Application of the Sea-Level Affecting Marshes Model (SLAMM 6) to Merritt 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 refugesystem, 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 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.**

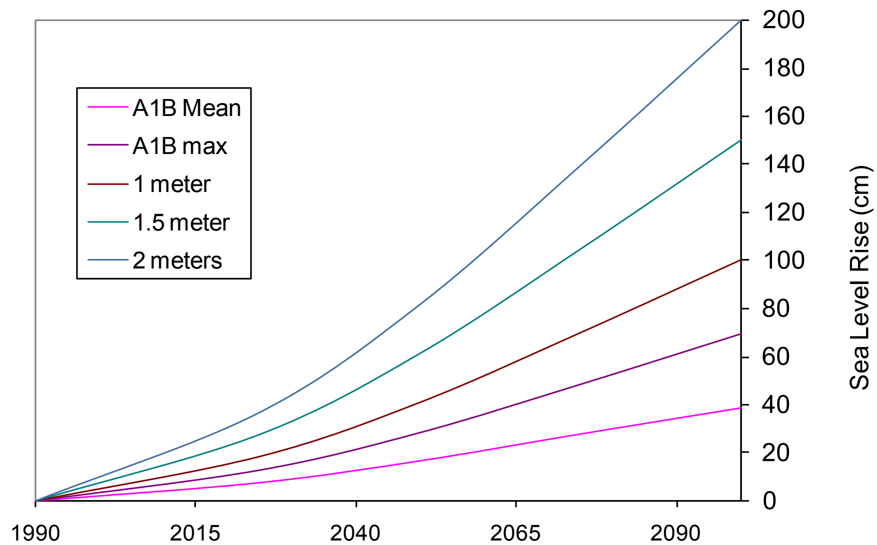


Figure 1. Summary of SLR scenarios utilized

Data Sources and Methods

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 southwestern most part of the study area outside the refuge that is from a 1984 photo. Converting the NWI survey into 10 m x 10 m cells indicated that the approximately 138,000 acre Merritt Island NWR (approved acquisition boundary including water) is composed of the following categories:

Land cover type		Area (acres)	Percentage (%)
	Estuarine Open Water	50132	36
	Undeveloped Dry Land	40577	29
	Inland Fresh Marsh	13299	10
	Swamp	11160	8
	Tidal Fresh Marsh	7323	5
	Inland Open Water	6679	5
	Tidal Swamp	2822	2
	Developed Dry Land	1835	1
	Estuarine Beach	1005	<1
	Irregularly-flooded Marsh	971	<1
	Mangrove	758	<1
	Tidal Flat	594	<1
	Inland Shore	475	<1
	Regularly-flooded Marsh	246	<1
	Ocean Beach	62	<1
	Transitional Salt Marsh	54	<1
	Open Ocean	6	<1
	Total (incl. water)	**137999**	**100**

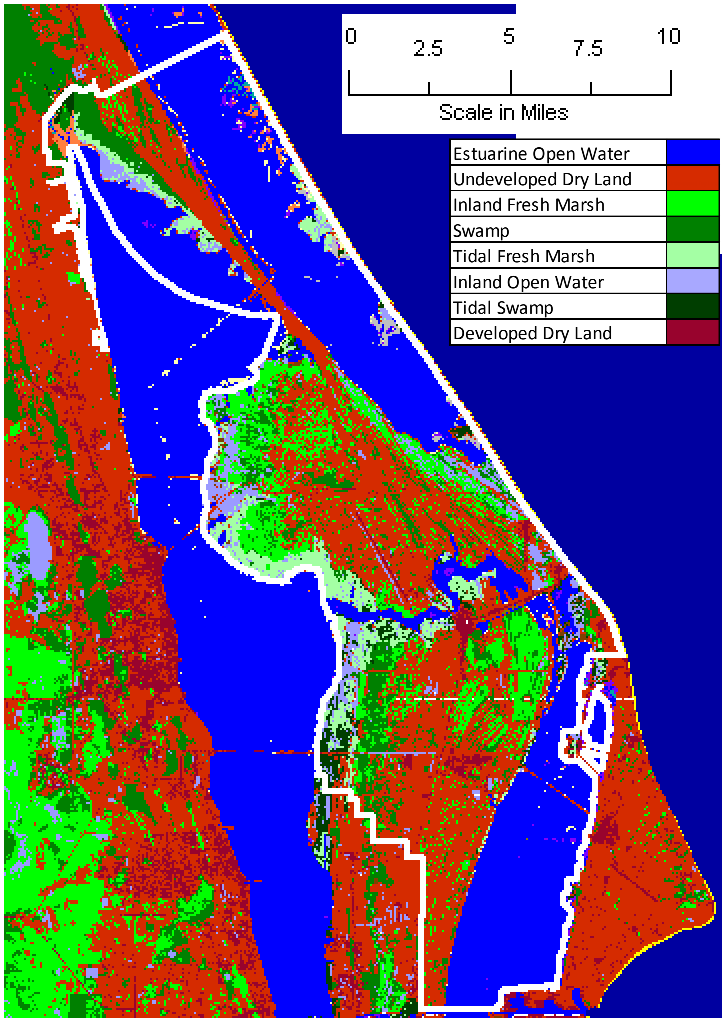


Figure 2. 2009 NWI coverage of the study area. Refuge boundaries are indicated in white.

Elevation Data. The layer covering the study area is a combination of a 2007 bare-earth Florida Division of Emergency Management (FDEM) LiDAR data for Brevard County and a 2006 LiDAR data for Volusa County.

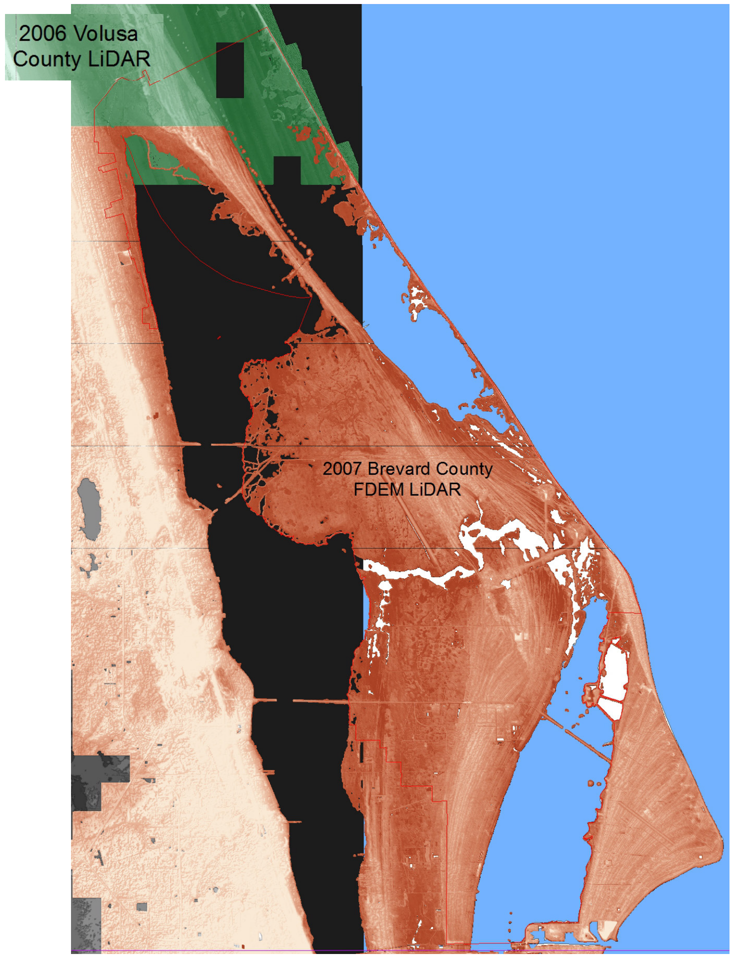


Figure 3. The coverage of the LiDAR data for the entire study area

Dikes and Impoundments. According to the National Wetland Inventory, there are several areas protected by dikes within the refuge. These are shown in yellow 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.

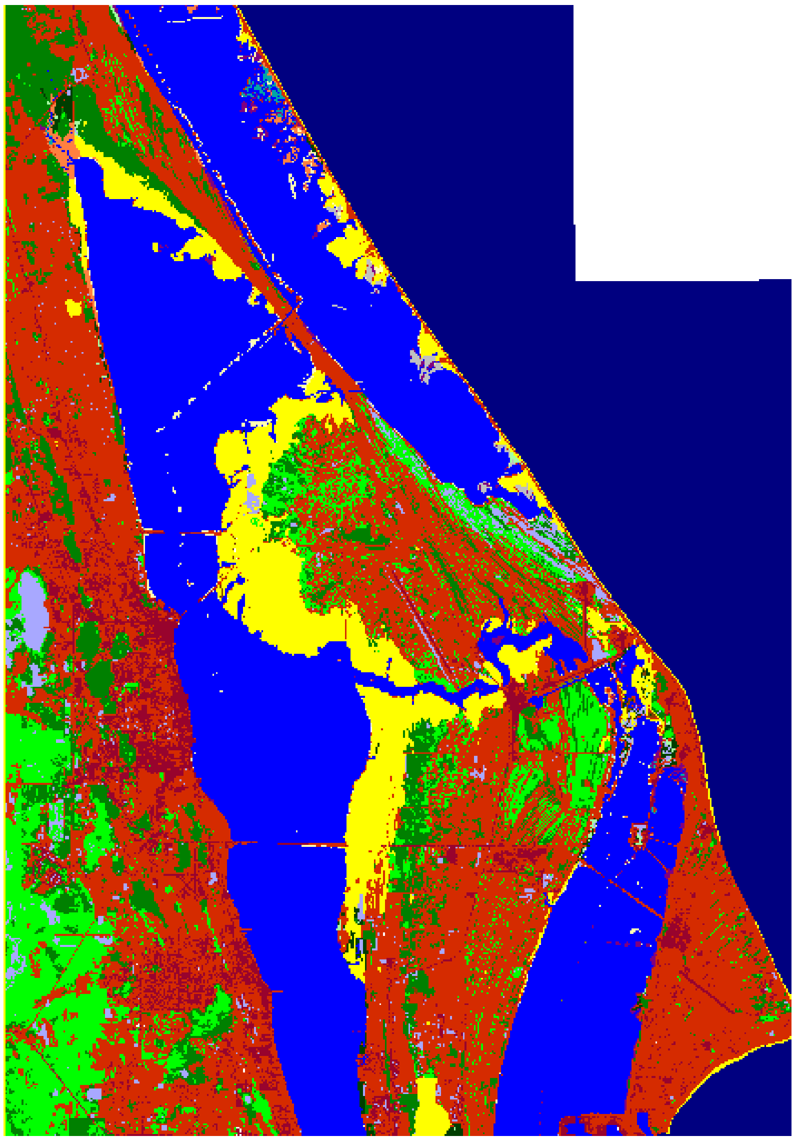


Figure 4. In yellow, areas protected by dikes

Model Timesteps. Model forecast data is output for years 2025, 2050, 2075 and 2100 with the initial condition date set to 2009, 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, Miami Beach (#8723170), Daytona Beach Shores (#8721120) and Mayport (#8720218) vary between 2.32 mm/yr and 2.40 mm/yr. For this simulation study, the average of 2.37 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 area.

Tide Ranges. The great diurnal tide range applied to the open ocean was estimated to be 1.20 m using the average of the NOAA oceanic gages in the region, which are quite similar in magnitude (#8721604, Trident Pier and #8721649, Cocoa Beach Atlantic Ocean). The tide range for the Banana River is much lower and is set at 0.28 m based on the NOAA gages at Turtle Mound, FL (#8721223) and Packwood Place, FL (#88721222). This small tidal range also accounts for tidal fluxes that are driven by wind. In this SLAMM application, different input subsite areas were defined reflecting these varying tidal ranges.

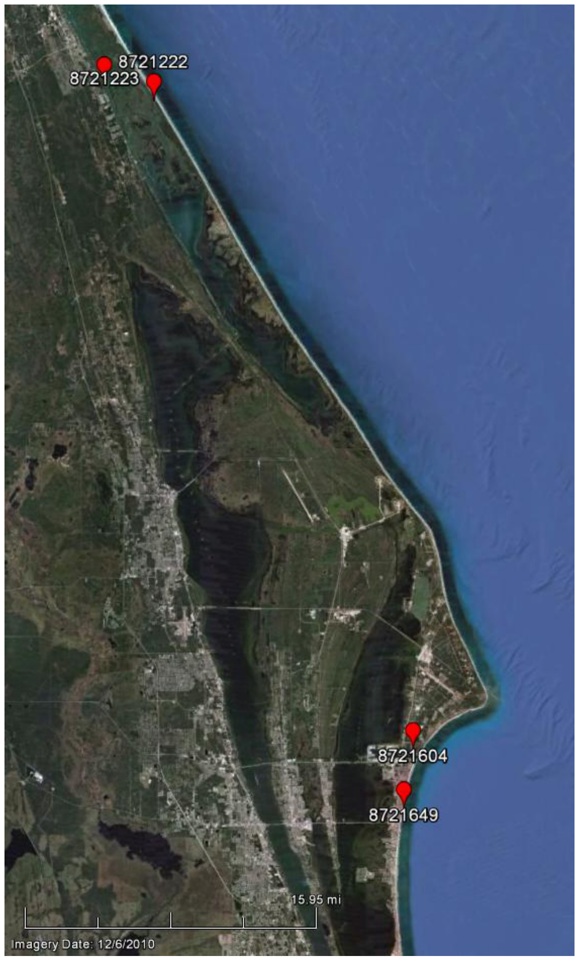


Figure 5. NOAA gauge station locations used for this study.

Table 1: NOAA tide gauge and values

Station ID	Site name	Tide range (m)	Salt elevation (m)
8721222	Packwood Place, FL	0.38	0.57
8721223	Turtle Mound, FL	0.17	0.26
8721604	Trident Pier, FL	1.19	1.79
8721649	Cocoa Beach, Atlantic Ocean, FL	1.21	1.82

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 marshes were set to 3.9 mm/yr, based on measured rates of accretion in Georgia marshes (Craft et al. 2009). This value is also very close to several studies measuring accretion rates on the Gulf Coast of Florida (St. Marks FL, 4.0 mm/yr from Cahoon et al. (1995), and Hendrickson (1997); Ochlockonee River FL, 4.05 mm/yr from Hendrickson (1997). For other marshes, the accretion values were set to the SLAMM defaults, as shown in Table 2.

Erosion rates. Erosion rates for marshes, swamps, and tidal flats were set to the SLAMM defaults of 1.8 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 from several NOAA gauge stations in the area that have this datum. The corrections vary between -0.30 m in the south part of the study area to -0.13 cm in the northern portion.

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 was 10 m.

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

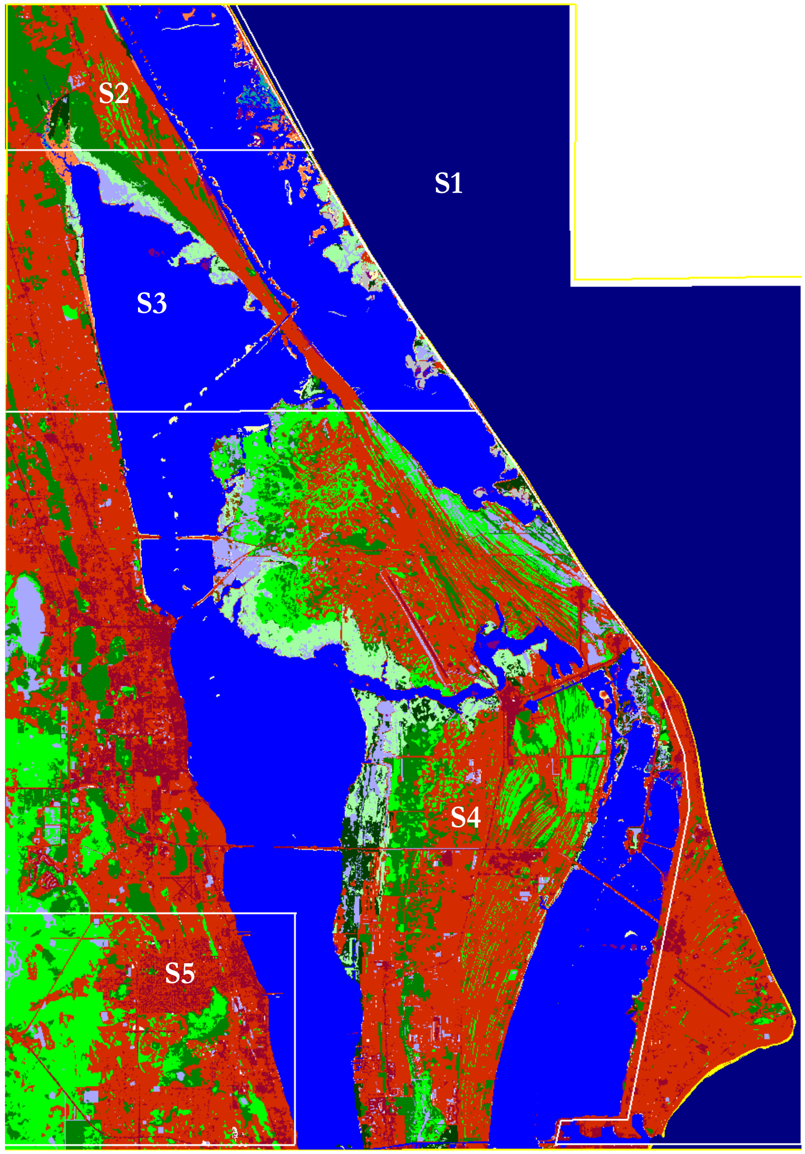


Figure 6. Input subsites for model application

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

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

Parameter	S1	S2	S3	S4	S5
NWI Photo Date (YYYY)	2009	2009	2009	2009	1984
DEM Date (YYYY)	2007	2006	2007	2007	2007
Direction Offshore [n,s,e,w]	East	East	East	East	East
Historic Trend (mm/yr)	2.37	2.37	2.37	2.37	2.37
MTL-NAVD88 (m)	-0.29	-0.13	-0.17	-0.21	-0.21
GT Great Diurnal Tide Range (m)	1.2	0.28	0.28	0.28	0.28
Salt Elev. (m above MTL)	0.9	0.21	0.21	0.21	0.21
Marsh Erosion (horz. m /yr)	1.8	1.8	1.8	1.8	1.8
Swamp Erosion (horz. m /yr)	1	1	1	1	1
T.Flat Erosion (horz. m /yr)	0.5	0.5	0.5	0.5	0.5
Reg.-Flood Marsh Accr (mm/yr)	3.9	3.9	3.9	3.9	3.9
Irreg.-Flood Marsh Accr (mm/yr)	4.7	4.7	4.7	4.7	4.7
Tidal-Fresh Marsh Accr (mm/yr)	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
Mangrove Accr (mm/yr)	7	7	7	7	7
Tidal Swamp Accr (mm/yr)	1.1	1.1	1.1	1.1	1.1
Swamp Accretion (mm/yr)	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
Freq. Overwash (years)	25	25	25	25	25
Use Elev Pre-processor [True,False]	FALSE	FALSE	FALSE	FALSE	FALSE

Results

The initial land cover in acres and percentage losses by 2100 of each wetland type for different SLR scenario are presented in Table 3. Land-cover losses are calculated in comparison to the initial 2009 NWI wetland coverage.

Table 3. Predicted loss rates of land categories by 2100 given simulated scenarios of eustatic SLR at Merritt 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	40577	11%	26%	41%	60%	74%
Inland Fresh Marsh	13299	-16%([1])	-6%	24%	42%	57%
Swamp	11160	4%	46%	65%	78%	88%
Tidal Fresh Marsh	7323	0%	0%	2%	3%	3%
Tidal Swamp	2822	9%	18%	20%	21%	21%
Developed Dry Land	1835	0%	1%	3%	12%	36%
Estuarine Beach	1005	47%	48%	47%	50%	52%
Irregularly-flooded Marsh	971	-14%	34%	82%	90%	92%
Mangrove	758	13%	17%	39%	72%	83%

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

Merritt Island National Wildlife Refuge is predicted to experience some effects from sea level rise even under the 0.39 and 0.69 m SLR by 2100 scenarios. For the A1B mean scenario (0.39 m by 2100), effects on the wetland coverage are generally limited; However, habitat loss is predicted to gradually increase as the rate of sea level increases.

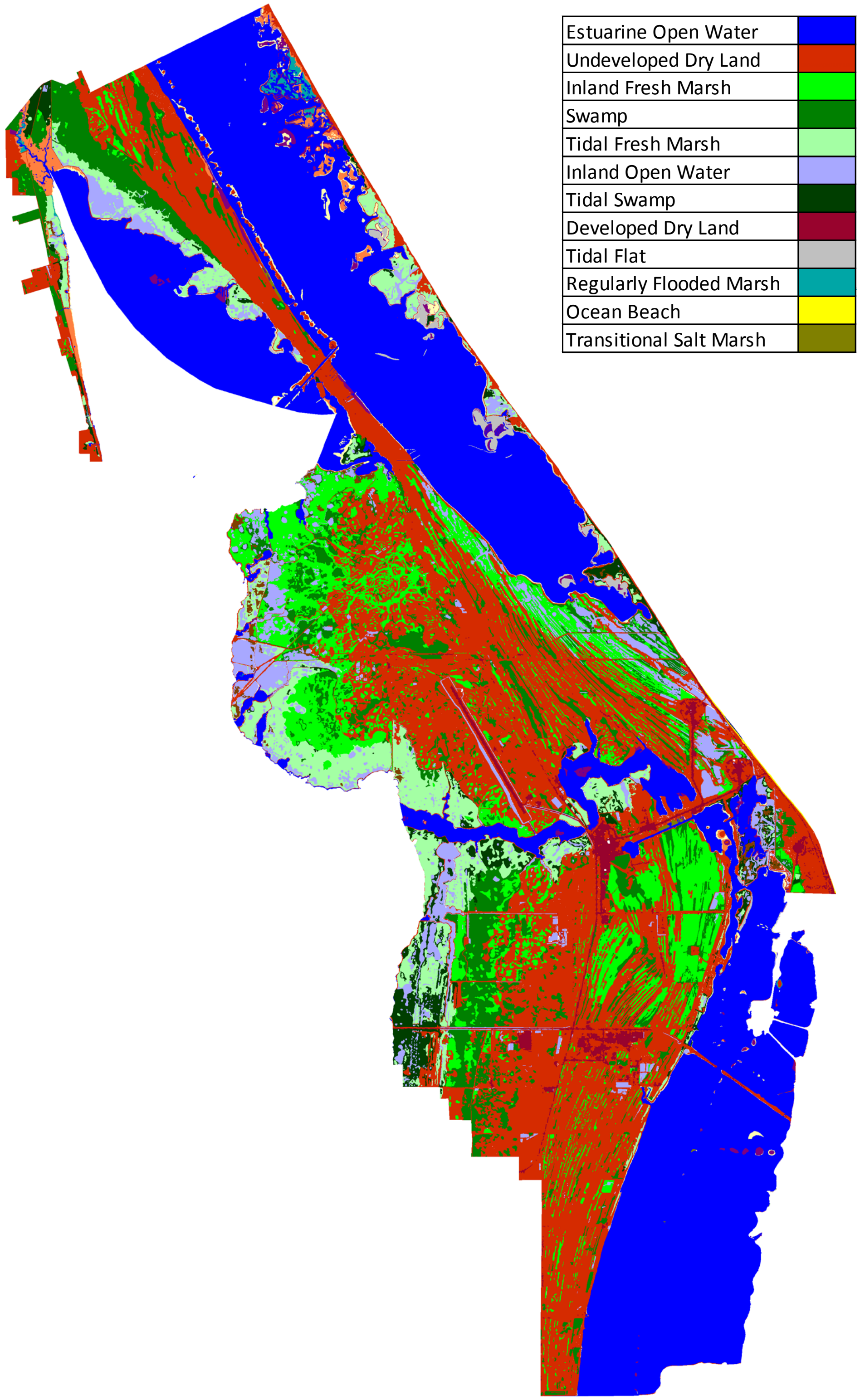
Almost all wetland types present today are projected to gradually experience losses as a result of SLR. Undeveloped-dry land is predicted to have losses from 11% for the most conservative SLR scenario studied, to more than 70% loss for the 2 m SLR by 2100 scenario. Inland-fresh marsh is predicted to be slightly more resilient. For the lower SLR scenarios this habitat type is predicted to increase due to soil saturation. However, for SLR above 1 m by 2100 losses are projected to be significant, up to almost 60% under the 2 m SLR scenario. Swamp, irregularly-flooded marsh and mangrove are predicted to be almost completely lost for the highest SLR scenario studied. Although the latter two cover a small area of the refuge, their loss implies a reduction in habitat richness.

Open water and tidal flat which initially cover just more than 40% of the refuge are predicted to increase coverage as sea level rises, with tidal flat extending from 594 acres to over 16000 acres under the 2 m SLR by 2100 scenario. In addition, regularly-flooded marsh and transitional marsh that today are present only in very small areas of the refuge are predicted to gradually increase their coverage to a combined 21% of the total refuge area.

