Application of the Sea-Level Affecting Marshes Model (SLAMM 6) to St. Marks 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 St. Marks NWR. The first application of SLAMM to the refuge, carried out in 2008, did not include LiDAR-derived elevation data and relied on wetland data obtained in 1972. The current application uses a bare-earth LiDAR elevation data and a wetland layer derived from aerial photos taken in 2010.

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.

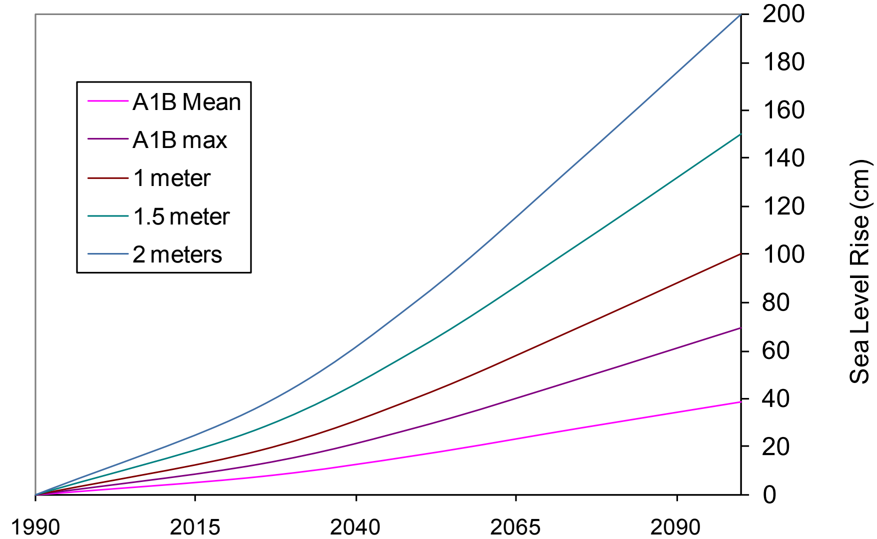


Figure 1. Summary of SLR scenarios utilized.

Data Sources and Methods

Wetland layer. Figure 2 shows the most recent available wetland layer obtained from the National Wetlands Inventory (NWI). The approved acquisition area was primarily based on a 2010 photo date. Two minor exceptions were the southeast corner, which was photo dated 1979, and the far eastern extreme which was dated 1983 (Figure 3). Converting the NWI survey into 10 m x 10 m cells indicated that the approximately 114,500 acre St. Marks NWR (approved acquisition boundary including water) is composed of the following categories:

Land cover type		Area (acres)	Percentage (%)
	Undeveloped Dry Land	38668	34
	Swamp	36792	32
	Irregularly-flooded Marsh	20901	18
	Inland Fresh Marsh	4245	4
	Estuarine Open Water	2352	2
	Tidal Swamp	2343	2
	Estuarine Beach	2317	2
	Inland Open Water	2205	2
	Cypress Swamp	1514	1
	Regularly-flooded Marsh	1469	1
	Tidal Fresh Marsh	724	1
	Transitional Salt Marsh	362	< 1
	Developed Dry Land	337	< 1
	Riverine Tidal	261	< 1
	Tidal Flat	14	< 1
	Total (incl. water)	**114511**	**100**

Elevation Data. The elevation layer covering the refuge area was based on several bare-earth LiDAR data layers collected in 2007, as shown in Figure 4. Within the approved acquisition boundary, only a small island in the southwestern part of the study area was not covered by LiDAR data and therefore elevations were filled using 1975 and 1978 NED data. Since this area did not have full LiDAR coverage, the SLAMM elevation pre-processor was applied (Clough et al. 2010).

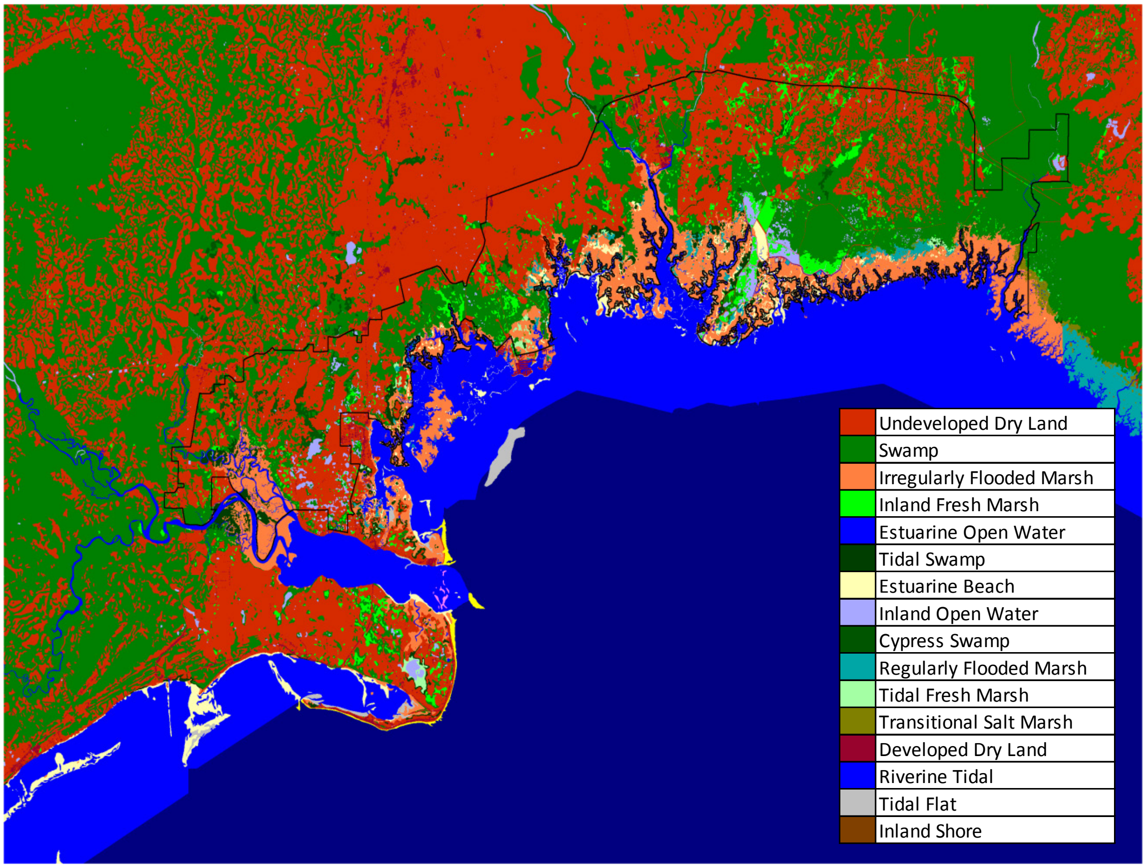


Figure 2. NWI coverage of the study area. Refuge boundaries are indicated in black.

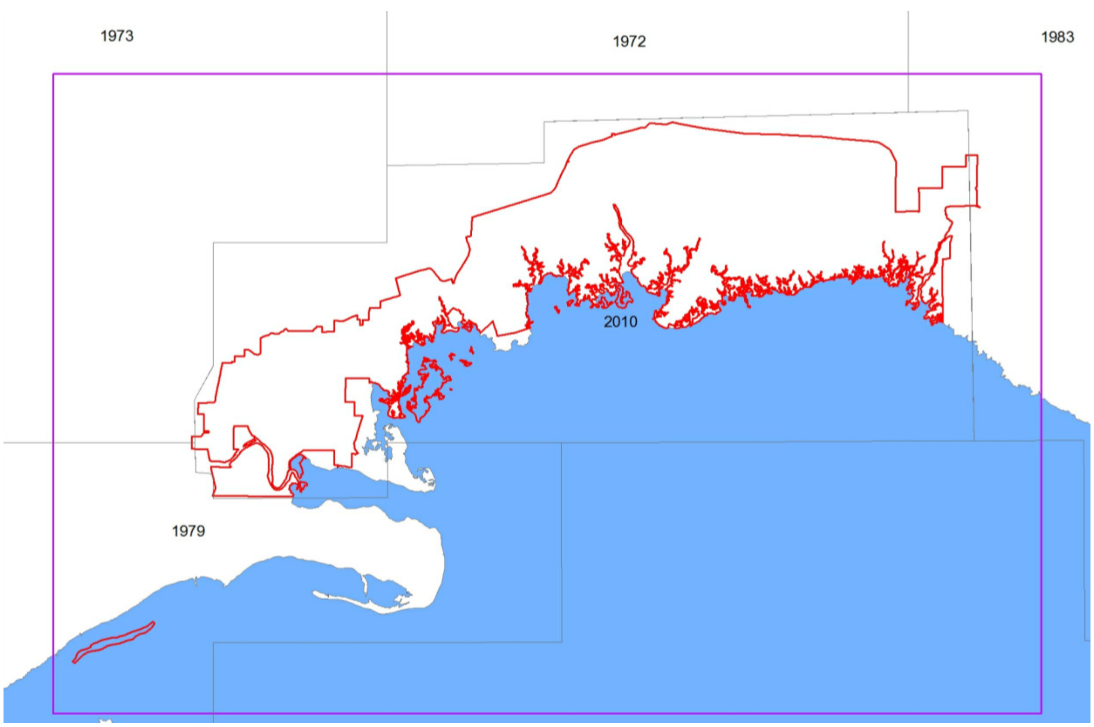


Figure 3. NWI layer photo dates for St. Marks NWR. Refuge boundaries shown in red

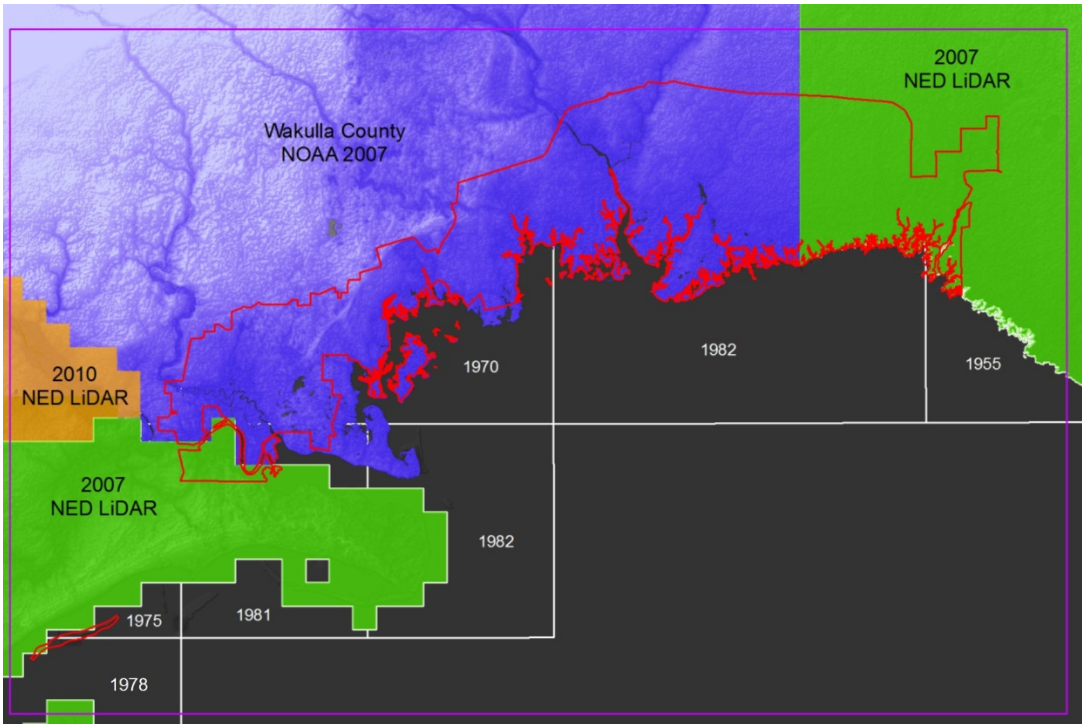


Figure 4. Elevation data and sources for St. Marks NWR. Approve acquisition boundaries shown in red.

Dikes and Impoundments. According to the National Wetland Inventory, there are areas protected by dikes or impoundments within the refuge. These occur near the mouth of the St. Marks River, as shown in Figure 5 .

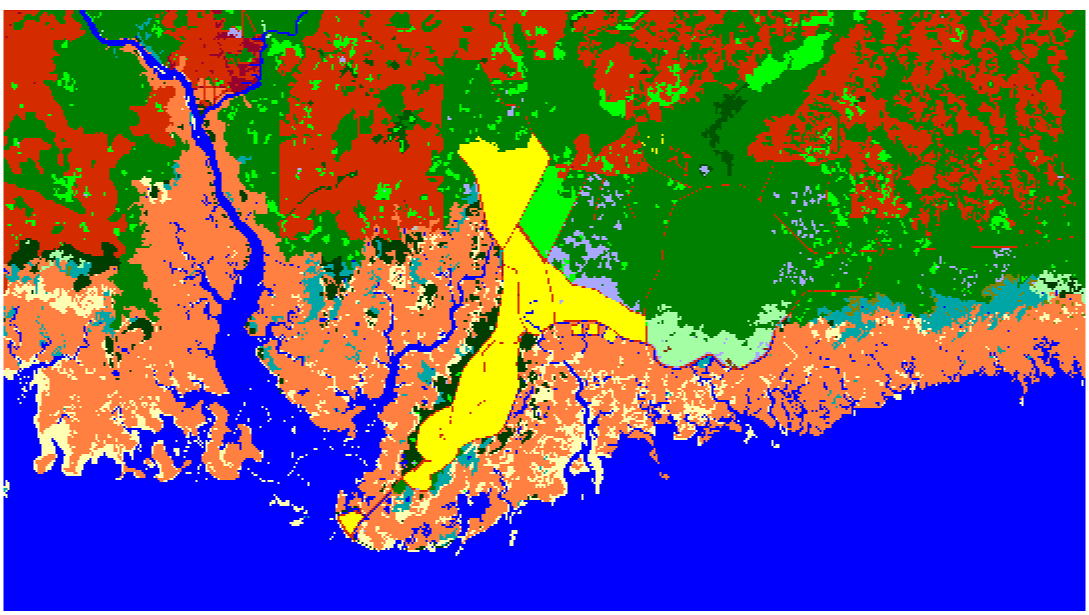


Figure 5. Location of diked areas in St. Marks NWR shown in yellow.

The connectivity algorithm was also used in this simulation in order to try to capture the effects of any natural or man-made impoundments that may not have been marked as diked. The connectivity module of SLAMM ensures that dry land only converts to wetland if there is an unimpeded path from open water to the dry land in question.

Historic sea level rise rates. The historic trend for relative sea level rise rate applied was 1.59 mm/yr, the average of the mean sea level trends measured at Apalachicola Key, FL (NOAA gauge # 8728690) and Cedar Key, FL (NOAA gauge # 8727520). Graphs of the mean sea level trend for each of these sites are shown in Figure 6.

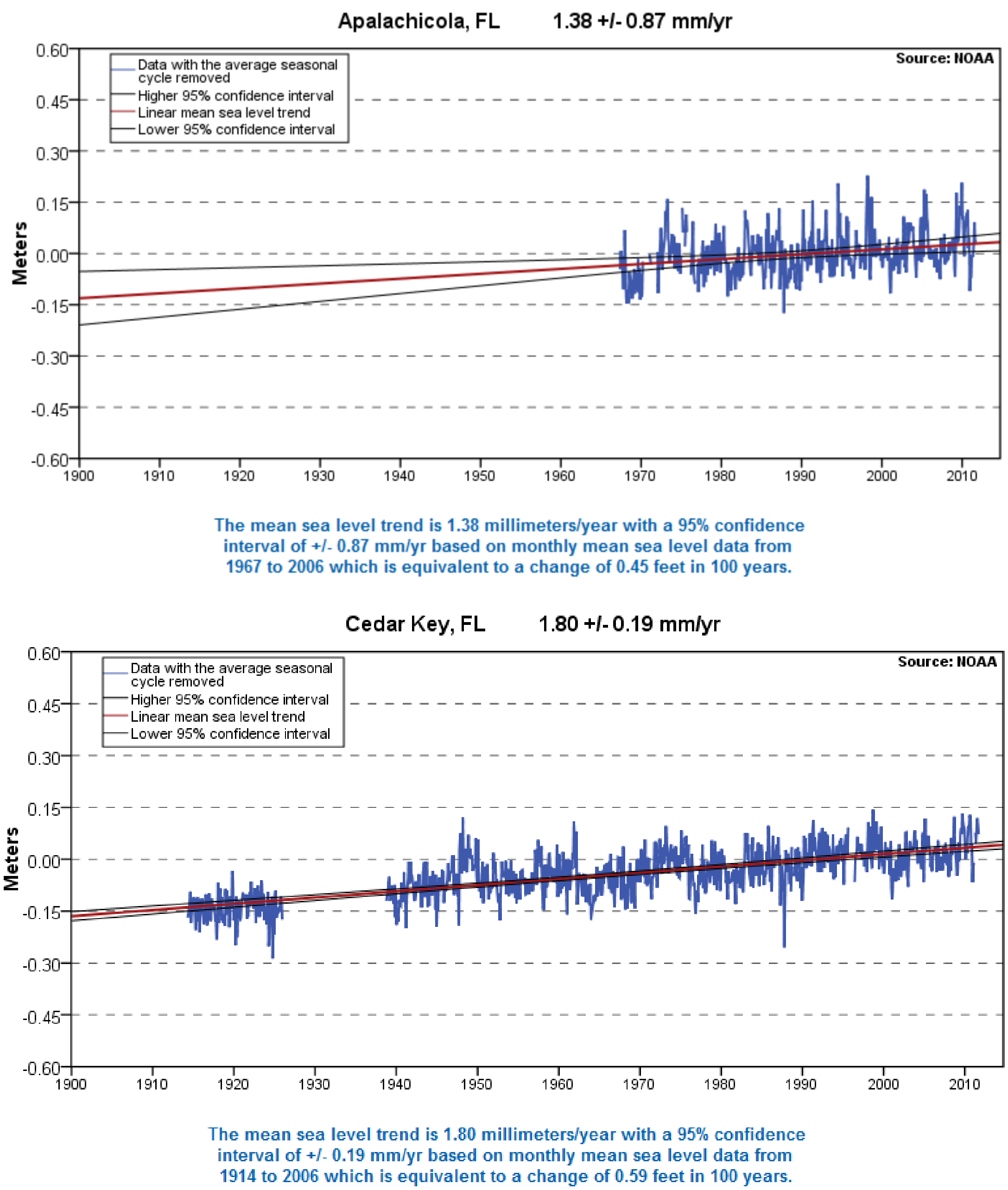


Figure 6. Mean sea level trends at the closest NOAA gauge stations to St. Marks NWR.

Tide Ranges. The great diurnal range (GT) was estimated using the data from the NOAA gauge stations present in the area (shown in Figure 7). Different input subsites were defined reflecting these varying tidal ranges.

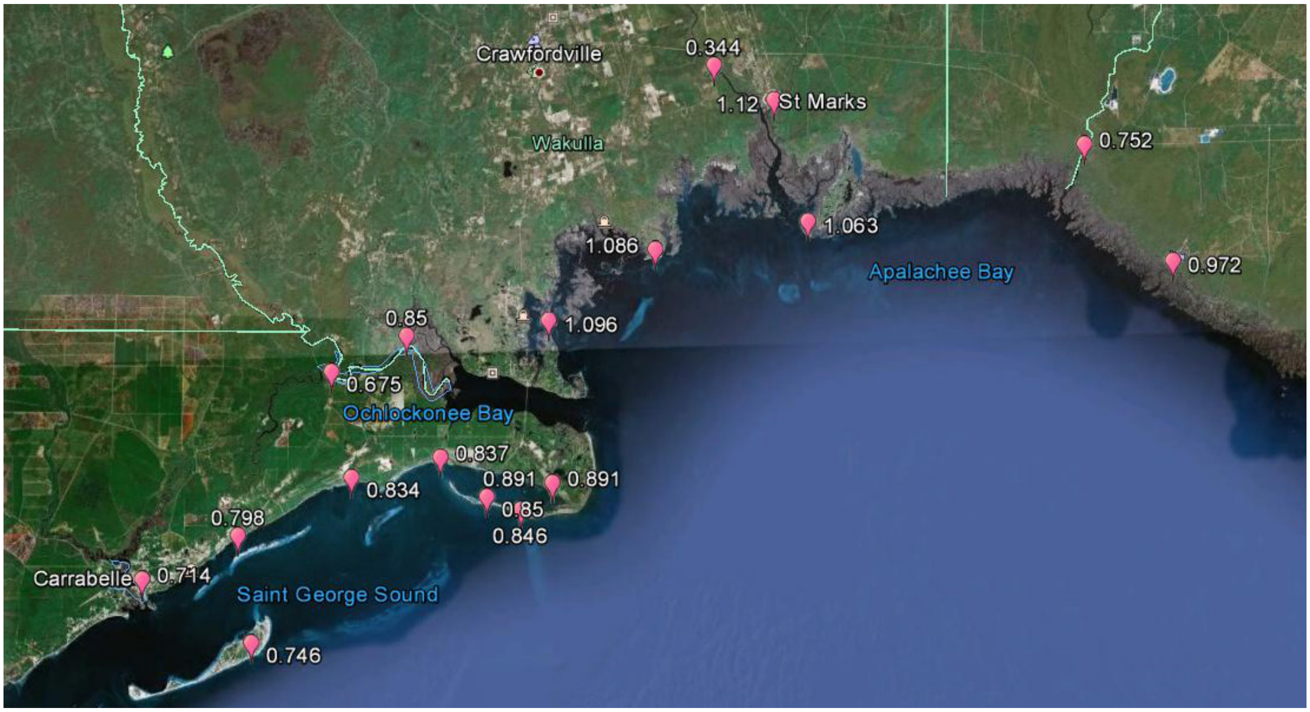


Figure 7. Spatial variability of the great diurnal range (GT) estimates. GT values shown in meters.

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 MTL in the area within the refuge.

Accretion rates. Accretion rates for regularly and irregularly-flooded marsh were set to 4.9 mm/yr based the average accretion rates measured in Apalachicola Bay and the Ochlockonee River estuary, along with the average accretion rate determined a study measuring accretion rates in the St. Marks refuge itself (4.7 mm/yr., Cahoon et al. 1995). Tidal fresh and inland fresh marsh accretion rates were set to 5.9 mm/yr. These accretion values were the same as those used in a recent application of SLAMM to Saint Andrew and Choctawhatchee Bays (Warren Pinnacle Consulting, Inc. 2011). Lacking site specific information, accretion rates of other wetland types were set to SLAMM default value.

Model Timesteps. Model forecast data is output for years 2025, 2050, 2075 and 2100 with the initial condition date set to 2010, the most recent wetland data available.

Erosion rates. – The Big Bend area of FL where St. Marks is situated is classified as a "zero-energy" coast, and has been found to be relatively stable under normal wave conditions. The previous application of SLAMM to St. Marks noted that erosion is not a big issue due to the shallow bathymetry of the gulf that results in a low energy coastline (Clough 2008).

Horizontal erosion of marshes and swamps occurs in SLAMM only at the wetland-to-open-water interface and only when adequate open water (fetch) exists for wave setup. Due to a lack of site-specific data, erosion rates for swamps and tidal flats were set to the SLAMM defaults of 1 m/yr and 0.2 mm/yr, respectively. However, shoreline change analyses led to the calculation of marsh erosion rates in Hogtown Bayou located in nearby Choctawhatchee Bay. According to Dr. Steve Kish, the erosion rate along the northern shore of this marsh from 1949 to 2007 was approximately 0.83 horizontal m/yr. "Since erosion may be in part associated with recent hurricane activity, this should be considered a minimum rate" (Kish 2011).

Elevation correction. MTL to NAVD88 corrections, applied on a subsite-by-subsite basis, ranged from 0.535 to -0.046 m were determined using data obtained from NOAA tide gauges, as shown in Figure 8. The "East Refuge" subsite was assigned a correction value of 0.155 based on data obtained from NOAA's VDATUM software.

Figure 8. Spatial variability of MTL to NAVD88 correction estimates (m).

Refuge boundaries. Modeled USFWS refuge boundaries for Florida 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 and elevation corrections, the study area was subdivided in the subsites illustrated in Figure 9.

