Application of the Sea-Level Affecting Marshes Model (SLAMM 5.0) to Rhode Island NWR Complex

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Introduction

Tidal marshes are among the most susceptible ecosystems to climate change, especially accelerated sea level rise (SLR). The International 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 could be 50 to 140 cm. Pfeffer et al. (2008) suggests that 200 cm by 2100 is at the upper end of plausible scenarios due to physical limitations on glaciological conditions. 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 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 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 Rhode Island NWR Complex.

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

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).

Sea-Level Rise Scenarios

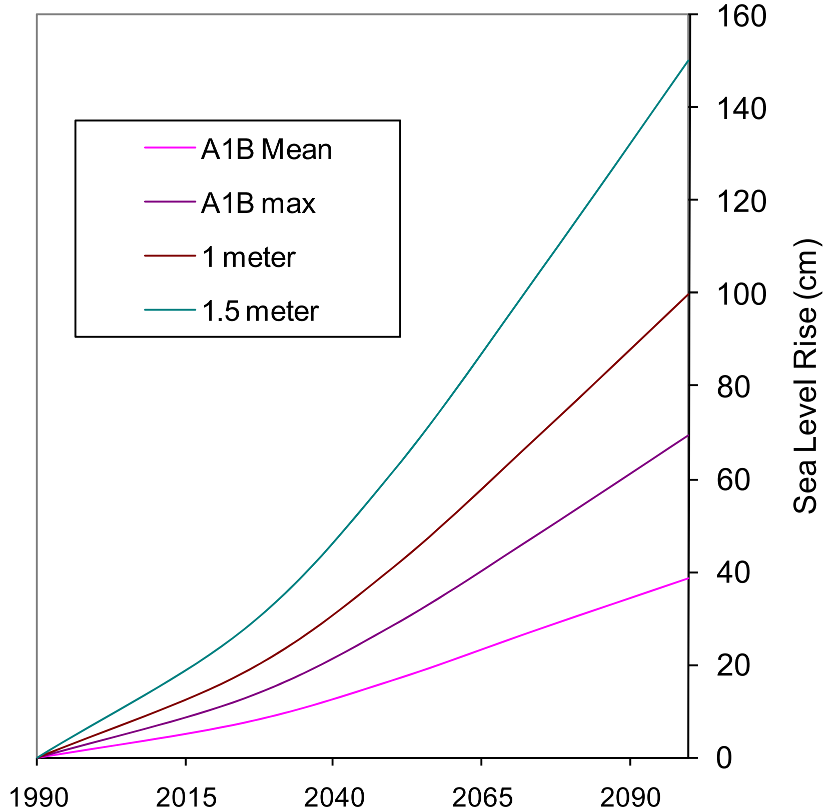
The primary set of eustatic (global) sea level rise scenarios used within SLAMM was derived from the work of the Intergovernmental Panel on Climate Change (IPCC 2001). SLAMM 5 was run using the following IPCC and fixed-rate scenarios:

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 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. 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)

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

The Rhode Island National Wildlife Refuge Complex is comprised of five refuges – Block Island, John H. Chafee, Ninigret, Sachuest Point, and Trustom Pond. A variety elevation datasets were used to cover the complex. LiDAR datasets were used from two sources: 1) the U.S. Army Corps of Engineers and 2) two foot contours as derived from a Rhode Island Coastline LiDAR Survey covering New Shoram, North Kingston, Westerly and Charleston (Fig. 2a). NED (National Elevation Dataset) elevations were used to cover those cells not covered with LiDAR.

The two LiDAR datasets were created from flights ranging from 2005 to 2007. For the portion of the refuge that lies outside of the LiDAR footprint, NED elevation data were based on several USGS surveys ranging in date from 1943 to 2001. An example map is illustrated below (Fig. 2b). The contour interval for these USGS maps was ten feet indicating considerable uncertainty between the shoreline and the first contour. For this reason, wetlands elevations in non LiDAR areas were estimated as a function of tidal range.

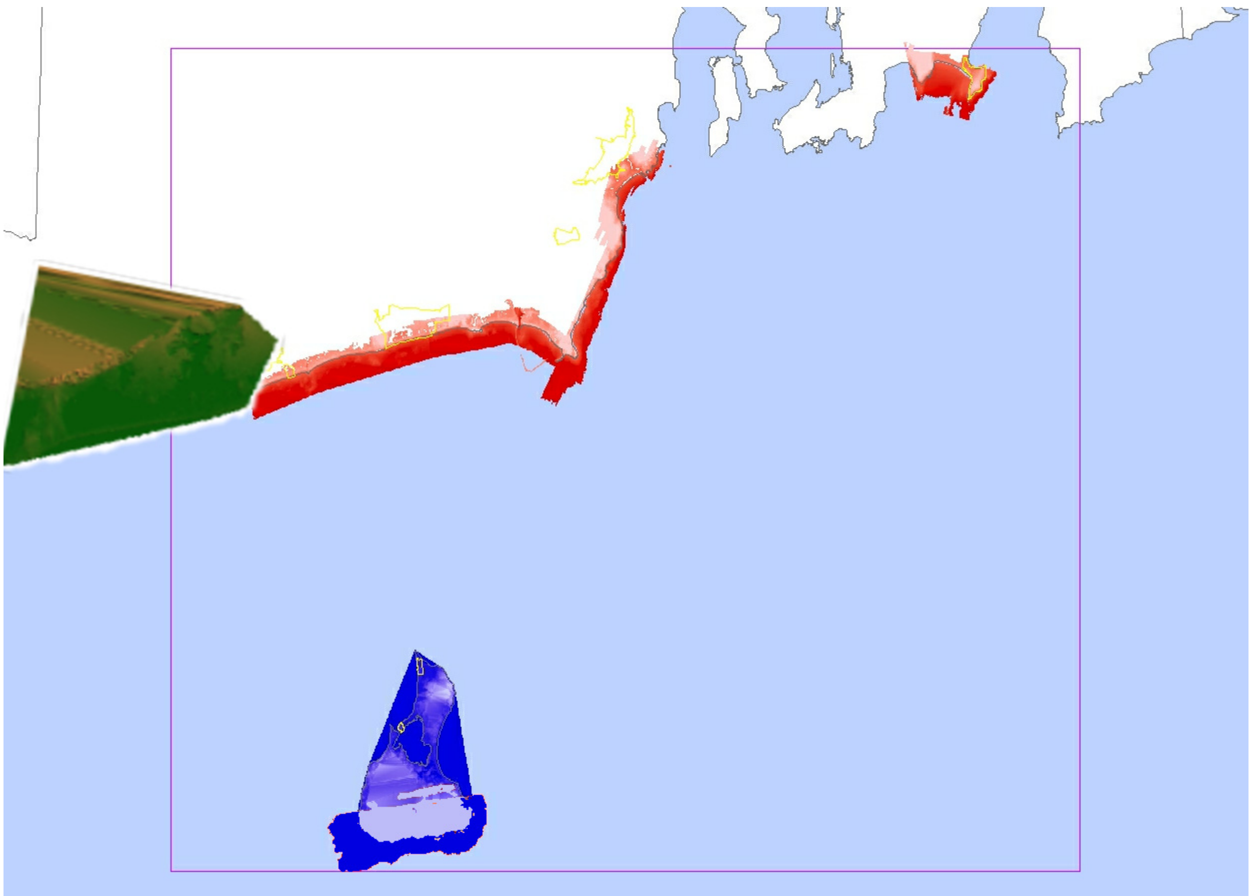


Figure 2a: Two-foot contour LiDAR coverage (green and blue) along with regular LiDAR coverage (red).

Figure 2b: Rhode Island Complex Excerpt from USGS Map.

The National Wetlands Inventory for Rhode Island Complex is based on a photo date of 2004. An examination of the NWI map overlaid on recent satellite photos indicates no significant differences in land classification between the two maps.

The historic trend for sea level rise was estimated at 2.58 mm/year using the closest long-term NOAA monitoring station (8452660, Newport, Rhode Island). This measured rate is slightly higher than the global average for the last 100 years (approximately 1.5-2.0 mm/year). Note that any effects of isostatic rebound that have affected this region for the last 100 years are measured within that historic trend and that same rate of isostatic rebound is projected forward into the next 100 years.

Converting the NWI survey into 30 meter cells indicates that the roughly six thousand acre refuge complex (approved acquisition boundaries including water) is primarily composed of the categories as shown below:

Block Island	
Undeveloped Dry Land	81.7%
Brackish Marsh	4.1%
Inland Fresh Marsh	3.6%
Ocean Beach	3.1%
Estuarine Beach	2.5%
Swamp	2.4%
Inland Open Water	1.8%

Ninigret	
Undeveloped Dry Land	81.5%
Swamp	4.7%
Developed Dry Land	4.1%
Brackish Marsh	2.8%
Estuarine Beach	2.2%
Estuarine Open Water	1.9%
Trans. Salt Marsh	1.0%

Trustom Pond	
Undeveloped Dry Land	74.6%
Inland Open Water	9.5%
Swamp	7.9%
Developed Dry Land	4.1%
Open Ocean	1.3%

John H. Chafee	
Undeveloped Dry Land	59.0%
Estuarine Open Water	14.3%
Brackish Marsh	11.1%
Swamp	10.0%
Developed Dry Land	4.0%

Sachuest Point	
Undeveloped Dry Land	71.4%
Brackish Marsh	14.9%
Ocean Beach	5.5%
Estuarine Beach	4.3%
Estuarine Open Water	1.4%
Open Ocean	1.2%

(Developed and undeveloped dry land are differentiated on the basis of the National Land Cover Dataset from 2001.)

Based on the NWI coverage, there are several small diked and impounded wetlands within Rhode Island NWR Complex, the Trustom Pond Refuge and John H. Chafee Refuge in particular (Fig. 3a, b). These areas were assumed to remain protected under all scenarios of sea level rise.

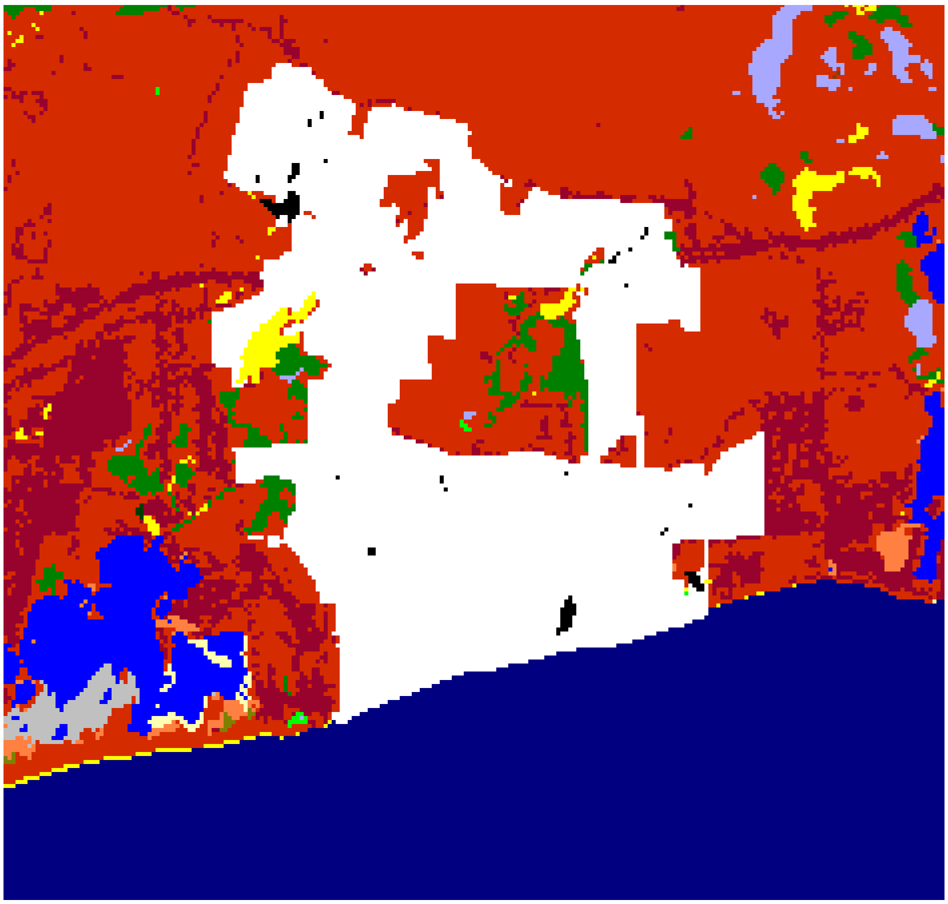


Figure 3a: Diked areas (black) within Trustom Pond NWR (white).

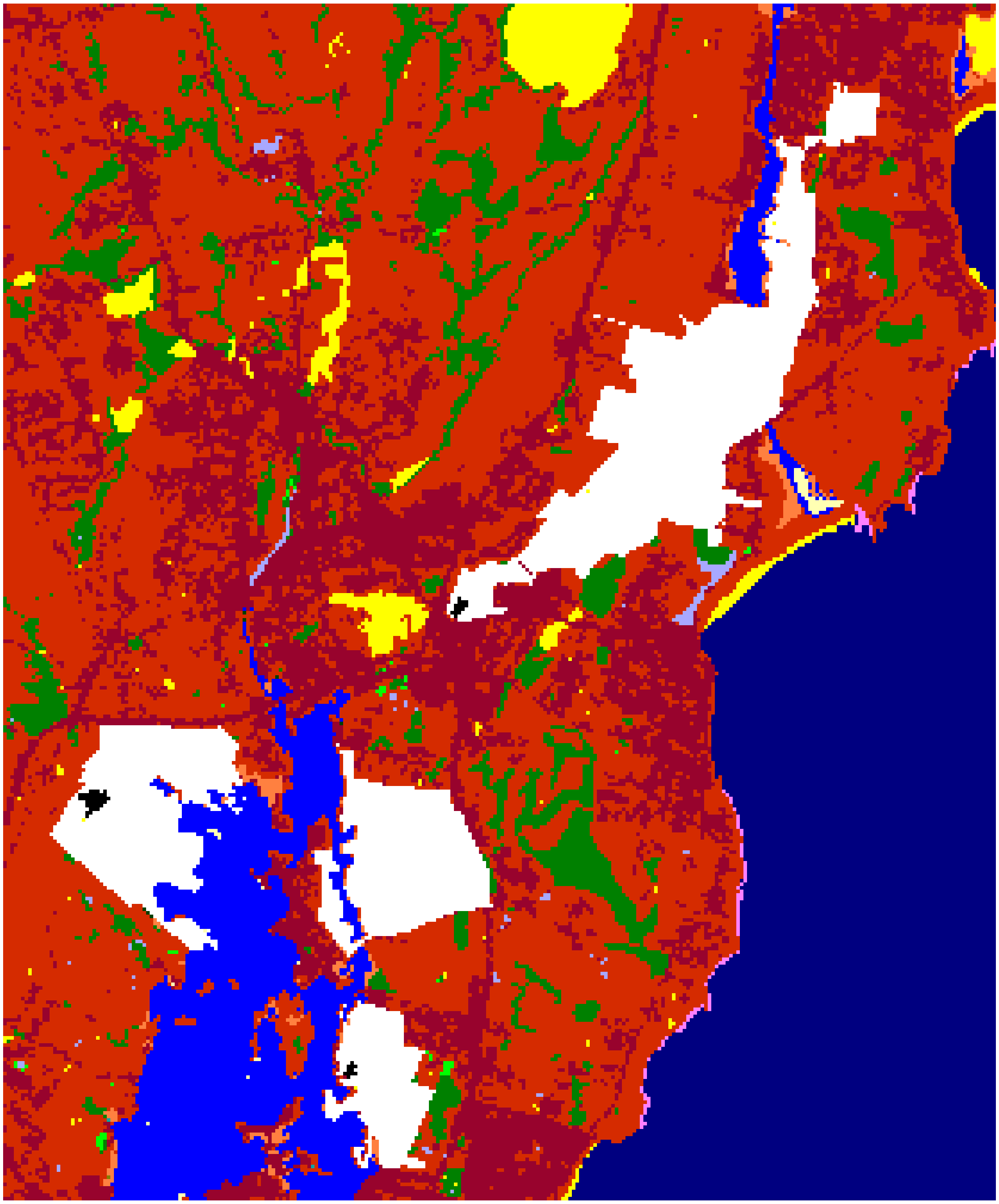


Figure 3b: Diked areas (black) within John H. Chafee NWR (white).

The NWR complex was broken into four sub-sites for more accurate processing (Fig. 5). The tide range for the Rhode Island South sub-site was estimated at 0.953 meters. The tide range for the Block Island sub-site was estimated at 0.95 meters. The ride range for the Rhode Island Central sub-site was estimated at 1.255 meters, and the tide range for the Rhode Island East sub-site was estimated at 1.06 meters. All tide ranges were determined using the average of the eight closest NOAA tide gages within the complex (8458022, Weekapaug Point, Block Island Sound, RI; 8459681, Block Island, RI; 8459338, Block Island, RI; 8455083, Point Judith, Harbor Of Refuge, RI; 8454341, Boston Neck, RI; 8453999, Beavertail Point, RI; 8451351, Sachuest, Flint Point, RI; 8454538, Wickford, Narragansett Bay, RI). Elevation data were converted from NAVD88 to a Mean Tide Level (MTL) basis using corrections based on USGS gages for RI South, and using the NOAA VDATUM product for all other sub-sites.

Figure 4: NOAA Gages Relevant to the Study Area.

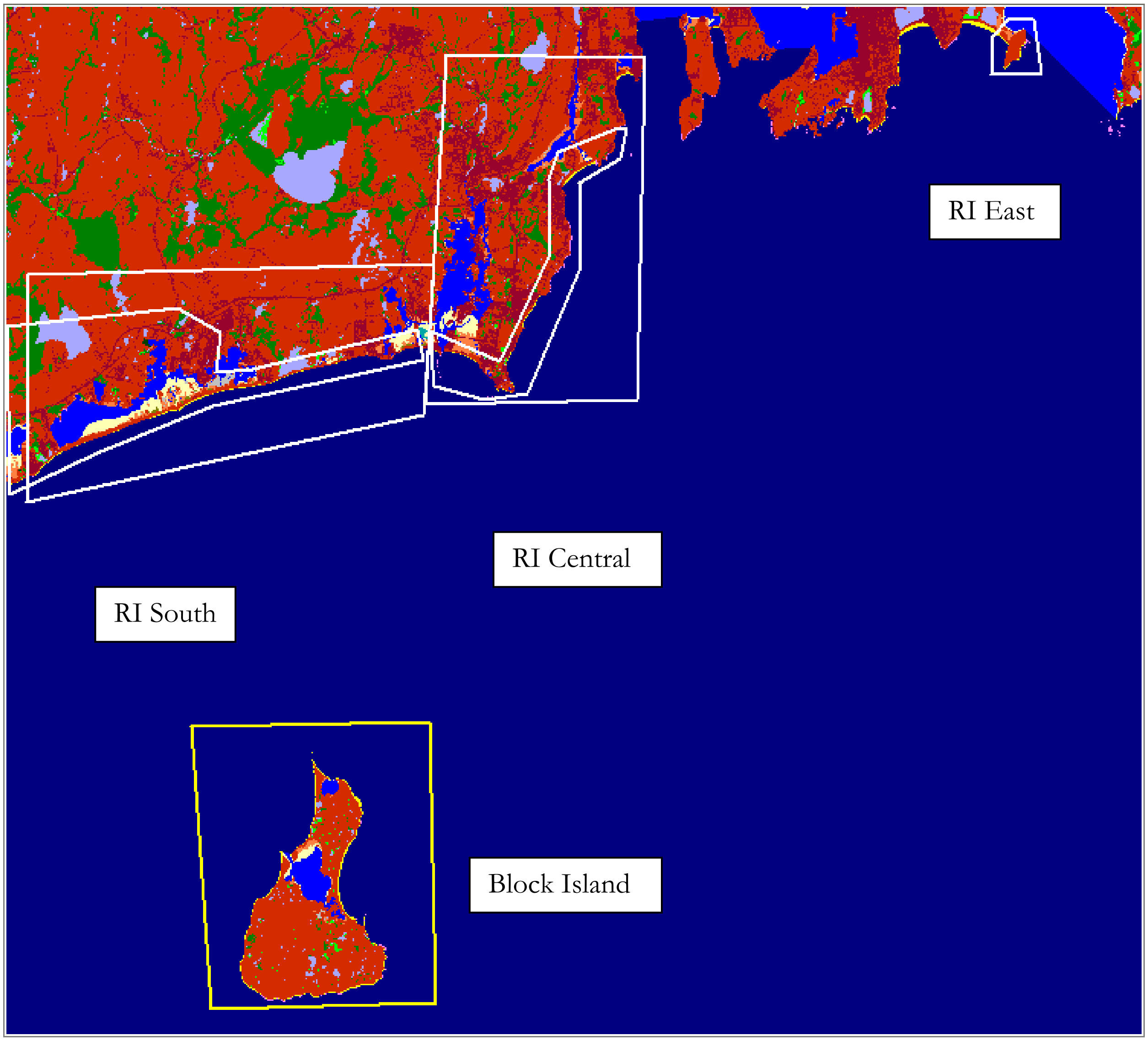


Figure 5: Rhode Island Complex Simulation Sub-sites

Accretion rates in salt marshes were set to 4.23, brackish marshes were set to 3.2 mm/year and the rates in tidal fresh marshes to 5.9 mm/year based on a study of accretion rates on the Rhode Island coast (S. Bricker-Urso, 1989). These accretion rates are assumed to remain constant over the course of the simulation.

Modeled U.S. Fish and Wildlife Service refuge boundaries 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. (Note that since the LiDAR data produce a more accurate DEM, only the elevations of wetlands classes lying outside of the LiDAR data in Rhode Island Complex were overwritten as a function of the local tidal range using the SLAMM elevation pre-processor.)