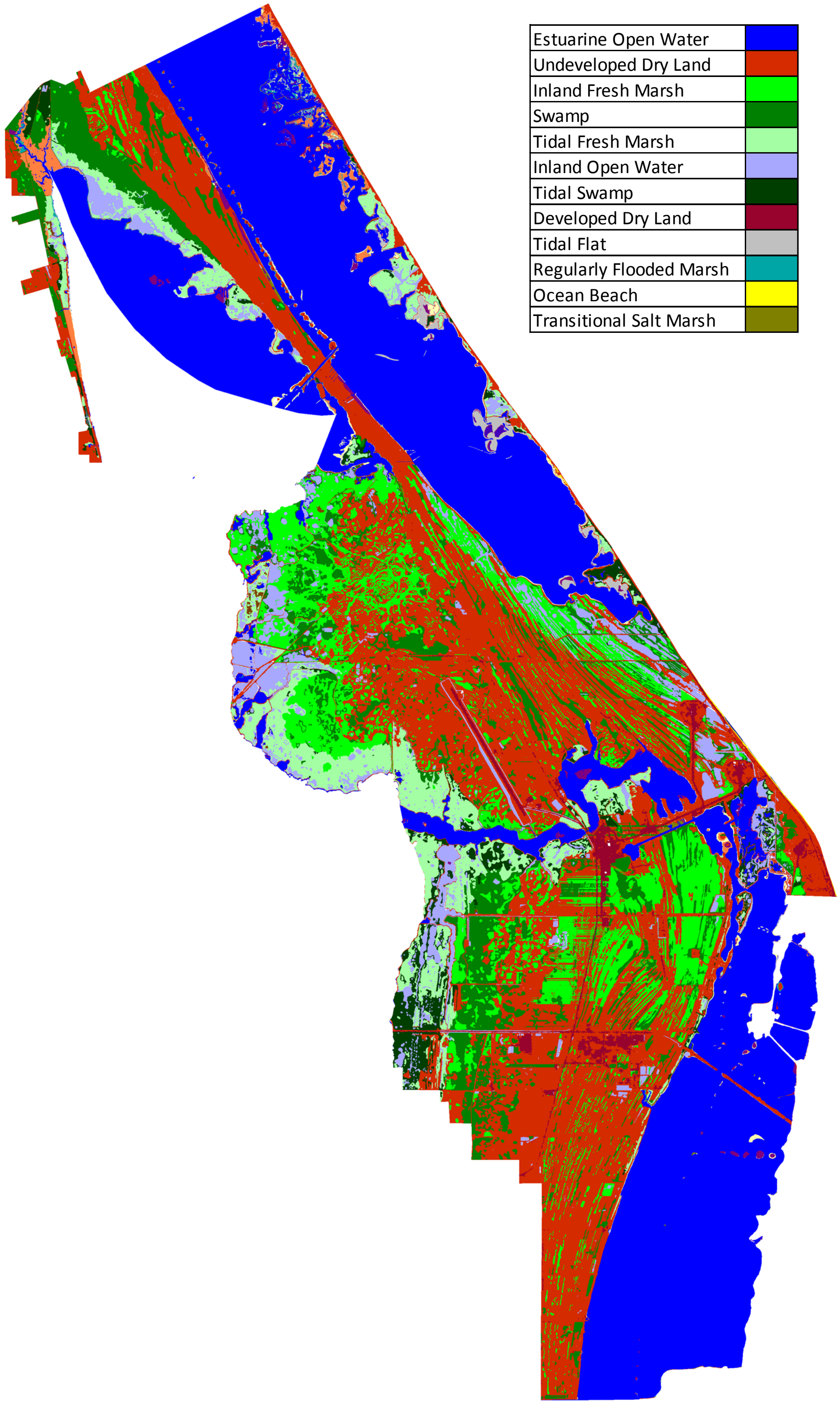
Merritt Island NWR
IPCC Scenario A1B-Mean, 0.39 m SLR eustatic by 2100

Results in Acres

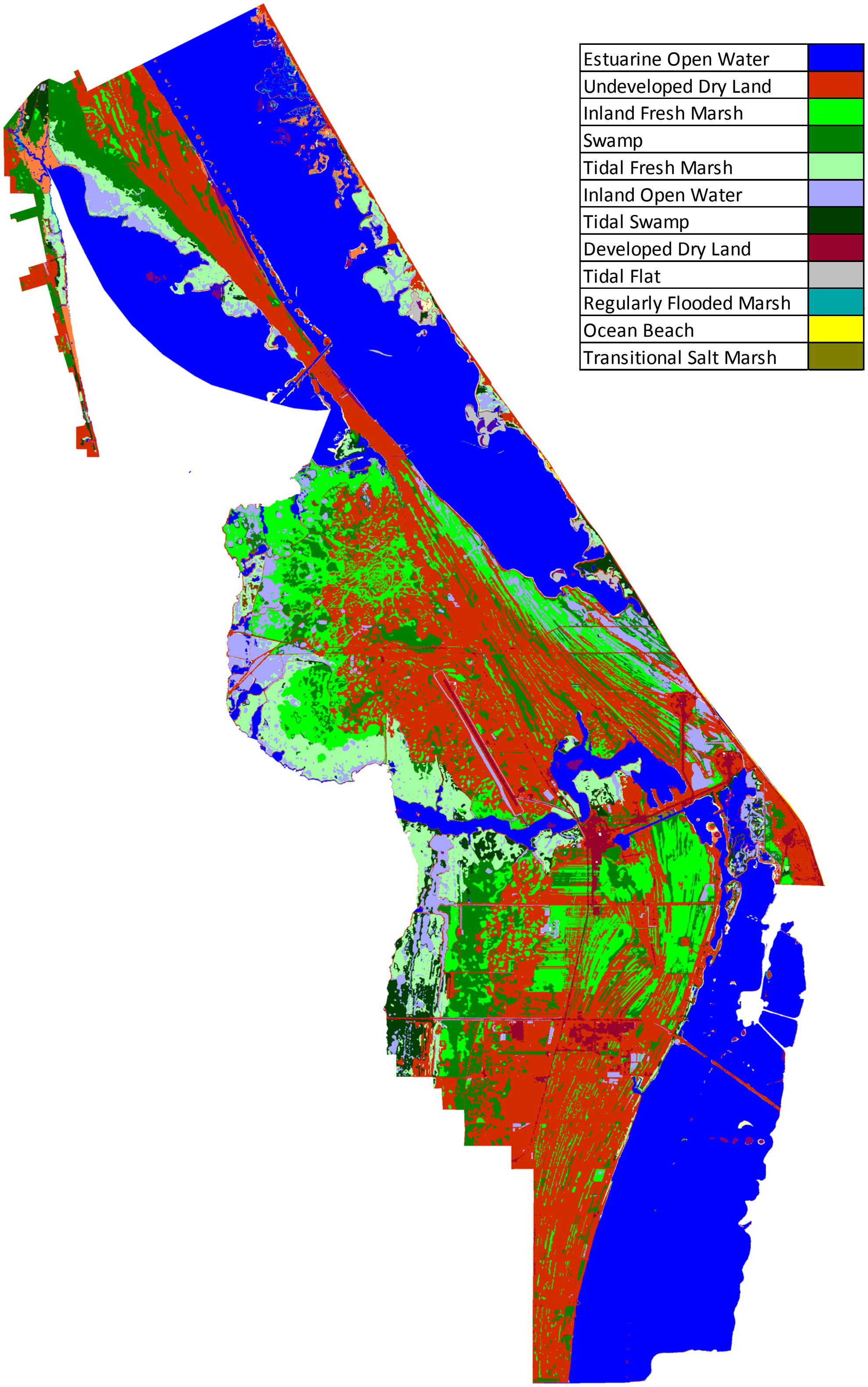
		Initial	2025	2050	2075	2100
	Estuarine Open Water	50132	50905	51158	51425	51686
	Undeveloped Dry Land	40577	38887	38445	37674	36293
	Inland Fresh Marsh	13299	14335	14606	15008	15473
	Swamp	11160	11535	11537	11384	10700
	Tidal Fresh Marsh	7323	7318	7318	7318	7318
	Inland Open Water	6679	6678	6670	6647	6597
	Tidal Swamp	2822	2786	2752	2669	2561
	Developed Dry Land	1835	1835	1835	1833	1830
	Estuarine Beach	1005	734	666	595	537
	Irregularly-flooded Marsh	971	898	932	1011	1110
	Mangrove	758	671	671	663	660
	Tidal Flat	594	678	612	561	560
	Inland Shore	475	221	209	178	121
	Regularly-flooded Marsh	246	269	207	242	528
	Ocean Beach	62	70	69	69	65
	Transitional Salt Marsh	54	168	303	710	1940
	Open Ocean	6	11	11	14	22
	Total (incl. water)	**137999**	**137999**	**137999**	**137999**	**137999**



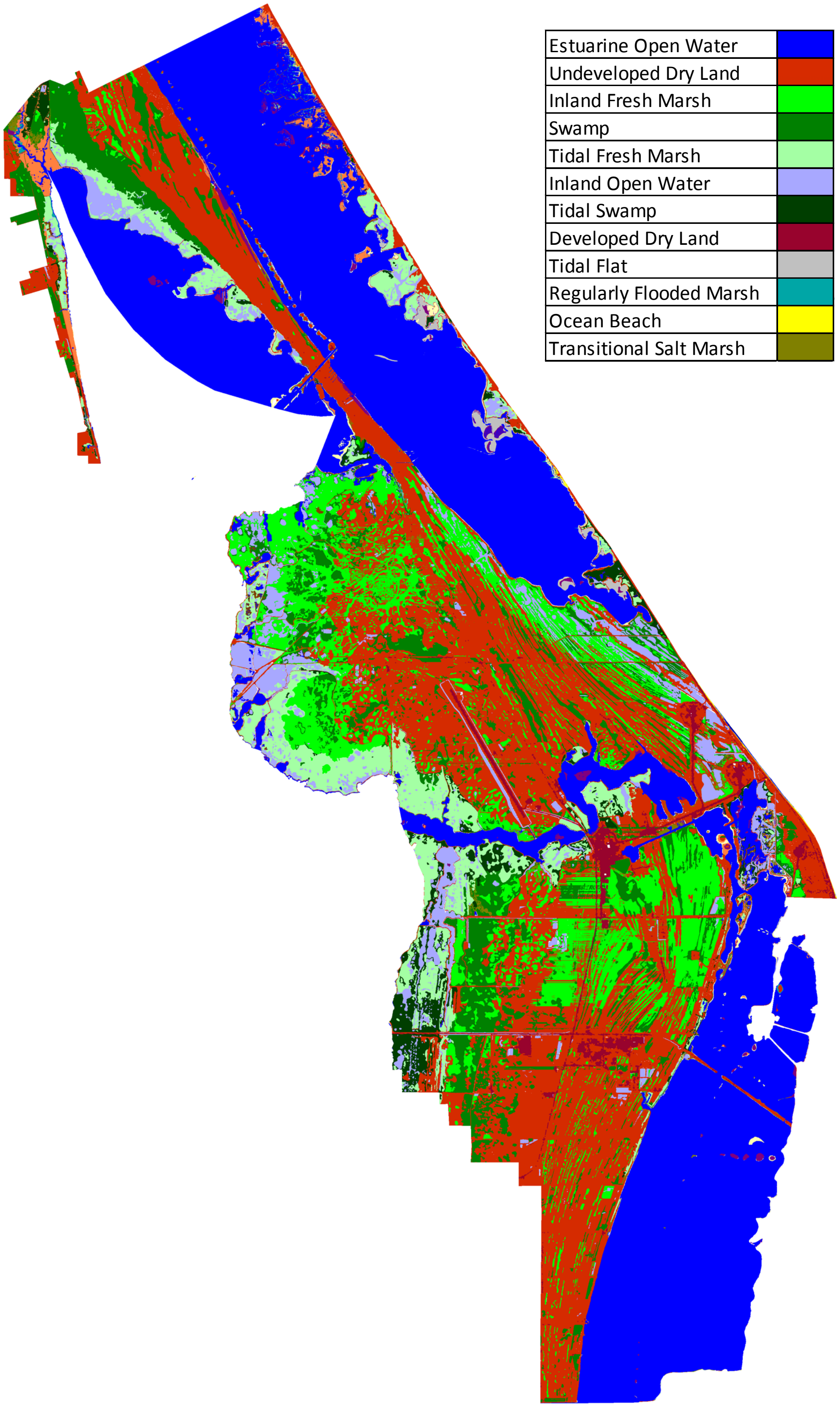
Merritt Island NWR, Initial Condition



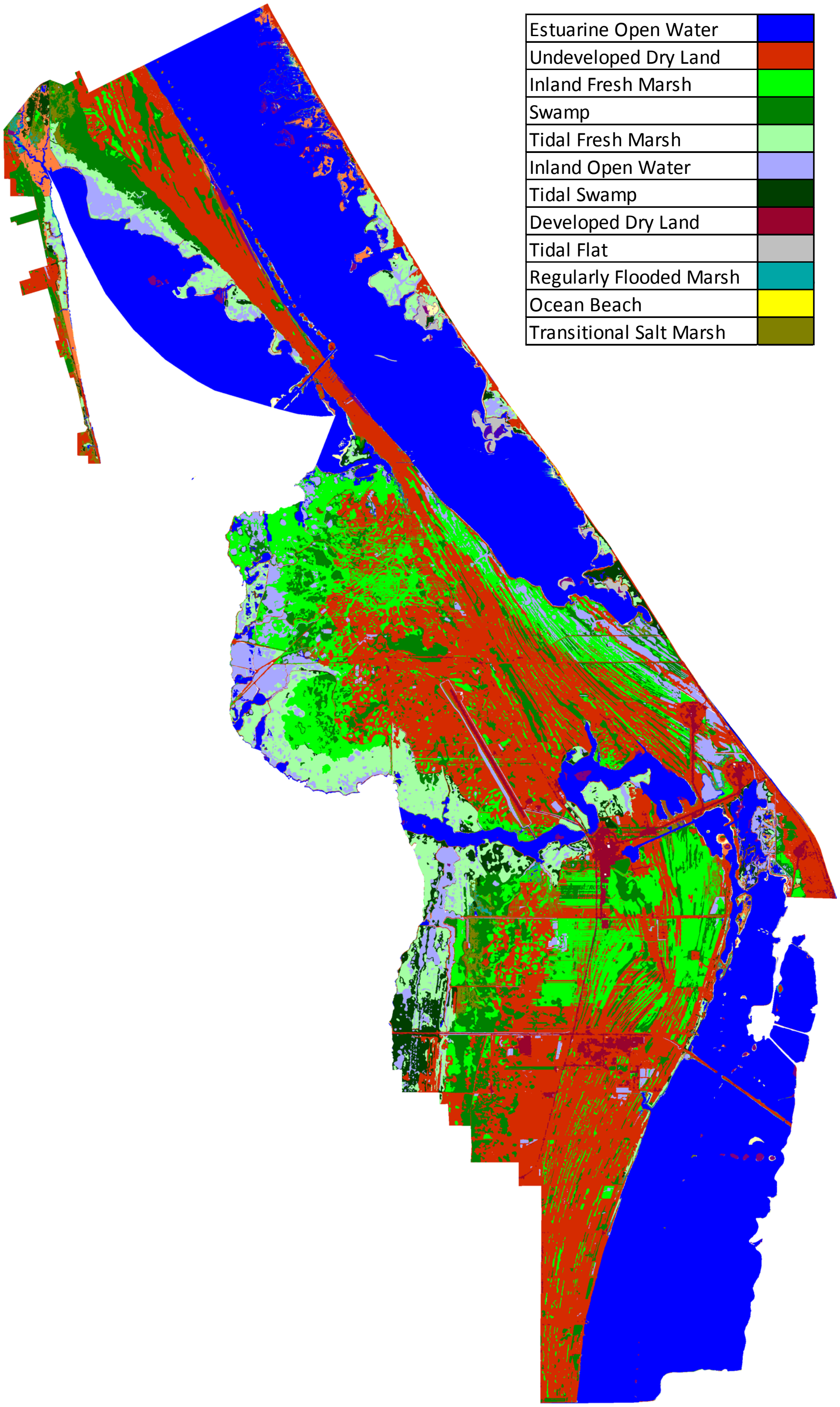
Merritt Island NWR, 2025, Scenario A1B Mean, 0.39 m SLR



Merritt Island NWR, 2050, Scenario A1B Mean, 0.39 m SLR



Merritt Island NWR, 2075, Scenario A1B Mean, 0.39 m SLR

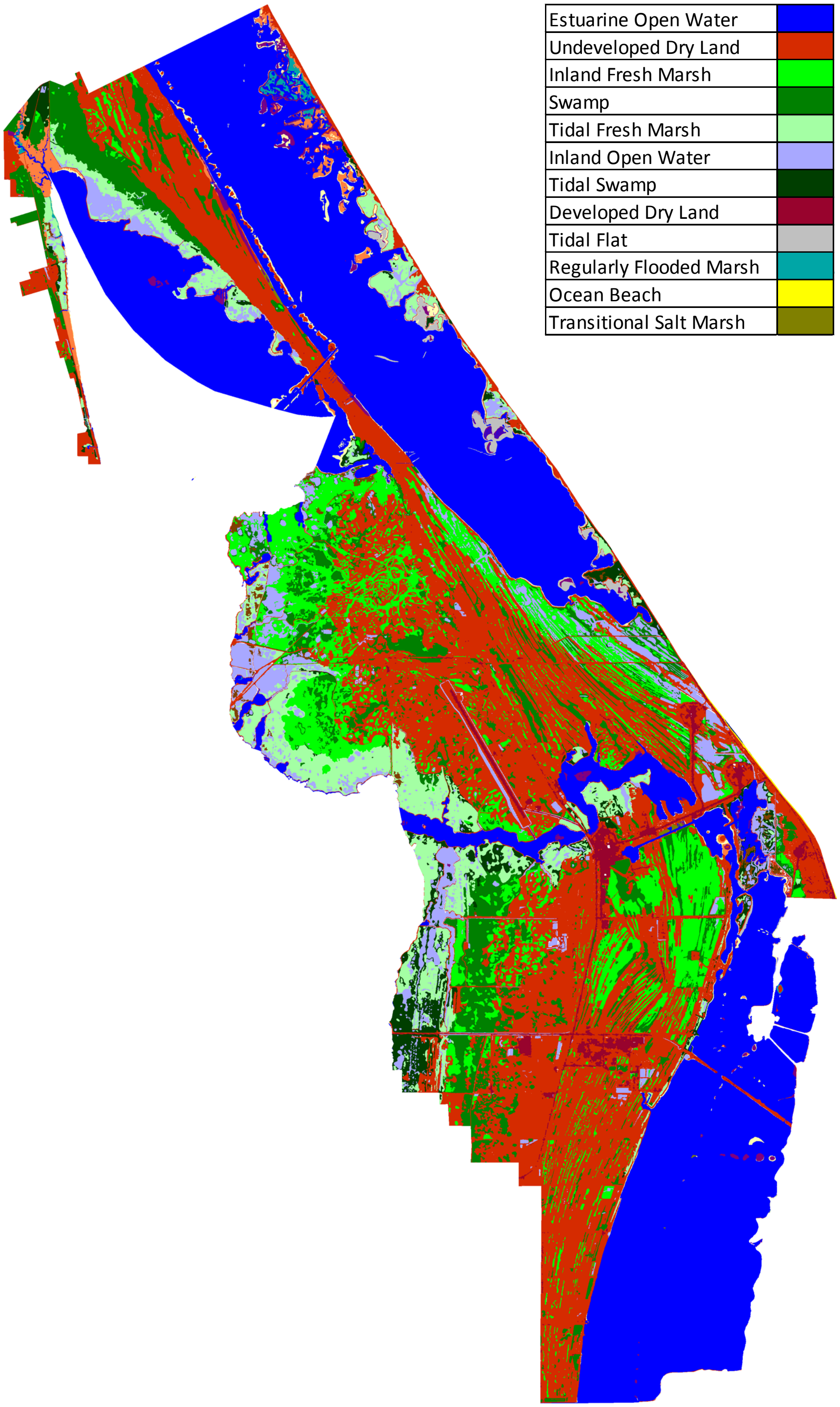


Merritt Island NWR, 2100, Scenario A1B Mean, 0.39 m SLR

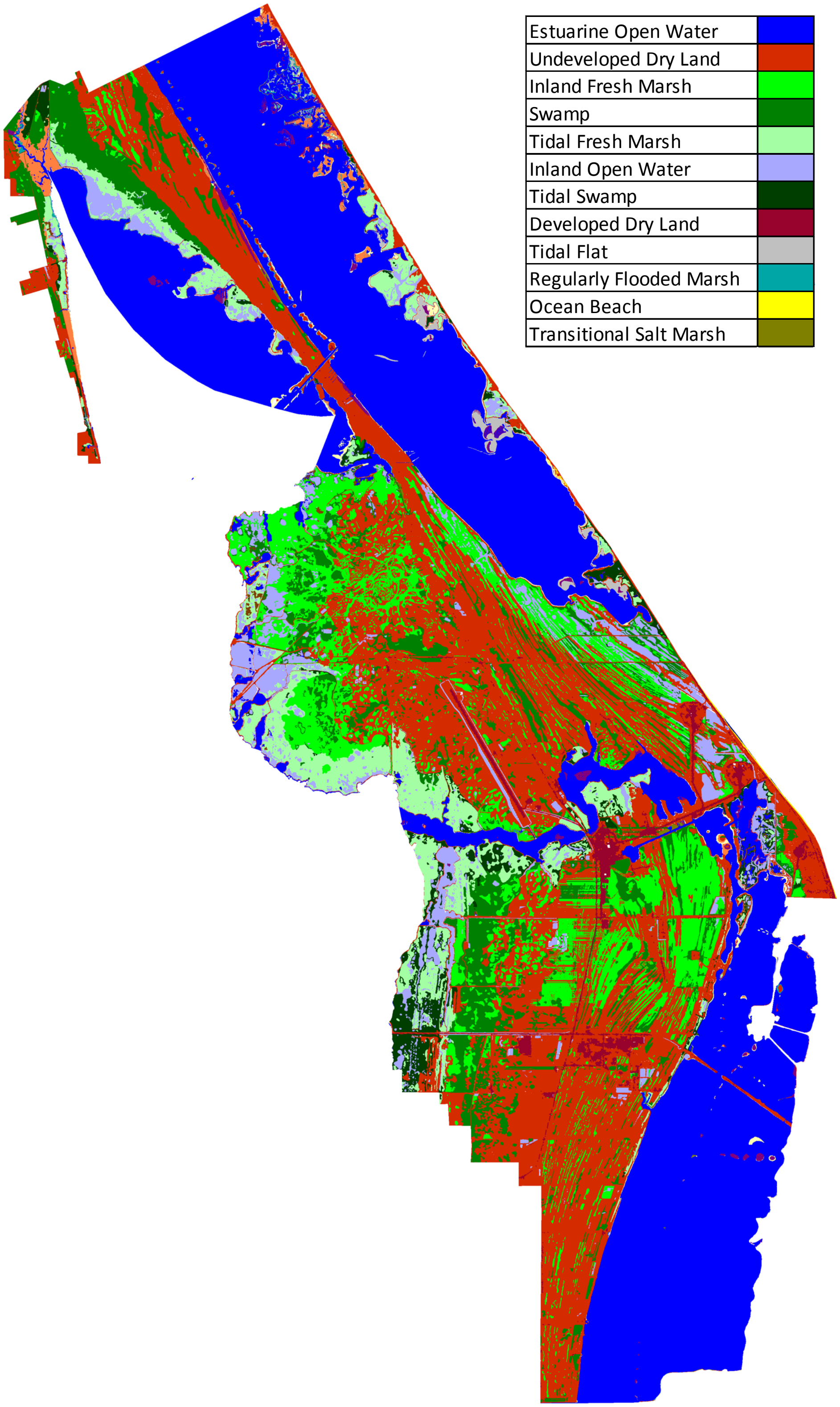
Merritt Island NWR
IPCC Scenario A1B-Max, 0.69 m SLR eustatic by 2100

Results in Acres

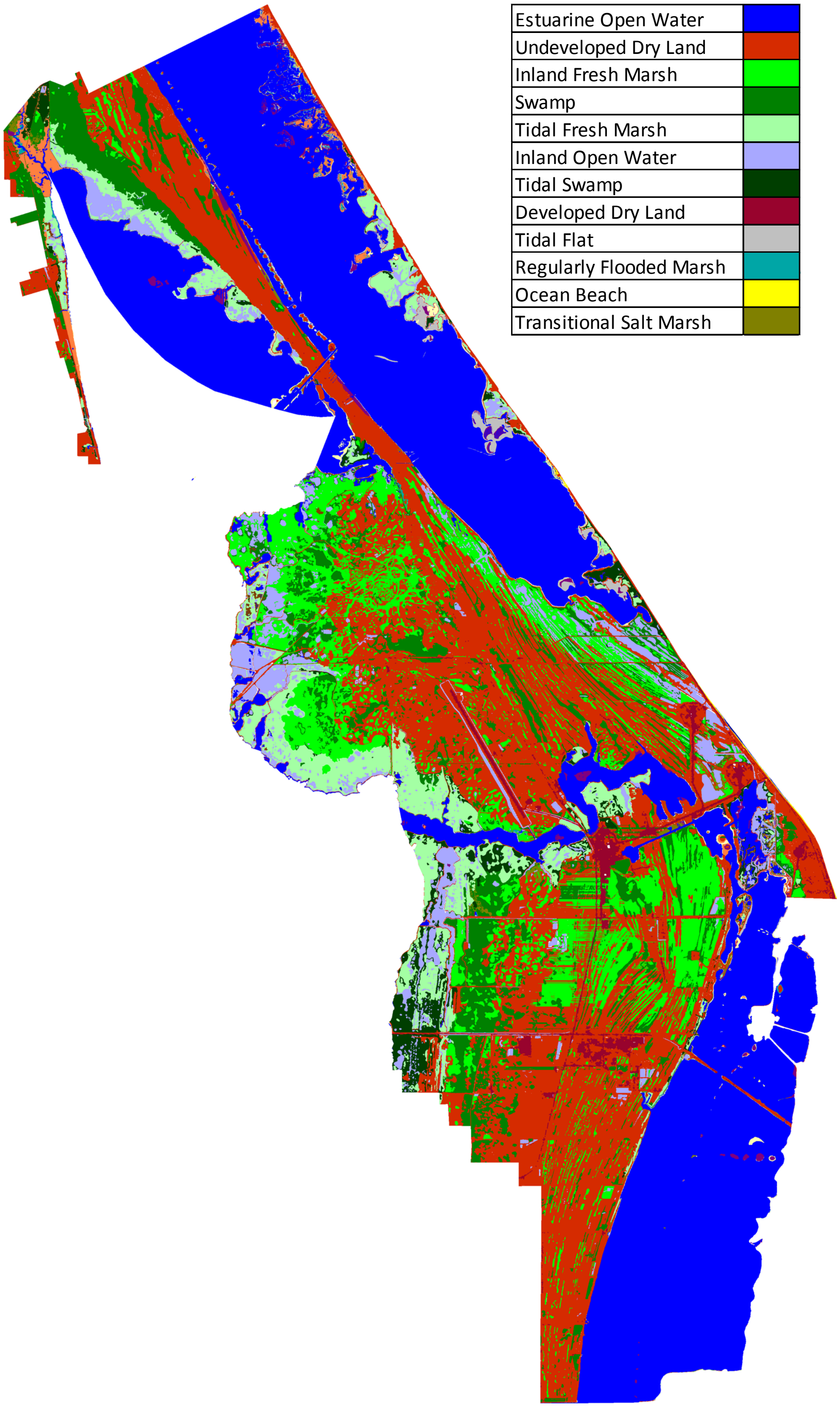
		Initial	2025	2050	2075	2100
	Estuarine Open Water	50132	50936	51300	51838	52487
	Undeveloped Dry Land	40577	38862	38204	36080	29939
	Inland Fresh Marsh	13299	14333	14547	14472	14068
	Swamp	11160	11533	11413	9723	6013
	Tidal Fresh Marsh	7323	7318	7318	7311	7295
	Inland Open Water	6679	6676	6635	6536	6321
	Tidal Swamp	2822	2778	2680	2468	2314
	Developed Dry Land	1835	1835	1835	1829	1809
	Estuarine Beach	1005	726	628	536	519
	Irregularly-flooded Marsh	971	905	942	885	644
	Mangrove	758	671	671	662	632
	Tidal Flat	594	674	687	668	1299
	Inland Shore	475	219	190	92	25
	Regularly-flooded Marsh	246	269	234	907	4292
	Ocean Beach	62	72	72	77	127
	Transitional Salt Marsh	54	182	631	3890	10165
	Open Ocean	6	11	12	26	50
	Total (incl. water)	**137999**	**137999**	**137999**	**137999**	**137999**



