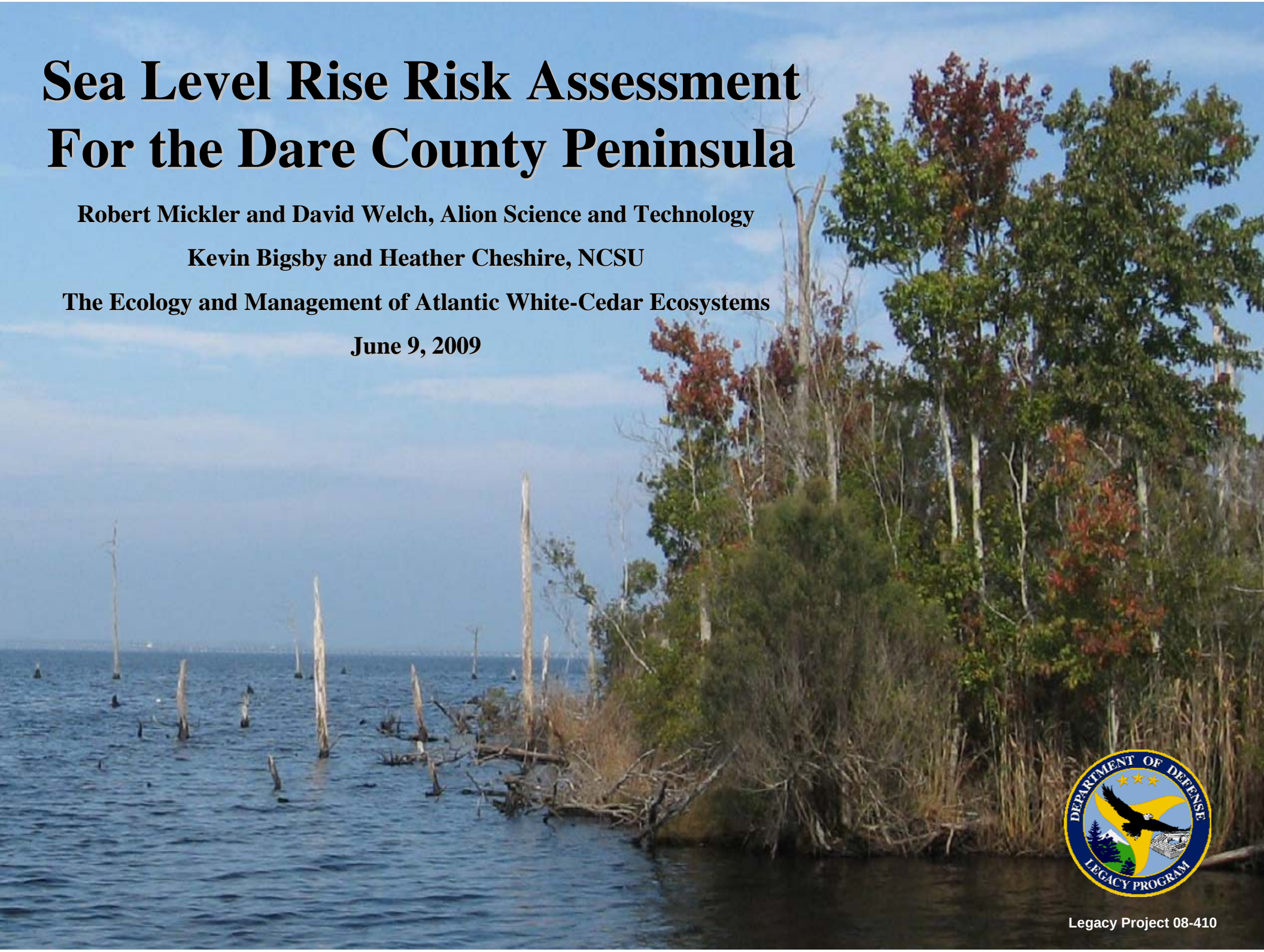
Sea Level Rise Risk Assessment For the Dare County Peninsula

Robert Mickler and David Welch, Alion Science and Technology

Kevin Bigsby and Heather Cheshire, NCSU

The Ecology and Management of Atlantic White-Cedar Ecosystems

June 9, 2009

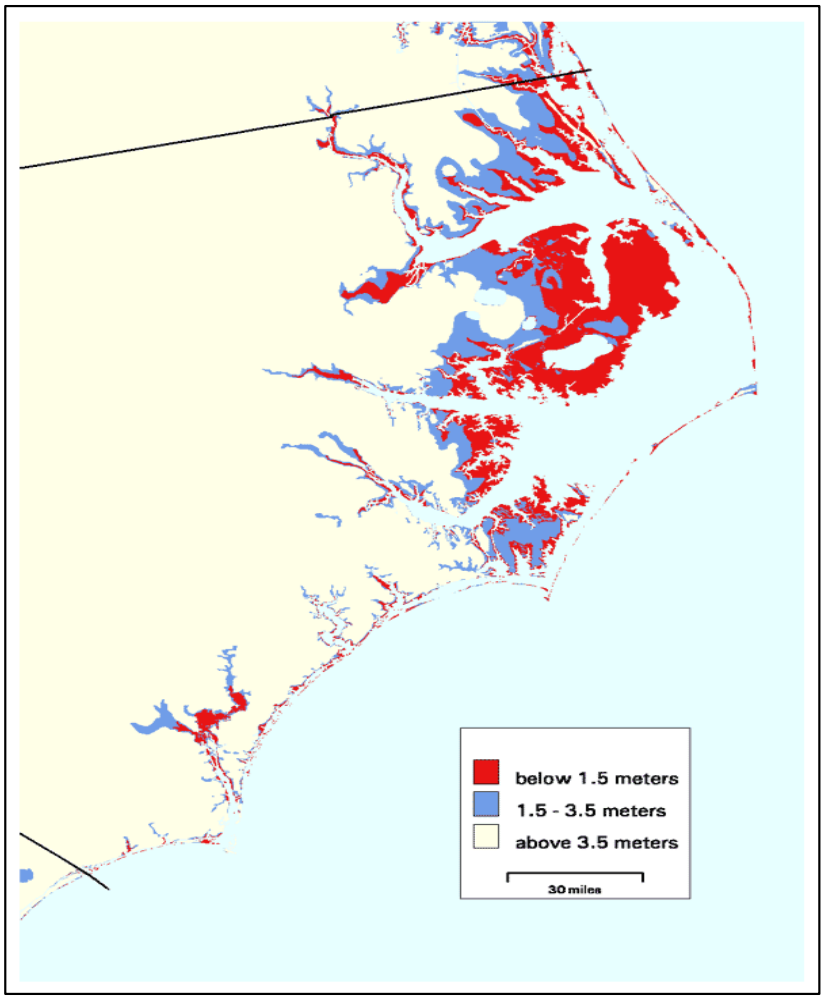


Legacy Project 08-410

Looking to the Future for Sustainability Solutions

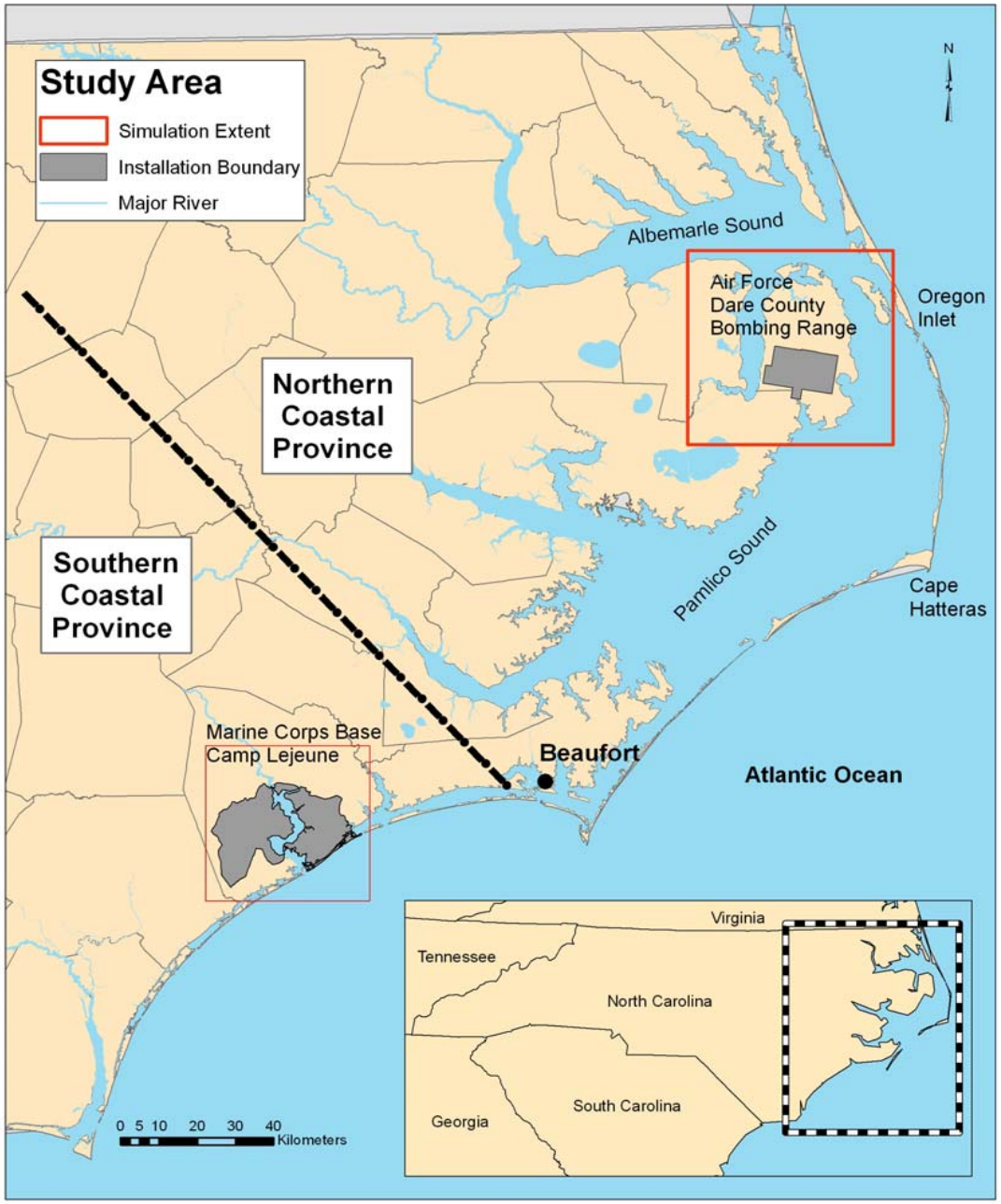
Lands Vulnerable to Sea Level Rise Along Atlantic and North Carolina Coasts

