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

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January 18, 2012

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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.

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.

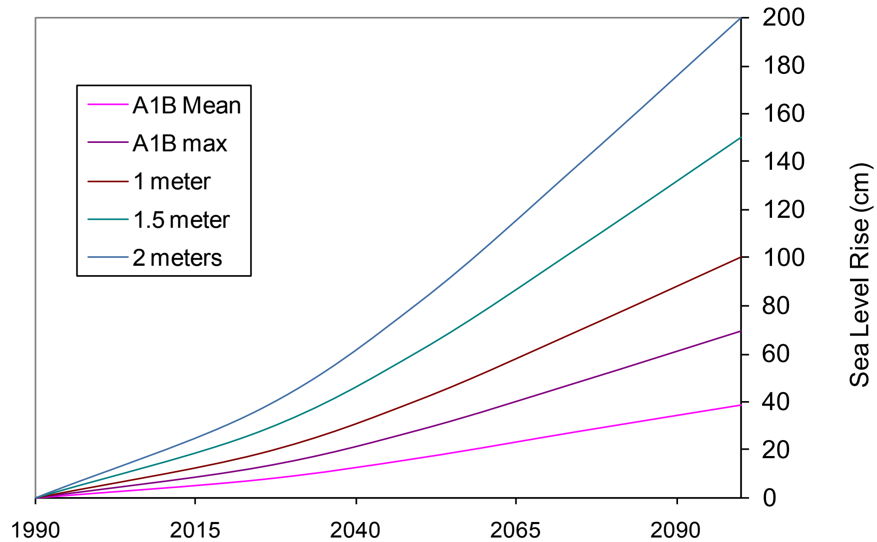


Figure 1. Summary of SLR scenarios utilized.

Data Sources and Methods

Wetland layer. Figure 2 shows the most recent available wetland layer obtained from a National Wetlands Inventory (NWI) photo dated 2007. Converting the NWI survey into 10 m x 10 m cells indicated that the approximately 5,400 acre Wolf Island NWR (approved acquisition boundary including water) is composed of the following categories:

Land cover type		Area (acres)	Percentage (%)
	Regularly-flooded Marsh	3899	72
	Estuarine Open Water	596	11
	Irregularly-flooded Marsh	522	10
	Estuarine Beach	205	4
	Open Ocean	70	1
	Undeveloped Dry Land	48	<1
	Ocean Beach	31	<1
	Transitional Salt Marsh	21	<1
	Tidal Fresh Marsh	11	<1
	Total (incl. water)	**5404**	**100**

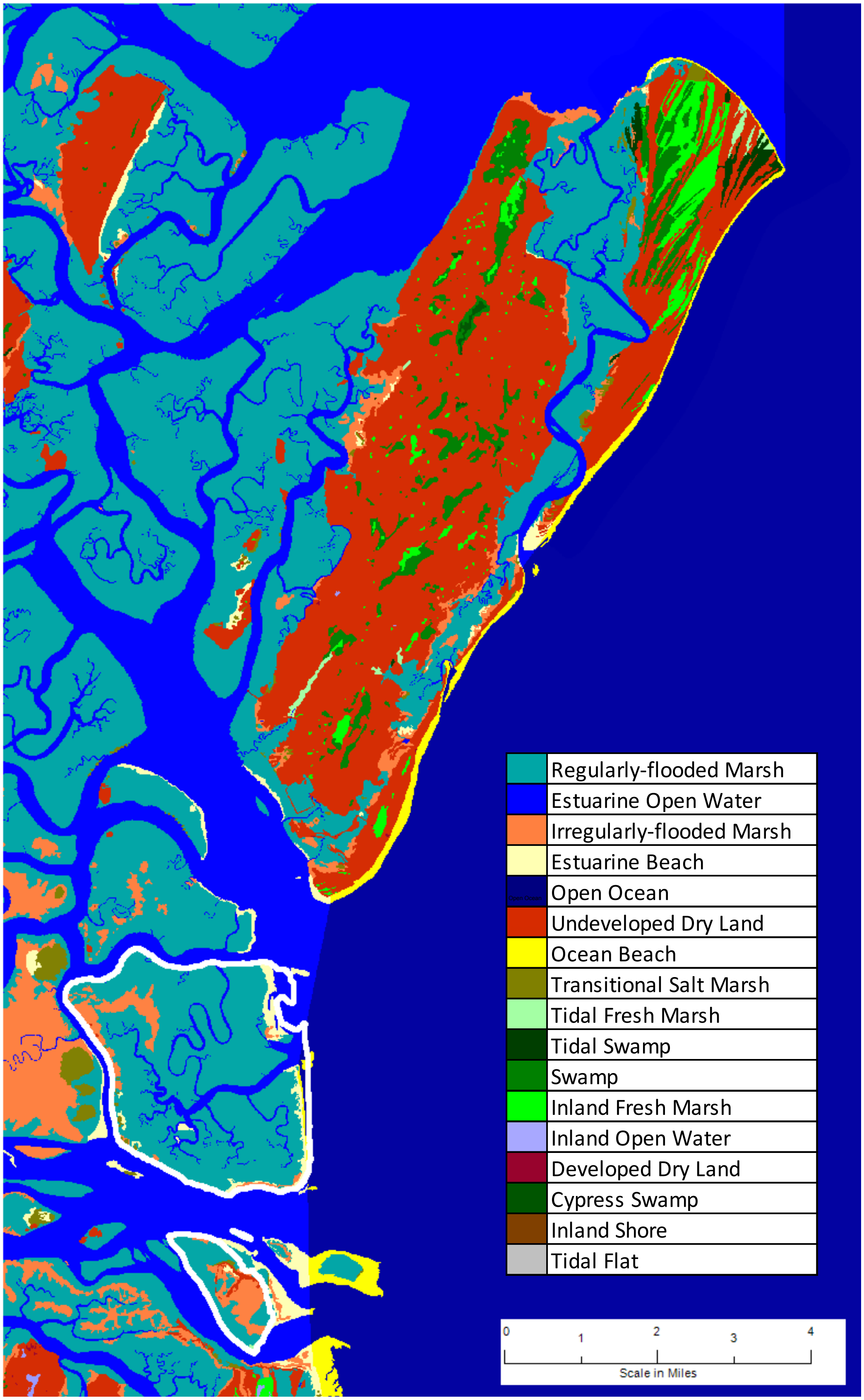


Figure 2. 2007 NWI coverage of the study area. Refuge boundaries are indicated in white.

Elevation Data. The layer covering the study area was based on 2010 bare-earth Georgia Coastal LiDAR data.

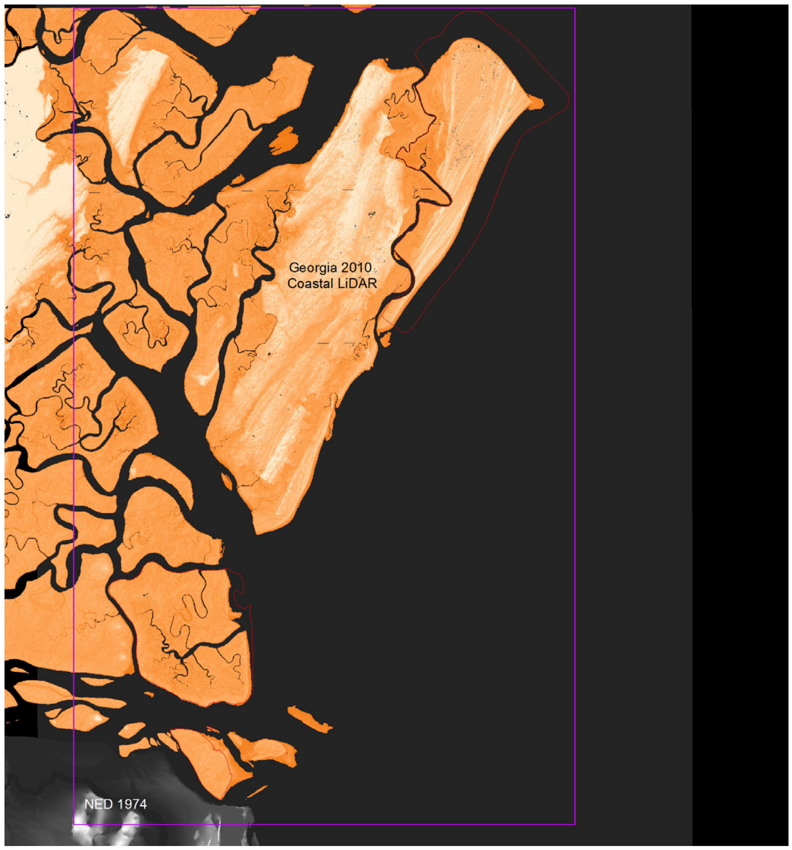


Figure 3. The coverage of the LiDAR data for the entire study area.

The southwest corner of the simulated rectangle, outside the refuge boundaries, was based on a 1974 NED contour map as shown in Figure 3. For this portion of the study area, the elevation pre-processor module of SLAMM was used to estimate elevations for wetlands as a function of the local tide range.

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

Model Timesteps. Model forecast data is output for years 2025, 2050, 2075 and 2100 with the initial condition date set to 2007, the most recent wetland data available.

Historic sea level rise rates. The historic trend for relative sea level rise rates recorded at the at NOAA gauge stations of the area, Fort Pulaski, Georgia (#8670870) and Fernandina Beach, Florida #8720030) vary between 2.98 mm/yr and 2.02 mm/yr. For this study, the average of 2.5 mm/yr has been used. 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 region.

Tide Ranges. The great diurnal range (GT) was estimated using the data from the NOAA gauge station #8675622 present in the area (shown in red in Figure 4) and several NOAA tide tables (shown in blue in Figure 4). Since the tide tables only provide data for the mean tidal range, the GT was derived by multiplying the mean range by a correction factor of 1.09 (obtained from observations at the NOAA gauge station #8675622). The GT spatial variability in the study area is shown in Figure 4. Different input subsites were defined reflecting these varying tidal ranges. For the refuge and coastal area the GT was set to average 2.24 m.

Figure 4. Spatial variability of the great diurnal range (GT) estimates.

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 1.2 Half Tide Units (HTU) for all input subsites, corresponding to 1.34 m above MTL in the area within the refuge.

Accretion rates. Accretion rates of regularly-flooded marsh was set to 1.9 mm/yr, irregularly-flooded marsh 4.3 mm/yr and tidal fresh marsh to 4.8 mm/yr based on data of 36 cores gathered in the surrounding area (Craft, personal communication). Lacking site specific information, accretion rates of other wetland types were set to SLAMM default value.

Erosion rates. Erosion rates for marshes, swamps, and tidal flats were set to the SLAMM defaults of 2 m/yr, 1 m/yr and 0.2 mm/yr, respectively. 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.

Elevation correction. MTL to NAVD88 corrections determined using NOAA's VDATUM software ranged from -0.053 to -0.097 m, as shown in Figure 5, and were applied on a subsite-by-subsite basis. A value of -0.087 m was applied to the subsite containing Wolf Island NWR.

Figure 5. Spatial variability of MTL to NAVD88 correction estimates.

Refuge boundaries. Modeled USFWS refuge boundaries for Georgia 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 10 m.

Input subsites and parameter summary. Based on spatial variability of the tide ranges, elevation corrections and different dates for the elevation and wetland grids, the study area was subdivided in the subsites illustrated in Figure 6.

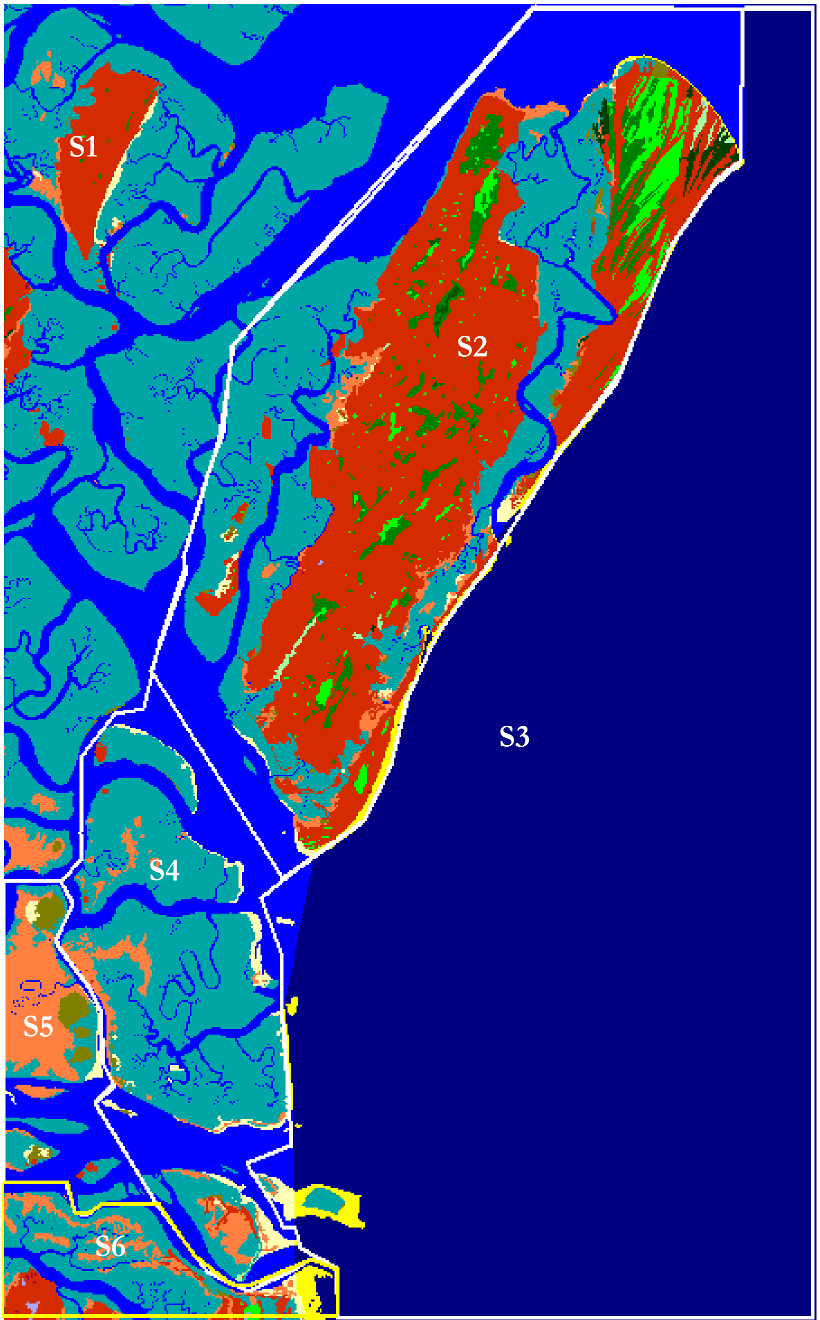


Figure 6. Input subsites for model application.

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. Input parameters for the area including the refuge (S4) are presented in boldface in the table.

Table 1. Summary of SLAMM input parameters for Wolf Island NWR.

Parameter	S1	S2	S3	S4	S5	S6
NWI Photo Date (YYYY)	2007	2007	2007	**2007**	2007	2007
DEM Date (YYYY)	2010	2010	2010	**2010**	2010	1974
Direction Offshore [n,s,e,w]	East	East	East	**East**	East	East
Historic Trend (mm/yr)	2.5	2.5	2.5	**2.5**	2.5	2.5
MTL-NAVD88 (m)	-0.057	-0.073	-0.089	**-0.087**	-0.0854	-0.0854
GT Great Diurnal Tide Range (m)	2.39	2.24	2.24	**2.24**	2.39	2.39
Salt Elev. (m above MTL)	1.43	1.34	1.34	**1.34**	1.43	1.43
Marsh Erosion (horz. m /yr)	2	2	2	**2**	2	2
Swamp Erosion (horz. m /yr)	1	1	1	**1**	1	1
T.Flat Erosion (horz. m /yr)	0.2	0.2	0.2	**0.2**	0.2	0.2
Reg.-Flood Marsh Accr (mm/yr)	1.9	1.9	1.9	**1.9**	1.9	1.9
Irreg.-Flood Marsh Accr (mm/yr)	4.3	4.3	4.3	**4.3**	4.3	4.3
Tidal-Fresh Marsh Accr (mm/yr)	4.8	4.8	4.8	**4.8**	4.8	4.8
Inland-Fresh Marsh Accr (mm/yr)	4	4	4	**4**	4	4
Tidal Swamp Accr (mm/yr)	1.1	1.1	1.1	**1.1**	1.1	1.1
Swamp Accretion (mm/yr)	0.3	0.3	0.3	**0.3**	0.3	0.3
Beach Sed. Rate (mm/yr)	0.5	0.5	0.5	**0.5**	0.5	0.5
Freq. Overwash (years)	25	25	25	**25**	25	25
Use Elev Pre-processor [True,False]	FALSE	FALSE	FALSE	**FALSE**	FALSE	TRUE

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 2007 NWI wetland coverage and wetland categories are sorted by decreasing initial land cover excluding open water.

Table 2. Predicted loss rates of land categories by 2100 given simulated scenarios of eustatic SLR at Wolf Island NWR.

Land cover category	Initial coverage (acres)	Land cover loss by 2100 for different SLR scenarios				
		0.39 m	0.69 m	1 m	1.5 m	2 m
Regularly-flooded Marsh	3899	11%	13%	21%	83%	99%
Irregularly-flooded Marsh	522	4%	4%	36%	97%	100%
Estuarine Beach	205	-48%([1])	-45%	-40%	-8%	12%
Undeveloped Dry Land	48	67%	88%	97%	100%	100%
Ocean Beach	31	97%	97%	97%	98%	99%
Transitional Salt Marsh	21	-131%	-12%	56%	93%	99%
Tidal Fresh Marsh	11	17%	91%	98%	100%	100%

([1]) A negative value indicates a gain with respect to initial coverage

Wetland coverage of the Wolf Island National Wildlife Refuge is predicted to be seriously altered by SLR. For the A1B scenarios (0.39 and 0.69 m SLR by 2100), effects on regularly and irregularly-flooded marshes (which combined currently cover 83% of the refuge) are generally limited. However, habitat loss is predicted to gradually increase as the rate of sea level increases, with an almost total loss of these marsh habitats under the 2 m SLR by 2100 scenario.

Estuarine beach appears to be more resilient to SLR, with observed gains by 2100 with SLR scenarios of 1.5 m or less. However, under the 2 m SLR this wetland category is also lost.
A similar trend is predicted for transitional salt marsh although losses start at 1 m SLR by 2100.

Undeveloped-dry land, ocean beach, and tidal fresh marsh are projected to be nearly completely lost at the 0.69 m SLR by 2100 scenario. Although these wetland categories cover a small area of the refuge, their loss implies a reduction in habitat richness.

Major land cover gains are summarized in Table 3. Open water, which initially covers just more than 12% of the refuge, is predicted to increase coverage as sea level rises, more than doubling coverage under the 2 m SLR by 2100 scenario. In addition, tidal flat is predicted to gradually occupy areas that were previously covered by salt marshes, comprising almost 70% of the total refuge area under the highest SLR scenario.

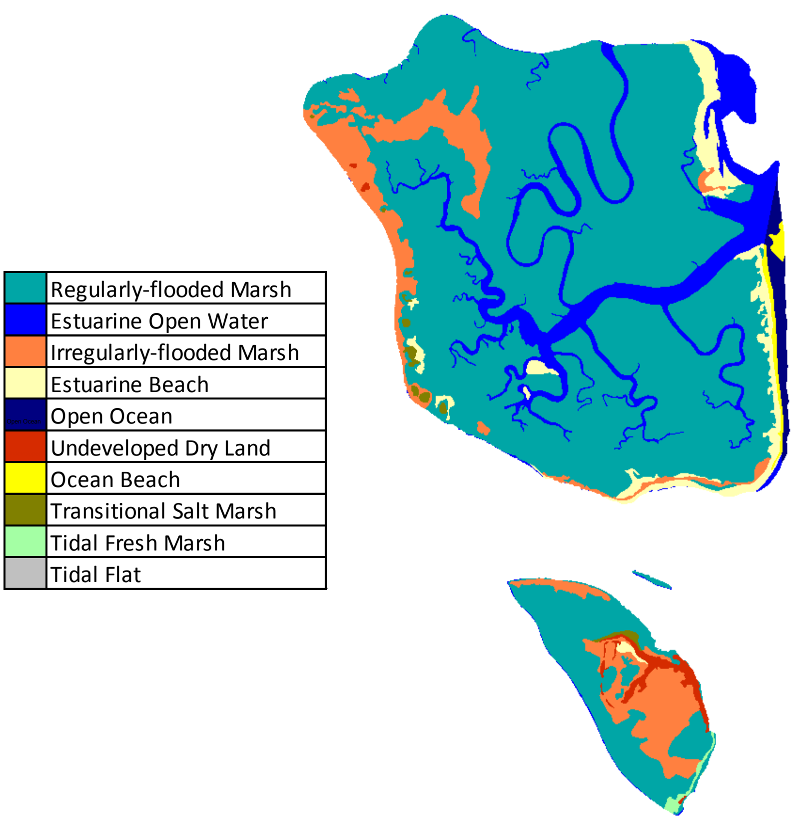
Table 3. Predicted land cover gains by 2100 given simulated scenarios of eustatic SLR at Wolf Island NWR.

