Application of the Sea-Level Affecting Marshes Model (SLAMM 6) to Cape May 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 refuges, 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 will be used in USFWS simulations, but only 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 estimated 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.

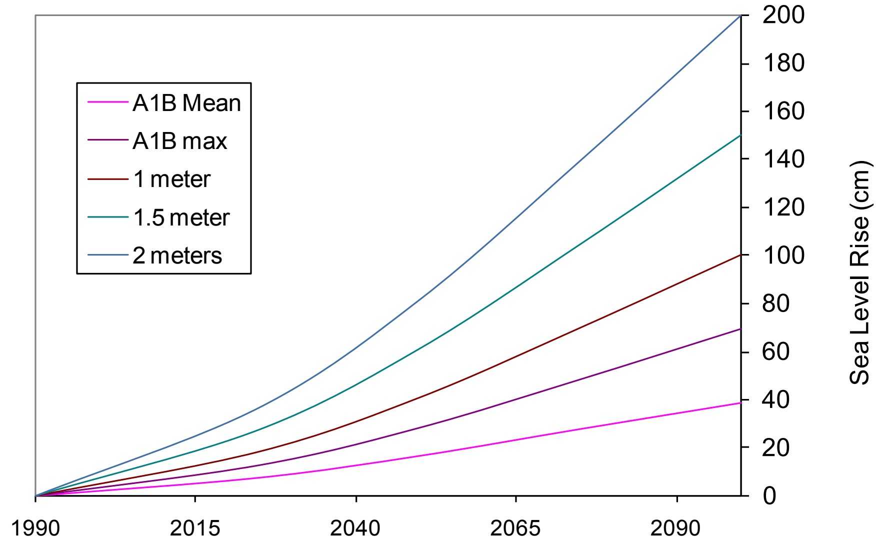


Figure 1. Summary of SLR scenarios utilized

Data Sources and Methods

Elevation Data. The layer used is 2008 bare-earth New Jersey Statewide LiDAR data.

Wetland layer. Figure 2 shows the most recent available wetlands layer obtained from a National Wetlands Inventory (NWI) photo dated 2009 with the exception of the southernmost part of the study area that is from a 1997 photo. Converting the NWI survey into 15 m x 15 m cells indicated that the approximately 21,400 acre Cape May NWR (approved acquisition boundary including water) is composed of the following categories:

Land cover type		Area (acres)	Percentage (%)
	Swamp	10620	50
	Undeveloped Dry Land	6012	28
	Irregularly-flooded Marsh	3640	17
	Estuarine Open Water	298	1
	Inland Open Water	256	1
	Open Ocean	240	1
	Developed Dry Land	130	<1
	Regularly-flooded Marsh	71	<1
	Inland Fresh Marsh	57	<1
	Transitional Salt Marsh	43	<1
	Tidal Swamp	16	<1
	Ocean Beach	12	<1
	Tidal Flat	10	<1
	Estuarine Beach	4	<1
	Tidal Fresh Marsh	3	<1
	Inland Shore	1	<1
	Total (incl. water)	**21413**	**100**

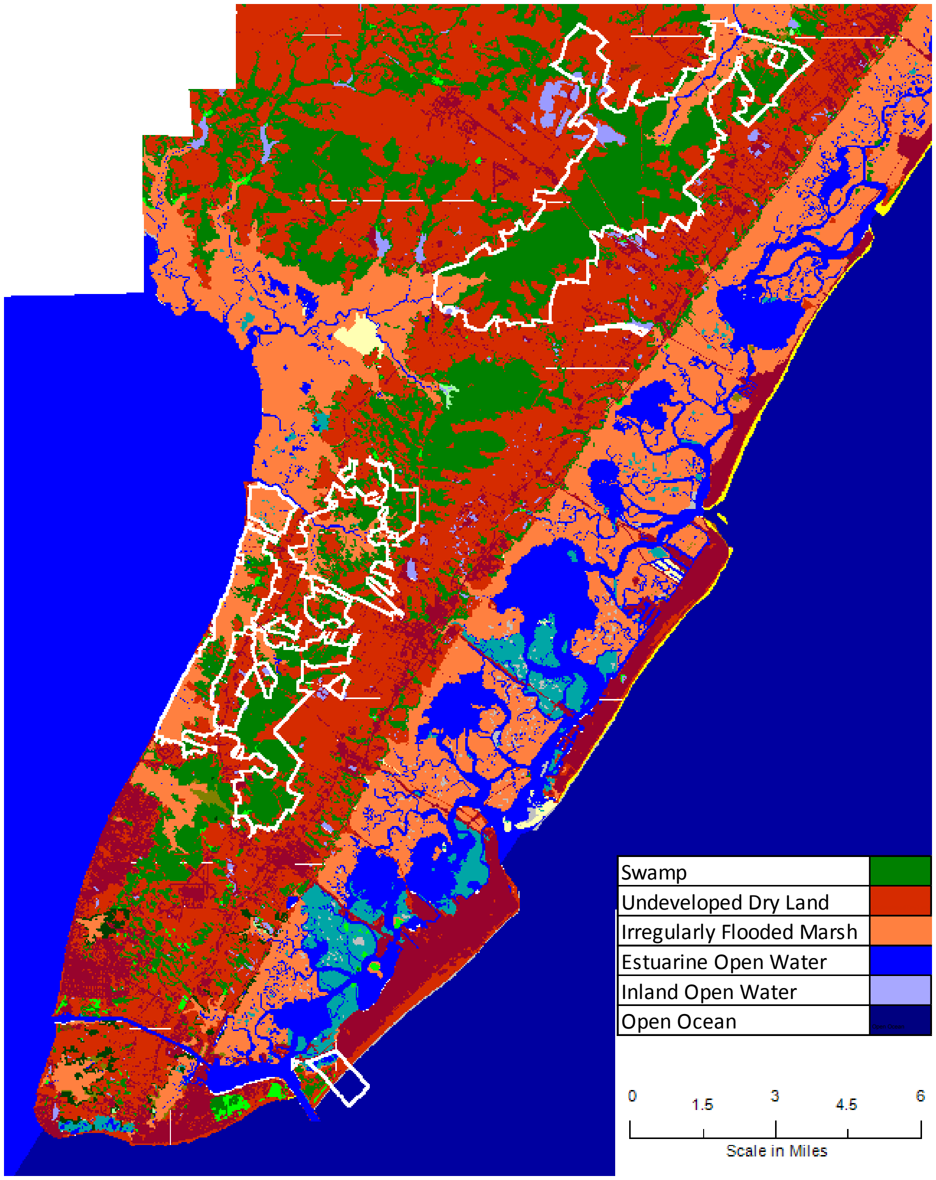


Figure 2. 2009 NWI coverage of the study area. Refuge boundaries are indicated in white. White segments are cells with no elevation data available.

Dikes and Impoundments. According to the National Wetland Inventory, there are only few small areas protected by dikes and they are not in the refuge.

Model Timesteps. Model forecast data is output for years 2025, 2050, 2075 and 2100 with the initial condition date set to 2009, the most recent wetland data available.

Historic sea level rise rates. The historic trend for relative sea level rise is estimated at 4.0 mm/yr using the average rate recorded at NOAA gauge stations in Cape May (#8536110) and Atlantic City, NJ (#8534720). The rate of sea level rise for this refuge is higher than the global (eustatic) SLR for the last 100 years (approximately 1.7 mm/year), suggesting some subsidence in this area.

Tide Ranges. The great diurnal range (GT) observed in the study area is between 1.05 m and 1.92 m based on measurements at the NOAA gauge stations (shown in Figure 4) and tide tables. In this SLAMM application, different input subsite areas were defined reflecting these varying tidal ranges.

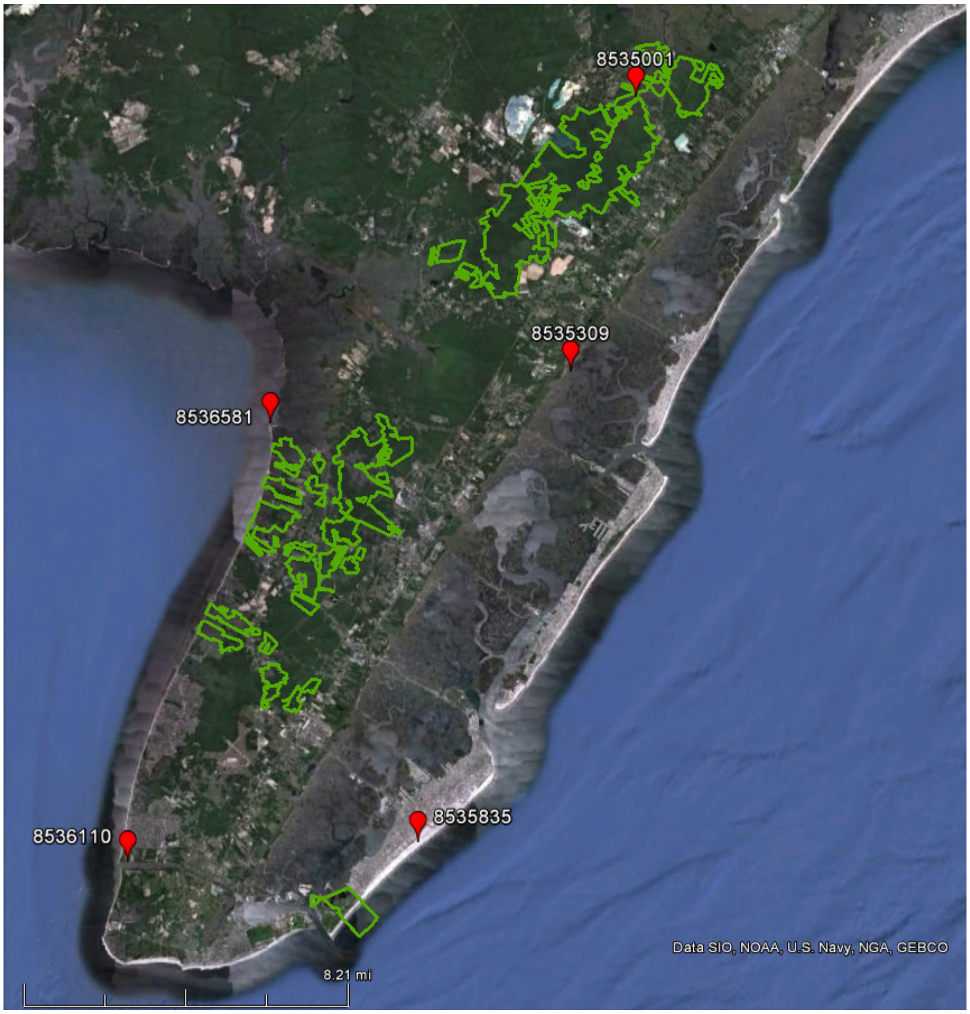


Figure 3. NOAA gauge station locations used for this study. Refuge boundaries in green

Table 1: NOAA tide gauge and values

Station ID	Site name	Tide range (m)	Salt elevation (m)
8535001	Cedar Swamp, Tuckahoe River, NJ	1.05	0.79
8535309	Townsend Sound, NJ	1.27	0.96
8536581	Bidwell Creek Entrance, Delaware Bay, NJ	1.92	1.44
8535835	Wildwood Crest, NJ	1.50	1.13
8536110	Cape May, NJ	1.66	1.25

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.

Accretion rates. Accretion rates in salt and irregularly-flooded marshes were set to 3.75 mm/year, the mean of two accretion values measured in the nearby EB Forsythe National Wildlife Refuge (Erwin et al. 2006). For other marshes, the accretion values were set to the SLAMM defaults, as shown in Table 1.

Erosion rates. Erosion rates for marshes, swamps, and tidal flats were set to SLAMM defaults of 2 m/yr, 1 m/yr and 0.5 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. The MTL to NAVD88 corrections are derived by looking at pertinent locations on the maps of vertical datum transformation provided by NOAA. The corrections vary between -13.2 cm in Cap May to -7 cm in the northern portion of the study area.

Refuge boundaries. Modeled USFWS refuge boundaries for New Jersey 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 was 15 m x 15 m cells.

Input subsites and parameter summary. Based on spatial variability of the tide ranges and different NWI photo dates, the study area was subdivided in the subsites illustrated in Figure 5.

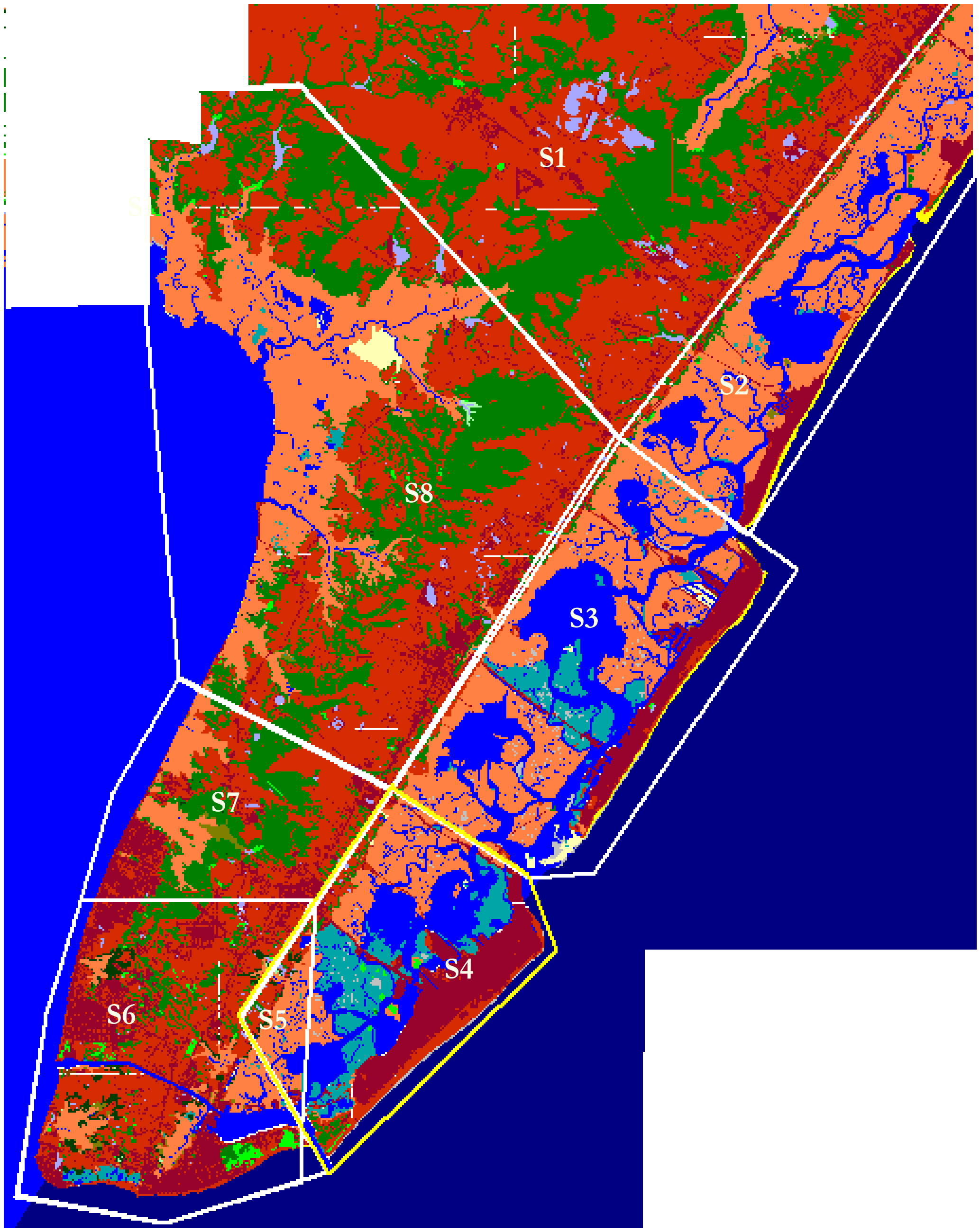


Figure 4. Input subsites for model application

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 2. Summary of SLAMM input parameters for Cape May NWR.

Parameter	S1	S2	S3	S4	S5	S6	S7	S8
NWI Photo Date (YYYY)	2009	2009	2009	2009	1997	1997	2009	2009
DEM Date (YYYY)	2008	2008	2008	2008	2008	2008	2008	2008
Direction Offshore [n,s,e,w]	East	East	East	East	East	South	West	West
Historic Trend (mm/yr)	4.03	4.03	4.03	4.03	4.03	4.03	4.03	4.03
MTL-NAVD88 (m)	-0.07	-0.07	-0.063	-0.101	-0.101	-0.132	-0.132	-0.131
GT Great Diurnal Tide Range (m)	1.05	1.27	1.47	1.5	1.5	1.66	1.66	1.92
Salt Elev. (m above MTL)	0.79	0.96	1.1	1.13	1.13	1.25	1.25	1.44
Marsh Erosion (horz. m /yr)	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8
Swamp Erosion (horz. m /yr)	1	1	1	1	1	1	1	1
T.Flat Erosion (horz. m /yr)	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Reg.-Flood Marsh Accr (mm/yr)	3.75	3.75	3.75	3.75	3.75	3.75	3.75	3.75
Irreg.-Flood Marsh Accr (mm/yr)	3.75	3.75	3.75	3.75	3.75	3.75	3.75	3.75
Tidal-Fresh Marsh Accr (mm/yr)	5.9	5.9	5.9	5.9	5.9	5.9	5.9	5.9
Inland-Fresh Marsh Accr (mm/yr)	4	4	4	4	4	4	4	4
Mangrove Accr (mm/yr)	7	7	7	7	7	7	7	7
Tidal Swamp Accr (mm/yr)	1.1	1.1	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	0.3	0.3
Beach Sed. Rate (mm/yr)	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Freq. Overwash (years)	35	35	35	35	35	35	35	35
Use Elev Pre-processor [True,False]	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE

Results

The initial land cover in acres and percentage loss of each wetland type by 2100 under each SLR scenario examine in this analysis are presented in Table 2. Land-cover losses are calculated in comparison to the 2009 NWI wetland layer.

Table 3. Predicted loss rates of land categories by 2100 given simulated scenarios of eustatic SLR at Cape May 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**
Swamp	10620	19%	26%	33%	44%	55%
Undeveloped Dry Land	6012	6%	9%	13%	20%	28%
Irregularly-flooded Marsh	3640	26%	68%	94%	99%	100%

Land categories shown comprise over 1% of the initial coverage.

The wetland coverage of the refuge is predicted to be greatly affected by sea-level rise. All existing wetland habitats in the refuge (swamp, irregularly-flooded marsh) are predicted to experience substantial losses while several low elevation habitats (regularly-flooded marsh, transitional salt marsh, tidal flat) are predicted to significantly increase their coverage in the refuge by 2100. Tidal flat and open water are predicted to increasingly take over refuge land with increasing SLR.

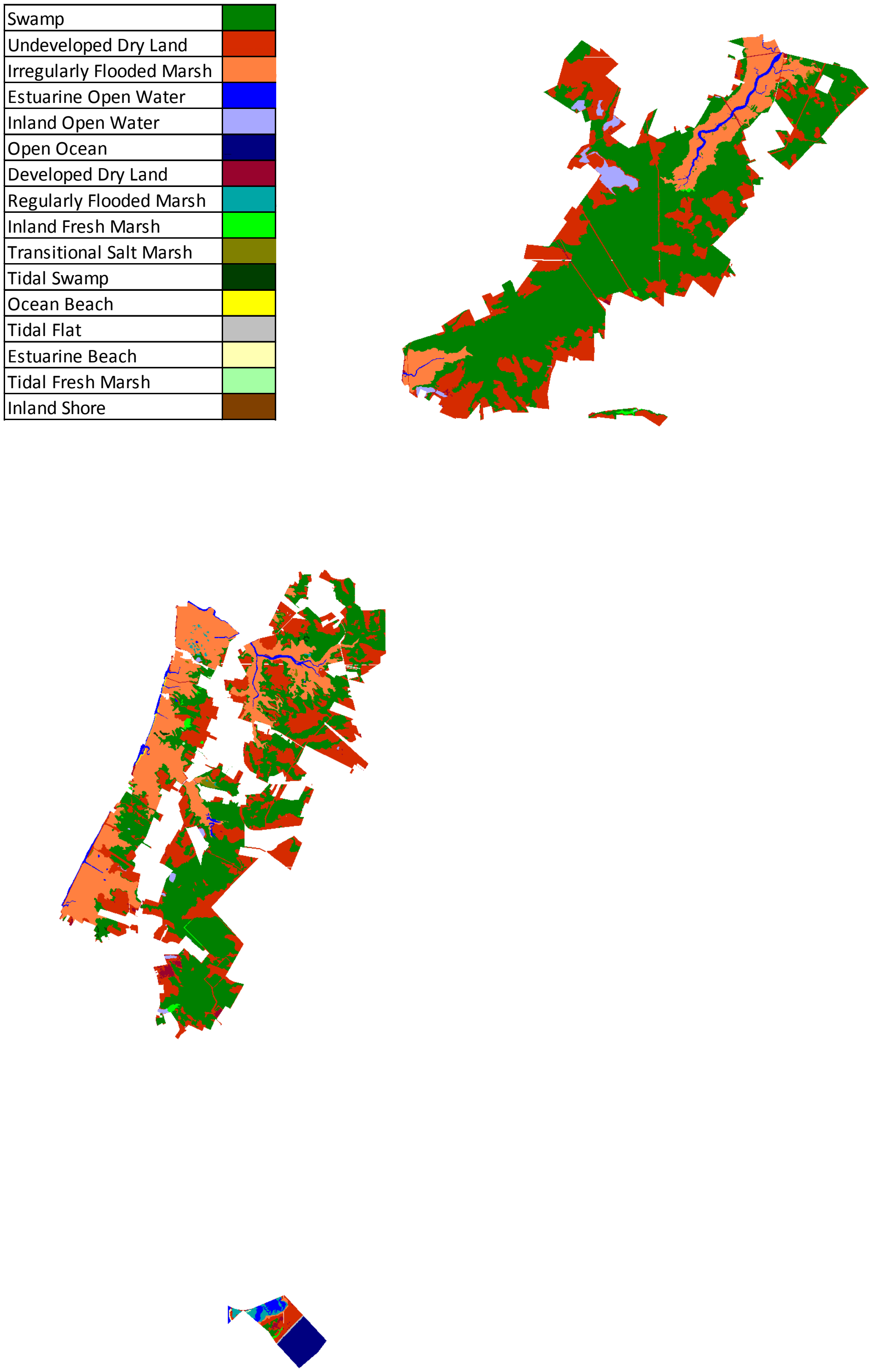
Irregularly-flooded marsh is predicted to be nearly completely lost in SLR scenarios greater than 1 m. Most of the irregularly-flooded "high" marsh habitat is predicted to convert to regularly-flooded marsh. Regularly-flooded marsh is predicted to increase for all simulated SLR scenarios. However, as sea level continues to rise, for SLR greater than 1.5 m by 2100, this wetland type is also predicted to be unable to keep pace with the relatively high local sea-level rise trend.

Swamp, which is currently the dominant wetland type in the refuge with 50% coverage, is predicted to be increasingly affected as sea level rises, culminating in a maximum loss of 55% under the 2 m of SLR by 2100 scenario. SLAMM predicts areas that are currently classified as swamp will convert to transitional salt marsh and regularly-flooded marsh. Areas covered by undeveloped dry land are predicted to undergo similar changes, although lower percentage losses are predicted.