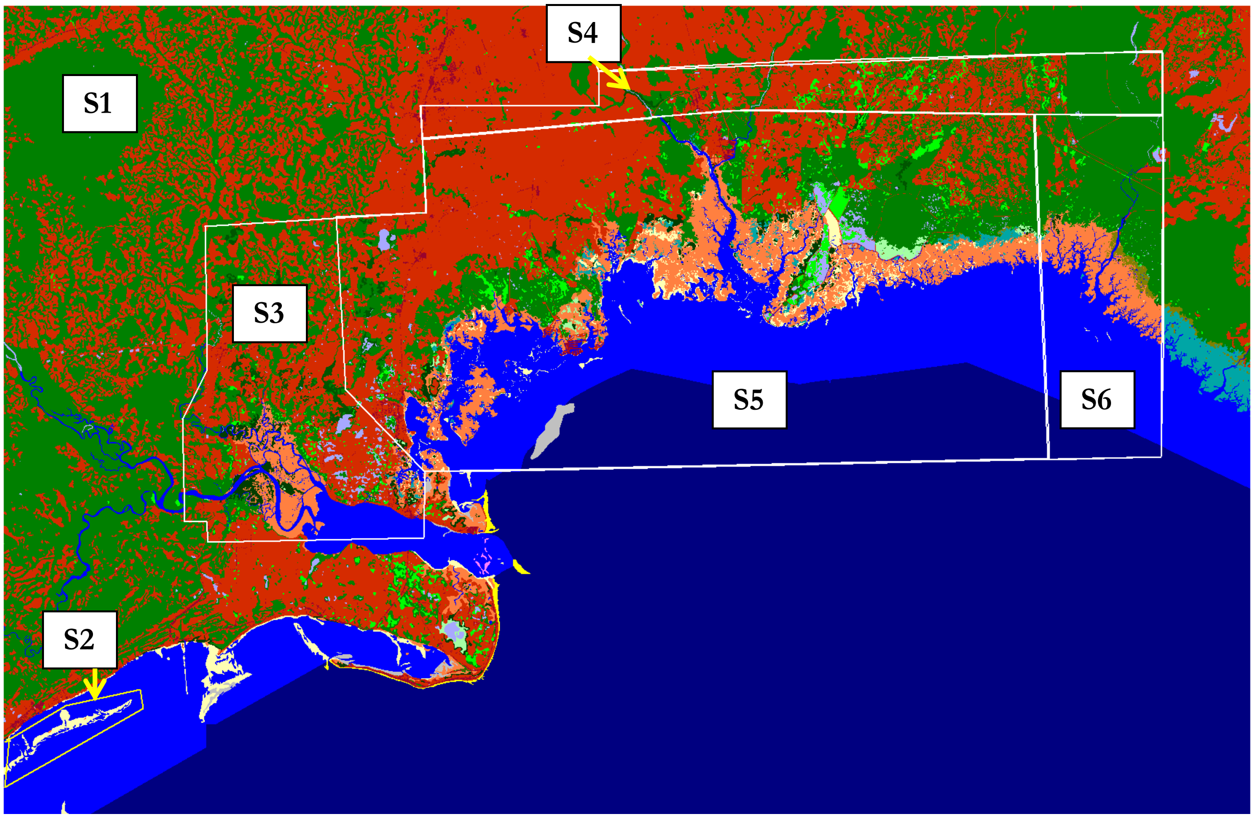


Figure 9. Input subsites for model application.

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.

Table 1. Summary of SLAMM input parameters for St. Marks NWR.

Subsite	S1	S2	S3	S4	S5	S6
Parameter	Contextual Area	Refuge NED	West Refuge	St. Marks Upstream	Center Refuge	East Refuge
NWI Photo Date (YYYY)	1976	1979	2010	2010	2010	2010
DEM Date (YYYY)	2007	1975	2007	2007	2007	2007
Direction Offshore [n,s,e,w]	South	South	South	South	South	West
Historic Trend (mm/yr)	1.59	1.59	1.59	1.59	1.59	1.59
MTL-NAVD88 (m)	0.017	-0.035	0.04	0.535	0.03	0.155
GT Great Diurnal Tide Range (m)	0.82	0.81	0.85	0.34	1.1	0.75
Salt Elev. (m above MTL)	0.55	0.54	0.57	0.23	0.73	0.5
Marsh Erosion (horz. m /yr)	0.83	0.83	0.83	0.83	0.83	0.83
Swamp Erosion (horz. m /yr)	1	1	1	1	1	1
T.Flat Erosion (horz. m /yr)	0.5	0.5	0.5	0.5	0.5	0.5
Reg.-Flood Marsh Accr (mm/yr)	4.9	4.9	4.9	4.9	4.9	4.9
Irreg.-Flood Marsh Accr (mm/yr)	4.9	4.9	4.9	4.9	4.9	4.9
Tidal-Fresh Marsh Accr (mm/yr)	5.9	5.9	5.9	5.9	5.9	5.9
Inland-Fresh Marsh Accr (mm/yr)	5.9	5.9	5.9	5.9	5.9	5.9
Mangrove Accr (mm/yr)	7	7	7	7	7	7
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	TRUE	FALSE	FALSE	FALSE	FALSE

Results

Percentage losses by 2100 for each land-cover type given different SLR scenarios are presented in Table 2. Land-cover losses are calculated in comparison to the initial 2010 SLAMM wetland coverage and 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 St. Marks NWR.

	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	2%	5%	8%	16%	28%
Swamp	15%	26%	36%	53%	69%
Irregularly-flooded Marsh	9%	19%	55%	92%	97%
Inland Fresh Marsh	4%	6%	10%	22%	36%
Tidal Swamp	20%	45%	65%	85%	95%
Estuarine Beach	14%	27%	38%	73%	96%
Cypress Swamp	0%	1%	4%	6%	39%
Tidal Fresh Marsh	7%	13%	44%	77%	94%
Developed Dry Land	7%	15%	22%	31%	38%
Inland Shore	2%	12%	20%	74%	83%

Wetlands covering St. Marks NWR are predicted to be fairly resilient to the effects of SLR under the A1B Mean SLR scenario (0.39 m by 2100). However, under the 0.69 m by 2100 scenario and above important losses of swamp, irregularly-flooded marsh, tidal swamp, estuarine beach, and tidal fresh marsh occur. The irregularly-flooded marsh habitat appears to be the most endangered wetland type, with 92% of these wetlands predicted lost at 1.5 m of SLR by 2100 and higher.

Losses of wetland habitats of one type may be balanced with gains in other habitat categories. Major land cover gains are summarized in Table 3. Estuarine open water is predicted to progressively increase coverage as sea level rises, from the current coverage of 2% up to 20% coverage of the refuge area under the 2 m SLR by 2100 scenario. Large gains in tidal flat, regularly-flooded marsh, and transitional salt marsh are also projected.

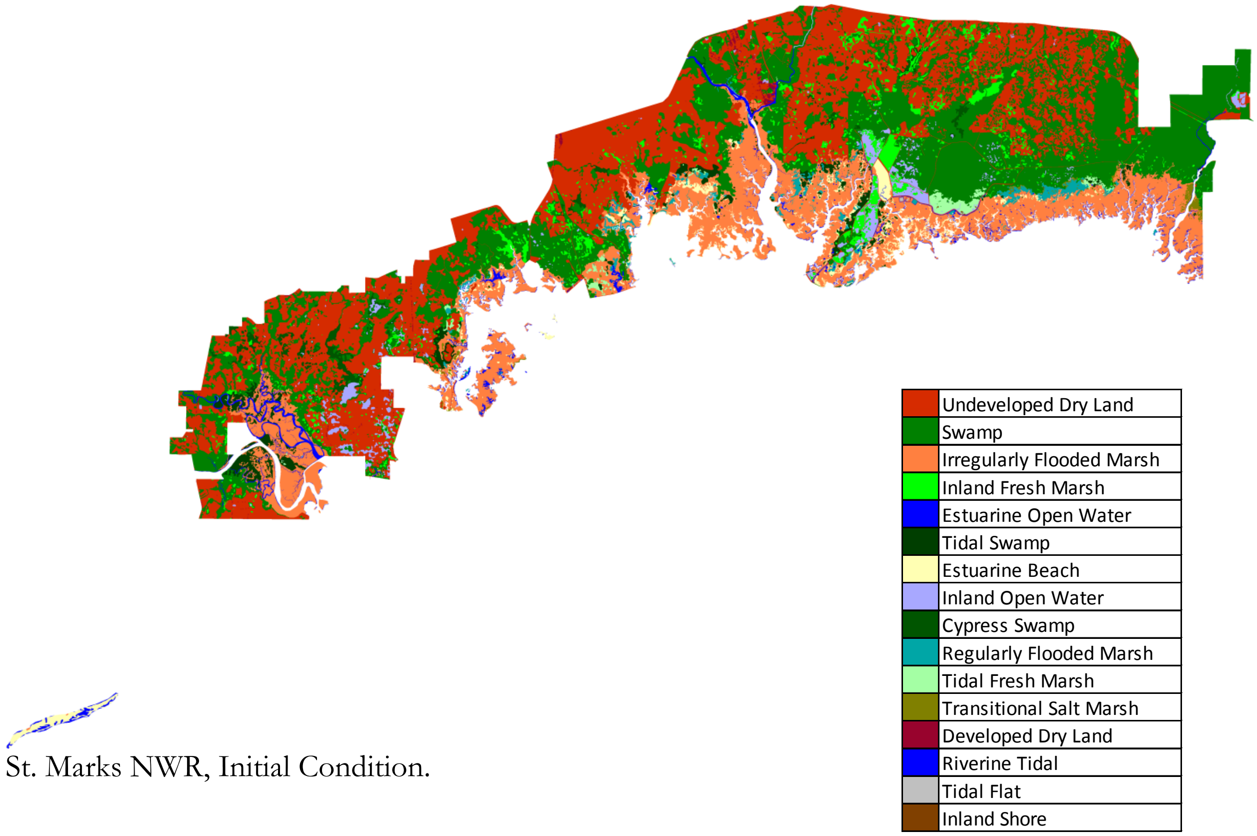
Table 3. Predicted land cover gains by 2100 given simulated scenarios of eustatic SLR at St. Marks NWR.

	Initial	Land cover change by 2100 for different SLR scenarios (Acres)				
		0.39 m	0.69 m	1 m	1.5 m	2 m
Estuarine Open Water	2352	877	1978	3816	11198	21277
Regularly-flooded Marsh	1469	2926	9929	17407	13012	11996
Transitional Salt Marsh	362	5421	4780	5177	8856	13768
Tidal Flat	14	337	1342	5386	17680	17589

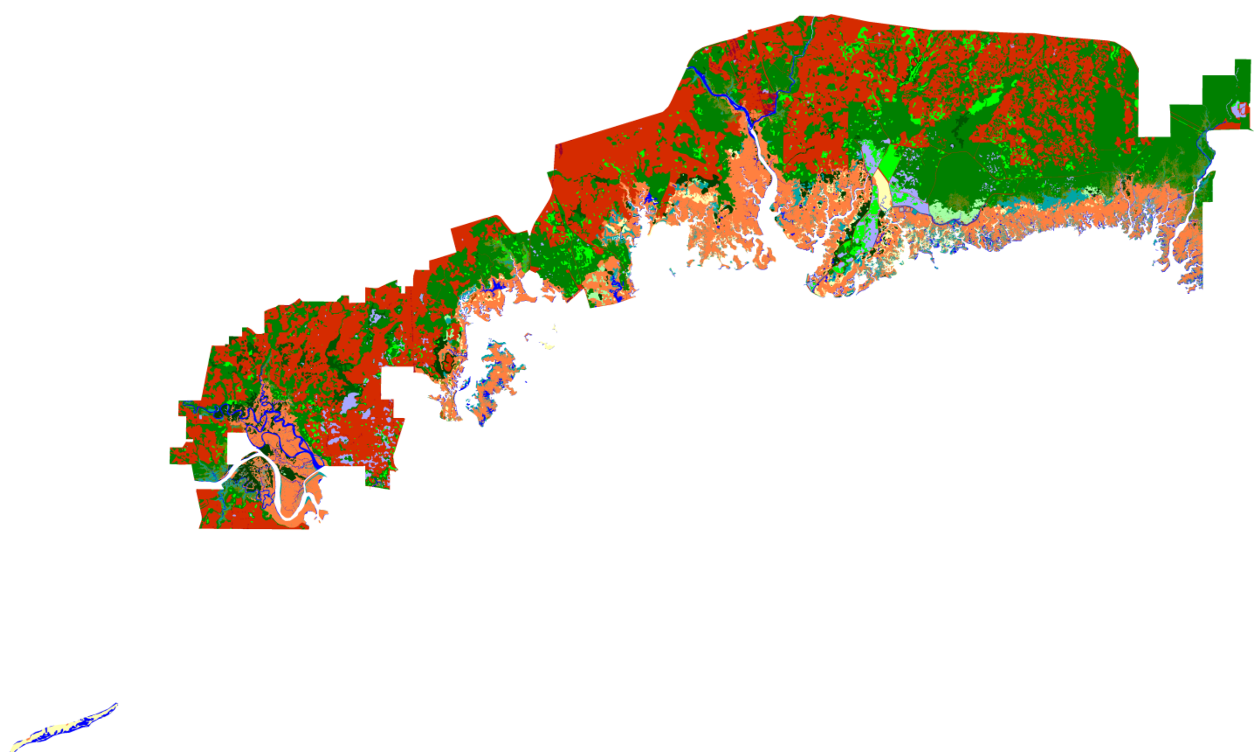
IPCC Scenario A1B-Mean, 0.39 m SLR eustatic by 2100

Results in Acres

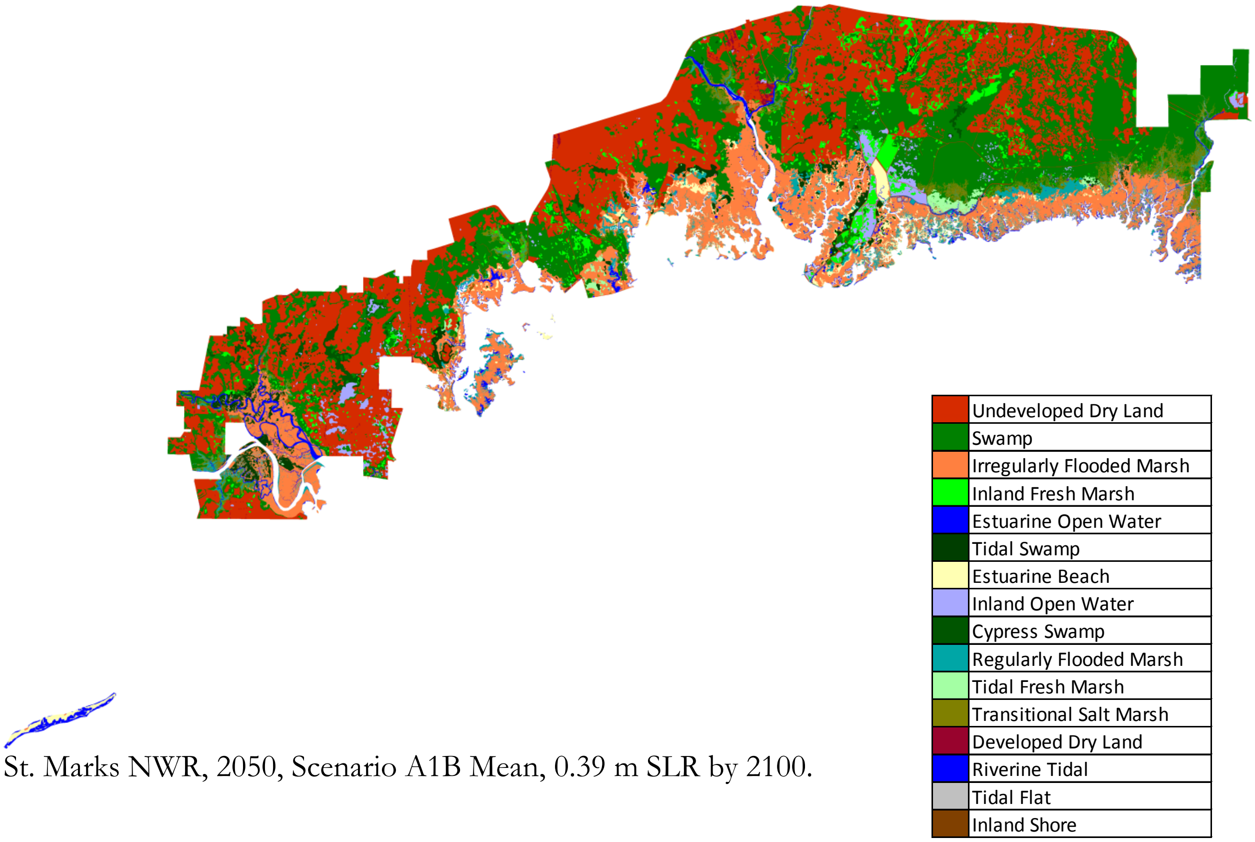
		Initial	2025	2050	2075	2100
	Undeveloped Dry Land	38668	38436	38342	38199	38021
	Swamp	36792	34594	33642	32400	31105
	Irregularly-flooded Marsh	20901	18828	18885	18955	19027
	Inland Fresh Marsh	4245	4089	4088	4087	4087
	Estuarine Open Water	2352	2697	2853	3023	3229
	Tidal Swamp	2343	2222	2164	2035	1875
	Estuarine Beach	2317	2247	2169	2070	1982
	Inland Open Water	2205	2165	2151	2132	2118
	Cypress Swamp	1514	1508	1507	1507	1507
	Regularly-flooded Marsh	1469	4140	4108	4206	4395
	Tidal Fresh Marsh	724	670	670	670	670
	Transitional Salt Marsh	362	2101	3127	4427	5783
	Developed Dry Land	337	325	321	317	313
	Riverine Tidal	261	62	53	46	41
	Tidal Flat	14	420	422	430	351
	Inland Shore	8	8	8	8	8
	Total (incl. water)	**114511**	**114511**	**114511**	**114511**	**114511**



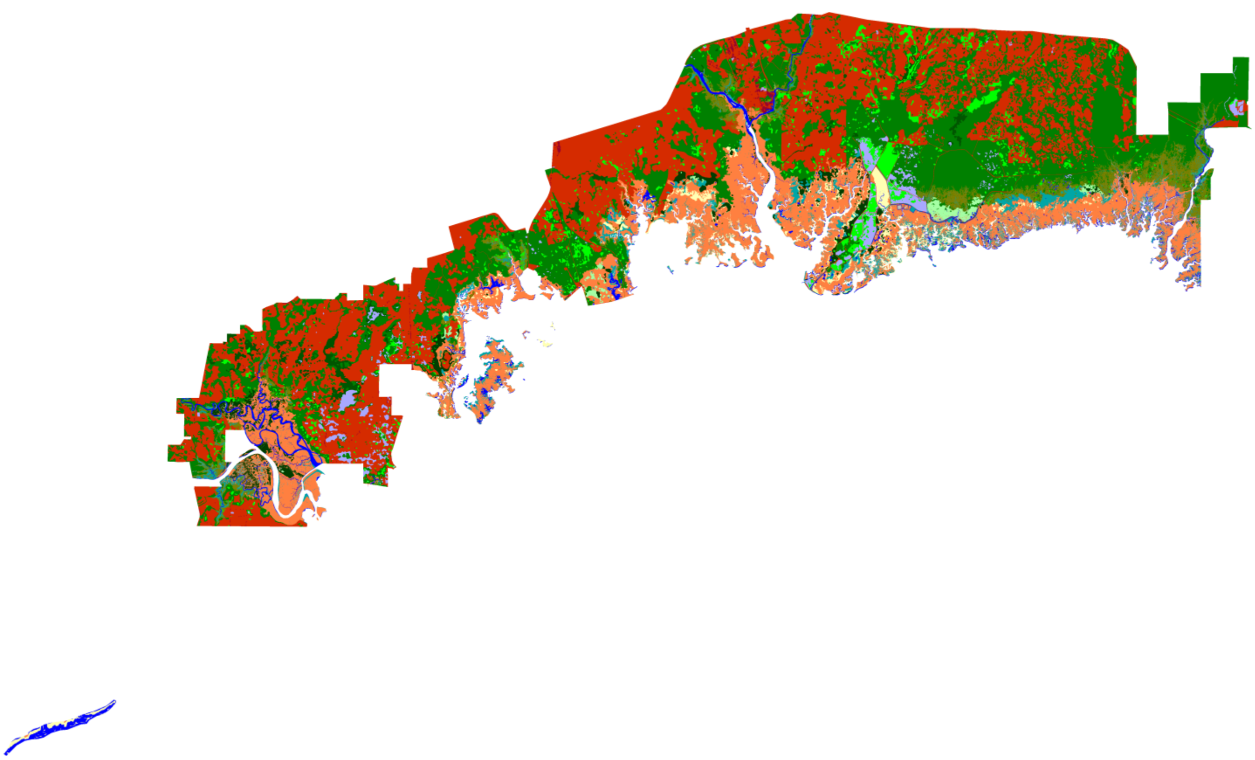
St. Marks NWR, Initial Condition.



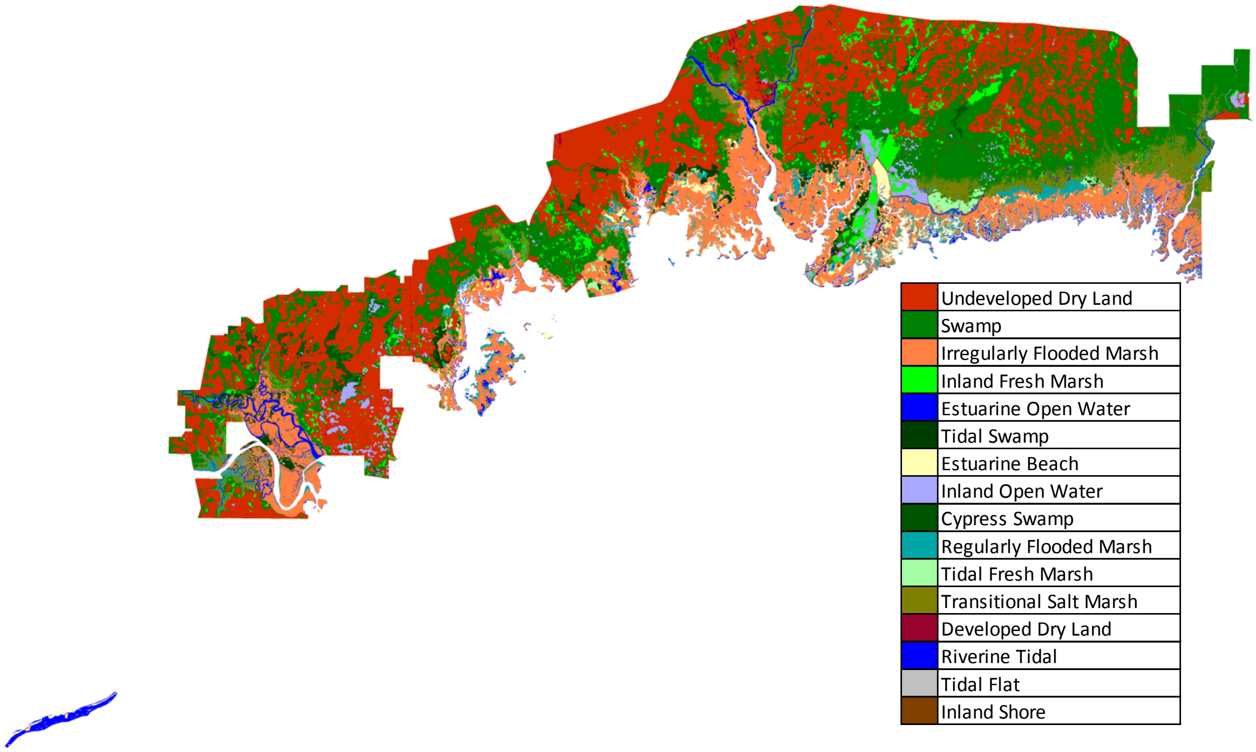
St. Marks NWR, 2025, Scenario A1B Mean, 0.39 m SLR



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



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

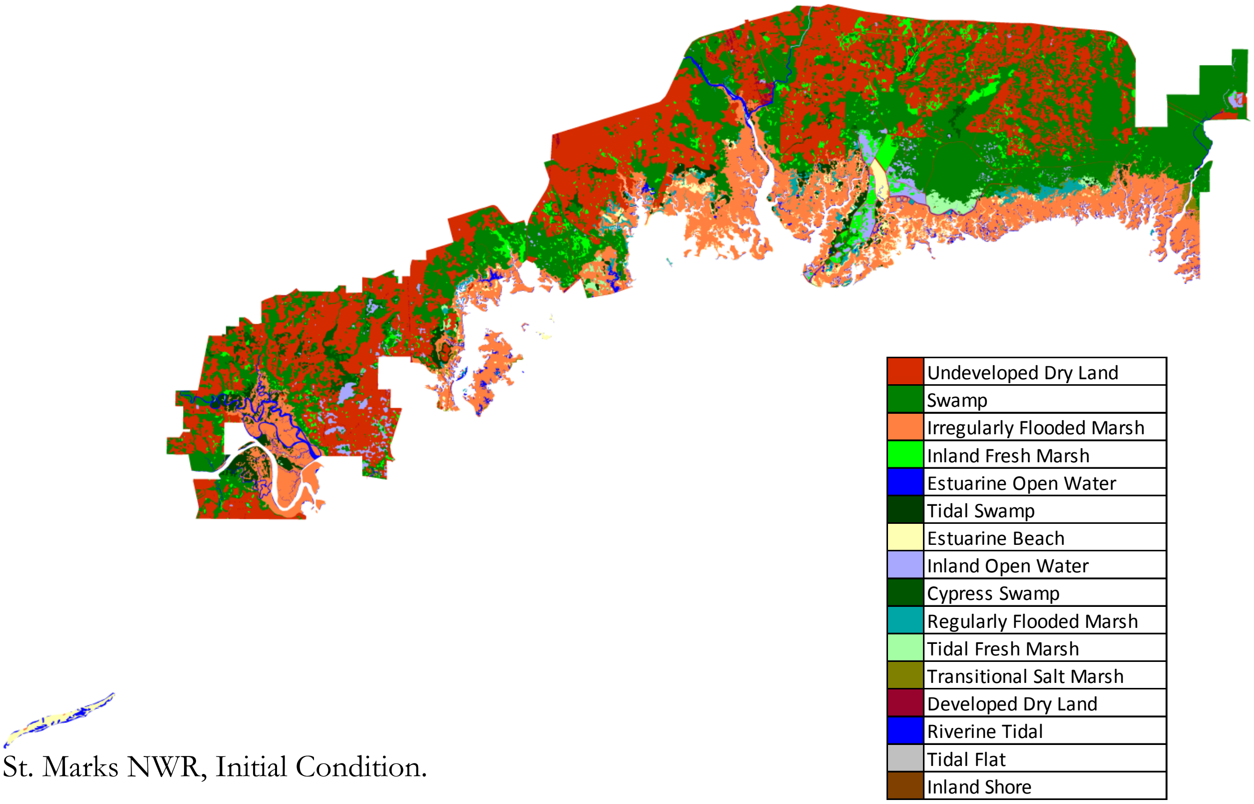


St. Marks NWR, 2100, Scenario A1B Mean, 0.39 m SLR by 2100.