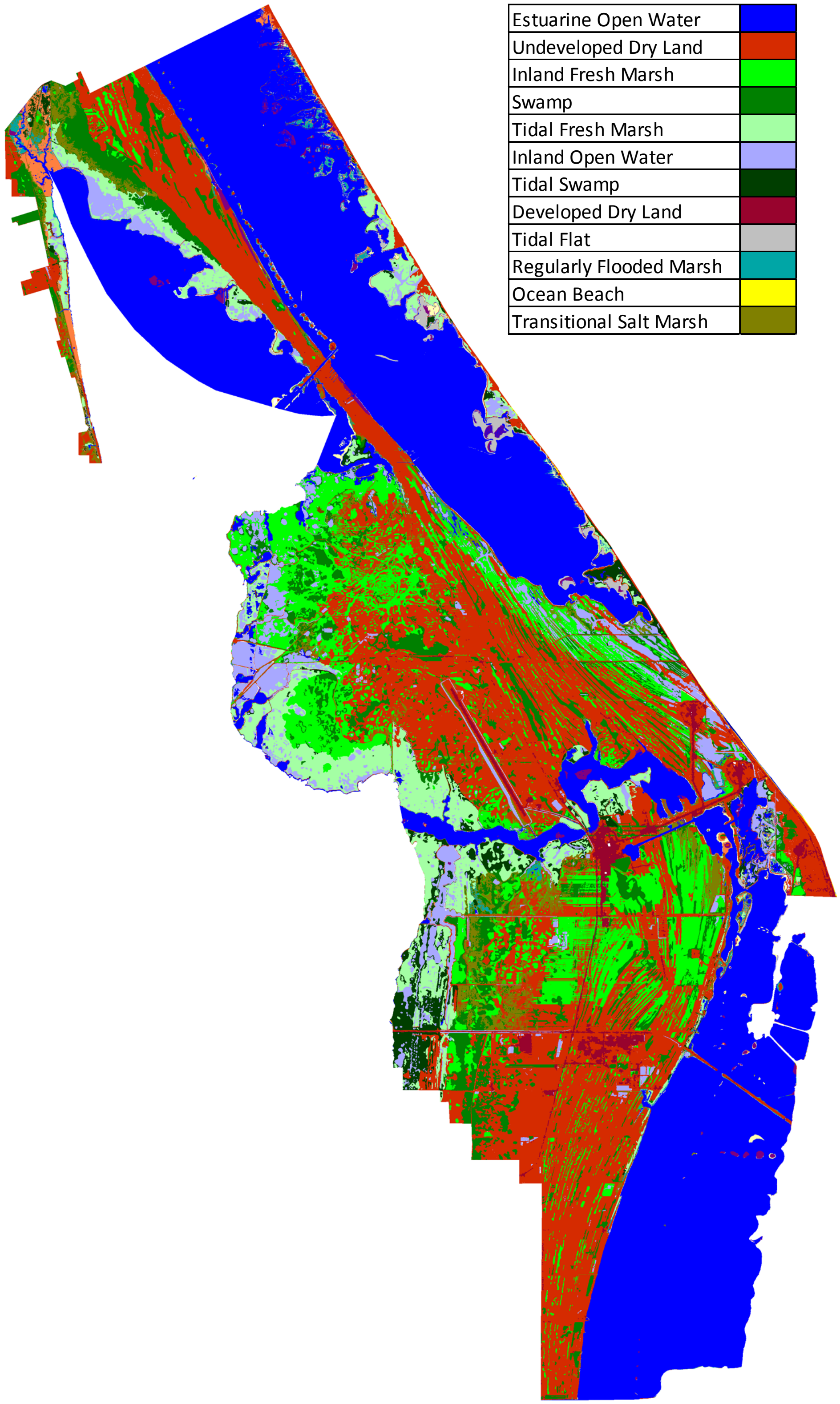
Merritt Island NWR, Initial Condition



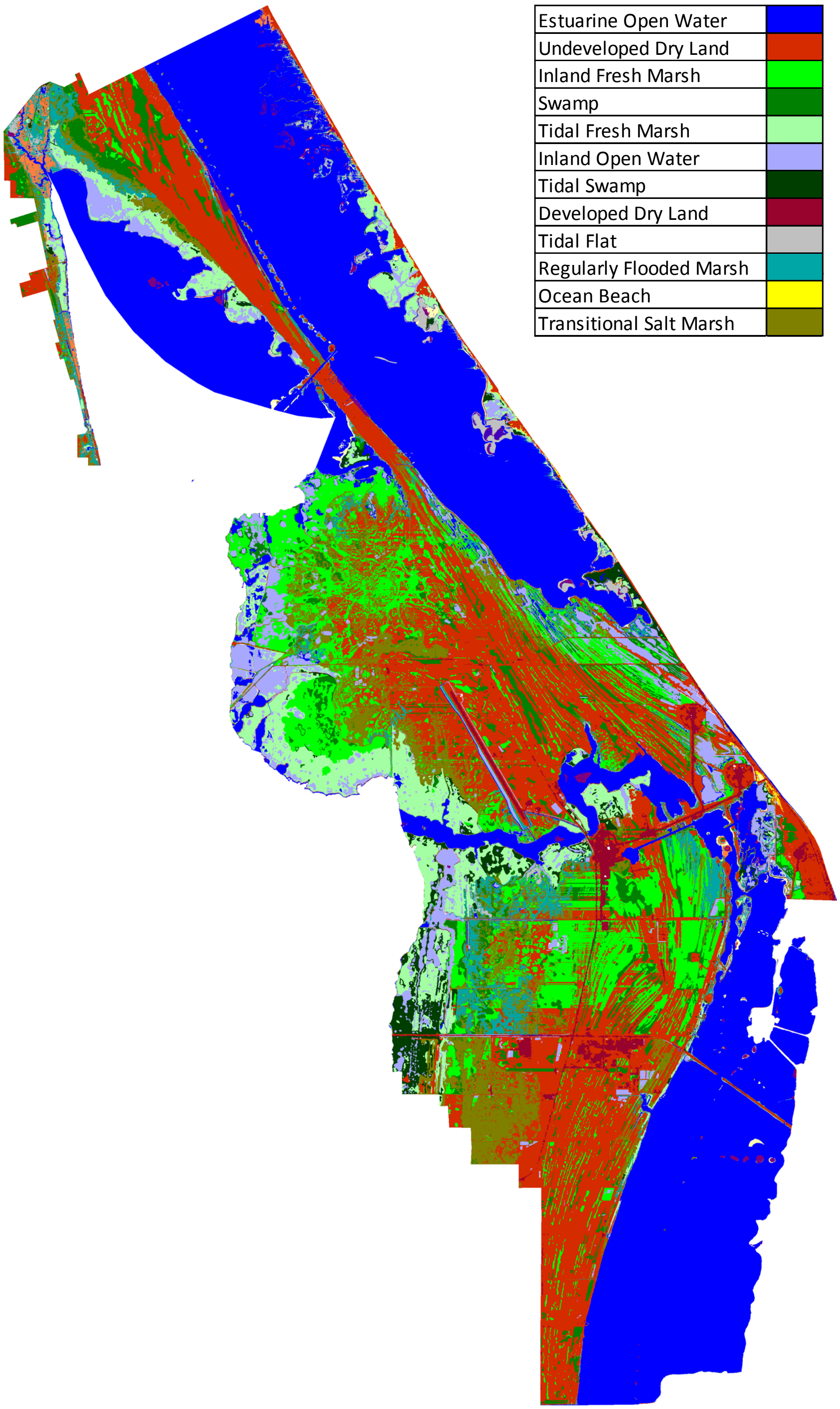
Merritt Island NWR, 2025, Scenario A1B Maximum, 0.69 m SLR



Merritt Island NWR, 2050, Scenario A1B Maximum, 0.69 m SLR



Merritt Island NWR, 2075, Scenario A1B Maximum, 0.69 m SLR

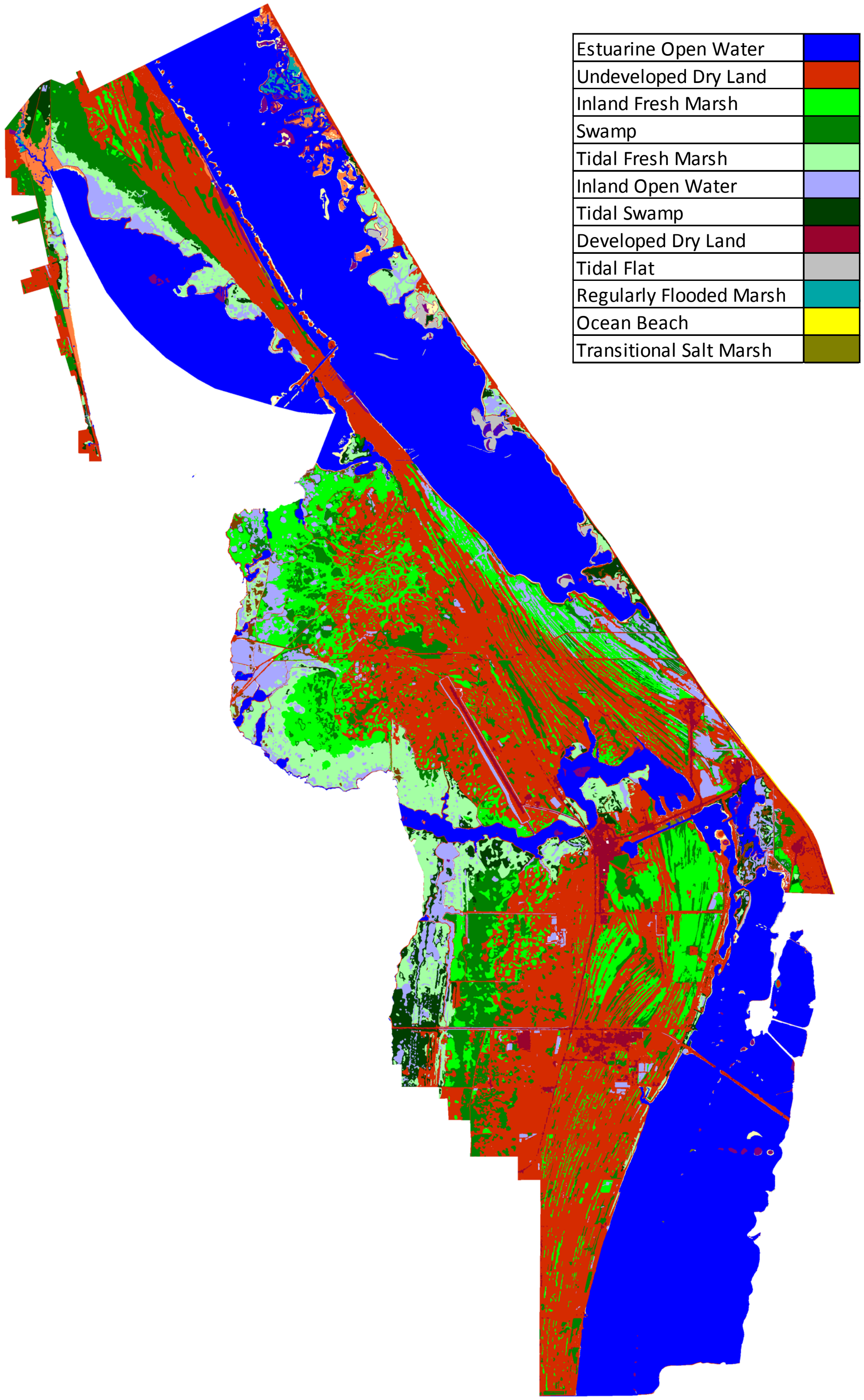


Merritt Island NWR, 2100, Scenario A1B Maximum, 0.69 m SLR

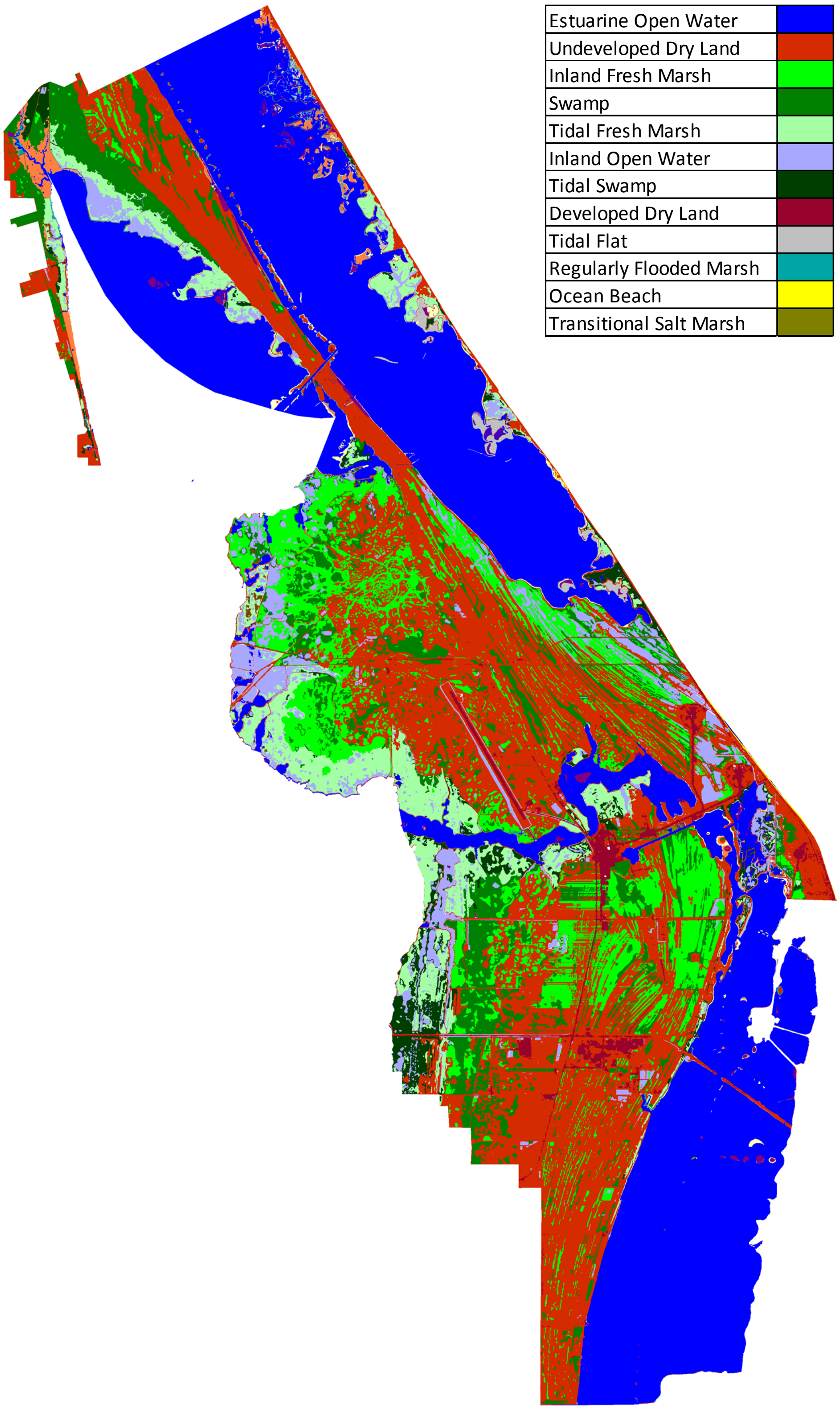
Merritt Island NWR
1 m eustatic SLR by 2100

Results in Acres

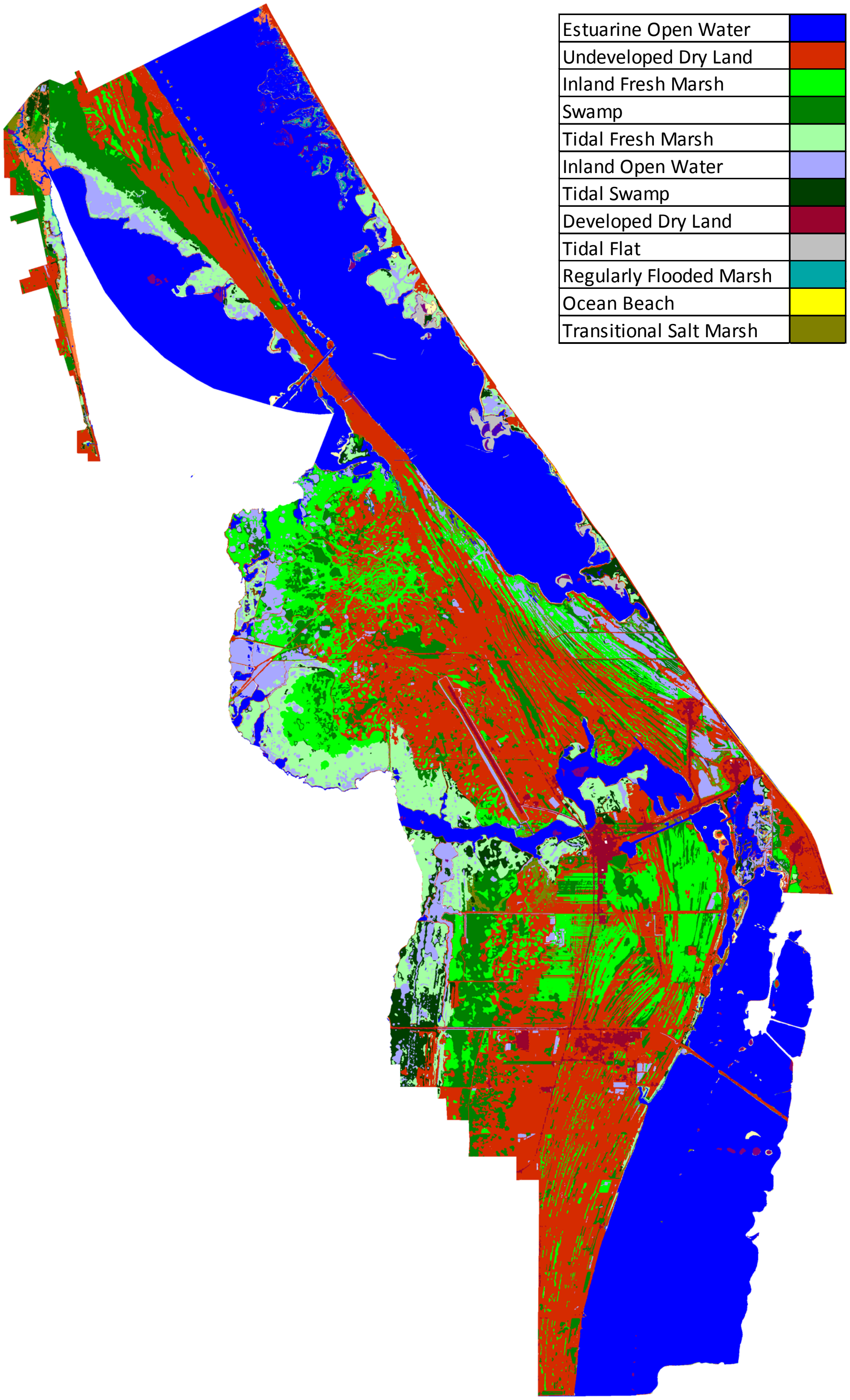
		Initial	2025	2050	2075	2100
	Estuarine Open Water	50132	50969	51476	52332	53379
	Undeveloped Dry Land	40577	38827	37741	31368	24138
	Inland Fresh Marsh	13299	14331	14308	12276	10076
	Swamp	11160	11529	11237	6156	3909
	Tidal Fresh Marsh	7323	7318	7307	7261	7198
	Inland Open Water	6679	6676	6607	6383	6123
	Tidal Swamp	2822	2768	2578	2321	2260
	Developed Dry Land	1835	1835	1834	1814	1774
	Estuarine Beach	1005	717	587	519	533
	Irregularly-flooded Marsh	971	895	841	551	171
	Mangrove	758	671	645	541	463
	Tidal Flat	594	682	733	919	2351
	Inland Shore	475	217	155	35	10
	Regularly-flooded Marsh	246	278	447	1961	13866
	Ocean Beach	62	73	76	102	217
	Transitional Salt Marsh	54	203	1412	13424	11450
	Open Ocean	6	11	15	38	83
	Total (incl. water)	**137999**	**137999**	**137999**	**137999**	**137999**