(Titus and Richman, 2000)



North Carolina Geological Provinces

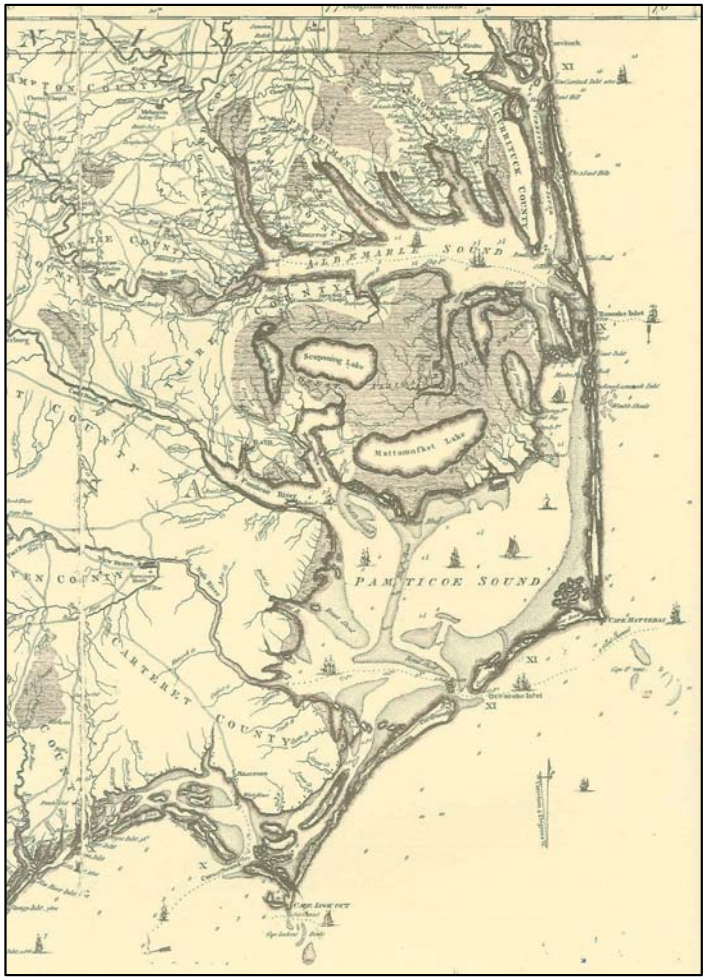
Vulnerability to sea-level rise on the diverse Albemarle-Pamlico Peninsula is very high: about two-thirds of the peninsula is less than 1.5 m (5 ft) above sea level (Heath, 1975), and approximately 30 percent is less than 0.9 m (3 ft) above sea level (Poulter, 2005). Shoreline retreat rates in parts of the peninsula are already high, up to 7.6 m (25 ft) per year (Riggs and Ames, 2003).Geological processes and features affect sea level rise for Dare. Dare lies within the Northern Coastal Province in North Carolina which consists of soft, unconsolidated sediments on gentle slopes. Its highly dissected coastline and offshore barrier islands indicates an eroding shore and sinking mainland.



Looking to the Past for Sustainability Solutions

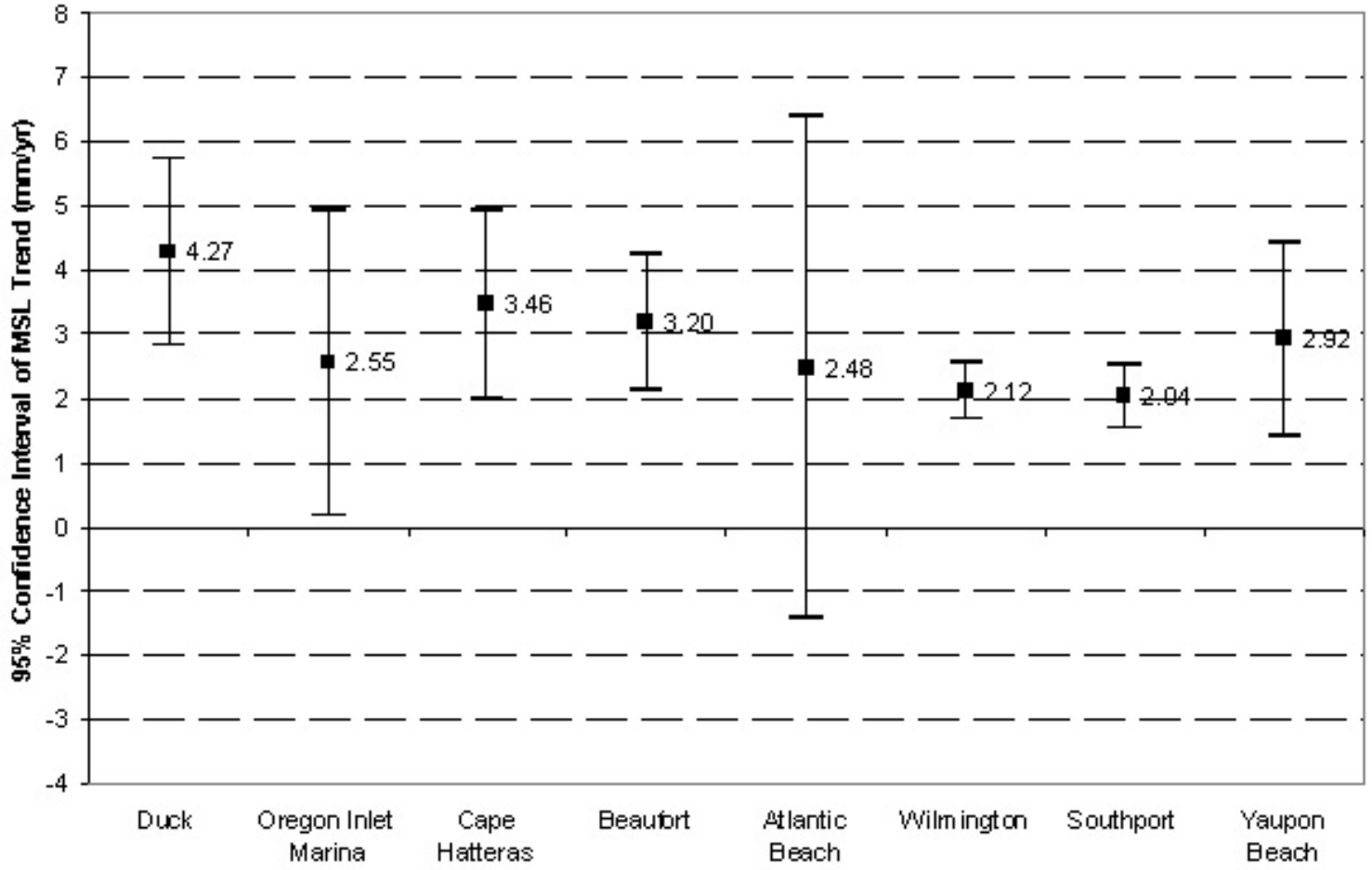
The Mouzon map of 1755 and Price-Strother map of 1808

Early maps show the closing of Roanoke Inlet (outlet of the Albemarle Sound to the Atlantic Ocean) between 1780 and 1810. The Roanoke Marches still connect Dare peninsula to Roanoke Island



