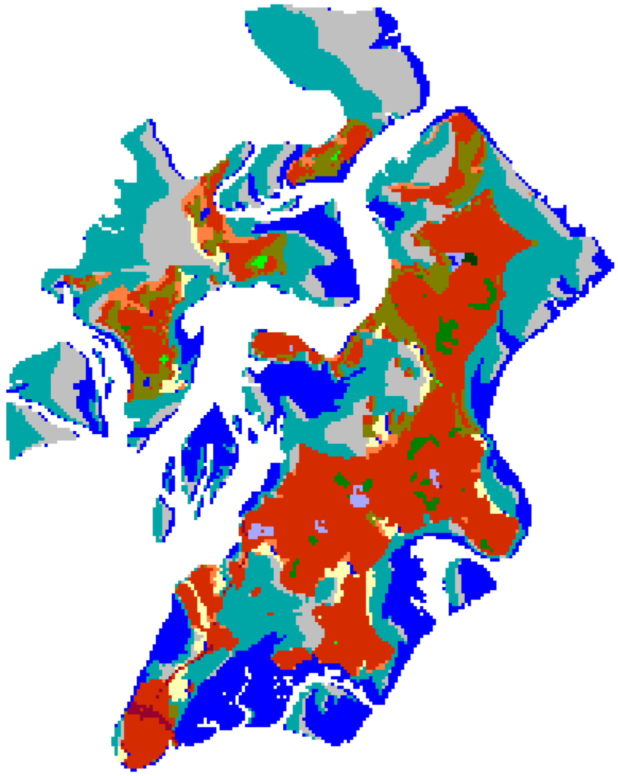
Pinckney Island NWR, 2025, Scenario A1B Mean, 0.39 m SLR by 2100.



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



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

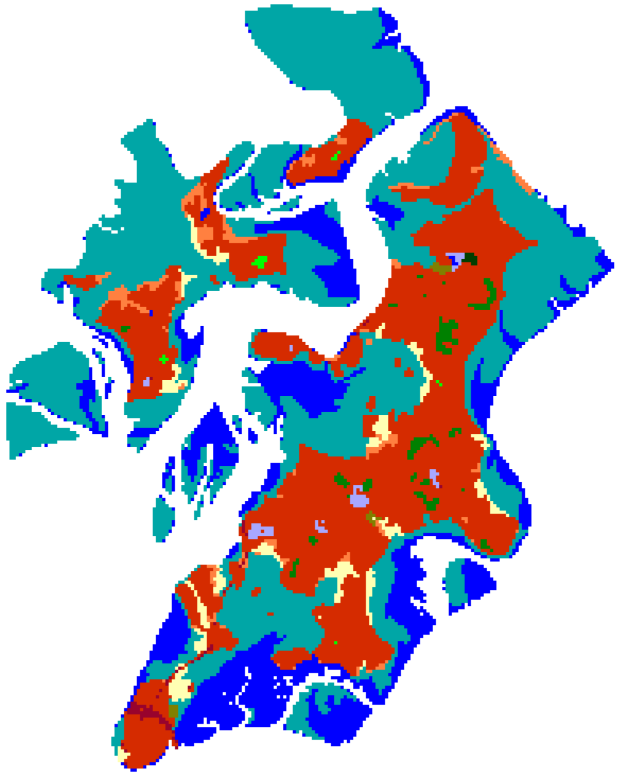


Pinckney Island NWR, 2100, Scenario A1B Mean, 0.39 m SLR by 2100.

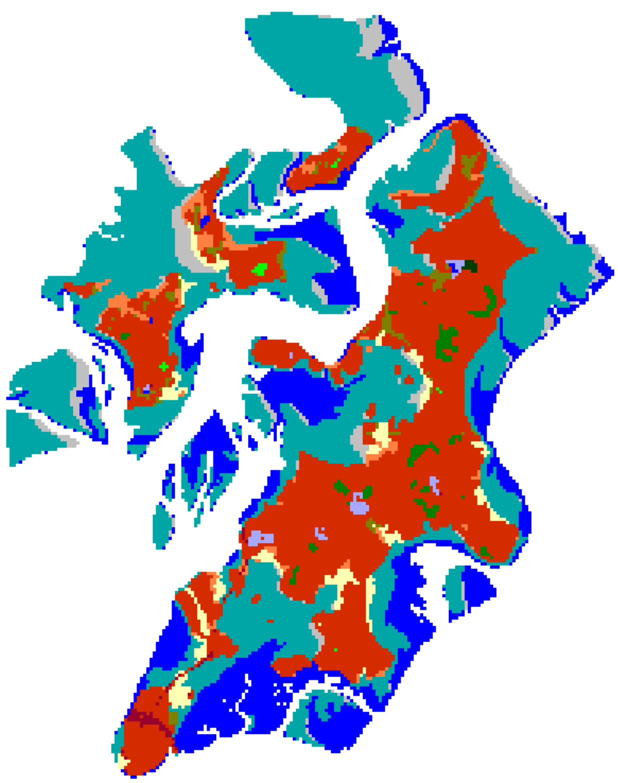
IPCC Scenario A1B-Max, 0.69 m SLR eustatic by 2100

Results in Acres

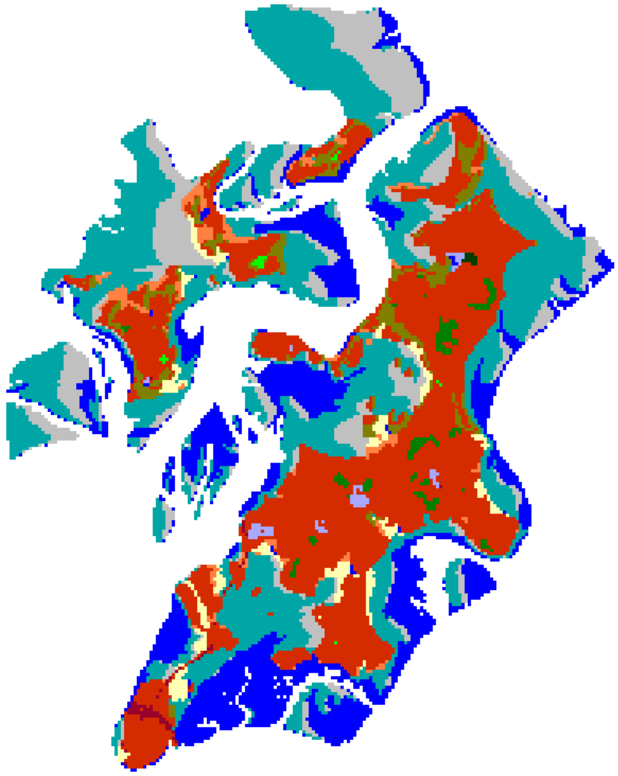
		Initial	2025	2050	2075	2100
	Regularly-flooded Marsh	1777	1587	1283	872	457
	Undeveloped Dry Land	1293	1246	1168	1067	929
	Estuarine Open Water	710	734	760	791	823
	Estuarine Beach	95	92	87	80	71
	Irregularly-flooded Marsh	81	73	68	60	50
	Swamp	41	41	40	39	37
	Inland Open Water	19	18	18	18	18
	Developed Dry Land	16	15	15	15	14
	Transitional Salt Marsh	8	56	133	233	373
	Inland Fresh Marsh	5	5	5	4	4
	Tidal Swamp	3	3	3	3	3
	Tidal Flat	0	178	467	866	1270
	Total (incl. water)	**4047**	**4047**	**4047**	**4047**	**4047**



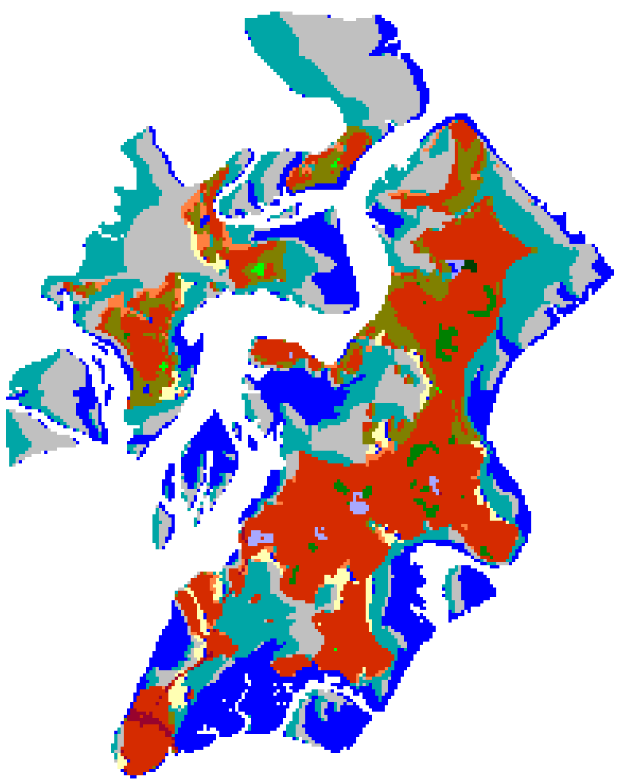
Pinckney Island NWR, Initial Condition.



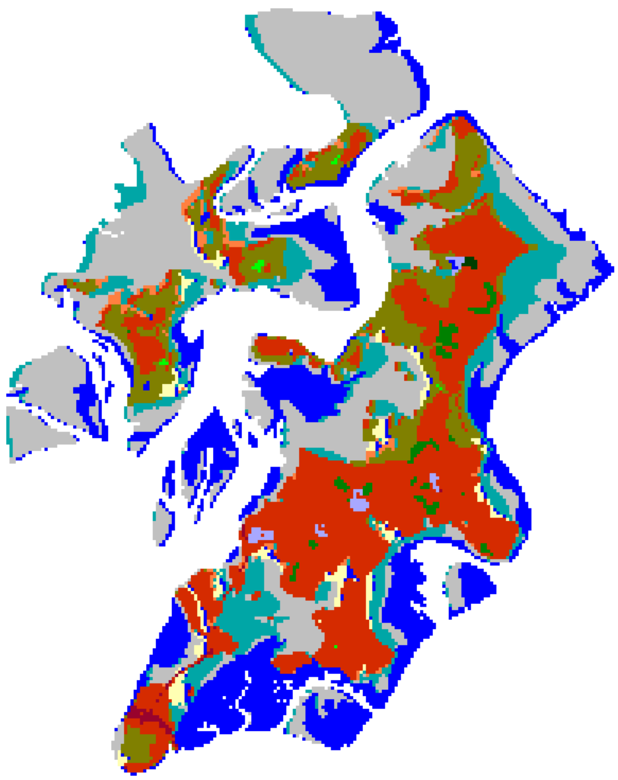
Pinckney Island NWR, 2025, Scenario A1B Maximum, 0.69 m SLR by 2100.



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



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

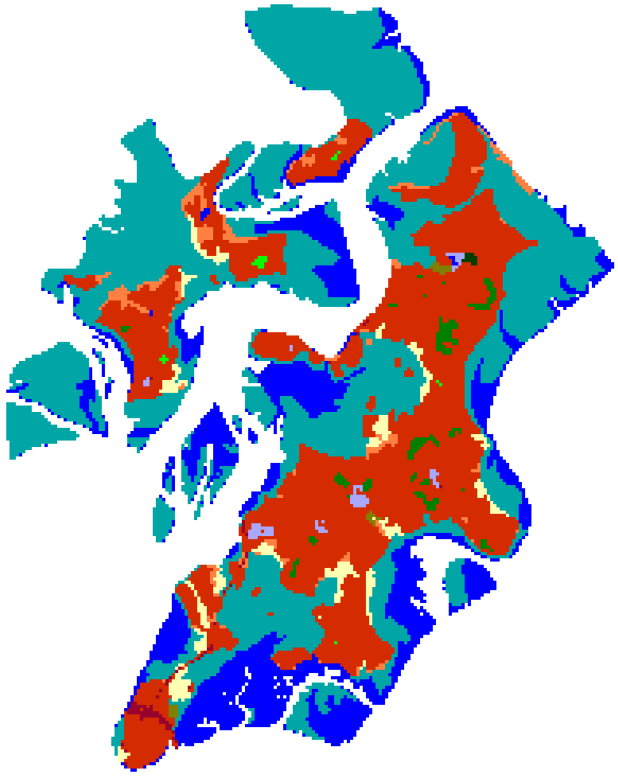


Pinckney Island NWR, 2100, Scenario A1B Maximum, 0.69 m SLR by 2100.