Land cover category	Initial coverage (acres)	Land cover by 2100 for different SLR scenarios (acres)				
		0.39 m	0.69 m	1 m	1.5 m	2 m
Open water	666	740	811	893	1160	1455
Tidal Flat	0	319	376	798	3348	3717

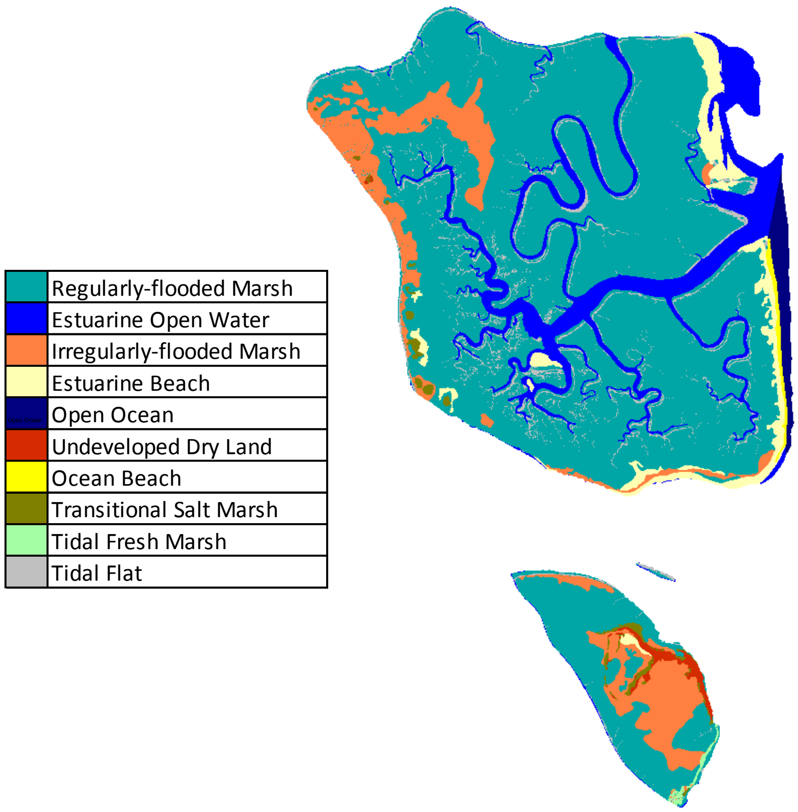
Wolf Island NWR
IPCC Scenario A1B-Mean, 0.39 m SLR eustatic by 2100

Results in Acres

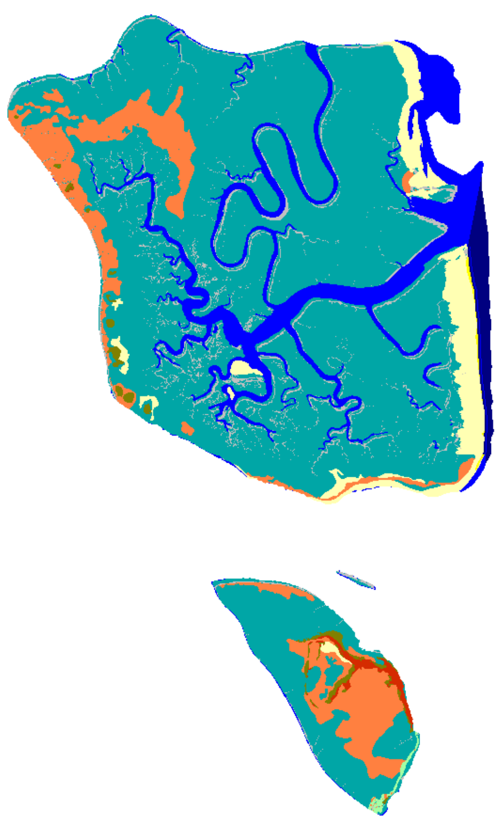
		Initial	2025	2050	2075	2100
	Regularly-flooded Marsh	3899	3708	3675	3521	3466
	Estuarine Open Water	596	605	618	620	646
	Irregularly-flooded Marsh	522	501	501	501	501
	Estuarine Beach	205	203	201	283	304
	Open Ocean	70	80	80	91	93
	Undeveloped Dry Land	48	31	26	21	16
	Ocean Beach	31	20	17	4	1
	Transitional Salt Marsh	21	36	40	46	49
	Tidal Fresh Marsh	11	9	9	9	9
	Tidal Flat	0	212	237	308	319
	Total (incl. water)	**5404**	**5404**	**5404**	**5404**	**5404**



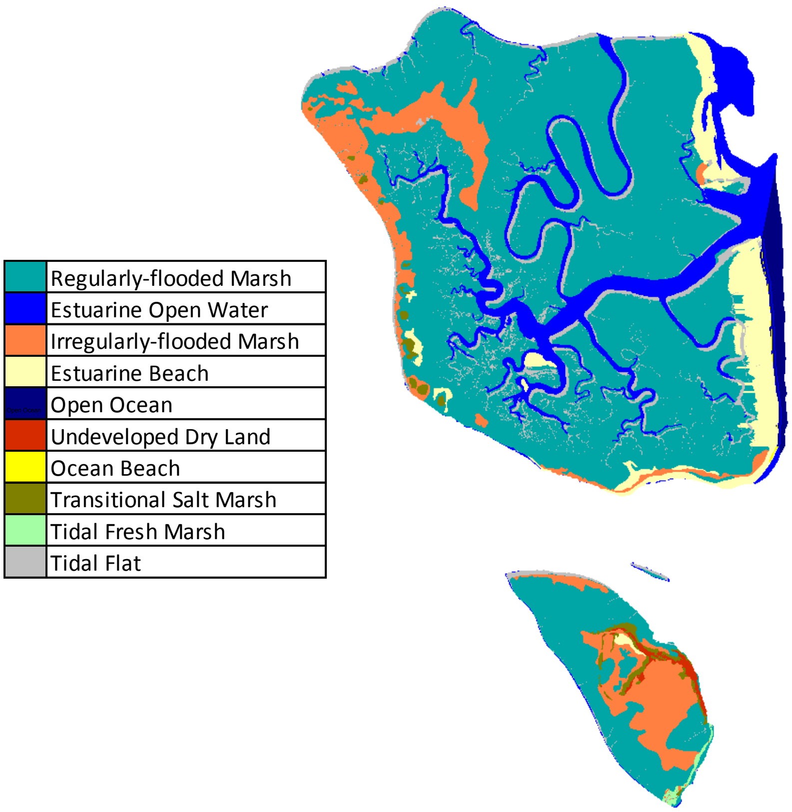
Wolf Island NWR, Initial Condition.



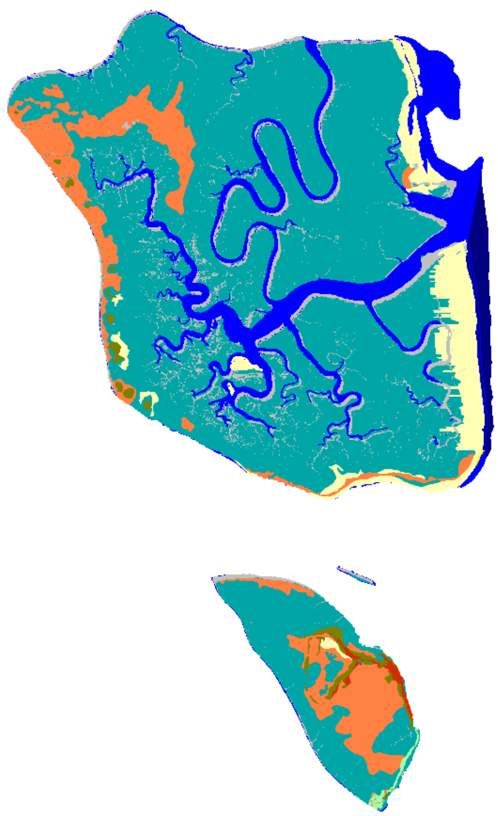
Wolf Island NWR, 2025, Scenario A1B Mean, 0.39 m SLR



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



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

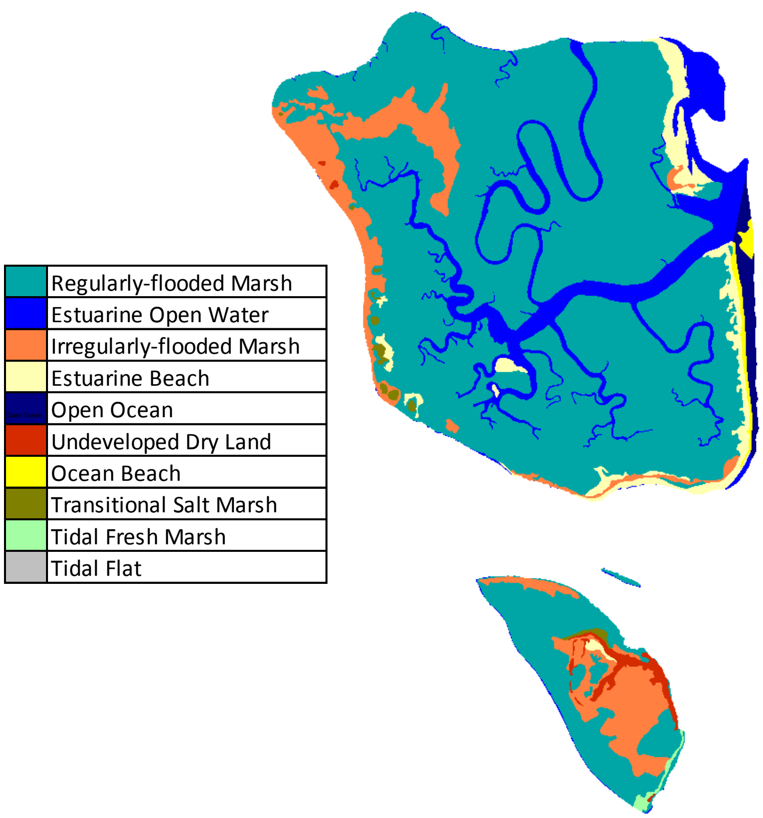


Wolf Island NWR, 2100, Scenario A1B Mean, 0.39 m SLR by 2100.

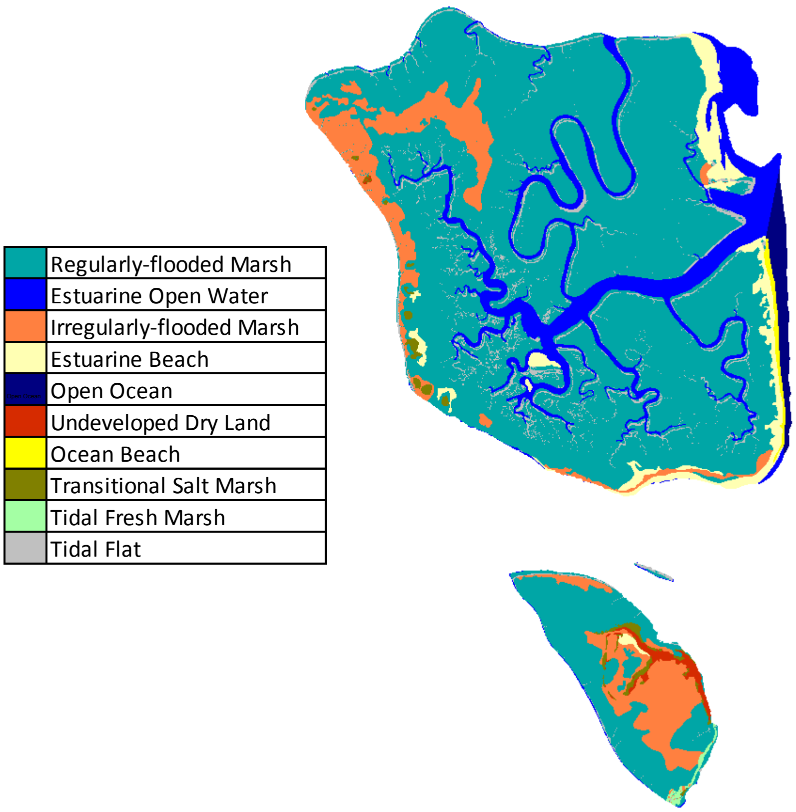
Wolf Island NWR
IPCC Scenario A1B-Max, 0.69 m SLR eustatic by 2100

Results in Acres

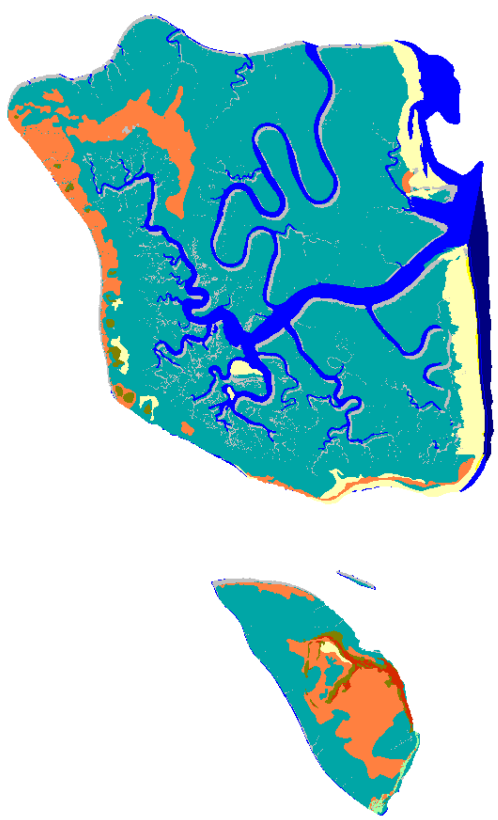
		Initial	2025	2050	2075	2100
	Regularly-flooded Marsh	3899	3696	3599	3481	3388
	Estuarine Open Water	596	605	624	652	717
	Irregularly-flooded Marsh	522	501	502	505	501
	Estuarine Beach	205	203	200	279	297
	Open Ocean	70	80	80	92	93
	Undeveloped Dry Land	48	30	22	14	6
	Ocean Beach	31	20	17	4	1
	Transitional Salt Marsh	21	37	41	33	24
	Tidal Fresh Marsh	11	9	7	2	1
	Tidal Flat	0	224	311	343	376
	Total (incl. water)	**5404**	**5404**	**5404**	**5404**	**5404**



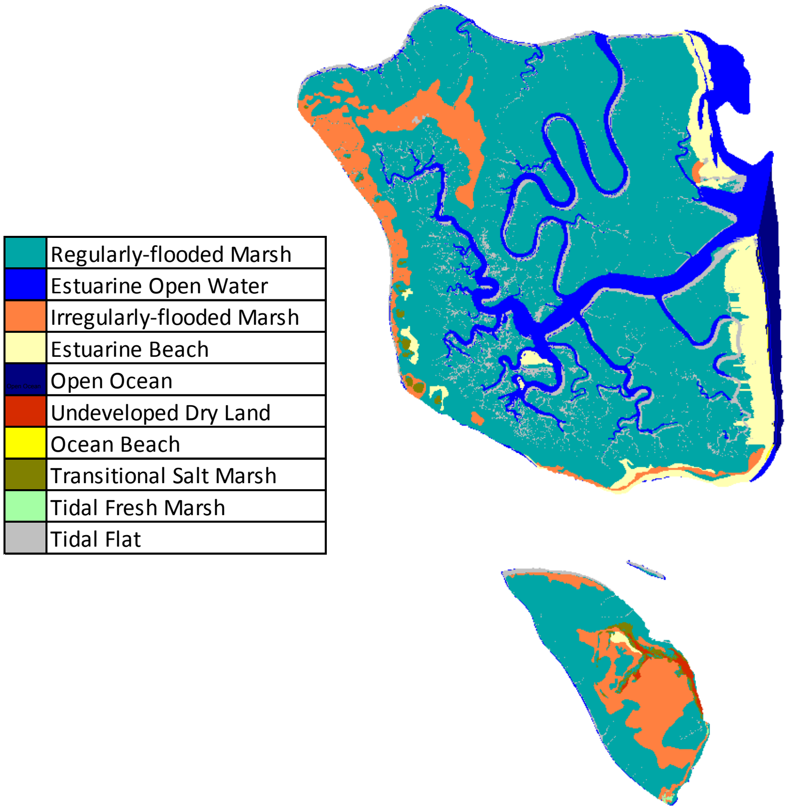
Wolf Island NWR, Initial Condition.



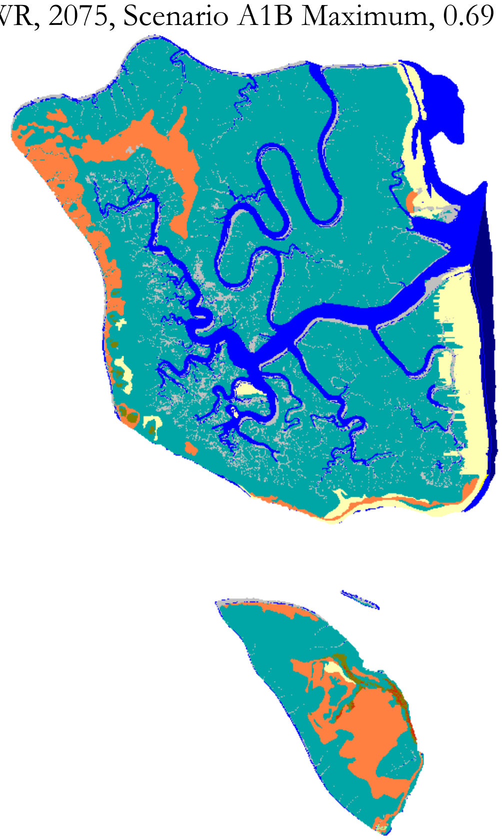
Wolf Island NWR, 2025, Scenario A1B Maximum, 0.69 m SLR by 2100.



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



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

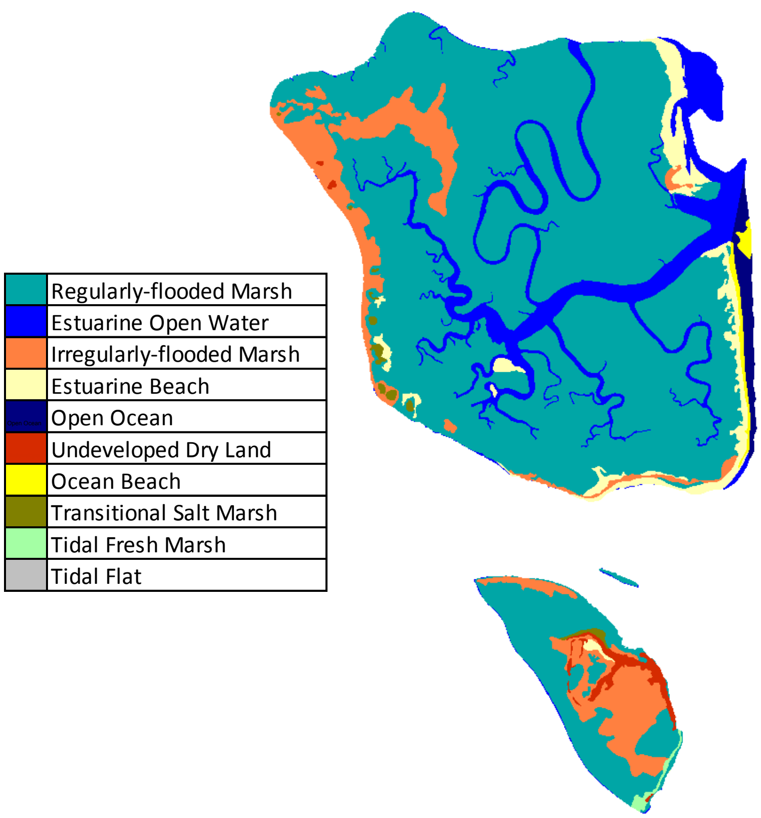


Wolf Island NWR, 2100, Scenario A1B Maximum, 0.69 m SLR by 2100.