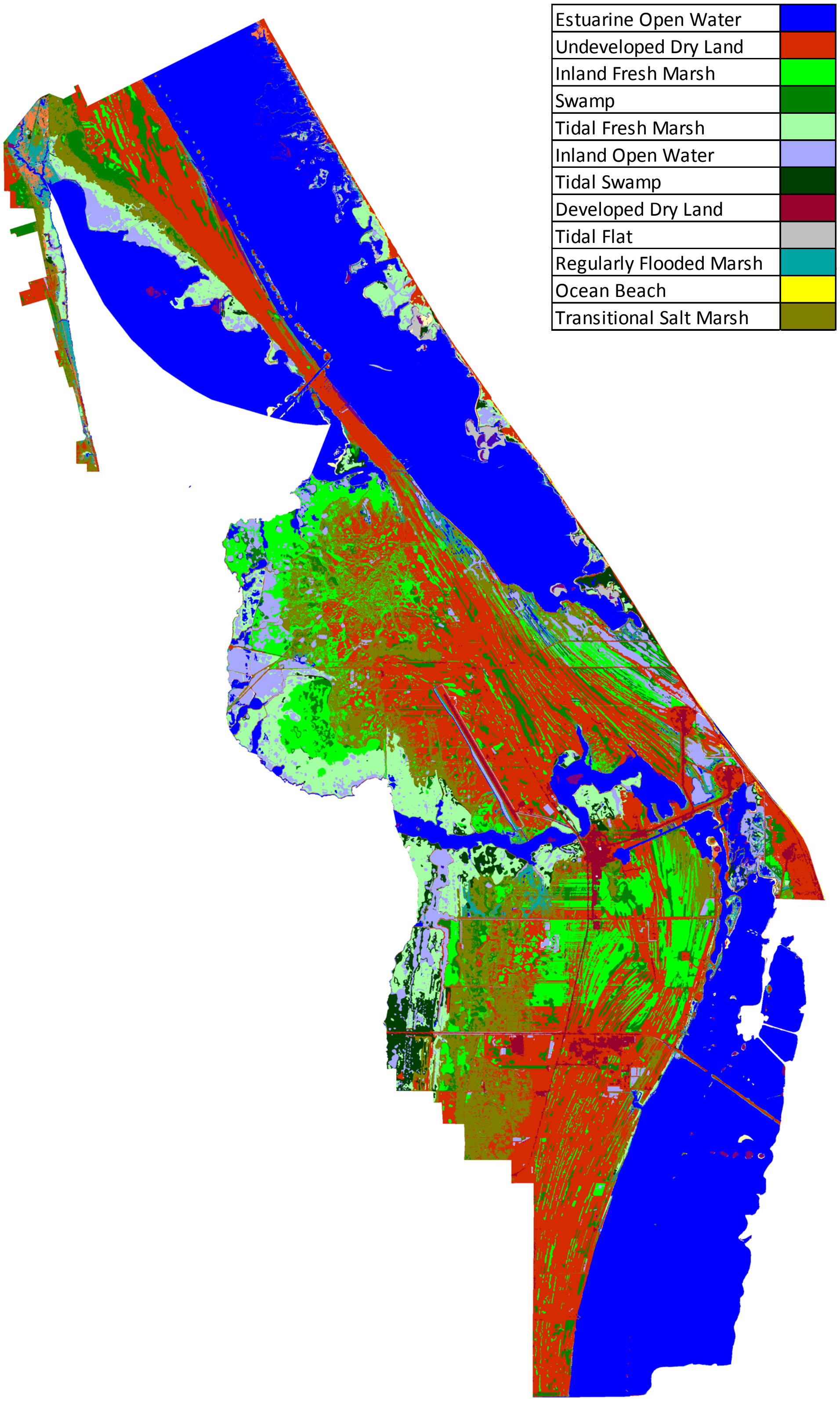
Merritt Island NWR, Initial Condition



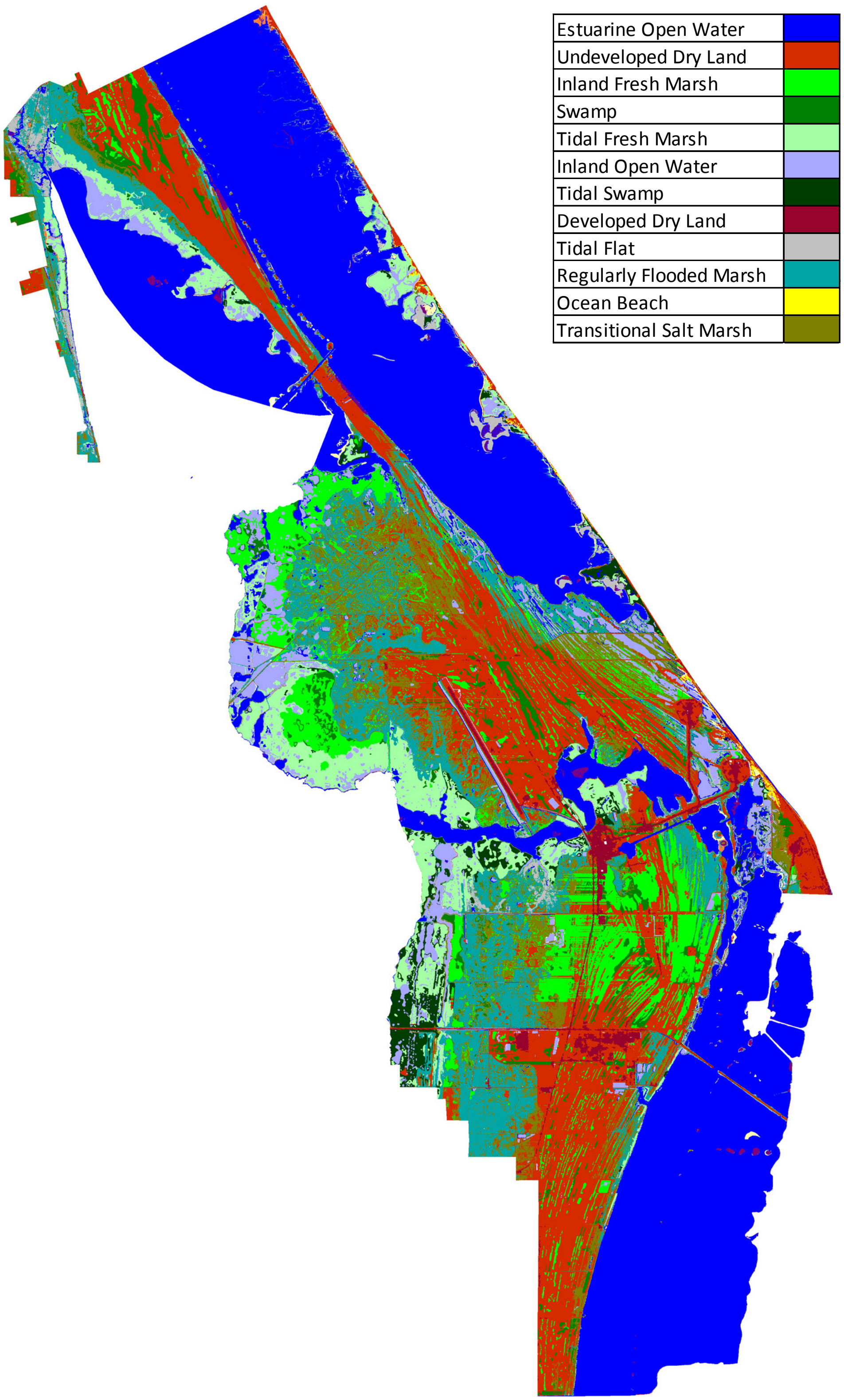
Merritt Island NWR, 2025, 1 m SLR



Merritt Island NWR, 2050, 1 m SLR



Merritt Island NWR, 2075, 1 m SLR

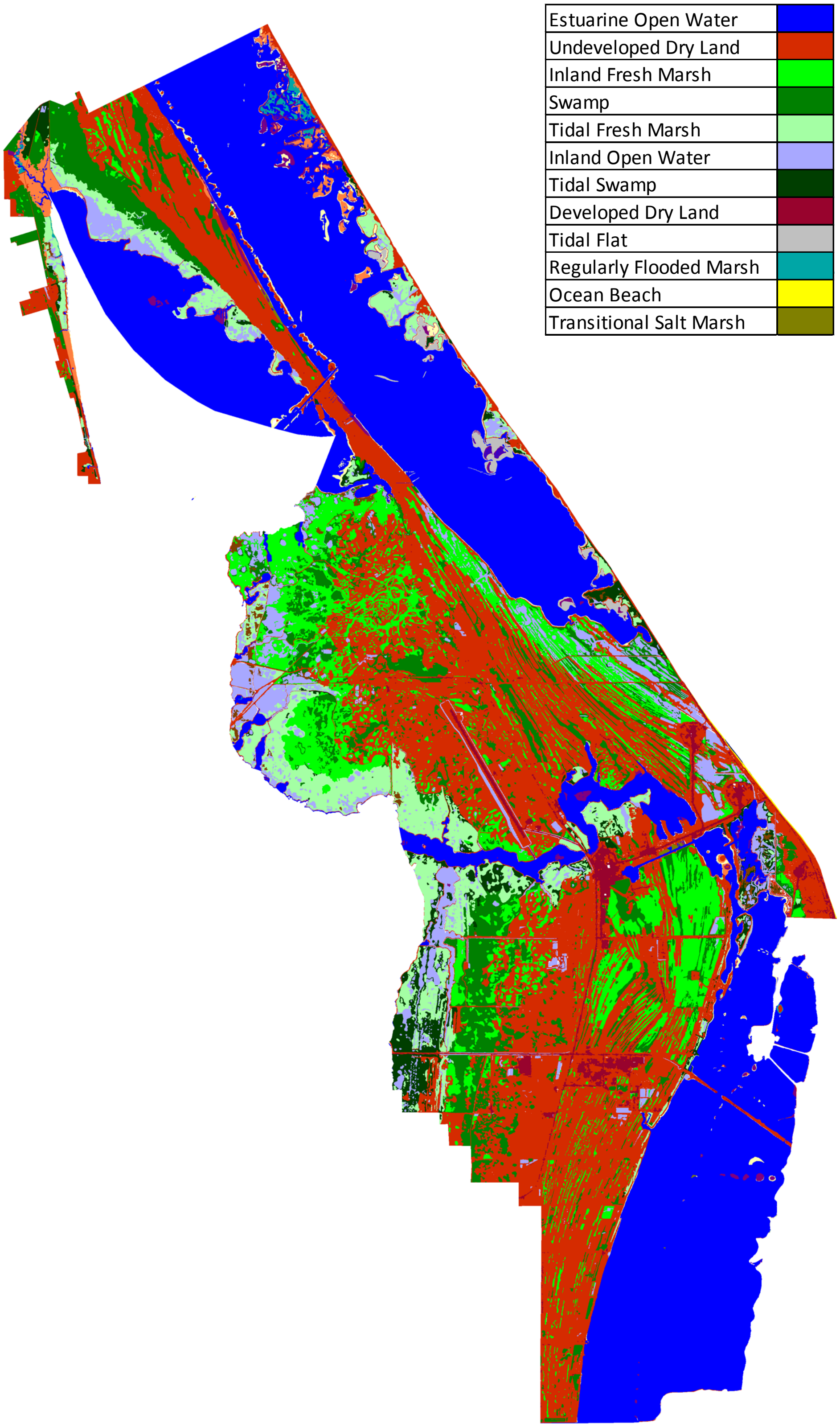


Merritt Island NWR, 2100, 1 m SLR

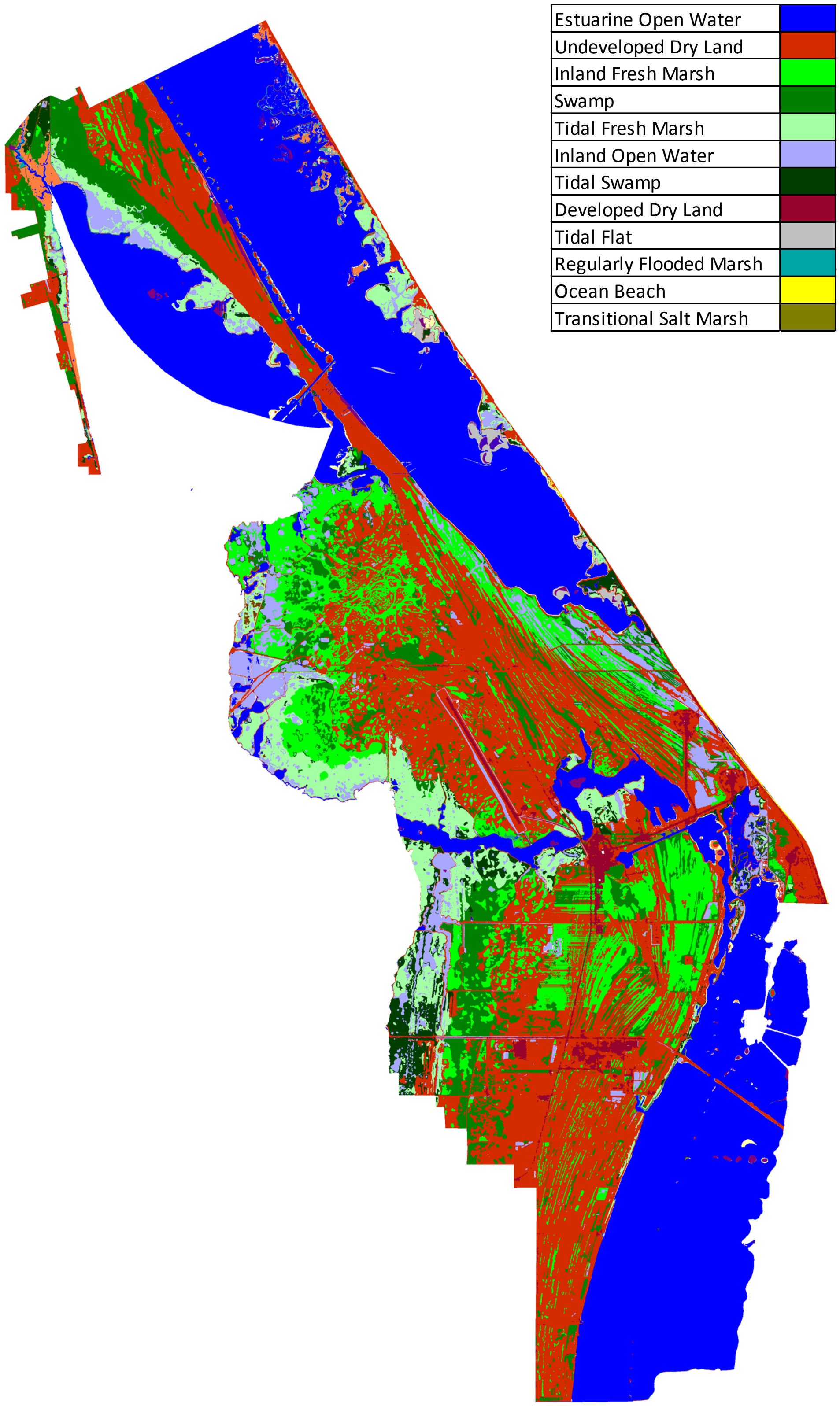
Merritt Island NWR
1.5 m eustatic SLR by 2100

Results in Acres

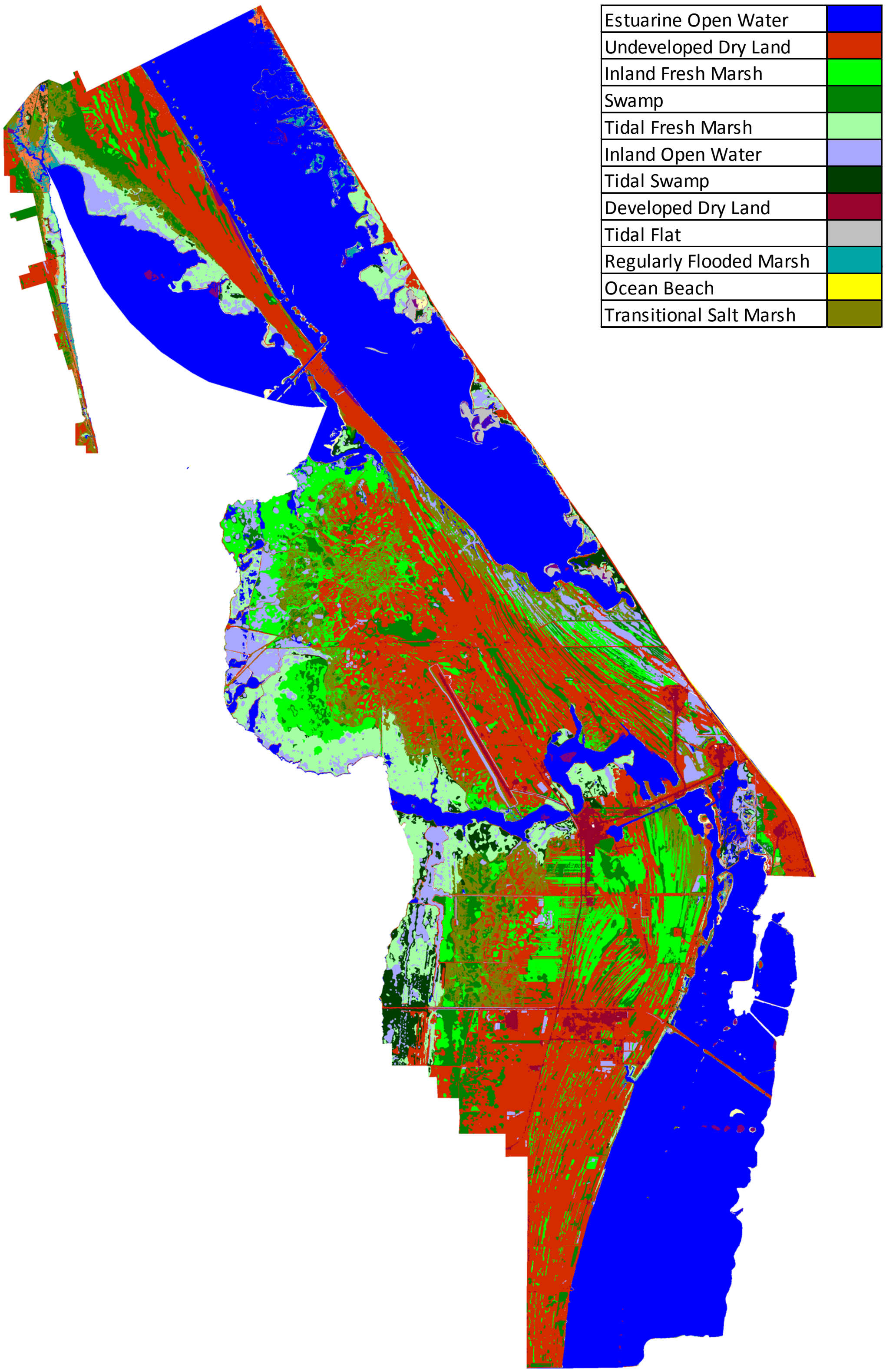
		Initial	2025	2050	2075	2100
	Estuarine Open Water	50132	51050	51831	52966	54604
	Undeveloped Dry Land	40577	38759	35569	24794	16411
	Inland Fresh Marsh	13299	14321	12179	9050	7713
	Swamp	11160	11516	8571	3938	2435
	Tidal Fresh Marsh	7323	7314	7263	7170	7135
	Inland Open Water	6679	6669	6557	6176	5935
	Tidal Swamp	2822	2745	2405	2260	2243
	Developed Dry Land	1835	1835	1826	1777	1611
	Estuarine Beach	1005	701	550	558	498
	Irregularly-flooded Marsh	971	857	699	238	96
	Mangrove	758	659	534	363	212
	Tidal Flat	594	686	813	1289	9096
	Inland Shore	475	211	76	10	4
	Regularly-flooded Marsh	246	329	764	8856	18416
	Ocean Beach	62	75	79	256	256
	Transitional Salt Marsh	54	260	8257	18248	11118
	Open Ocean	6	11	26	50	218
	Total (incl. water)	**137999**	**137999**	**137999**	**137999**	**137999**



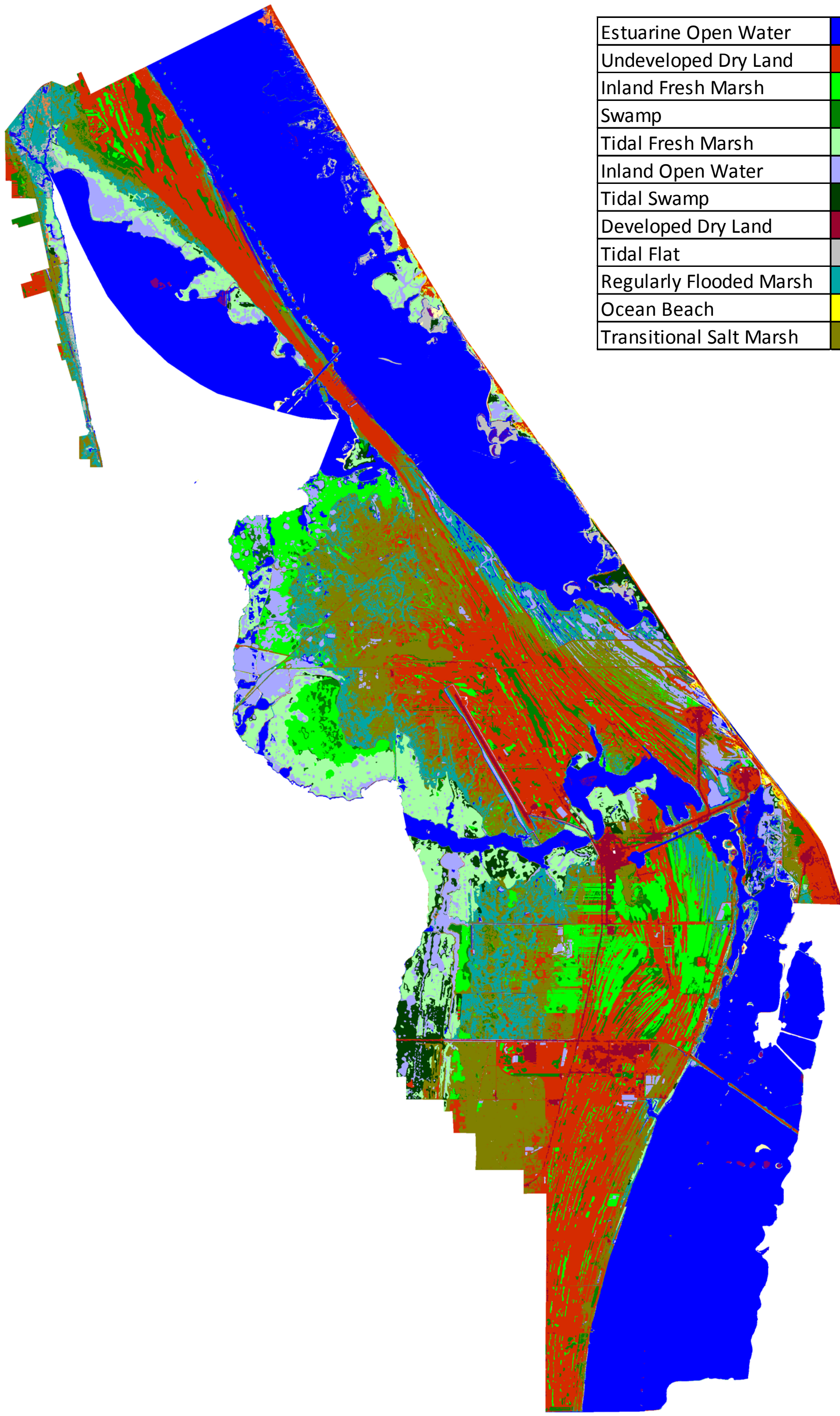
Merritt Island NWR, Initial Condition



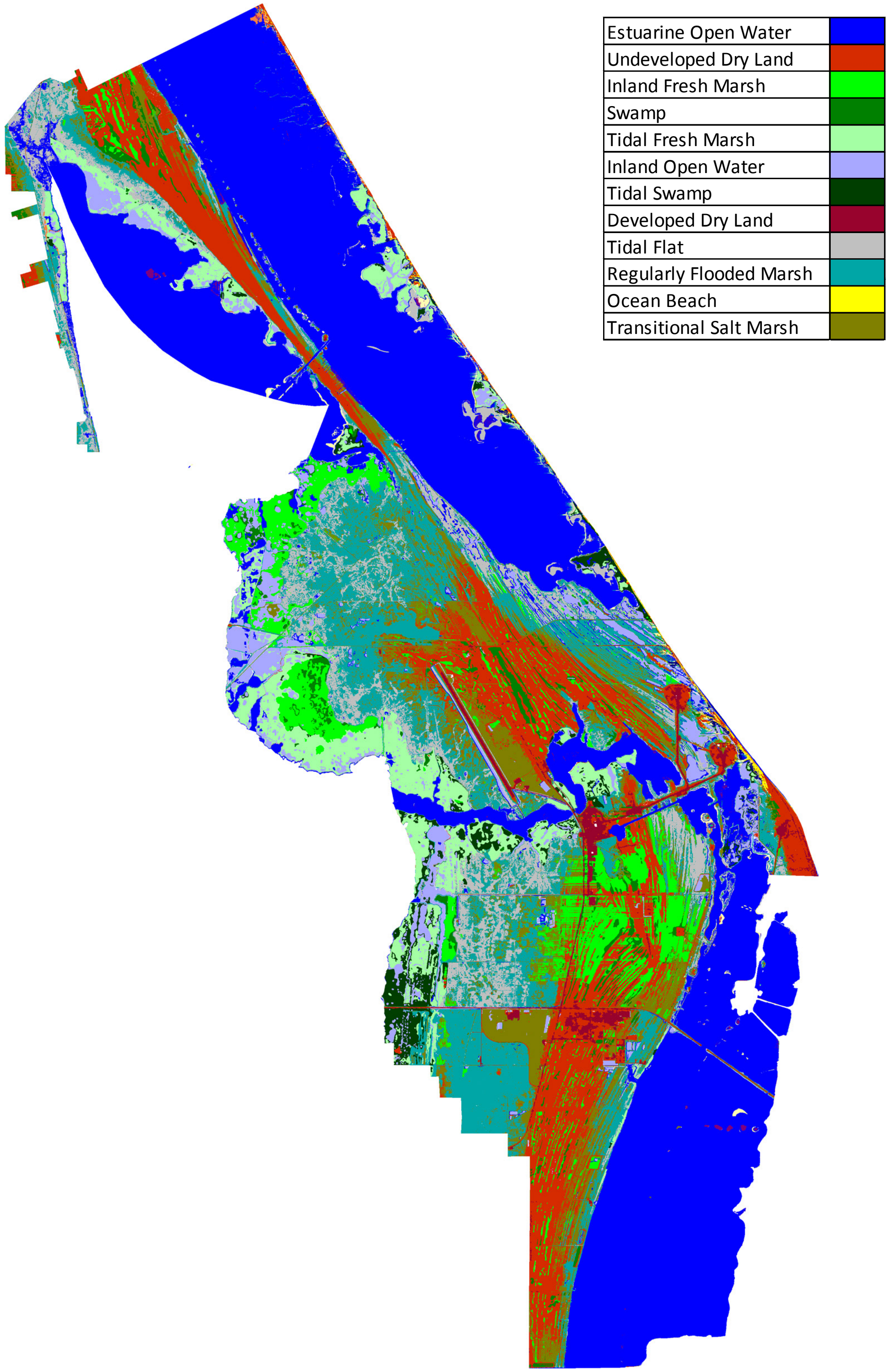
Merritt Island NWR, 2025, 1.5 m SLR



Merritt Island NWR, 2050, 1.5 m SLR



Merritt Island NWR, 2075, 1.5 m SLR

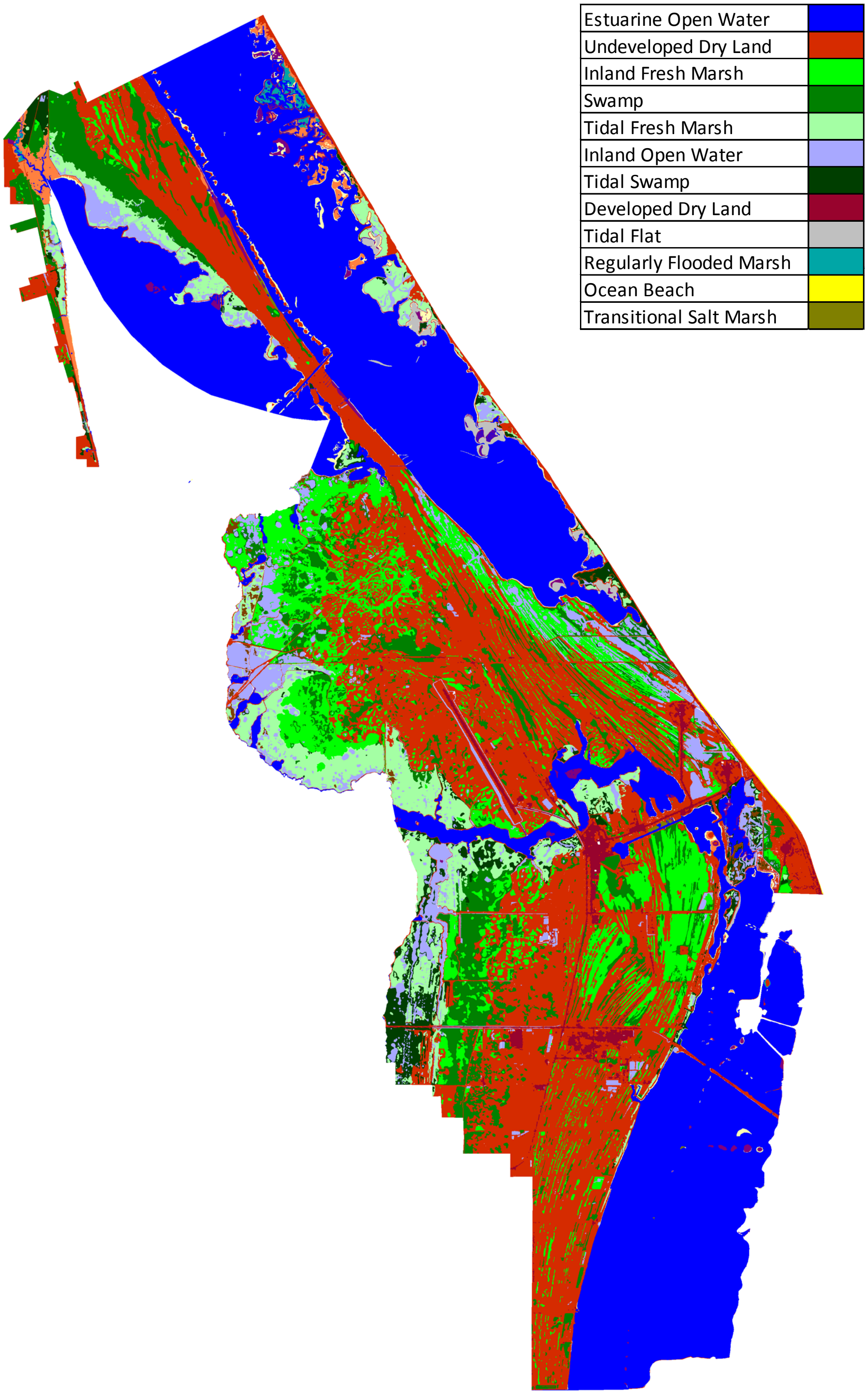


Merritt Island NWR, 2100, 1.5 m SLR

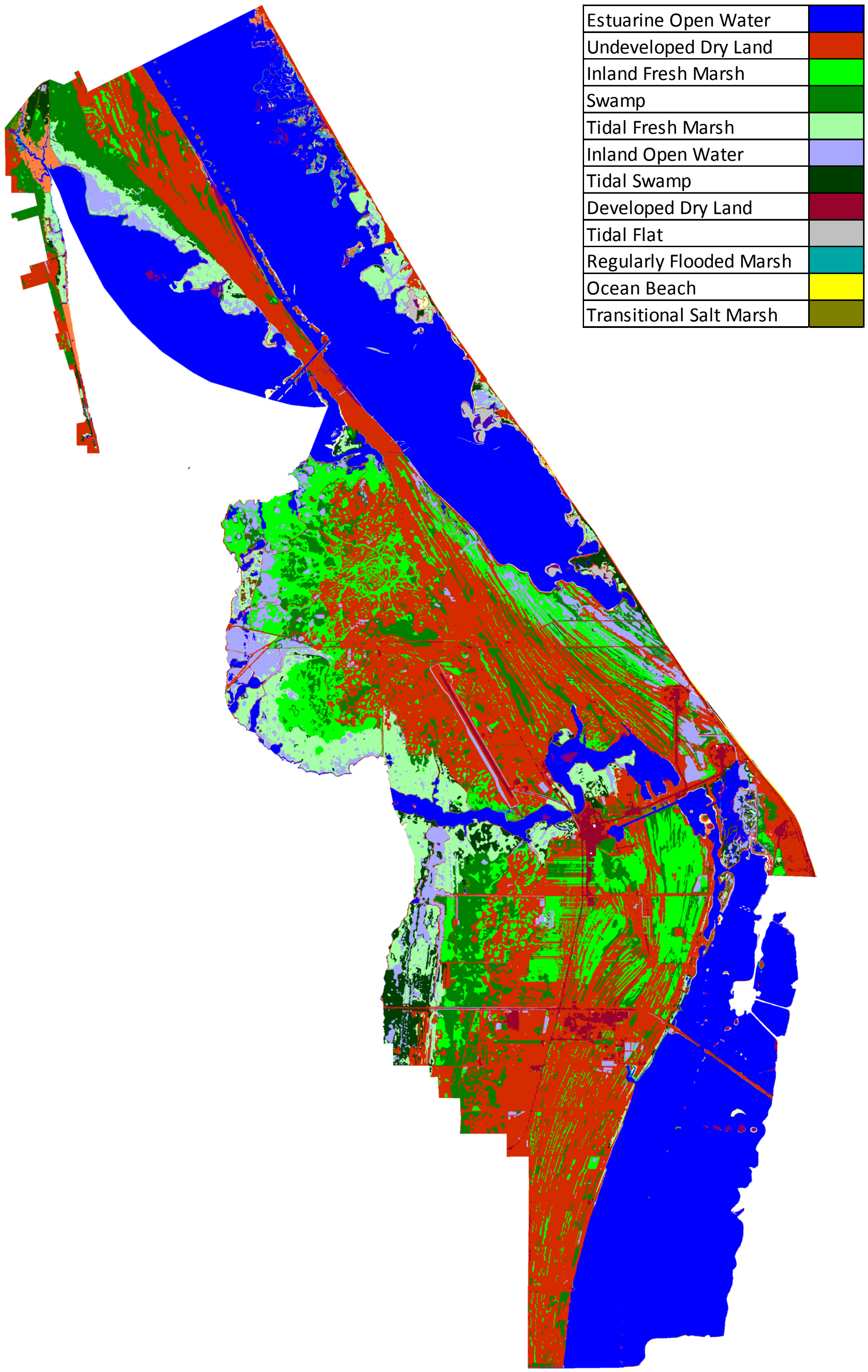
Merritt Island NWR
2 m eustatic SLR by 2100