Historical Trends in NOAA Coastal Water Level Stations

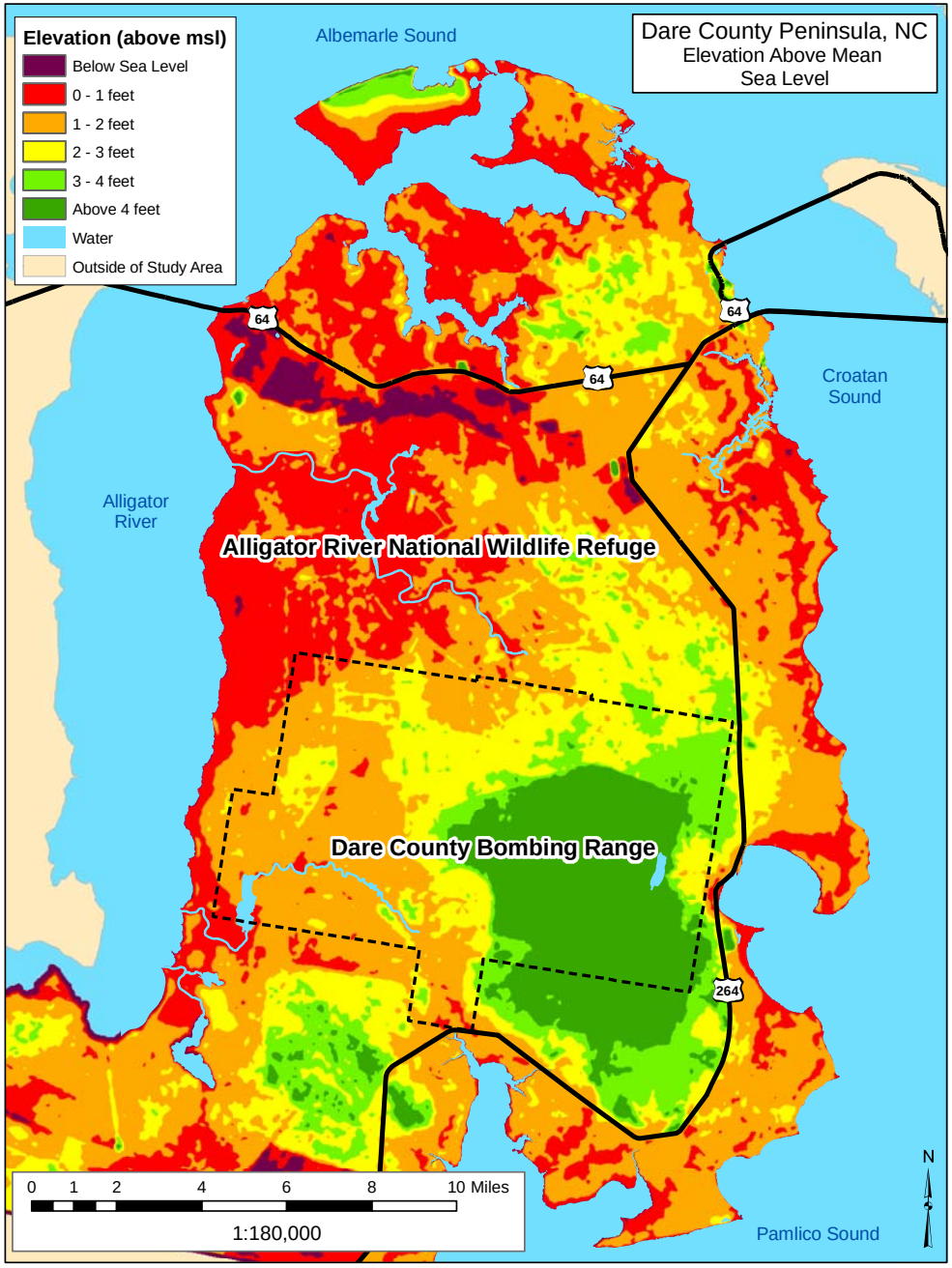
Mean sea level trends calculated for the eight North Carolina stations. The stations with the longest data intervals (68 years at Wilmington and 56 years at Southport) have the narrowest confidence intervals. The trends range from 2.04 mm/yr at Southport to 4.27 mm/yr at Duck. The average for all eight North Carolina stations is 2.88 mm/yr. There appears to be a regional gradient with the trends increasing from south to north. This implies that the land is sinking more rapidly along the northern portion of the coastline. (NOAA Technical Report NOS CO-OPS 041)



Global Change Impacts

The impacts of sea level rise and long-term climatic changes to the frequency and severity of severe weather events pose risks to coastal ecosystems.

Lidar digital elevation data and receding shoreline on Dare County peninsula illustrate future and current risks.

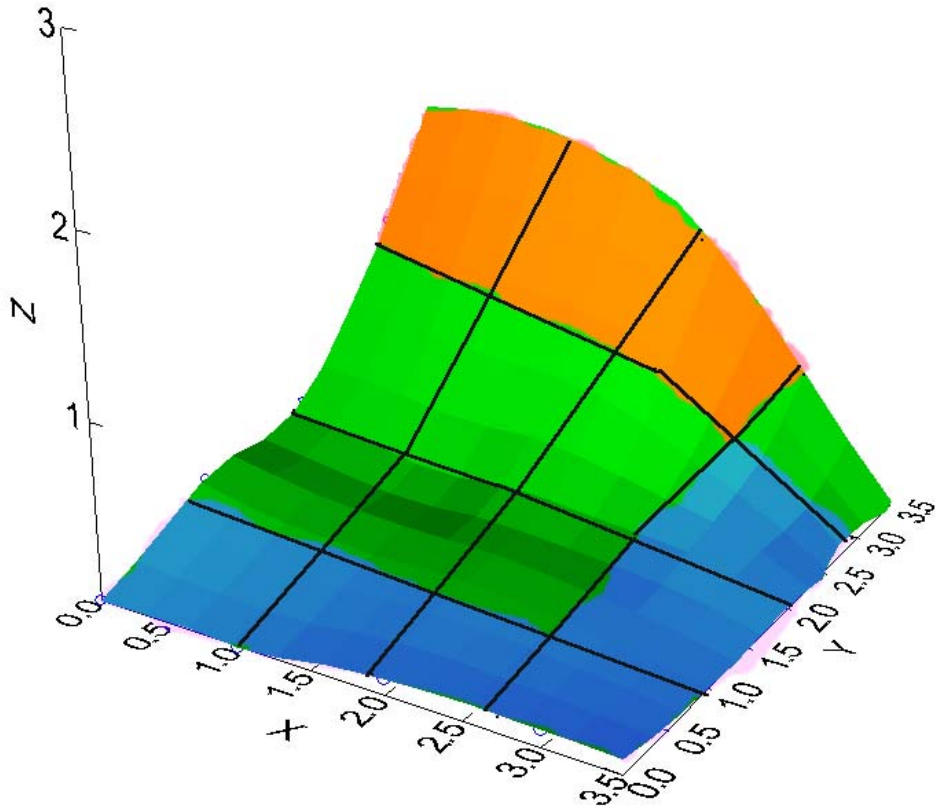


The SLAMM Model (Sea Level Affecting Marshes Model) Development Overview

- Intermittently under development since 1985
  - SLAMM was developed with US EPA funding by Dr. Richard A. Park (Park et al. 1986)
  - SLAMM2 was used to simulate 20% of the coast of the contiguous US for the 1991 EPA Report to Congress
  - SLAMM3 was developed in 1993, applied to Puget Sound and Florida (Geocarto International, 1993)
  - SLAMM4 was produced in 1998, cell size resolution vastly improved, Windows GUI and mapping component added
  - SLAMM5 developed with 3-year US EPA STAR grant

Model Process Overview

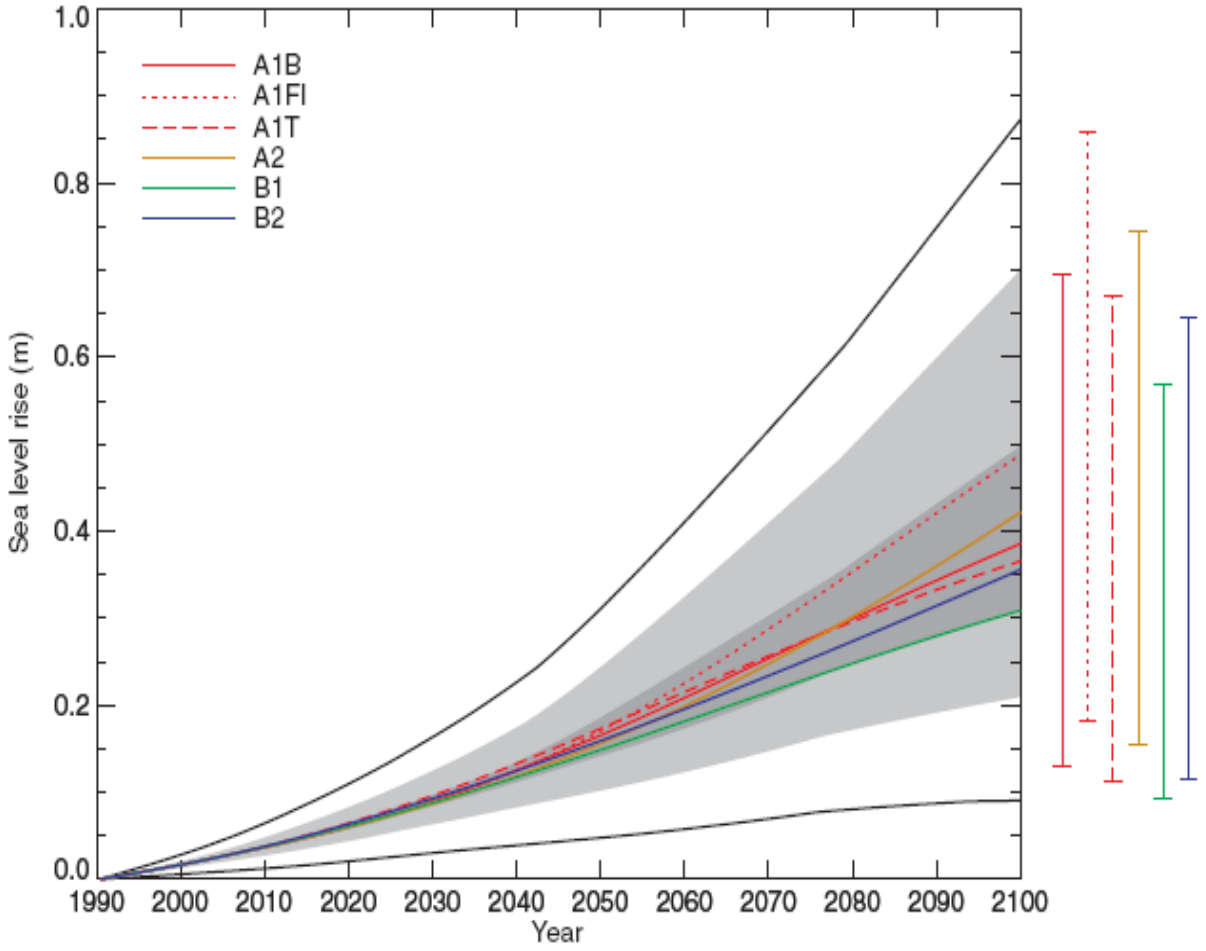
- Inundation: Calculated based on the minimum elevation and slope of the cell.
- Erosion: Triggered given a maximum fetch threshold and proximity of the marsh to estuarine water or open ocean.
- Overwash: Barrier islands undergo overwash at a fixed storm interval. Beach migration and transport of sediments are calculated.
- Saturation: Migration of coastal swamps and fresh marshes onto adjacent uplands-- response of the water table to rising sea level.
- Accretion: Vertical rise of marsh due to buildup of organic and inorganic matter on the marsh surface. Rate differs by marsh-type.



