Application of the Sea-Level Affecting Marshes Model (SLAMM 6) to Currituck 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 most Region 1 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, J.K., R.A. Park, and P.W. Mausel. 1992; Park, R.A., J.K. Lee, and D. Canning 1993; Galbraith, H., R. Jones, R.A. Park, J.S. Clough, S. Herrod-Julius, B. Harrington, and G. Page. 2002; National Wildlife Federation et al., 2006; Glick, Clough, 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 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 or 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, Park, Fuller, 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 (CREM 2008). Site-specific factors that increase or decrease model uncertainty may be covered in the *Discussion* section of this report.

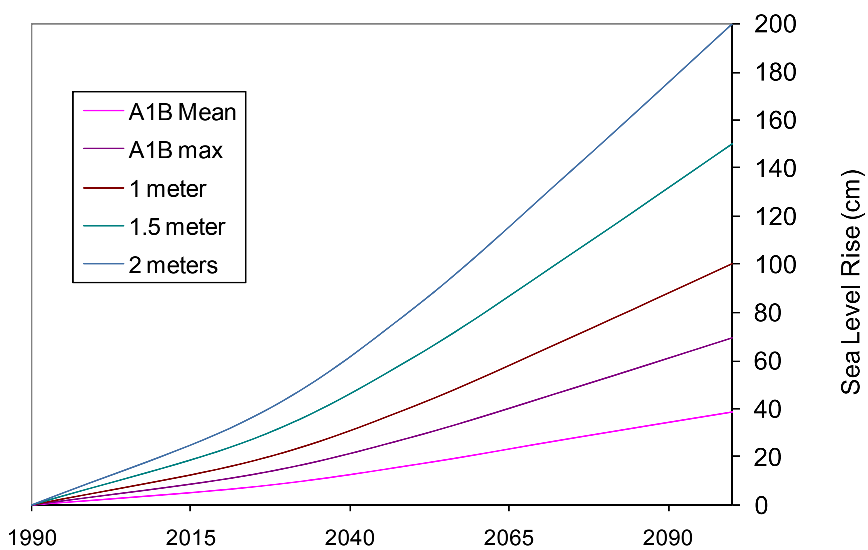
Sea Level Rise Scenarios

SLAMM 6 was run using scenario A1B from the Special Report on Emissions Scenarios (SRES) – mean and maximum estimates. 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. In particular, the A1B scenario assumes that energy sources will be balanced across all sources. Under the A1B scenario, the IPCC WGI Fourth Assessment Report (IPCC, 2007) suggests a likely range of 0.21 to 0.48 meters of sea level rise by 2090-2099 "excluding future rapid dynamical changes in ice flow." The A1B-mean scenario that was run as a part of this project falls near the middle of this estimated range, predicting 0.39 meters of global sea level rise by 2100. A1B-maximum predicts 0.69 meters of global SLR by 2100.

The latest literature (Chen et al., 2006, Monaghan et al., 2006) indicates that the eustatic rise in sea levels is progressing more rapidly than was previously assumed, perhaps due to the dynamic changes in ice flow omitted within the IPCC report's calculations. A recent paper in the journal *Science* (Rahmstorf, 2007) suggests that, taking into account possible model error, a feasible range by 2100 of 50 to 140 cm. 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 meters 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 sea level rises for the end of the 21st century are too low." (US Climate Change Science Program, 2008) 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.

To allow for flexibility when interpreting the results, SLAMM was also run assuming 1 meter, 1½ meters, and 2 meters of eustatic sea-level rise by the year 2100. The A1B- maximum scenario was scaled up to produce these bounding scenarios (Figure 1).

Figure 1: Summary of SLR Scenarios Utilized



Methods and Data Sources

The digital elevation map used in this simulation is a mosaic of two LiDAR-derived DEMs from NOAA (2008), and the National Elevation Dataset (2003, Figure 1). The NOAA LiDAR at the northernmost tip of the study area was not a bare-earth coverage but represented the best available elevation data for that region. Also, as can be seen to some degree in the image below, some wetland areas were apparently not covered by the LiDAR as they uniformly had elevations of zero. For these regions, wetland elevations were estimated using the SLAMM elevation pre-processor.

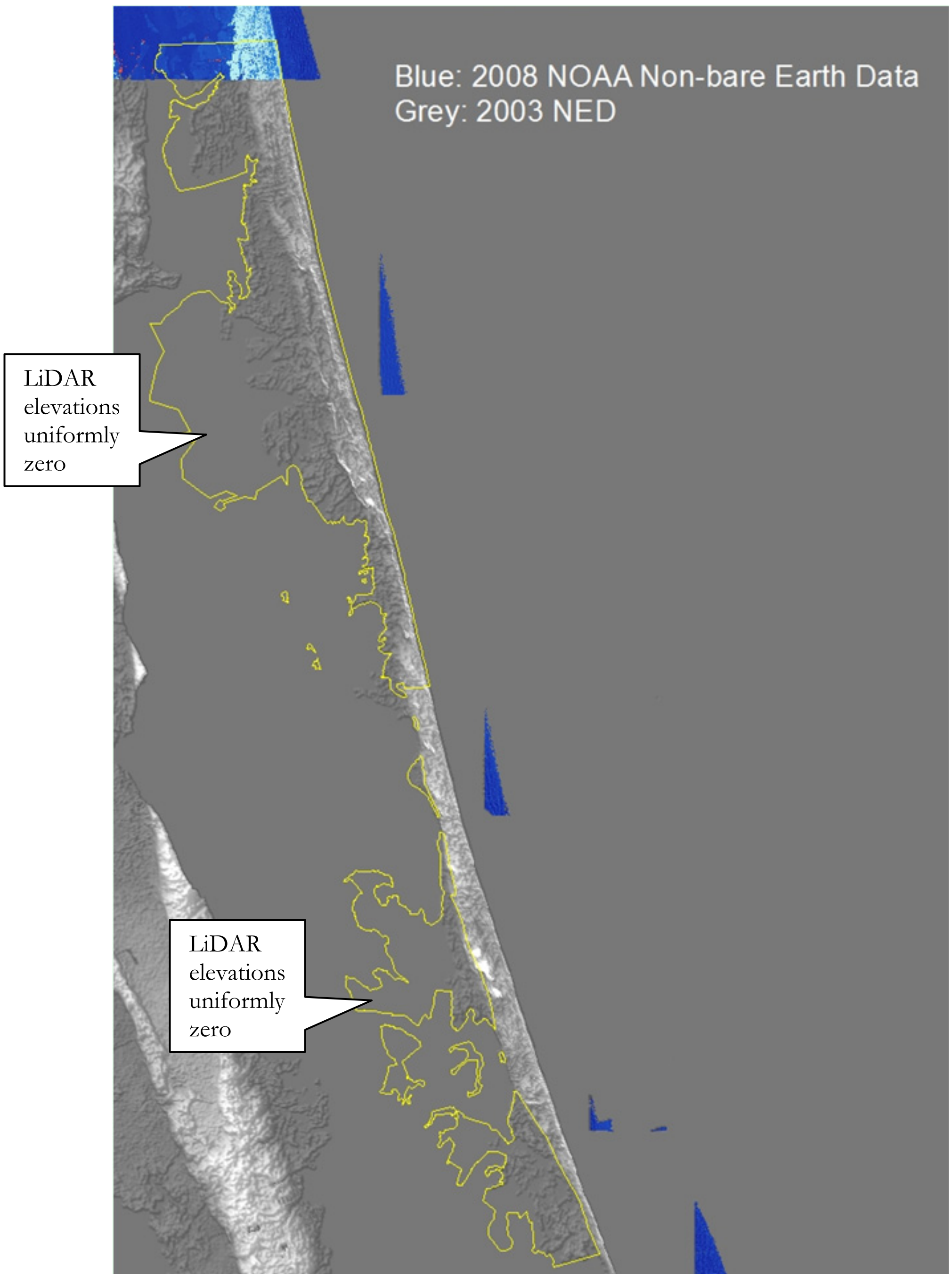


Figure 1: Composition of DEM used in model simulation.

The wetland layer for the study area was produced by the National Wetlands Inventory and is based on a 2008 photo date (Figure 2). Converting the NWI survey into 30 meter cells indicates that the approximately twenty thousand acre refuge (approved acquisition boundary including water) is composed of the following categories (excluding categories below 1%):

	Estuarine Open Water	38.9%
	Regularly Flooded Marsh	22.0%
	Undeveloped Dry Land	17.5%
	Irregularly Flooded Marsh	10.7%
	Tidal Swamp	5.8%
	Swamp	1.7%
	Transitional Salt Marsh	1.1%
	Ocean Beach	1.1%

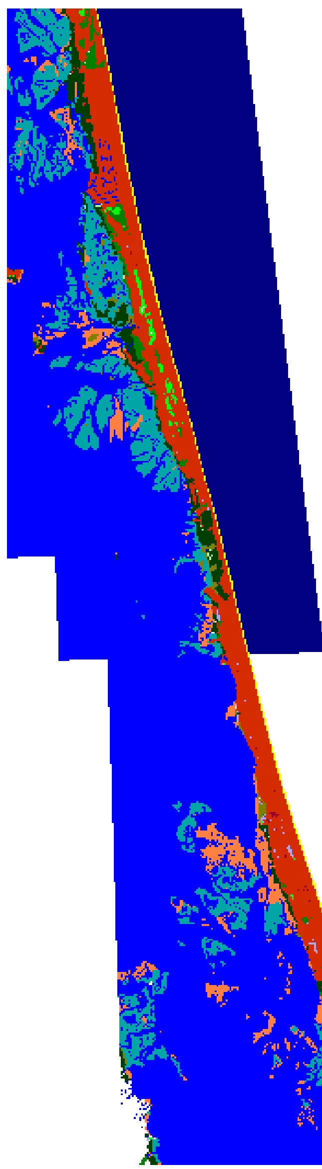


Figure 2: Currituck NWR wetlands layer (including contextual regions)

According to the Refuge Manager of Currituck, Michael Hoff, there is one diked area within Currituck NWR that is surrounded by a naturally elevated boundary (Figure 3). As this area was not manmade it was not added to the model's dike layer. The model's connectivity algorithm will then predict when saline inundation is likely to occur at this location.

Figure 3: Naturally impounded location (opaque shape) within the Currituck NWR (pink line).

The historic trend for sea level rise was estimated at 2.57 mm/year using the value of the nearest NOAA gage with long-term SLR data (8656483, Beaufort, NC). The rate of sea level rise for this refuge has therefore been somewhat higher that the global average for the last 100 years (approximately 1.7 mm/year, IPCC 2007a). This differential between local and global SLR is predicted to persist throughout all model simulations.

Two tide range values were used for this site. The tide value behind the barrier island was estimated at 0.2 meters using 1999 USGS quadrangle for Barco, NC. The ocean-side tide value of 1.17 meters was determined using the NOAA tide gage at Sandbridge, VA (8639428) (Figure 4).

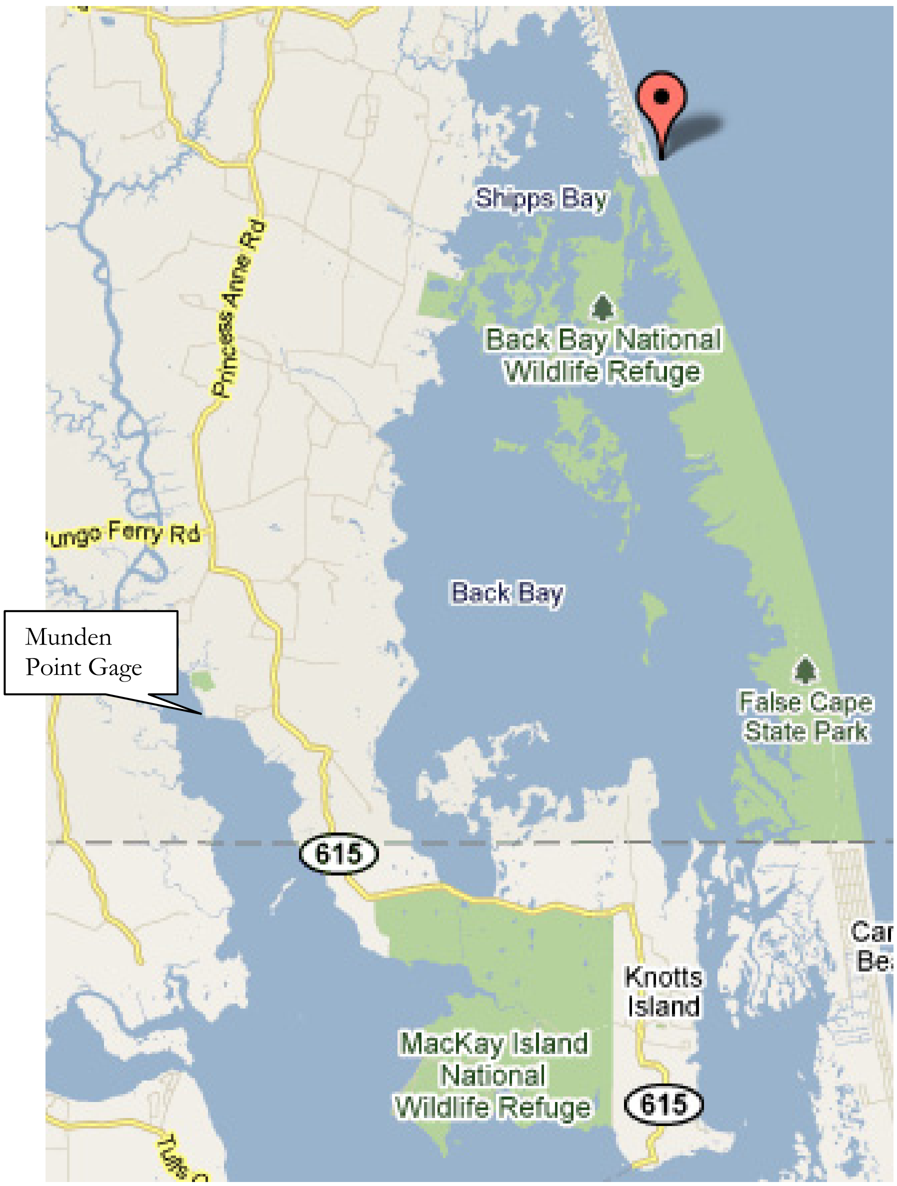


Figure 4: Location of NOAA tides gages used in refuge model application.

In the portions of this site located behind barrier islands, the elevation at which estuarine water is predicted to regularly inundate the land (the salt elevation) was estimated based on a frequency of inundation analysis using one year of verified hourly water data from from the Munden Point, North Landing River, VA gage (8639908). This procedure was done to incorporate the effects of wind tides within estimates of land inundation. This consideration is especially important at this site given the low magnitude of lunar tides. The boundary between regularly-flooded wetlands and dry lands was assumed to occur where water penetrates at least once every 30 days, or approximately 0.4 meters above the measured mean tide level.

Both regularly flooded and irregularly flooded marshes were parameterized using the nearest-available accretion data (Cedar Island, NC) with accretion rates set to 3.7 mm/year (Cahoon 1995). Tidal fresh marsh accretion values were set to 5.9 mm/year based upon an average of fresh marsh accretion rates within the region (Reed 2008, n=8)

The MTL to NAVD88 correction was derived using the NOAA VDATUM product. The vertical-datum correction factor of -0.13 meters was used for this study area.

Modeled U.S. Fish and Wildlife Service refuge boundaries for North Carolina are based on Approved Acquisition Boundaries as published on the FWS National Wildlife Refuge Data and Metadata website. The cell-size used for this analysis was 30 meter by 30 meter cells. Additionally, the SLAMM model will track partial conversion of cells based on elevation and slope.

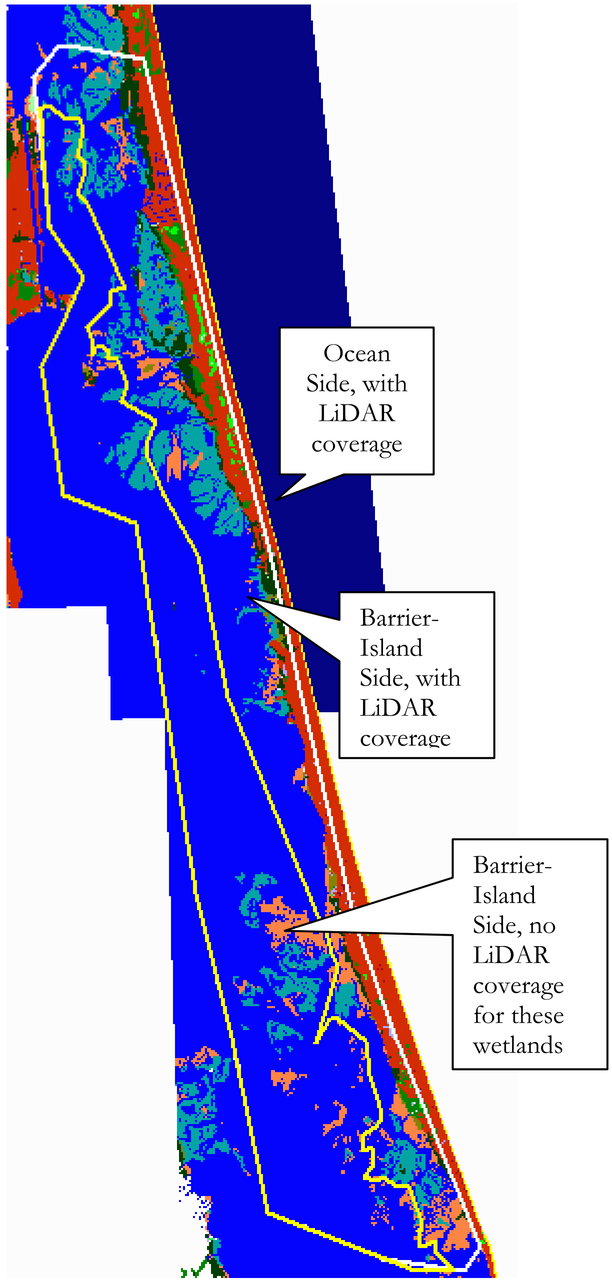


Figure 5: Yellow lines demarcate sub-site boundaries for the Currituck NWR SLAMM simulation.

SUMMARY OF SLAMM INPUT PARAMETERS FOR CURRITUCK NWR

Parameter	Ocean Side	Barrier Side, LiDAR	Barrier Side
Description	with LiDAR	with LiDAR	No LiDAR
NWI Photo Date (YYYY)	2008	2008	2008
DEM Date (YYYY)	2003	2003	2003
Direction Offshore [n,s,e,w]	East	West	West
Historic Trend (mm/yr)	2.82	2.82	2.82
MTL-NAVD88 (m)	-0.13	-0.13	-0.13
GT Great Diurnal Tide Range (m)	1.17	0.2	0.2
Salt Elev. (m above MTL)	0.78	0.4	0.4
Marsh Erosion (horz. m /yr)	1.8	1.8	1.8
Swamp Erosion (horz. m /yr)	1	1	1
T.Flat Erosion (horz. m /yr)	0.5	0.5	0.5
Reg. Flood Marsh Accr (mm/yr)	3.7	3.7	3.7
Irreg. Flood Marsh Accr (mm/yr)	3.7	3.7	3.7
Tidal Fresh Marsh Accr (mm/yr)	5.9	5.9	5.9
Beach Sed. Rate (mm/yr)	0.5	0.5	0.5
Freq. Overwash (years)	11	11	11
Use Elev Pre-processor [True,False]	FALSE	FALSE	True

Results

Currituck NWR is predicted by SLAMM to show significant effects from the impacts of SLR, in all but the most conservative estimates of global SLR. The majority of both irregularly and regularly flooded marshes, which combined constitute roughly one third of the refuge, are lost in any scenario of 1 meter of SLR or greater. Refuge swamp and tidal swamp are inundated with similar severity.

