Application of the Sea-Level Affecting Marshes Model (SLAMM 5.0) to Alligator River National Wildlife Refuge

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Introduction

Tidal marshes are among the most susceptible ecosystems to climate change, especially accelerated sea level rise (SLR). Sea level is predicted to increase by 30 cm to 100 cm by 2100 based on the International Panel on Climate Change (IPCC) Special Report on Emissions Scenarios (SRES) (Meehl et al. 2007). Rising sea level may result in tidal marsh submergence (Moorhead and Brinson 1995) and habitat migration as salt marshes transgress landward and replace tidal freshwater and brackish 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 4 refuges. This analysis is designed to assist in the production of comprehensive conservation plans (CCPs) for each refuge. A CCP is a document that provides a framework for guiding refuge management decisions. All refuges are required by law to complete a CCP by 2012.

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 5.0) 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 25-year time-step due to 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.

SLAMM Version 5.0 is the latest version of the SLAMM Model, developed in 2006/2007 and based on SLAMM 4.0. SLAMM 5.0 provides the following refinements:

- The capability to simulate fixed levels of sea-level rise by 2100 in case IPCC estimates of sea-level rise prove to be too conservative;
- Additional model categories such as "Inland Shore," "Irregularly Flooded (Brackish) Marsh," and "Tidal Swamp."
- *Optional.* In a defined estuary, salt marsh, brackish marsh, and tidal fresh marsh can migrate based on changes in salinity, using a simple though geographically-realistic salt wedge model. This optional model was not used when creating results for Alligator River National Wildlife Refuge.

Model results presented in this report were produced using SLAMM version 5.0.1 which was released in early 2008 based on only minor refinements to the original SLAMM 5.0 model. Specifically, the accretion rates for swamps were modified based on additional literature review. For a thorough accounting of SLAMM model processes and the underlying assumptions and equations, please see the SLAMM 5.0.1 technical documentation (Clough and Park, 2008). This document is available at http://warrenpinnacle.com/prof/SLAMM

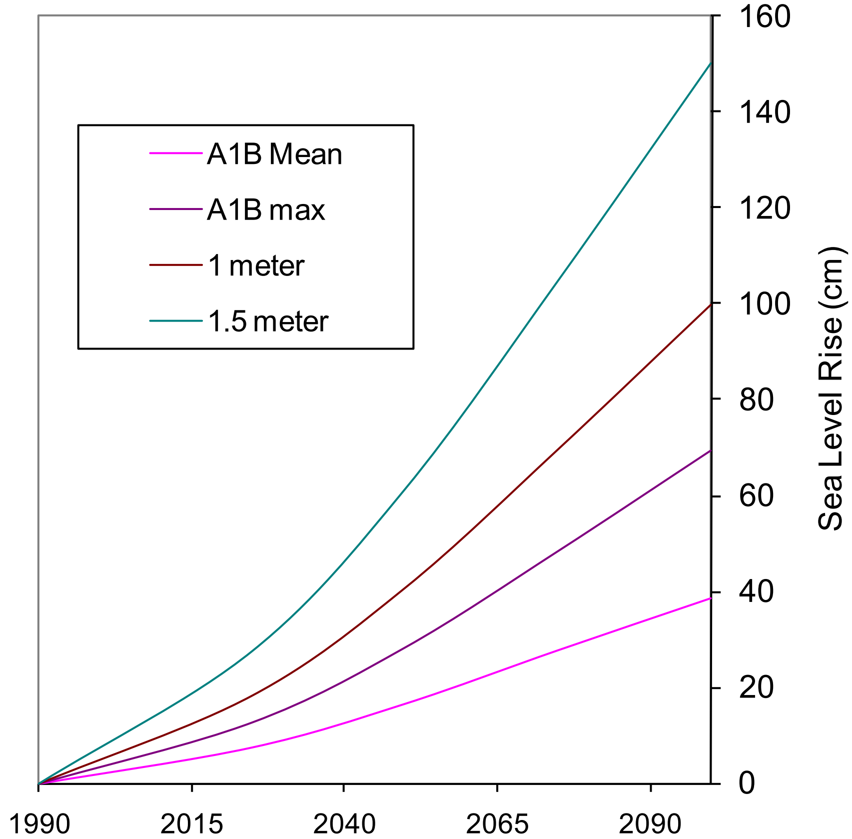
Sea-Level Rise Scenarios

The primary set of eustatic (global) sea level rise scenarios used within SLAMM was derived from the work of the Intergovernmental Panel on Climate Change (IPCC 2001). SLAMM 5 was run using the following IPCC and fixed-rate scenarios:

Scenario	Eustatic SLR by 2025 (cm)	Eustatic SLR by 2050 (cm)	Eustatic SLR by 2075 (cm)	Eustatic SLR by 2100 (cm)
A1B Mean	8	17	28	39
A1B Max	14	30	49	69
1 meter	13	28	48	100
1.5 meter	18	41	70	150

Recent 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 might be 50 to 140 cm. To allow for flexibility when interpreting the results, SLAMM was also run assuming 1 meter, 1½ 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

High-resolution LIDAR data are available for Alligator River NWR as is the case for all of coastal North Carolina. These elevation data are available through the National Elevation Dataset (NED), which was updated in 2008 to reflect these high-quality data. The error in vertical resolution for LIDAR data can be as low as 5-10 cm.

The National Wetlands Inventory for Alligator River is based on a photo date of 1982. This survey, when converted to 30 meter cells, suggests that on that date, the approximately two hundred forty thousand acre refuge (approved acquisition boundary) was primarily composed of swamp lands as shown below:

Swamp	76%
Inland Fresh Marsh	7%
Dry Land	6%
Brackish Marsh	5%
Trans. Salt Marsh	4%
Saltmarsh	1%
Inland Open Water	1%
Estuarine Open Water	1%

The historic trend for sea level rise was estimated at 3 mm/year using the approximate average of the long term trends measured at Wilmington, North Carolina (NOAA station 8658120) and Beaufort, North Carolina (8656483).

The tide range for this site was estimated at 0.192 meters using the average of the five closest NOAA stations as shown below. (Tide ranges are MHHW-MLLW in meters.)

8652905	LAKE WORTH, STUMPY POINT BAY, NC	**0.197**
8652547	ROANOKE MARSHES LIGHT, CROATAN SOUND, NC	**0.181**
8652247	MANNS HARBOR, CROATAN SOUND, NC	**0.124**
8652648	OLD HOUSE CHANNEL	**0.275**
8652437	OYSTER CREEK, CROATAN SOUND, NC	**0.183**

The NED vertical datum of NAVD88 was related to mean tide level using the NOAA stations at Rodanthe, Pamlico Sound (8653215) And Cape Hatteras Fishing Pier (8654400).

Accretion rates for salt-marsh were set to 3.85 mm/year based on a study of vertical accretion in Cedar Island NC (Cahoon, Reed, and Day, 1995). An alternative study set the rate at 3.0 but was based further from the refuge (Benninger and Chanton's 1985 study of North River, NC)

Modeled U.S. Fish and Wildlife Service refuge boundaries are based on Approved Acquisition Boundaries as received from Kimberly Eldridge, lead cartographer with U.S. Fish and Wildlife Service, and are current as of June 2008.

The cell-size used for this analysis was 30 meter by 30 meter cells. However, the SLAMM model does track partial conversion of cells based on elevation and slope.

The National Wetlands Inventory does not indicate that any lands in Alligator River NWR are protected by dikes or impounded. For this reason, the refuge was not considered protected by dikes.

A conversation with Michael Bryant, the U.S. Fish and Wildlife Service refuge manager for Alligator River occurred in July of 2008. His staff has communicated to him that the refuge is becoming more saline in recent years with significant effects on non salt-tolerant vegetation. Furthermore, vertical accretion of wetlands is often reduced due to compaction of highly organic peat soils under conditions of saline inundation. This indicates that assumptions of constant vertical accretion may be somewhat conservative in this modeling (overly protective). Within the refuge, Michael Bryant reports seeing a transition from swamp forest to fresh water marsh to salt water marsh (spartina.) As shown in the results section, this SLAMM analysis indicates that this transition is likely to significantly increase in scope under conditions of accelerated sea level rise.

SUMMARY OF SLAMM INPUT PARAMETERS FOR ALLIGATOR RIVER

Site		**Alligator River**
NED Source Date (yyyy)	,	2000
NWI_photo_date (yyyy)	,	1982
Direction_OffShore (N|S|E|W)	,	E
Historic_trend (mm/yr)	,	3
NAVD88_correction (MTL-NAVD88 in meters)	,	-0.07
Water Depth (m below MLW- N/A)	,	2
TideRangeOcean (meters: MHHW-MLLW)	,	0.192
TideRangeInland (meters)	,	0.192
Mean High Water Spring (m above MTL)	,	0.128
MHSW Inland (m above MTL)	,	0.128
Marsh Erosion (horz meters/year)	,	1.8
Swamp Erosion (horz meters/year)	,	1
TFlat Erosion (horz meters/year) [from 0.5]	,	0.5
Salt marsh vertical accretion (mm/yr) Final	,	3.85
Brackish March vert. accretion (mm/yr) Final	,	4.7
Tidal Fresh vertical accretion (mm/yr) Final	,	5.9
Beach/T.Flat Sedimentation Rate (mm/yr)	,	0.5
Frequency of Large Storms (yr/washover)	,	25
Use Elevation Preprocessor for Wetlands	,	FALSE

Results

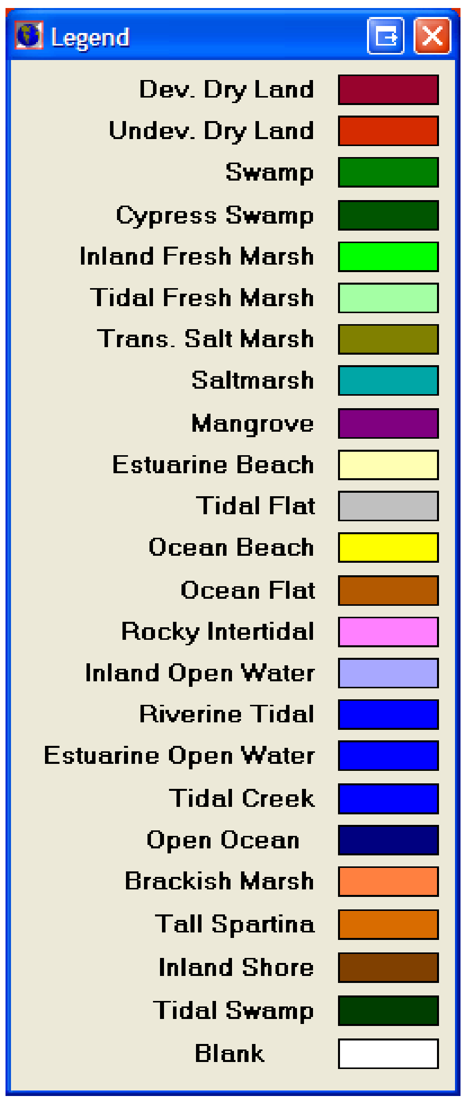
Wetland Coverage Predictions

The microtidal climate of Alligator River combined with relatively low accretion rates result in a site that is predicted to be quite vulnerable to increased rates of sea level rise. Even under the lowest rate of sea level rise simulated, 62% of this site's swamp is predicted to be lost, converted to marsh, tidal flats, and open water. Dry land is also predicted to be especially vulnerable with 90% lost under all scenarios. (Dry land is currently not assumed protected by dikes.)

SLR by 2100 (m)	0.39	0.69	1	1.5
Swamp	62%	84%	93%	98%
Inland Fresh Marsh	0%	5%	22%	41%
Dry Land	90%	94%	97%	99%
Brackish Marsh	7%	47%	90%	100%

Loss rates of Top Four Land Categories as a Function of Eustatic Sea Level Rise

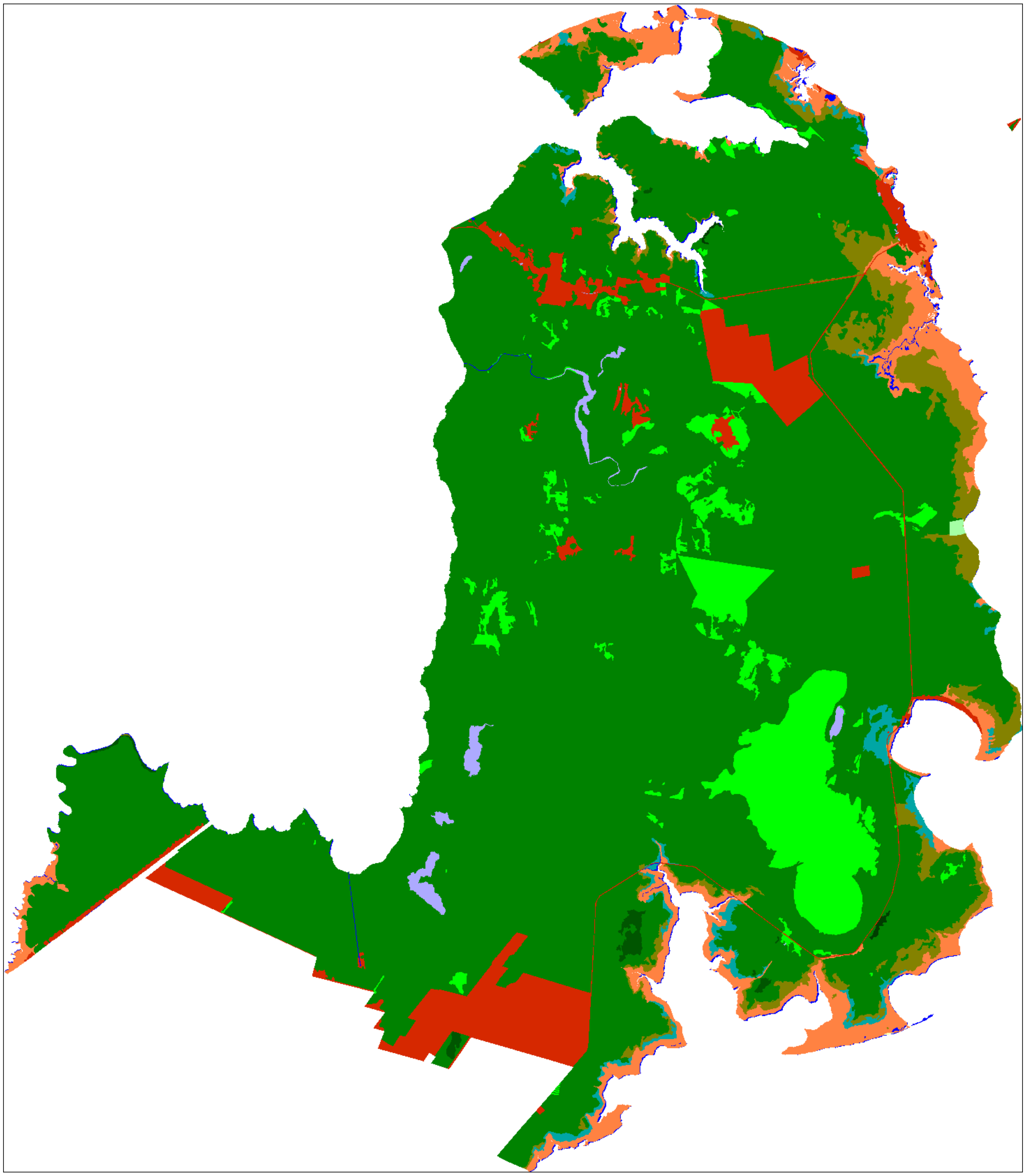
Maps of SLAMM input and output that follow will use the following legend:



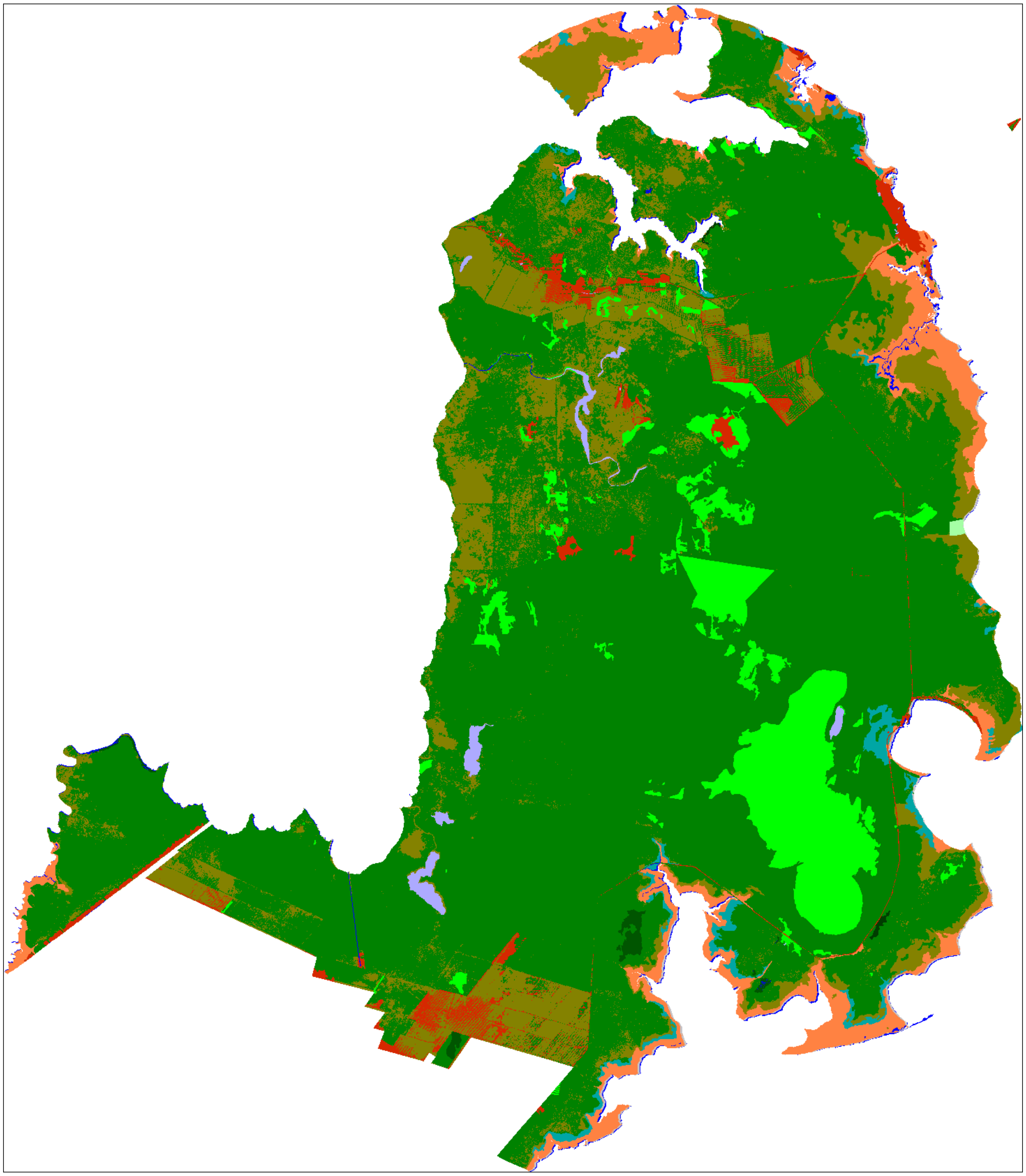
Alligator River
IPCC Scenario A1B-Mean, 0.39 M SLR Eustatic by 2100

Results in Acres

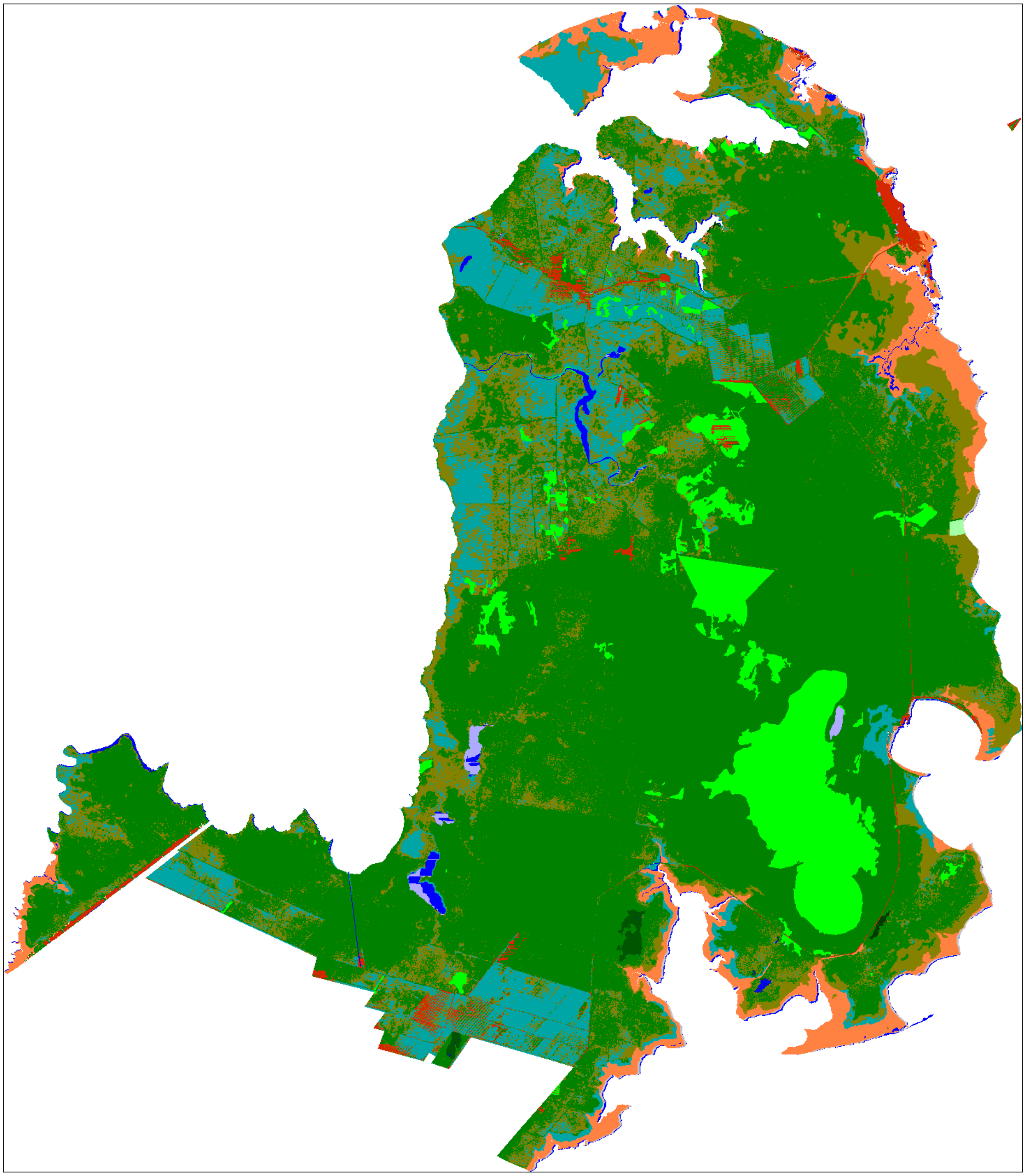
	Initial	2025	2050	2075	2100
Swamp	182591.4	163667.9	138521.4	99766.2	68634.4
Inland Fresh Marsh	16455.8	16456.0	16573.6	16623.1	16631.4
Dry Land	13809.3	5397.8	3029.4	1896.5	1366.1
Brackish Marsh	12178.7	11649.8	11491.6	11444.5	11271.1
Trans. Salt Marsh	8674.0	35905.3	39681.0	48520.4	40771.6
Saltmarsh	2655.2	2633.6	26149.9	40010.7	54380.7
Inland Open Water	1342.1	1339.3	555.8	433.7	336.7
Estuarine Open Water	1246.5	1302.7	2353.0	4938.6	25014.1
Cypress Swamp	640.9	602.9	498.2	388.0	264.2
Tidal Swamp	100.1	97.4	85.3	63.3	30.4
Tidal Fresh Marsh	96.7	96.7	96.7	96.7	97.4
Riverine Tidal	30.7	30.7	3.3	0.4	0.4
Estuarine Beach	17.6	2.9	52.1	68.3	70.8
Tidal Flat	0.0	656.4	747.8	15588.7	20969.7
Total (incl. water)	**239839.2**	**239839.2**	**239839.2**	**239839.2**	**239839.2**