•Cells with elevation, slope, aspect, wetland type
•Cell size can be variable but many DEMs have 30 m resolution
•Cells will track movement of multiple land-type categories

IPCC Sea Level Rise Scenarios

- Model incorporates IPCC Projections as well as fixed rates of SLR
- Global (Eustatic) Rates of SLR are corrected for local effects using long-term tide gauge trends
- Sea level rise scenarios for DCBR were selected to bracket the range of sea level rise responses and includes an extreme glacial melt scenario



Dare County Peninsula NVC Alliances and Atlantic White-Cedar (8,827 acres)

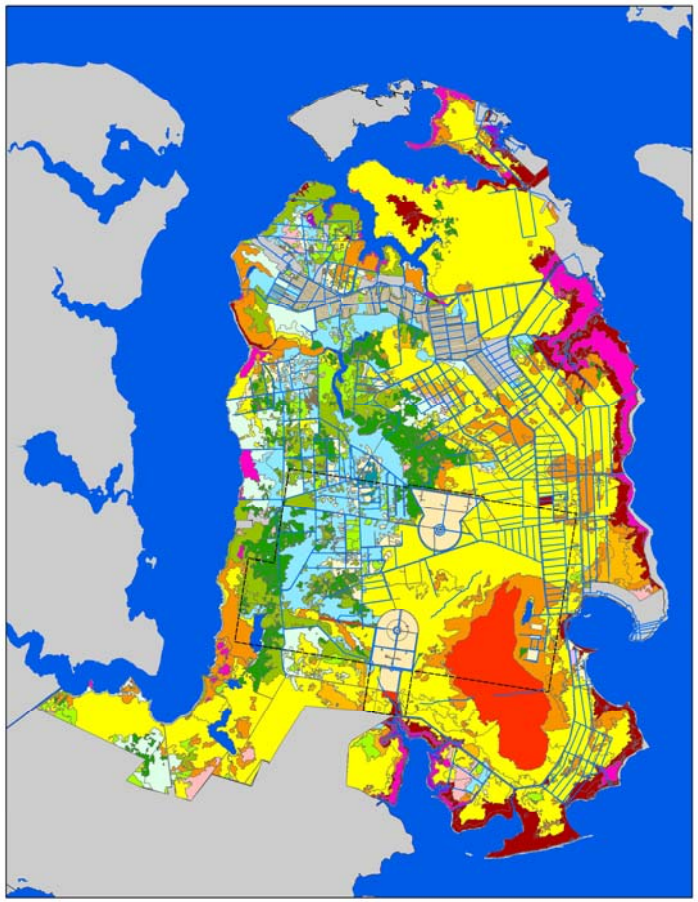
Legend

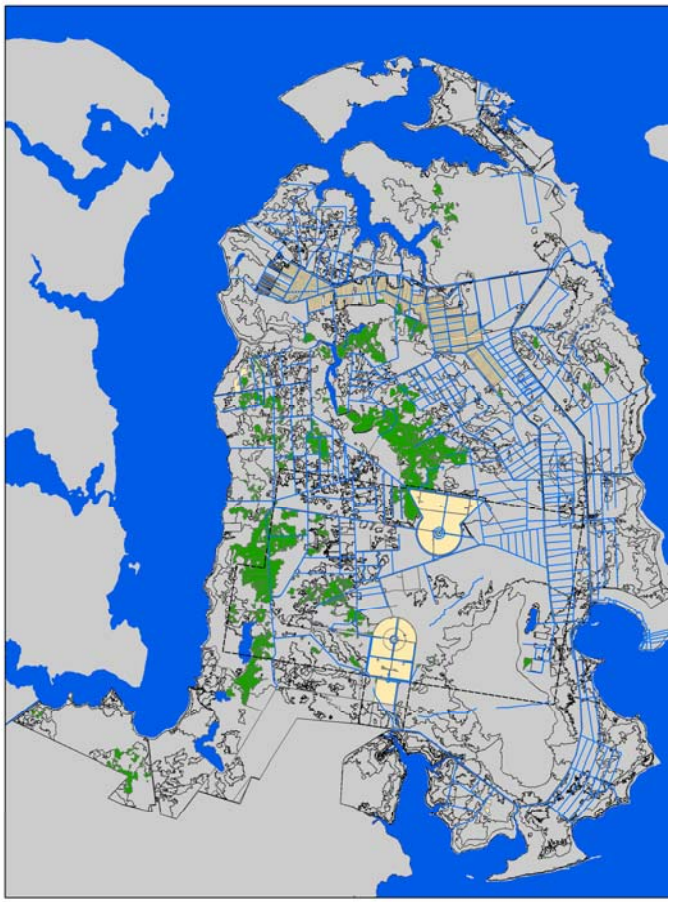
- Mainland ditches_polyline
- Dare County Bombing Range
- Water

Alliances

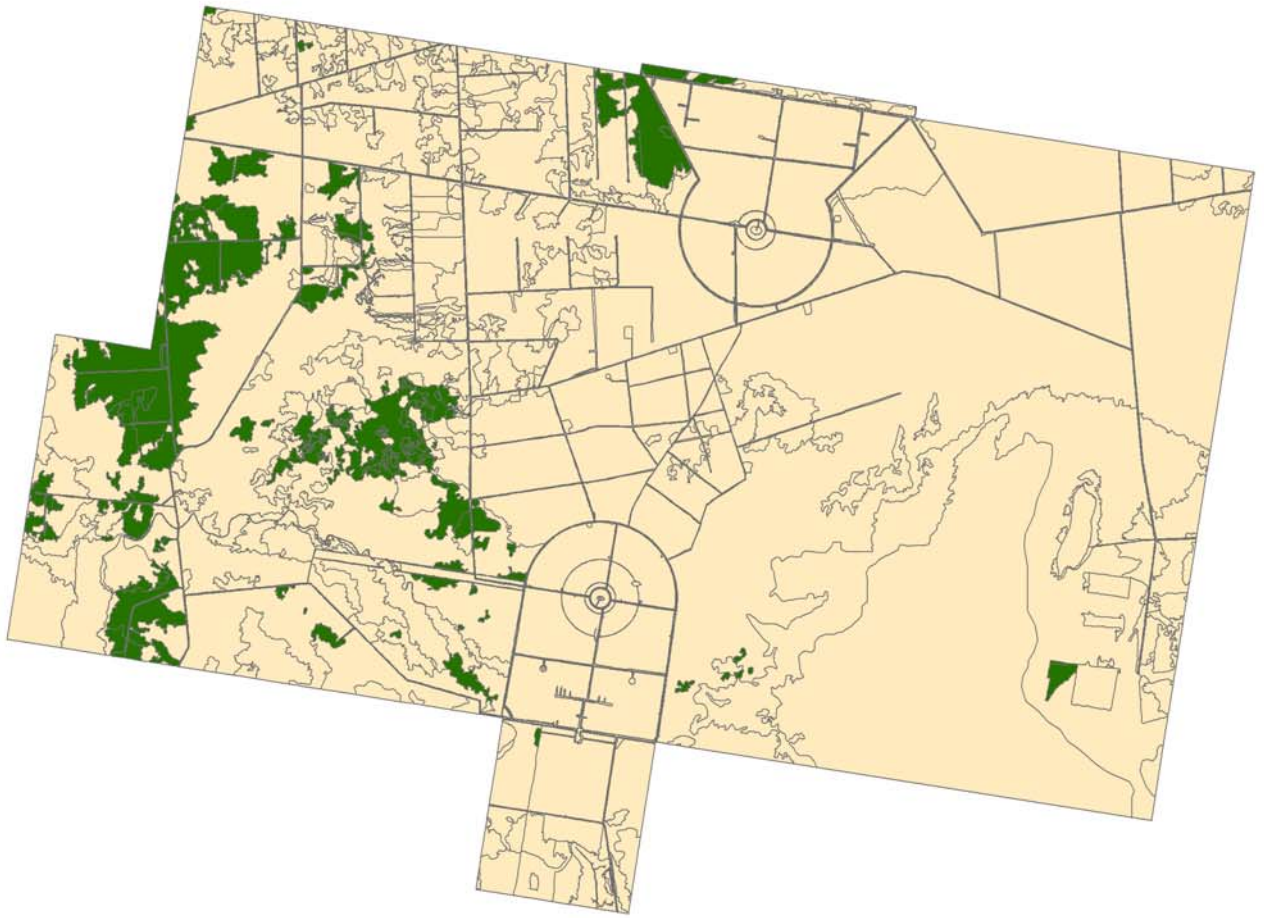
Vegetation Classified By National Vegetation Classification Alliance