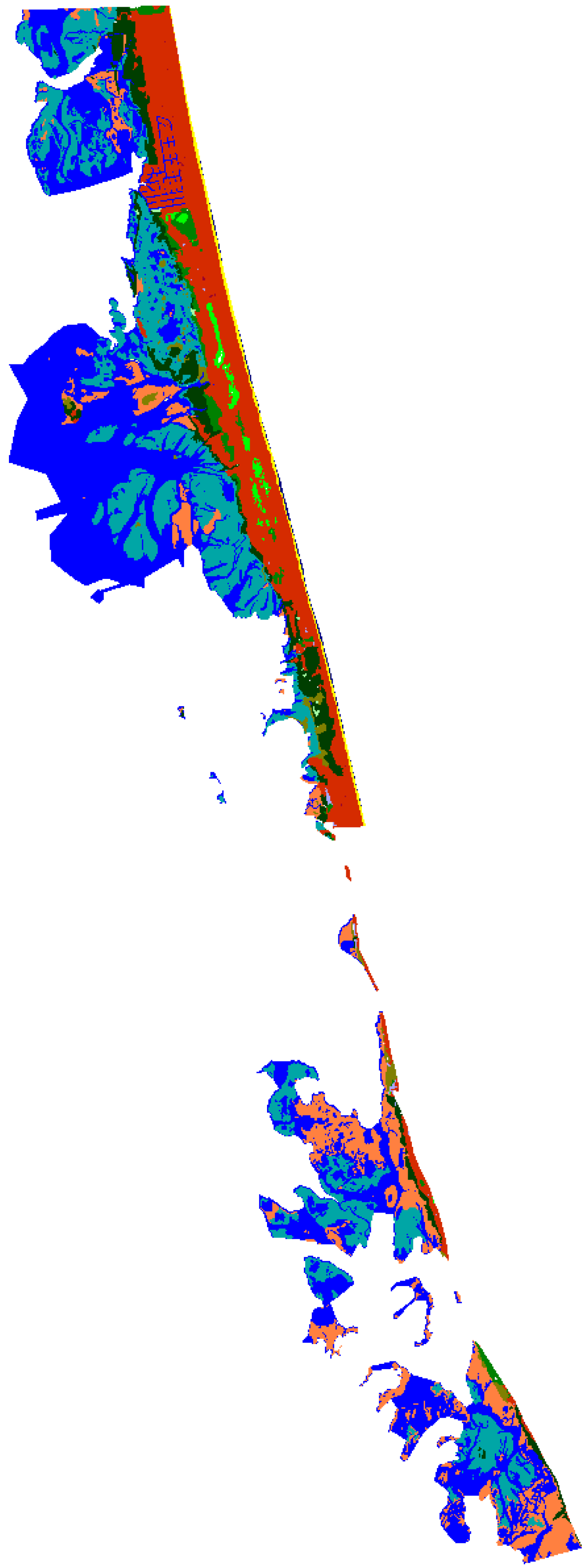
SLR by 2100 (m)	0.39	0.69	1	1.5	2
Regularly Flooded Marsh	-1%	45%	66%	74%	75%
Undeveloped Dry Land	9%	18%	29%	49%	66%
Irregularly Flooded Marsh	21%	61%	82%	93%	97%
Tidal Swamp	34%	63%	77%	89%	91%
Swamp	41%	65%	79%	89%	92%

Predicted Loss Rates of Land Categories by 2100 Given Simulated Scenarios of Eustatic Sea Level Rise

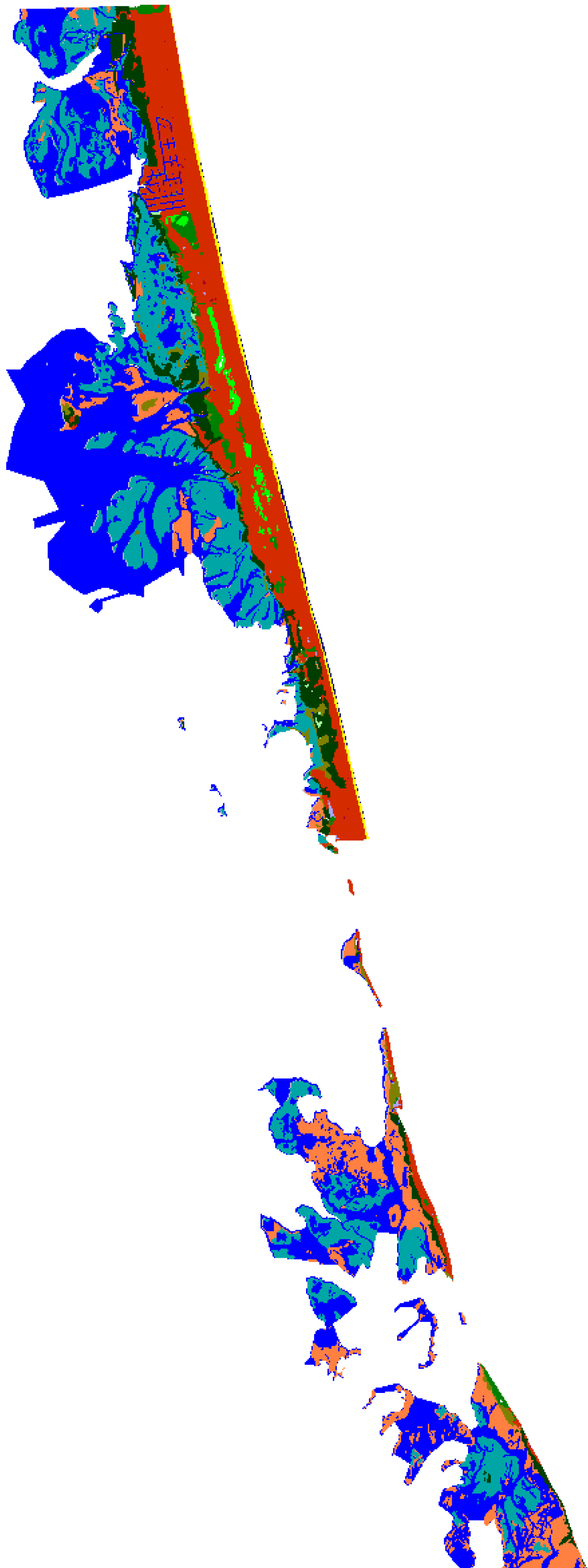
Currituck NWR
IPCC Scenario A1B-Mean, 0.39 M SLR Eustatic by 2100

Results in Acres

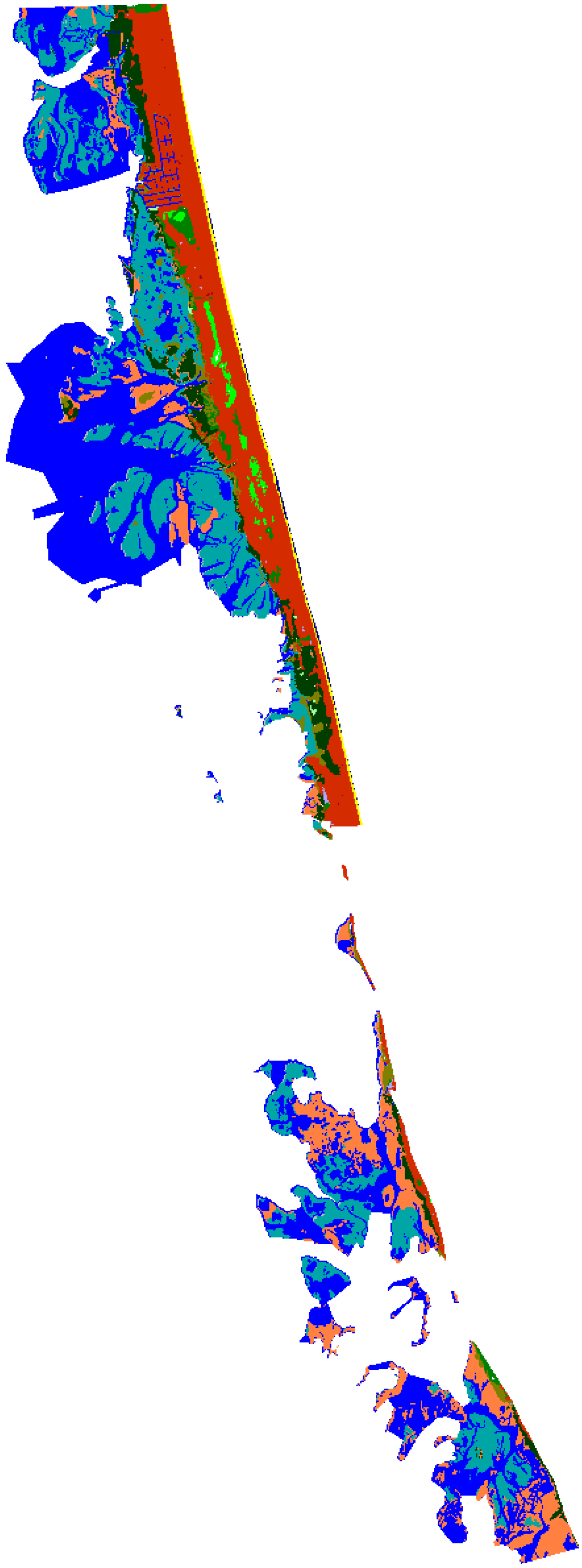
		Initial	2025	2050	2075	2100
	Estuarine Open Water	7771.1	7812.1	7910.8	8059.6	8208.3
	Regularly Flooded Marsh	4392.7	4303.6	4299.4	4378.6	4453.7
	Undeveloped Dry Land	3488.9	3429.1	3370.9	3275.6	3169.0
	Irregularly Flooded Marsh	2127.6	2093.6	2105.5	1982.9	1675.5
	Tidal Swamp	1160.5	1123.9	1058.9	932.5	760.5
	Swamp	330.0	296.6	259.5	220.6	194.6
	Transitional Salt Marsh	219.7	299.4	388.2	497.8	599.7
	Ocean Beach	212.4	212.3	212.2	212.9	212.0
	Inland Fresh Marsh	157.5	157.0	157.0	157.0	157.0
	Open Ocean	58.3	58.6	59.0	59.7	62.1
	Inland Open Water	26.2	20.0	18.9	13.1	11.8
	Tidal Fresh Marsh	15.8	15.8	15.8	15.8	15.8
	Developed Dry Land	9.1	8.9	8.8	8.7	8.6
	Estuarine Beach	2.7	3.5	2.7	0.2	0.3
	Tidal Flat	0.0	138.1	104.8	157.3	443.6
	Total (incl. water)	**19972.5**	**19972.5**	**19972.5**	**19972.5**	**19972.5**



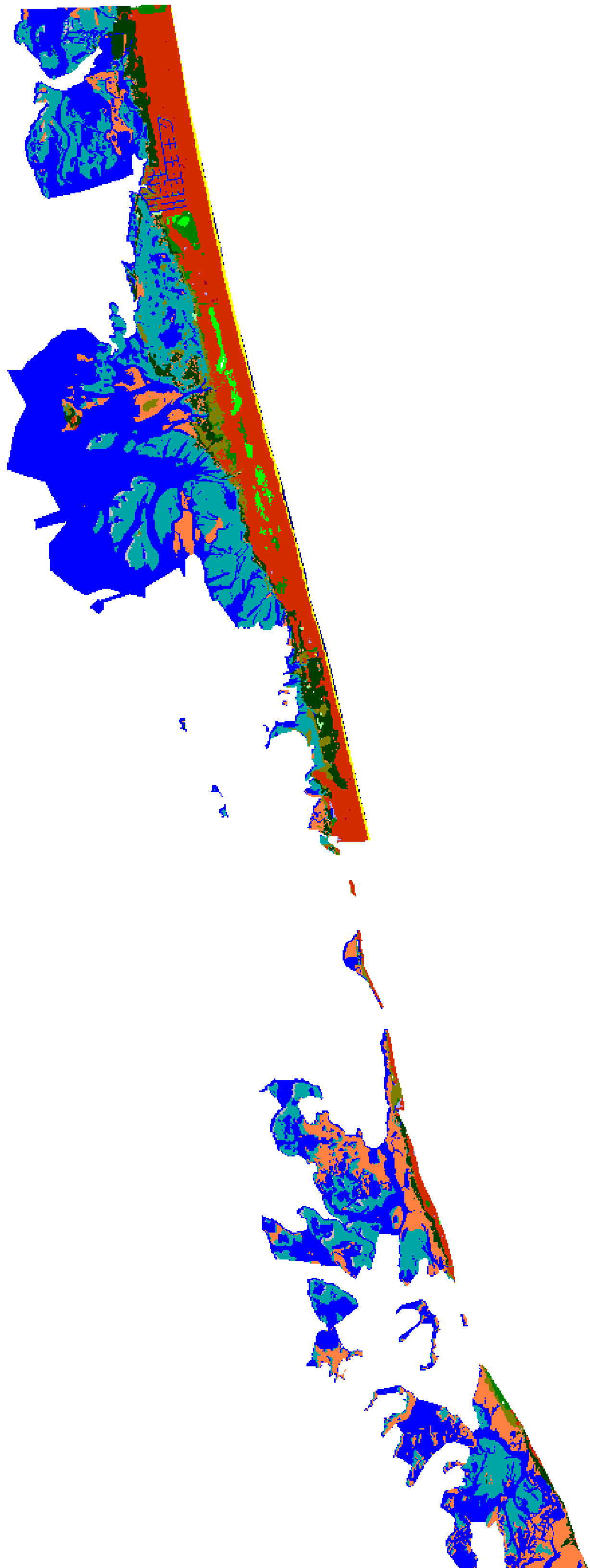
Currituck NWR, Initial Condition



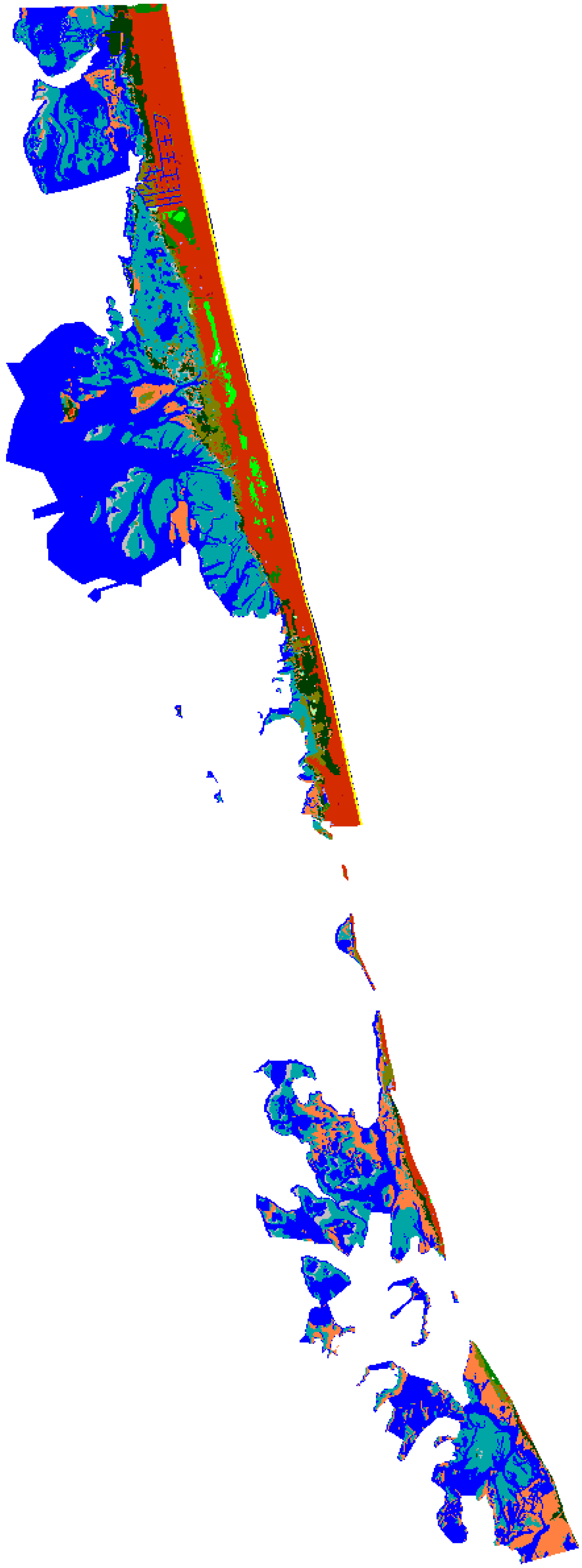
Curritick NWR, 2025, Scenario A1B Mean



Currituck NWR, 2050, Scenario A1B Mean



Currituck NWR, 2075, Scenario A1B Mean

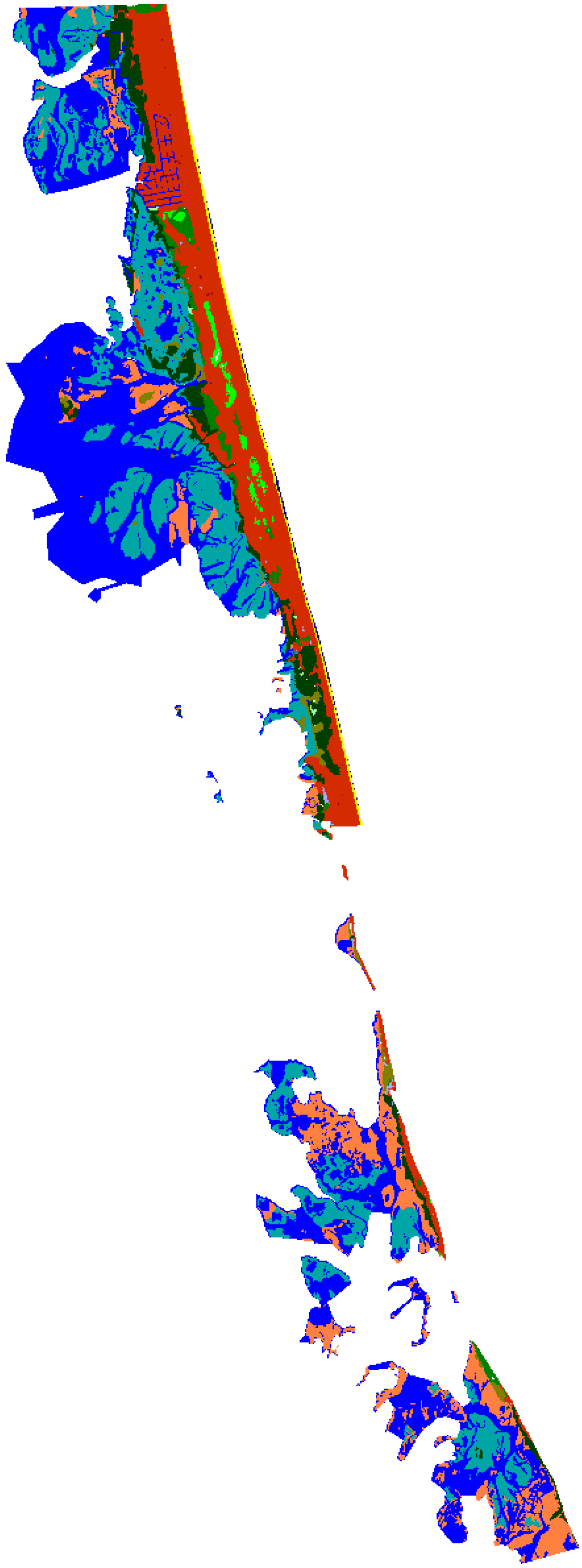


Currituck NWR, 2100, Scenario A1B Mean

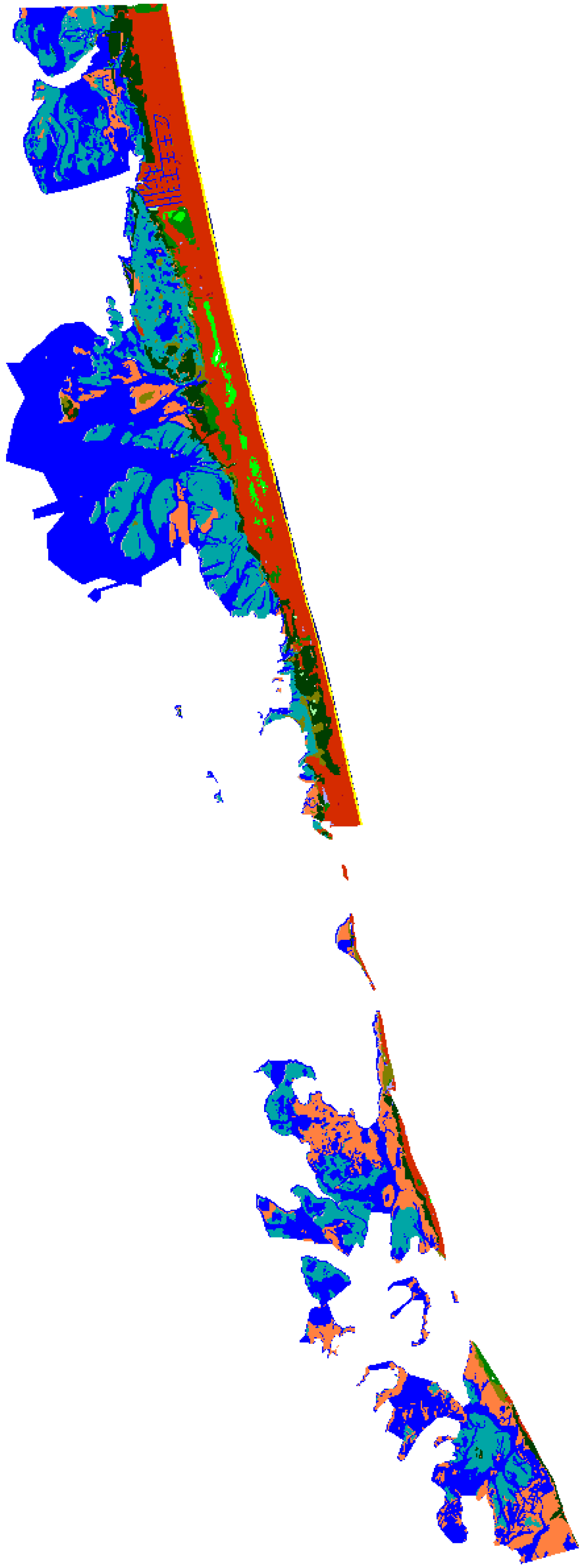
Currituck NWR
IPCC Scenario A1B-Max, 0.69 M SLR Eustatic by 2100

Results in Acres

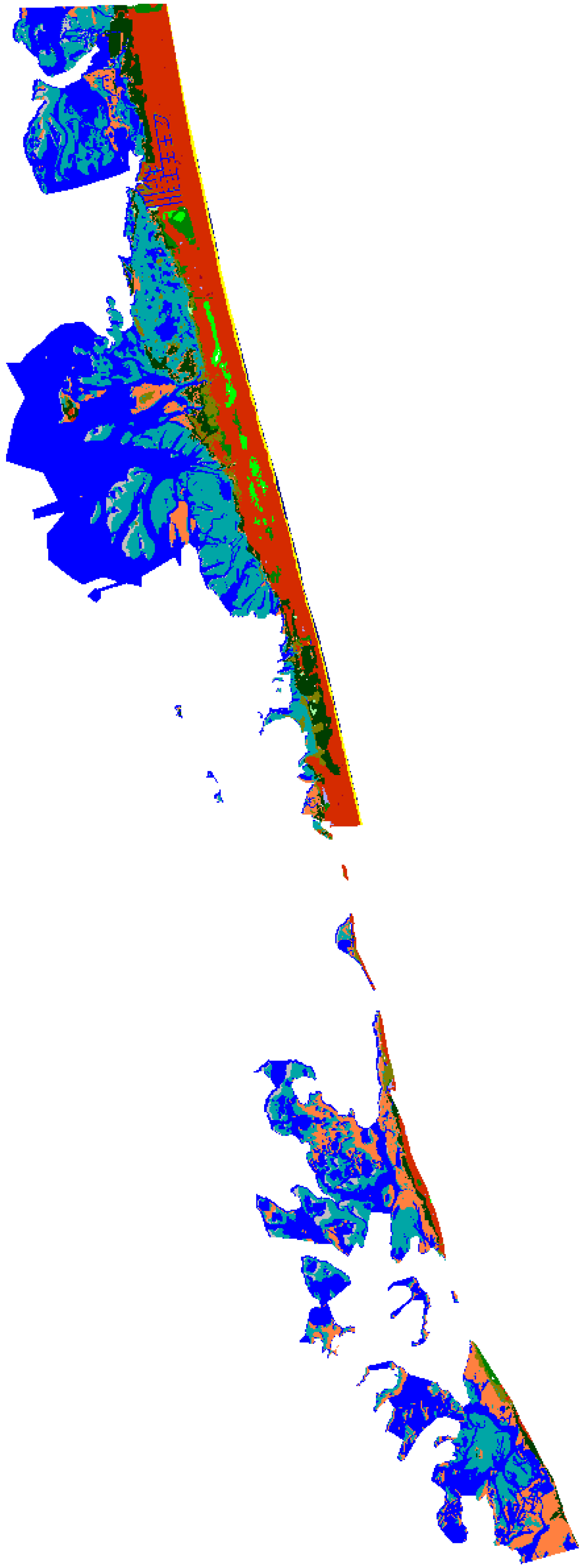
		Initial	2025	2050	2075	2100
	Estuarine Open Water	7771.1	7841.8	8033.5	8438.5	9927.6
	Regularly Flooded Marsh	4392.7	4307.0	4411.0	3396.3	2426.3
	Undeveloped Dry Land	3488.9	3420.7	3311.2	3132.9	2848.1
	Irregularly Flooded Marsh	2127.6	2067.1	1667.6	1182.1	836.4
	Tidal Swamp	1160.5	1108.0	961.8	663.1	434.1
	Swamp	330.0	292.6	230.8	185.7	115.3
	Transitional Salt Marsh	219.7	306.1	433.1	535.6	619.6
	Ocean Beach	212.4	212.3	212.5	210.9	201.4
	Inland Fresh Marsh	157.5	157.0	157.0	156.7	145.2
	Open Ocean	58.3	58.7	59.4	64.3	89.7
	Inland Open Water	26.2	20.0	16.5	11.3	9.8
	Tidal Fresh Marsh	15.8	15.8	15.8	15.8	15.3
	Developed Dry Land	9.1	8.8	8.8	8.6	8.1
	Estuarine Beach	2.7	3.5	0.4	0.3	0.7
	Tidal Flat	0.0	153.1	453.2	1970.3	2295.0
	Total (incl. water)	**19972.5**	**19972.5**	**19972.5**	**19972.5**	**19972.5**