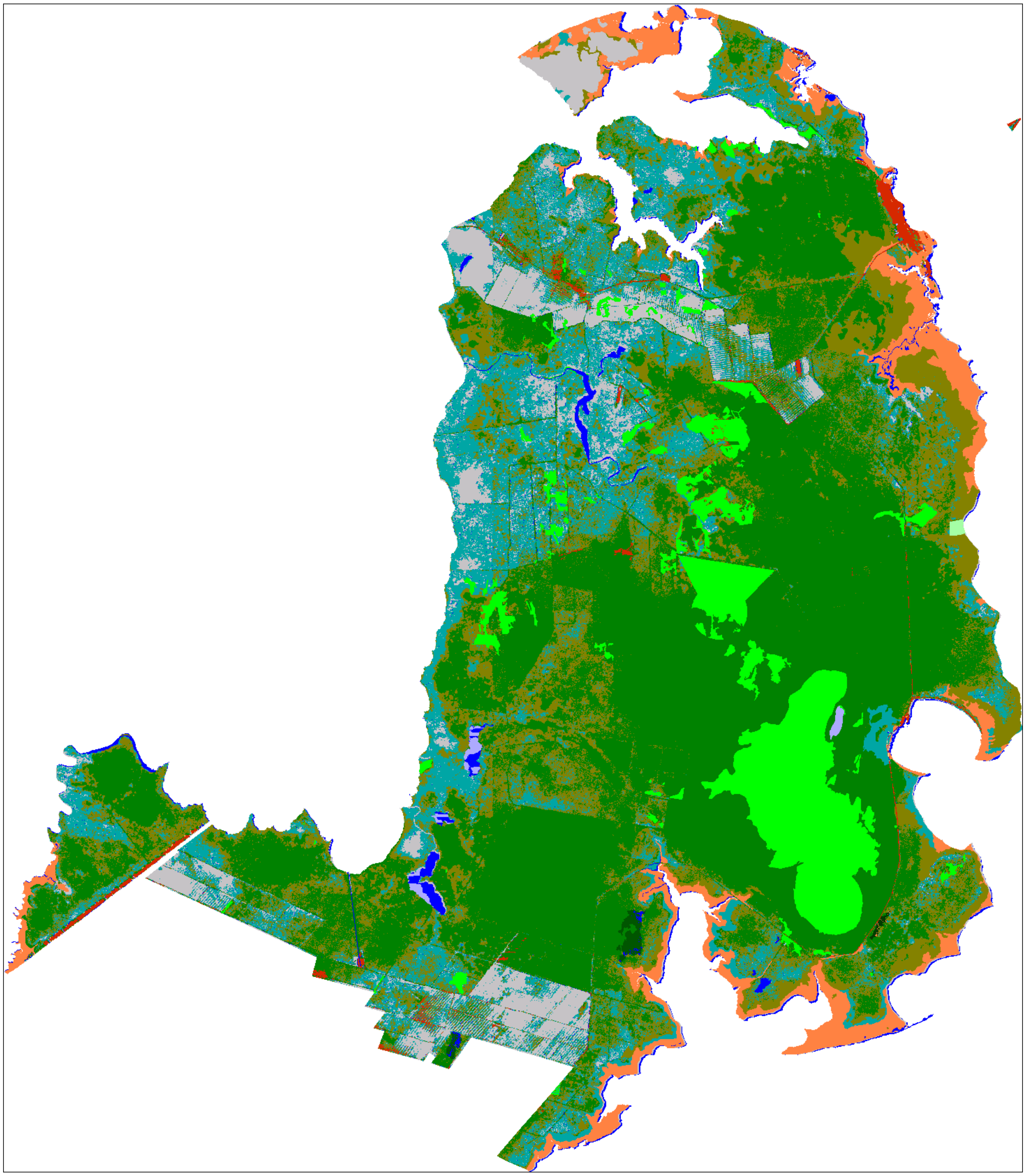
Alligator River NWR Initial Condition



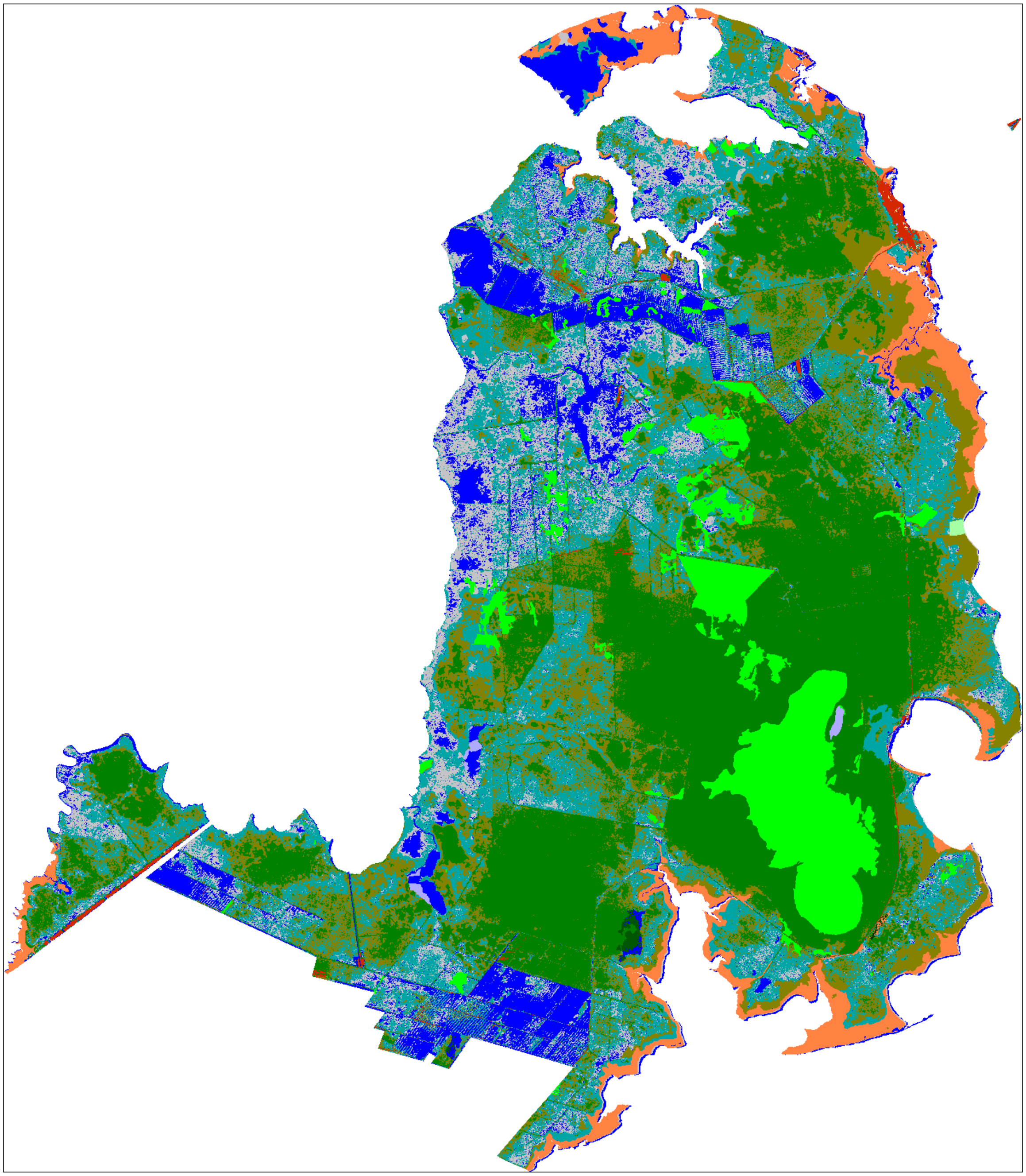
Alligator River NWR, 2025 IPCC Scenario A1B-Mean



Alligator River NWR, 2050 IPCC Scenario A1B-Mean



Alligator River NWR, 2075 IPCC Scenario A1B-Mean

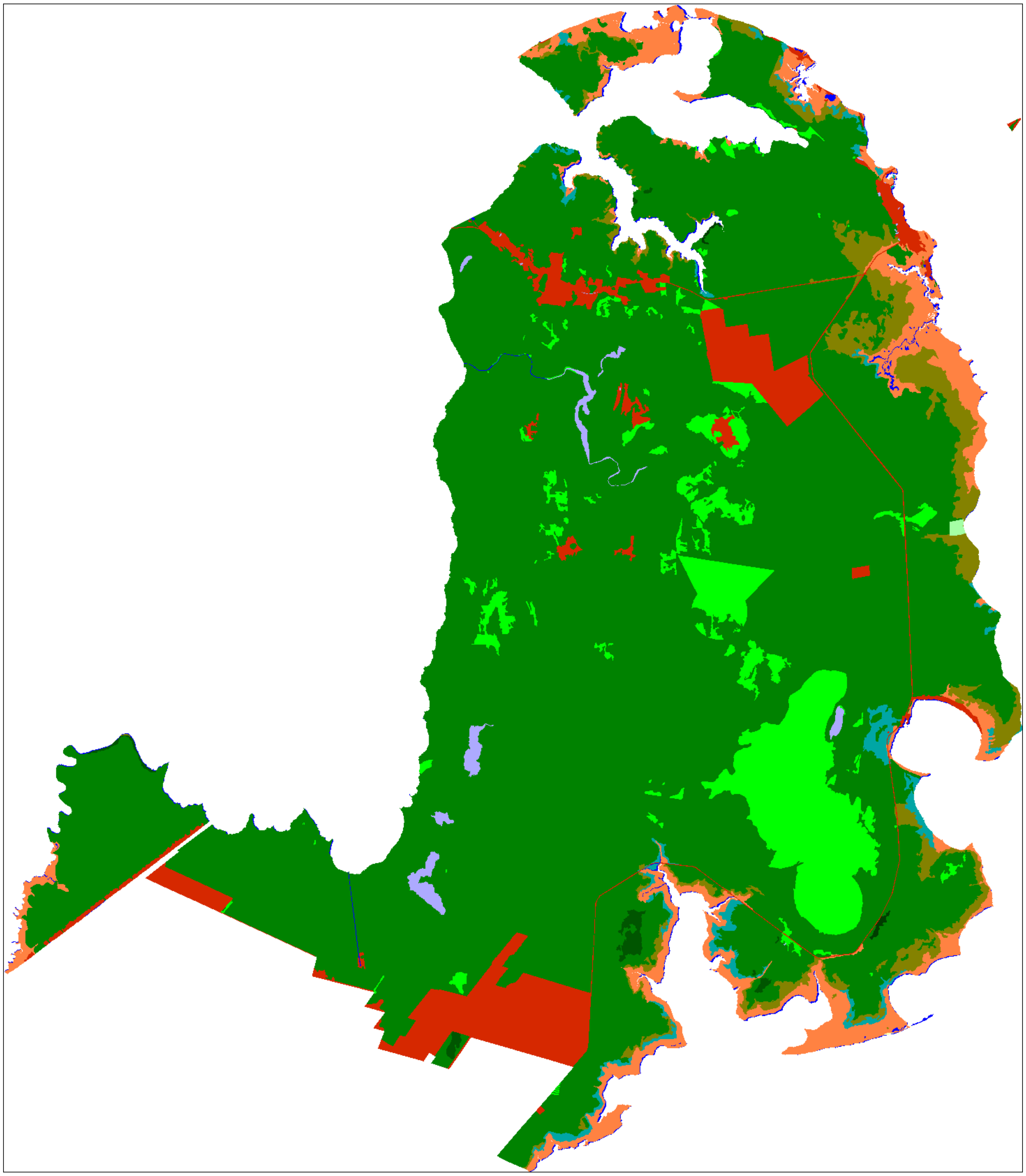


Alligator River NWR, 2100 IPCC Scenario A1B-Mean

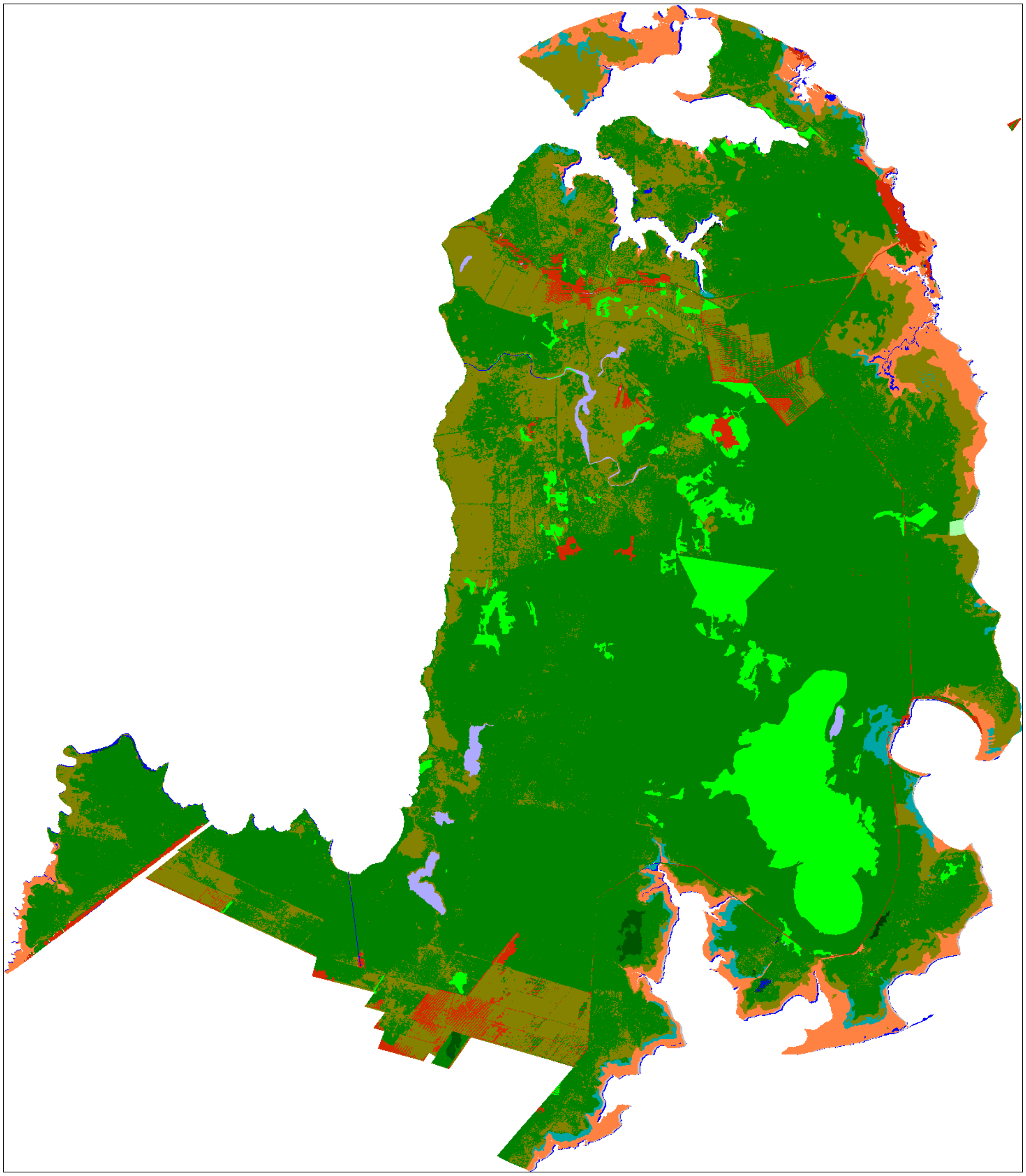
Alligator River
IPCC Scenario A1B-Max, 0.69 M SLR Eustatic by 2100

Results in Acres

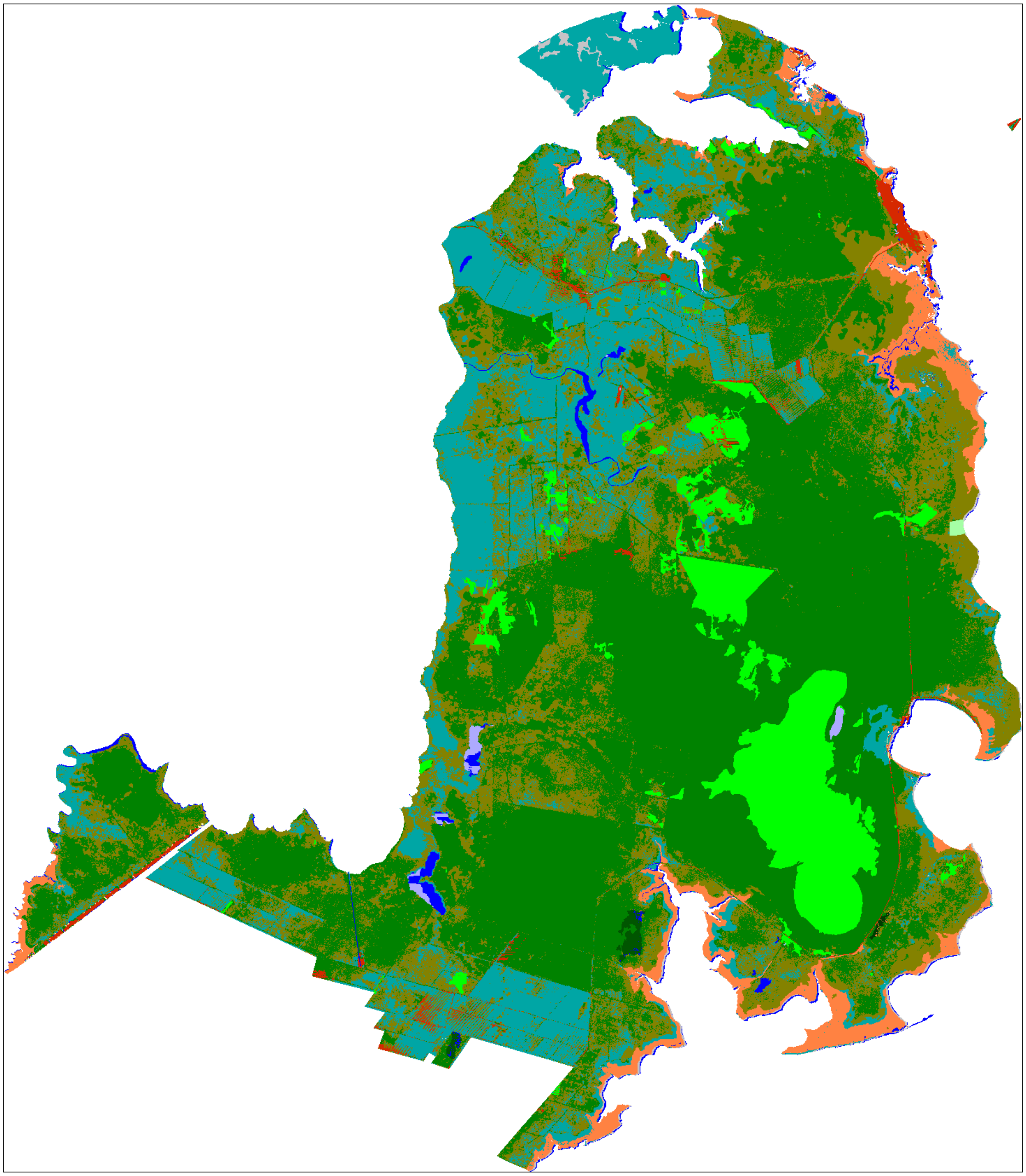
	Initial	2025	2050	2075	2100
Swamp	182591.4	153538.3	106469.1	57500.6	29491.7
Inland Fresh Marsh	16455.8	16434.7	16313.8	16112.3	15614.7
Dry Land	13809.3	4769.0	2152.2	1190.5	784.4
Brackish Marsh	12178.7	11608.7	9489.3	8586.9	6450.0
Trans. Salt Marsh	8674.0	46313.6	57839.8	57328.5	33493.1
Saltmarsh	2655.2	2973.2	42629.1	53746.9	56238.9
Inland Open Water	1342.1	1339.0	483.9	327.6	274.2
Estuarine Open Water	1246.5	1356.0	2725.1	7399.5	51548.2
Cypress Swamp	640.9	559.8	410.9	218.5	130.5
Tidal Swamp	100.1	92.8	64.3	10.8	0.9
Tidal Fresh Marsh	96.7	96.7	96.7	96.4	82.2
Riverine Tidal	30.7	30.7	0.7	0.4	0.0
Estuarine Beach	17.6	65.6	96.5	119.5	134.4
Tidal Flat	0.0	661.0	1067.7	37200.8	45596.0
Total (incl. water)	**239839.2**	**239839.2**	**239839.2**	**239839.2**	**239839.2**



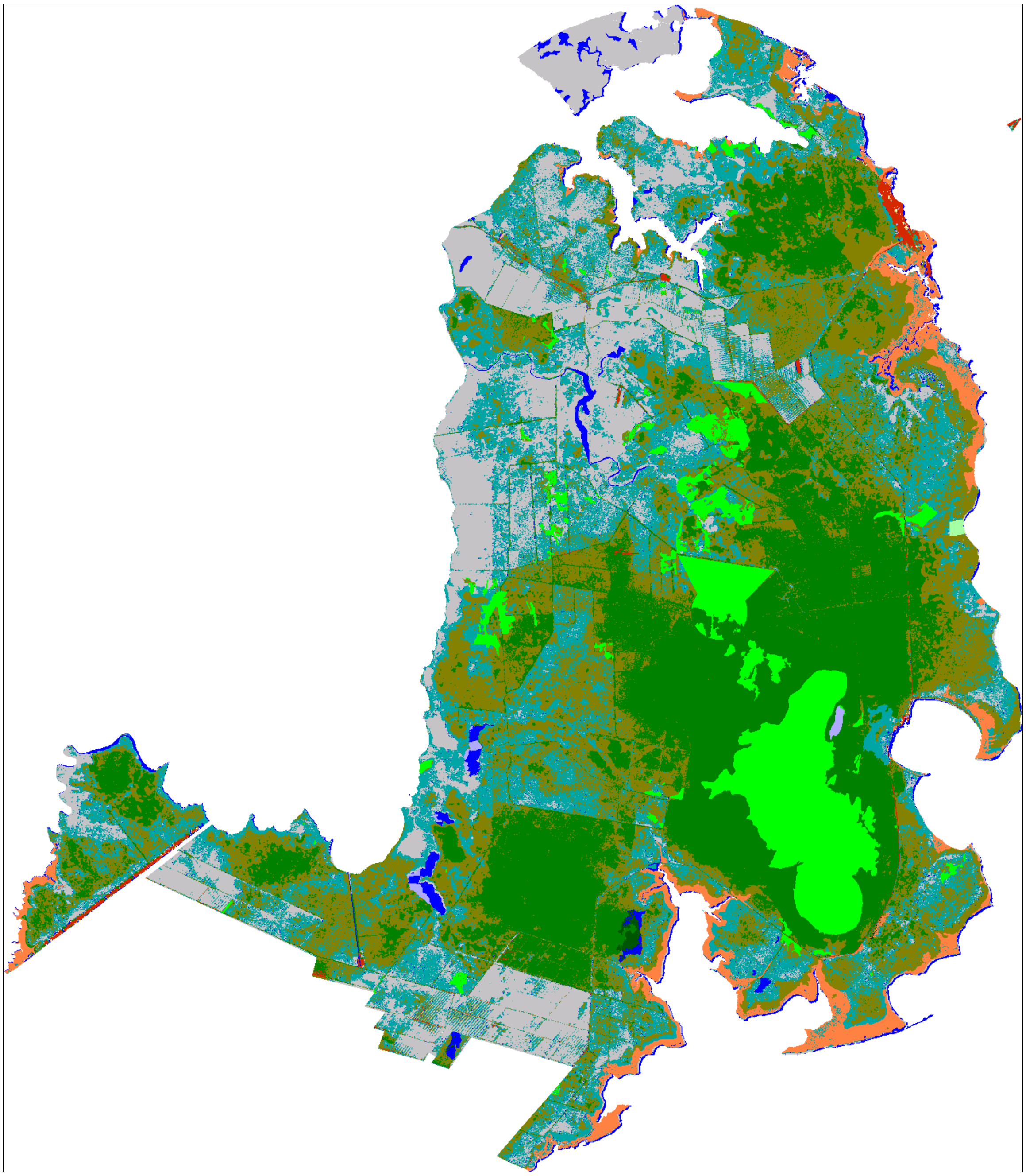
Alligator River NWR Initial Condition



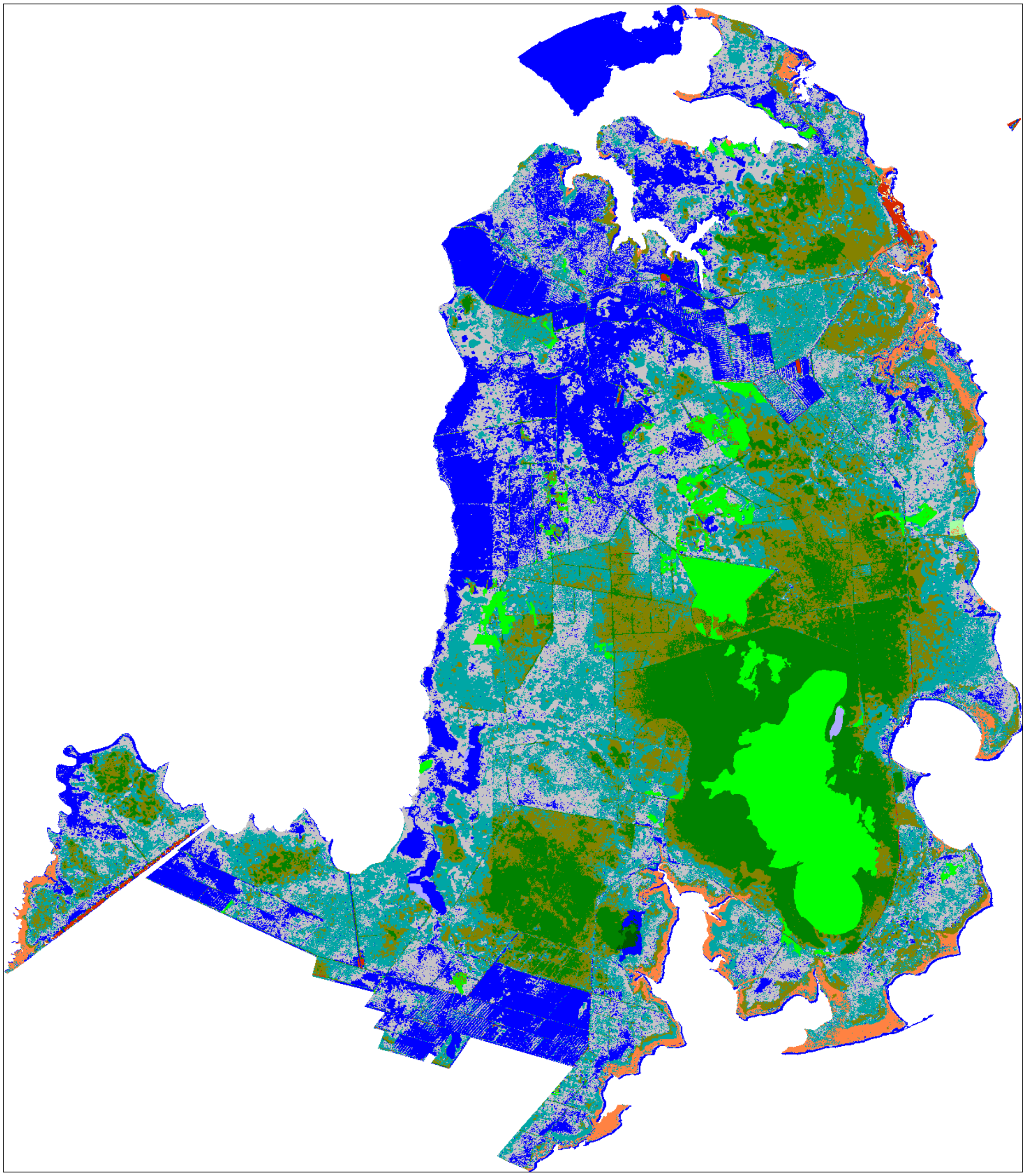
Alligator River NWR, 2025 IPCC Scenario A1B-Maximum