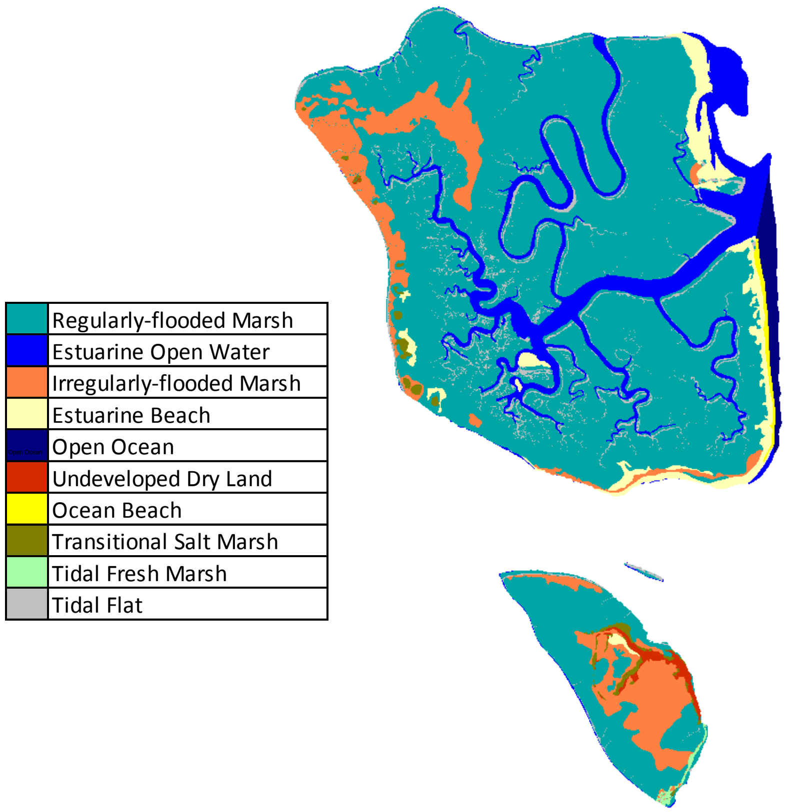
Wolf Island NWR
1 m eustatic SLR by 2100

Results in Acres

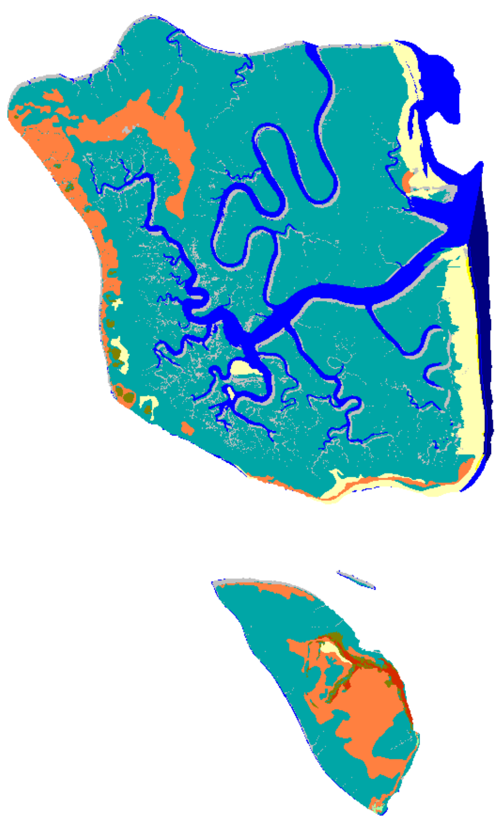
		Initial	2025	2050	2075	2100
	Regularly-flooded Marsh	3899	3681	3576	3424	3078
	Estuarine Open Water	596	606	635	698	799
	Irregularly-flooded Marsh	522	502	505	490	336
	Estuarine Beach	205	203	199	275	288
	Open Ocean	70	80	80	92	94
	Undeveloped Dry Land	48	29	18	7	1
	Ocean Beach	31	20	17	4	1
	Transitional Salt Marsh	21	37	35	21	9
	Tidal Fresh Marsh	11	9	2	1	0
	Tidal Flat	0	239	337	393	798
	Total (incl. water)	**5404**	**5404**	**5404**	**5404**	**5404**



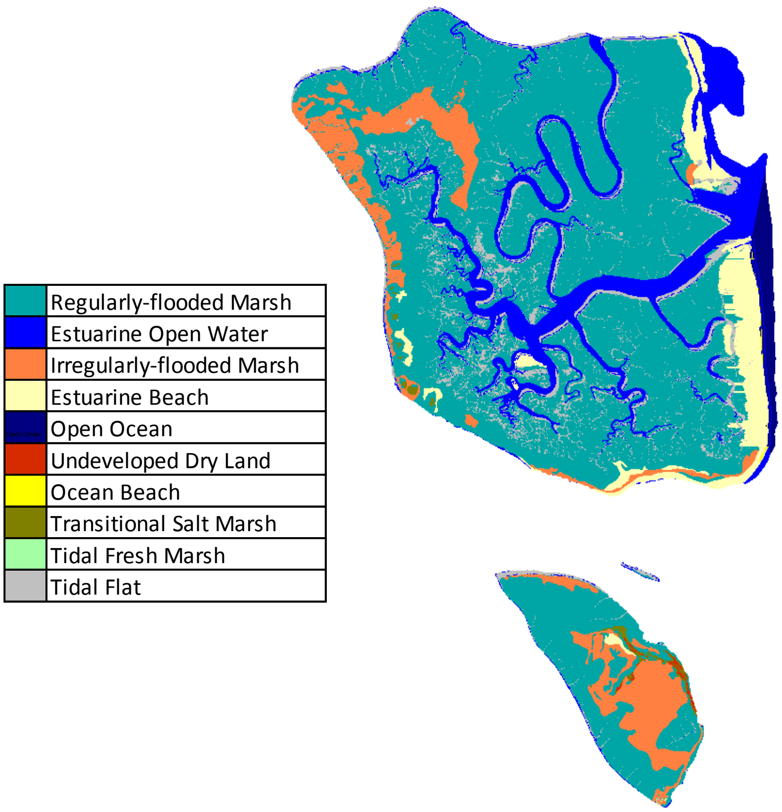
Wolf Island NWR, Initial Condition.



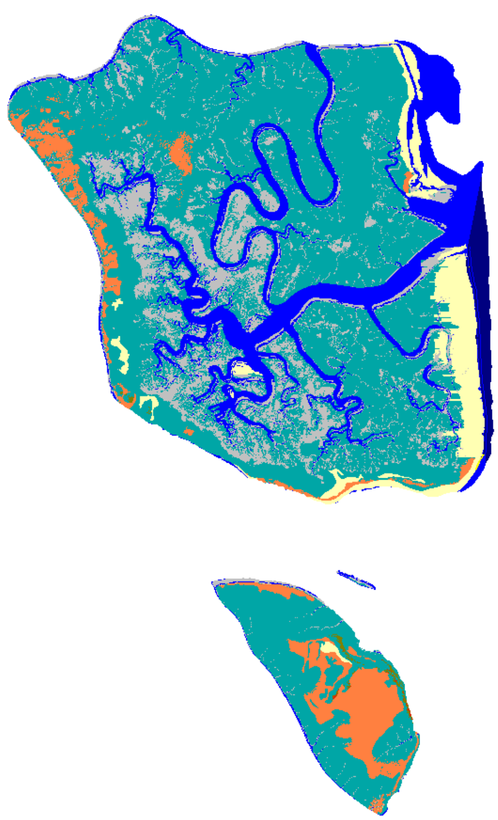
Wolf Island NWR, 2025, 1 m SLR by 2100.



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



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

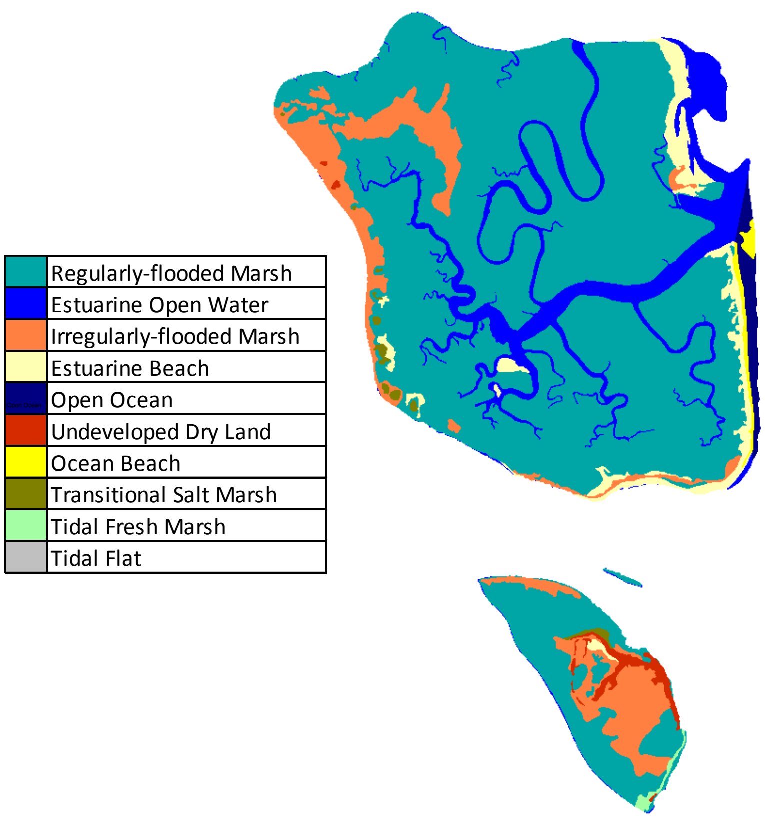


Wolf Island NWR, 2100, 1 m SLR by 2100.

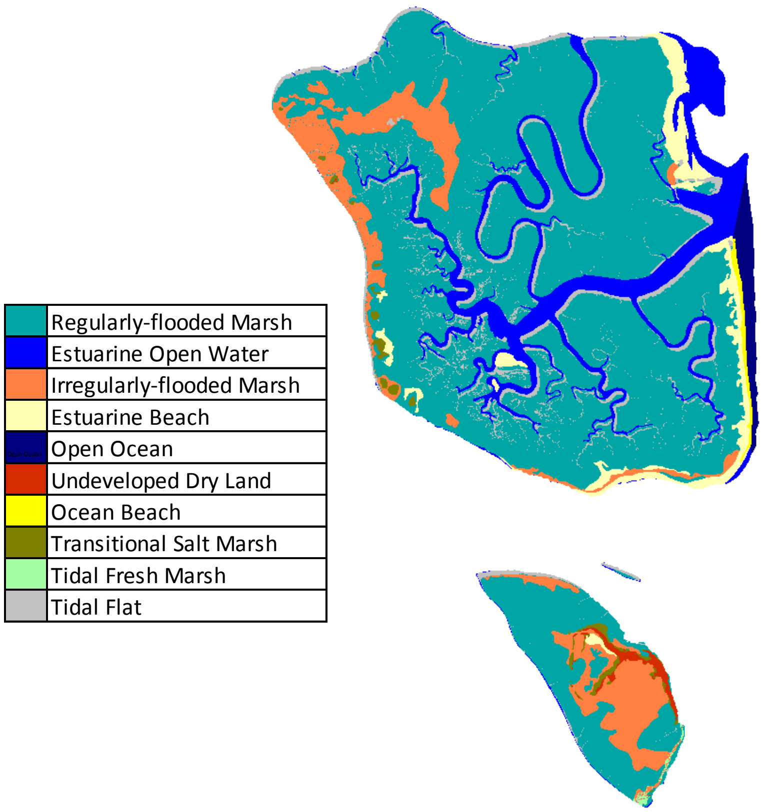
Wolf Island NWR
1.5 m eustatic SLR by 2100

Results in Acres

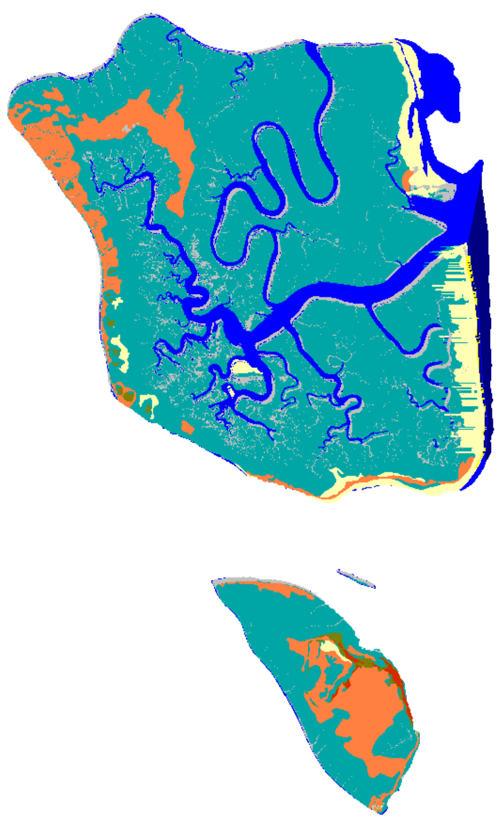
	Initial	2025	2050	2075	2100
Regularly-flooded Marsh	3899	3625	3541	3070	659
Estuarine Open Water	596	607	671	787	1065
Irregularly-flooded Marsh	522	504	498	241	15
Estuarine Beach	205	203	197	249	221
Open Ocean	70	80	81	92	95
Undeveloped Dry Land	48	27	13	1	0
Ocean Beach	31	20	16	4	1
Transitional Salt Marsh	21	36	24	14	1
Tidal Fresh Marsh	11	5	1	0	0
Tidal Flat	0	297	363	945	3348
Total (incl. water)	**5404**	**5404**	**5404**	**5404**	**5404**



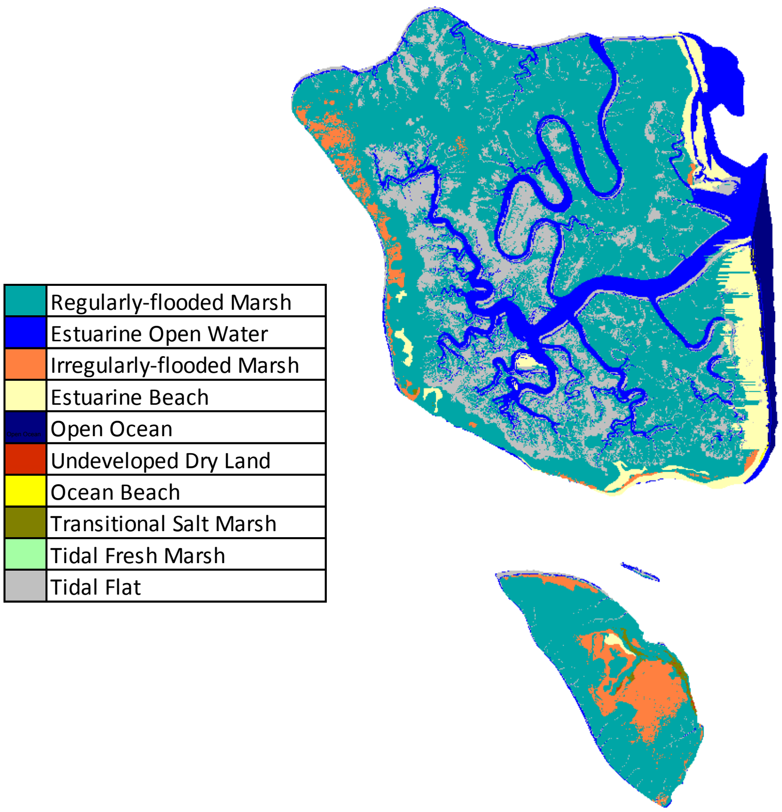
Wolf Island NWR, Initial Condition.



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



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



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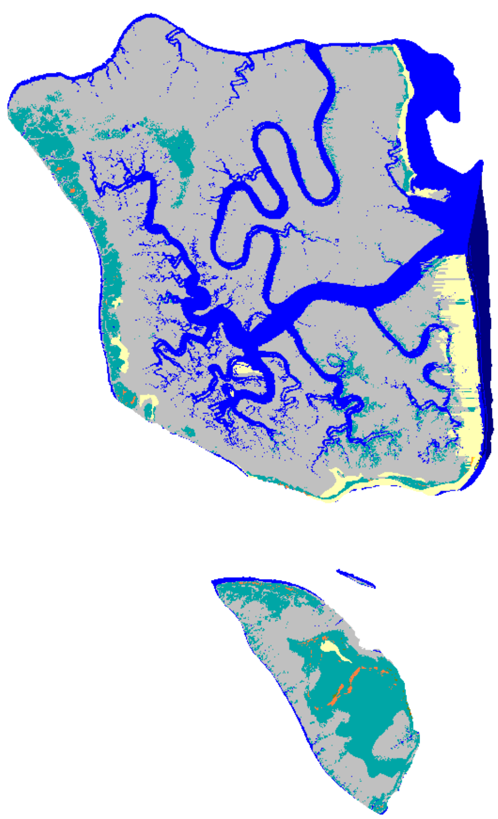
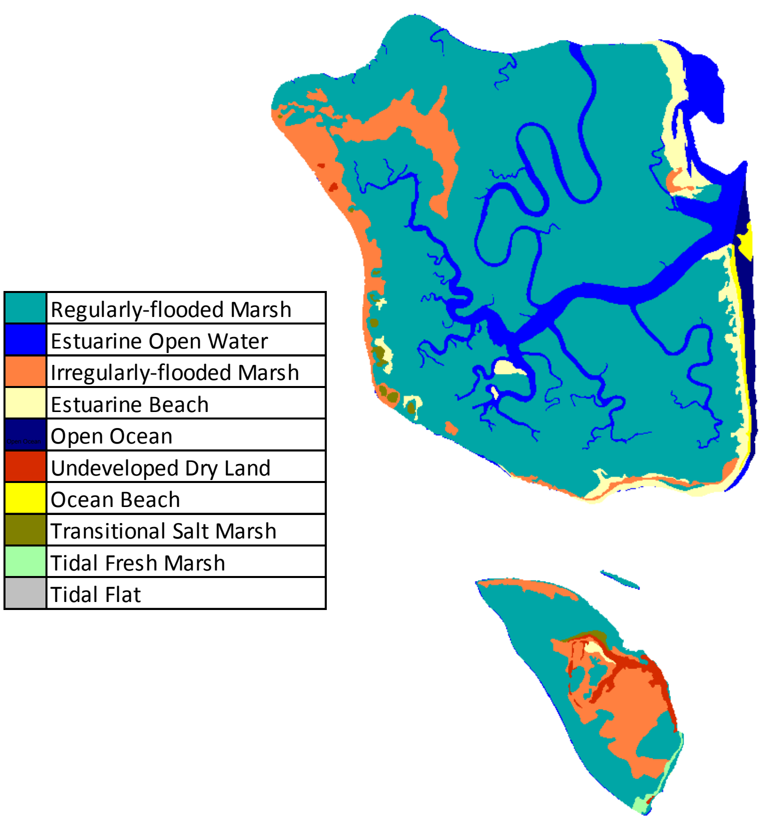


Wolf Island NWR, 2100, 1.5 m SLR by 2100.