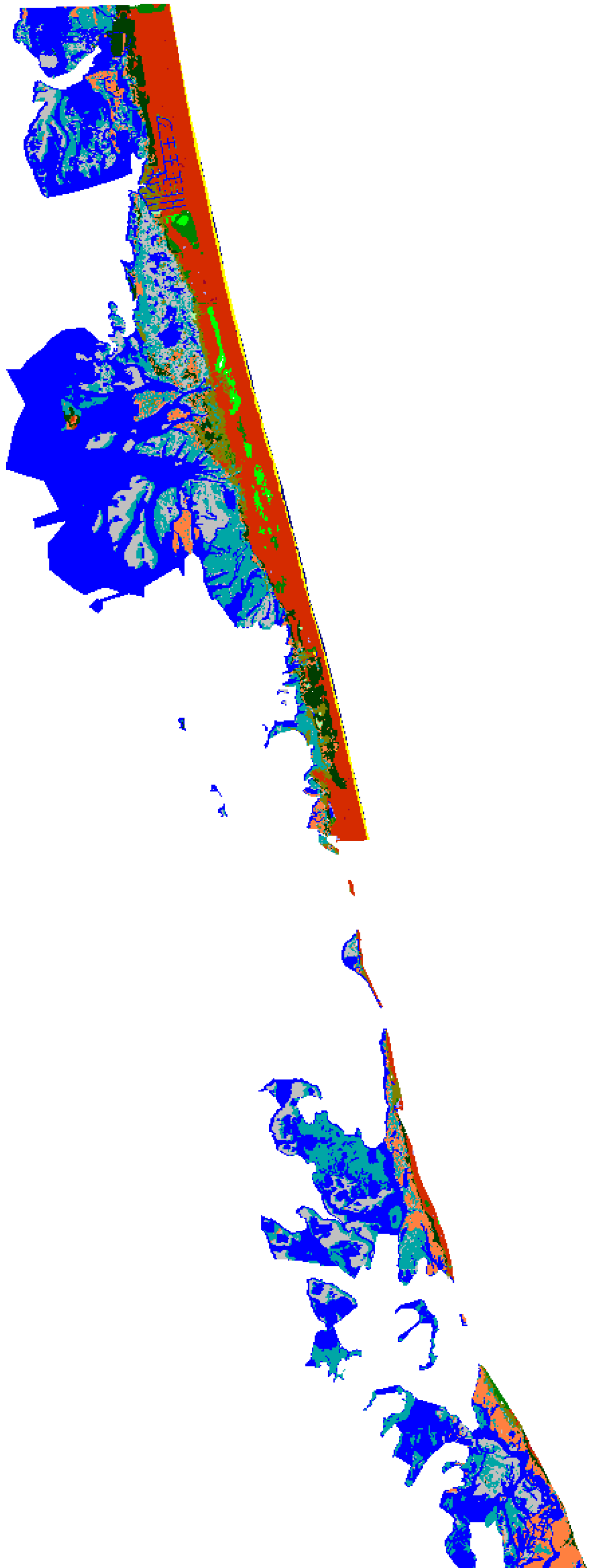
Currituck NWR, Initial Condition



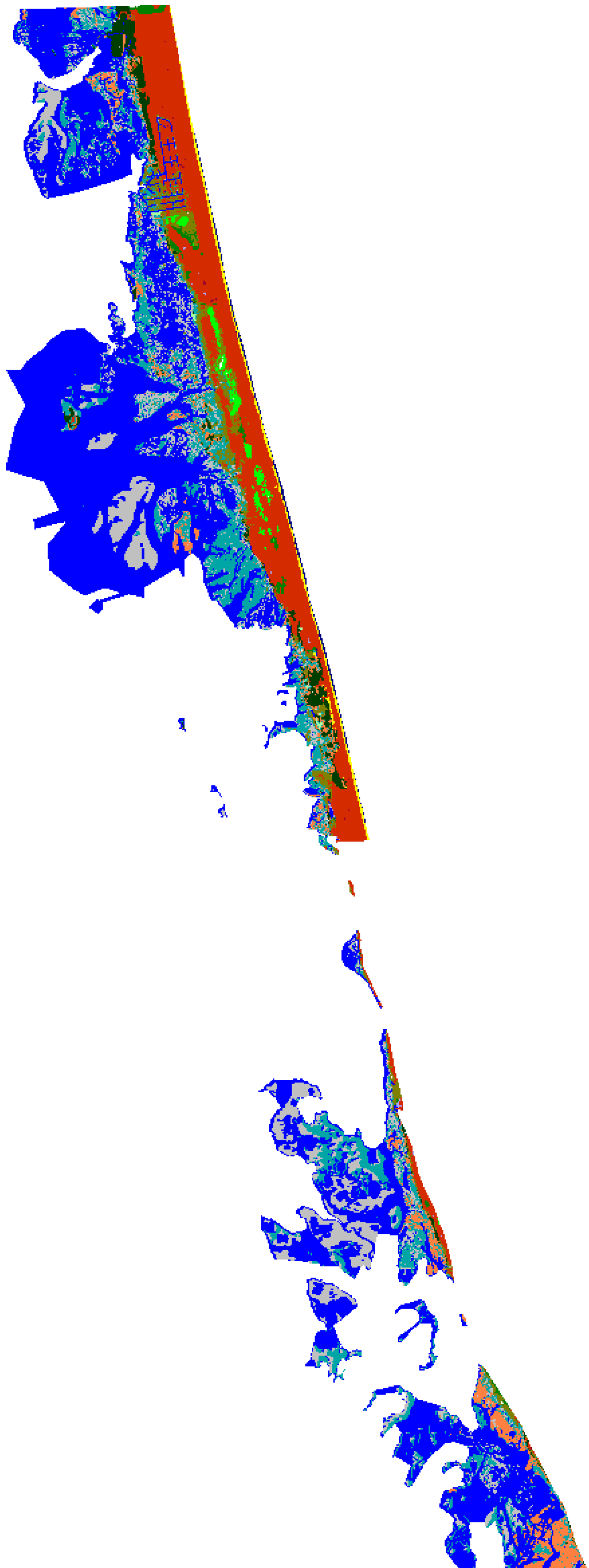
Currituck NWR, 2025, Scenario A1B Maximum



Currituck NWR, 2050, Scenario A1B Maximum



Currituck NWR, 2075, Scenario A1B Maximum

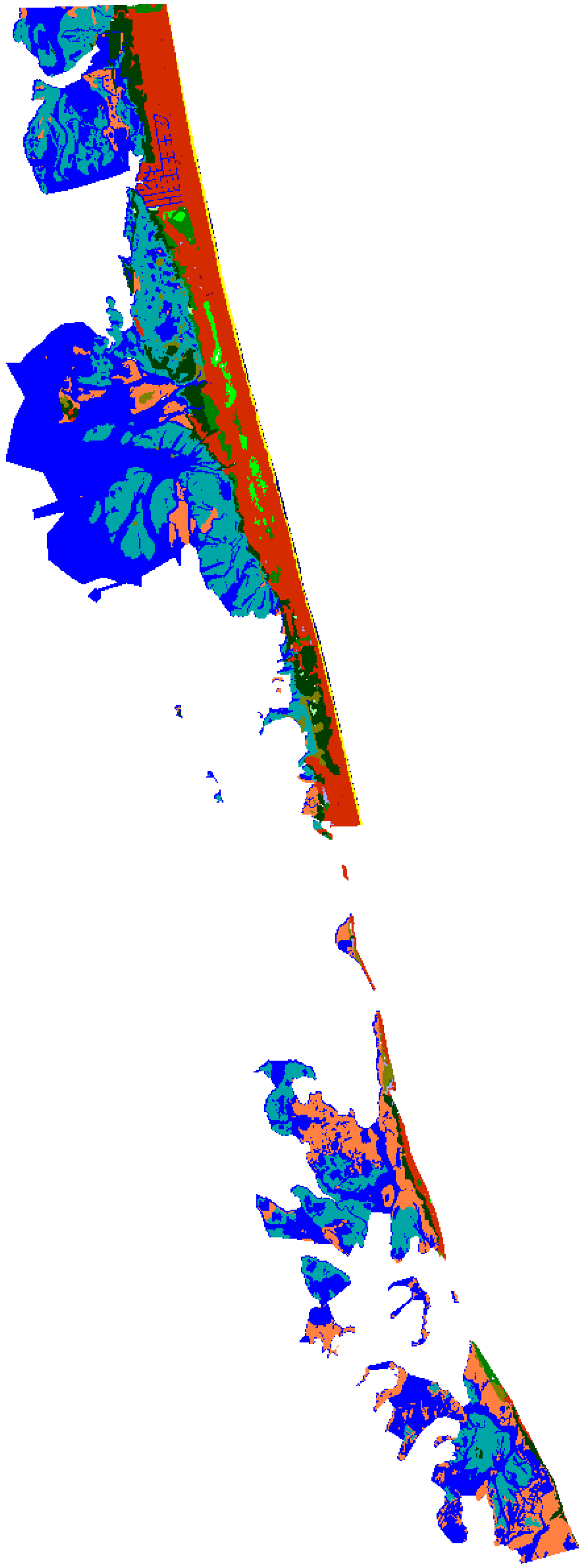


Currituck NWR, 2100, Scenario A1B Maximum

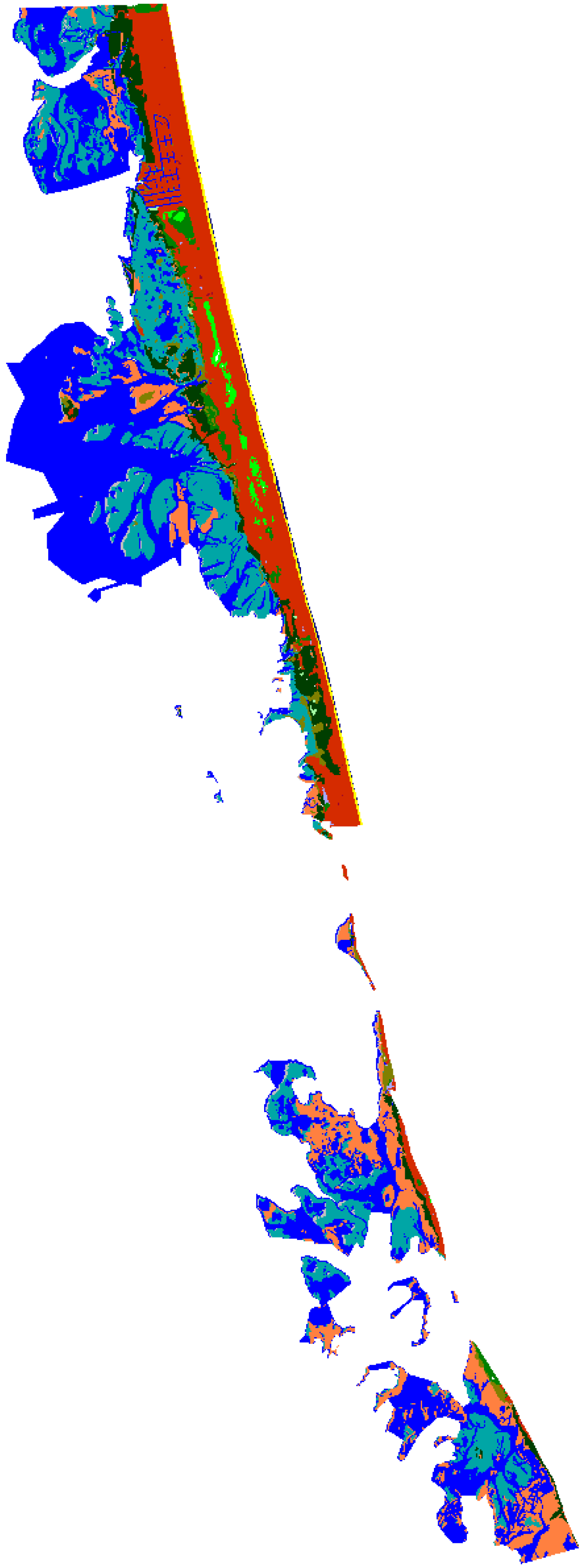
Currituck NWR
1 Meter Eustatic SLR by 2100

Results in Acres

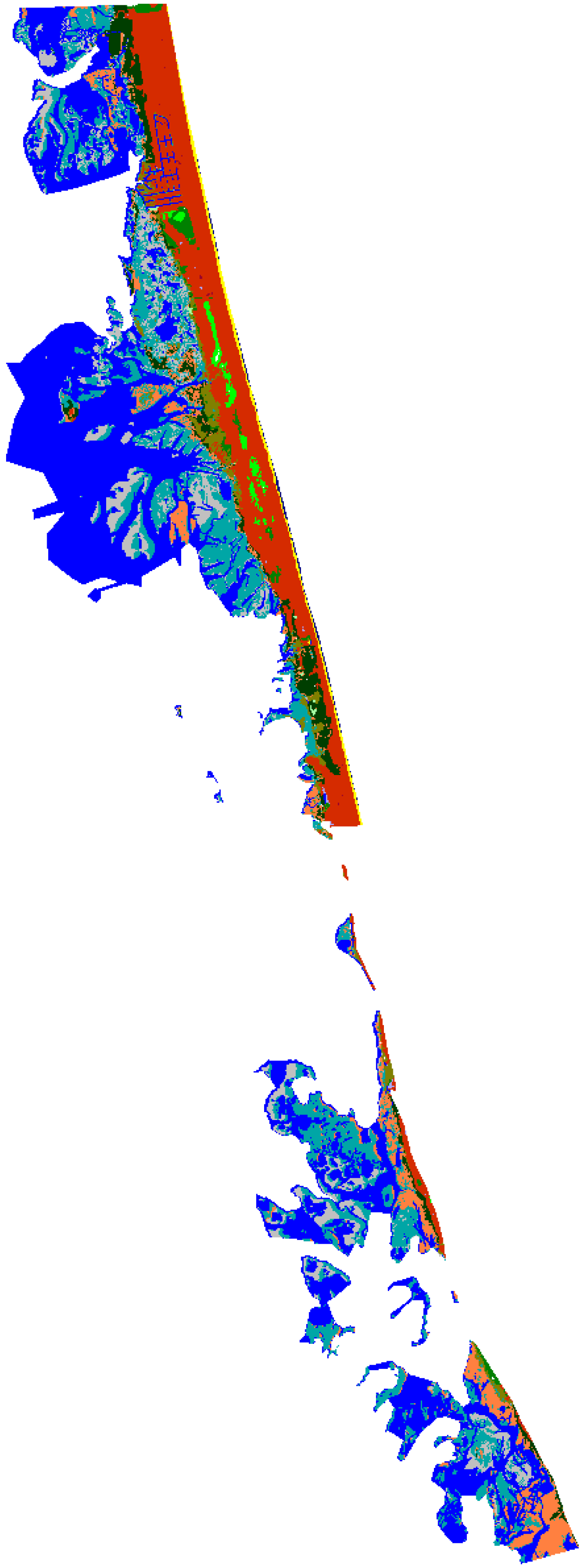
		Initial	2025	2050	2075	2100
	Estuarine Open Water	7771.1	7868.5	8165.8	9421.3	11683.2
	Regularly Flooded Marsh	4392.7	4315.3	3700.1	2303.1	1500.8
	Undeveloped Dry Land	3488.9	3408.6	3242.4	2909.3	2474.6
	Irregularly Flooded Marsh	2127.6	1992.0	1311.4	909.4	390.2
	Tidal Swamp	1160.5	1090.7	819.6	458.0	262.8
	Swamp	330.0	281.6	208.3	128.4	69.4
	Transitional Salt Marsh	219.7	317.6	460.4	572.4	575.3
	Ocean Beach	212.4	212.3	212.3	183.9	206.6
	Inland Fresh Marsh	157.5	157.0	157.0	127.1	85.8
	Open Ocean	58.3	58.8	60.8	103.5	169.9
	Inland Open Water	26.2	19.8	13.1	10.2	4.7
	Tidal Fresh Marsh	15.8	15.8	15.7	13.8	8.9
	Developed Dry Land	9.1	8.8	8.7	8.1	6.6
	Estuarine Beach	2.7	3.5	0.4	0.8	2.8
	Tidal Flat	0.0	222.2	1596.5	2823.1	2530.8
	Total (incl. water)	**19972.5**	**19972.5**	**19972.5**	**19972.5**	**19972.5**