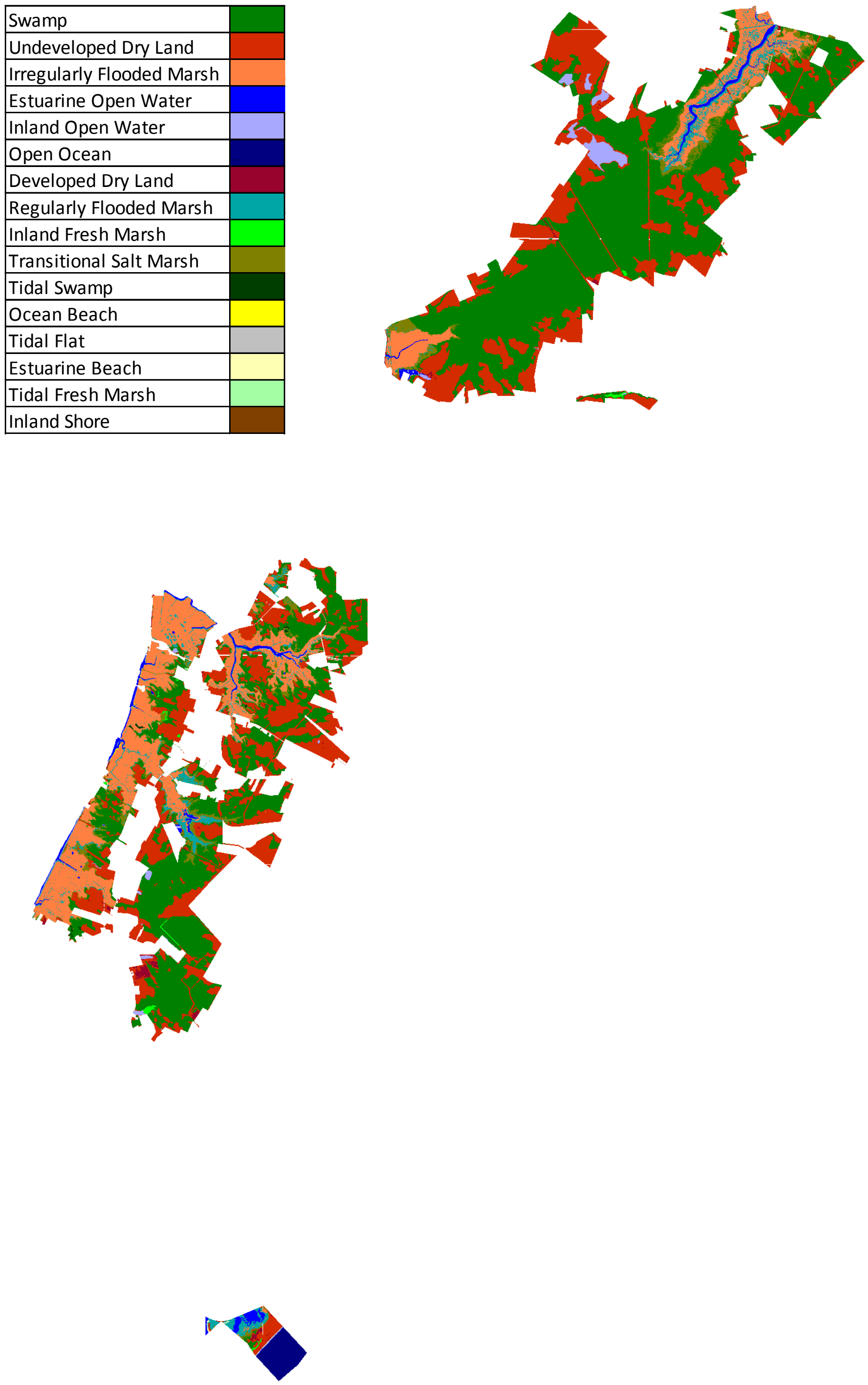
Cape May NWR
IPCC Scenario A1B-Mean, 0.39 m SLR eustatic by 2100

Results in Acres

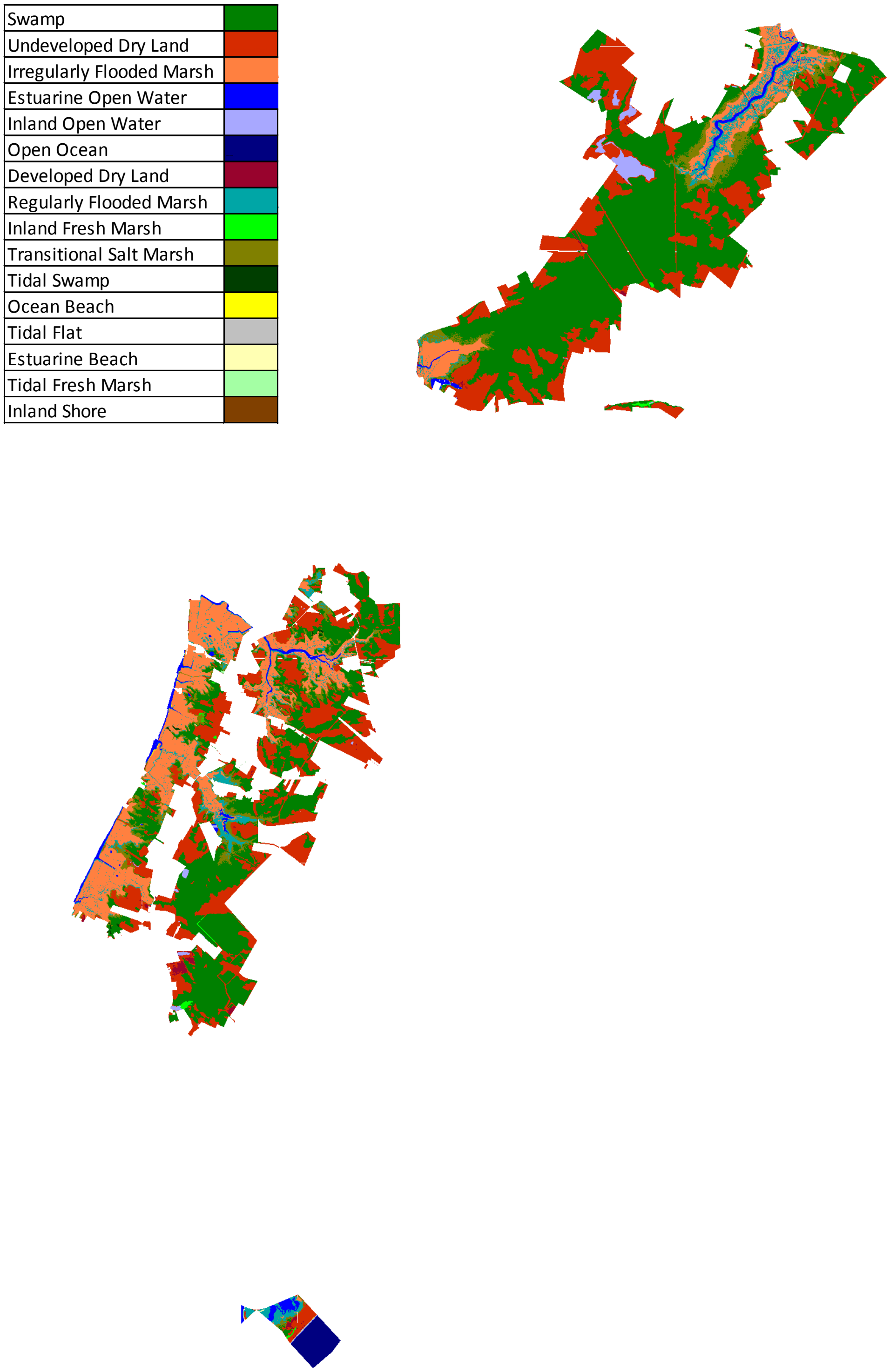
		Initial	2025	2050	2075	2100
	Swamp	10620	9784	9448	9029	8603
	Undeveloped Dry Land	6012	5868	5824	5759	5671
	Irregularly-flooded Marsh	3640	3246	3150	2962	2702
	Estuarine Open Water	298	325	355	370	389
	Inland Open Water	256	235	226	223	222
	Open Ocean	240	240	240	240	240
	Developed Dry Land	130	108	105	101	94
	Regularly-flooded Marsh	71	721	885	1185	1626
	Inland Fresh Marsh	57	43	41	39	38
	Transitional Salt Marsh	43	781	1093	1461	1775
	Tidal Swamp	16	14	13	11	9
	Ocean Beach	12	8	5	3	5
	Tidal Flat	10	32	22	24	33
	Estuarine Beach	4	3	3	2	2
	Tidal Fresh Marsh	3	2	2	2	2
	Inland Shore	1	1	1	1	1
	Total (incl. water)	**21413**	**21413**	**21413**	**21413**	**21413**



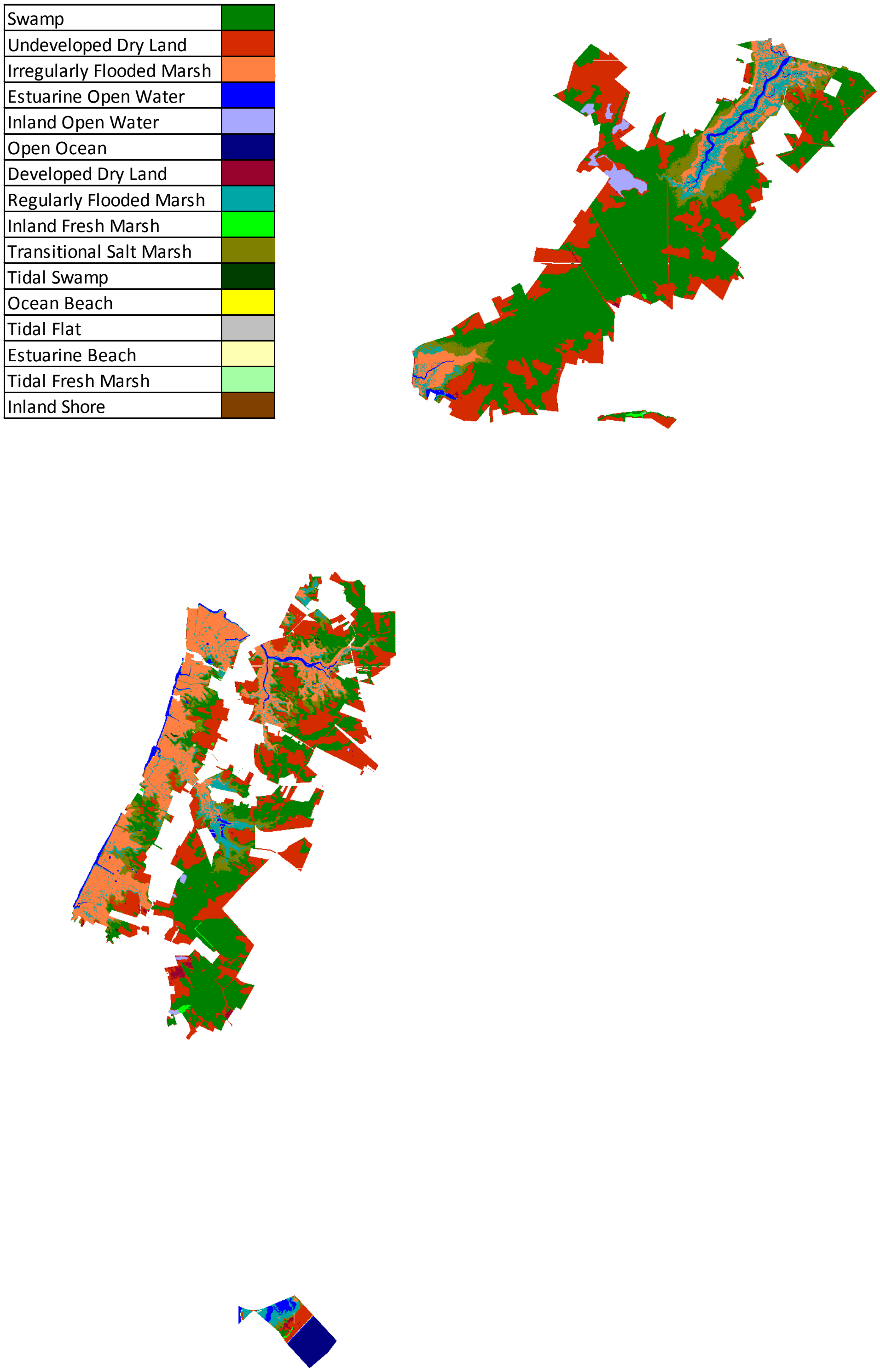
Cape May NWR, Initial Condition



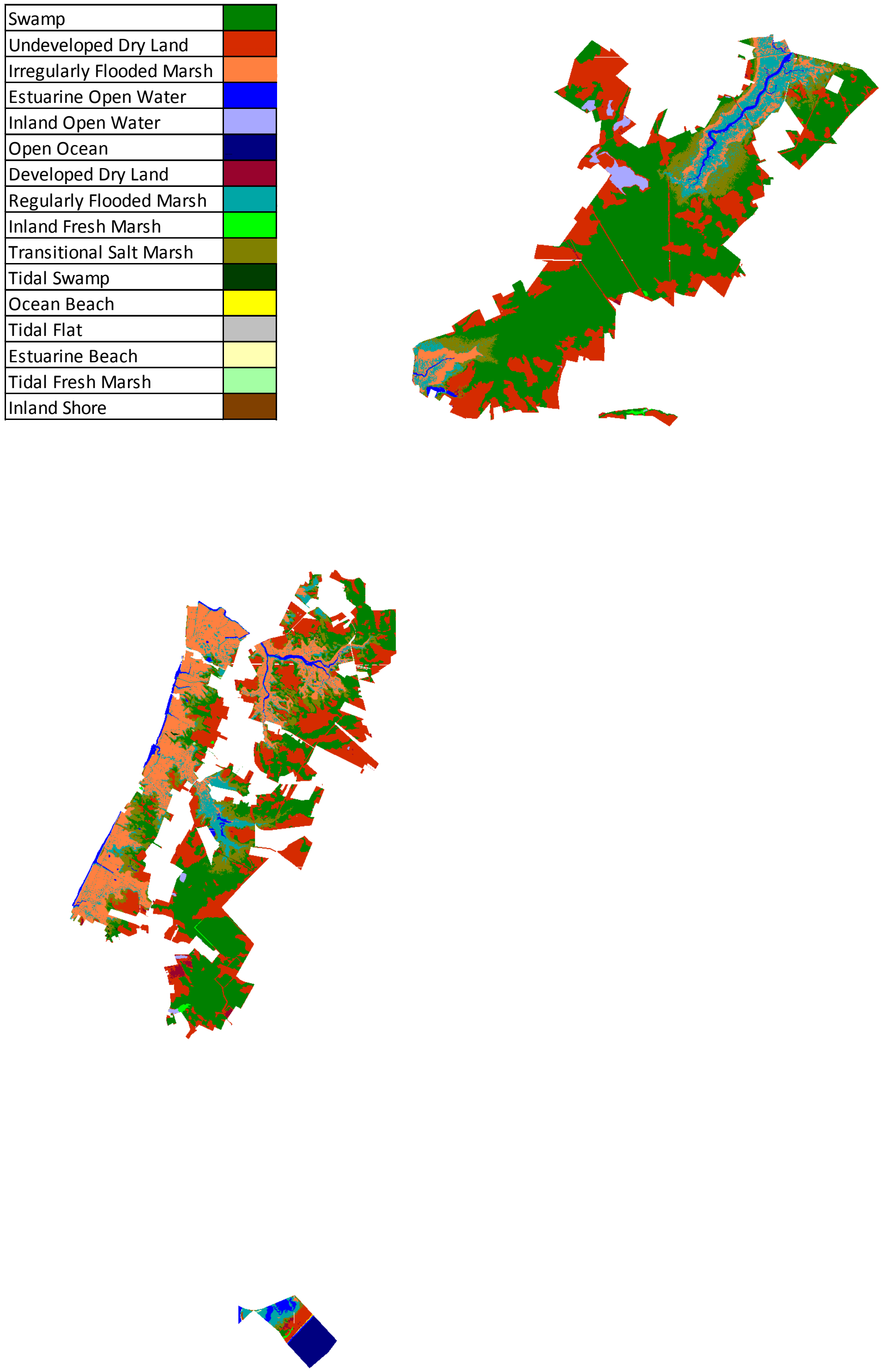
Cape May NWR, 2025, Scenario A1B Mean, 0.39 m SLR



Cape May NWR, 2050, Scenario A1B Mean, 0.39 m SLR



Cape May NWR, 2075, Scenario A1B Mean, 0.39 m SLR

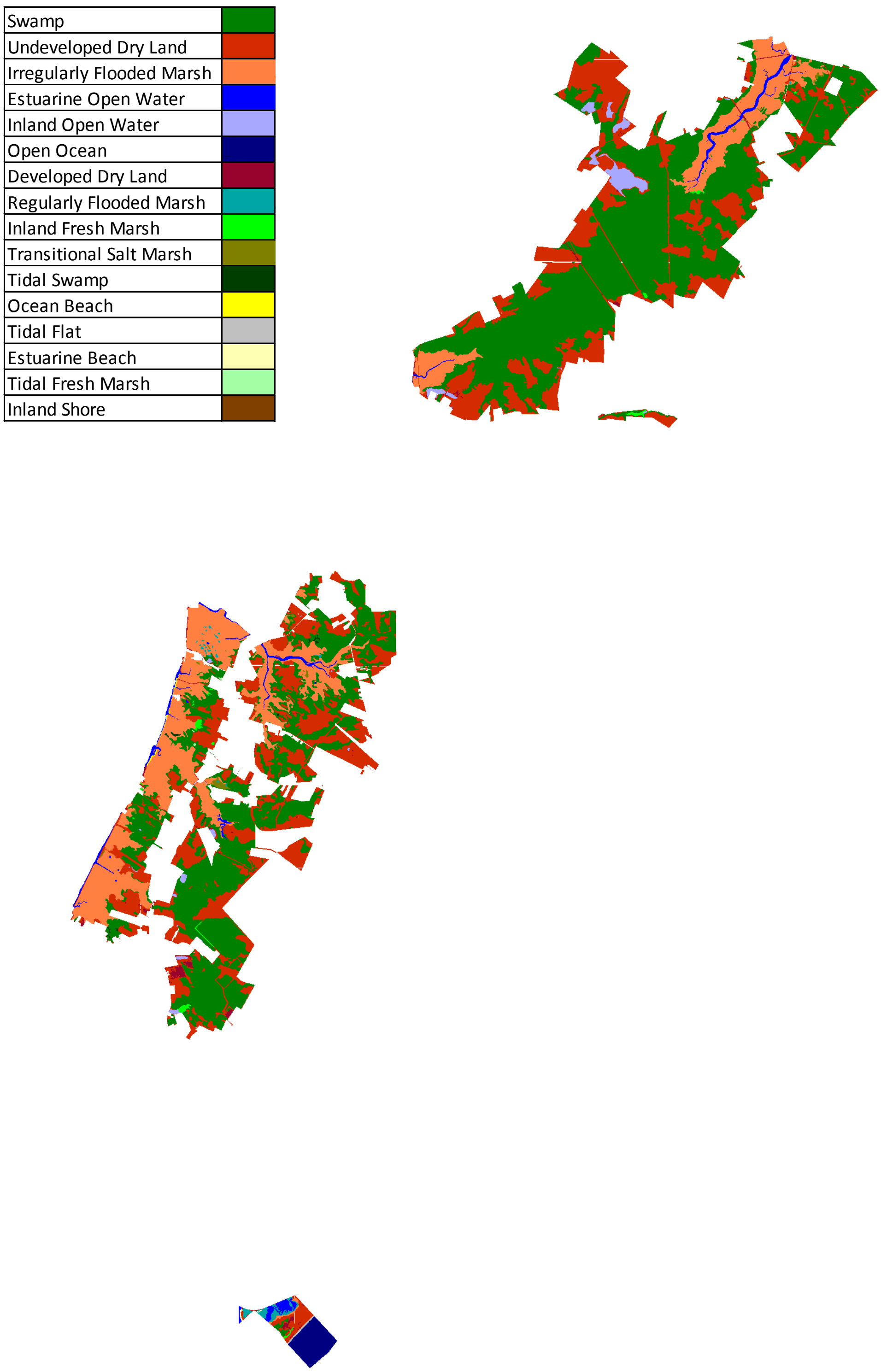


Cape May NWR, 2100, Scenario A1B Mean, 0.39 m SLR

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

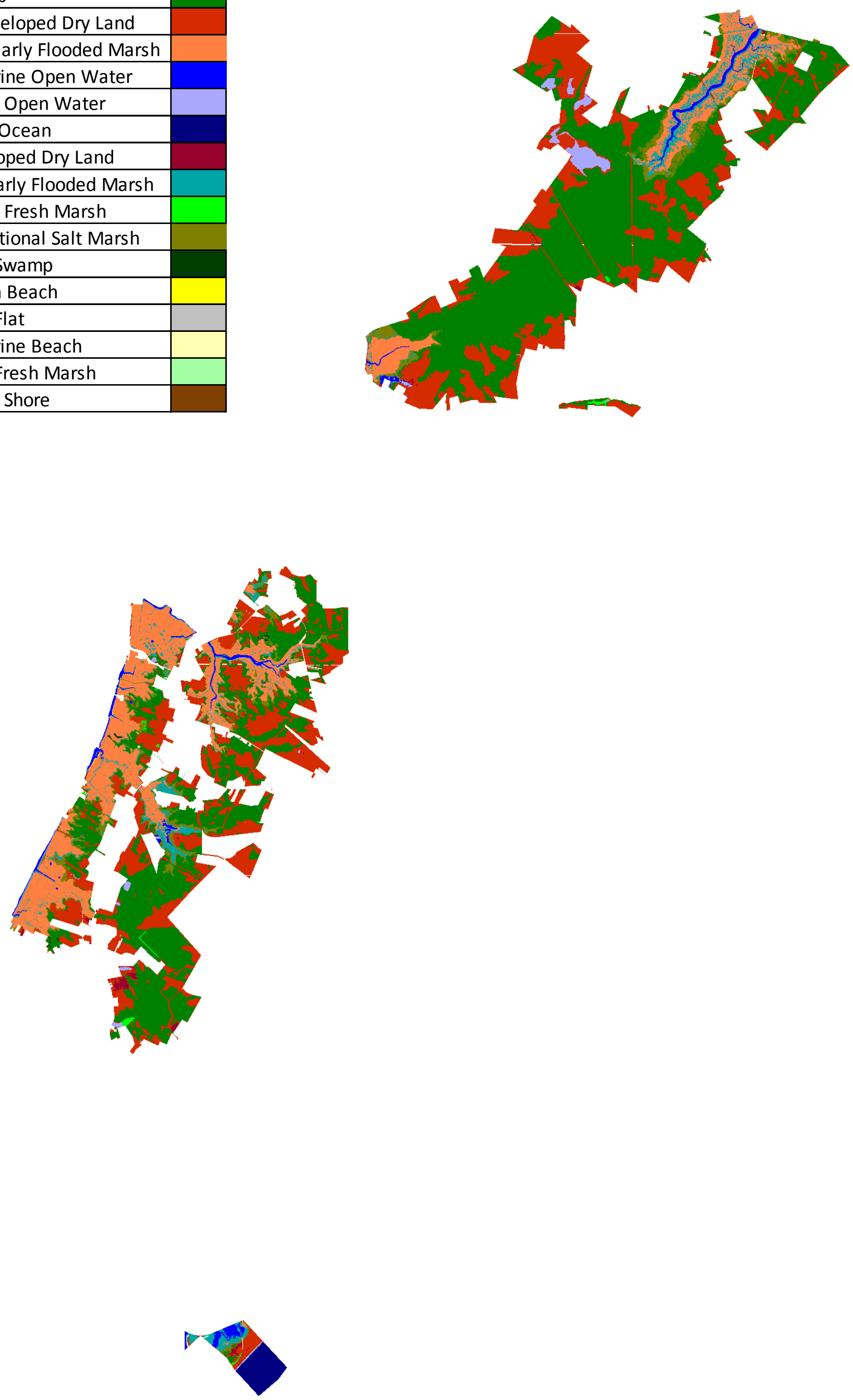
Results in Acres

		Initial	2025	2050	2075	2100
	Swamp	10620	9727	9219	8550	7827
	Undeveloped Dry Land	6012	5861	5793	5663	5469
	Irregularly-flooded Marsh	3640	3207	2926	2211	1177
	Estuarine Open Water	298	326	358	386	428
	Inland Open Water	256	235	225	222	222
	Open Ocean	240	240	240	240	240
	Developed Dry Land	130	107	103	94	85
	Regularly-flooded Marsh	71	788	1239	2471	4123
	Inland Fresh Marsh	57	42	39	38	37
	Transitional Salt Marsh	43	817	1219	1474	1712
	Tidal Swamp	16	14	12	8	6
	Ocean Beach	12	8	5	6	16
	Tidal Flat	10	34	30	45	67
	Estuarine Beach	4	3	3	2	3
	Tidal Fresh Marsh	3	2	2	2	1
	Inland Shore	1	1	1	1	1
	Total (incl. water)	**21413**	**21413**	**21413**	**21413**	**21413**

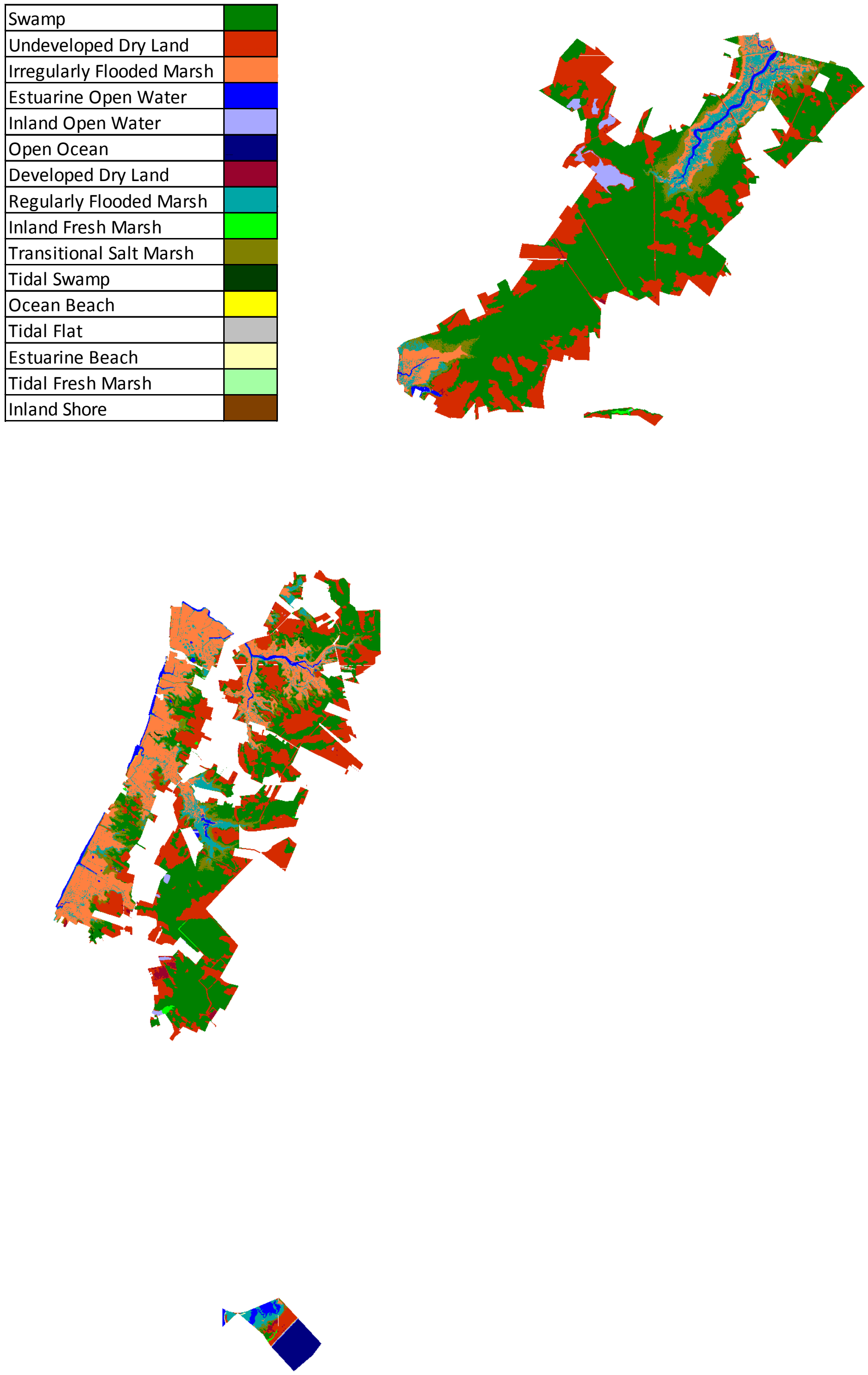


Cape May NWR, Initial Condition

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

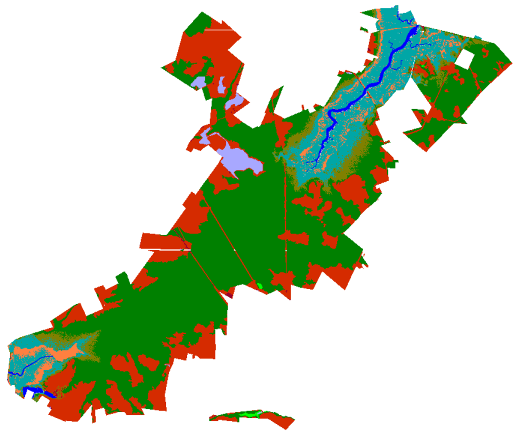


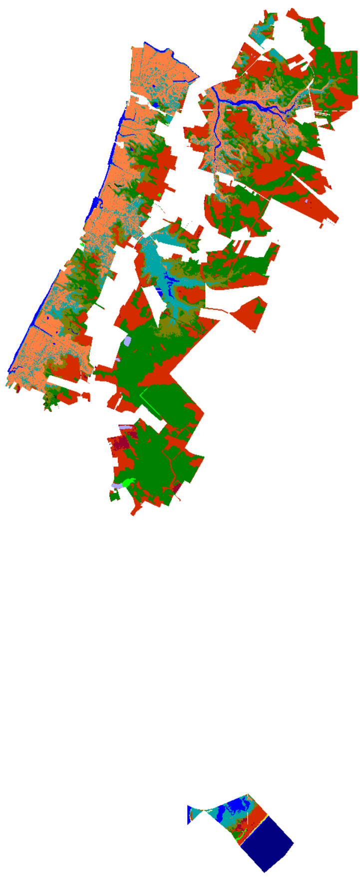
Cape May NWR, 2025, Scenario A1B Maximum, 0.69 m SLR



