Application of the Sea-Level Affecting Marshes Model (SLAMM 6) to Blackbeard 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 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.

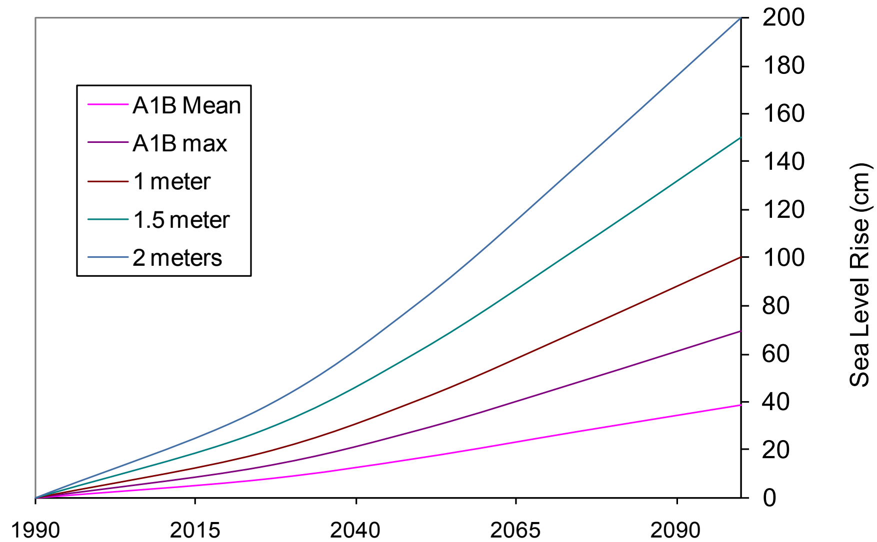


Figure 1. Summary of SLR scenarios utilized.

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 8,000 acre Blackbeard Island NWR (approved acquisition boundary including water) is composed of the following categories:

Land cover type	Area (acres)	Percentage (%)
Open Ocean	2147	27
Undeveloped Dry Land	1869	23
Estuarine Open Water	1185	15
Regularly-flooded Marsh	1081	13
Inland Fresh Marsh	628	8
Swamp	488	6
Ocean Beach	223	3
Tidal Swamp	198	2
Transitional Salt Marsh	96	1
Irregularly-flooded Marsh	69	<1
Tidal Fresh Marsh	49	<1
Estuarine Beach	30	<1
Total (incl. water)	**8064**	**100**

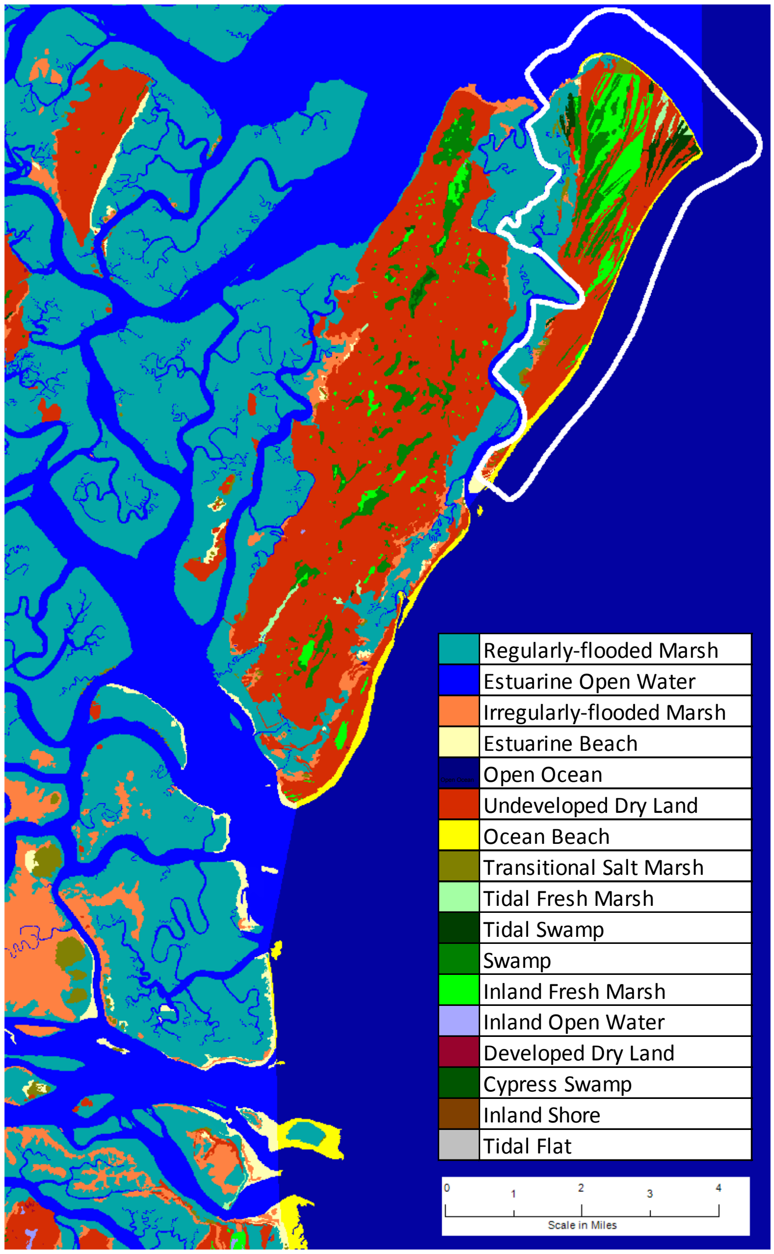


Figure 2. 2007 NWI coverage of the study area. Refuge boundaries are indicated in white.

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

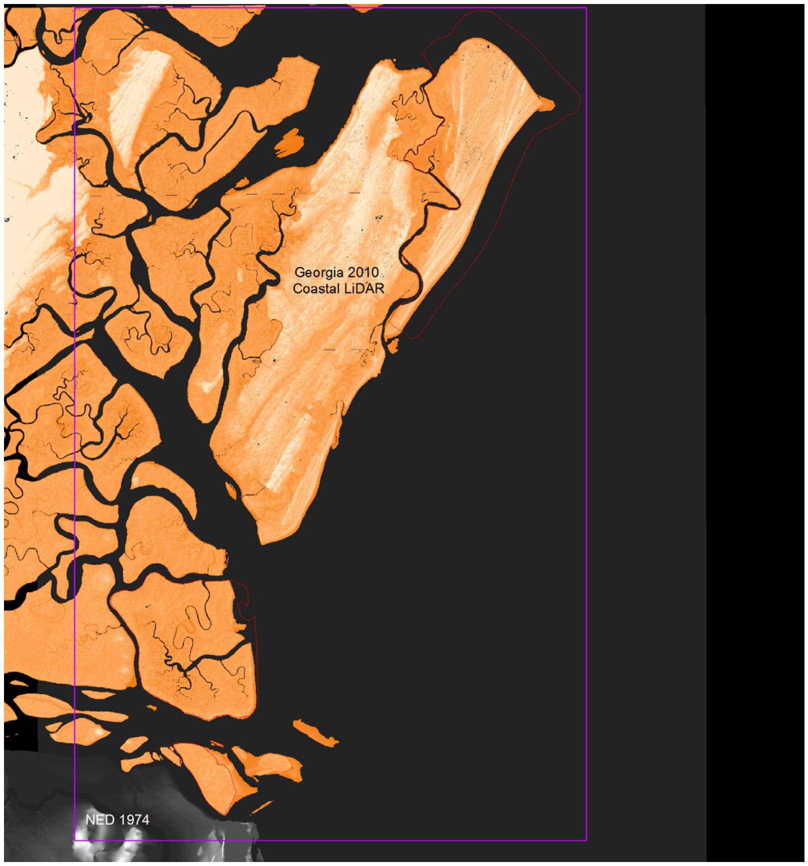


Figure 3. The coverage of the LiDAR data for the entire study area.

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 some wetlands protected by dikes or impoundments within the refuge. These are shown in black and yellow stripes in Figure 4. The model assumes that those lands protected by dikes are not subject to inundation until they reach 2 m below mean tide level.

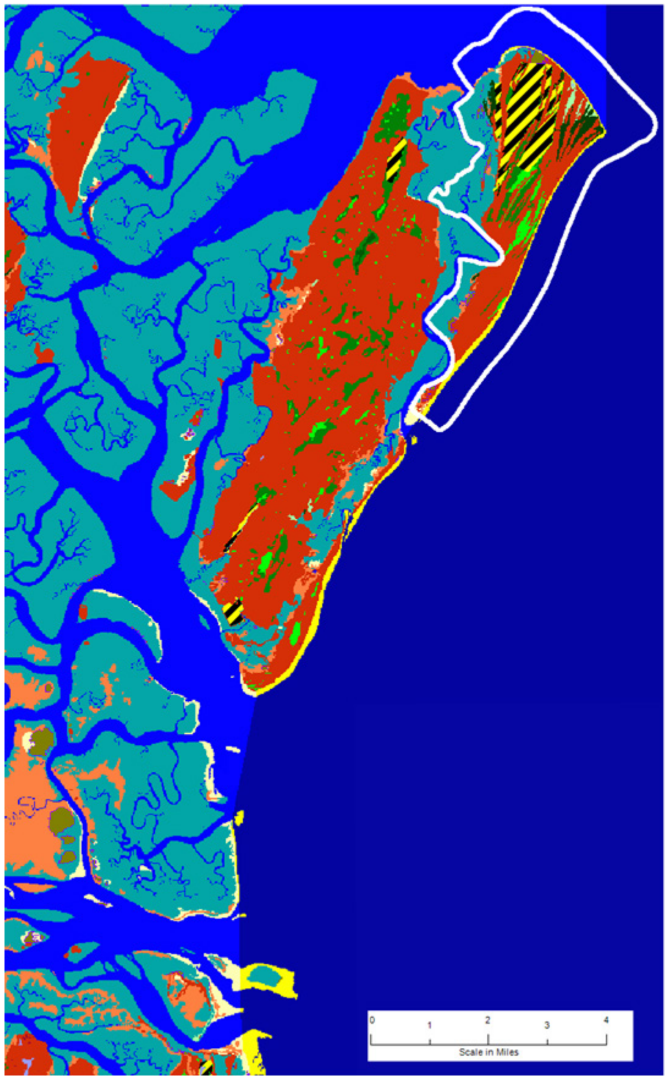


Figure 4. In yellow and black stripes, areas protected by dikes.

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 5) and several NOAA tide tables (shown in blue in Figure 5). 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 5. Different input subsites were defined reflecting these varying tidal ranges. For the refuge and coastal areas the GT was set to the average 2.24 m.

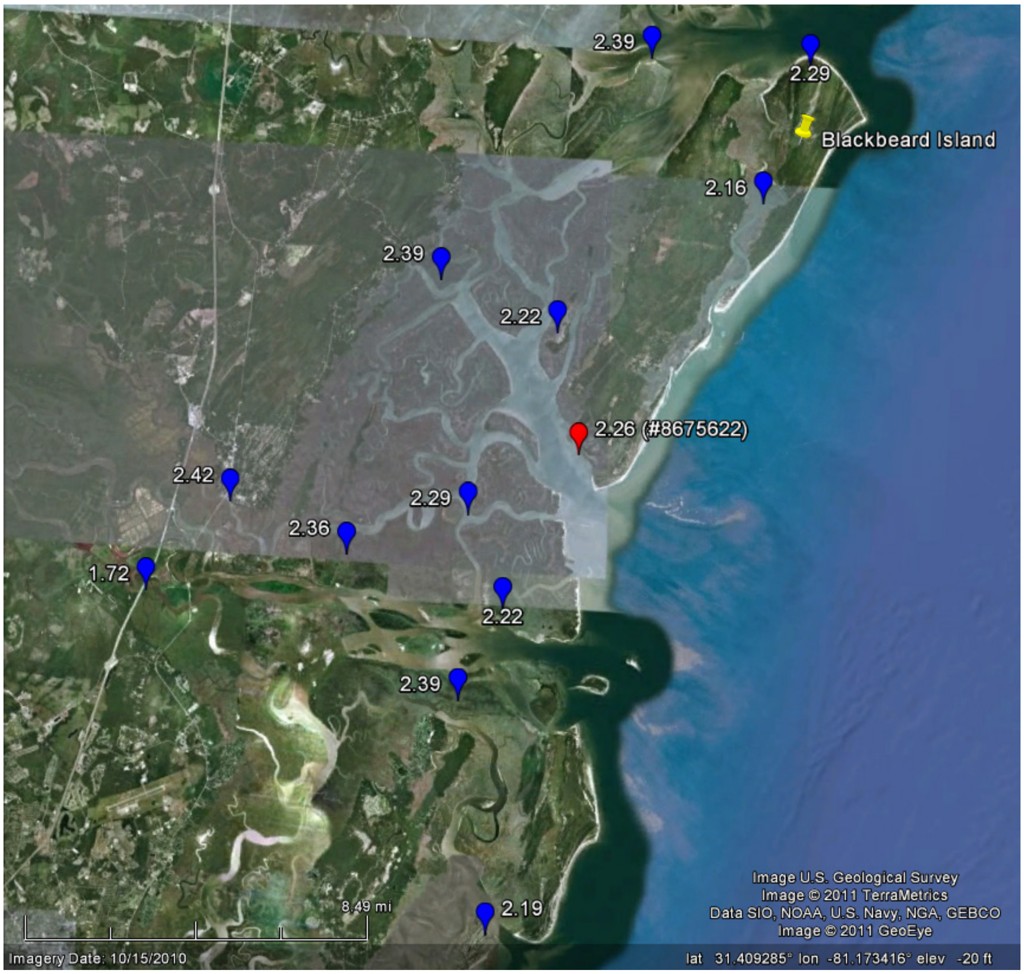


Figure 5. Spatial variability of the great diurnal range (GT) estimates.

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 within the refuge area.

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 6, and were applied on a subsite-by-subsite basis. A value of -0.073 m was applied to the subsite containing Blackbeard Island NWR.

Figure 6. 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 7.

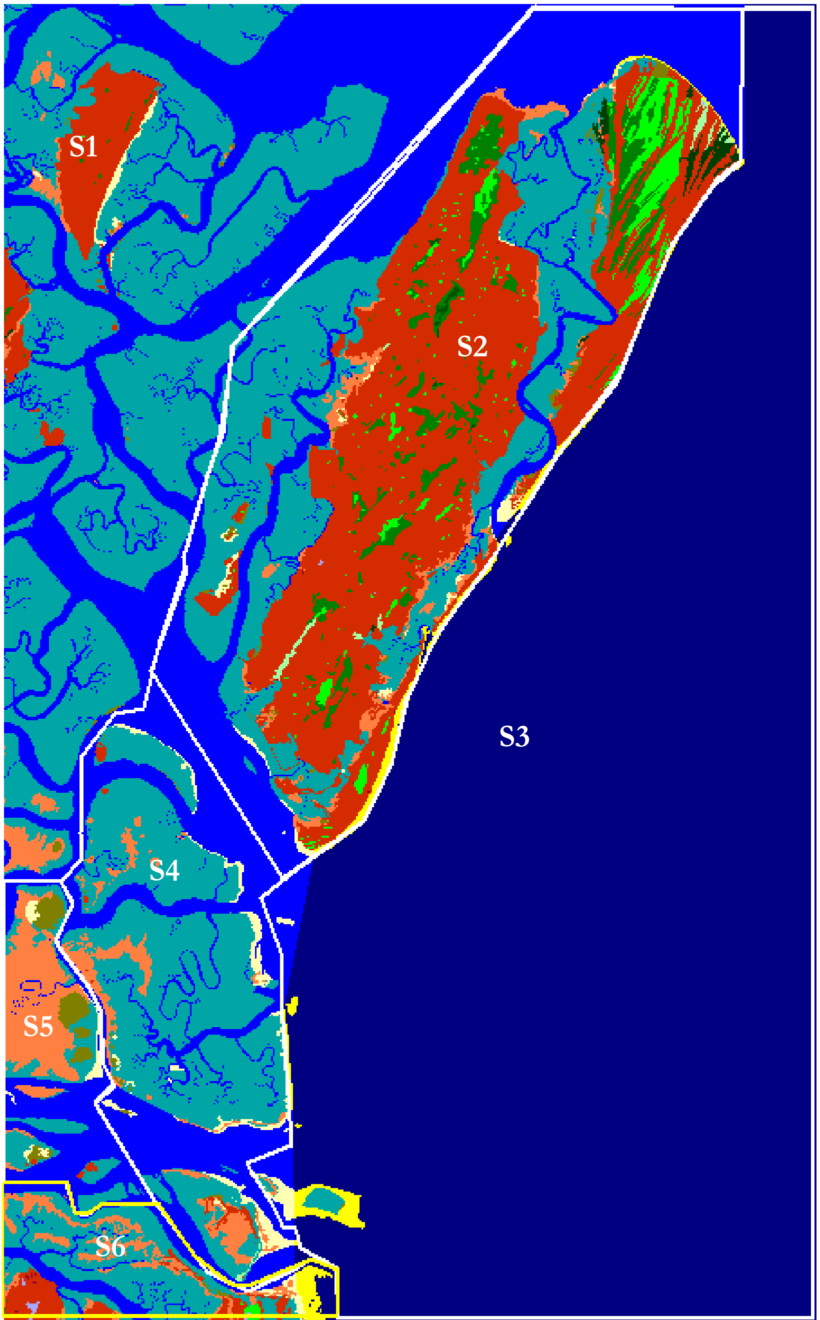


Figure 7. Input subsites for model application.

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 (S2) are presented in boldface in the table.

Table 1. Summary of SLAMM input parameters for Blackbeard 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 Blackbeard 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
Undeveloped Dry Land	1869	8%	15%	33%	59%	78%
Regularly-flooded Marsh	1081	16%	19%	27%	29%	16%
Inland Fresh Marsh	628	-1%([1])	0%	13%	21%	23%
Swamp	488	0%	1%	28%	38%	42%
Tidal Swamp	198	9%	16%	31%	69%	86%
Irregularly-flooded Marsh	69	-1%	-8%	-4%	-89%	-2%
Tidal Fresh Marsh	49	1%	1%	4%	72%	90%

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

Undeveloped dry land comprises the majority of the refuge (23%) and this category is predicted to be increasingly lost as sea level rise rates increase. Although only 33% is predicted to be lost under the 1 m of SLR by 2100 scenario, a maximum of 78% loss is predicted to occur under the 2 m SLR by 2100 scenario. In comparison, regularly-flooded marsh appears to be more resilient to SLR across all studied scenarios, with a maximum projected loss of 29% under the 1.5 m of SLR by 2100 scenario. Similarly, inland fresh marsh and swamp are predicted to suffer losses starting at SLR scenarios above 0.69 m by 2100. It is worth mentioning that this resilience is in part due to the fact that some of the land covered by these wetland categories is protected by dikes.

Tidal swamp and tidal fresh marsh make up a very small portion of the refuge and are predicted to have minor losses up to 1 m SLR by 2100. Under SLR scenarios higher than 1 m by 2100 losses became important, with almost complete disappearance of these categories under the 2 m SLR scenario. Conversely, irregularly-flooded marsh is predicted to increase up until 1.5 m SLR by 2100. However, for at higher SLR rates irregularly-flooded marsh gain is predicted to be minimal compared to the current wetland coverage. Although these wetland categories cover a small area of the refuge, their loss implies a reduction in habitat richness.

Major land cover gains predicted are summarized in Table 3. Open water, which initially covers about 41% of the refuge, is predicted to increase coverage as sea level rises, reaching almost 50% coverage under the 2 m SLR scenario by 2100. Beach is also predicted to expand its coverage area as sea level rises. Tidal flat, which is not currently present in the refuge, is predicted to gradually occupy areas that were previously covered by salt tidal marshes, covering up to 10% of the total refuge area under the highest SLR scenario. In addition, transitional salt marsh is predicted to slowly occupy boundary areas previously covered by undeveloped dry land or swamp.

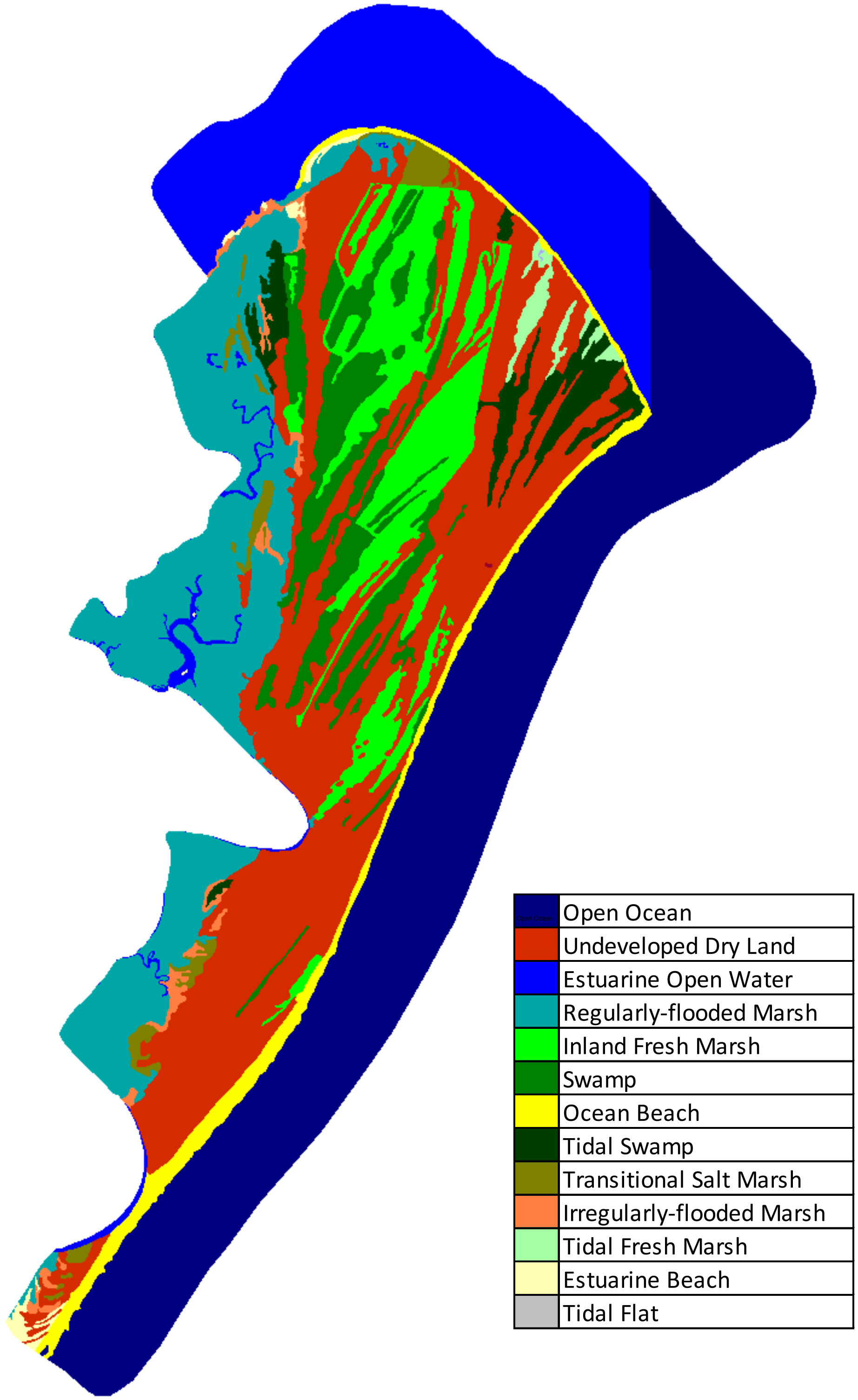
Table 3. Predicted land cover gains by 2100 given simulated scenarios of eustatic SLR at Blackbeard Island NWR.