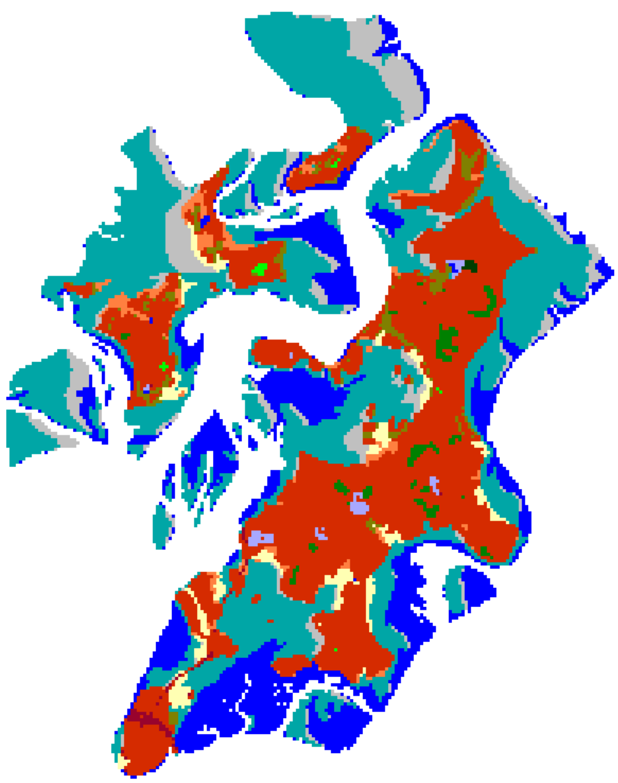
1 m eustatic SLR by 2100

Results in Acres

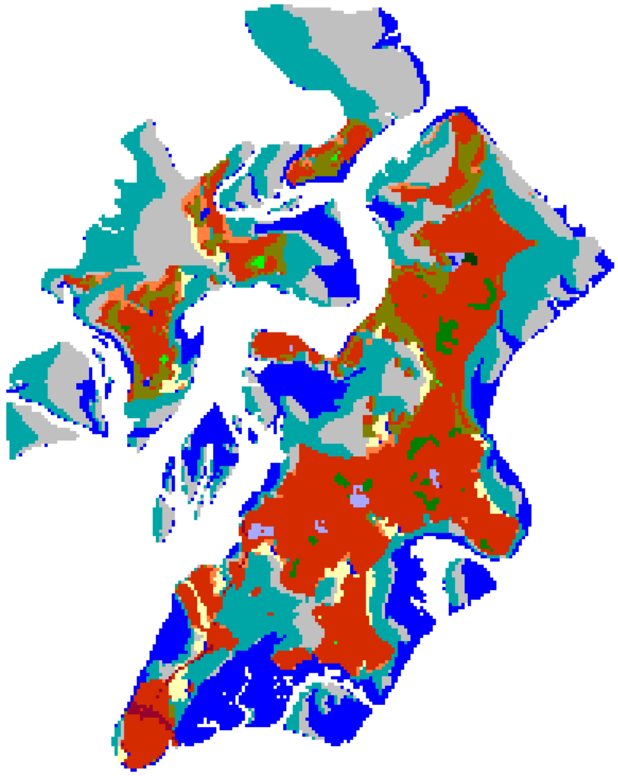
		Initial	2025	2050	2075	2100
	Regularly-flooded Marsh	1777	1477	1019	434	332
	Undeveloped Dry Land	1293	1222	1114	961	216
	Estuarine Open Water	710	738	768	803	843
	Estuarine Beach	95	90	83	72	60
	Irregularly-flooded Marsh	81	70	60	44	28
	Swamp	41	41	40	37	24
	Inland Open Water	19	18	18	18	14
	Developed Dry Land	16	15	15	15	2
	Transitional Salt Marsh	8	79	185	339	1007
	Inland Fresh Marsh	5	5	4	4	2
	Tidal Swamp	3	3	3	3	3
	Tidal Flat	0	290	737	1318	1515
	Total (incl. water)	**4047**	**4047**	**4047**	**4047**	**4047**



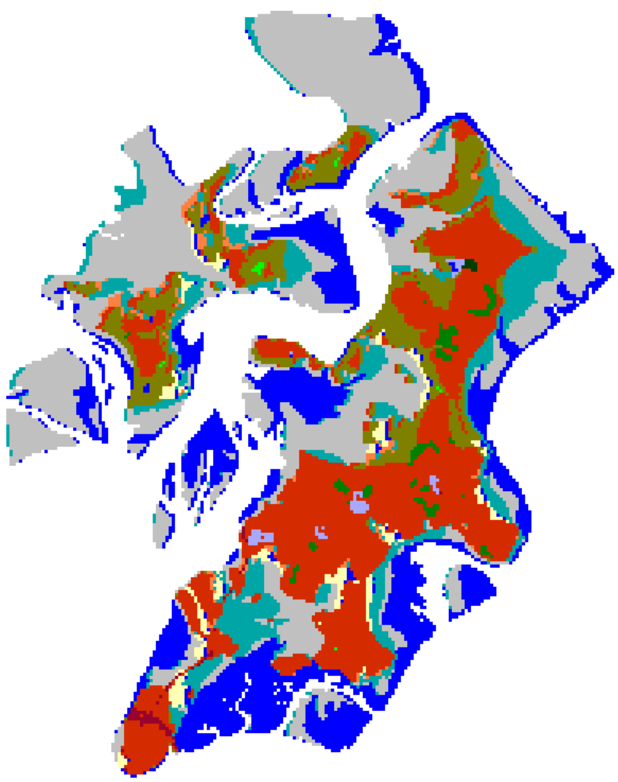
Pinckney Island NWR, Initial Condition.



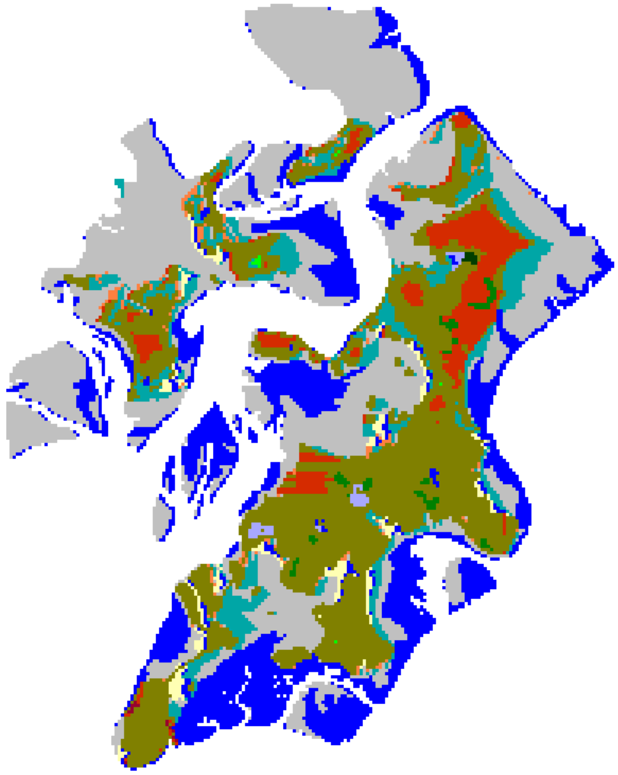
Pinckney Island NWR, 2025, 1 m SLR by 2100.



Pinckney Island NWR, 2050, 1 m SLR by 2100.



Pinckney Island NWR, 2075, 1 m SLR by 2100.

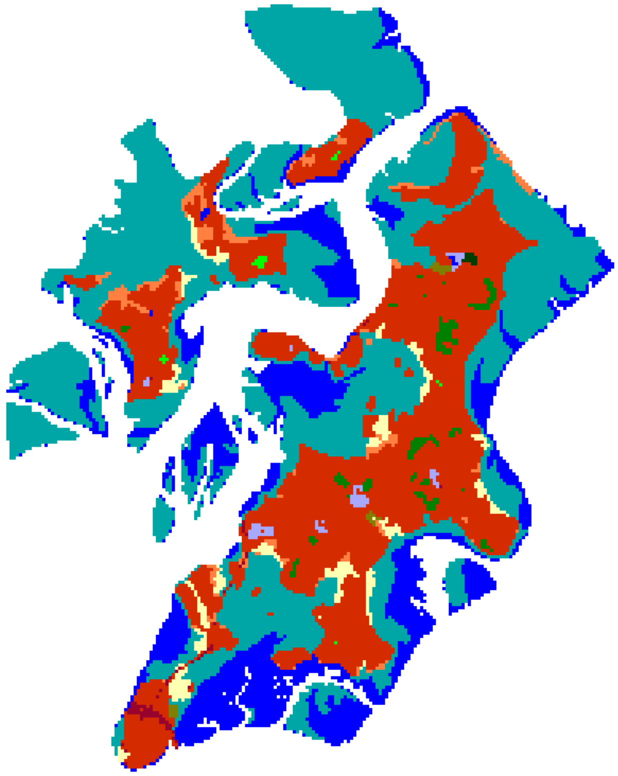


Pinckney Island NWR, 2100, 1 m SLR by 2100.

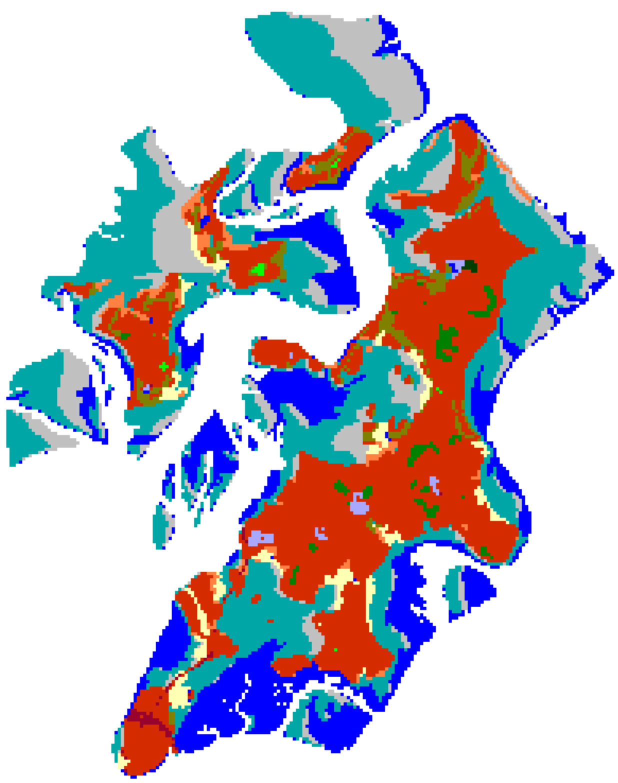
1.5 m eustatic SLR by 2100

Results in Acres

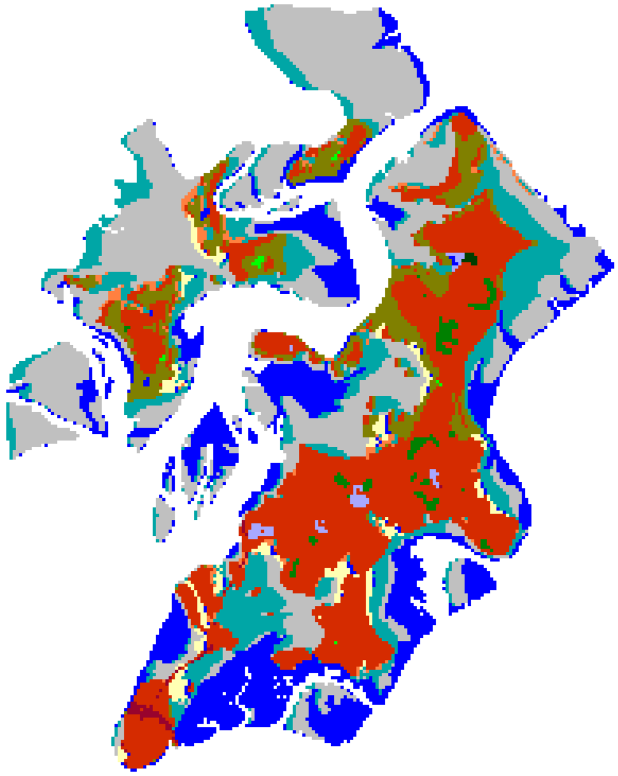
		Initial	2025	2050	2075	2100
	Regularly-flooded Marsh	1777	1290	590	367	453
	Undeveloped Dry Land	1293	1186	1027	222	51
	Estuarine Open Water	710	743	779	824	1539
	Estuarine Beach	95	88	77	60	41
	Irregularly-flooded Marsh	81	68	48	21	1
	Swamp	41	40	38	24	3
	Inland Open Water	19	18	18	14	3
	Developed Dry Land	16	15	15	3	0
	Transitional Salt Marsh	8	114	272	948	881
	Inland Fresh Marsh	5	5	4	1	0
	Tidal Swamp	3	3	3	3	3
	Tidal Flat	0	477	1178	1561	1073
	Total (incl. water)	**4047**	**4047**	**4047**	**4047**	**4047**