- Administrative
- Surface Hydrology
- (Willow Oak, Water Oak, Diamondleaf Oak) Temporarily Flooded Forest Alliance
- (Diamondleaf Oak, Willow Oak) Seasonally Flooded Forest Alliance
- Sweetgum - (Red Maple) Seasonally Flooded Forest Alliance
- Baldcypress - Swamp Blackgum - (Water Tupelo) Saturated Forest Alliance
- Swamp Blackgum - Red Maple - (Tuliptree) Saturated Forest Alliance
- Diamondleaf Oak - Swamp Blackgum Saturated Forest Alliance
- Atlantic White-cedar Saturated Forest Alliance
- Loblolly Pine - Atlantic White-cedar - Red Maple - Swamp Blackgum Saturated Forest All
- Loblolly Pine - Sweetgum - Red Maple Saturated Forest Alliance
- Loblolly Pine Saturated Forest Alliance
- Pond Pine Saturated Woodland Alliance
- Sweetbay - Swampbay Saturated Forest Alliance
- Shining Fetterbush - Little Gallberry Saturated Wooded Shrubland Alliance
- Honeycups - Shining Fetterbush - (Big Gallberry, Little Gallberry) Saturated Shrubland Al
- Saltmeadow Cordgrass - (Saltgrass) Tidal Herbaceous Alliance
- Sawgrass Tidal Temperate Herbaceous Alliance
- Black Needlerush Tidal Herbaceous Alliance
- Common Reed Tidal Herbaceous Alliance
- Non-Federal Land





Atlantic White Cedar
2009 Hardwood Herbicide Application



Dare County Bombing Range Vegetation Classification

Other Vegetation Alliances

Atlantic White Cedar (3,063 acres)

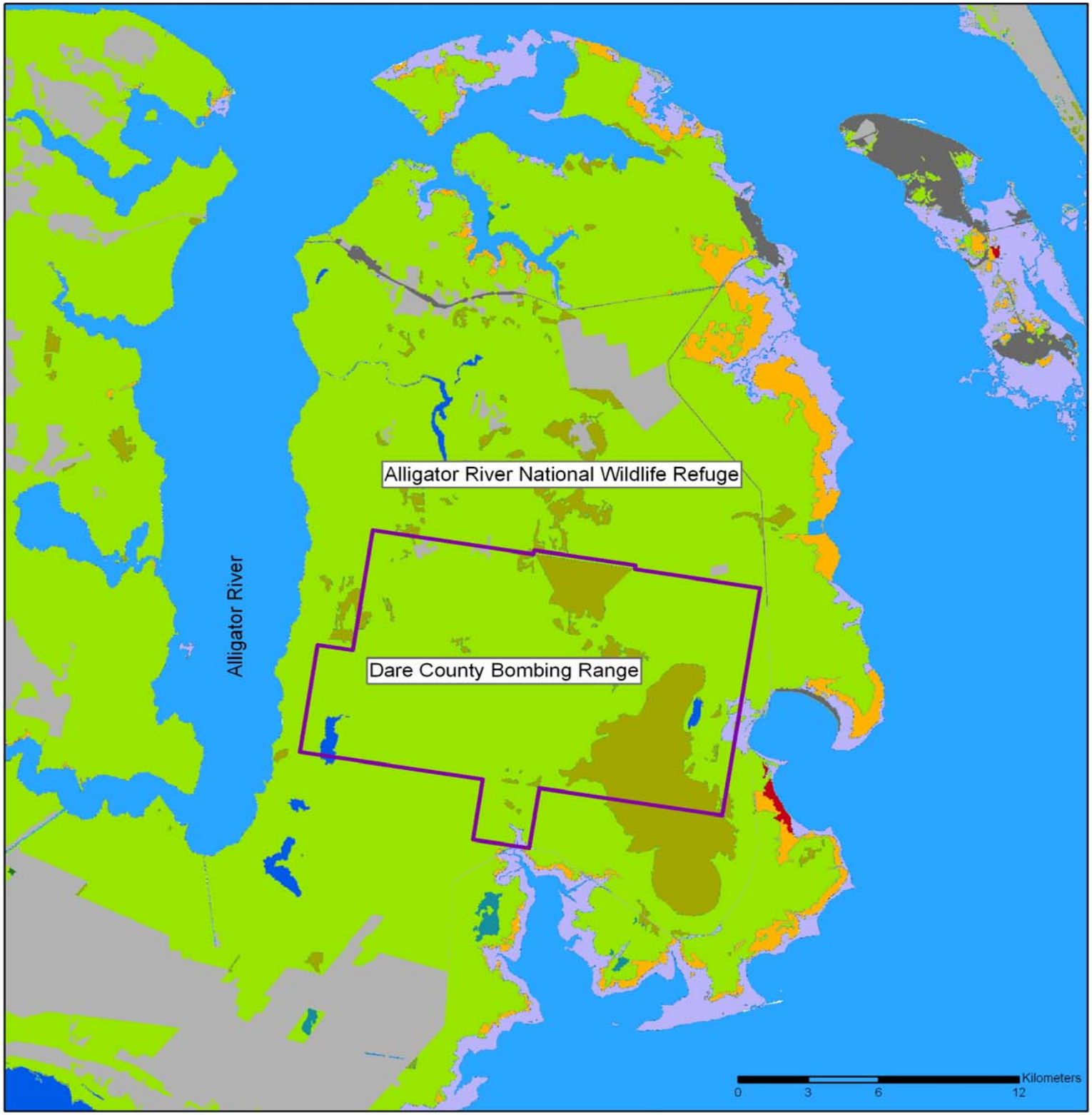
0 0.5 1 2 3 4 Miles

By Robert A. Mickler
Alion Science and Technology
April 3, 2009

ALION SCIENCE AND TECHNOLOGY

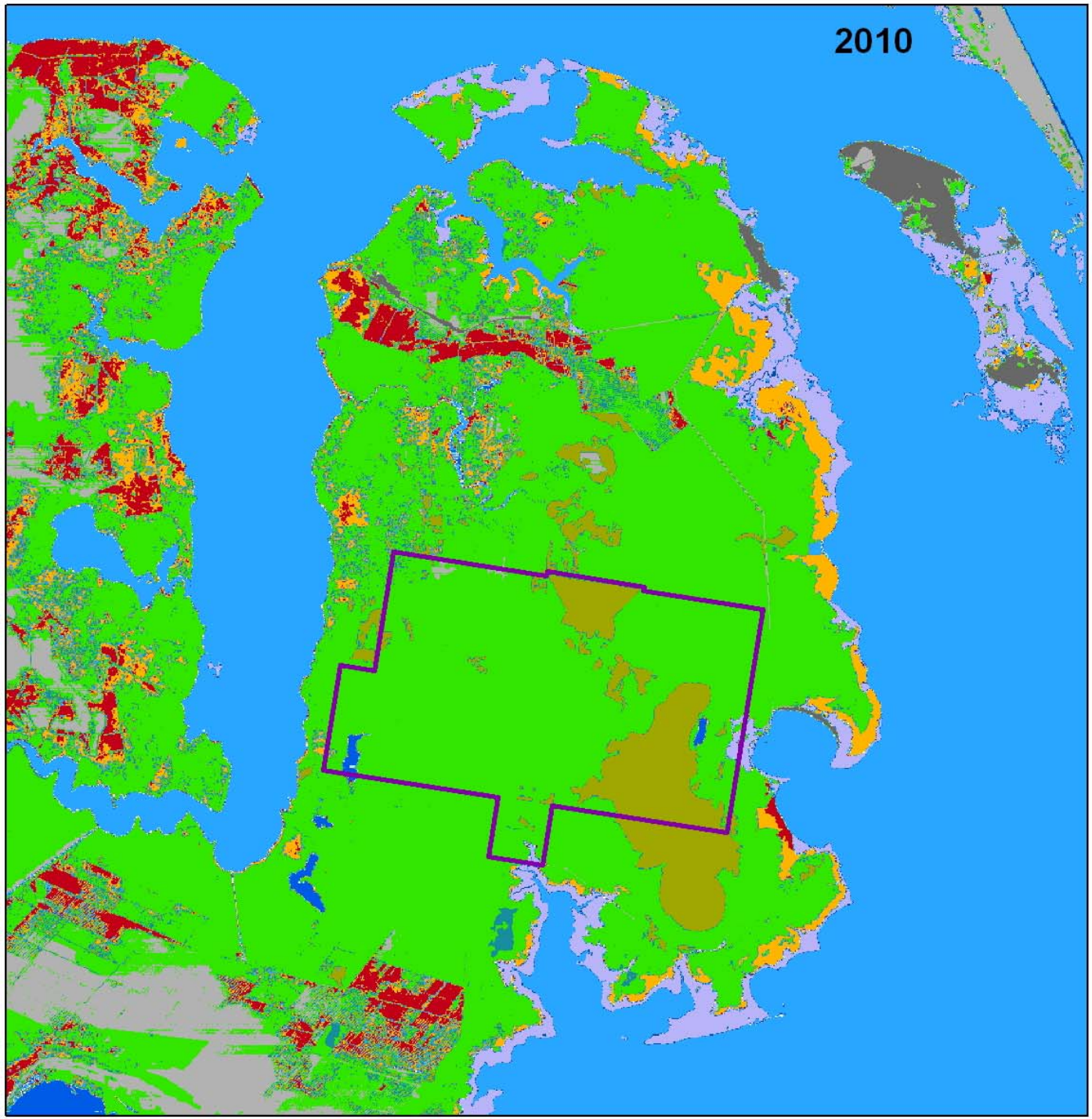
Dare County Bombing Range
Initial Land Cover/ Land Use