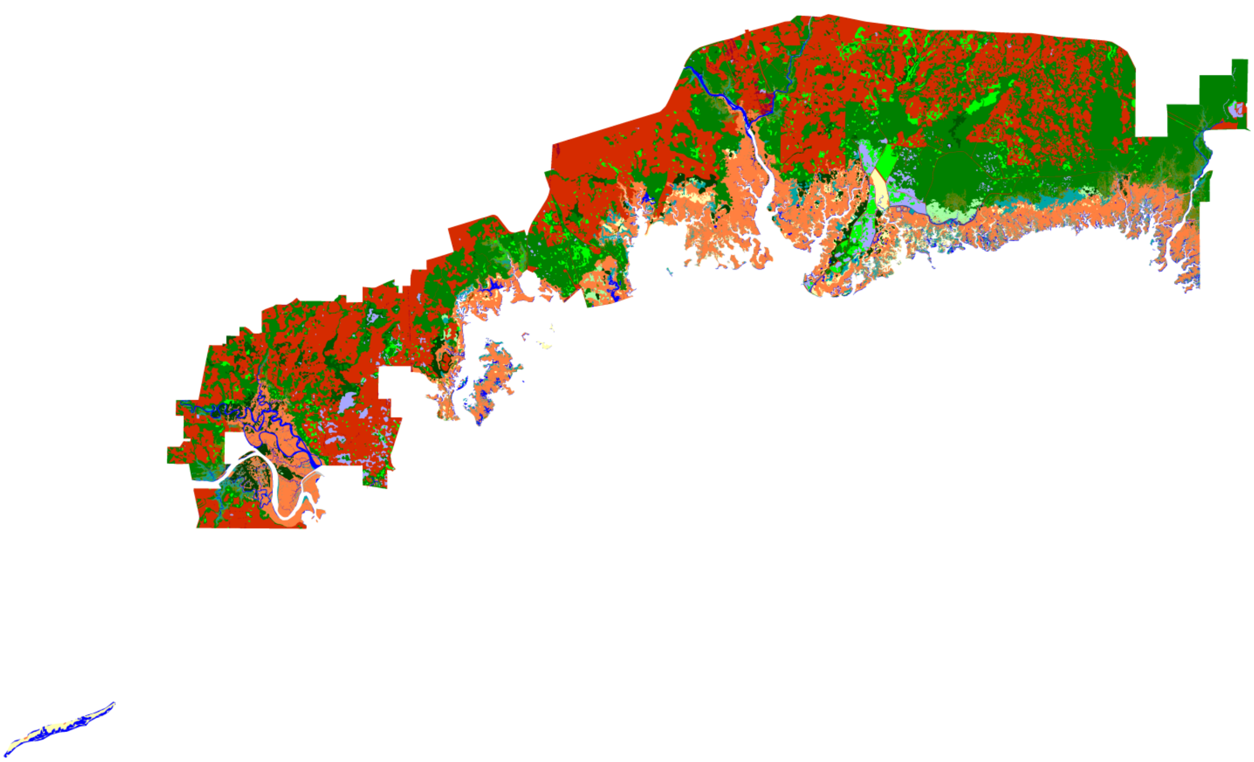
Raster 1
IPCC Scenario A1B-Max, 0.69 m SLR eustatic by 2100

Results in Acres

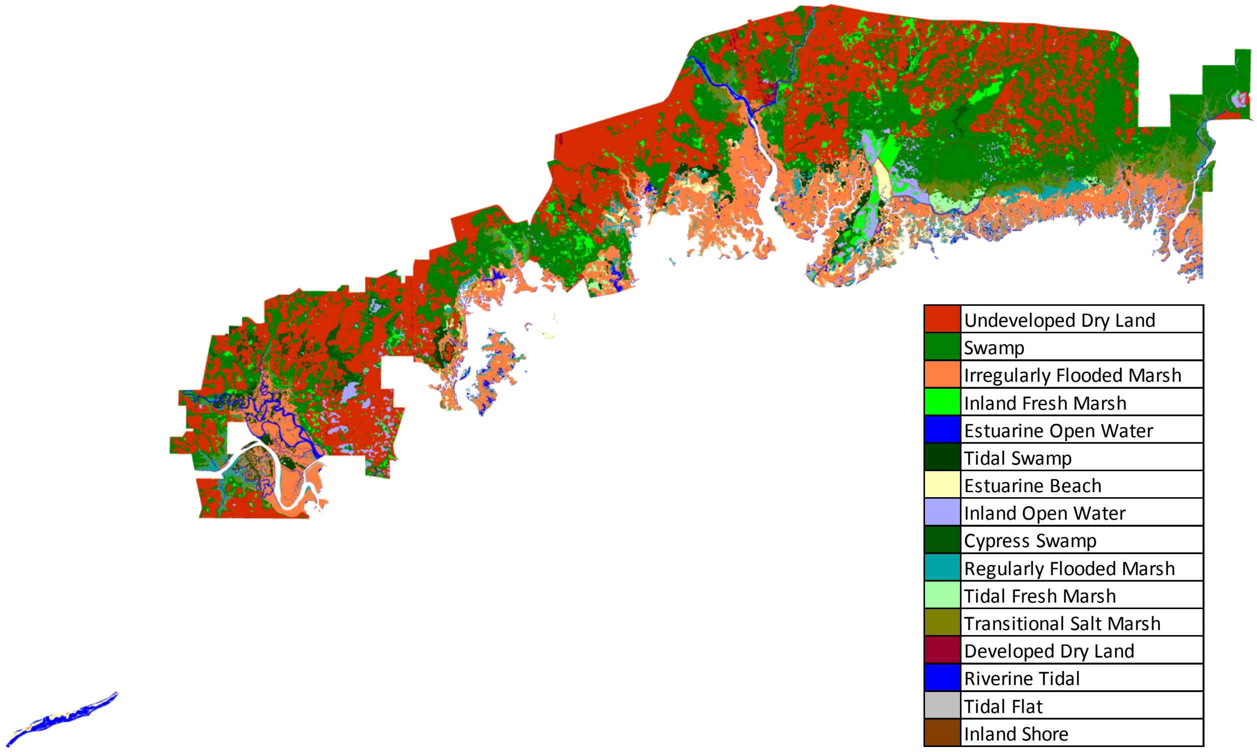
		Initial	2025	2050	2075	2100
	Undeveloped Dry Land	38668	38413	38201	37686	36873
	Swamp	36792	34337	32528	29927	27051
	Irregularly-flooded Marsh	20901	18835	18877	18255	16976
	Inland Fresh Marsh	4245	4084	4077	4050	4008
	Estuarine Open Water	2352	2761	3028	3453	4330
	Tidal Swamp	2343	2203	2024	1669	1292
	Estuarine Beach	2317	2202	2072	1900	1693
	Inland Open Water	2205	2160	2135	2111	1944
	Cypress Swamp	1514	1508	1507	1503	1496
	Regularly-flooded Marsh	1469	4060	4236	6725	11398
	Tidal Fresh Marsh	724	670	670	662	632
	Transitional Salt Marsh	362	2268	4014	5104	5142
	Developed Dry Land	337	323	317	308	286
	Riverine Tidal	261	60	48	38	28
	Tidal Flat	14	620	768	1112	1356
	Inland Shore	8	8	8	8	7
	Total (incl. water)	**114511**	**114511**	**114511**	**114511**	**114511**



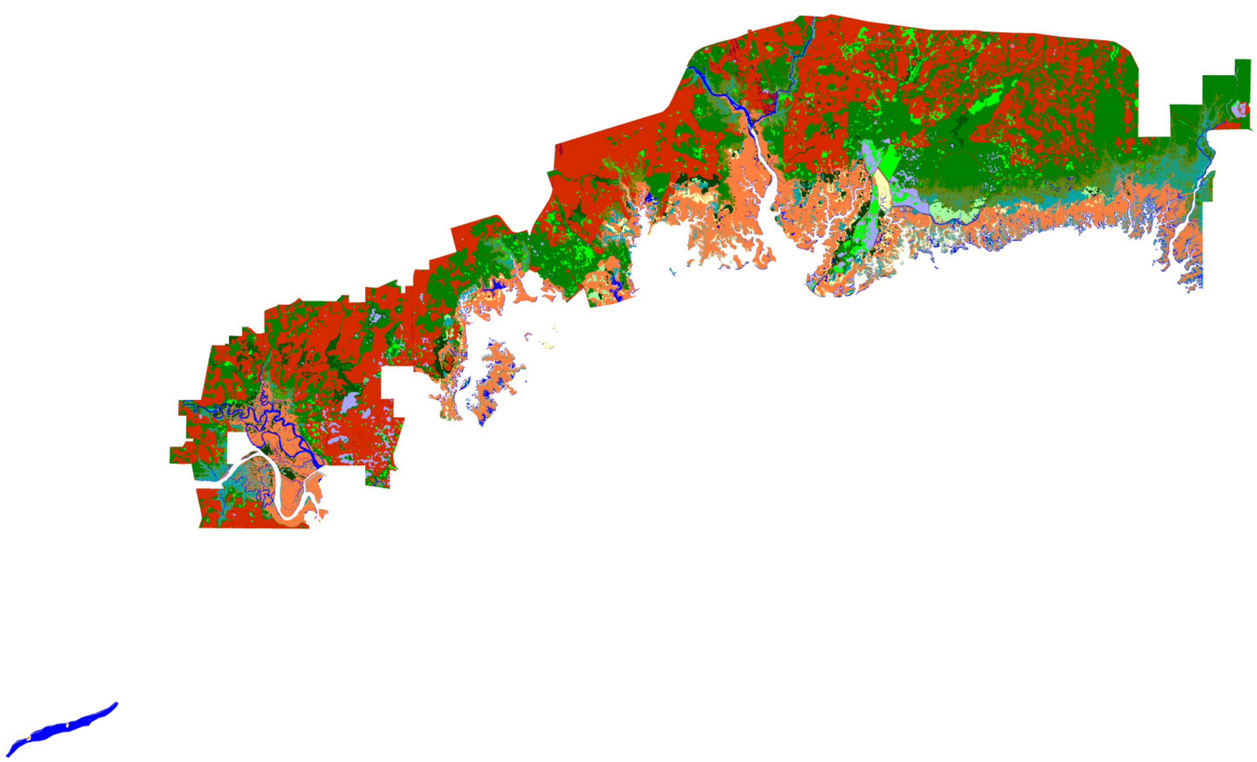
St. Marks NWR, Initial Condition.



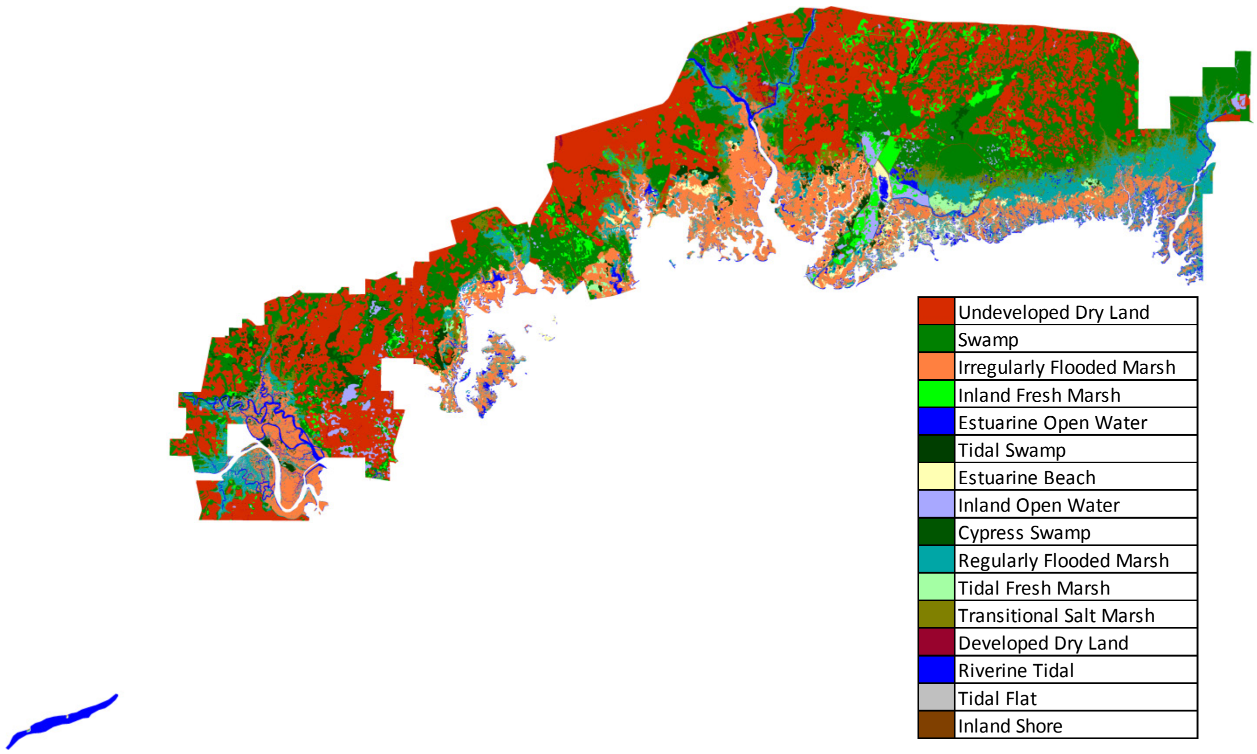
St. Marks NWR, 2025, Scenario A1B Maximum, 0.69 m SLR by 2100.



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



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

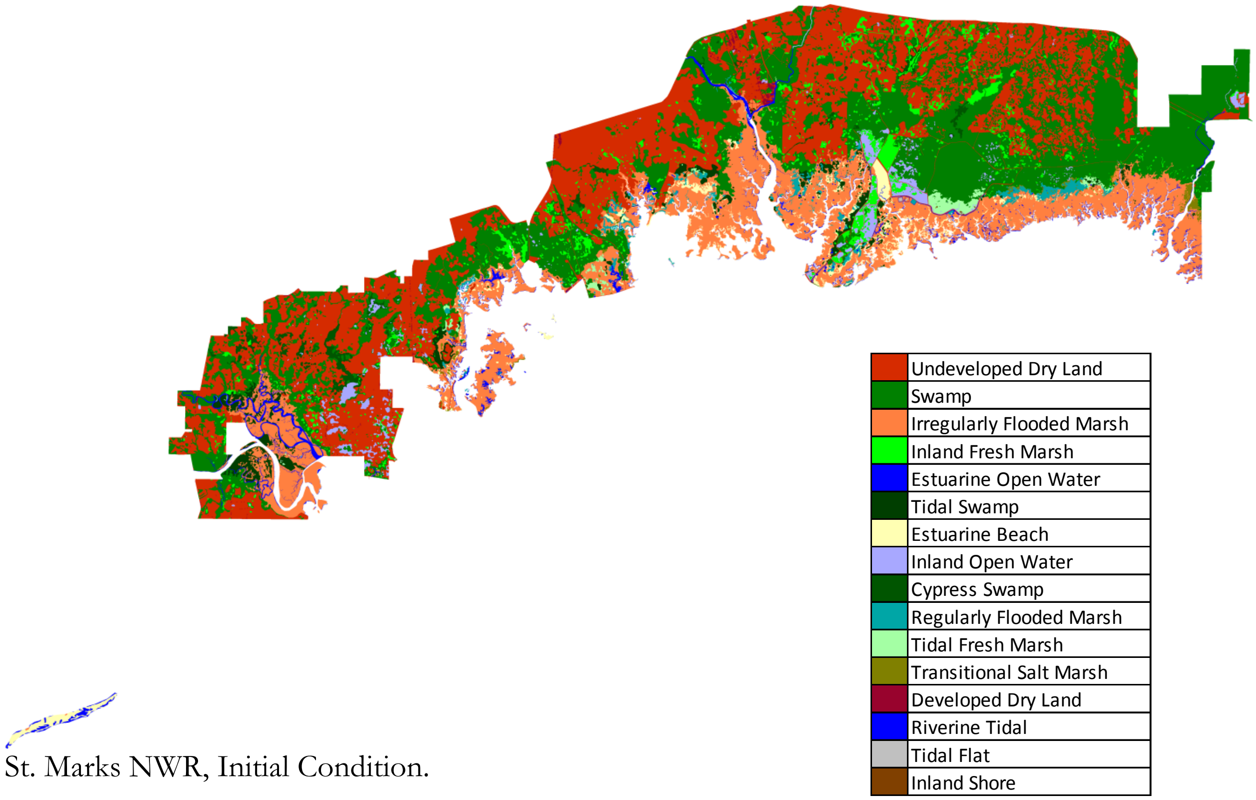


St. Marks NWR, 2100, Scenario A1B Maximum, 0.69 m SLR by 2100.

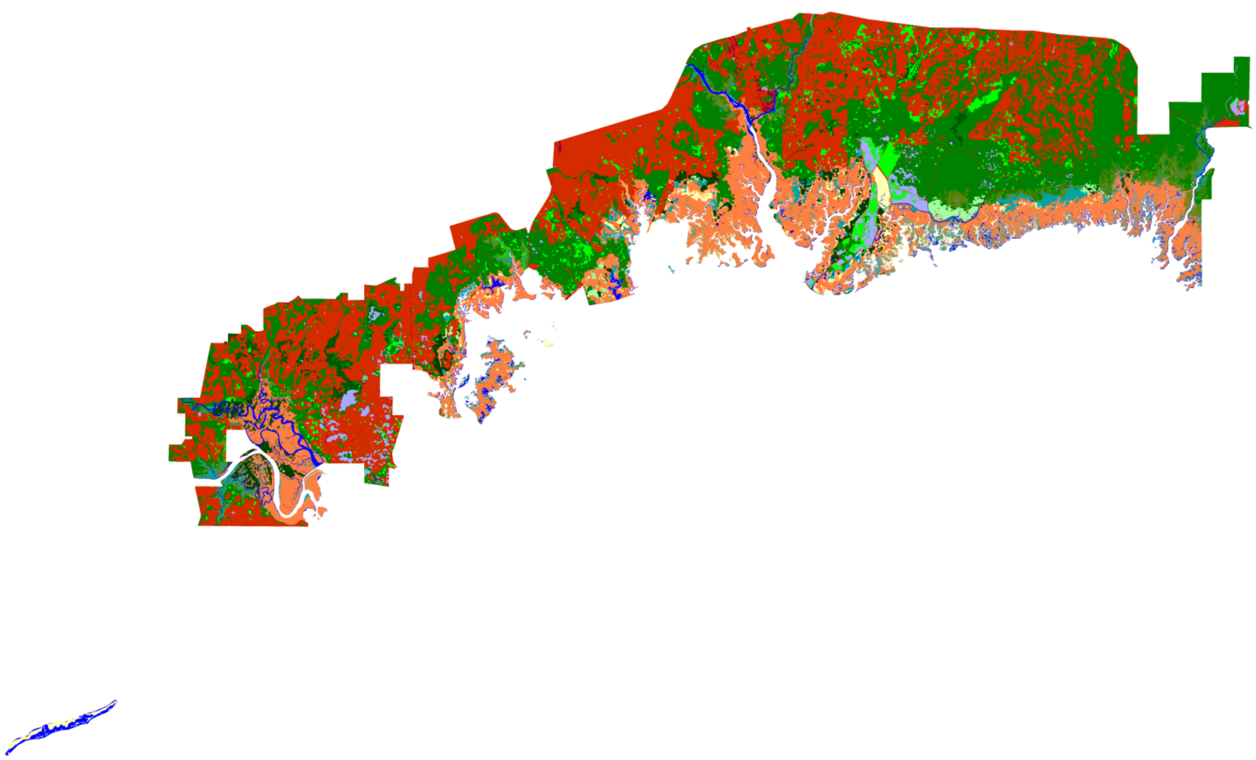
Raster 1
1 m eustatic SLR by 2100

Results in Acres

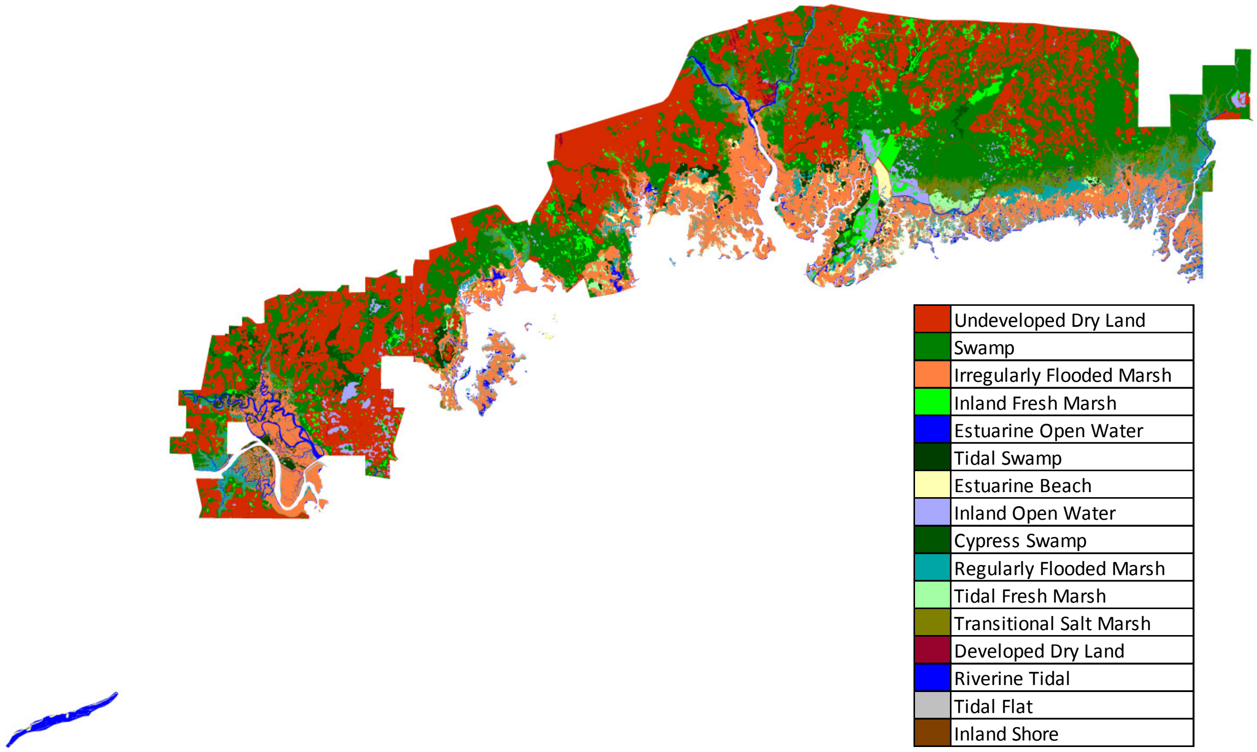
		Initial	2025	2050	2075	2100
	Undeveloped Dry Land	38668	38389	37993	36967	35541
	Swamp	36792	34055	31208	27284	23400
	Irregularly-flooded Marsh	20901	18808	18056	15008	9503
	Inland Fresh Marsh	4245	4078	4028	3927	3810
	Estuarine Open Water	2352	2818	3224	4219	6168
	Tidal Swamp	2343	2180	1832	1288	830
	Estuarine Beach	2317	2153	1968	1714	1436
	Inland Open Water	2205	2157	2117	2005	1854
	Cypress Swamp	1514	1507	1507	1497	1458
	Regularly-flooded Marsh	1469	4152	5790	12115	18876
	Tidal Fresh Marsh	724	670	642	538	408
	Transitional Salt Marsh	362	2433	4451	5317	5539
	Developed Dry Land	337	323	314	289	263
	Riverine Tidal	261	58	43	30	19
	Tidal Flat	14	723	1331	2308	5400
	Inland Shore	8	8	8	7	6
	Total (incl. water)	**114511**	**114511**	**114511**	**114511**	**114511**



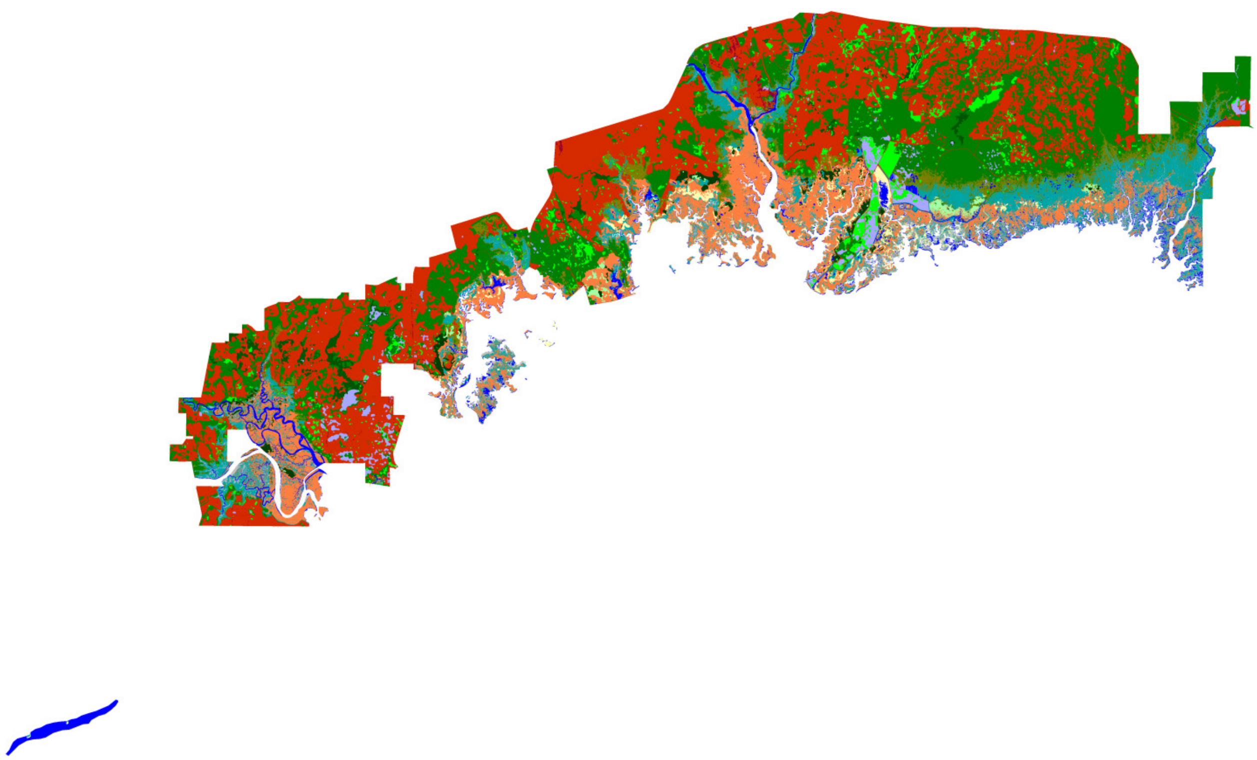
St. Marks NWR, Initial Condition.