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	3332	3416	3458	3526	3714	3935
Beach	253	224	260	349	535	687
Tidal Flat	0	246	323	520	882	881
Transitional Salt Marsh	96	135	170	484	392	372

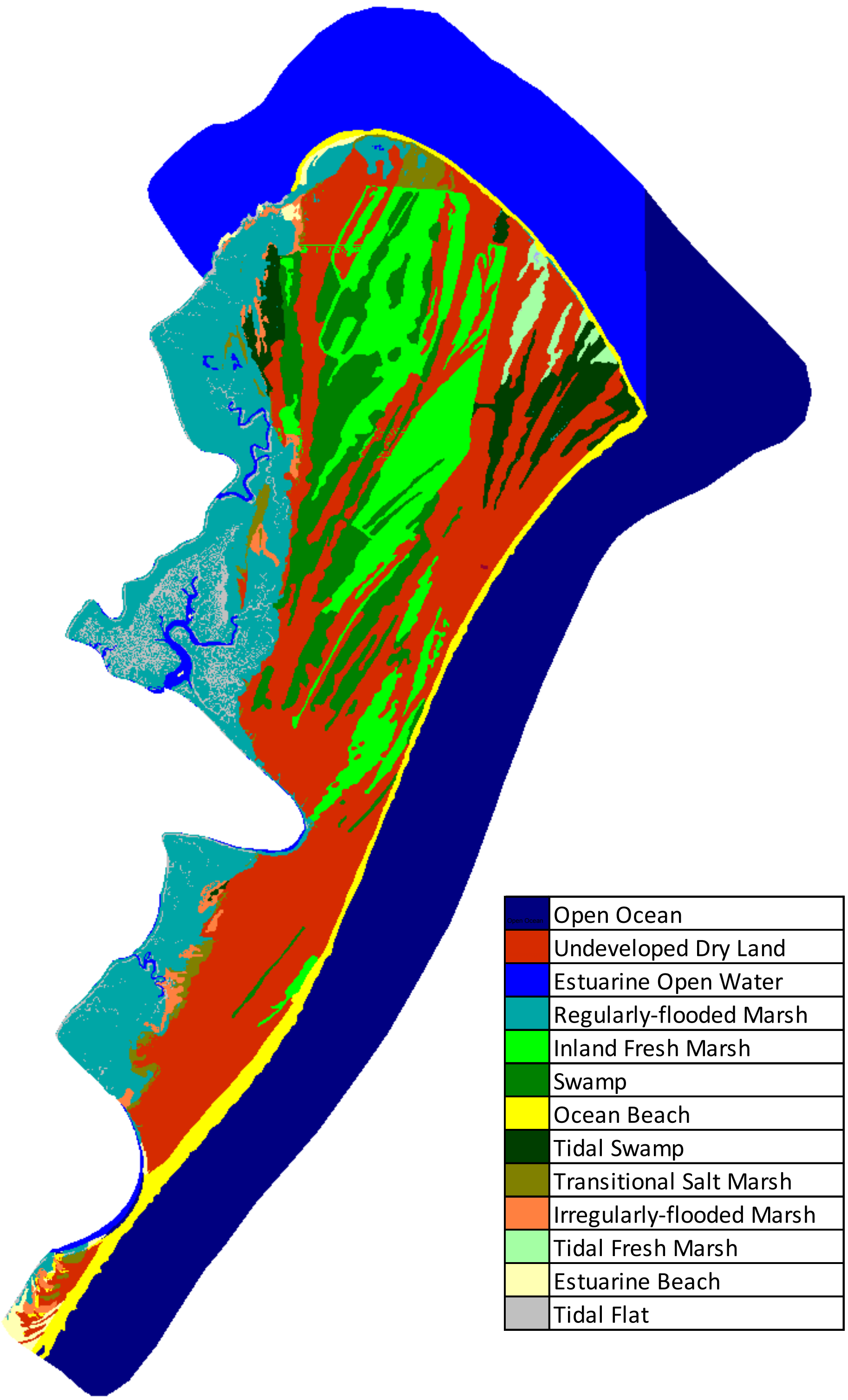
Blackbeard Island NWR
IPCC Scenario A1B-Mean, 0.39 m SLR eustatic by 2100

Results in Acres

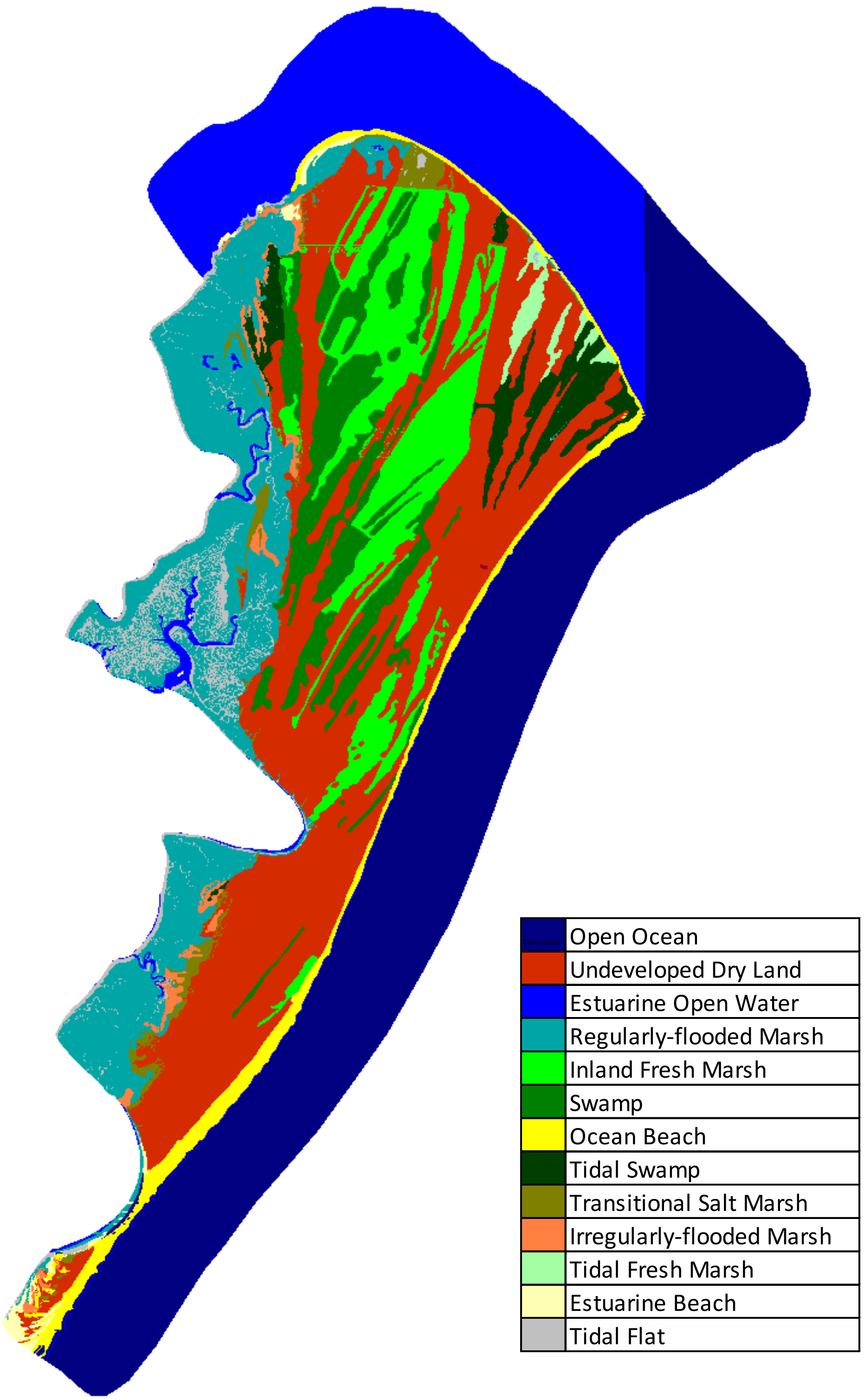
		Initial	2025	2050	2075	2100
	Open Ocean	2147	2150	2150	2162	2174
	Undeveloped Dry Land	1869	1797	1785	1753	1718
	Estuarine Open Water	1185	1195	1211	1220	1241
	Regularly-flooded Marsh	1081	993	957	925	903
	Inland Fresh Marsh	628	636	636	636	636
	Swamp	488	488	488	488	488
	Ocean Beach	223	216	205	194	184
	Tidal Swamp	198	189	185	183	180
	Transitional Salt Marsh	96	89	100	119	135
	Irregularly-flooded Marsh	69	67	70	69	70
	Tidal Fresh Marsh	49	48	48	48	48
	Estuarine Beach	30	34	34	38	39
	Tidal Flat	0	159	192	227	246
	Total (incl. water)	**8064**	**8064**	**8064**	**8064**	**8064**



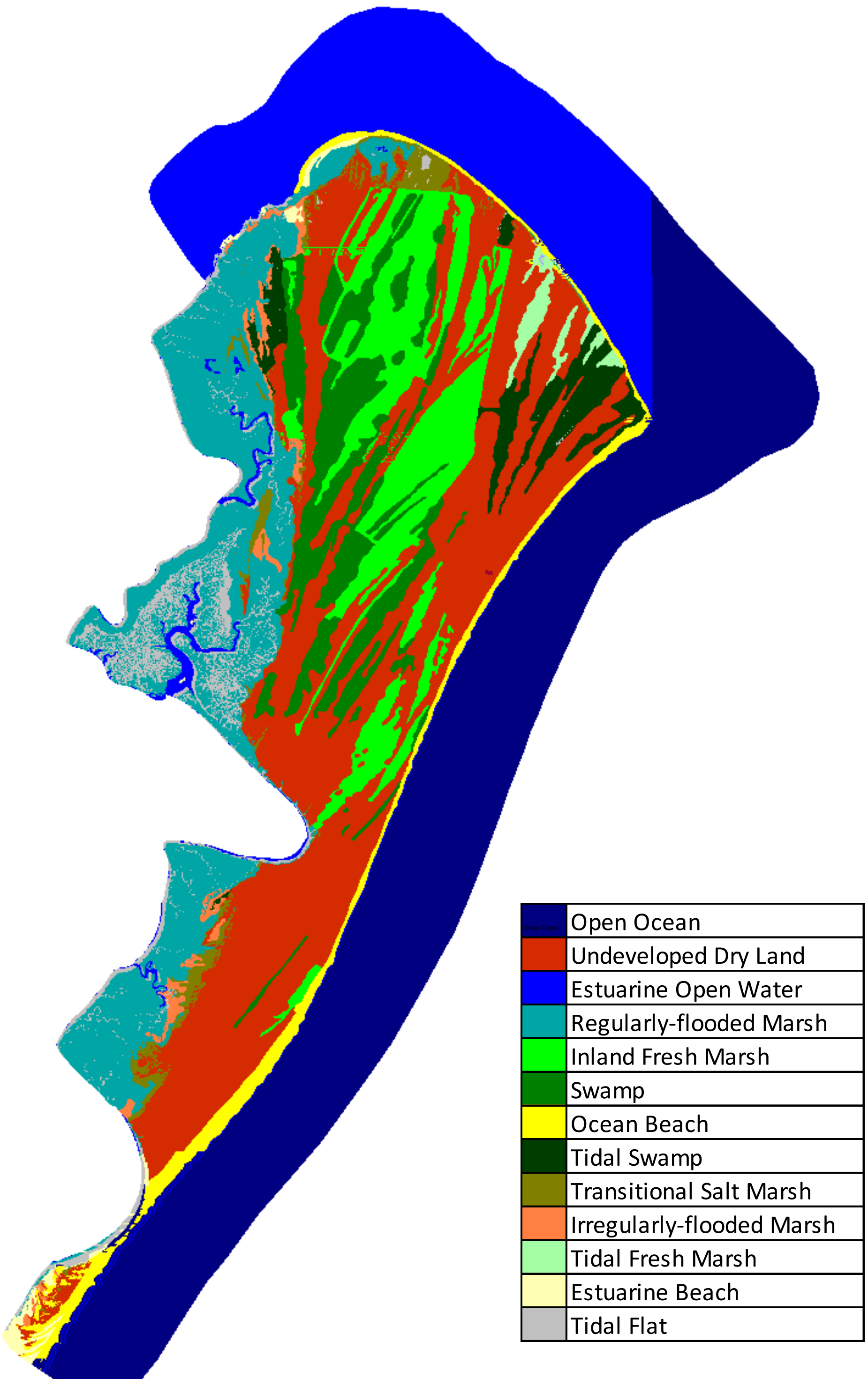
Blackbeard Island NWR, Initial Condition.



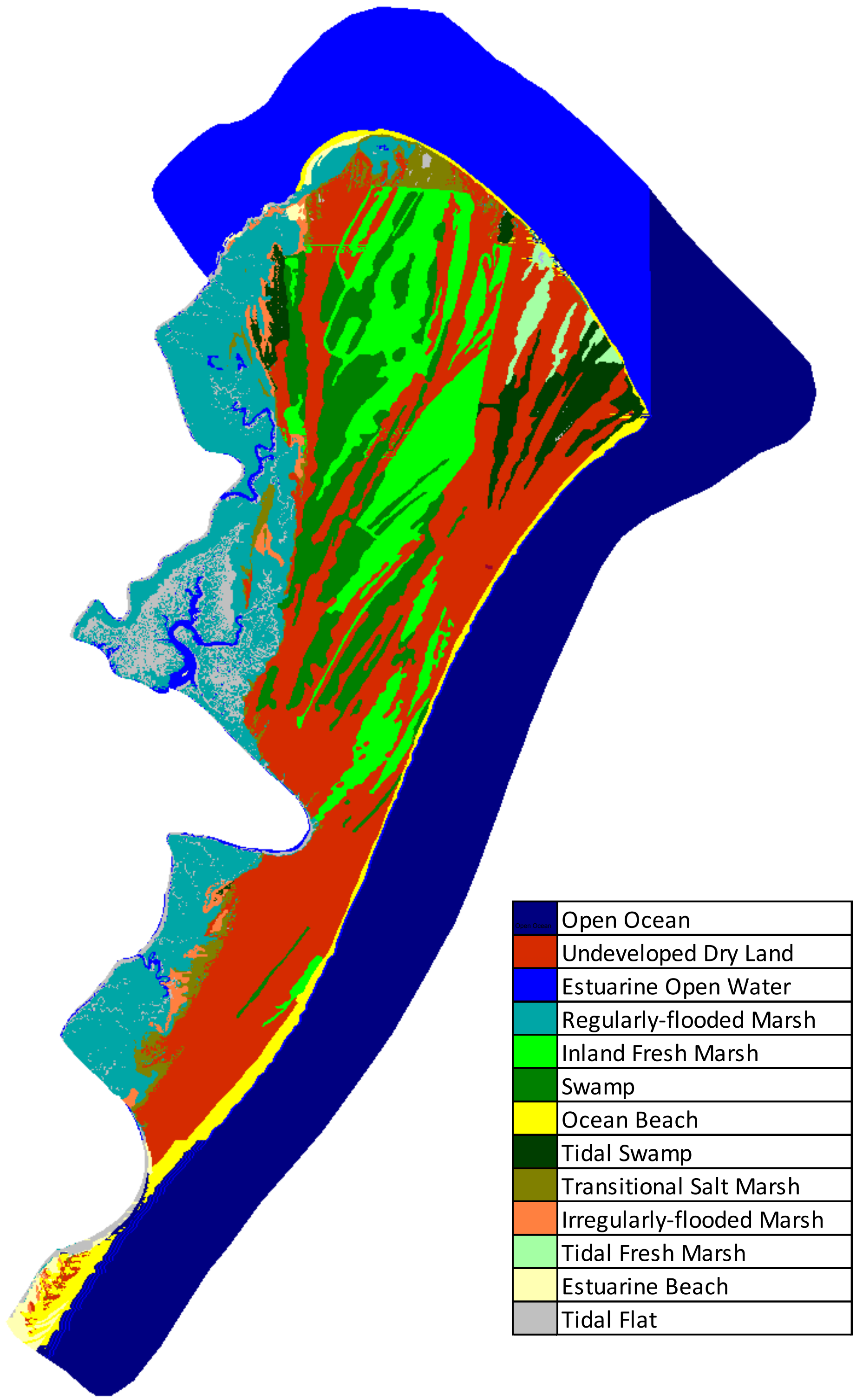
Blackbeard Island NWR, 2025, Scenario A1B Mean, 0.39 m SLR by 2100.



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



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

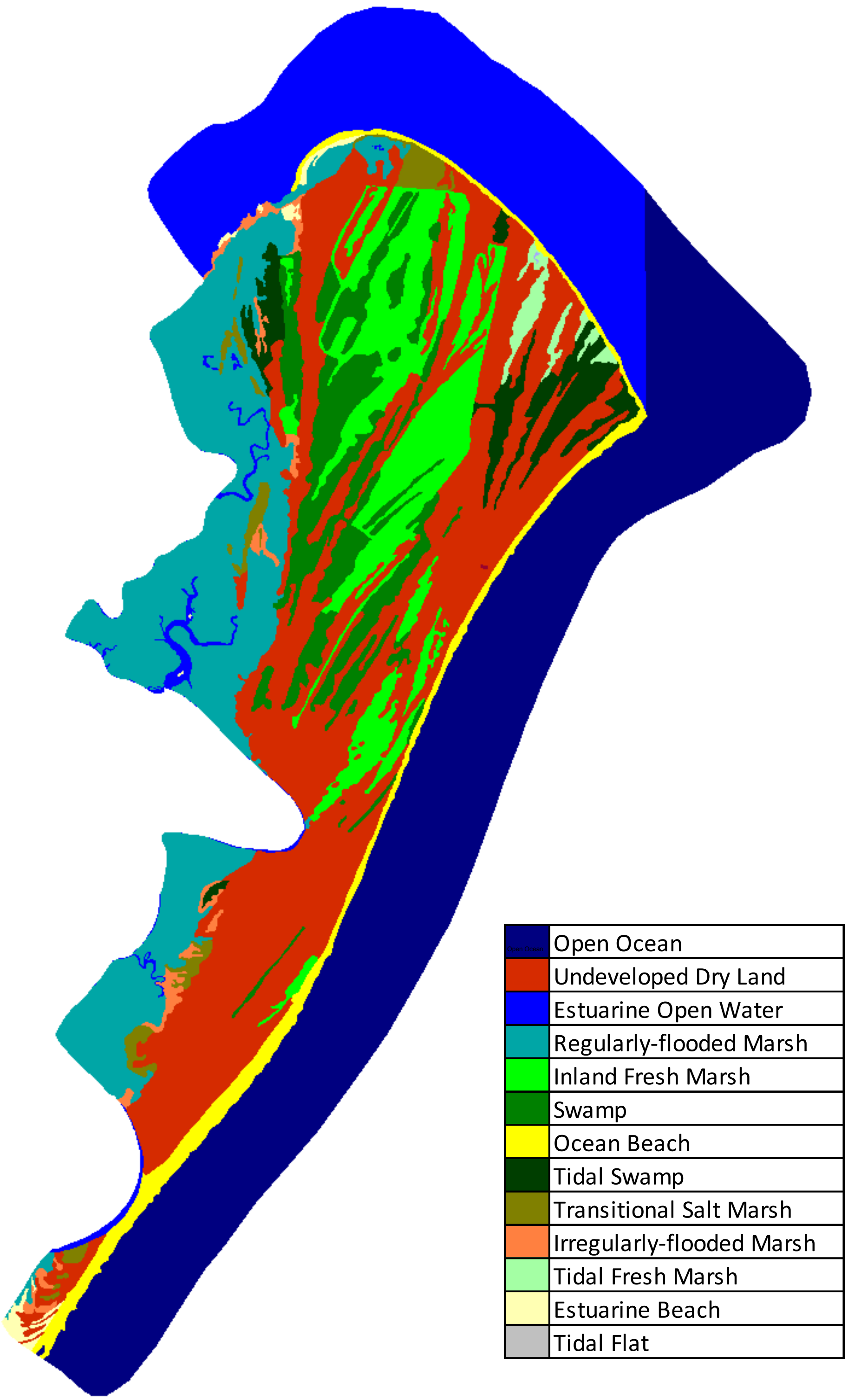


Blackbeard Island NWR, 2100, Scenario A1B Mean, 0.39 m SLR by 2100.

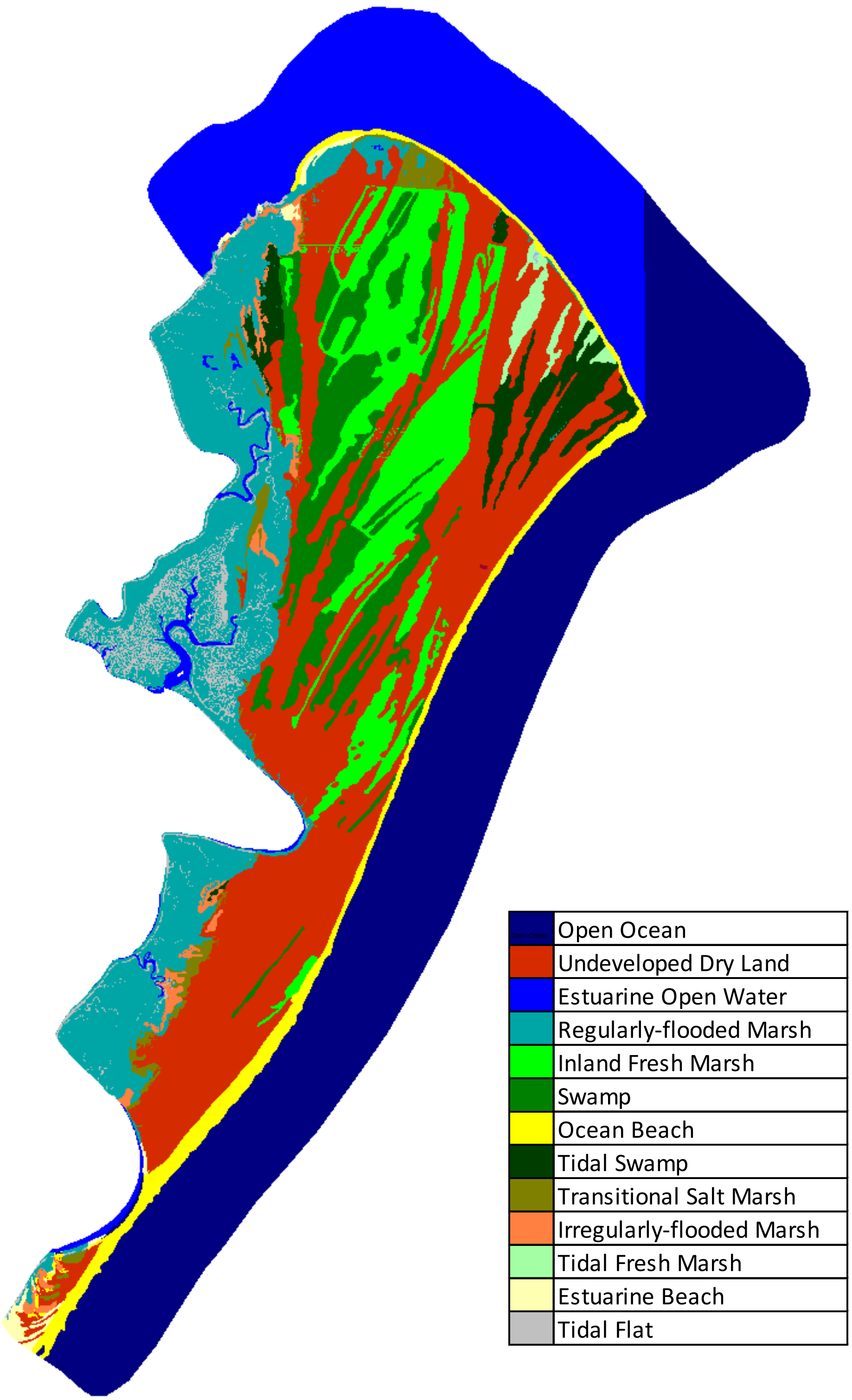
Blackbeard Island NWR
IPCC Scenario A1B-Max, 0.69 m SLR eustatic by 2100

Results in Acres

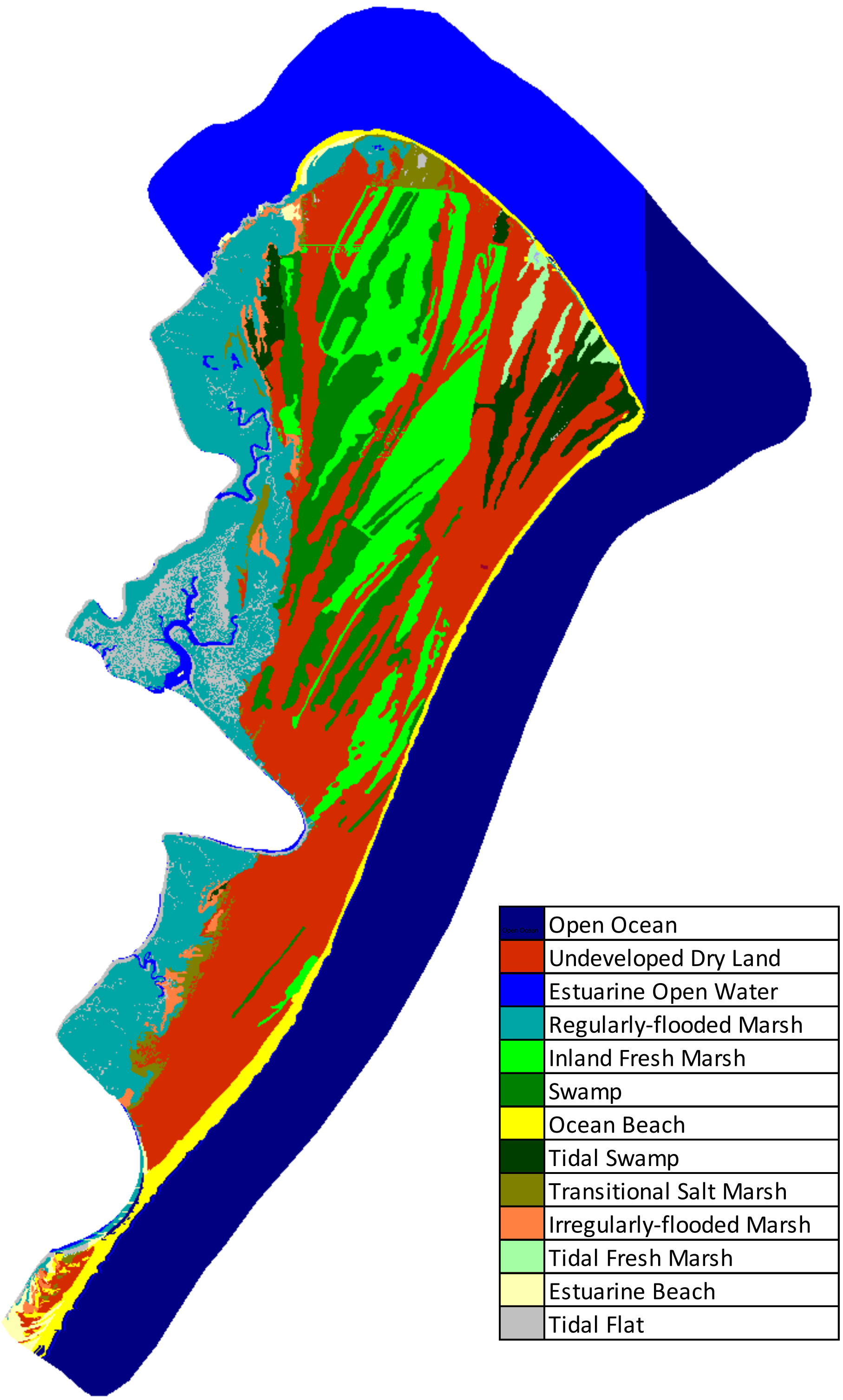
		Initial	2025	2050	2075	2100
	Open Ocean	2147	2150	2151	2163	2178
	Undeveloped Dry Land	1869	1795	1767	1706	1579
	Estuarine Open Water	1185	1196	1214	1237	1280
	Regularly-flooded Marsh	1081	985	934	903	874
	Inland Fresh Marsh	628	636	636	635	626
	Swamp	488	488	488	487	482
	Ocean Beach	223	216	207	201	216
	Tidal Swamp	198	187	183	177	167
	Transitional Salt Marsh	96	90	107	128	170
	Irregularly-flooded Marsh	69	68	70	70	75
	Tidal Fresh Marsh	49	48	48	48	48
	Estuarine Beach	30	34	34	38	45
	Tidal Flat	0	168	223	270	323
	Total (incl. water)	**8064**	**8064**	**8064**	**8064**	**8064**



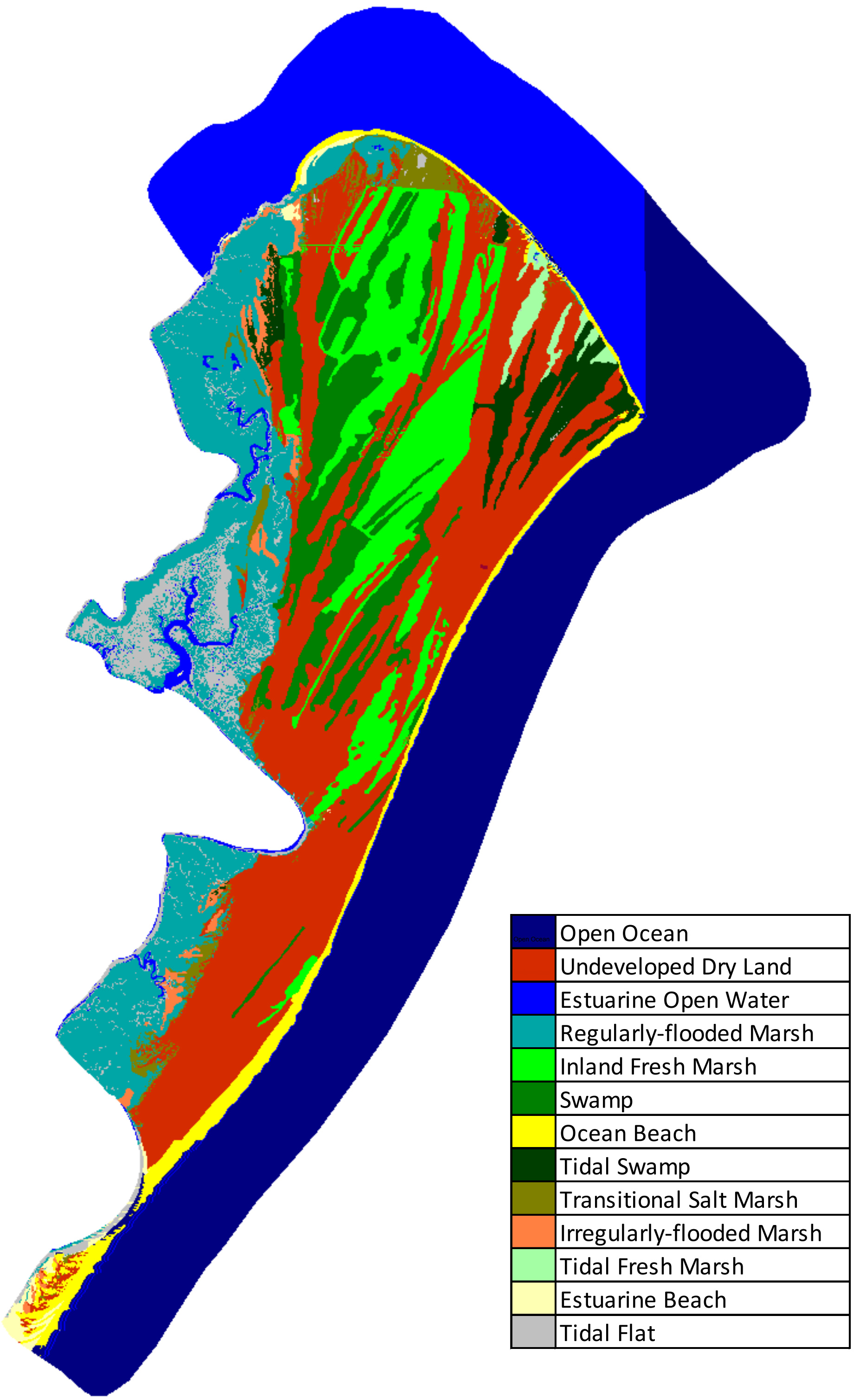
Blackbeard Island NWR, Initial Condition.