Alligator River NWR, 2050 IPCC Scenario A1B-Maximum



Alligator River NWR, 2075 IPCC Scenario A1B-Maximum

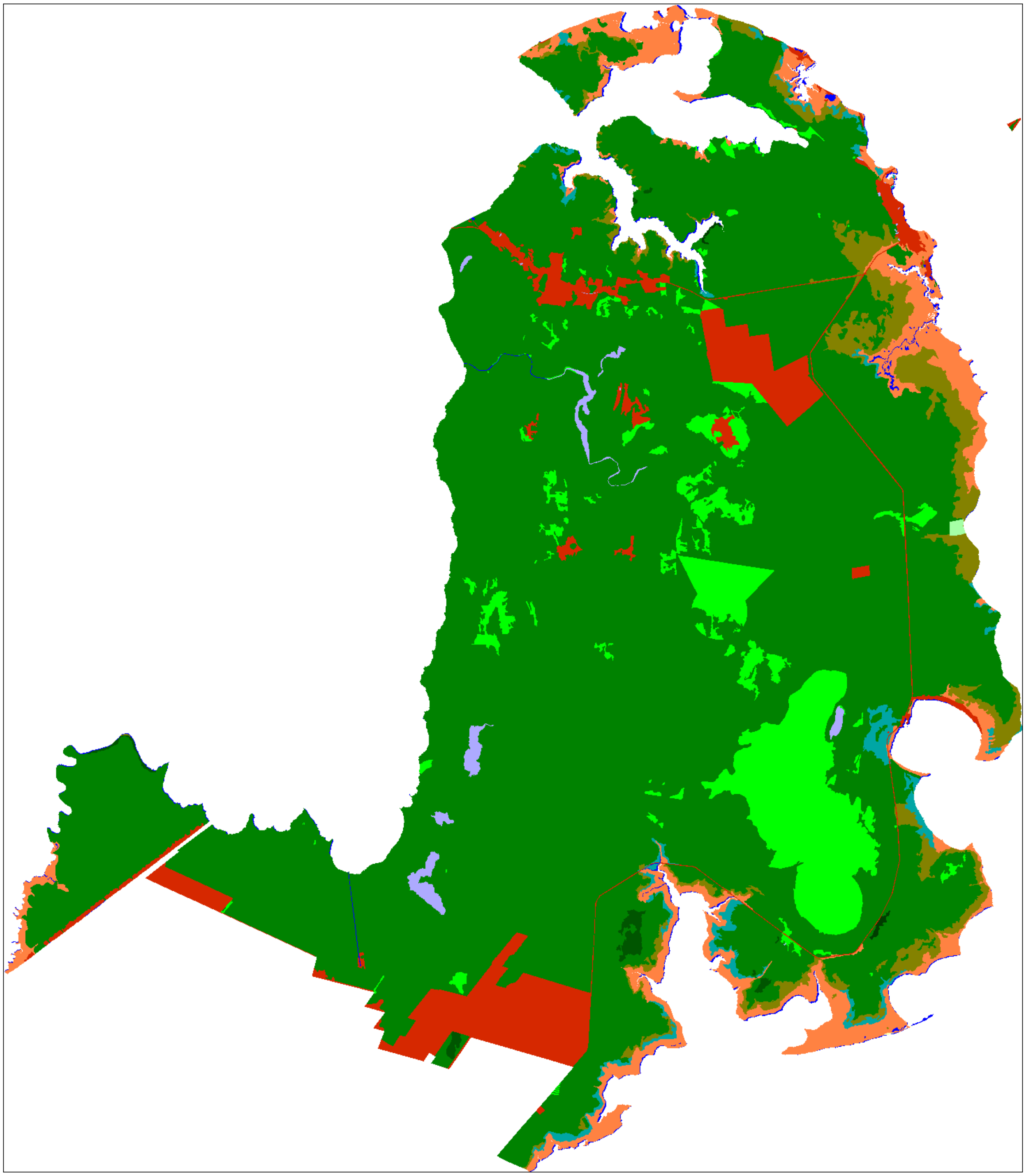


Alligator River NWR, 2100 IPCC Scenario A1B-Maximum

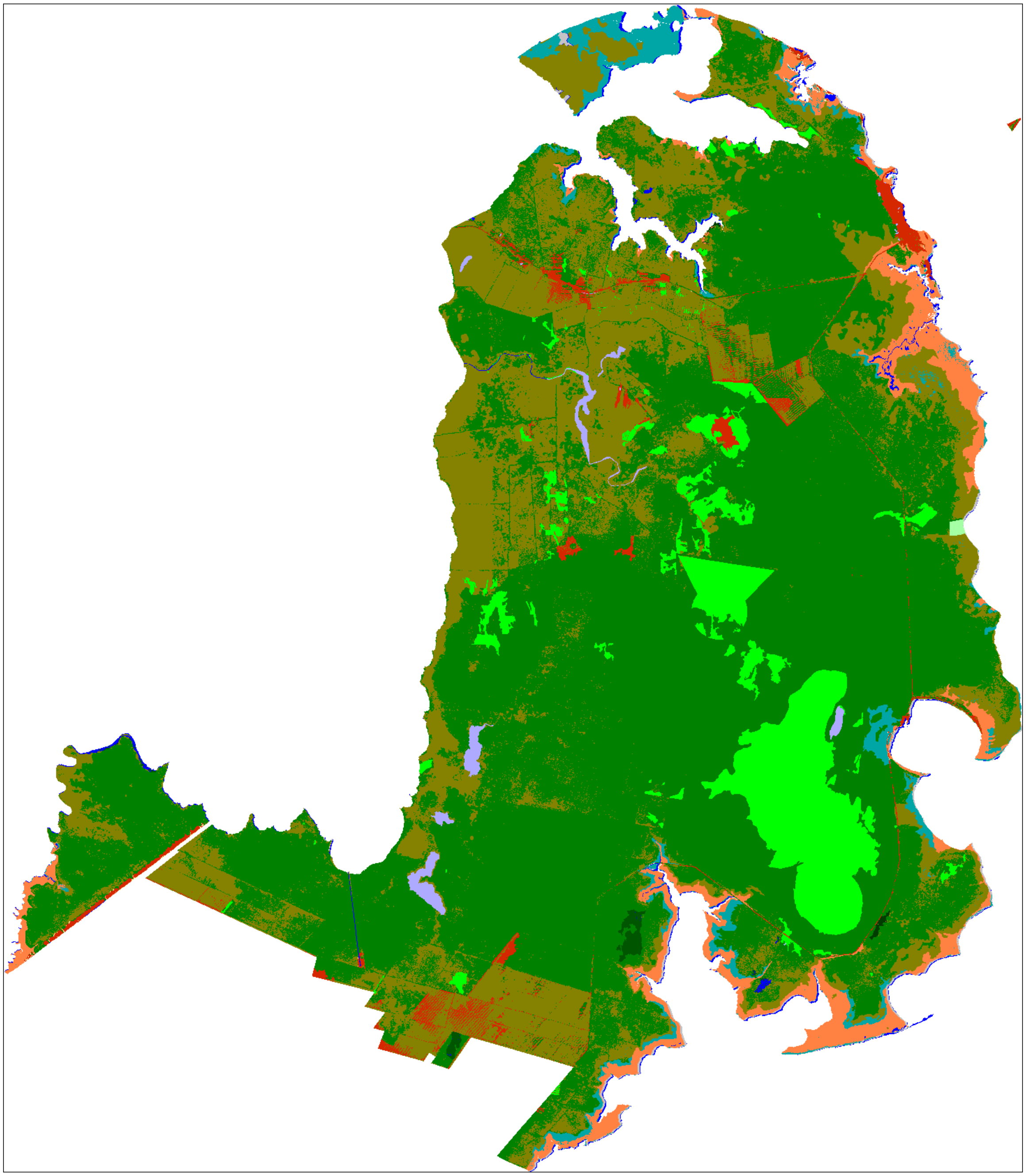
Alligator River
1 Meter Eustatic SLR by 2100

Results in Acres

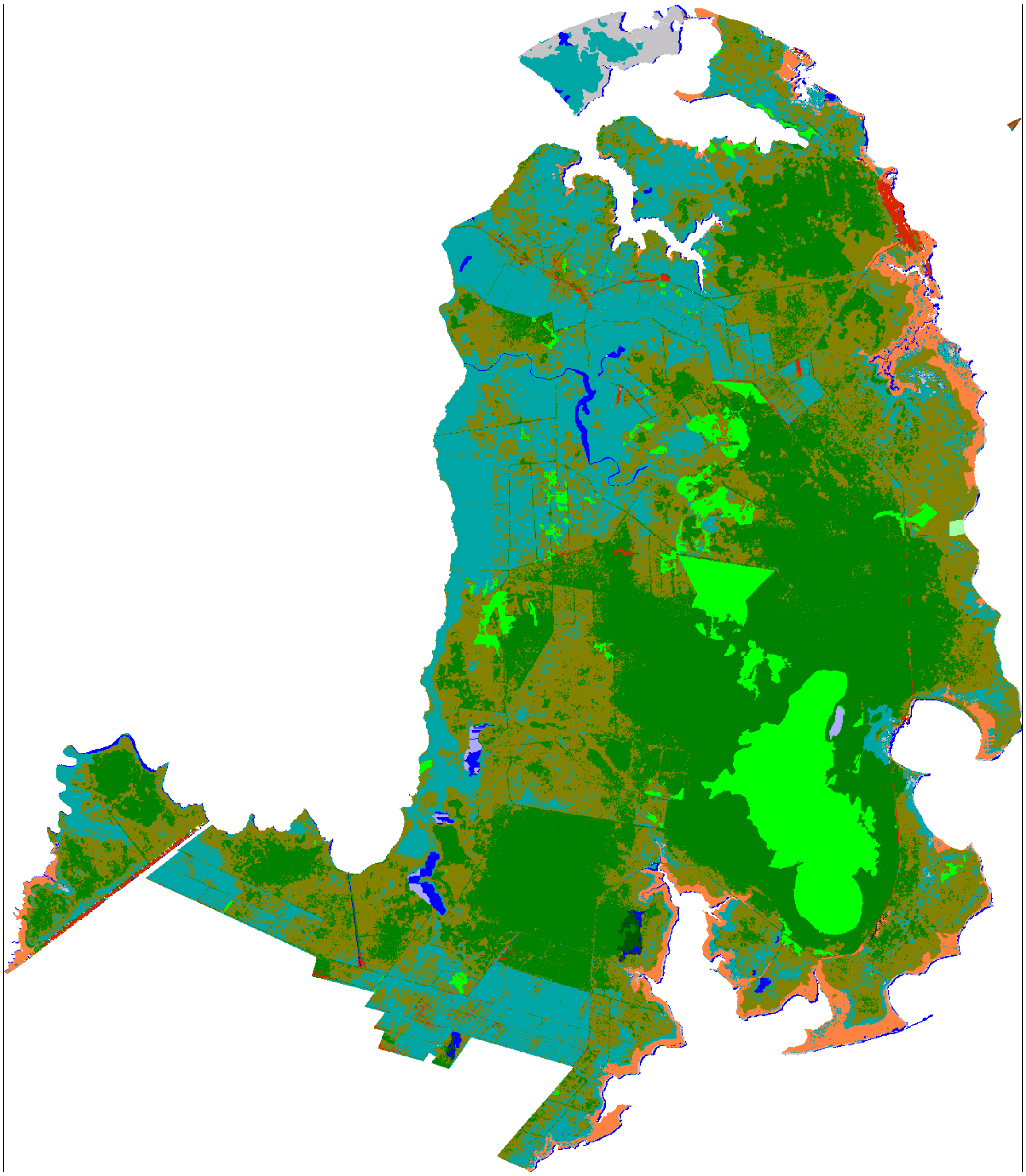
	Initial	2025	2050	2075	2100
Swamp	182591.4	140820.5	75926.6	31781.9	13041.7
Inland Fresh Marsh	16455.8	16175.6	15965.5	14647.9	12898.7
Dry Land	13809.3	4125.8	1509.0	811.9	477.1
Brackish Marsh	12178.7	9668.2	8567.7	4937.4	1157.7
Trans. Salt Marsh	8674.0	59806.7	74842.8	48964.8	21463.2
Saltmarsh	2655.2	4877.0	55947.5	76837.6	52327.0
Inland Open Water	1342.1	1338.6	416.3	281.1	257.1
Estuarine Open Water	1246.5	1419.5	3324.1	10674.5	68498.8
Cypress Swamp	640.9	509.3	296.5	136.2	49.7
Tidal Swamp	100.1	84.0	29.9	0.9	0.0
Tidal Fresh Marsh	96.7	96.7	95.6	18.8	0.0
Riverine Tidal	30.7	30.7	0.0	0.0	0.0
Estuarine Beach	17.6	90.3	141.7	172.2	157.2
Tidal Flat	0.0	796.4	2776.0	50573.8	69511.1
Total (incl. water)	**239839.2**	**239839.2**	**239839.2**	**239839.2**	**239839.2**



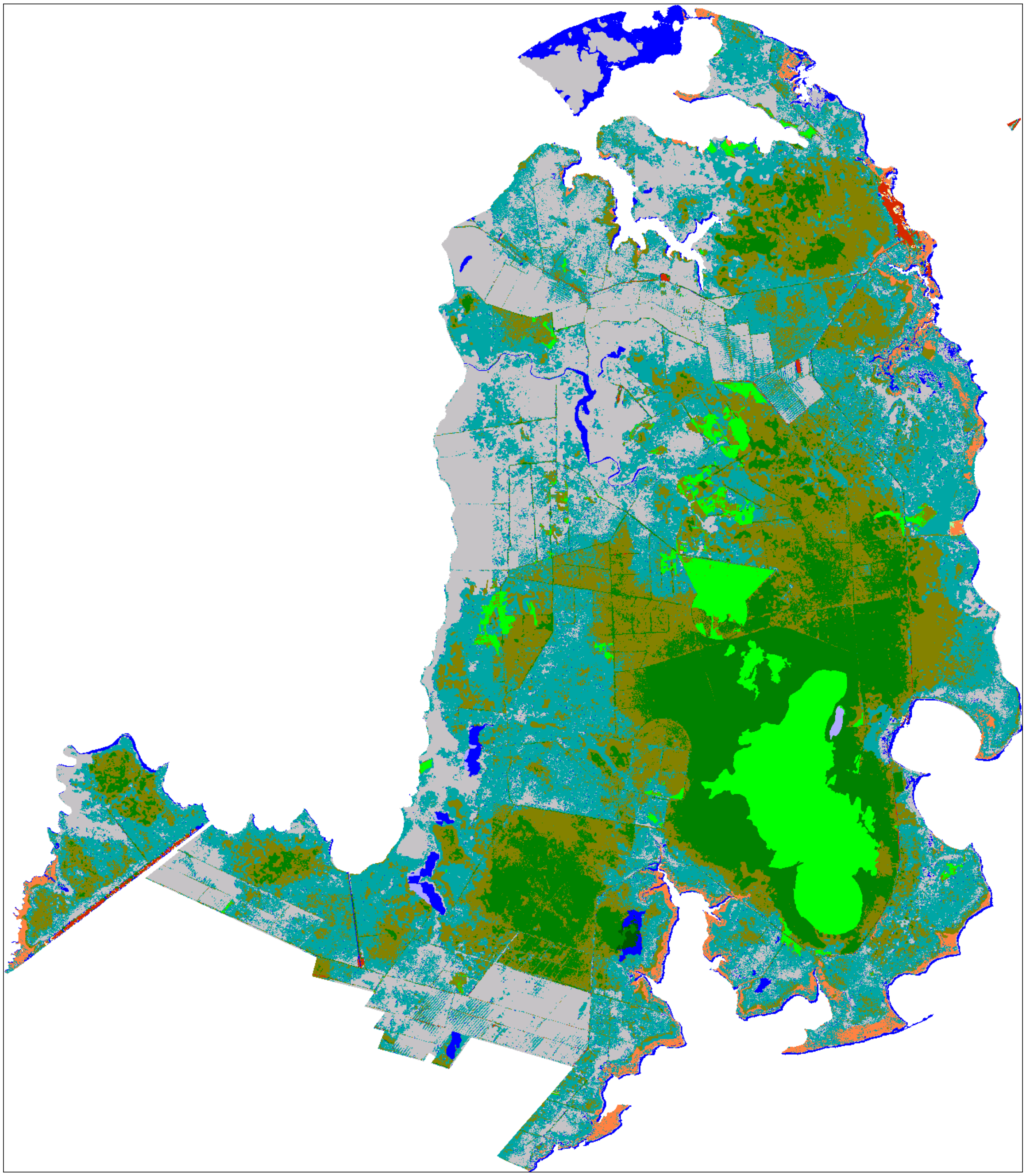
Alligator River NWR Initial Condition



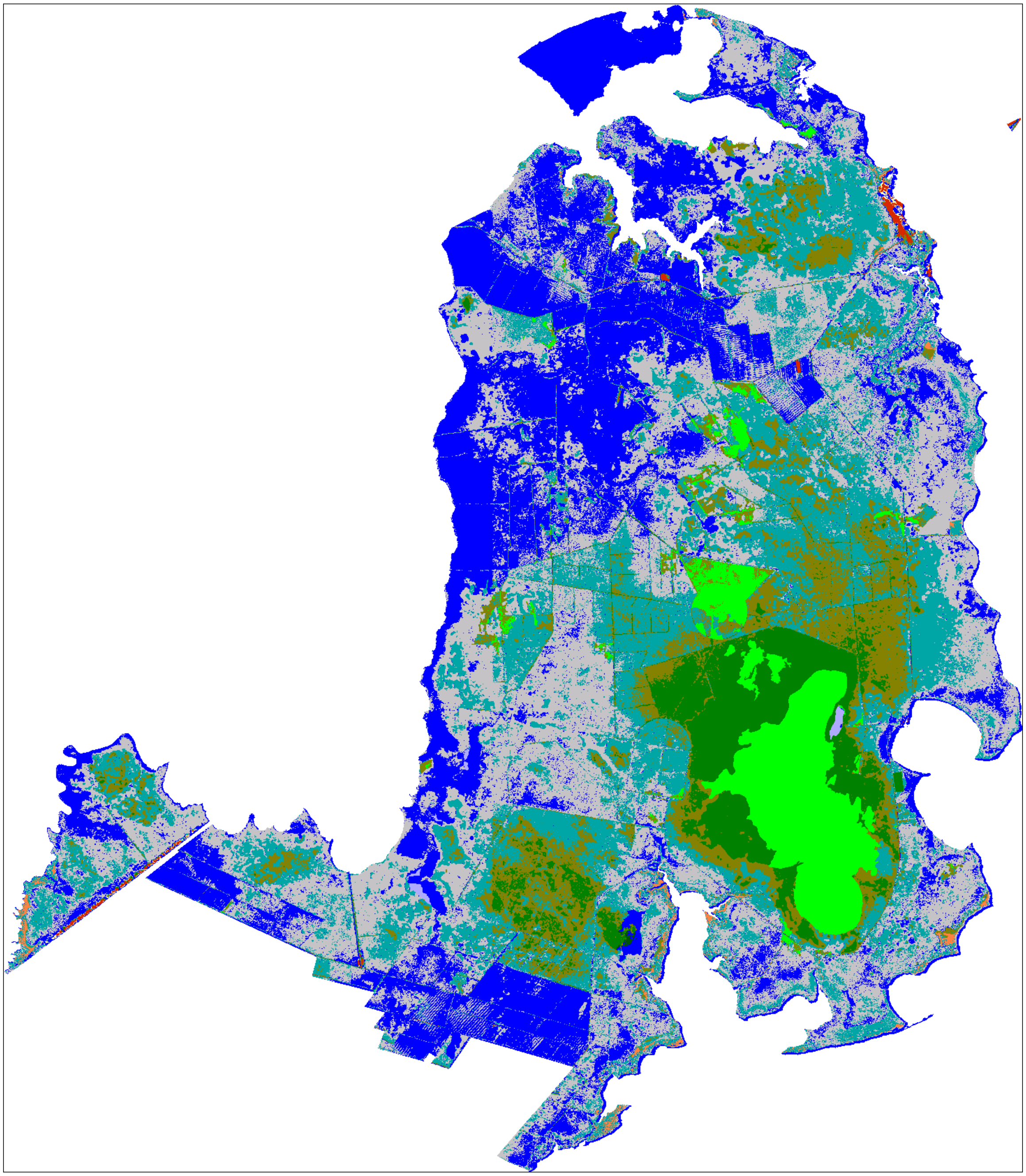
Alligator River NWR, 2025 1 meter Eustatic by 2100



Alligator River NWR, 2050 1 meter Eustatic by 2100



Alligator River NWR, 2075 1 meter Eustatic by 2100

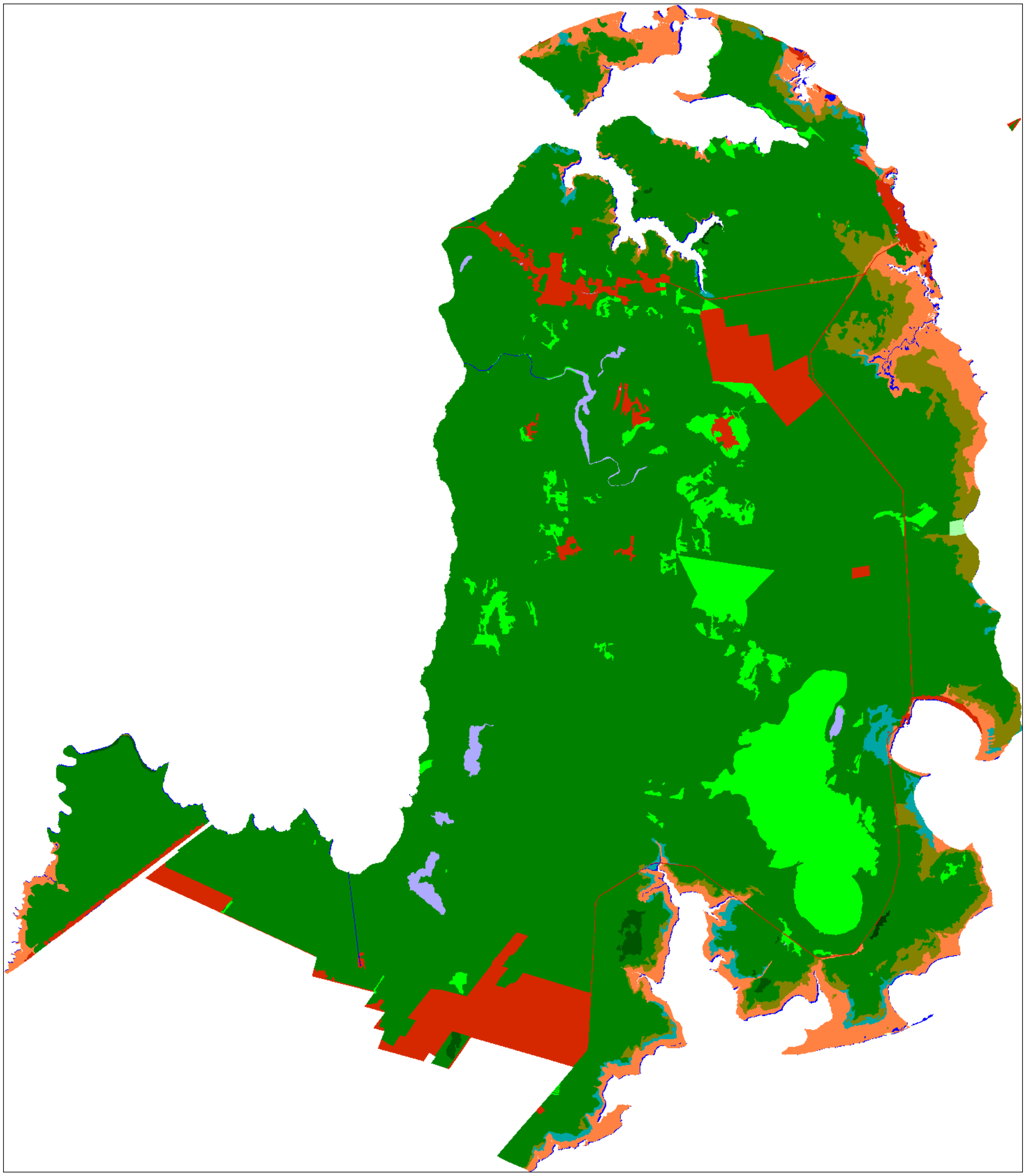


Alligator River NWR, 2100 1 meter Eustatic by 2100

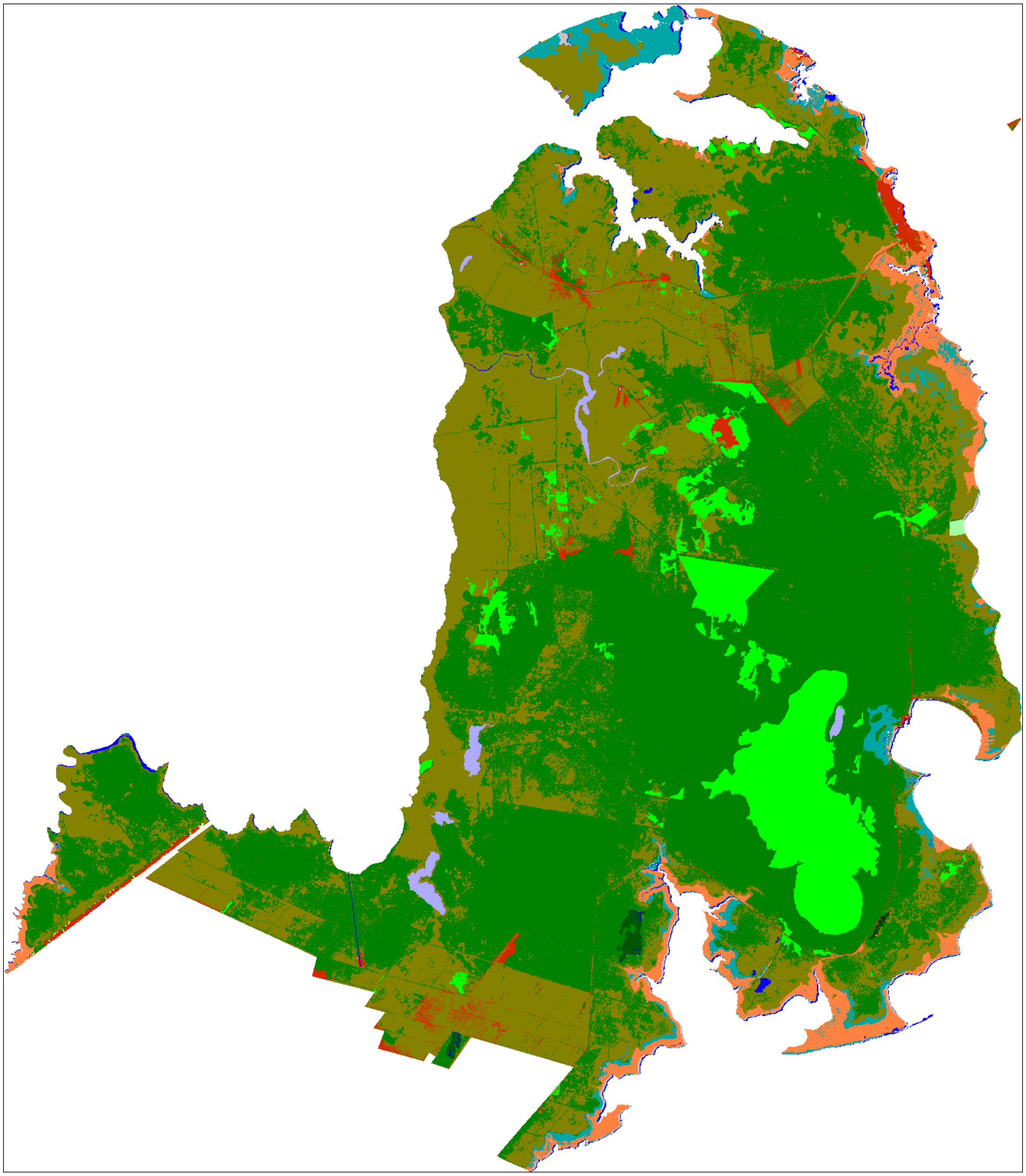
Alligator River
1.5 Meters Eustatic SLR by 2100