Results in Acres

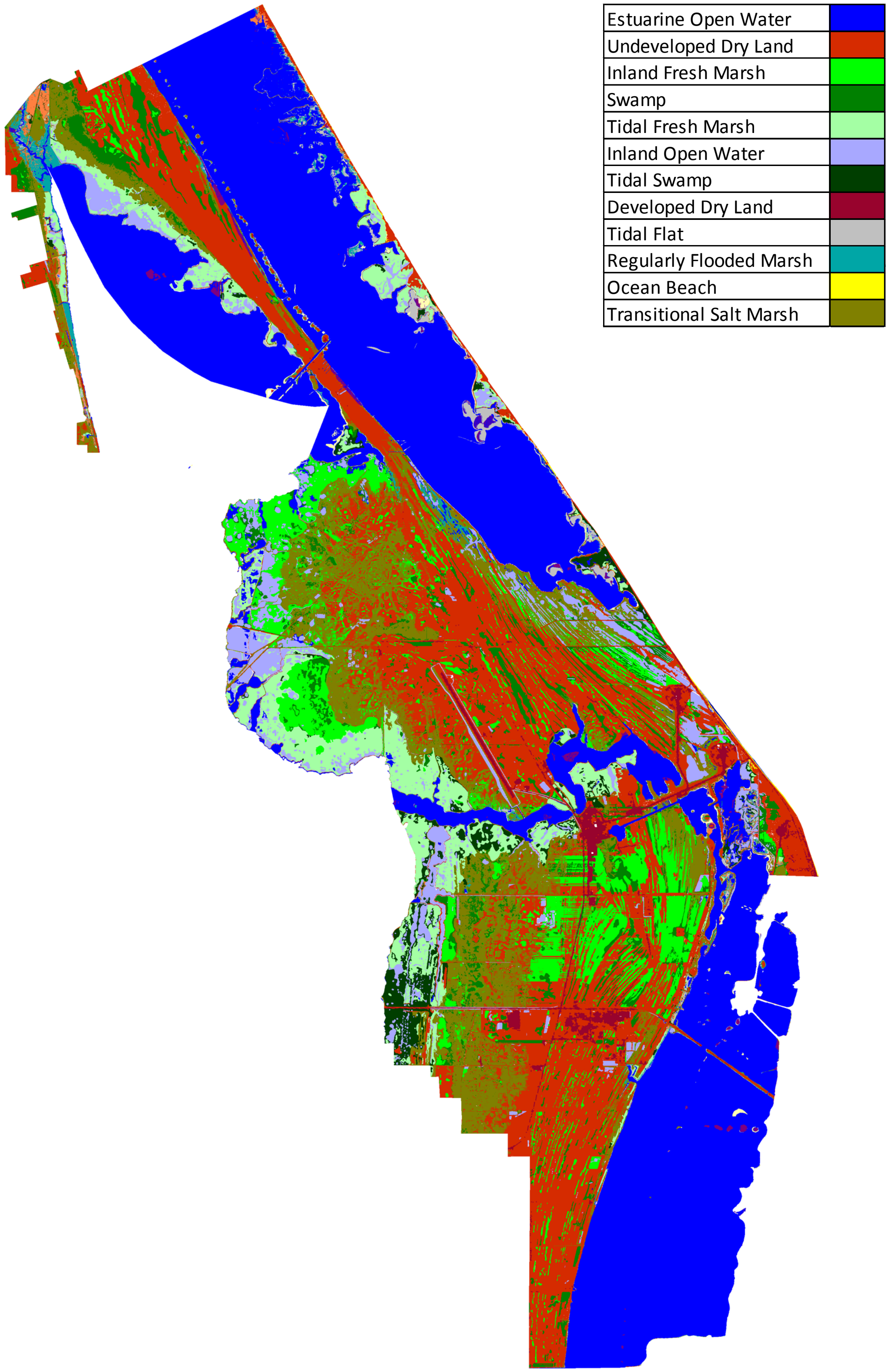
		Initial	2025	2050	2075	2100
	Estuarine Open Water	50132	51138	52067	53491	55449
	Undeveloped Dry Land	40577	38685	31612	18838	10614
	Inland Fresh Marsh	13299	14198	10185	7745	5781
	Swamp	11160	11486	5926	2777	1322
	Tidal Fresh Marsh	7323	7309	7204	7136	7096
	Inland Open Water	6679	6645	6514	6061	5867
	Tidal Swamp	2822	2713	2308	2246	2230
	Developed Dry Land	1835	1835	1814	1662	1178
	Estuarine Beach	1005	684	547	572	481
	Irregularly-flooded Marsh	971	801	557	142	75
	Mangrove	758	634	451	212	132
	Tidal Flat	594	689	960	1604	17171
	Inland Shore	475	204	34	5	3
	Regularly-flooded Marsh	246	417	1121	17035	18133
	Ocean Beach	62	76	107	355	277
	Transitional Salt Marsh	54	474	16563	18043	11865
	Open Ocean	6	11	29	75	326
	Total (incl. water)	**137999**	**137999**	**137999**	**137999**	**137999**



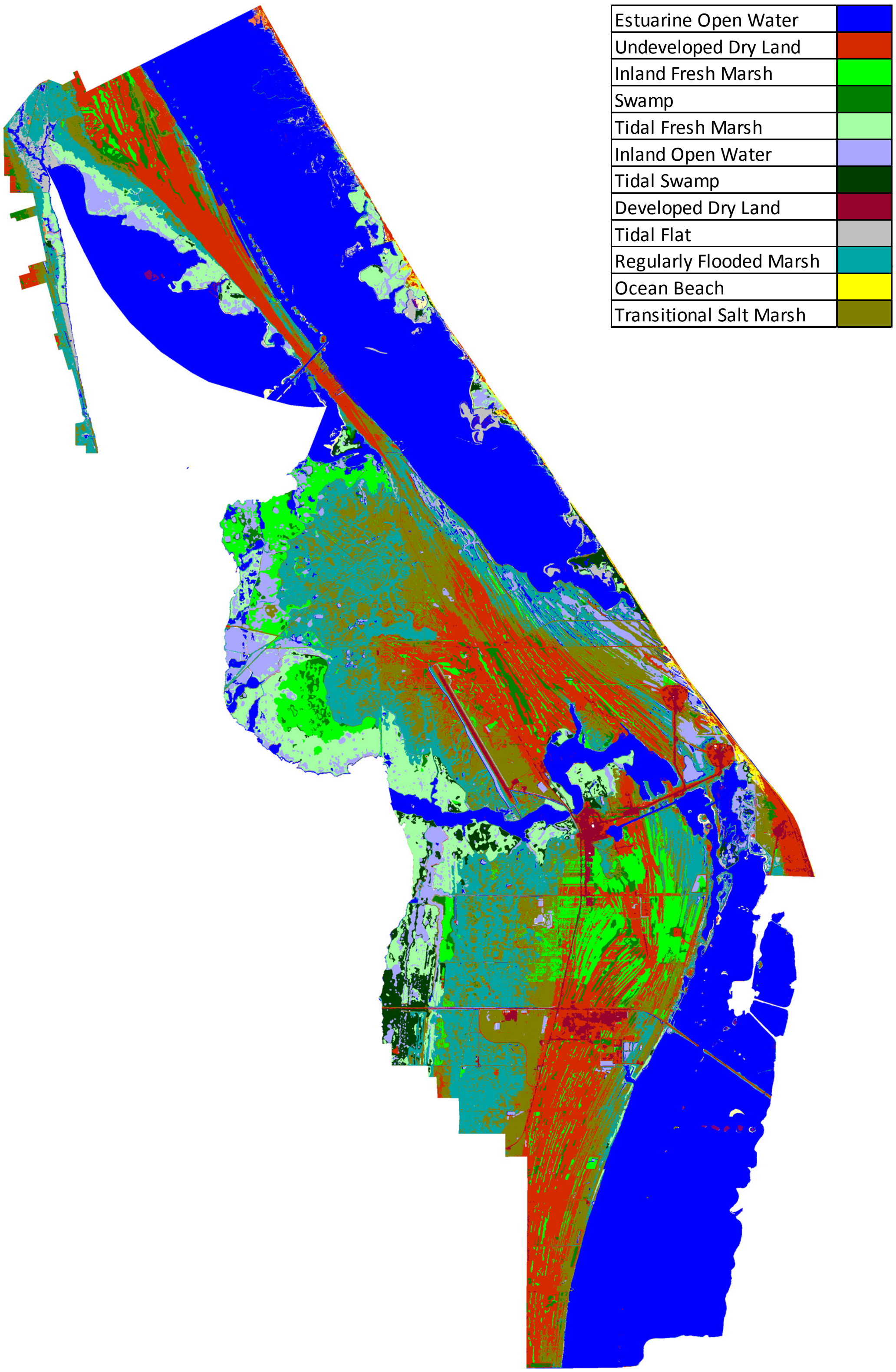
Merritt Island NWR, Initial Condition



Merritt Island NWR, 2025, 2 m SLR



Merritt Island NWR, 2050, 2 m SLR



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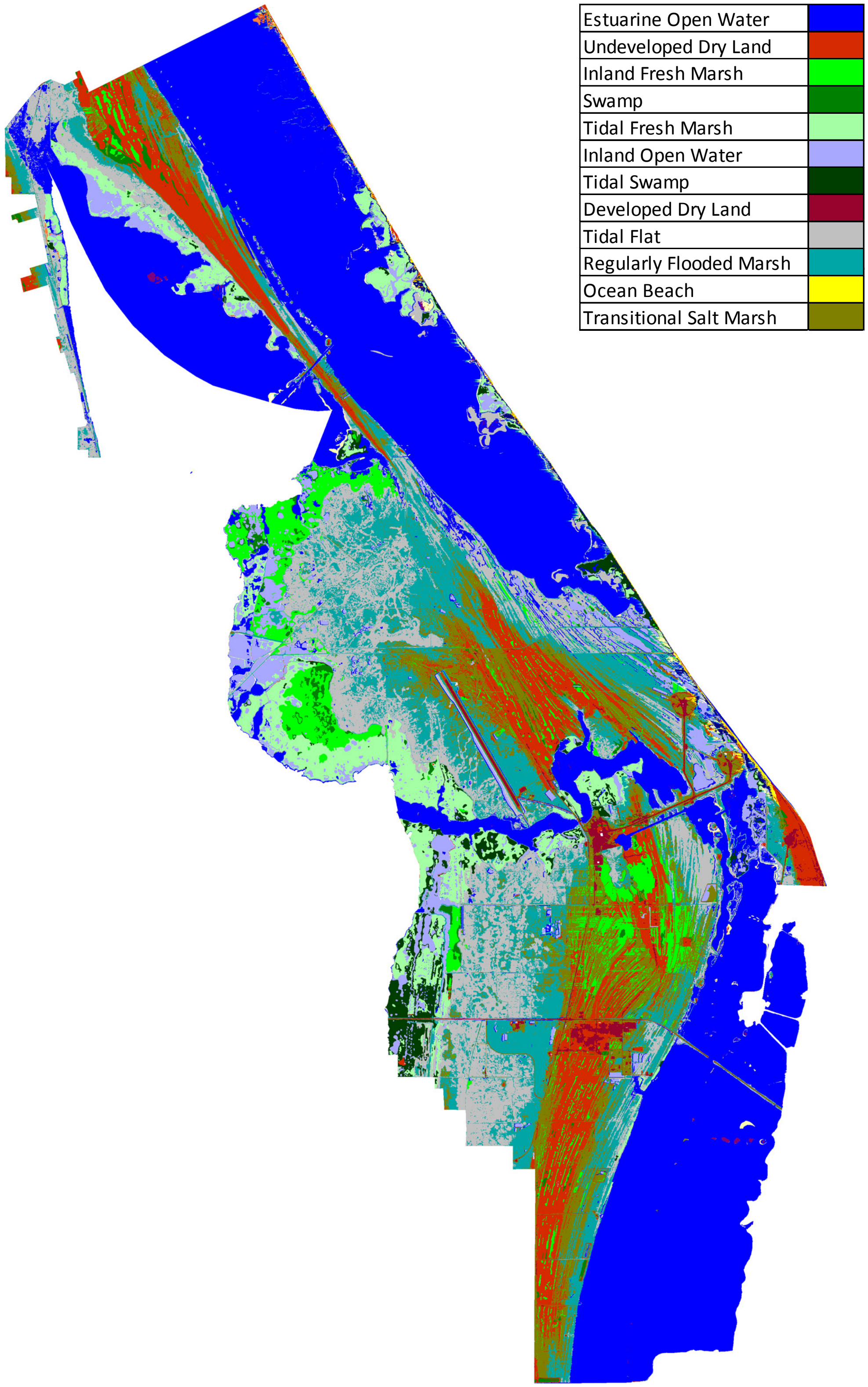

Merritt Island NWR, 2100, 2 m SLR

Discussion

SLAMM predictions for Merritt Island NWR suggest the refuge will be impacted by sea-level rise. Each wetland category that currently exists in the refuge is predicted to undergo increasingly significant losses with increasing sea-level rise. In contrast, some habitat types that are not currently present in the refuge or cover only a few acres, such as transitional salt marsh, regularly-flooded marsh, and tidal flat, are predicted to increase their coverage across all SLR scenarios simulated.

Compared to a previous SLAMM analysis of the refuge, these new predictions confirm the sensitivity of the wetlands of Merritt Island NWR to SLR. The 2009 NWI layer is very similar to the 1984 wetland layer used in the previous study while the recent and more precise elevation layer of 2007 leads to the quantitative differences observed between the two analyses. Overall, wetlands appear to be more vulnerable to SLR in the current model application due to a more refined but lower elevation distribution. On the contrary, dry land appears to be more resilient. In contrast to previous simulations, irregularly-flooded marsh is now predicted to gain coverage in the lowest SLR scenario. However losses became more extreme as sea level continues to rise.

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, in the future, the variability and confidence of the results could be studied as a function of the uncertainty within the accretion inputs.

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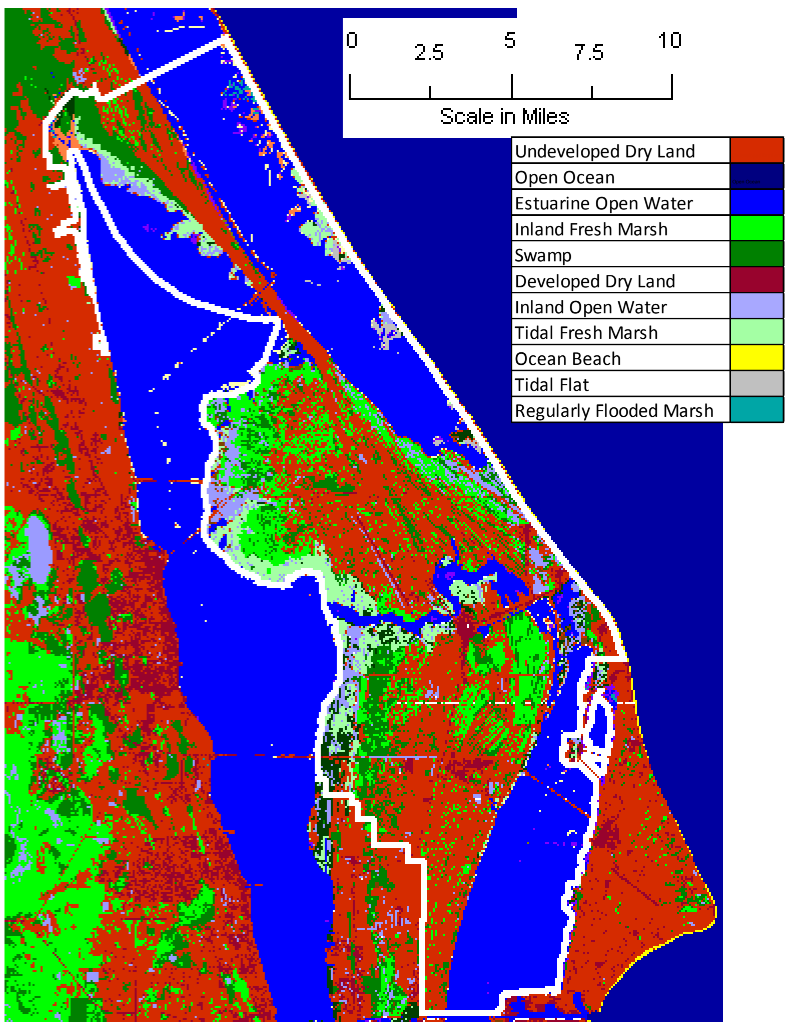
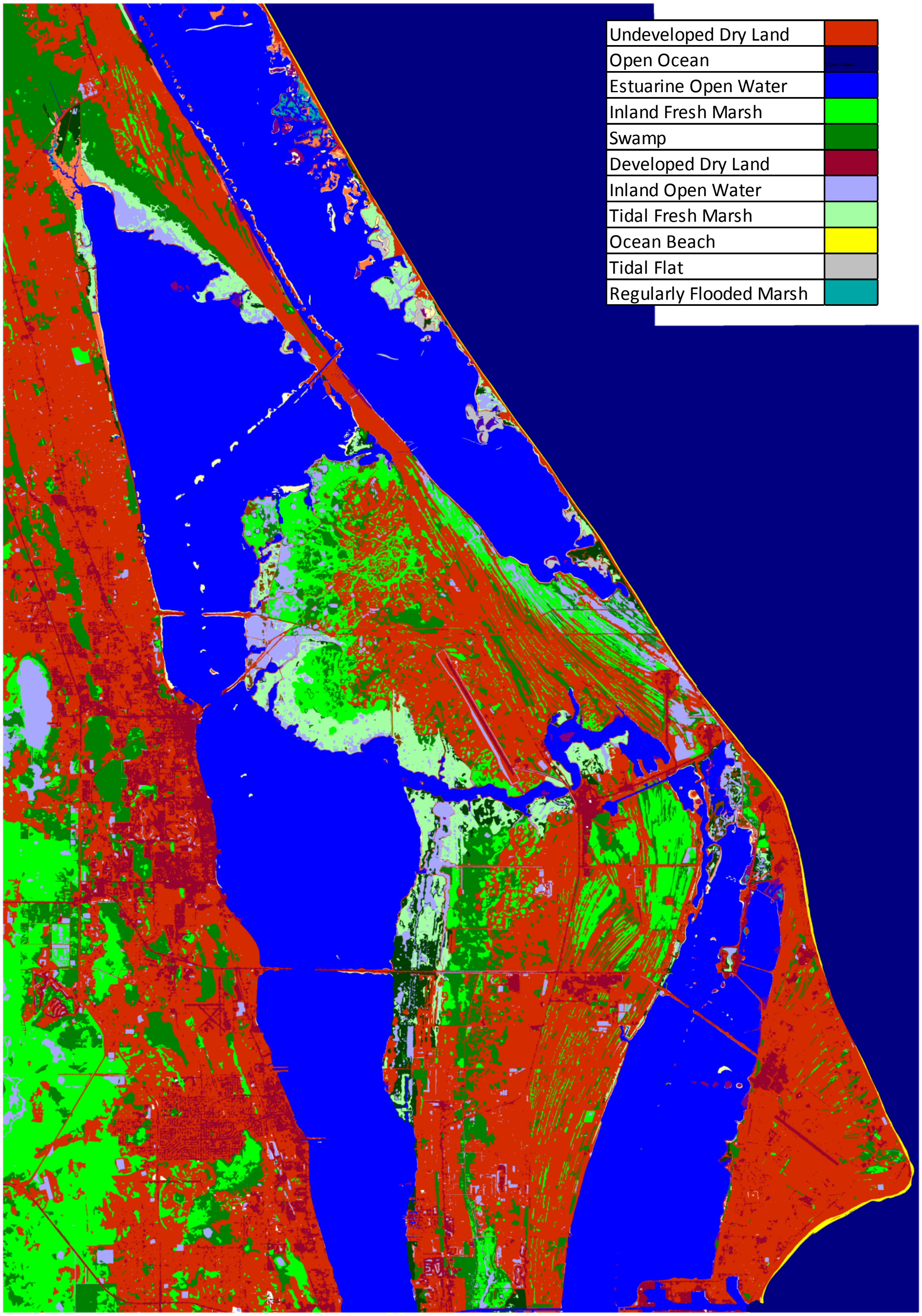
Appendix A: Contextual Results

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:

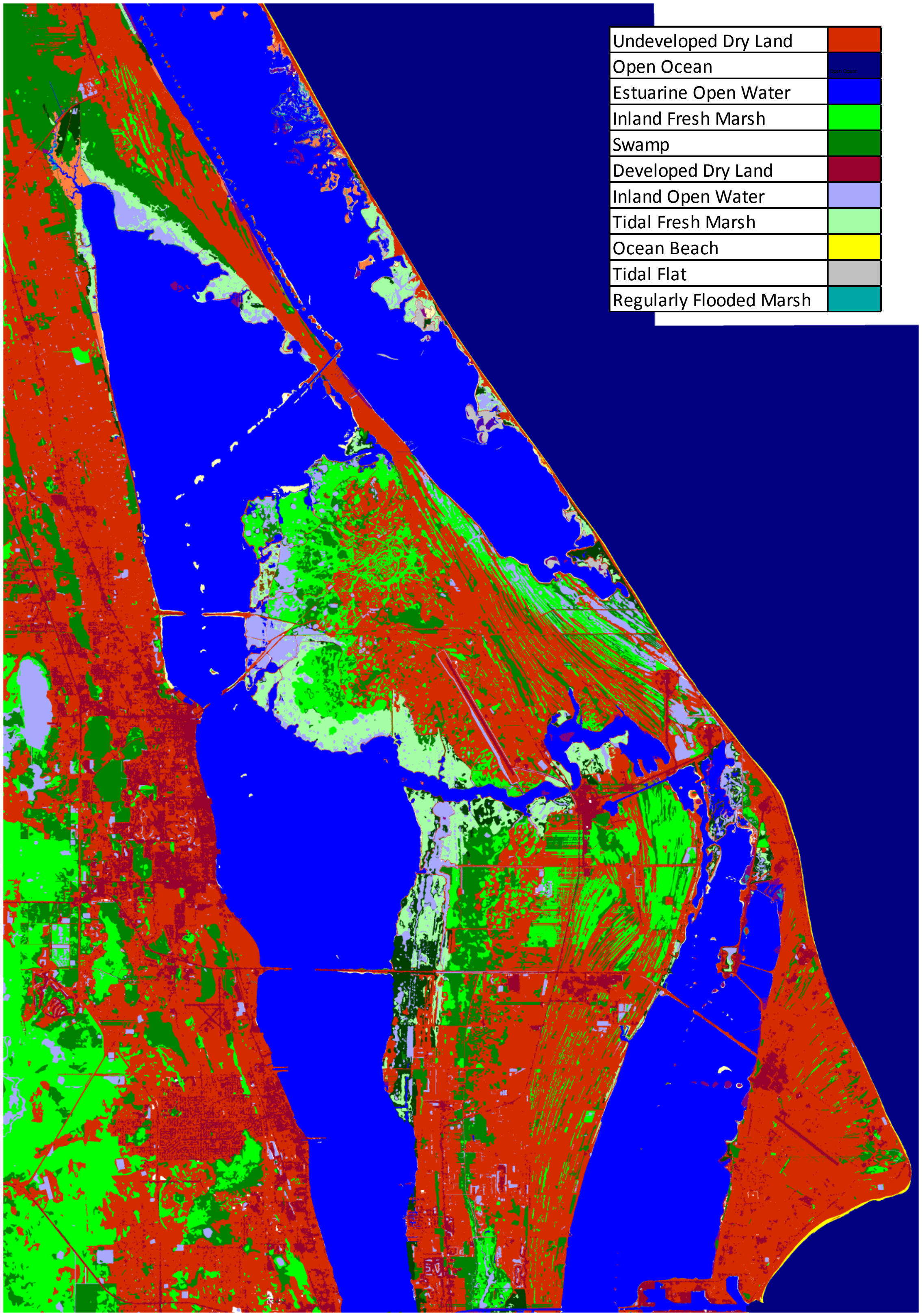
- Results were critically examined within USFWS refuges but not closely examined for the larger region.
- Site-specific parameters for the model were derived for USFWS refuges whenever possible and may not be regionally applicable.
- Especially in areas where dikes are present, an effort was made to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



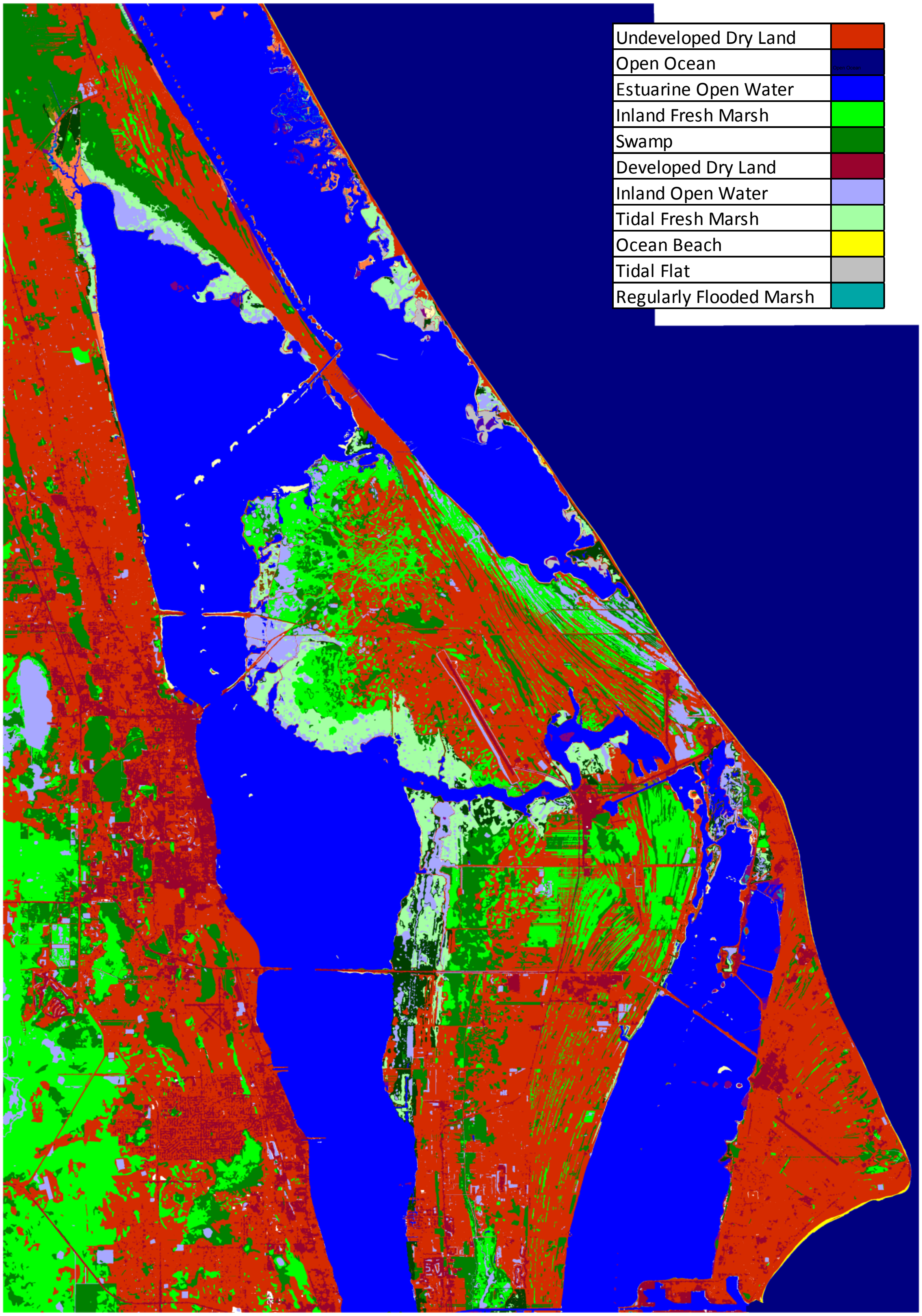
Merritt Island National Wildlife Refuge within simulation context (white).