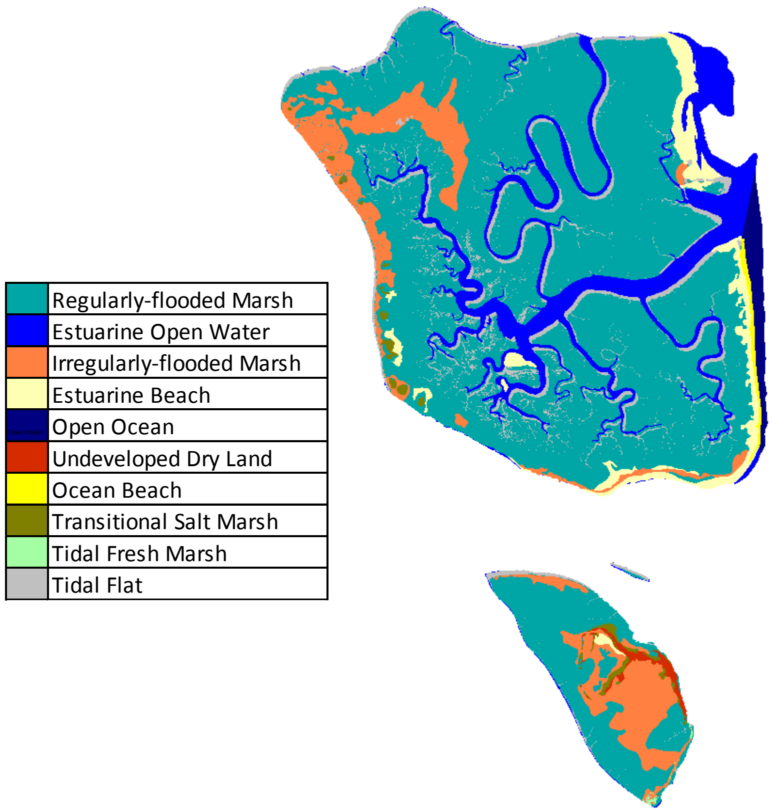
Wolf Island NWR
2 m eustatic SLR by 2100

Results in Acres

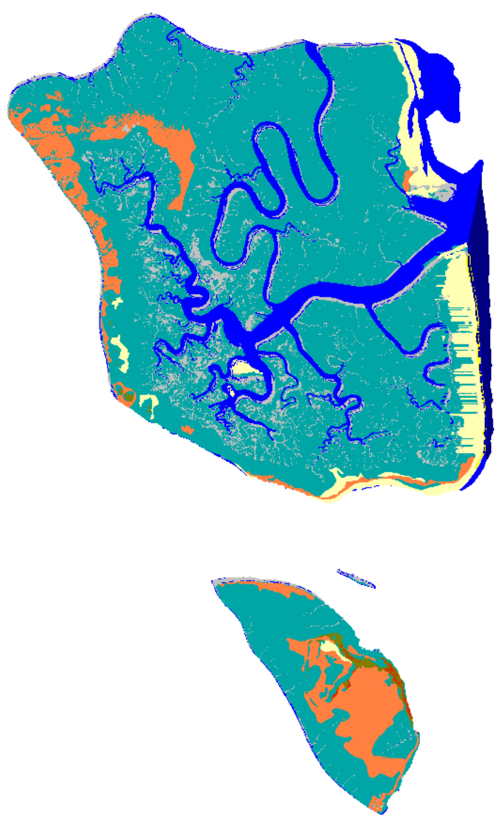
		Initial	2025	2050	2075	2100
	Regularly-flooded Marsh	3899	3606	3506	1208	49
	Estuarine Open Water	596	609	711	979	1358
	Irregularly-flooded Marsh	522	506	429	22	2
	Estuarine Beach	205	203	194	205	181
	Open Ocean	70	80	83	95	97
	Undeveloped Dry Land	48	25	7	0	0
	Ocean Beach	31	20	15	3	0
	Transitional Salt Marsh	21	35	23	7	0
	Tidal Fresh Marsh	11	3	0	0	0
	Tidal Flat	0	319	436	2886	3717
	Total (incl. water)	**5404**	**5404**	**5404**	**5404**	**5404**



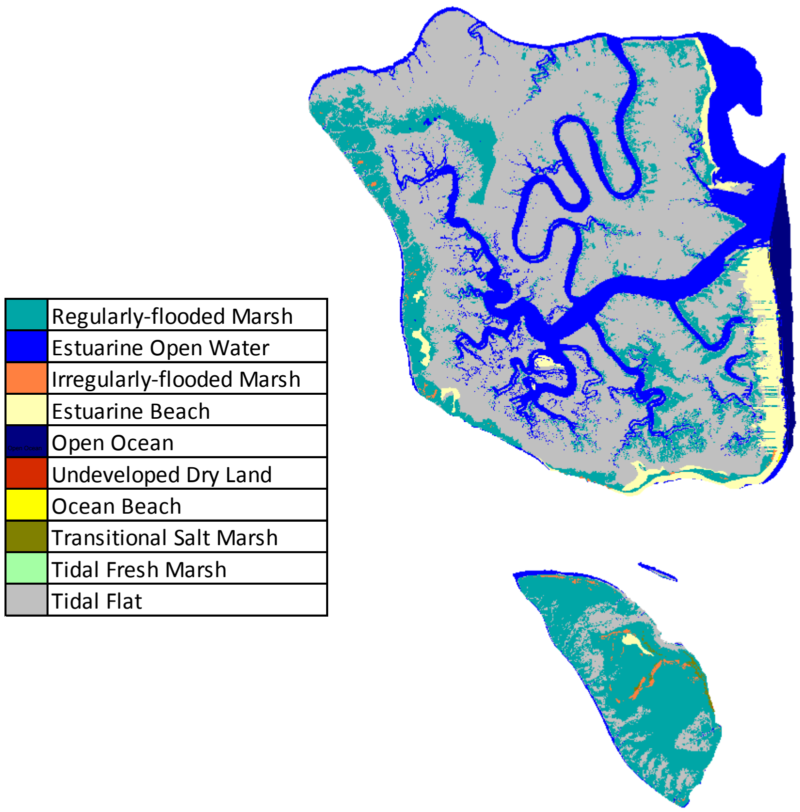
Wolf Island NWR, Initial Condition.



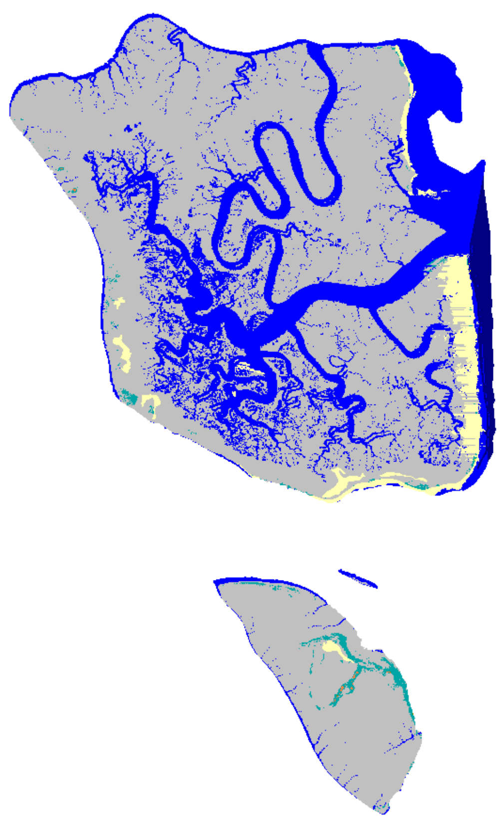
Wolf Island NWR, 2025, 2 m SLR by 2100.



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



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



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

Discussion

SLAMM predictions for Wolf Island NWR suggest the refuge wetland coverage will be substantially altered as a result of sea-level rise. Regularly- and irregularly-flooded marshes that currently cover approximately 83% of the refuge are predicted to be increasingly converted to open water or tidal flat as sea level continues to rise with a total loss predicted for the 2 m SLR by 2100.

Compared to a previous SLAMM analysis of the refuge conducted in 2008, the current predictions confirm the sensitivity of the wetlands of Wolf Island NWR to SLR. However, salt marshes appear to be slightly more resilient with respect to the previous analysis. The wetland maps used for both studies are similar with the exception that some irregularly-flooded marshes were previously classified as regularly-flooded. Therefore, the likely explanation for this result is that the high-resolution LiDAR place marshes higher in the tidal frame than was predicted by the SLAMM elevation pre-processor. This is partially confirmed by the recent wetland map that identifies more refuge areas as irregularly-flooded.

Another difference between studies is that marsh conversion is now predicted to result in considerable tidal flats, while in the 2008 study wetlands converted mostly to open water. However, as it is difficult to parameterize tidal flat characteristics (erosion rates, for example) and to identify the precise lower-elevation boundary for tidal-flats, there is considerable uncertainty in predicting if an area will be covered by tidal flat or open water. In addition, depending on their substrate, some marsh lands may convert directly to open water rather than tidal flats. Given these caveats, results are reasonably consistent between the two studies.

While data-layer updates have considerably improved the SLAMM projections reported here, input layers, parameter inputs, and the conceptual model continue to have uncertainties that should be kept in mind when interpreting these 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). 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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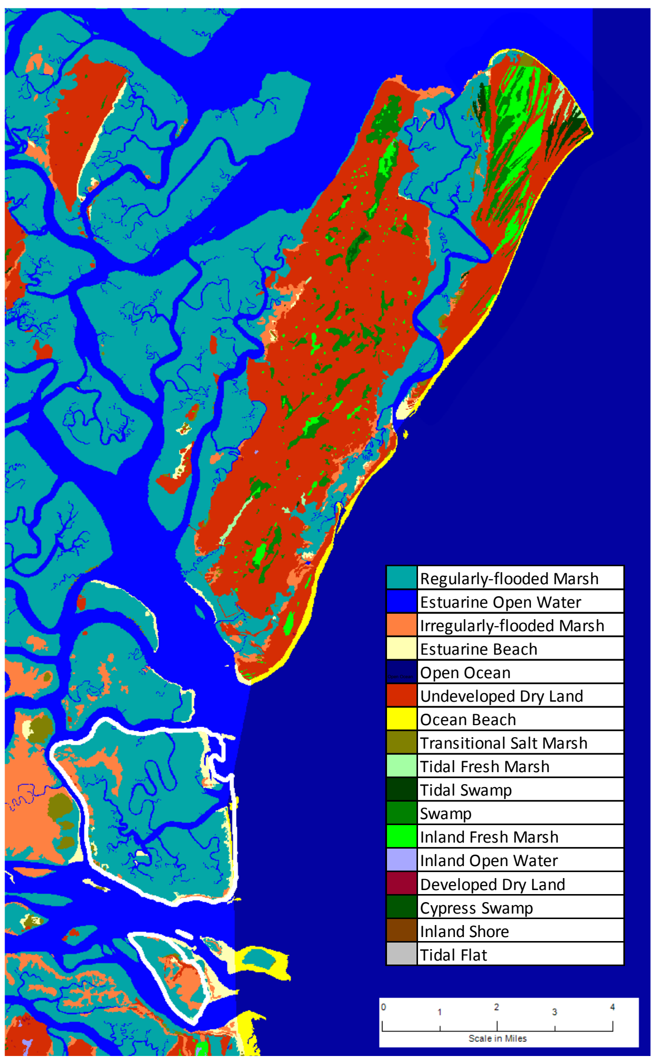
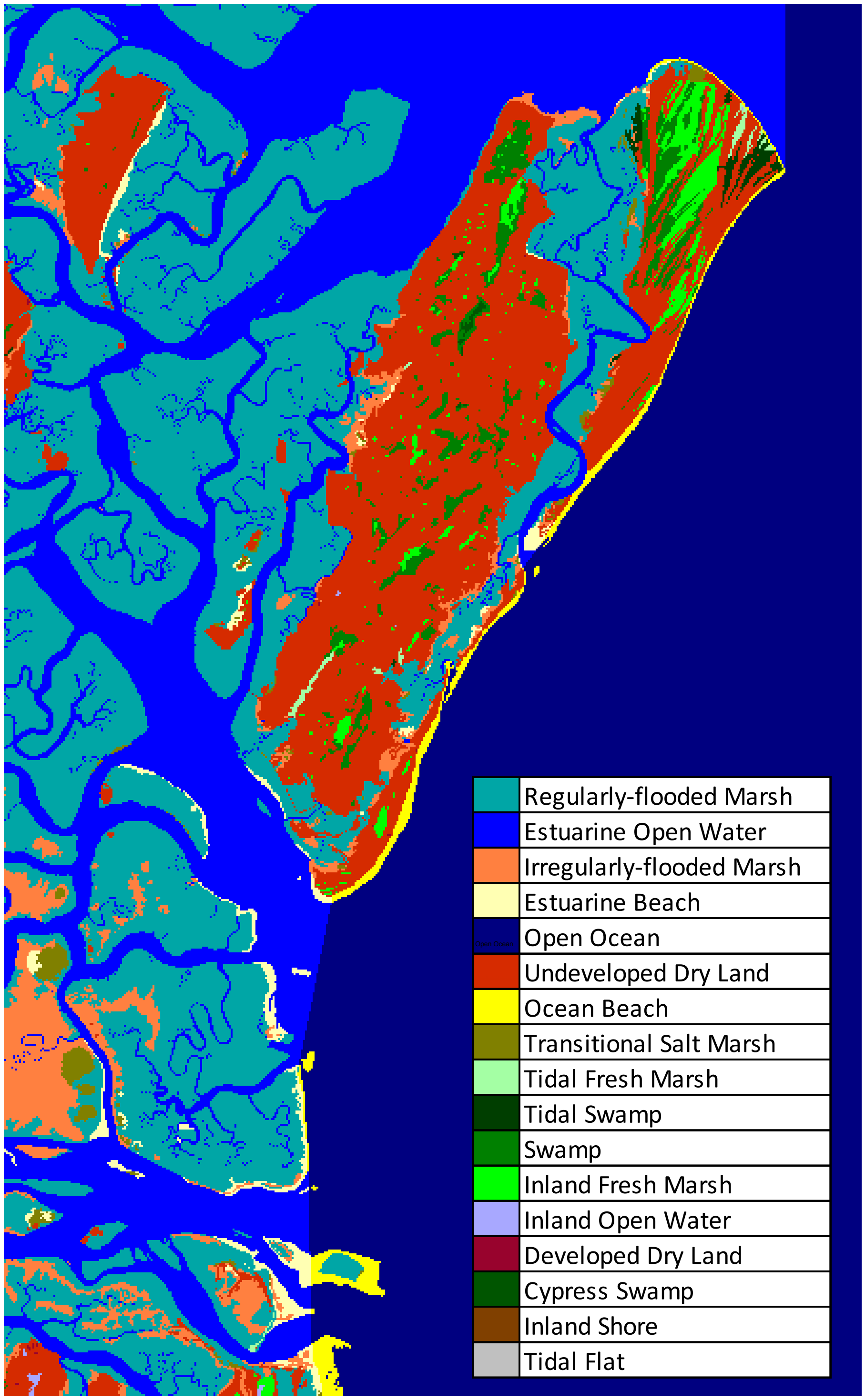
Appendix A: Contextual Results

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:

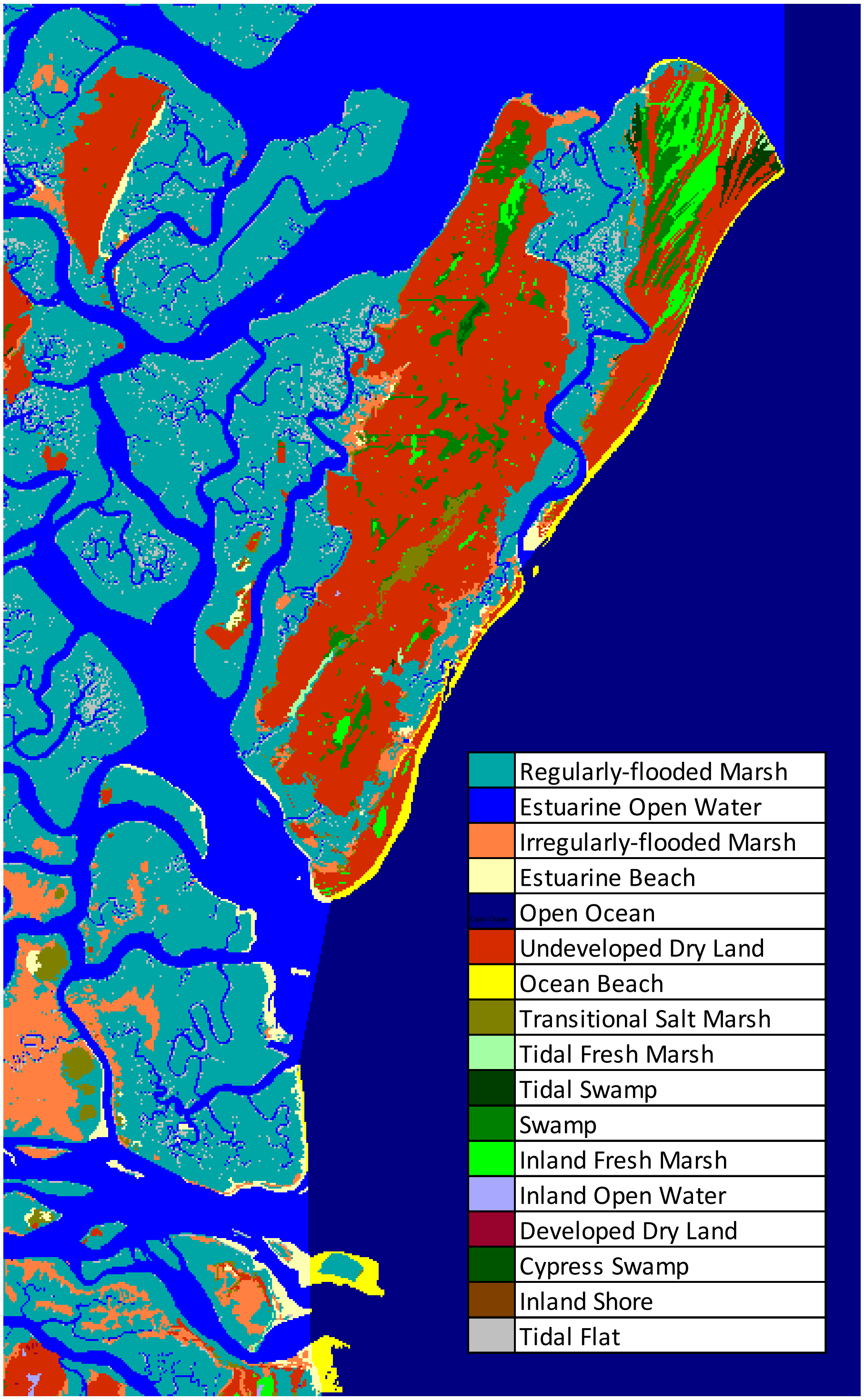
- Results were critically examined within USFWS refuges but not closely examined for the larger region.
- Site-specific parameters for the model were derived for USFWS refuges whenever possible and may not be regionally applicable.
- Especially in areas where dikes are present, an effort was made to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



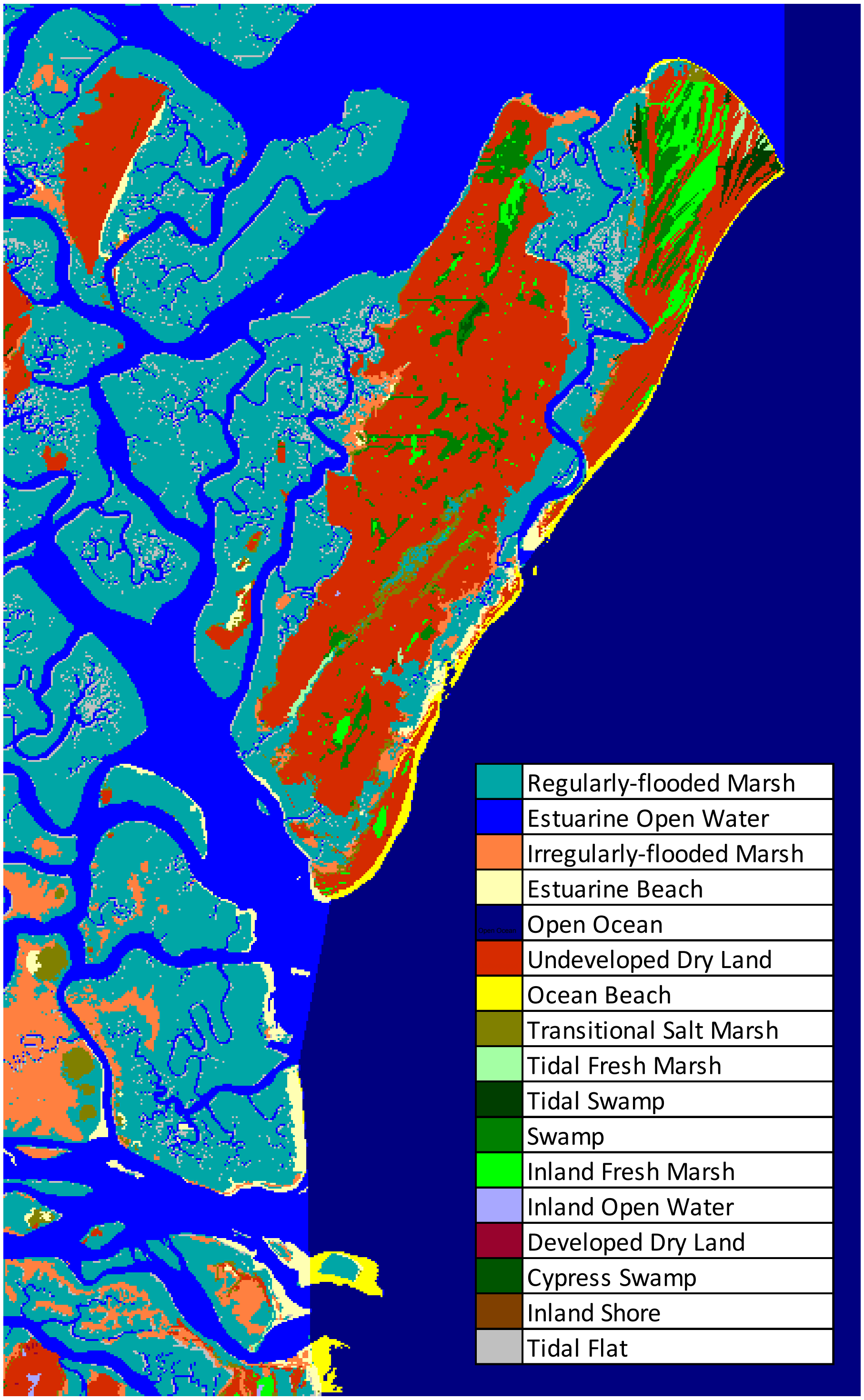
Wolf Island National Wildlife Refuge within simulation context (white).