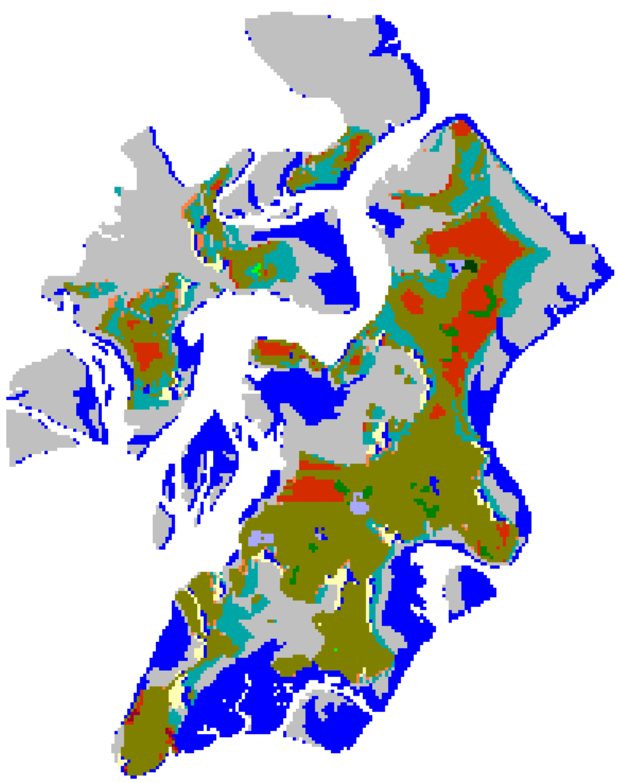
Pinckney Island NWR, Initial Condition.



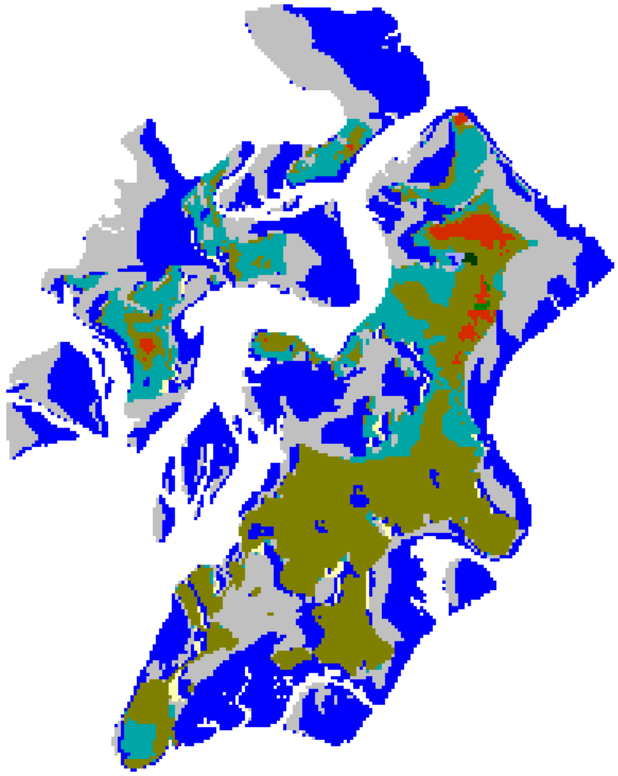
Pinckney Island NWR, 2025, 1.5 m SLR by 2100.



Pinckney Island NWR, 2050, 1.5 m SLR by 2100.



Pinckney Island NWR, 2075, 1.5 m SLR by 2100.

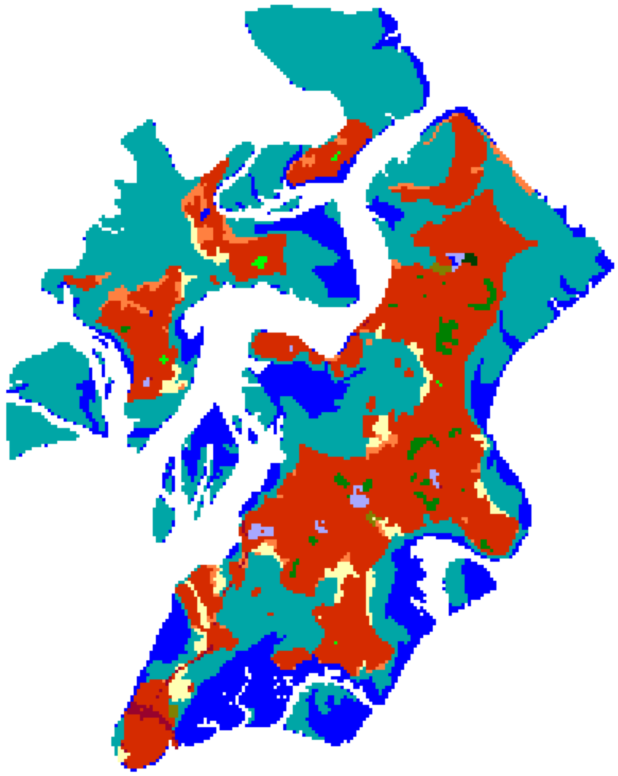


Pinckney Island NWR, 2100, 1.5 m SLR by 2100.

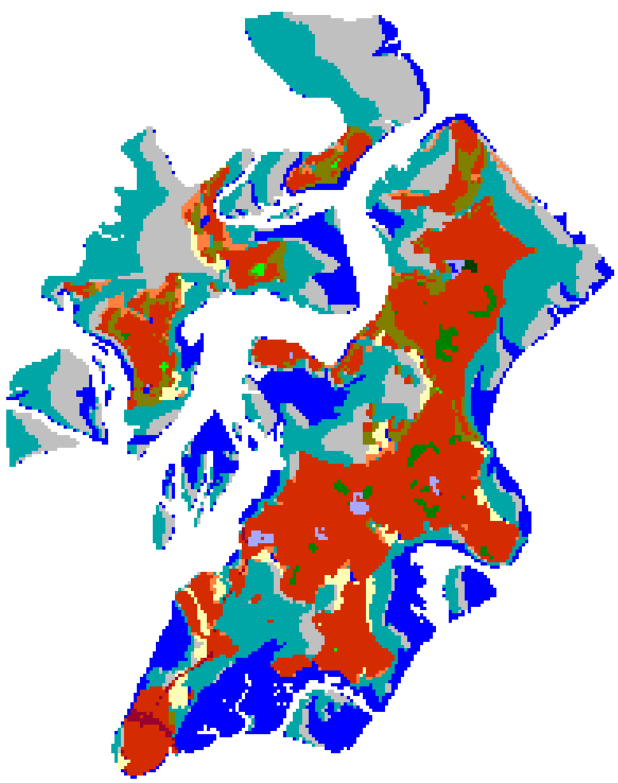
2 m eustatic SLR by 2100

Results in Acres

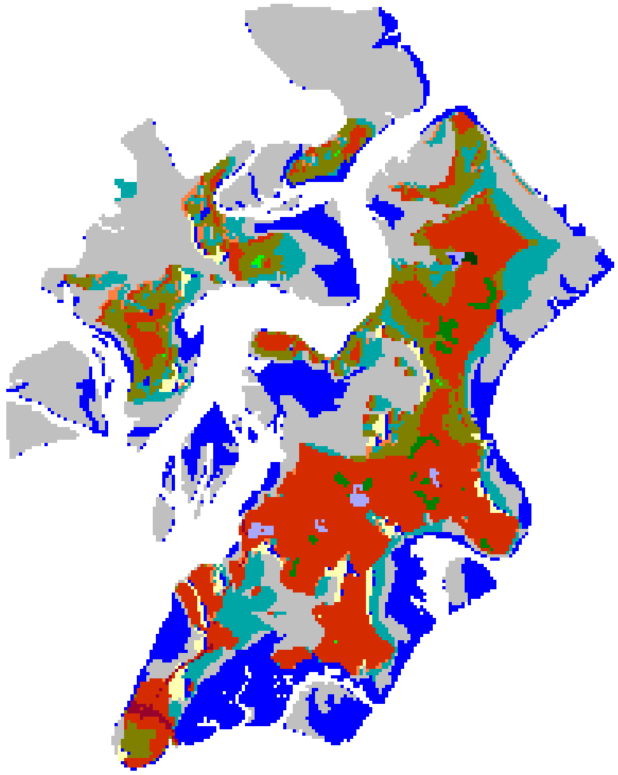
		Initial	2025	2050	2075	2100
	Regularly-flooded Marsh	1777	1102	382	397	1211
	Undeveloped Dry Land	1293	1147	904	73	10
	Estuarine Open Water	710	747	788	1314	2344
	Estuarine Beach	95	86	70	46	24
	Irregularly-flooded Marsh	81	62	33	2	0
	Swamp	41	40	35	4	0
	Inland Open Water	19	18	18	14	3
	Developed Dry Land	16	15	14	0	0
	Transitional Salt Marsh	8	152	345	938	79
	Inland Fresh Marsh	5	4	3	0	0
	Tidal Swamp	3	3	3	3	3
	Tidal Flat	0	670	1453	1256	374
	Total (incl. water)	**4047**	**4047**	**4047**	**4047**	**4047**

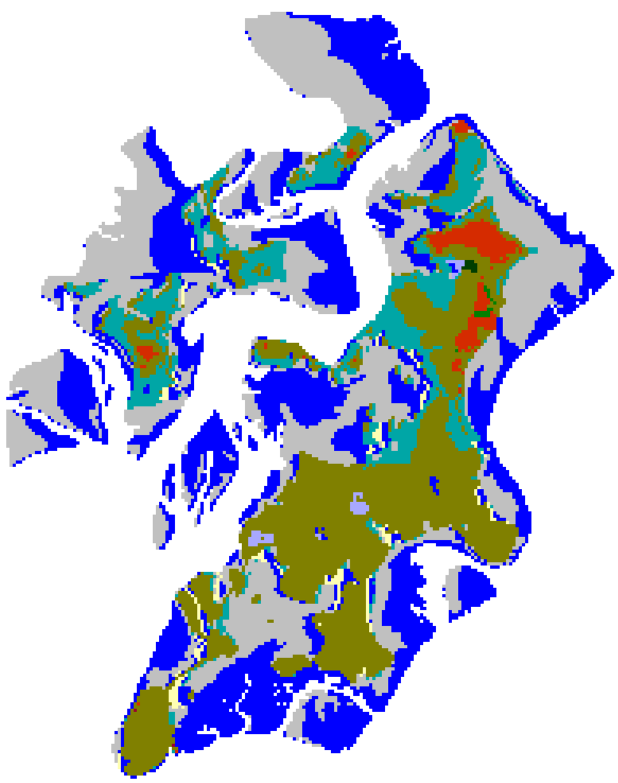


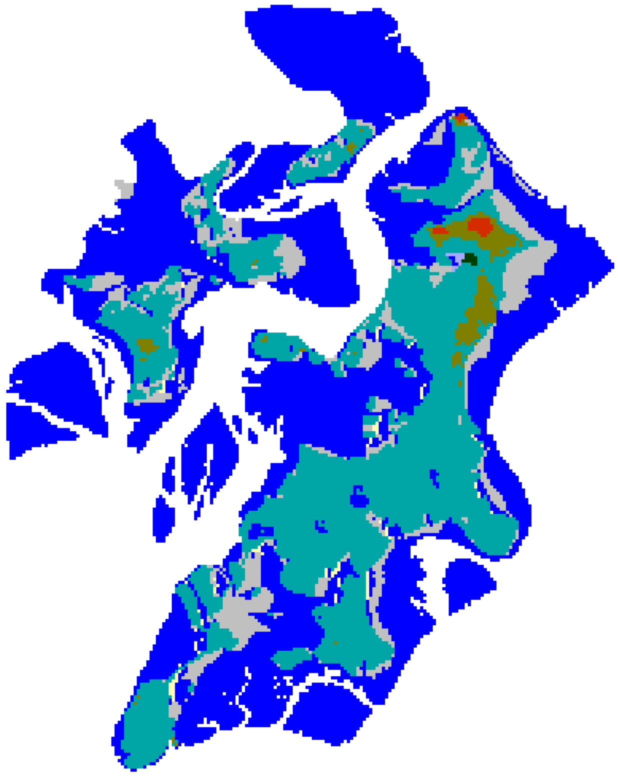
Pinckney Island NWR, Initial Condition.