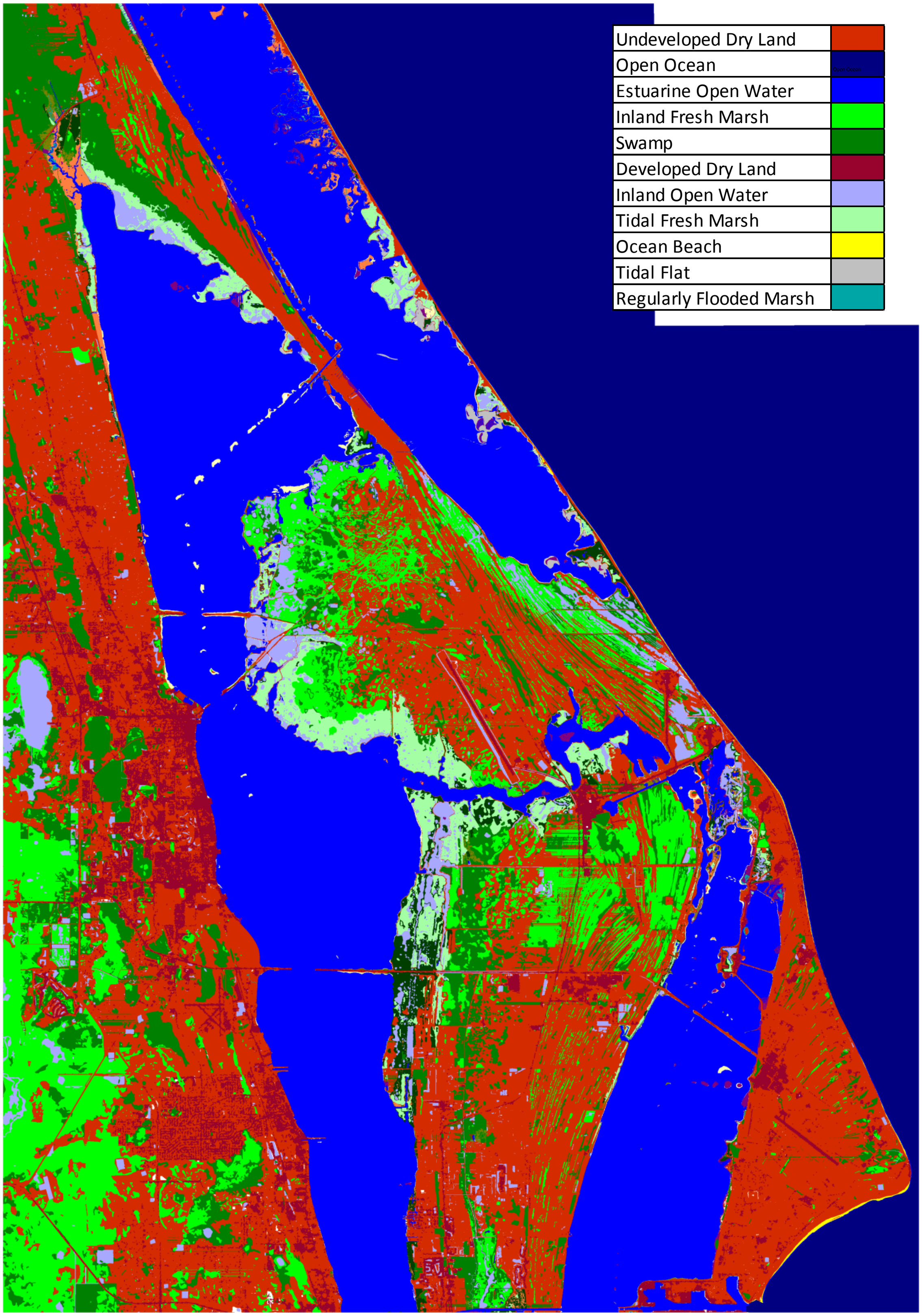
Merritt Island NWR, Initial Condition



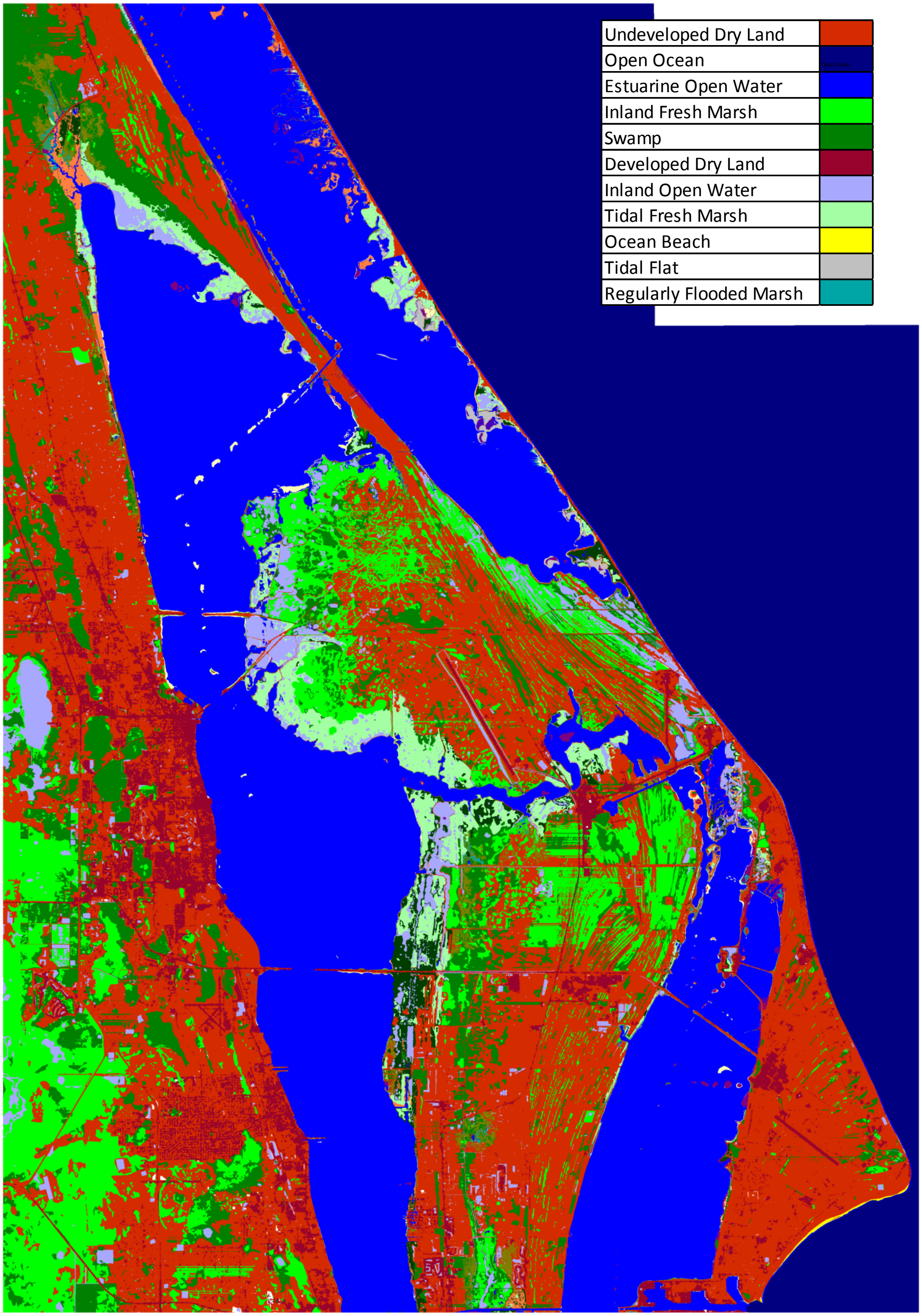
Merritt Island NWR, 2025, Scenario A1B Mean, 0.39 m SLR



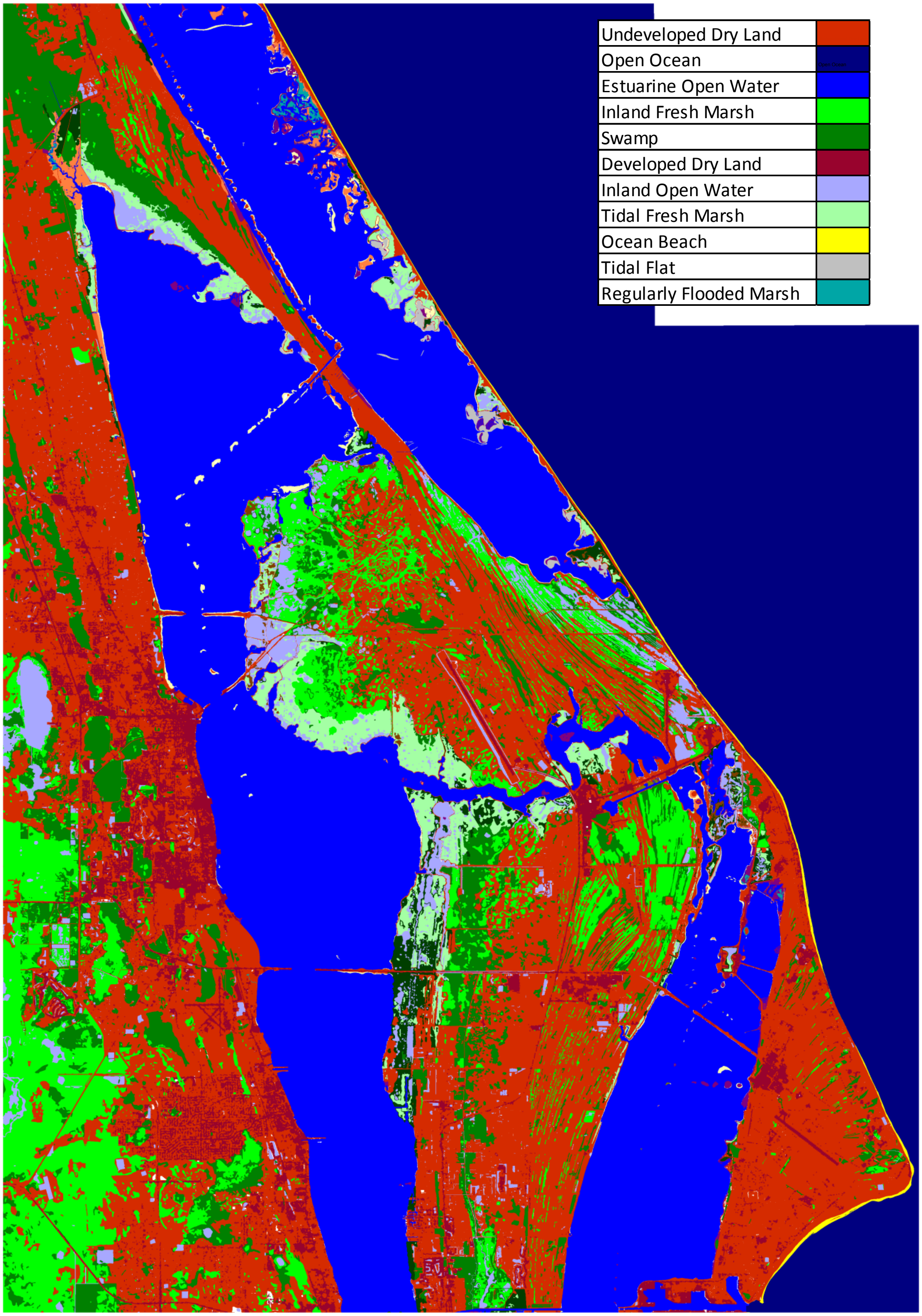
Merritt Island NWR, 2050, Scenario A1B Mean, 0.39 m SLR



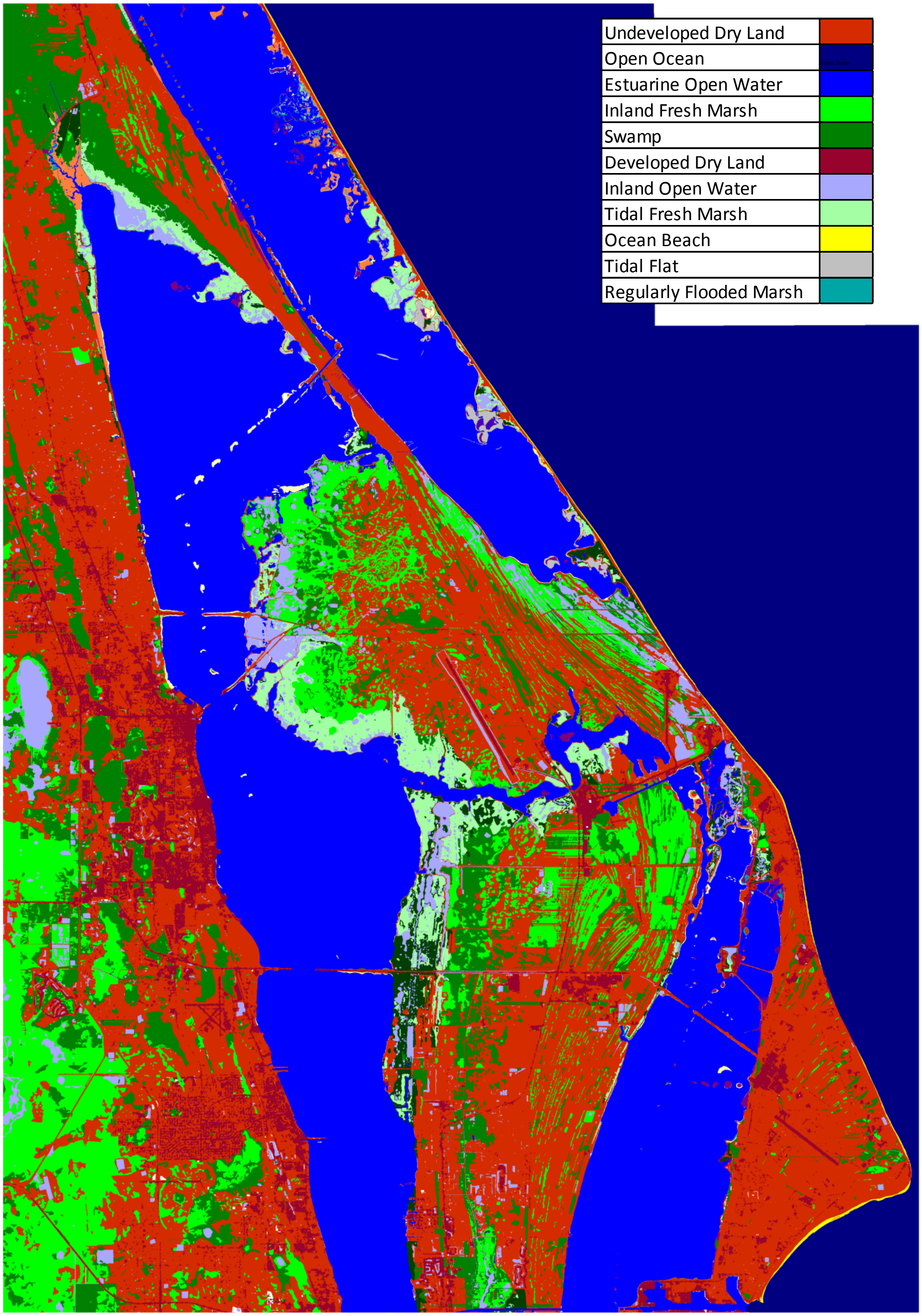
Merritt Island NWR, 2075, Scenario A1B Mean, 0.39 m SLR



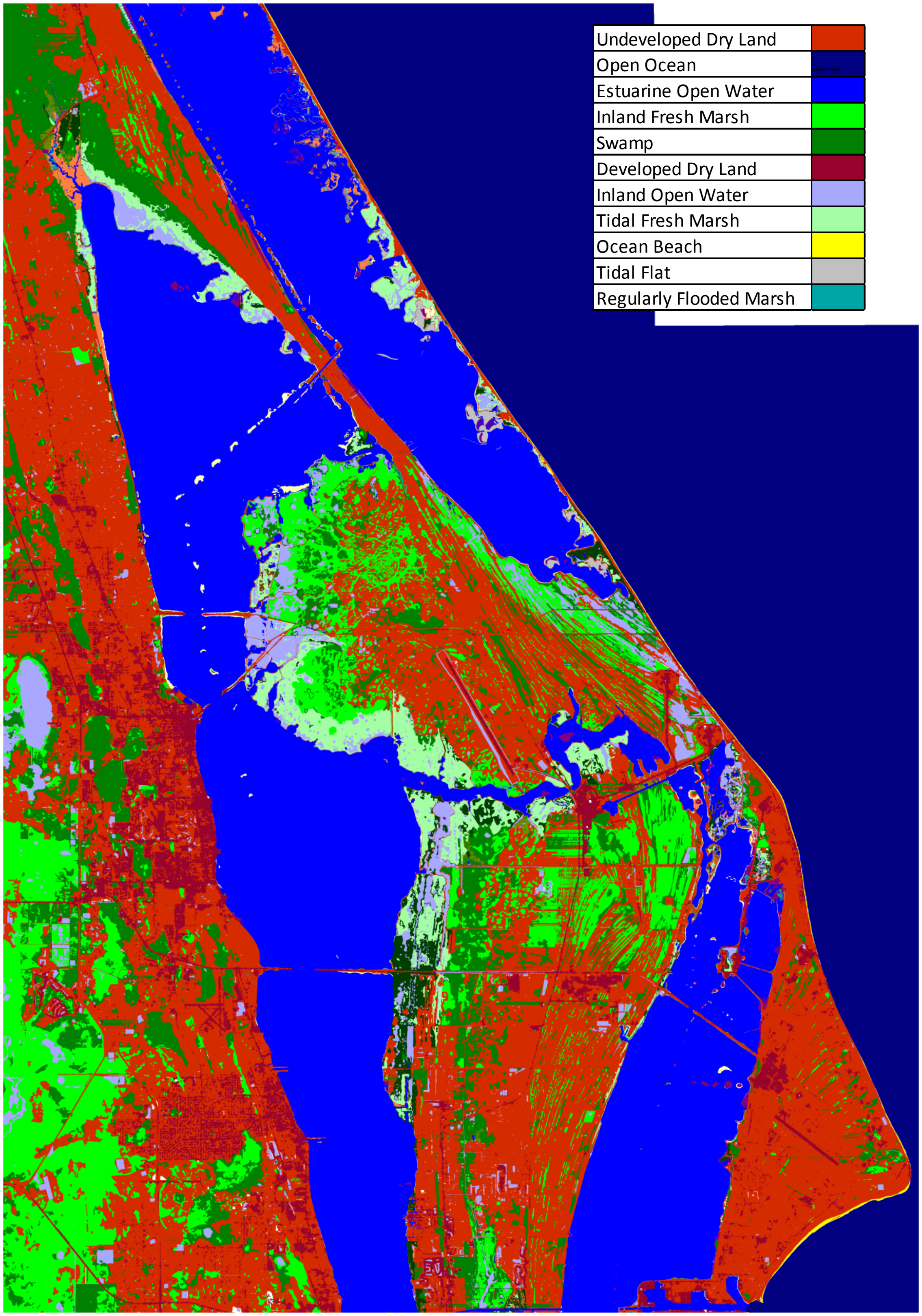
Merritt Island NWR, 2100, Scenario A1B Mean, 0.39 m SLR



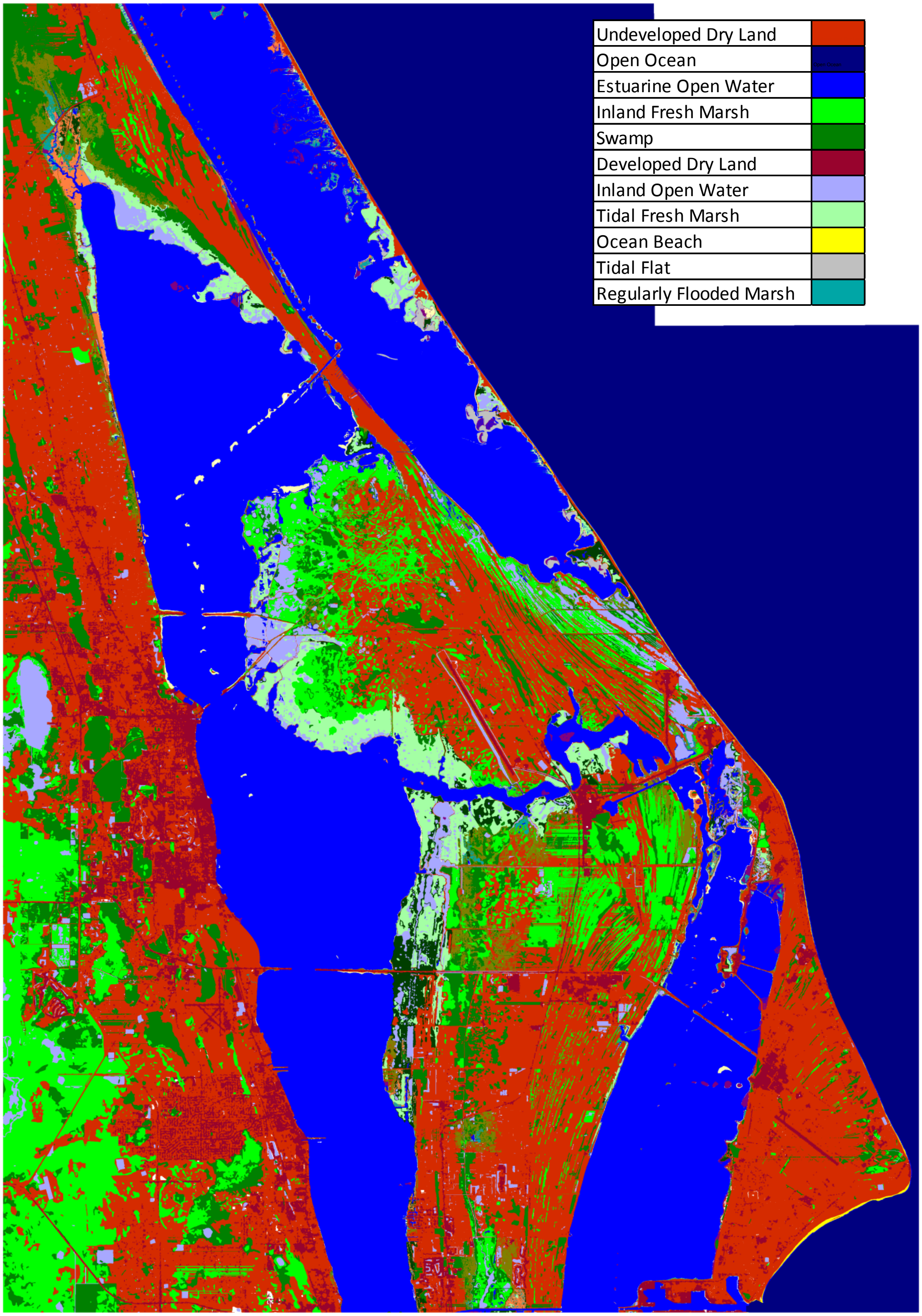
Merritt Island NWR, Initial Condition



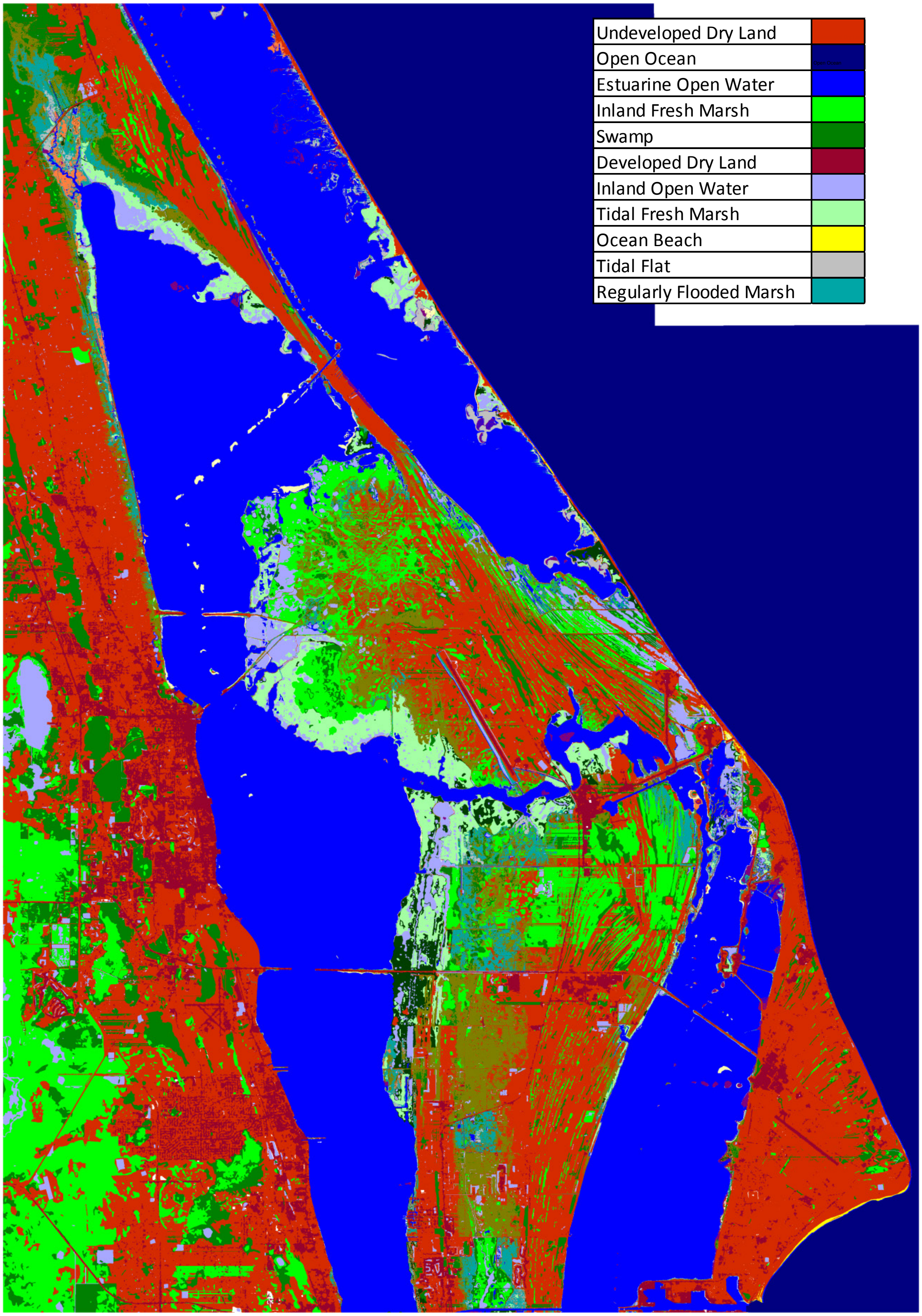
Merritt Island NWR, 2025, Scenario A1B Maximum, 0.69 m SLR



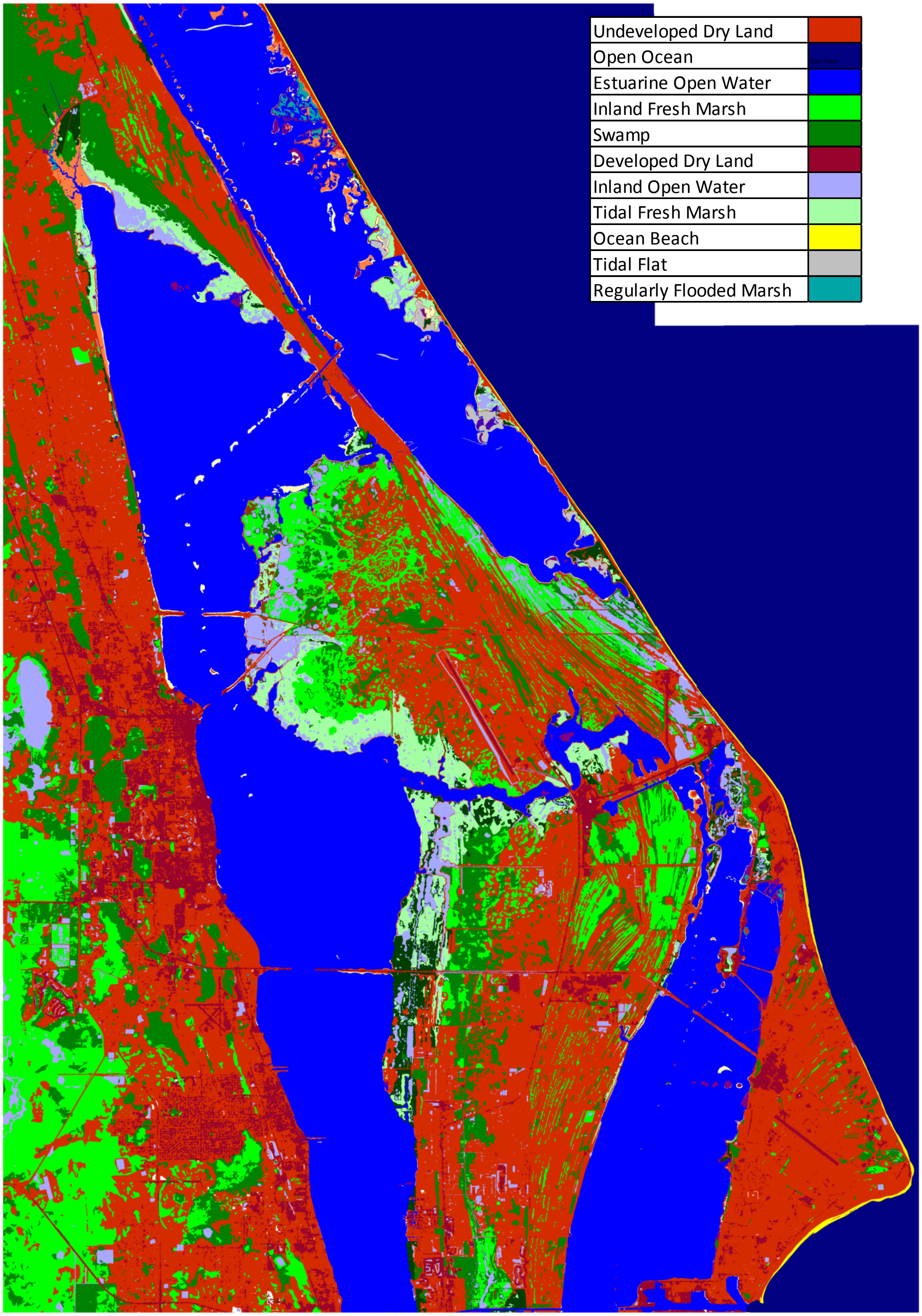
Merritt Island NWR, 2050, Scenario A1B Maximum, 0.69 m SLR