Results in Acres

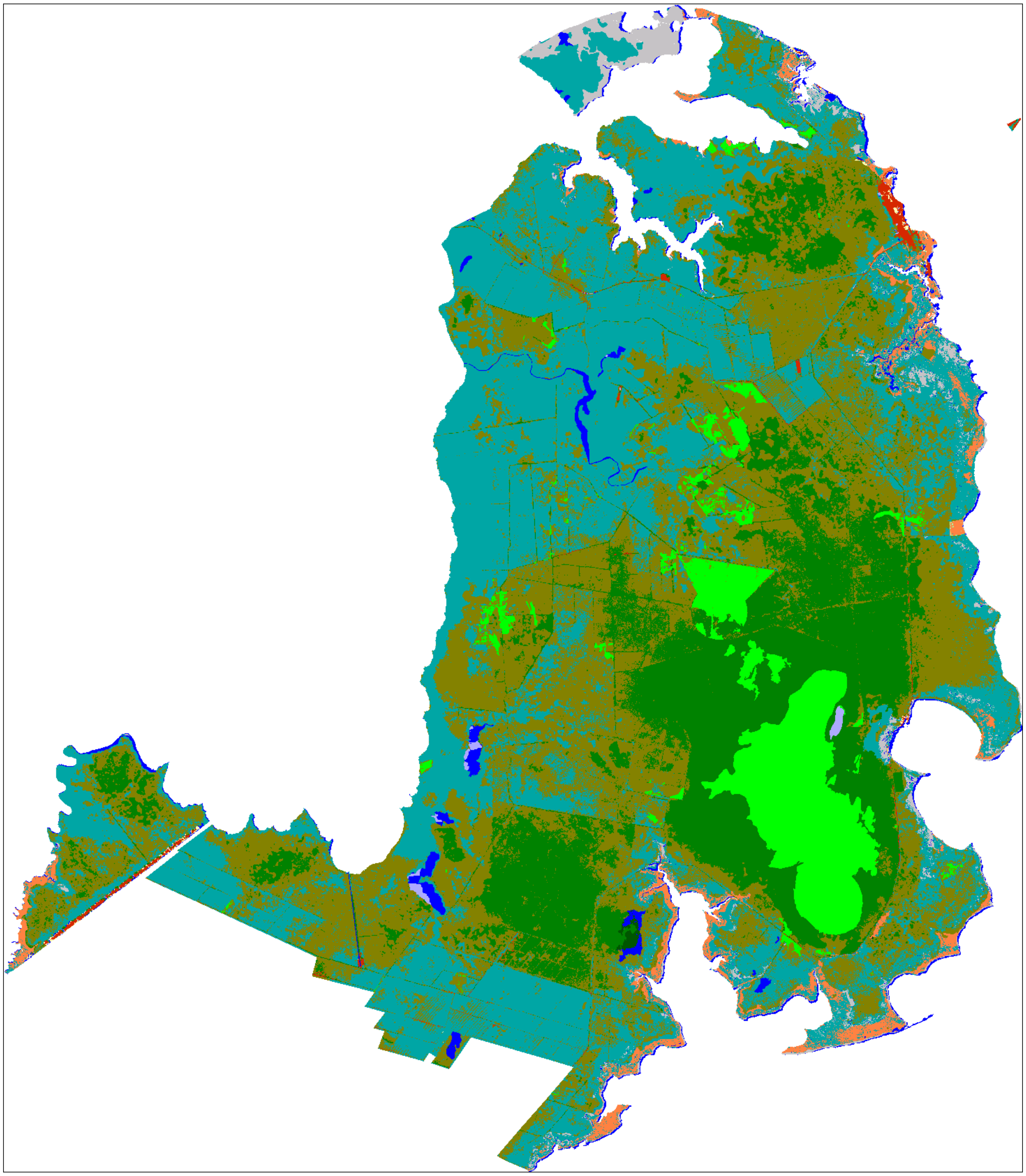
	Initial	2025	2050	2075	2100
Swamp	182591.4	116585.4	44061.2	12502.8	3391.0
Inland Fresh Marsh	16455.8	15967.3	14380.2	11683.5	9698.4
Dry Land	13809.3	3156.2	982.9	462.9	180.5
Brackish Marsh	12178.7	9080.4	5160.5	396.1	5.1
Trans. Salt Marsh	8674.0	84777.1	79153.8	34838.8	11213.7
Saltmarsh	2655.2	5826.9	87273.6	83731.2	35187.6
Inland Open Water	1342.1	1338.1	317.8	259.1	175.5
Estuarine Open Water	1246.5	1513.4	4085.4	13588.5	102523.3
Cypress Swamp	640.9	438.5	166.3	43.0	0.0
Tidal Swamp	100.1	67.1	2.6	0.0	0.0
Tidal Fresh Marsh	96.7	96.1	8.9	0.0	0.0
Riverine Tidal	30.7	30.7	0.0	0.0	0.0
Estuarine Beach	17.6	139.3	202.6	226.9	165.6
Tidal Flat	0.0	822.6	4043.2	82106.4	77298.6
Total (incl. water)	**239839.2**	**239839.2**	**239839.2**	**239839.2**	**239839.2**



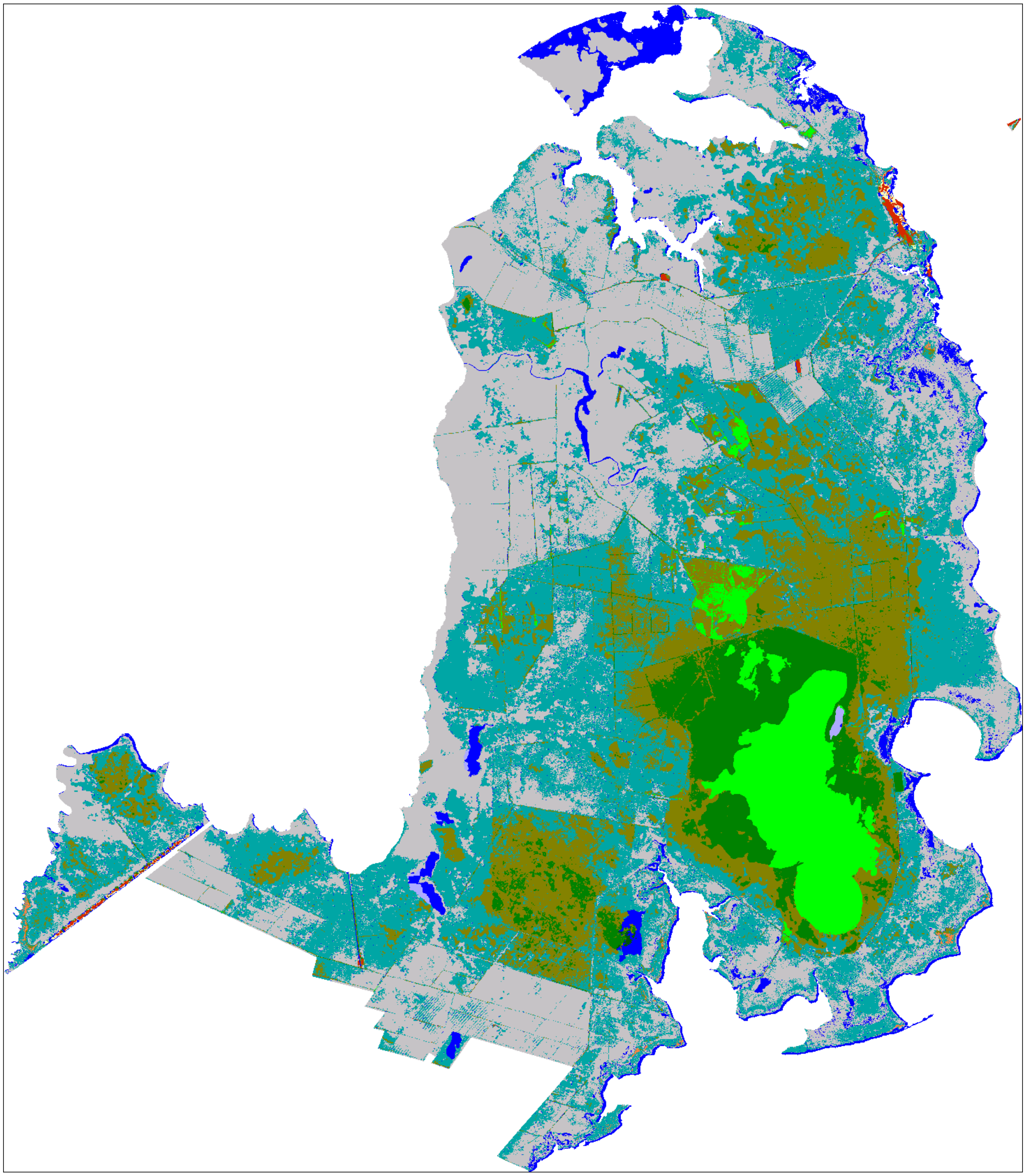
Alligator River NWR, Initial Condition



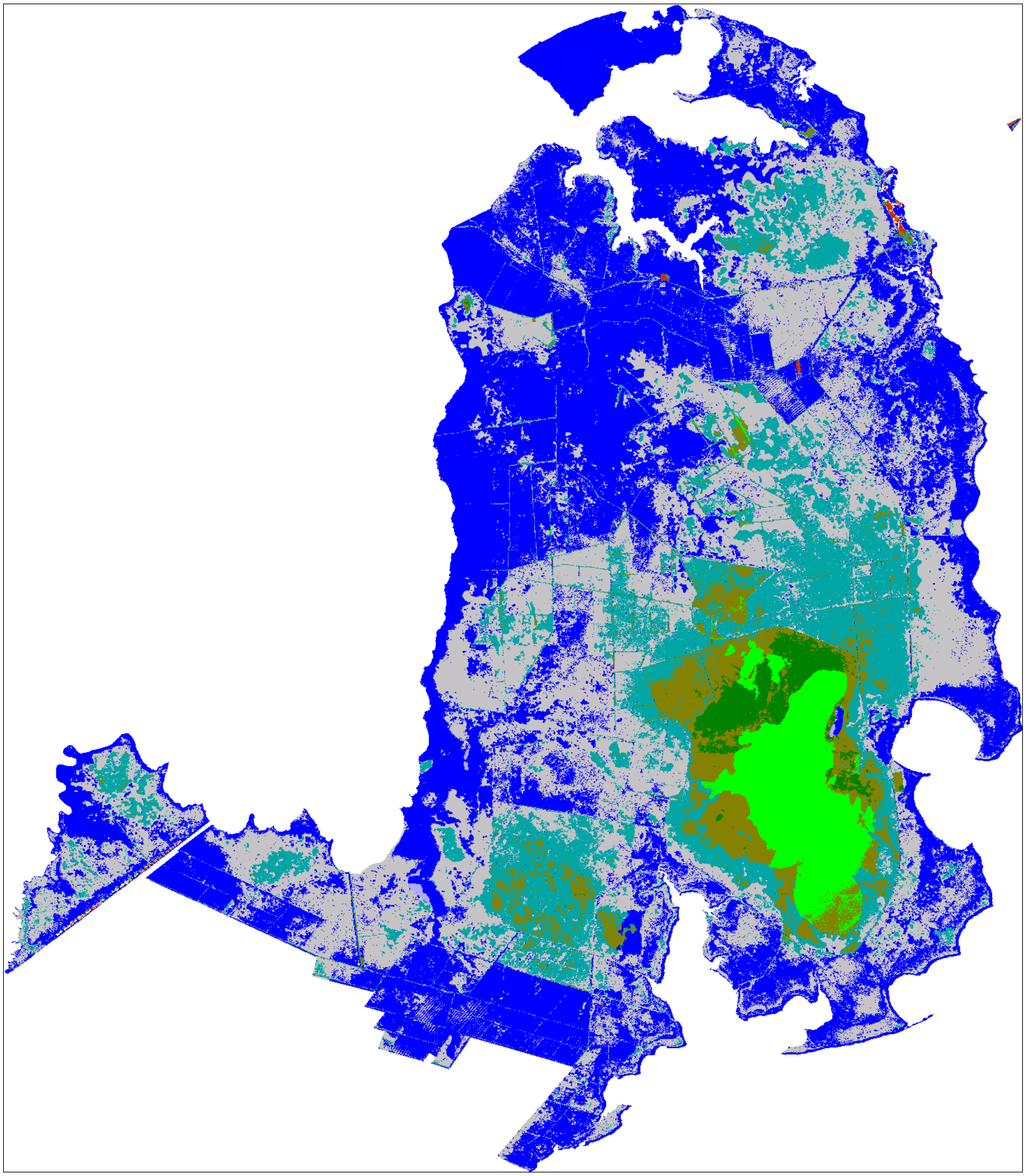
Alligator River NWR, 2025, 1.5 meter Eustatic by 2100



Alligator River NWR, 2050, 1.5 meter Eustatic by 2100



Alligator River NWR, 2075, 1.5 meter Eustatic by 2100



Alligator River NWR, 2100, 1.5 meter Eustatic by 2100

Discussion

Alligator River National Wildlife Refuge is already under pressure due to increasing sea levels. This modeling analysis indicates that, under current IPCC scenarios, this pressure is likely to get much more severe over the next 90 years. The swamp land and dry land at this site seem significantly vulnerable to the pressures of salt water intrusion and inundation.

Results for this site are based on high quality LiDAR elevation data. This reduces modeling uncertainty for this site. Additional model testing could compare model results against more up-to-date land-cover data for the site to determine how effectively the model has represented changes in the 25 years since the National Wetlands Inventory photo-date.

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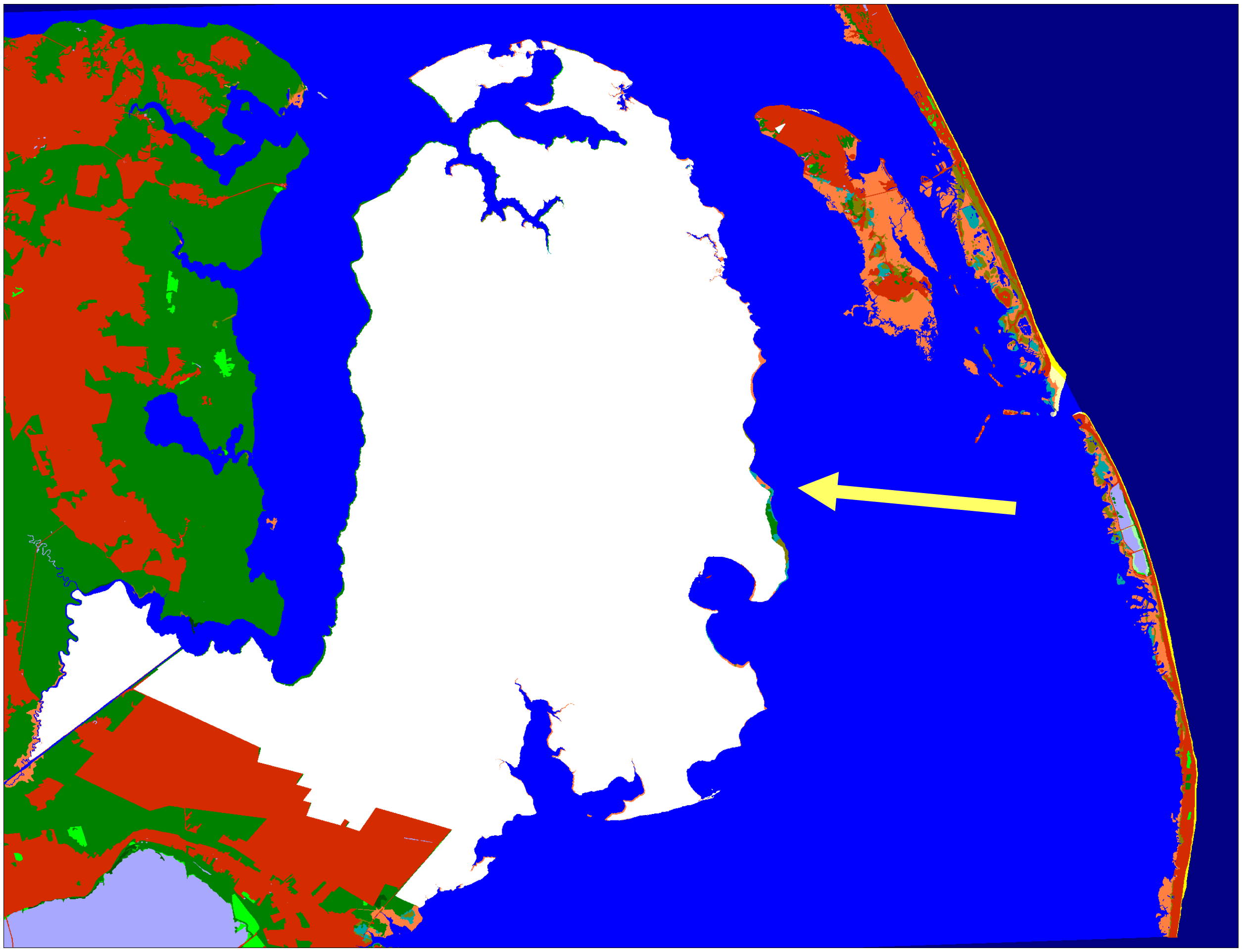
Appendix A: Contextual Results

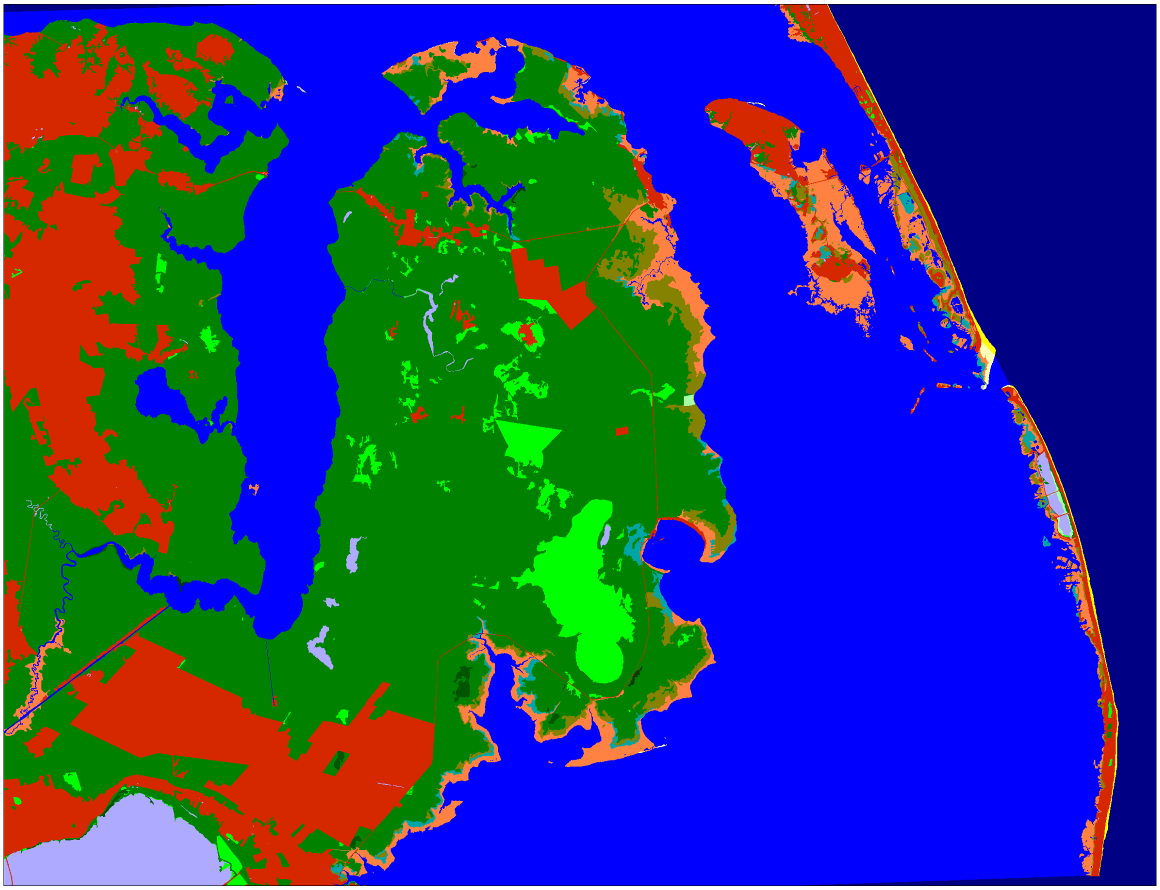
The SLAMM model does take into account the context of the surrounding lands or open water when calculating effects. For example, erosion rates are calculated based on the maximum fetch (wave action) which is estimated by assessing contiguous open water to a given marsh cell. Another example is that inundated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