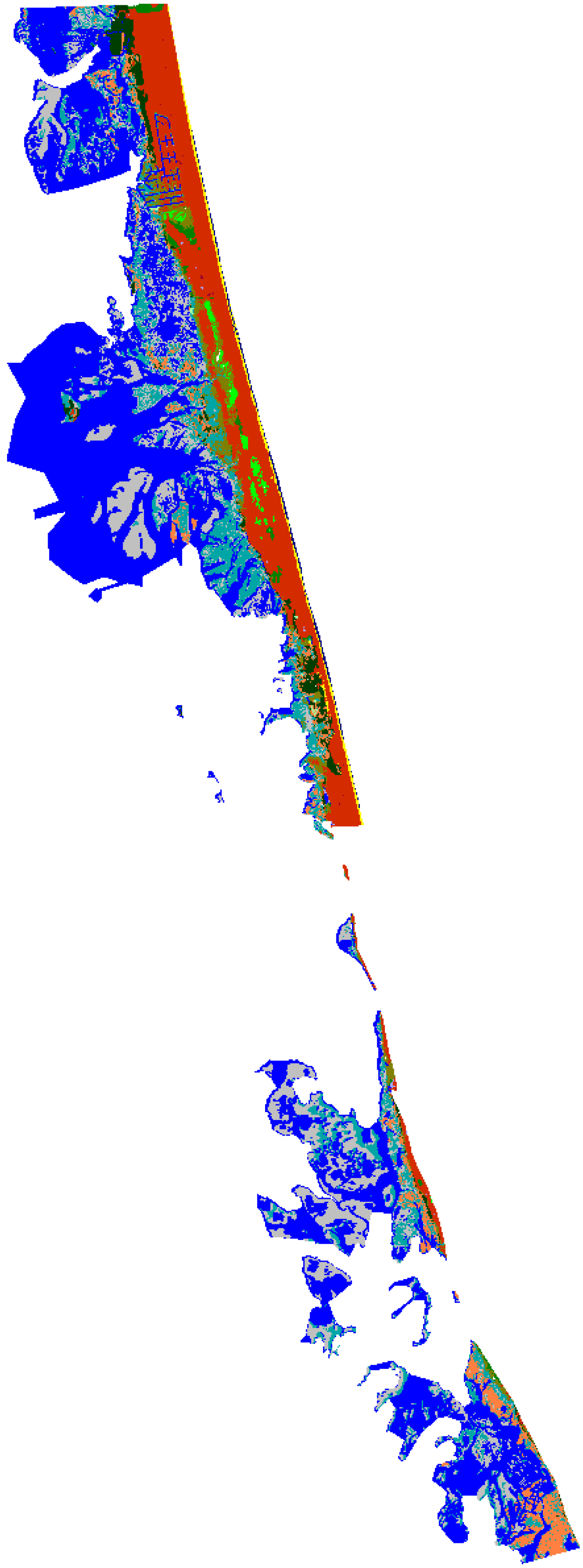
Currituck NWR, Initial Condition



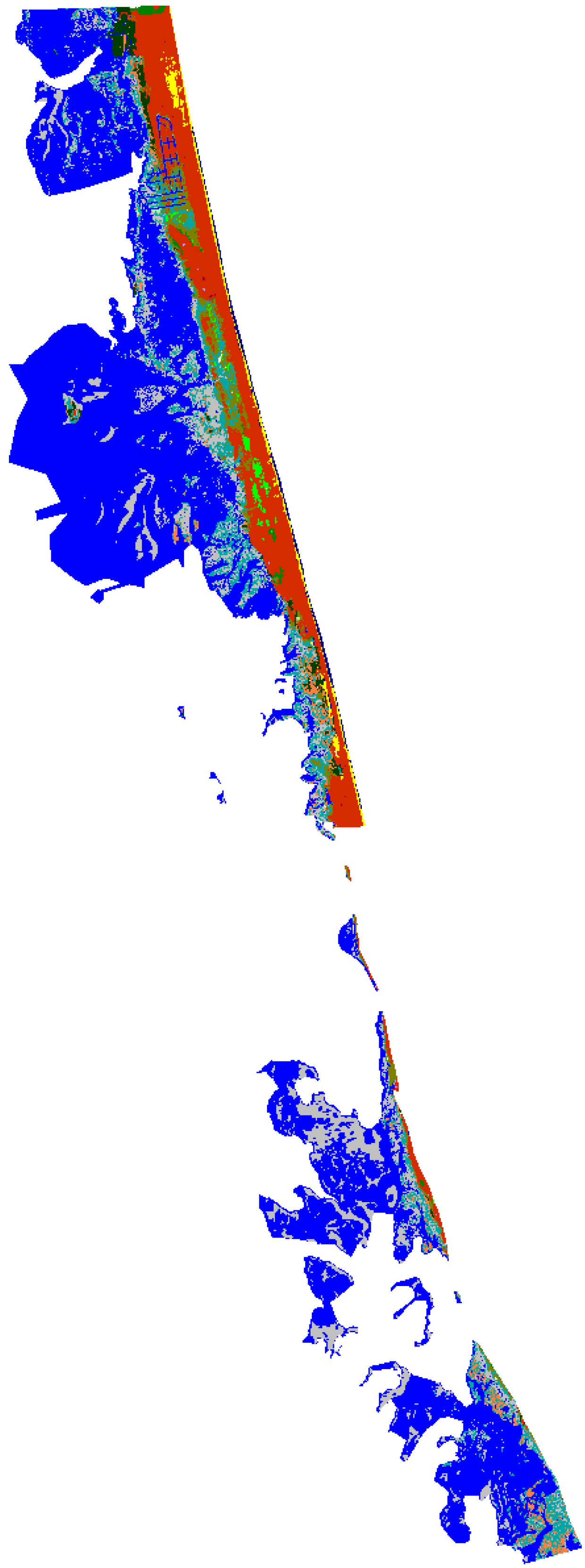
Currituck NWR, 2025, 1 meter



Currituck NWR, 2050, 1 meter



Currituck NWR, 2075, 1 meter

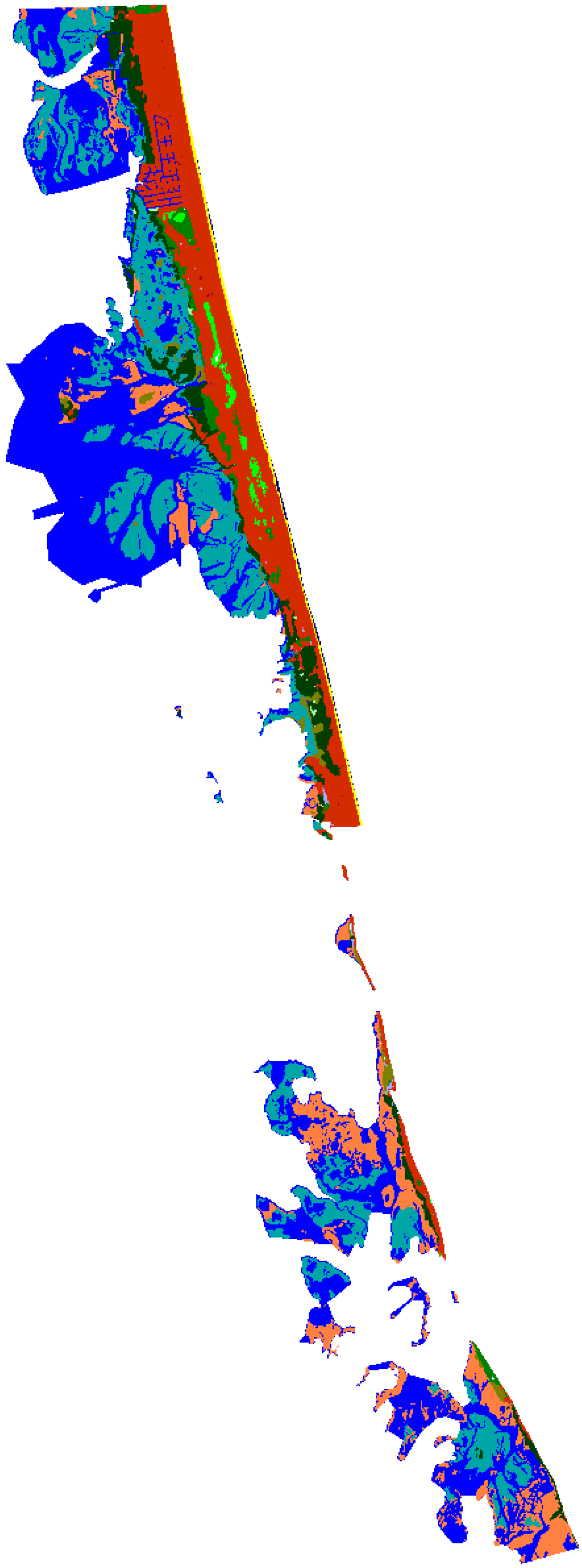


Currituck NWR, 2100, 1 meter

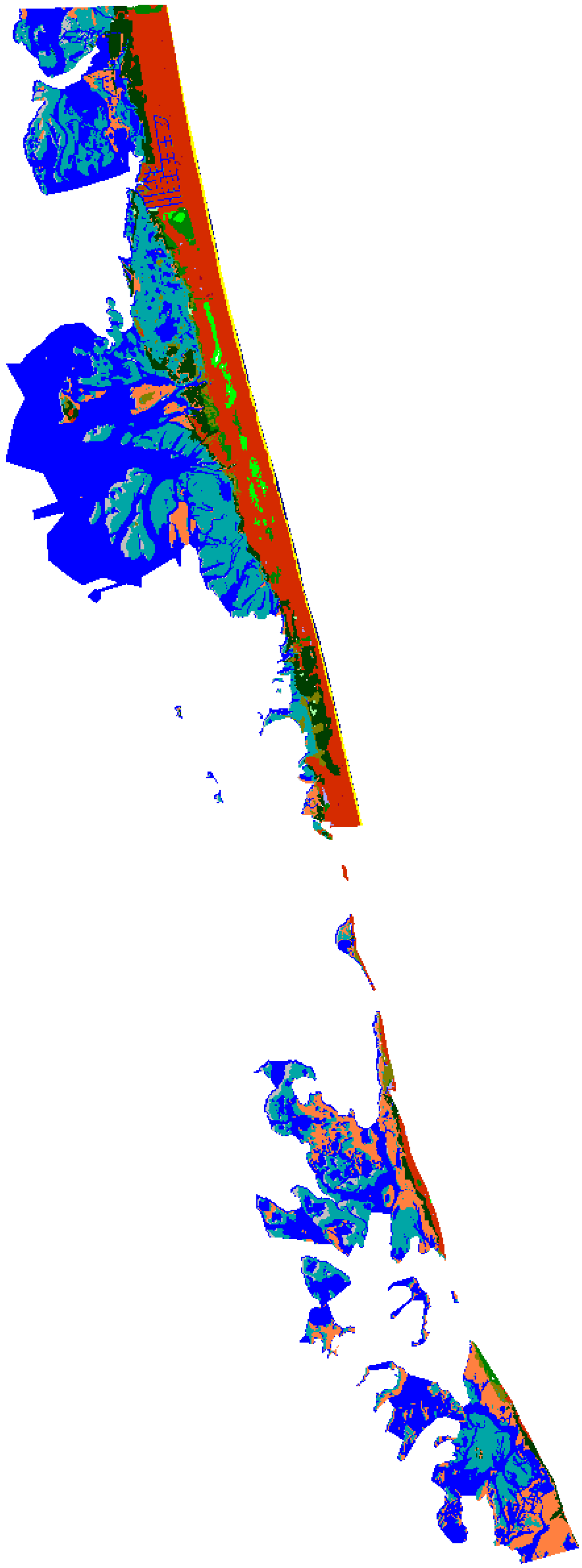
Currituck NWR
1.5 Meters Eustatic SLR by 2100

Results in Acres

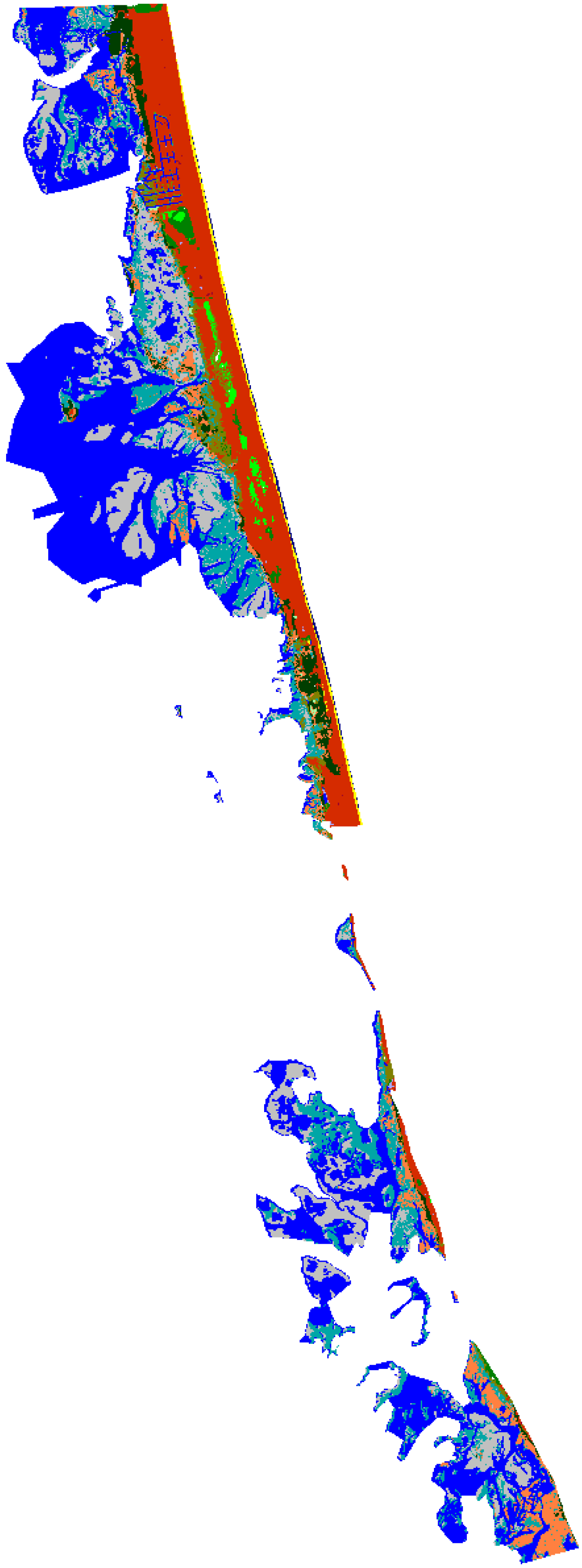
		Initial	2025	2050	2075	2100
	Estuarine Open Water	7771.1	7897.6	8371.4	11133.1	13963.0
	Regularly Flooded Marsh	4392.7	4440.2	2596.3	1655.0	1129.5
	Undeveloped Dry Land	3488.9	3382.9	3090.6	2513.8	1783.7
	Irregularly Flooded Marsh	2127.6	1706.2	1113.3	454.4	140.9
	Tidal Swamp	1160.5	1055.2	601.4	265.2	133.0
	Swamp	330.0	263.7	180.8	72.2	37.8
	Transitional Salt Marsh	219.7	339.5	501.2	687.8	600.9
	Ocean Beach	212.4	212.2	160.8	74.9	156.5
	Inland Fresh Marsh	157.5	157.0	133.4	72.5	34.4
	Open Ocean	58.3	59.0	118.6	292.8	398.1
	Inland Open Water	26.2	19.1	11.3	4.9	2.2
	Tidal Fresh Marsh	15.8	15.8	14.1	6.6	2.4
	Developed Dry Land	9.1	8.8	8.5	6.9	4.9
	Estuarine Beach	2.7	3.4	0.6	1.5	27.1
	Tidal Flat	0.0	411.9	3070.3	2730.9	1557.9
	Total (incl. water)	**19972.5**	**19972.5**	**19972.5**	**19972.5**	**19972.5**



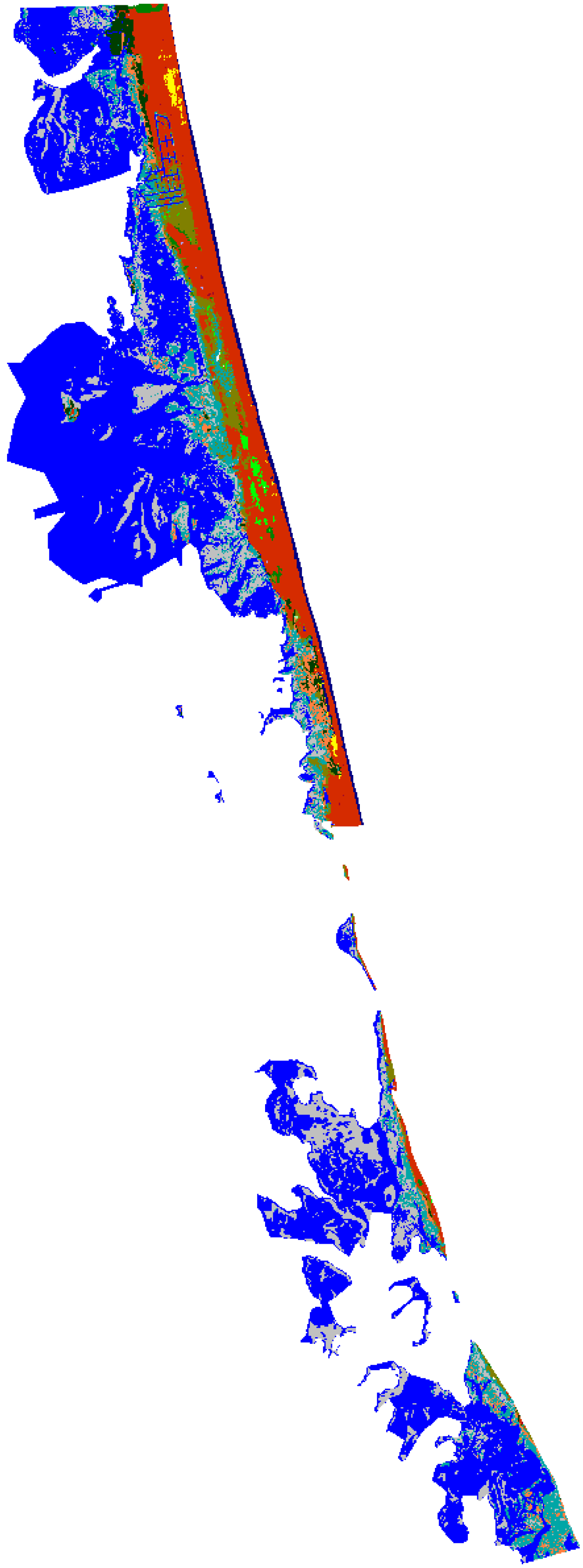
Currituck NWR, Initial Condition



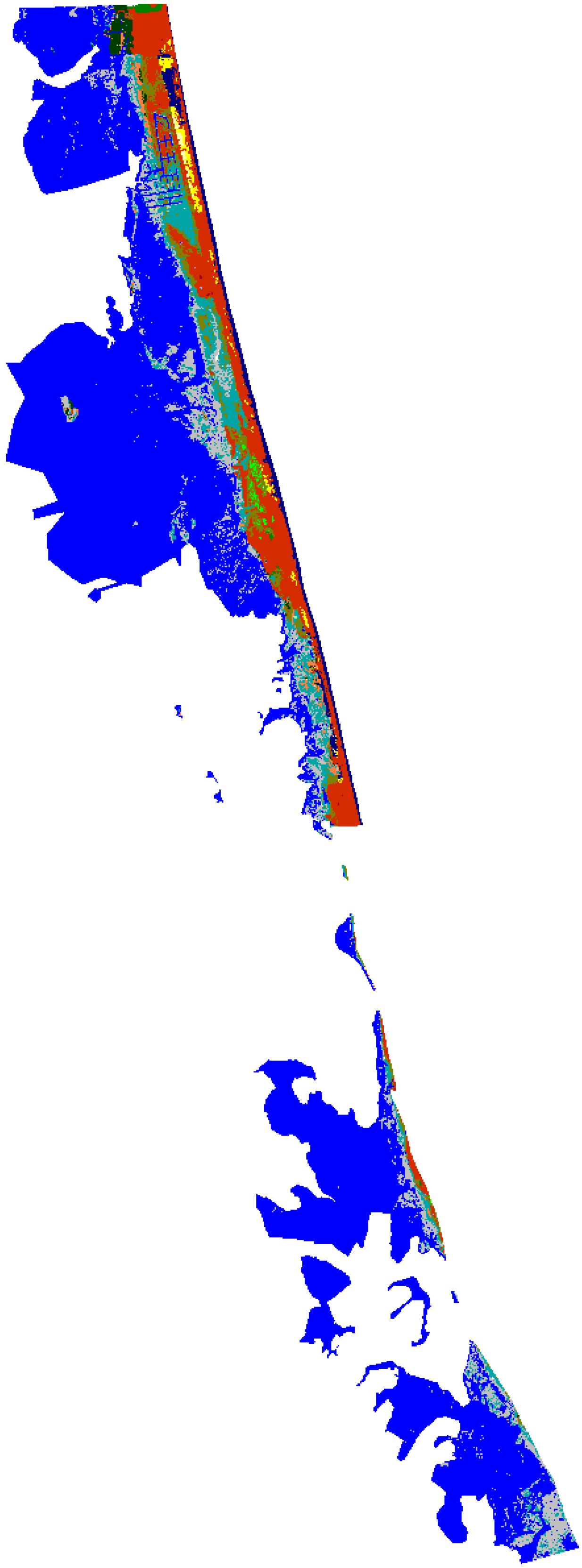
Currituck NWR, 2025, 1.5 meter



Curritruck NWR, 2050, 1.5 meter



Curritck NWR, 2075, 1.5 meter

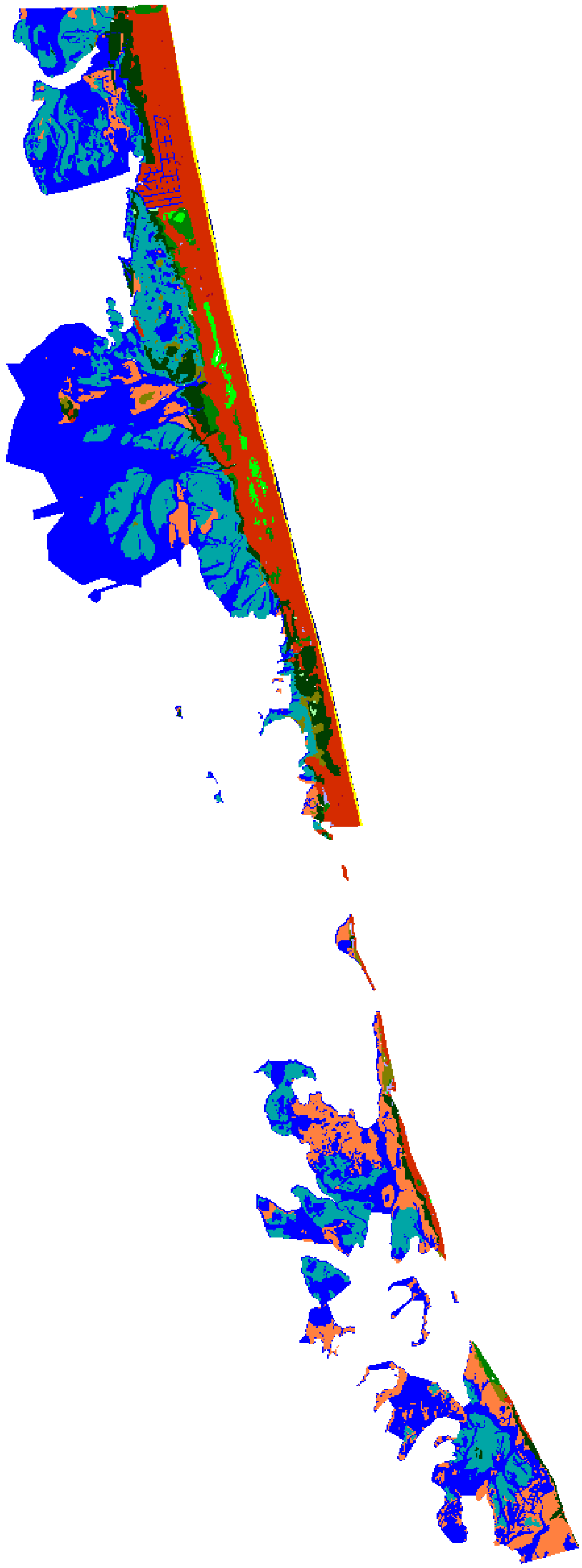


Currituck NWR, 2100, 1.5 meter

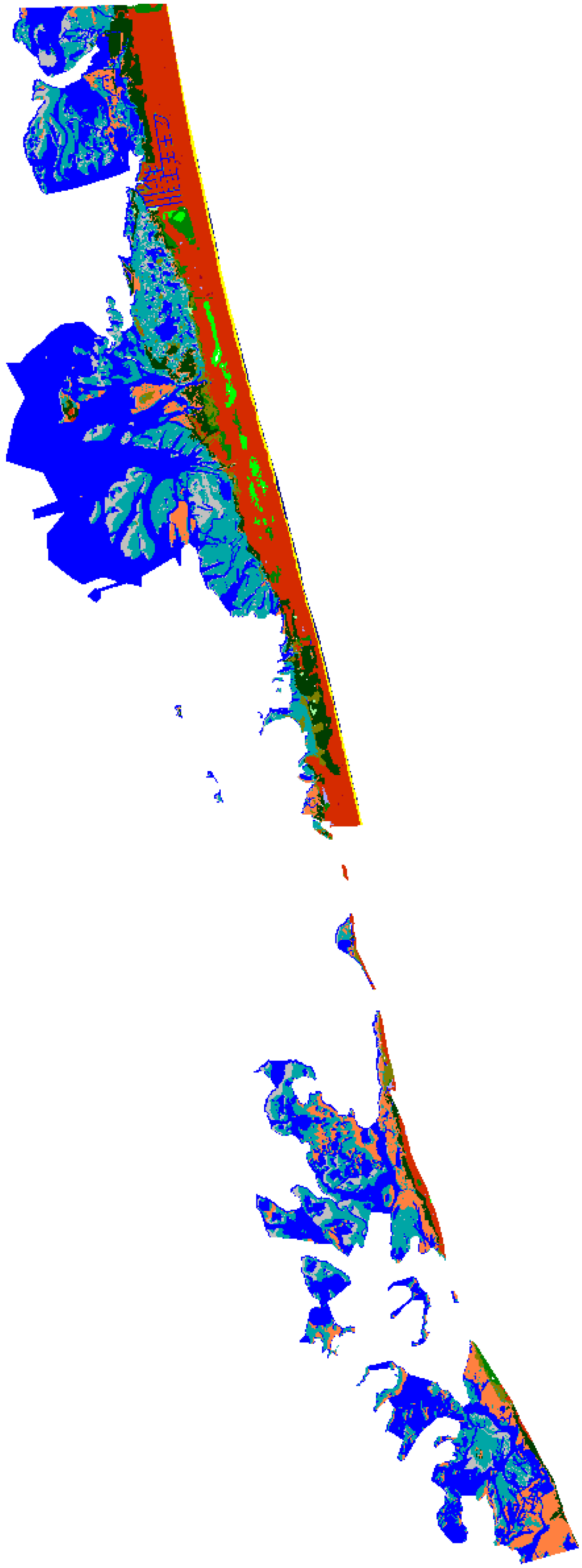
Currituck NWR
2 Meters Eustatic SLR by 2100