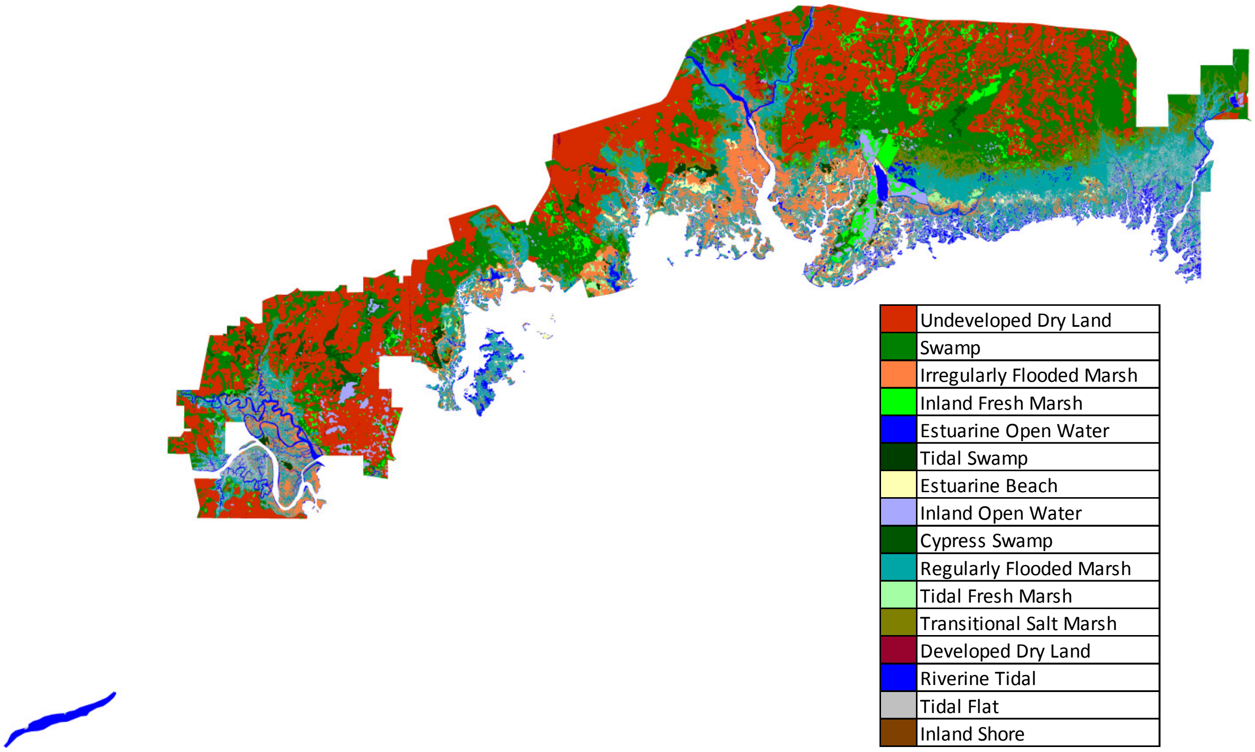


St. Marks NWR, 2025, 1 m SLR by 2100.



St. Marks NWR, 2050, 1 m SLR by 2100.


St. Marks NWR, 2075, 1 m SLR by 2100.

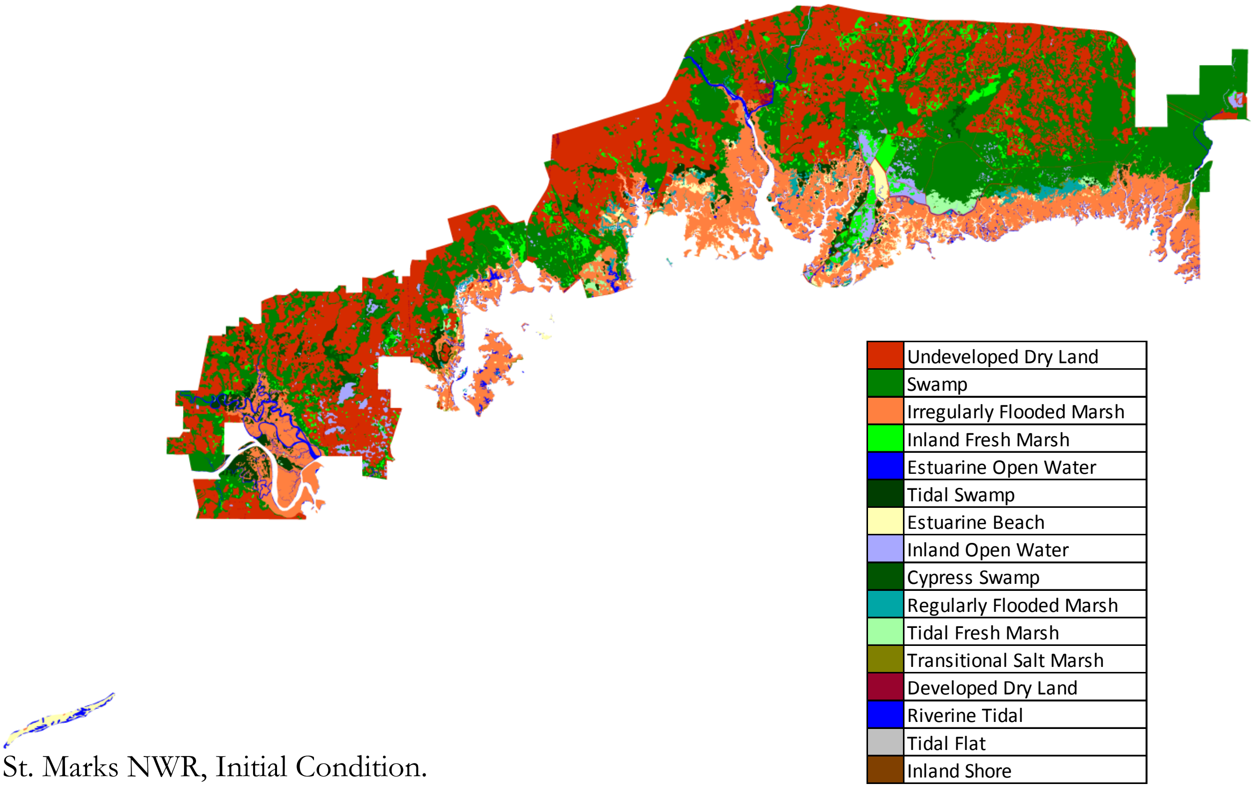


St. Marks NWR, 2100, 1 m SLR by 2100.

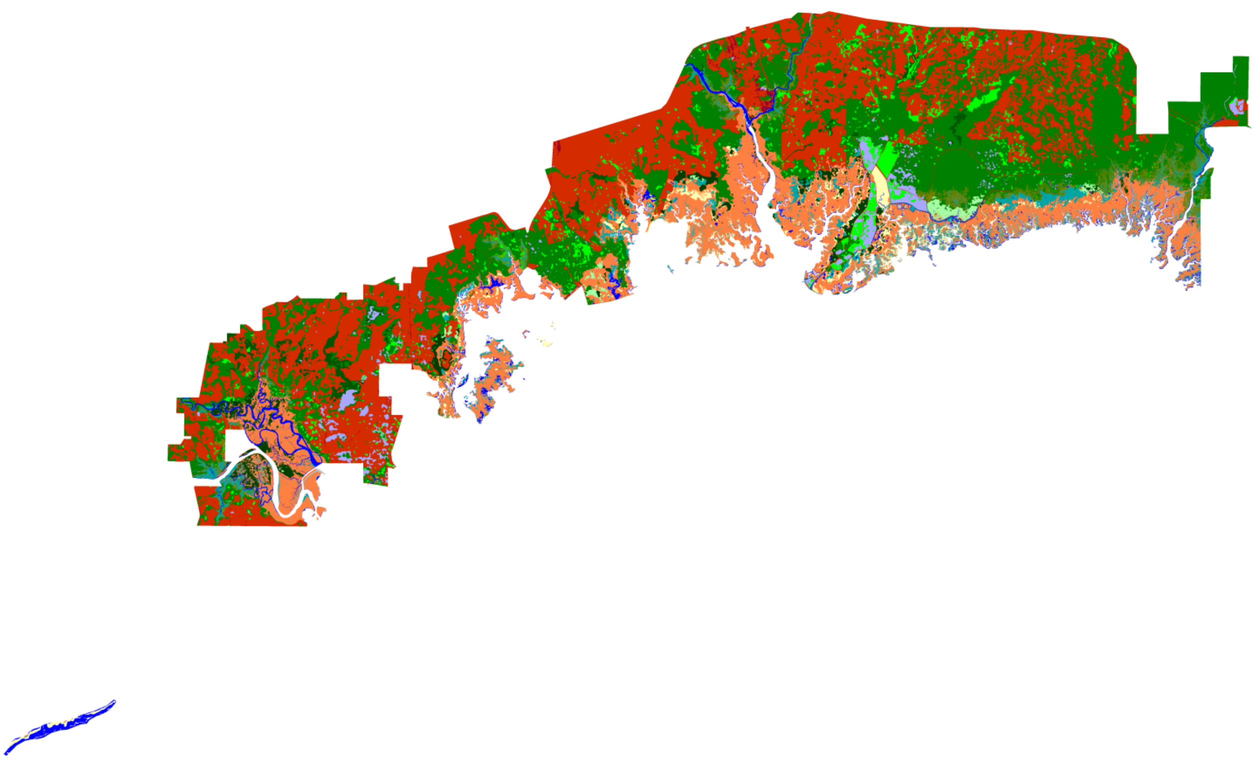
Raster 1
1.5 m eustatic SLR by 2100

Results in Acres

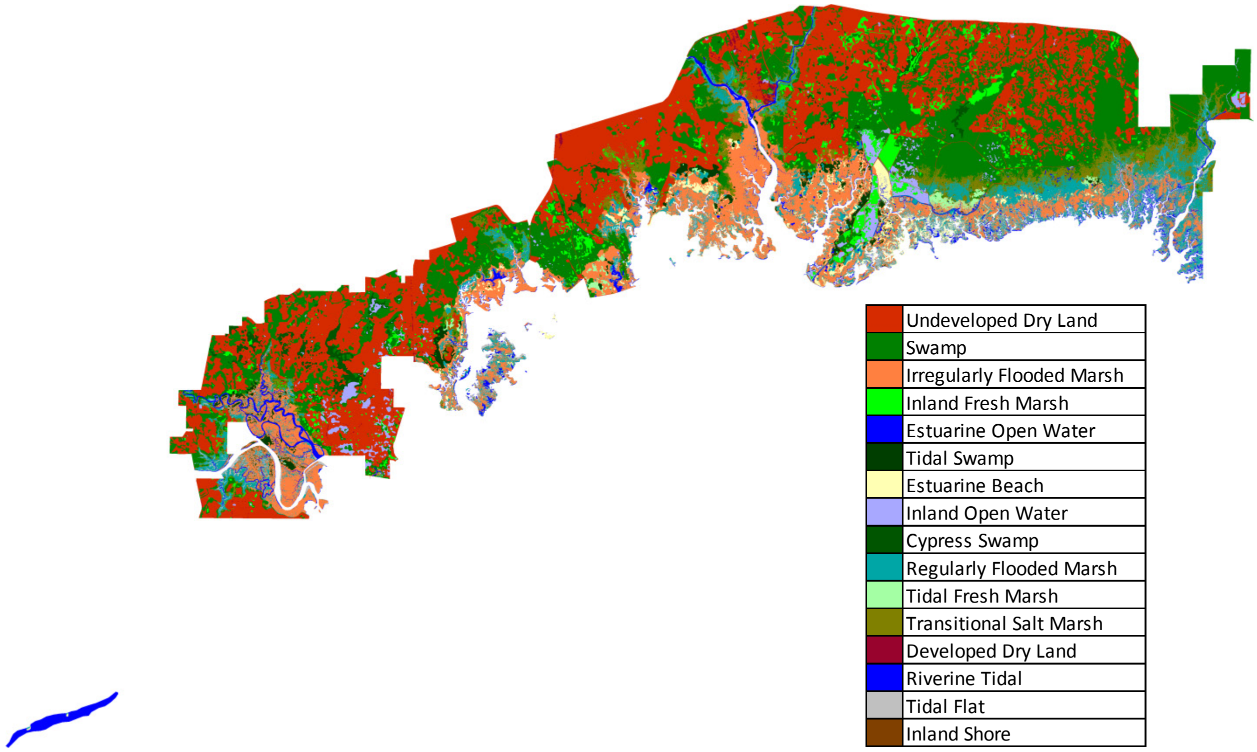
		Initial	2025	2050	2075	2100
	Undeveloped Dry Land	38668	38328	37458	35534	32673
	Swamp	36792	33520	29108	23340	17398
	Irregularly-flooded Marsh	20901	18498	15416	6153	1646
	Inland Fresh Marsh	4245	4059	3922	3676	3300
	Estuarine Open Water	2352	2909	3556	6416	13550
	Tidal Swamp	2343	2130	1511	797	345
	Estuarine Beach	2317	2077	1882	1439	624
	Inland Open Water	2205	2152	2101	1892	1744
	Cypress Swamp	1514	1507	1501	1458	1425
	Regularly-flooded Marsh	1469	4651	9275	18211	14482
	Tidal Fresh Marsh	724	659	526	311	165
	Transitional Salt Marsh	362	2742	5547	8011	9217
	Developed Dry Land	337	320	304	263	234
	Riverine Tidal	261	55	37	20	13
	Tidal Flat	14	896	2360	6986	17694
	Inland Shore	8	8	8	6	2
	Total (incl. water)	**114511**	**114511**	**114511**	**114511**	**114511**



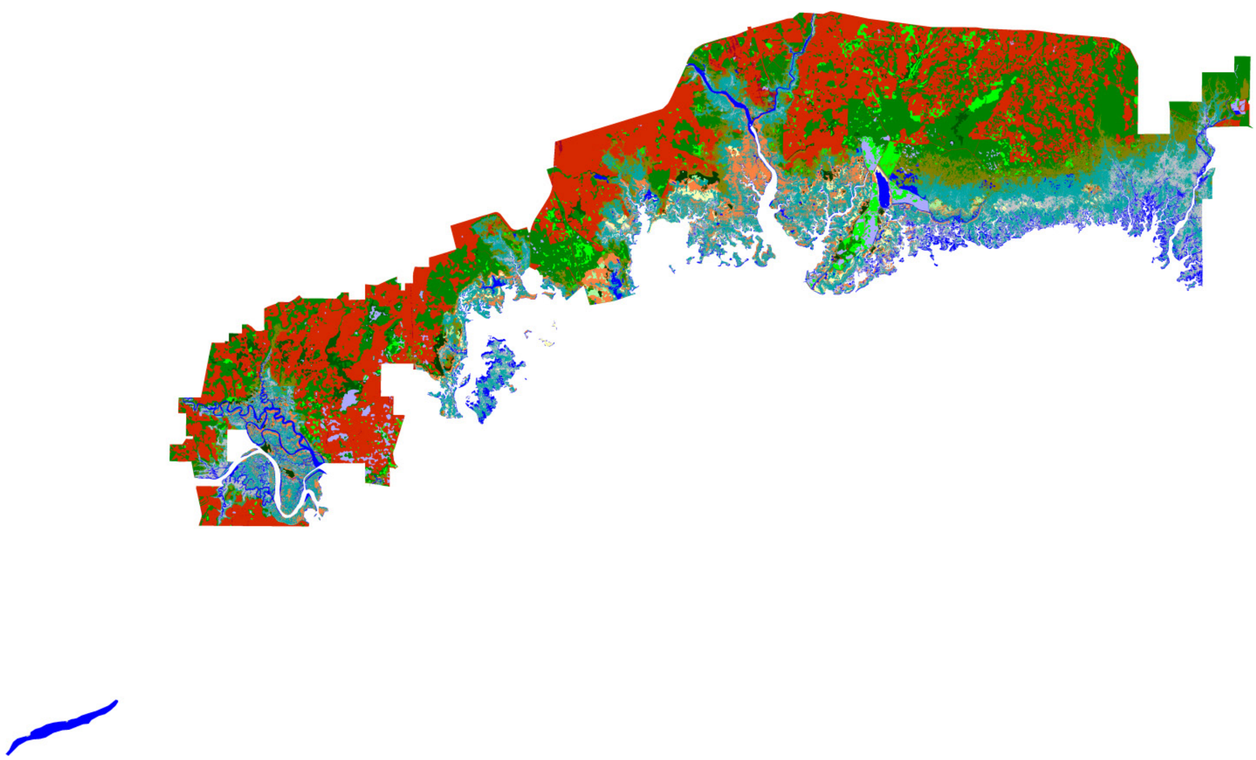
St. Marks NWR, Initial Condition.



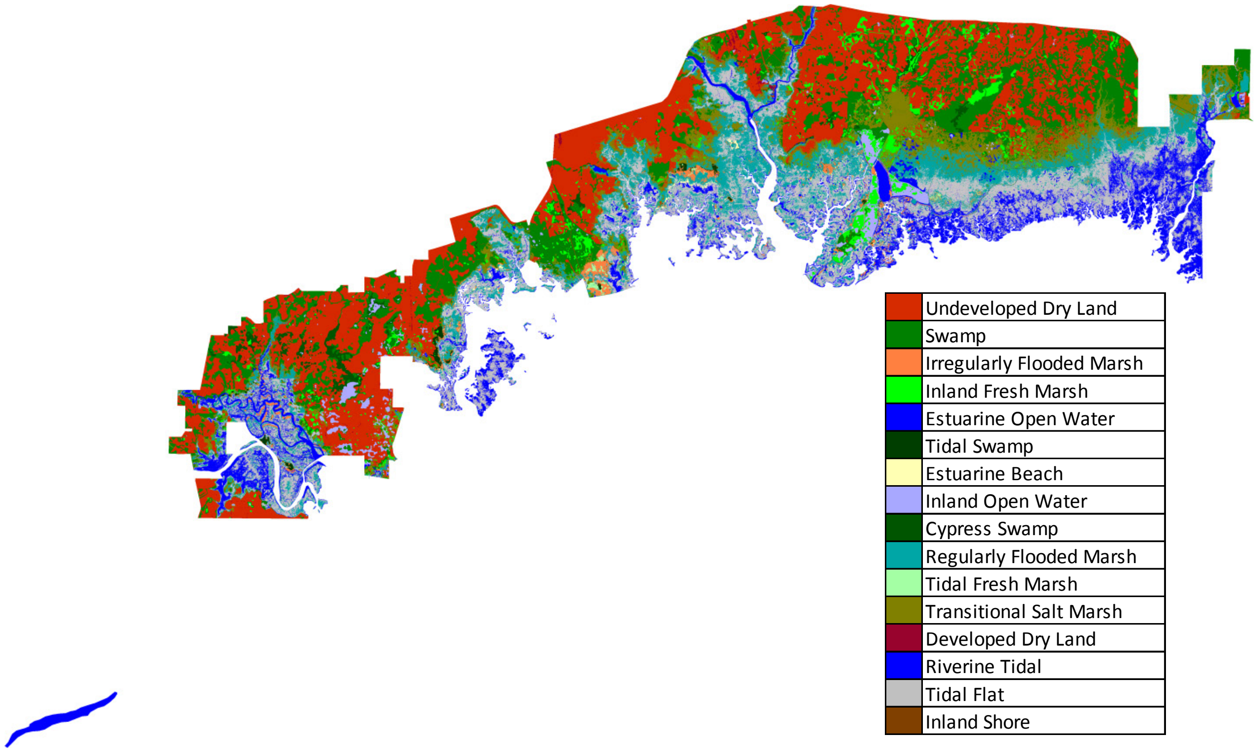
St. Marks NWR, 2025, 1.5 m SLR by 2100.



St. Marks NWR, 2050, 1.5 m SLR by 2100.



St. Marks NWR, 2075, 1.5 m SLR by 2100.

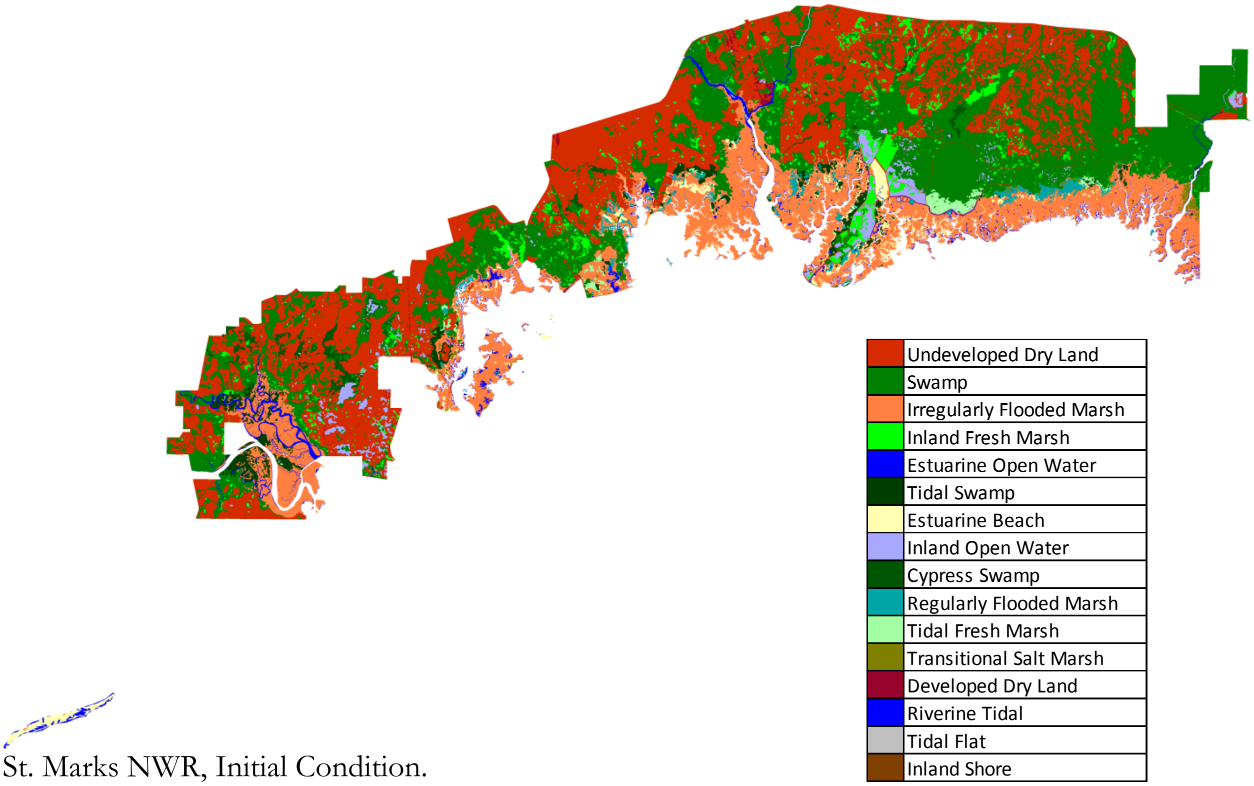


St. Marks NWR, 2100, 1.5 m SLR by 2100.