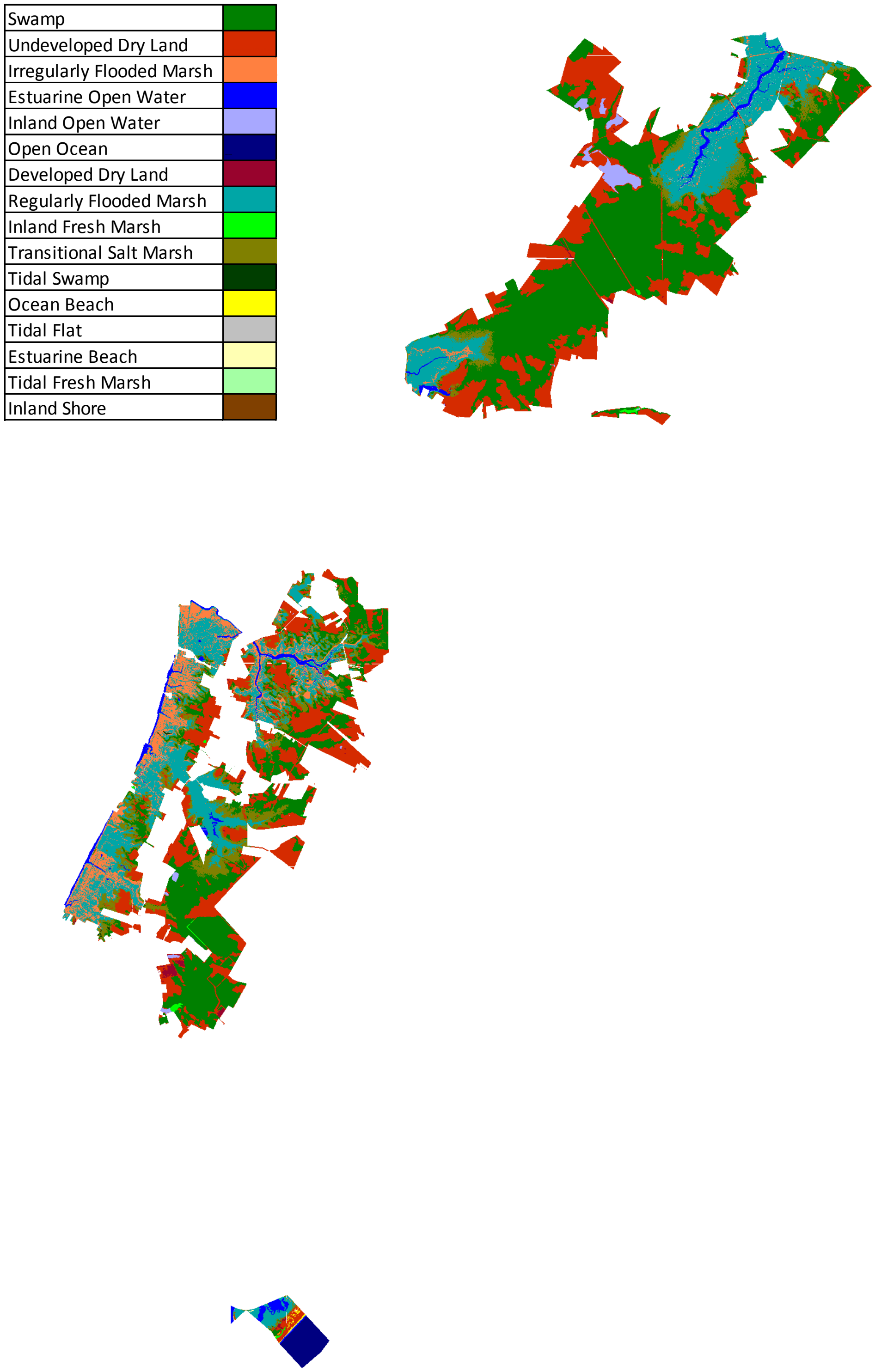
Cape May NWR, 2050, Scenario A1B Maximum, 0.69 m SLR

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





Cape May NWR, 2075, Scenario A1B Maximum, 0.69 m SLR

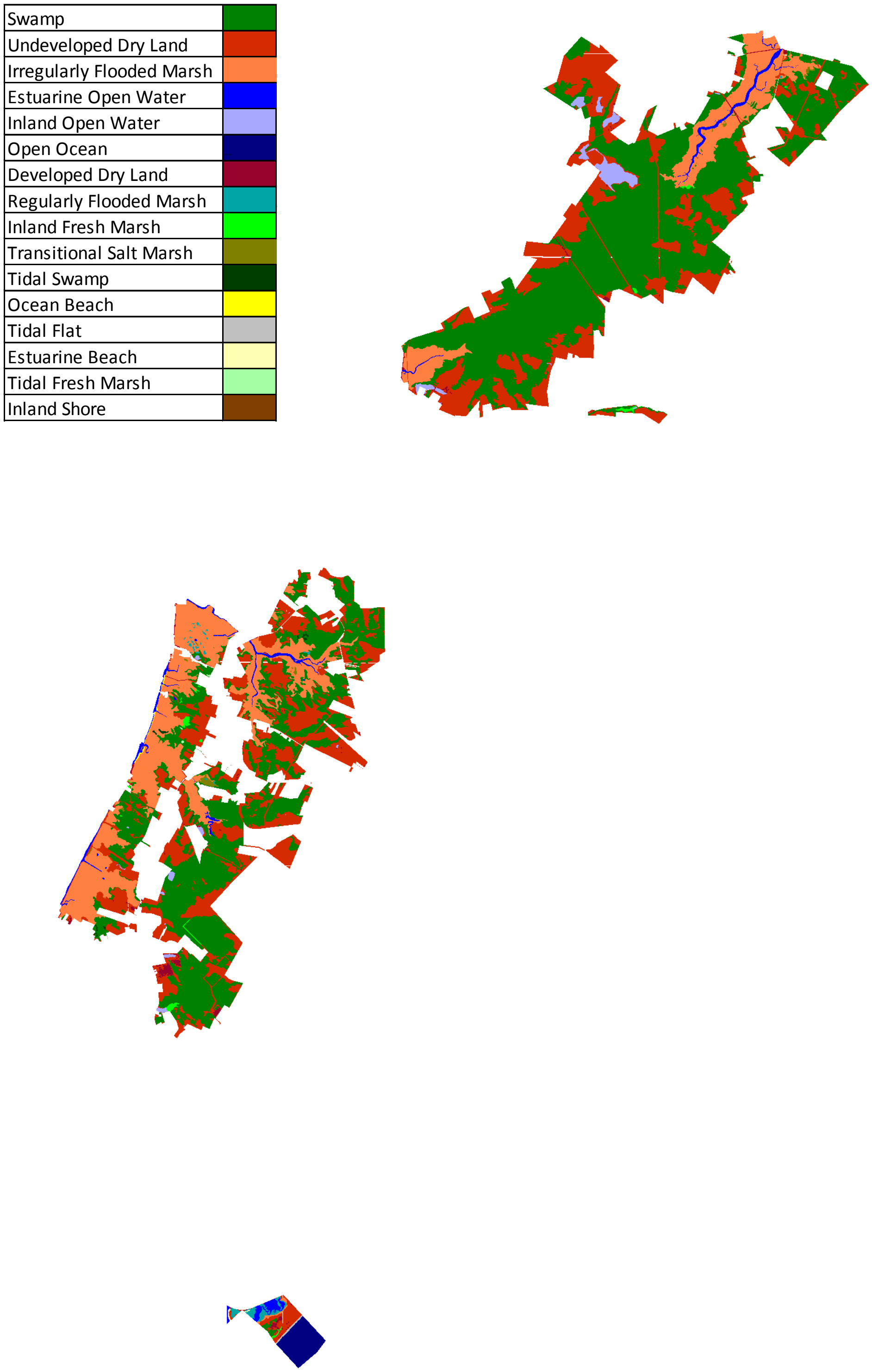


Cape May NWR, 2100, Scenario A1B Maximum, 0.69 m SLR

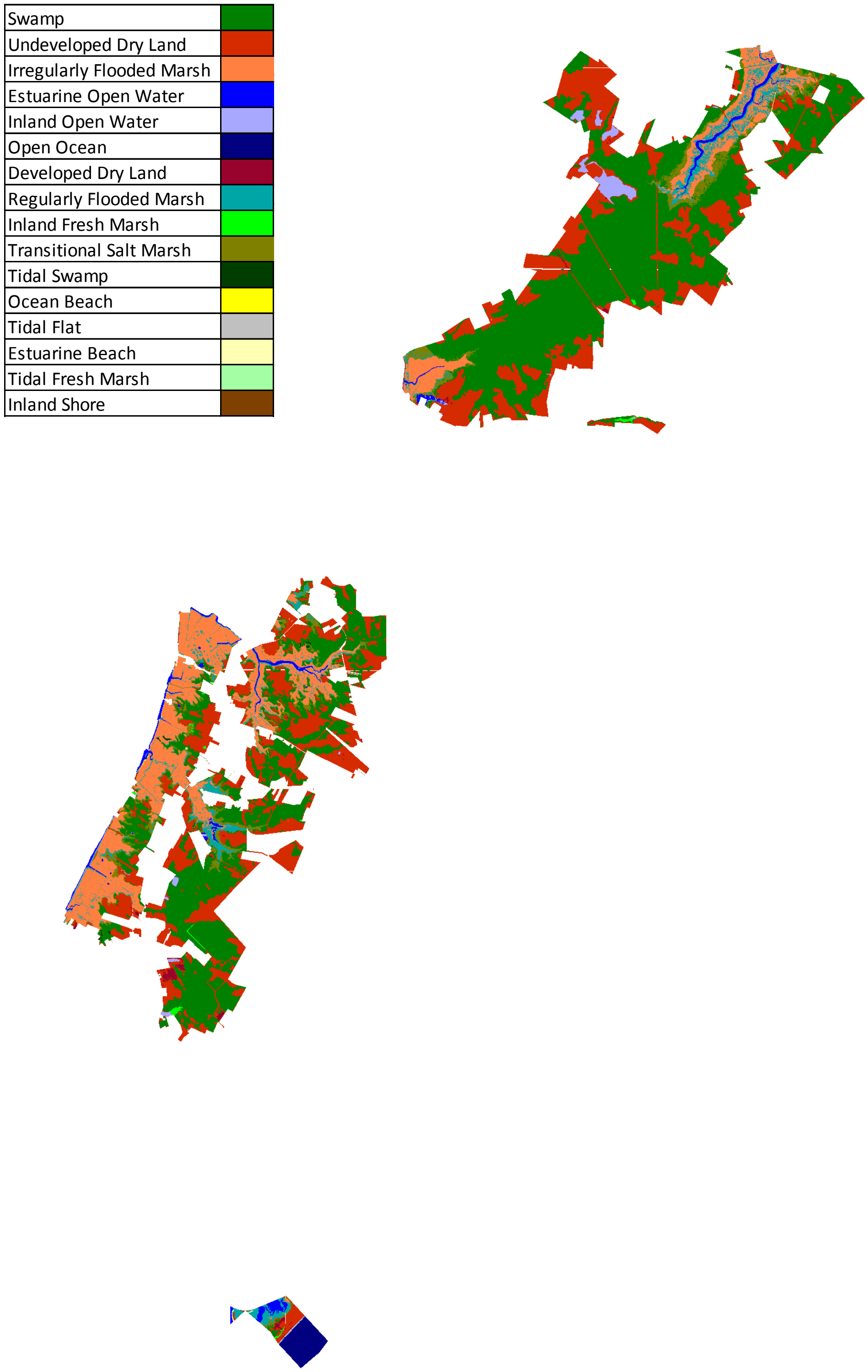
Cape May NWR
1 m eustatic SLR by 2100

Results in Acres

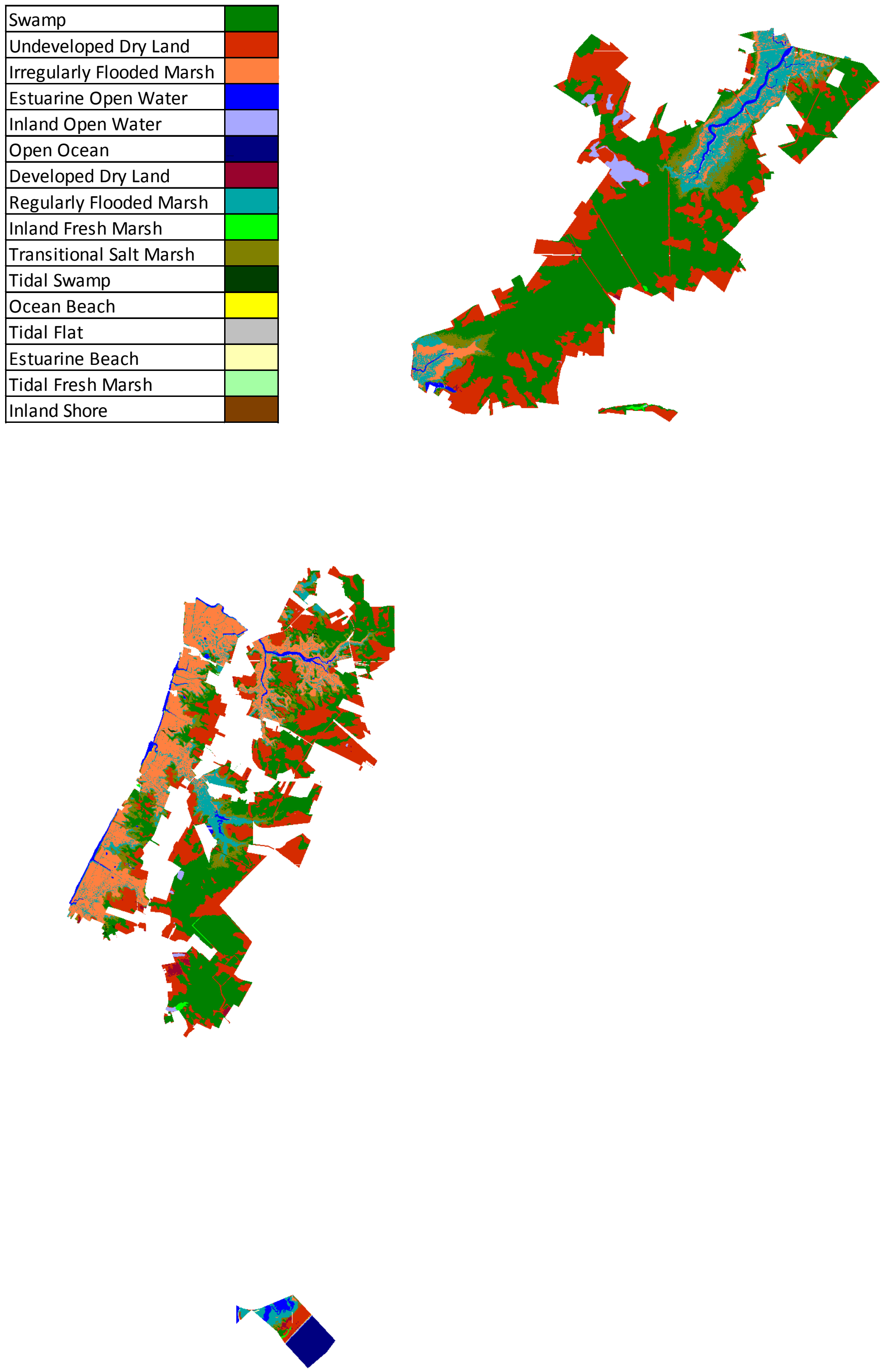
		Initial	2025	2050	2075	2100
	Swamp	10620	9667	8979	8037	7119
	Undeveloped Dry Land	6012	5854	5752	5539	5233
	Irregularly-flooded Marsh	3640	3161	2561	1130	215
	Estuarine Open Water	298	332	362	407	494
	Inland Open Water	256	229	224	222	221
	Open Ocean	240	240	240	240	240
	Developed Dry Land	130	107	100	88	77
	Regularly-flooded Marsh	71	867	1823	4037	5842
	Inland Fresh Marsh	57	41	38	37	37
	Transitional Salt Marsh	43	852	1268	1577	1652
	Tidal Swamp	16	13	10	7	3
	Ocean Beach	12	8	6	9	34
	Tidal Flat	10	35	44	80	238
	Estuarine Beach	4	3	2	2	6
	Tidal Fresh Marsh	3	2	2	1	0
	Inland Shore	1	1	1	1	1
	Total (incl. water)	**21413**	**21413**	**21413**	**21413**	**21413**



Cape May NWR, Initial Condition



Cape May NWR, 2025, 1 m SLR



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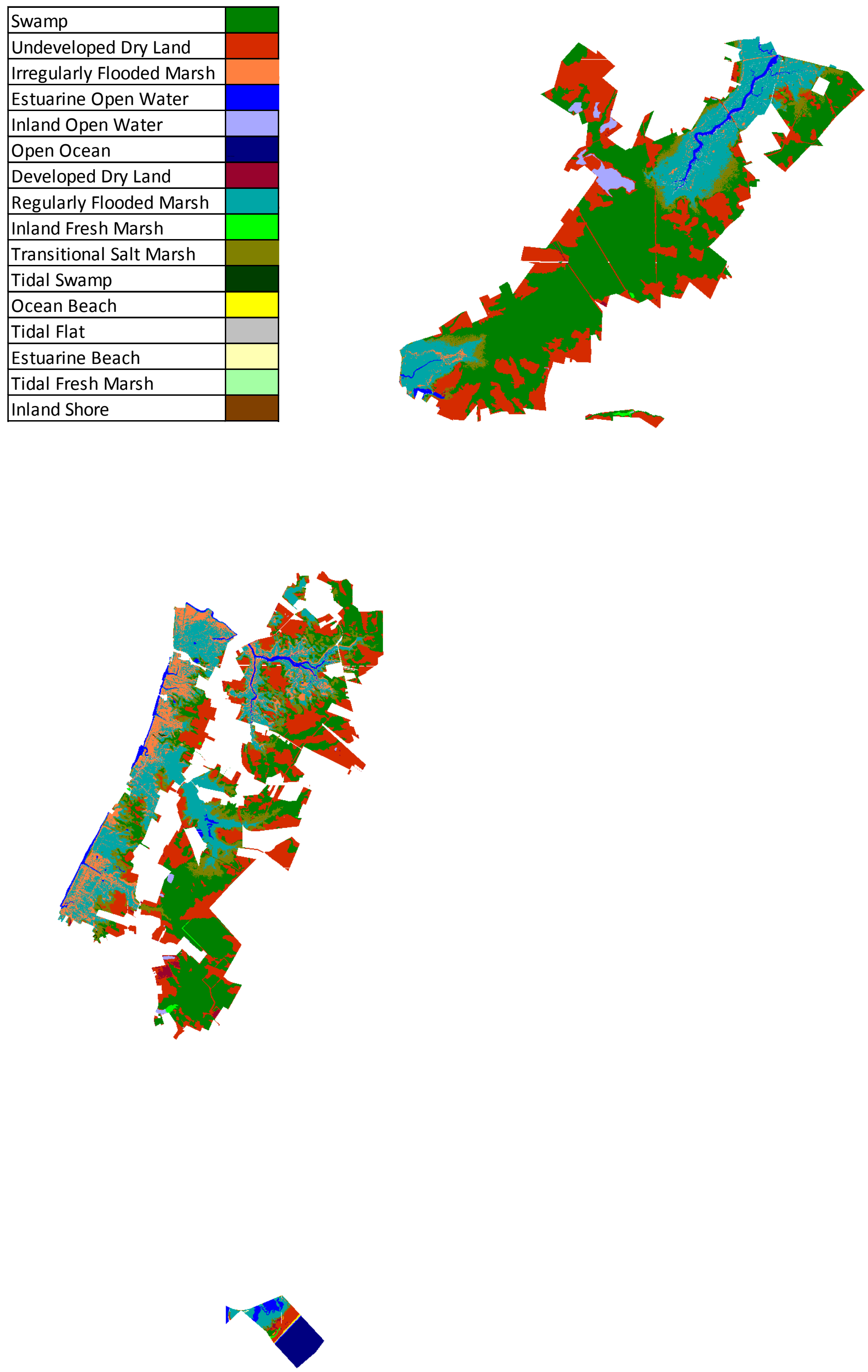
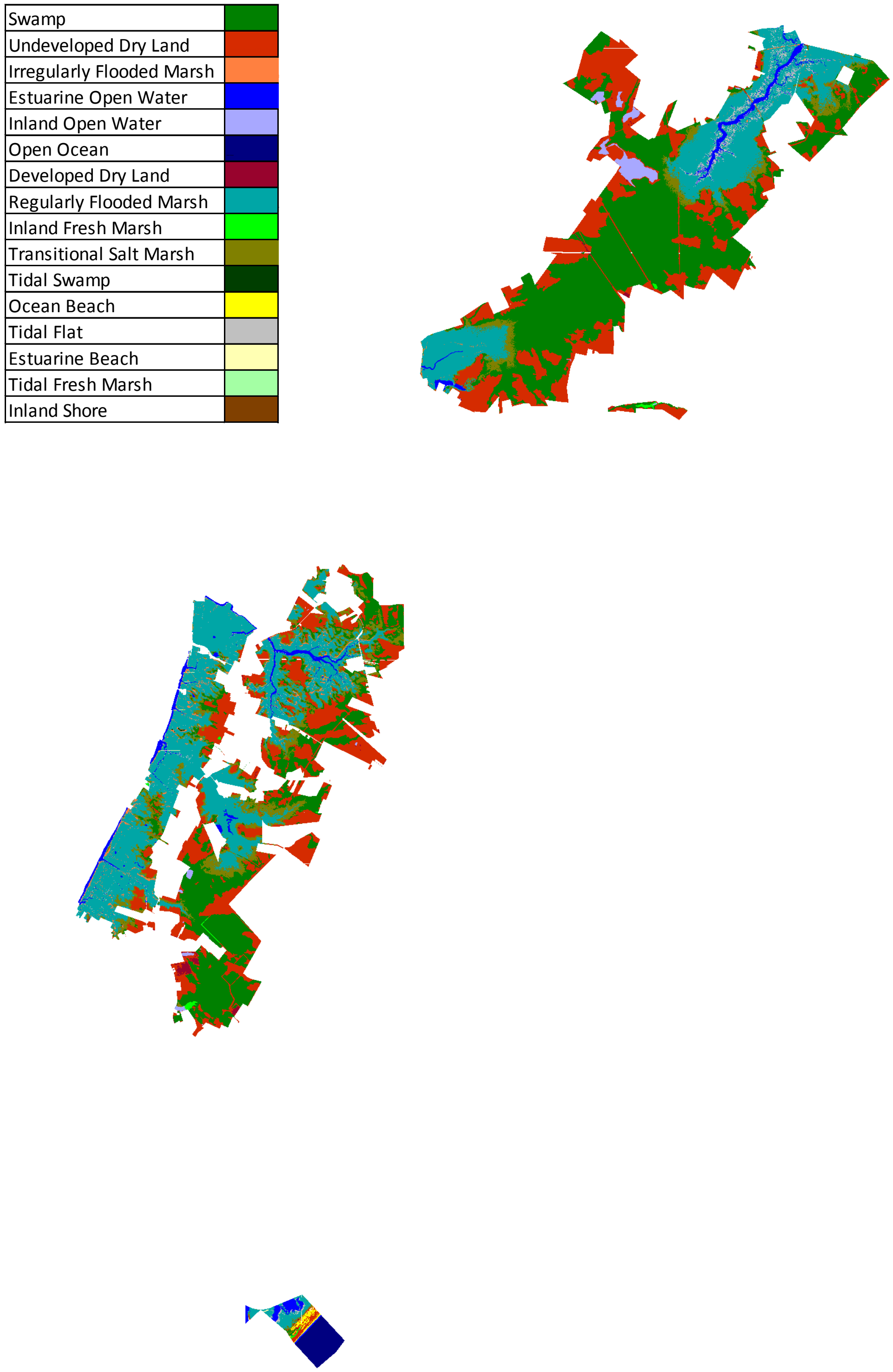