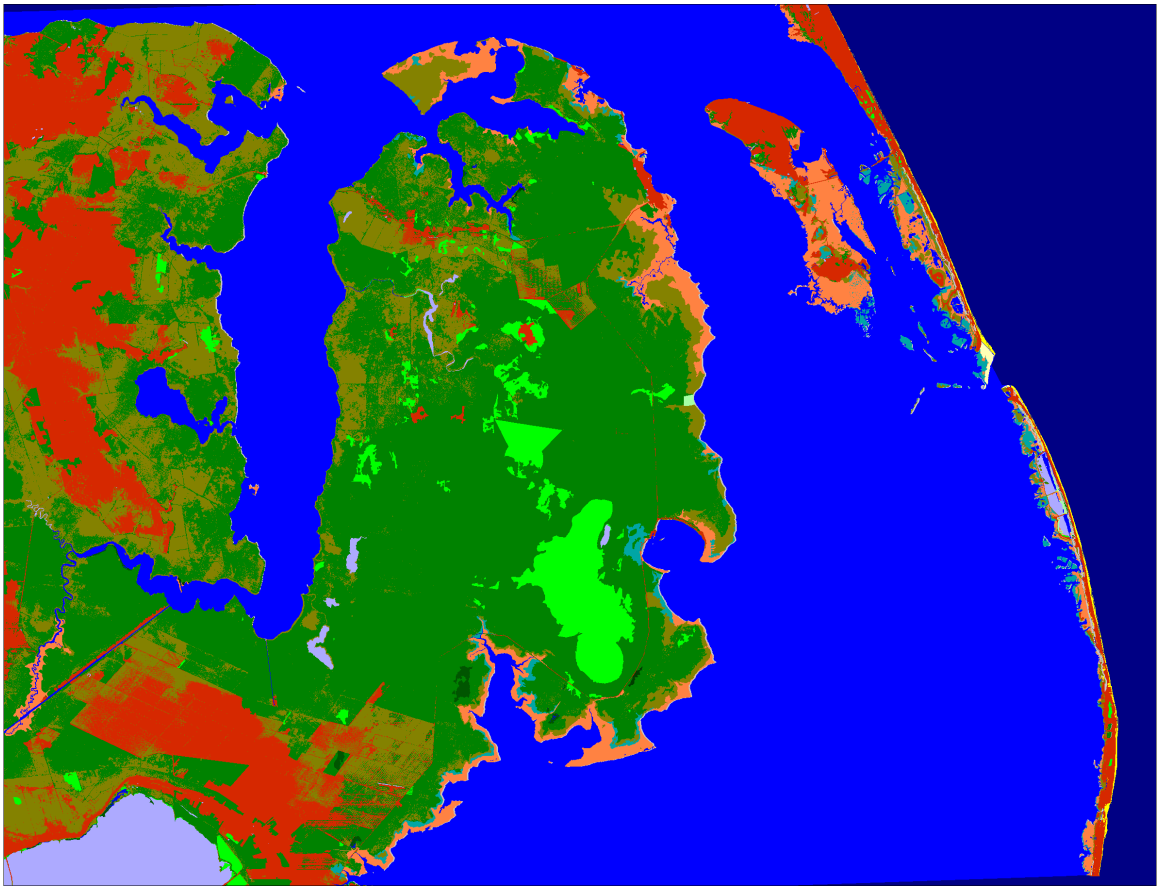
- Results were closely examined (quality assurance) within USFWS refuges but not closely examined for the larger region.
- Site-specific parameters for the model were derived for USFWS refuges whenever possible and may not be regionally applicable.
- Especially in areas where dikes are present, an effort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



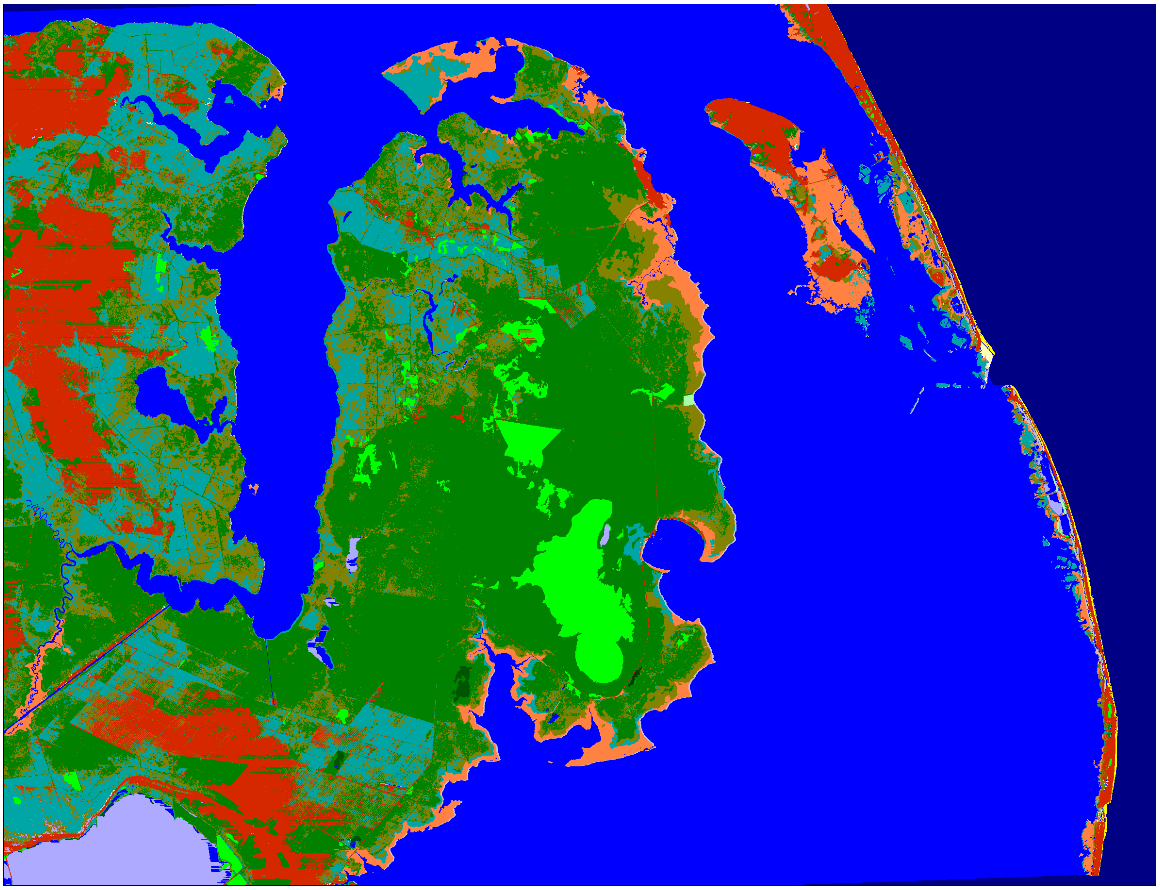
Location of Alligator River National Wildlife Refuge (white region) within North Carolina simulation context



North Carolina Initial Condition



North Carolina 2025 IPCC Scenario A1B-Mean



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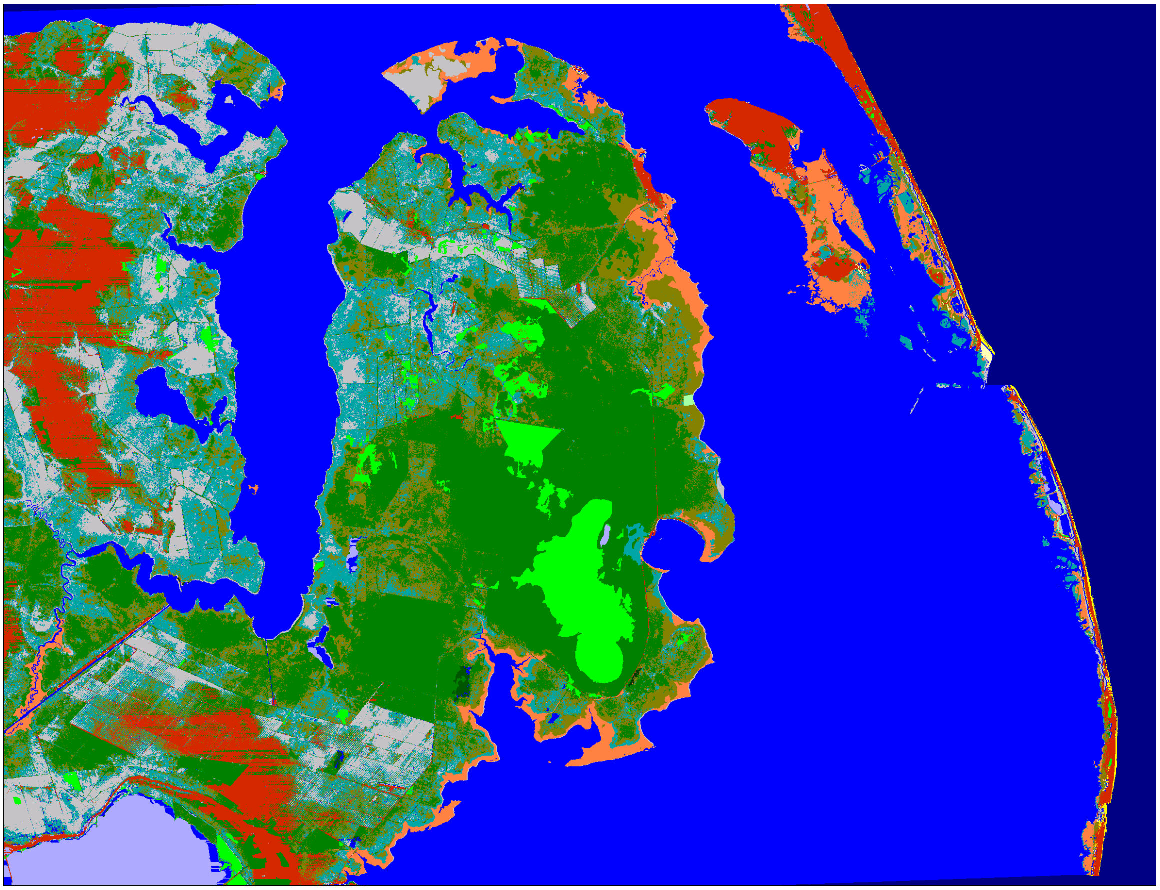
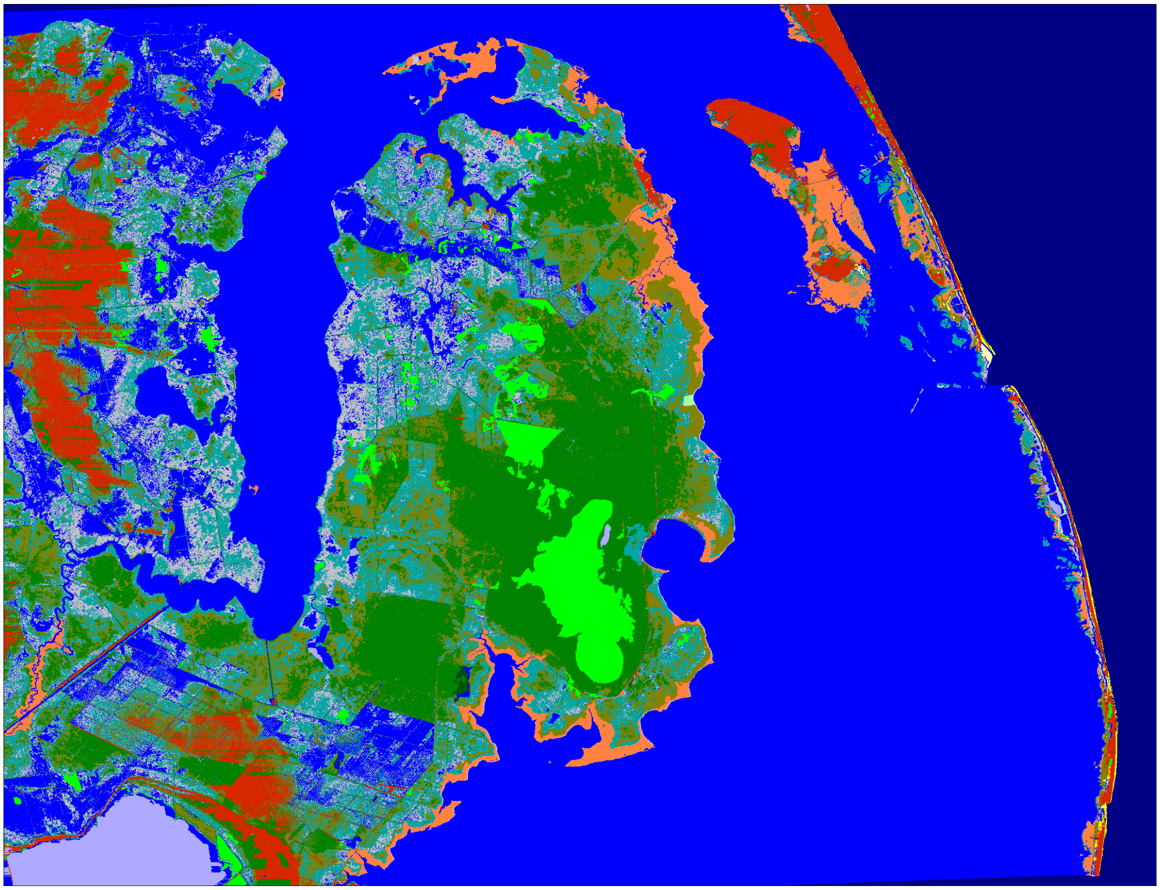
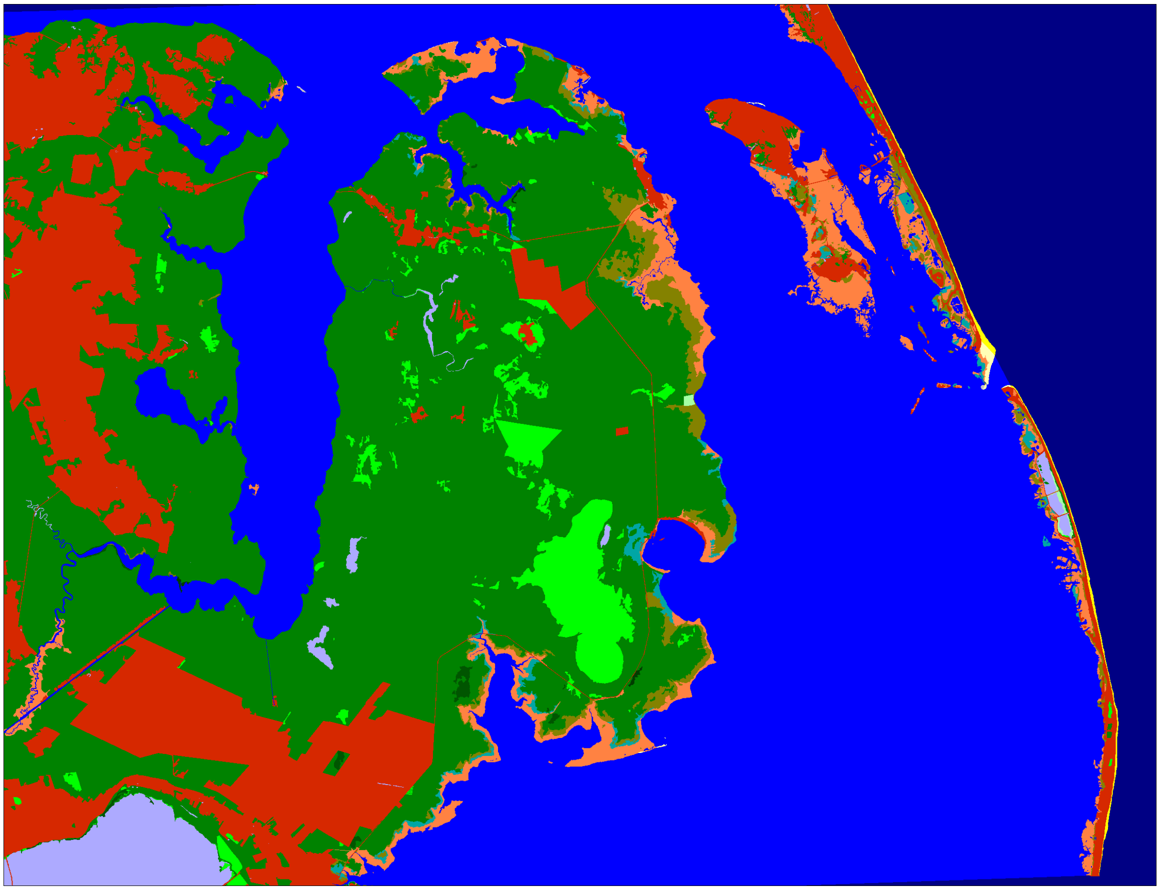


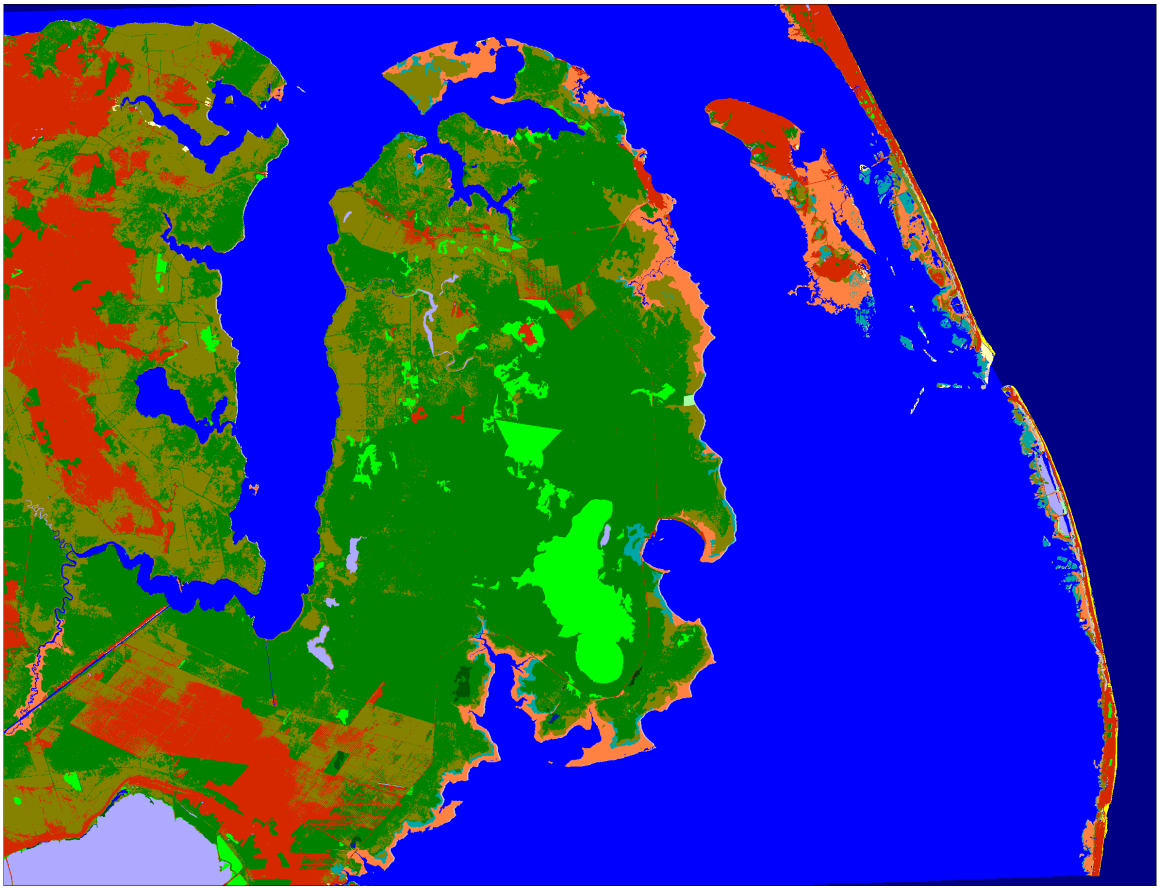
North Carolina 2075 IPCC Scenario A1B-Mean



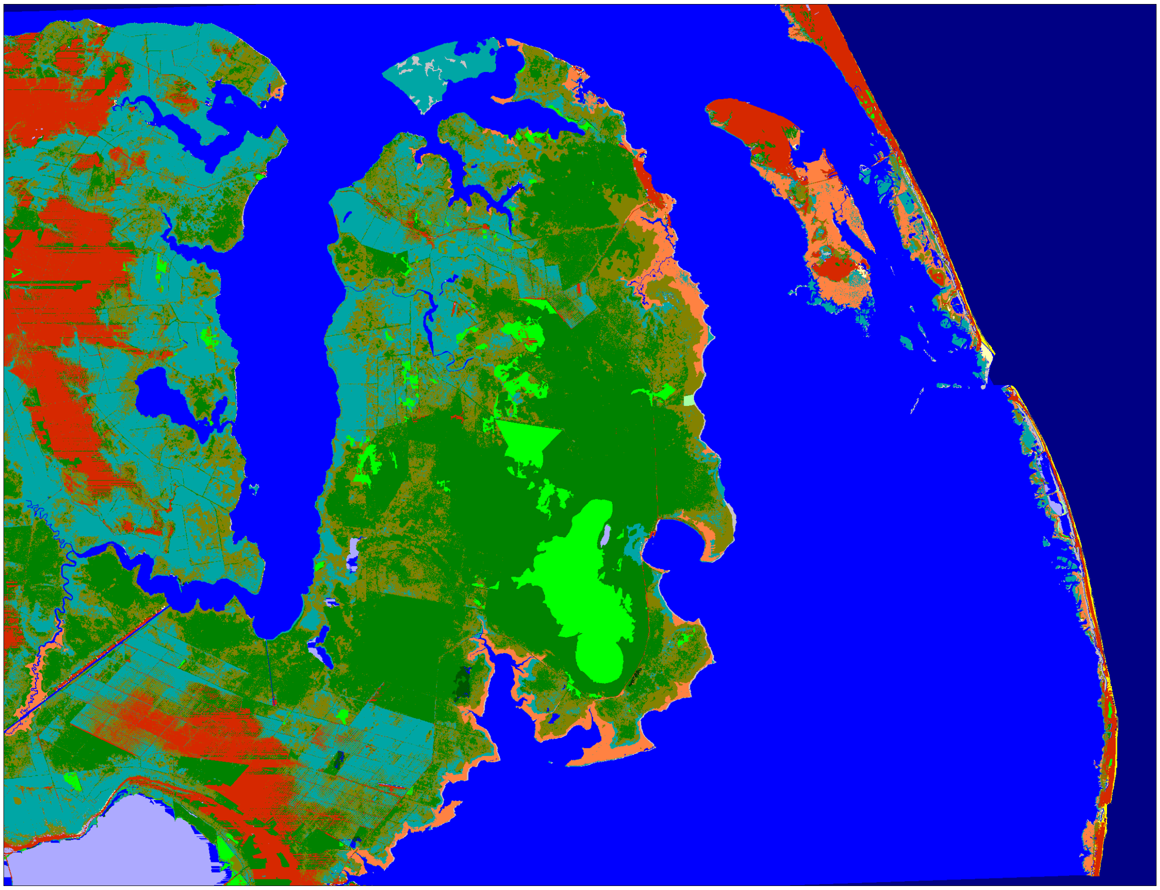
North Carolina 2100 IPCC Scenario A1B-Mean



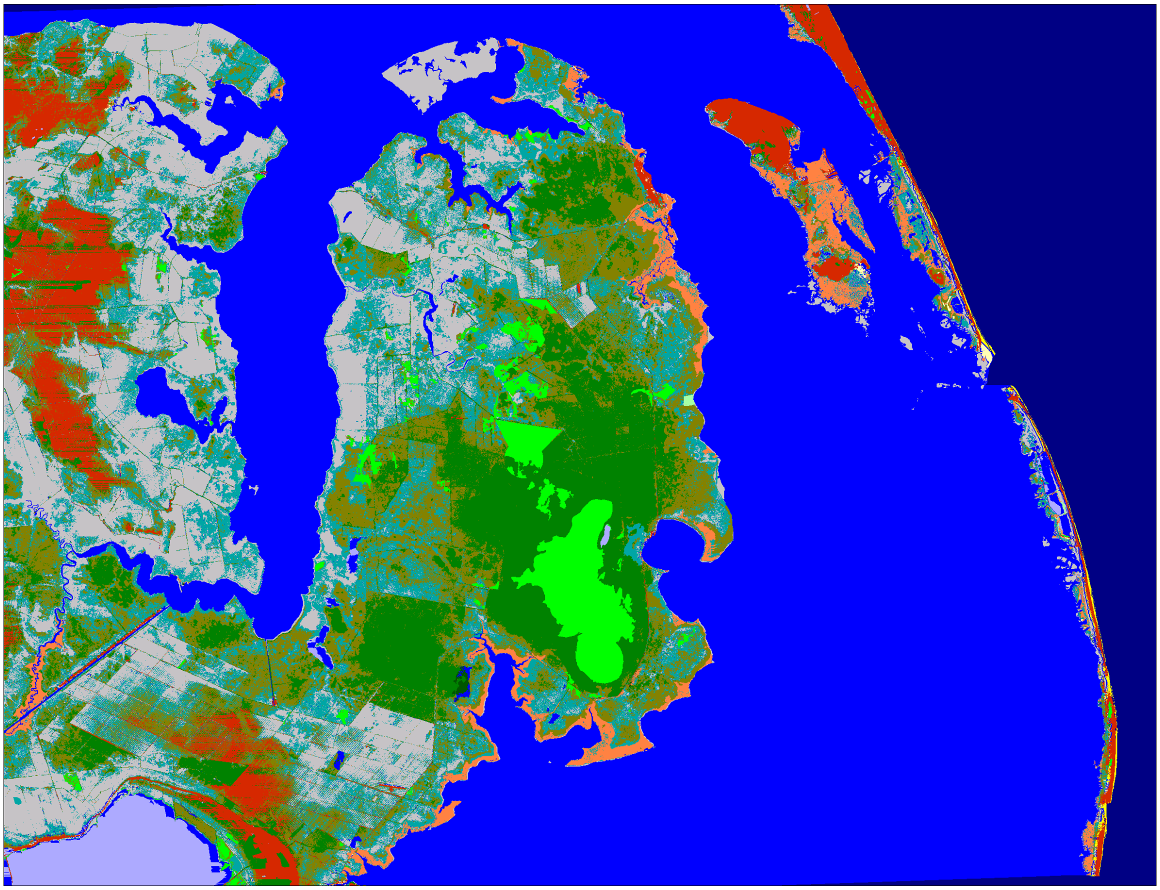
North Carolina Initial Condition



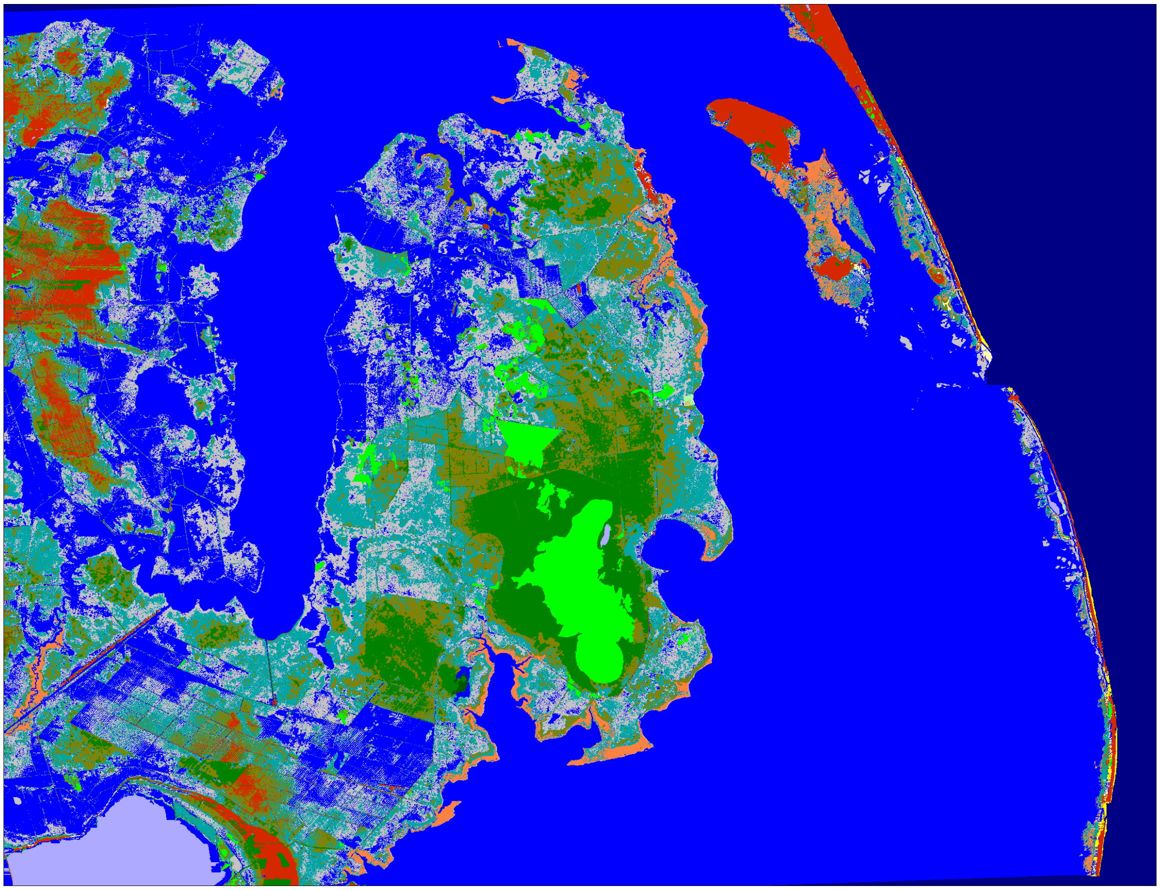
North Carolina 2025 IPCC Scenario A1B-Maximum