- **DCBR Boundary**
- Developed dryland
- Undeveloped dryland
- Forested wetland
- Cypress swamp
- Freshwater marsh
- Scrub shrub
- Salt marsh
- Estuarine beach
- Tidal flat
- Inland open water
- Riverine tidal open water
- Estuarine open water
- Open Ocean
- Brackish marsh
- Tidal swamp



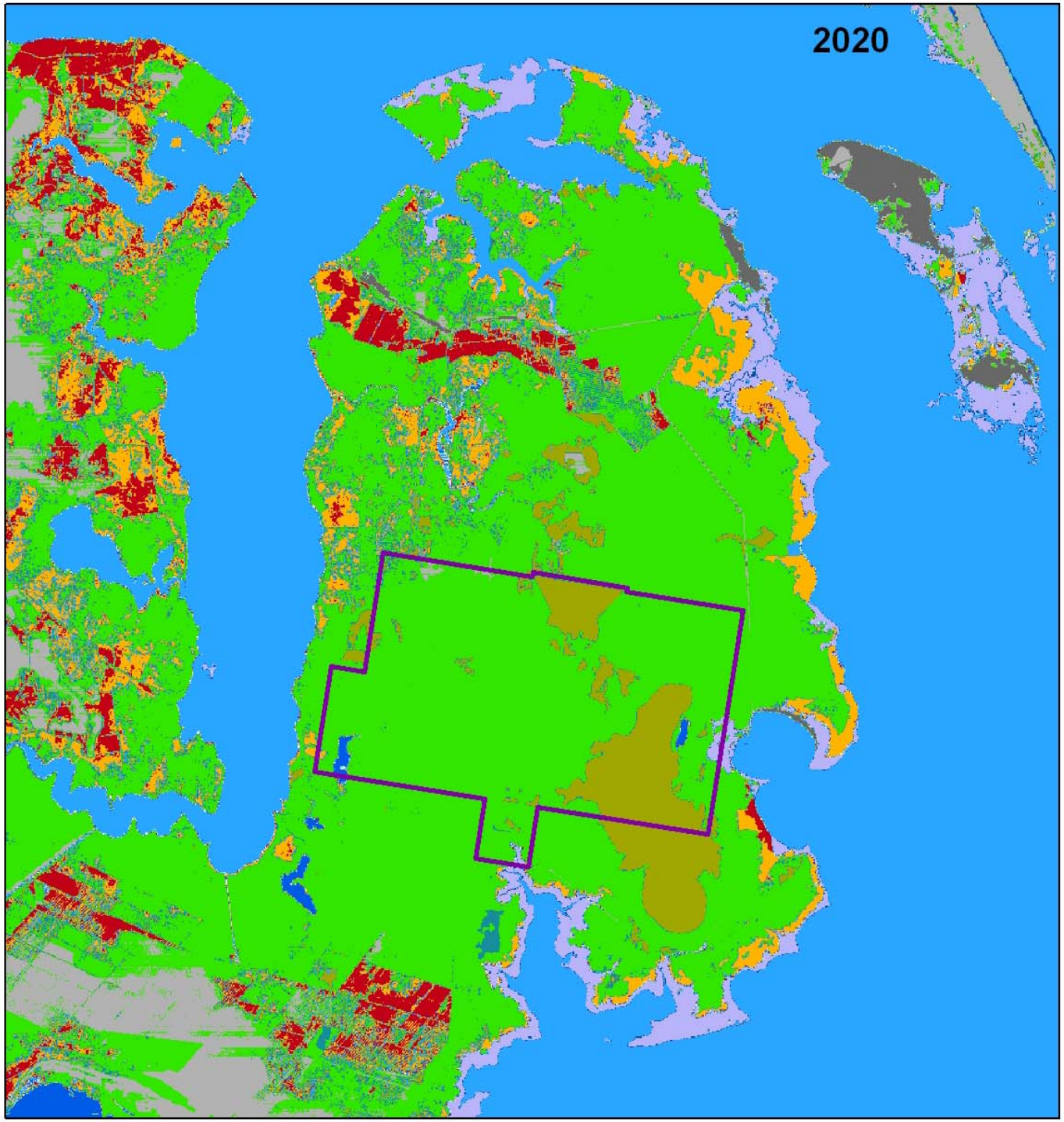
Air Force Dare County Bombing Range
Sea Level Rise Simulation

IPCC Scenario A1B Minimum: 0.13 m by 2100



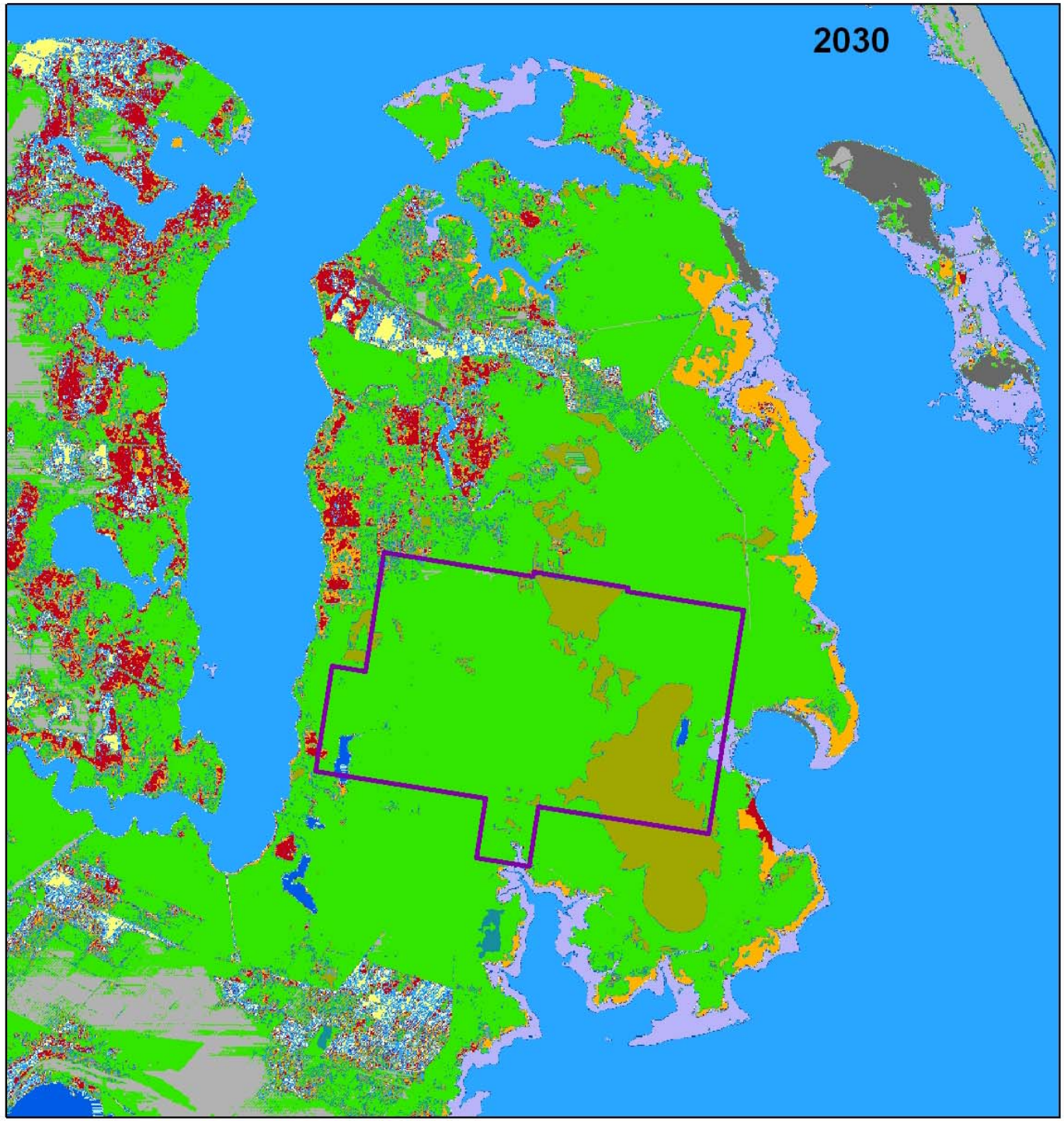
Air Force Dare County Bombing Range
Sea Level Rise Simulation