Cape May NWR, 2075, 1 m SLR

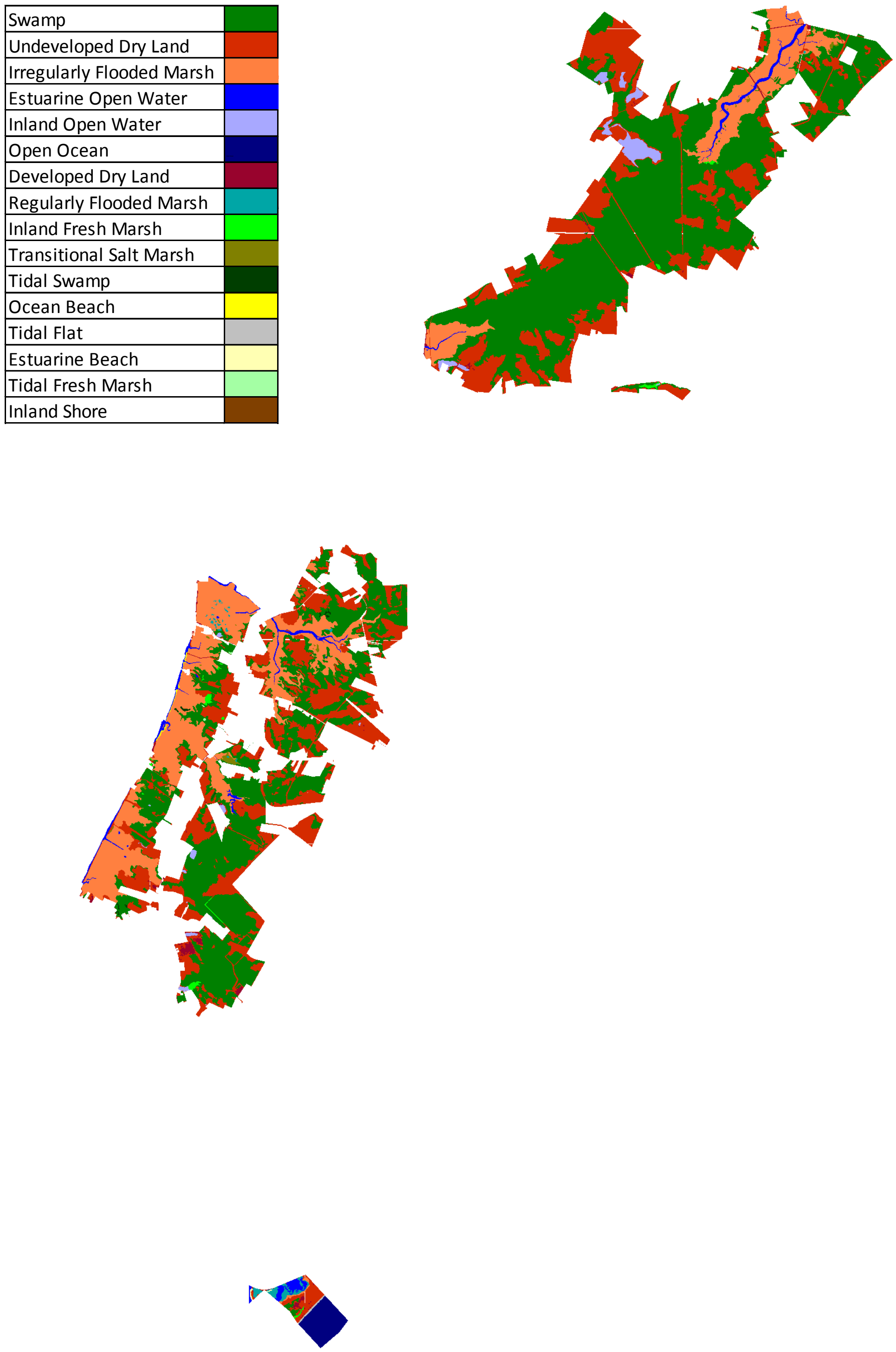


Cape May NWR, 2100, 1 m SLR

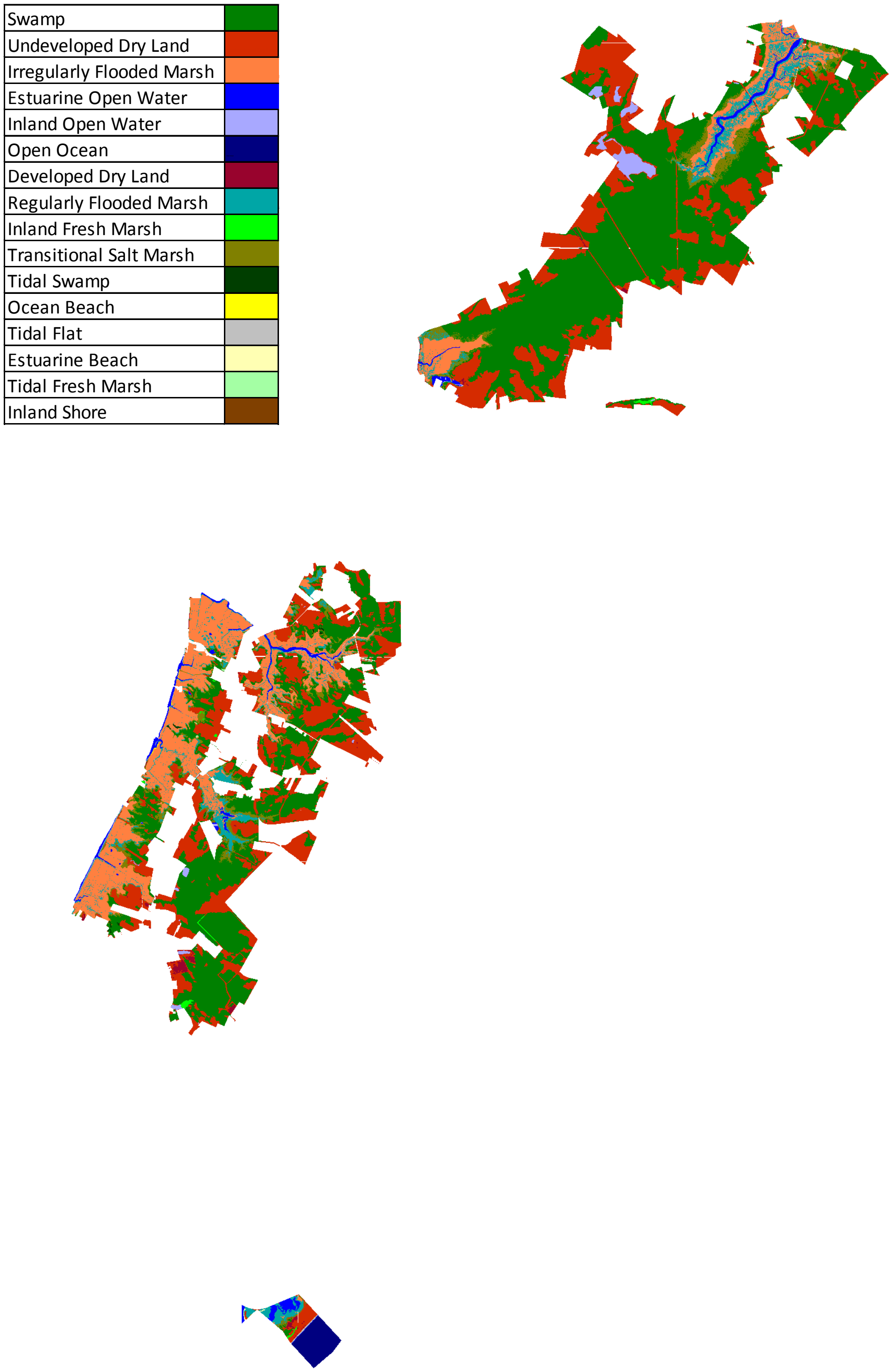
Cape May NWR
1.5 m eustatic SLR by 2100

Results in Acres

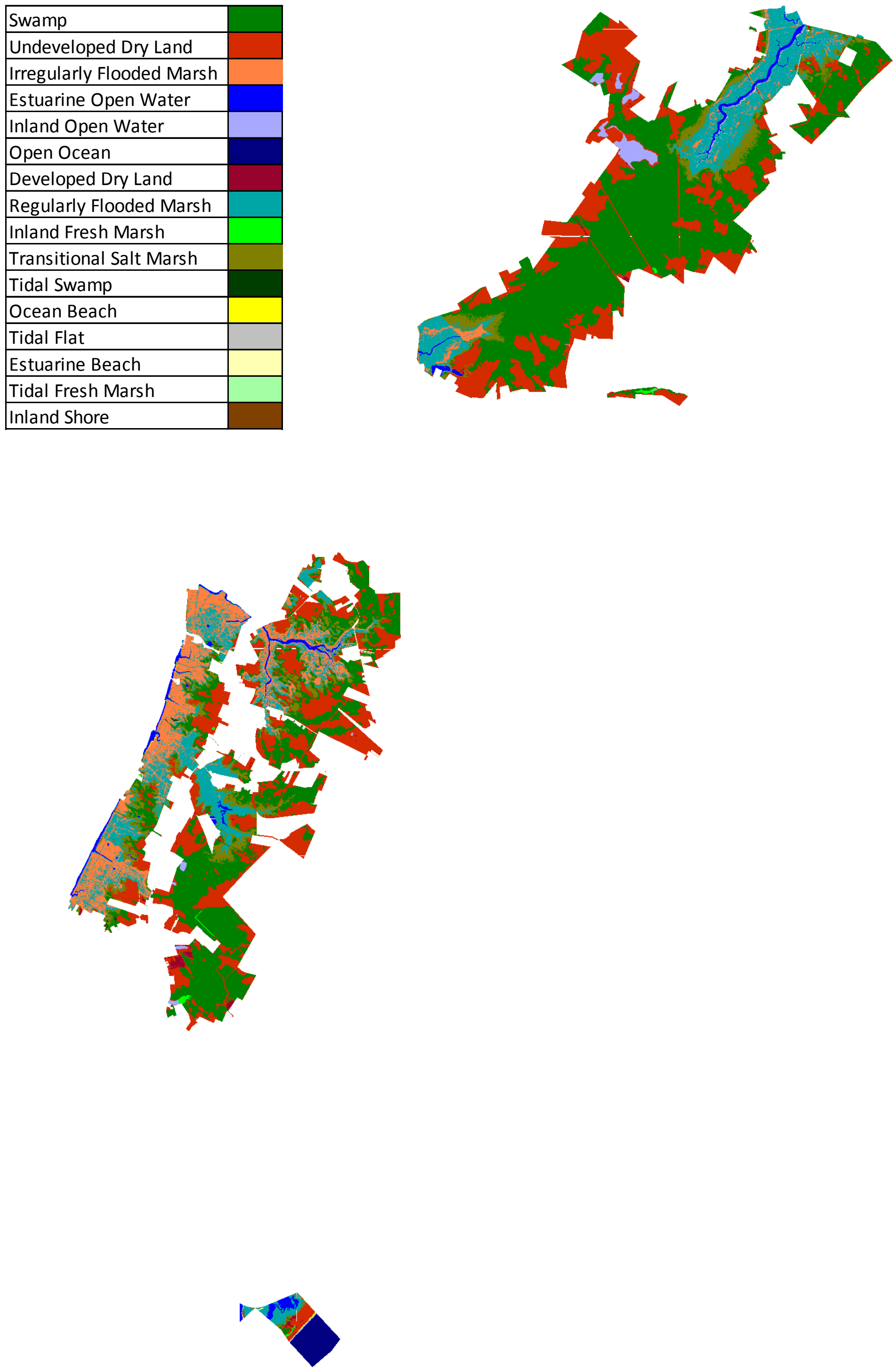
		Initial	2025	2050	2075	2100
	Swamp	10620	9568	8555	7254	5923
	Undeveloped Dry Land	6012	5842	5670	5285	4826
	Irregularly-flooded Marsh	3640	3071	1725	182	47
	Estuarine Open Water	298	334	374	460	802
	Inland Open Water	256	228	223	222	221
	Open Ocean	240	240	240	240	240
	Developed Dry Land	130	106	94	78	69
	Regularly-flooded Marsh	71	1015	2970	5484	6158
	Inland Fresh Marsh	57	40	38	37	35
	Transitional Salt Marsh	43	903	1431	1817	1885
	Tidal Swamp	16	13	8	4	1
	Ocean Beach	12	8	8	31	52
	Tidal Flat	10	39	72	316	1146
	Estuarine Beach	4	3	2	3	6
	Tidal Fresh Marsh	3	2	1	0	0
	Inland Shore	1	1	1	1	1
	Total (incl. water)	**21413**	**21413**	**21413**	**21413**	**21413**



Cape May NWR, Initial Condition



Cape May NWR, 2025, 1.5 m SLR



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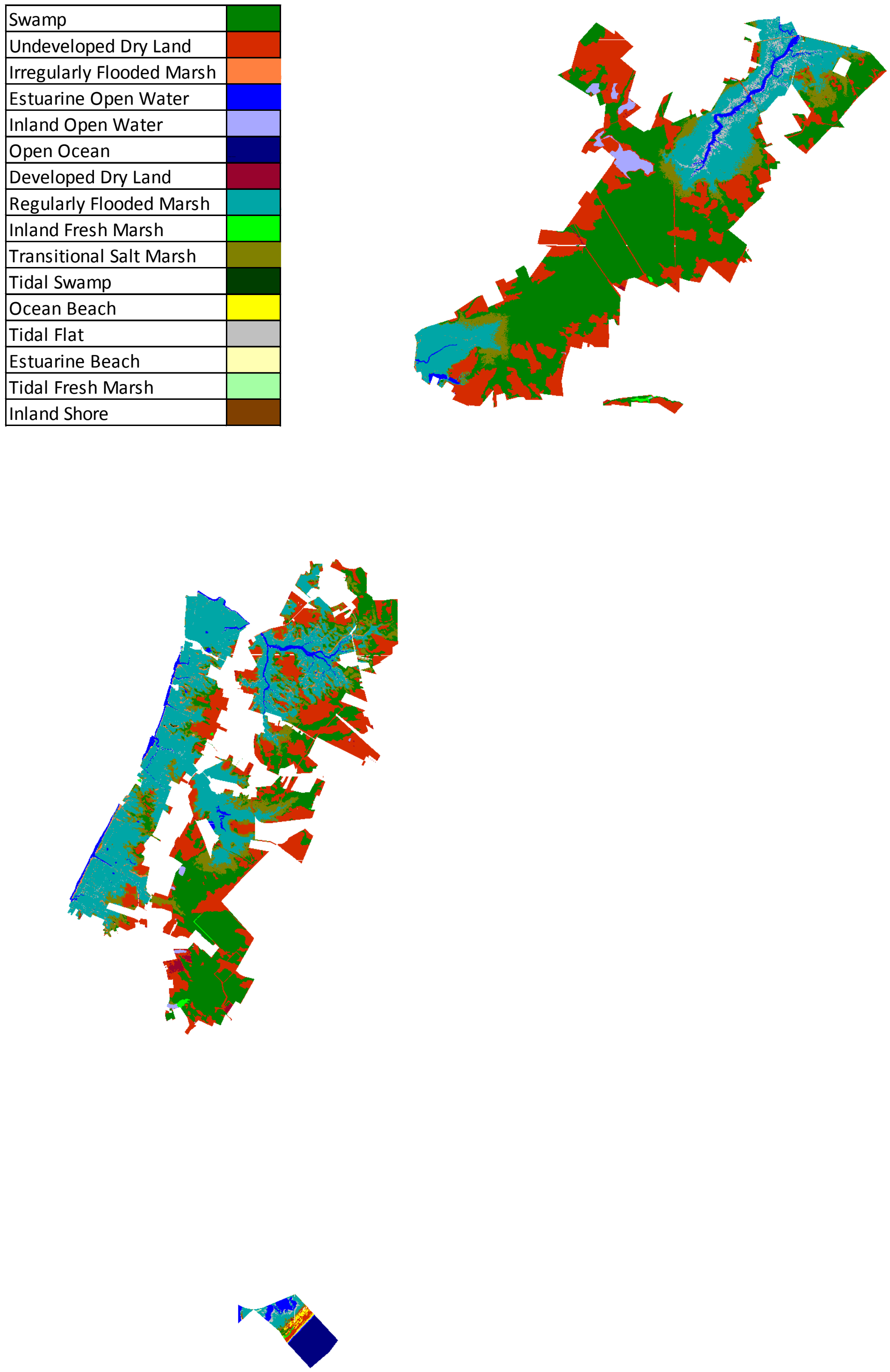
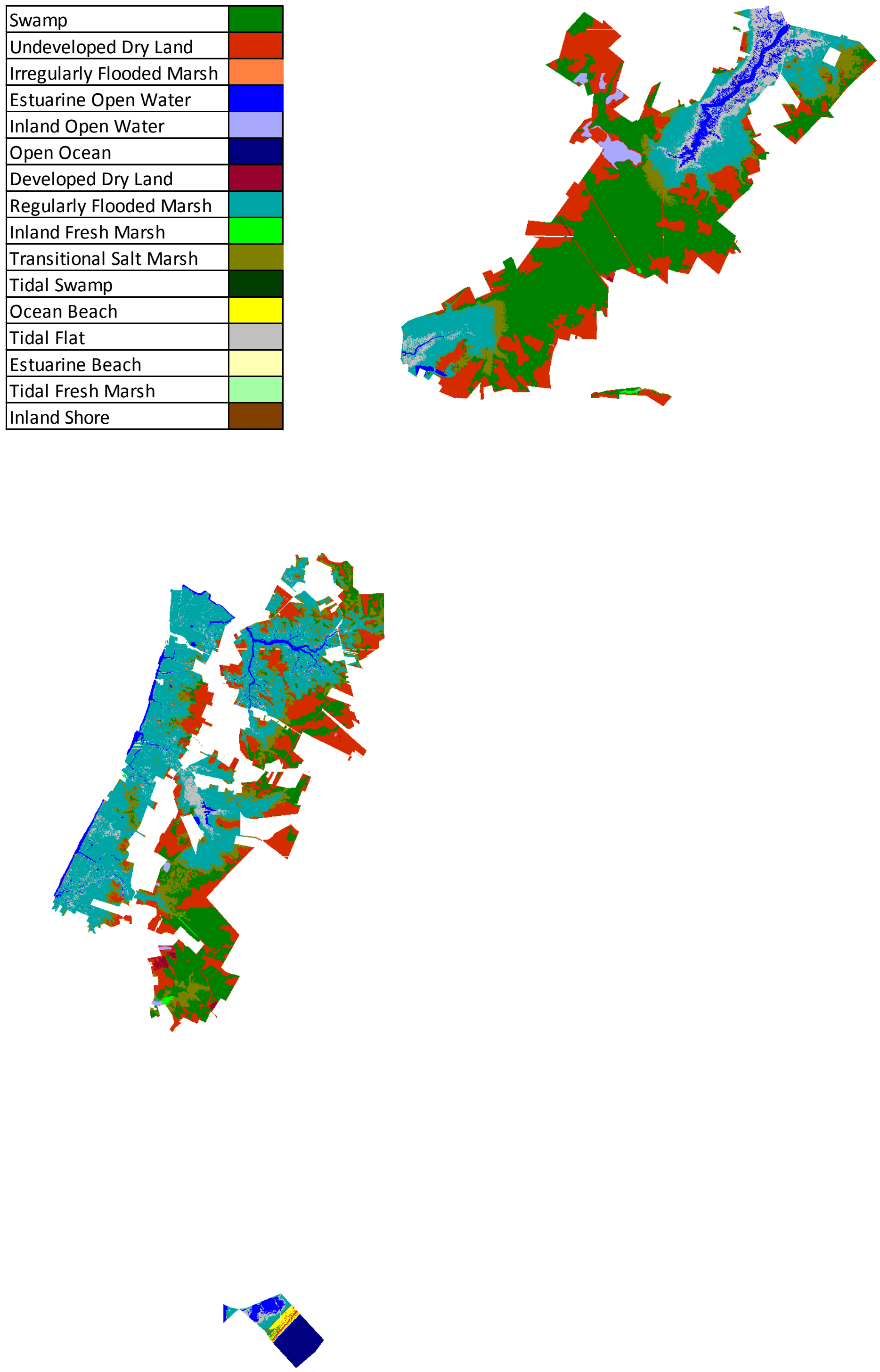


Cape May NWR, 2075, 1.5 m SLR

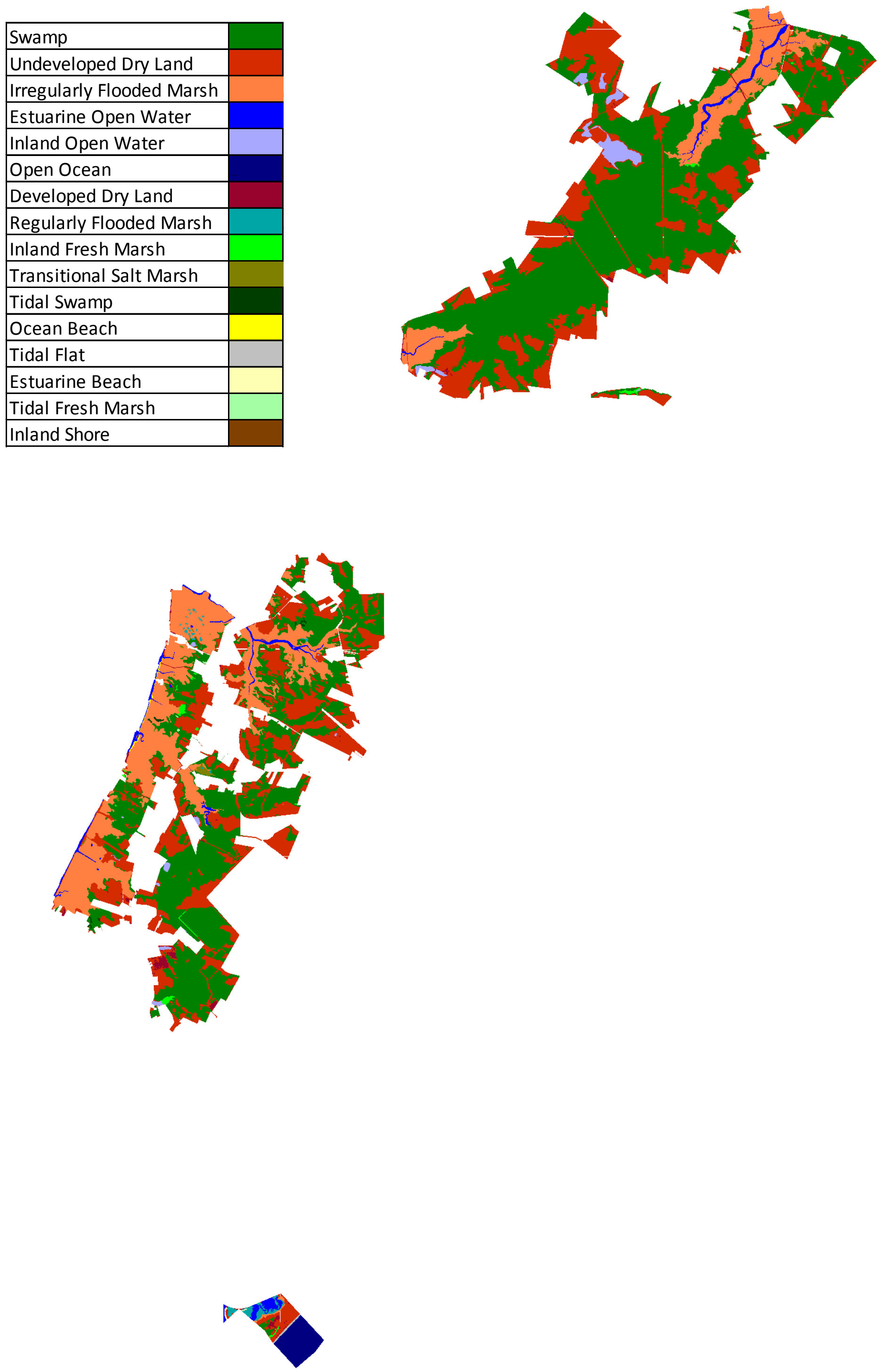


Cape May NWR, 2100, 1.5 m SLR

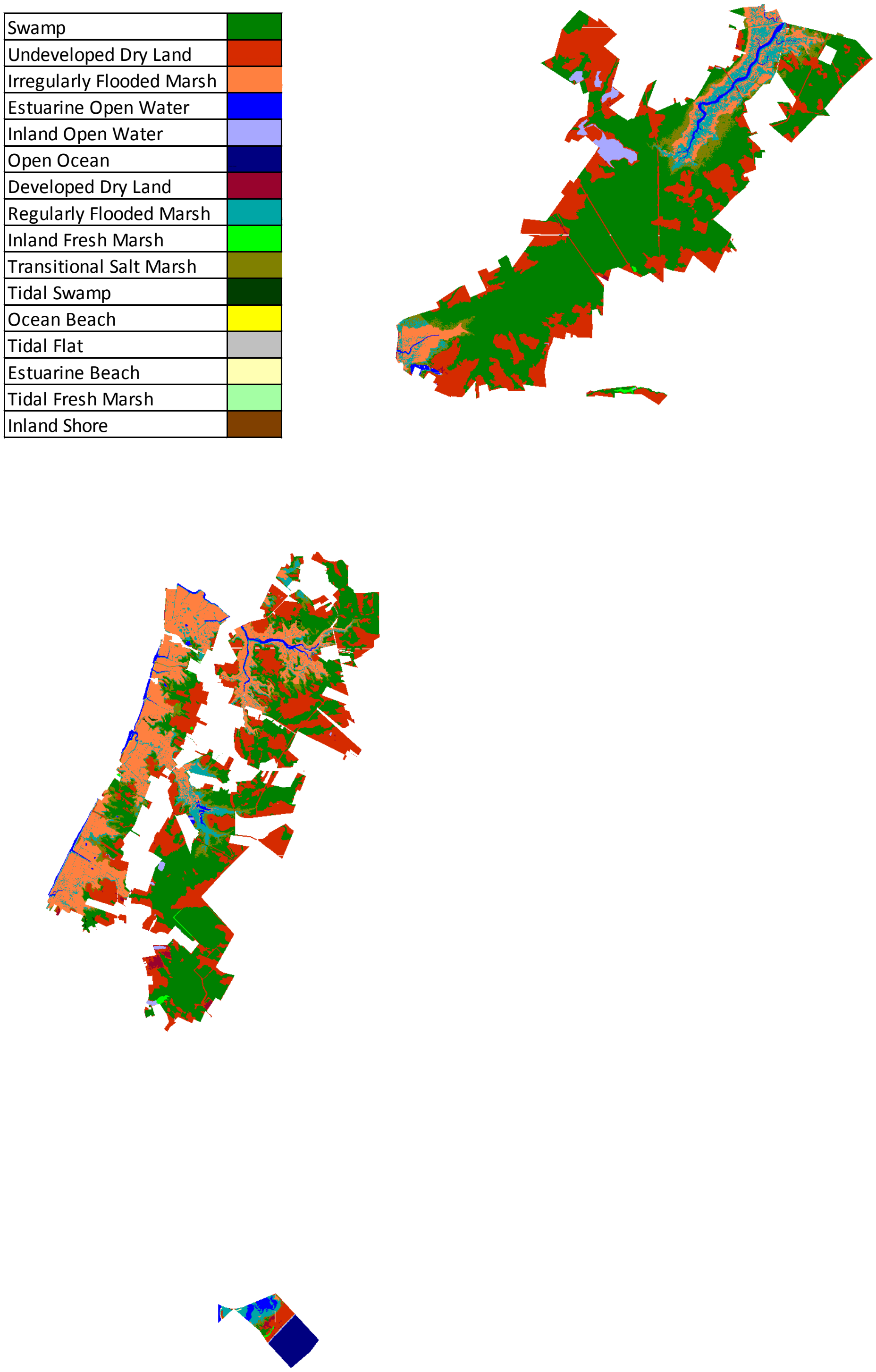
Cape May NWR
2 m eustatic SLR by 2100

Results in Acres

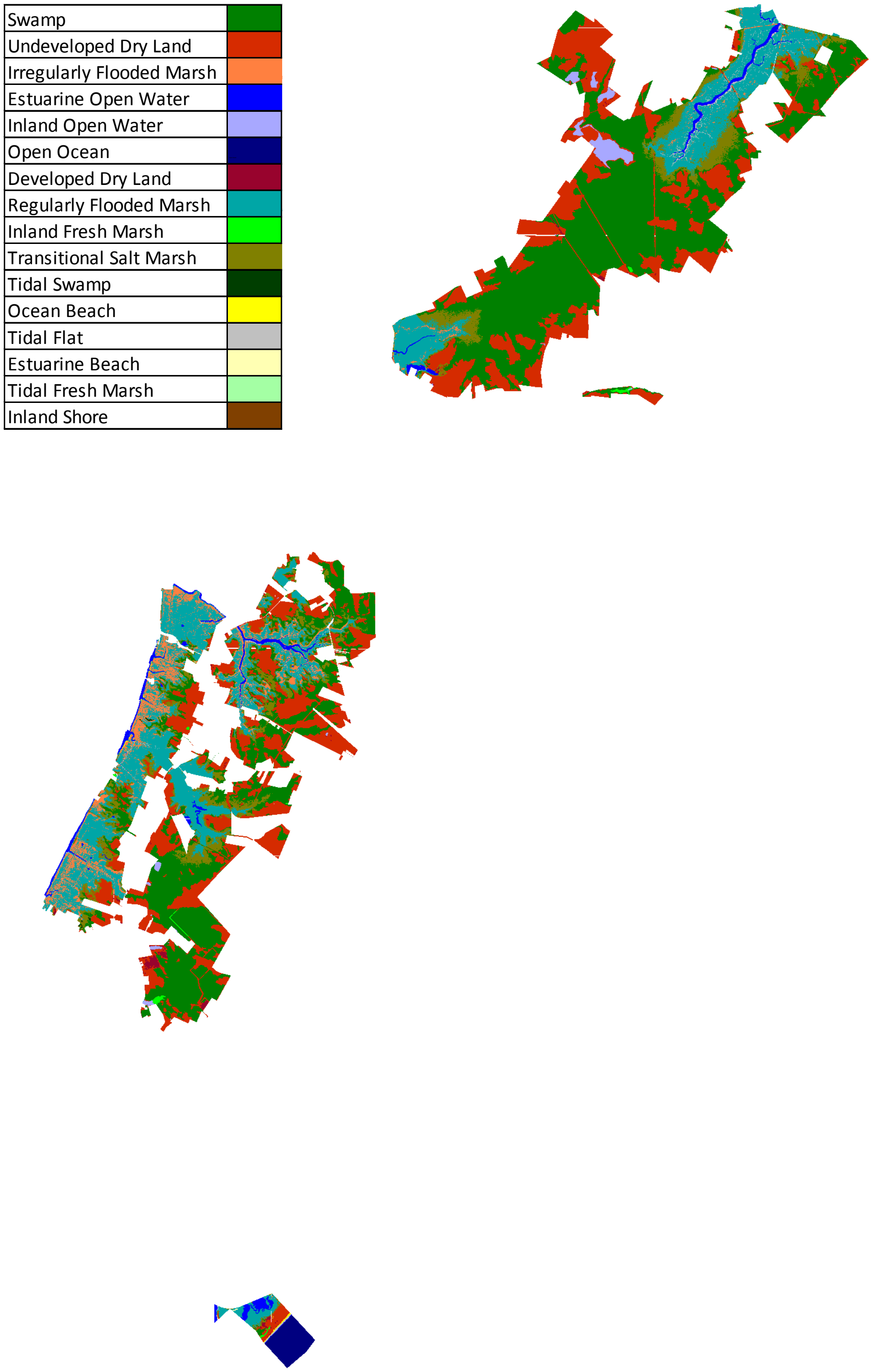
		Initial	2025	2050	2075	2100
	Swamp	10620	9467	8143	6490	4823
	Undeveloped Dry Land	6012	5829	5572	5021	4346
	Irregularly-flooded Marsh	3640	2957	851	68	13
	Estuarine Open Water	298	335	386	533	1528
	Inland Open Water	256	227	222	221	219
	Open Ocean	240	240	240	240	241
	Developed Dry Land	130	105	90	72	66
	Regularly-flooded Marsh	71	1189	4052	5530	4111
	Inland Fresh Marsh	57	40	38	35	26
	Transitional Salt Marsh	43	953	1682	2186	2342
	Tidal Swamp	16	13	7	2	0
	Ocean Beach	12	8	10	46	60
	Tidal Flat	10	44	119	965	3633
	Estuarine Beach	4	3	2	3	3
	Tidal Fresh Marsh	3	2	1	0	0
	Inland Shore	1	1	1	1	1
	Total (incl. water)	**21413**	**21413**	**21413**	**21413**	**21413**