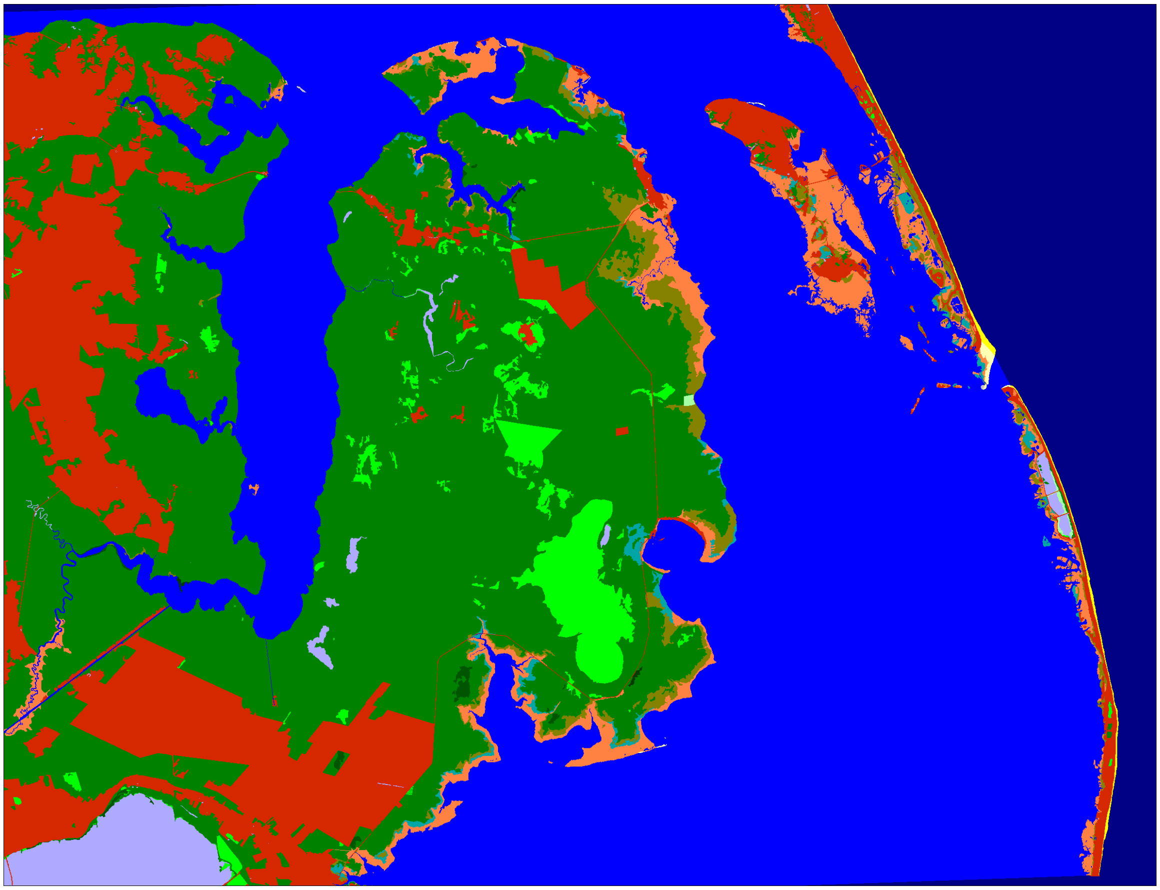
North Carolina 2050 IPCC Scenario A1B-Maximum



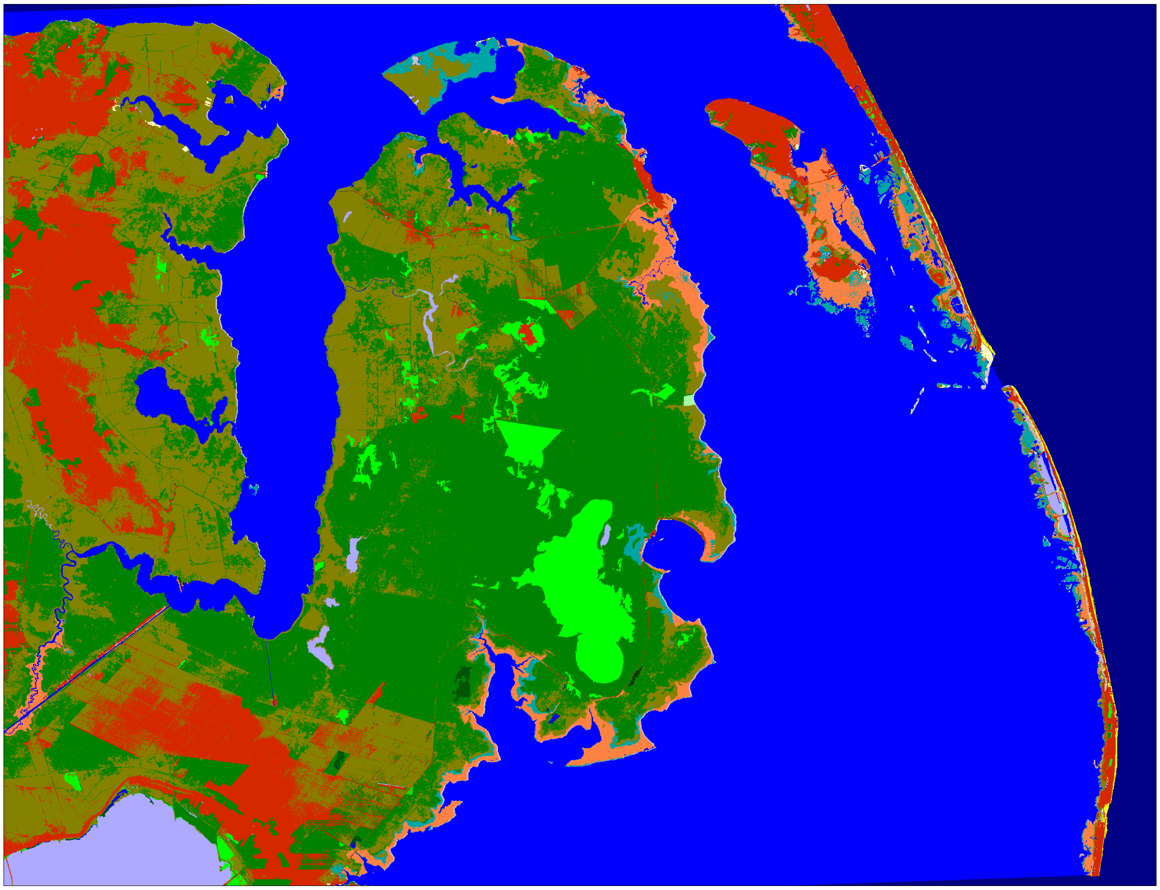
North Carolina 2075 IPCC Scenario A1B-Maximum



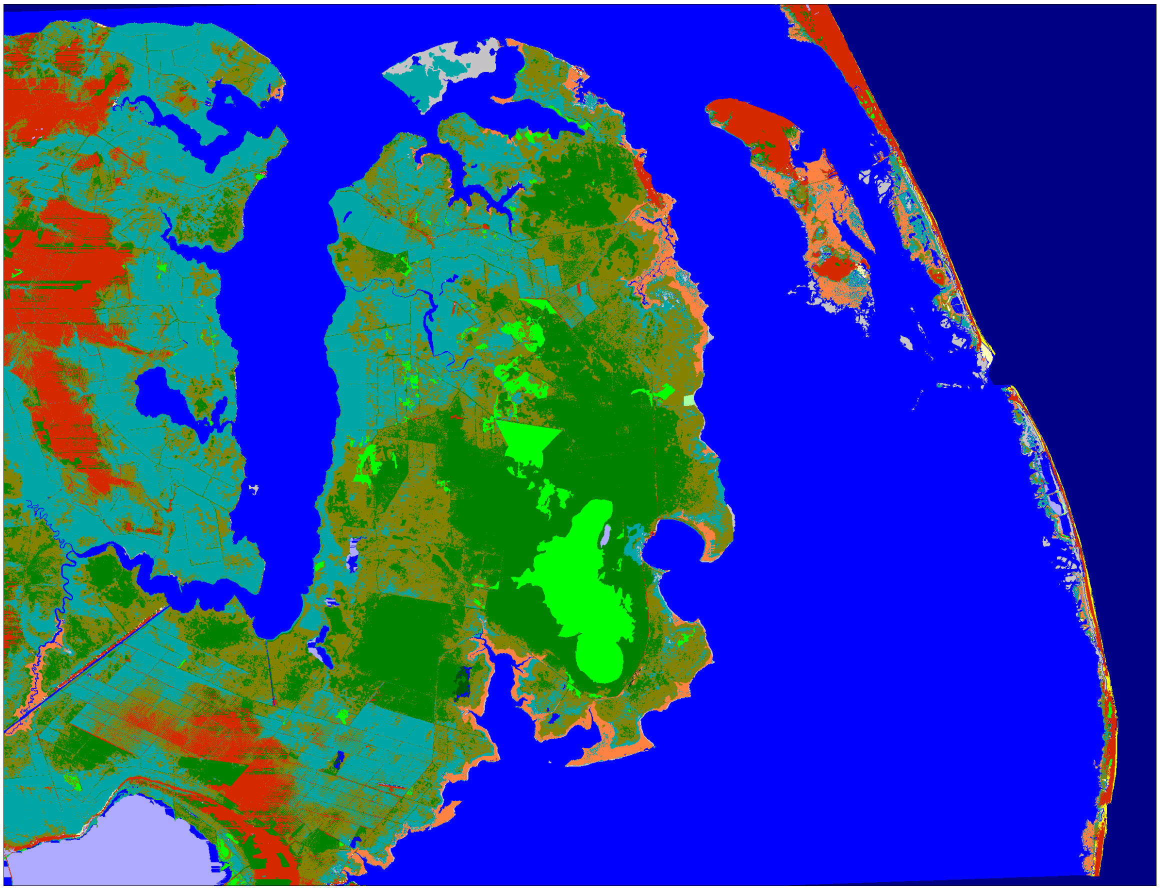
North Carolina 2100 IPCC Scenario A1B-Maximum



North Carolina Initial Condition



North Carolina 2025, 1 meter Eustatic by 2100



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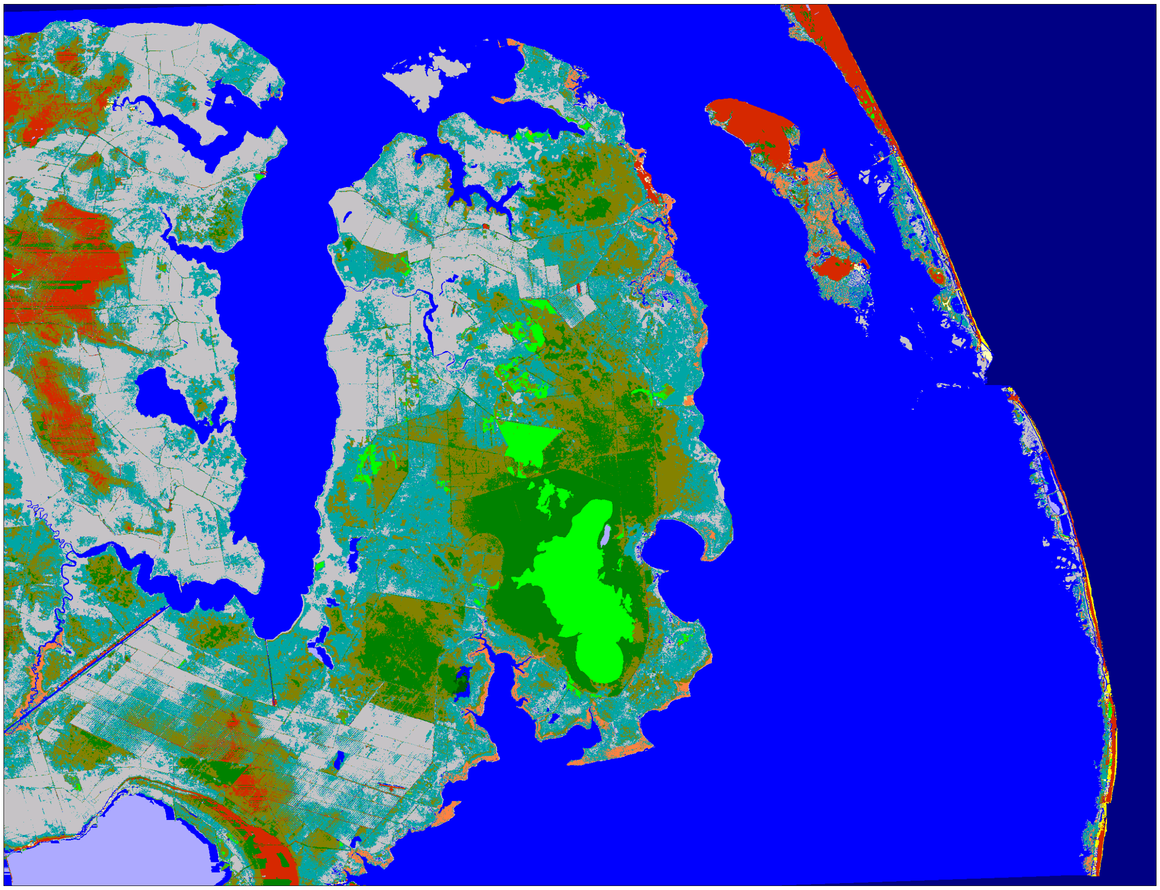
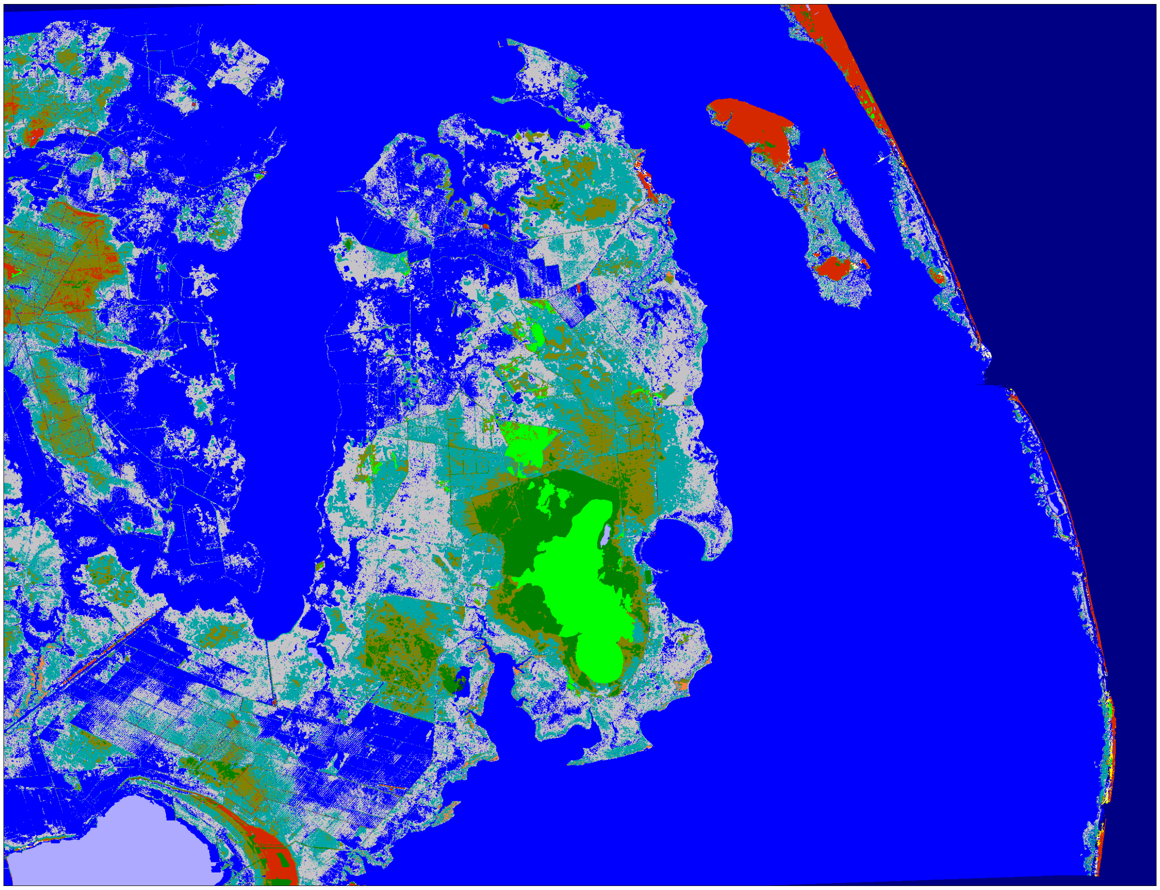
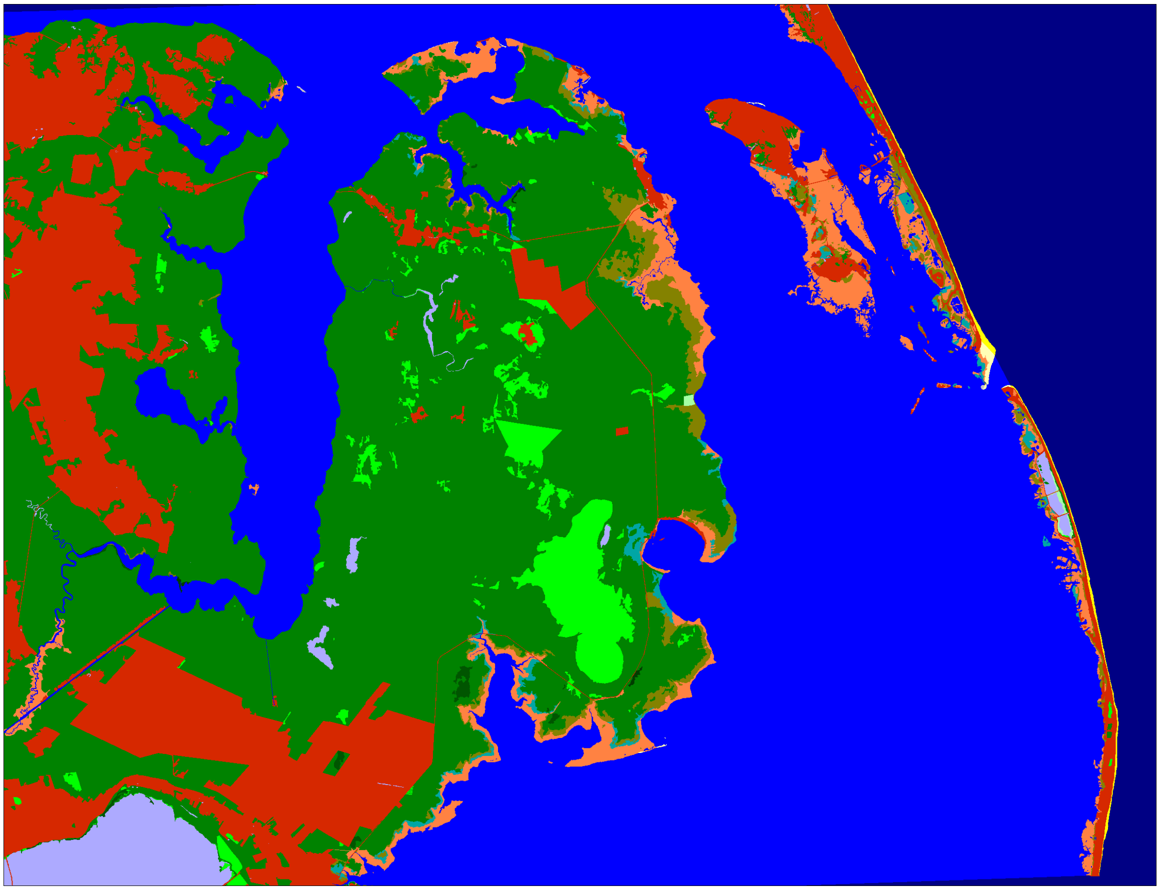


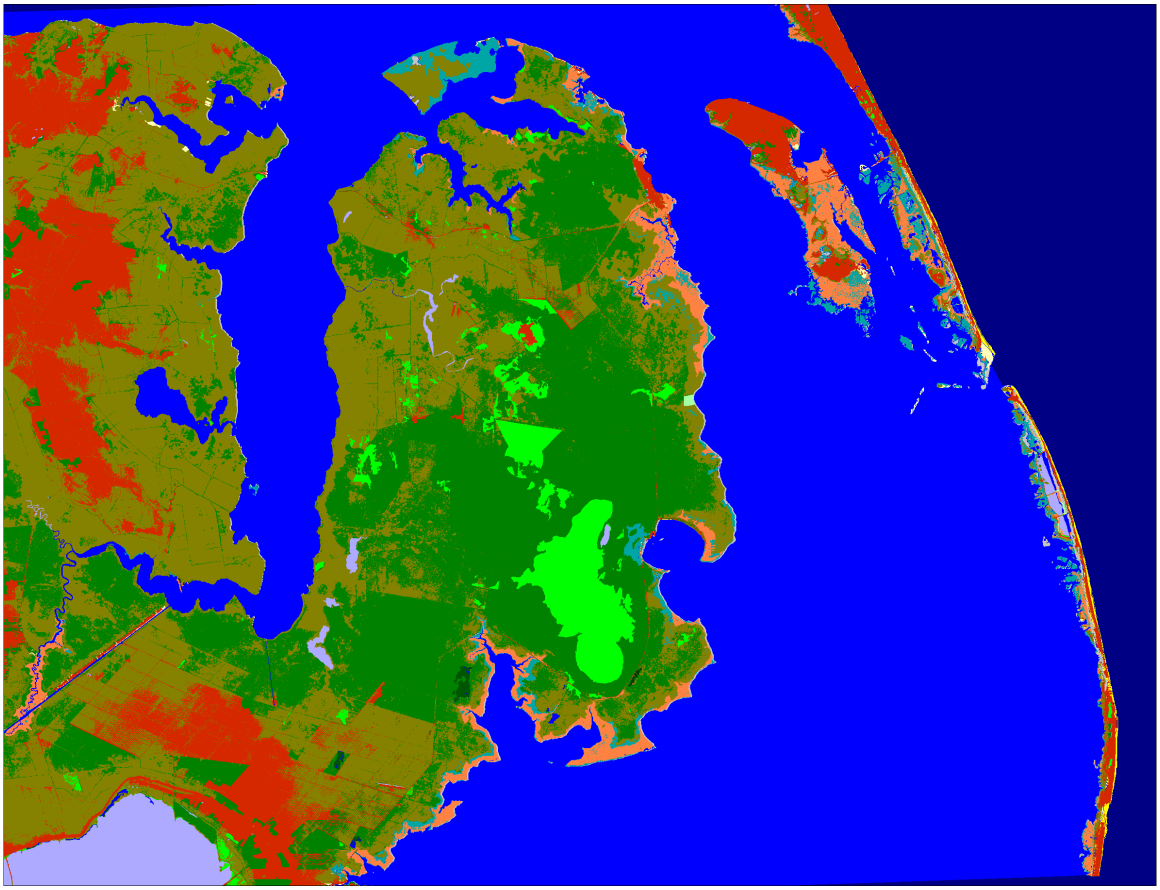
North Carolina 2075, 1 meter Eustatic by 2100