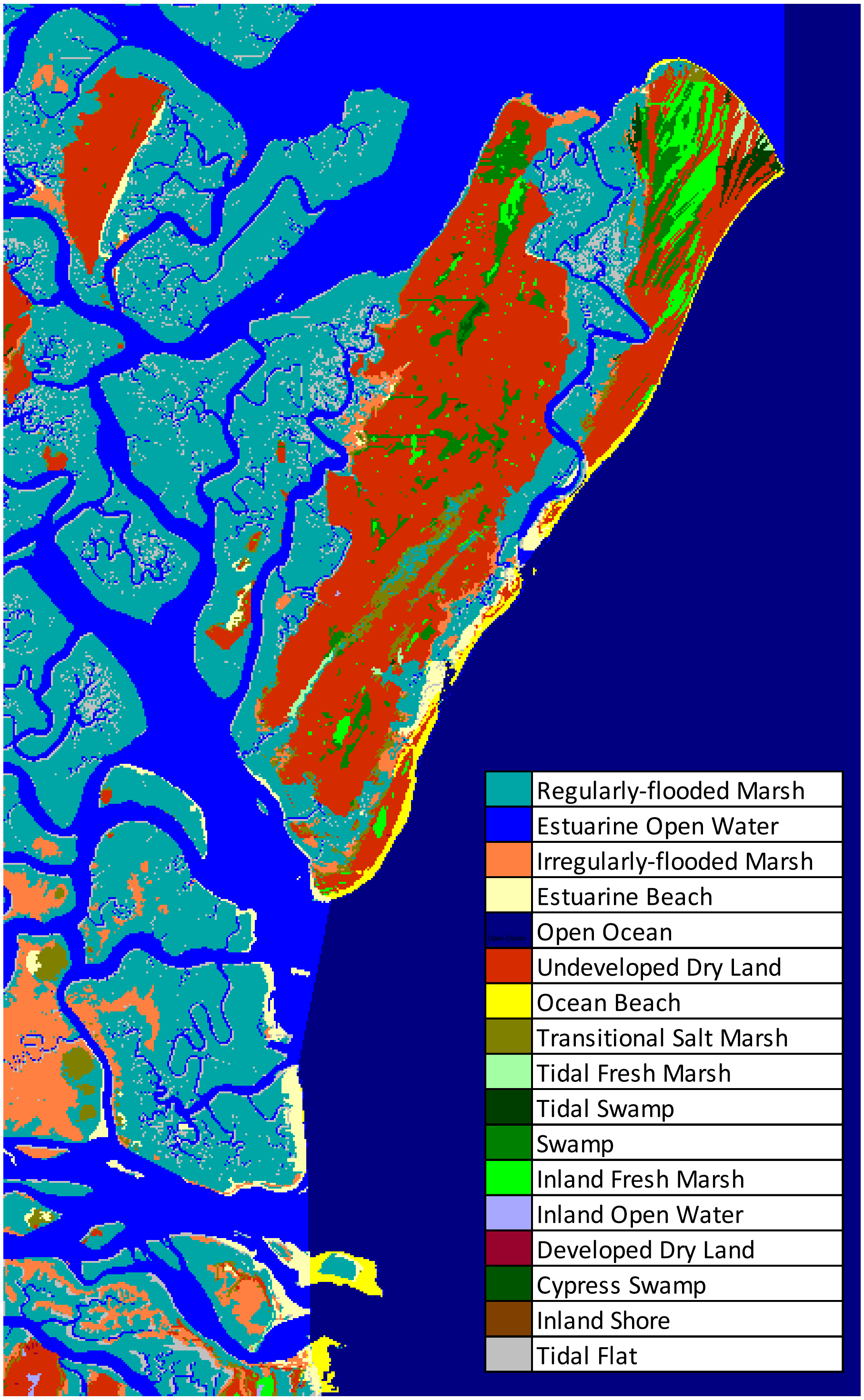
Wolf Island NWR, Initial Condition.



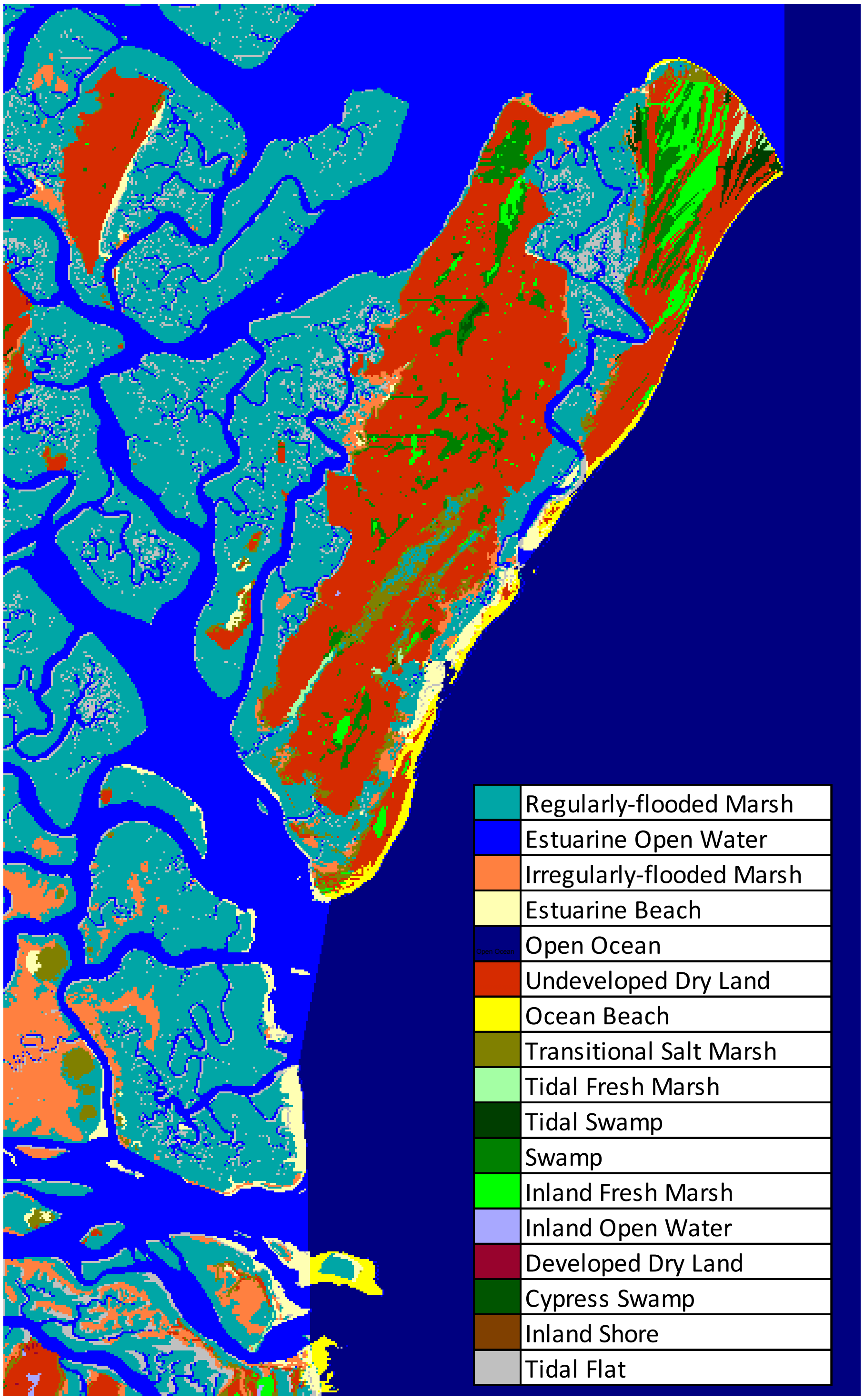
Wolf Island NWR, 2025, Scenario A1B Mean, 0.39 m SLR by 2100.



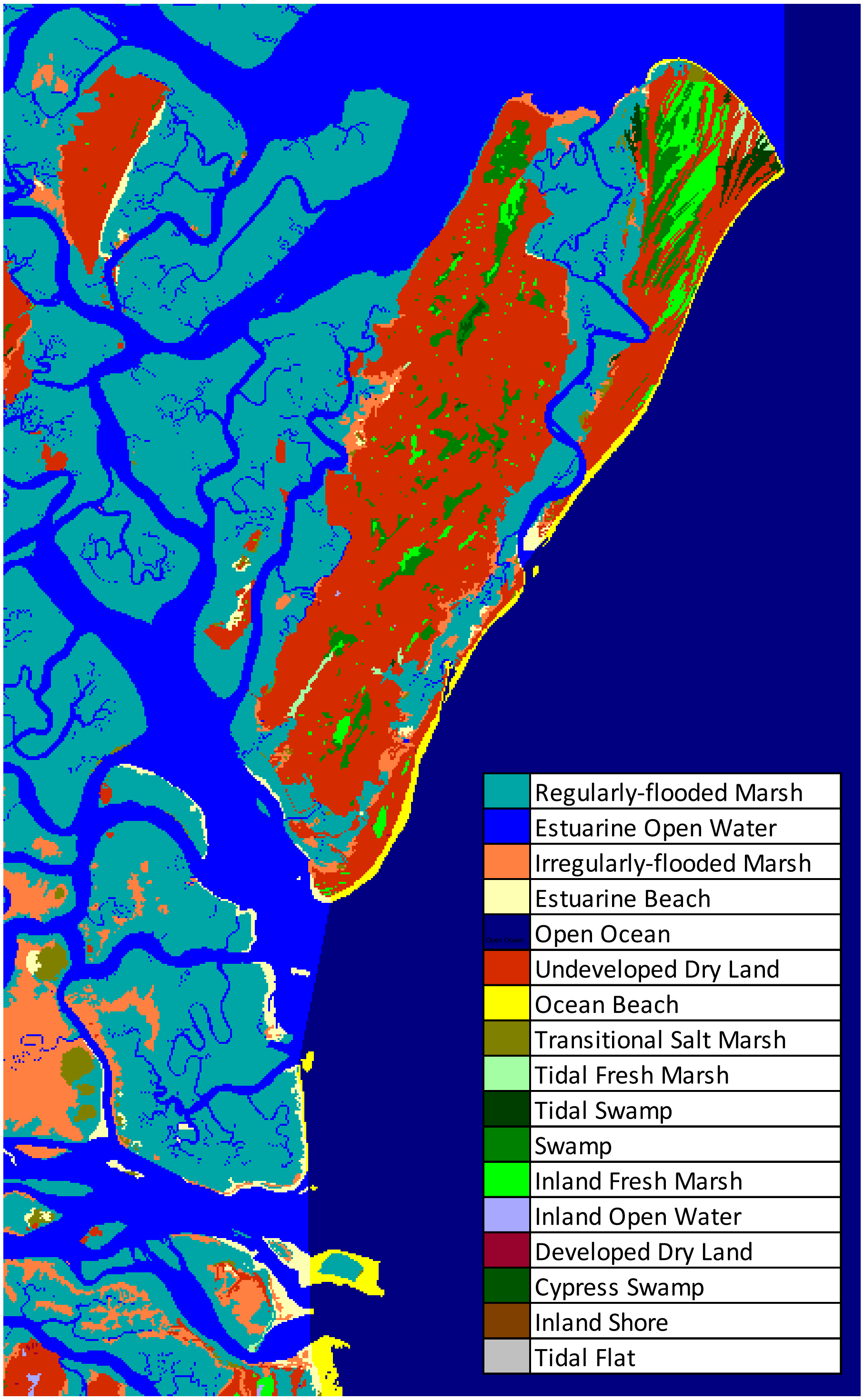
Wolf Island NWR, 2050, Scenario A1B Mean, 0.39 m SLR by 2100.



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



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



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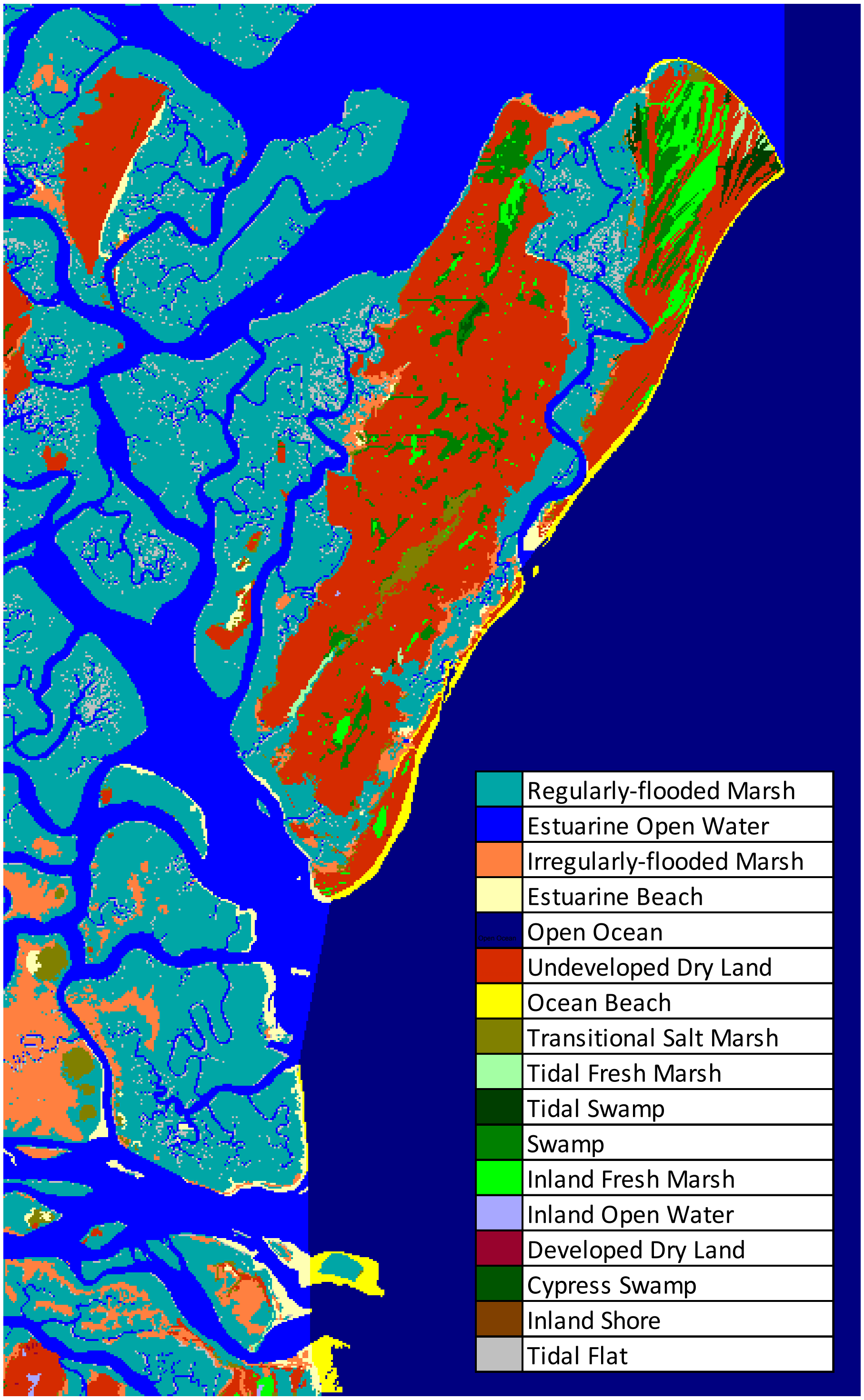
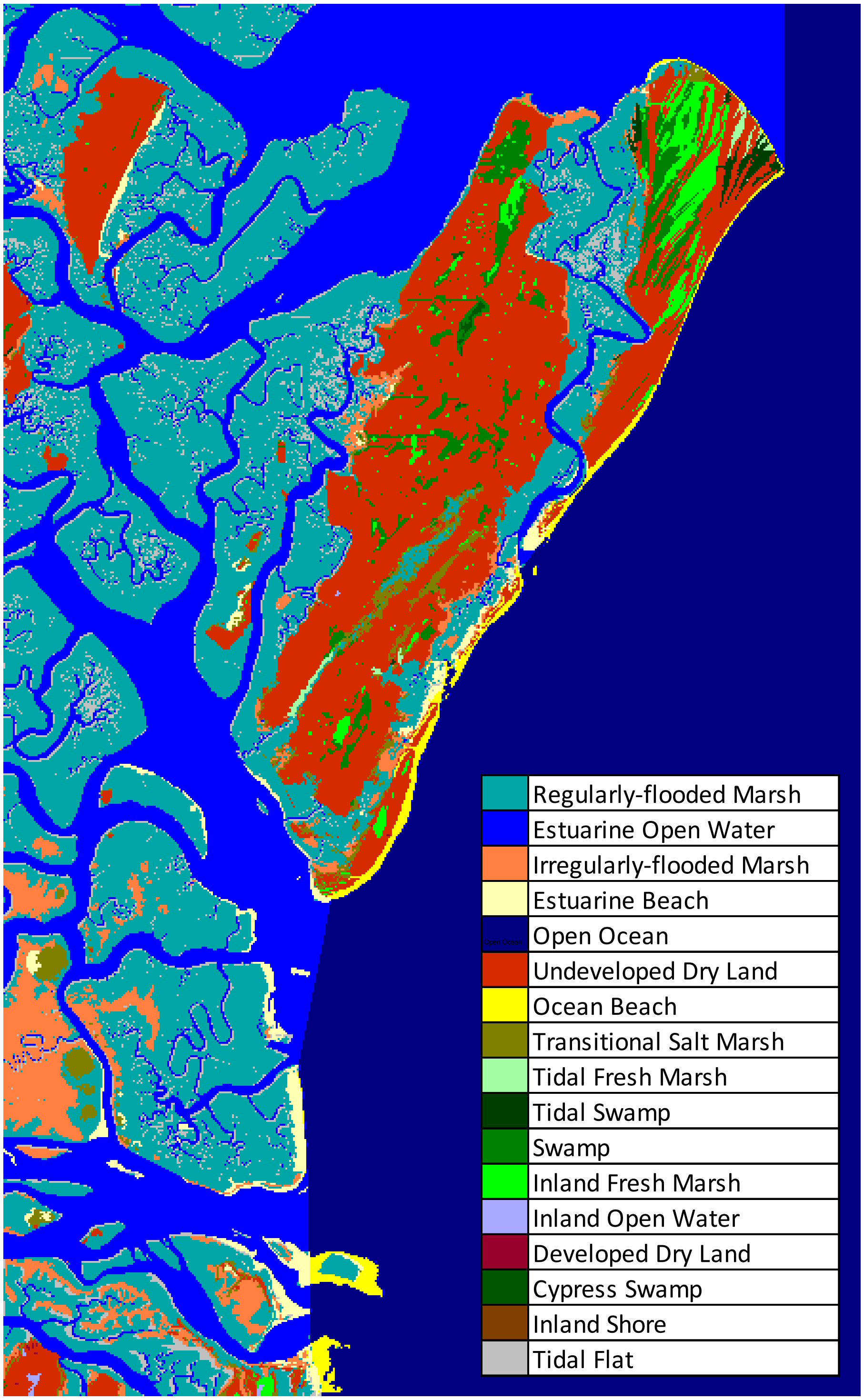


Wolf Island NWR, 2025, Scenario A1B Maximum, 0.69 m SLR by 2100.