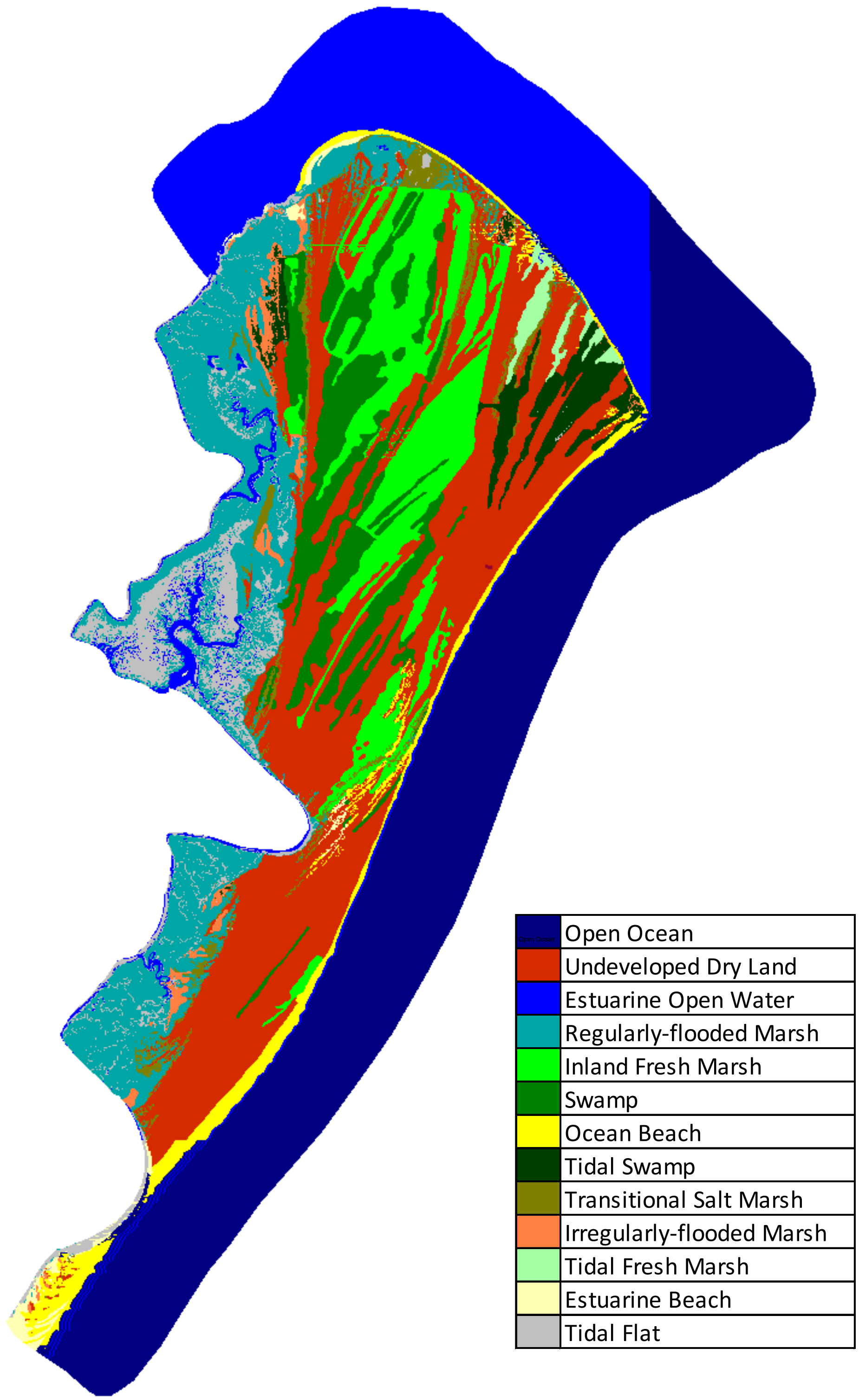
Blackbeard Island NWR, 2025, Scenario A1B Maximum, 0.69 m SLR by 2100.



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



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

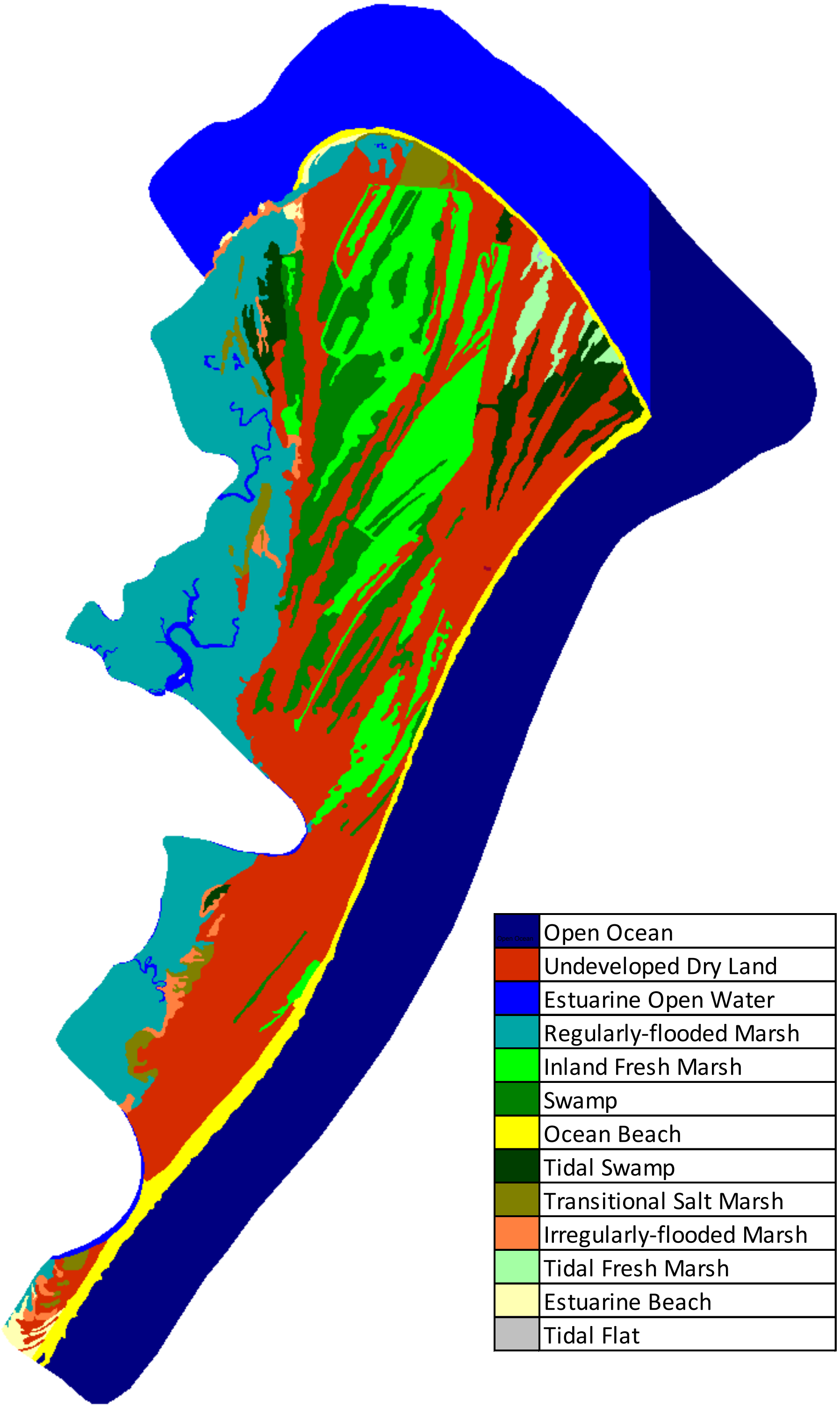


Blackbeard Island NWR, 2100, Scenario A1B Maximum, 0.69 m SLR by 2100.

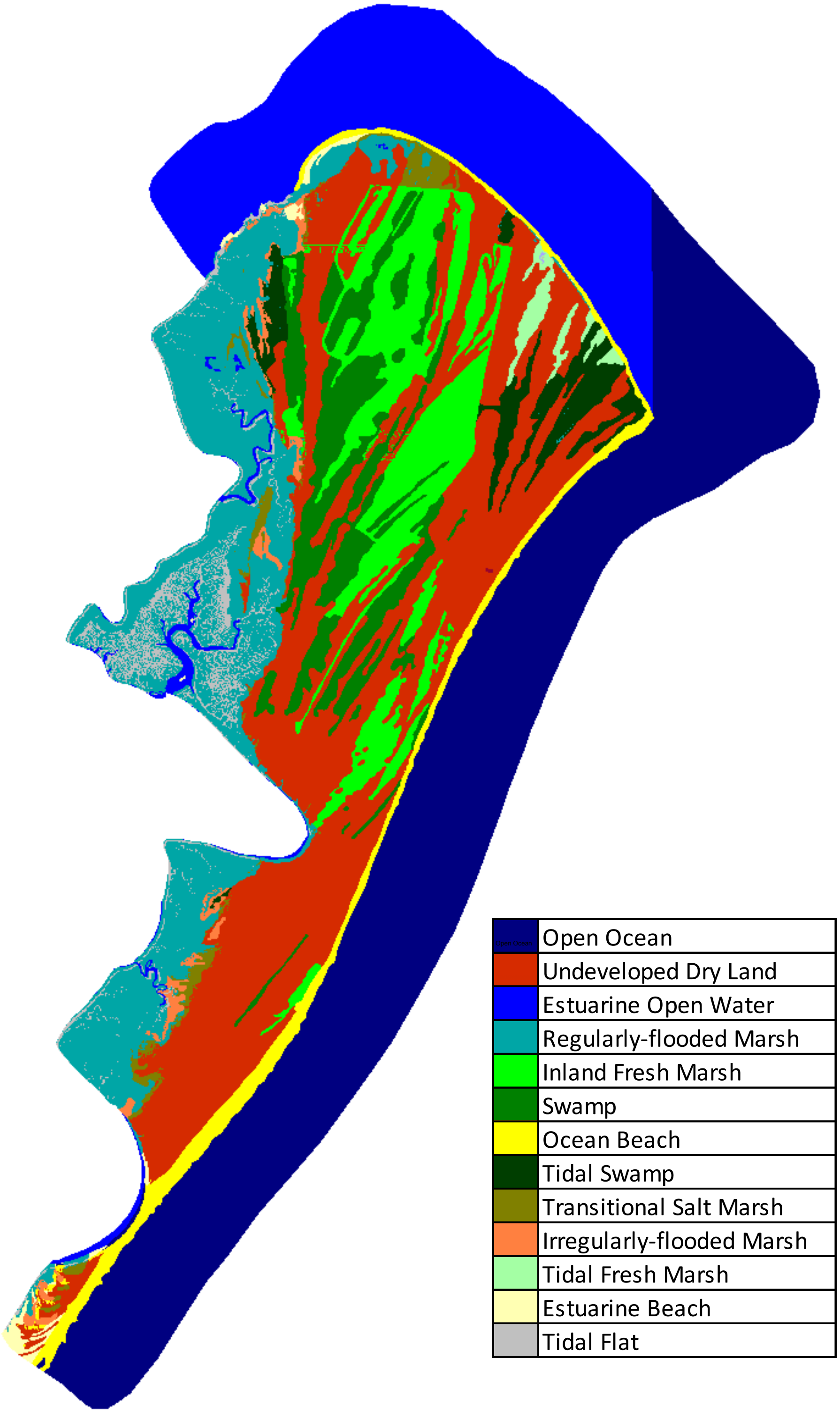
Blackbeard Island NWR
1 m eustatic SLR by 2100

Results in Acres

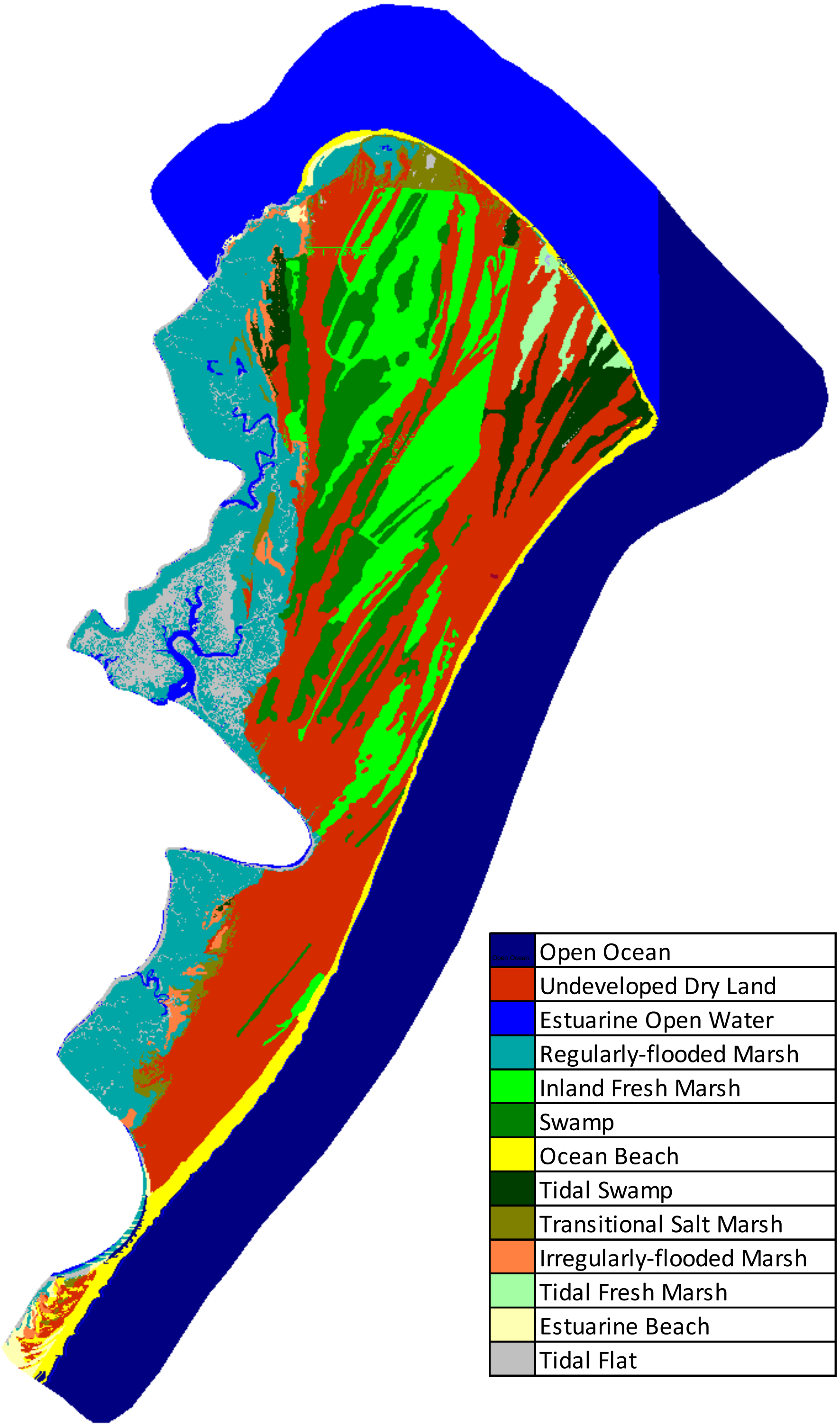
		Initial	2025	2050	2075	2100
	Open Ocean	2147	2150	2151	2165	2182
	Undeveloped Dry Land	1869	1792	1743	1602	1243
	Estuarine Open Water	1185	1196	1221	1262	1343
	Regularly-flooded Marsh	1081	978	918	881	784
	Inland Fresh Marsh	628	636	635	612	548
	Swamp	488	488	488	483	353
	Ocean Beach	223	217	210	234	303
	Tidal Swamp	198	186	181	168	137
	Transitional Salt Marsh	96	89	115	167	484
	Irregularly-flooded Marsh	69	68	70	70	71
	Tidal Fresh Marsh	49	48	48	48	47
	Estuarine Beach	30	34	34	42	46
	Tidal Flat	0	179	249	329	520
	Total (incl. water)	**8064**	**8064**	**8064**	**8064**	**8064**



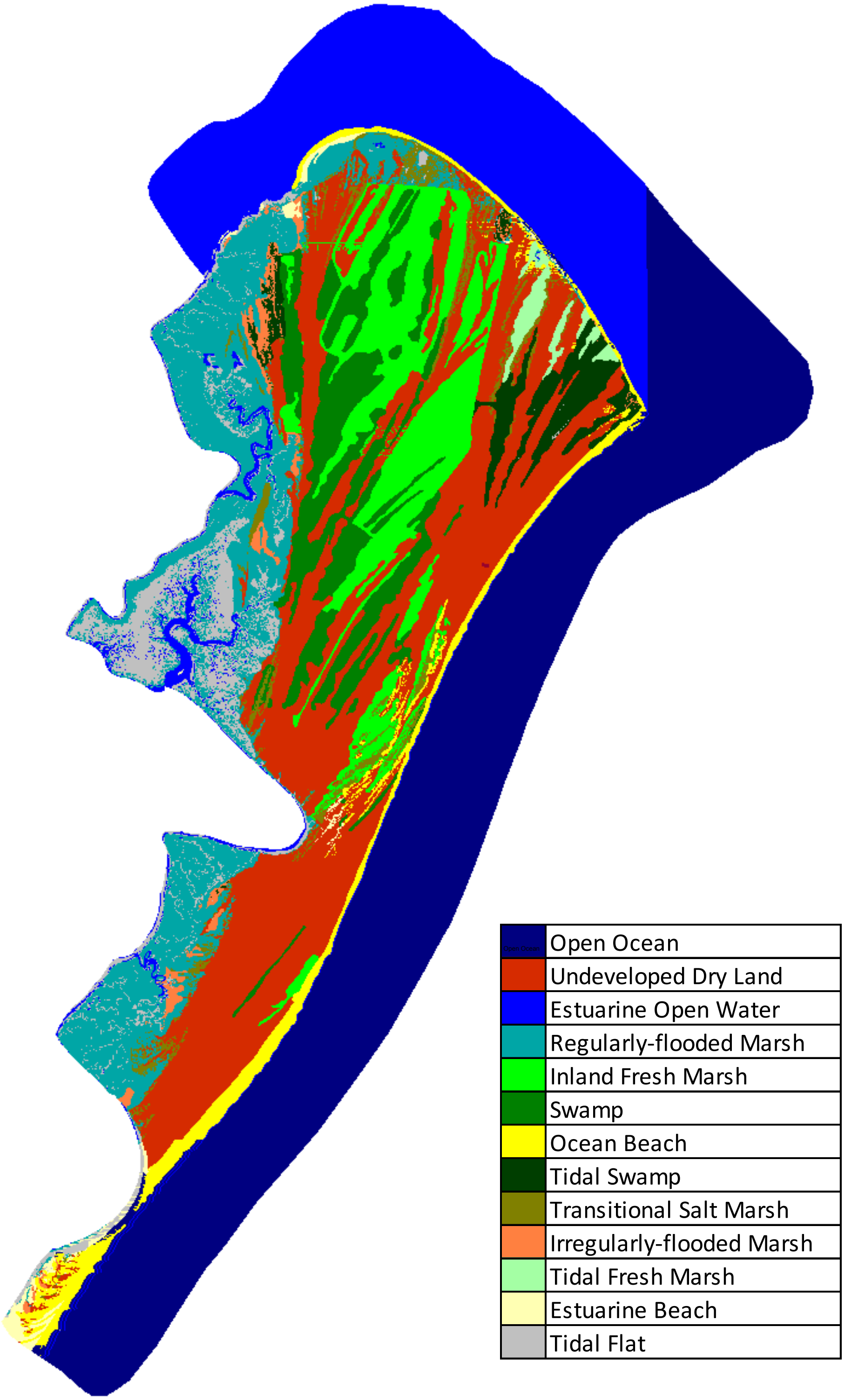
Blackbeard Island NWR, Initial Condition.



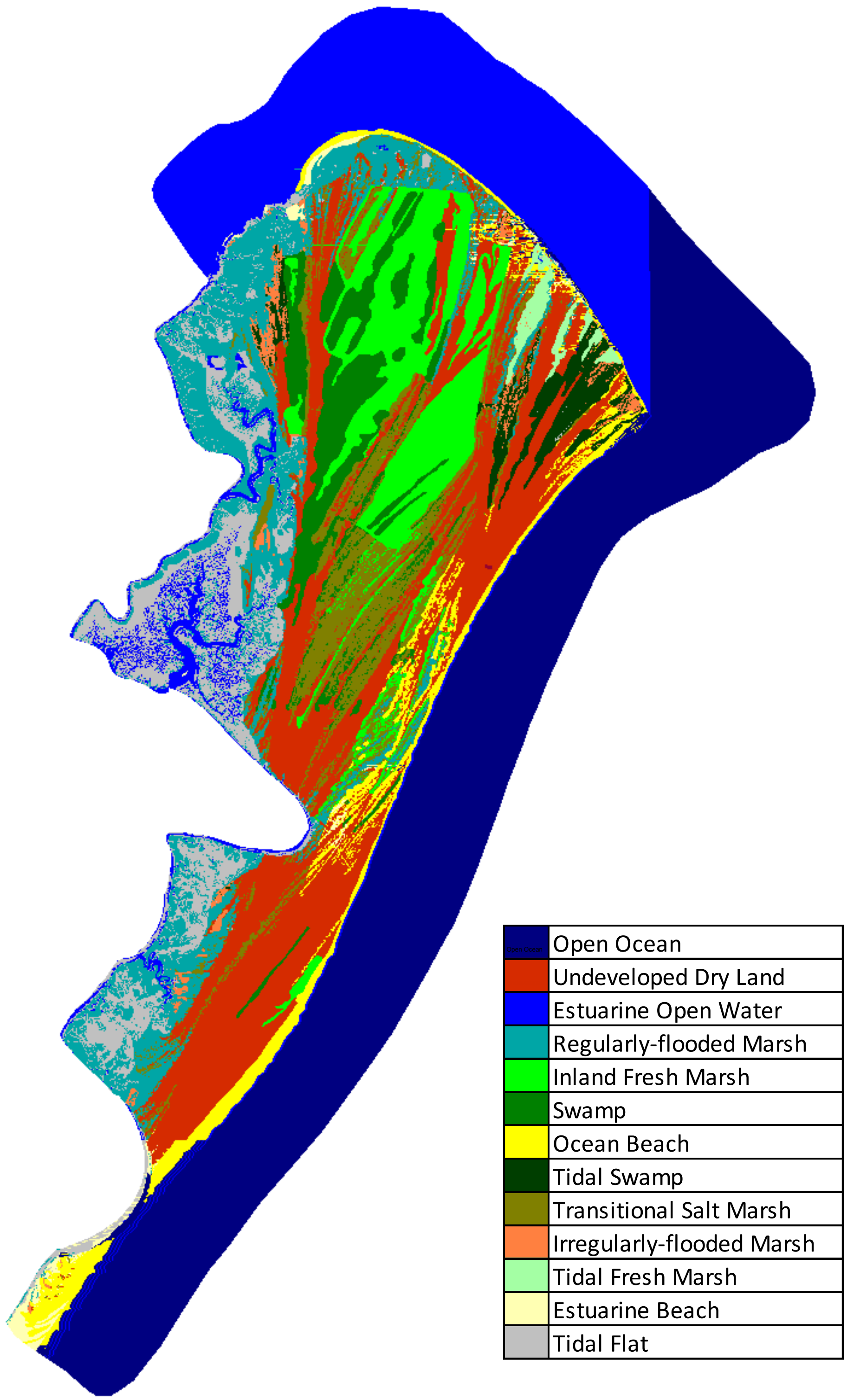
Blackbeard Island NWR, 2025, 1 m SLR by 2100.



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



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

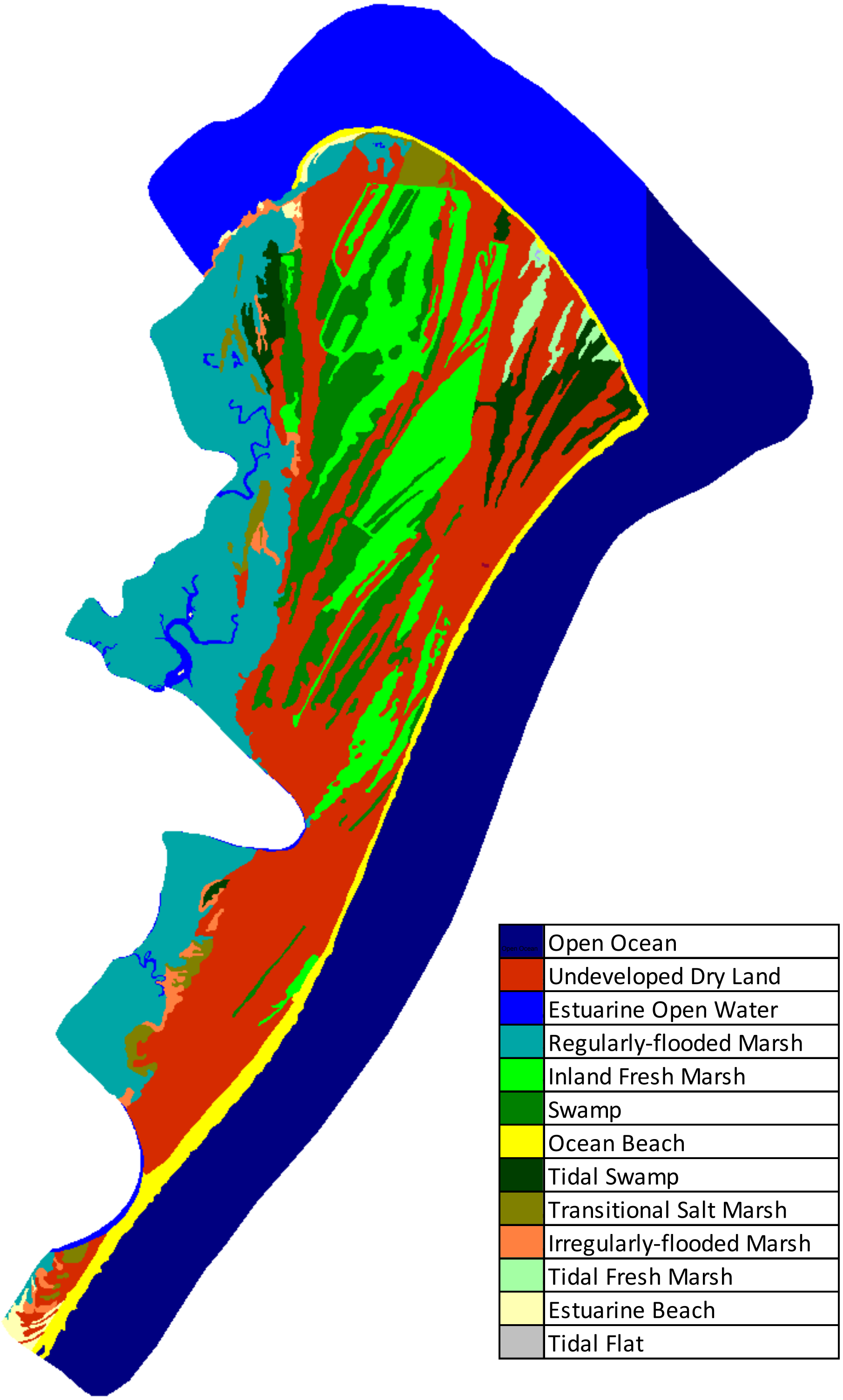


Blackbeard Island NWR, 2100, 1 m SLR by 2100.