Results in Acres

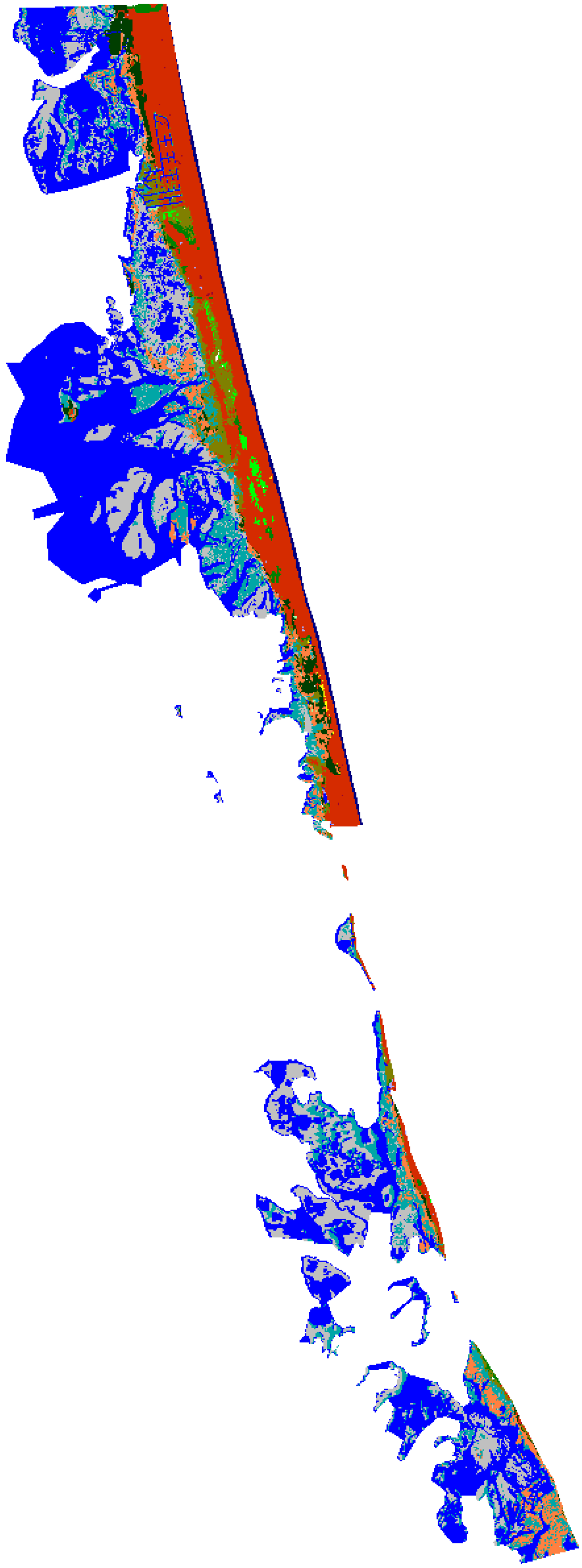
		Initial	2025	2050	2075	2100
	Estuarine Open Water	7771.1	7936.6	8883.6	12458.9	14520.8
	Regularly Flooded Marsh	4392.7	4077.6	2129.7	1649.0	1080.2
	Undeveloped Dry Land	3488.9	3358.2	2909.9	2028.7	1182.9
	Irregularly Flooded Marsh	2127.6	1515.0	992.1	288.4	61.9
	Tidal Swamp	1160.5	1010.7	438.3	160.0	104.6
	Swamp	330.0	249.8	124.0	44.4	27.1
	Transitional Salt Marsh	219.7	355.5	673.3	802.3	635.9
	Ocean Beach	212.4	212.3	79.5	160.7	150.5
	Inland Fresh Marsh	157.5	157.0	92.5	38.3	4.6
	Open Ocean	58.3	59.2	208.0	330.0	602.6
	Inland Open Water	26.2	17.8	10.2	3.6	0.4
	Tidal Fresh Marsh	15.8	15.8	9.8	2.7	0.0
	Developed Dry Land	9.1	8.8	8.1	5.7	3.6
	Estuarine Beach	2.7	3.3	0.8	24.3	26.8
	Tidal Flat	0.0	995.2	3412.6	1975.7	1570.8
	Total (incl. water)	**19972.5**	**19972.5**	**19972.5**	**19972.5**	**19972.5**



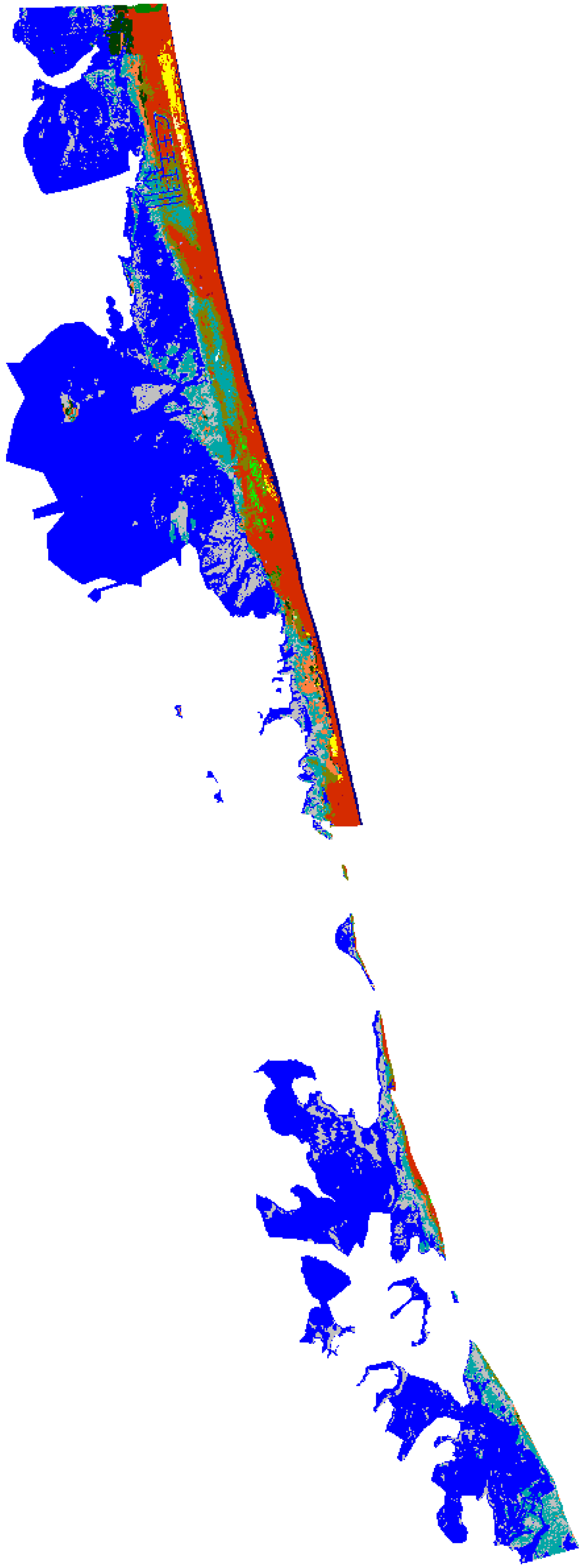
Currit
uck NWR, Initial Condition



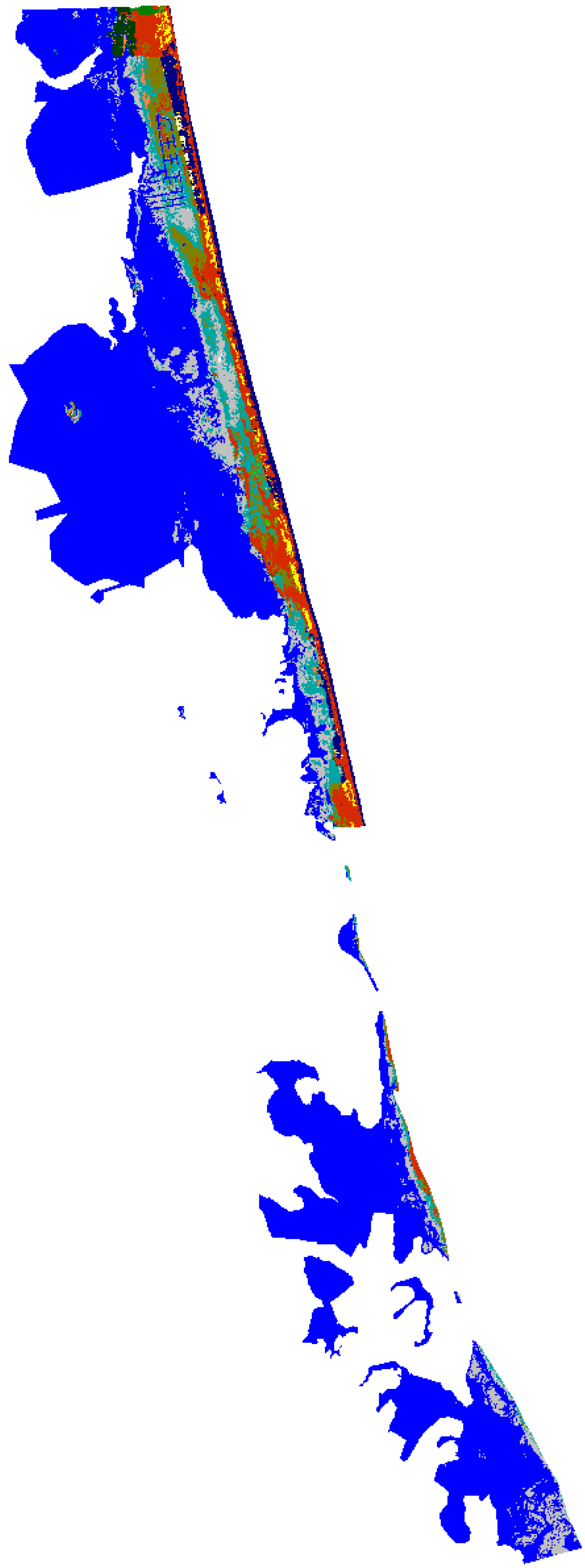
Currituck NWR, 2025, 2 meters



Currituck NWR, 2050, 2 meters



Currituck NWR, 2075, 2 meters



Currituck NWR, 2100, 2 meters

Discussion

SLAMM predicts that the Currituck National Wildlife Refuge will lose much of its wetland area to inundation, particularly given higher sea-level rise scenarios. Once SLR exceeds predicted accretion rates the marshes begin to lose elevation relative to water. These marshes convert first to tidal flats and eventually to open water. Initial marsh elevations are available in most sites, but these predictions are more uncertain in the western portions of the study area where the LiDAR digital elevation map did not cover (Figure 5). In these locations, initial marsh elevations are estimated as a function of tidal range and are not based on an external data source.

On the ocean side, beach erosion is modeled by SLAMM using the Bruun Rule, a relatively simple means of predicting horizontal shore erosion. Dry lands and fresh-water marshes were assumed to be lost once water penetrates these areas more than once every thirty days. However, tide ranges were kept constant, both on the ocean side and the bay side, throughout the range of SLR scenarios modeled.

The digital elevation map (DEM) for this site is based on high-vertical-resolution LiDAR data but the DEM at the northernmost tip of the island was not processed to bare-earth at the time of the model run (Figure 1). This increases uncertainty in inundation effects in that portion of the refuge.

Model accretion data are another source of uncertainty. They were regionally based rather than site-specific and also held constant throughout the model simulation. While SLAMM 6 has the capability to model feedbacks between cell inundation frequency and accretion rates, insufficient data were available at this site to define this relationship.

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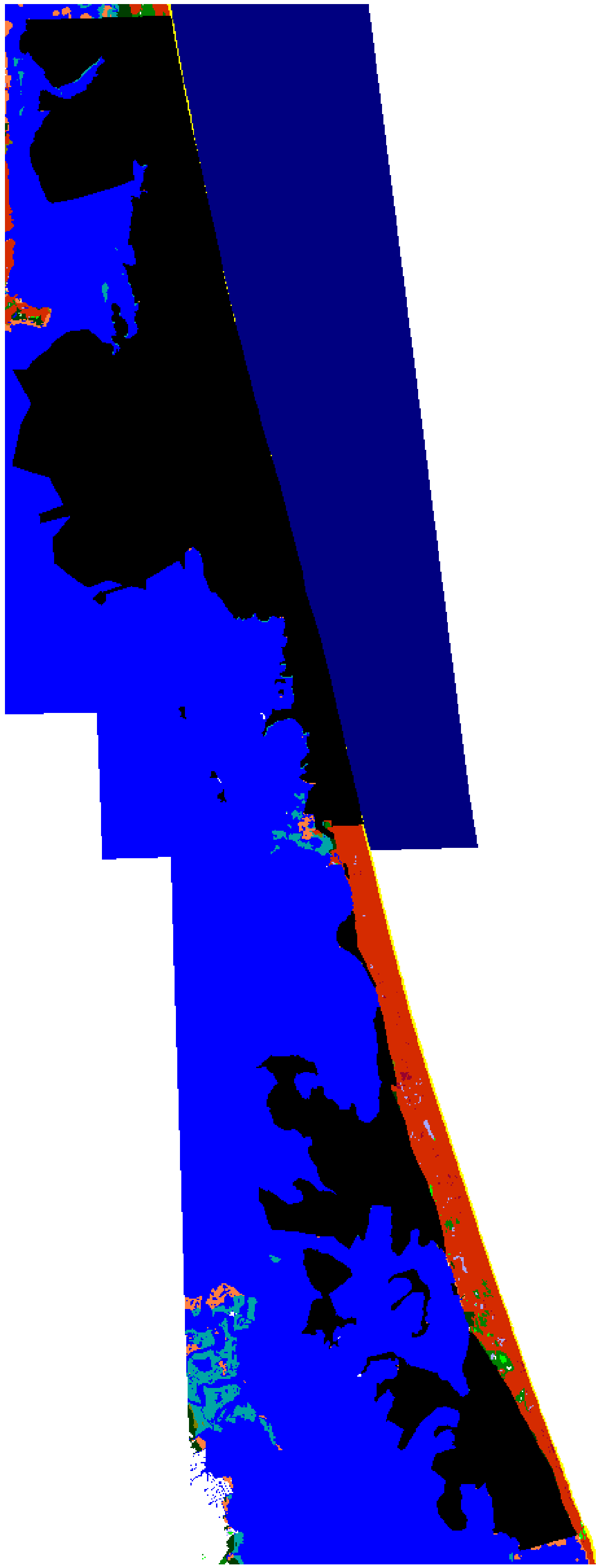
Appendix A: Contextual Results

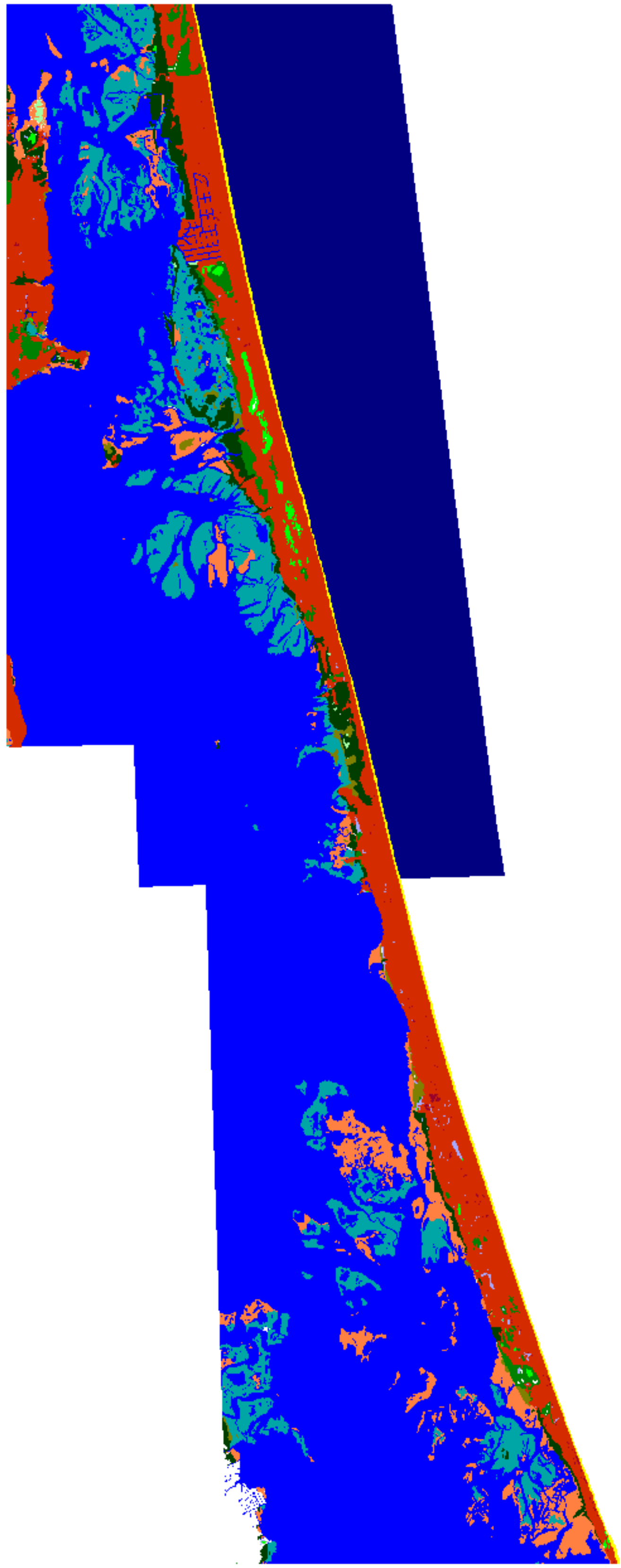
The SLAMM model does take into account the context of the surrounding lands or open water when calculating effects. For example, erosion rates are calculated based on the maximum fetch (wave action) which is estimated by assessing contiguous open water to a given marsh cell. Another example is that inundated dry lands will convert to marshes or ocean beach depending on their proximity to open ocean.

For this reason, an area larger than the boundaries of the USFWS refuge was modeled. These results maps are presented here with the following caveats:

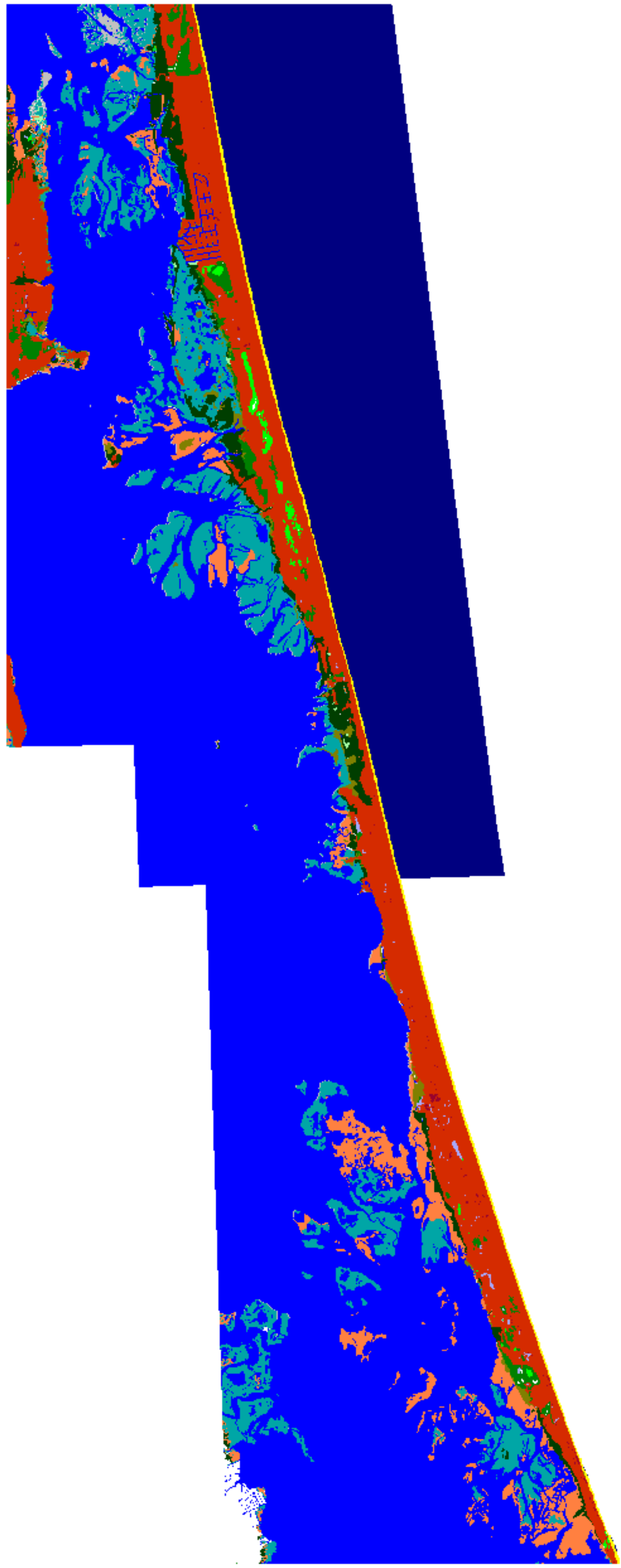
- Results were closely examined (quality assurance) within USFWS refuges but not closely examined for the larger region.
- Site-specific parameters for the model were derived for USFWS refuges whenever possible and may not be regionally applicable.
- Especially in areas where dikes are present, an effort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



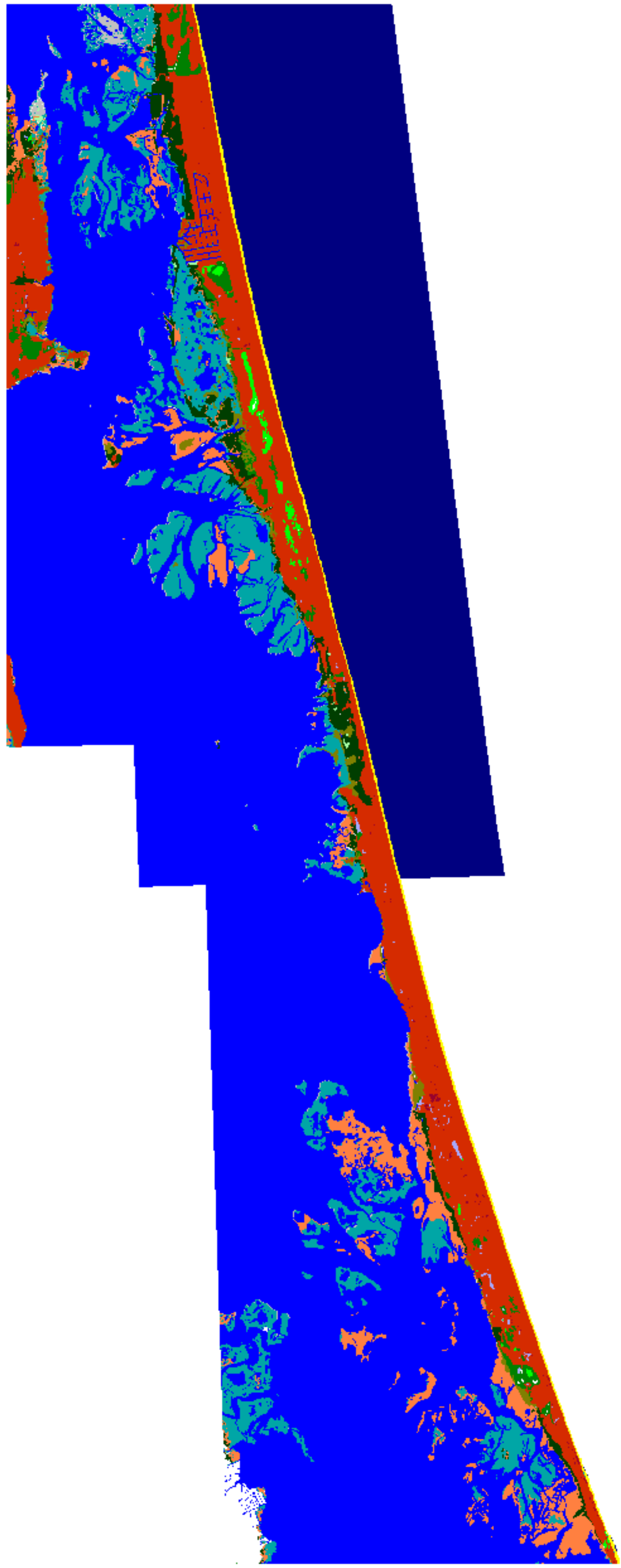
Currituck National Wildlife Refuge (black region) within simulation context.