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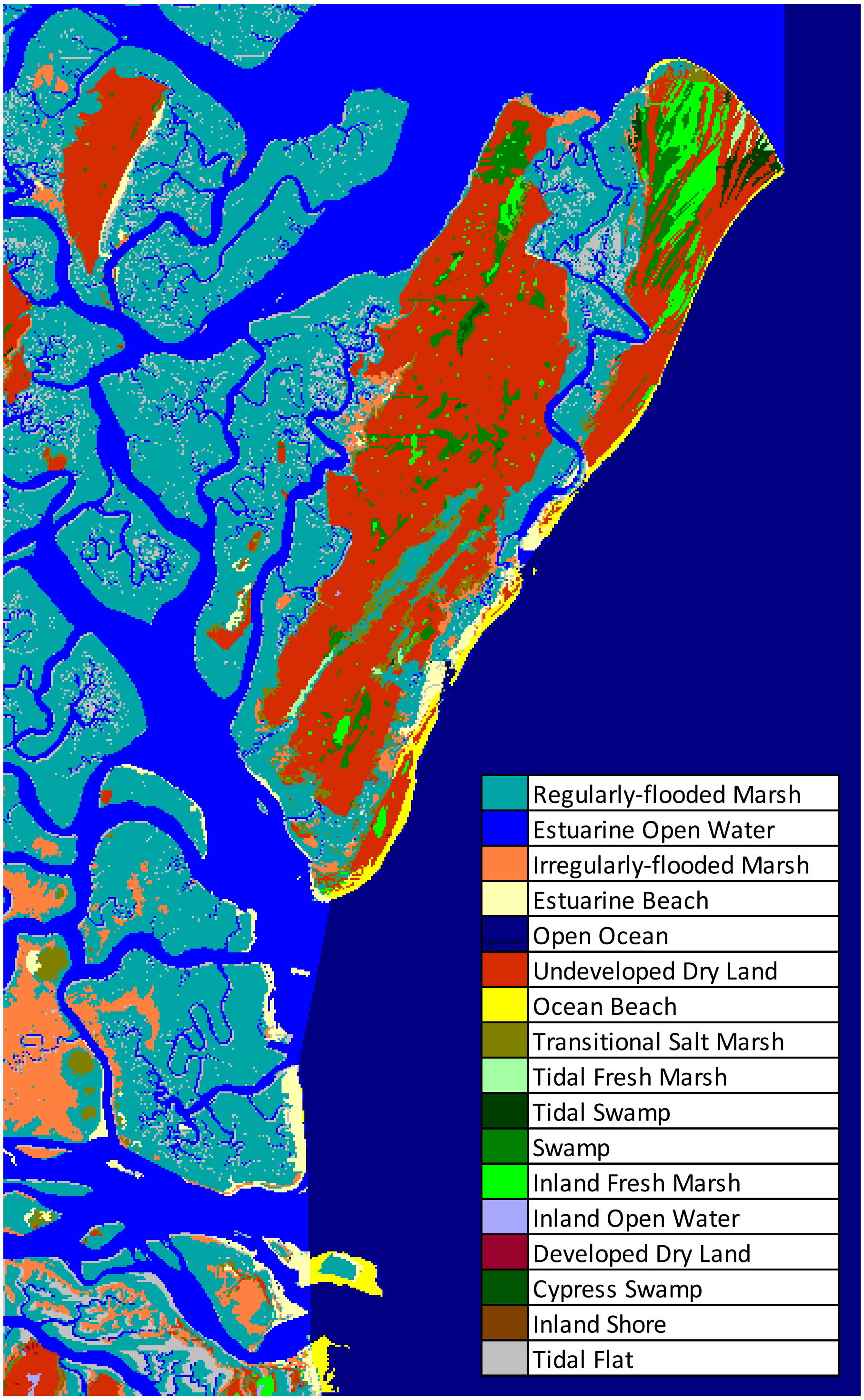
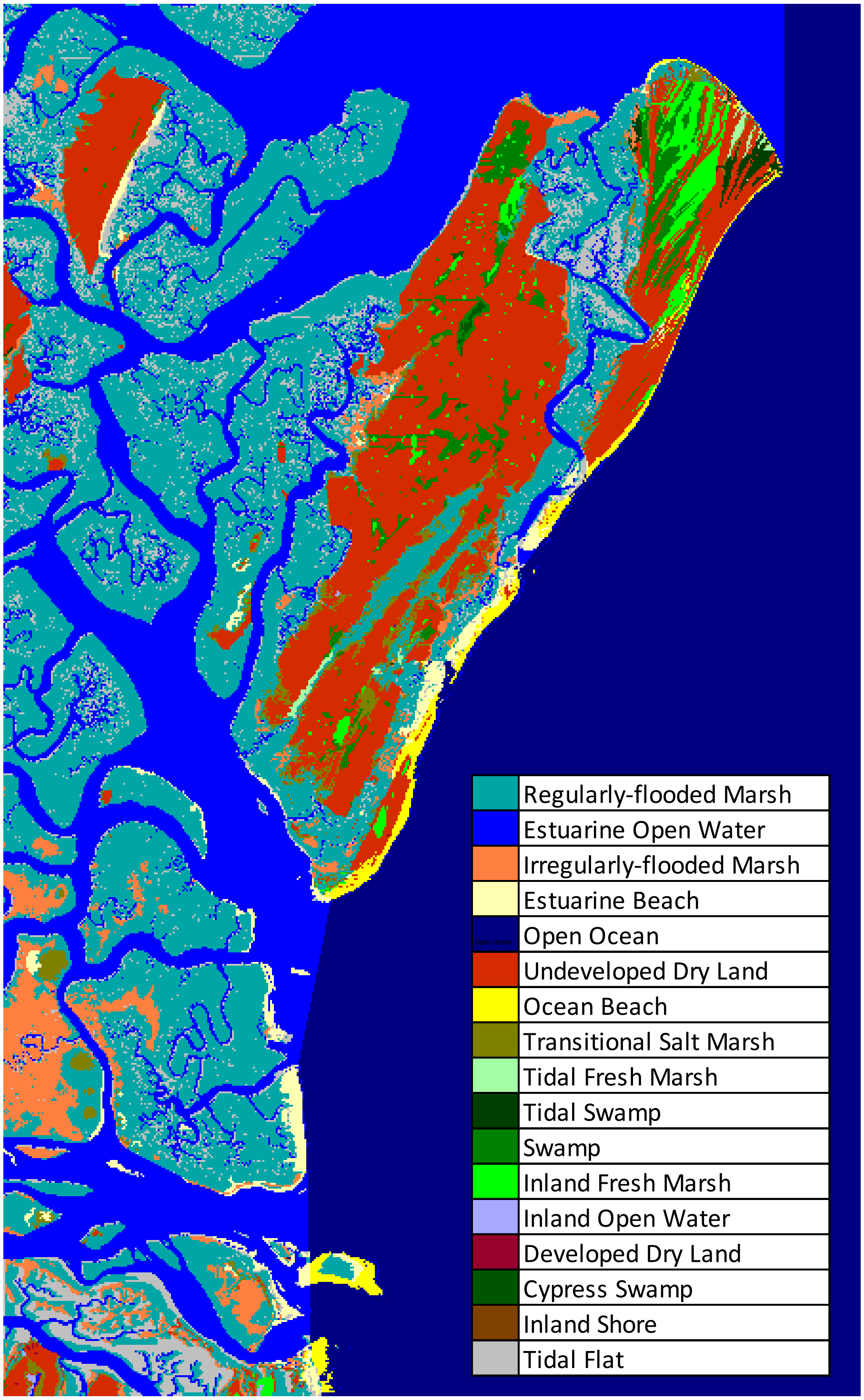


Wolf Island NWR, 2075, Scenario A1B Maximum, 0.69 m SLR by 2100.



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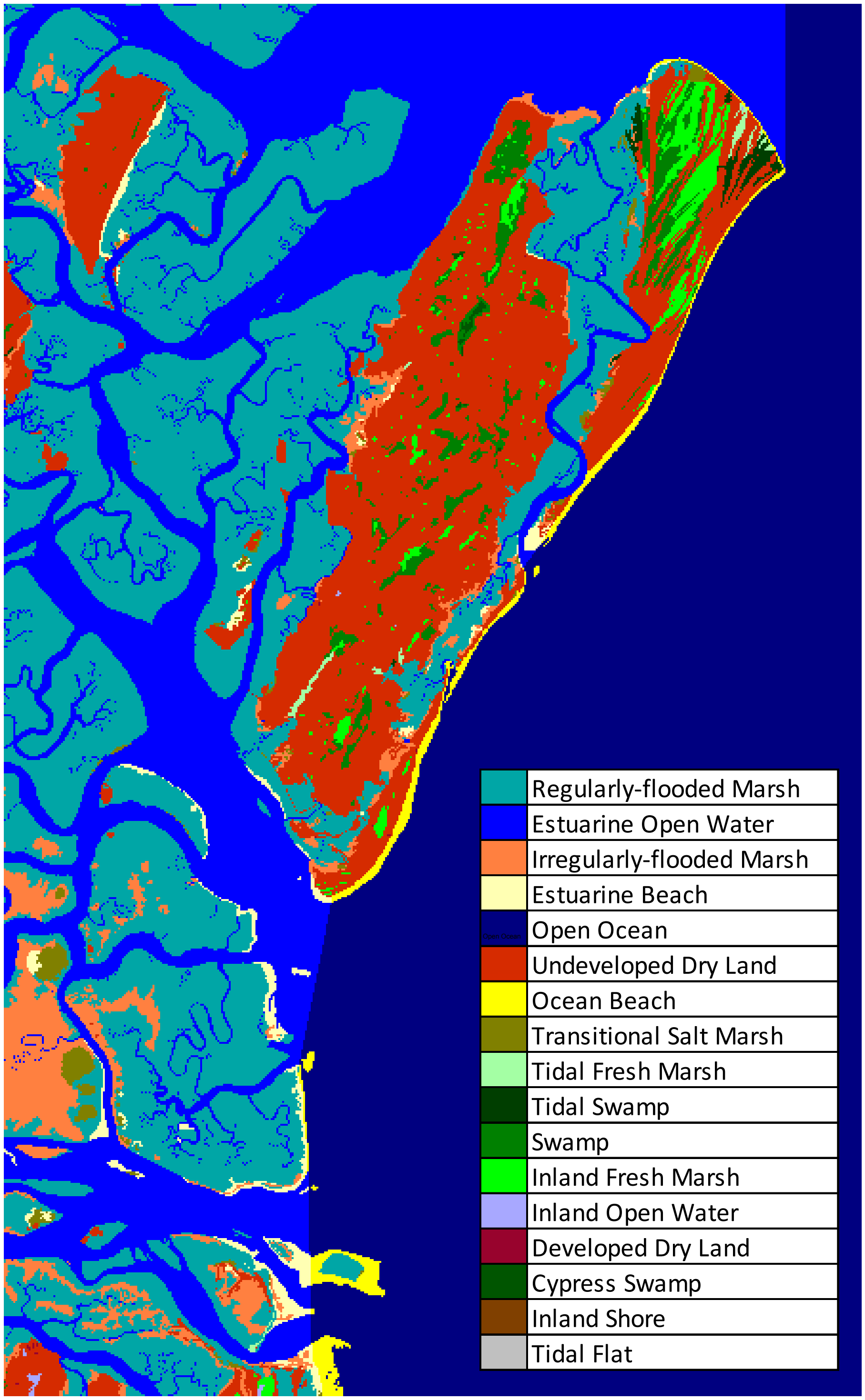

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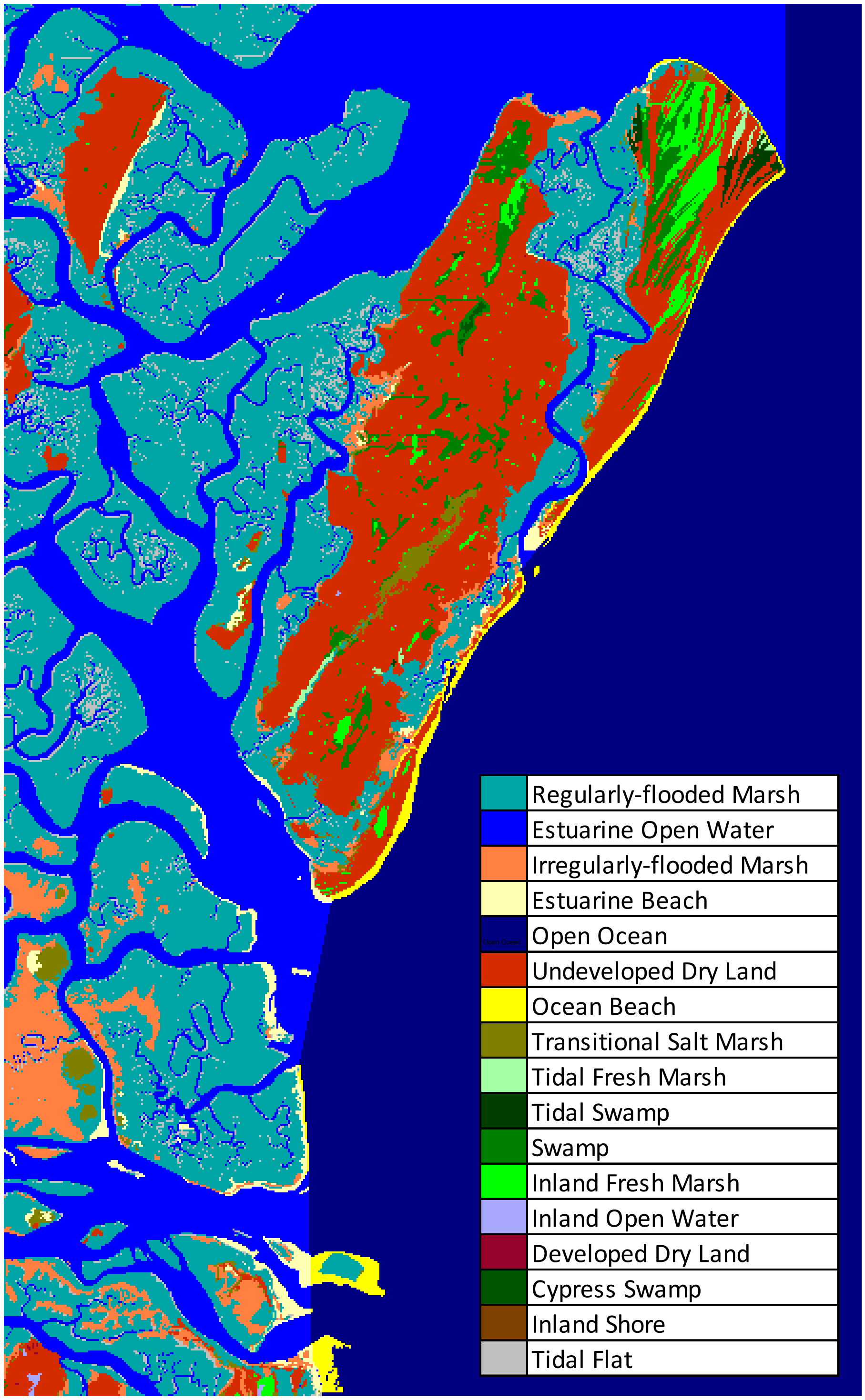
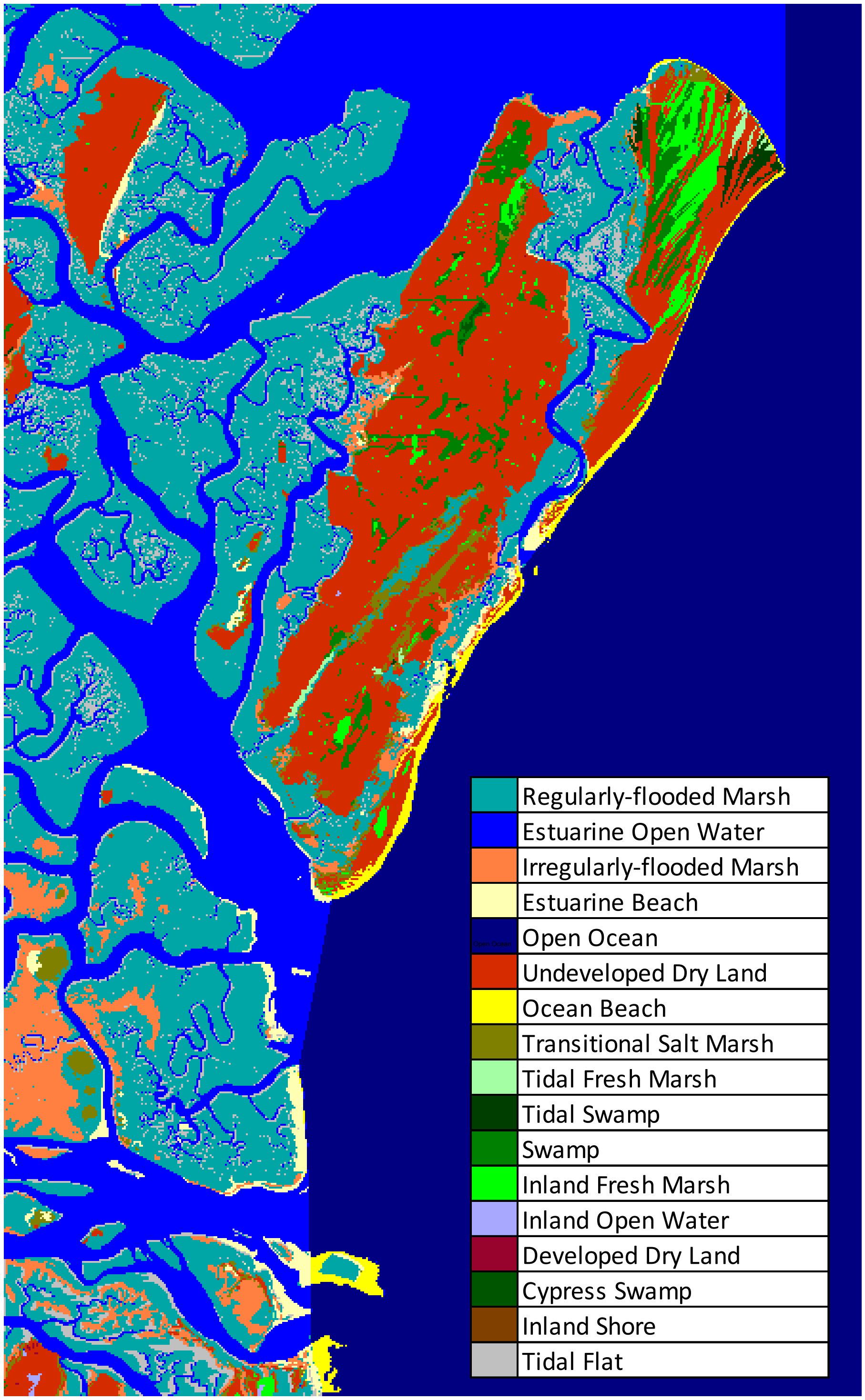
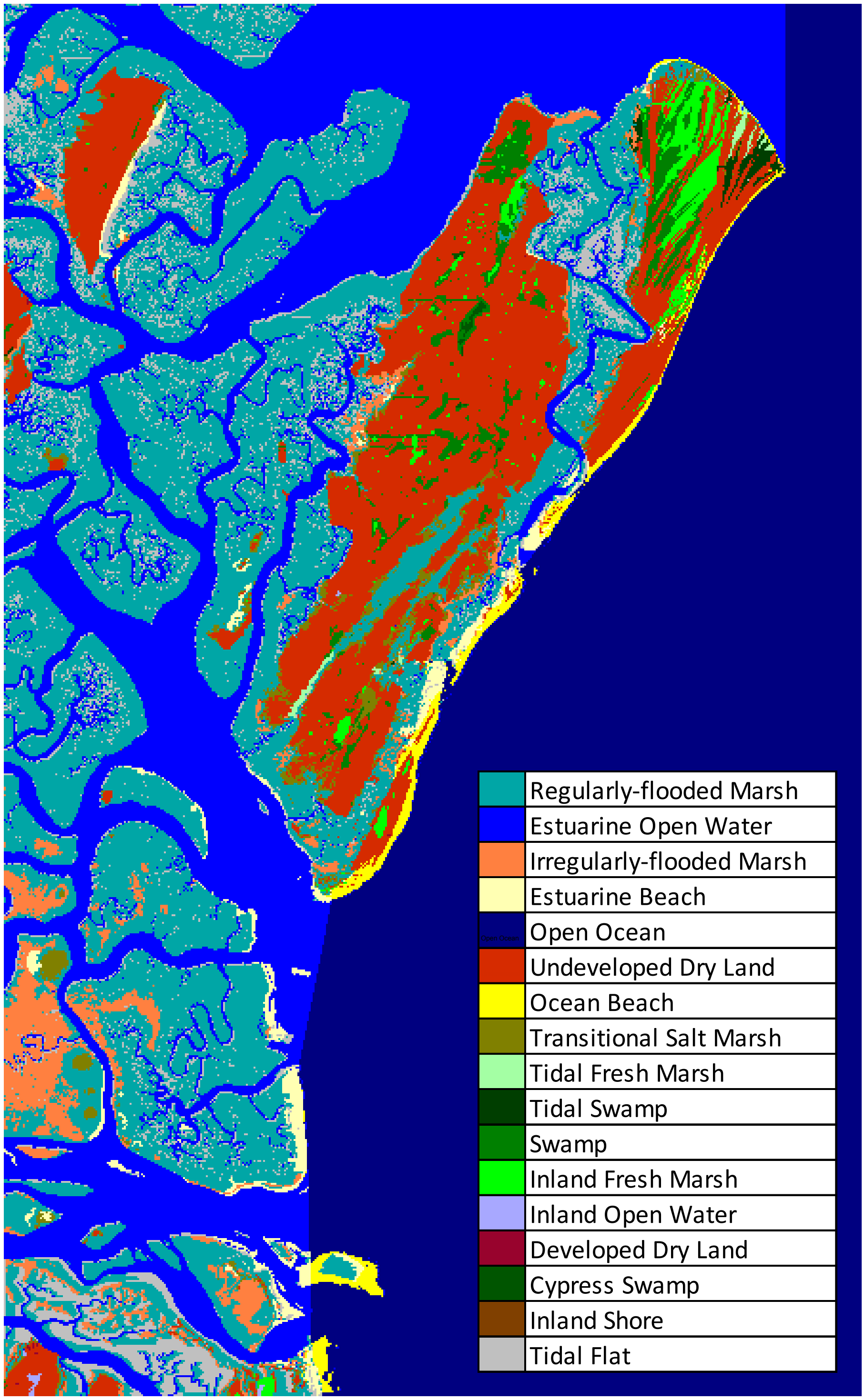