SUMMARY OF SLAMM INPUT PARAMETERS FOR RHODE ISLAND NWR COMPLEX

Description	Rhode Island	RI Block Island	RI South	RI South LIDAR	RI Central	RI Central LIDAR	RI East
DEM Source Date (yyyy)	1967	1943	2001	2006	1957	2006	2006
NWI_photo_date (yyyy)	2004	2004	2004	2004	2004	2004	2004
Direction_OffShore (N|S|E|W)	S	W	S	S	E	E	S
Historic_trend (mm/yr)	2.58	2.58	2.58	2.58	2.58	2.58	2.58
NAVD88_correction (MTL-NAVD88 in meters)	-0.107	-0.0985	-0.107	-0.107	-0.079	-0.079	-0.068
Water Depth (m below MLW- N/A)	2	2	2	2	2	2	2
TideRangeOcean (meters: MHHW-MLLW)	1.02	0.95	0.953	0.953	1.255	1.255	1.063
TideRangeInland (meters)	1.02	0.95	0.953	0.953	1.255	1.255	1.063
Mean High Water Spring (m above MTL)	0.678	0.632	0.634	0.634	0.835	0.835	0.707
MHSW Inland (m above MTL)	0.678	0.632	0.634	0.634	0.835	0.835	0.707
Marsh Erosion (horz meters/year)	1.8	1.8	1.8	1.8	1.8	1.8	1.8
Swamp Erosion (horz meters/year)	1	1	1	1	1	1	1
TFlat Erosion (horz meters/year) [from 0.5]	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Salt marsh vertical accretion (mm/yr) Final	4.23	4.23	4.23	4.23	4.23	4.23	4.23
Brackish March vert. accretion (mm/yr) Final	3.2	3.2	3.2	3.2	3.2	3.2	3.2
Tidal Fresh vertical accretion (mm/yr) Final	5.9	5.9	5.9	5.9	5.9	5.9	5.9
Beach/T.Flat Sedimentation Rate (mm/yr)	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Frequency of Large Storms (yr/washover)	50	50	50	50	50	50	50
Use Elevation Preprocessor for Wetlands	TRUE	TRUE	TRUE	FALSE	TRUE	FALSE	FALSE

Results

Results are presented separately for the five refuges within the complex in the following order:

Block Island NWR
Ninigret NWR
Trustom Pond NWR
John H. Chafee NWR
Sachuest Point NWR

Block Island NWR

Block Island NWR is predicted to lose from 9% to 17% of dry land by 2100. Over 87% of brackish or irregularly flooded marsh, which makes up over 4% of the refuge, is predicted to convert to more saline, regularly flooded marsh or to tidal flats or open water by 2100.

SLR by 2100 (m)	0.39	0.69	1	1.5
Dry Land	9%	11%	13%	17%
Brackish Marsh	87%	93%	99%	100%
Inland Fresh Marsh	17%	22%	30%	70%
Ocean Beach	80%	76%	97%	98%
Estuarine Beach	66%	61%	60%	55%
Swamp	66%	76%	85%	92%

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

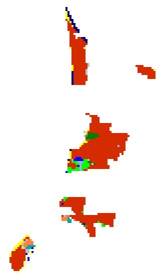
Block Island NWR
IPCC Scenario A1B-Mean, 0.39 M SLR Eustatic by 2100

Results in Acres

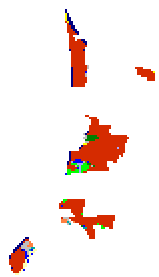
	Initial	2025	2050	2075	2100
Dry Land	209.1	195.7	194.4	192.5	190.4
Brackish Marsh	10.5	4.2	2.7	2.1	1.4
Inland Fresh Marsh	9.1	8.6	8.1	7.7	7.6
Ocean Beach	8.0	14.3	2.9	1.7	1.6
Estuarine Beach	6.4	4.4	3.4	2.5	2.2
Swamp	6.2	4.1	3.7	2.8	2.1
Inland Open Water	4.7	2.0	2.0	1.6	1.6
Open Ocean	2.0	6.5	18.9	22.0	23.4
Tidal Flat	0.0	5.1	8.2	9.6	9.3
Estuarine Open Water	0.0	4.8	8.1	11.3	14.3
Saltmarsh	0.0	3.2	3.0	1.9	1.7
Trans. Salt Marsh	0.0	3.0	0.6	0.3	0.3
Total (incl. water)	**256.0**	**256.0**	**256.0**	**256.0**	**256.0**

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

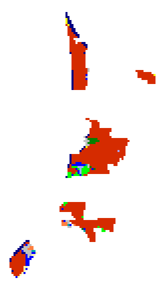
Block Island NWR, Initial Condition



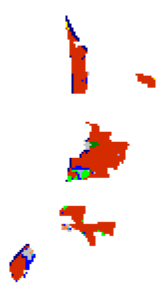
Block Island NWR, 2025, Scenario A1B Mean



Rhode Island Complex, 2050, Scenario A1B Mean



Rhode Island Complex, 2075, Scenario A1B Mean

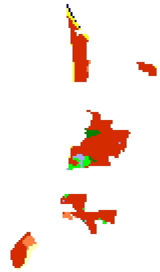


Rhode Island Complex, 2100, Scenario A1B Mean

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

Results in Acres

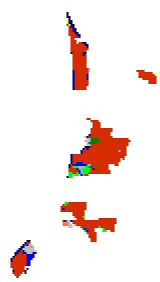
	Initial	2025	2050	2075	2100
Dry Land	209.1	195.4	193.2	190.0	186.1
Brackish Marsh	10.5	4.1	2.1	1.3	0.7
Inland Fresh Marsh	9.1	8.6	8.0	7.5	7.1
Ocean Beach	8.0	12.7	1.9	1.6	1.9
Estuarine Beach	6.4	4.7	3.2	2.5	2.5
Swamp	6.2	4.1	3.5	2.5	1.5
Inland Open Water	4.7	2.0	1.8	1.6	0.2
Open Ocean	2.0	8.4	20.9	23.9	26.5
Tidal Flat	0.0	5.1	9.7	10.3	8.0
Estuarine Open Water	0.0	4.9	9.0	12.7	19.2
Saltmarsh	0.0	3.4	2.2	1.5	1.6
Trans. Salt Marsh	0.0	2.6	0.5	0.6	0.7
Total (incl. water)	**256.0**	**256.0**	**256.0**	**256.0**	**256.0**



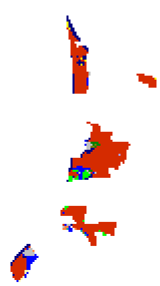
Block Island NWR, Initial Condition

Block Island NWR, 2025, Scenario A1B Maximum

Rhode Island Complex, 2050, Scenario A1B Maximum



Rhode Island Complex, 2075, Scenario A1B Maximum



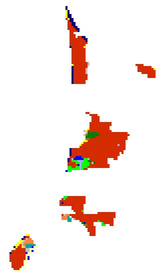
Rhode Island Complex, 2100, Scenario A1B Maximum

Block Island NWR
1 Meter Eustatic SLR by 2100

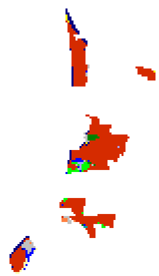
Results in Acres

	Initial	2025	2050	2075	2100
Dry Land	209.1	195.0	191.8	187.0	181.7
Brackish Marsh	10.5	3.9	1.8	0.9	0.1
Inland Fresh Marsh	9.1	8.6	7.9	7.1	6.4
Ocean Beach	8.0	11.4	1.9	1.8	0.3
Estuarine Beach	6.4	4.6	2.7	2.4	2.6
Swamp	6.2	4.0	3.3	2.1	0.9
Inland Open Water	4.7	2.0	1.6	0.2	0.2
Open Ocean	2.0	10.0	21.9	26.1	31.6
Tidal Flat	0.0	5.2	10.9	9.9	7.4
Estuarine Open Water	0.0	5.1	9.6	16.1	22.4
Saltmarsh	0.0	3.6	2.0	1.0	1.8
Trans. Salt Marsh	0.0	2.7	0.6	1.4	0.5
Total (incl. water)	**256.0**	**256.0**	**256.0**	**256.0**	**256.0**

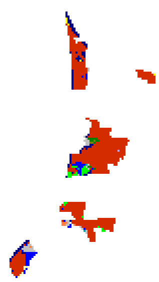
Block Island NWR, Initial Condition



Block Island NWR, 2025, 1 Meter



Rhode Island Complex, 2050, 1 Meter



Rhode Island Complex, 2075, 1 Meter

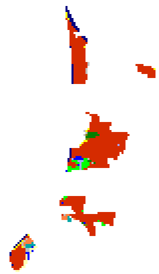
Rhode Island Complex, 2100, 1 Meter

Block Island NWR
1.5 Meters Eustatic SLR by 2100

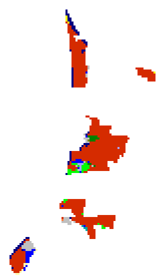
Results in Acres

	Initial	2025	2050	2075	2100
Dry Land	209.1	194.3	189.4	181.9	174.4
Brackish Marsh	10.5	3.6	1.1	0.2	0.0
Inland Fresh Marsh	9.1	8.5	7.6	5.5	2.7
Ocean Beach	8.0	10.2	1.4	0.5	0.1
Estuarine Beach	6.4	4.4	2.2	2.5	2.9
Swamp	6.2	3.9	2.7	1.2	0.5
Inland Open Water	4.7	2.0	1.6	0.2	0.2
Open Ocean	2.0	11.7	24.6	31.4	37.3
Tidal Flat	0.0	5.4	11.2	8.7	7.1
Estuarine Open Water	0.0	5.2	10.9	20.5	27.5
Saltmarsh	0.0	3.9	2.1	1.3	1.7
Trans. Salt Marsh	0.0	2.9	1.1	2.0	1.5
Total (incl. water)	**256.0**	**256.0**	**256.0**	**256.0**	**256.0**

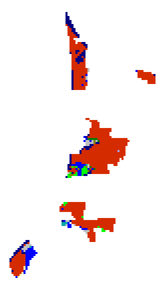
Block Island NWR, Initial Condition



Block Island NWR, 2025, 1.5 Meter



Rhode Island Complex, 2050, 1.5 Meter



Rhode Island Complex, 2075, 1.5 Meter

Rhode Island Complex, 2100, 1.5 Meter

Ninigret NWR

SLR by 2100 (m)	0.39	0.69	1	1.5
Undeveloped Dry Land	5%	8%	10%	15%
Swamp	19%	31%	37%	47%
Developed Dry Land	2%	13%	19%	28%
Brackish Marsh	37%	62%	86%	96%

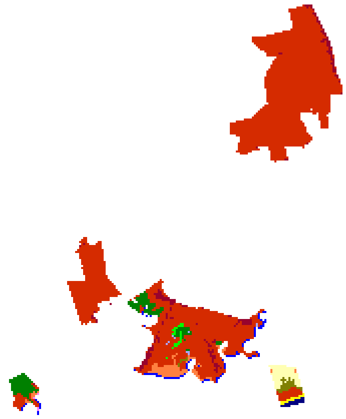
Predicted Loss Rates of Land Categories by 2100 Given Simulated Scenarios of Eustatic Sea Level Rise

Ninigret NWR is predicted to lose between 5 and 15% of undeveloped dry land, which comprises the majority of the refuge. Swamp and Brackish marsh are also at risk depending on the scenario that is utilized.

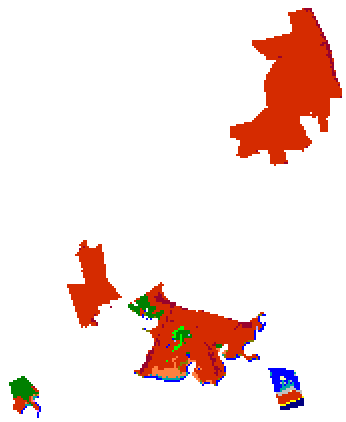
Ninigret NWR
IPCC Scenario A1B-Mean, 0.39 M SLR Eustatic by 2100

Results in Acres

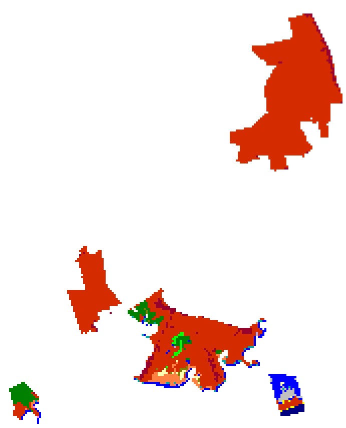
	Initial	2025	2050	2075	2100
Undeveloped Dry Land	922.7	901.9	893.4	883.7	874.0
Swamp	53.4	47.7	46.3	44.9	43.1
Developed Dry Land	46.9	46.7	46.6	46.4	46.1
Brackish Marsh	31.6	23.1	22.3	21.1	19.8
Estuarine Beach	25.4	2.0	6.7	14.5	21.6
Estuarine Open Water	22.0	47.6	55.8	68.4	74.8
Trans. Salt Marsh	11.3	26.4	12.2	9.1	8.4
Open Ocean	6.0	7.7	9.2	9.6	9.6
Inland Fresh Marsh	5.8	5.5	5.3	5.0	4.9
Ocean Beach	4.2	3.1	1.8	1.4	1.3
Inland Open Water	2.2	0.9	0.7	0.7	0.4
Rocky Intertidal	0.9	0.5	0.4	0.4	0.3
Saltmarsh	0.0	12.3	22.2	18.5	23.1
Tidal Flat	0.0	7.1	9.6	9.0	4.8
Total (incl. water)	**1132.4**	**1132.4**	**1132.4**	**1132.4**	**1132.4**



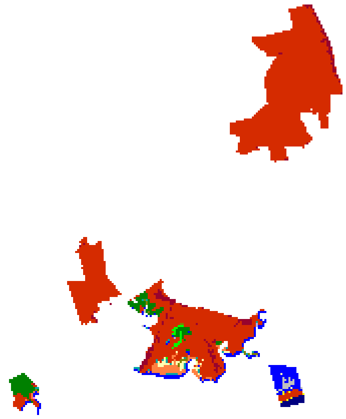
Ninigret NWR, Initial Condition



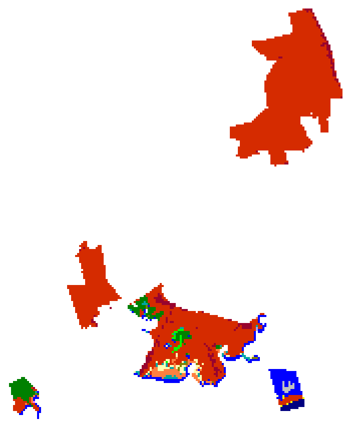
Ninigret NWR, 2025, Scenario A1B Mean



Ninigret NWR, 2050, Scenario A1B Mean



Ninigret NWR, 2075, Scenario A1B Mean

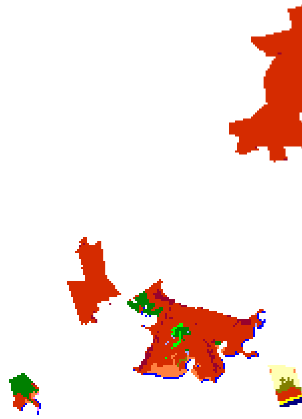


Ninigret NWR, 2100, Scenario A1B Mean

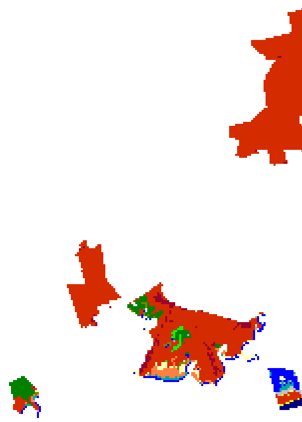
Ninigret NWR
IPCC Scenario A1B-Max, 0.69 M SLR Eustatic by 2100

Results in Acres

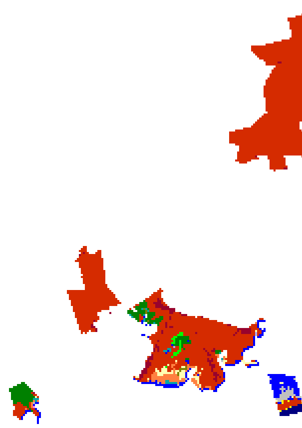
	Initial	2025	2050	2075	2100
Undeveloped Dry Land	922.7	897.9	888.6	874.8	850.7
Swamp	53.4	47.3	45.2	42.6	36.9
Developed Dry Land	46.9	46.7	46.5	45.9	40.8
Brackish Marsh	31.6	22.5	20.2	16.5	11.9
Estuarine Beach	25.4	23.5	23.7	33.6	53.0
Estuarine Open Water	22.0	48.0	63.4	75.9	87.6
Trans. Salt Marsh	11.3	9.2	4.9	4.5	8.3
Open Ocean	6.0	8.1	9.7	10.1	11.0
Inland Fresh Marsh	5.8	5.5	5.1	4.6	4.3
Ocean Beach	4.2	2.9	1.5	1.0	0.7
Inland Open Water	2.2	0.9	0.7	0.4	0.4
Rocky Intertidal	0.9	0.5	0.4	0.3	0.2
Saltmarsh	0.0	13.1	11.9	14.6	20.8
Tidal Flat	0.0	6.5	10.6	7.6	5.7
Total (incl. water)	**1132.4**	**1132.4**	**1132.4**	**1132.4**	**1132.4**



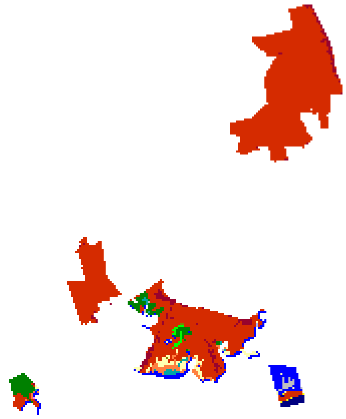
Ninigret NWR, Initial Condition



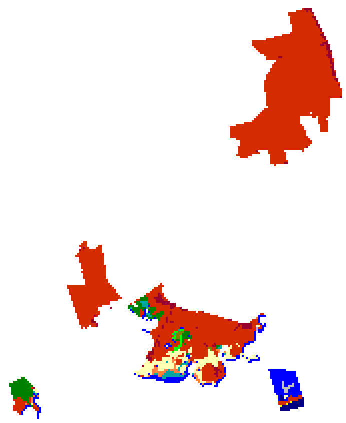
Ninigret NWR, 2025, Scenario A1B Maximum



Ninigret NWR, 2050, Scenario A1B Maximum



Ninigret NWR, 2075, Scenario A1B Maximum

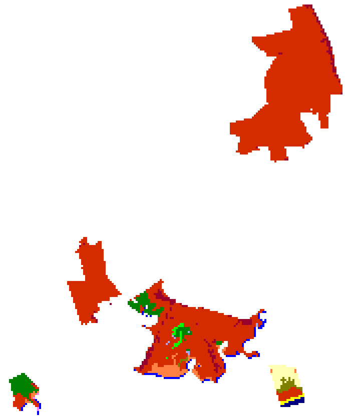


Ninigret NWR, 2100, Scenario A1B Maximum

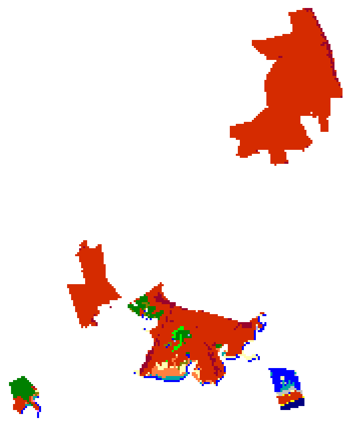
Ninigret NWR
1 Meter Eustatic SLR by 2100

Results in Acres

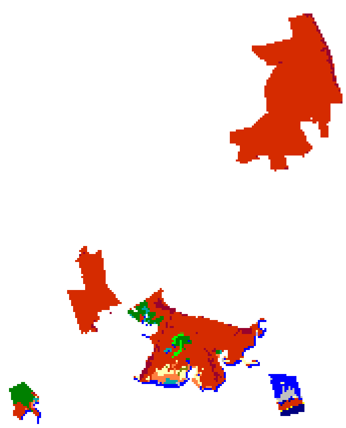
	Initial	2025	2050	2075	2100
Undeveloped Dry Land	922.7	896.0	882.8	855.8	827.0
Swamp	53.4	46.8	44.1	39.8	33.4
Developed Dry Land	46.9	46.7	46.4	41.6	38.2
Brackish Marsh	31.6	21.8	17.6	10.0	4.4
Estuarine Beach	25.4	25.2	27.7	50.1	61.7
Estuarine Open Water	22.0	48.3	66.1	85.2	112.4
Trans. Salt Marsh	11.3	9.7	4.7	8.0	10.4
Open Ocean	6.0	8.4	10.3	10.6	11.6
Inland Fresh Marsh	5.8	5.4	4.9	4.3	3.4
Ocean Beach	4.2	2.5	1.1	0.6	0.0
Inland Open Water	2.2	0.9	0.4	0.4	0.4
Rocky Intertidal	0.9	0.4	0.3	0.2	0.1
Saltmarsh	0.0	13.9	14.6	14.1	20.0
Tidal Flat	0.0	6.1	11.4	11.7	9.3
Total (incl. water)	**1132.4**	**1132.4**	**1132.4**	**1132.4**	**1132.4**