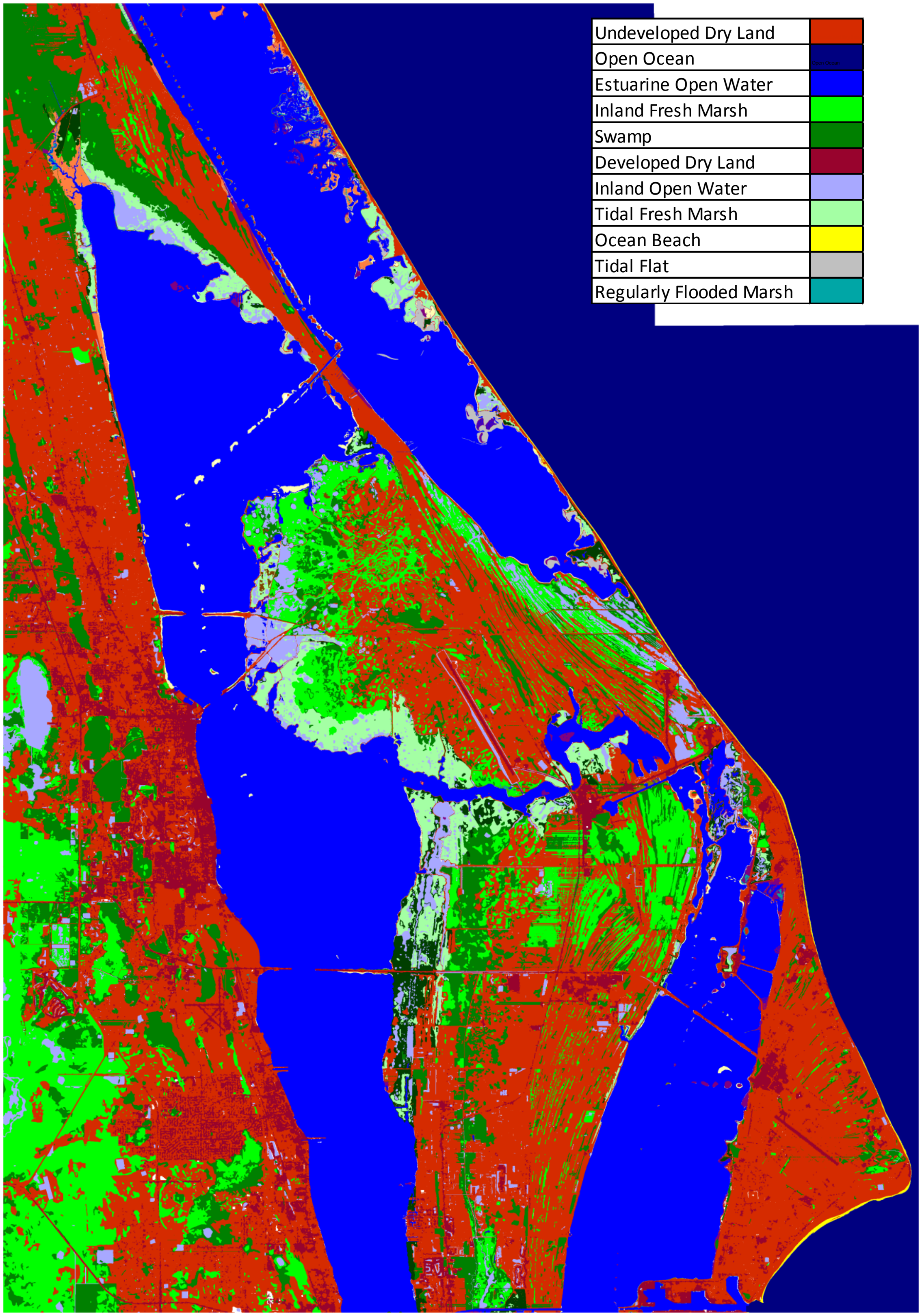
Merritt Island NWR, 2075, Scenario A1B Maximum, 0.69 m SLR



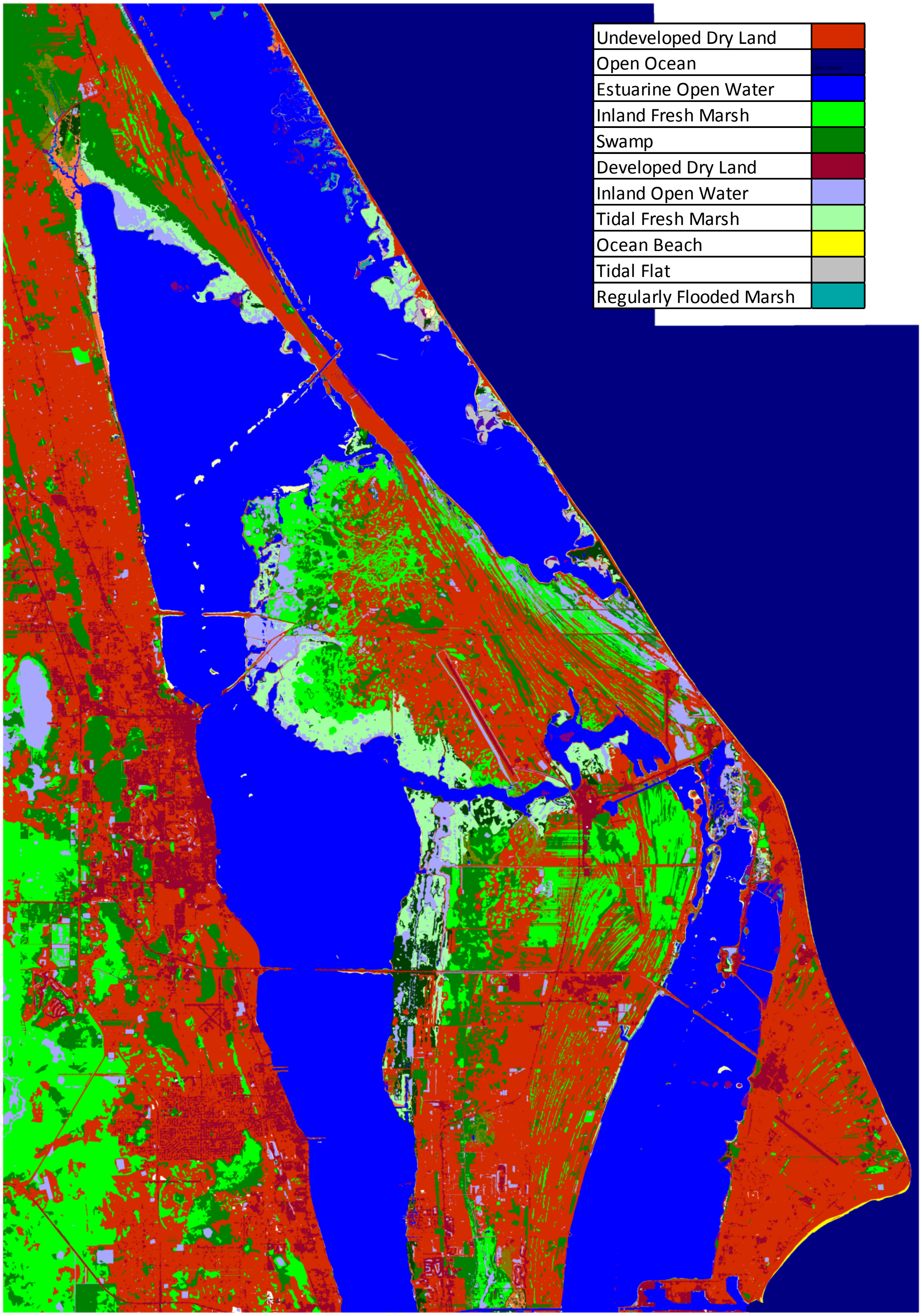
Merritt Island NWR, 2100, Scenario A1B Maximum, 0.69 m SLR