Pinckney Island NWR, 2025, 2 m SLR by 2100.


Pinckney Island NWR, 2050, 2 m SLR by 2100.


Pinckney Island NWR, 2075, 2 m SLR by 2100.



Pinckney Island NWR, 2100, 2 m SLR by 2100.

Discussion

Pinckney Island NWR is projected to undergo widespread changes in wetland habitat based on accelerated SLR. Major changes to the composition of the refuge wetlands are predicted to occur under SLR scenarios as low as 0.69 m by 2100. Under this scenario the majority of regularly-flooded marsh is predicted to be lost. Simulations of 1 m eustatic SLR by 2100 and greater project substantial shifts in several habitat types, with severe near complete loss of several habitat types predicted at 2 m of SLR by 2100.

One important caveat of these results is the lack of high-quality LiDAR elevation data for the refuge. Because contour data was used, the SLAMM pre-processor was utilized to estimate elevation ranges for all of the non-diked wetlands as a function of tide range and known relationships between wetland types and tide ranges. The pre-processor assumes wetland elevations to be uniformly distributed over their feasible vertical elevation ranges or "tidal frames"—an assumption that may not reflect reality. If wetlands elevations are actually clustered high in the tidal frame they would be less vulnerable to SLR. On the contrary, if in reality wetlands are towards the bottom, they are more vulnerable than what is predicted by the simulation results.

An additional cause of uncertainty within these predictions is the model's estimation of marsh accretion rates. Although region-specific accretion rates were used, these rates were held temporally constant. Vertical marsh accretion rates may react to an increase in sea level rise due to more frequent inundation and higher sediment trapping within marshes. This could potentially lead to additional marsh resilience. Insufficient data were available to define a relationship between marsh elevation, sea-level rise, and accretion rates at this time. Future model runs for this site could potentially evaluate the importance of this potential feedback as part of a model sensitivity or uncertainty analysis.

This SLAMM simulation utilized the best available data layers and parameter inputs; however, these data and the conceptual model continue to have uncertainties that should be kept in mind when interpreting model results. Perhaps most importantly, the extent of future sea-level rise is unknown, as are the drivers of climate change used by scientists when projecting SLR rates. Future levels of economic activity, fuel type (e.g., fossil or renewable, etc.), fuel consumption, and greenhouse gas emissions 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). More in general, to better support managers and decision-makers, the results presented here could be studied as a function of input-data uncertainty to provide a range of possible outcomes and their likelihood.

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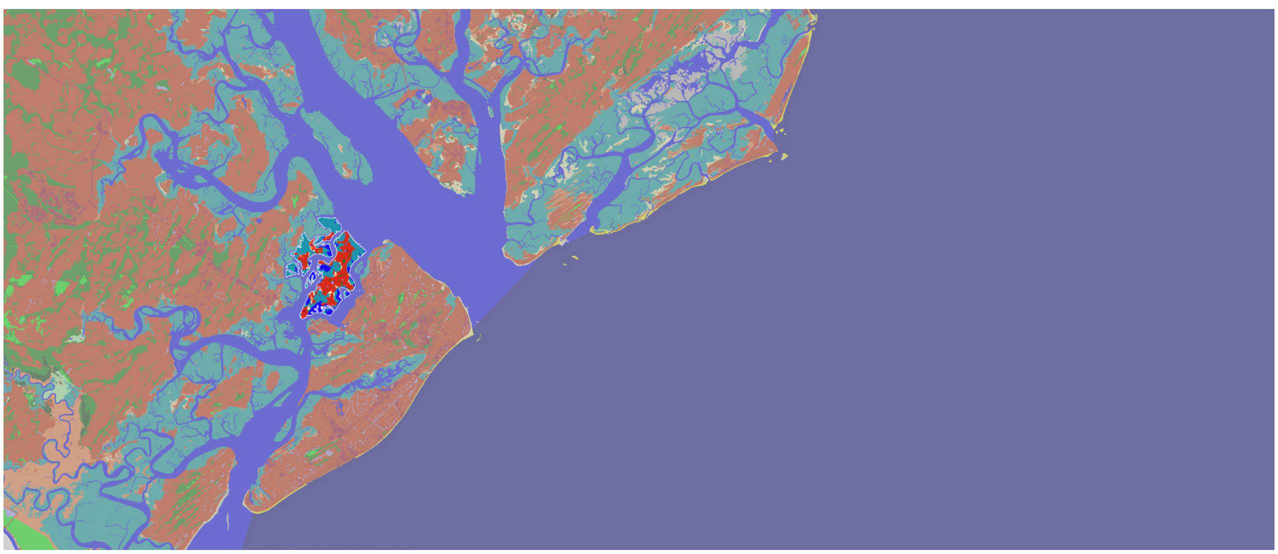
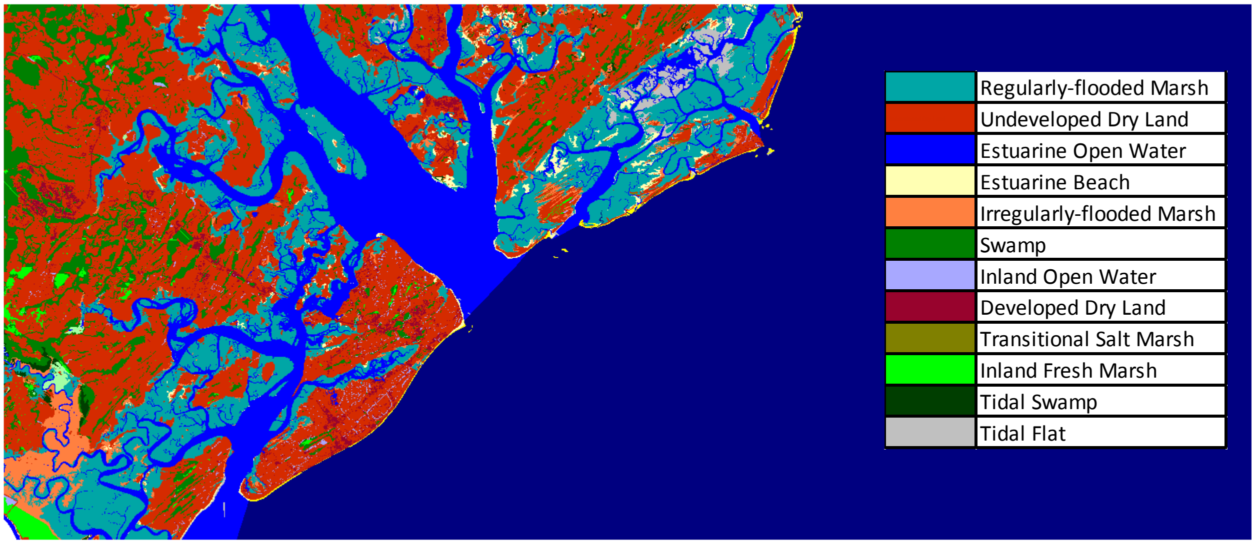
Appendix A: Contextual Results

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:

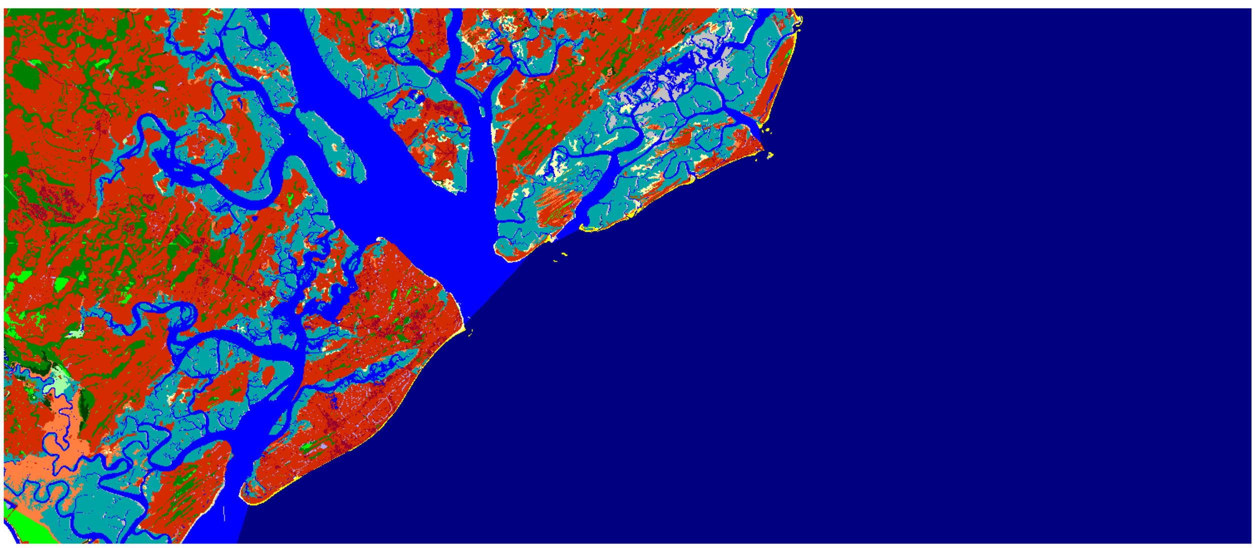
- Results were critically examined within USFWS refuges but not closely examined for the larger region.
- Site-specific parameters for the model were derived for USFWS refuges whenever possible and may not be regionally applicable.
- Especially in areas where dikes are present, an effort was made to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



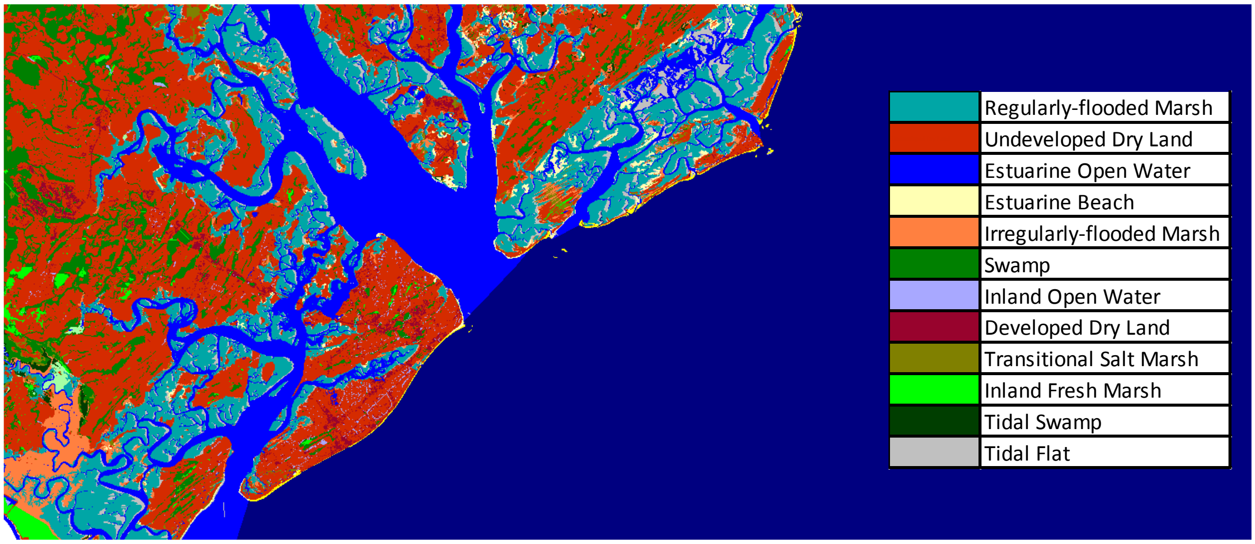
Pinckney Island National Wildlife Refuge within simulation context (refuge outlined in white).