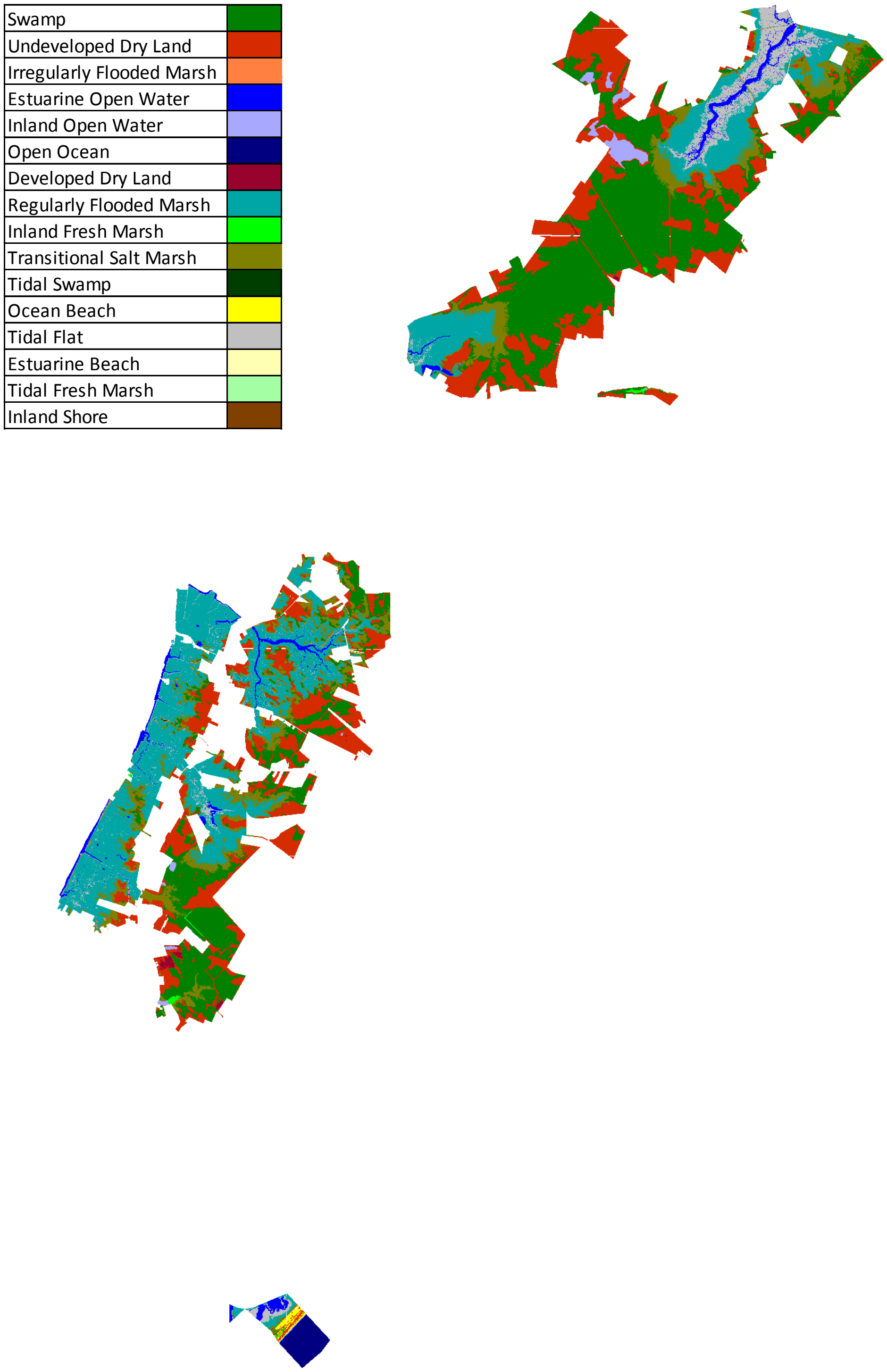
Cape May NWR, Initial Condition



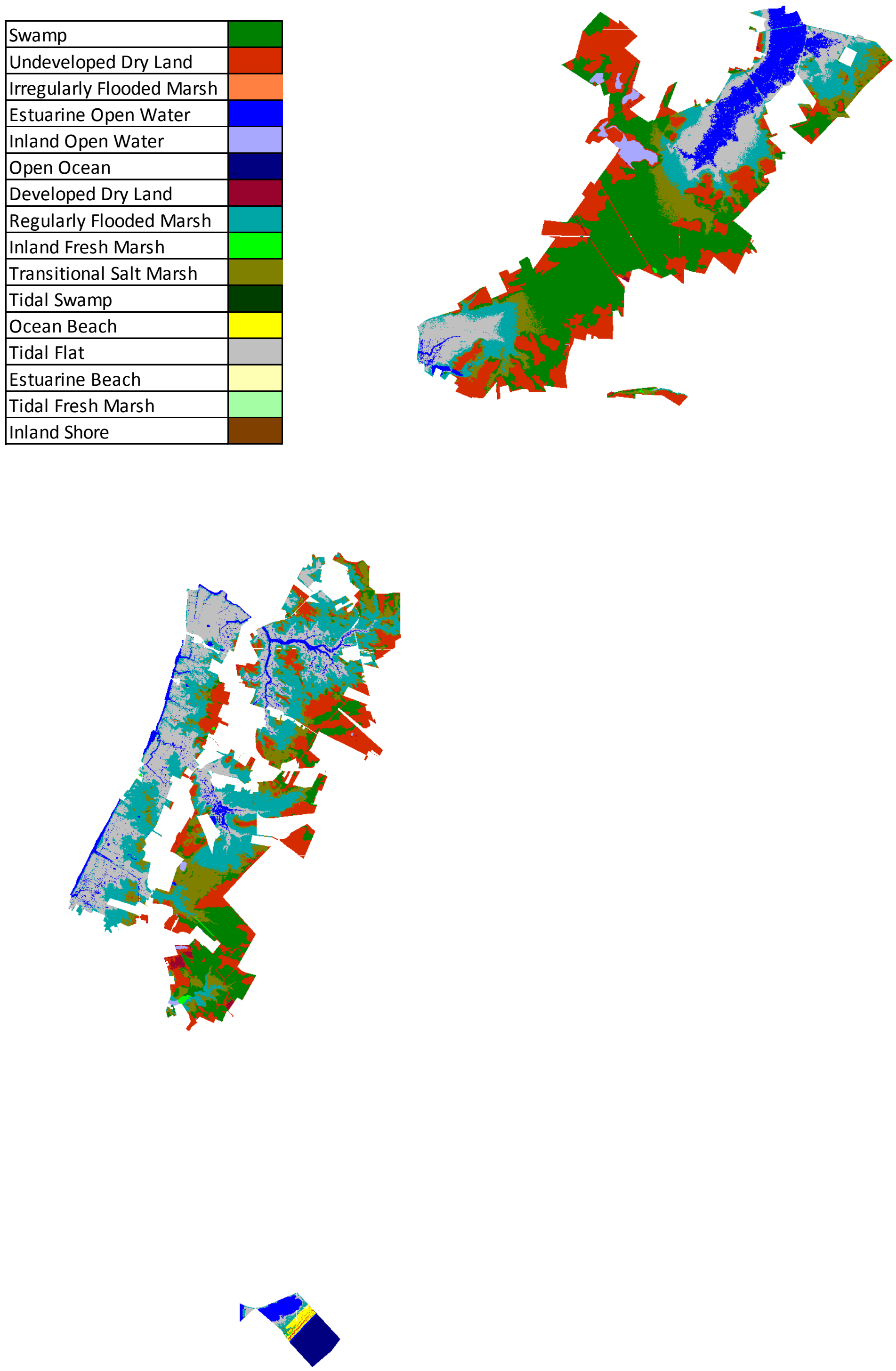
Cape May NWR, 2025, 2 m SLR



Cape May NWR, 2050, 2 m SLR



Cape May NWR, 2075, 2 m SLR



Cape May NWR, 2100, 2 m SLR

Discussion

SLAMM predictions for Cape May NWR suggest the refuge will be impacted by sea level rise. Each category of wetlands that currently exists in the park is predicted to undergo significant losses. As salt water penetrates further inland, increasing land cover is predicted to be converted to transitional salt marsh and regularly-flooded marsh.

Compared to a previous SLAMM analysis of the refuge, these new predictions confirm the sensitivity of the wetlands to SLR. The 2008 NWI layer is similar to the previous layer used (from a 1995 photo), with the exception that most of the land previously classified as tidal swamp is now designated as swamp. The recent and more precise elevation layer of 2009 leads to the quantitative differences observed between the two analyses. The previous study relied on a 1955 non-digital elevation map (except for the south most part of the refuge where 2005 LiDAR data were used). Losses of swamp are more significant at lower SLR scenarios than previously predicted via SLAMM. In addition, irregularly-flooded marsh appears more sensitive to SLR in the current analysis. Irregularly-flooded marsh is predicted to be nearly gone given a SLR greater than 1.5 m by 2100; this was not predicted in the previous analysis. On the contrary, undeveloped dry land is predicted to be more resilient to the effects of SLR in the current analysis.

The results reported here are influenced by the relatively high local SLR trend (4 mm/yr). This historic trend value is assumed to be a combination of the historic eustatic SLR (estimated at approximately 1.75 mm/yr) and local land subsidence (or other local factors). Research in the region indicates local subsidence rates in the Cape May NWR area could be relatively high due to groundwater withdrawal (Sun et al. 1999).

For salt marshes, accretion data were taken from the available literature and applied to the entire study area. However, as accretion rates are key parameters of the wetland response to SLR, the robustness of the results could be studied as a function of the uncertainties of the accretion models used.

While model and data updates have helped to reduce the uncertainty in the predictions reported here, uncertainty in the future sea-level rise is important to keep in mind when interpreting these results. To account for these uncertainties, results presented here investigated effects for a wide range of possible sea level rise scenarios, from a more conservative rise (0.39 m by 2100) to a more accelerated process (2 m by 2100).

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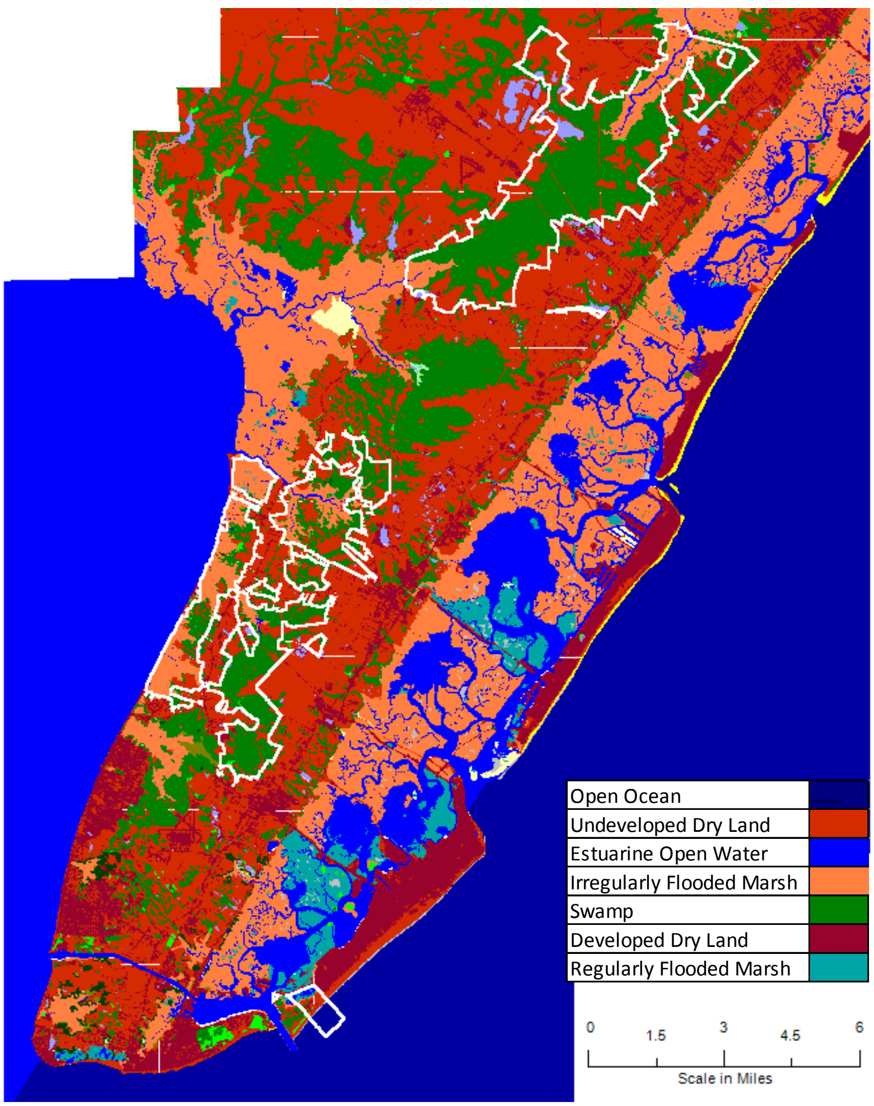
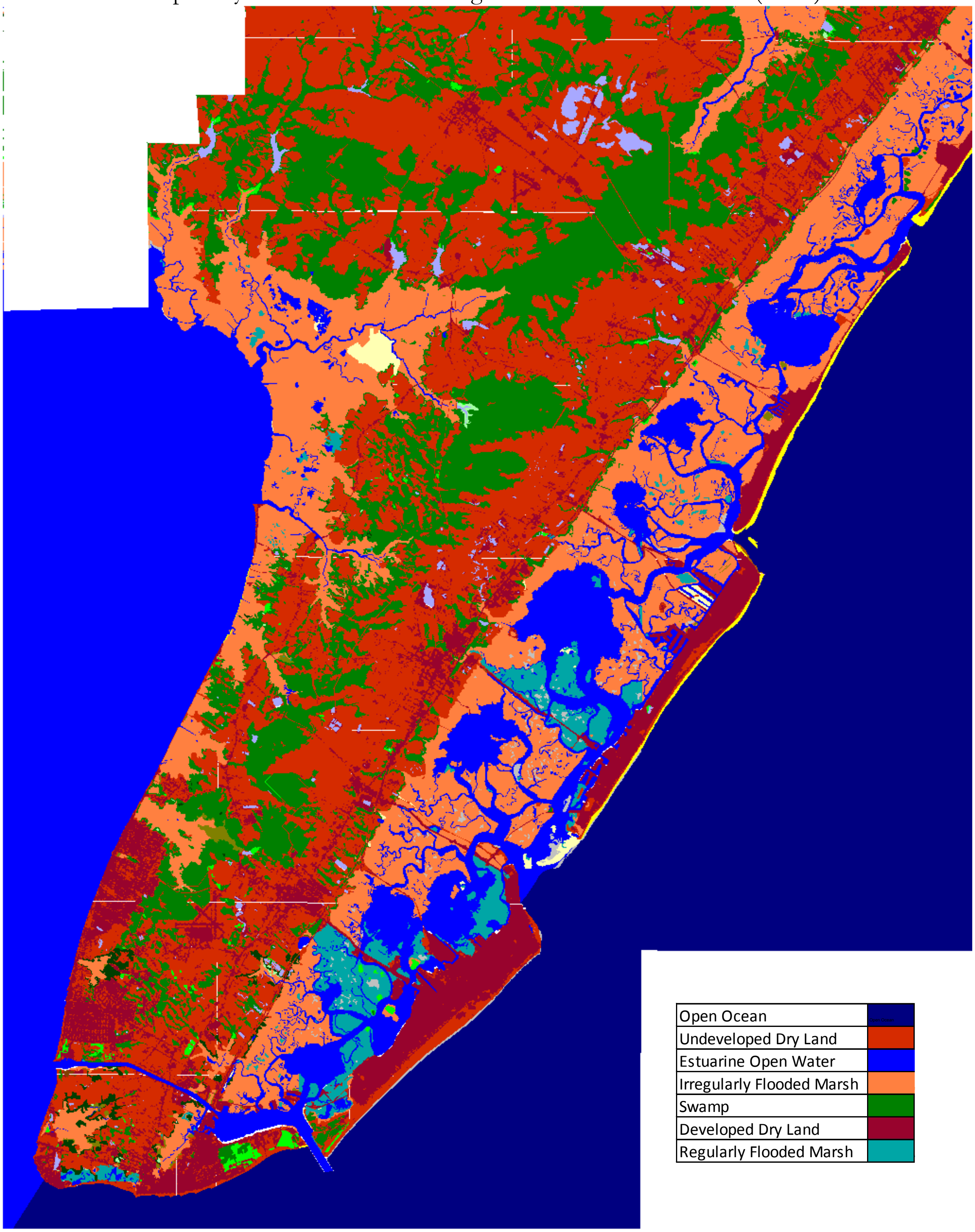
Appendix A: Contextual Results

The SLAMM model does take into account the context of the surrounding lands or open water when calculating effects. For example, erosion rates are calculated based on the maximum fetch (wave action) which is estimated by assessing contiguous open water to a given marsh cell. Another example is that inundated dry lands will convert to marshes or ocean beach depending on their proximity to open ocean. Therefore, an area larger than the boundaries of the USFWS refuge was modeled. Maps of these results are presented here with the following caveats:

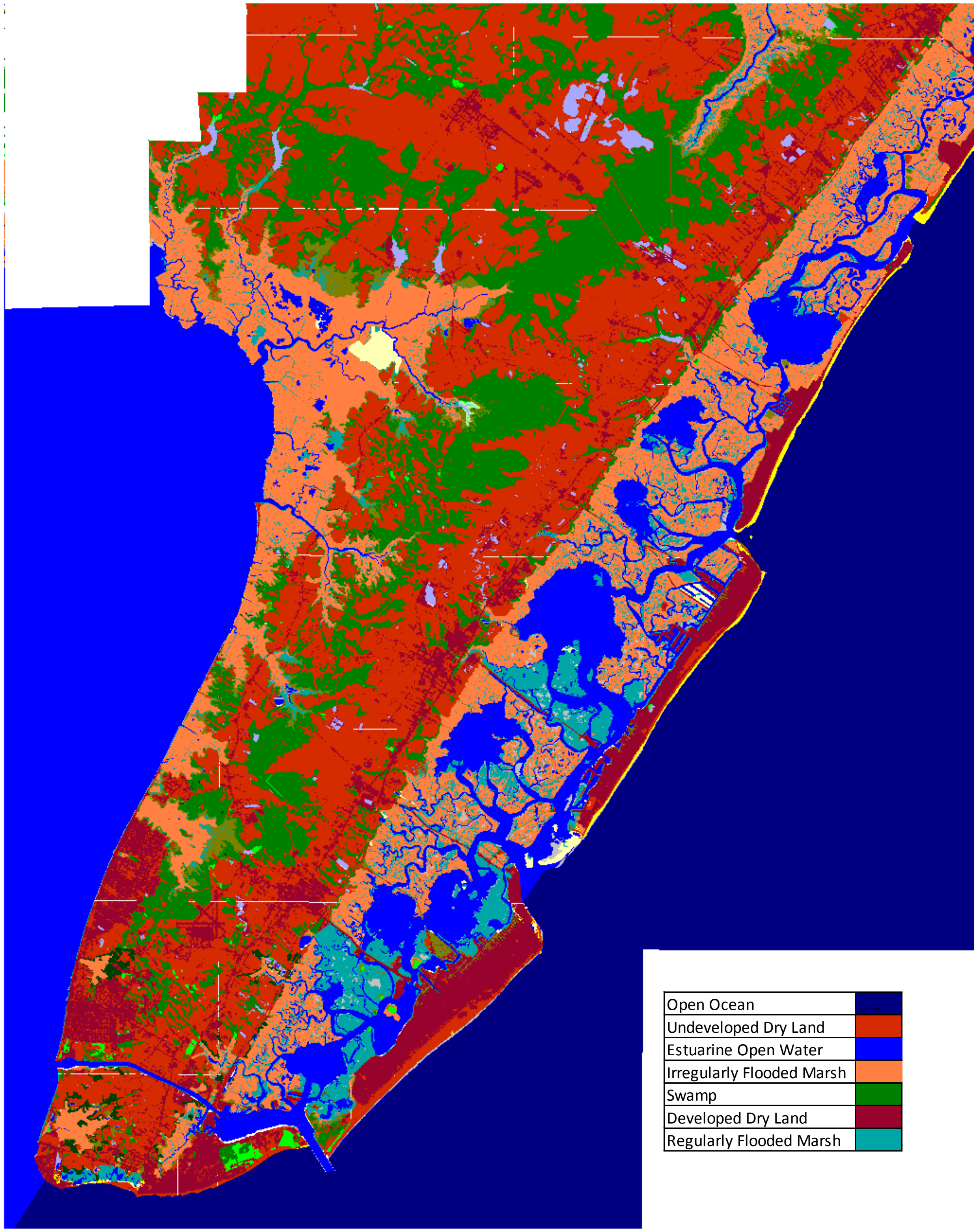
- Results were critically examined within USFWS refuges but not closely examined for the larger region.
- Site-specific parameters for the model were derived for USFWS refuges whenever possible and may not be regionally applicable.
- Especially in areas where dikes are present, an effort was made to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



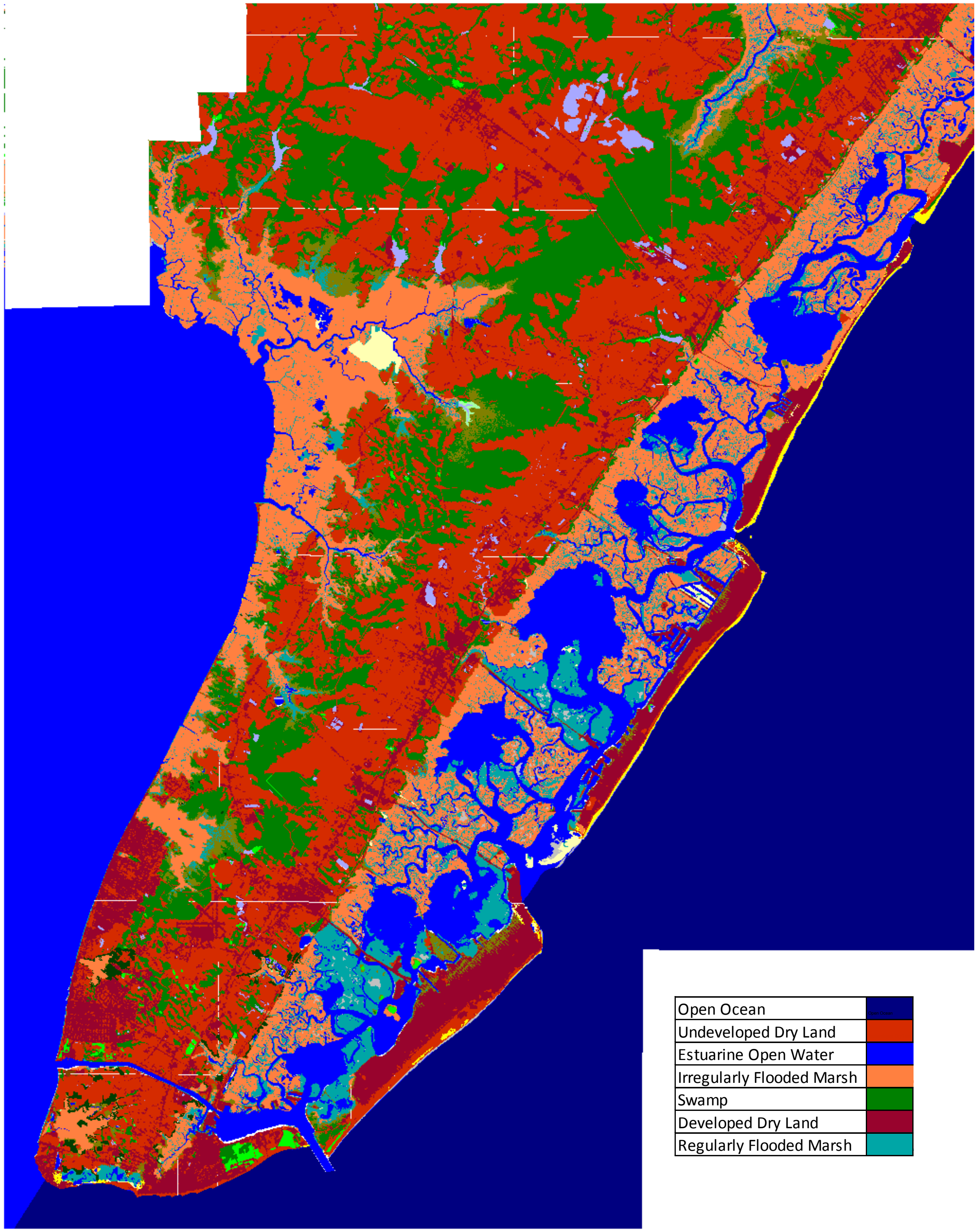
Cape May National Wildlife Refuge within simulation context (white).