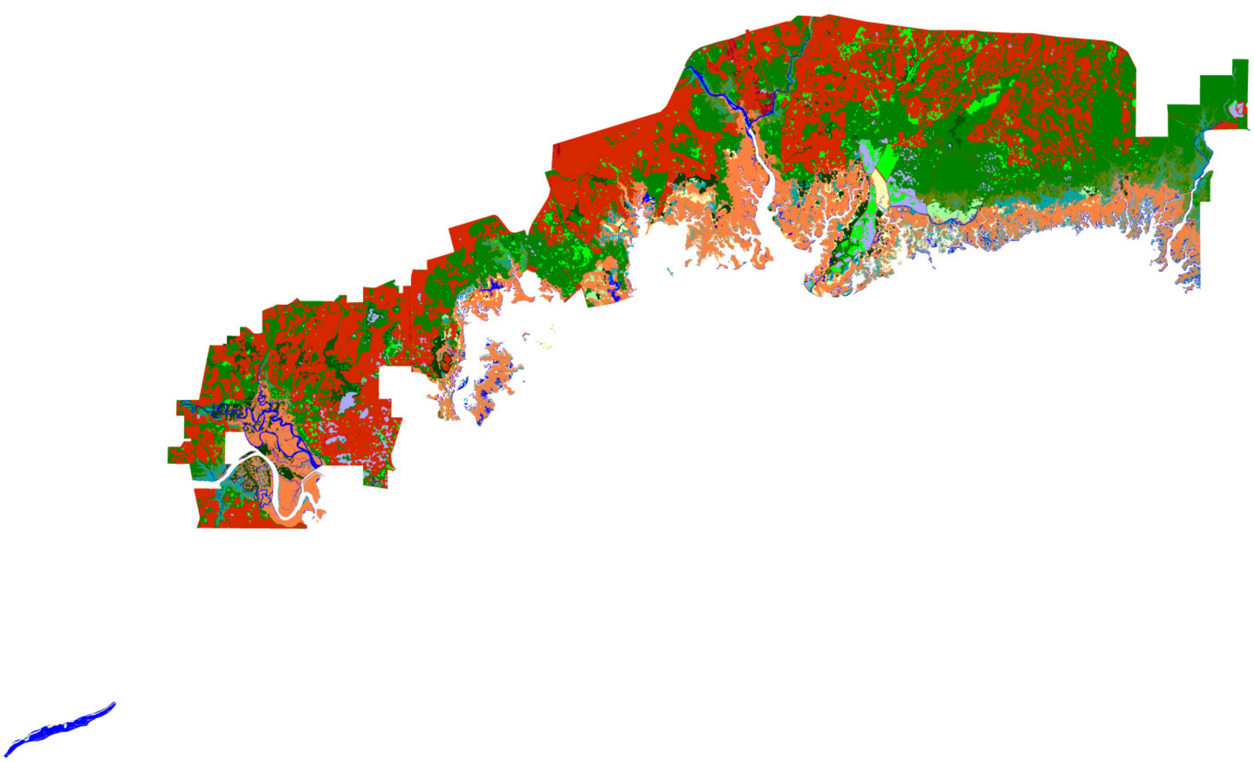
Raster 1
2 m eustatic SLR by 2100

Results in Acres

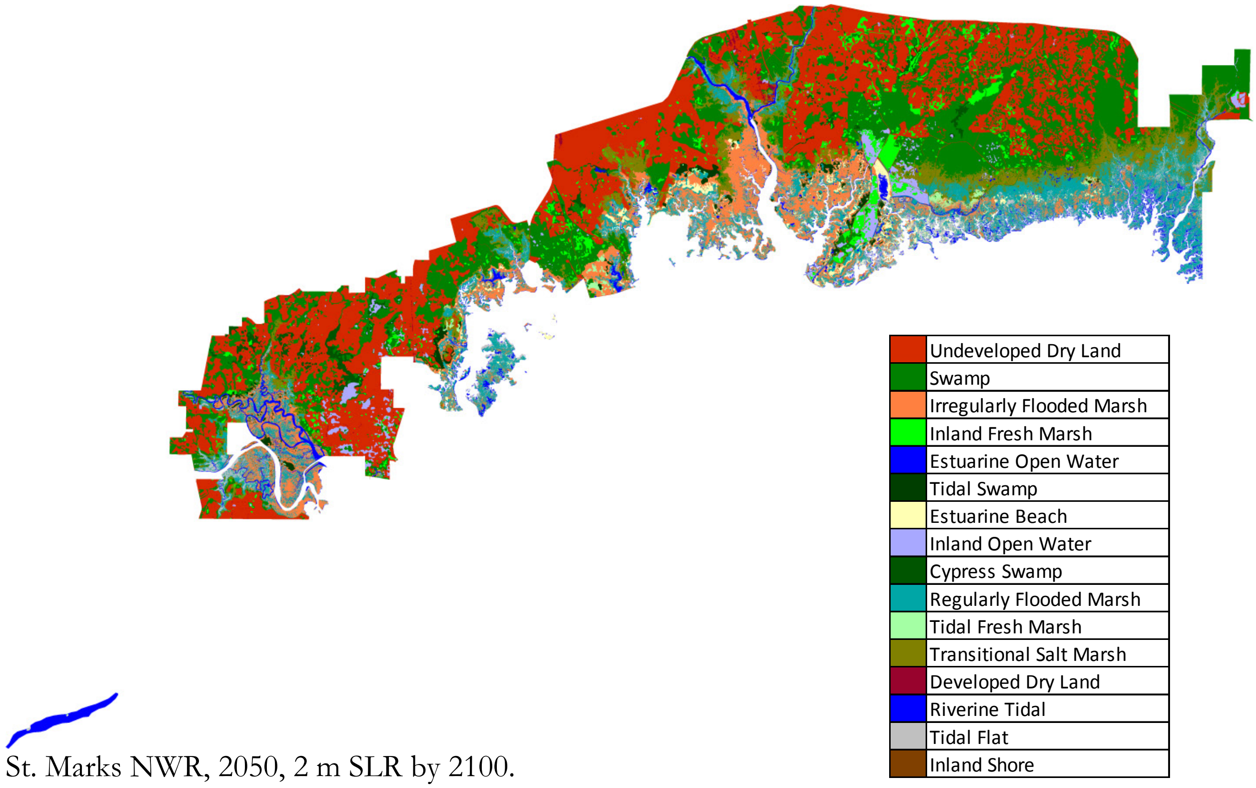
		Initial	2025	2050	2075	2100
	Undeveloped Dry Land	38668	38270	36888	33729	27818
	Swamp	36792	32968	26946	19148	11538
	Irregularly-flooded Marsh	20901	18143	11124	2067	612
	Inland Fresh Marsh	4245	4034	3807	3312	2738
	Estuarine Open Water	2352	3001	4192	8991	23629
	Tidal Swamp	2343	2066	1202	454	128
	Estuarine Beach	2317	2001	1703	973	82
	Inland Open Water	2205	2146	2082	1828	1577
	Cypress Swamp	1514	1507	1477	1442	924
	Regularly-flooded Marsh	1469	5163	13279	18175	13465
	Tidal Fresh Marsh	724	639	399	168	47
	Transitional Salt Marsh	362	3030	7719	11503	14130
	Developed Dry Land	337	319	287	244	209
	Riverine Tidal	261	52	31	15	10
	Tidal Flat	14	1164	3371	12458	17603
	Inland Shore	8	8	7	4	1
	Total (incl. water)	**114511**	**114511**	**114511**	**114511**	**114511**



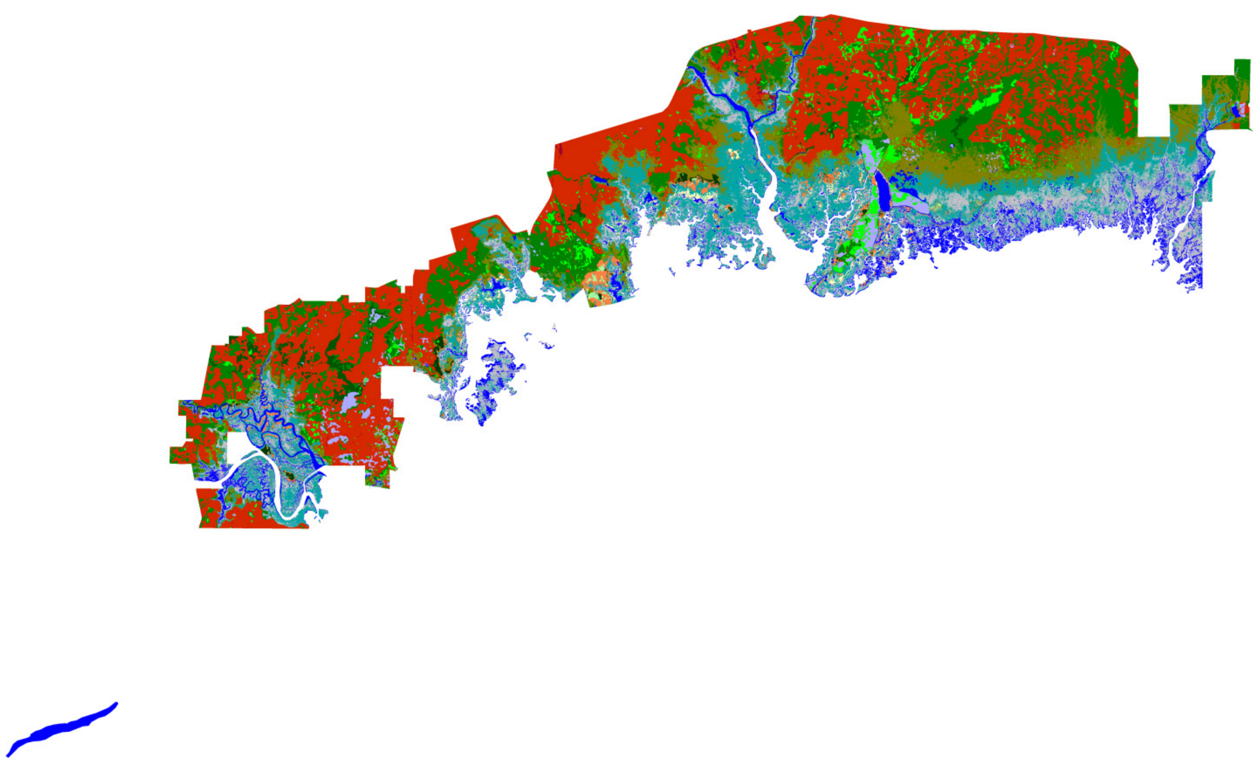
St. Marks NWR, Initial Condition.



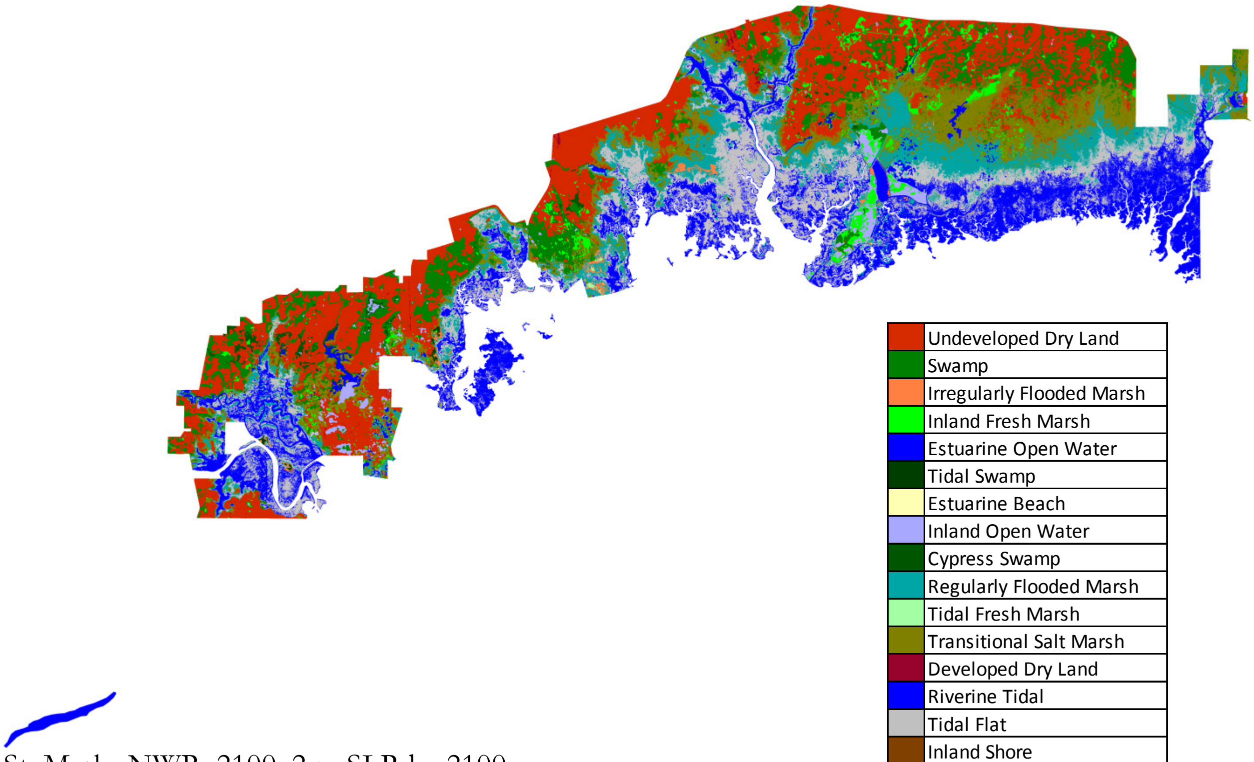
St. Marks NWR, 2025, 2 m SLR by 2100.



St. Marks NWR, 2050, 2 m SLR by 2100.



St. Marks NWR, 2075, 2 m SLR by 2100.



St. Marks NWR, 2100, 2 m SLR by 2100.

Discussion

SLAMM predictions for St. Marks NWR suggest that refuge wetland coverage is relatively resilient to sea-level rise under the 0.39 m by 2100 scenario (the lowest SLR scenario examined), but quite susceptible at higher SLR scenarios. Swamp and irregularly-flooded marsh, which currently make up 50% of the refuge wetlands, are projected to be reduced by 53% and 92%, respectively, under the 1.5 m of SLR by 2100 scenario. Simulations suggest irregularly-flooded marsh, estuarine beach, tidal swamp, and tidal-fresh marsh habitats will be nearly eliminated under the 2 m of SLR by 2100 scenario. These losses suggest accelerated SLR may lead to a loss in habitat richness in the refuge.

Some uncertainty exists in the input data parameters due to lack of sufficient site-specific erosion data. Although some of the erosion data applied was based on data collected in nearby Choctawhatchee Bay, there is high variability in erosion rates both spatially and temporally. Since St. Marks NWR is located in a portion of the Big Bend region of the Florida coast that is considered to be a low-energy coast with little wave action (U.S. Department of the Interior, Fish and Wildlife Service Southeast Region 2006), the erosion values applied may overestimate the non-storm related erosion rates.

Compared to the previous SLAMM analysis of the refuge conducted in 2008, current predictions show similar trends in wetland losses. However, the high-resolution LiDAR data and refined wetlands data layer allow for a more precise analysis of wetland losses and the potential timing of loss.

While data-layer updates have considerably improved the SLAMM projections reported here, input layers, parameter inputs (as mentioned above), 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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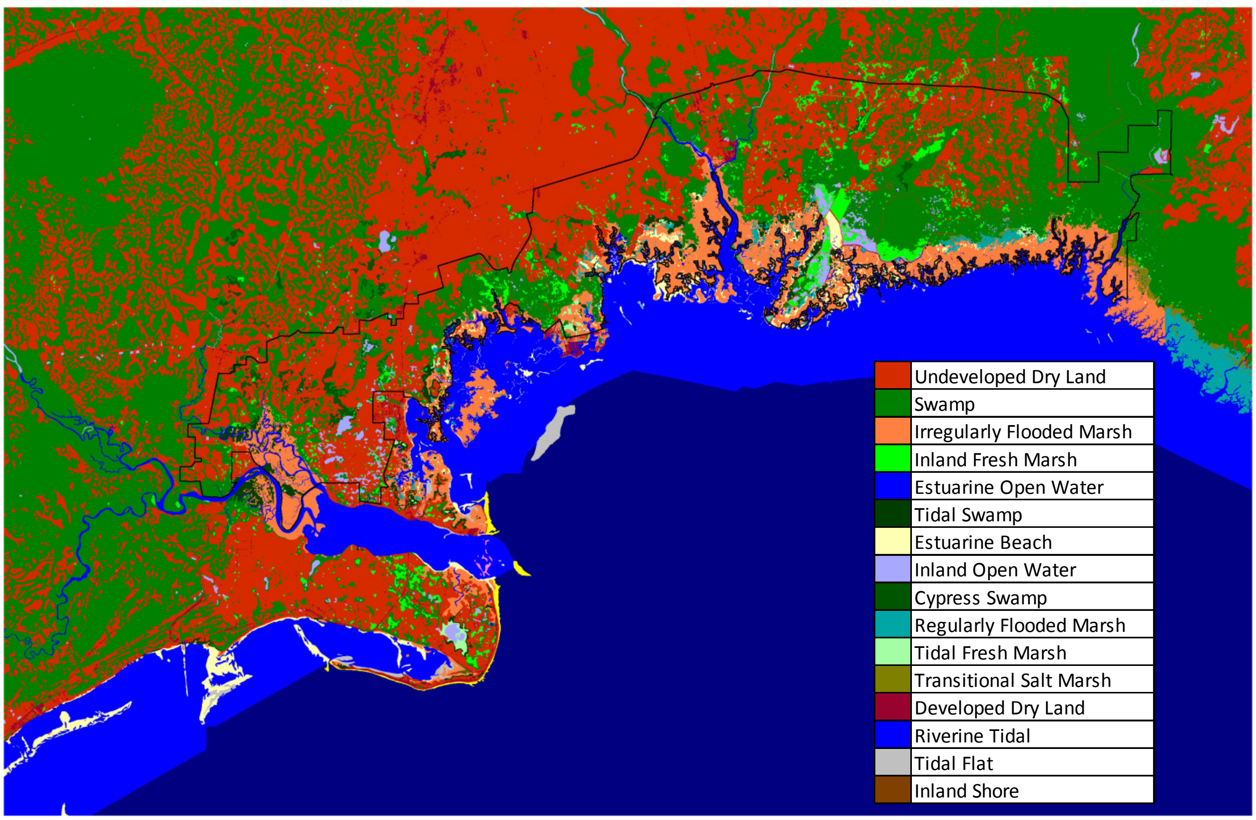
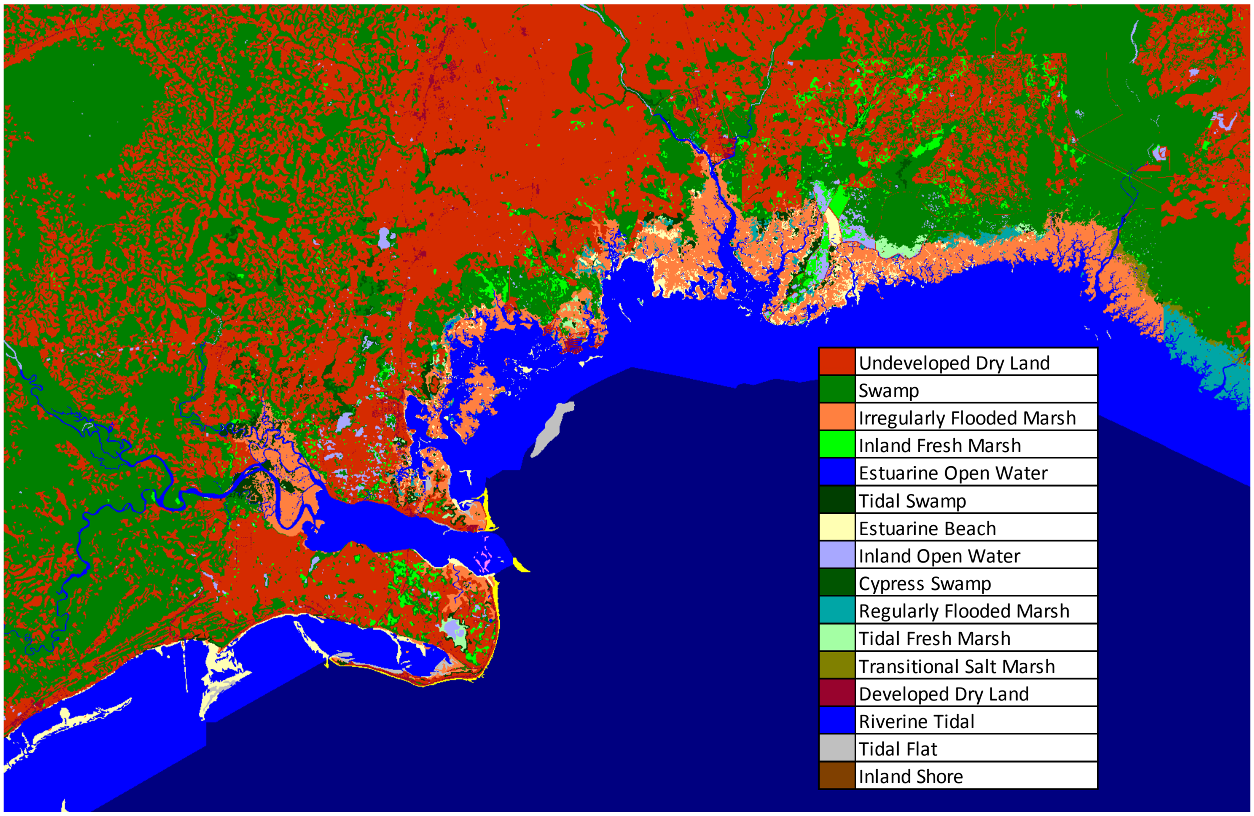
Appendix A: Contextual Results

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:

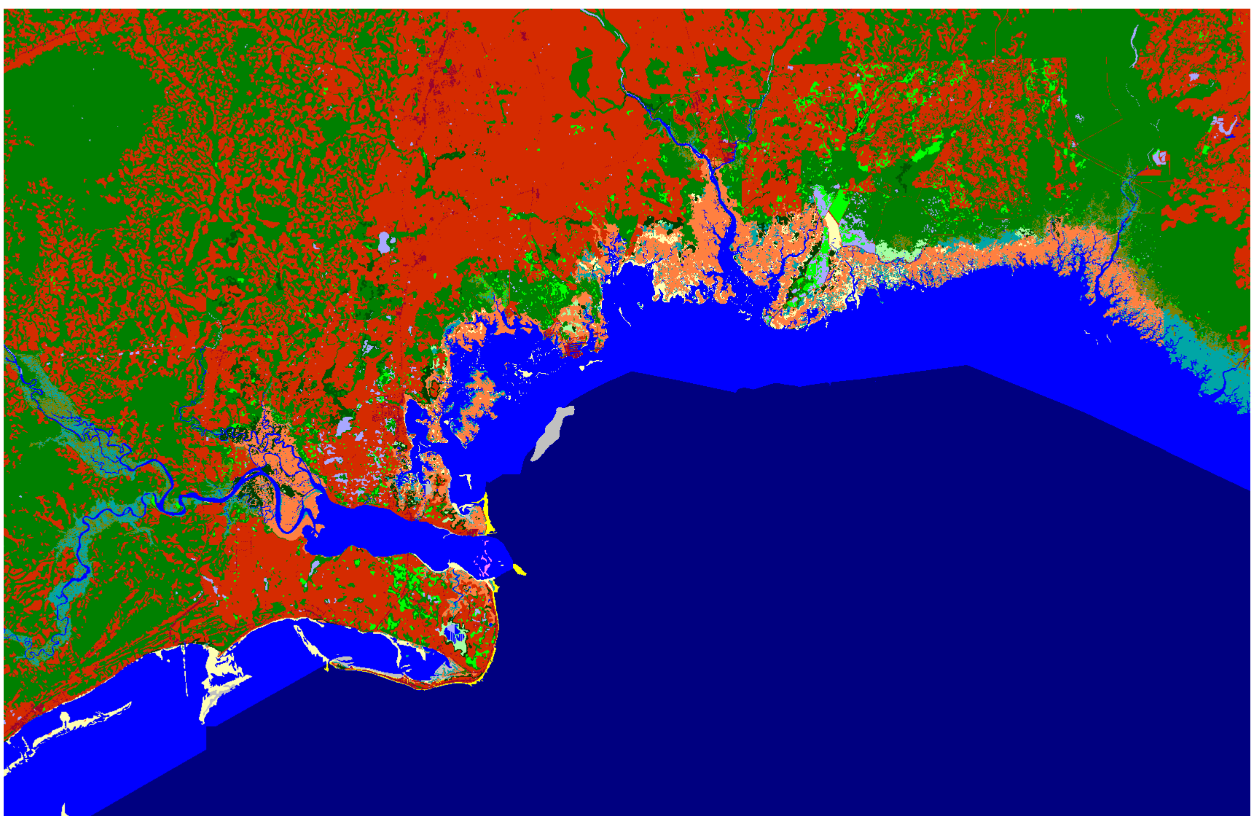
- Results were critically examined within USFWS refuges but not closely examined for the larger region.
- Site-specific parameters for the model were derived for USFWS refuges whenever possible and may not be regionally applicable.
- Especially in areas where dikes are present, an effort was made to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

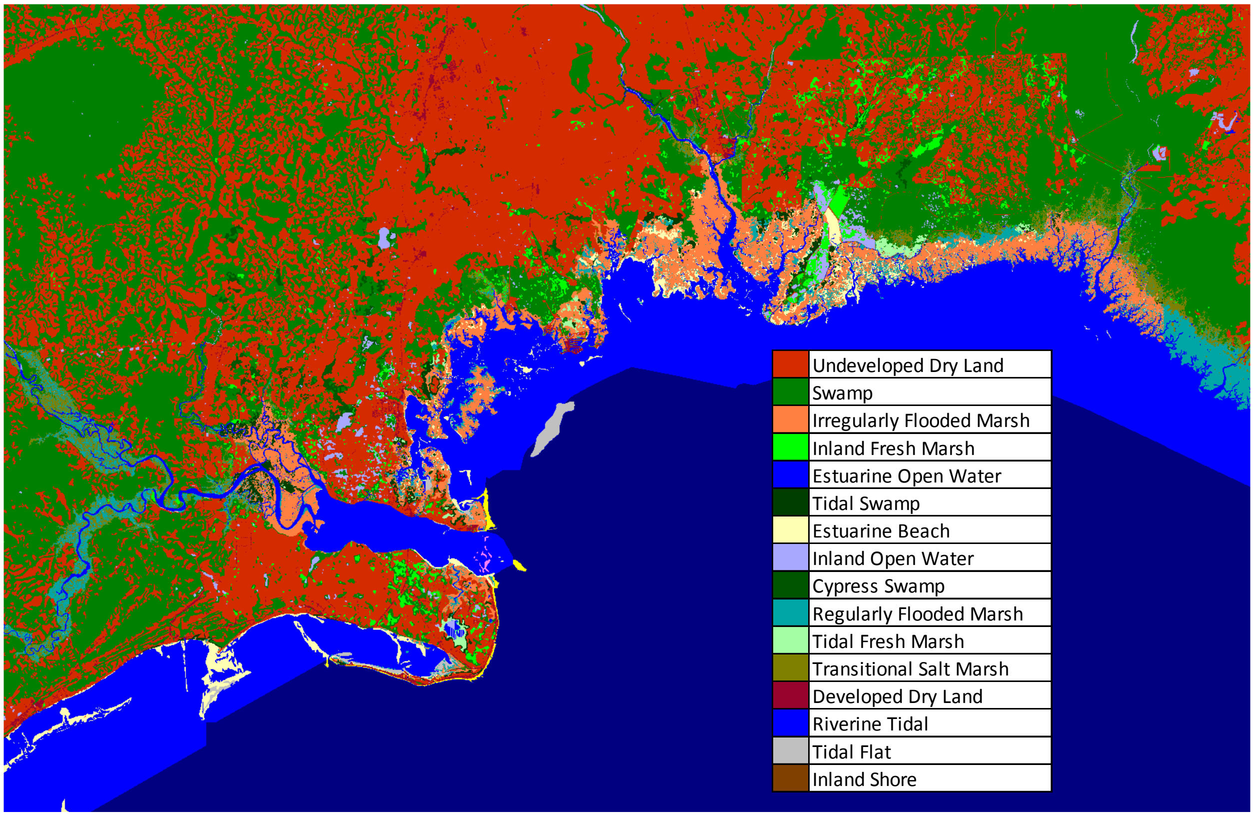


St. Marks National Wildlife Refuge within simulation context (black).