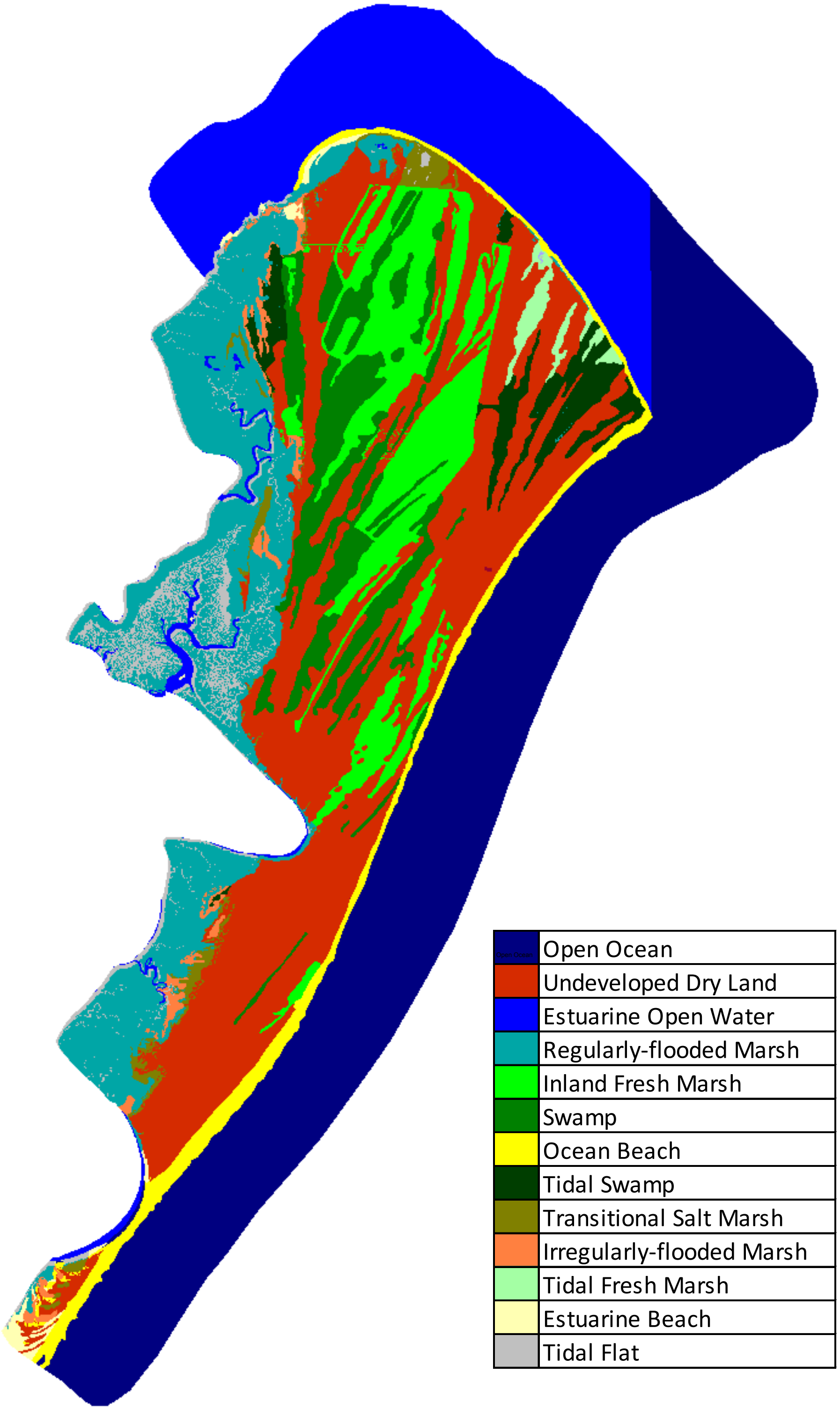
Blackbeard Island NWR
1.5 m eustatic SLR by 2100

Results in Acres

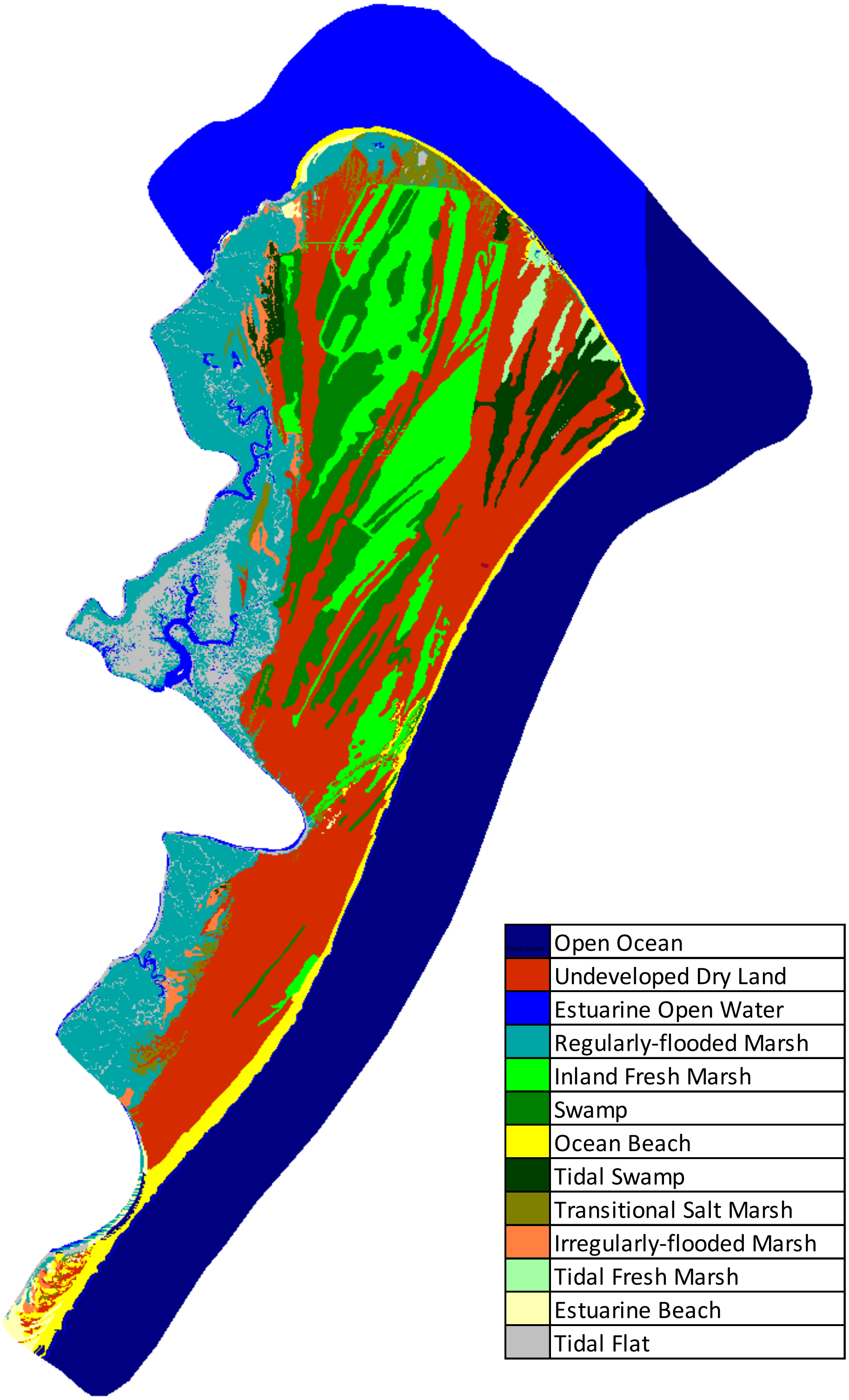
		Initial	2025	2050	2075	2100
	Open Ocean	2147	2150	2152	2177	2208
	Undeveloped Dry Land	1869	1782	1697	1249	772
	Estuarine Open Water	1185	1197	1238	1324	1506
	Regularly-flooded Marsh	1081	960	895	688	766
	Inland Fresh Marsh	628	636	627	531	494
	Swamp	488	488	485	354	305
	Ocean Beach	223	218	220	315	485
	Tidal Swamp	198	185	175	135	61
	Transitional Salt Marsh	96	92	132	565	392
	Irregularly-flooded Marsh	69	68	70	71	130
	Tidal Fresh Marsh	49	48	48	40	14
	Estuarine Beach	30	34	35	48	50
	Tidal Flat	0	203	291	565	882
	Total (incl. water)	**8064**	**8064**	**8064**	**8064**	**8064**



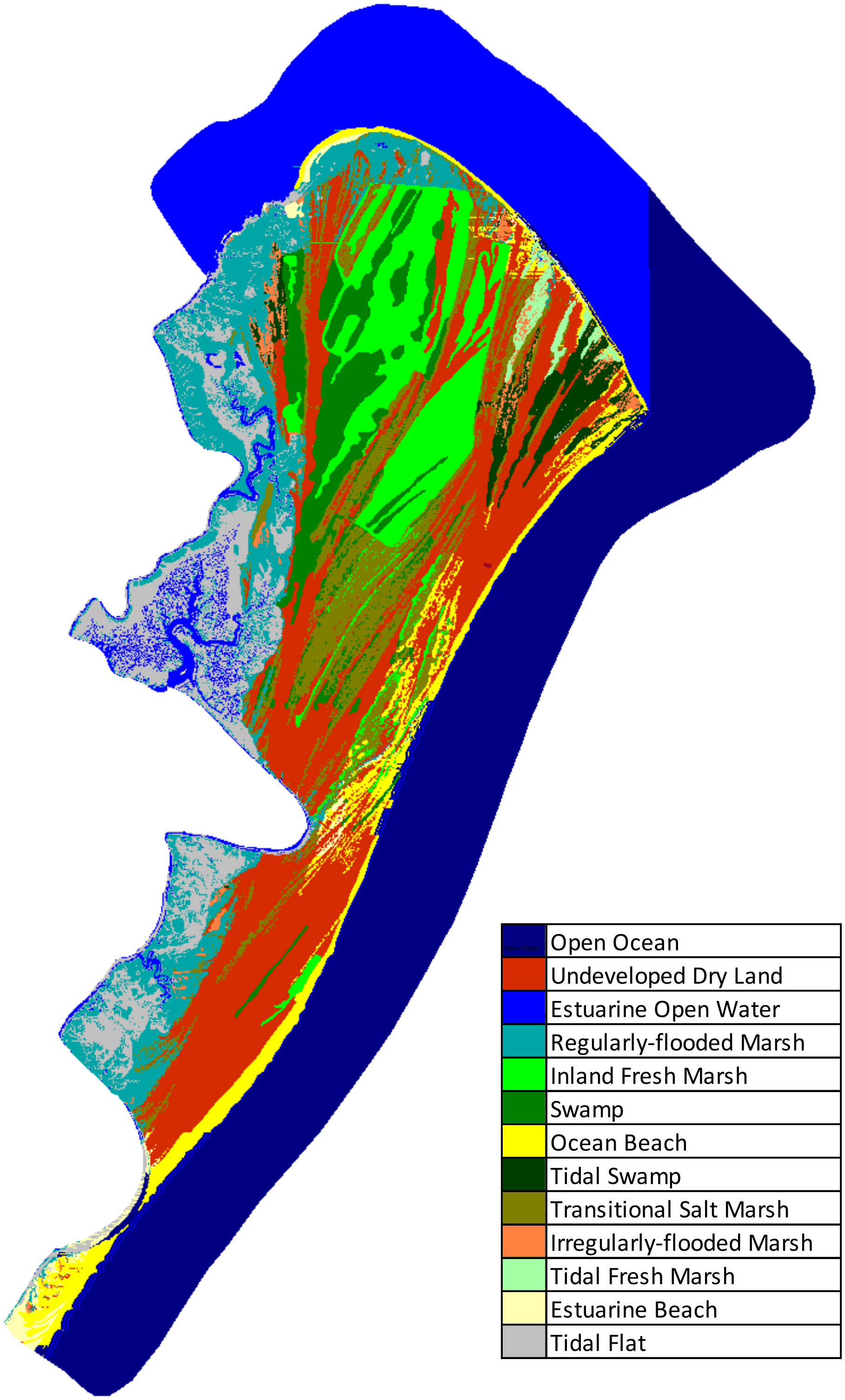
Blackbeard Island NWR, Initial Condition.



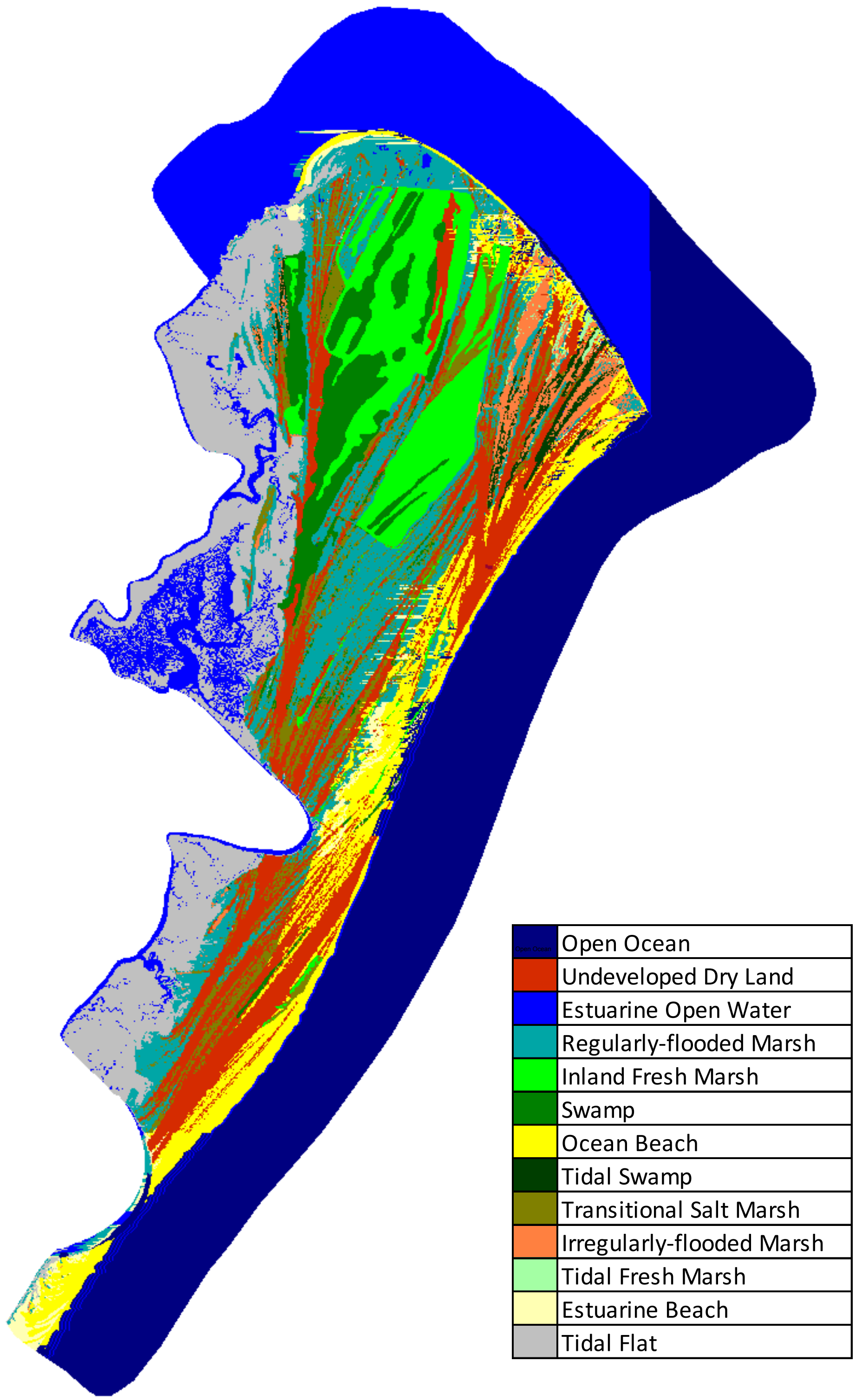
Blackbeard Island NWR, 2025, 1.5 m SLR by 2100.



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



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

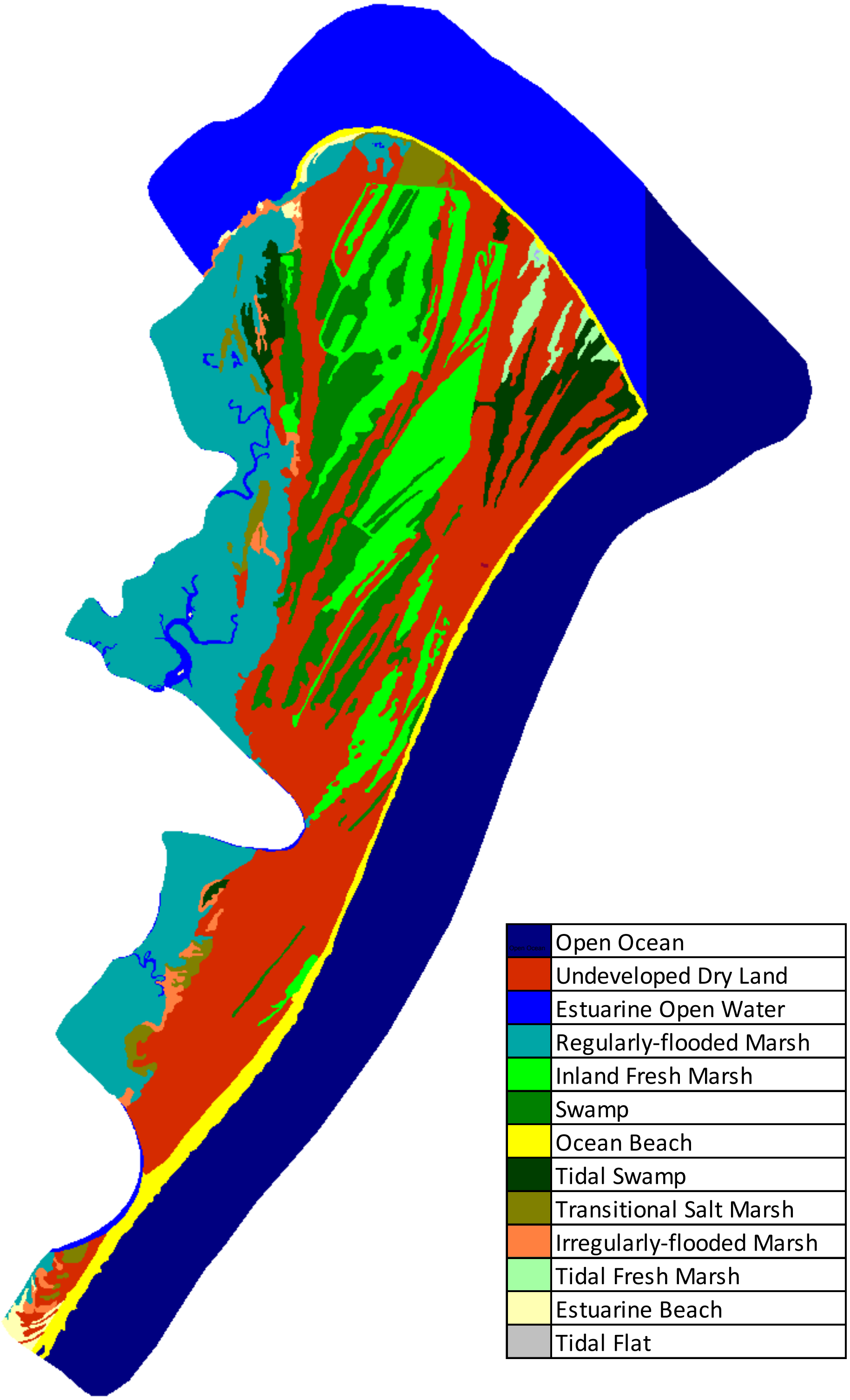


Blackbeard Island NWR, 2100, 1.5 m SLR by 2100.

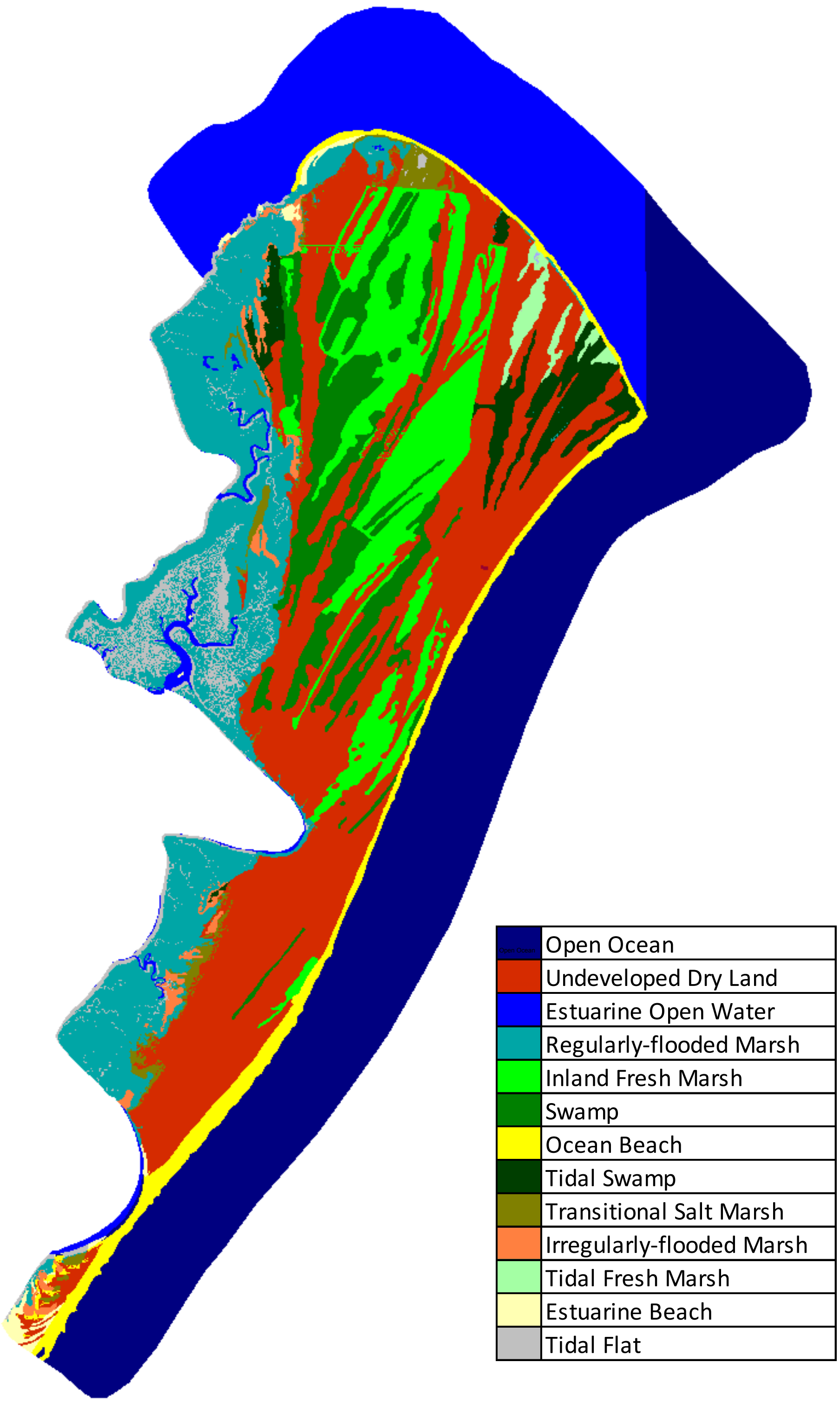
Blackbeard Island NWR
2 m eustatic SLR by 2100