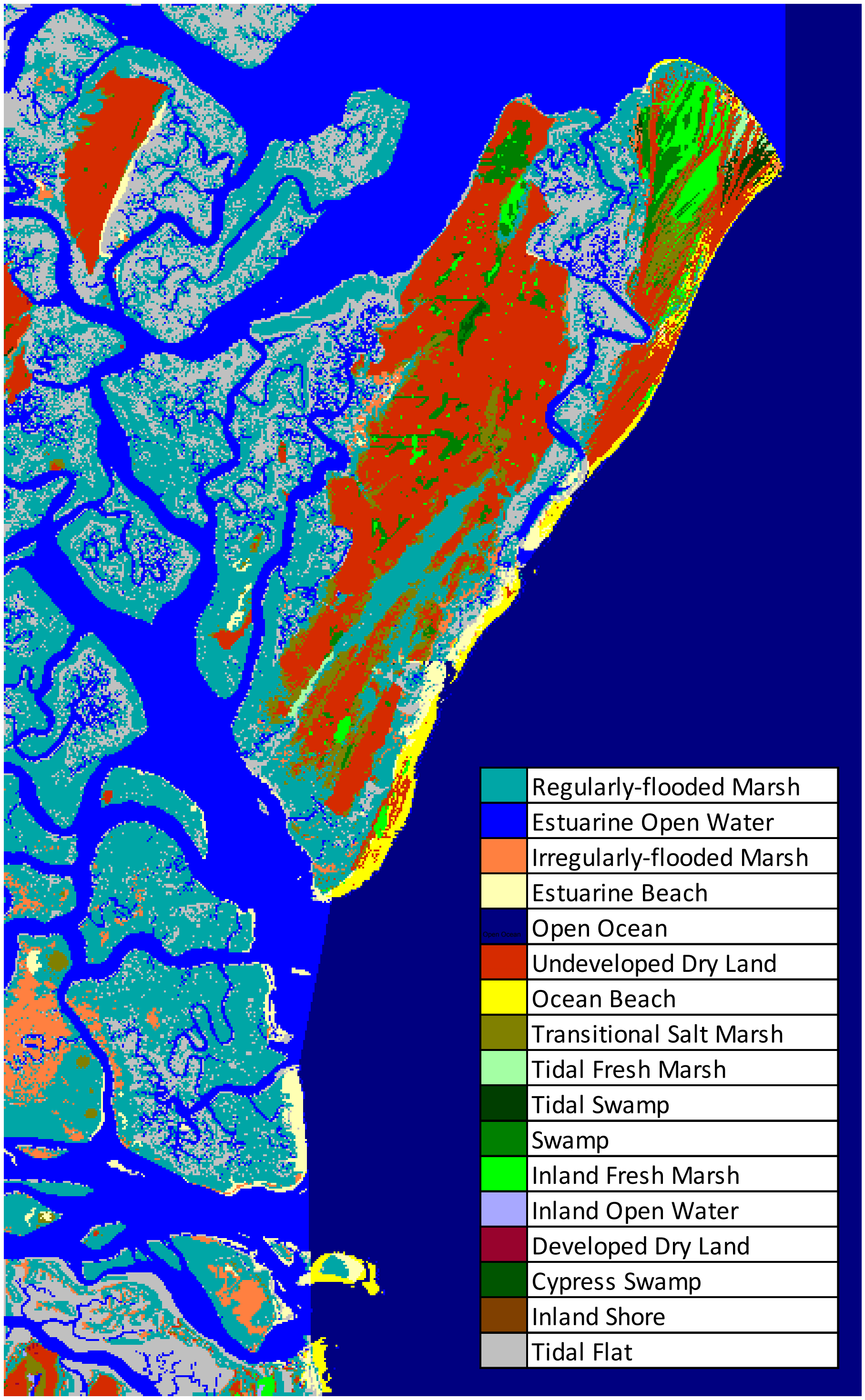
Wolf Island NWR, 2025, 1 m SLR by 2100.



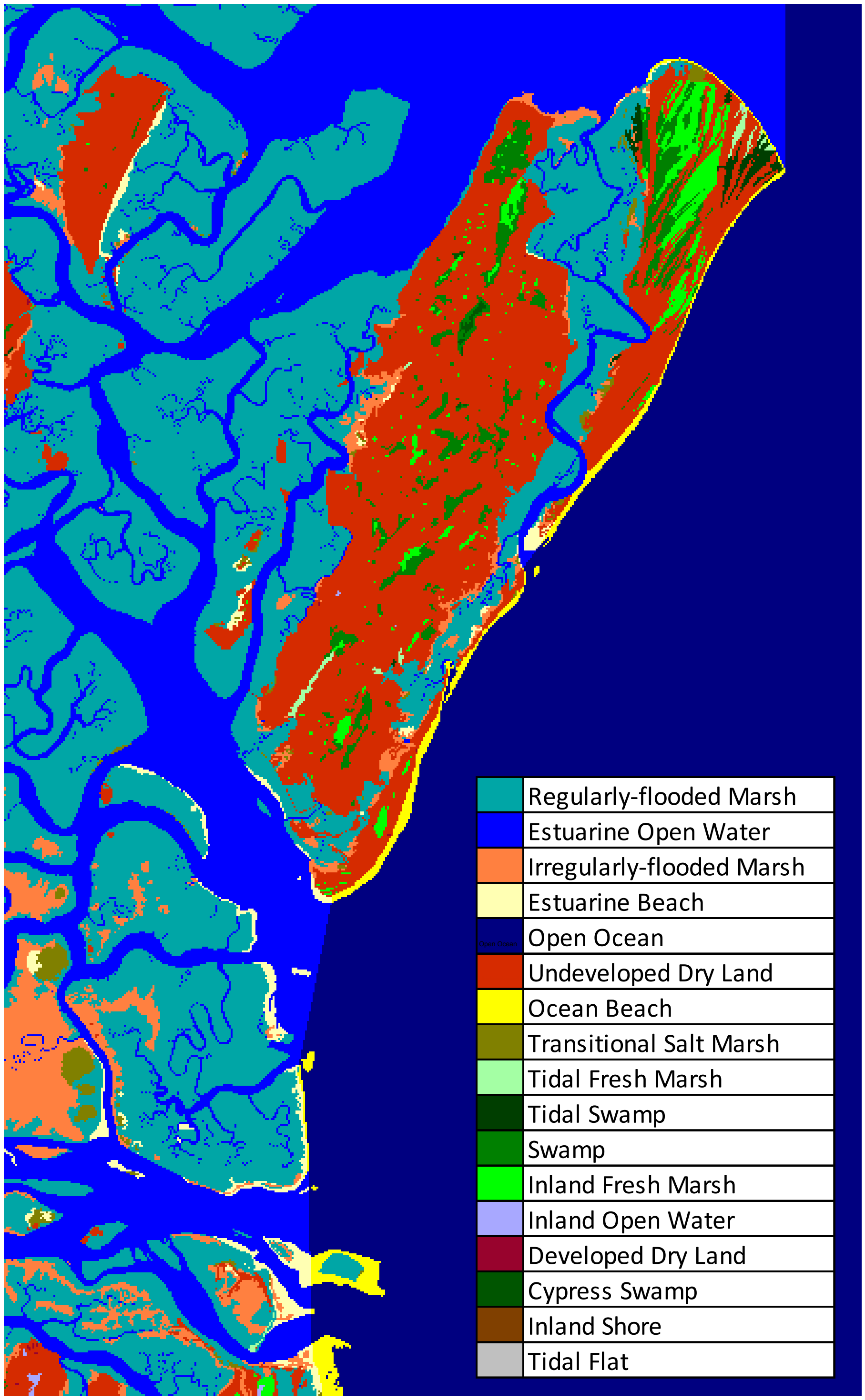
Wolf Island NWR, 2050, 1 m SLR by 2100.



Wolf Island NWR, 2075, 1 meter



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



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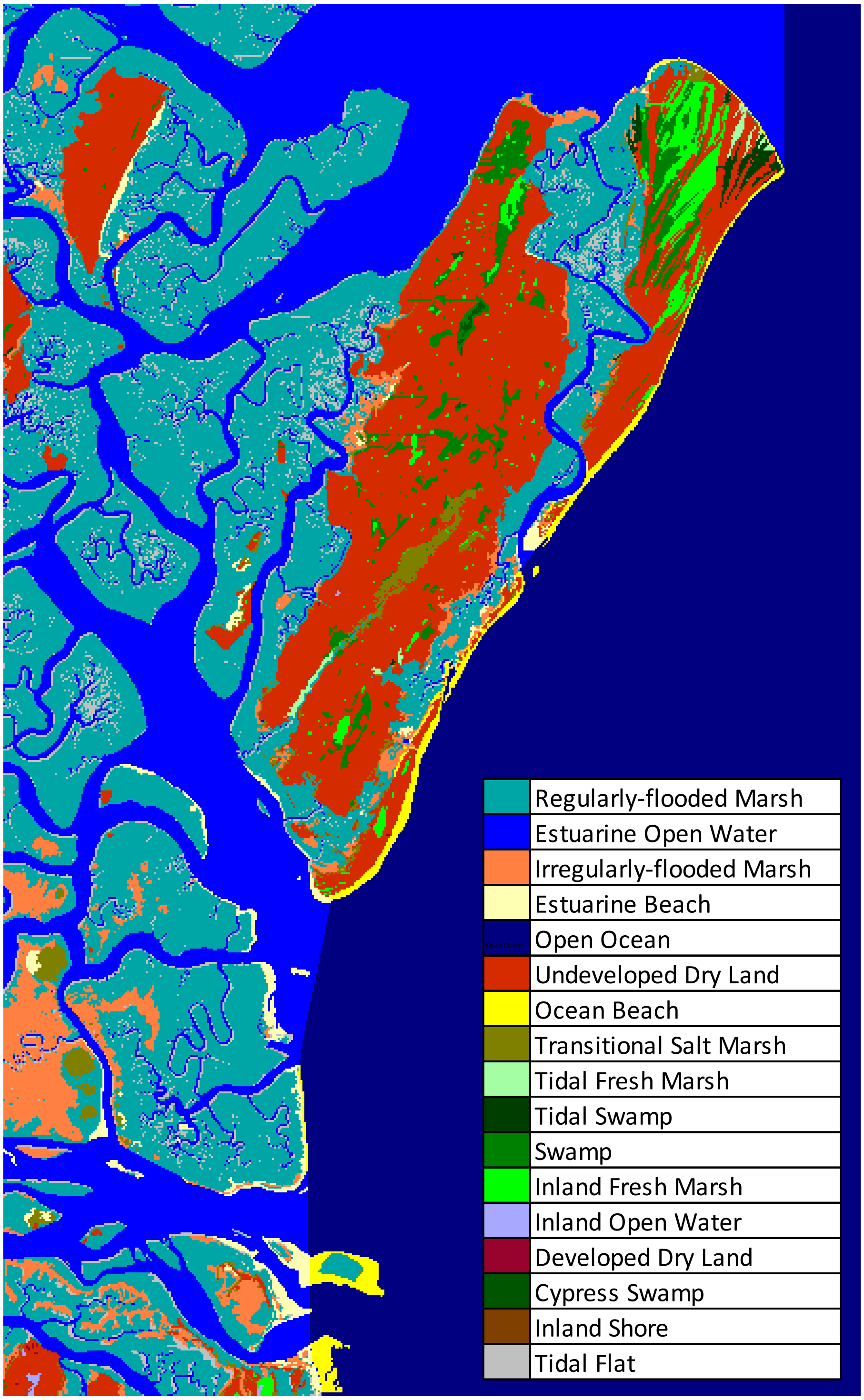

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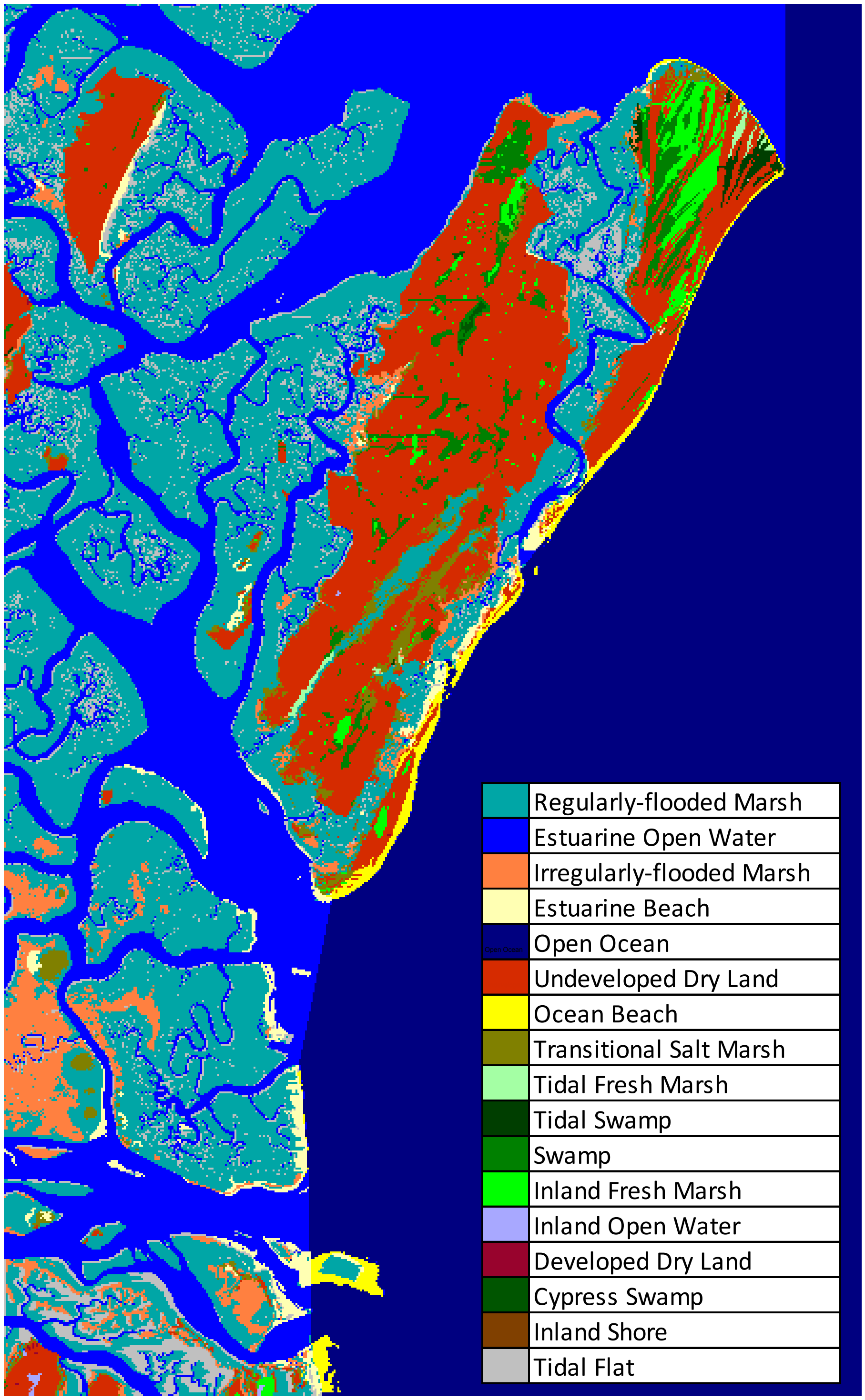

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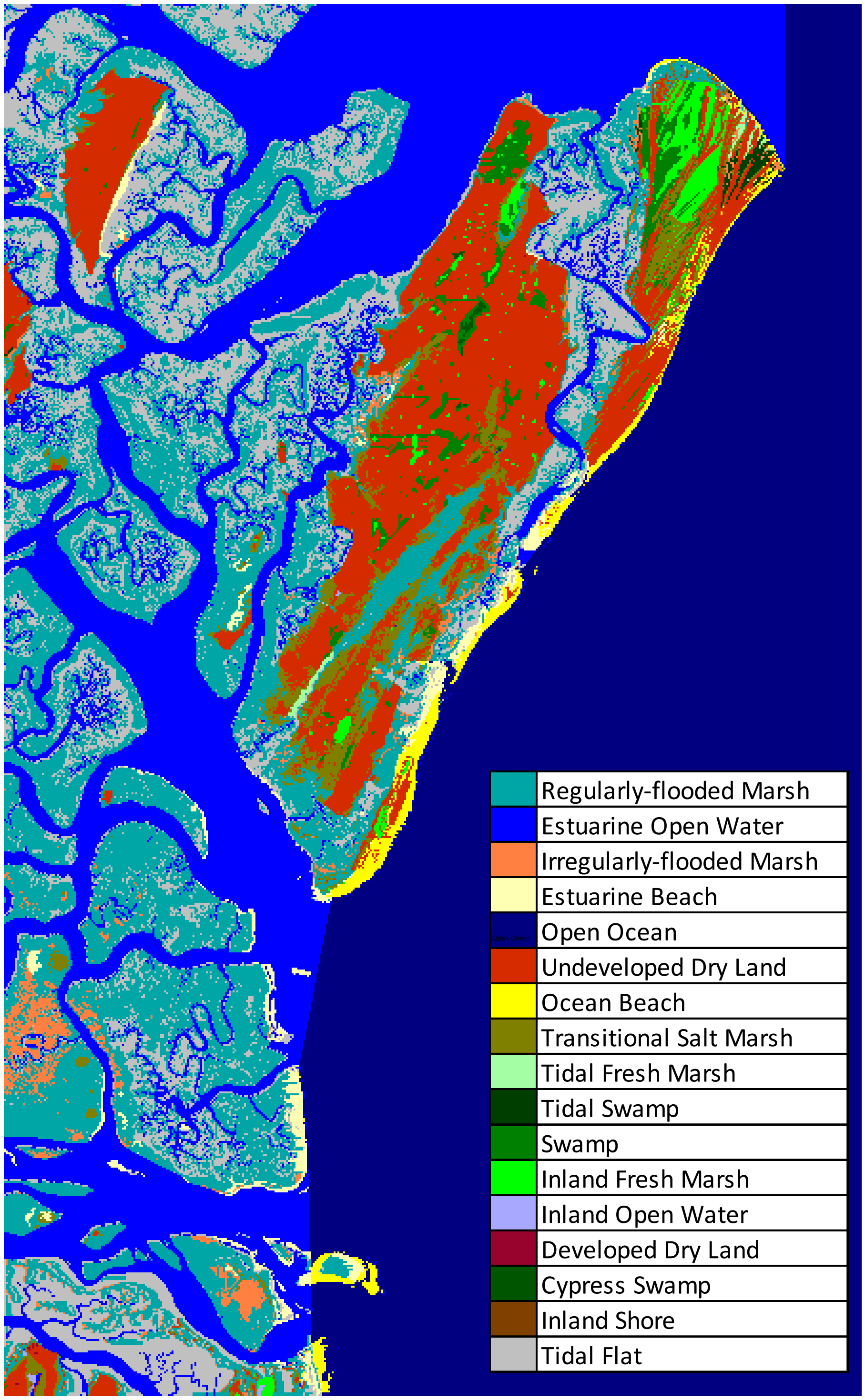