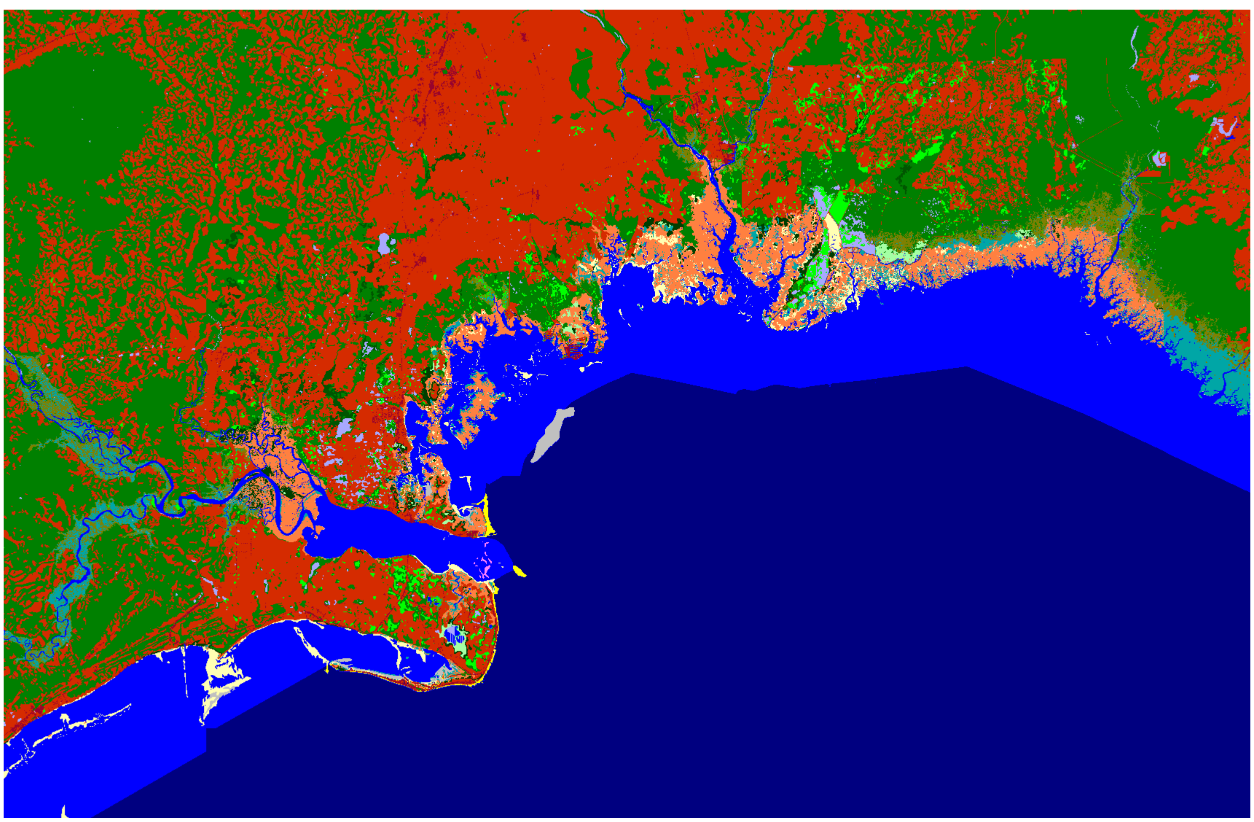


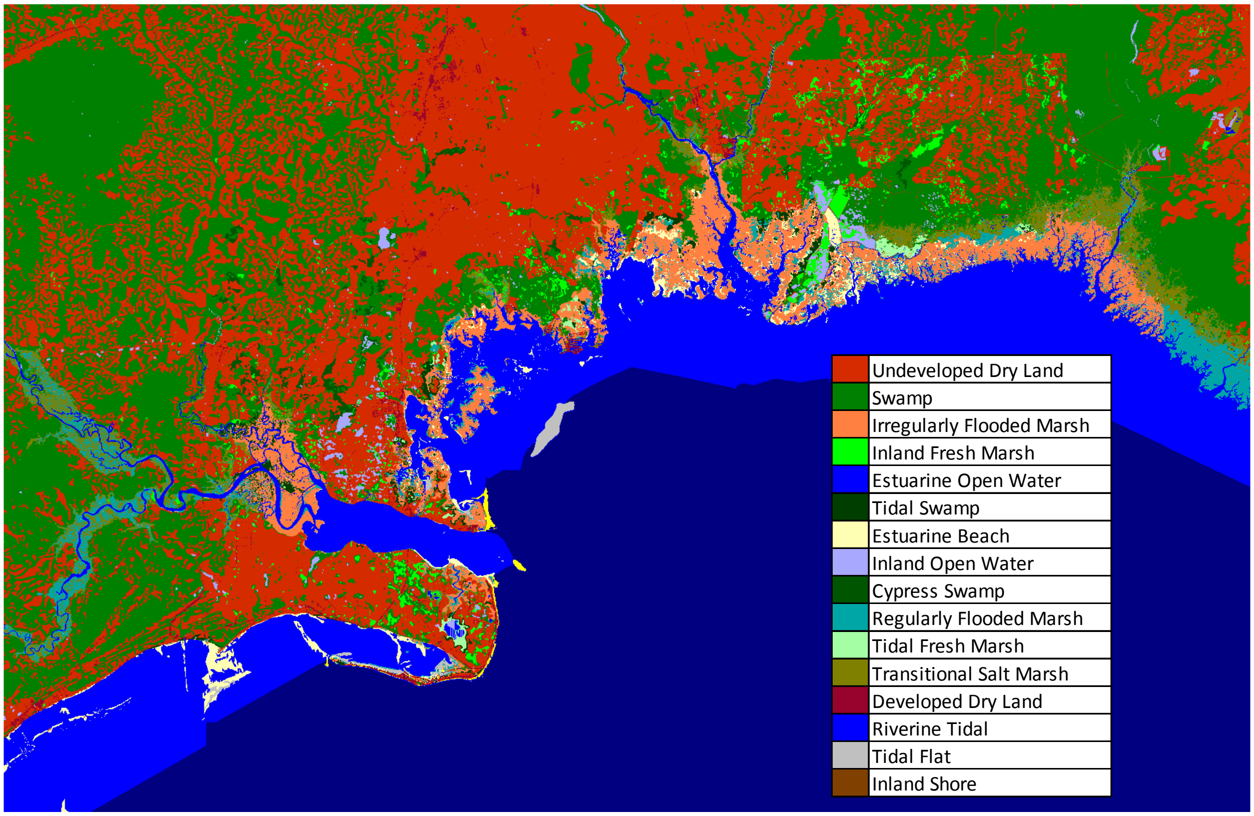
St. Marks NWR, Initial Condition.


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



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


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



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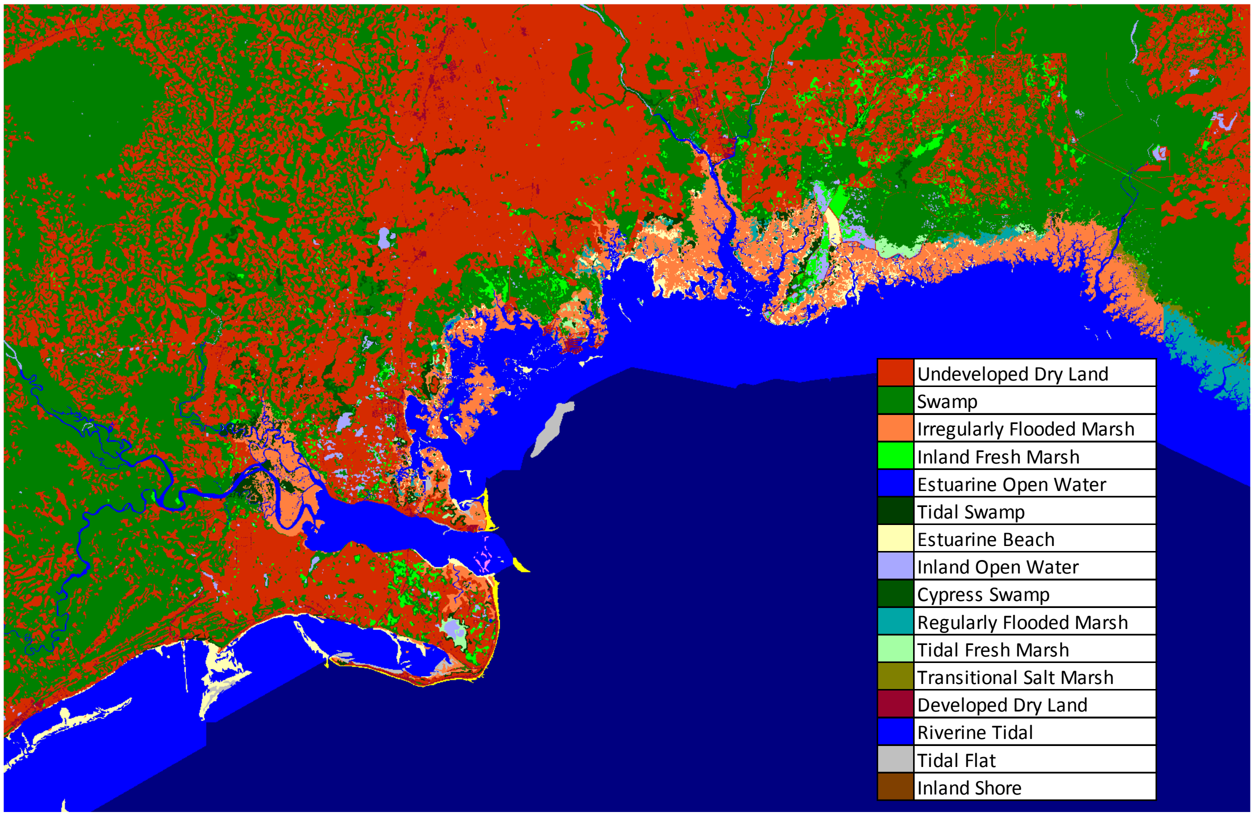
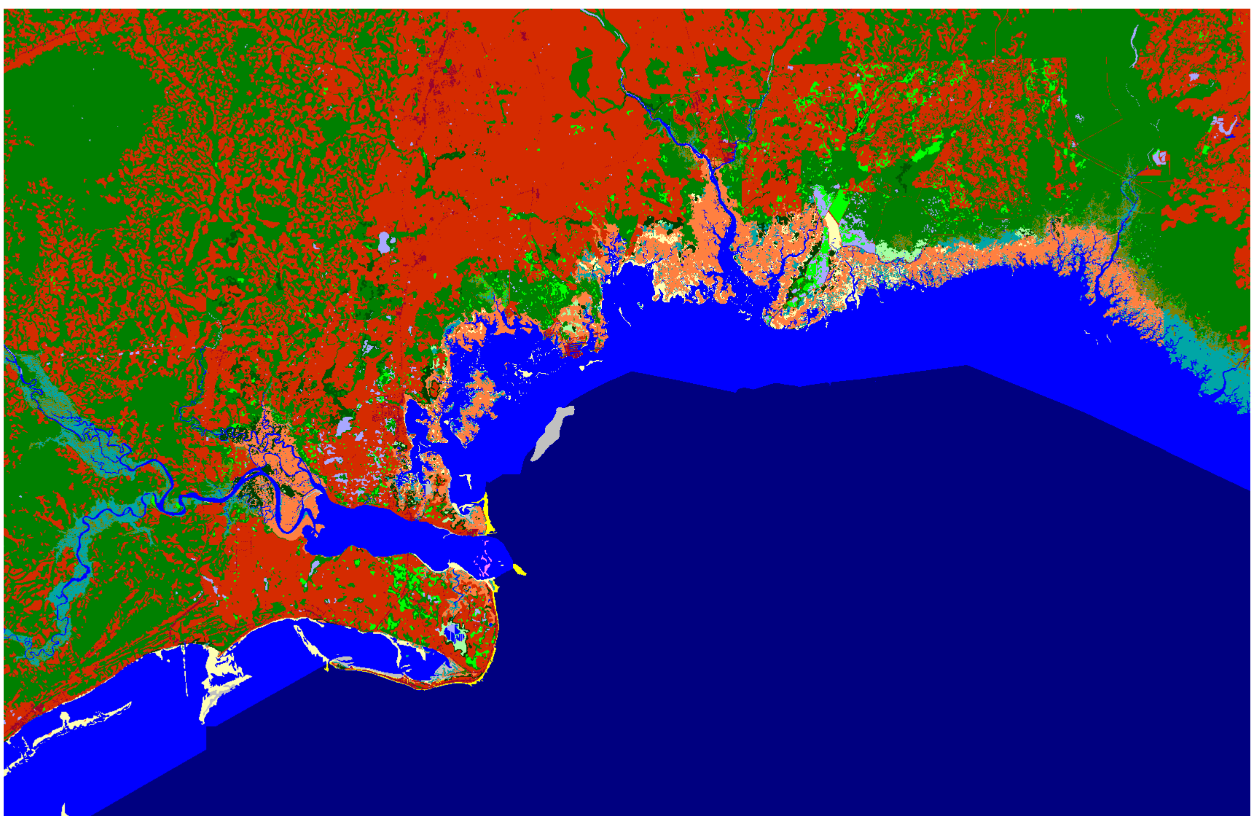
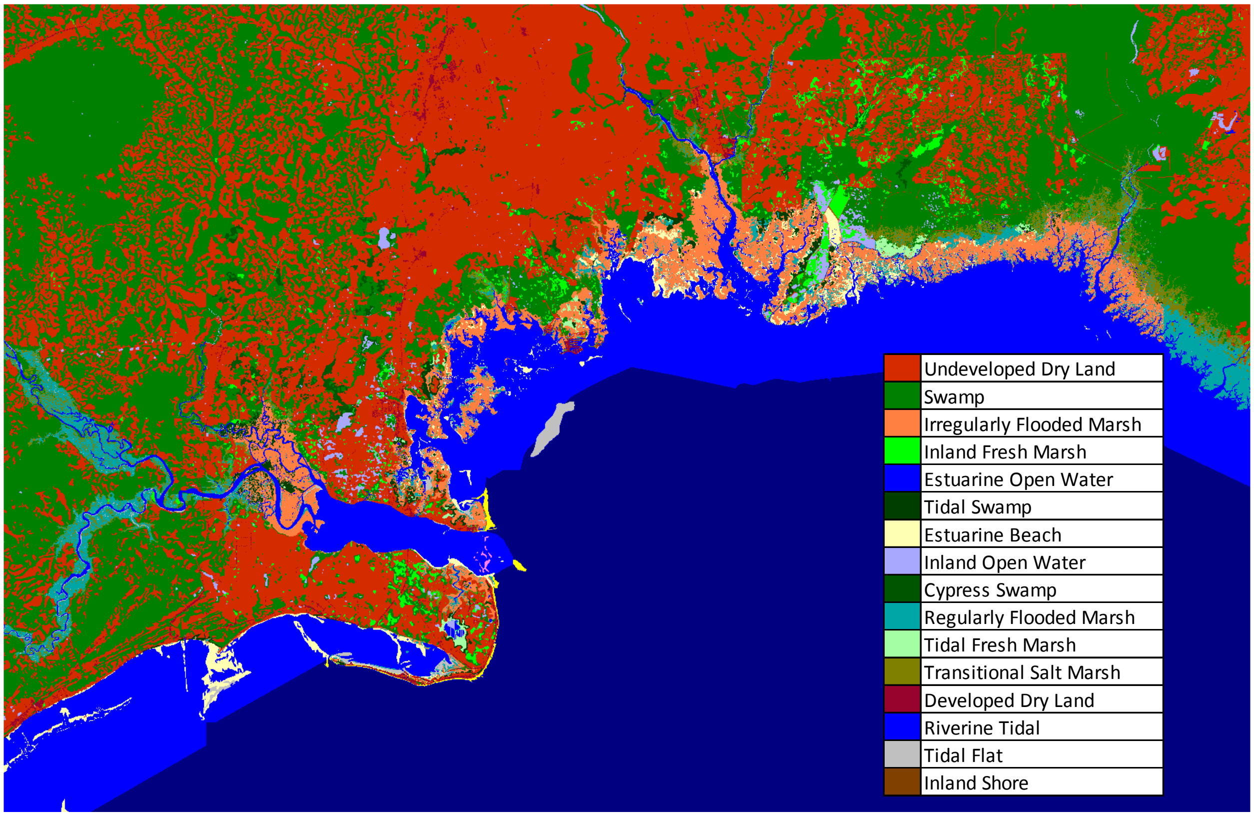
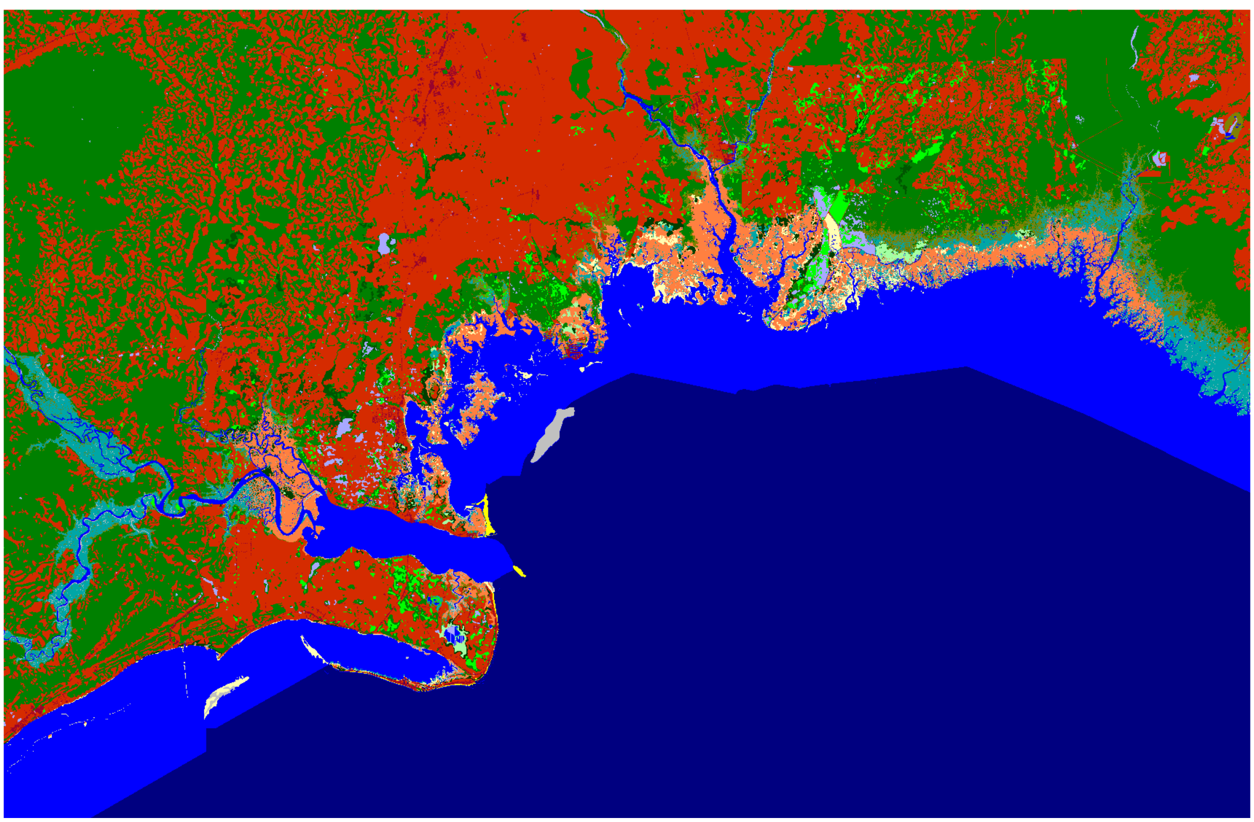


St. Marks NWR, Initial Condition.

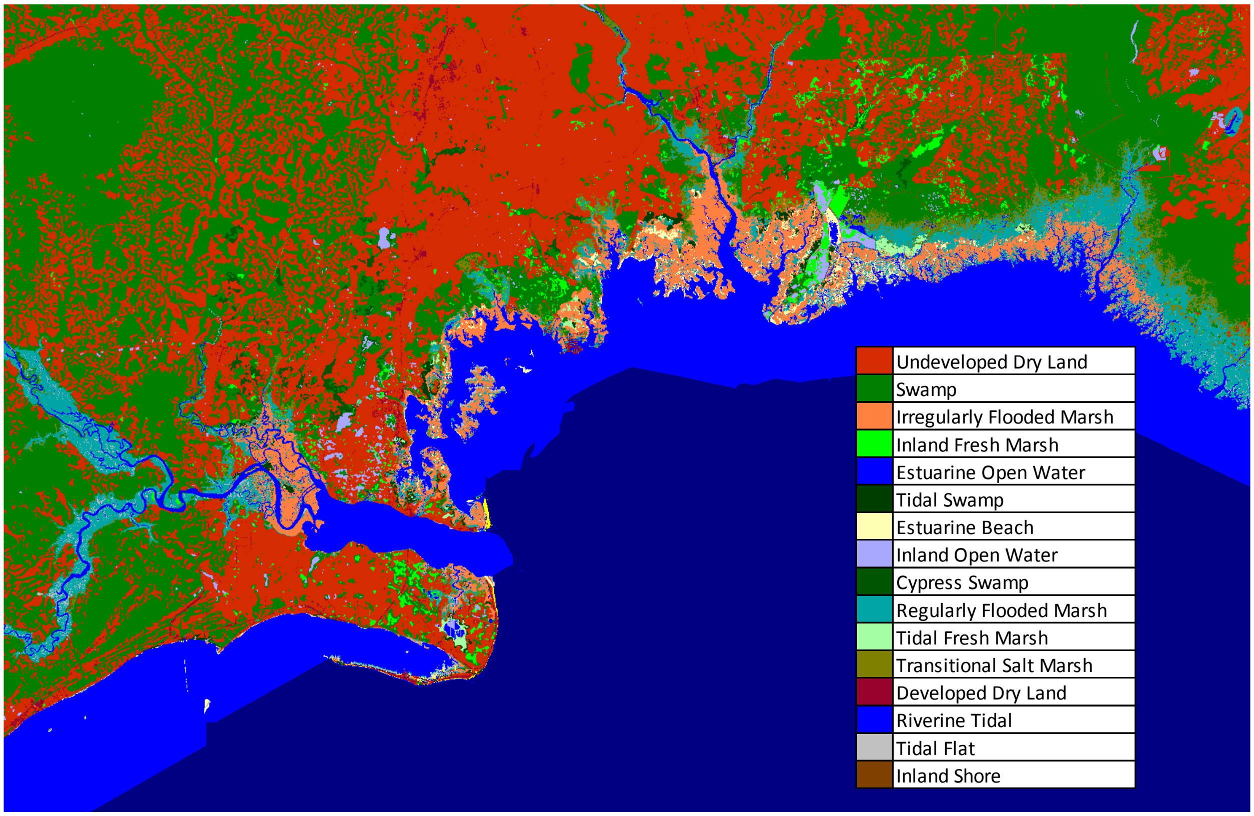

St. Marks NWR, 2025, Scenario A1B Maximum, 0.69 m SLR by 2100.