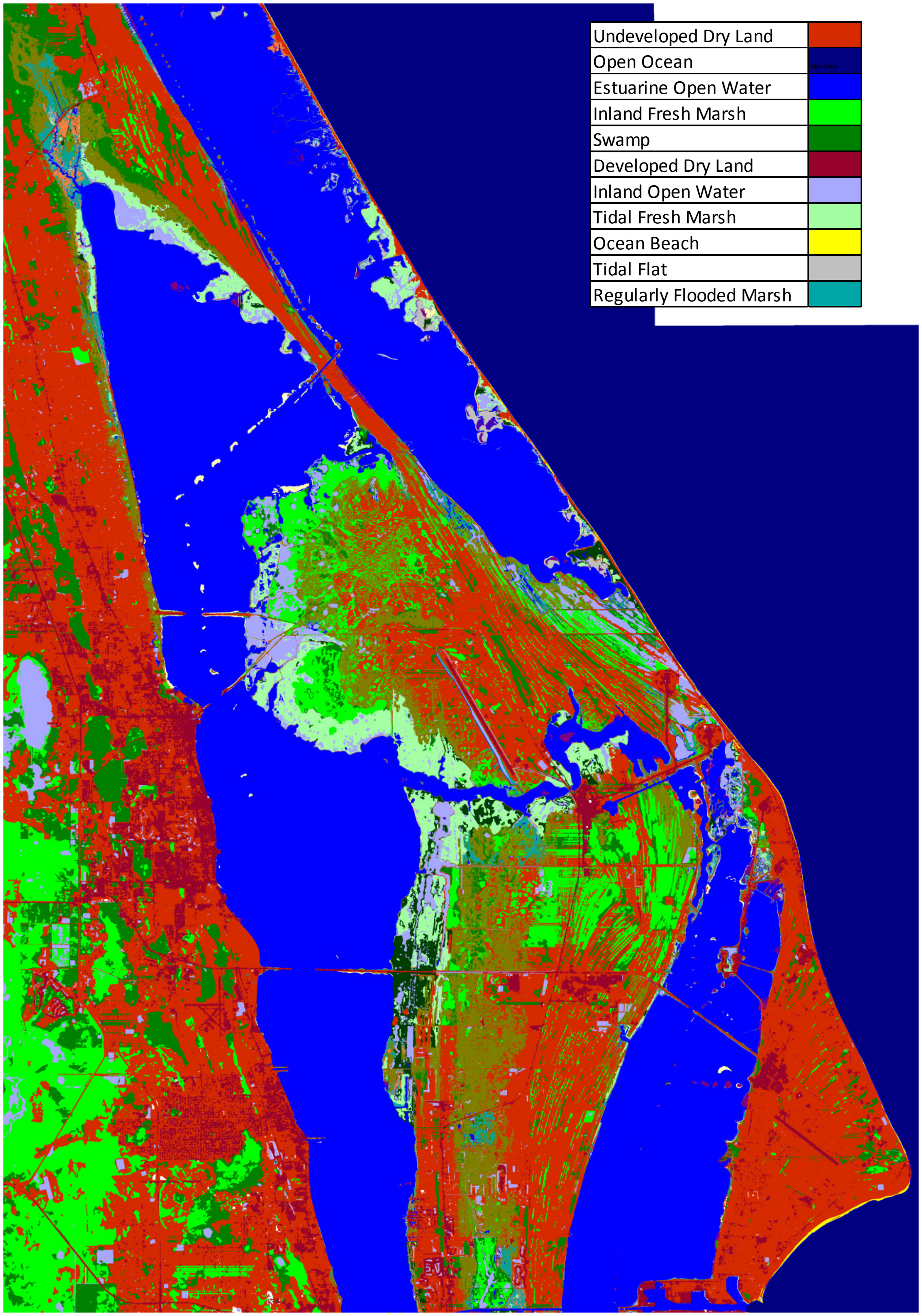
Merritt Island NWR, Initial Condition



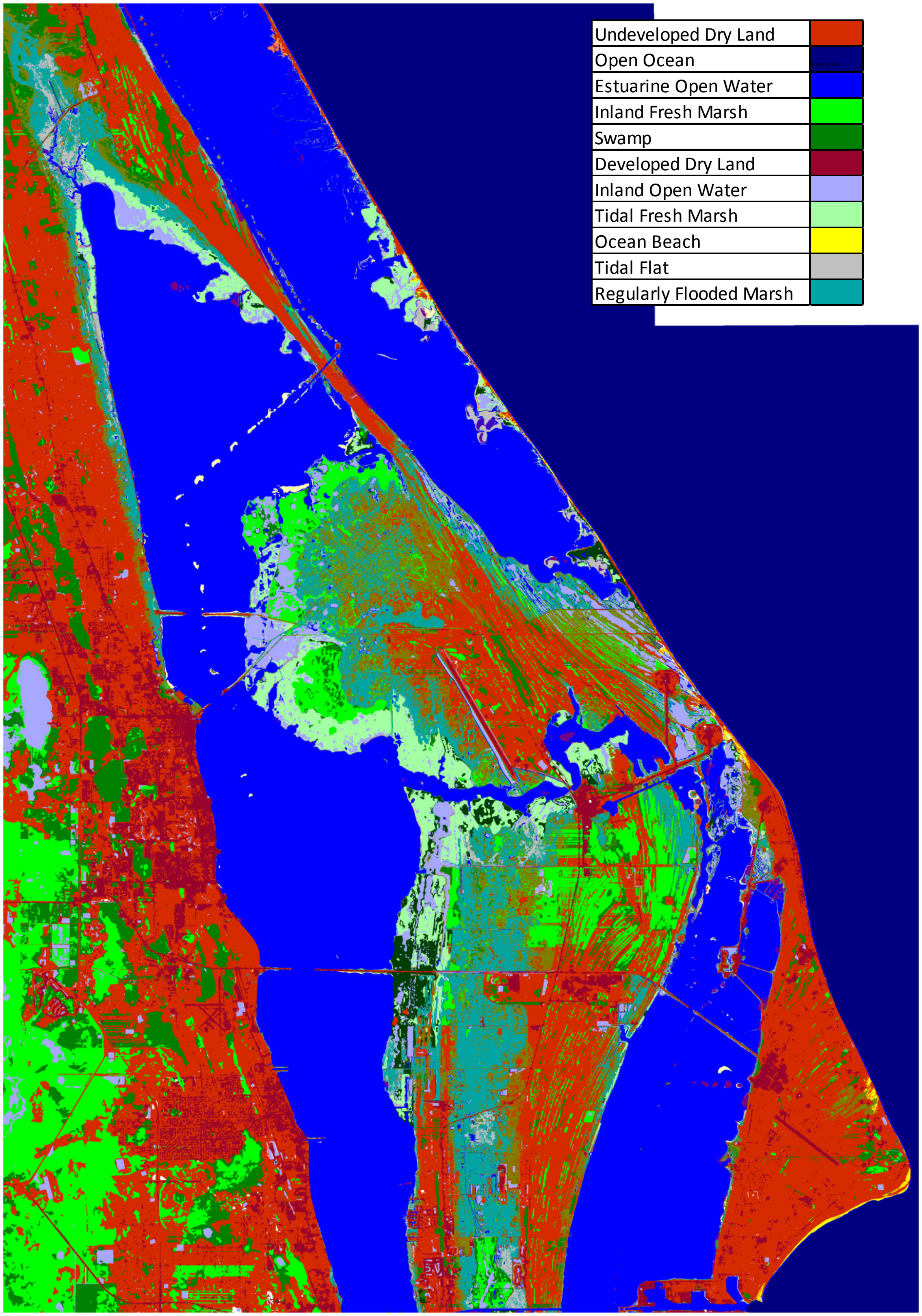
Merritt Island NWR, 2025, 1 m SLR



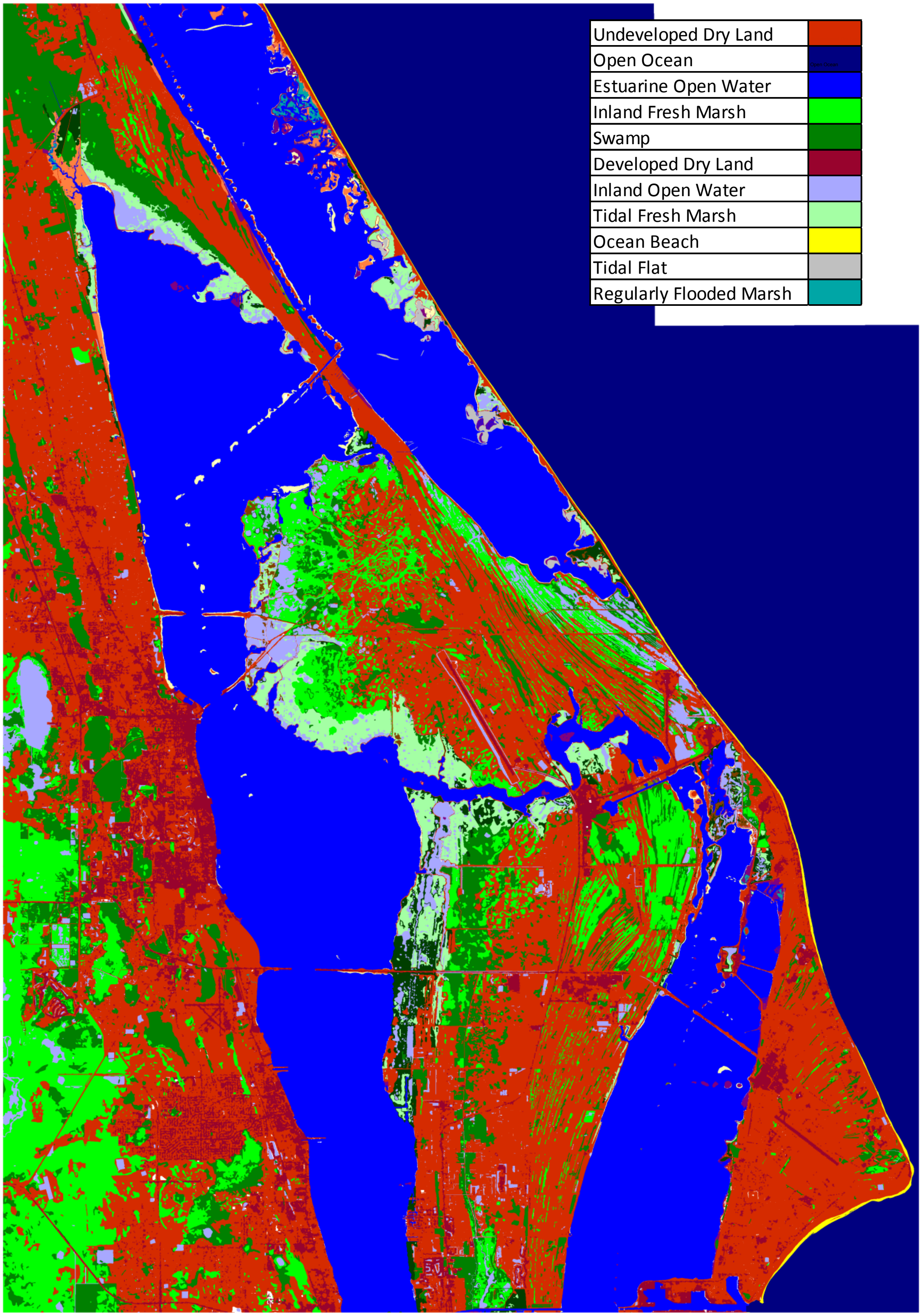
Merritt Island NWR, 2050, 1 m SLR



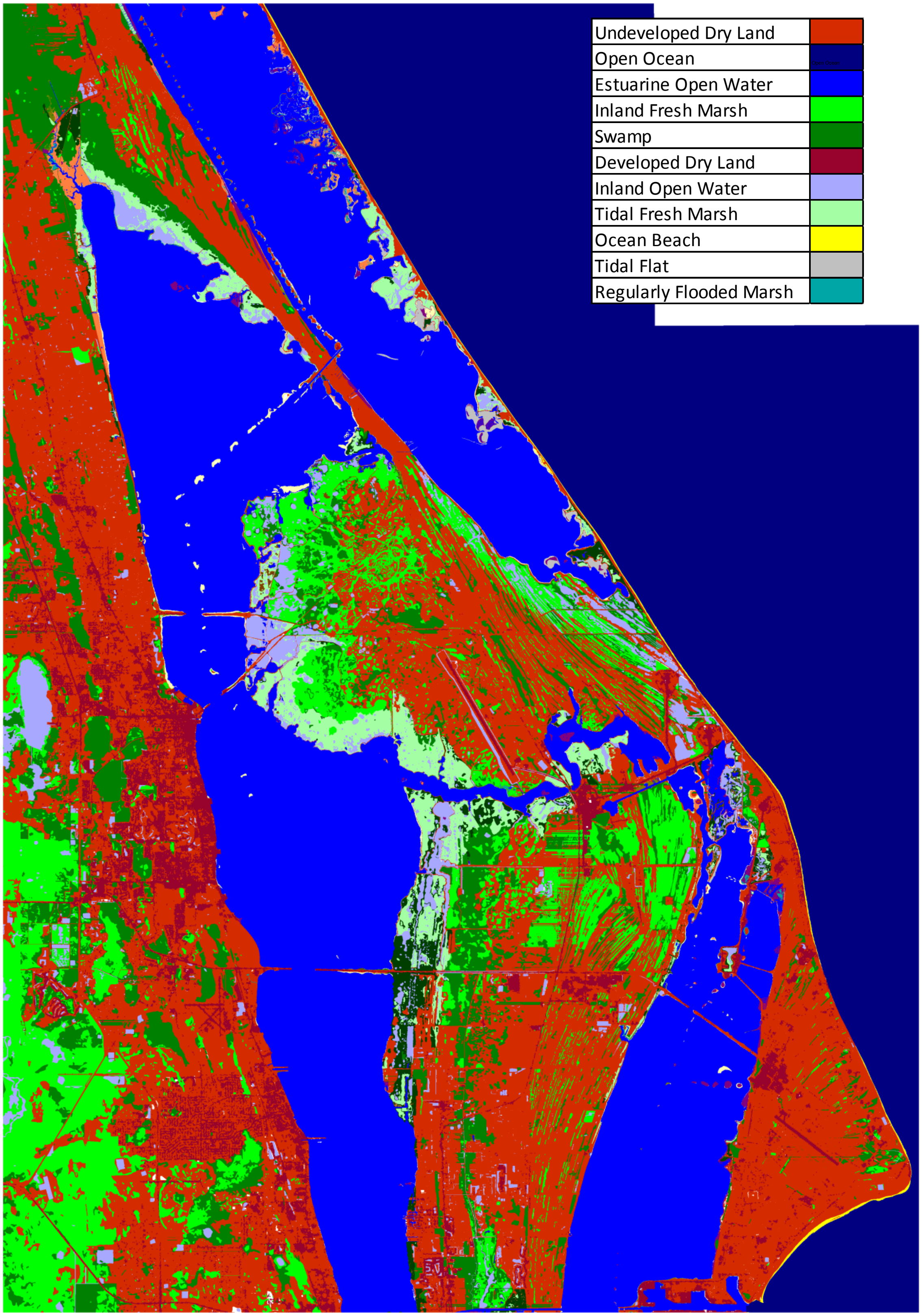
Merritt Island NWR, 2075, 1 meter



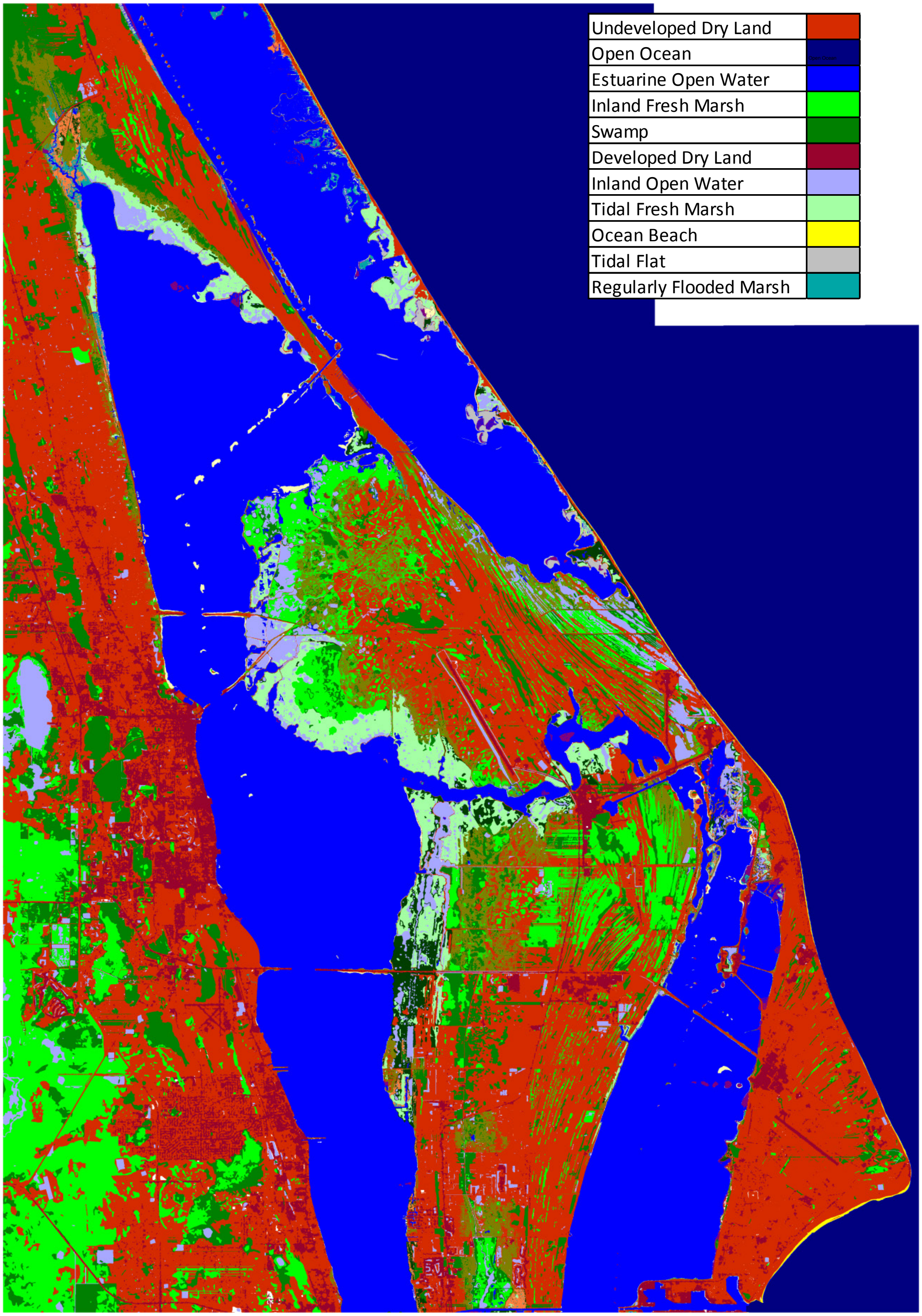
Merritt Island NWR, 2100, 1 m SLR



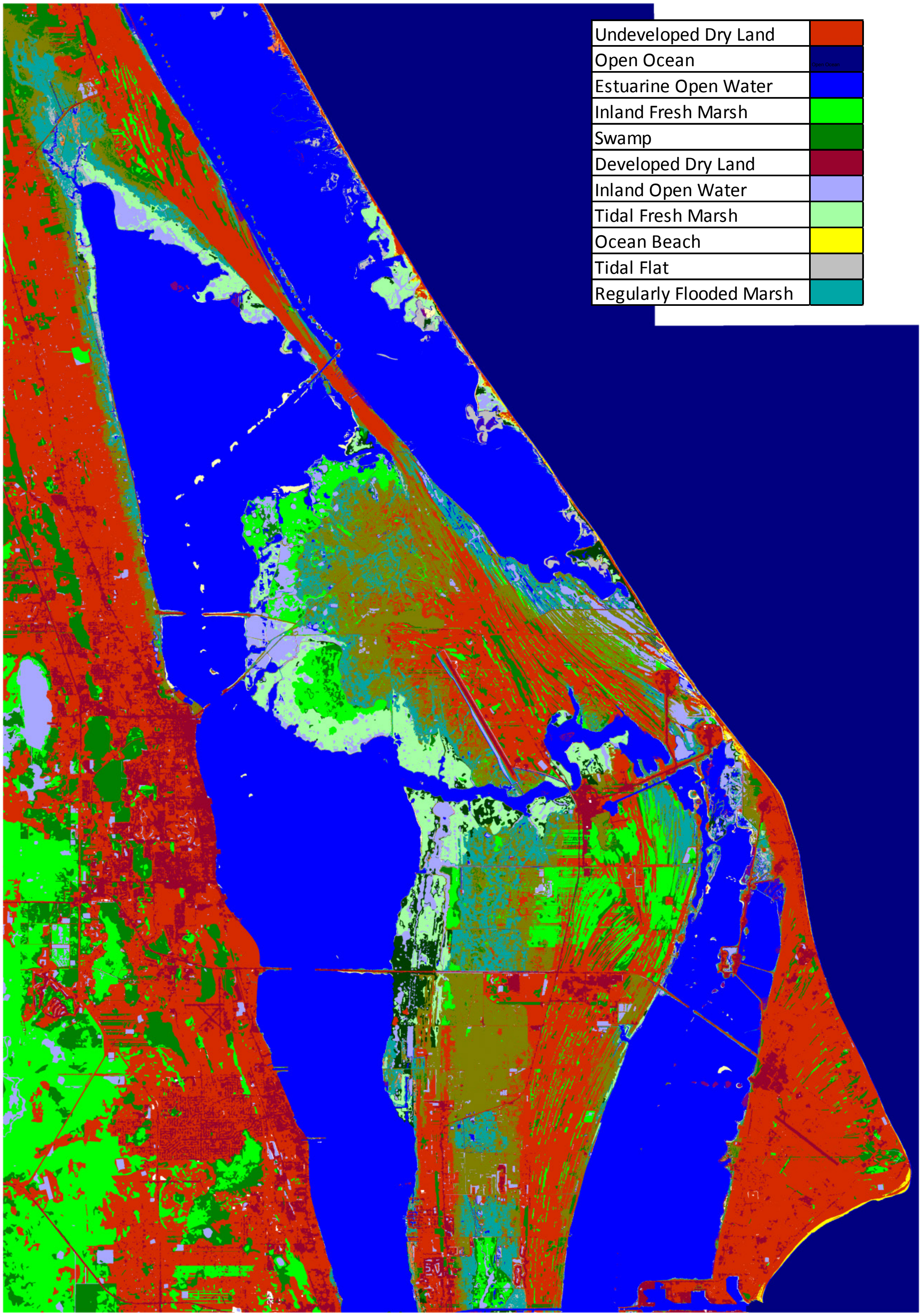
Merritt Island NWR, Initial Condition



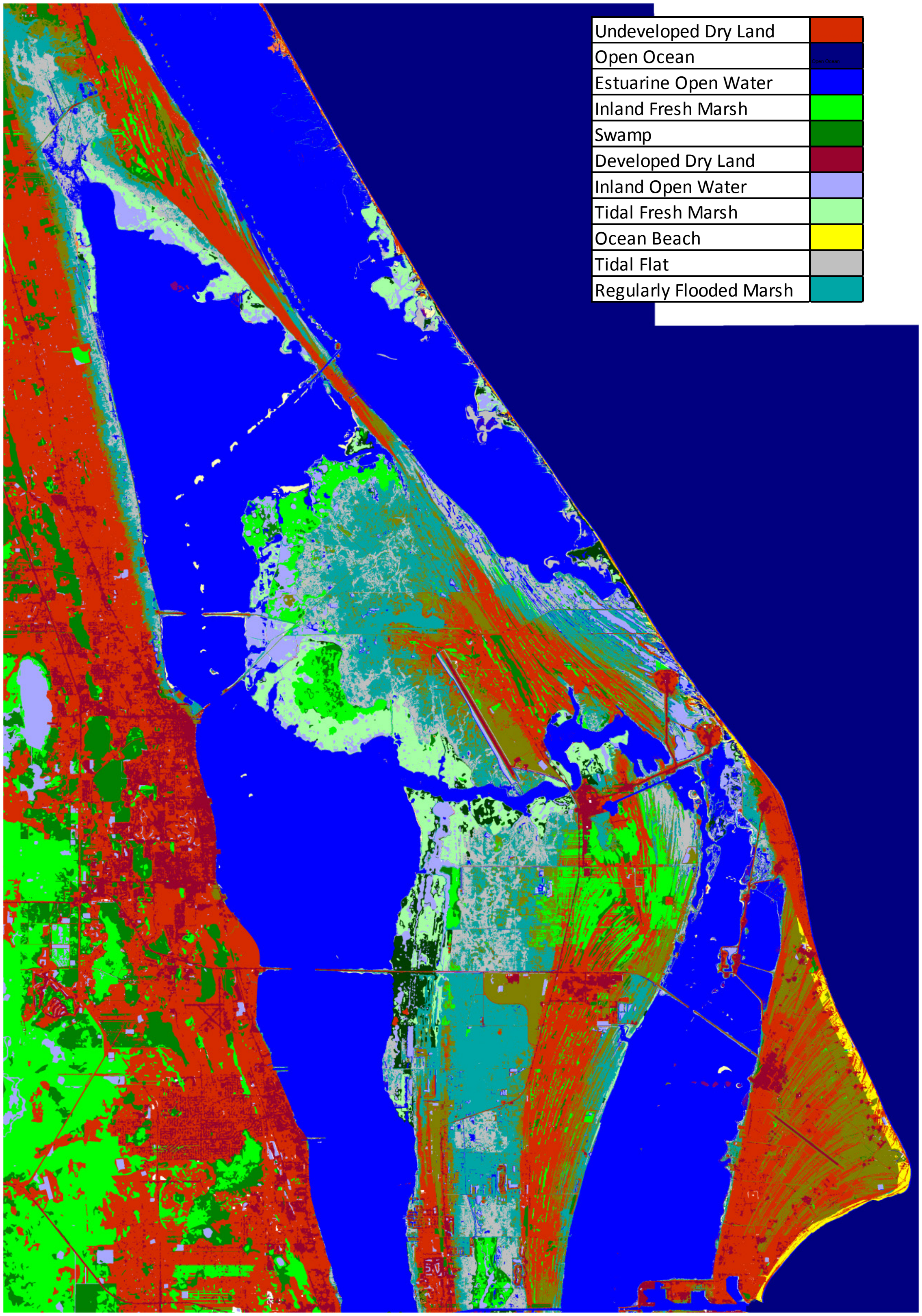
Merritt Island NWR, 2025, 1.5 m SLR



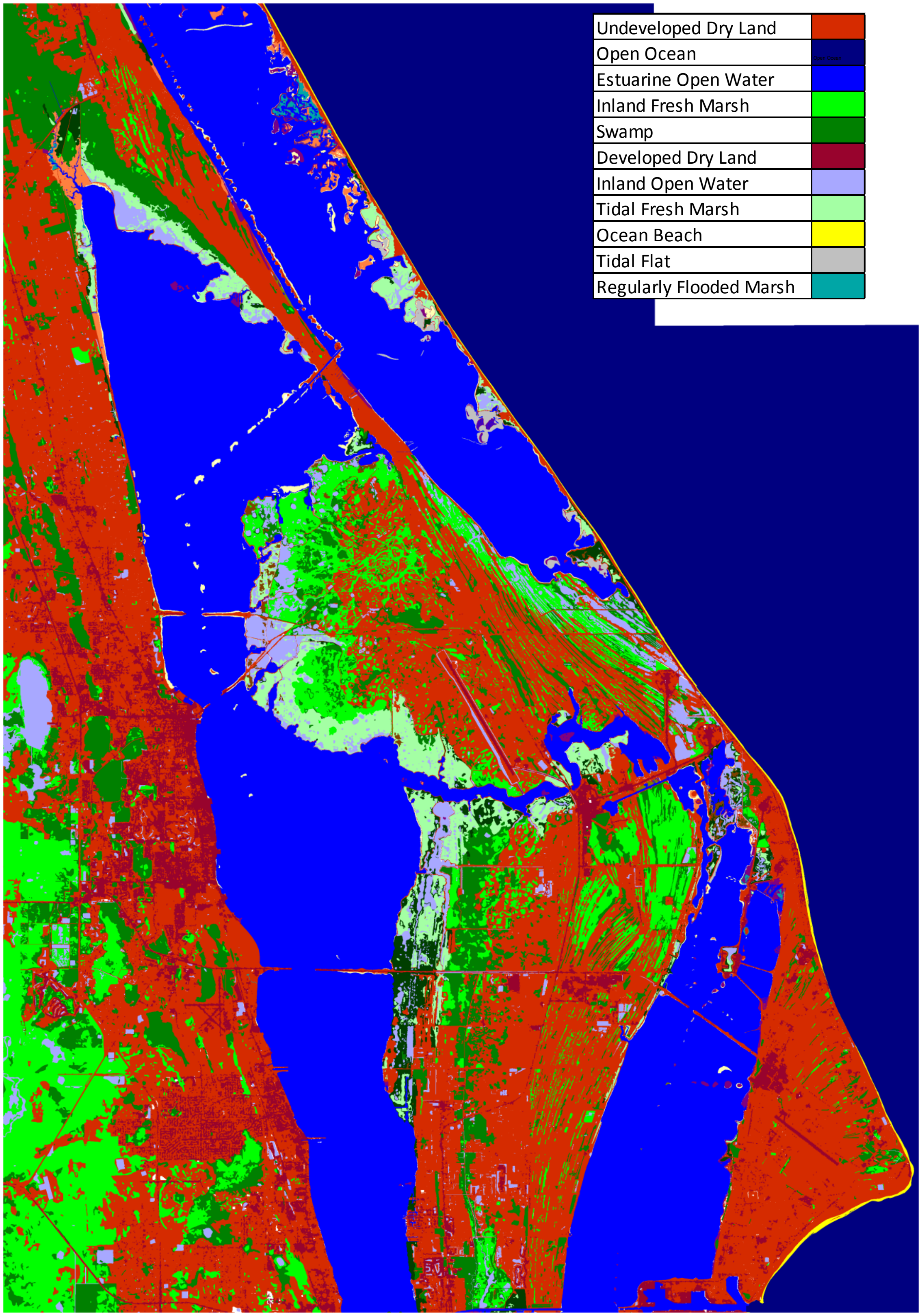
Merritt Island NWR, 2050, 1.5 m SLR



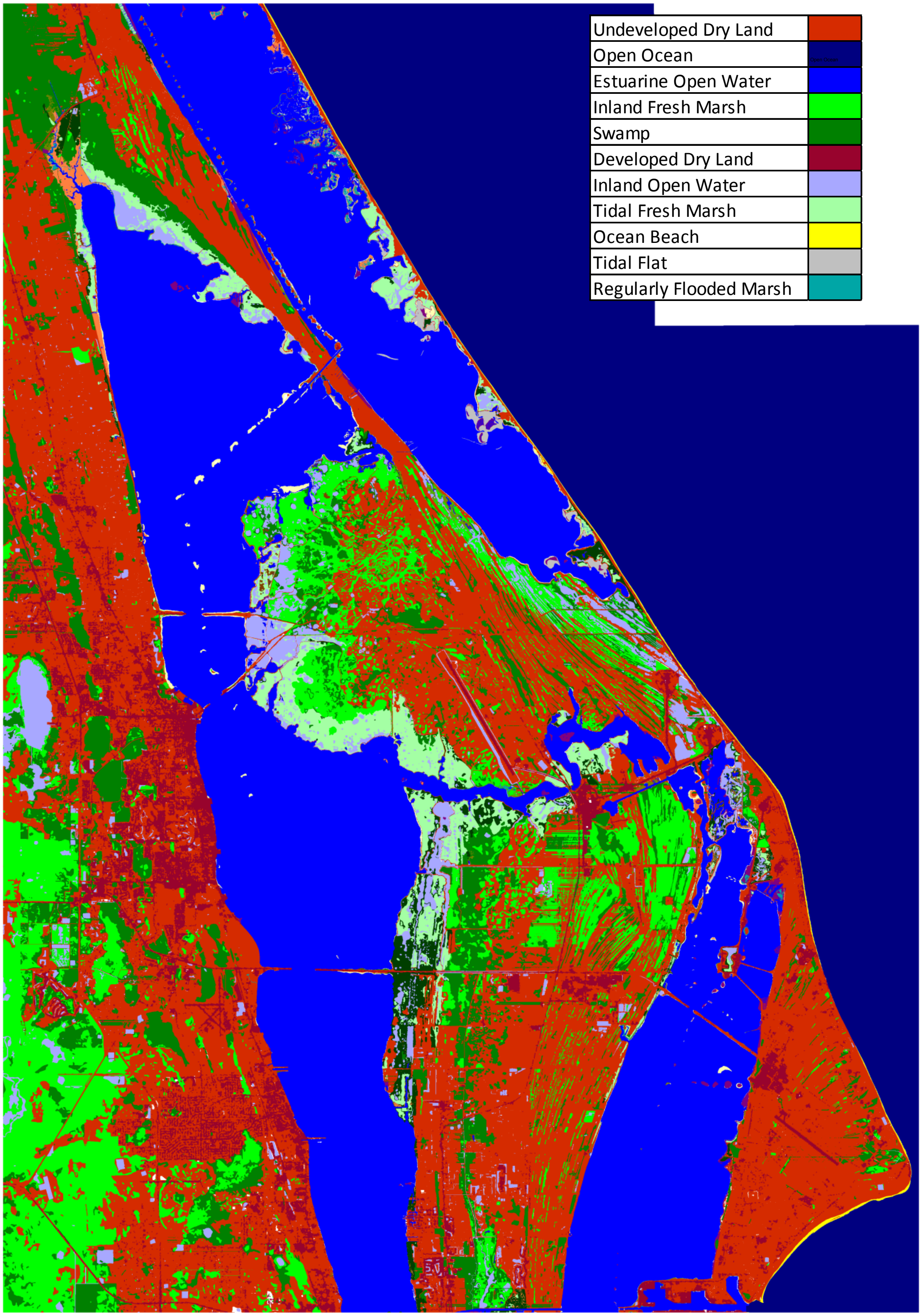
Merritt Island NWR, 2075, 1.5 m SLR



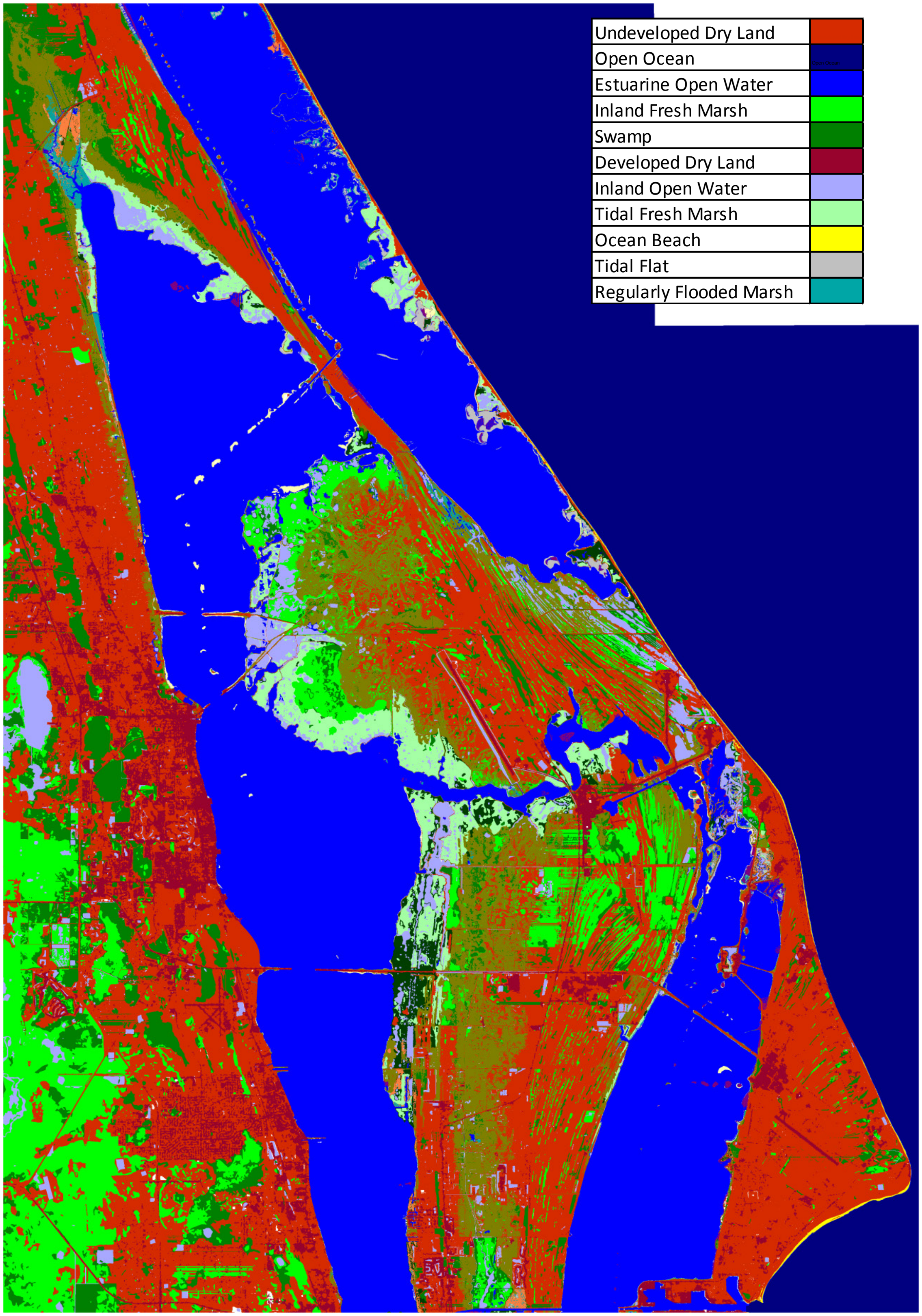
Merritt Island NWR, 2100, 1.5 m SLR



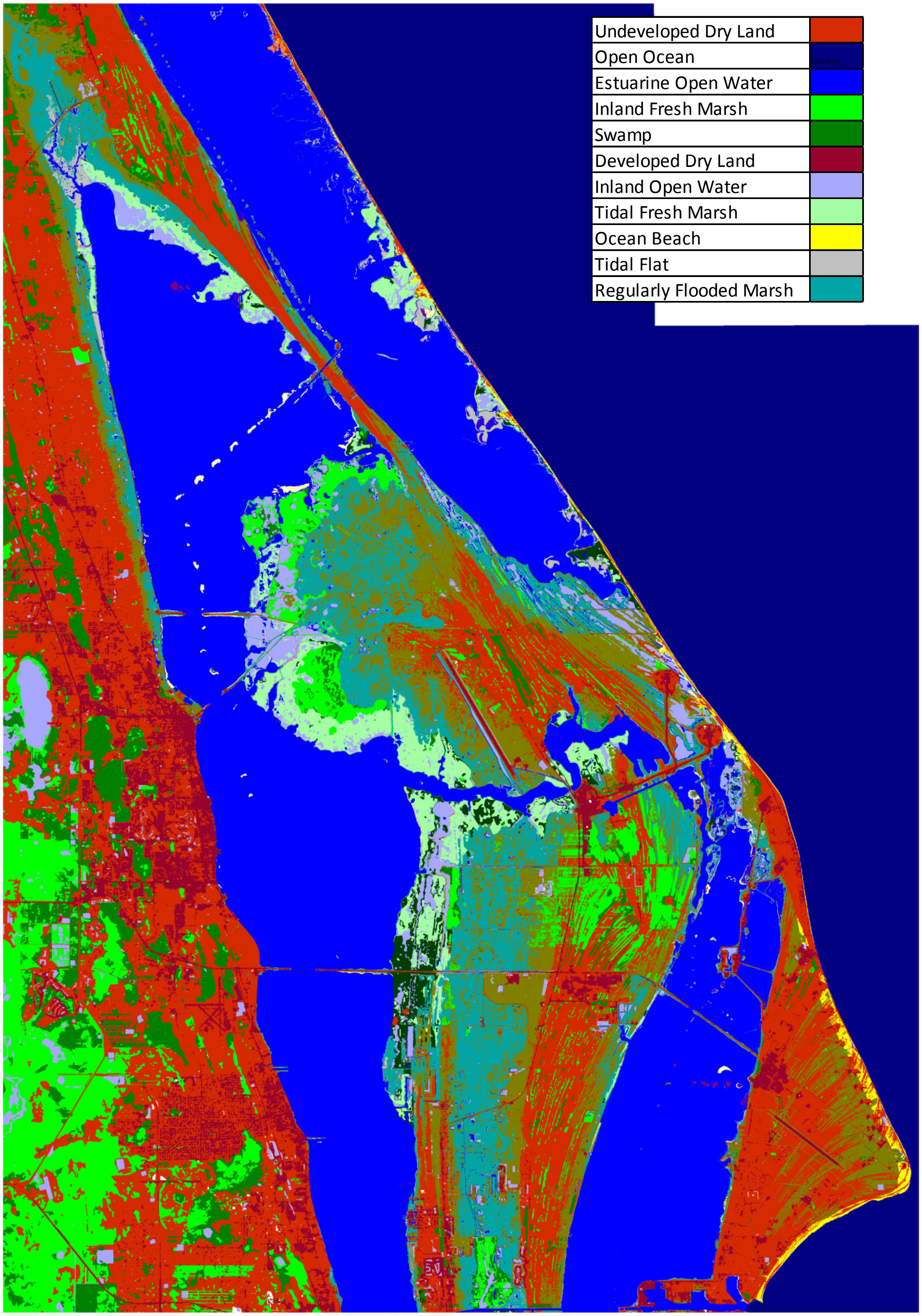
Merritt Island NWR, Initial Condition



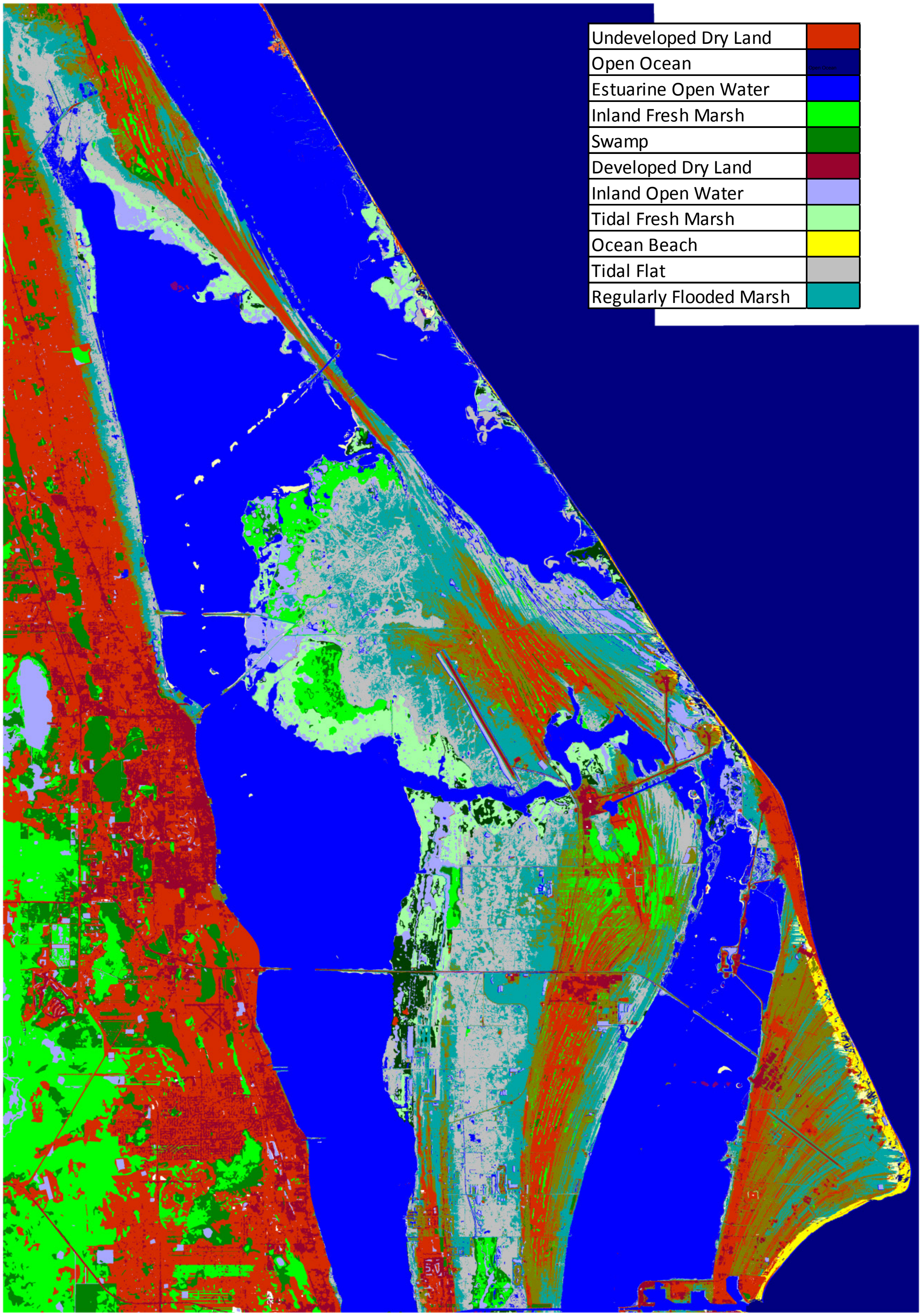
Merritt Island NWR, 2025, 2 m SLR



Merritt Island NWR, 2050, 2 m SLR



Merritt Island NWR, 2075, 2 m SLR



Merritt Island NWR, 2100, 2 m SLR