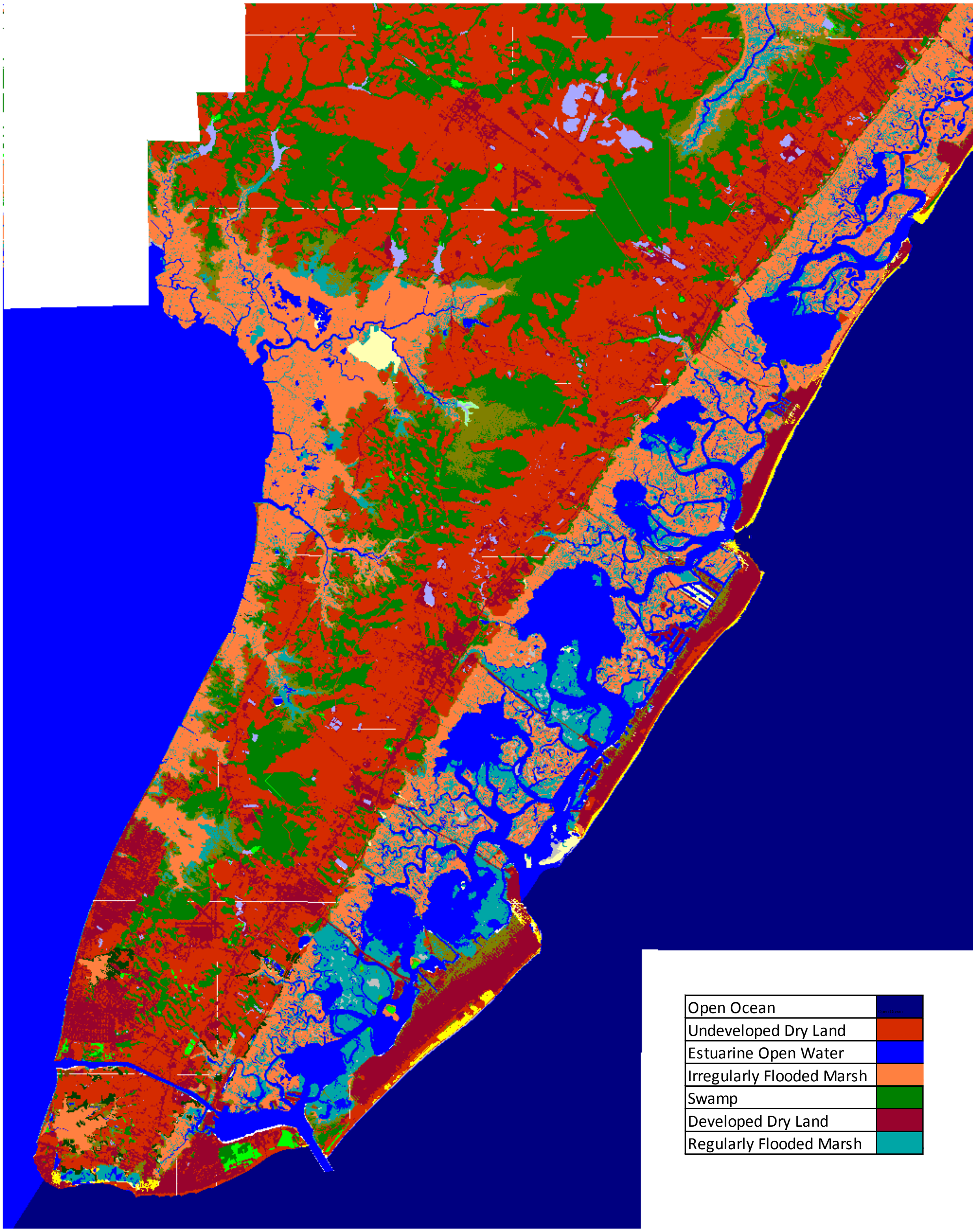
Cape May NWR, Initial Condition



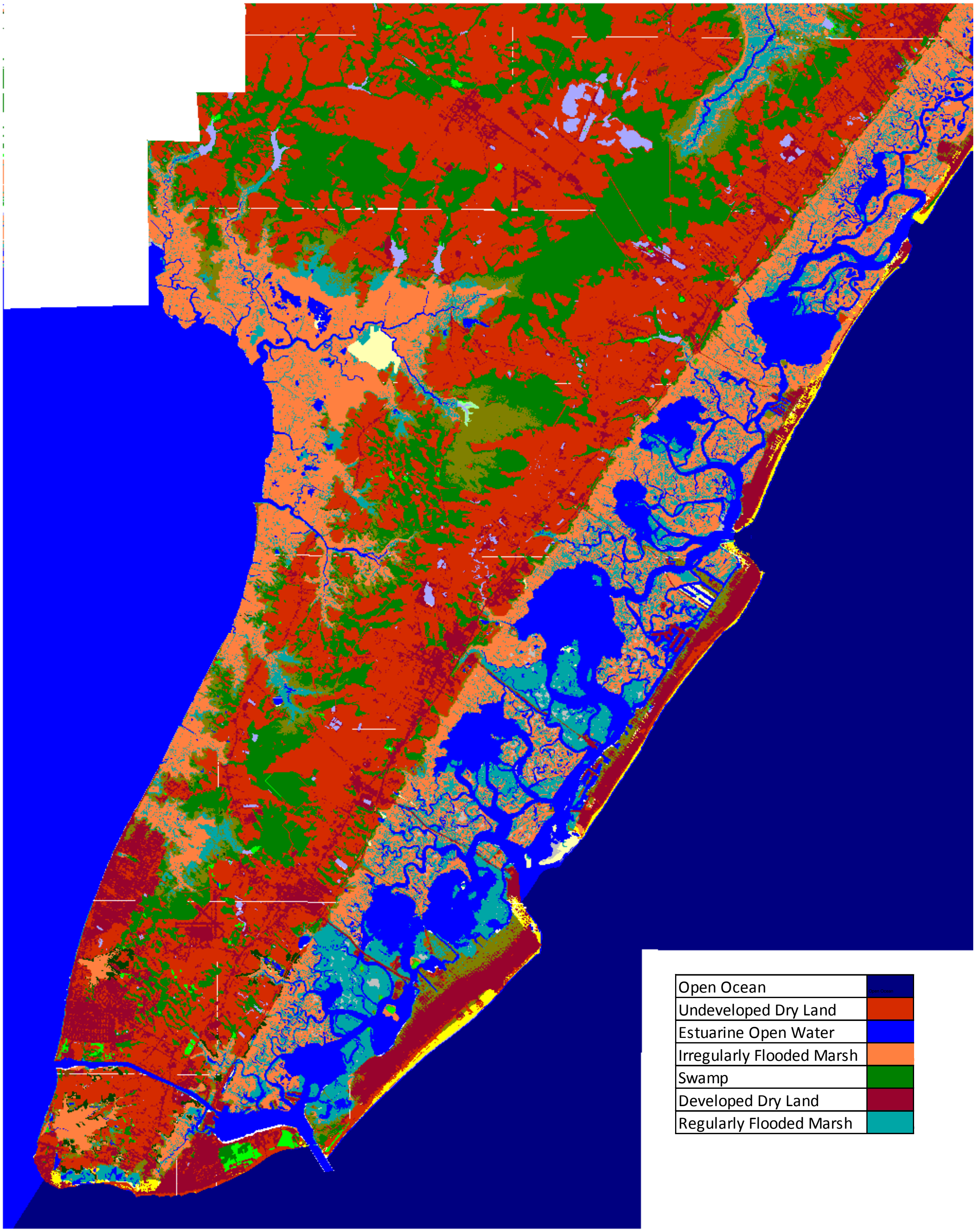
Cape May NWR, 2025, Scenario A1B Mean, 0.39 m SLR



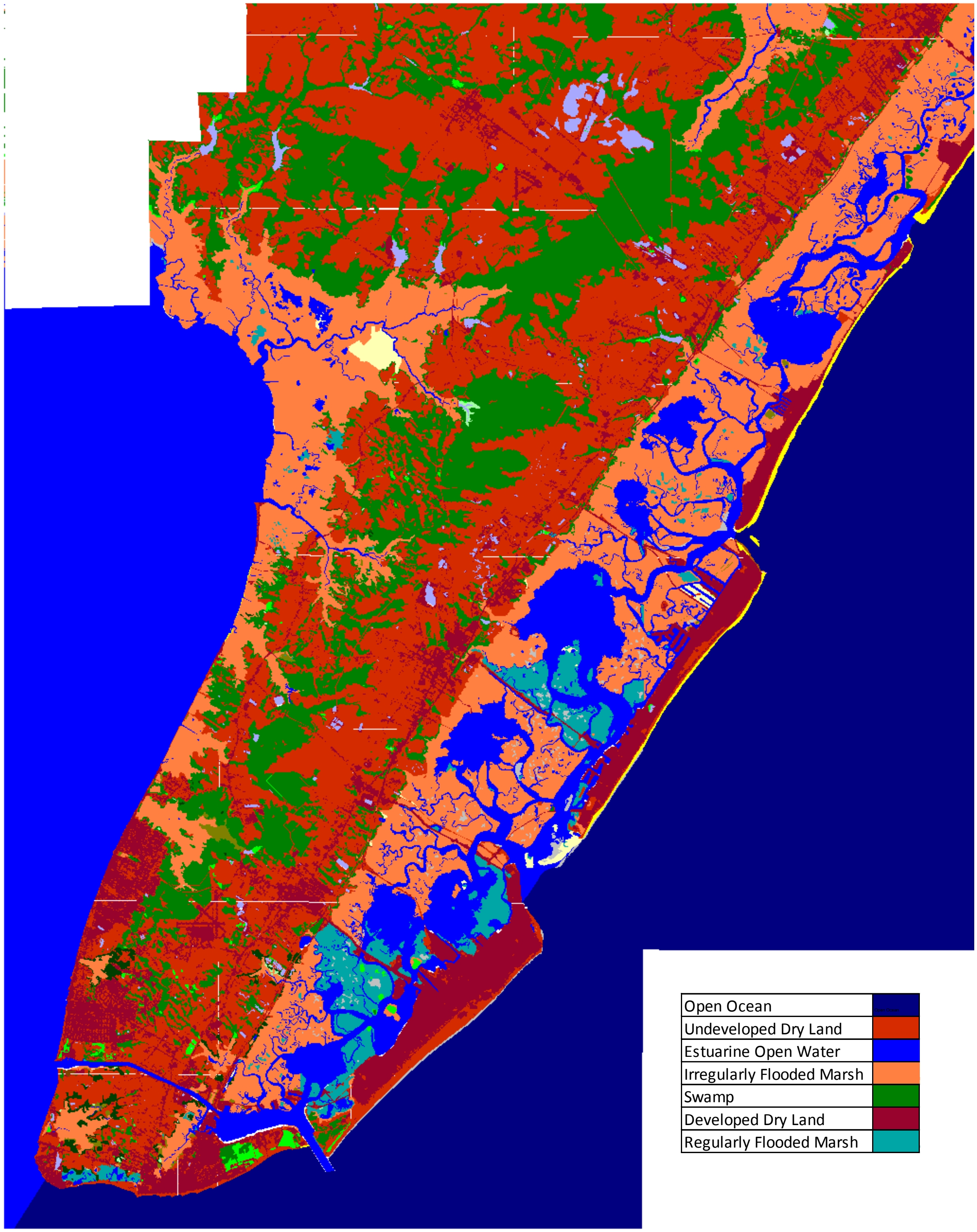
Cape May NWR, 2050, Scenario A1B Mean, 0.39 m SLR



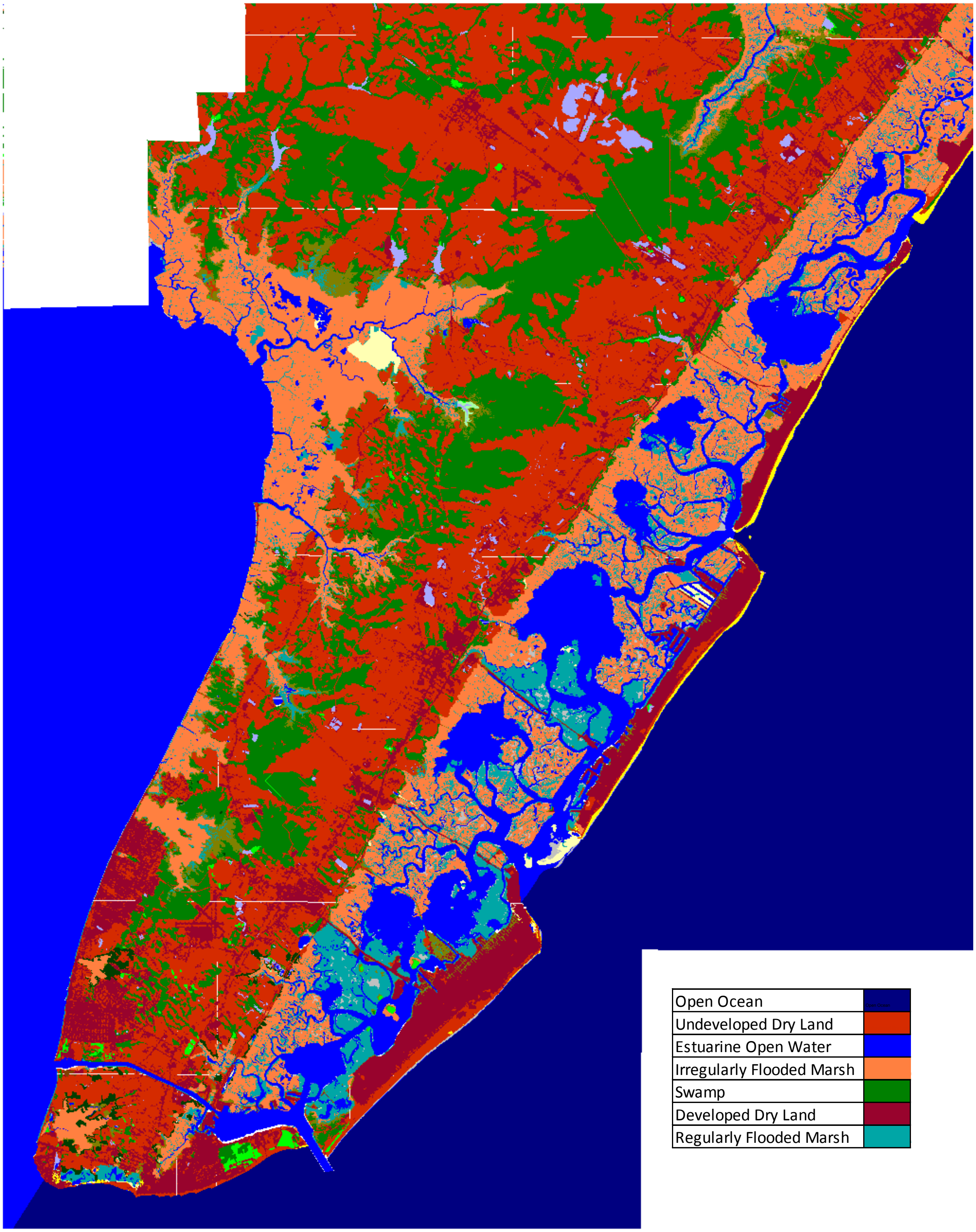
Cape May NWR, 2075, Scenario A1B Mean, 0.39 m SLR



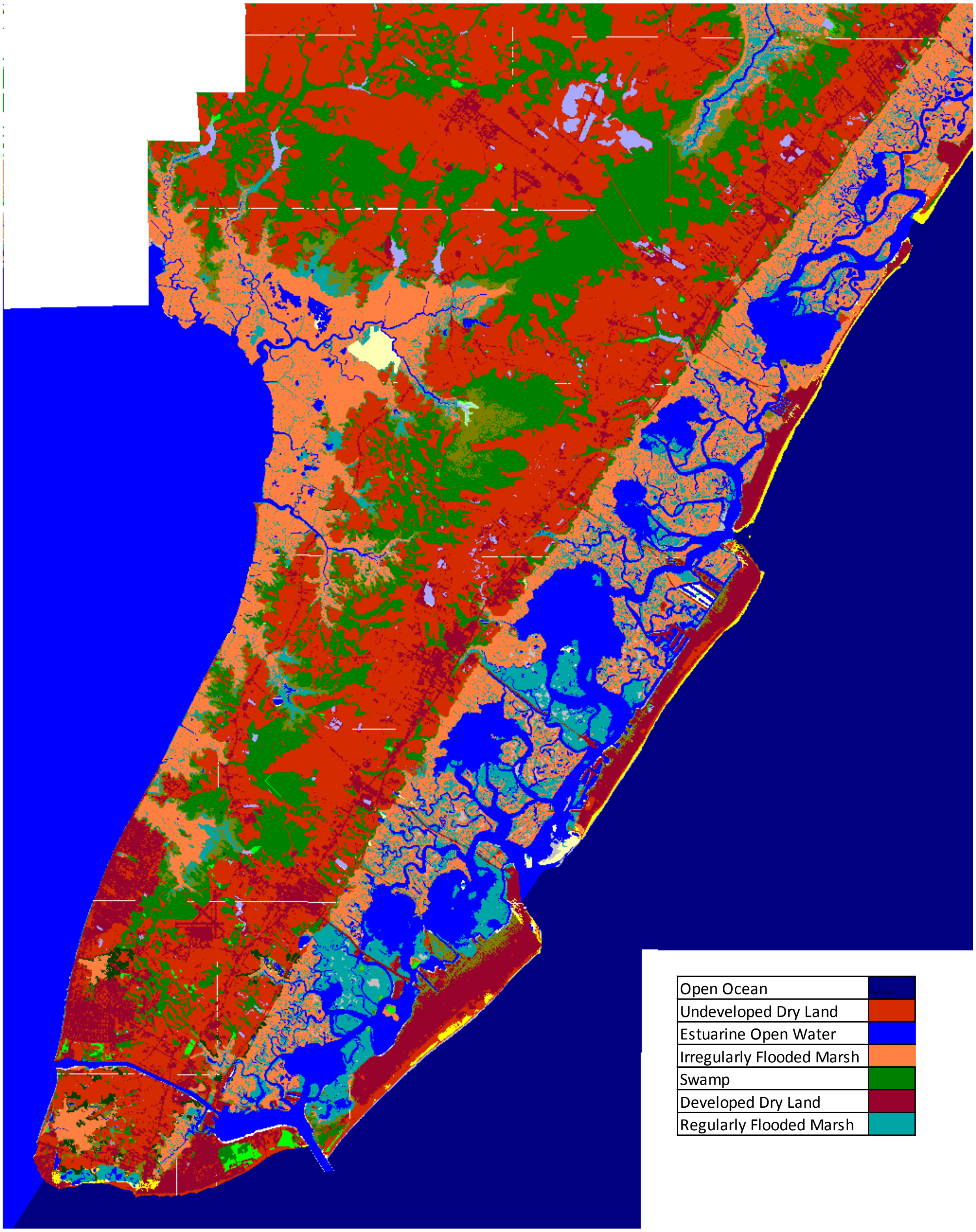
Cape May NWR, 2100, Scenario A1B Mean, 0.39 m SLR



Cape May NWR, Initial Condition



Cape May NWR, 2025, Scenario A1B Maximum, 0.69 m SLR



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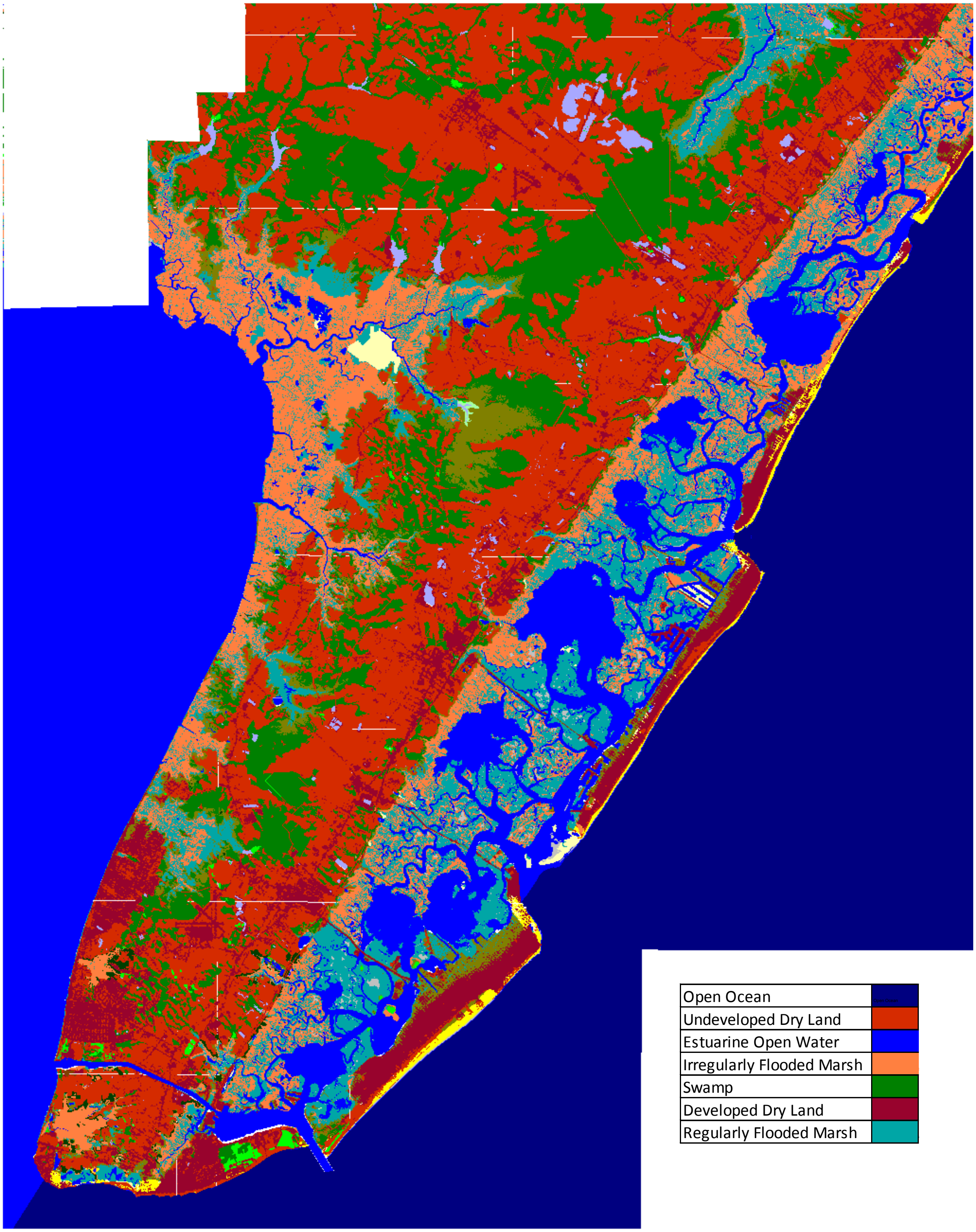