Results in Acres

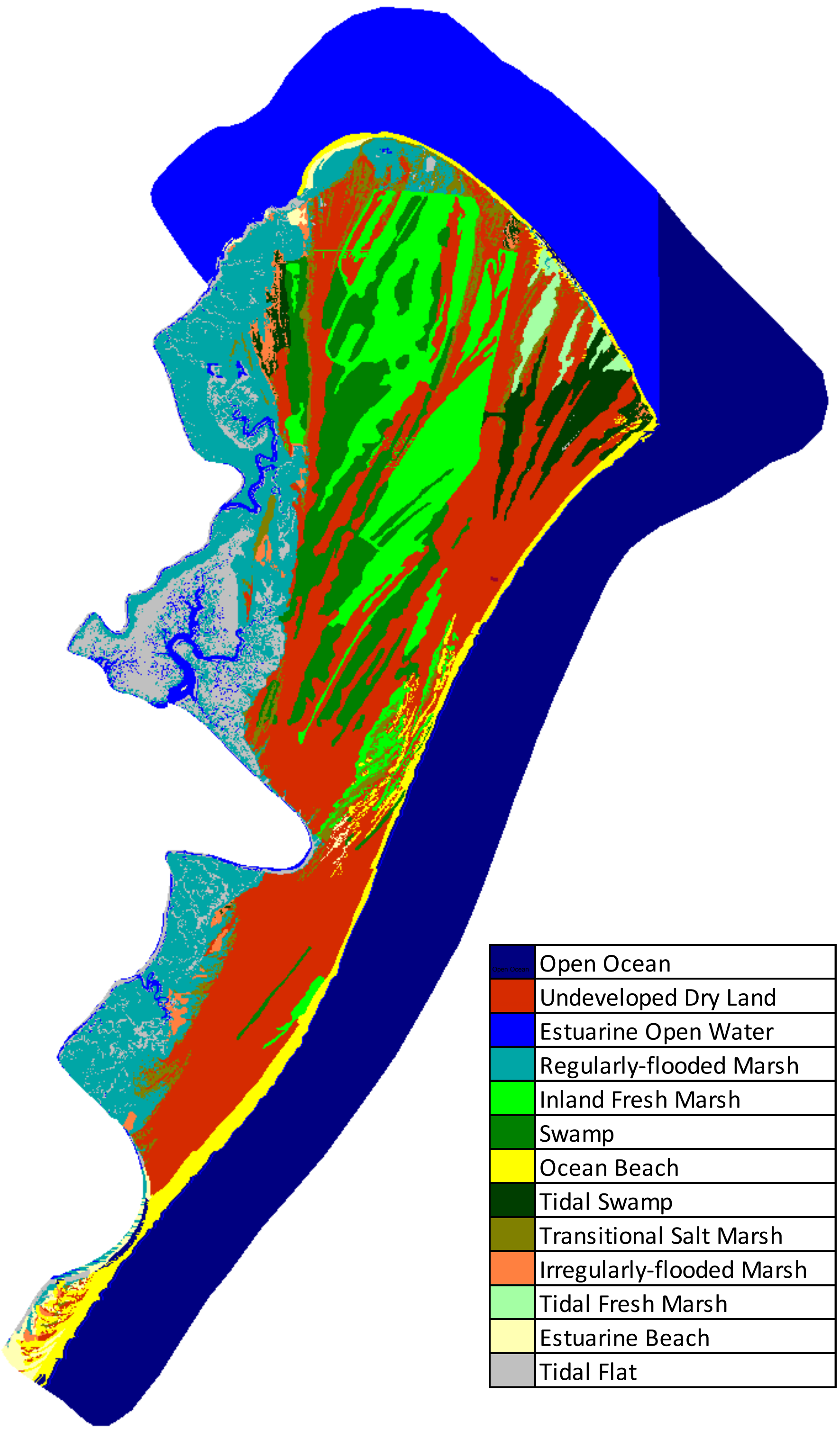
		Initial	2025	2050	2075	2100
	Open Ocean	2147	2150	2153	2189	2232
	Undeveloped Dry Land	1869	1775	1590	938	418
	Estuarine Open Water	1185	1198	1261	1434	1703
	Regularly-flooded Marsh	1081	952	852	390	904
	Inland Fresh Marsh	628	636	595	496	481
	Swamp	488	488	483	316	283
	Ocean Beach	223	219	245	437	625
	Tidal Swamp	198	184	165	79	27
	Transitional Salt Marsh	96	93	217	716	372
	Irregularly-flooded Marsh	69	68	62	128	70
	Tidal Fresh Marsh	49	48	48	16	5
	Estuarine Beach	30	34	38	41	62
	Tidal Flat	0	218	355	883	881
	Total (incl. water)	**8064**	**8064**	**8064**	**8064**	**8064**



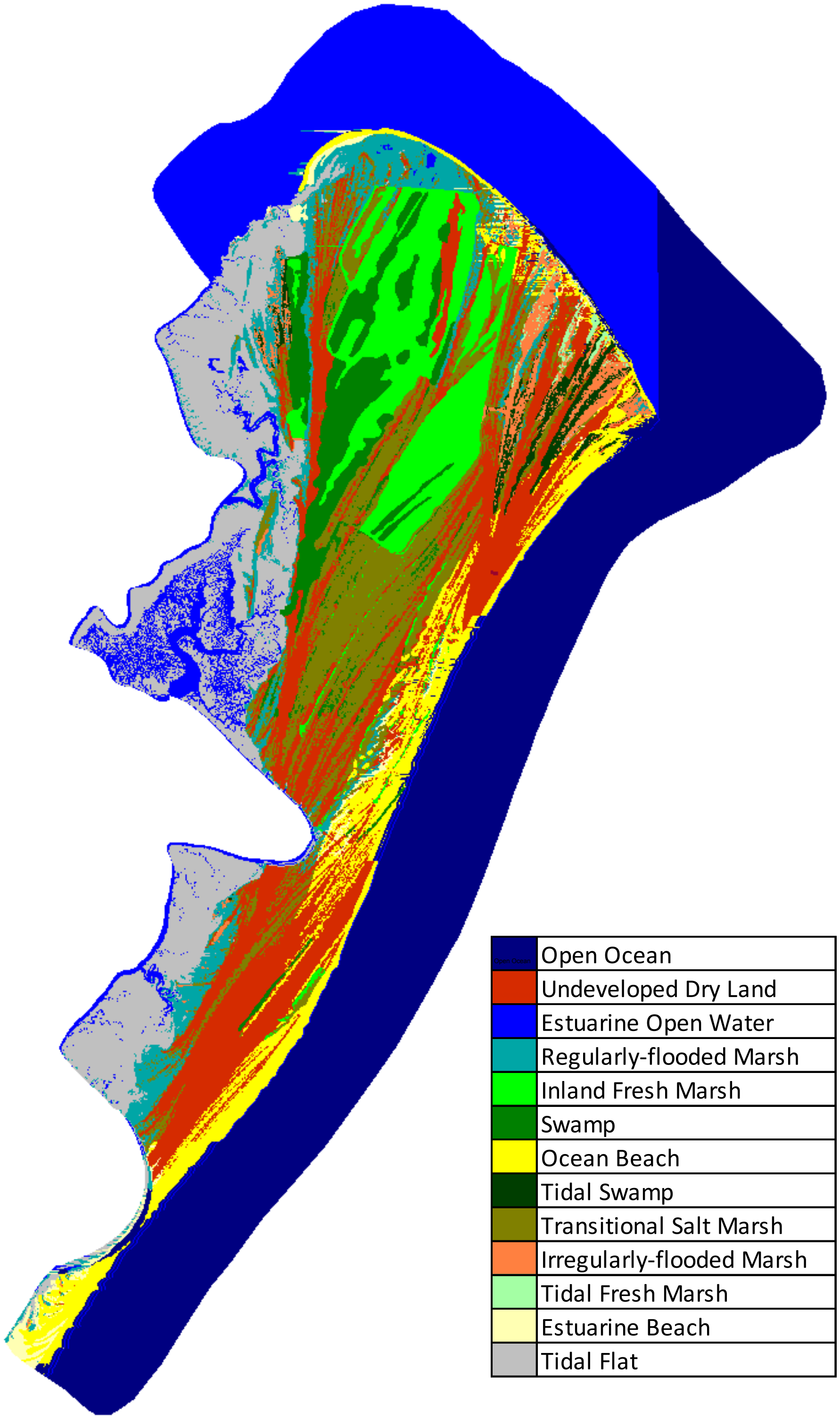
Blackbeard Island NWR, Initial Condition.



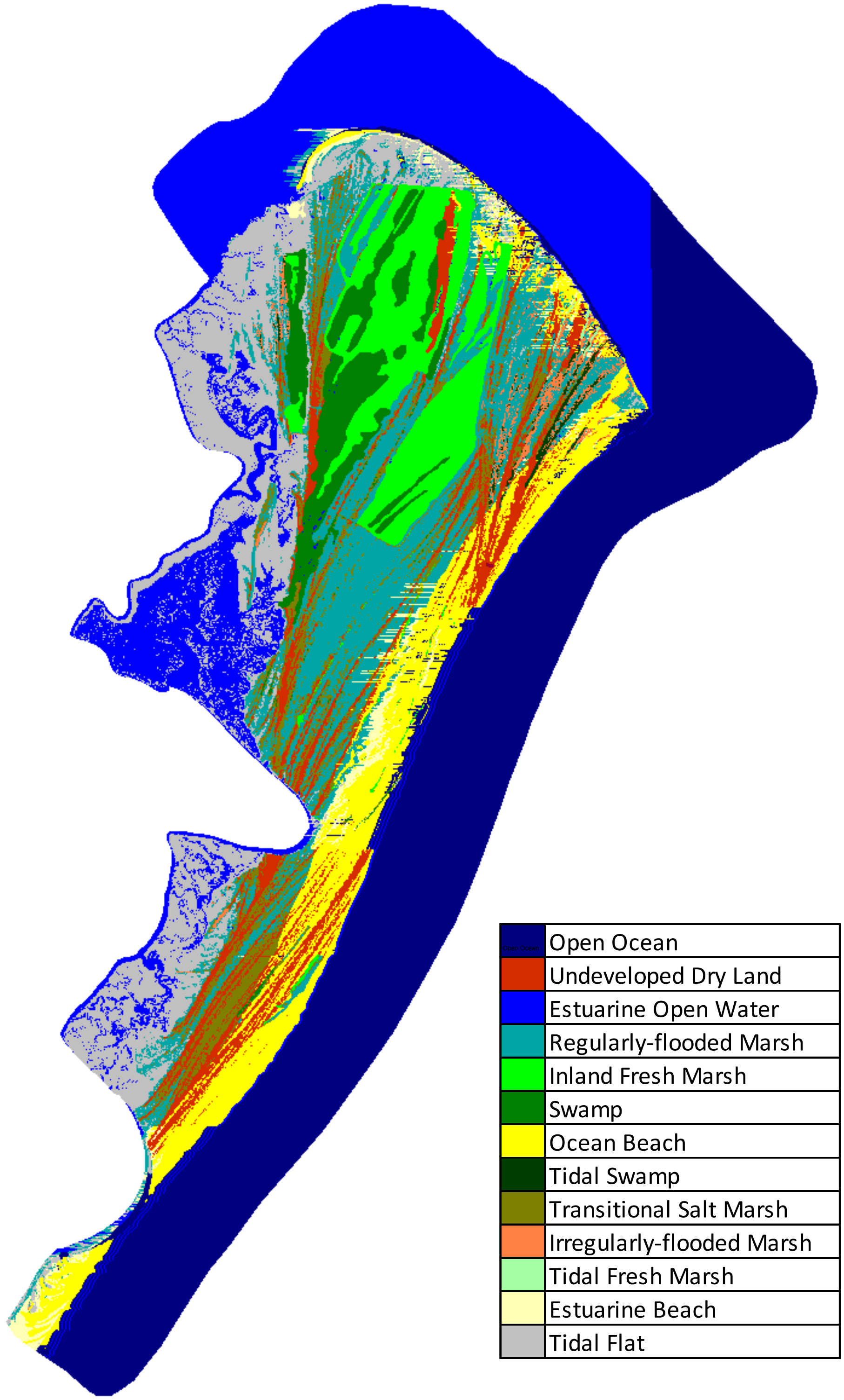
Blackbeard Island NWR, 2025, 2 m SLR by 2100.



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



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



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

Discussion

SLAMM projections for Blackbeard Island NWR suggest that undeveloped dry land is subject to the greatest losses of the existing landcover types in the refuge. Conversely, regularly-flooded marsh is predicted to be fairly resilient to SLR as it migrates to locations that were previously dry land. Inland-fresh marsh and swamp also exhibit resilience to SLR, mostly due to their predicted protection by existing dikes. Open water and tidal flat are predicted to increasingly cover the refuge, up to a combined 60% under the 2 m by 2100 SLR scenario. This is an increase from approximately 40% coverage today.

Making a comparison to the 2008 SLAMM analysis of the refuge is difficult since the NWI and elevation maps have been updated, and this analysis used updated approved acquisition refuge boundaries that differ from the boundaries used in the previous report. In terms of fractional losses, undeveloped dry land, inland fresh marsh, and swamp appear to be more fragile with respect to SLR than shown in previous simulation results, likely due to more accurate elevation data that place these marshes lower in the tidal frame. The overall coverage of salt marshes is predicted to have a lower loss rate than predicted in the previous study.

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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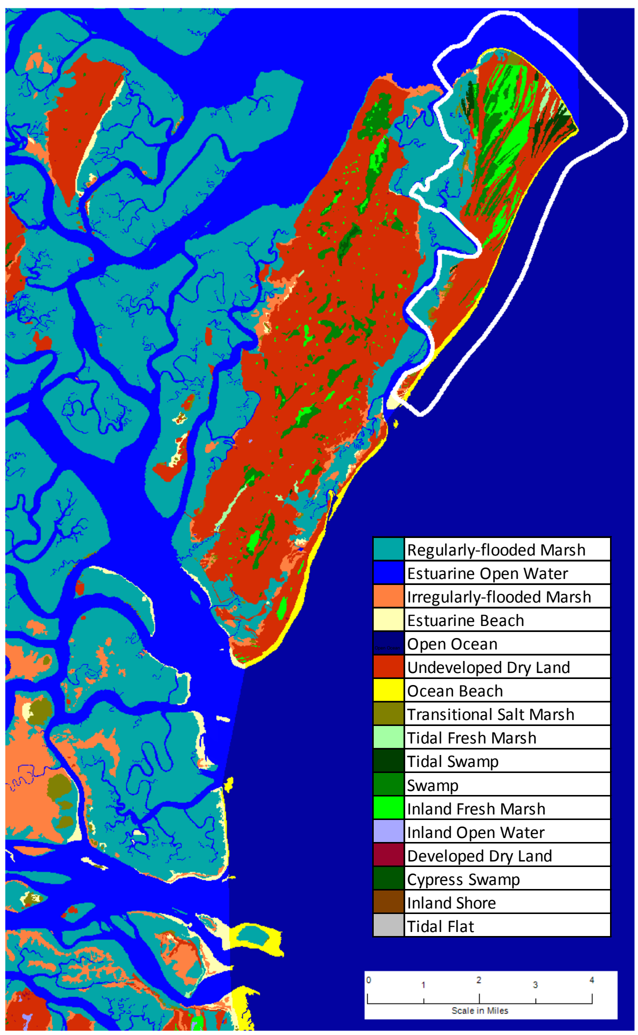
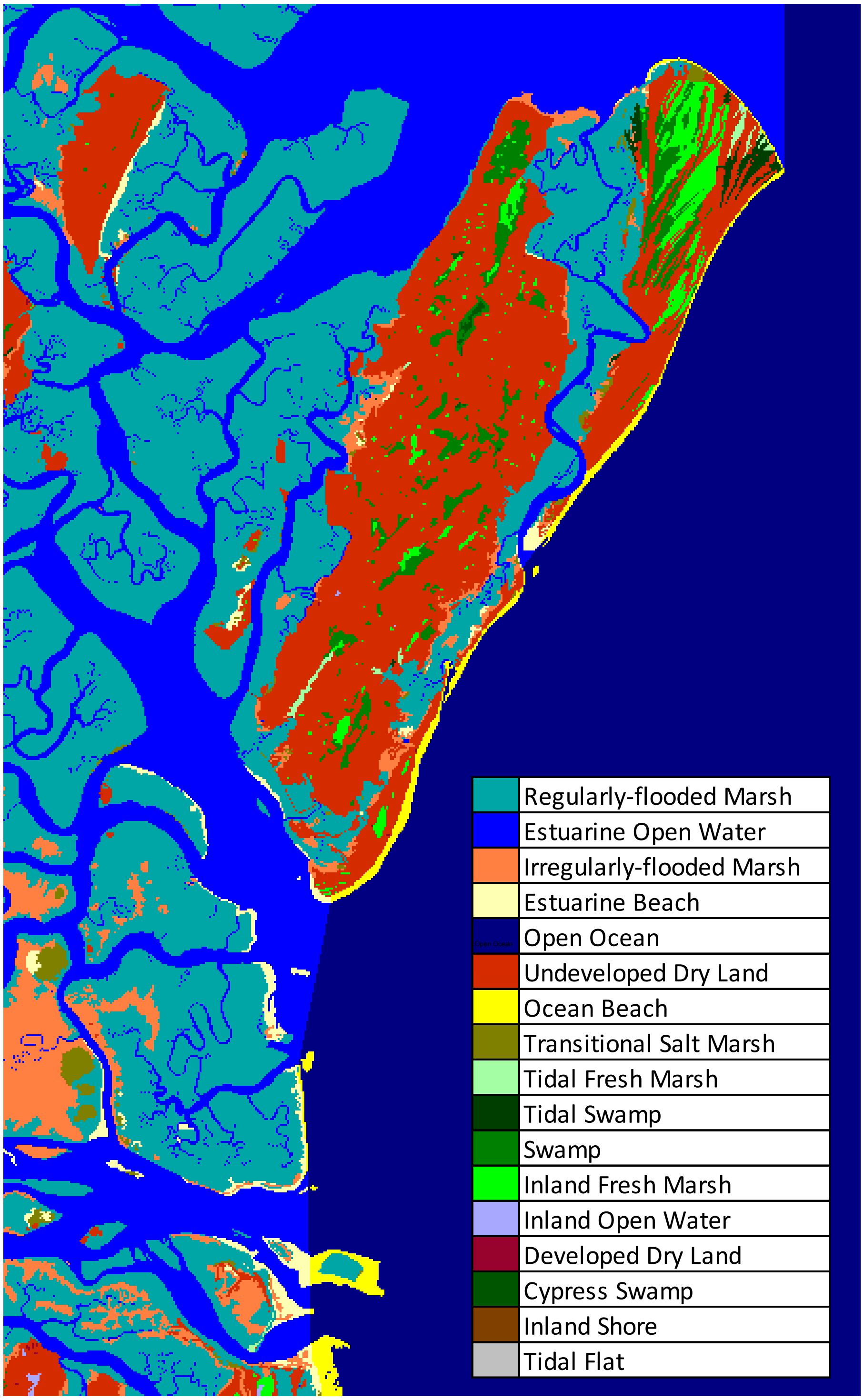
Appendix A: Contextual Results

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:

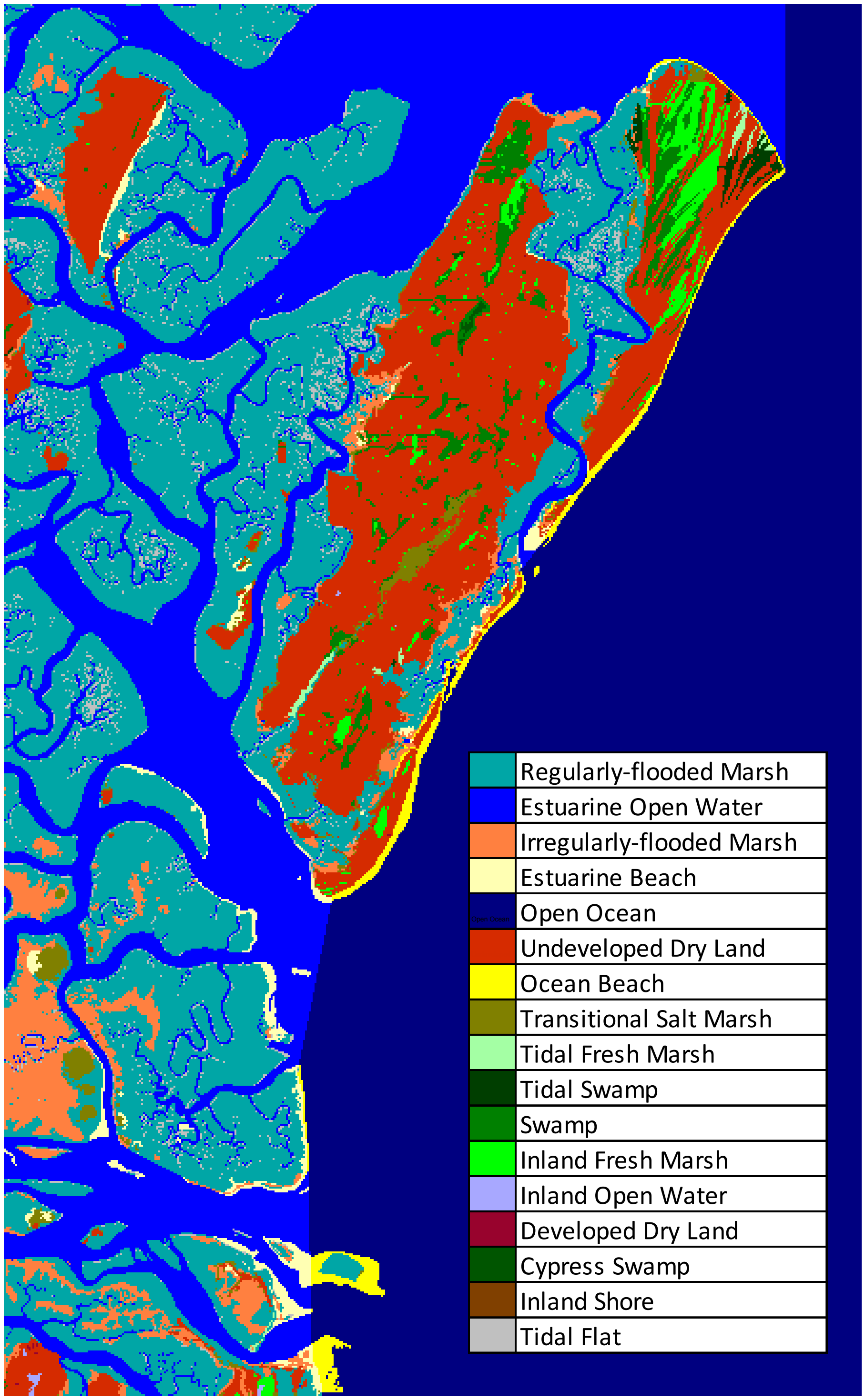
- Results were critically examined within USFWS refuges but not closely examined for the larger region.
- Site-specific parameters for the model were derived for USFWS refuges whenever possible and may not be regionally applicable.
- Especially in areas where dikes are present, an effort was made to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



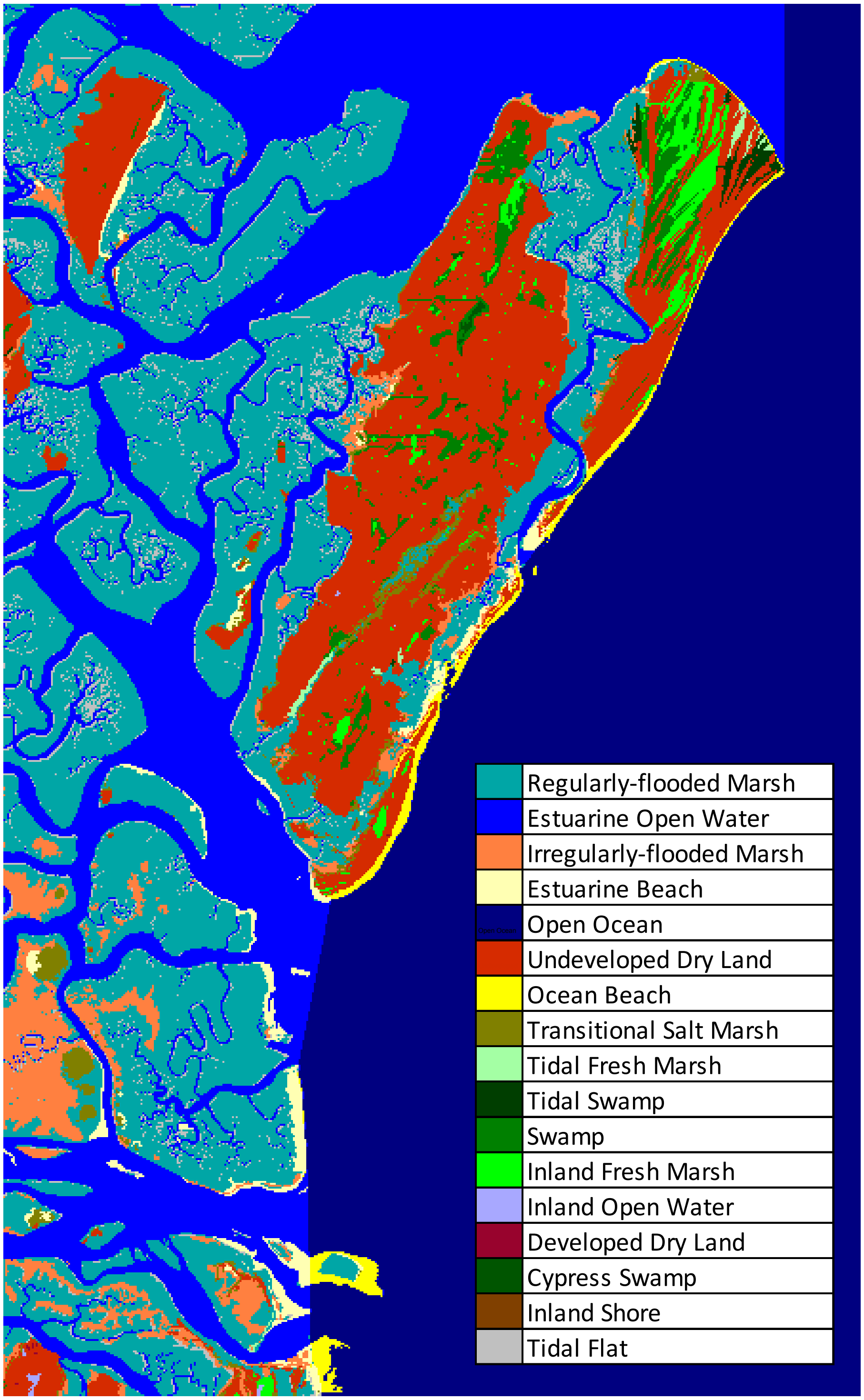
Blackbeard Island National Wildlife Refuge within simulation context (white).



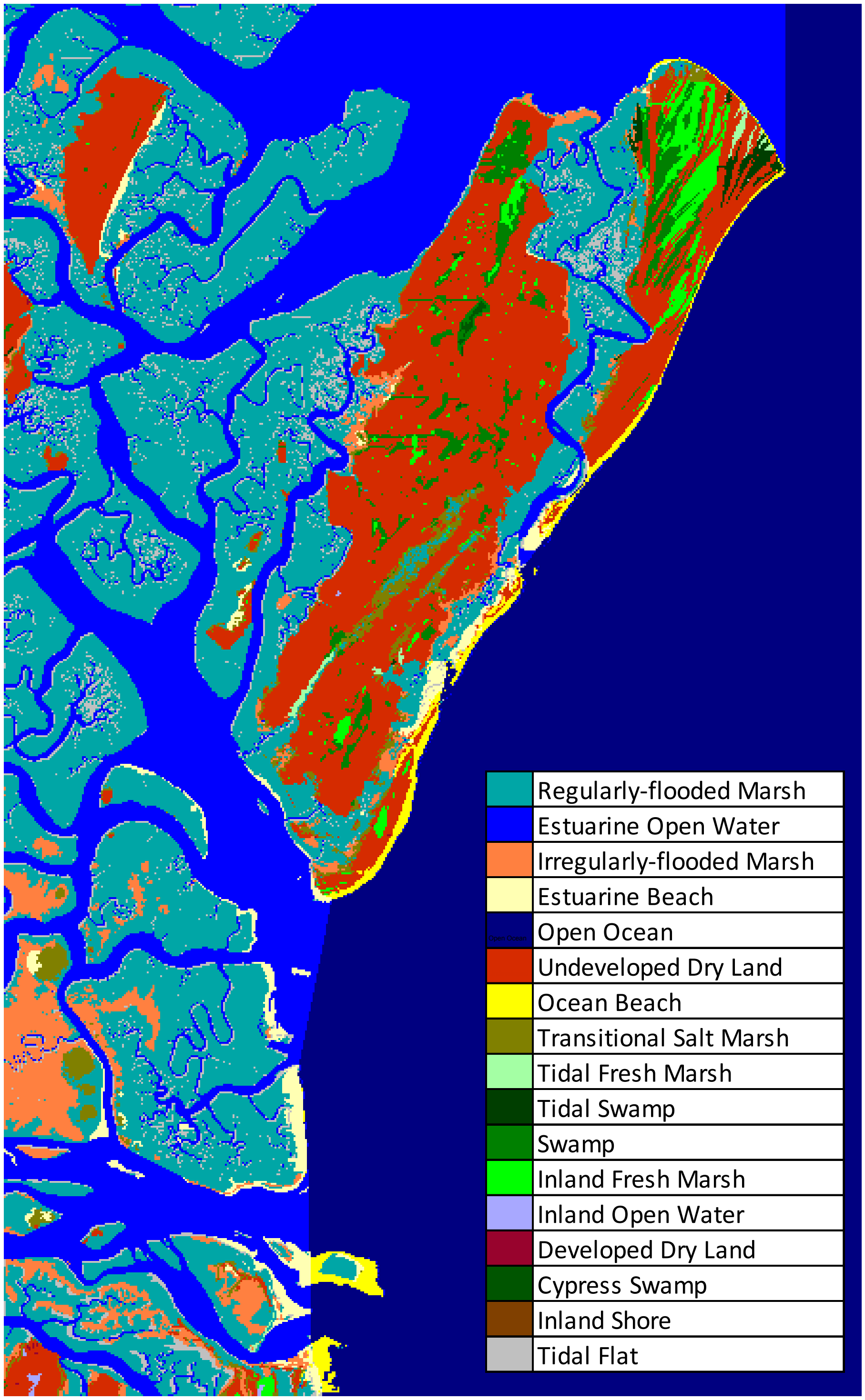
Blackbeard Island NWR, Initial Condition.