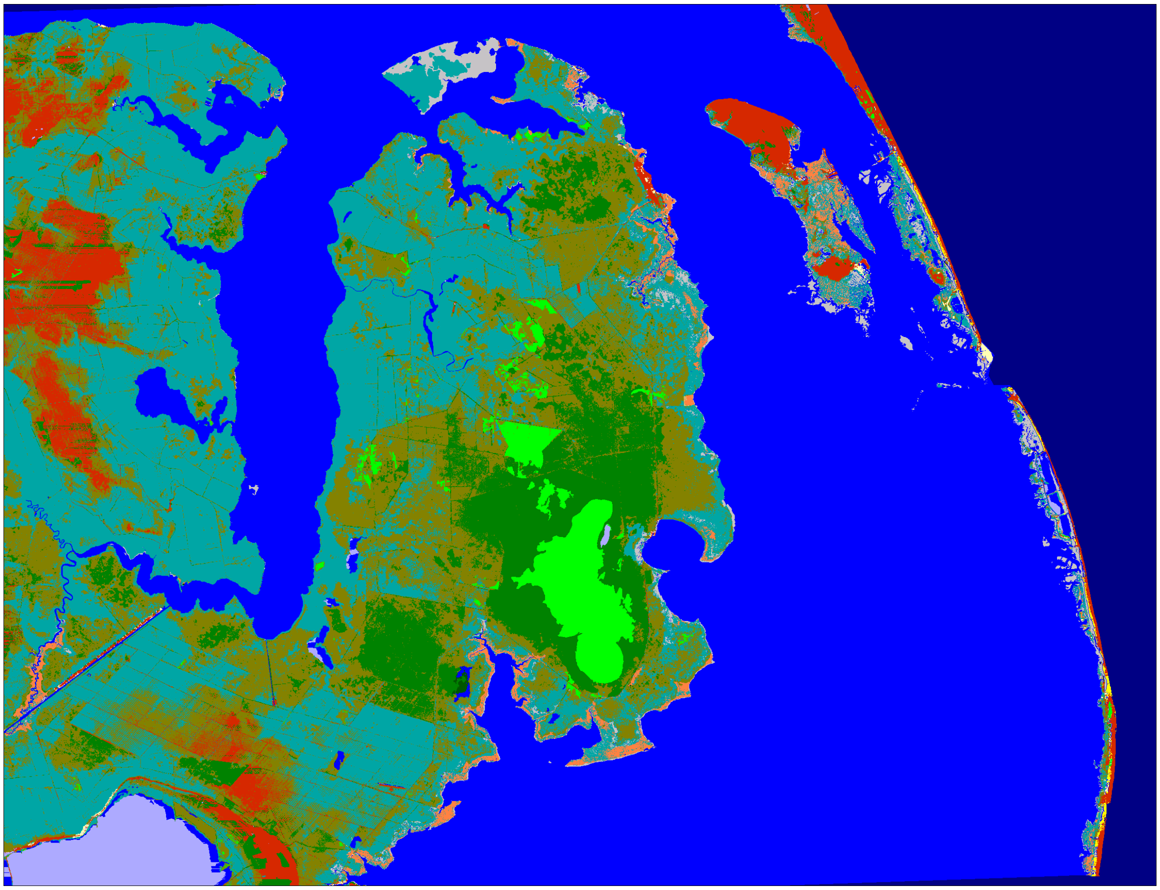
North Carolina 2100, 1 meter Eustatic by 2100



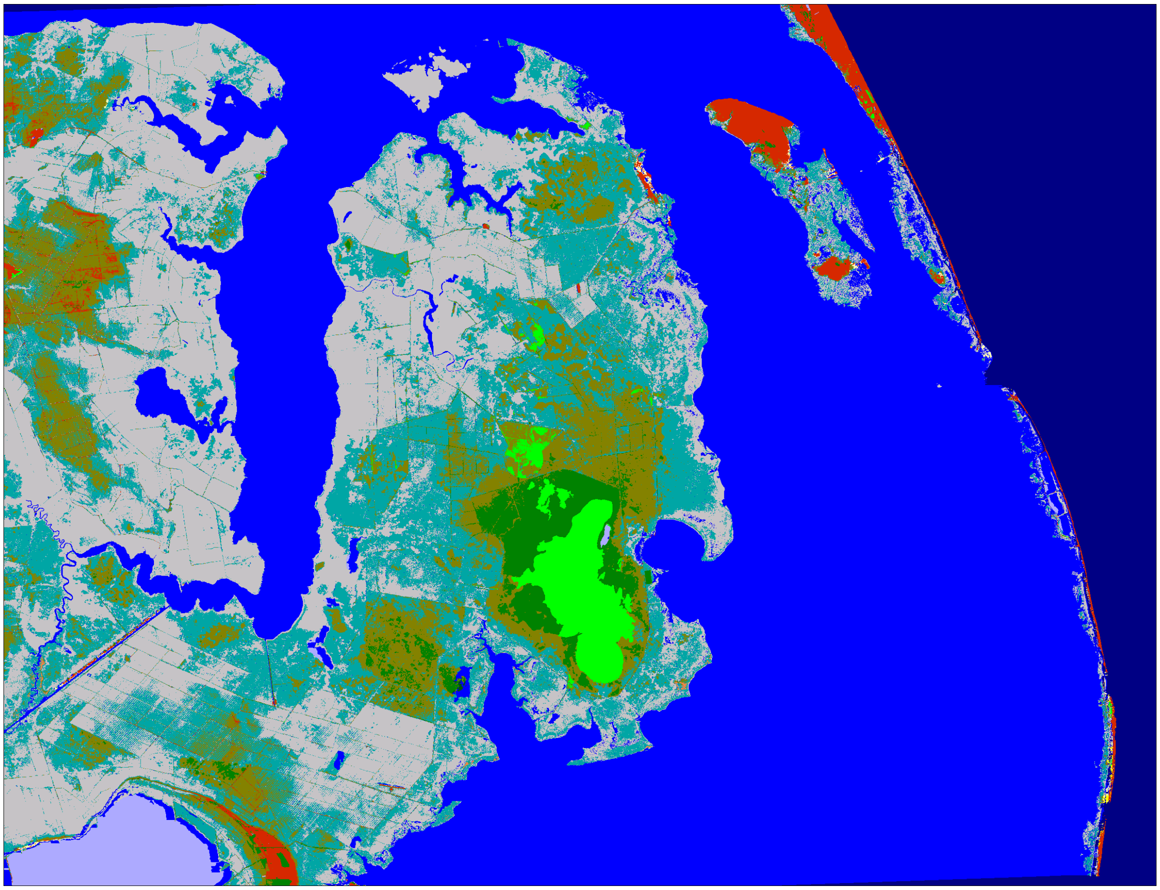
North Carolina Initial Condition



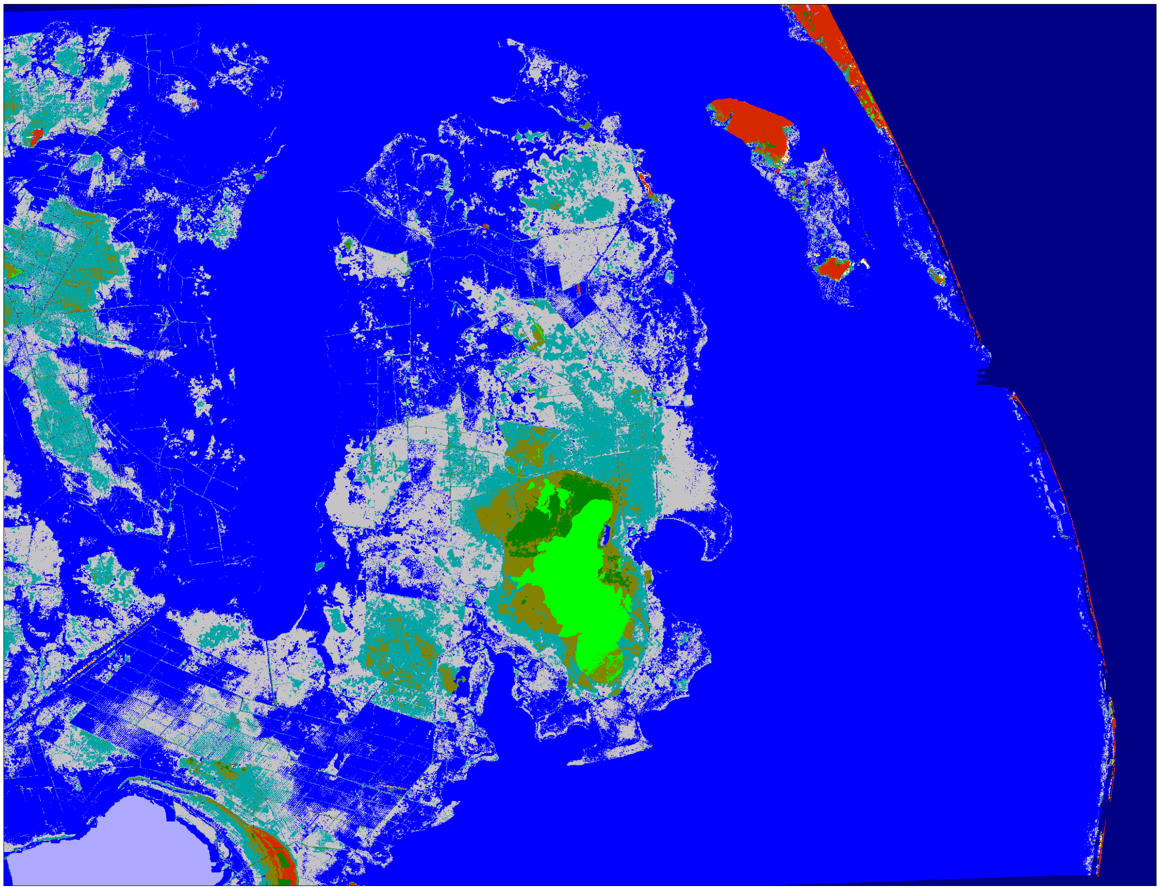
North Carolina 2025, 1.5 meter Eustatic by 2100



North Carolina 2050, 1.5 meter Eustatic by 2100



North Carolina 2075, 1.5 meter Eustatic by 2100



North Carolina 2100, 1.5 meter Eustatic by 2100

Addendum A: Road Inundation Analysis

SLAMM 6 has recently been updated with an infrastructure module that integrates roads layers into an existing SLAMM simulation. This infrastructure has two effects on SLAMM simulations. First, SLAMM can now predict the vulnerability of road infrastructure with respect to sea-level rise. Second, the effects of road elevations on wetland projections and water paths is accounted for in wetland-fate predictions.

SLAMM accounts for road lengths within in each cell containing a portion of the road and includes separate road-specific elevations within each cell. The heights of 30-, 60-, and 90-day inundations are input parameters based on data from local tide gages. During the simulation, SLAMM searches for water inundation pathways using the connectivity algorithm to estimate how frequently each segment of road will be inundated. At the end of a SLAMM simulation road maps are produced and numerical data describing the total length of roads that are inundated are summarized into the following categories

- km of roads inundated more frequently than every 30 days (highly vulnerable)
- km of roads inundated once each 30-60 day period
- km of roads inundated once each 60-90 day period and
- km of roads inundated less frequently than once each 90 days (rarely flooded)

These data are summarized in an output Excel file and graphical results are shown below.

Road Data

The road data within the Alligator River refuge were derived from the US Fish and Wildlife Service Road Inventory Program (RIP) shown in red lines in Figure 1. Road classes were not identified as the data did not have this feature available.

- *Road Elevations.* The elevation of the road in each model cell was derived from the 2008 NED LiDAR layer using the following procedure:

  - All elevations within a 15 m buffer around the road lines were extracted using a high resolution elevation layer with a 3 m cell size (compared to the SLAMM simulation resolution of a 30 m cell size);
  - Within each cell, the road elevation was chosen as the 95th percentile of the elevations included in the buffer area. This conservative approach was used to exclude elevations from ditches on the sides of the roads should the buffer zone include those features.
  - Finally, to better represent road effects, the elevations of cells containing roads were set to the road elevation rather than the average elevations of the cell as it is done for a classic SLAMM simulation. This affects both road inundation frequency and water connectivity pathways.

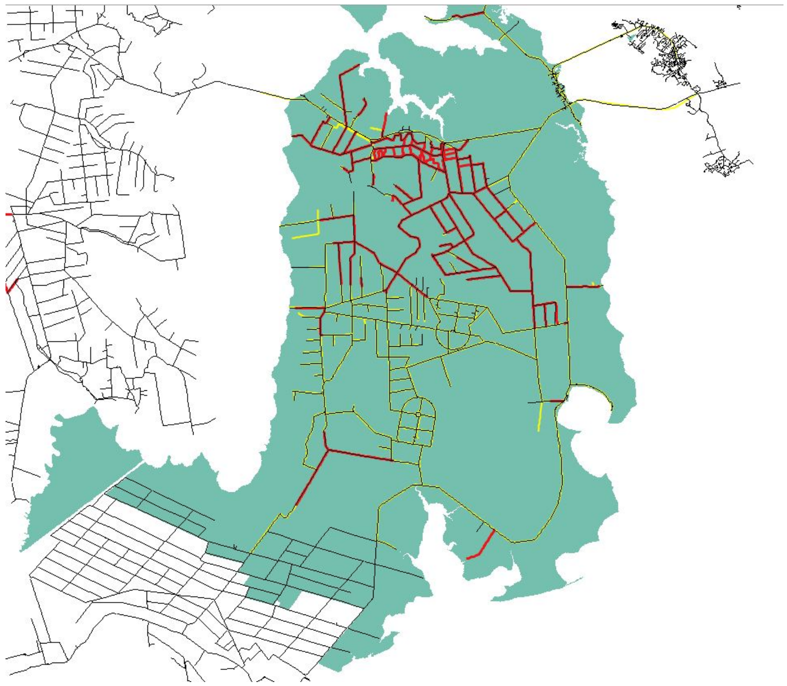


Figure 1. Road data set available for the study area. Green area represents the approved acquisition boundary for the refuge. Grey lines is an ESRI road layer, yellow layer are roads received from refuge and red lines reflects the Cycle 4 GIS (RIP).

A comparison of the elevation maps without and with road data included is show Figure 2. The observed difference is due to the fact that in the first case, figure A, elevations were averaged within each 30mx30m cell of the study area while in figure B more accurate road elevations are now assigned to the cells that contain road portions and therefore the roads become more distinguishable.

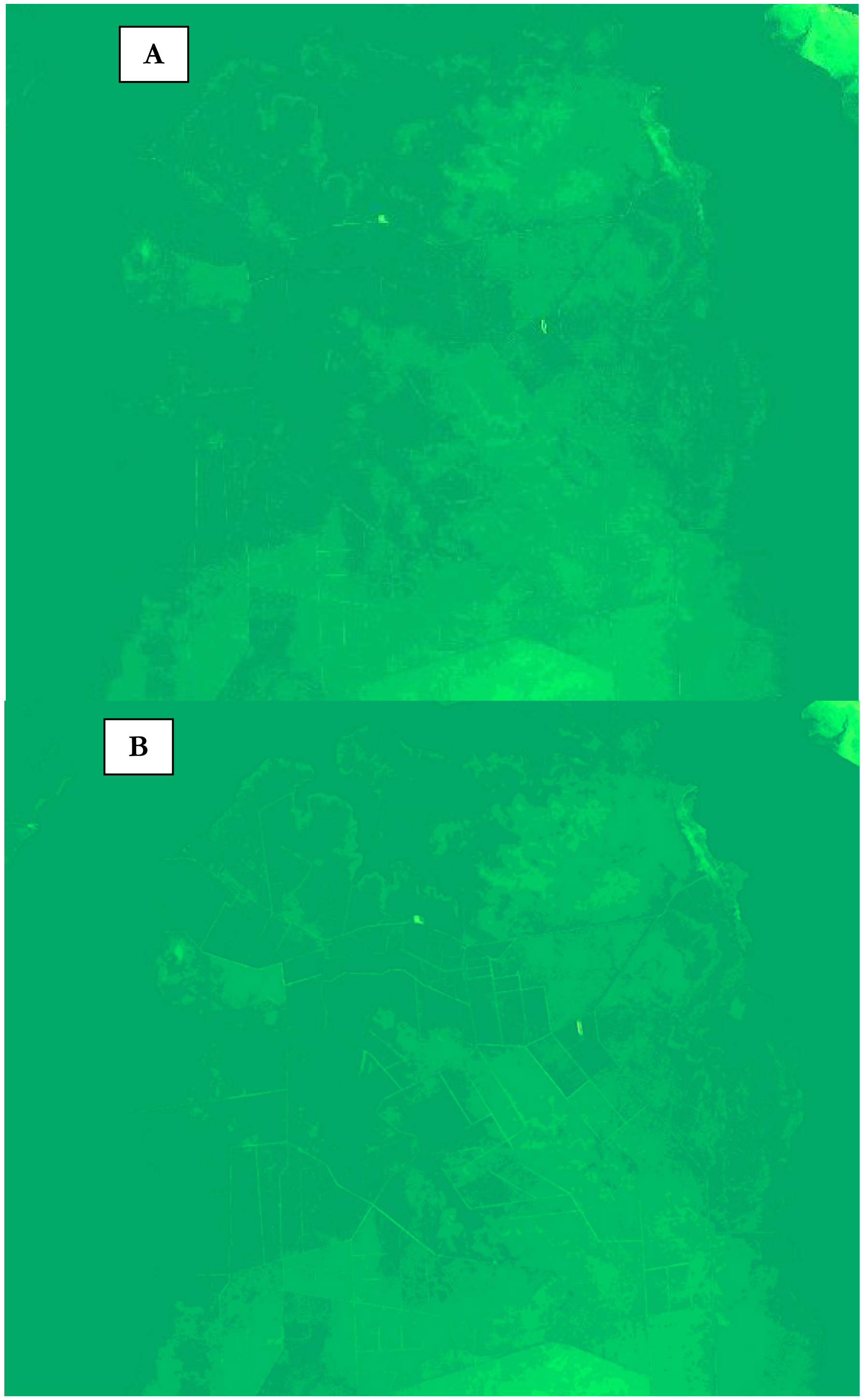


Figure 2. Digital Elevation Maps without (A) and with (B) road elevation data included.

- *Inundation Parameters.* The historical inundation data from an available NOAA gauge station in Lake Worth, NC are shown in Figure 3 below.

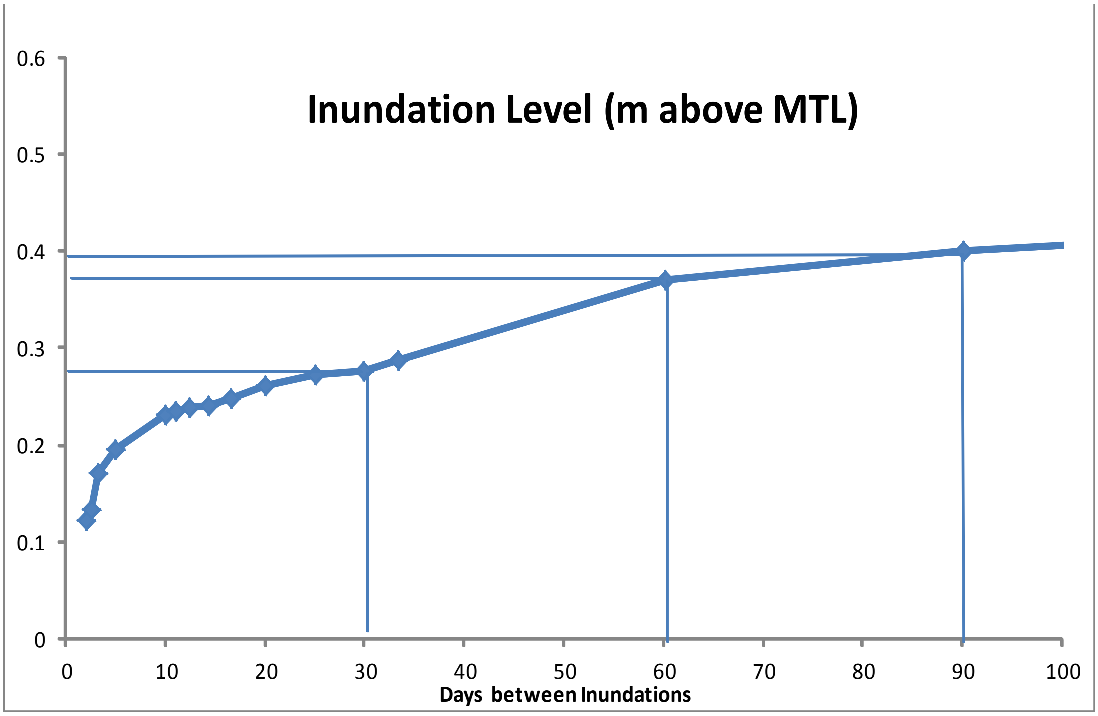


Figure 3. Inundation data at NOAA Gauge Station #8652905 in Lake Worth, NC.

From these historical inundation data, frequency-of-inundation elevations for the study area are estimated as follows: elevations less than 0.28 m above MTL are inundated at least once every 30 days, elevations between 0.28 m and 0.38 m are inundated on average once between every 30 to 60 days, elevations between 0.38 m and 0.40 m between 60 and 90 days, while elevations greater than 0.40 m are inundated with a frequency that is less than once per 90 days.

Road Inundation Projections

Predictably, roads within the refuge are more frequently inundated with increasing sea level. The total inundated road lengths at different inundation frequencies under the simulated SLR scenarios are summarized in Table 6.

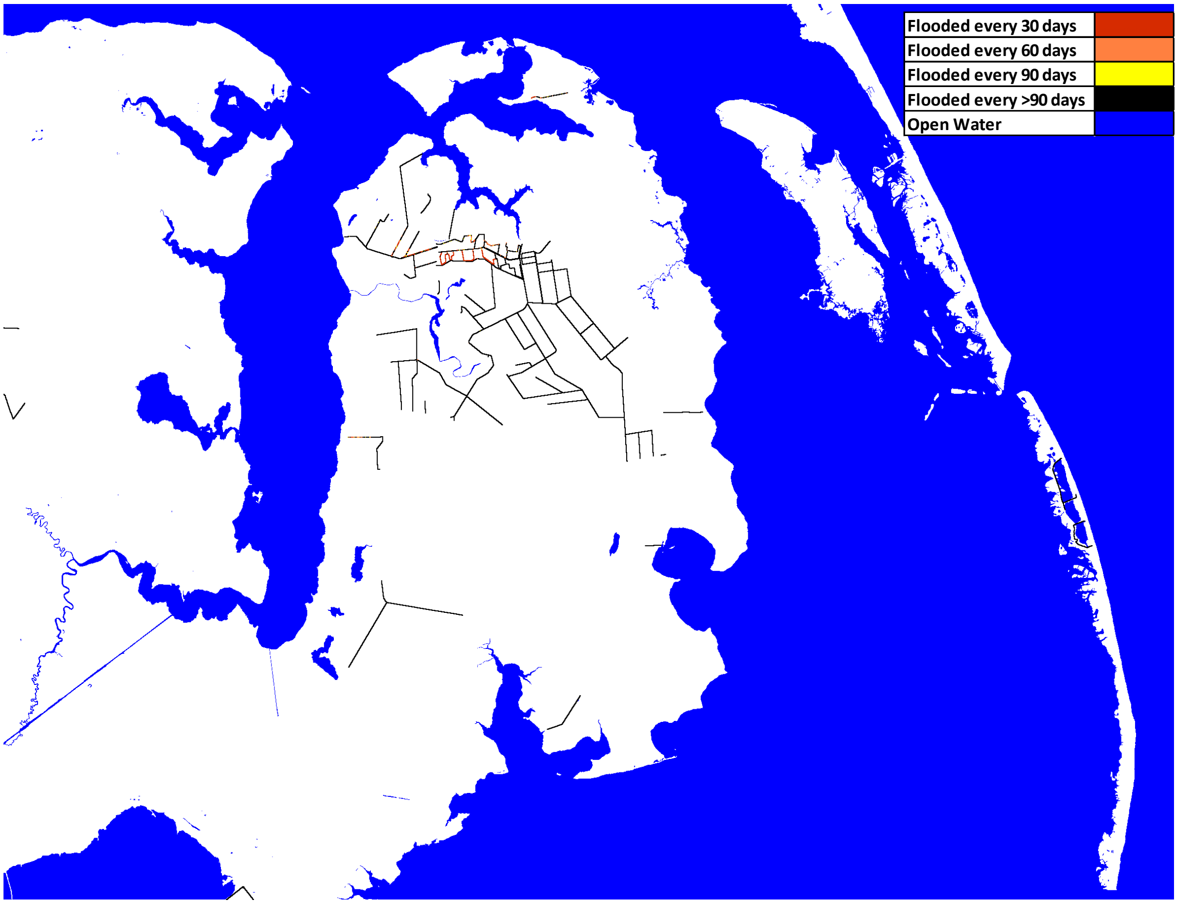
Table 1. Predicted length of inundated roads by 2100 given simulated scenarios of eustatic SLR at Alligator River NWR.