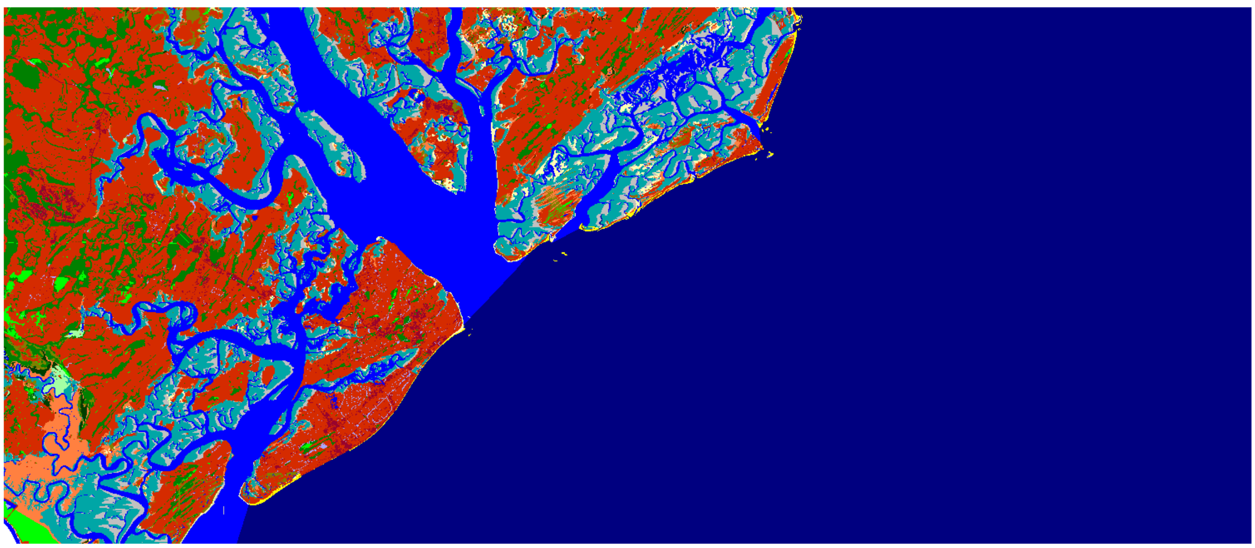
Pinckney Island NWR, Initial Condition.



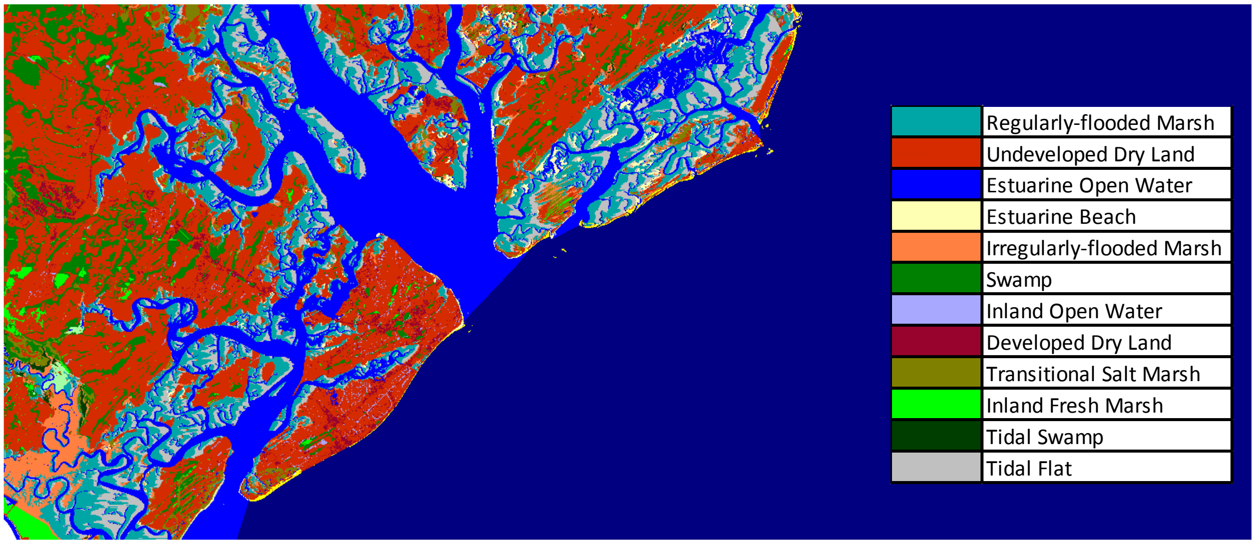
Pinckney Island NWR, 2025, Scenario A1B Mean, 0.39 m SLR by 2100.



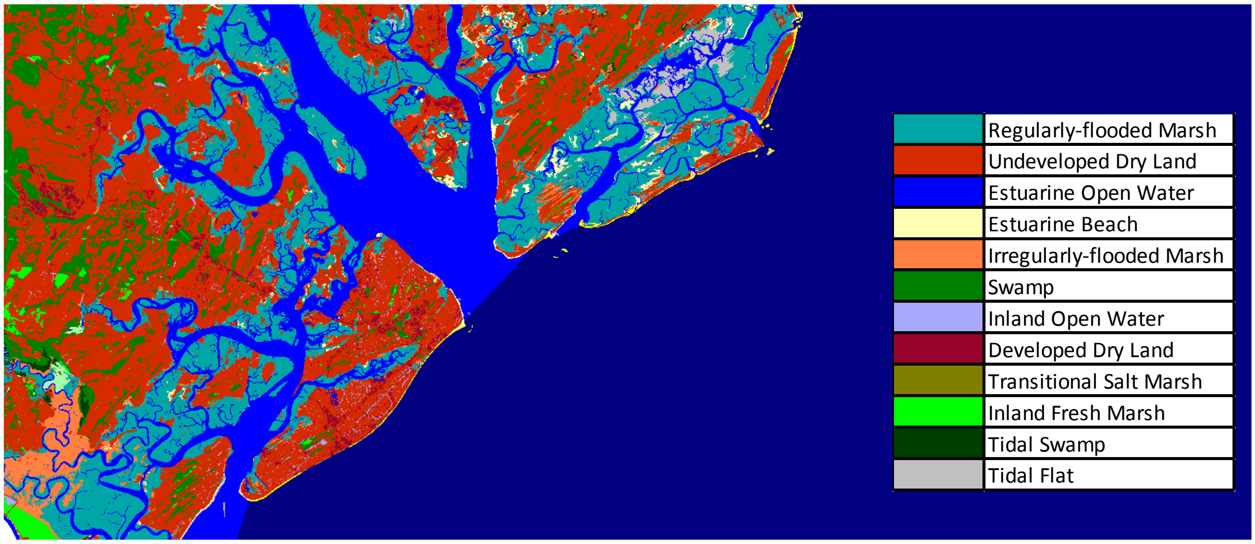
Pinckney Island NWR, 2050, Scenario A1B Mean, 0.39 m SLR by 2100.



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



Pinckney Island NWR, 2100, Scenario A1B Mean, 0.39 m SLR by 2100.



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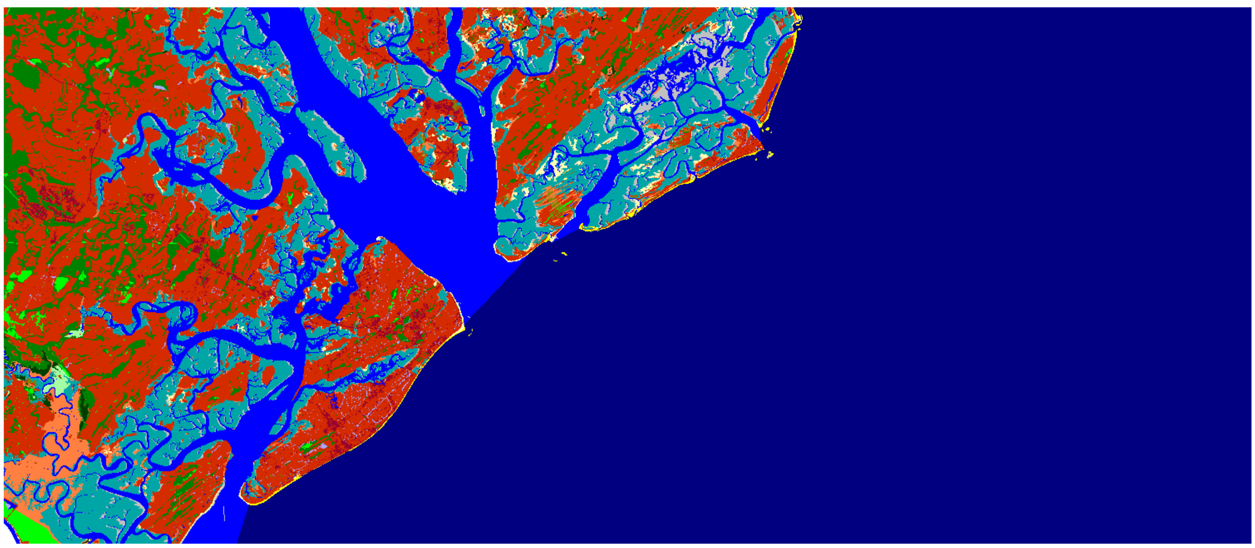
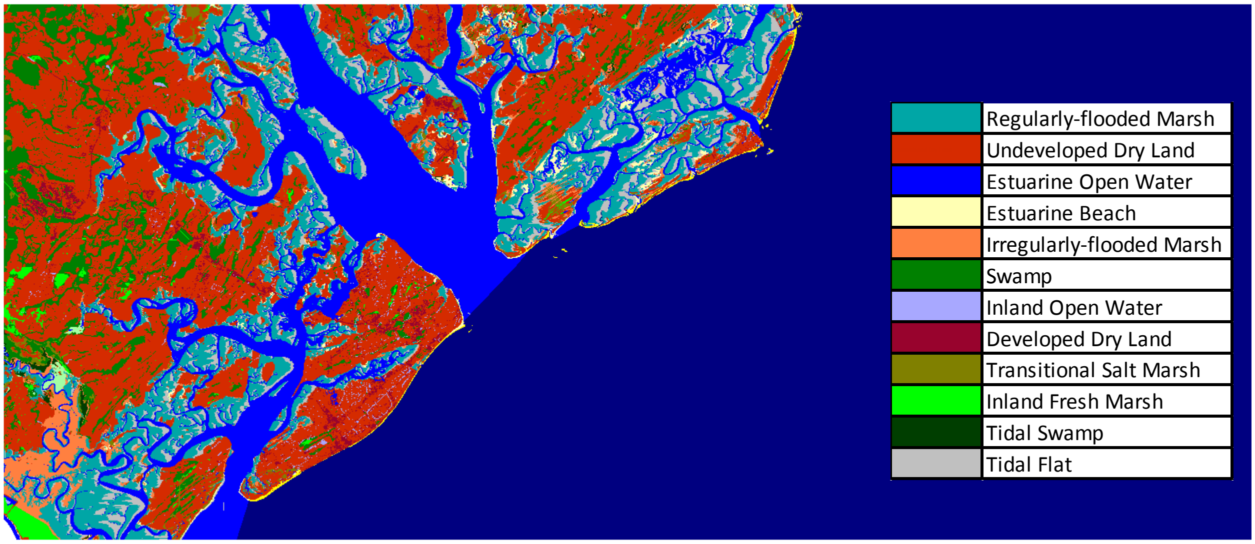
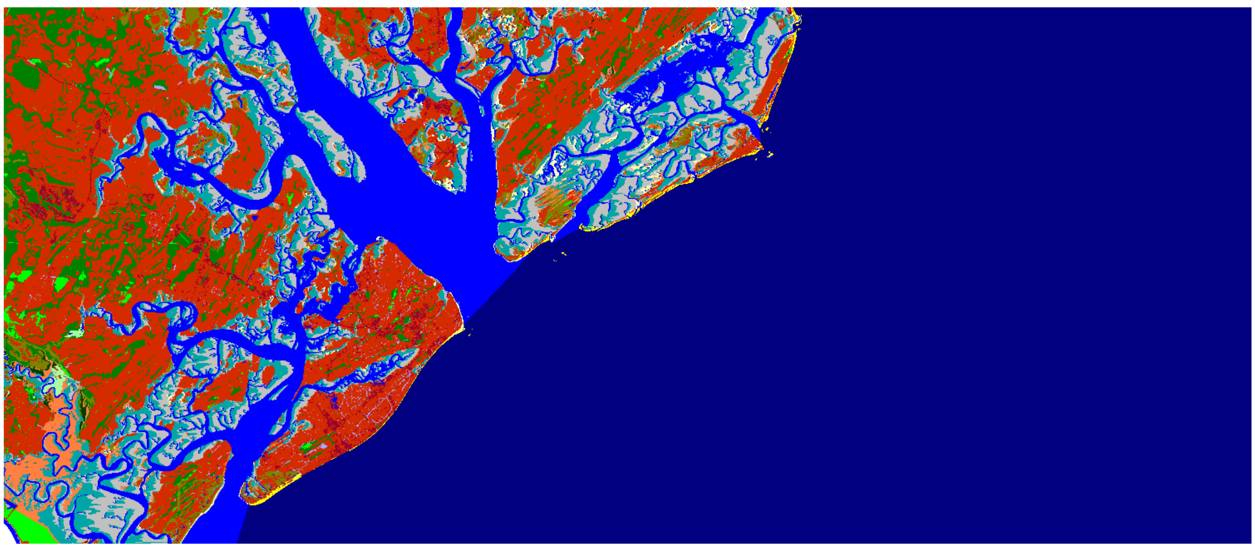


Pinckney Island NWR, 2025, Scenario A1B Maximum, 0.69 m SLR by 2100.