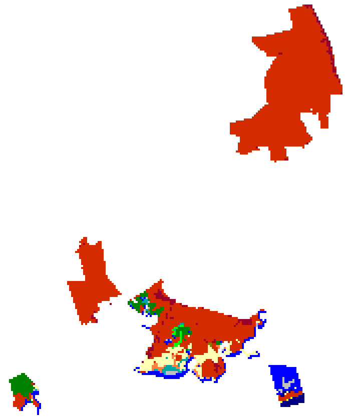
Ninigret NWR, Initial Condition



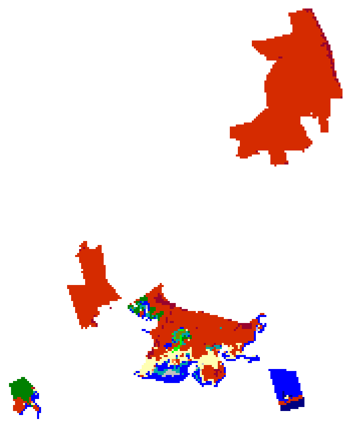
Ninigret NWR, 2025, 1 meter



Ninigret NWR, 2050, 1 meter



Ninigret NWR, 2075, 1 meter

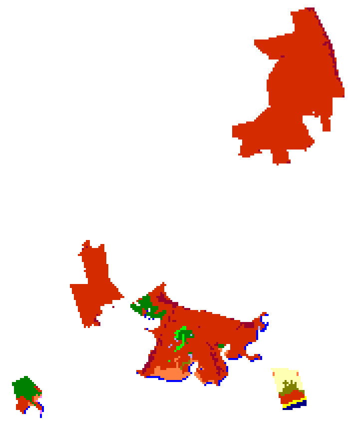


Ninigret NWR, 2100, 1 meter

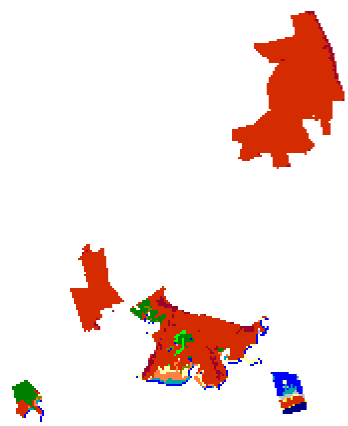
Ninigret NWR
1.5 Meters Eustatic SLR by 2100

Results in Acres

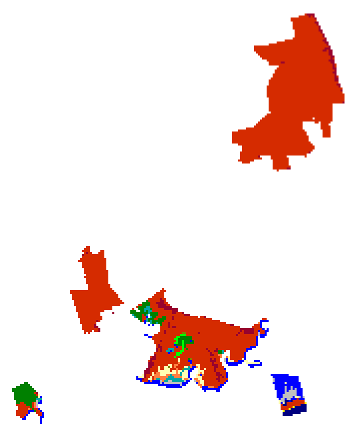
	Initial	2025	2050	2075	2100
Undeveloped Dry Land	922.7	893.4	871.6	827.4	787.5
Swamp	53.4	46.2	41.9	33.1	28.4
Developed Dry Land	46.9	46.6	45.6	38.3	33.9
Brackish Marsh	31.6	20.6	12.7	3.7	1.1
Estuarine Beach	25.4	27.7	34.8	56.9	50.7
Estuarine Open Water	22.0	49.0	70.8	114.8	175.3
Trans. Salt Marsh	11.3	10.5	6.4	17.0	13.9
Open Ocean	6.0	9.0	10.6	11.6	13.1
Inland Fresh Marsh	5.8	5.3	4.6	2.9	0.2
Ocean Beach	4.2	2.1	0.7	0.0	0.0
Inland Open Water	2.2	0.7	0.4	0.4	0.4
Rocky Intertidal	0.9	0.4	0.3	0.1	0.1
Saltmarsh	0.0	15.4	17.7	15.2	20.0
Tidal Flat	0.0	5.6	14.3	10.9	7.7
Total (incl. water)	**1132.4**	**1132.4**	**1132.4**	**1132.4**	**1132.4**



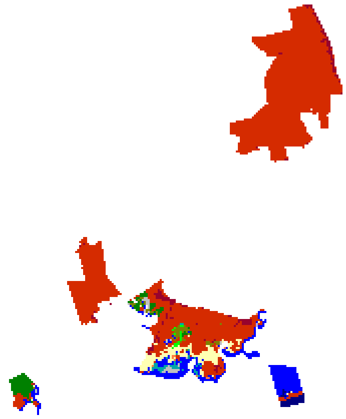
Ninigret NWR, Initial Condition



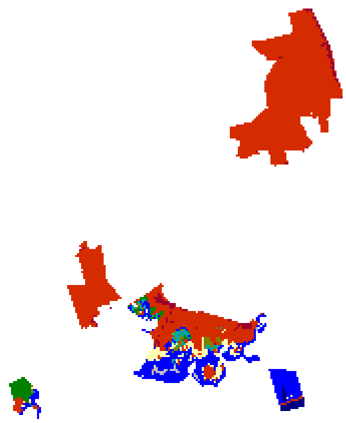
Ninigret NWR, 2025, 1.5 meter



Ninigret NWR, 2050, 1.5 meter



Ninigret NWR, 2075, 1.5 meter



Ninigret NWR, 2100, 1.5 meter

Trustom Pond NWR

SLR by 2100 (m)	0.39	0.69	1	1.5
Undeveloped Dry Land	1%	2%	2%	3%
Swamp	1%	1%	1%	2%
Developed Dry Land	0%	0%	0%	1%
Inland Fresh Marsh	2%	6%	12%	13%

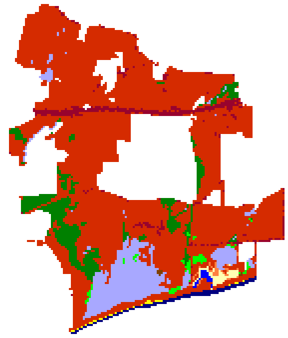
Predicted Loss Rates of Land Categories by 2100 Given Simulated Scenarios of Eustatic Sea Level Rise

Based on land elevations, Trustom Pond NWR is predicted to be more resilient than other refuges in Rhode Island with only 3% of dry land lost under even the highest predicted rates of SLR.

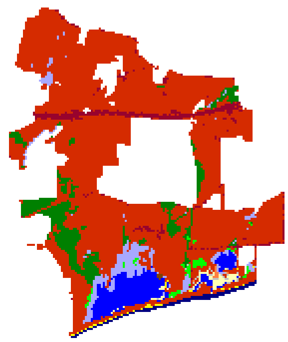
Trustom Pond NWR
IPCC Scenario A1B-Mean, 0.39 M SLR Eustatic by 2100

Results in Acres

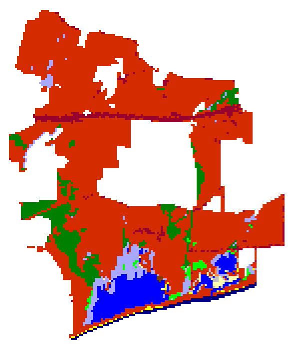
	Initial	2025	2050	2075	2100
Undeveloped Dry Land	1862.8	1850.0	1847.5	1843.8	1840.5
Swamp	196.6	196.1	195.4	194.8	194.1
Estuarine Open Water	6.9	143.6	156.2	165.2	170.8
Developed Dry Land	101.6	101.6	101.6	101.6	101.4
Inland Open Water	237.3	109.4	107.0	105.9	104.3
Open Ocean	33.4	33.4	33.8	34.4	35.9
Inland Fresh Marsh	22.2	21.8	21.8	21.8	21.8
Estuarine Beach	17.3	17.1	12.1	10.5	9.9
Tidal Flat	0.0	9.3	8.2	5.5	3.9
Ocean Beach	7.3	9.6	9.7	9.6	10.0
Trans. Salt Marsh	0.0	0.2	0.7	1.4	1.9
Inland Shore	2.2	2.2	2.2	2.2	2.2
Brackish Marsh	9.6	2.9	1.2	0.6	0.3
Saltmarsh	0.0	0.0	0.0	0.0	0.3
Total (incl. water)	**2497.3**	**2497.3**	**2497.3**	**2497.3**	**2497.3**



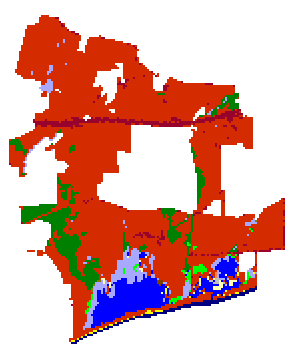
Trustom Pond NWR, Initial Condition



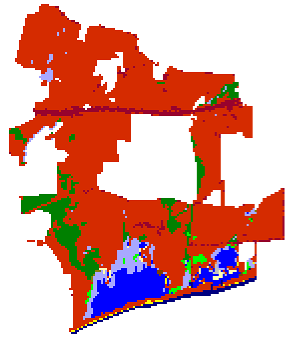
Trustom Pond NWR, 2025, Scenario A1B Mean



Trustom Pond NWR, 2050, Scenario A1B Mean



Trustom Pond NWR, 2075, Scenario A1B Mean

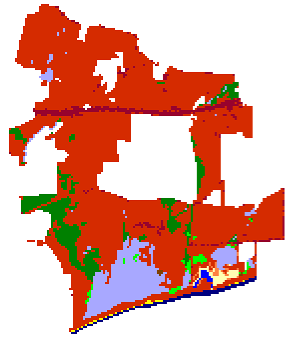


Trustom Pond NWR, 2100, Scenario A1B Mean

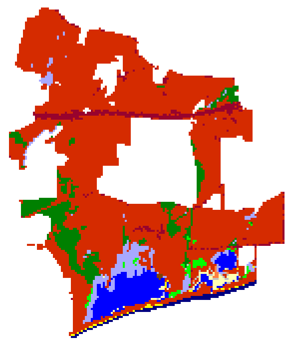
Trustom Pond NWR
IPCC Scenario A1B-Max, 0.69 M SLR Eustatic by 2100

Results in Acres

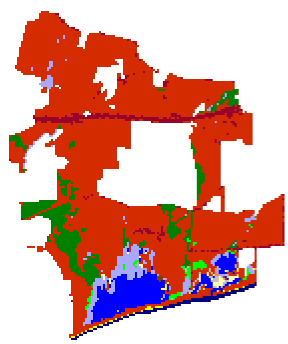
	Initial	2025	2050	2075	2100
Undeveloped Dry Land	1862.8	1849.4	1844.9	1838.7	1831.3
Swamp	196.6	196.0	195.2	194.4	195.1
Estuarine Open Water	6.9	144.2	157.5	169.3	181.2
Developed Dry Land	101.6	101.6	101.6	101.4	101.2
Inland Open Water	237.3	109.2	106.5	103.6	96.5
Open Ocean	33.4	33.5	34.3	35.7	38.8
Inland Fresh Marsh	22.2	21.8	21.8	21.5	21.0
Estuarine Beach	17.3	16.8	12.3	11.5	11.8
Tidal Flat	0.0	9.7	9.0	5.6	3.9
Ocean Beach	7.3	9.6	9.5	9.9	9.9
Trans. Salt Marsh	0.0	0.3	1.1	1.8	1.6
Inland Shore	2.2	2.2	2.2	2.1	2.0
Brackish Marsh	9.6	2.9	1.2	0.6	0.3
Saltmarsh	0.0	0.0	0.1	1.0	2.7
Total (incl. water)	**2497.3**	**2497.3**	**2497.3**	**2497.3**	**2497.3**



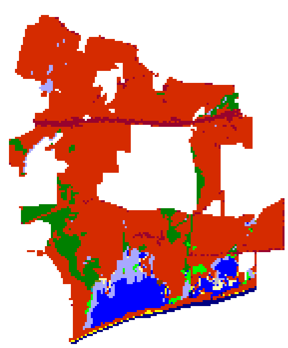
Trustom Pond NWR, Initial Condition



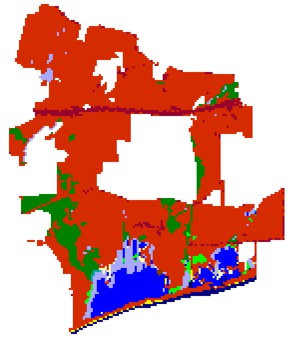
Trustom Pond NWR, 2025, Scenario A1B Maximum



Trustom Pond NWR, 2050, Scenario A1B Maximum



Trustom Pond NWR, 2075, Scenario A1B Maximum

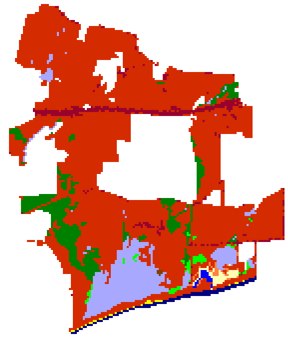


Trustom Pond NWR, 2100, Scenario A1B Maximum

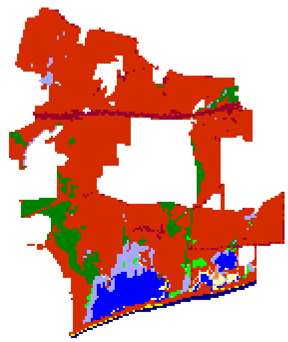
Trustom Pond NWR
1 Meter Eustatic SLR by 2100

Results in Acres

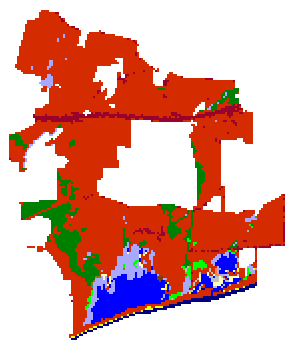
	Initial	2025	2050	2075	2100
Undeveloped Dry Land	1862.8	1848.7	1842.1	1832.3	1823.6
Swamp	196.6	195.9	194.7	195.5	194.8
Estuarine Open Water	6.9	144.6	159.5	178.3	193.5
Developed Dry Land	101.6	101.6	101.5	101.2	101.1
Inland Open Water	237.3	109.2	106.1	97.4	90.5
Open Ocean	33.4	33.6	34.9	37.3	49.9
Inland Fresh Marsh	22.2	21.8	21.4	20.5	19.5
Estuarine Beach	17.3	16.3	12.8	12.8	9.6
Tidal Flat	0.0	10.3	9.1	5.0	4.6
Ocean Beach	7.3	9.7	9.5	9.6	1.5
Trans. Salt Marsh	0.0	0.5	1.7	2.4	2.3
Inland Shore	2.2	2.2	2.2	2.1	1.8
Brackish Marsh	9.6	2.8	1.2	0.6	0.3
Saltmarsh	0.0	0.0	0.5	2.2	4.2
Total (incl. water)	**2497.3**	**2497.3**	**2497.3**	**2497.3**	**2497.3**



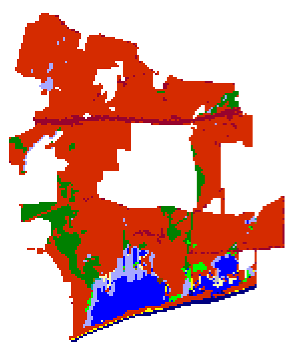
Trustom Pond NWR, Initial Condition



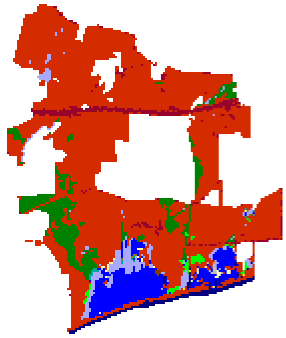
Trustom Pond NWR, 2025, 1 meter



Trustom Pond NWR, 2050, 1 meter



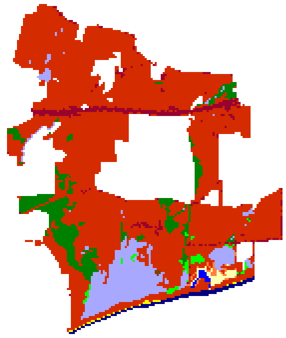
Trustom Pond NWR, 2075, 1 meter


Trustom Pond NWR, 2100, 1 meter

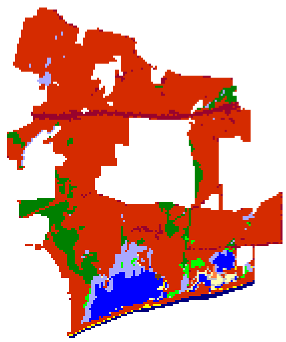
Trustom Pond NWR
1.5 Meters Eustatic SLR by 2100

Results in Acres

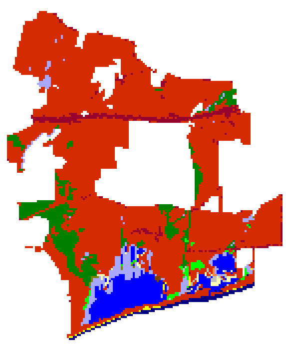
	Initial	2025	2050	2075	2100
Undeveloped Dry Land	1862.8	1847.4	1837.4	1824.2	1800.5
Swamp	196.6	195.6	194.7	194.8	192.6
Estuarine Open Water	6.9	145.3	170.3	190.7	209.8
Developed Dry Land	101.6	101.6	101.4	101.2	101.0
Inland Open Water	237.3	109.2	99.0	92.1	85.8
Open Ocean	33.4	34.0	38.2	48.6	57.1
Inland Fresh Marsh	22.2	21.6	20.6	19.4	19.3
Estuarine Beach	17.3	16.1	13.2	10.7	12.6
Tidal Flat	0.0	10.9	7.6	5.1	4.8
Ocean Beach	7.3	9.7	7.5	1.9	4.4
Trans. Salt Marsh	0.0	0.9	3.0	3.2	4.3
Inland Shore	2.2	2.2	2.1	1.9	1.4
Brackish Marsh	9.6	2.8	1.2	0.6	0.3
Saltmarsh	0.0	0.0	0.9	3.0	3.2
Total (incl. water)	**2497.3**	**2497.3**	**2497.3**	**2497.3**	**2497.3**



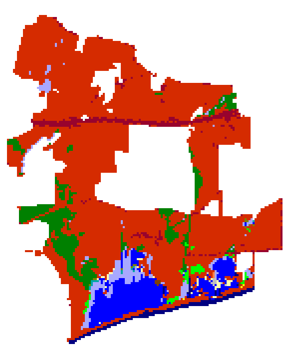
Trustom Pond NWR, Initial Condition



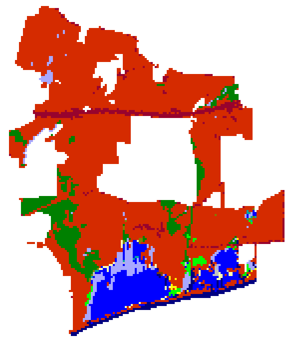
Trustom Pond NWR, 2025, 1.5 meter



Trustom Pond NWR, 2050, 1.5 meter



Trustom Pond NWR, 2075, 1.5 meter



Trustom Pond NWR, 2100, 1.5 meter

John H. Chafee NWR

SLR by 2100 (m)	0.39	0.69	1	1.5
Undeveloped Dry Land	12%	15%	17%	20%
Brackish Marsh	40%	91%	99%	99%
Swamp	-19%	-19%	-19%	-16%
Developed Dry Land	17%	19%	21%	23%

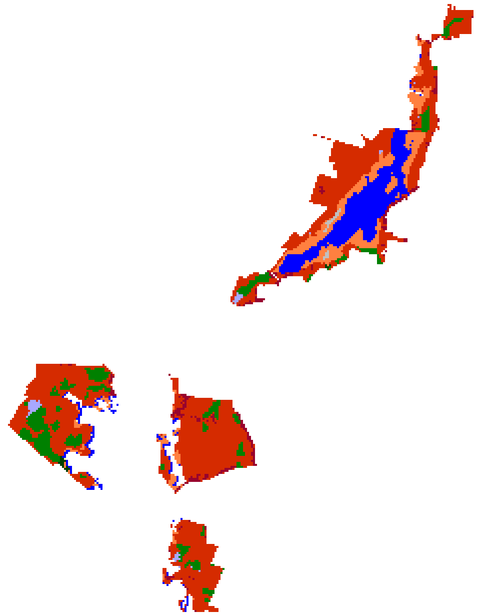
Predicted Loss Rates of Land Categories by 2100 Given Simulated Scenarios of Eustatic Sea Level Rise

Some dry land in Chafee NWR is predicted to convert to swamp land due to soil saturation. Brackish marsh is expected to be over 90% lost in all but the lowest SLR scenario.