Currituck Context, Initial Condition



Currituck Context, 2025, Scenario A1B Mean



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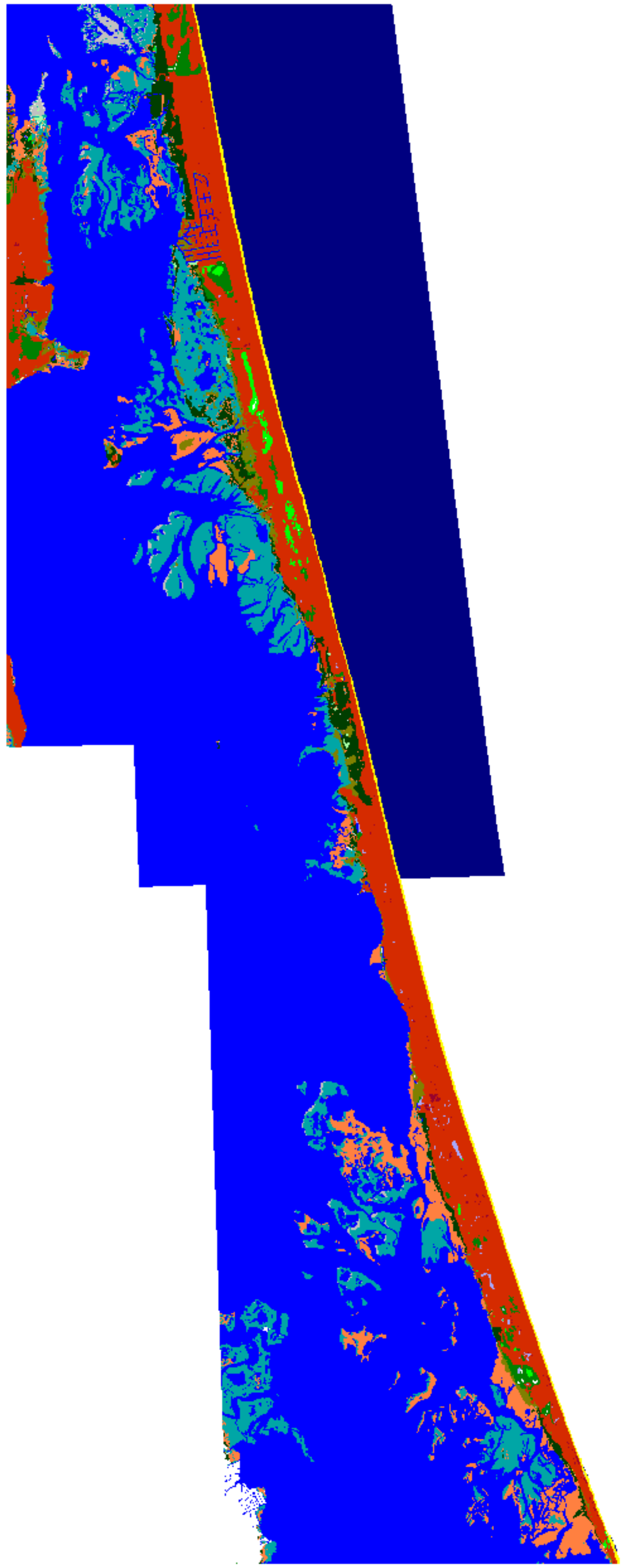

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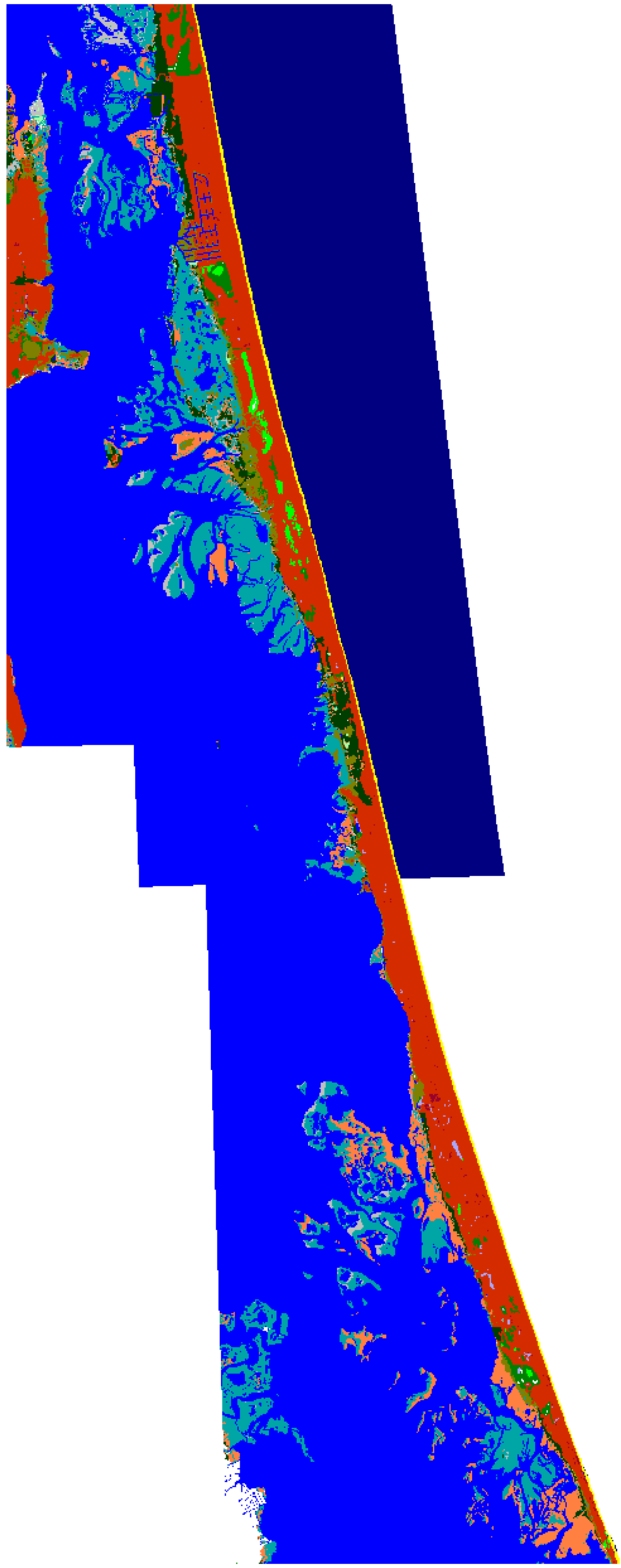

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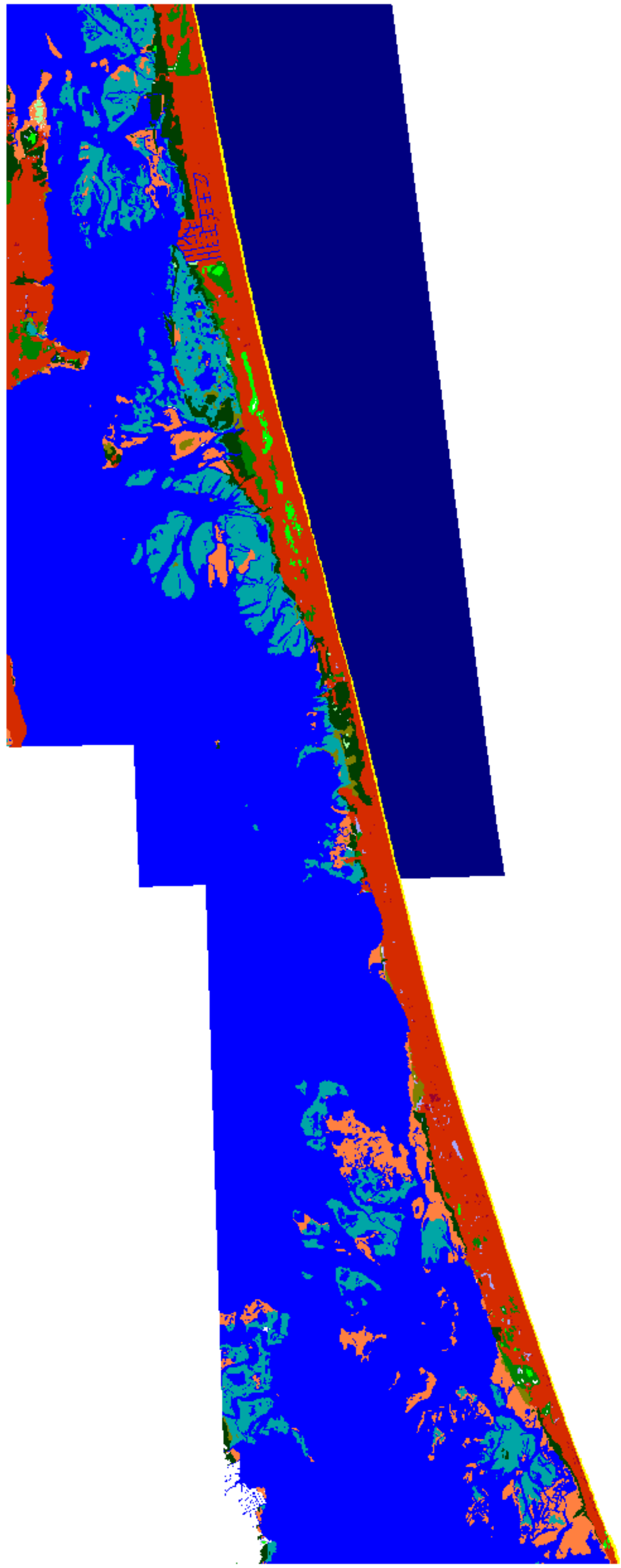
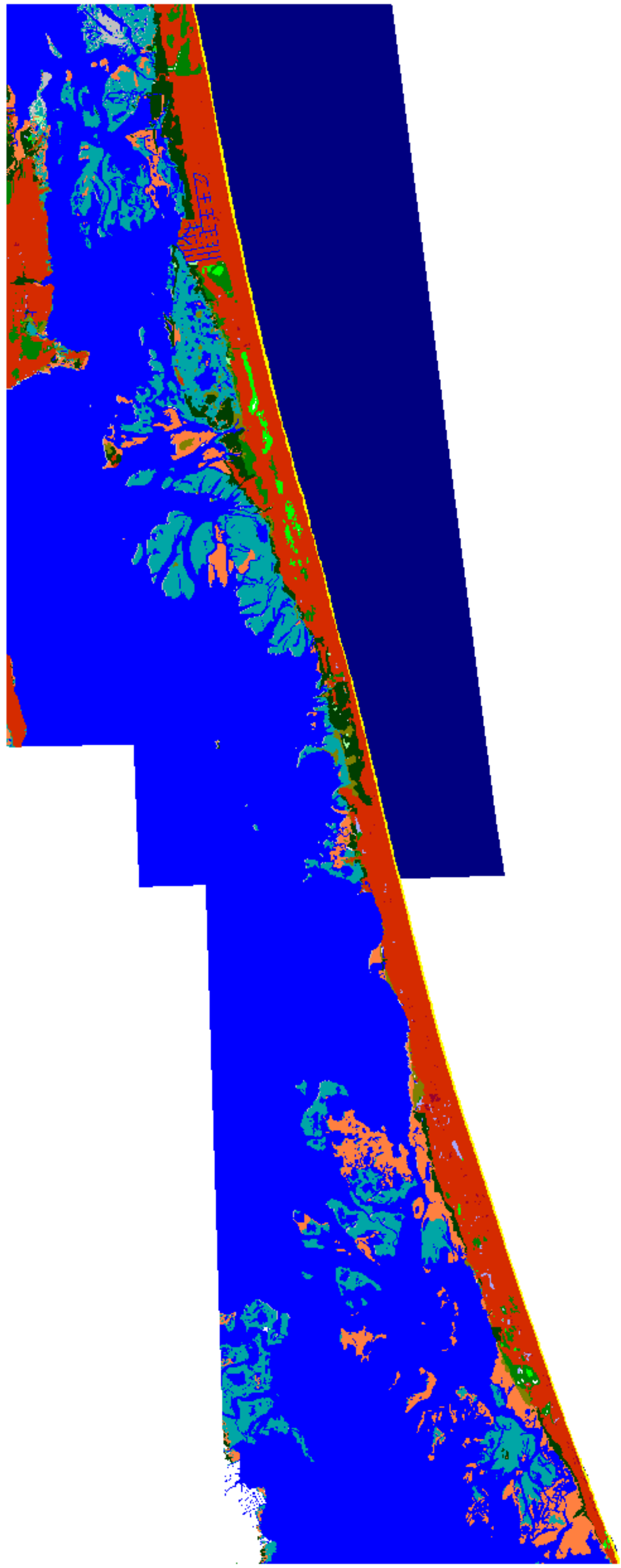
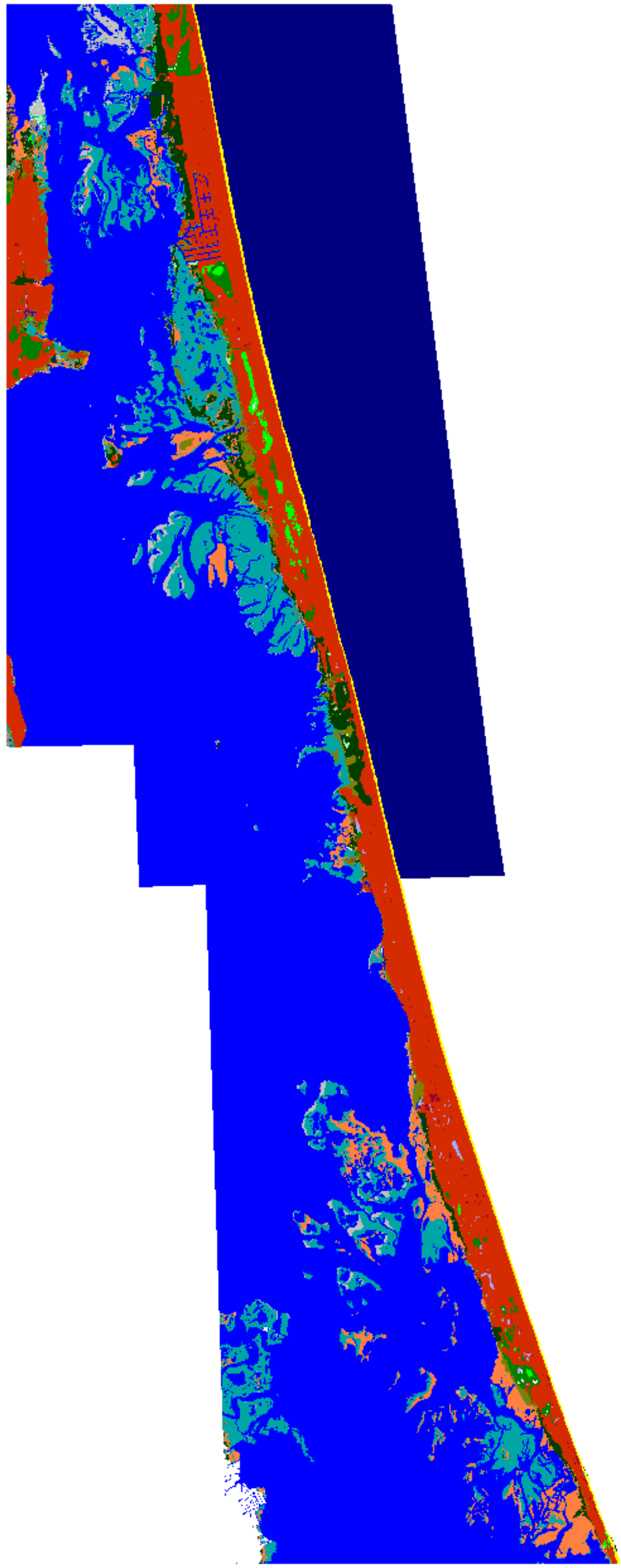


Currituck Context, Initial Condition



Curritucк Context, 2025, Scenario A1B Maximum



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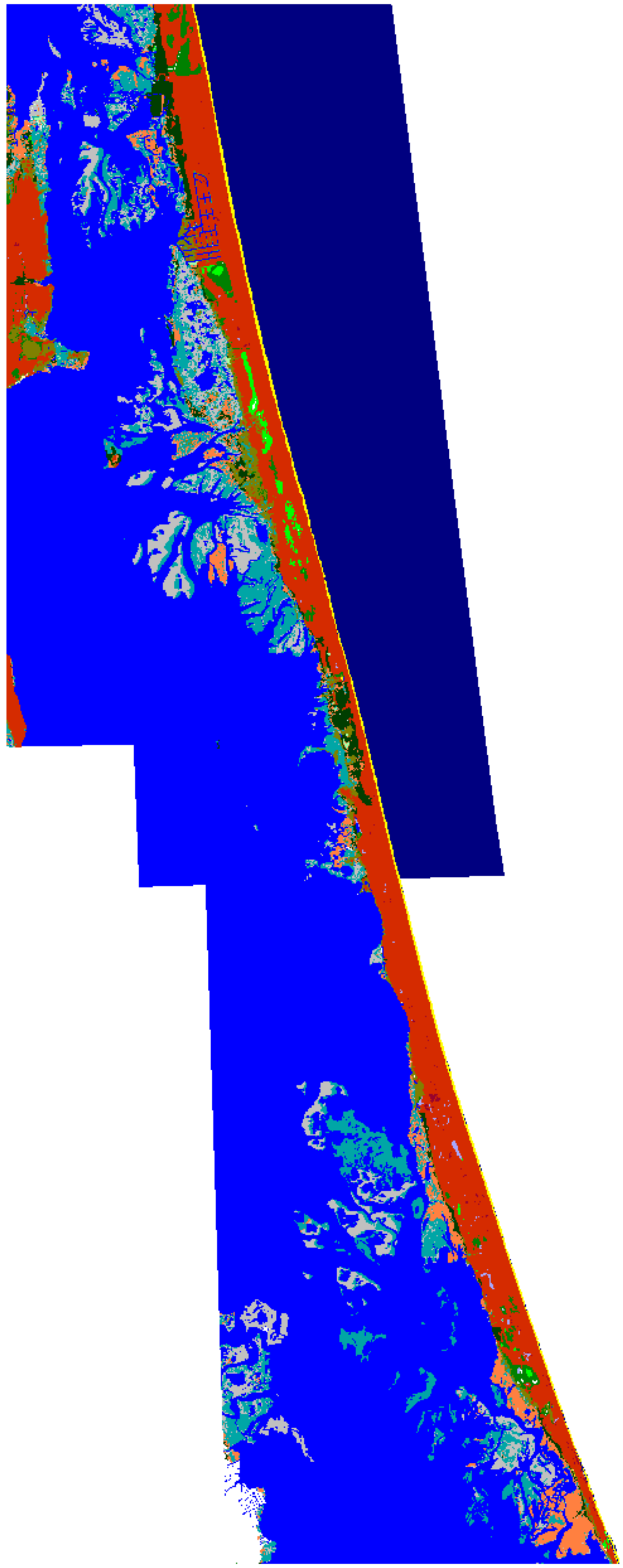