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



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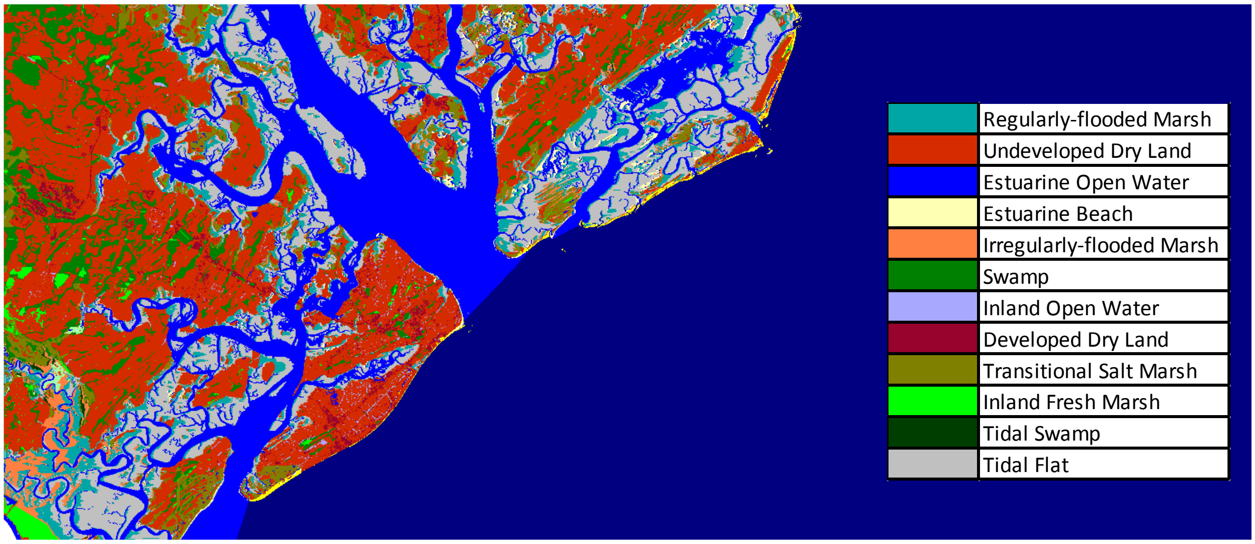
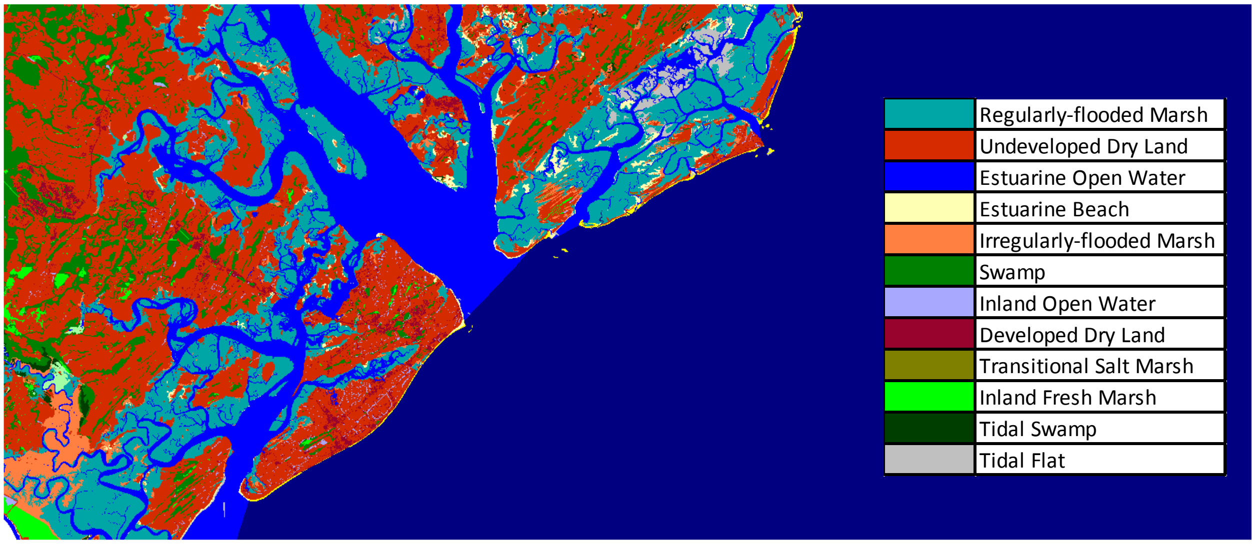
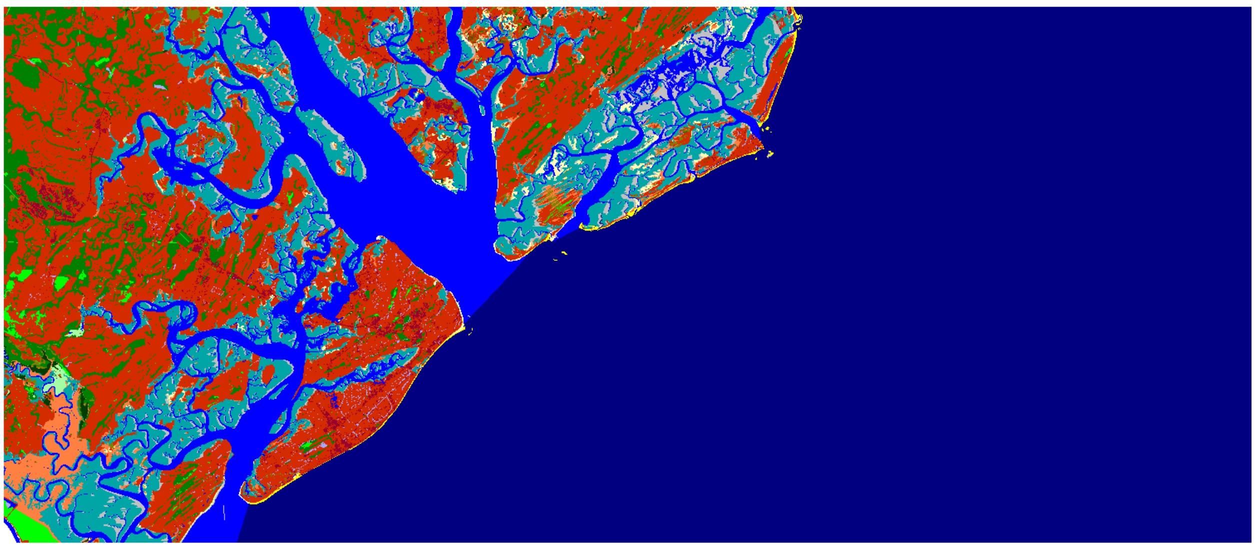


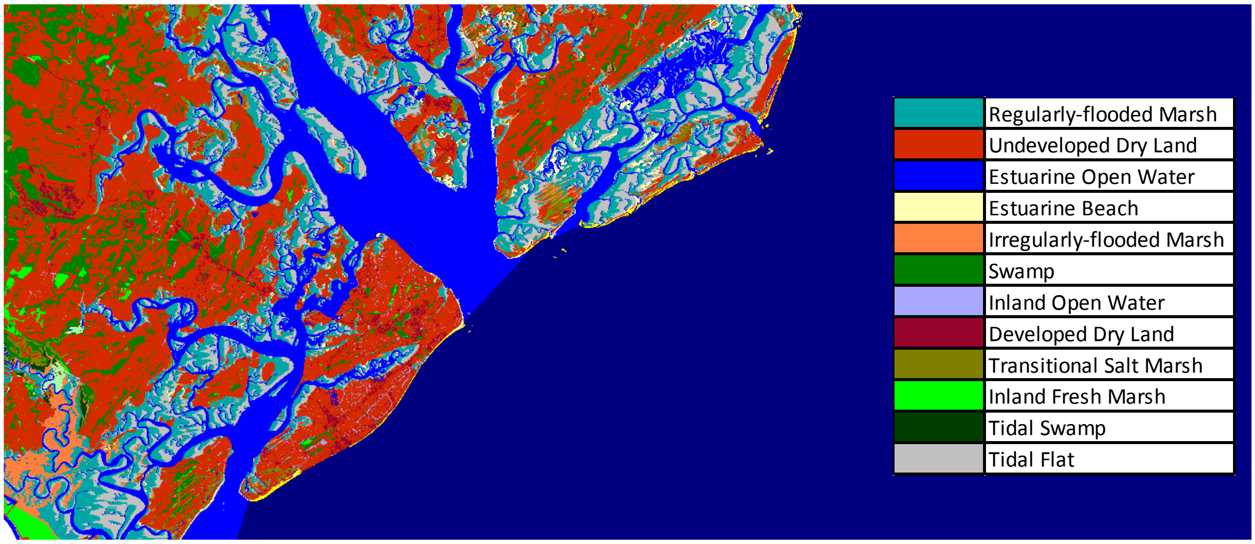
Pinckney Island NWR, 2100, Scenario A1B Maximum, 0.69 m SLR by 2100.



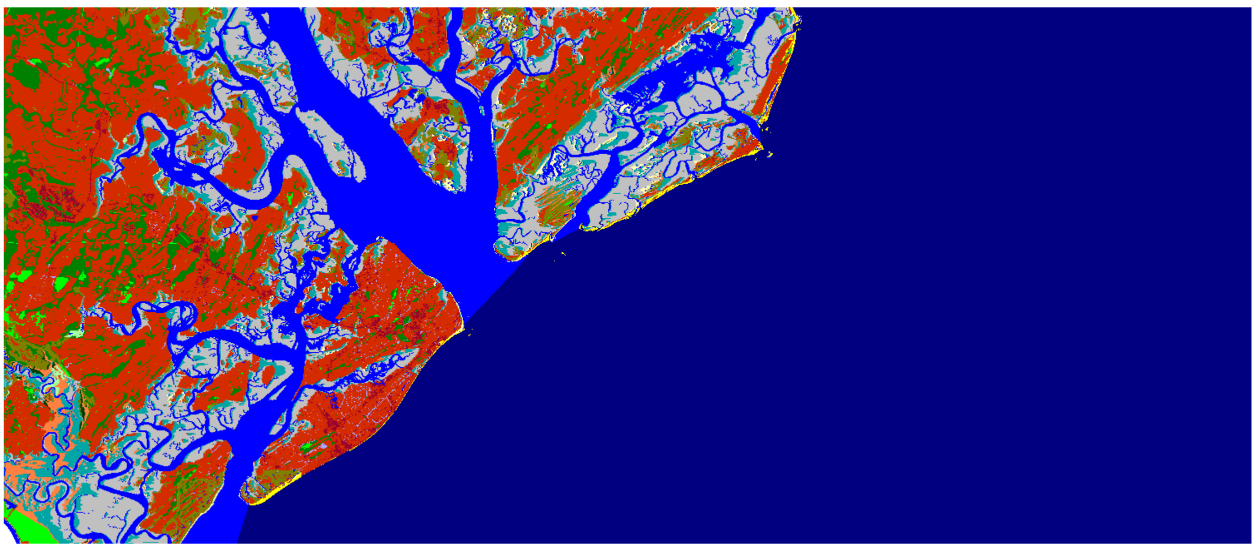
Pinckney Island NWR, Initial Condition.



Pinckney Island NWR, 2025, 1 m SLR by 2100.