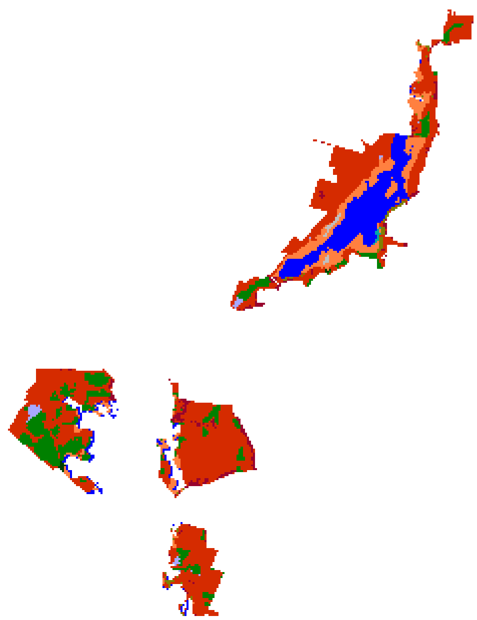
John H. Chafee NWR
IPCC Scenario A1B-Mean, 0.39 M SLR Eustatic by 2100

Results in Acres

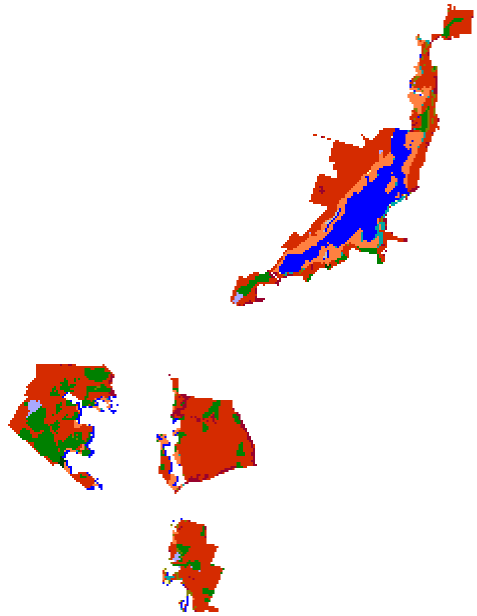
	Initial	2025	2050	2075	2100
Undeveloped Dry Land	1068.8	1013.9	990.0	963.2	941.7
Estuarine Open Water	258.9	260.4	263.2	267.0	270.8
Brackish Marsh	201.3	199.2	186.5	154.0	120.4
Swamp	181.7	223.5	222.4	220.2	216.3
Developed Dry Land	71.8	61.1	60.6	60.1	59.5
Inland Open Water	15.6	15.6	15.3	15.3	15.3
Tidal Flat	6.9	5.4	3.6	6.9	3.7
Tidal Swamp	4.7	3.5	3.5	3.3	3.3
Estuarine Beach	0.9	0.8	6.2	11.3	15.5
Trans. Salt Marsh	0.0	23.8	31.6	54.6	71.8
Saltmarsh	0.0	3.2	27.6	54.4	92.1
Total (incl. water)	**1810.5**	**1810.5**	**1810.5**	**1810.5**	**1810.5**



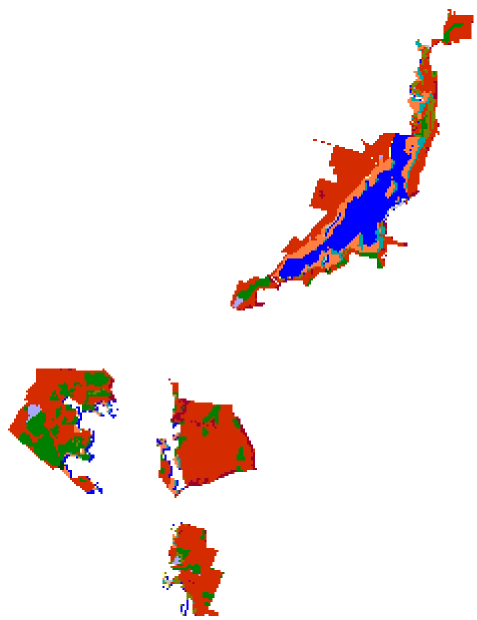
John H. Chafee NWR, Initial Condition



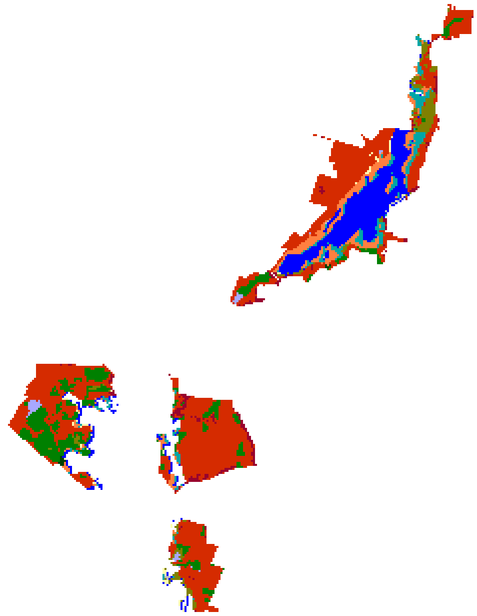
John H. Chafee NWR, 2025, Scenario A1B Mean



John H. Chafee NWR, 2050, Scenario A1B Mean



John H. Chafee NWR, 2075, Scenario A1B Mean

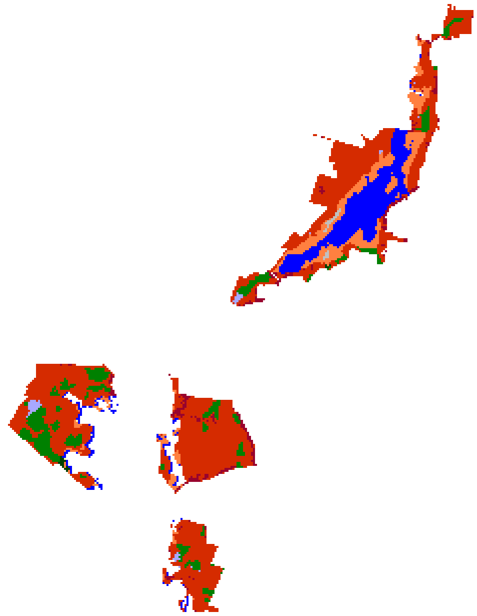


John H. Chafee NWR, 2100, Scenario A1B Mean

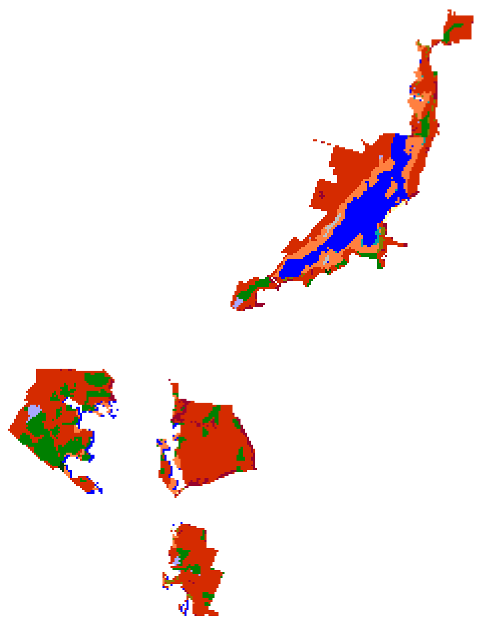
John H. Chafee NWR
IPCC Scenario A1B-Max, 0.69 M SLR Eustatic by 2100

Results in Acres

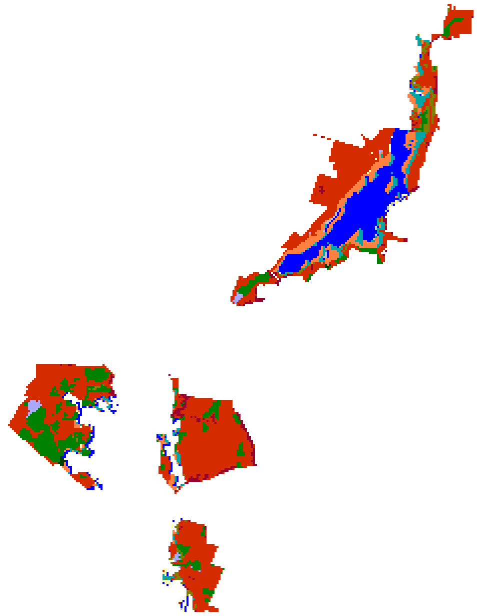
	Initial	2025	2050	2075	2100
Undeveloped Dry Land	1068.8	1007.9	971.0	935.4	912.9
Estuarine Open Water	258.9	260.5	265.5	271.4	290.4
Brackish Marsh	201.3	189.3	130.9	53.6	17.7
Swamp	181.7	223.4	220.3	214.6	216.6
Developed Dry Land	71.8	60.9	60.3	59.3	57.9
Inland Open Water	15.6	15.6	15.3	15.3	15.3
Tidal Flat	6.9	5.4	6.3	6.0	14.1
Tidal Swamp	4.7	3.5	3.4	3.2	3.0
Estuarine Beach	0.9	9.3	13.3	20.1	24.9
Trans. Salt Marsh	0.0	21.5	45.1	50.5	27.9
Saltmarsh	0.0	13.1	79.1	181.2	229.9
Total (incl. water)	**1810.5**	**1810.5**	**1810.5**	**1810.5**	**1810.5**



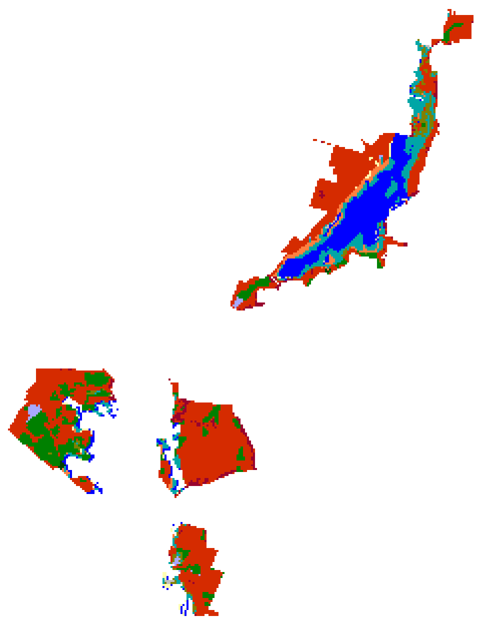
John H. Chafee NWR, Initial Condition



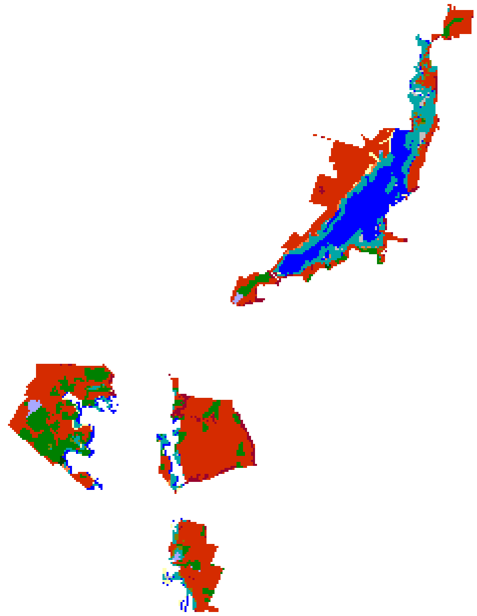
John H. Chafee NWR, 2025, Scenario A1B Maximum



John H. Chafee NWR, 2050, Scenario A1B Maximum



John H. Chafee NWR, 2075, Scenario A1B Maximum

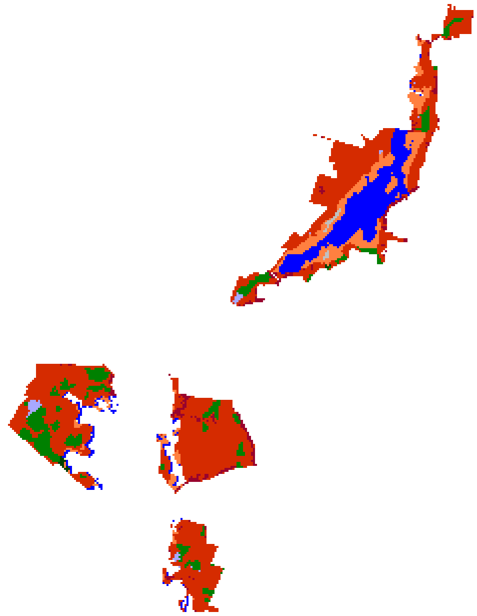


John H. Chafee NWR, 2100, Scenario A1B Maximum

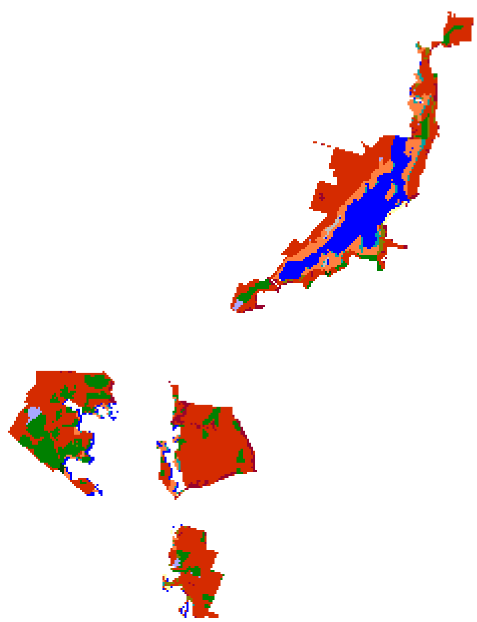
John H. Chafee NWR
1 Meter Eustatic SLR by 2100

Results in Acres

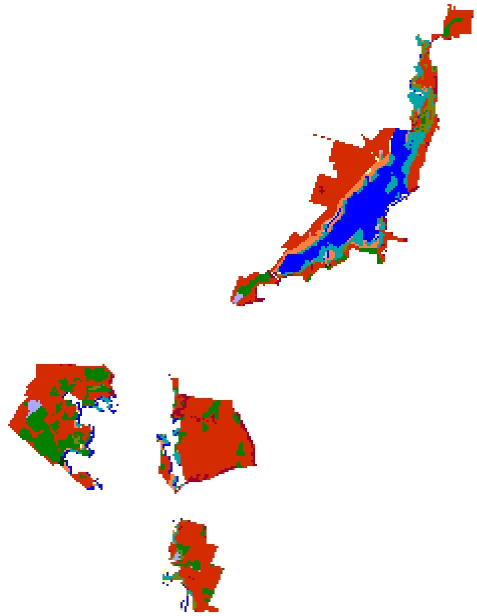
	Initial	2025	2050	2075	2100
Undeveloped Dry Land	1068.8	1001.3	953.3	917.8	882.7
Estuarine Open Water	258.9	260.6	266.6	293.3	327.6
Brackish Marsh	201.3	172.8	70.2	11.0	2.6
Swamp	181.7	222.6	217.5	215.6	216.0
Developed Dry Land	71.8	60.8	59.8	58.2	56.7
Inland Open Water	15.6	15.6	15.3	15.3	15.3
Tidal Flat	6.9	5.3	6.1	50.7	131.4
Tidal Swamp	4.7	3.5	3.3	3.0	2.7
Estuarine Beach	0.9	11.0	16.3	23.9	27.0
Trans. Salt Marsh	0.0	27.4	50.8	31.0	25.8
Saltmarsh	0.0	29.7	151.2	190.6	122.7
Total (incl. water)	**1810.5**	**1810.5**	**1810.5**	**1810.5**	**1810.5**



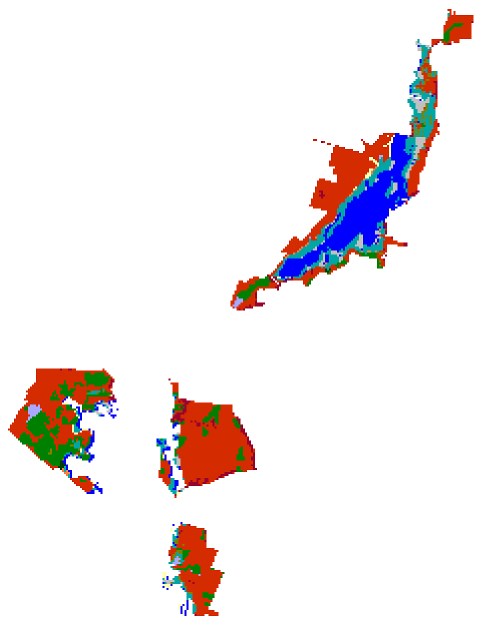
John H. Chafee NWR, Initial Condition



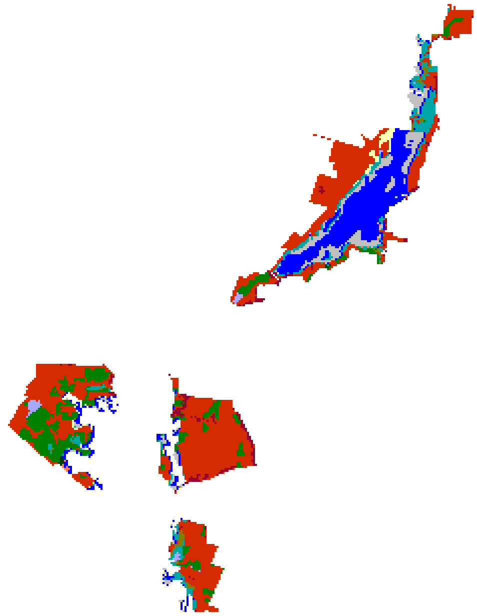
John H. Chafee NWR, 2025, 1 meter



John H. Chafee NWR, 2050, 1 meter



John H. Chafee NWR, 2075, 1 meter

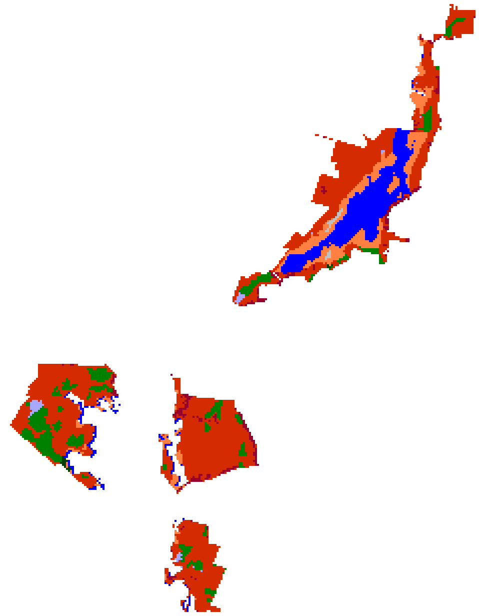


John H. Chafee NWR, 2100, 1 meter

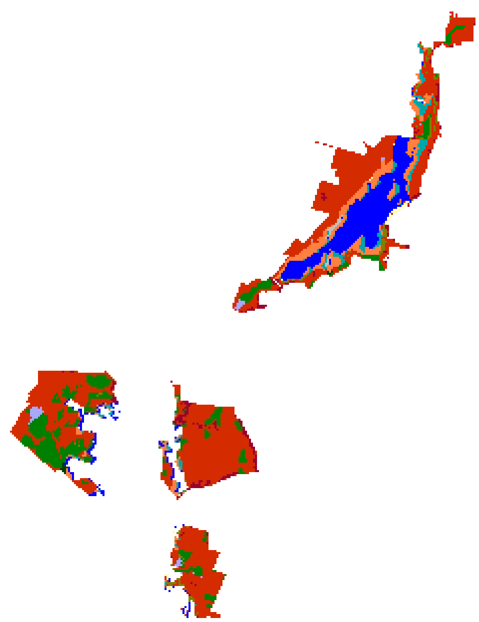
John H. Chafee NWR
1.5 Meters Eustatic SLR by 2100

Results in Acres

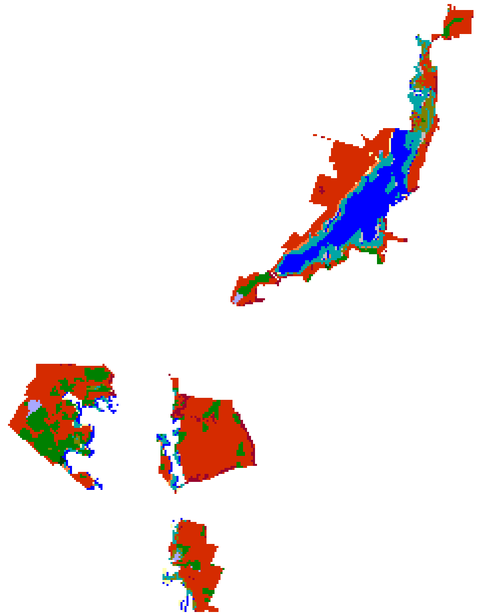
	Initial	2025	2050	2075	2100
Undeveloped Dry Land	1068.8	990.8	932.2	884.3	853.9
Estuarine Open Water	258.9	260.8	283.4	317.9	479.7
Brackish Marsh	201.3	139.1	24.5	2.3	1.8
Swamp	181.7	220.7	213.7	215.7	210.3
Developed Dry Land	71.8	60.6	59.1	56.7	55.3
Inland Open Water	15.6	15.6	15.3	15.3	15.3
Tidal Flat	6.9	5.1	16.8	148.0	97.1
Tidal Swamp	4.7	3.4	3.1	2.7	1.9
Estuarine Beach	0.9	13.5	21.1	27.3	21.7
Trans. Salt Marsh	0.0	37.5	55.1	34.6	28.0
Saltmarsh	0.0	63.4	186.1	105.6	45.5
Total (incl. water)	**1810.5**	**1810.5**	**1810.5**	**1810.5**	**1810.5**



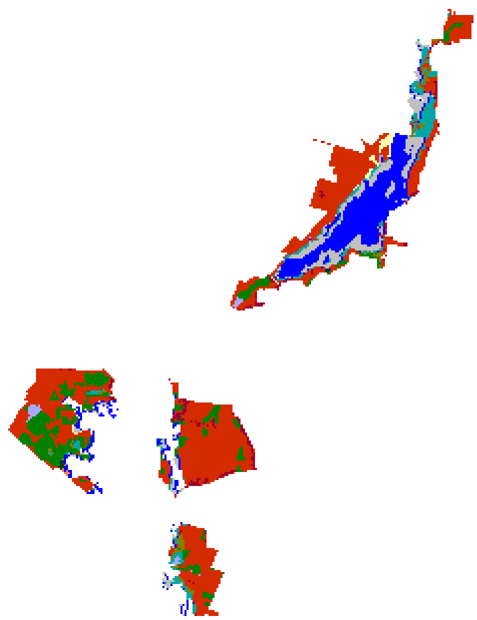
John H. Chafee NWR, Initial Condition



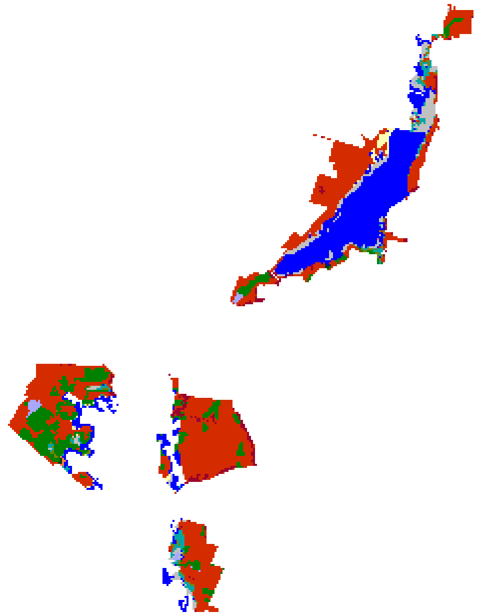
John H. Chafee NWR, 2025, 1.5 meter



John H. Chafee NWR, 2050, 1.5 meter



John H. Chafee NWR, 2075, 1.5 meter



John H. Chafee NWR, 2100, 1.5 meter

Sachuest Point NWR

SLR by 2100 (m)	**0.39**	**0.69**	**1**	**1.5**
Dry Land	3%	6%	8%	11%
Brackish Marsh	67%	90%	92%	95%
Ocean Beach	1%	3%	98%	100%
Estuarine Beach	55%	81%	77%	70%

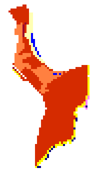
Predicted Loss Rates of Land Categories by 2100 Given Simulated Scenarios of Eustatic Sea Level Rise

Sachuest Point NWR is predicted to lose between 3% and 11% of dry land. As is the case for most of these marshes conversion or loss of brackish marsh is high under all scenarios.