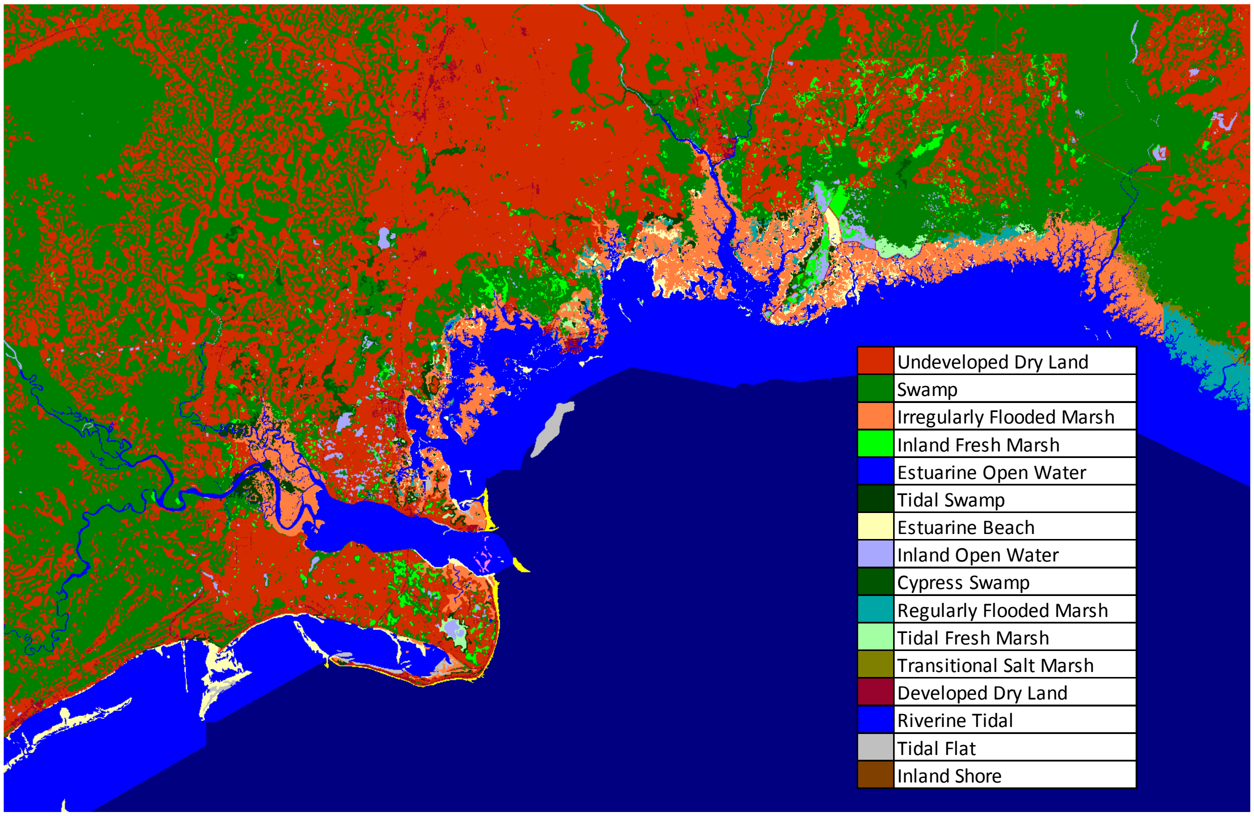
St. Marks NWR, 2050, Scenario A1B Maximum, 0.69 m SLR by 2100.



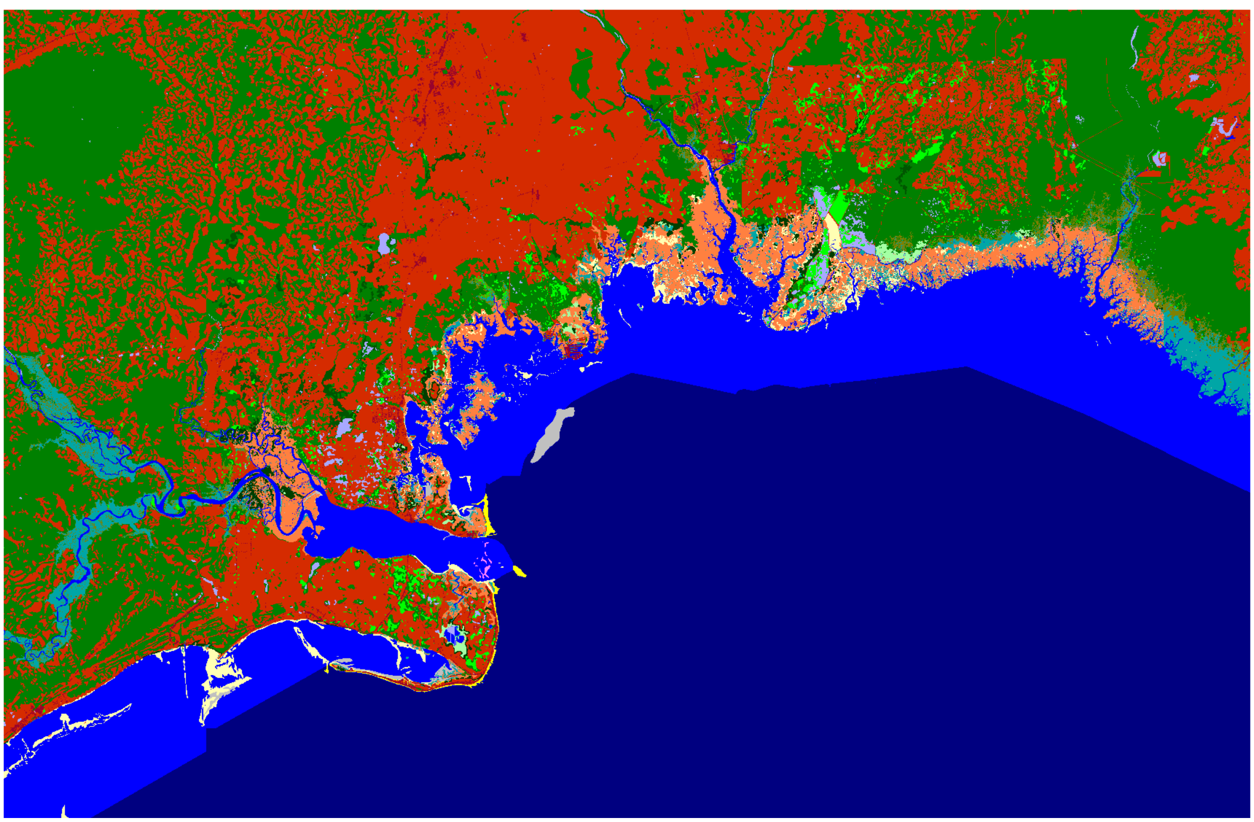
St. Marks NWR, 2075, Scenario A1B Maximum, 0.69 m SLR by 2100.



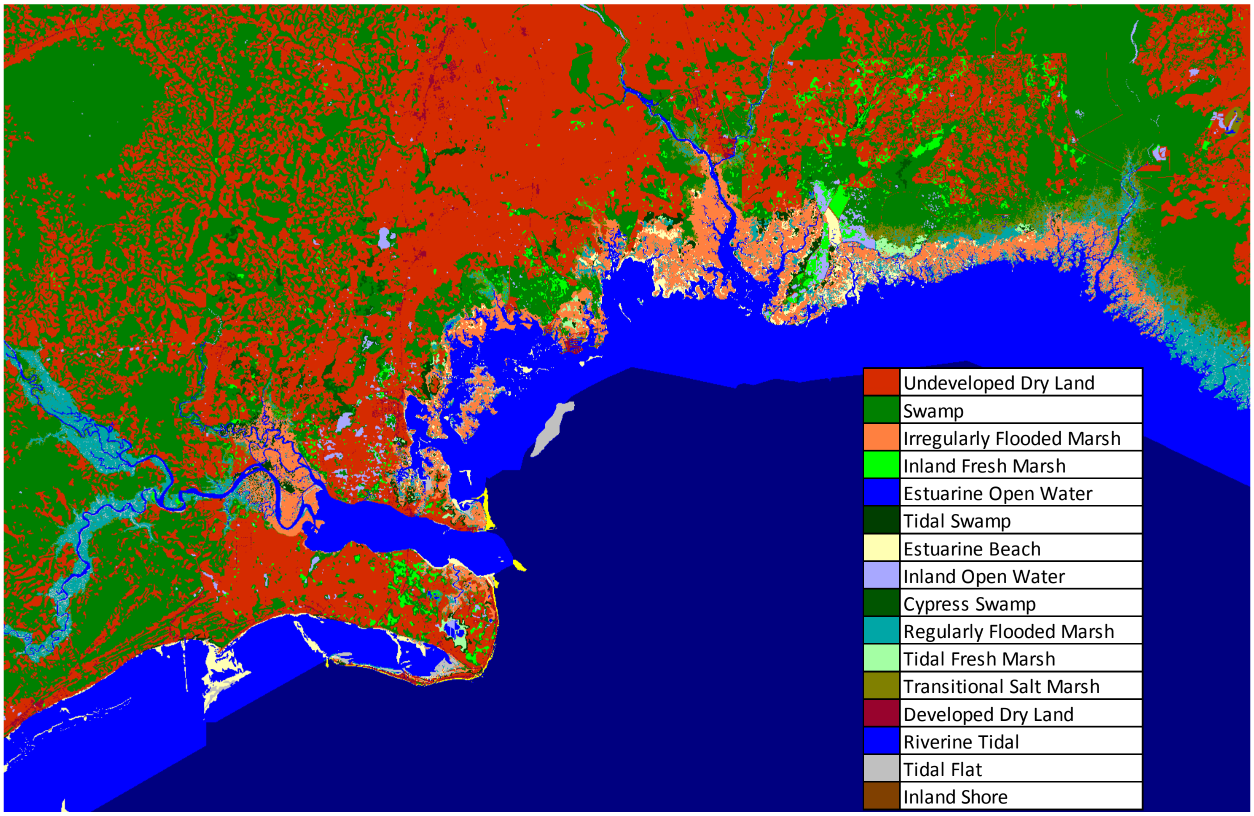
St. Marks NWR, 2100, Scenario A1B Maximum, 0.69 m SLR by 2100.



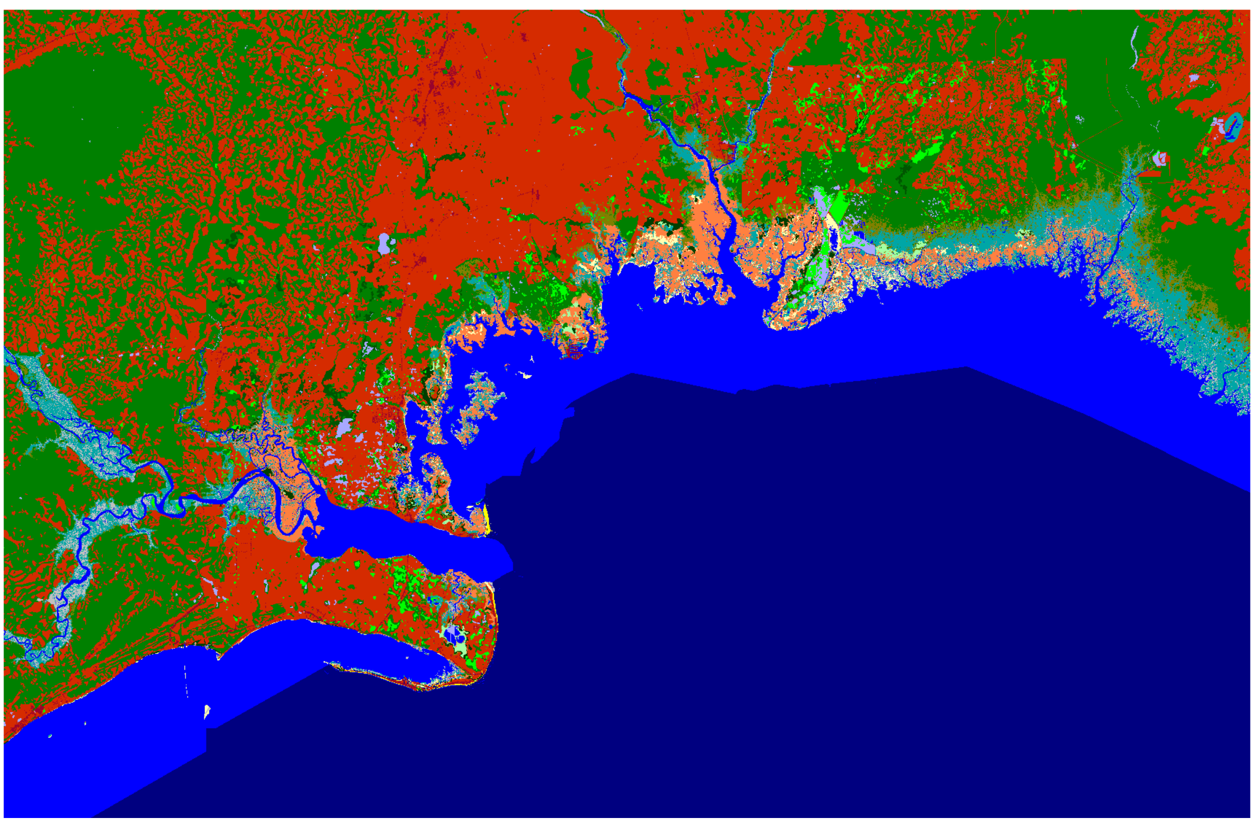
St. Marks NWR, Initial Condition.



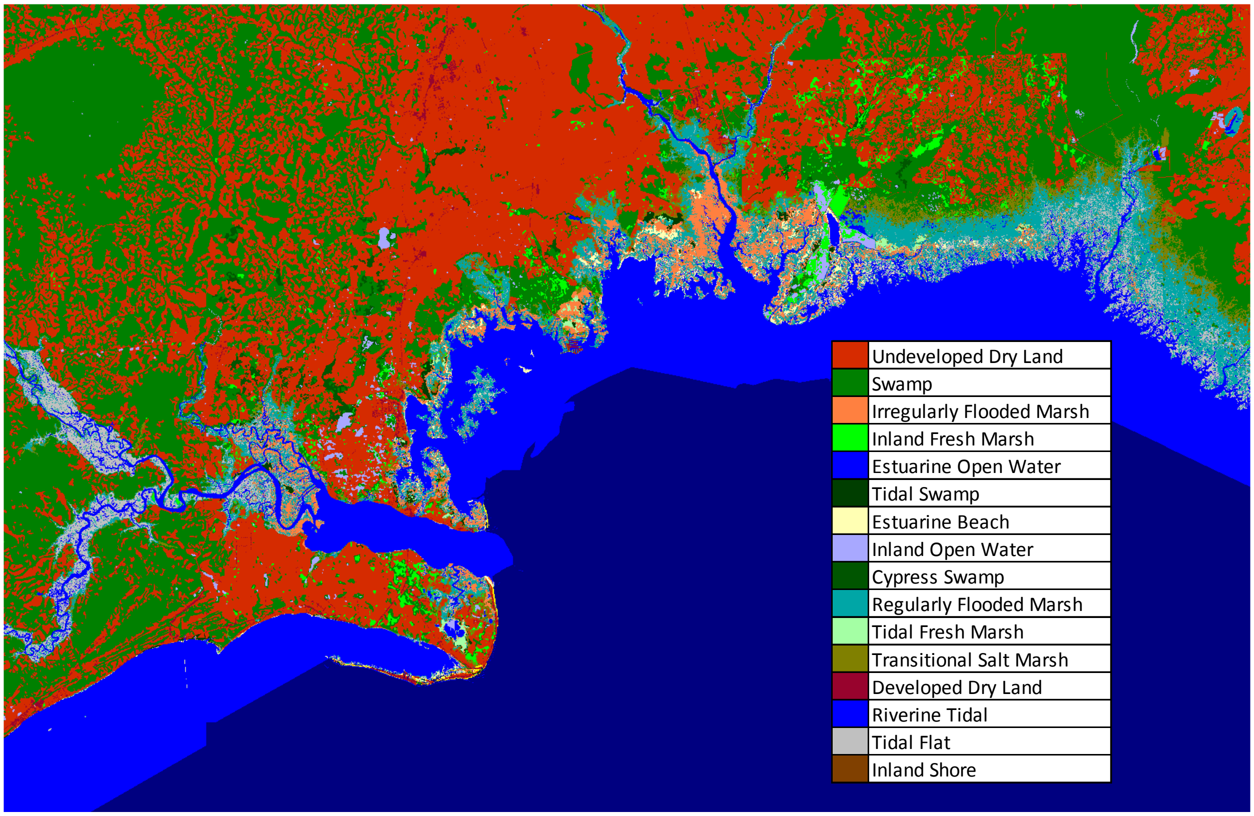
St. Marks NWR, 2025, 1 m SLR by 2100.



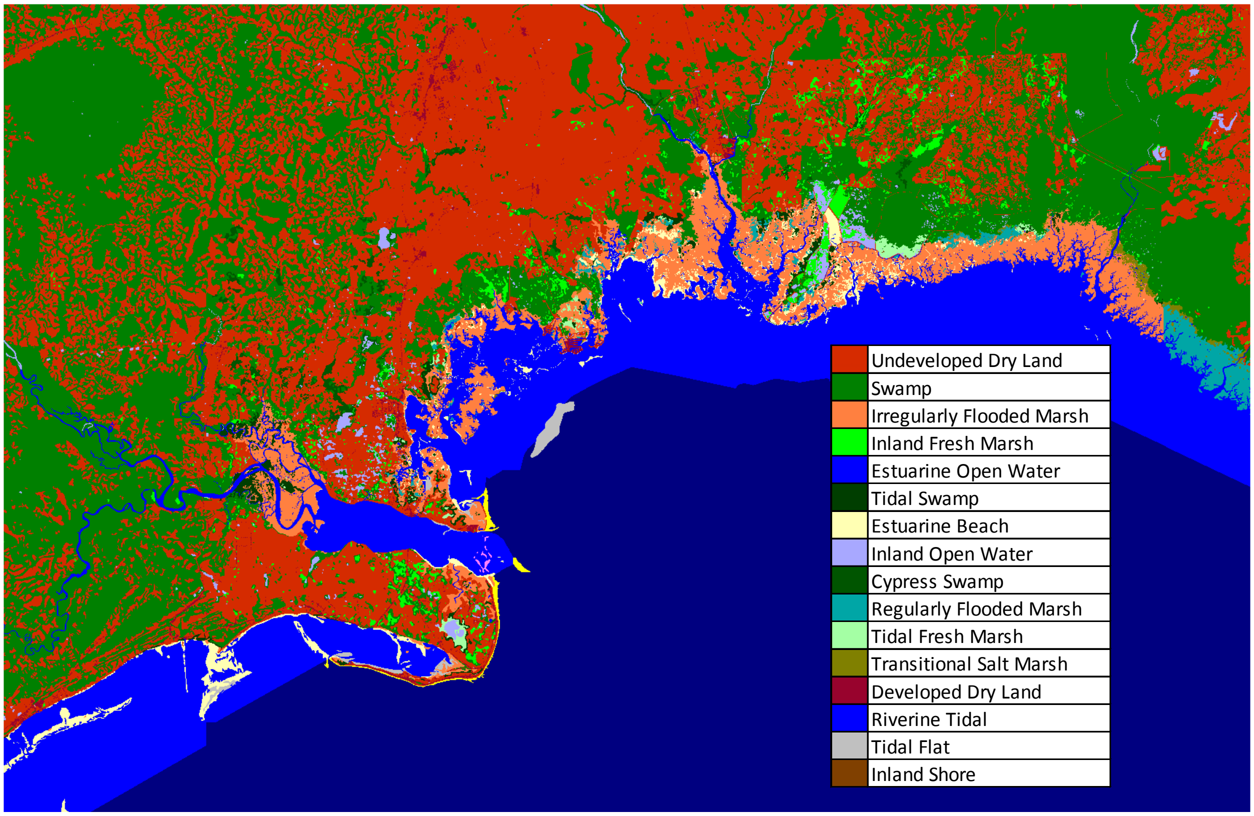
St. Marks NWR, 2050, 1 m SLR by 2100.



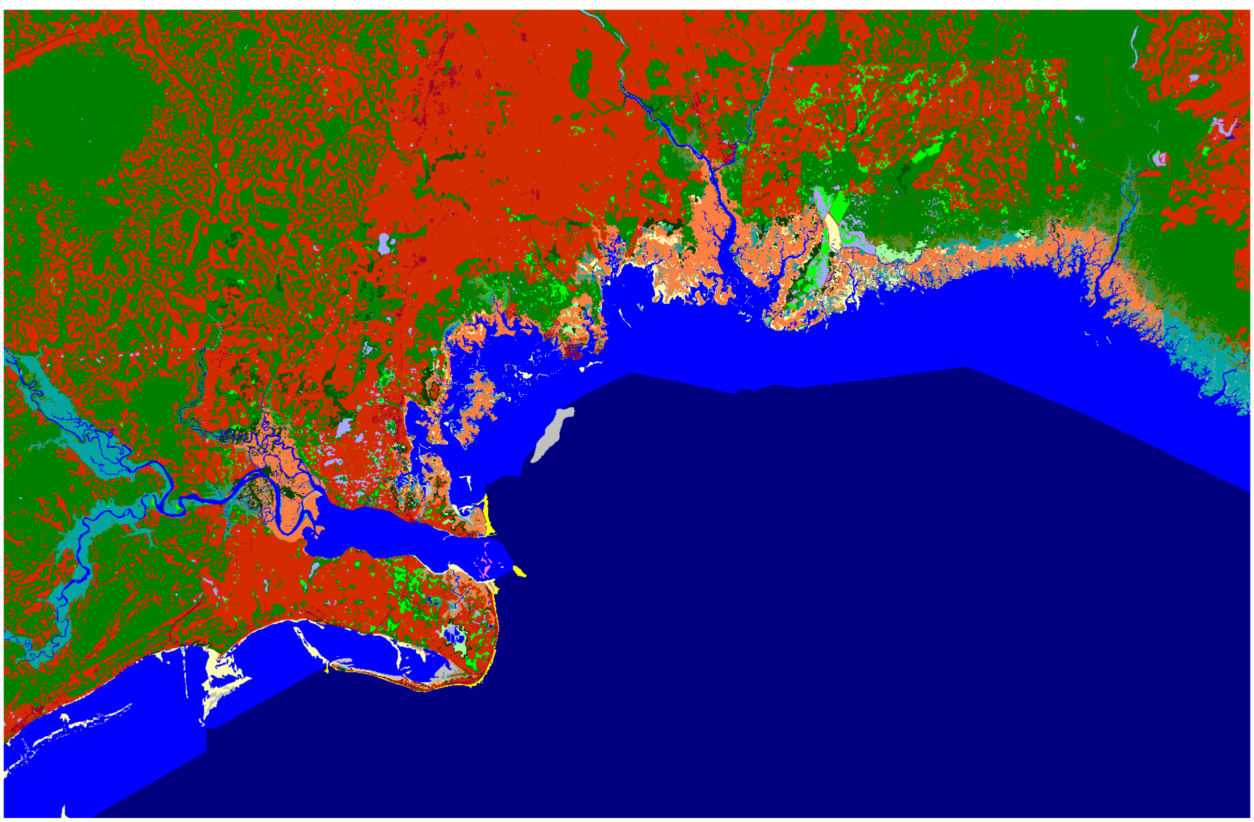
St. Marks NWR, 2075, 1 m SLR by 2100.