IPCC Scenario A1B Minimum: 0.13 m by 2100



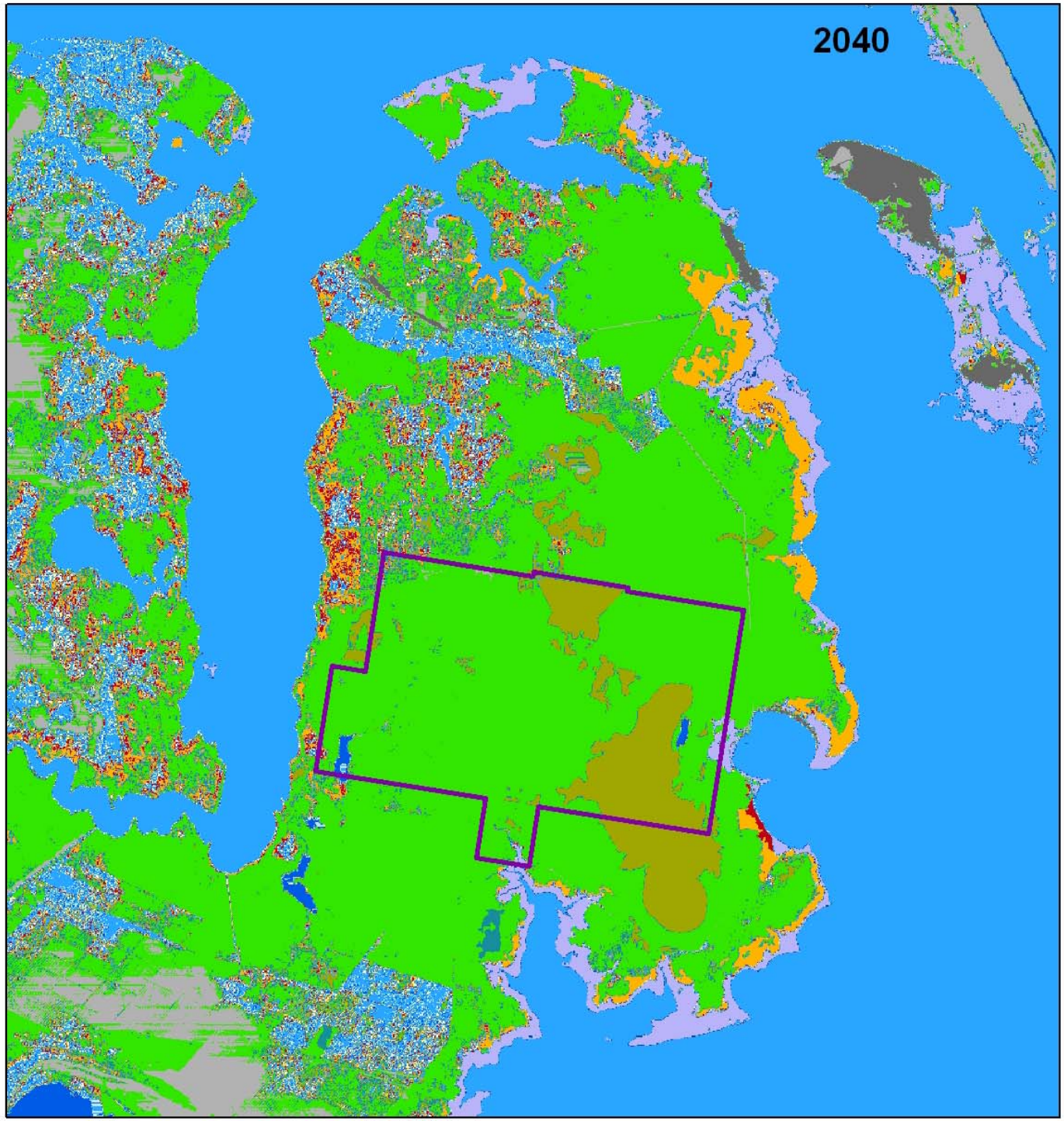
Air Force Dare County Bombing Range
Sea Level Rise Simulation

IPCC Scenario A1B Minimum: 0.13 m by 2100



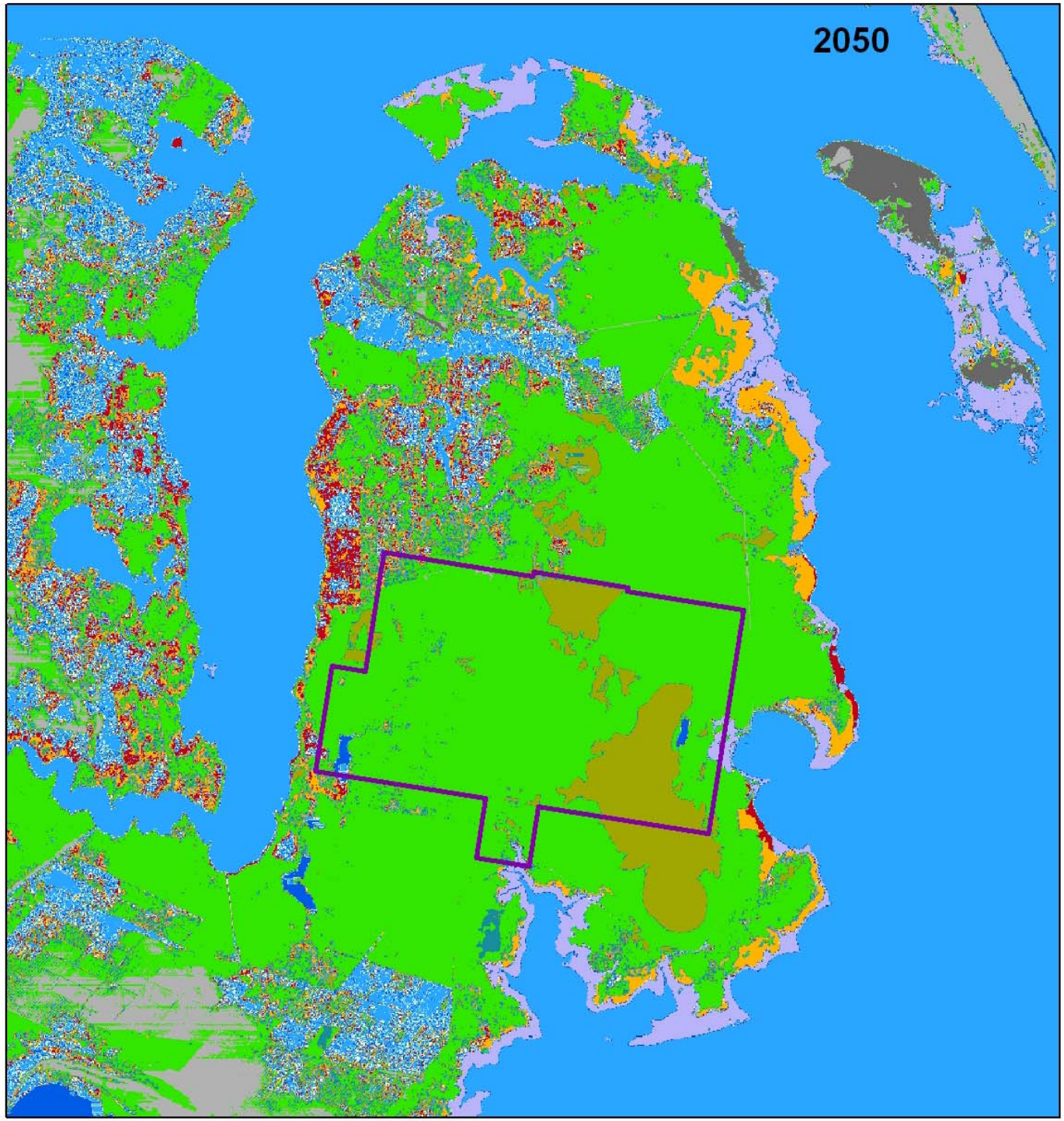
Air Force Dare County Bombing Range
Sea Level Rise Simulation

IPCC Scenario A1B Minimum: 0.13 m by 2100



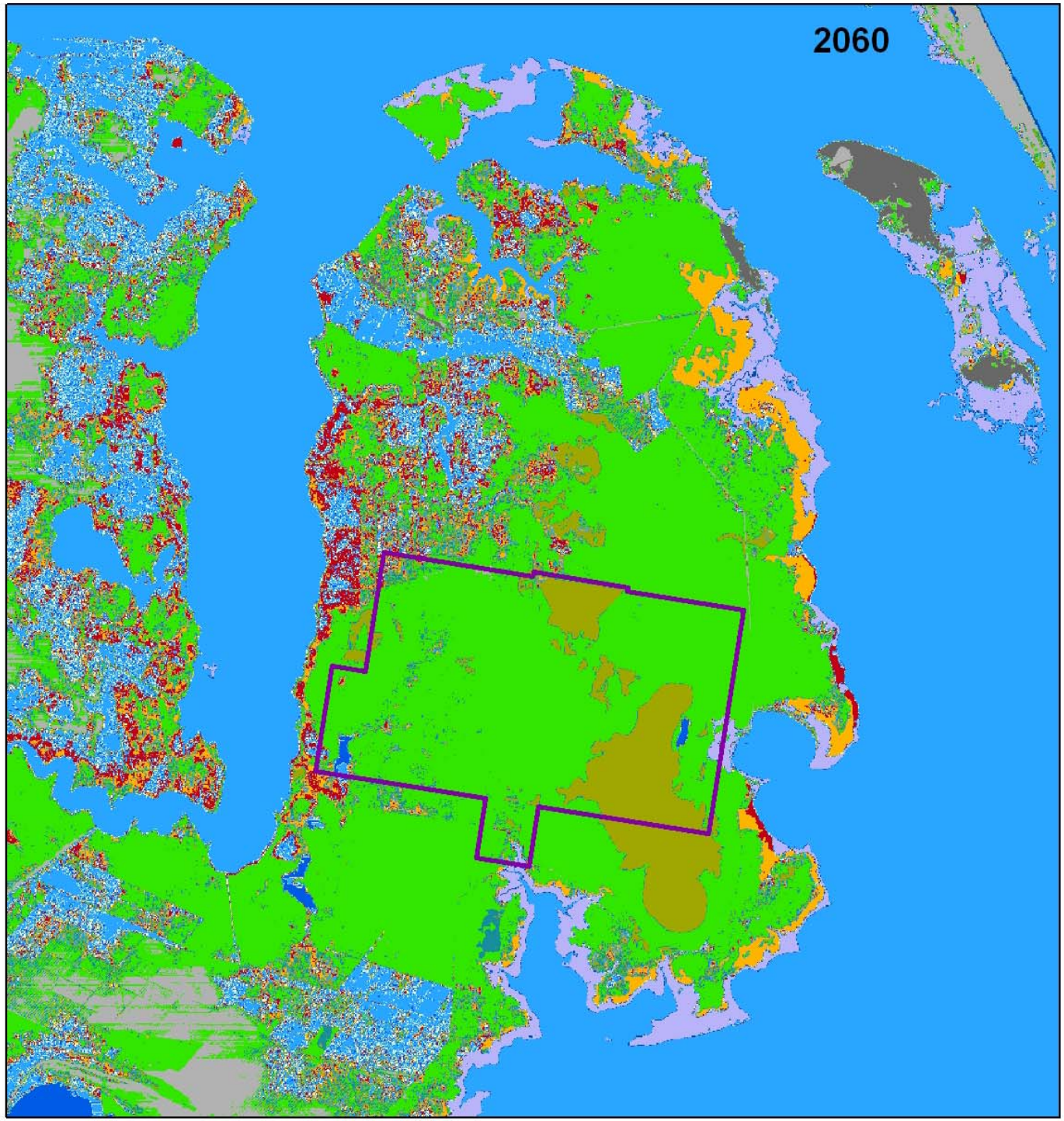
Air Force Dare County Bombing Range
Sea Level Rise Simulation