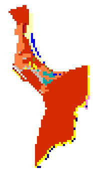
Sachuest Point NWR
IPCC Scenario A1B-Mean, 0.39 M SLR Eustatic by 2100

Results in Acres

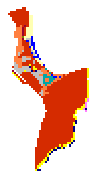
	Initial	2025	2050	2075	2100
Undeveloped Dry Land	197.5	194.7	194.1	192.7	190.8
Brackish Marsh	41.1	29.5	22.0	16.8	13.8
Ocean Beach	15.1	16.3	15.5	14.8	15.0
Estuarine Beach	12.0	10.9	8.6	6.9	5.4
Estuarine Open Water	3.8	4.4	7.7	11.2	14.7
Open Ocean	3.3	3.9	5.0	6.4	7.2
Developed Dry Land	2.0	1.8	1.8	1.7	1.6
Rocky Intertidal	1.6	1.5	1.5	1.3	1.2
Tidal Flat	0.0	7.5	14.4	17.2	18.4
Saltmarsh	0.0	4.7	5.3	6.5	7.2
Trans. Salt Marsh	0.0	1.2	0.6	0.9	1.1
Total (incl. water)	**276.4**	**276.4**	**276.4**	**276.4**	**276.4**



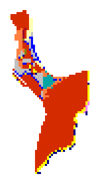
Sachuest Point NWR, Initial Condition



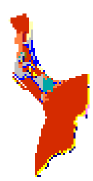
Sachuest Point NWR, 2025, Scenario A1B Mean



Sachuest Point NWR, 2050, Scenario A1B Mean



Sachuest Point NWR, 2075, Scenario A1B Mean

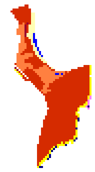


Sachuest Point NWR, 2100, Scenario A1B Mean

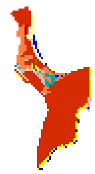
Sachuest Point NWR
IPCC Scenario A1B-Max, 0.69 M SLR Eustatic by 2100

Results in Acres

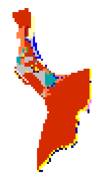
	Initial	2025	2050	2075	2100
Dry Land	197.5	194.6	193.2	189.8	186.3
Brackish Marsh	41.1	27.2	16.1	9.5	4.2
Ocean Beach	15.1	16.1	15.1	15.4	14.6
Estuarine Beach	12.0	10.2	7.4	4.2	2.2
Estuarine Open Water	3.8	4.5	8.1	14.3	22.7
Open Ocean	3.3	4.1	5.9	7.5	9.9
Developed Dry Land	2.0	1.8	1.7	1.6	1.3
Rocky Intertidal	1.6	1.5	1.4	1.2	1.2
Tidal Flat	0.0	9.2	17.9	21.6	23.2
Saltmarsh	0.0	5.8	8.9	9.7	9.9
Trans. Salt Marsh	0.0	1.3	0.8	1.5	0.9
Total (incl. water)	**276.4**	**276.4**	**276.4**	**276.4**	**276.4**



Sachuest Point NWR, Initial Condition

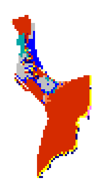


Sachuest Point NWR, 2025, Scenario A1B Maximum



Sachuest Point NWR, 2050, Scenario A1B Maximum

Sachuest Point NWR, 2075, Scenario A1B Maximum

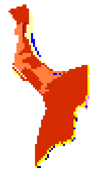


Sachuest Point NWR, 2100, Scenario A1B Maximum

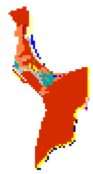
Sachuest Point NWR
1 Meter Eustatic SLR by 2100

Results in Acres

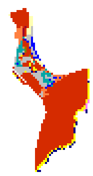
	Initial	2025	2050	2075	2100
Undeveloped Dry Land	197.5	194.4	191.9	186.8	182.1
Brackish Marsh	41.1	24.4	11.6	4.1	3.5
Ocean Beach	15.1	15.9	15.2	14.0	0.3
Estuarine Beach	12.0	9.4	6.1	2.3	2.8
Estuarine Open Water	3.8	4.5	8.5	19.9	36.4
Open Ocean	3.3	4.5	6.4	10.3	25.6
Developed Dry Land	2.0	1.8	1.7	1.4	1.2
Rocky Intertidal	1.6	1.5	1.3	1.2	1.1
Tidal Flat	0.0	10.0	21.8	26.3	20.5
Saltmarsh	0.0	8.6	10.9	8.3	1.9
Trans. Salt Marsh	0.0	1.5	1.0	1.7	1.1
Total (incl. water)	**276.4**	**276.4**	**276.4**	**276.4**	**276.4**



Sachuest Point NWR, Initial Condition

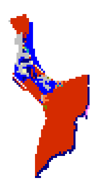


Sachuest Point NWR, 2025, 1 meter



Sachuest Point NWR, 2050, 1 meter

Sachuest Point NWR, 2075, 1 meter

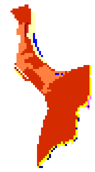


Sachuest Point NWR, 2100, 1 meter

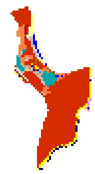
Sachuest Point NWR
1.5 Meters Eustatic SLR by 2100

Results in Acres

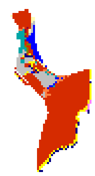
	Initial	2025	2050	2075	2100
Undeveloped Dry Land	197.5	194.0	189.1	182.5	176.3
Brackish Marsh	41.1	20.1	5.7	3.3	2.2
Ocean Beach	15.1	15.4	12.3	0.3	0.0
Estuarine Beach	12.0	8.3	3.4	3.2	3.6
Estuarine Open Water	3.8	4.6	14.4	35.4	56.1
Open Ocean	3.3	5.1	11.0	25.5	29.3
Developed Dry Land	2.0	1.8	1.6	1.2	1.1
Rocky Intertidal	1.6	1.5	1.2	1.1	0.9
Tidal Flat	0.0	11.3	24.7	20.3	3.5
Saltmarsh	0.0	12.6	11.1	2.3	2.0
Trans. Salt Marsh	0.0	1.7	1.9	1.4	1.4
Total (incl. water)	**276.4**	**276.4**	**276.4**	**276.4**	**276.4**



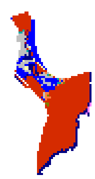
Sachuest Point NWR, Initial Condition



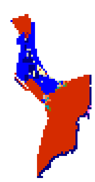
Sachuest Point NWR, 2025, 1.5 meter



Sachuest Point NWR, 2050, 1.5 meter



Sachuest Point NWR, 2075, 1.5 meter



Sachuest Point NWR, 2100, 1.5 meter

Discussion:

Model results for Rhode Island Complex indicate that it is somewhat vulnerable to the effects of sea level rise under all scenarios. The majority of brackish marsh is predicted to be lost in all scenarios above 0.39 meters. Because of increased frequency of inundation, most of this lost brackish marsh converts to salt marsh resulting in a large gain in refuge salt marsh. Under the highest scenarios run, areas initially covered by brackish marsh are completely lost to open water.

Dry land loss rates are variable among these refuges, ranging from 1% to 20% depending on the refuge and the SLR scenario run. This is a function of initial dry land elevations and the tidal ranges at each site along with projected scenarios of sea level rise.

Model results are based on high-quality LiDAR elevation data for three of the four complex sub-sites (Block Island, East, and South). This reduces uncertainty in model results in these particular zones. The rest of the complex, the Central sub-site in particular, is subject to significant uncertainty as cell elevations are based on the National Elevation Data set, derived from ten foot contours. This sub-site includes John H. Chafee National Wildlife Refuge which has the highest predicted rate of dry land lost.

The SLAMM model does account for the local effects of isostatic rebound by taking into account the historical sea level rise for each site. The historical rate of land movement is predicted to continue through the year 2100 (i.e. the rate of isostatic rebound is assumed to remain constant).

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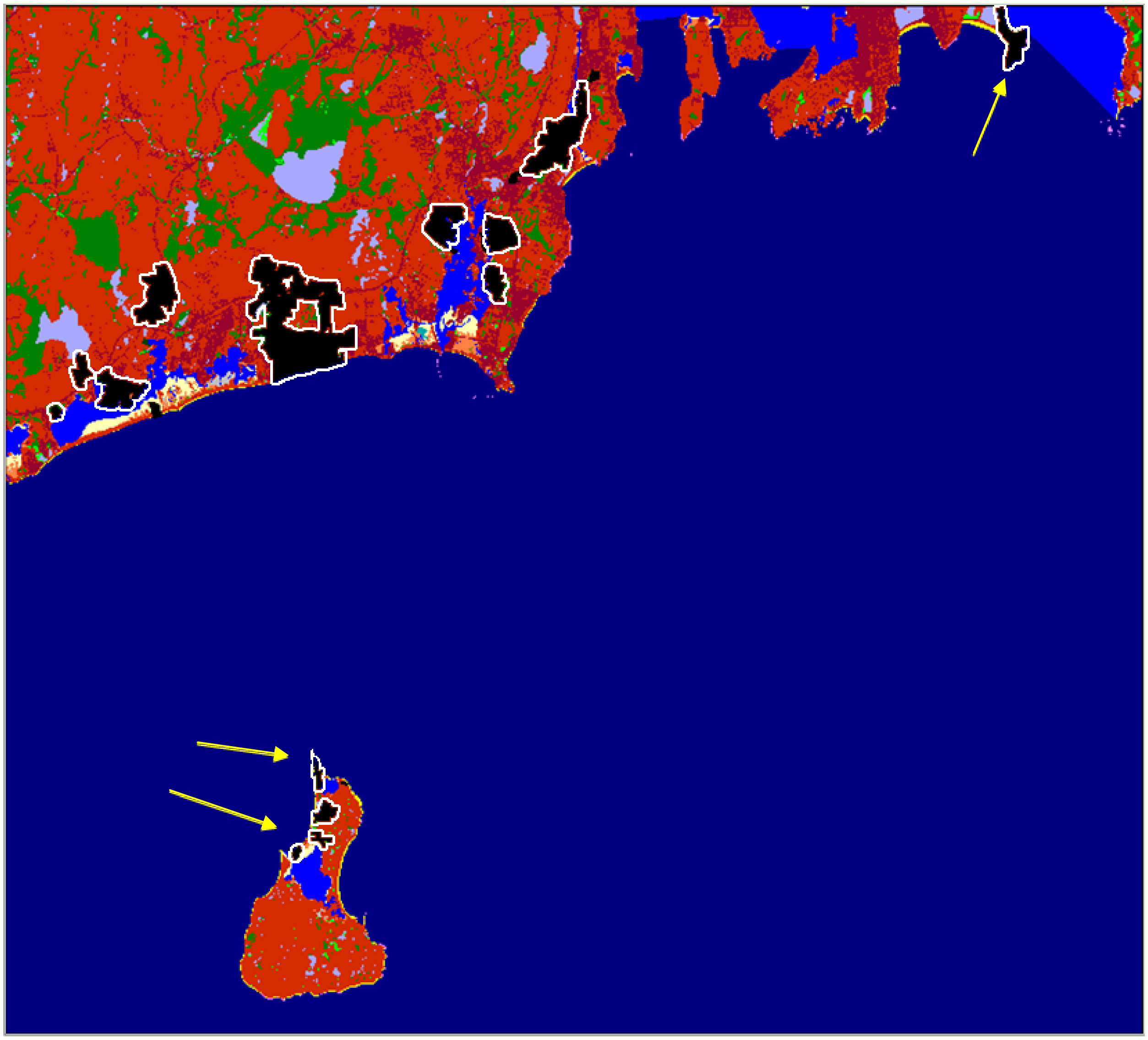
Appendix A: Contextual Results

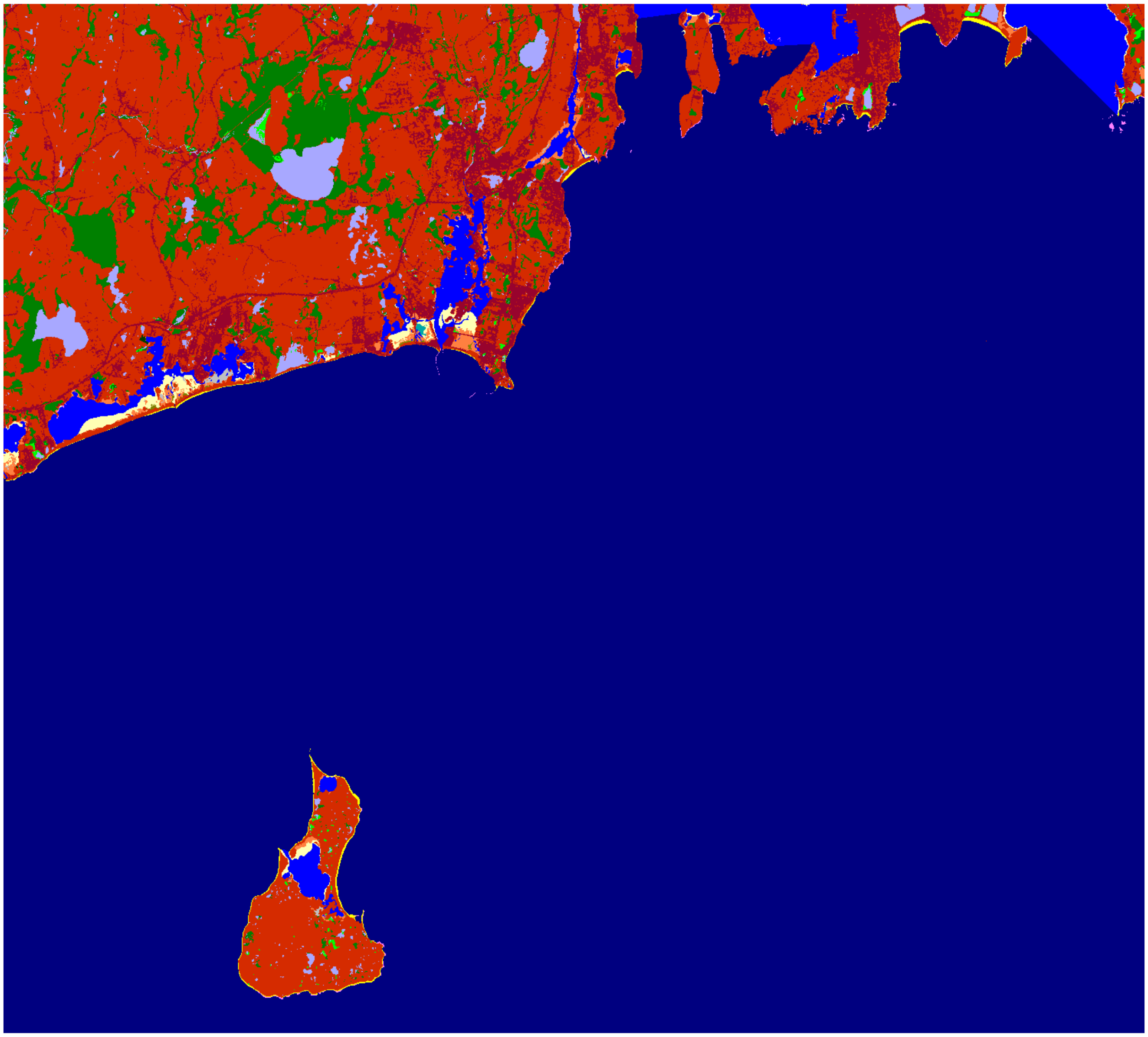
The SLAMM model does take into account the context of the surrounding lands or open water when calculating effects. For example, erosion rates are calculated based on the maximum fetch (wave action) which is estimated by assessing contiguous open water to a given marsh cell. Another example is that inundated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

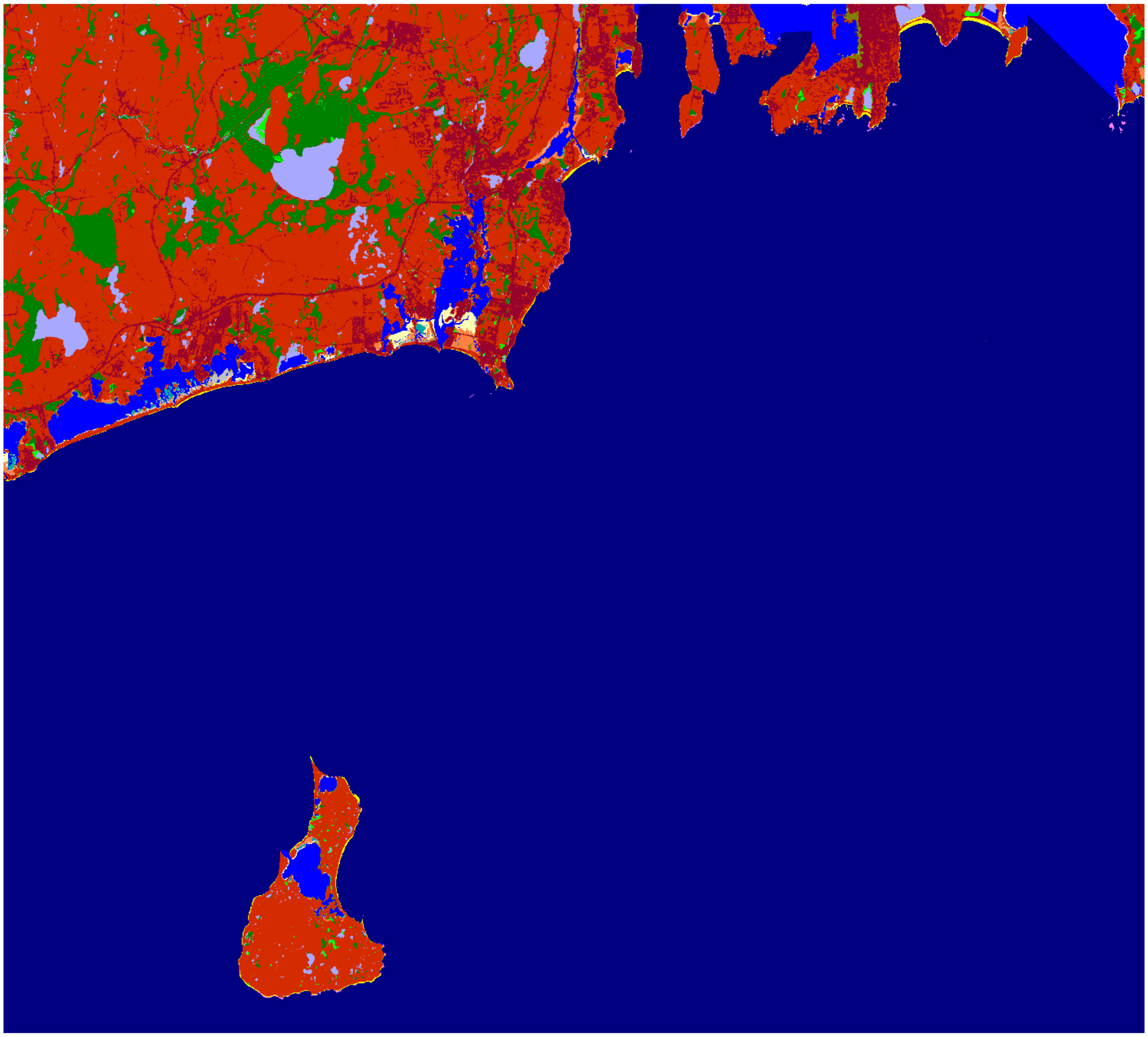
- Results were closely examined (quality assurance) within USFWS refuges but not closely examined for the larger region.
- Site-specific parameters for the model were derived for USFWS refuges whenever possible and may not be regionally applicable.
- Especially in areas where dikes are present, an effort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



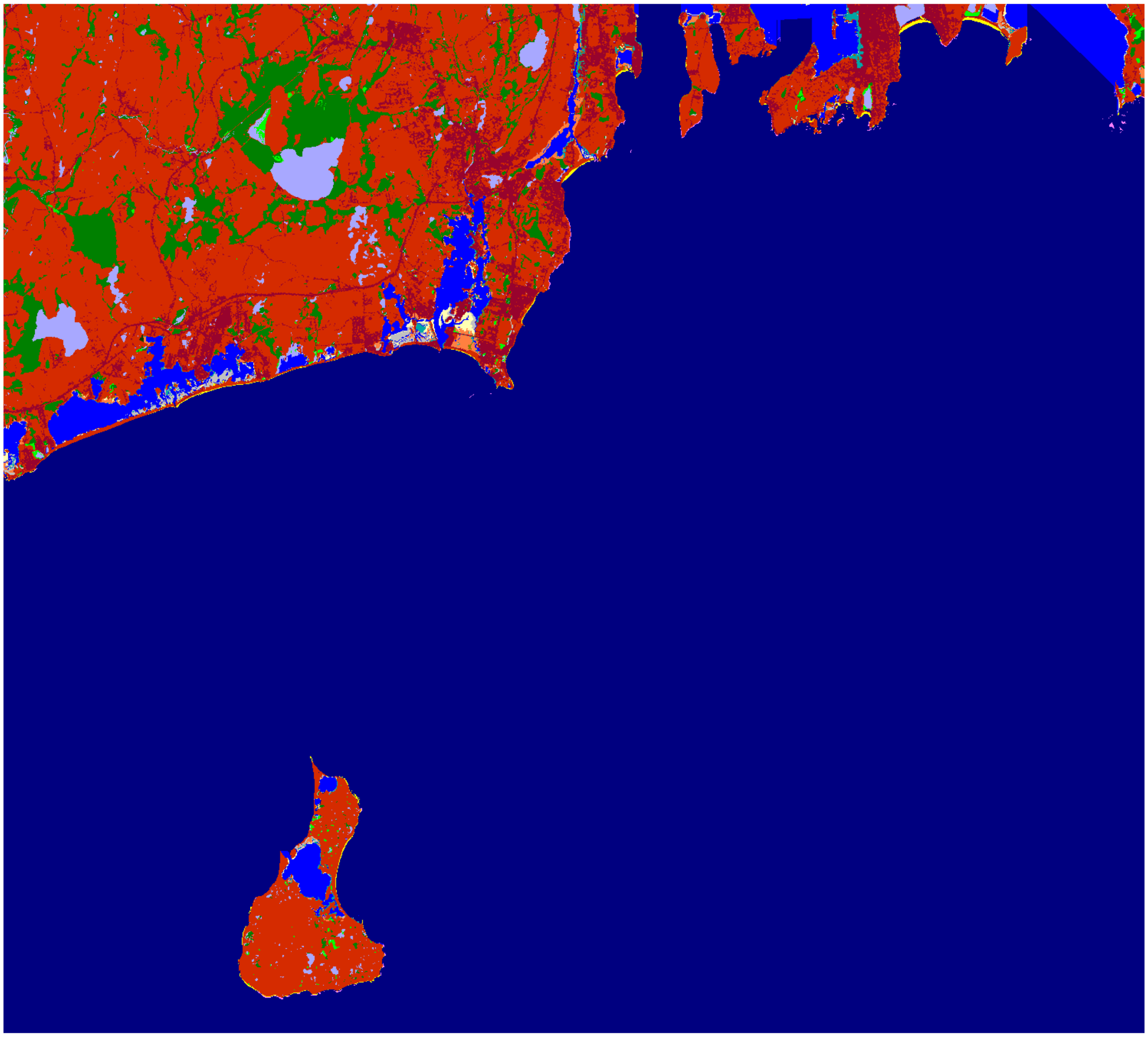
Location of Rhode Island Complex National Wildlife Refuge (black) within simulation context.