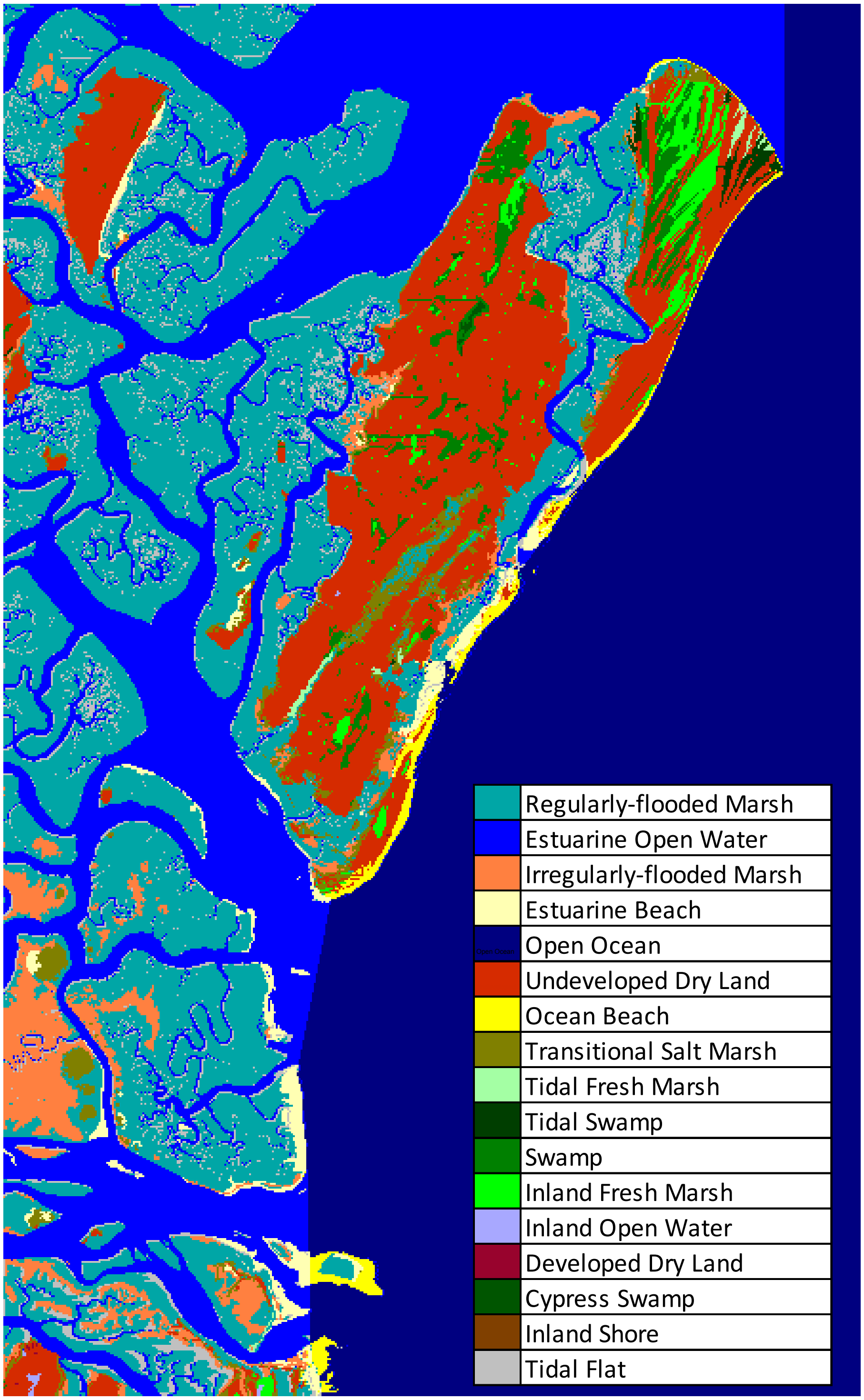
Blackbeard Island NWR, 2025, Scenario A1B Mean, 0.39 m SLR by 2100.



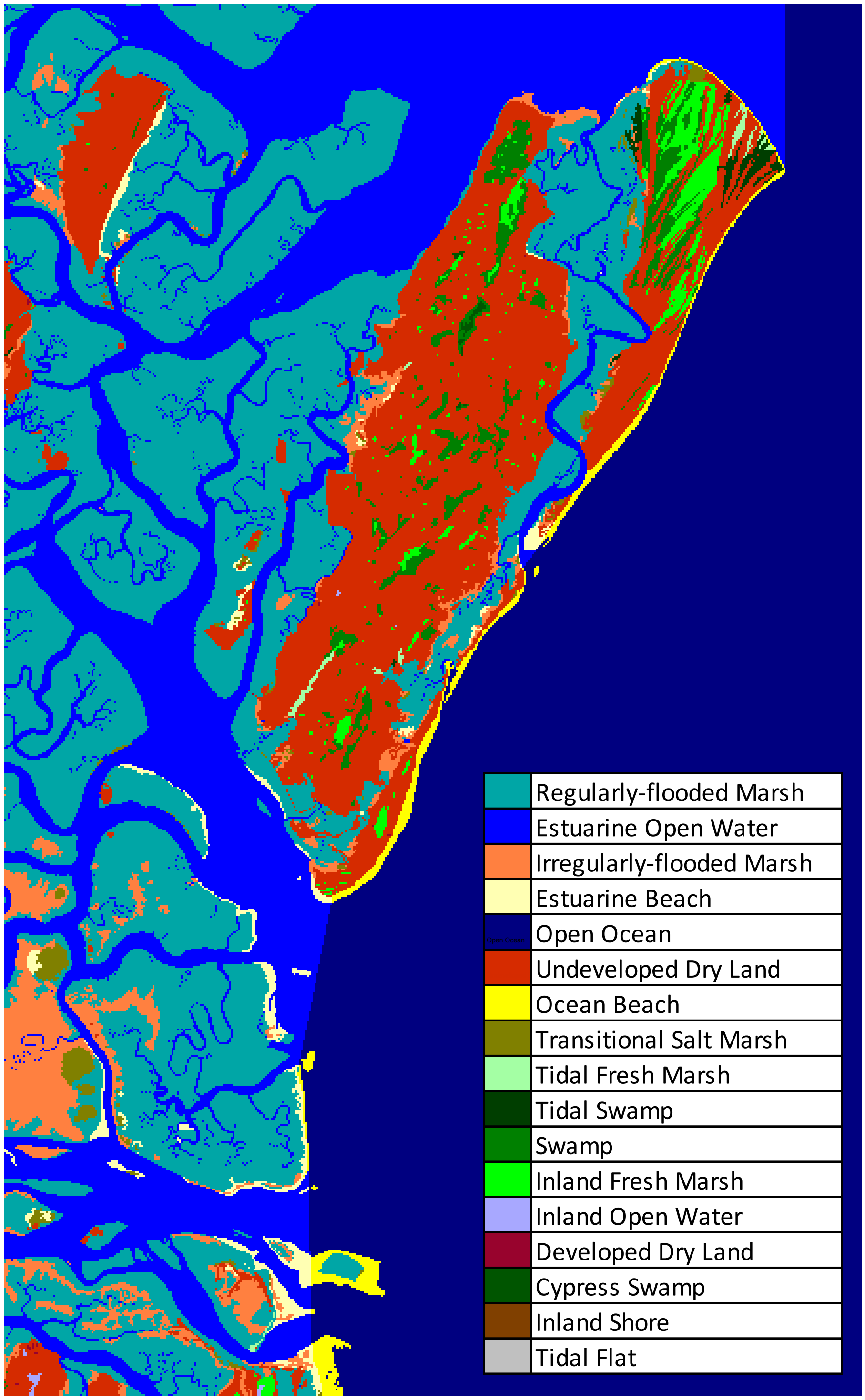
Blackbeard Island NWR, 2050, Scenario A1B Mean, 0.39 m SLR by 2100.



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



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



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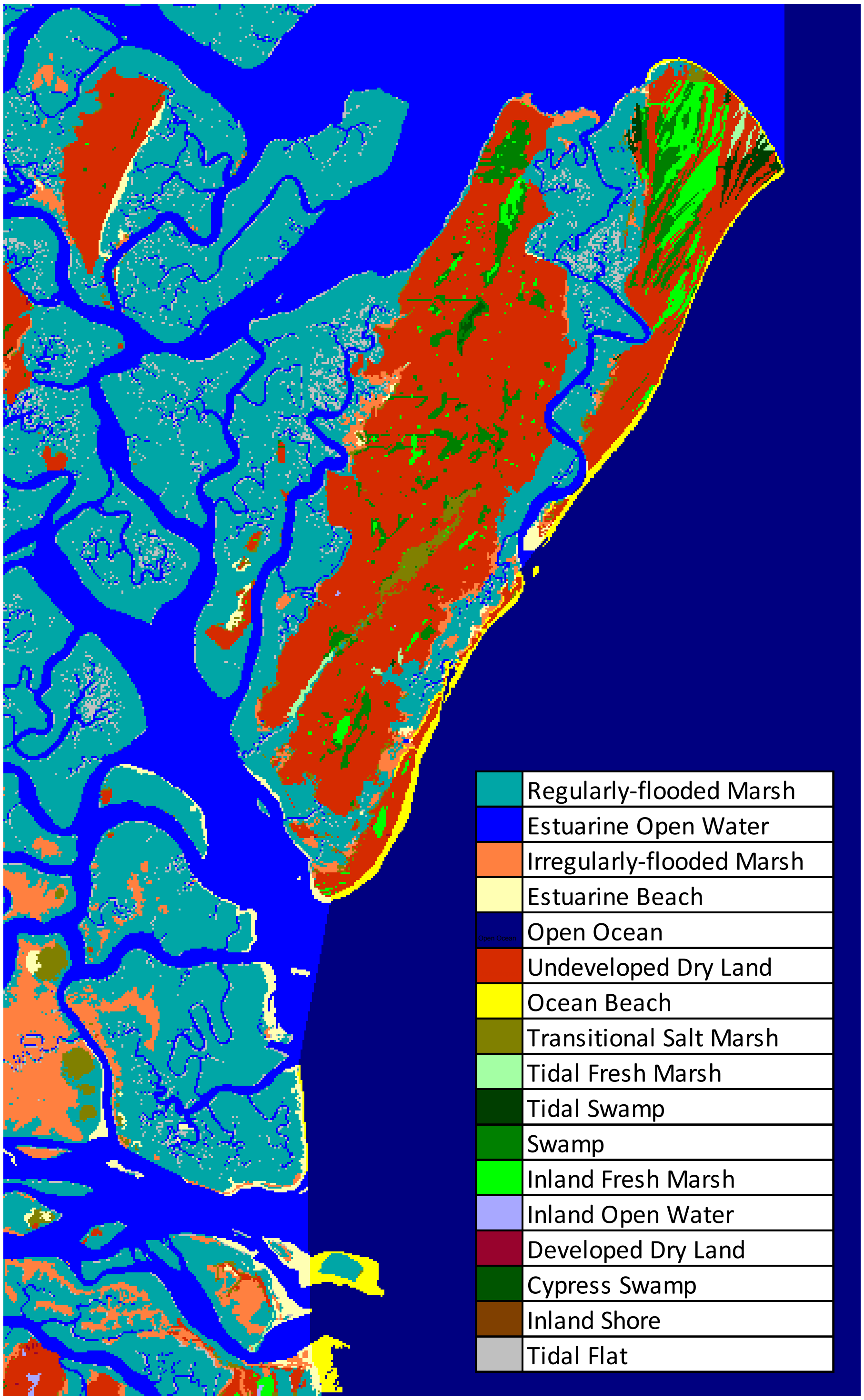
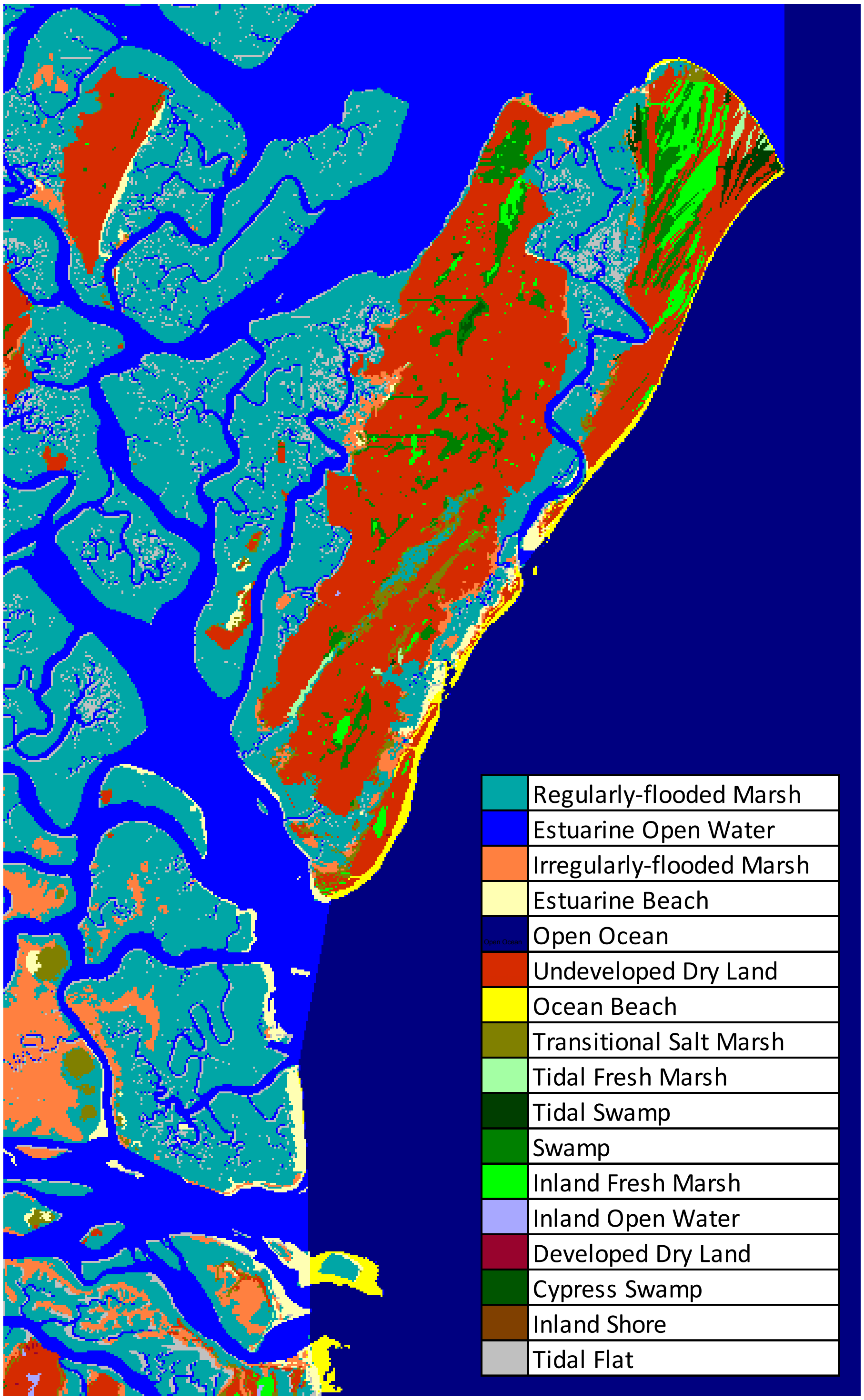
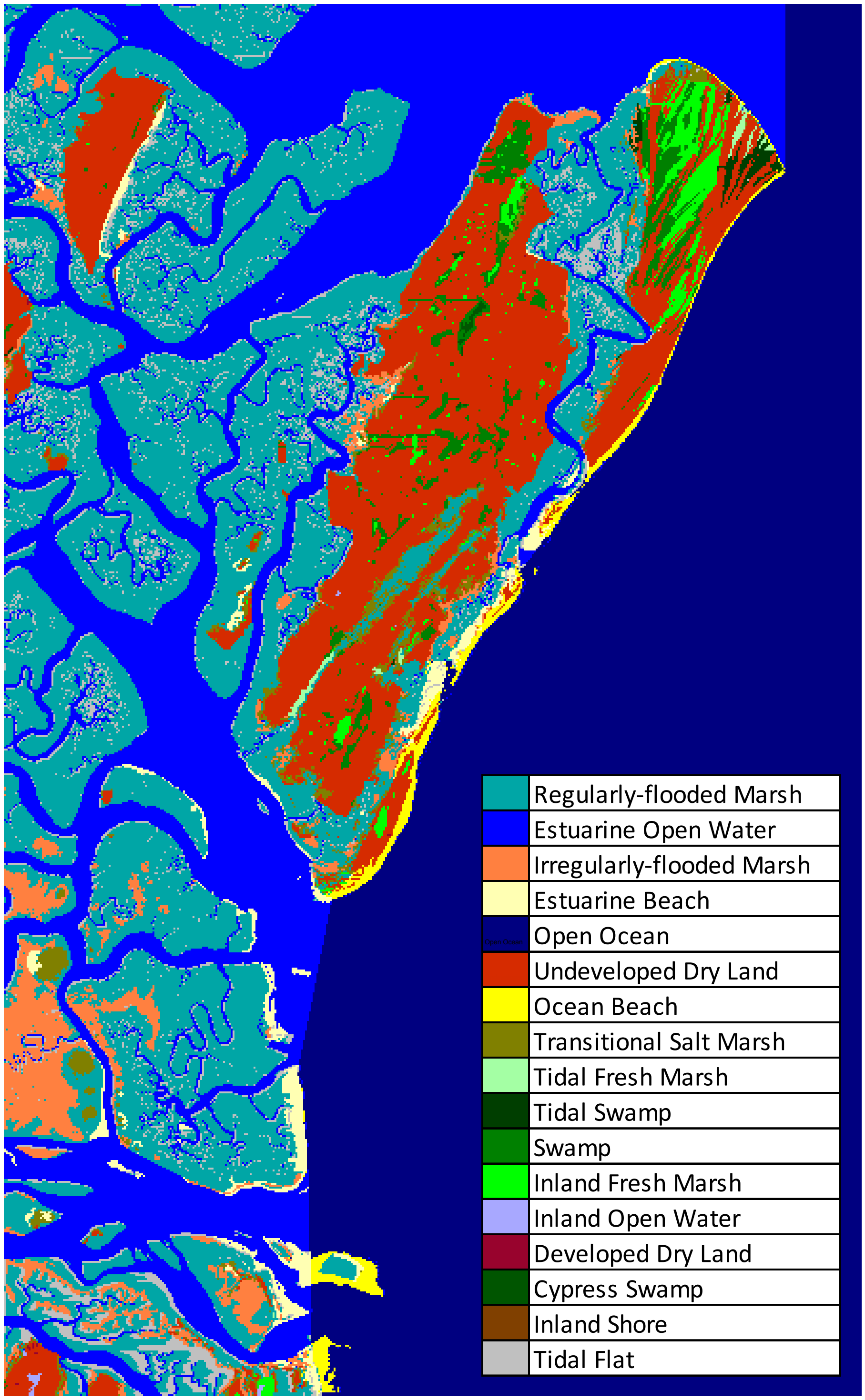


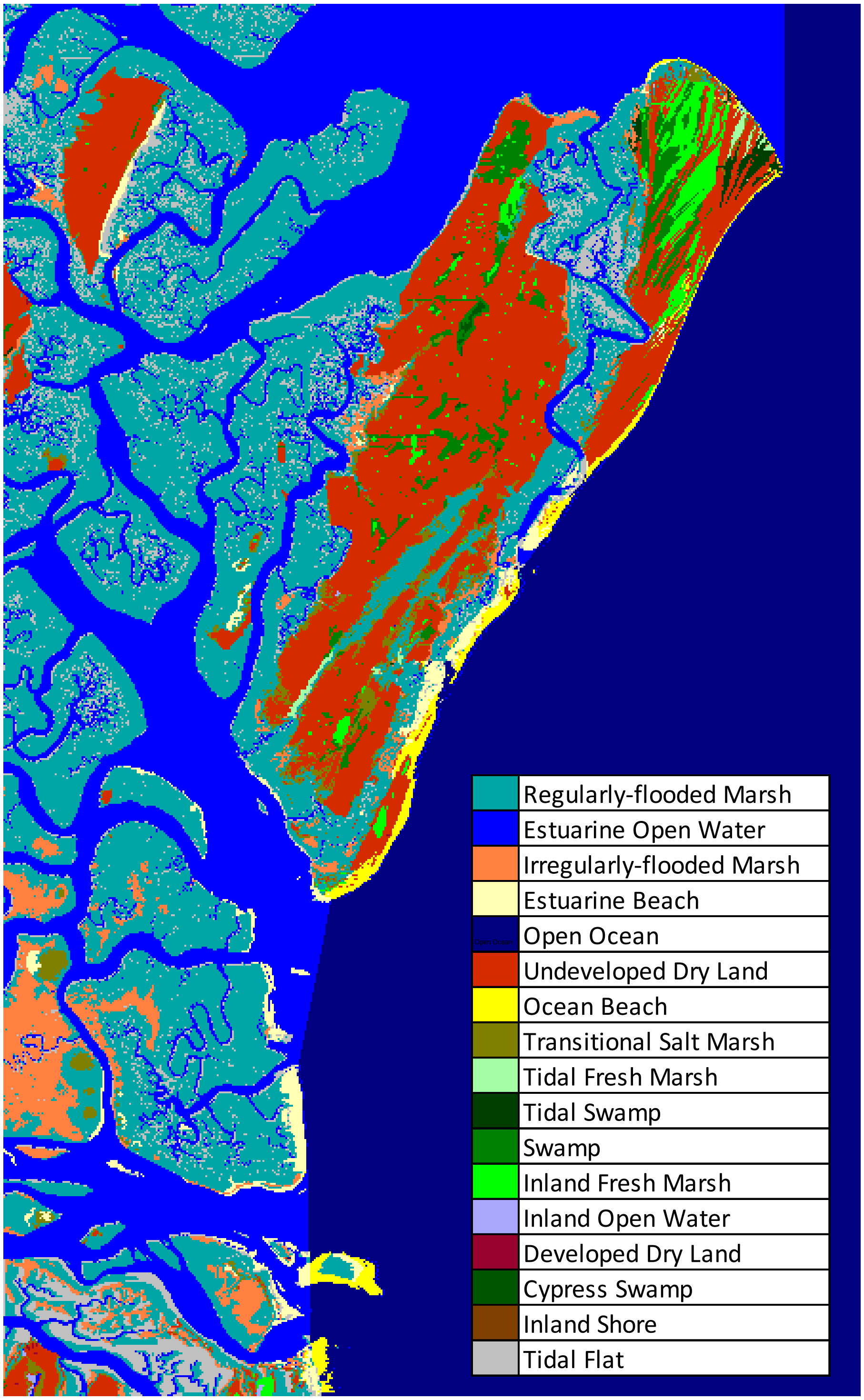
Blackbeard Island NWR, 2025, Scenario A1B Maximum, 0.69 m SLR by 2100.



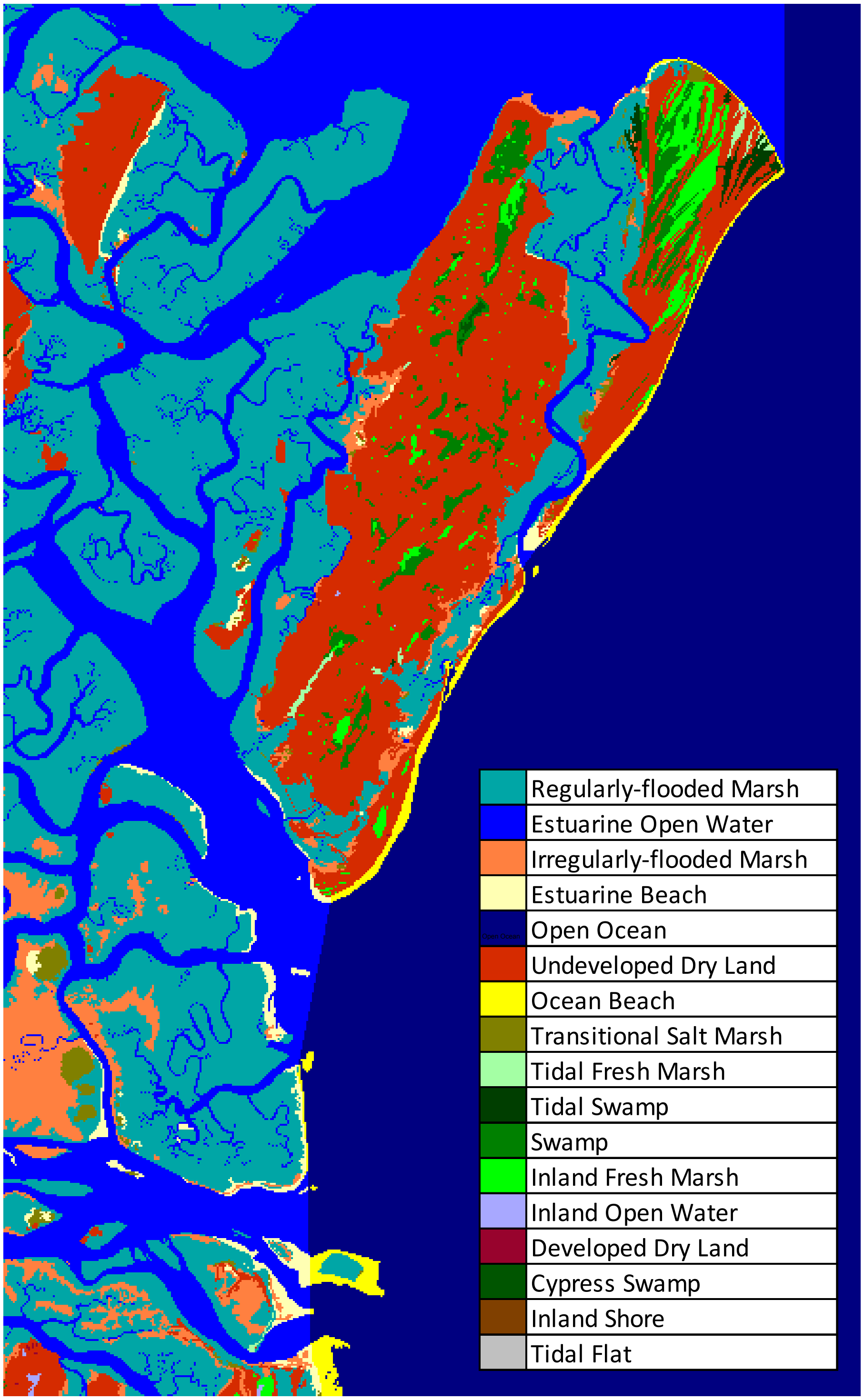
Blackbeard Island NWR, 2050, Scenario A1B Maximum, 0.69 m SLR by 2100.