Inundation Frequency (days)	Initial coverage (km)	Total length of inundated roads by 2100 for different SLR scenarios (km)				
		0.39 m	0.69 m	1 m	1.5 m	2 m
30 (most flooded)	8.00	57.92	111.14	160.04	194.96	202.71
60	3.52	16.14	16.69	9.01	3.10	0.17
90	1.21	5.00	5.24	3.05	0.60	0.00
>90 (rarely flooded)	190.35	124.01	70.00	30.97	4.41	0.19
Total	203.07	203.07	203.07	203.07	203.07	203.07

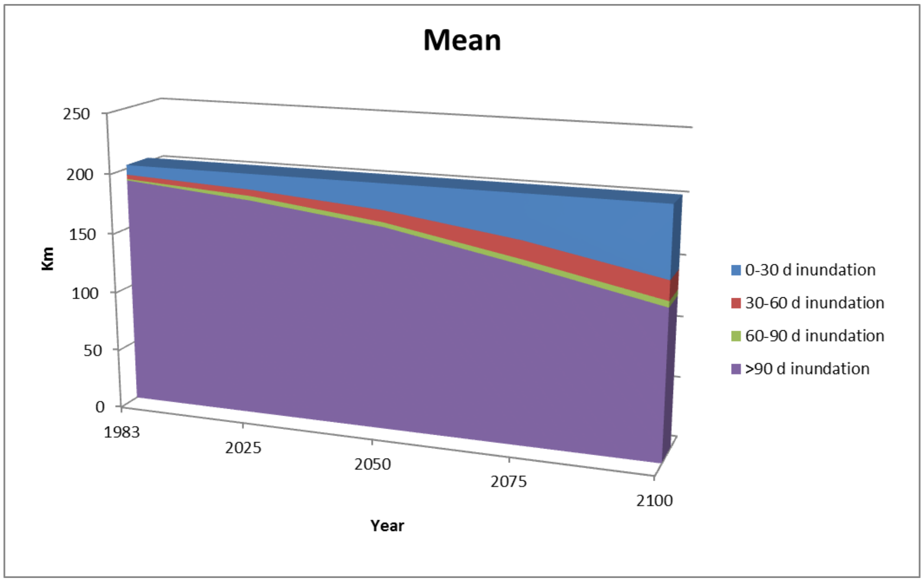
Of the total 203 km of roads today only a small fraction, 13 km are inundated with a frequency that is higher than every 1/90 days and they are located in the north section of the refuge. While small, this result may overestimate the actual observed road inundation frequencies since some northern roads in the farm unit are protected by an earthen dike. Refuge staff has confirmed that those areas are not inundated because of the existing dikes but a specific map of the dikes was not obtained. Overall, these predicted initial conditions results support and validate the consistency of the data and modeling approach by showing that some roads would be inundated if they were not protected.

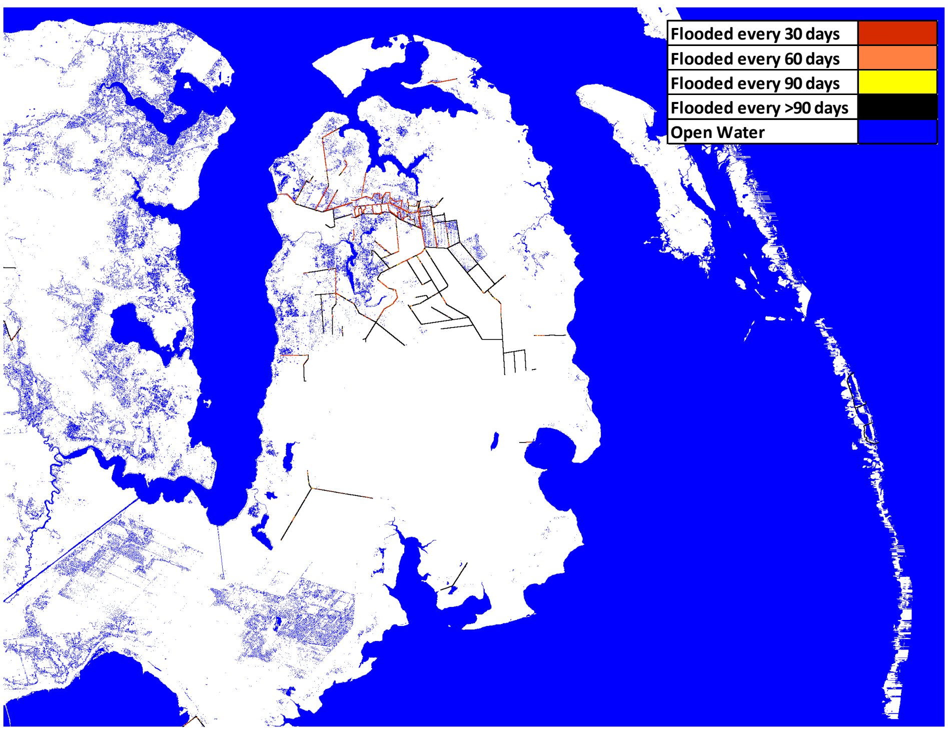
Under the most conservative SLR scenario, by 2100 almost 39% of the total road length becomes inundated at least once every 3 months. Under the 2 m SLR, almost all the roads are predicted to be inundated by 2100 at least once every 30 days. The intermediate SLR scenarios have predictions that lie between those of these two extreme SLR scenarios.

For planning and management purposes it is also important to know the location of roads that are vulnerable to inundation and the timing of their vulnerability. The below maps and graphs present the results in more detail. Even under the 0.39 m SLR by 2100 scenario, higher inundation frequency is observed already at 2025 because of the general low elevations of the area. Under all SLR scenarios the rate of inundation increases after 2025.

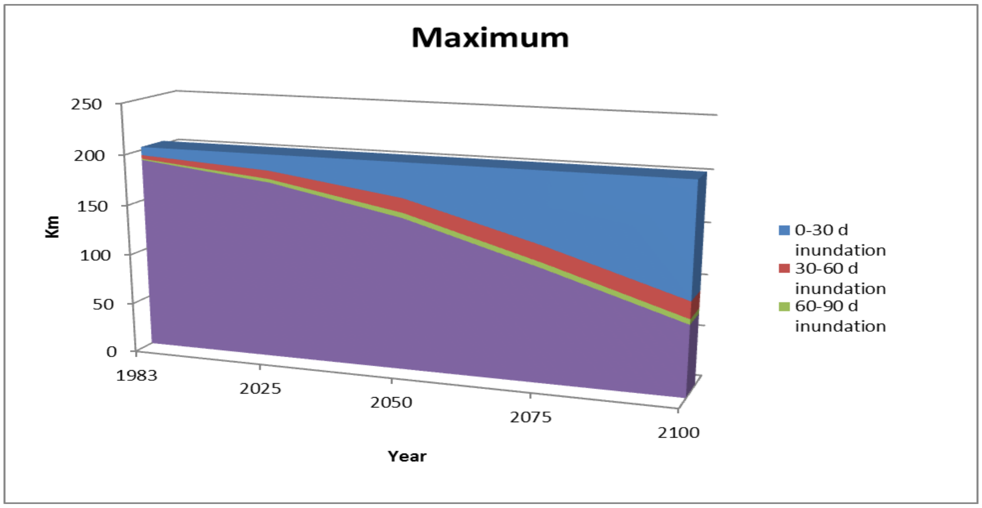


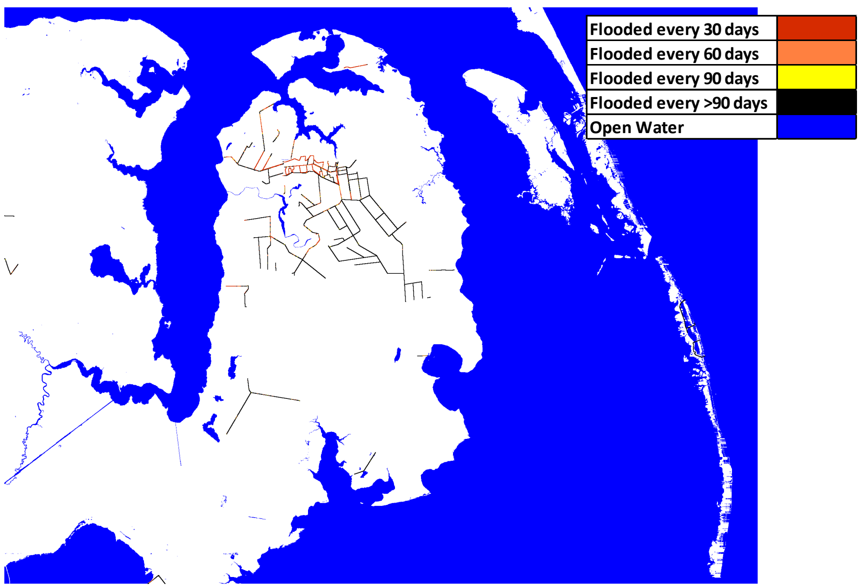
Alligator River NWR, Road Inundation, Initial conditions



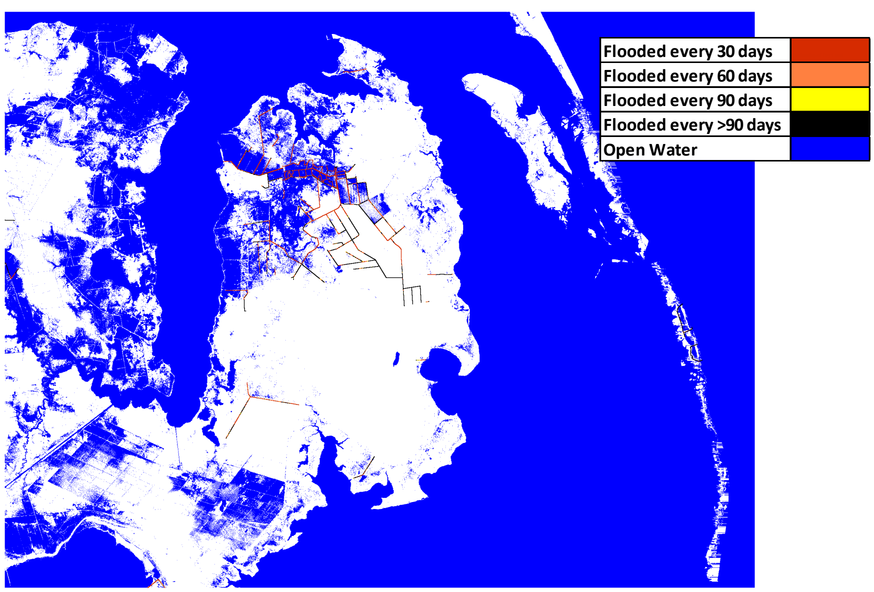


Alligator River NWR, Road Inundation, 0.39 m SLR by 2100, 2100.

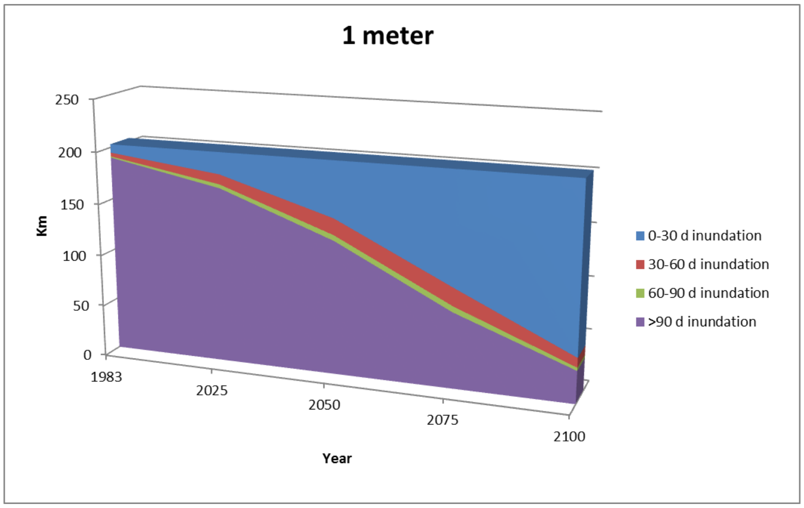


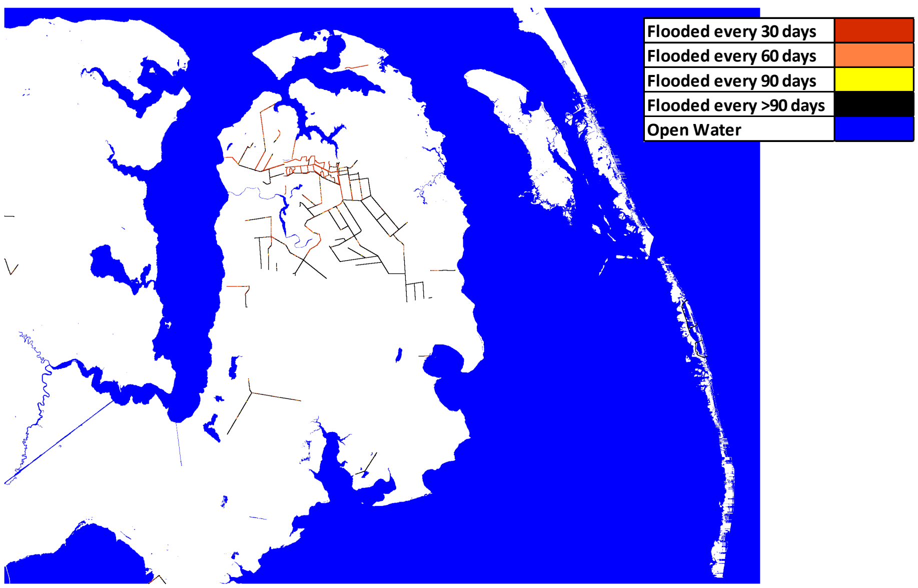


Alligator River NWR, Road Inundation, 0.69 m SLR by 2100, 2050.

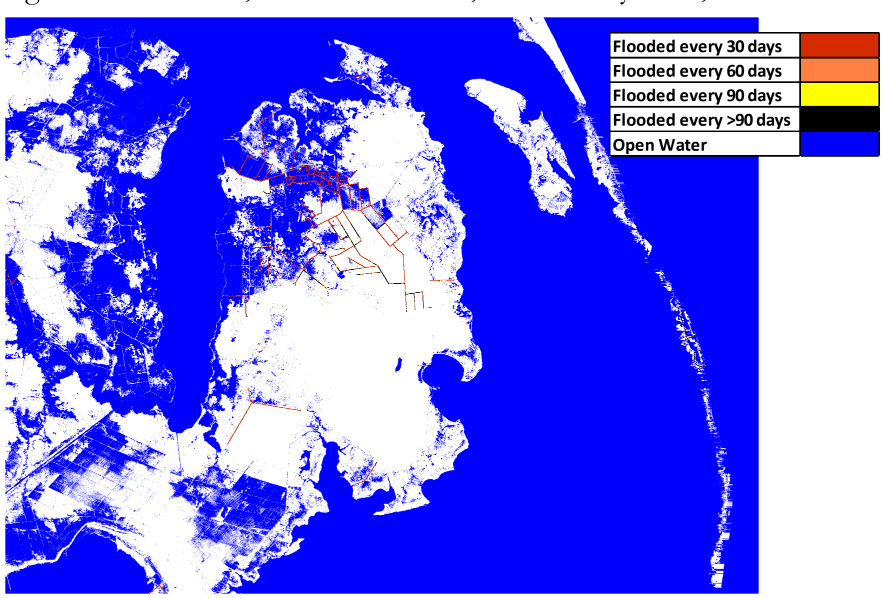


Alligator River NWR, Road Inundation, 0.69 m SLR by 2100, 2100

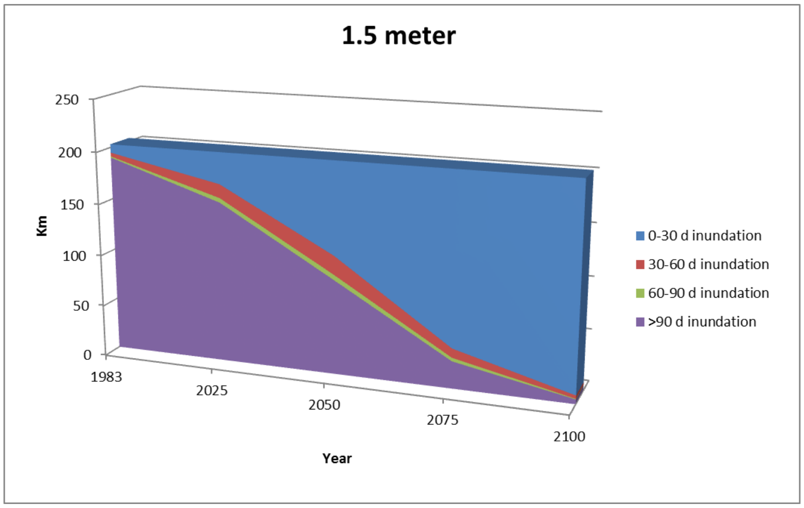


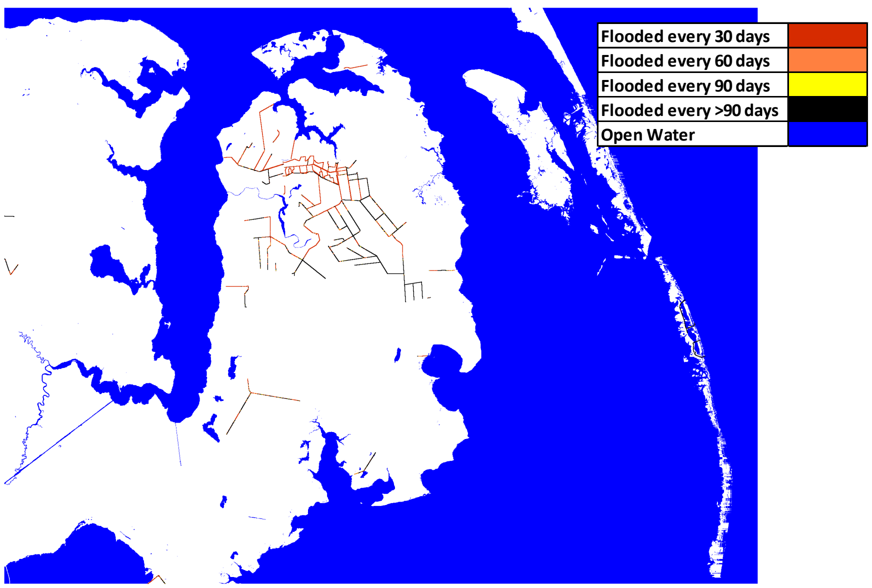


Alligator River NWR, Road Inundation, 1 m SLR by 2100, 2050.

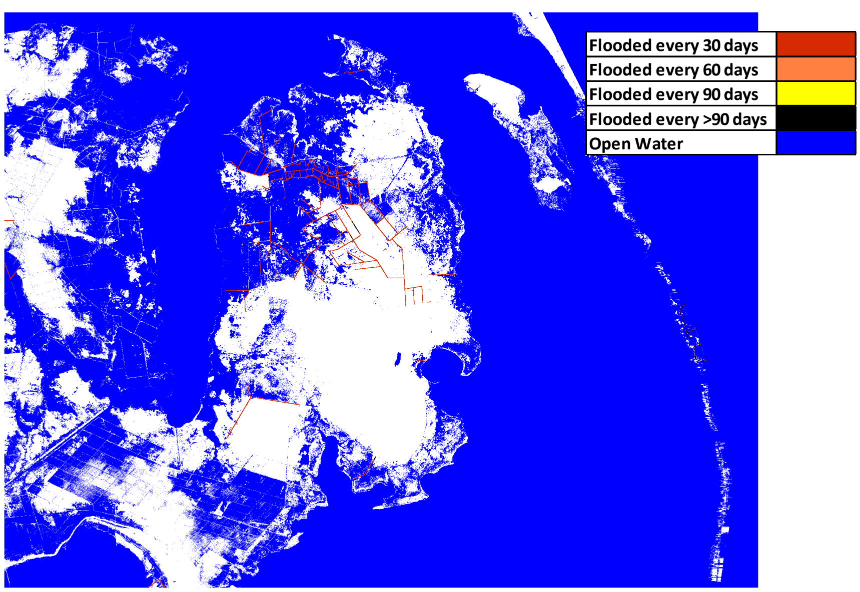


Alligator River NWR, Road Inundation, 1 m SLR by 2100, 2100.

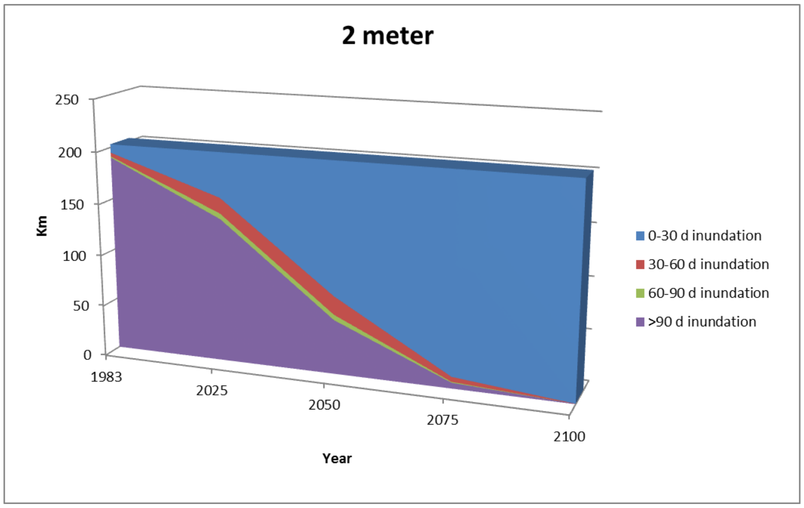


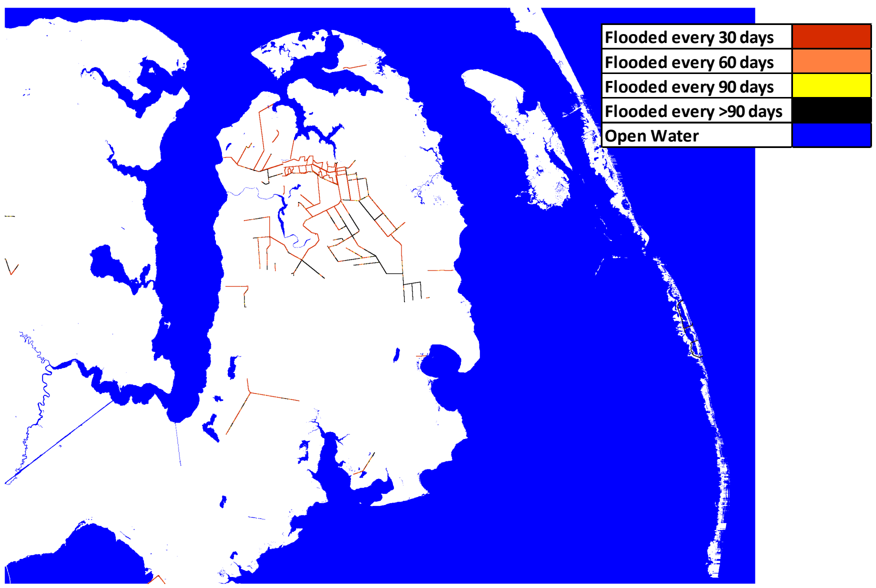


Alligator River NWR, Road Inundation, 1.5 m SLR by 2100, 2050.

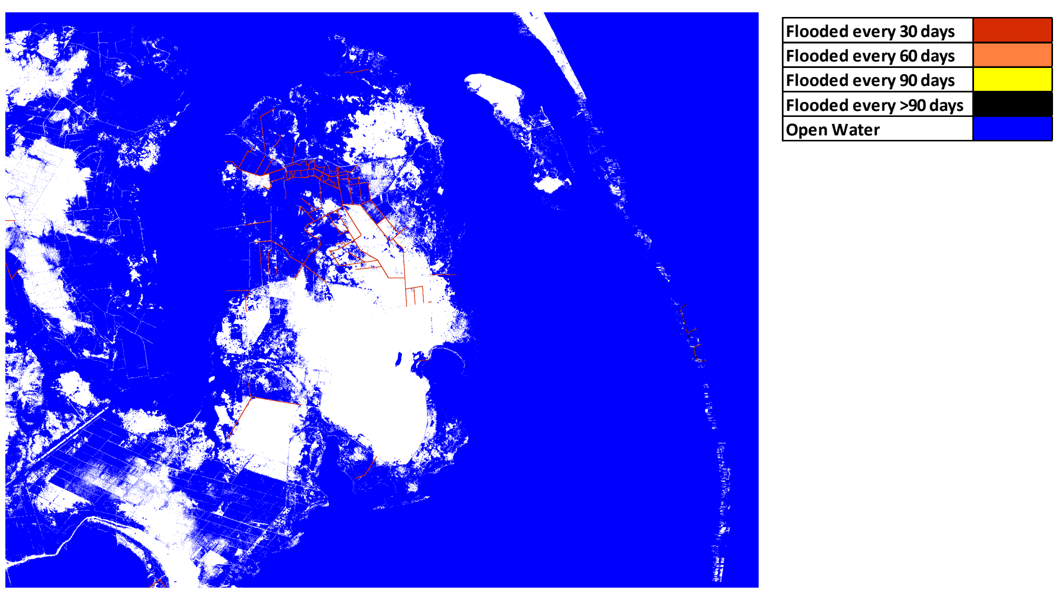


Alligator River NWR, Road Inundation, 1.5 m SLR by 2100, 2100.





Alligator River NWR, Road Inundation, 2 m SLR by 2100, 2050.



Alligator River NWR, Road Inundation, 2 m SLR by 2100, 2100.