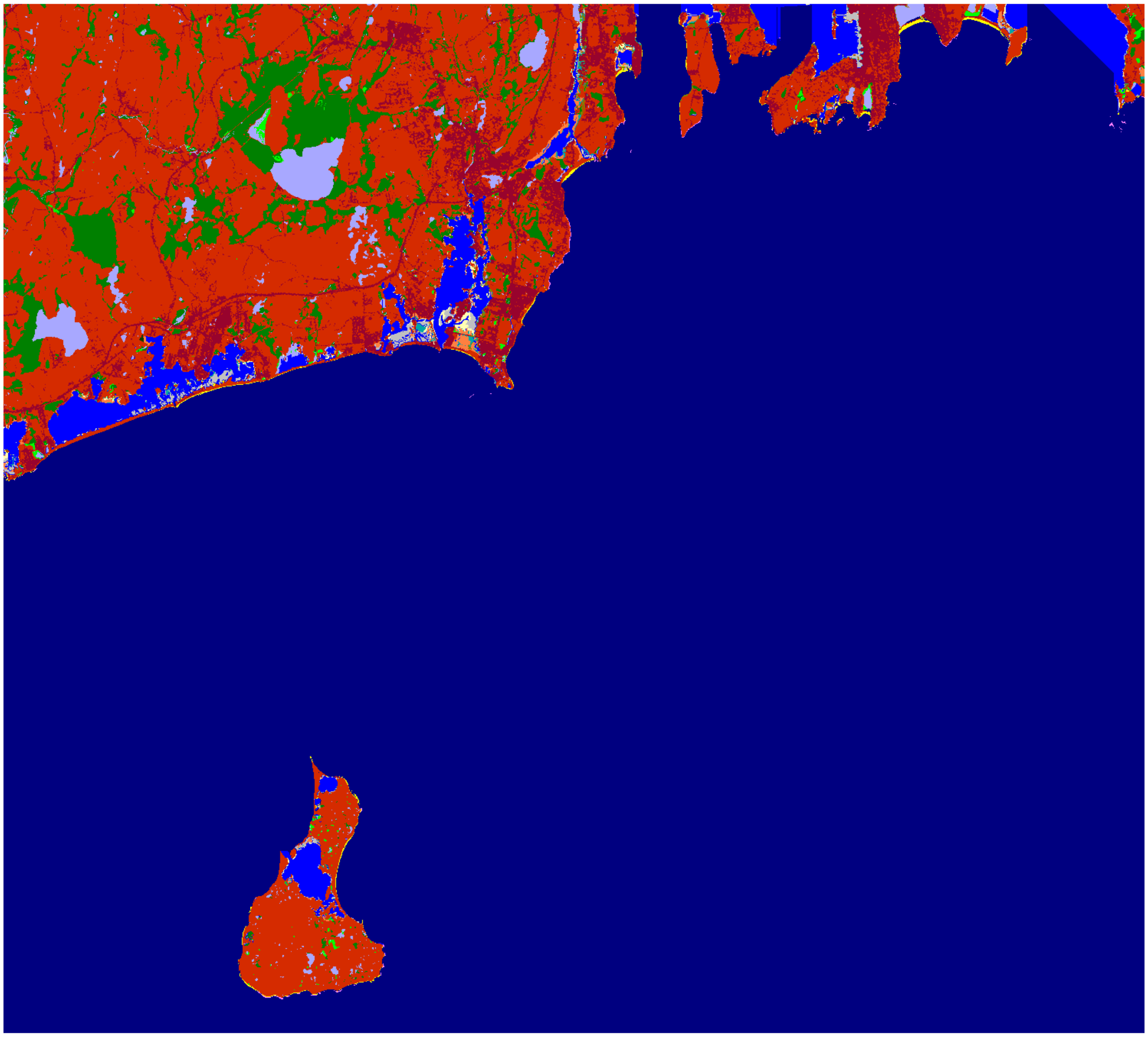
Rhode Island Complex Context, Initial Condition



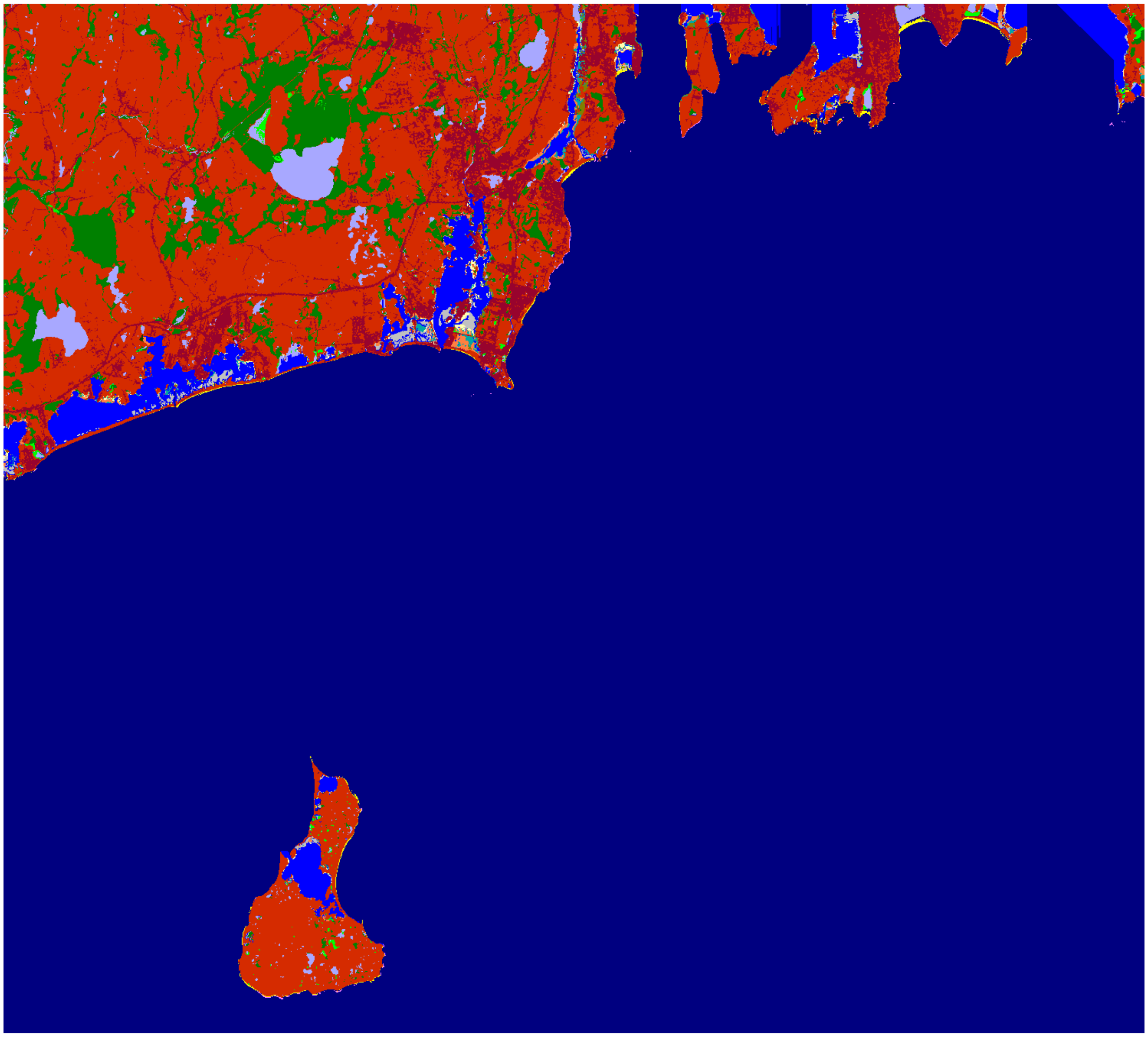
Rhode Island Complex Context, 2025, Scenario A1B Mean



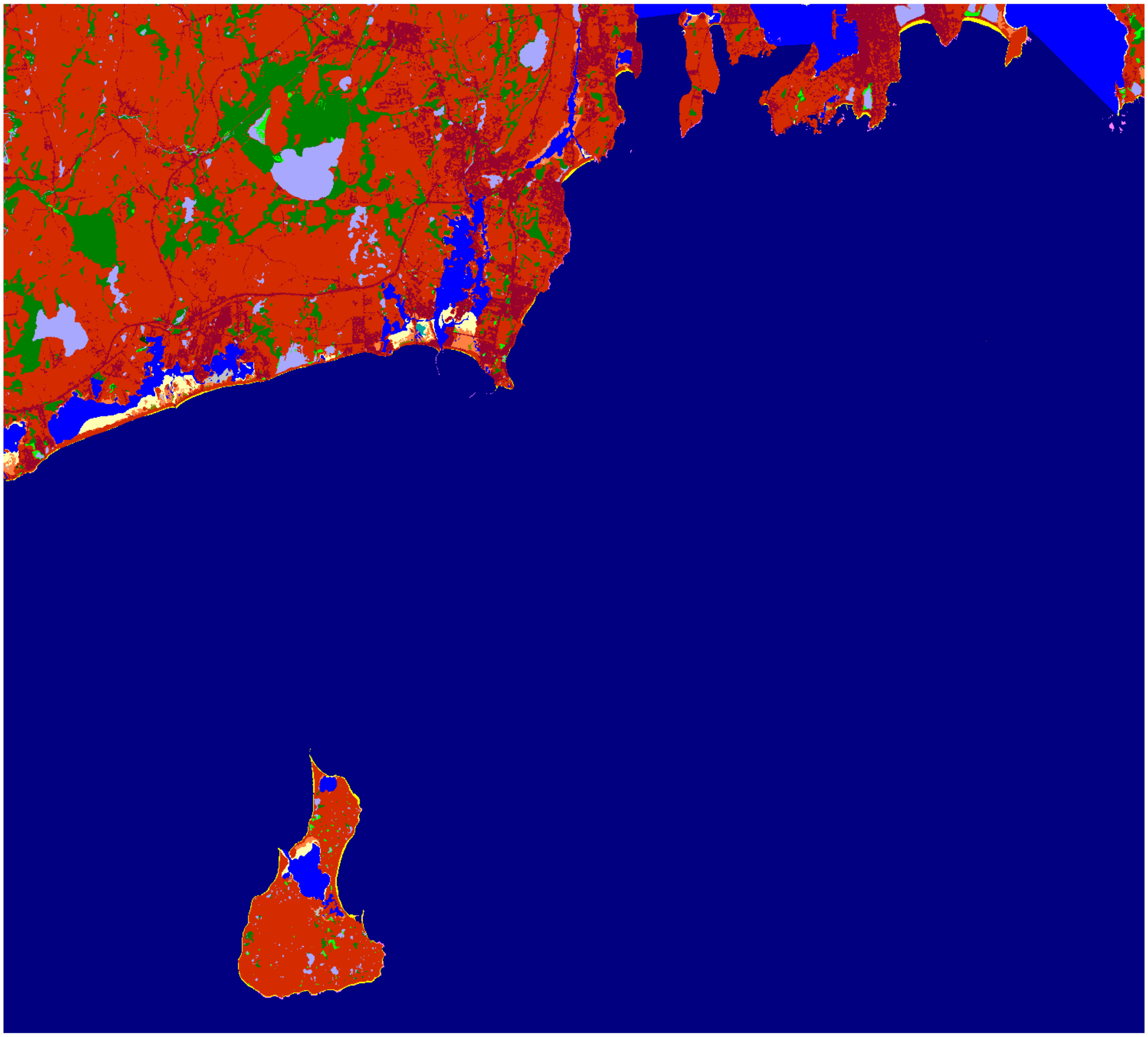
Rhode Island Complex Context, 2050, Scenario A1B Mean



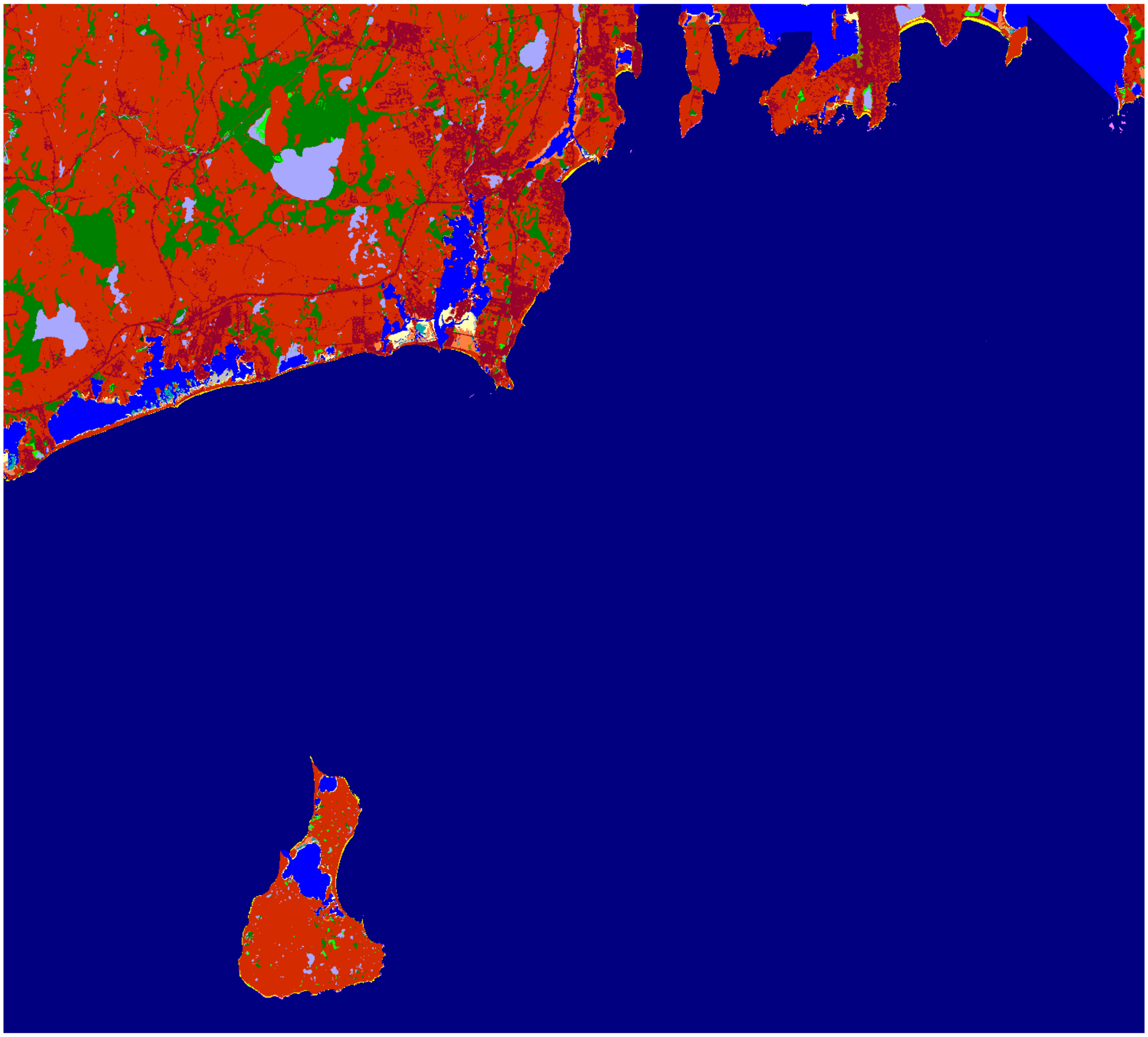
Rhode Island Complex Context, 2075, Scenario A1B Mean



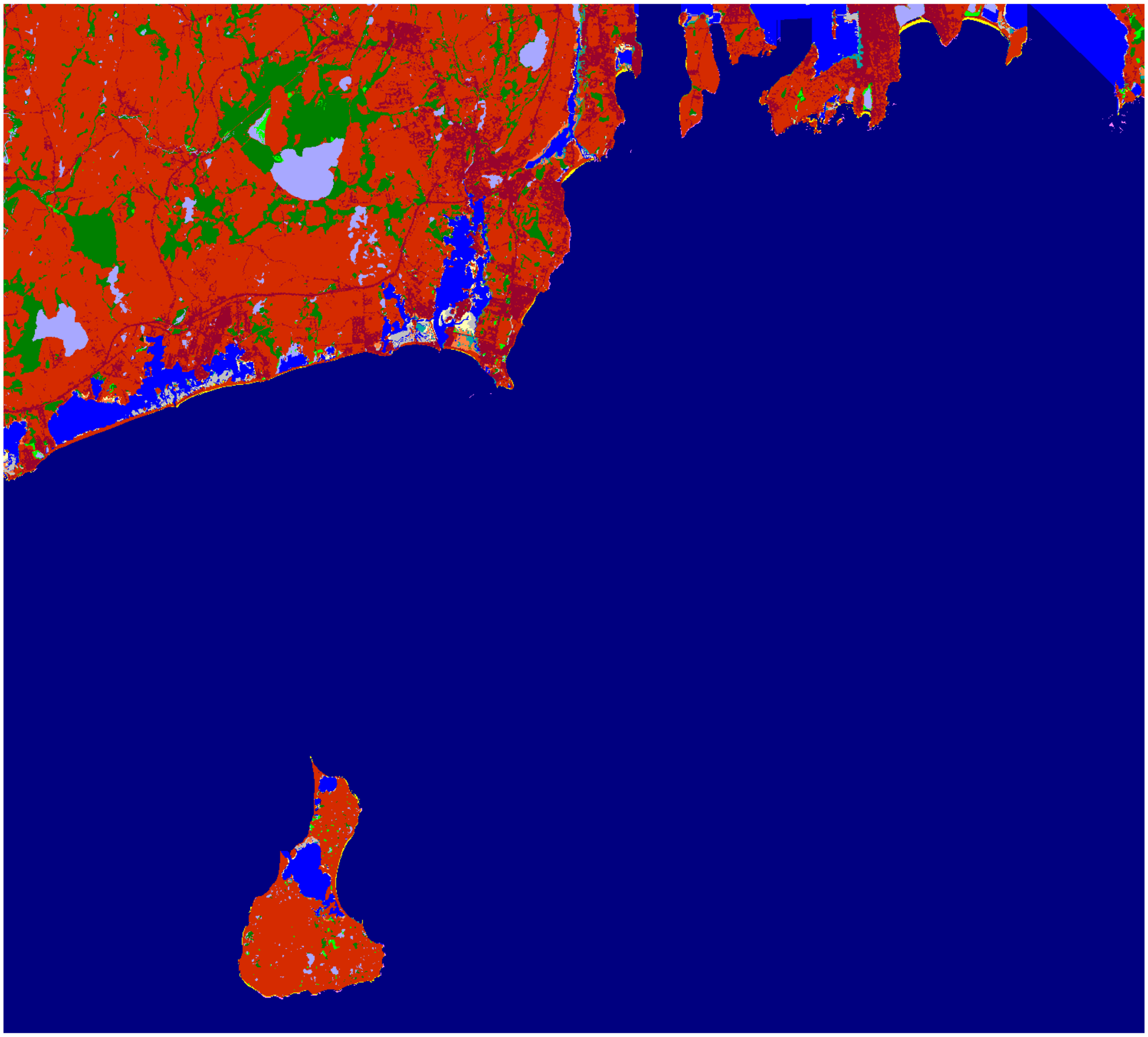
Rhode Island Complex Context, 2100, Scenario A1B Mean



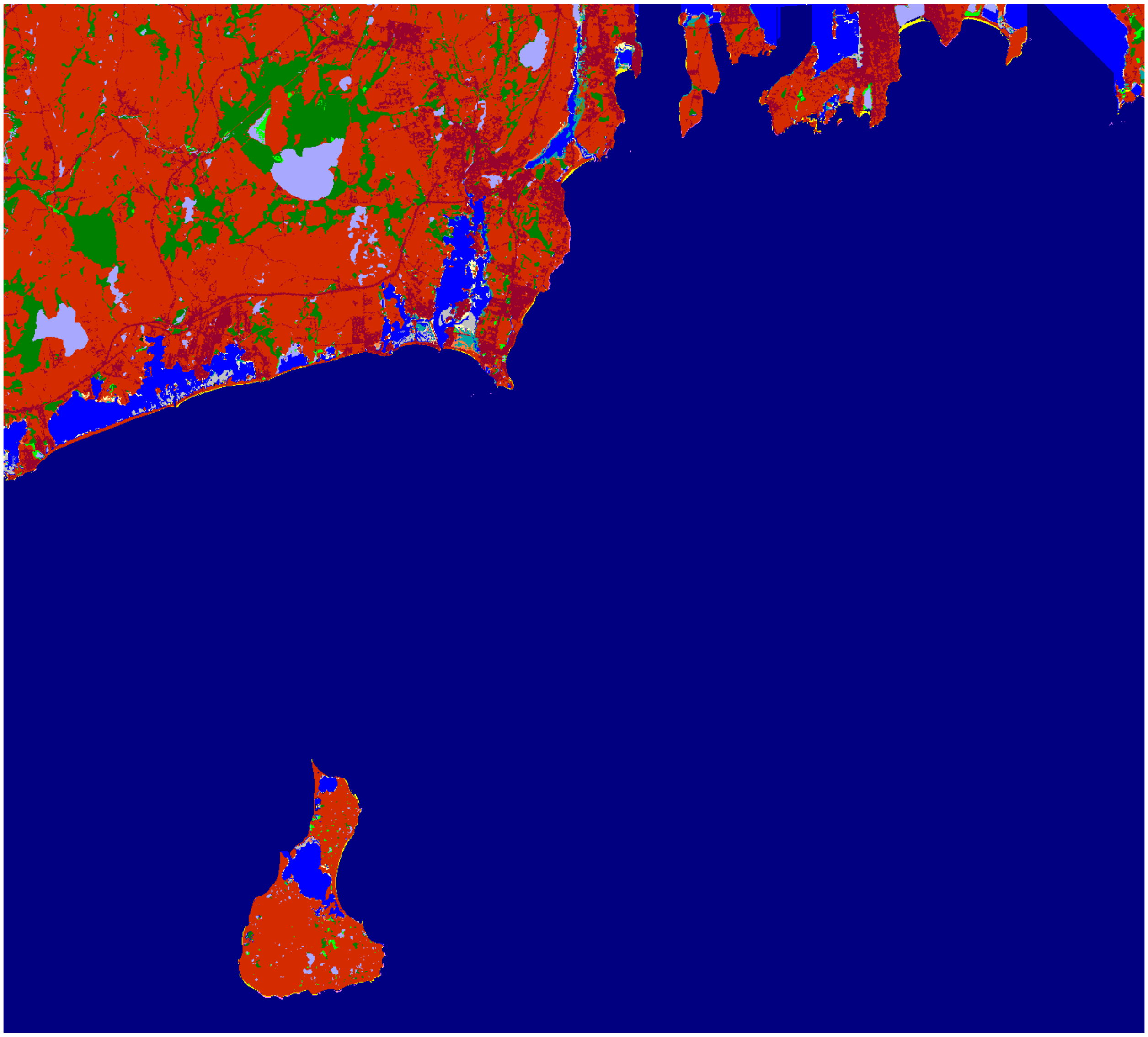
Rhode Island Complex Context, Initial Condition