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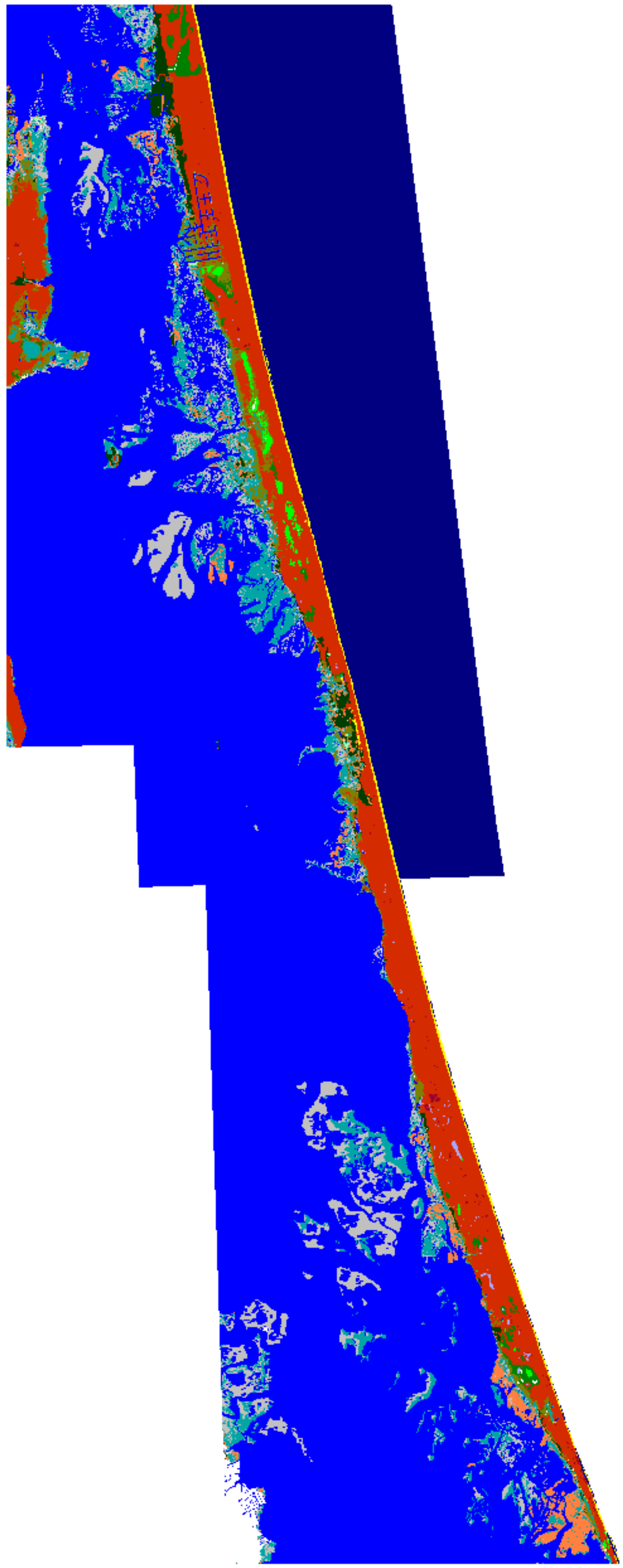
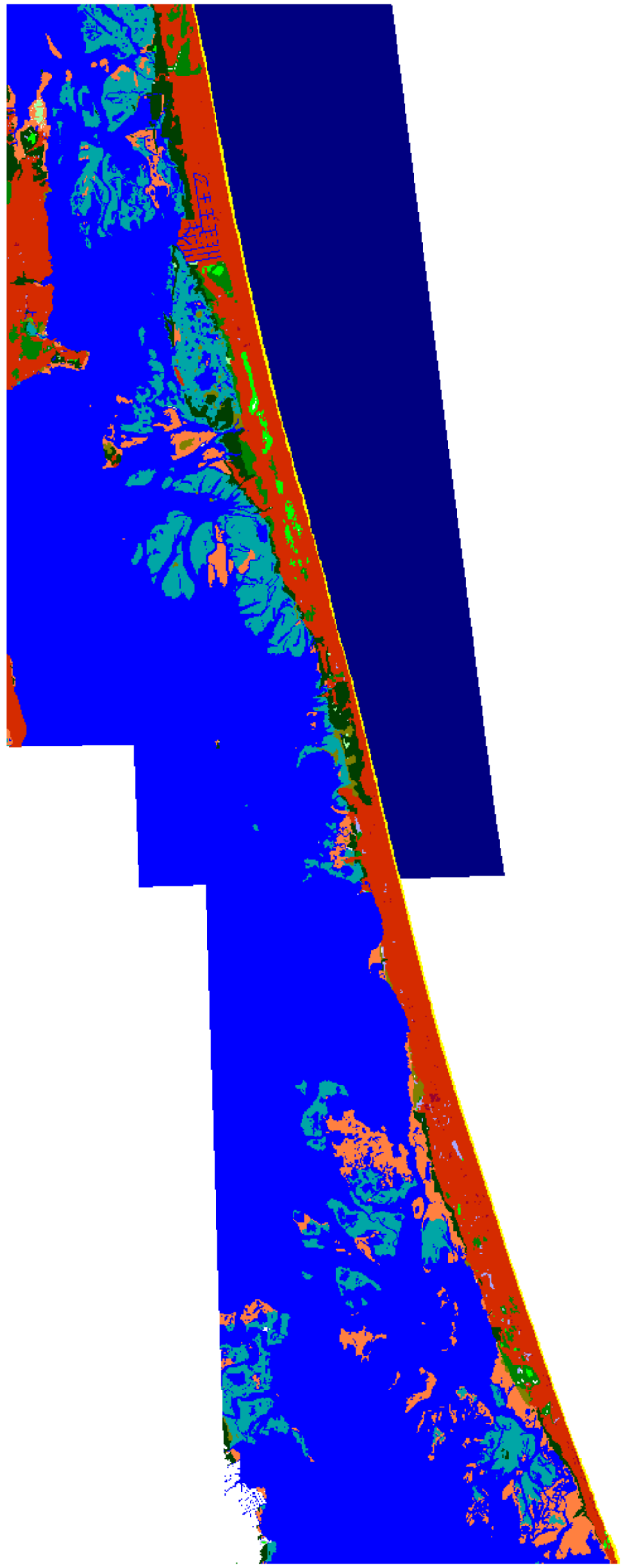
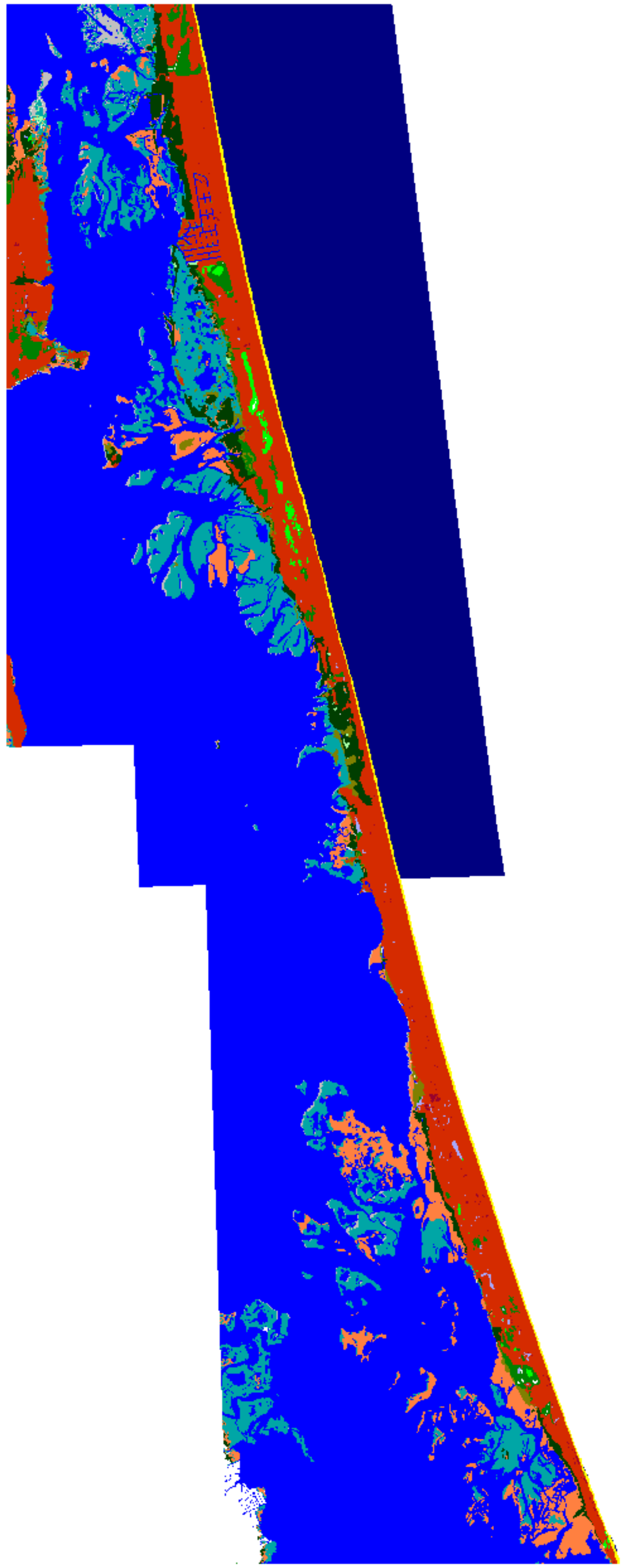


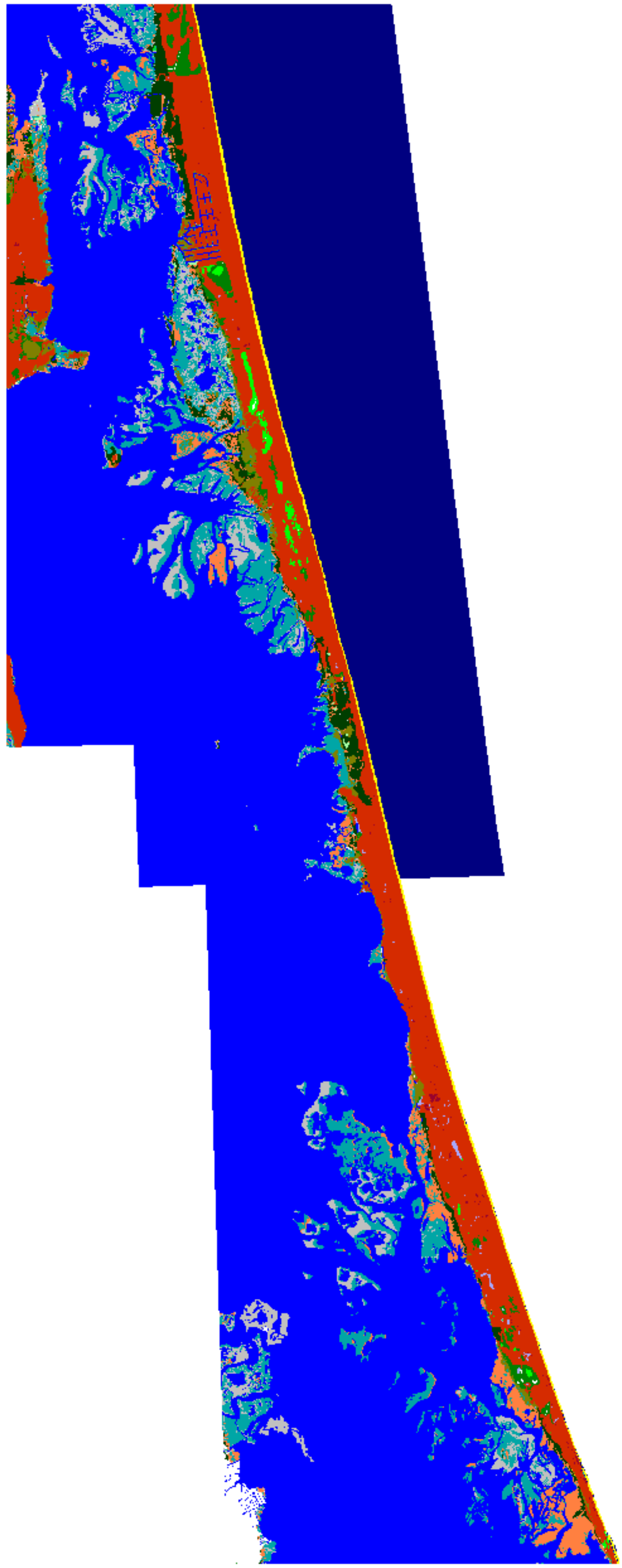
Currituck Context, 2100, Scenario A1B Maximum



Currituck Context, Initial Condition



Currituck Context, 2025, 1 meter



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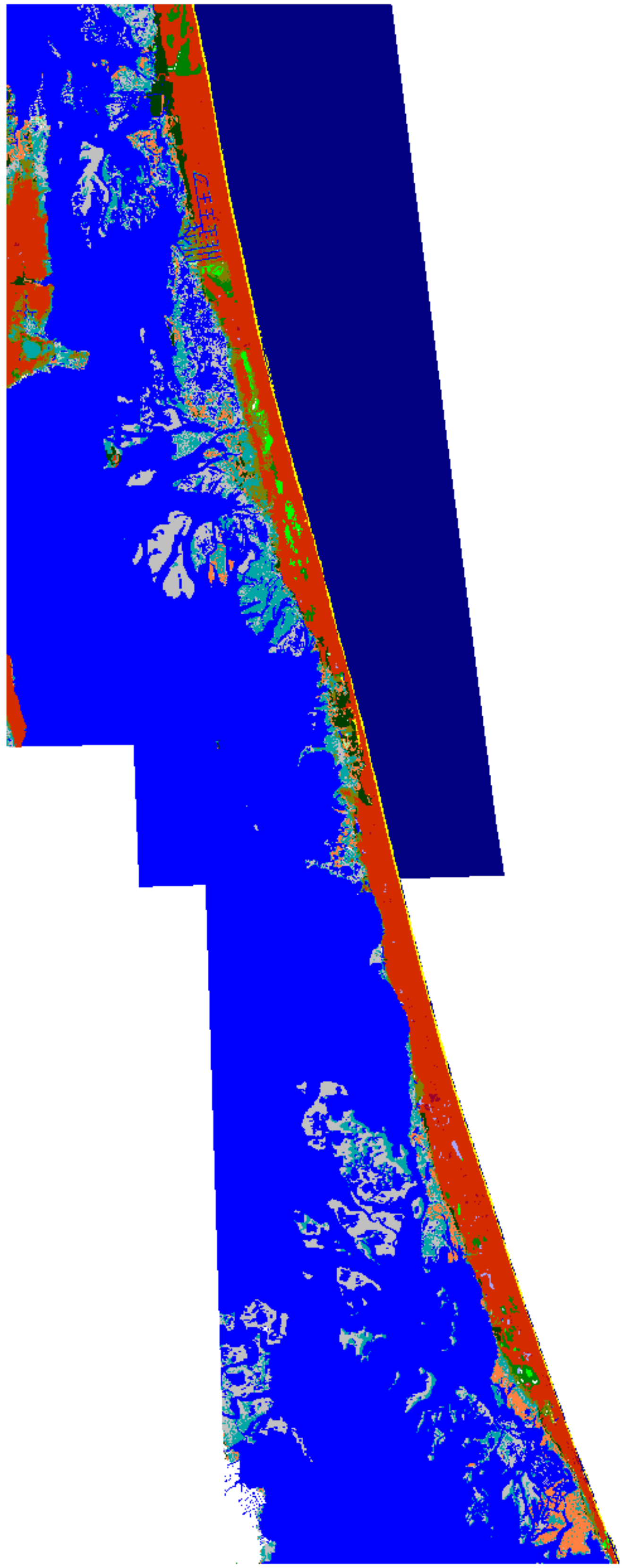

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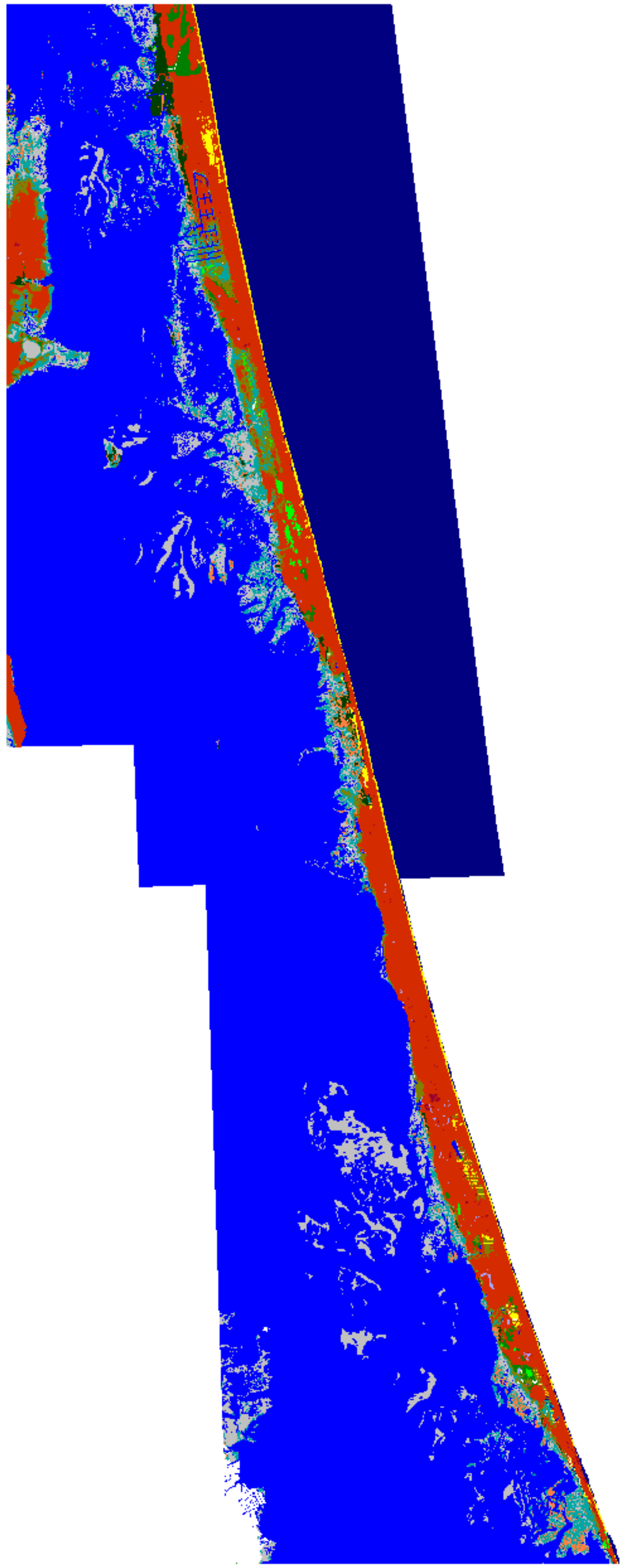

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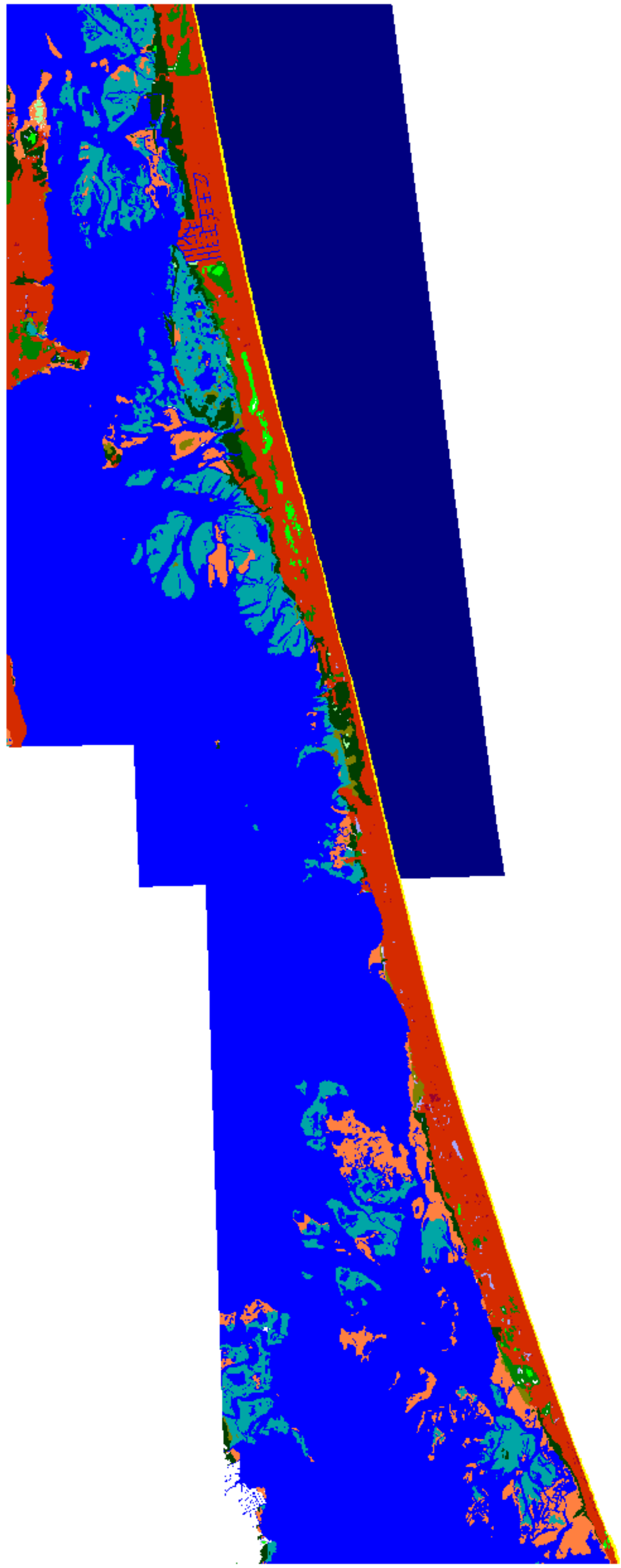

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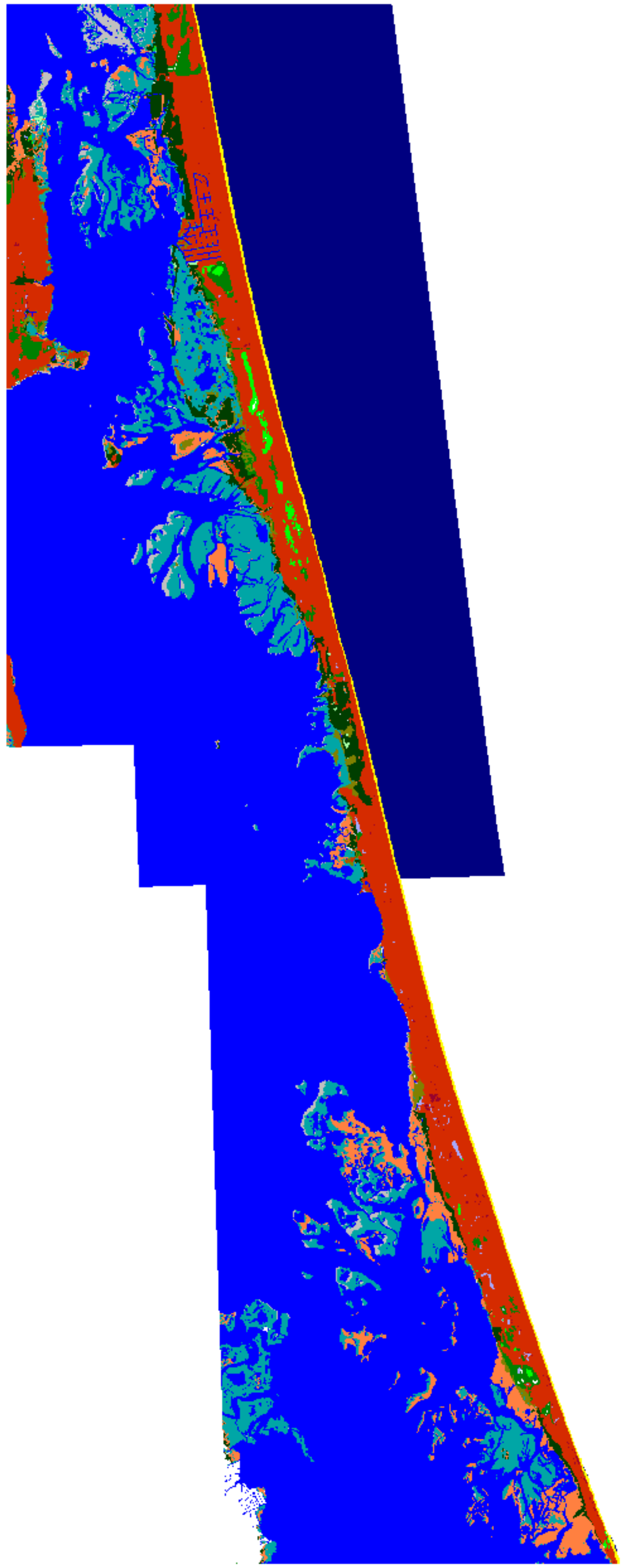
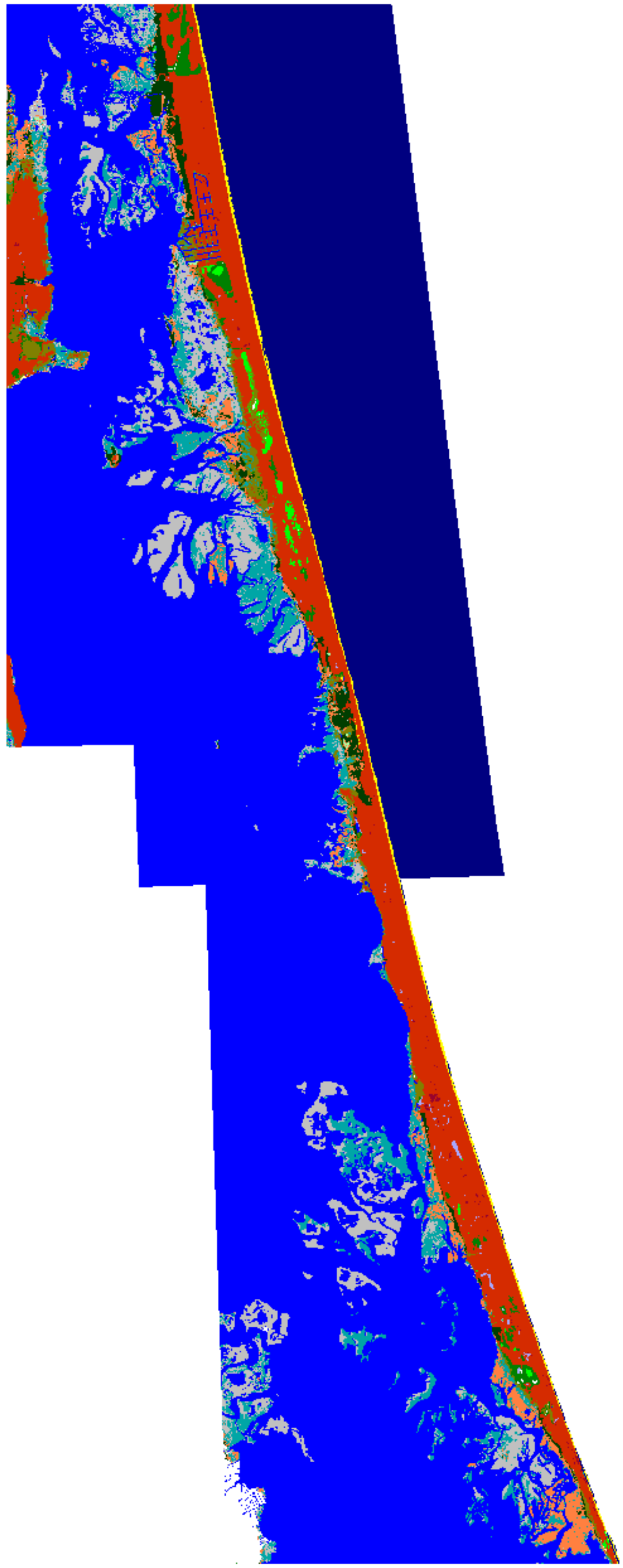
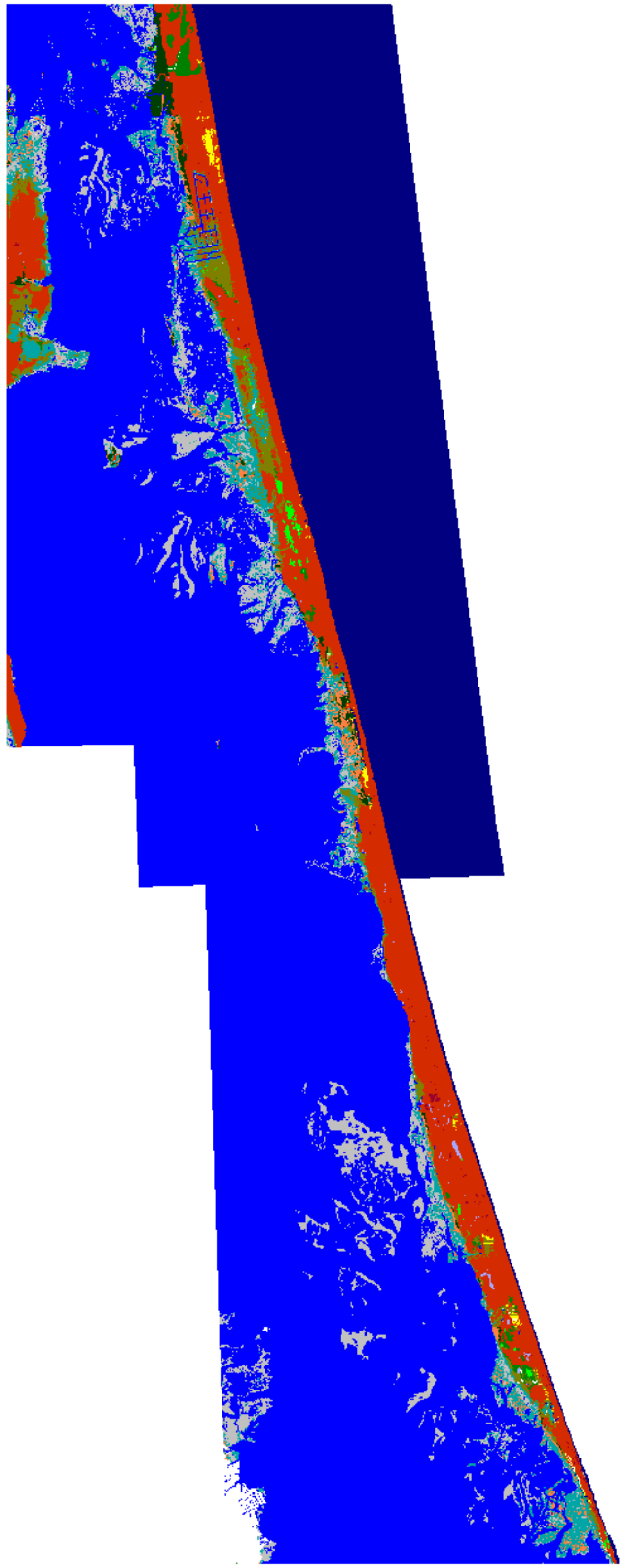