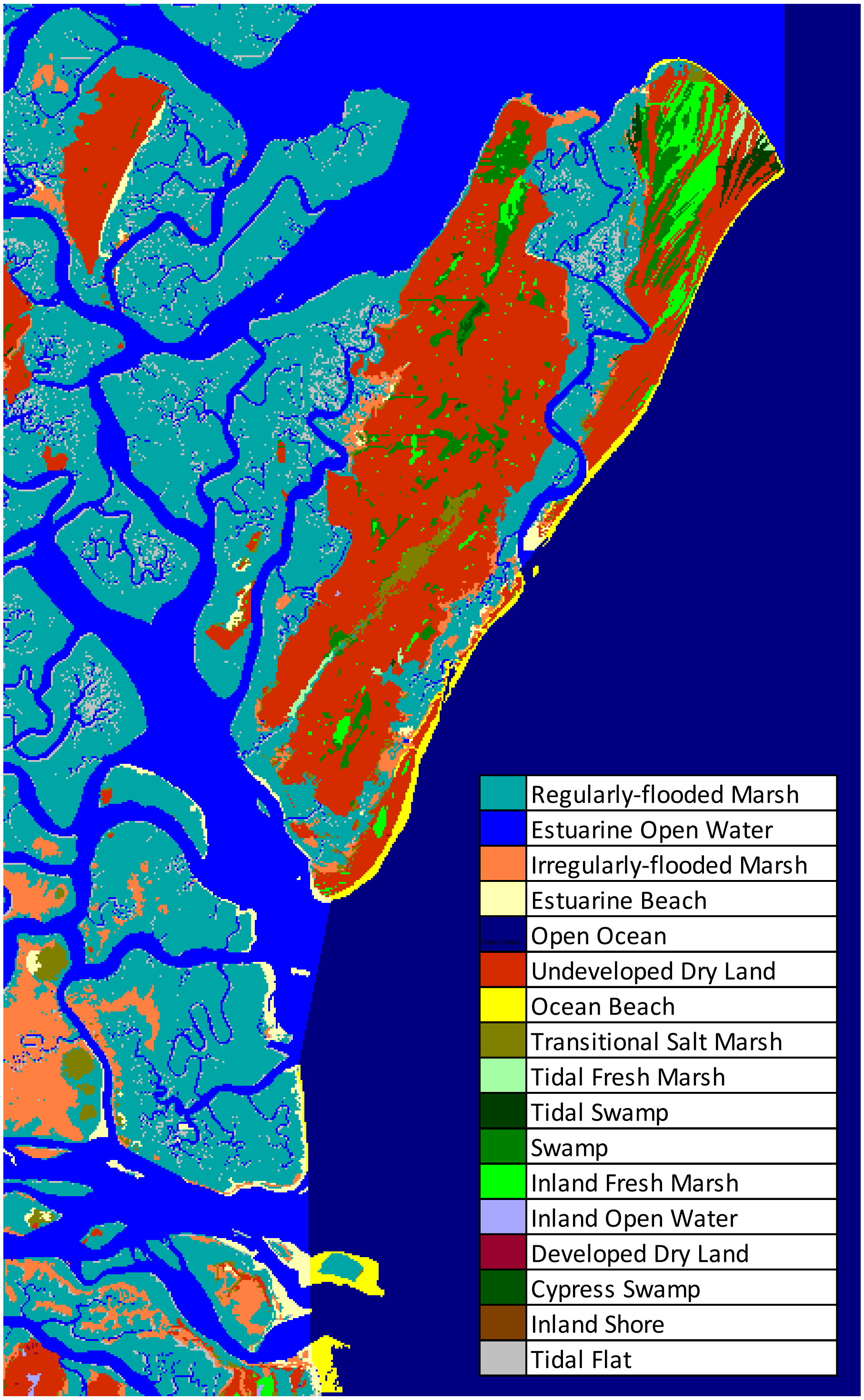
Blackbeard Island NWR, 2075, Scenario A1B Maximum, 0.69 m SLR by 2100.



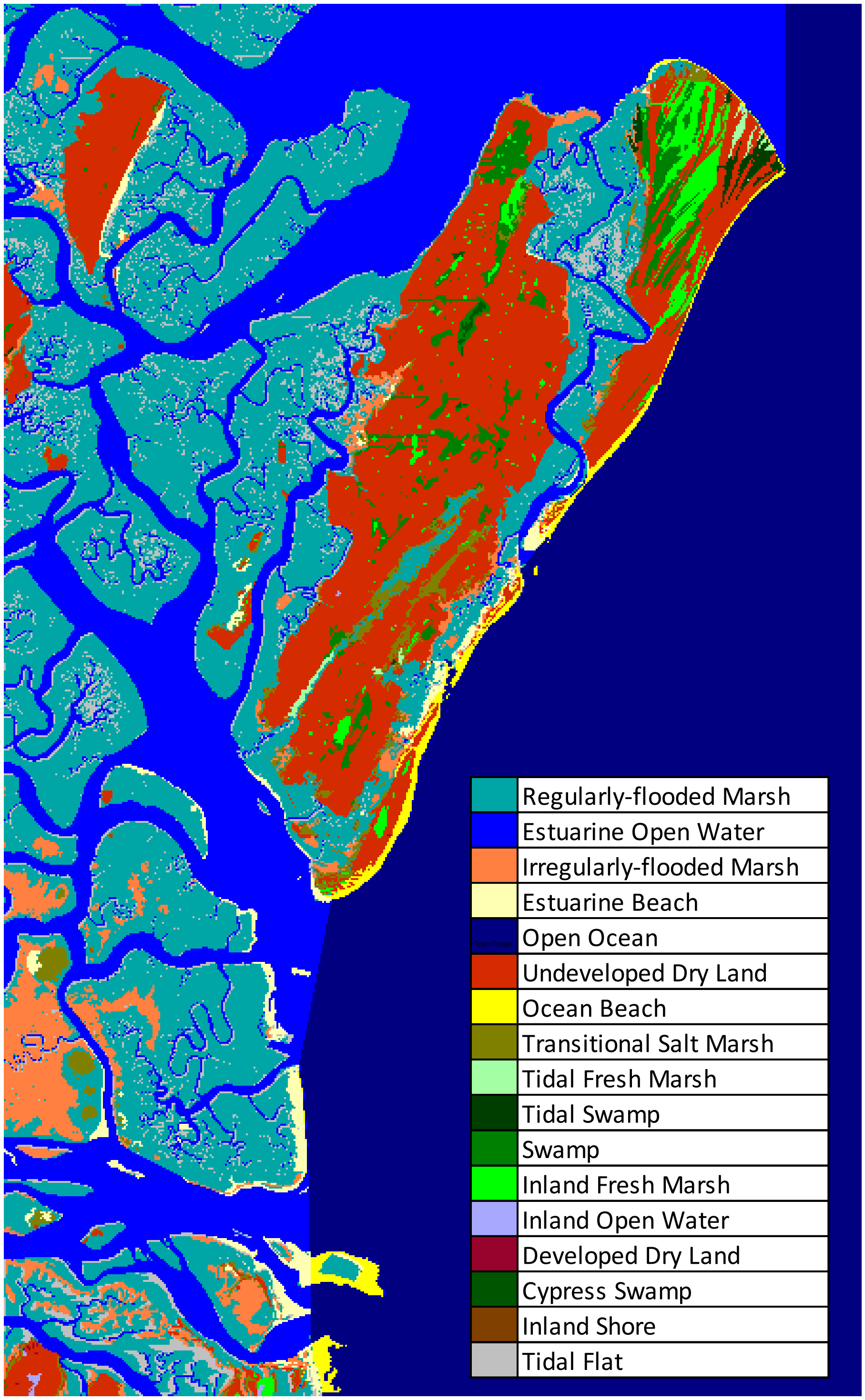
Blackbeard Island NWR, 2100, Scenario A1B Maximum, 0.69 m SLR by 2100.



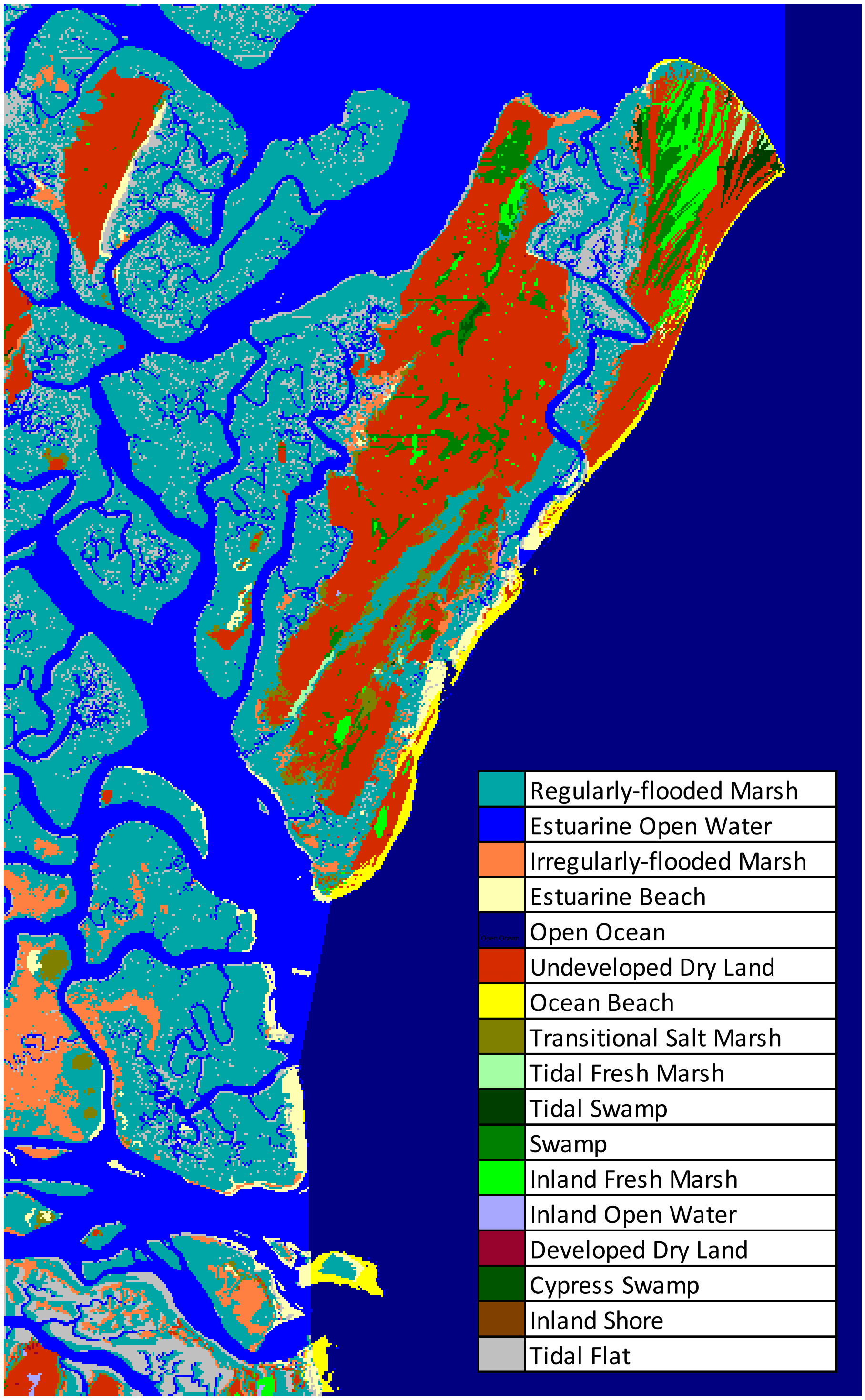
Blackbeard Island NWR, Initial Condition.



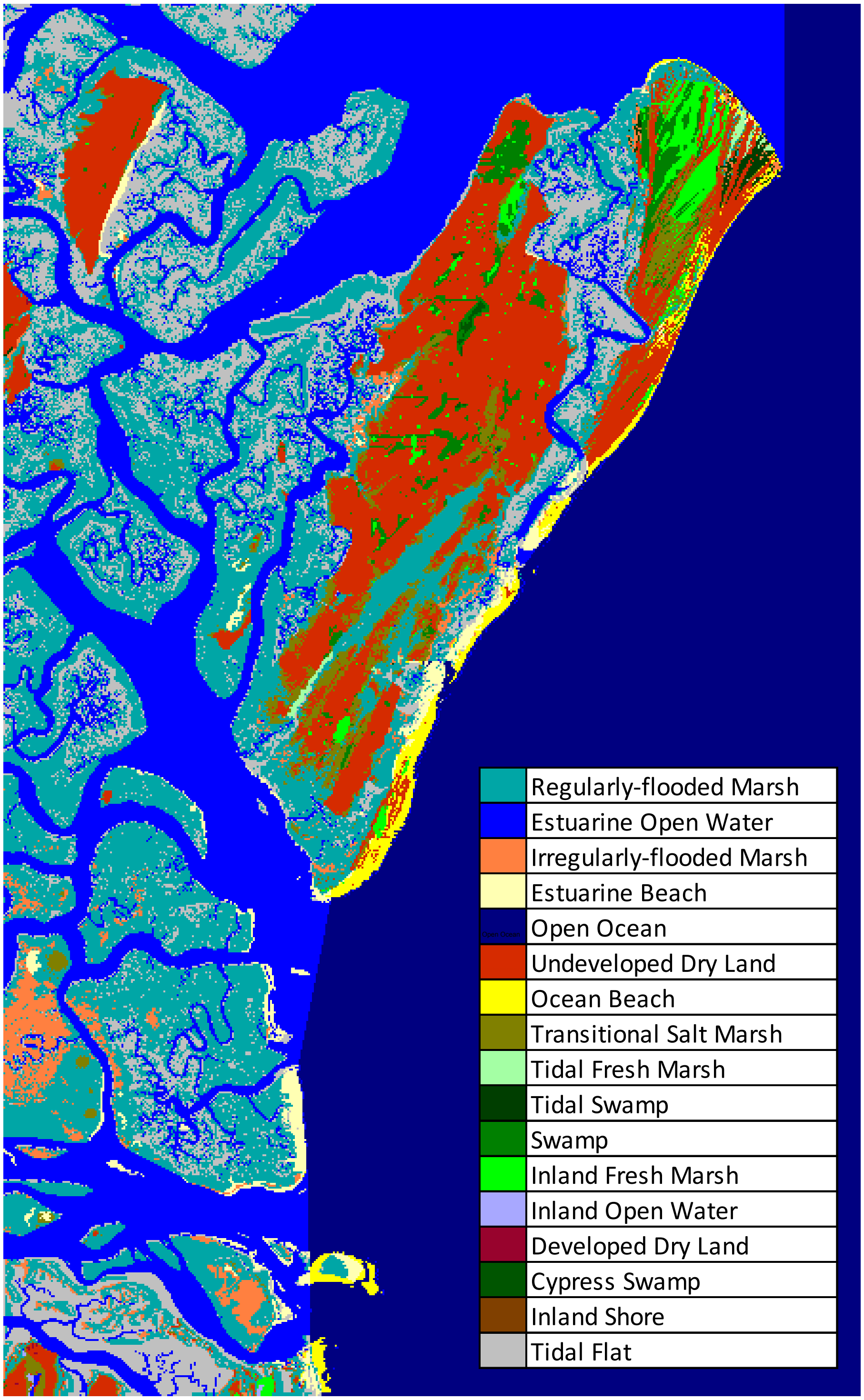
Blackbeard Island NWR, 2025, 1 m SLR by 2100.



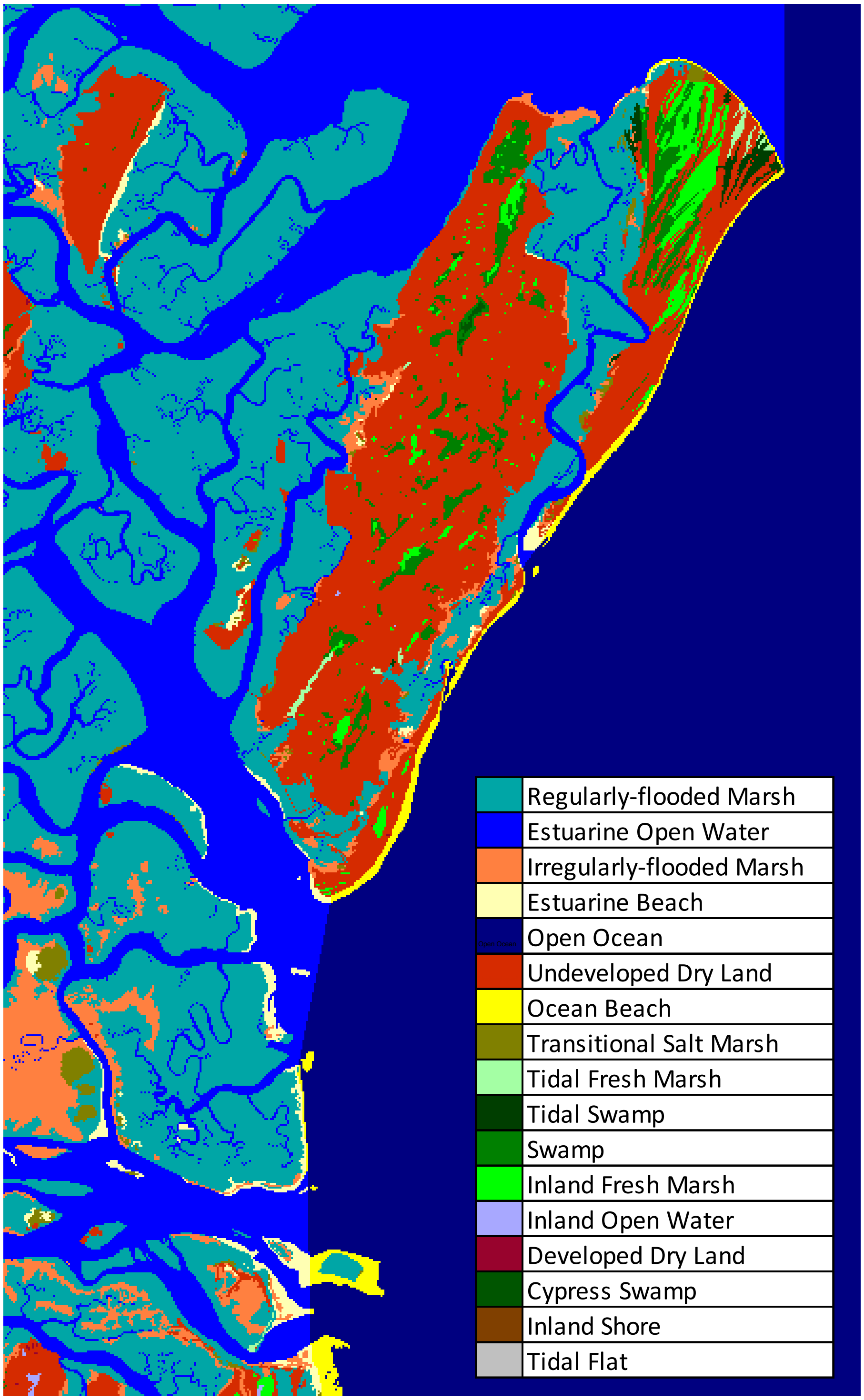
Blackbeard Island NWR, 2050, 1 m SLR by 2100.



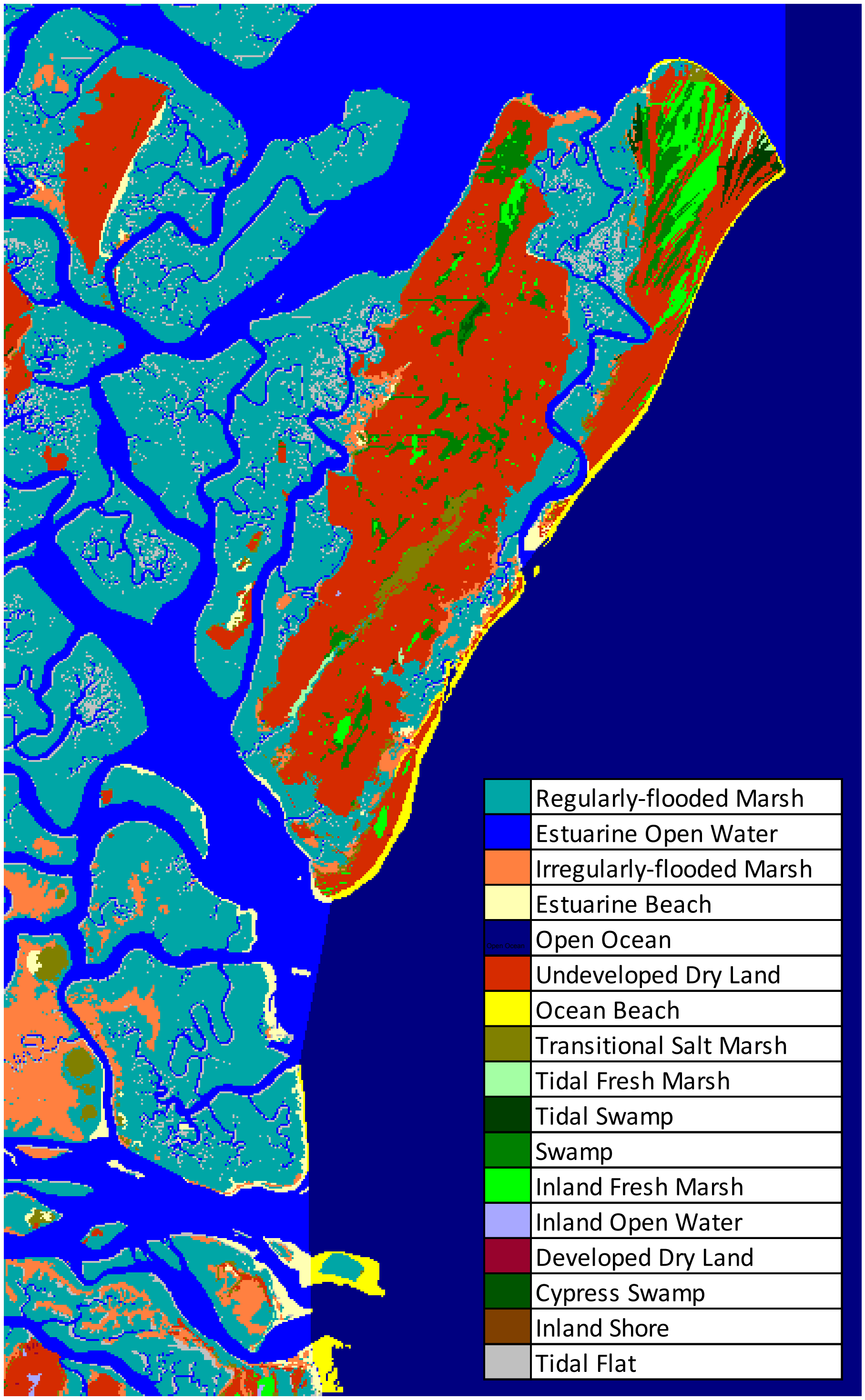
Blackbeard Island NWR, 2075, 1 meter



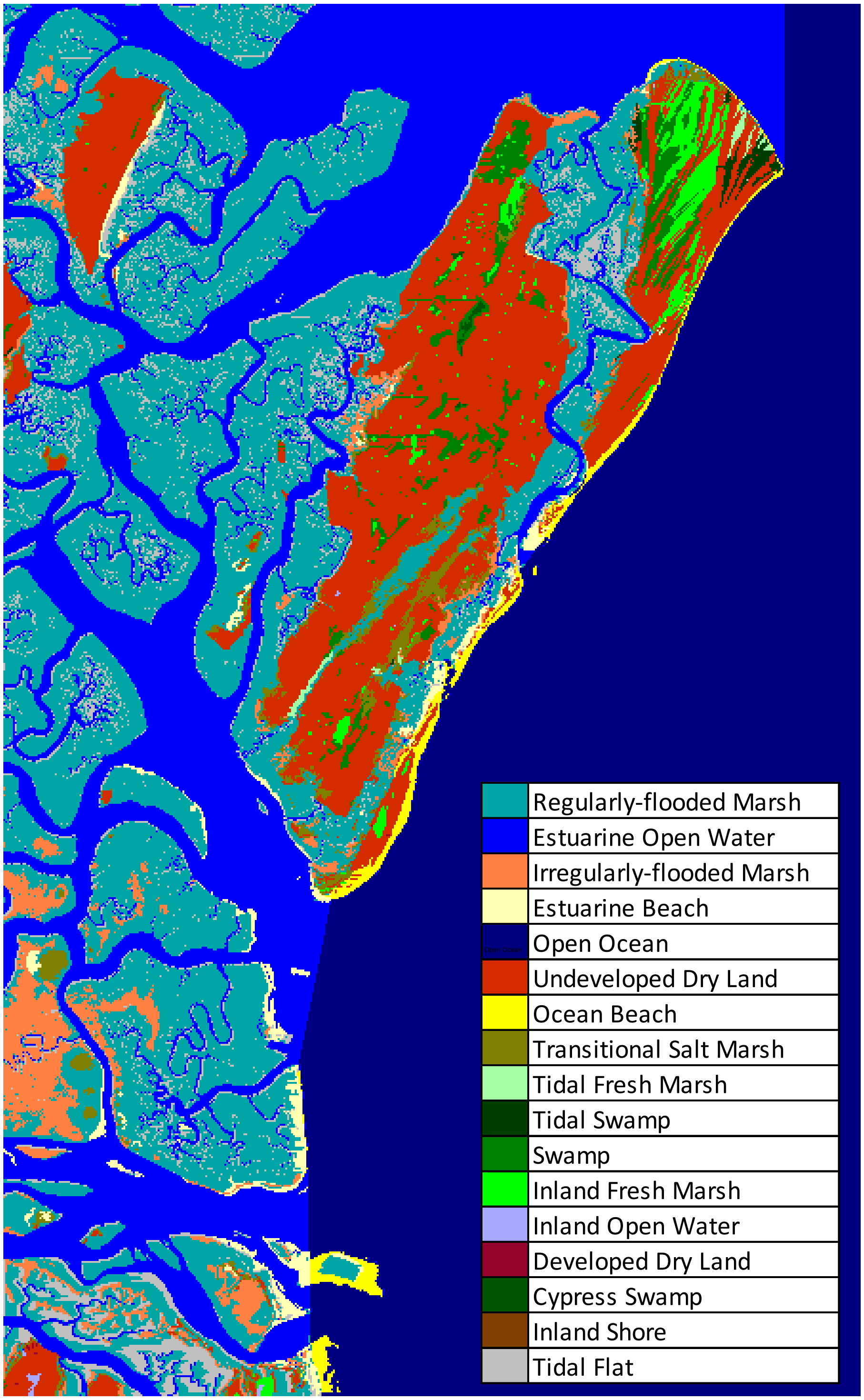
Blackbeard Island NWR, 2100, 1 m SLR by 2100.