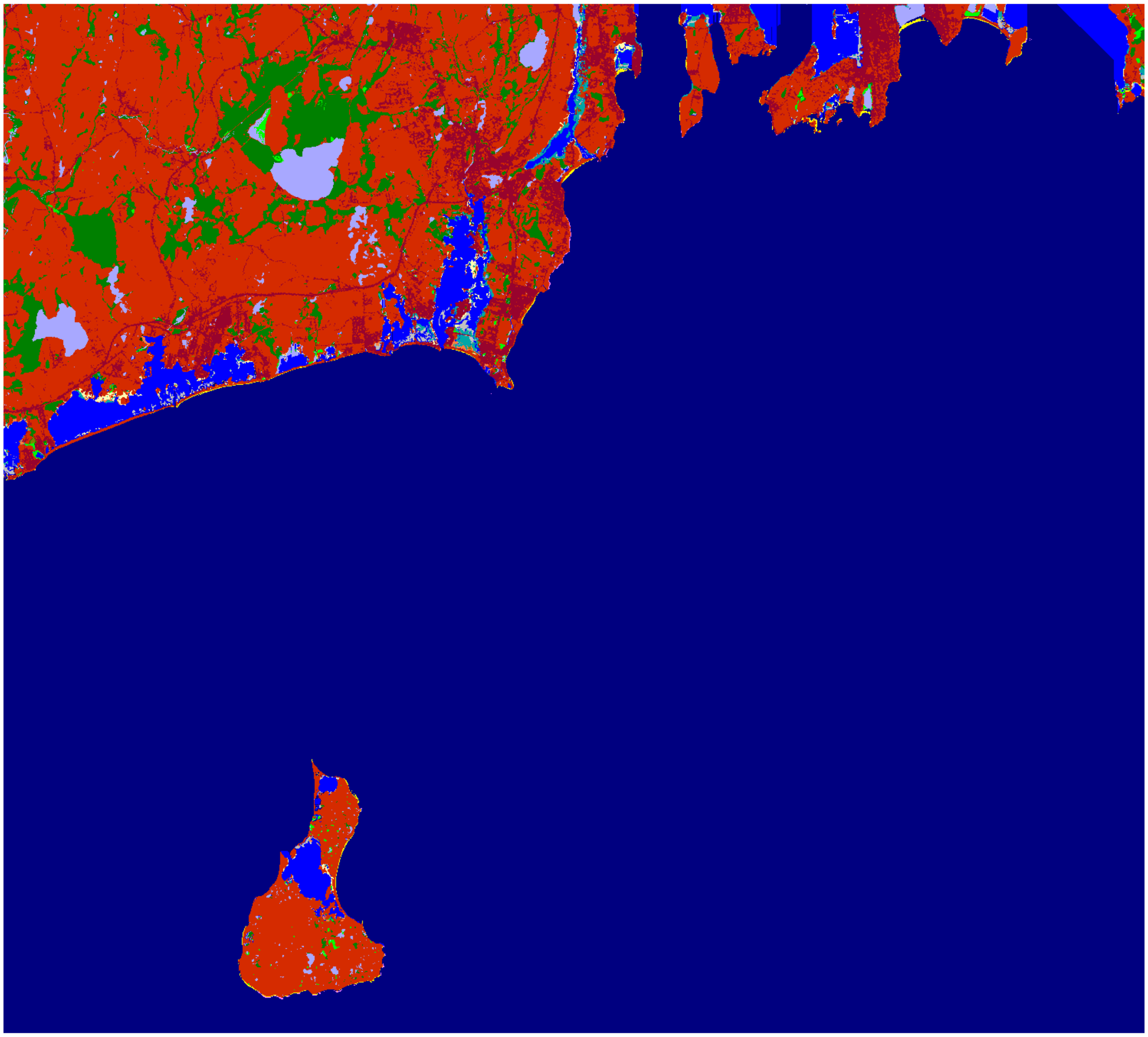
Rhode Island Complex Context, 2025, Scenario A1B Maximum



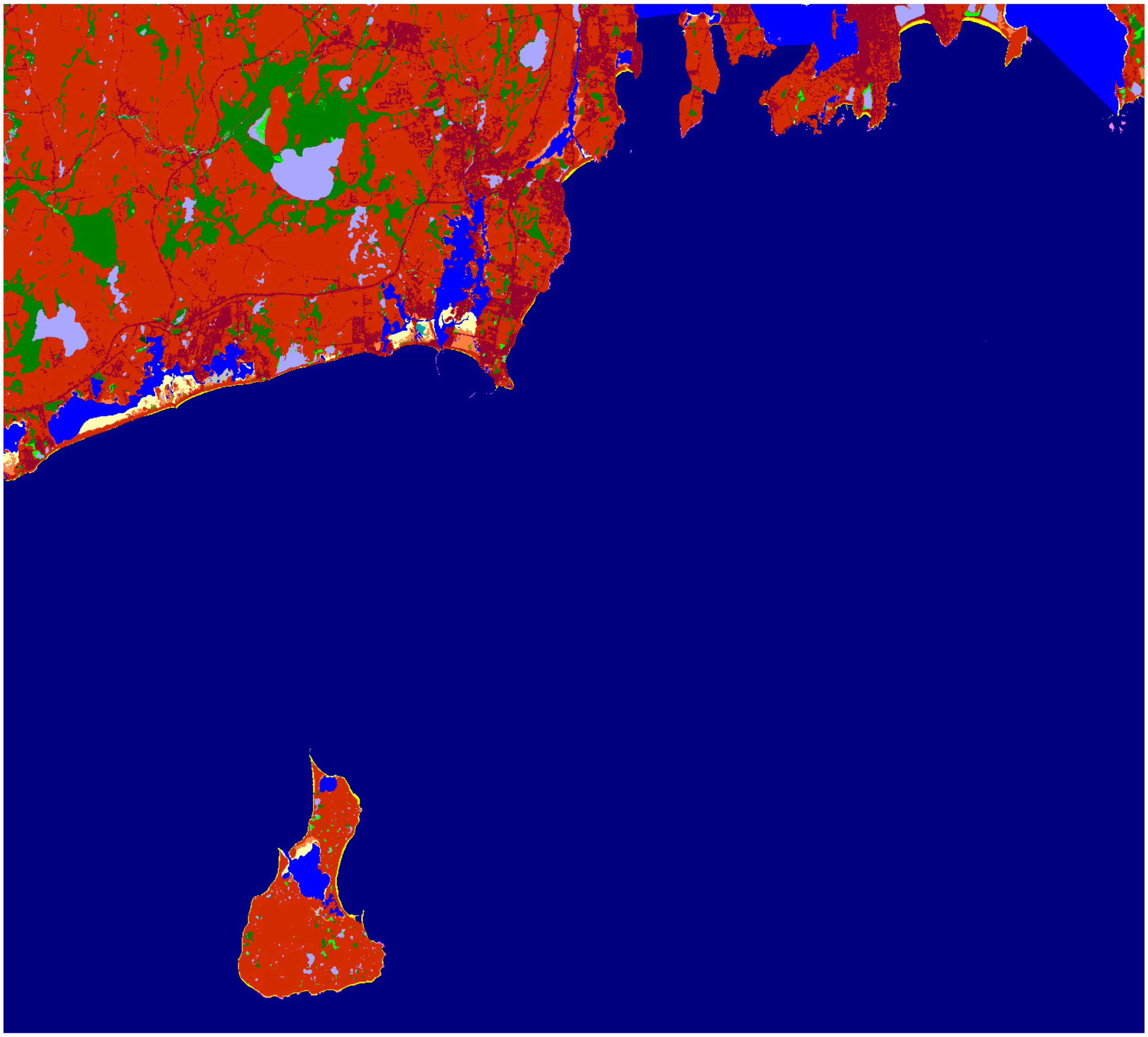
Rhode Island Complex Context, 2050, Scenario A1B Maximum



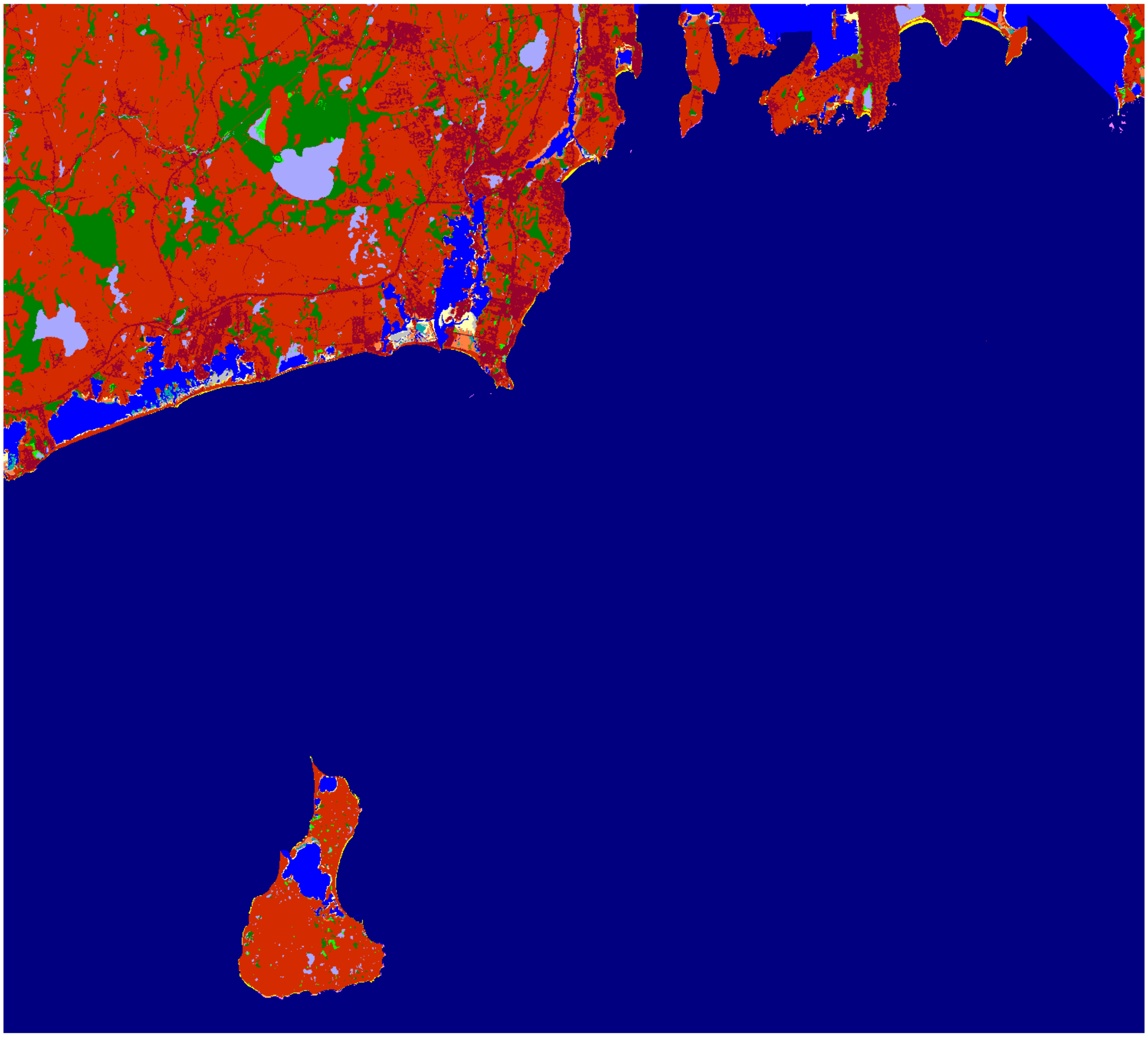
Rhode Island Complex Context, 2075, Scenario A1B Maximum



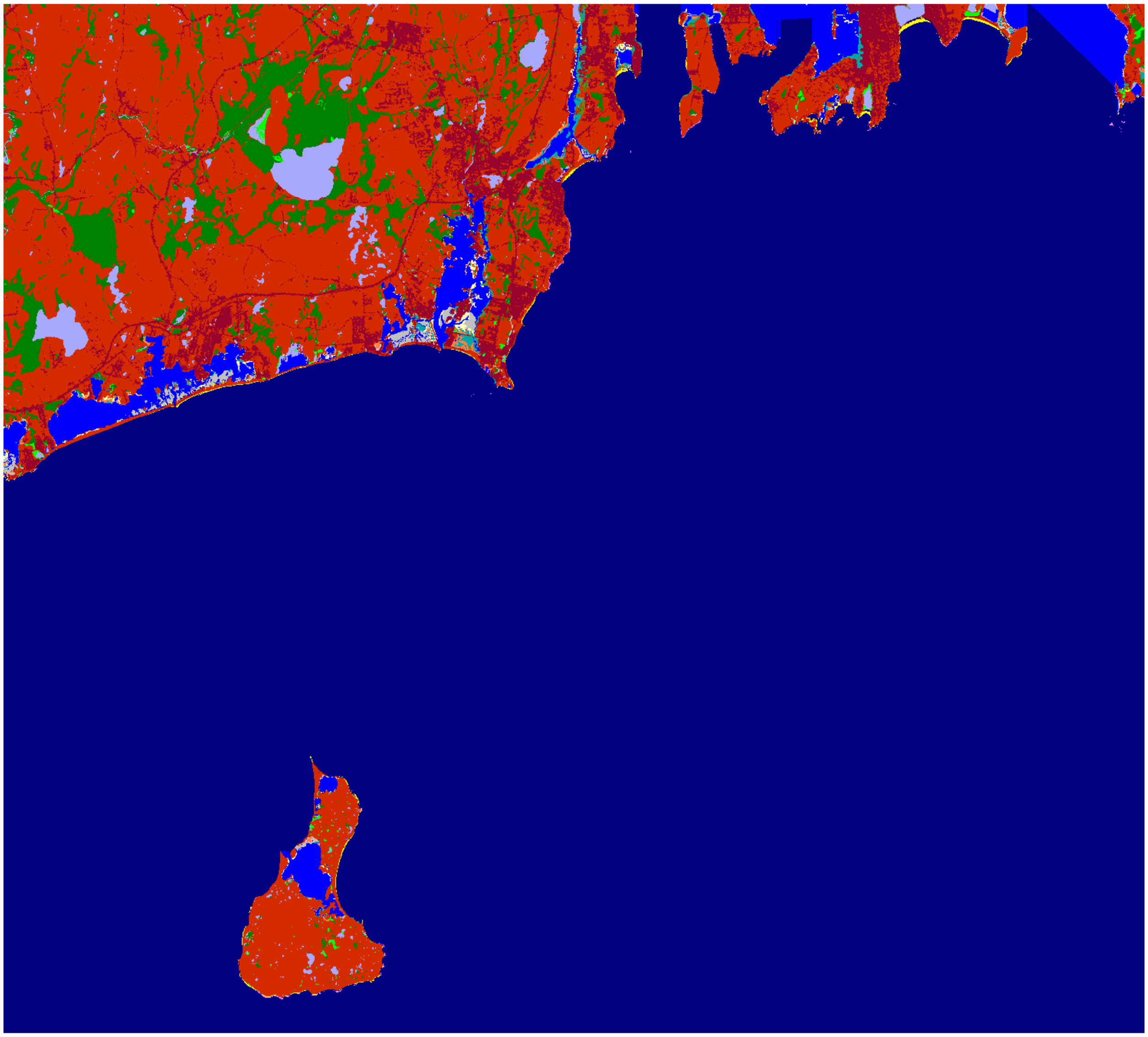
Rhode Island Complex Context, 2100, Scenario A1B Maximum



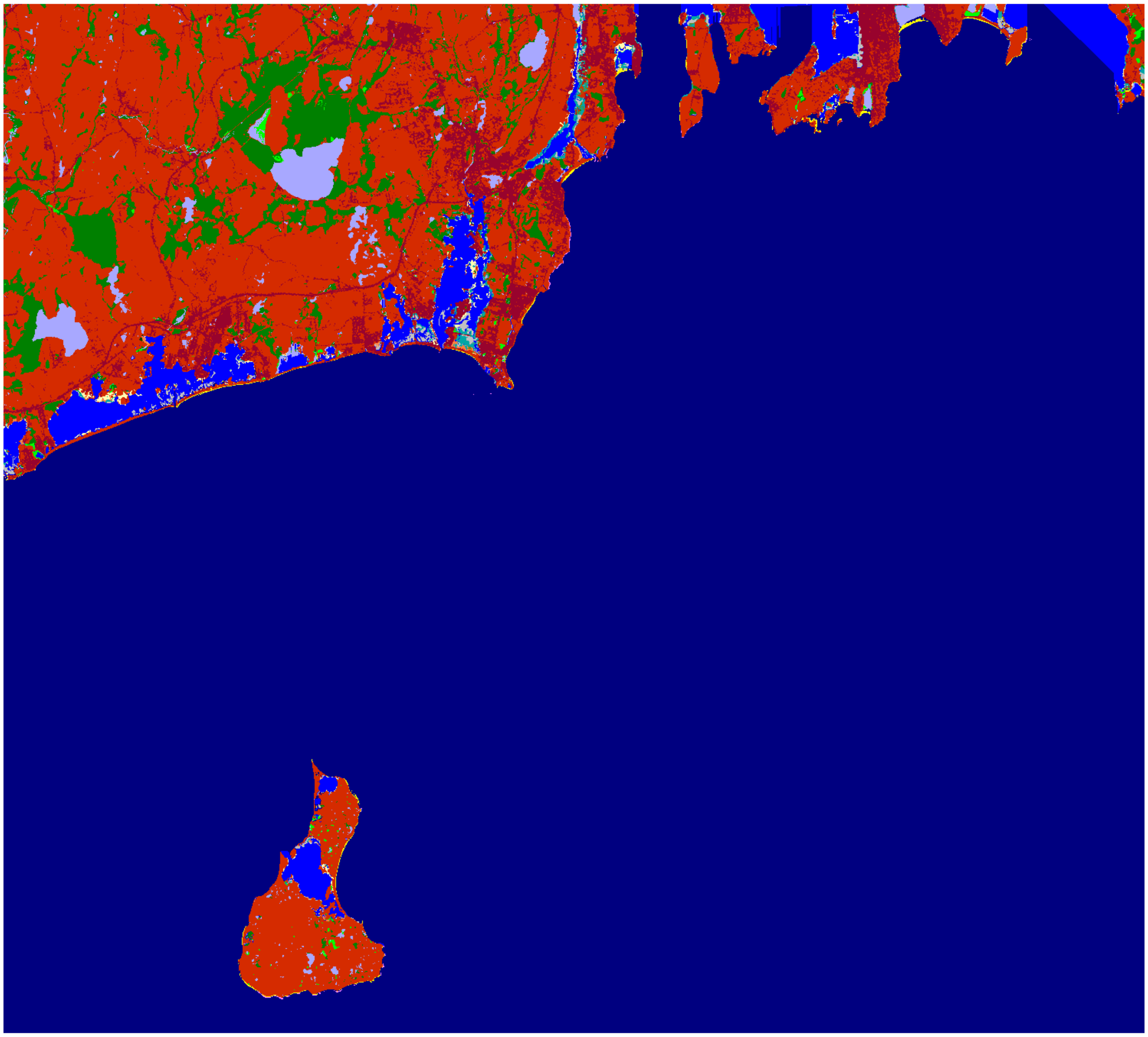
Rhode Island Complex Context, Initial Condition