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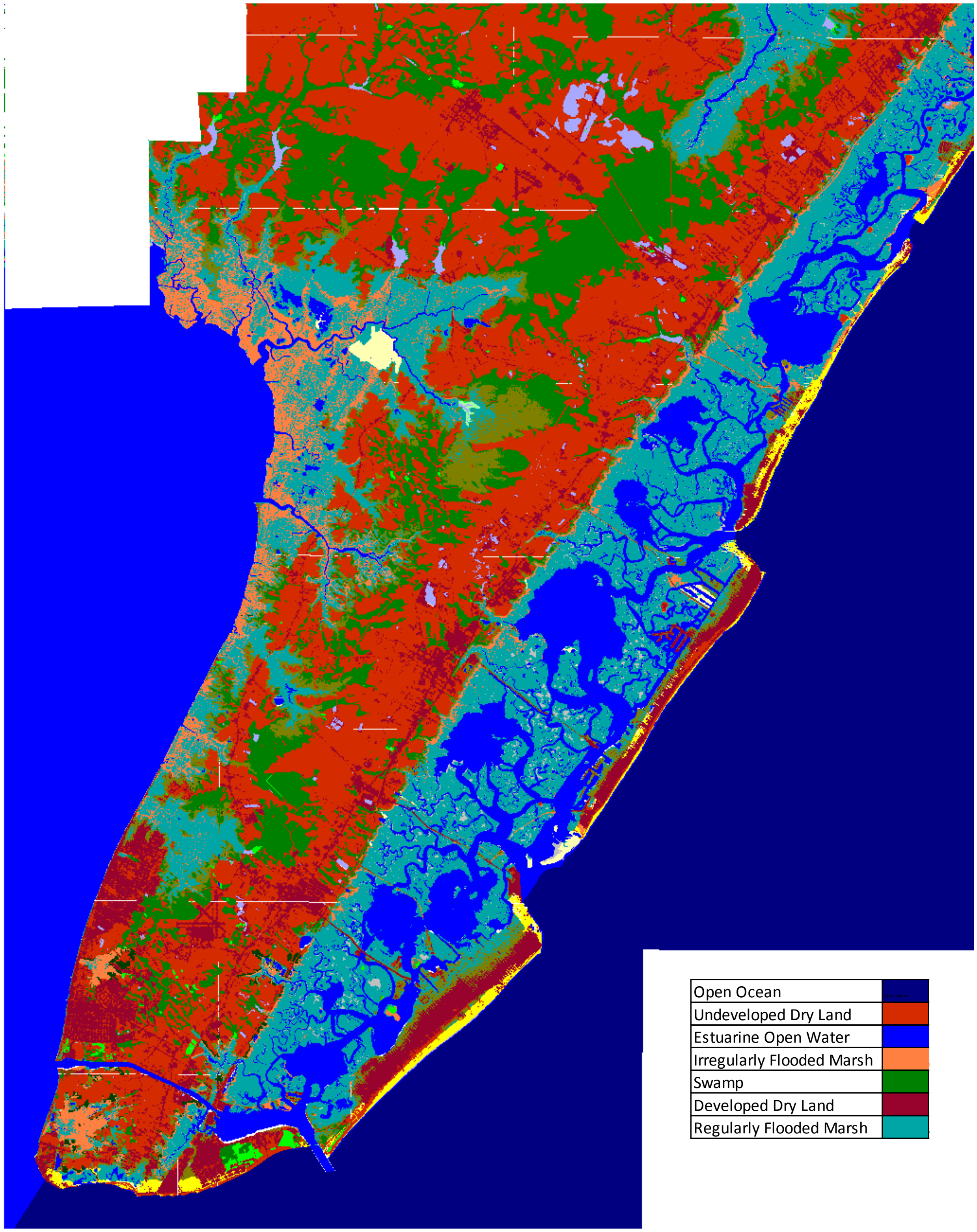
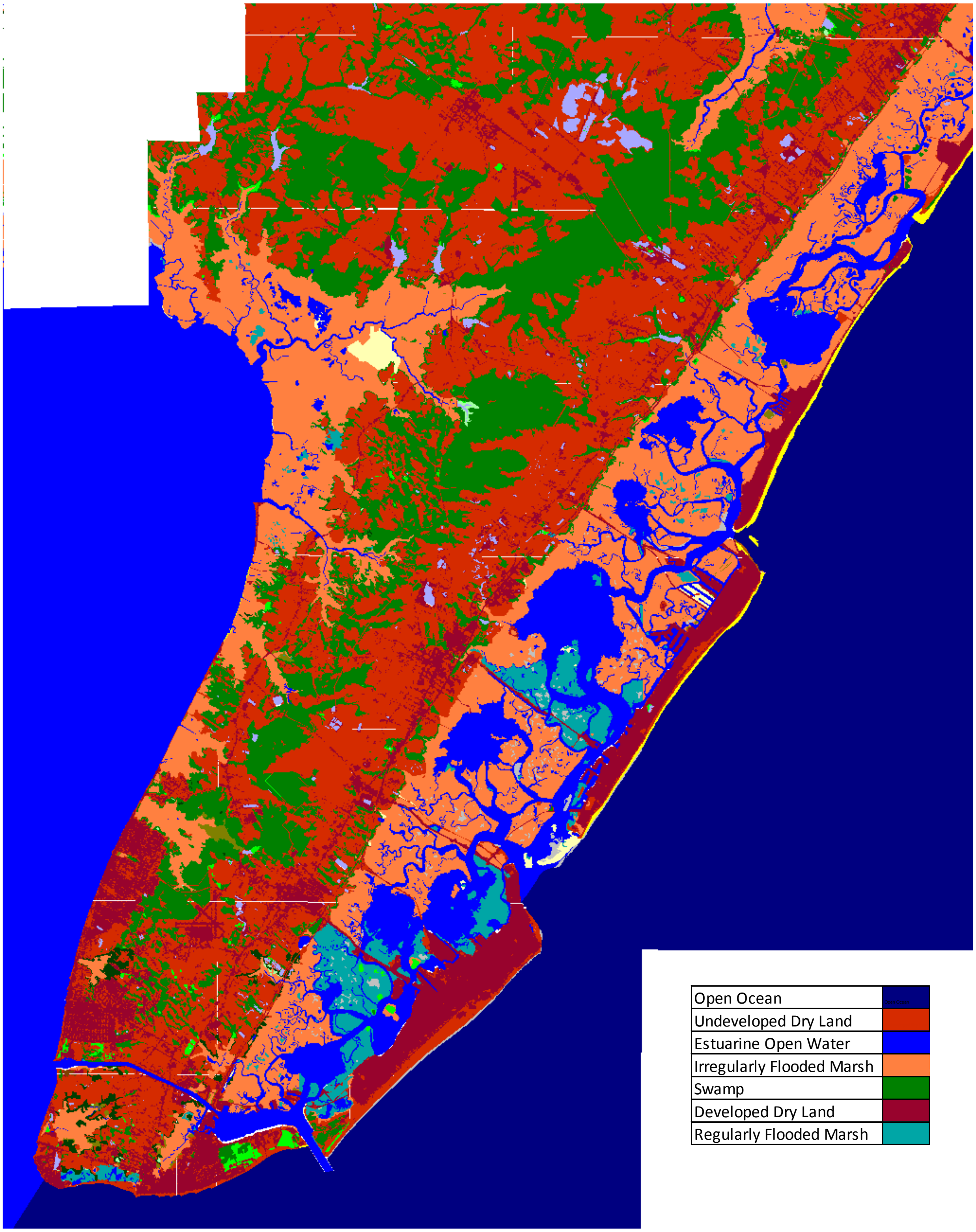
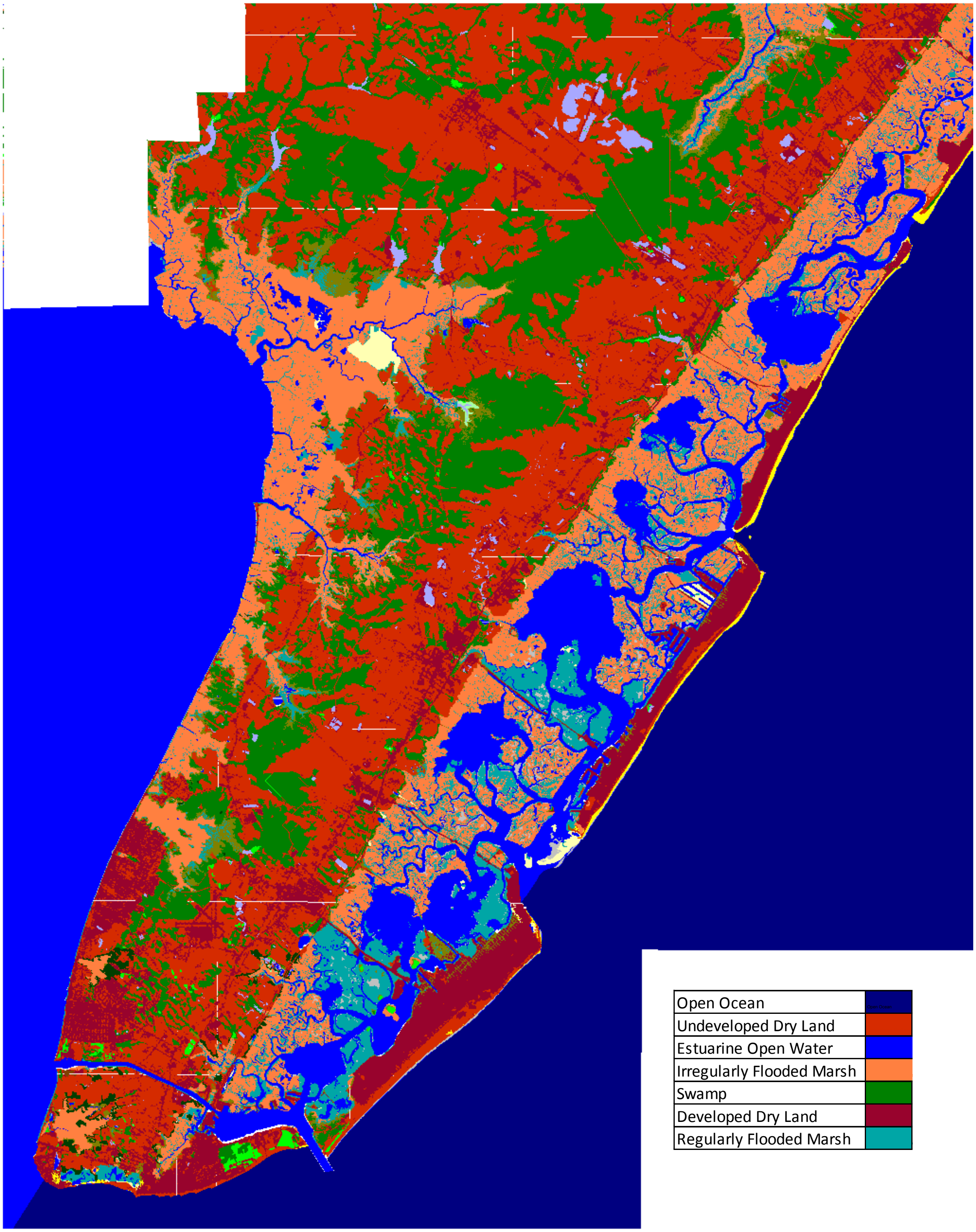


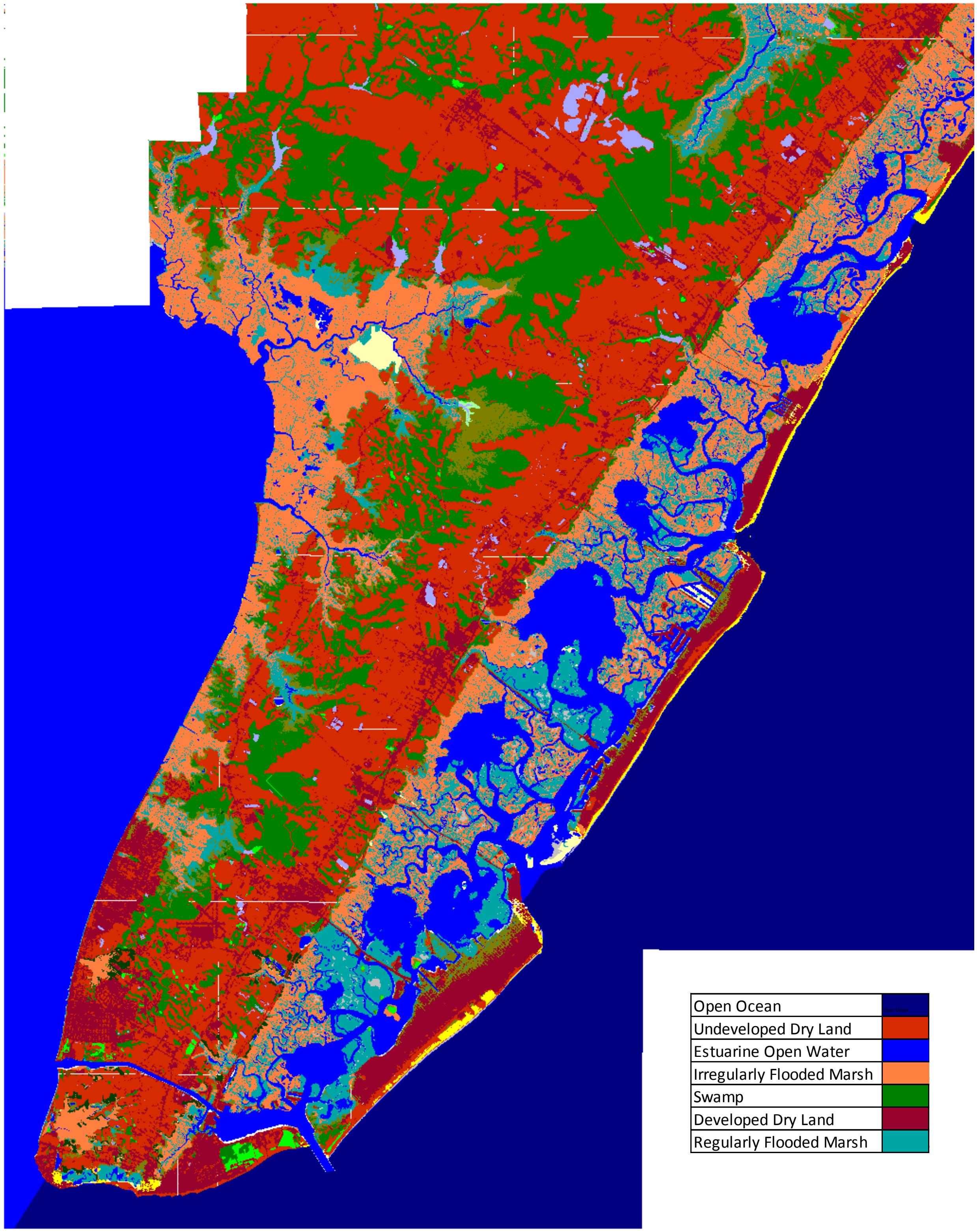
Cape May NWR, 2100, Scenario A1B Maximum, 0.69 m SLR



Cape May NWR, Initial Condition



Cape May NWR, 2025, 1 m SLR



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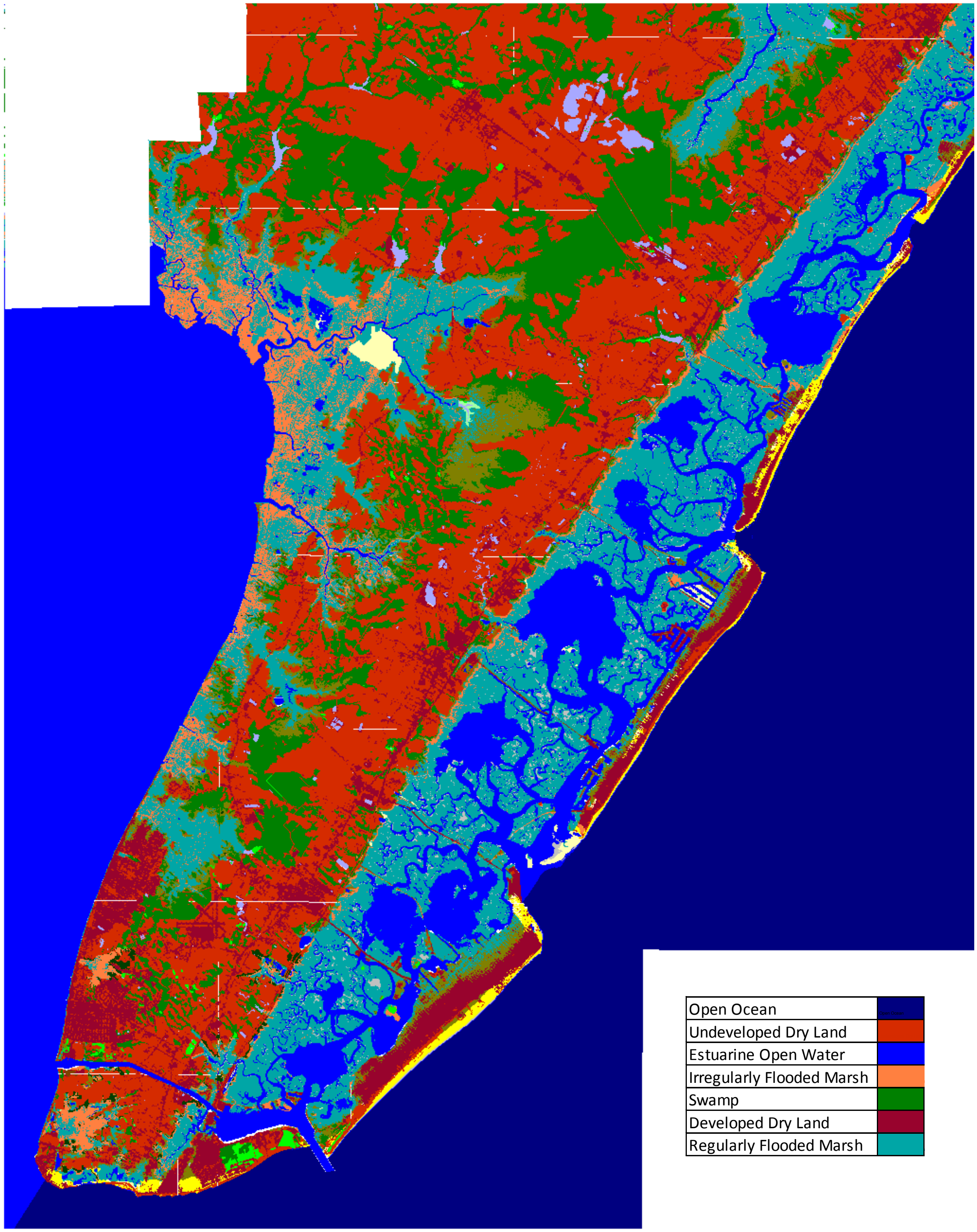

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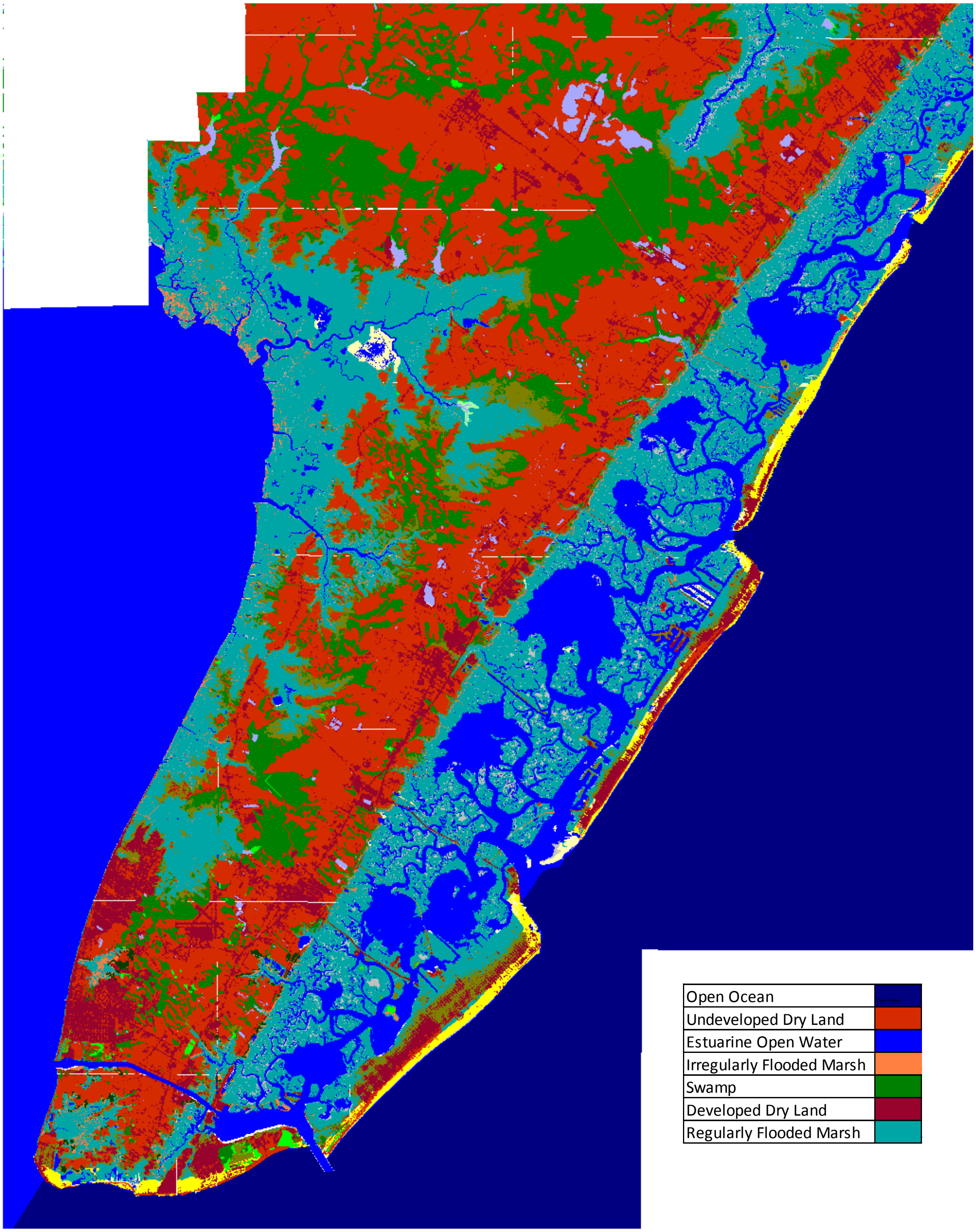

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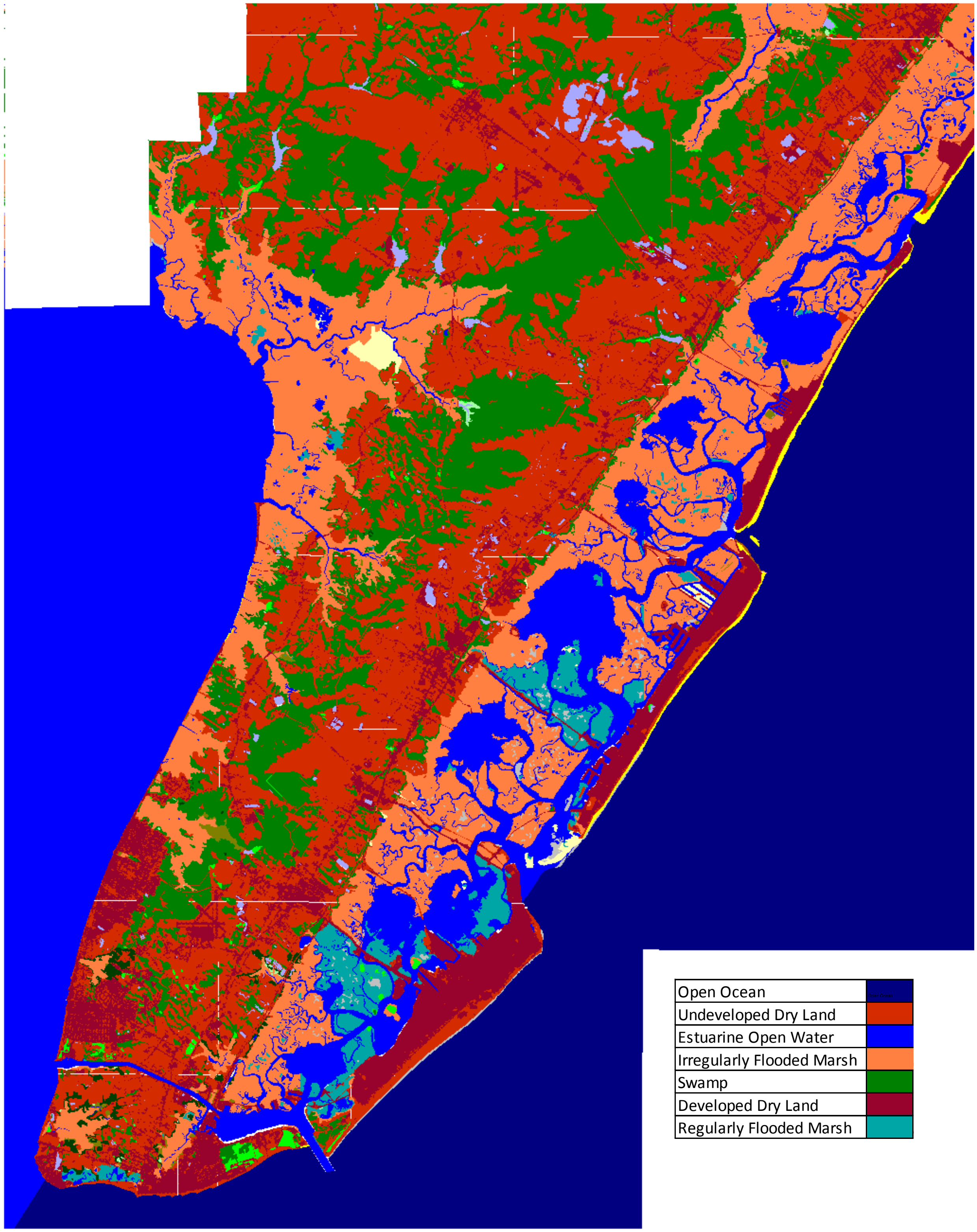

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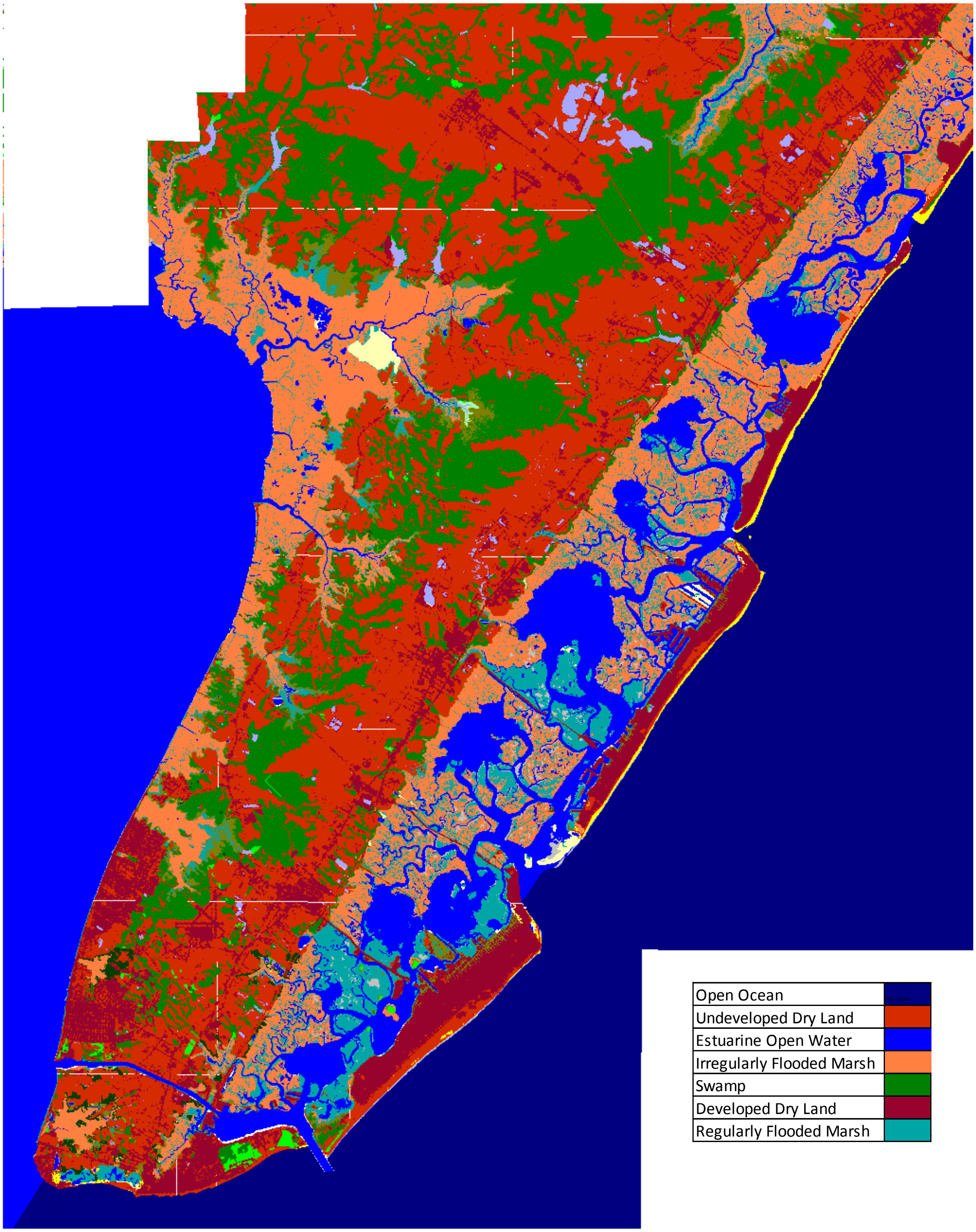