Pinckney Island NWR, 2050, 1 m SLR by 2100.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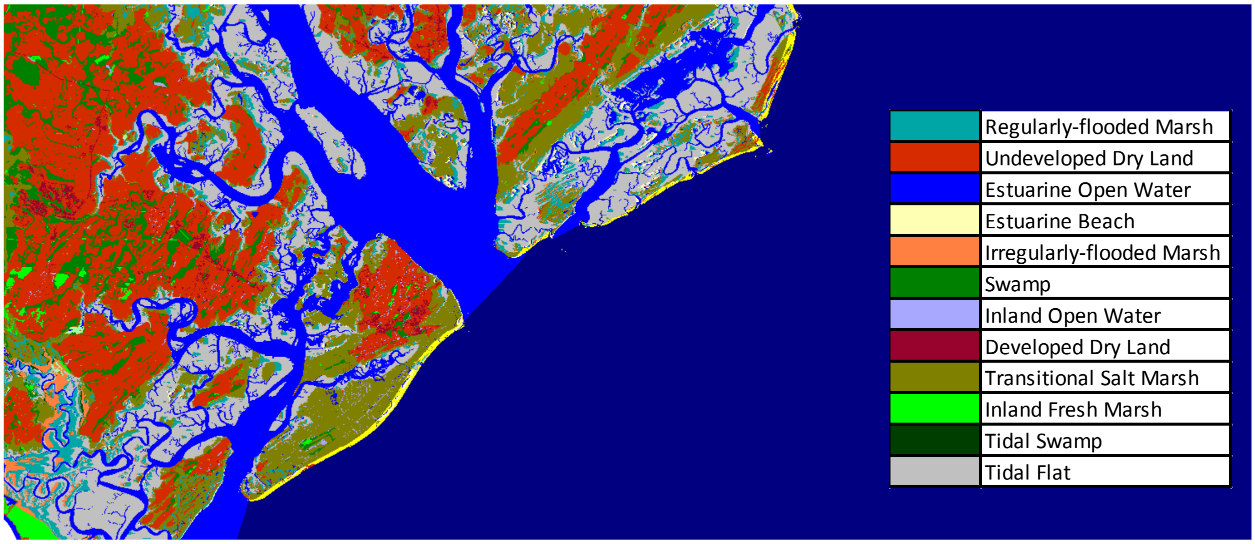

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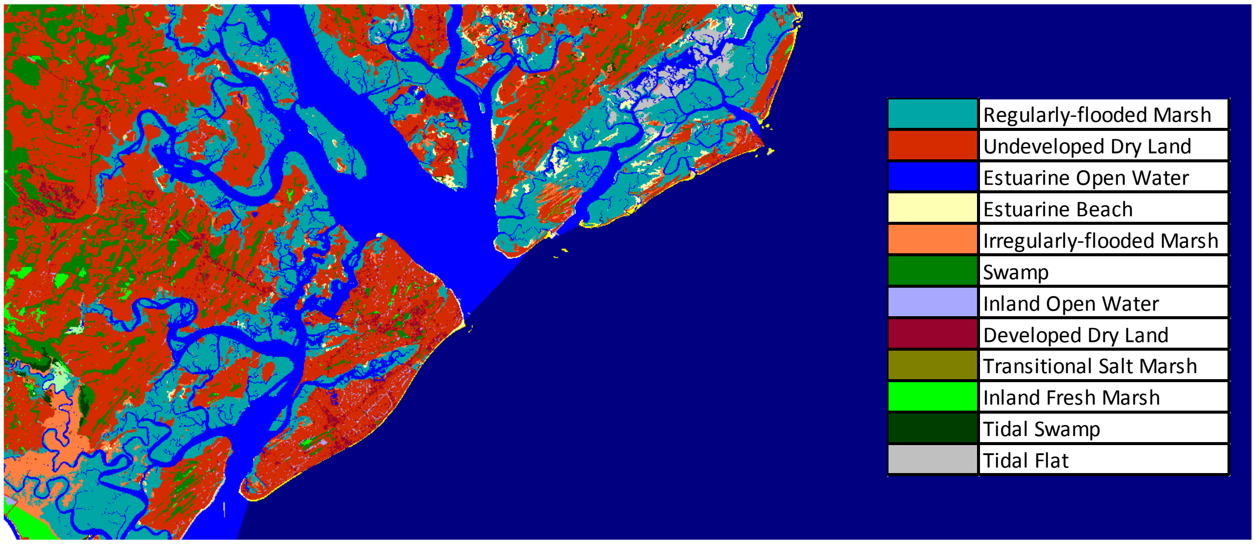

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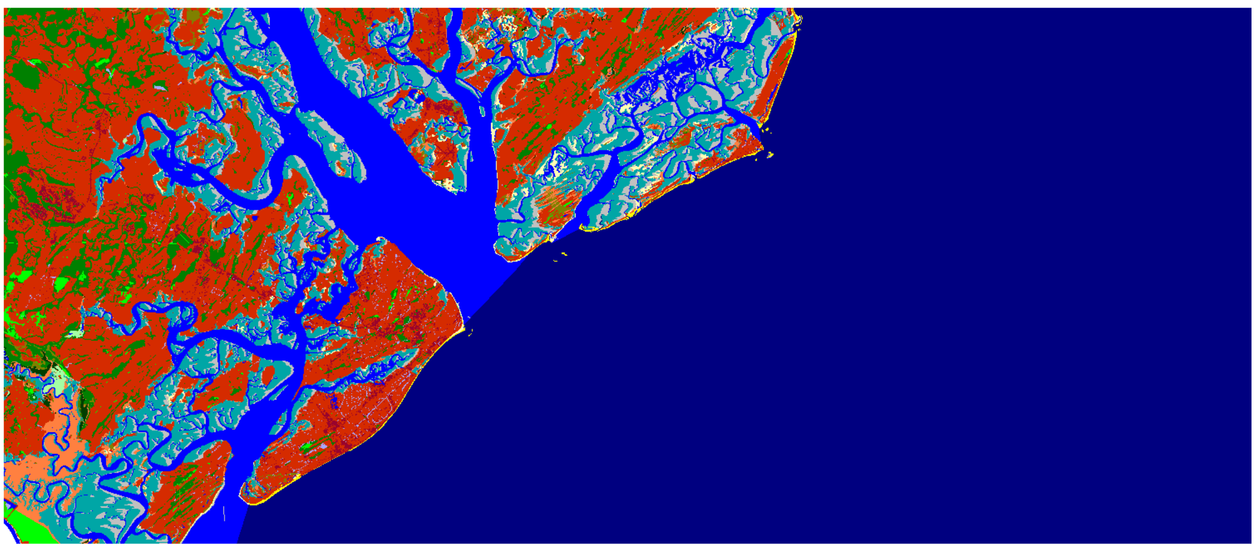

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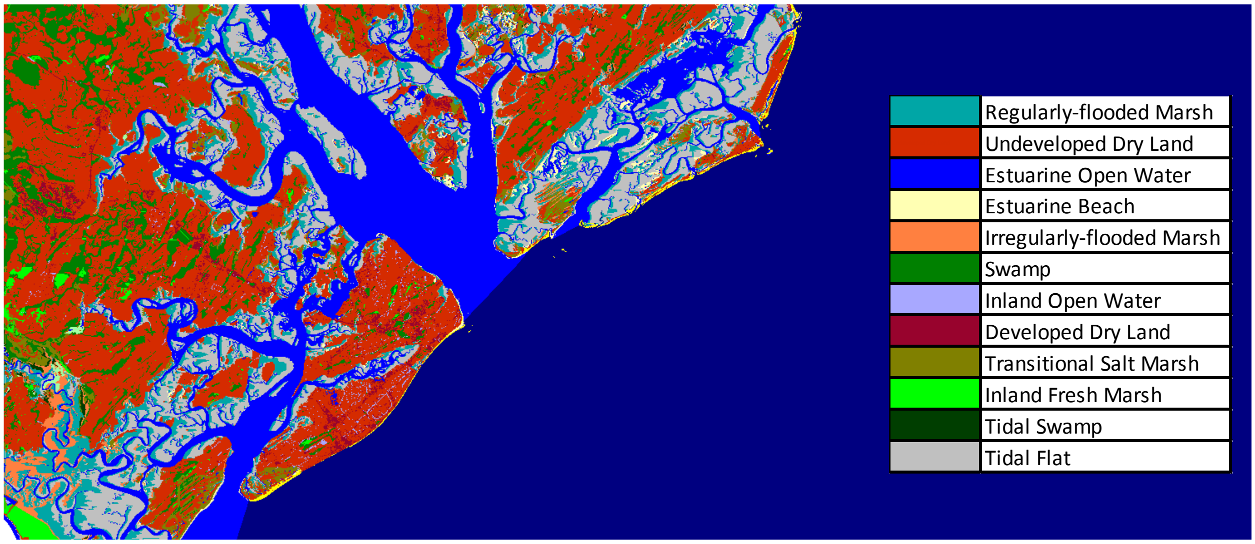
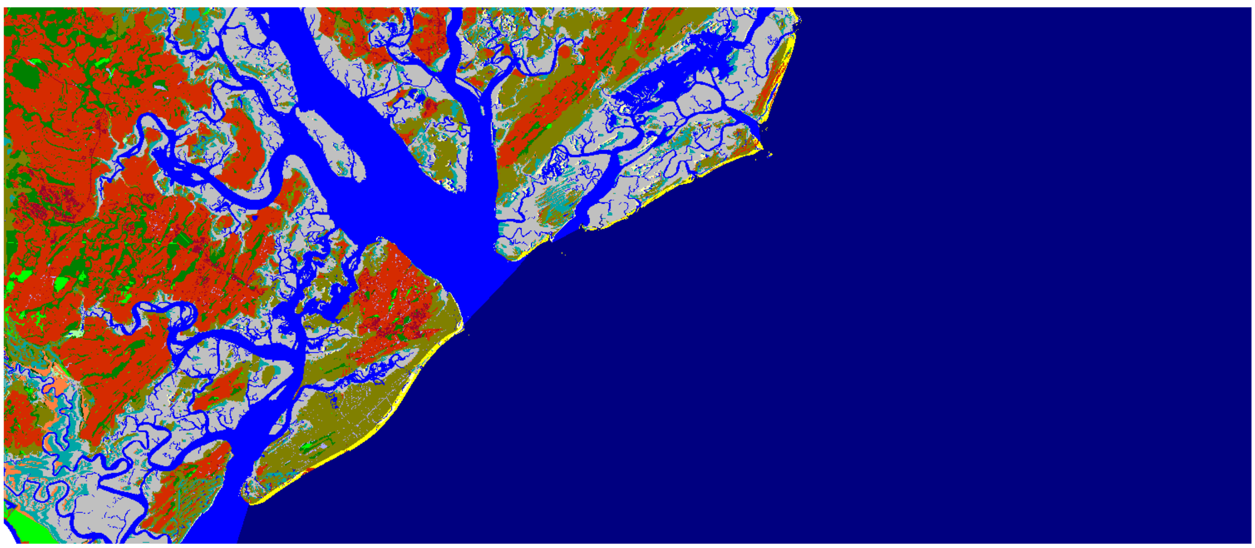