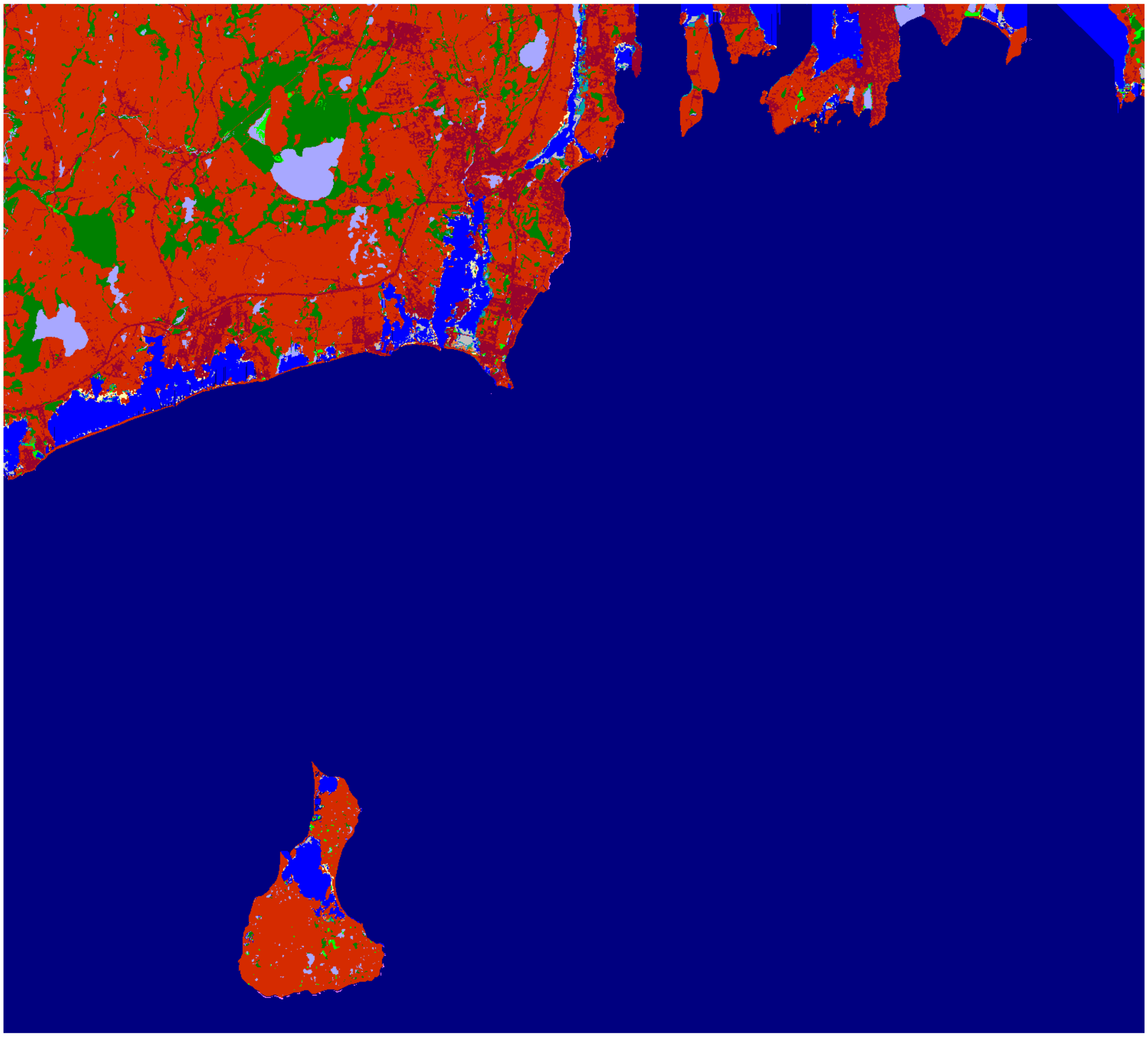
Rhode Island Complex Context, 2025, 1 meter



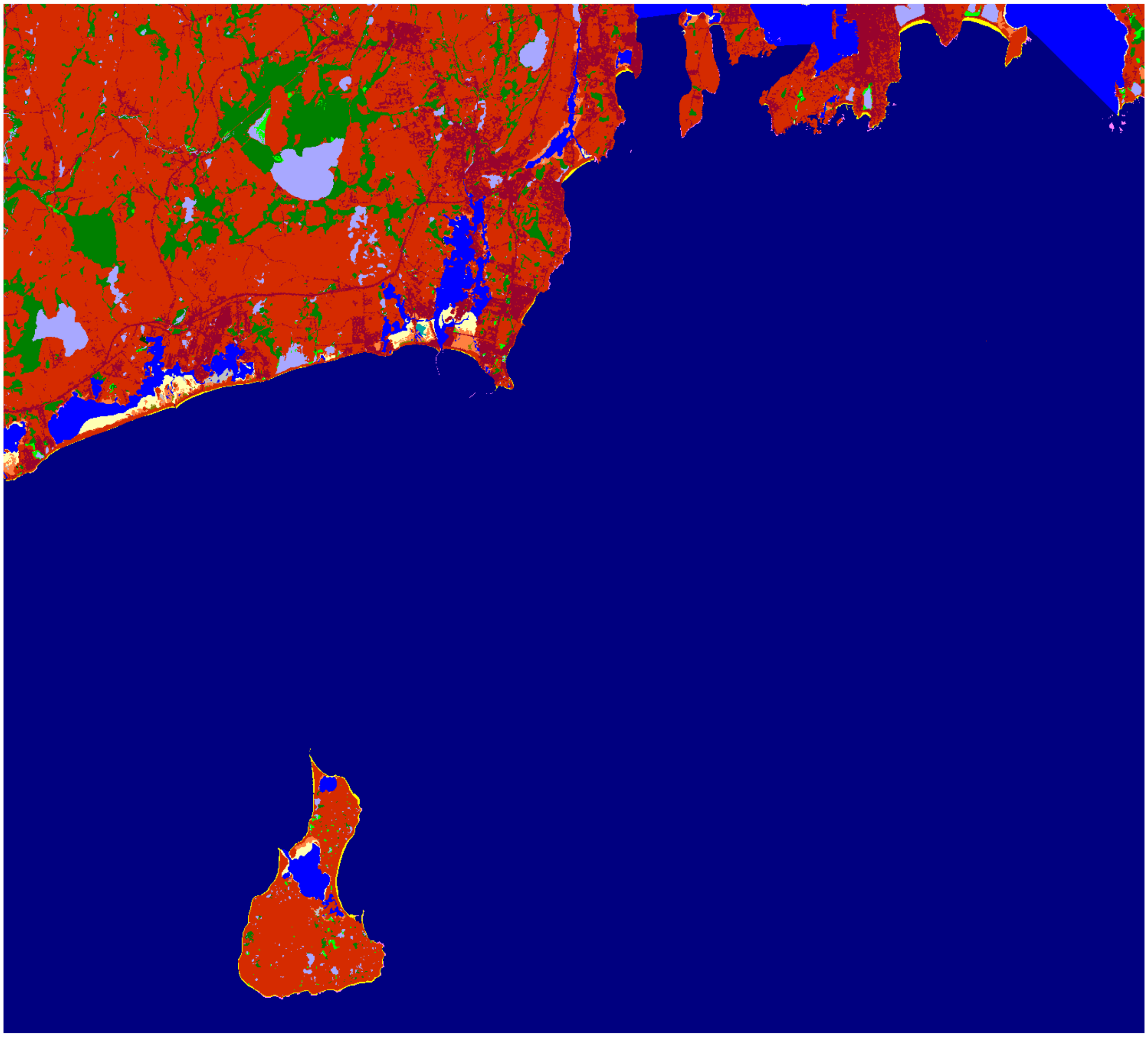
Rhode Island Complex Context, 2050, 1 meter



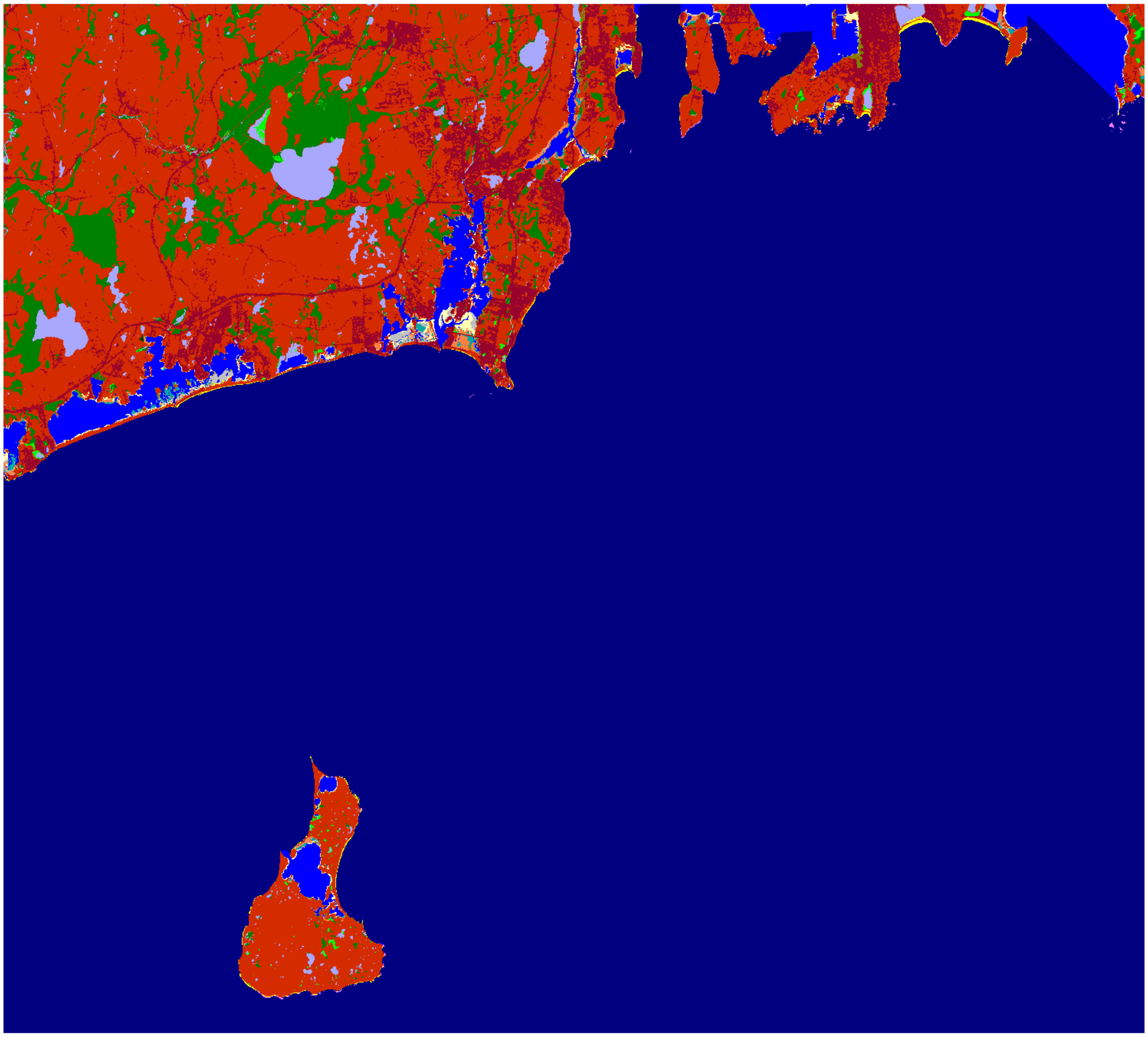
Rhode Island Complex Context, 2075, 1 meter



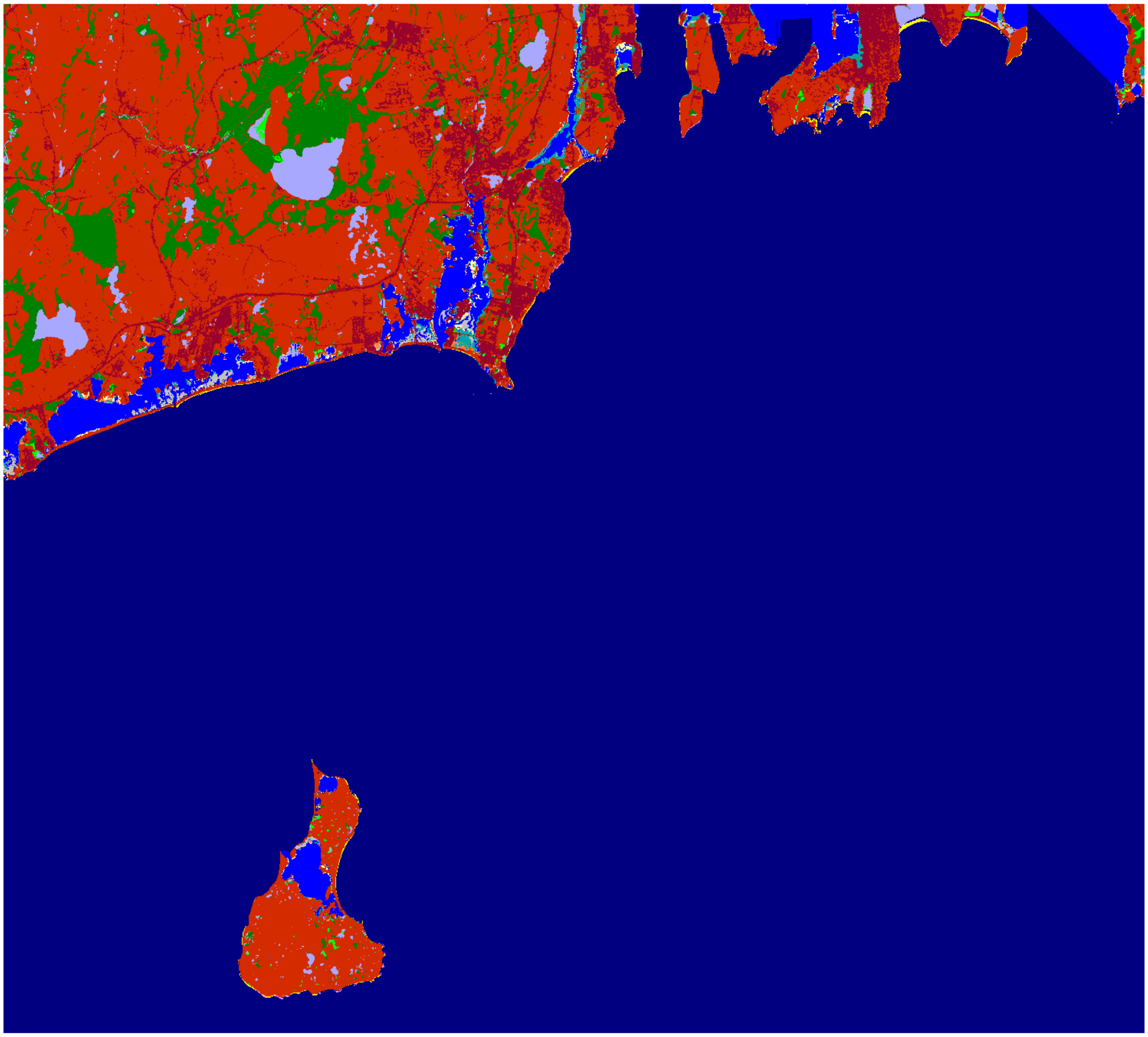
Rhode Island Complex Context, 2100, 1 meter



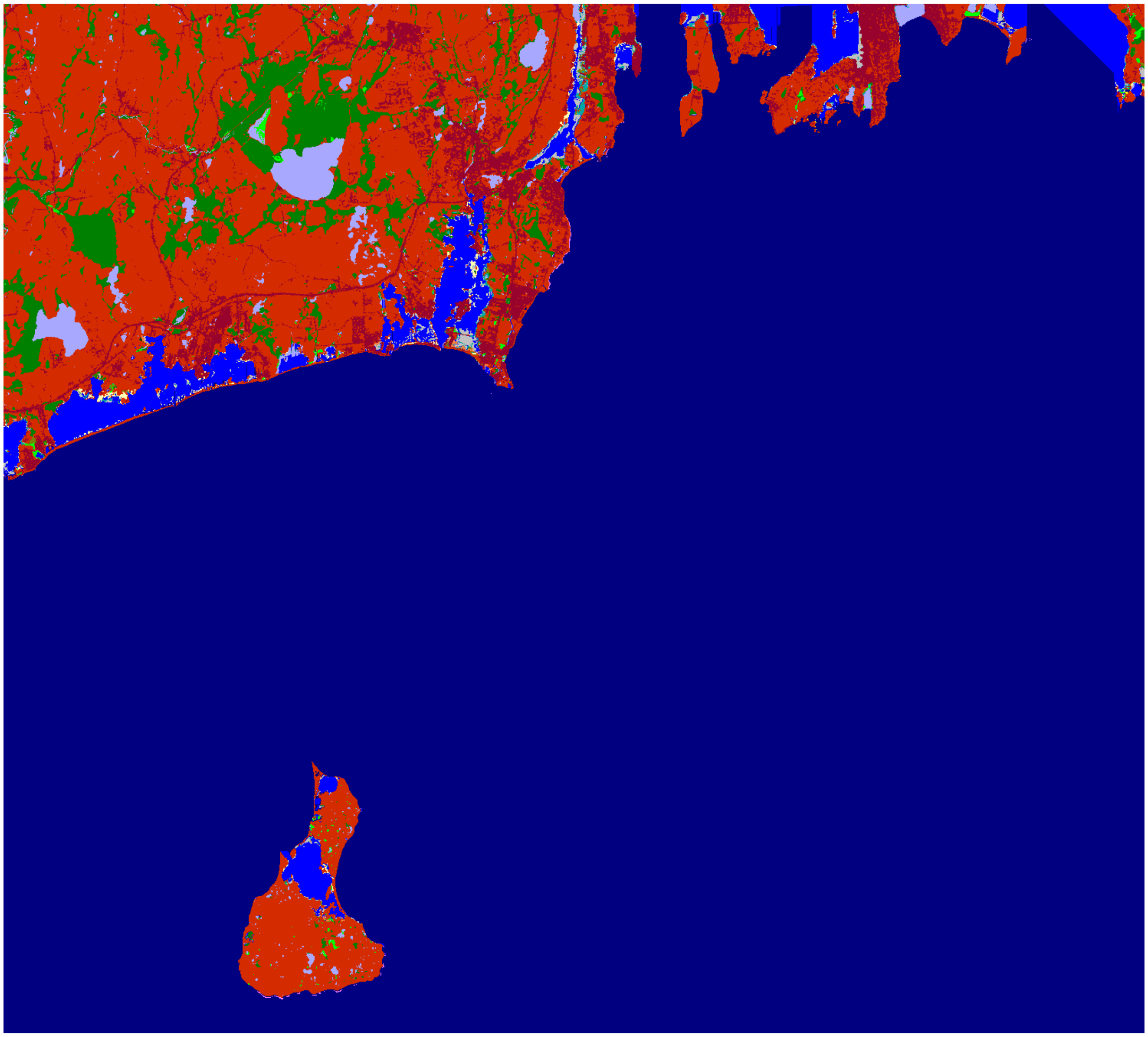
Rhode Island Complex Context, Initial Condition



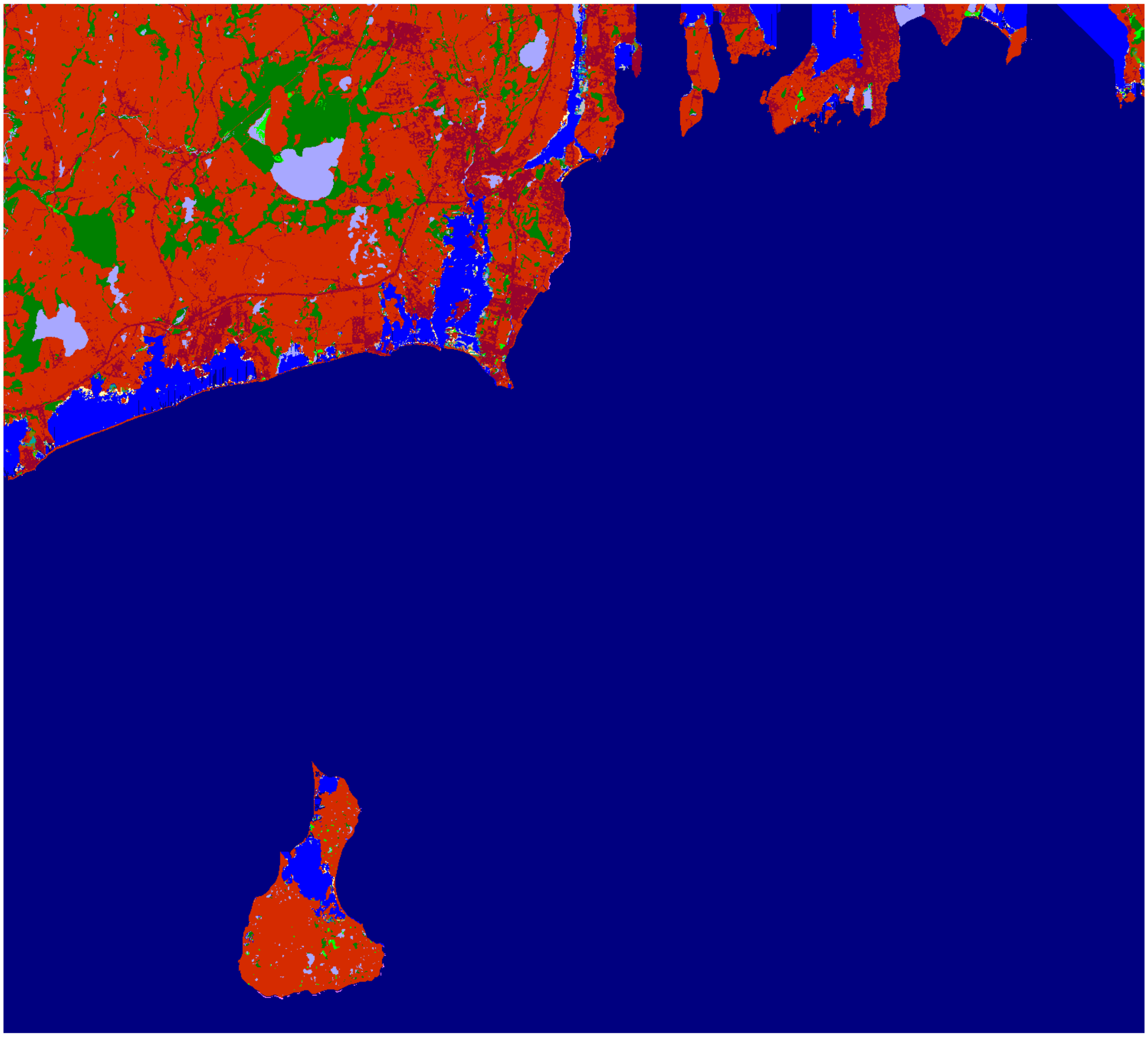
Rhode Island Complex Context, 2025, 1.5 meter



Rhode Island Complex Context, 2050, 1.5 meter



Rhode Island Complex Context, 2075, 1.5 meter



Rhode Island Complex Context, 2100, 1.5 meter