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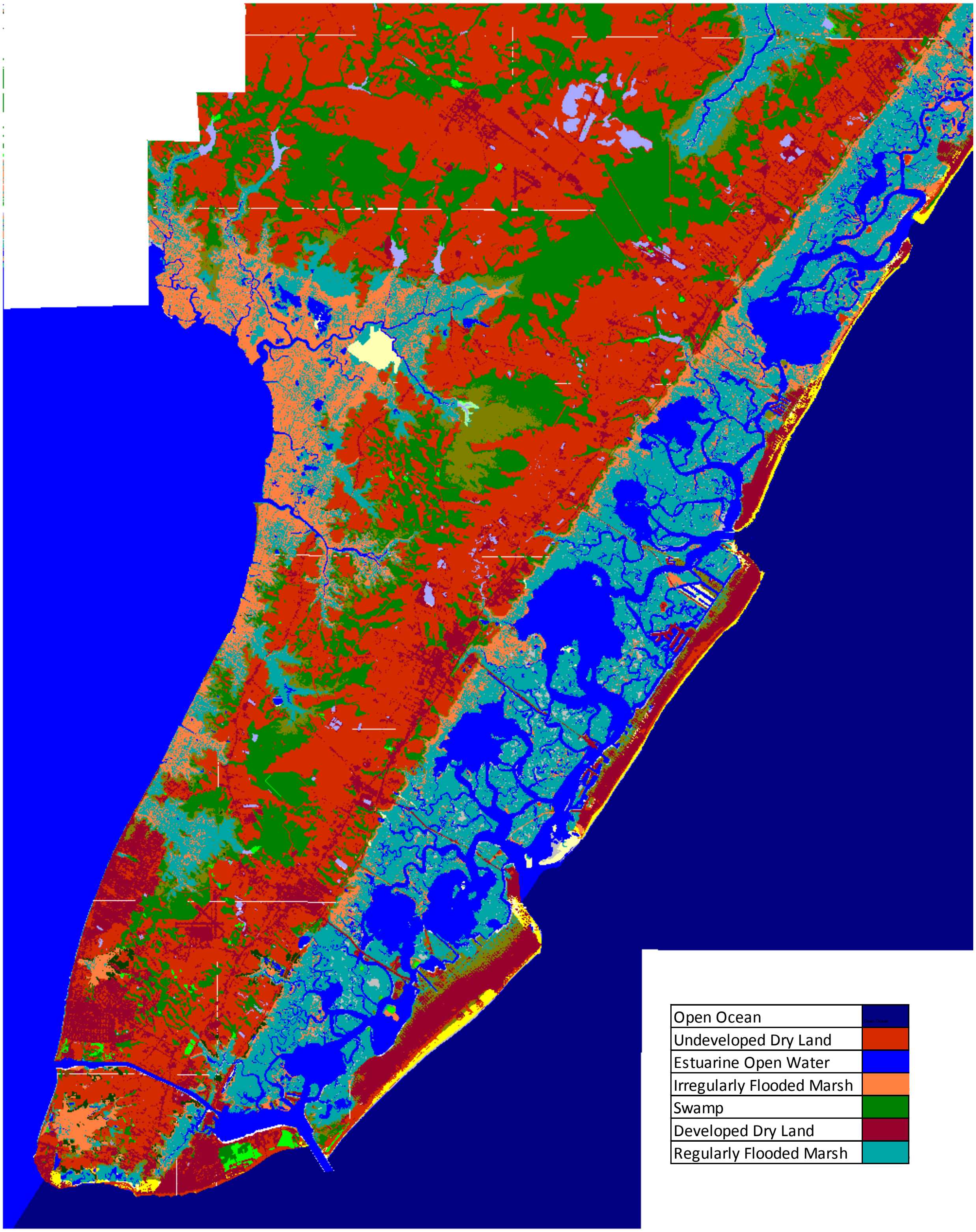
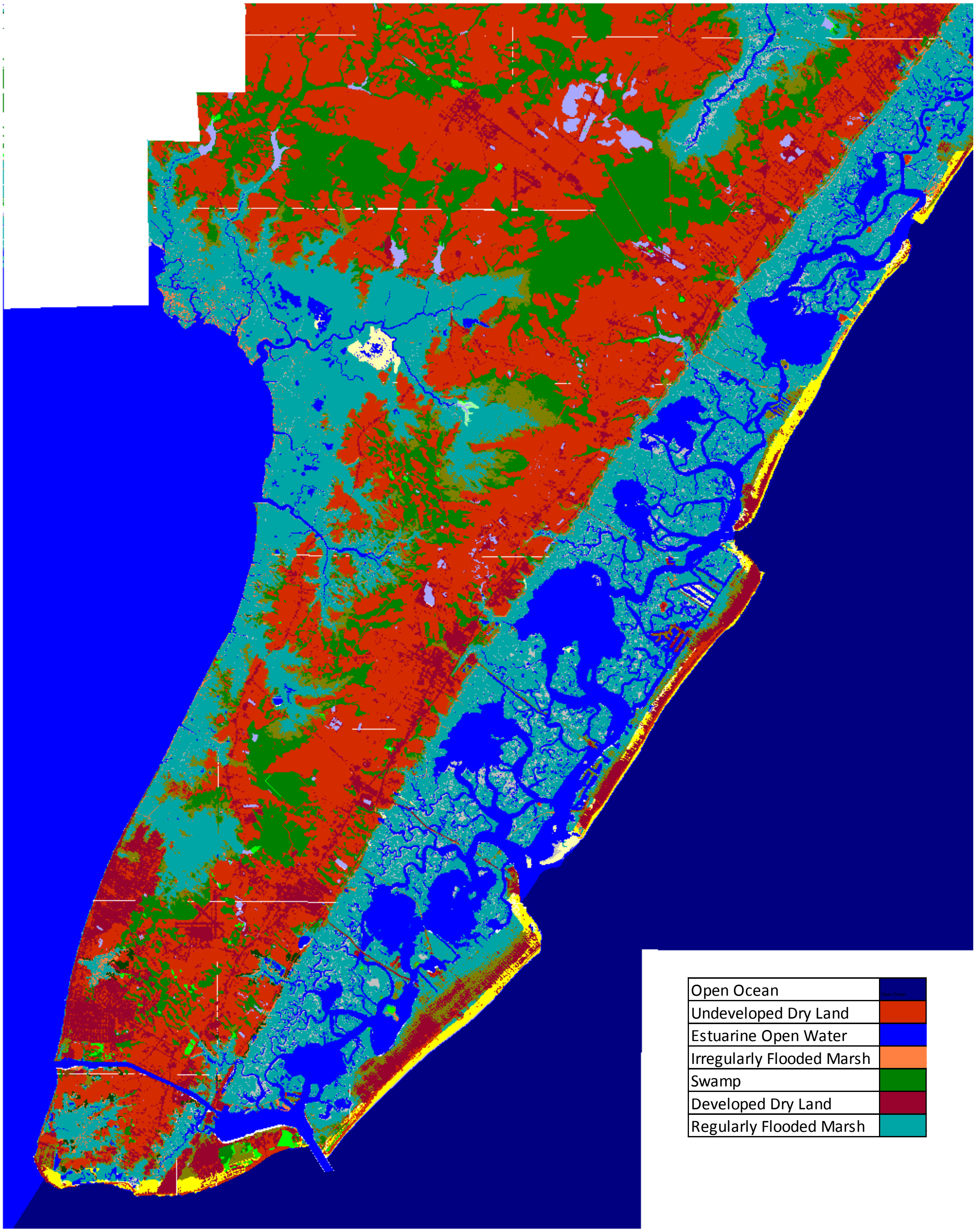
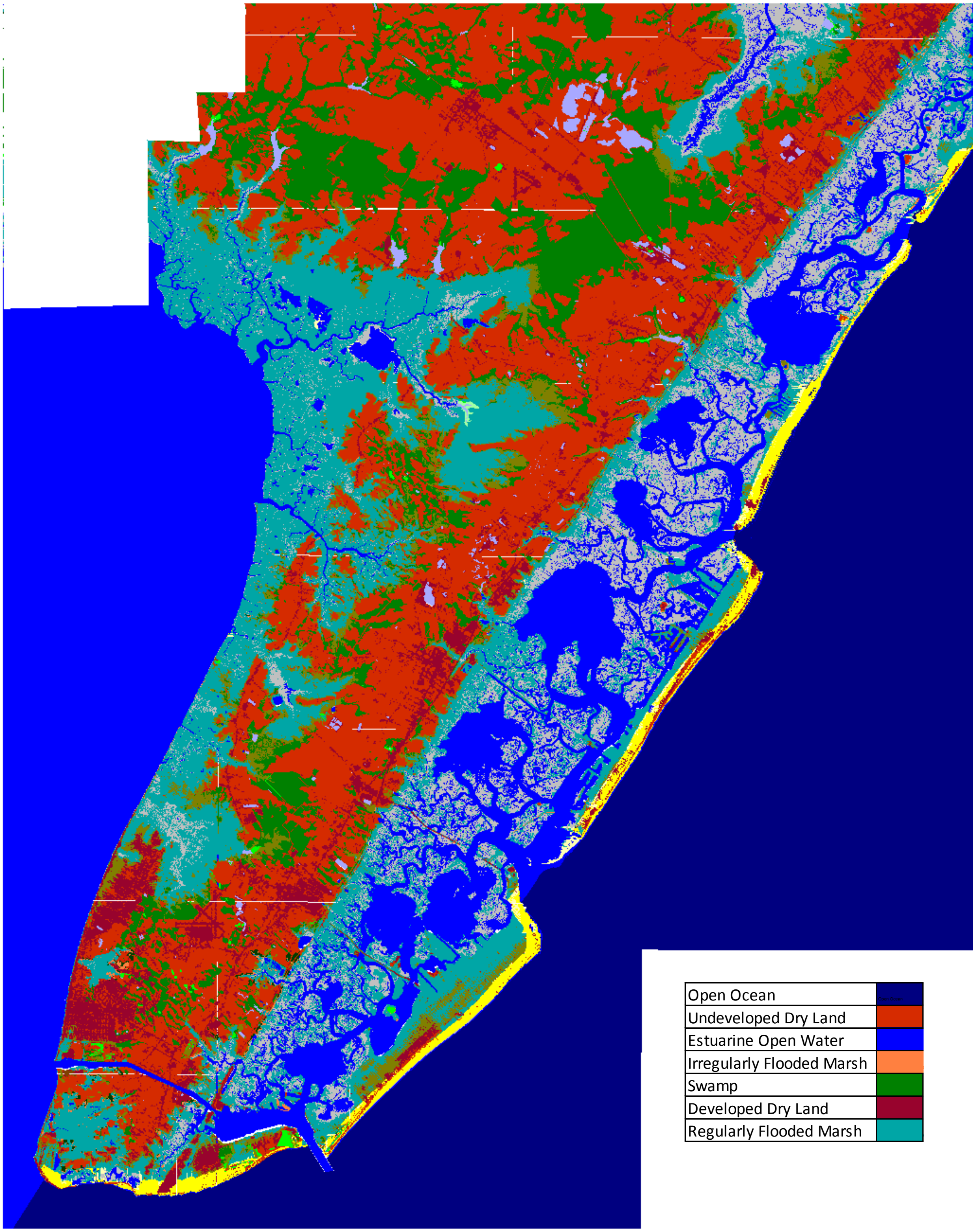


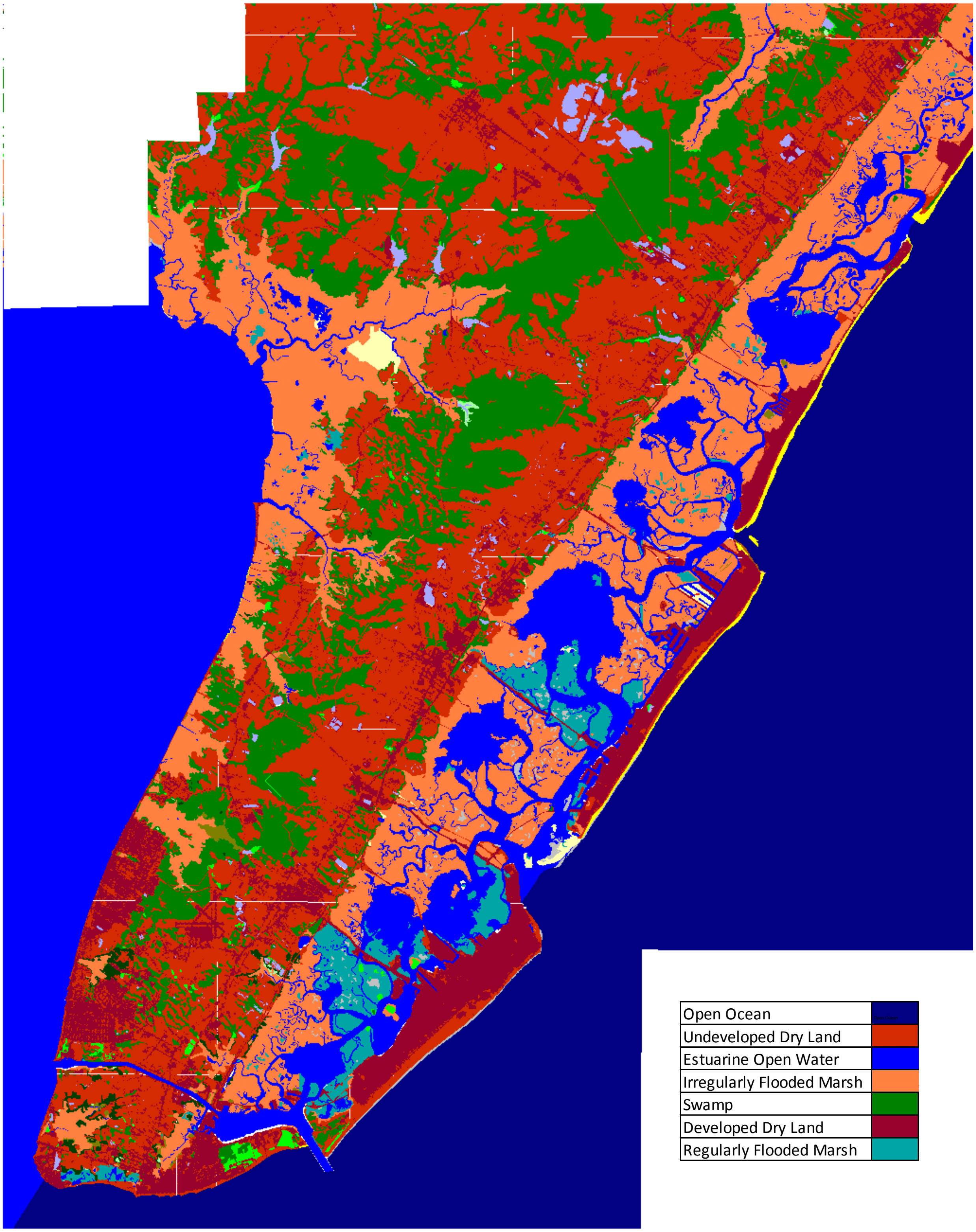
Cape May NWR, 2050, 1.5 m SLR



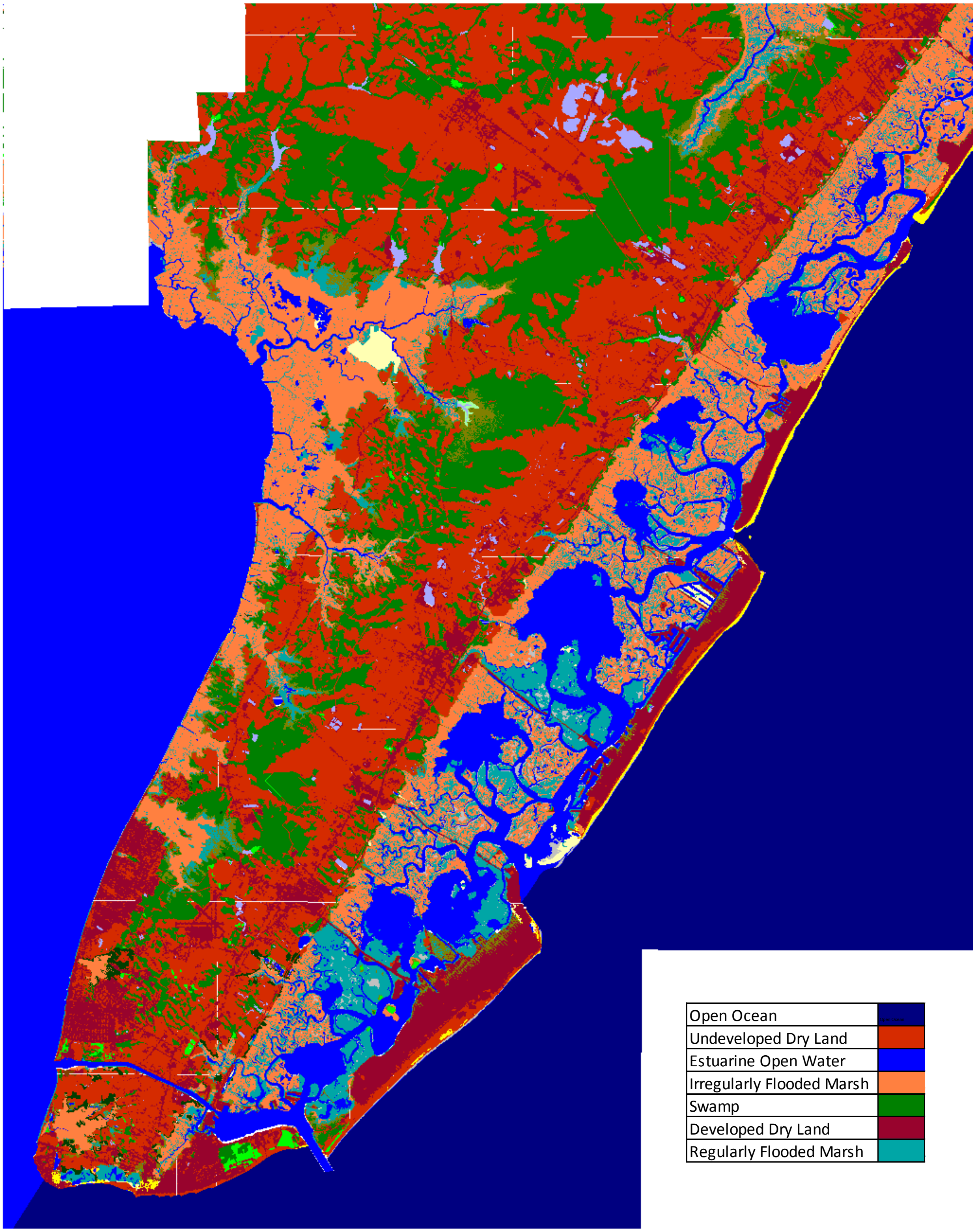
Cape May NWR, 2075, 1.5 m SLR



Cape May NWR, 2100, 1.5 m SLR



Cape May NWR, Initial Condition



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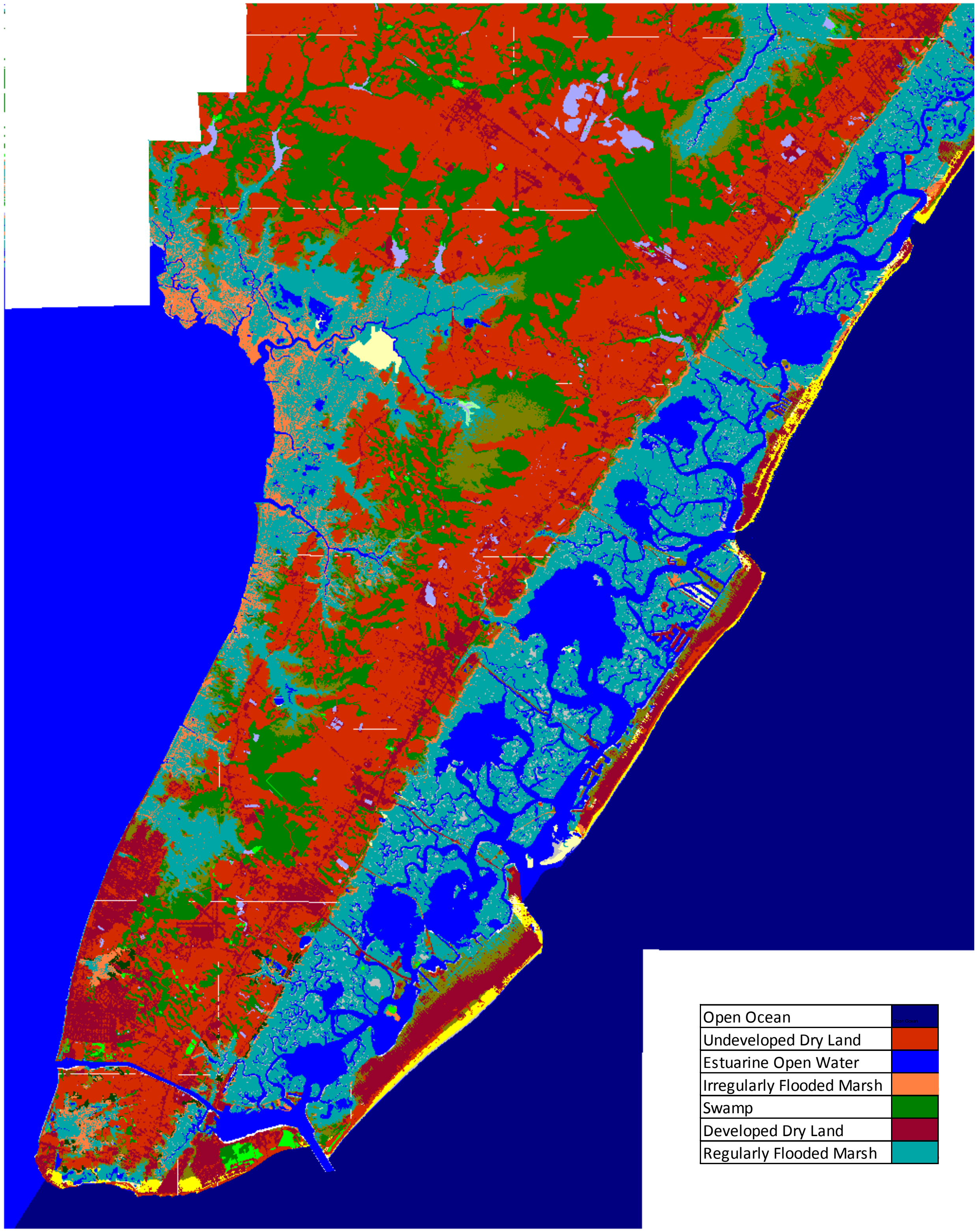
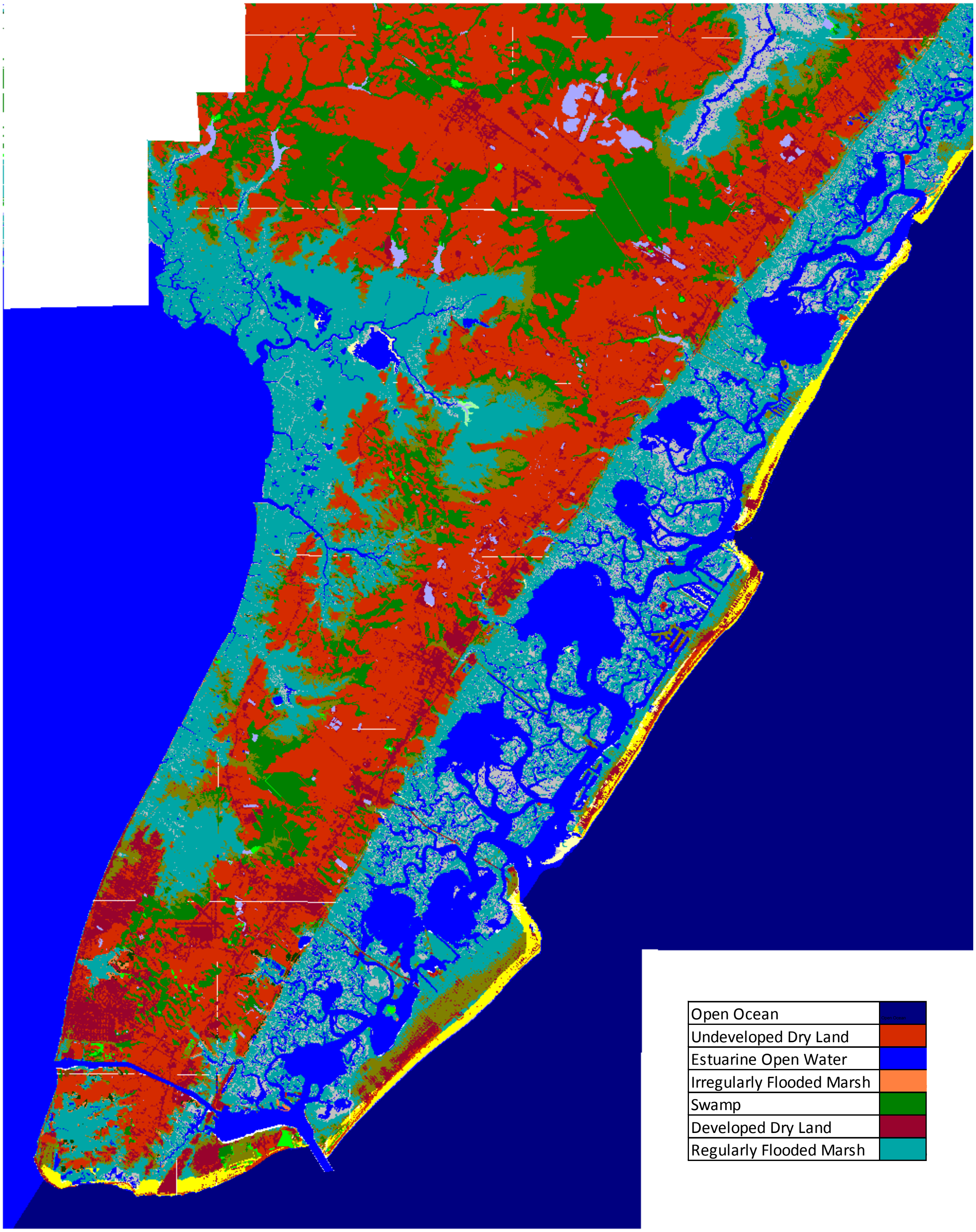
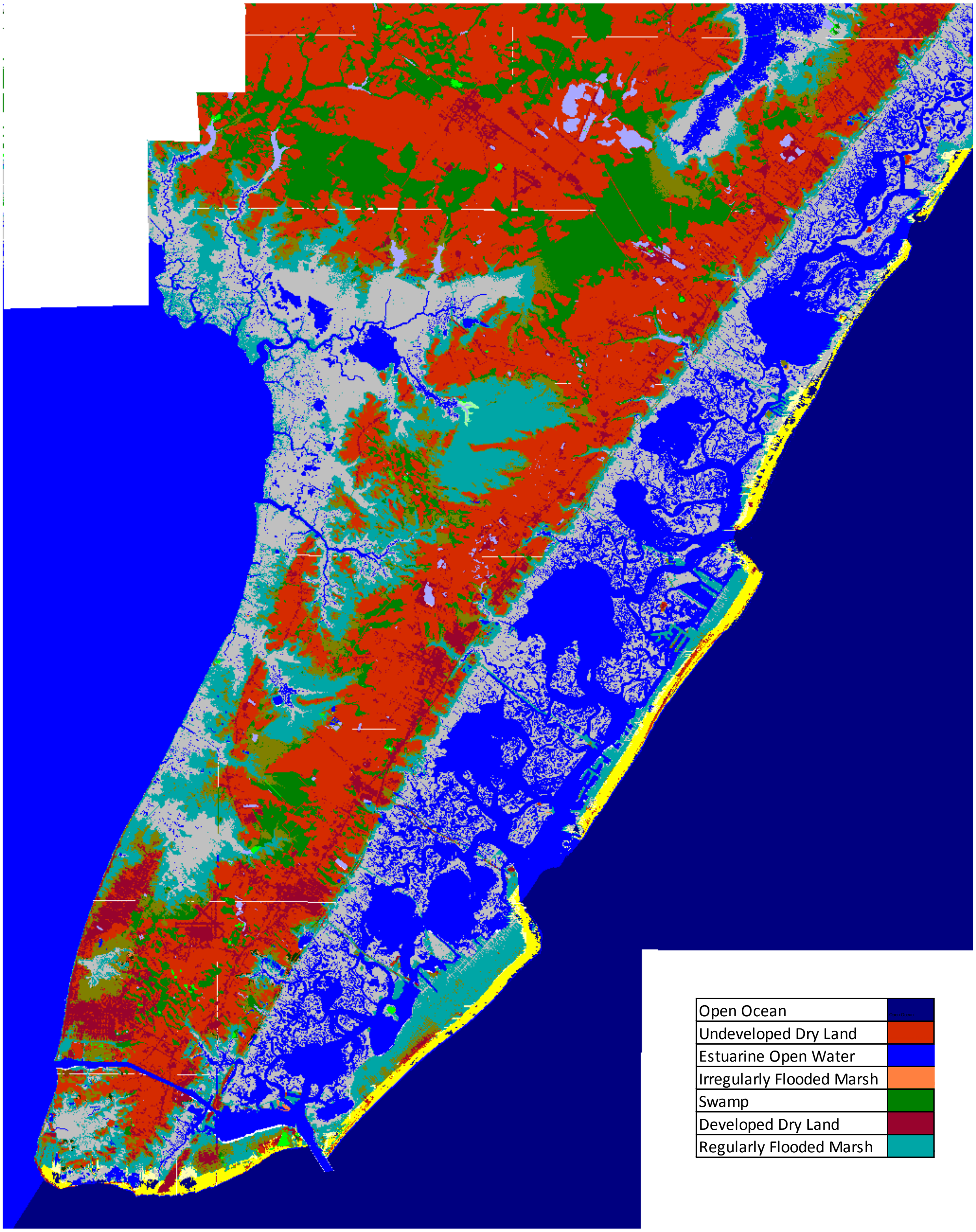


Cape May NWR, 2050, 2 m SLR



Cape May NWR, 2075, 2 m SLR



Cape May NWR, 2100, 2 m SLR