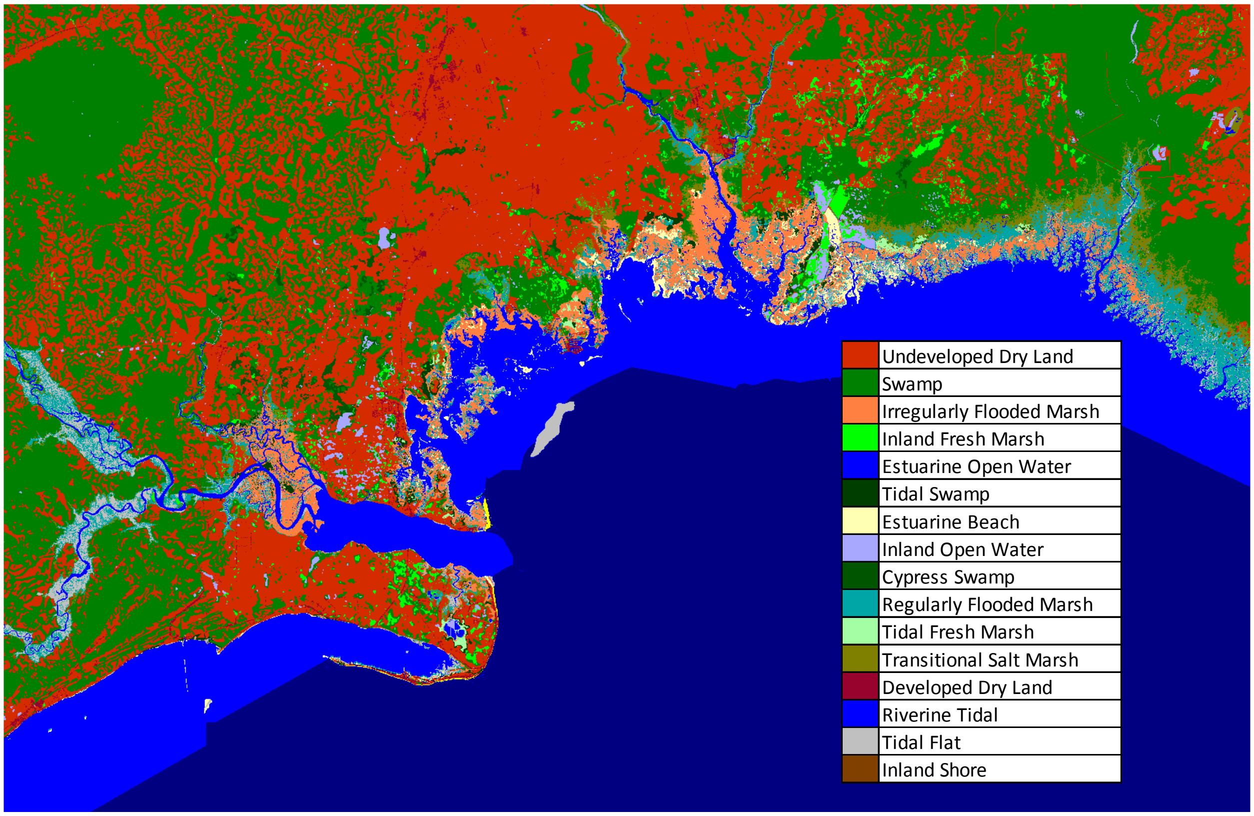
St. Marks NWR, 2100, 1 m SLR by 2100.



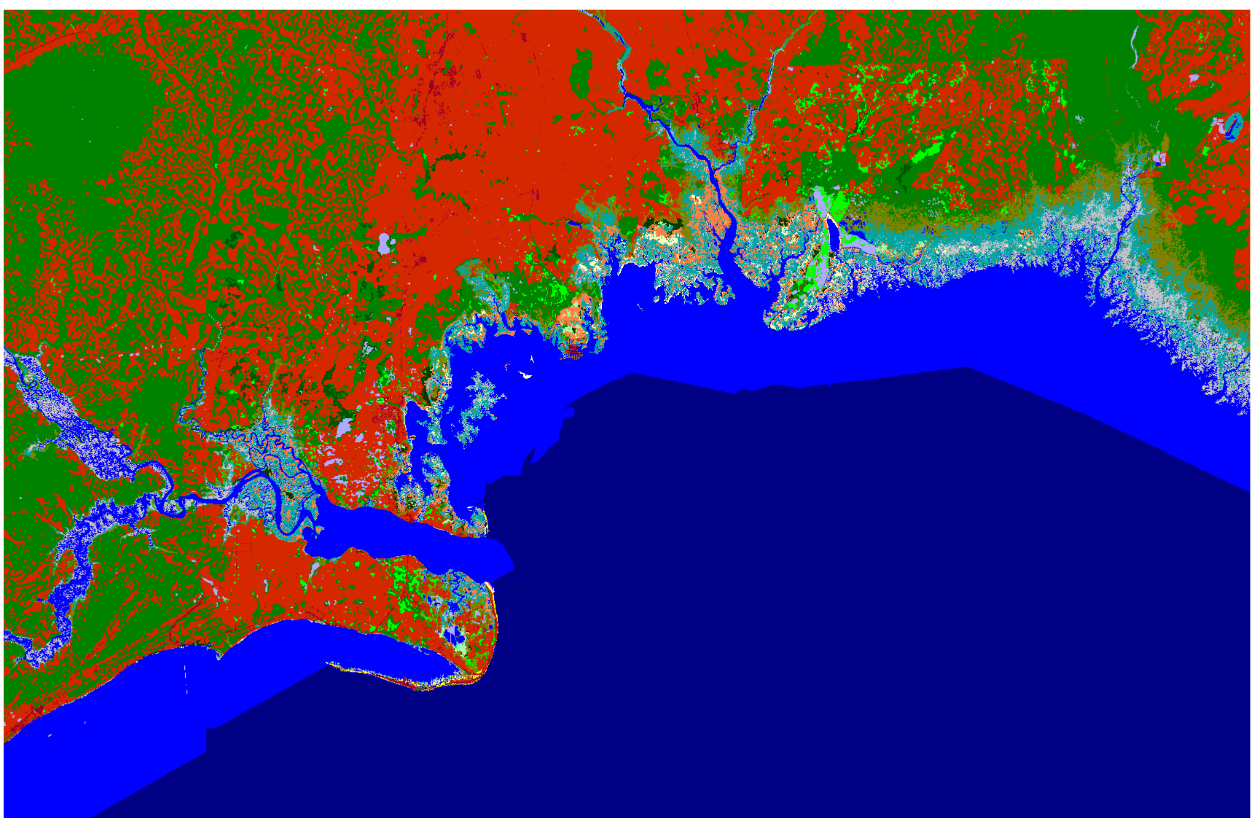
St. Marks NWR, Initial Condition.



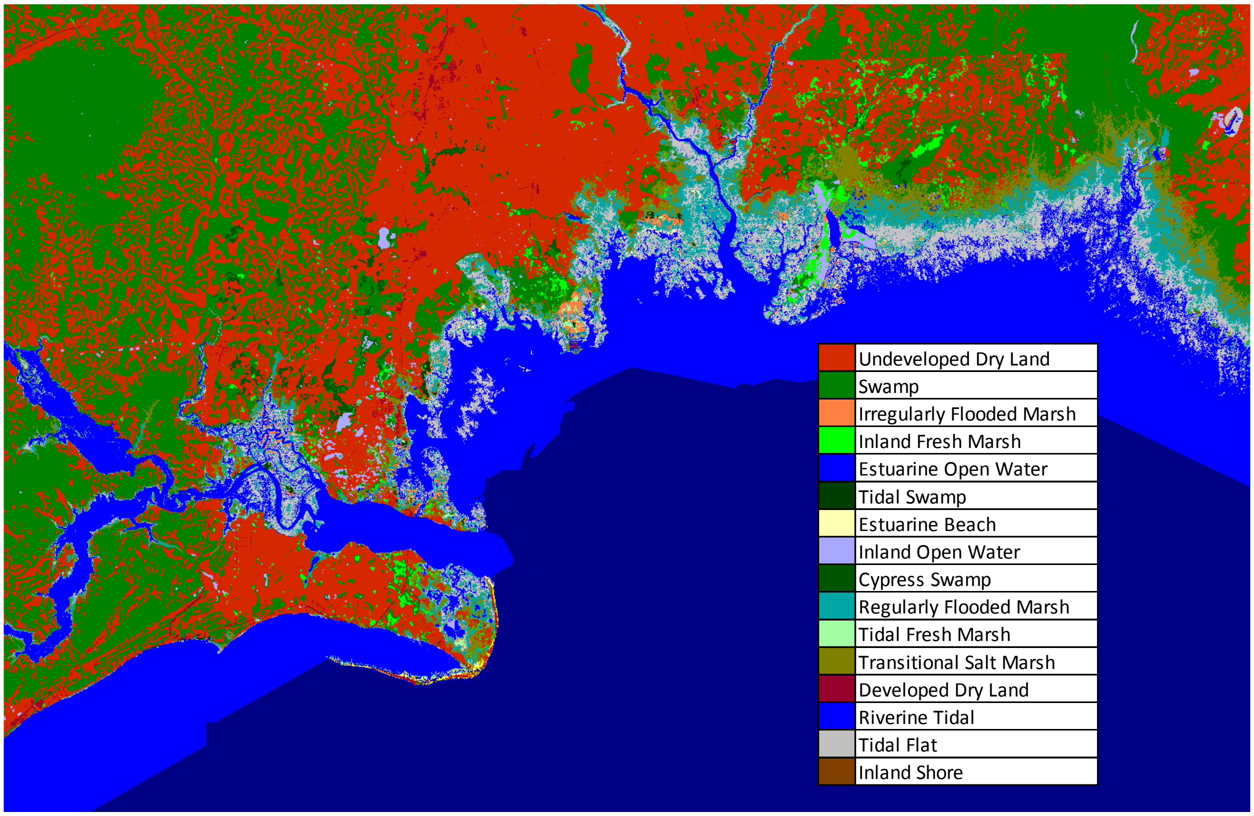
St. Marks NWR, 2025, 1.5 m SLR by 2100.



St. Marks NWR, 2050, 1.5 m SLR by 2100.



St. Marks NWR, 2075, 1.5 m SLR by 2100.



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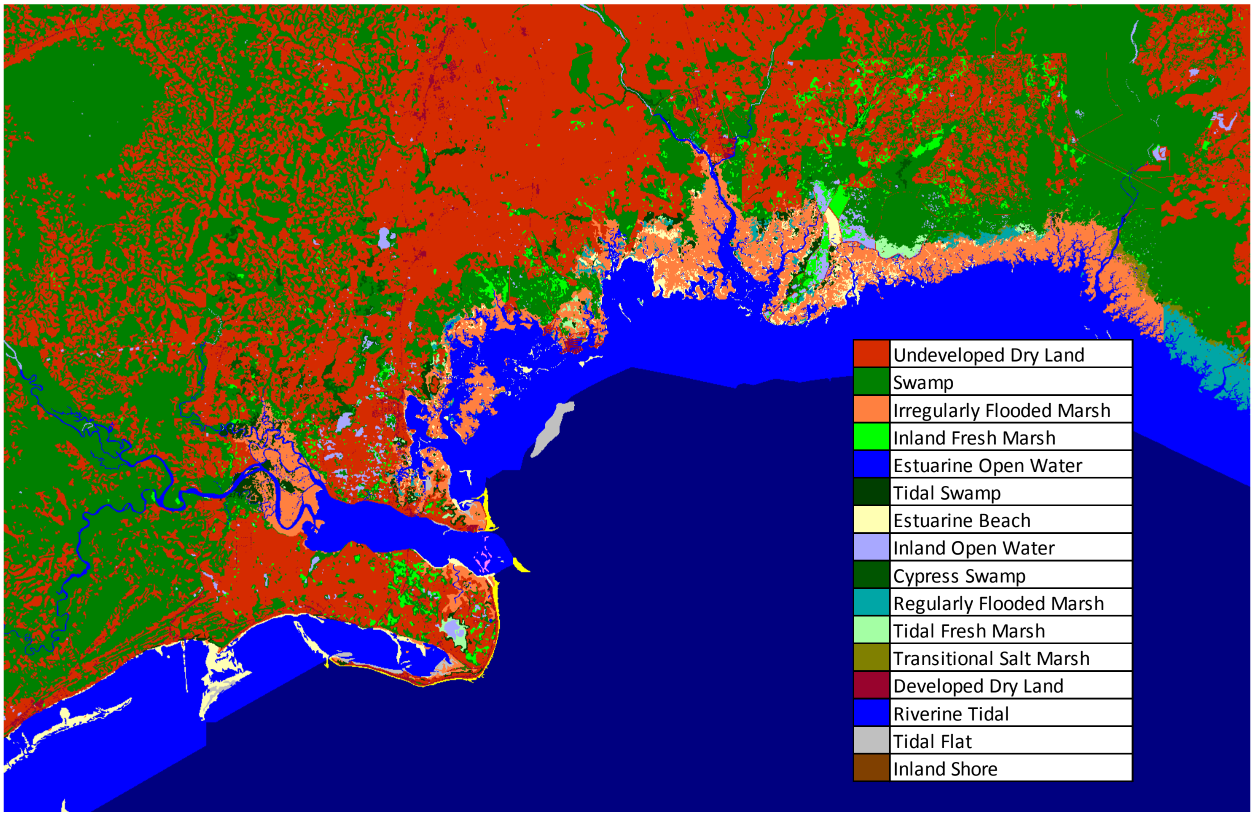
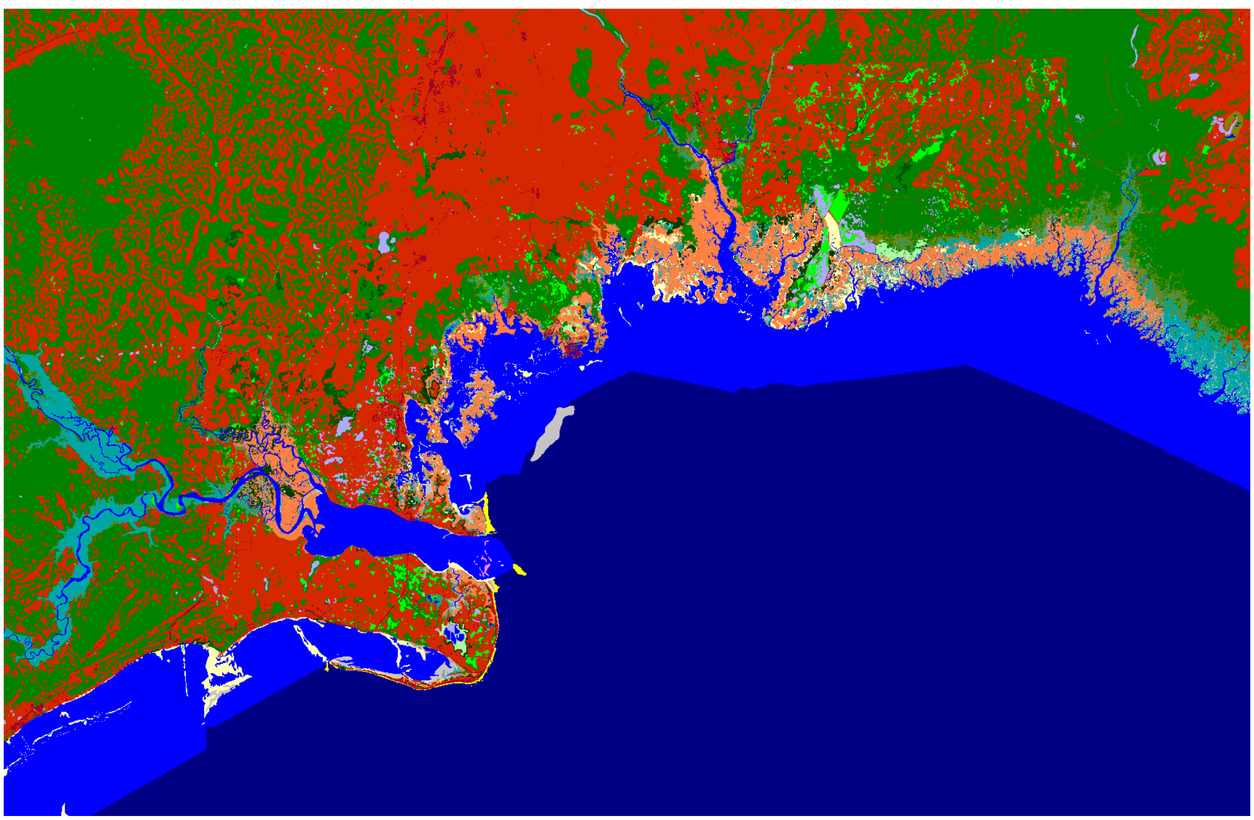
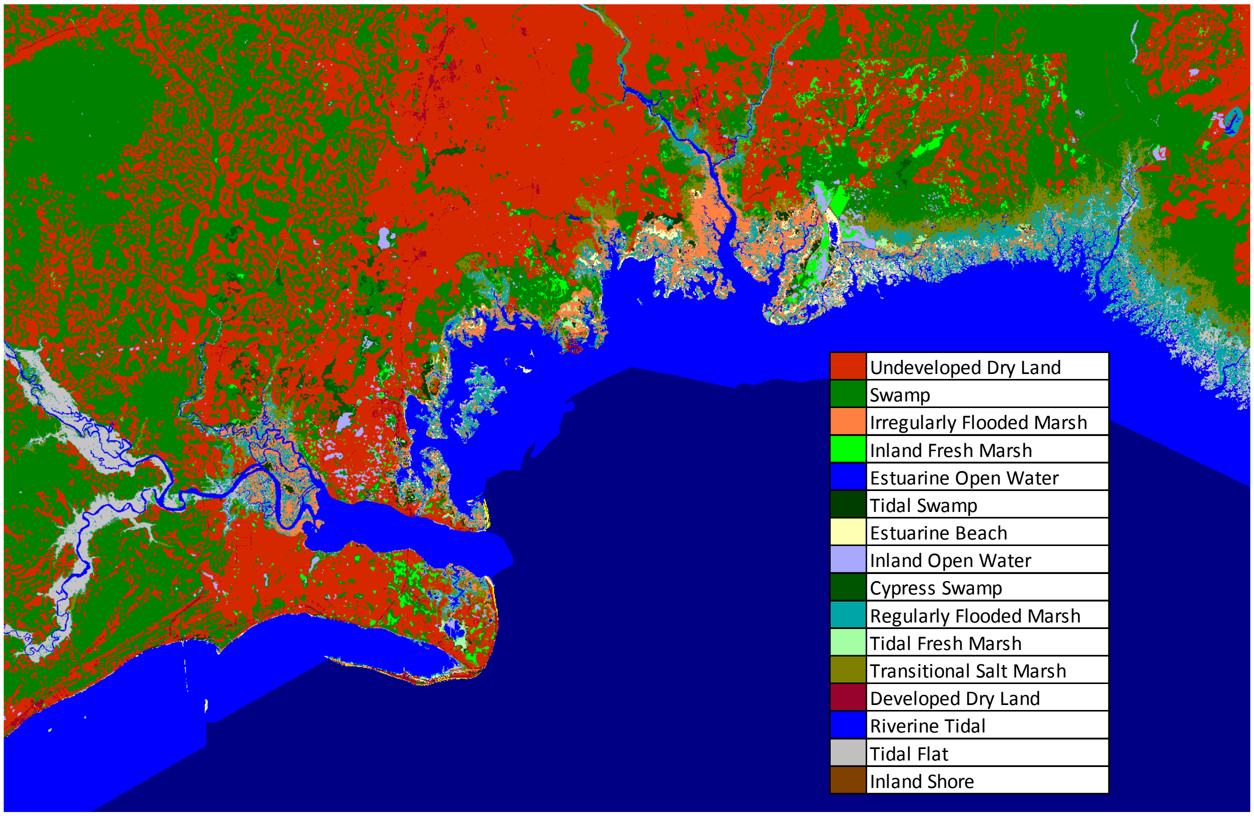


St. Marks NWR, Initial Condition.



St. Marks NWR, 2025, 2 m SLR by 2100.



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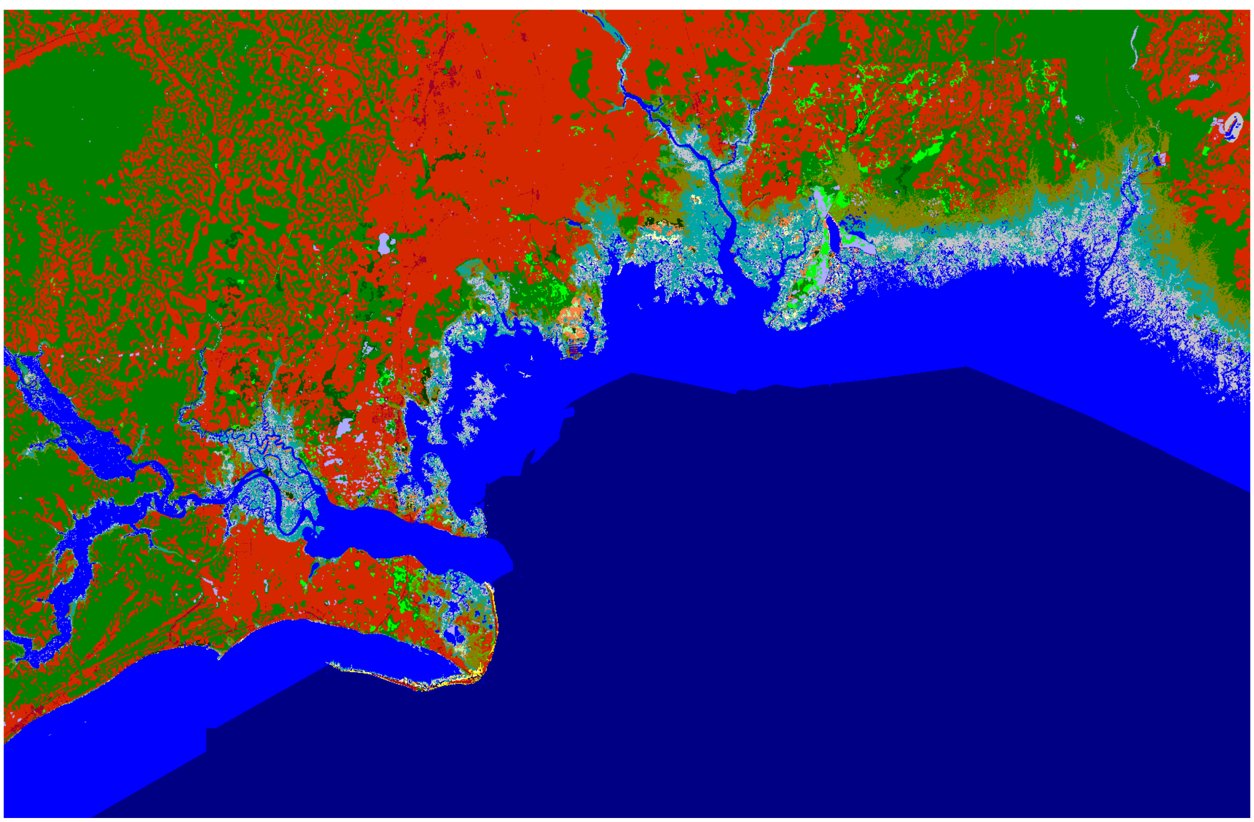

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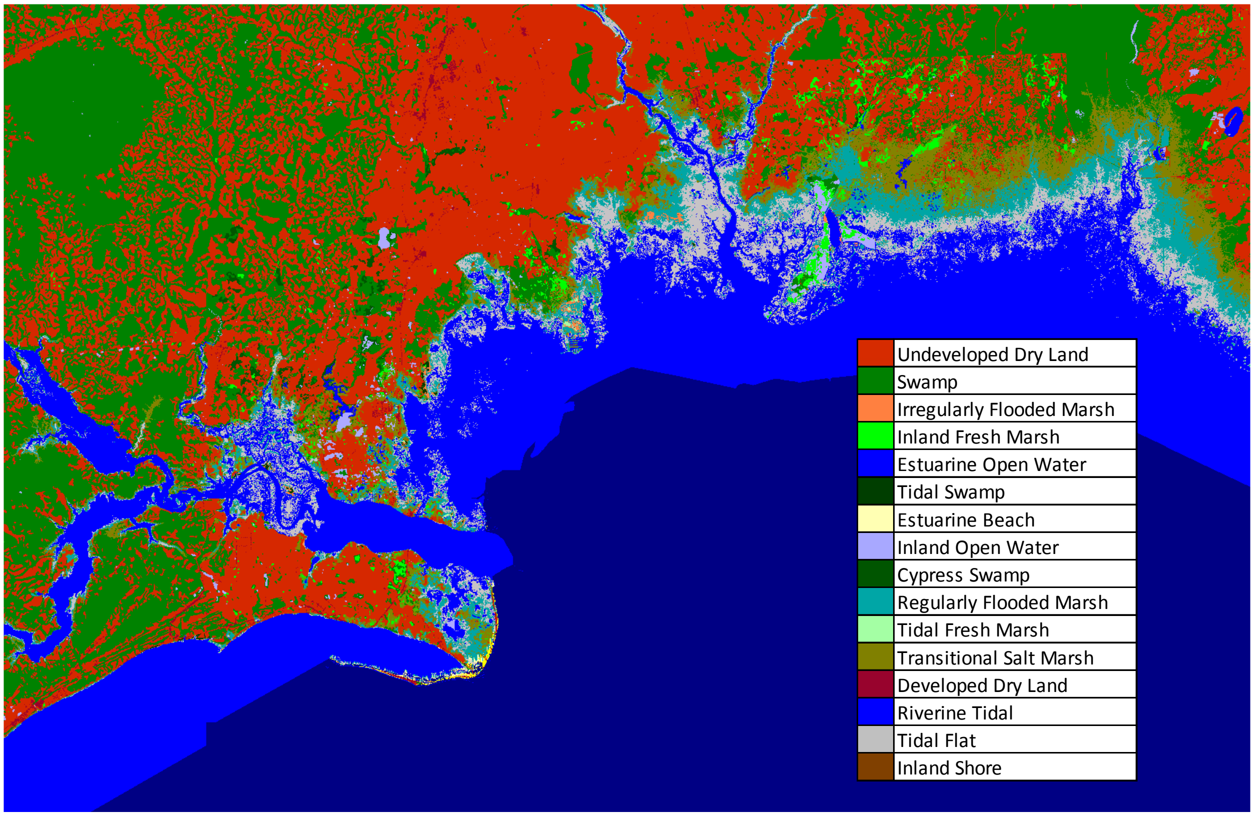

St. Marks NWR, 2100, 2 m SLR by 2100.