Blackbeard Island NWR, Initial Condition.



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



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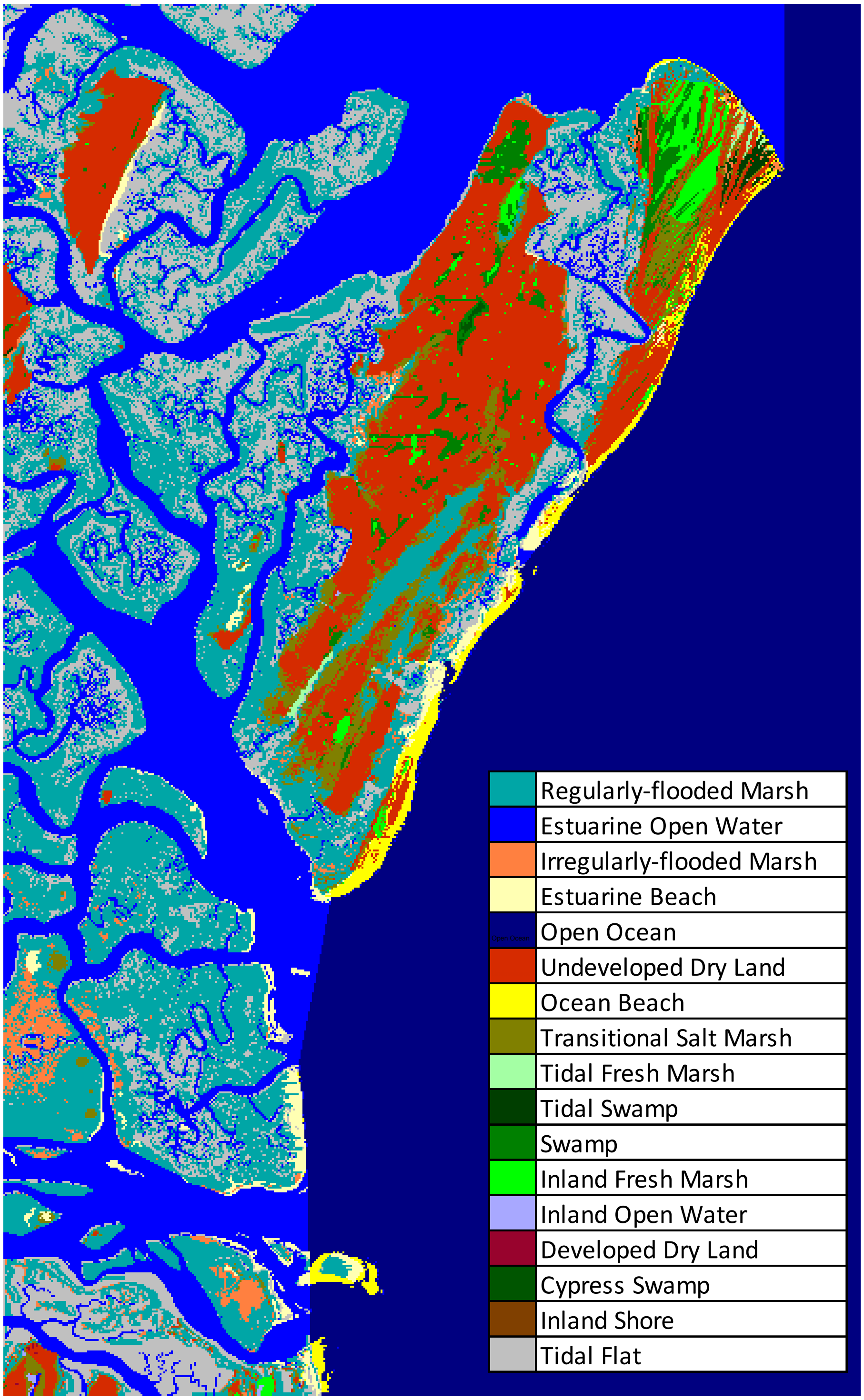
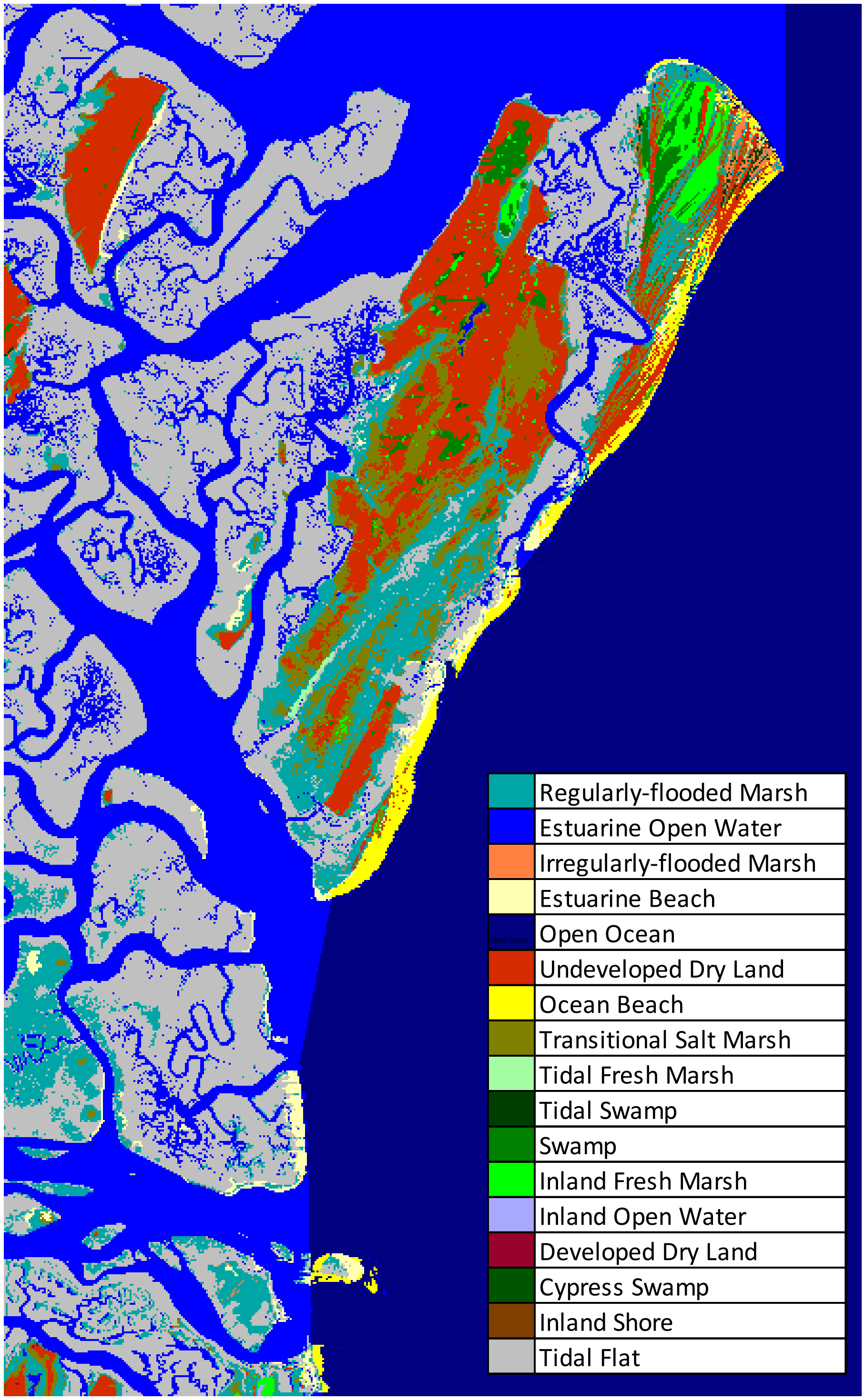
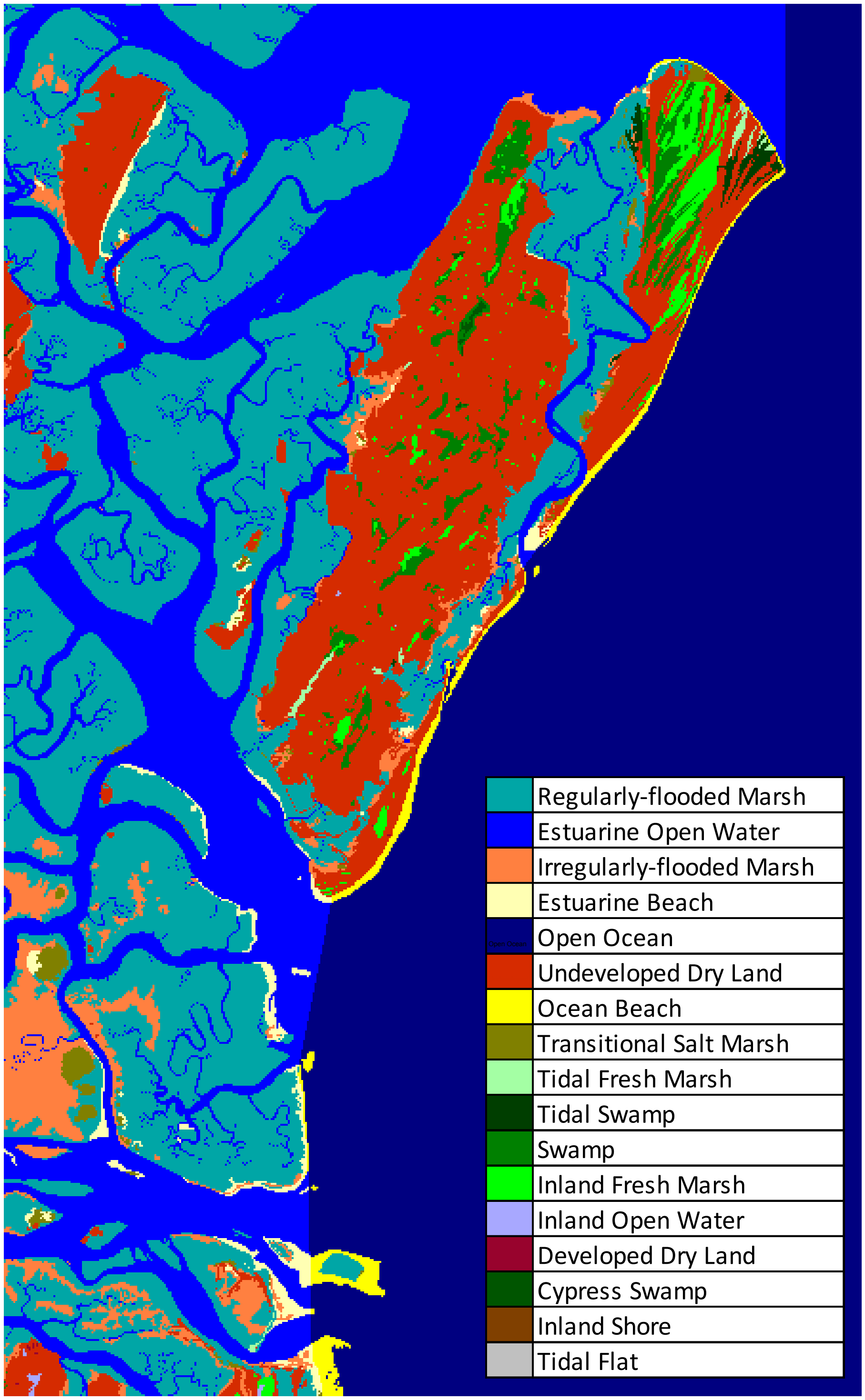


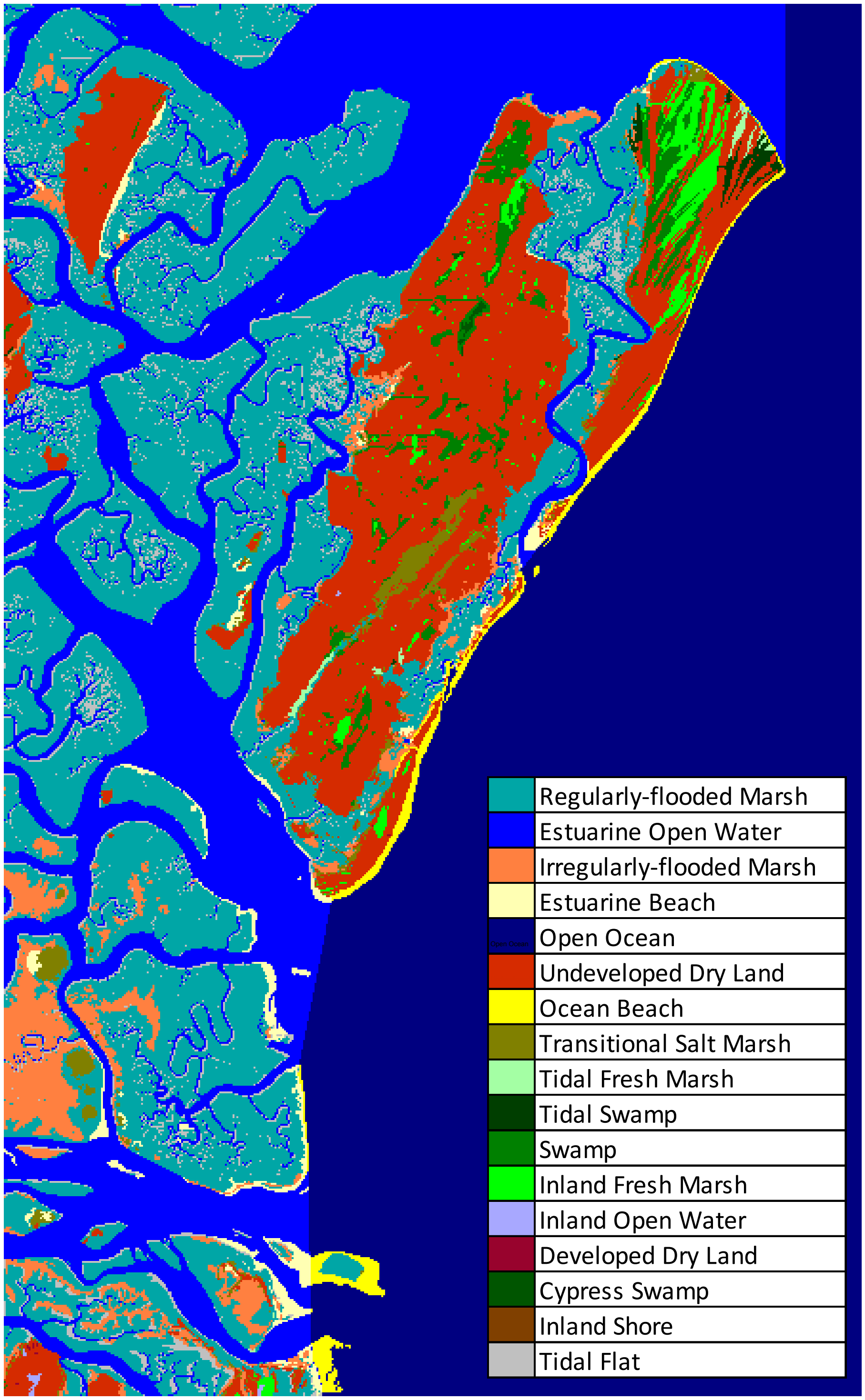
Blackbeard Island NWR, 2075, 1.5 m SLR by 2100.



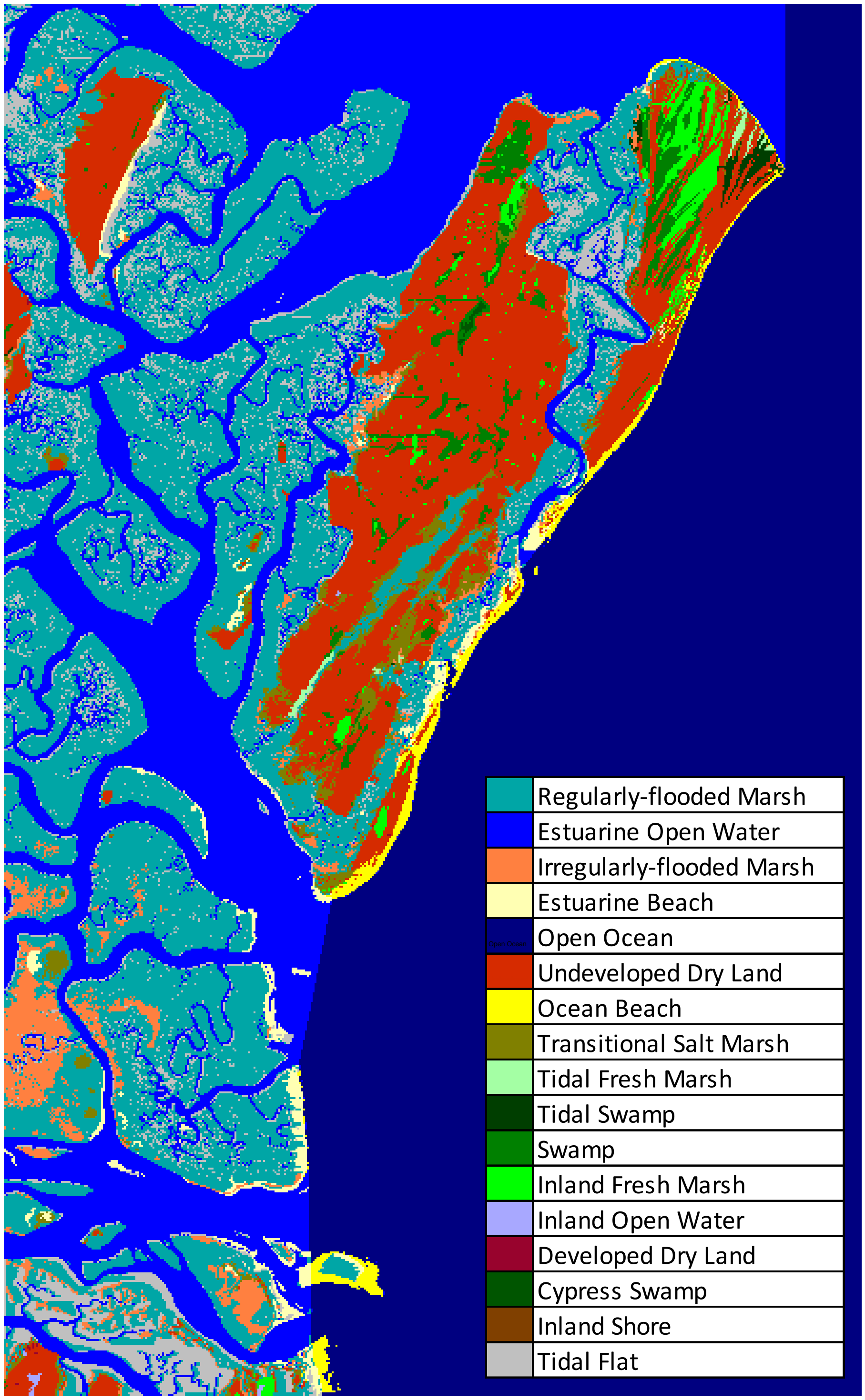
Blackbeard Island NWR, 2100, 1.5 m SLR by 2100.



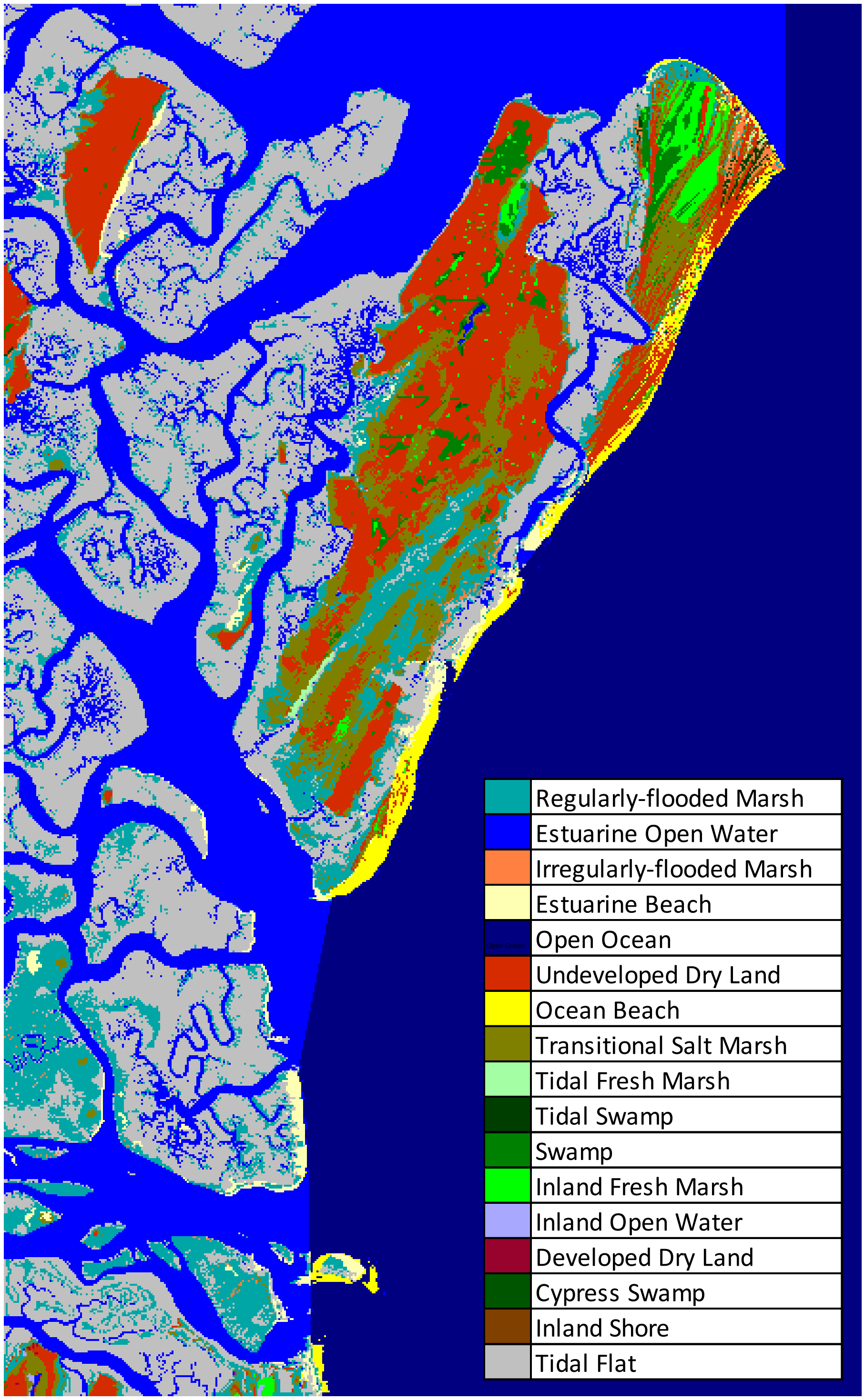
Blackbeard Island NWR, Initial Condition.



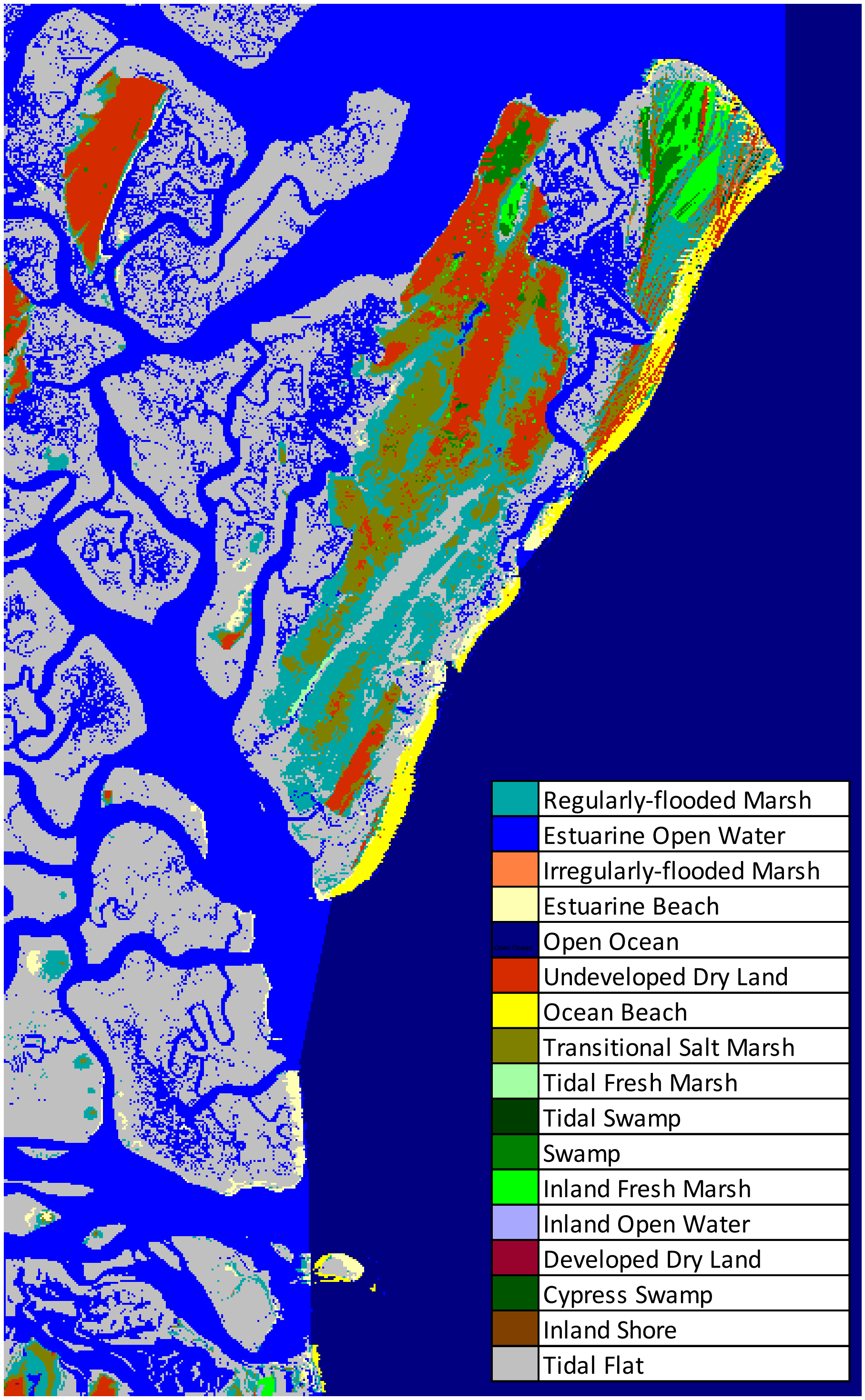
Blackbeard Island NWR, 2025, 2 m SLR by 2100.



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



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



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