Pinckney Island NWR, 2050, 1.5 m SLR by 2100.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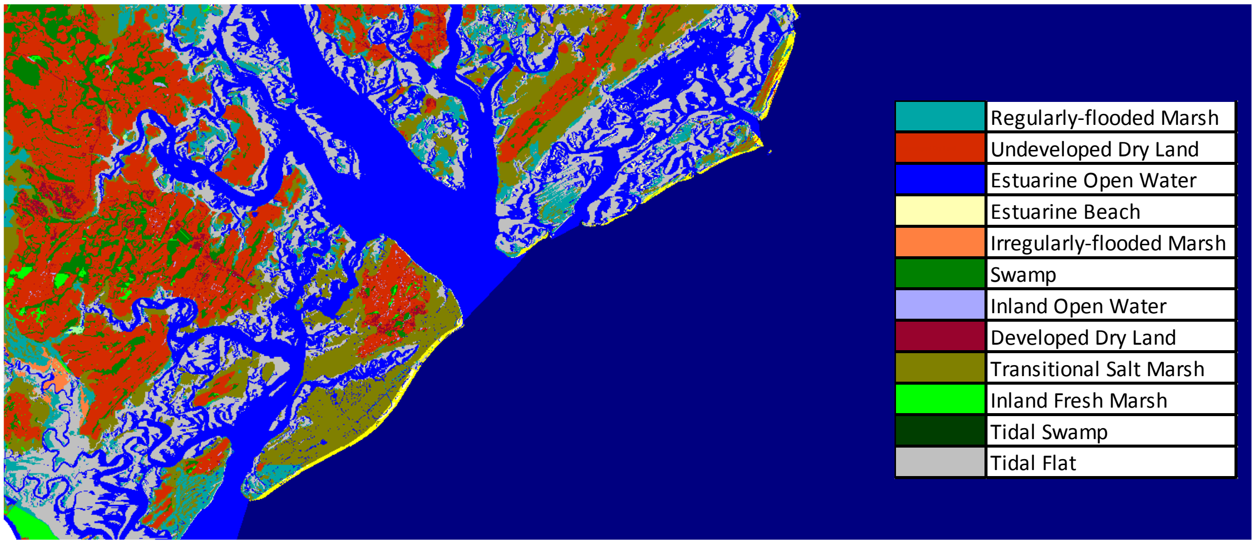
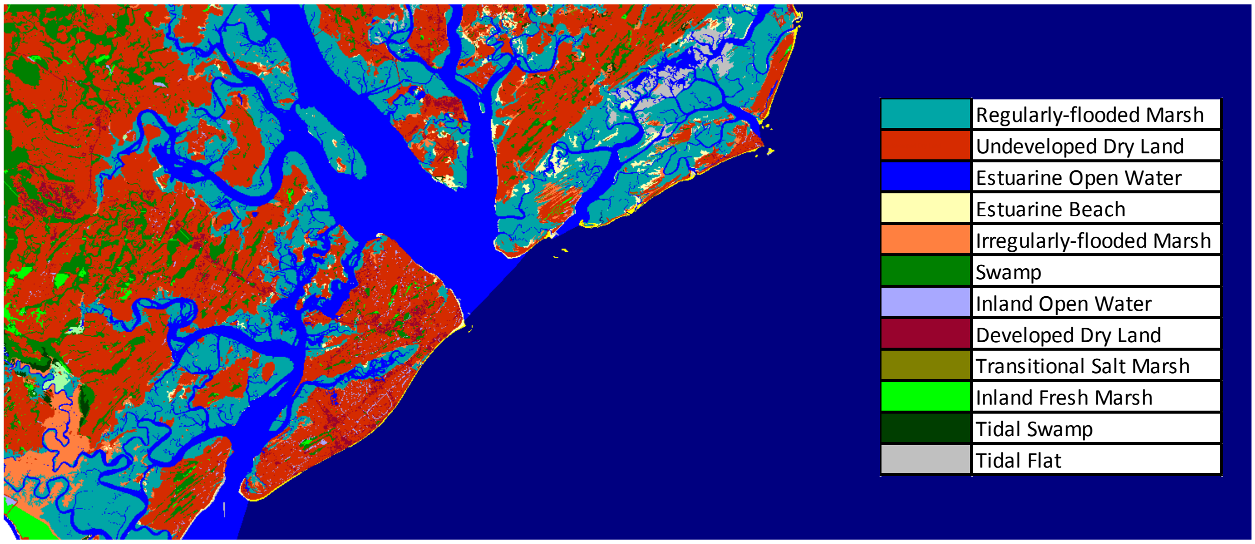
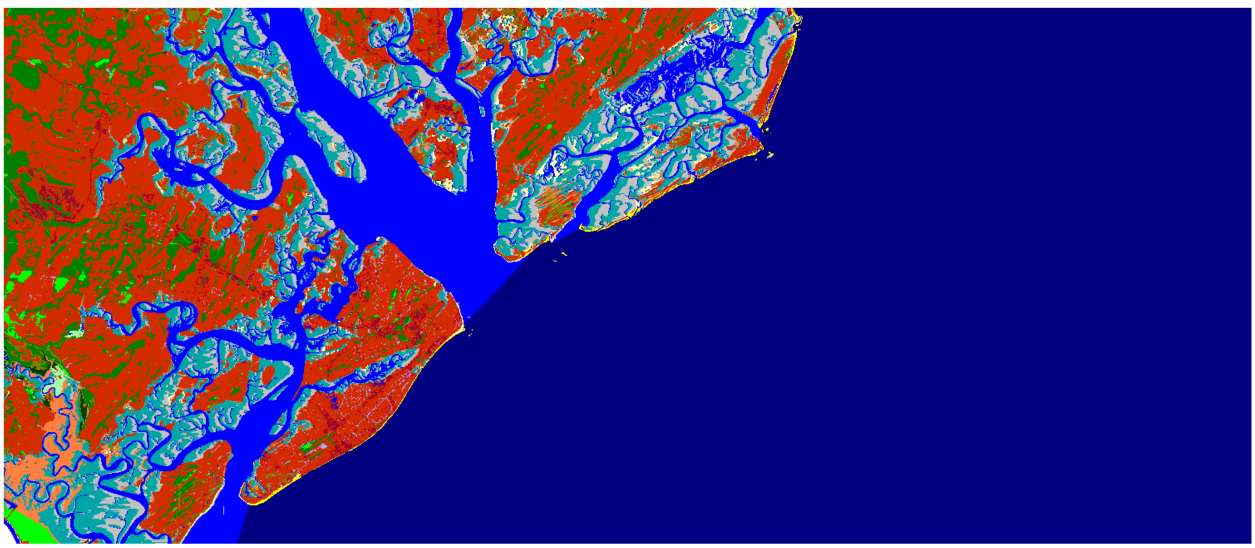


Pinckney Island NWR, 2100, 1.5 m SLR by 2100.



Pinckney Island NWR, Initial Condition.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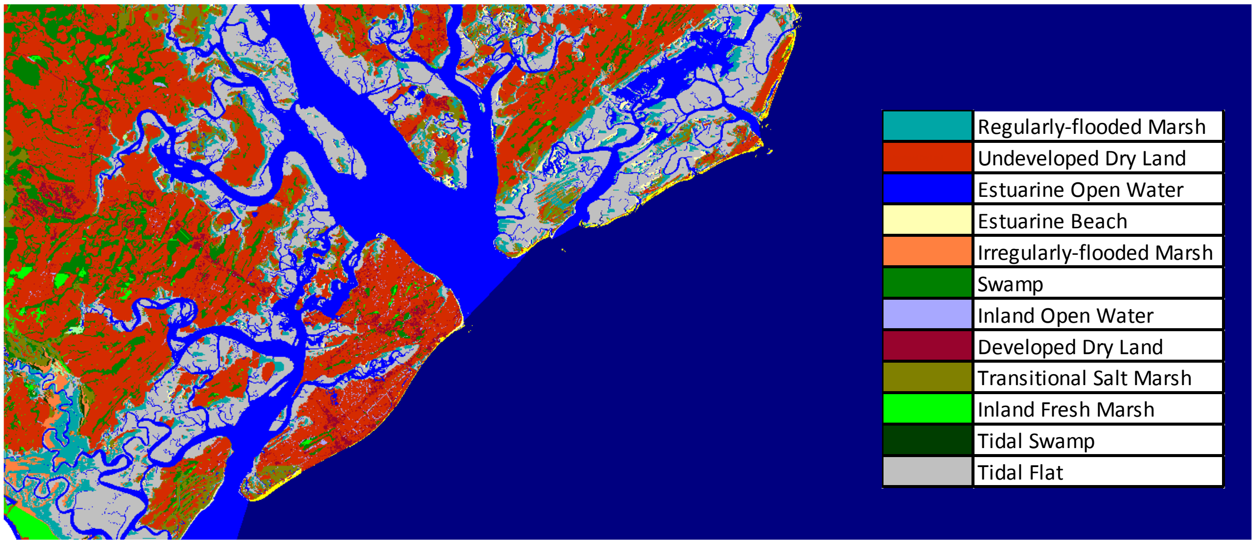
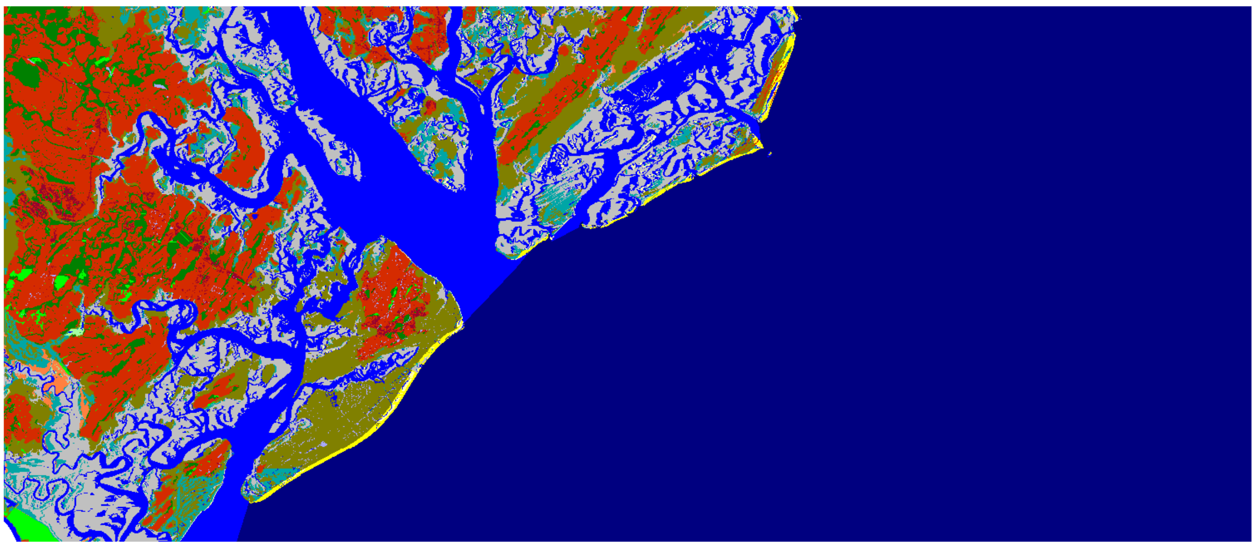
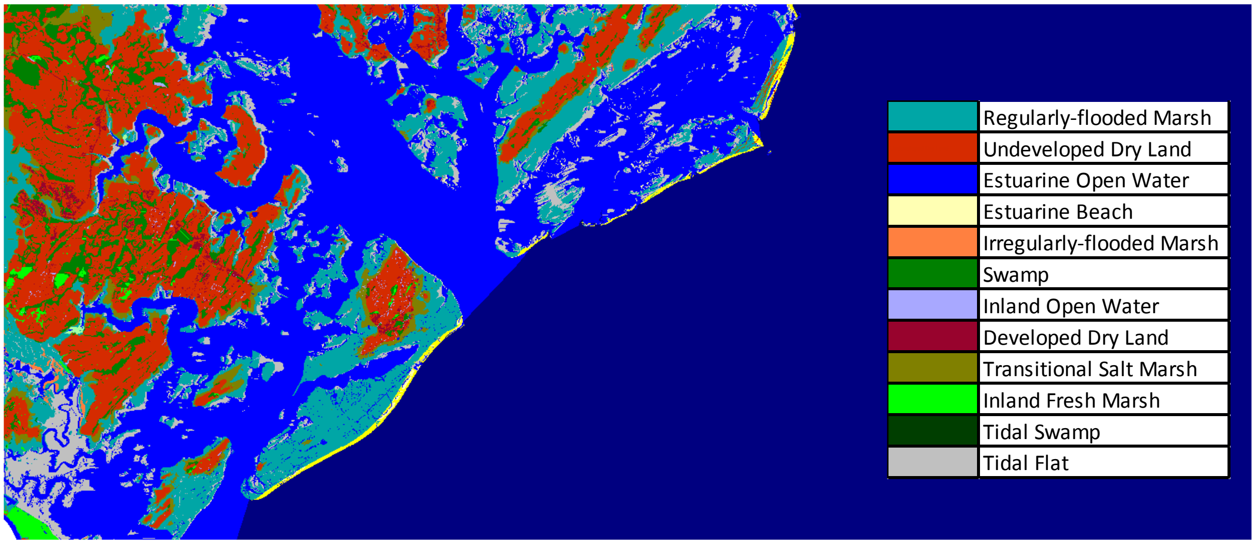


Pinckney Island NWR, 2050, 2 m SLR by 2100.



Pinckney Island NWR, 2075, 2 m SLR by 2100.



Pinckney Island NWR, 2100, 2 m SLR by 2100.