Currituck Context, 2025, 1.5 meter



Currituck Context, 2050, 1.5 meter



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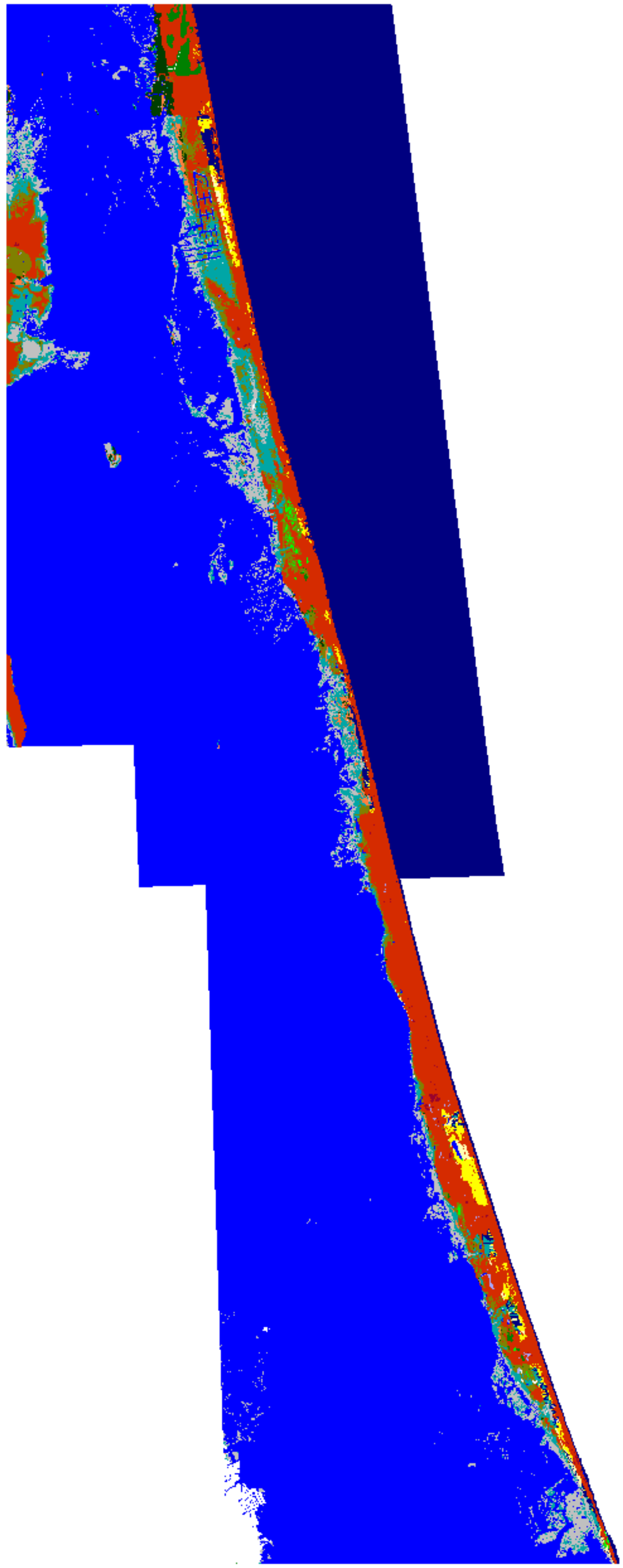
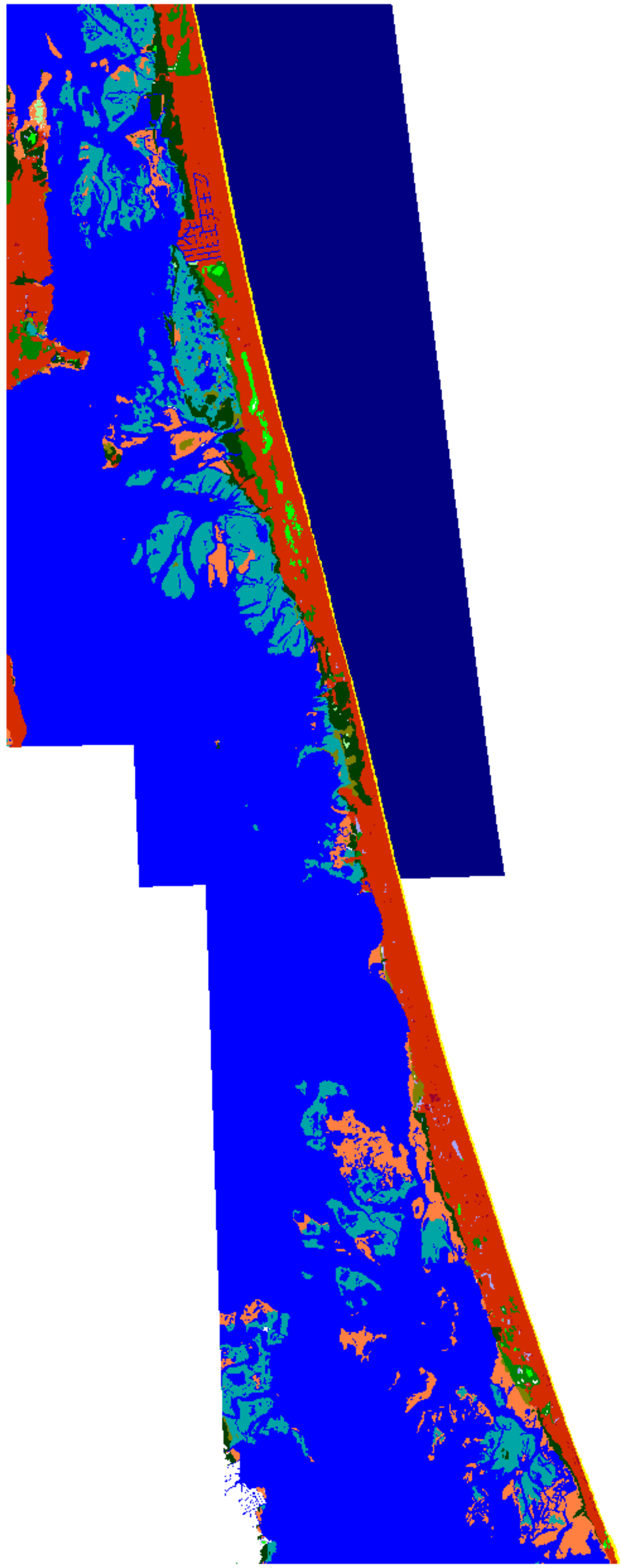
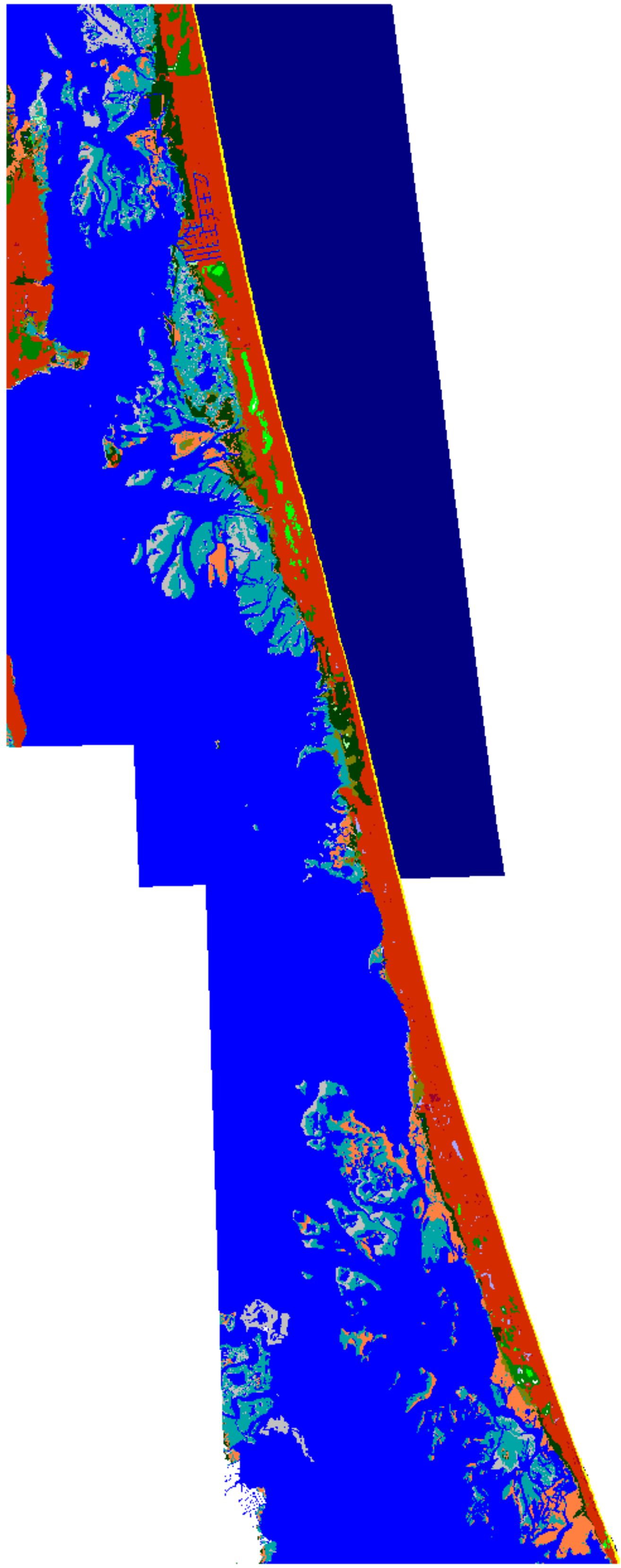


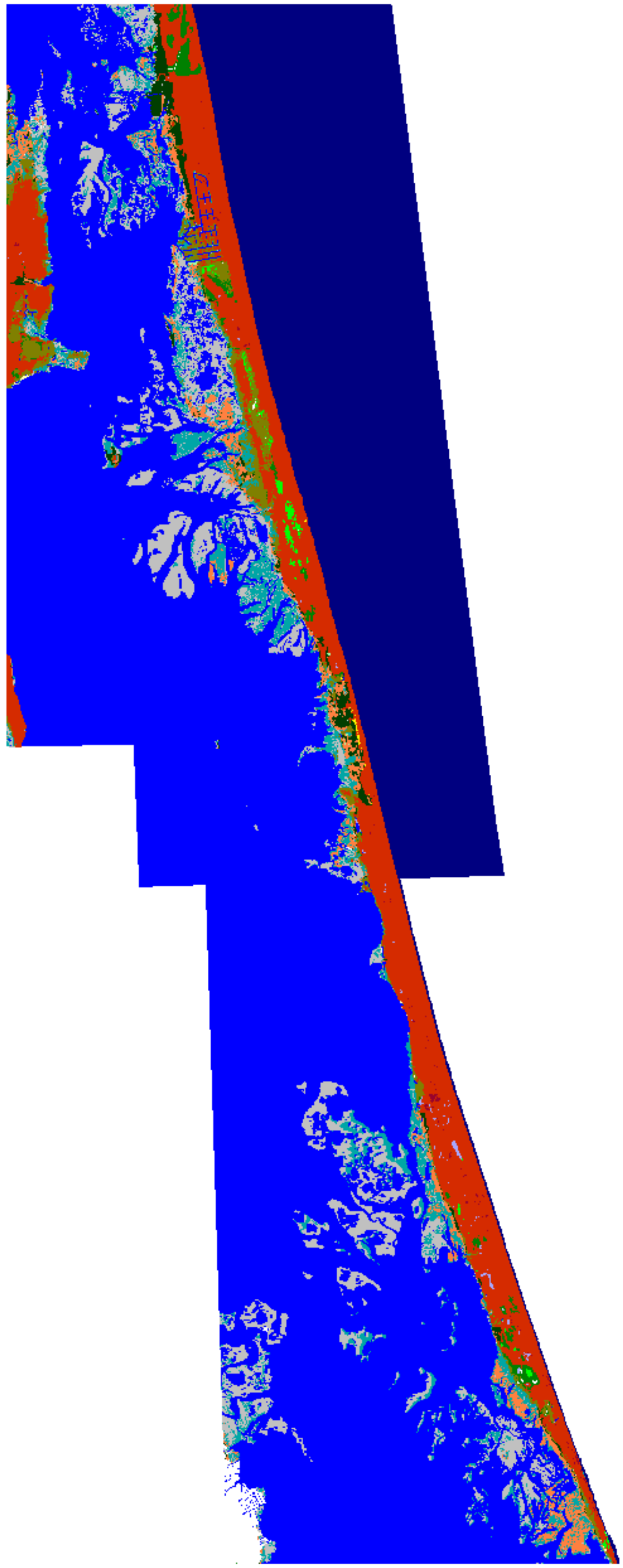
Currituck Context, 2100, 1.5 meter



Currituck Context, Initial Condition



Currituck Context, 2025, 2 meter



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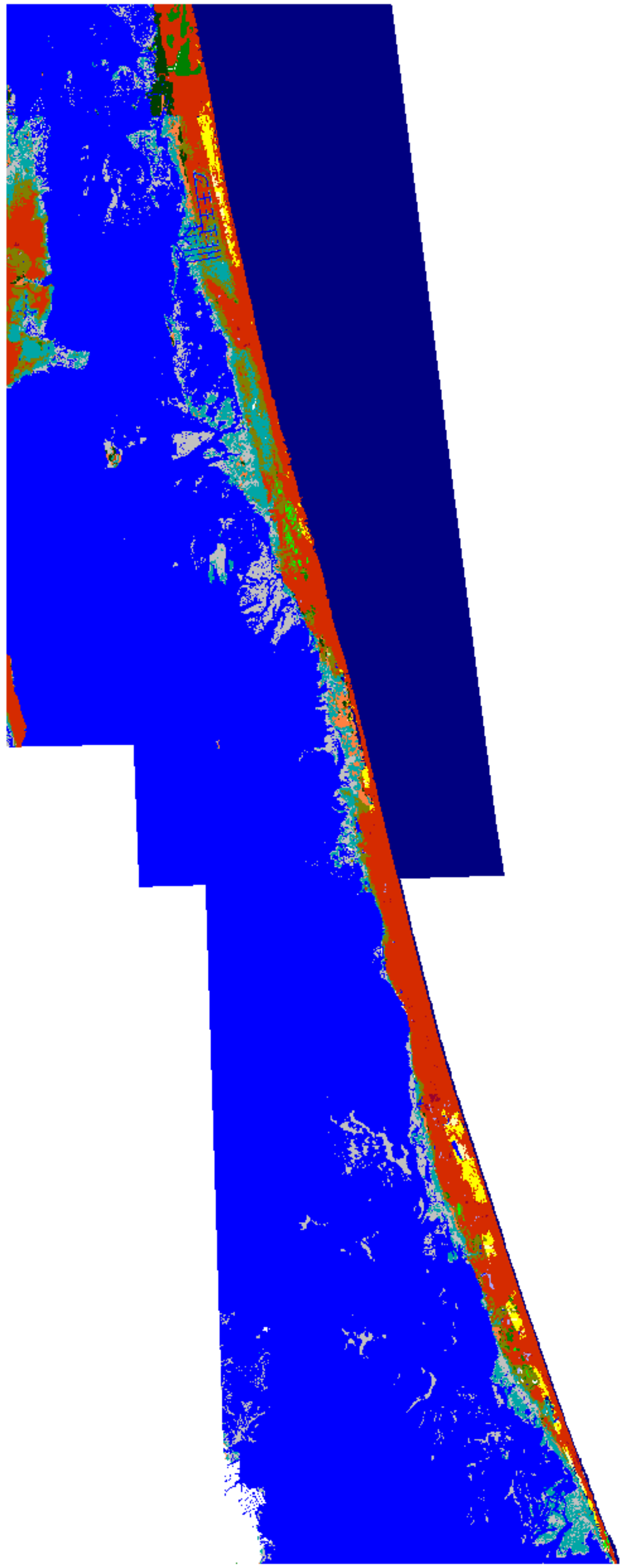
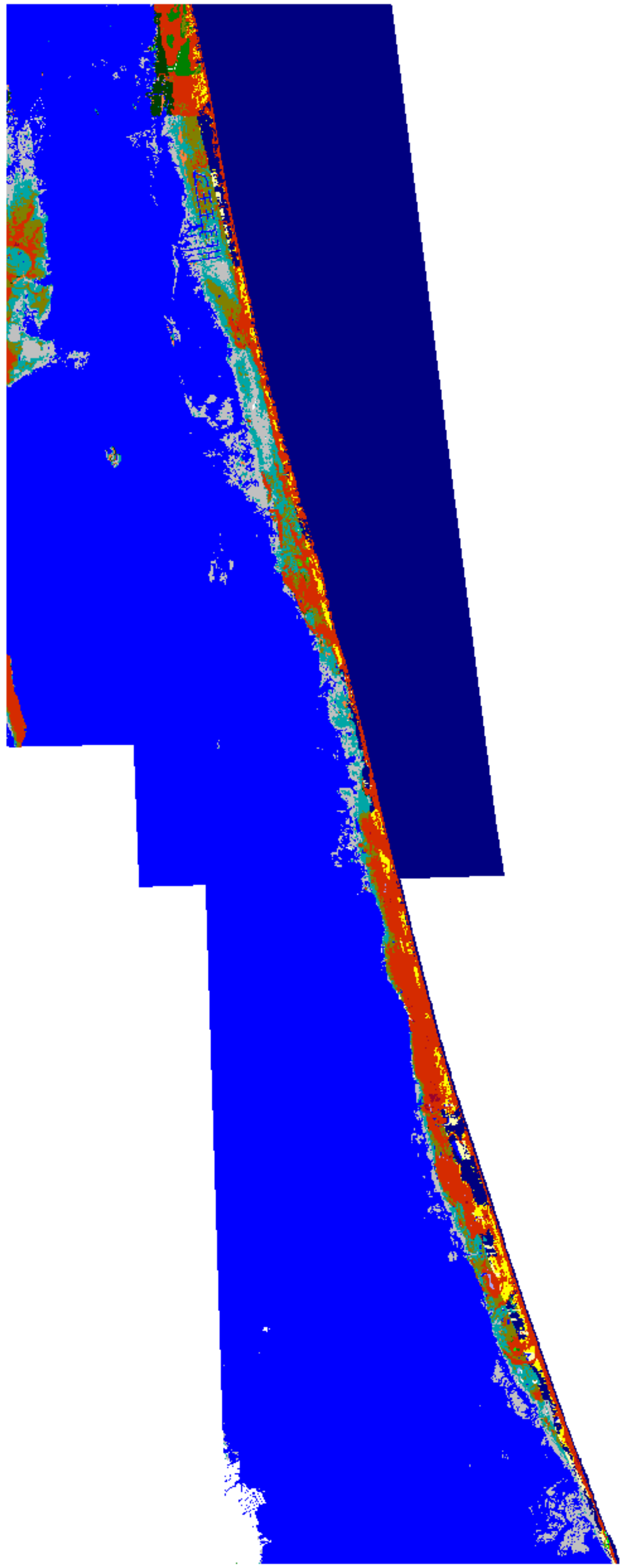


Currituck Context, 2075, 2 meter



Currituck Context, 2100, 2 meter