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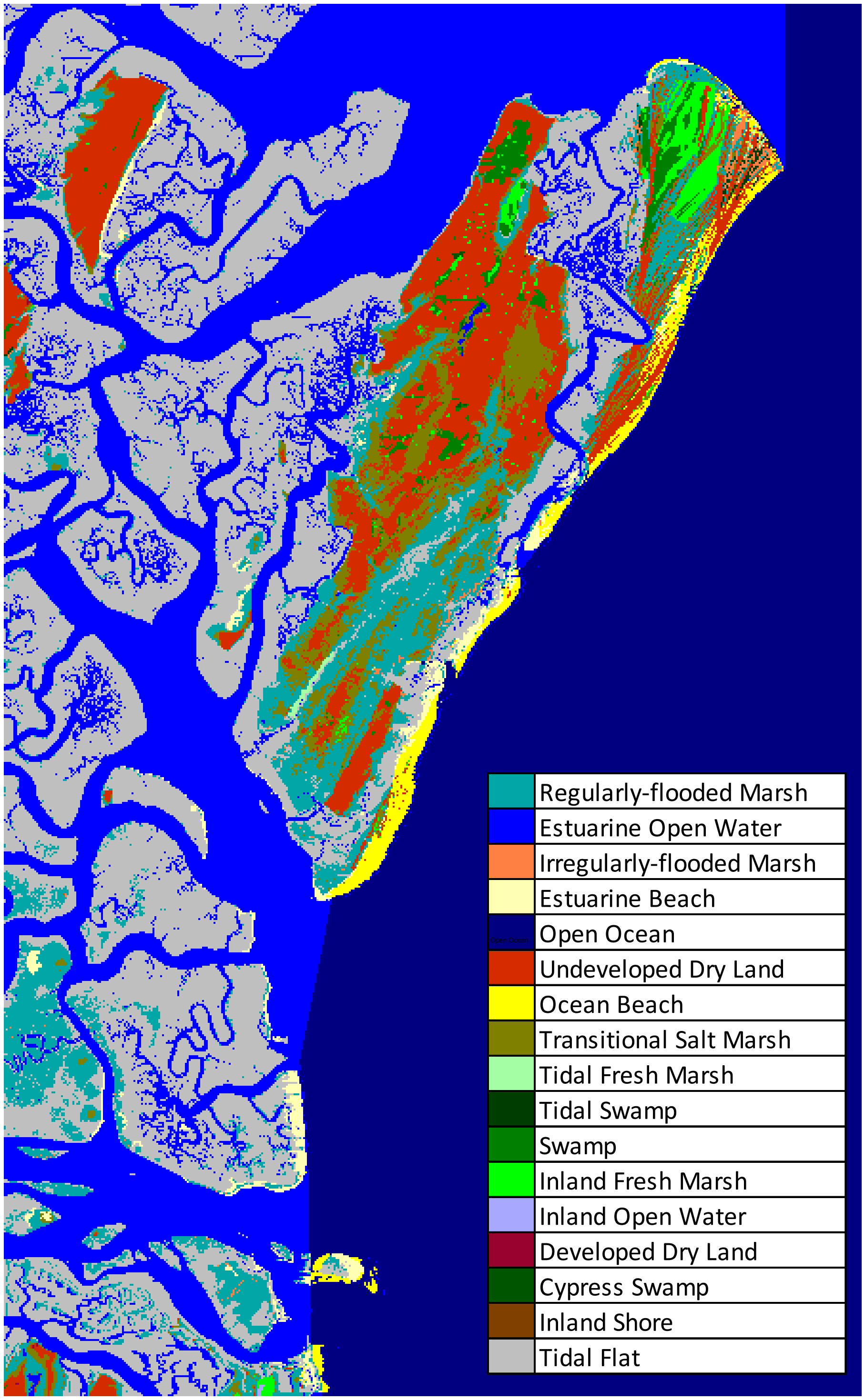
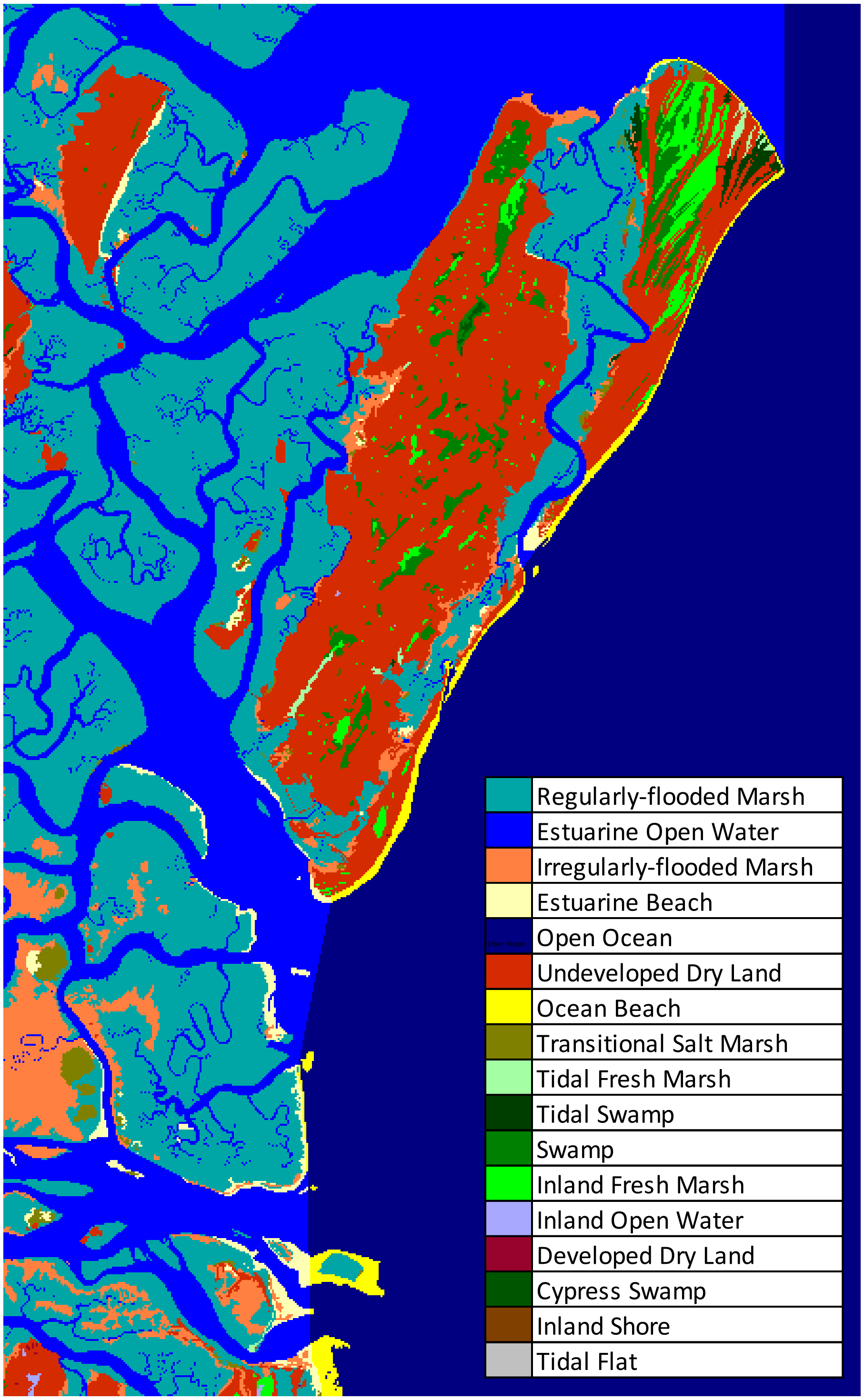
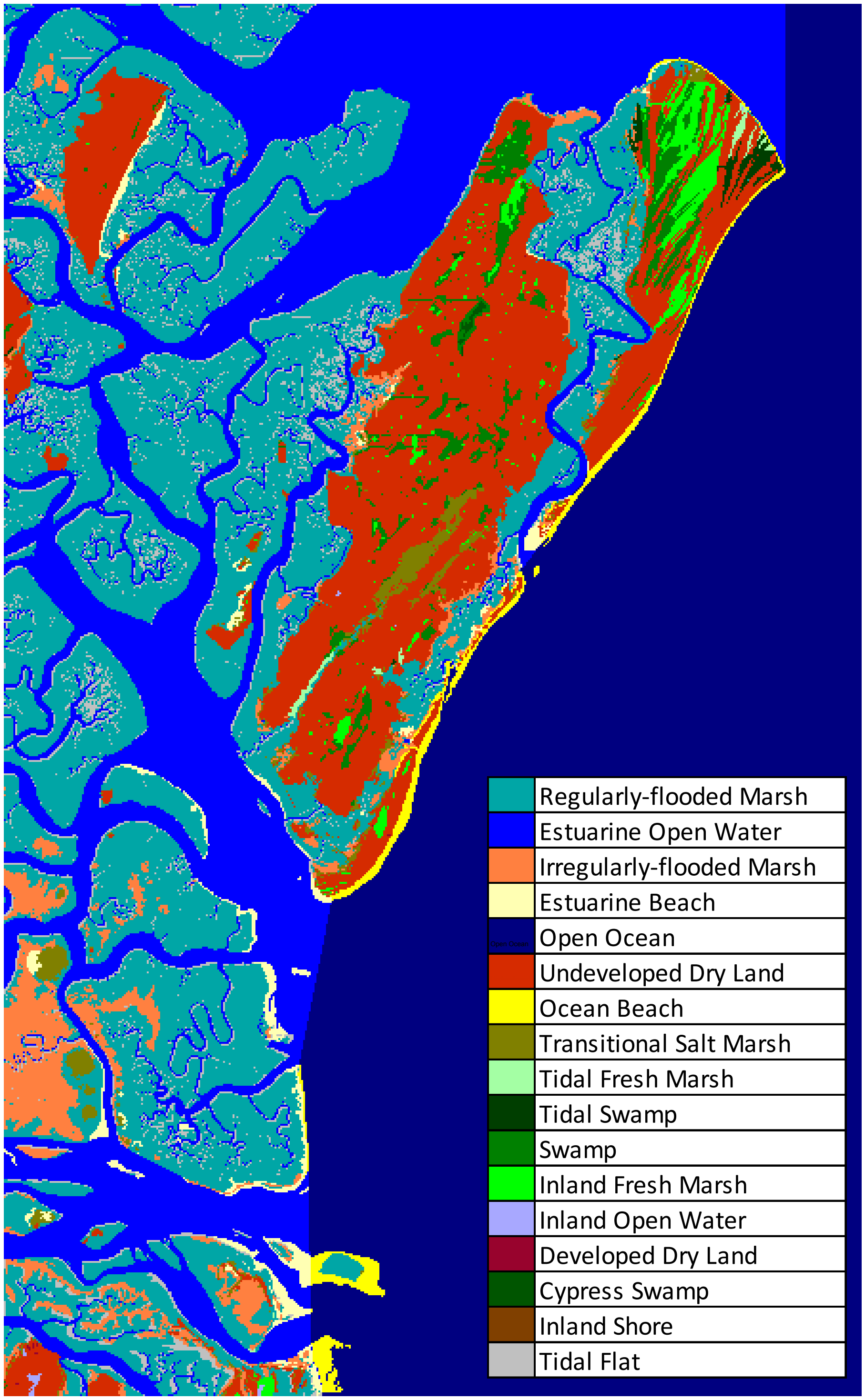


Wolf Island NWR, 2100, 1.5 m SLR by 2100.



Wolf Island NWR, Initial Condition.



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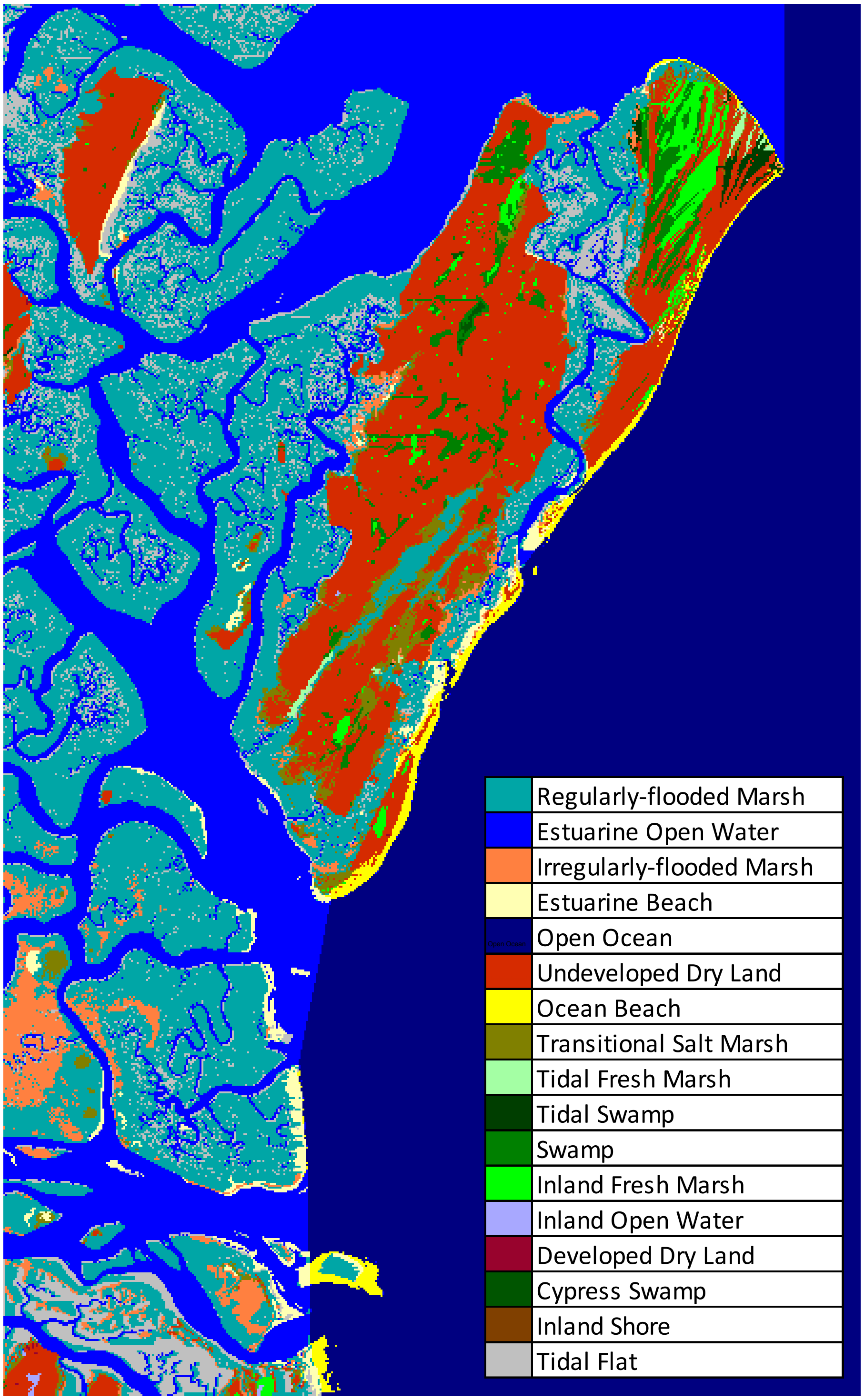

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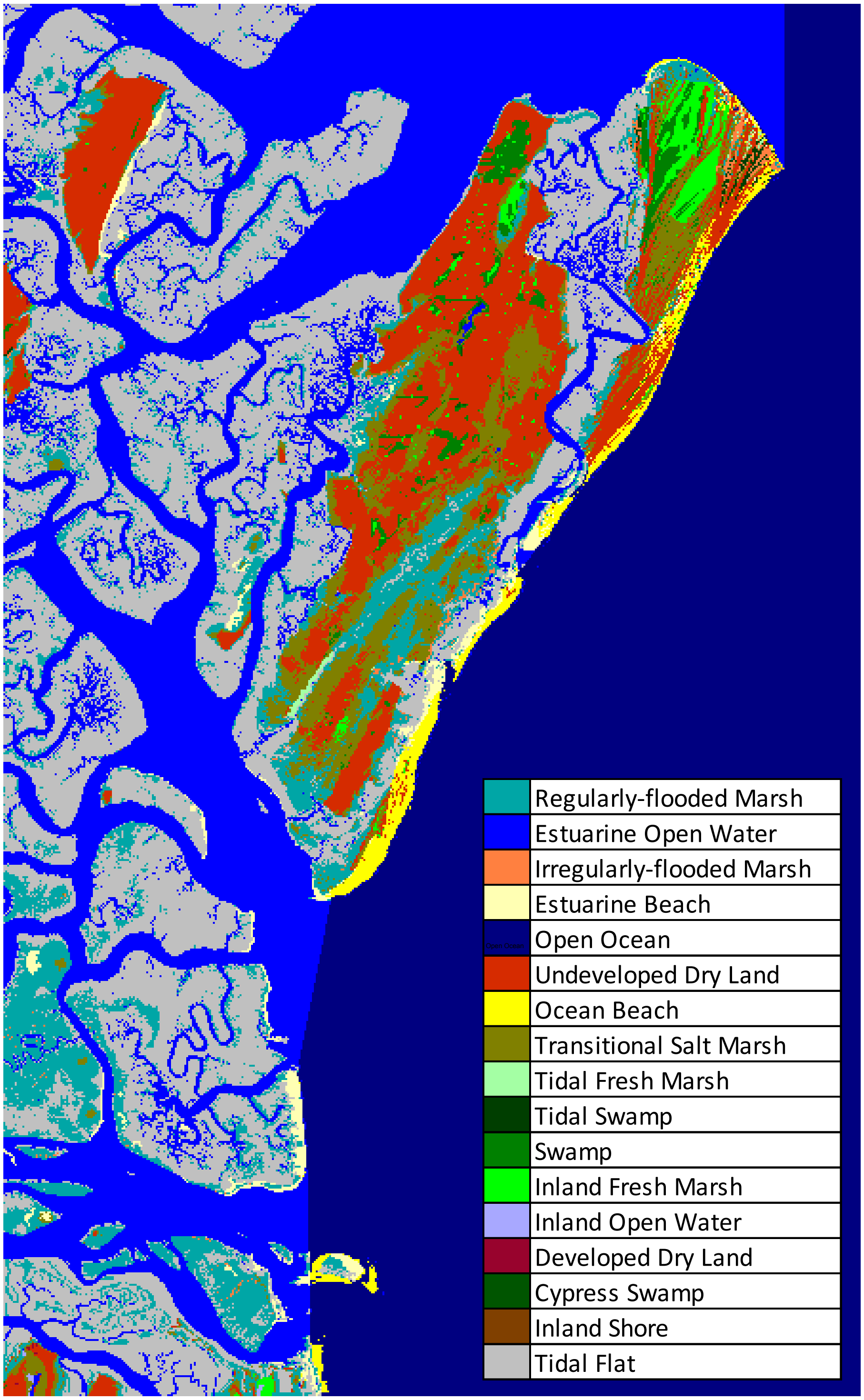

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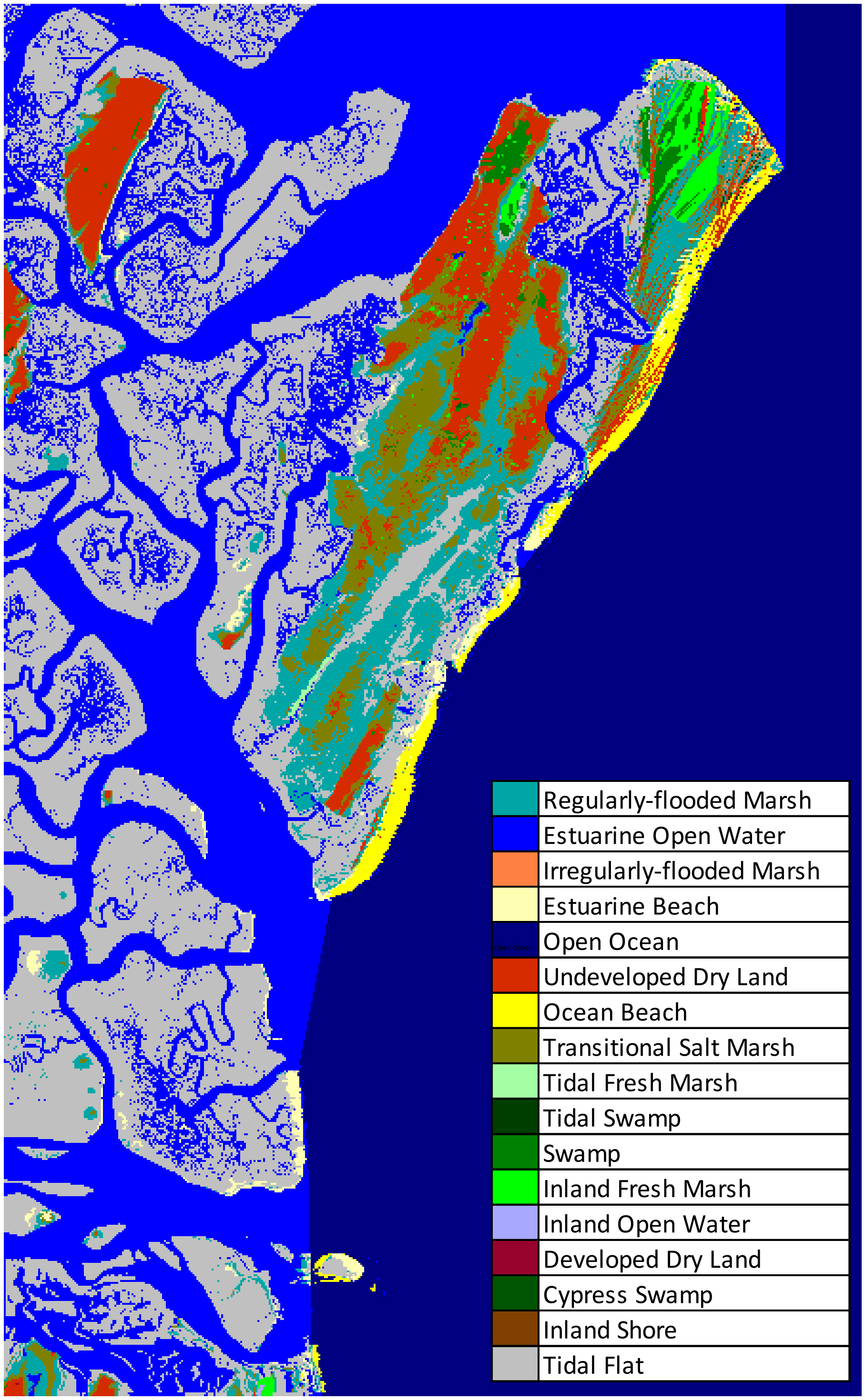

Wolf Island NWR, 2100, 2 m SLR by 2100.