IPCC Scenario A1B Minimum: 0.13 m by 2100



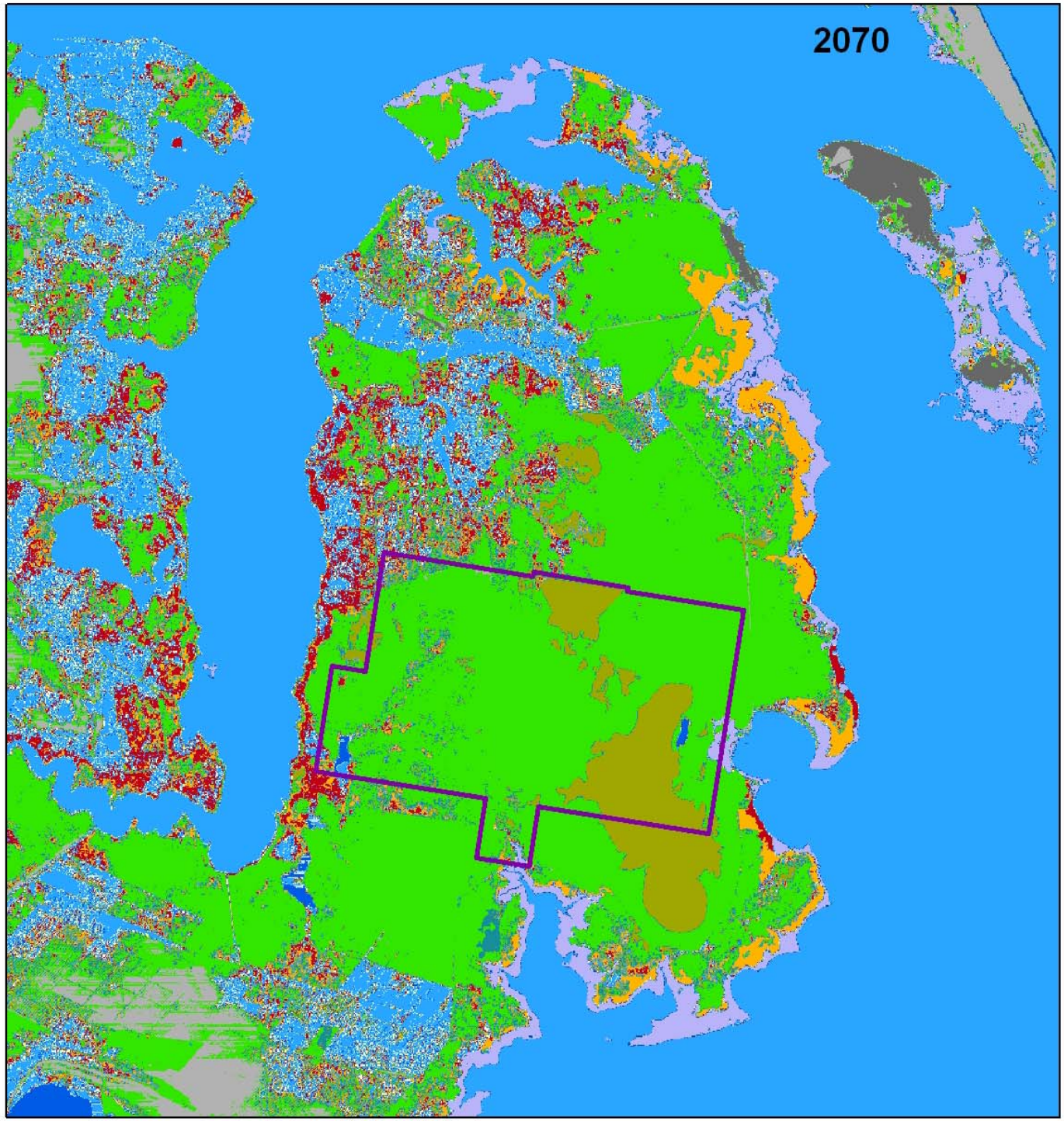
Air Force Dare County Bombing Range
Sea Level Rise Simulation

IPCC Scenario A1B Minimum: 0.13 m by 2100



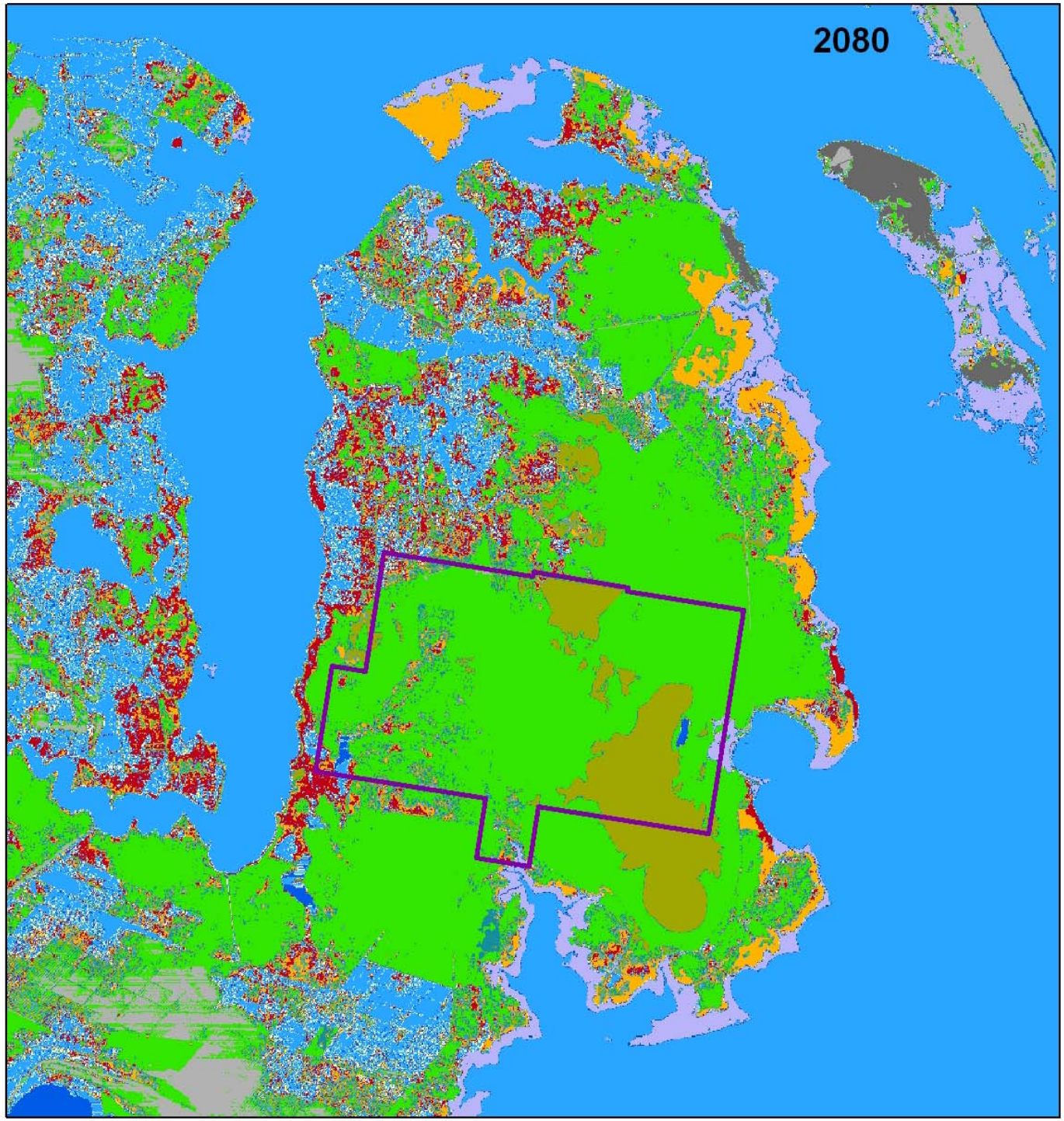
Air Force Dare County Bombing Range
Sea Level Rise Simulation

IPCC Scenario A1B Minimum: 0.13 m by 2100



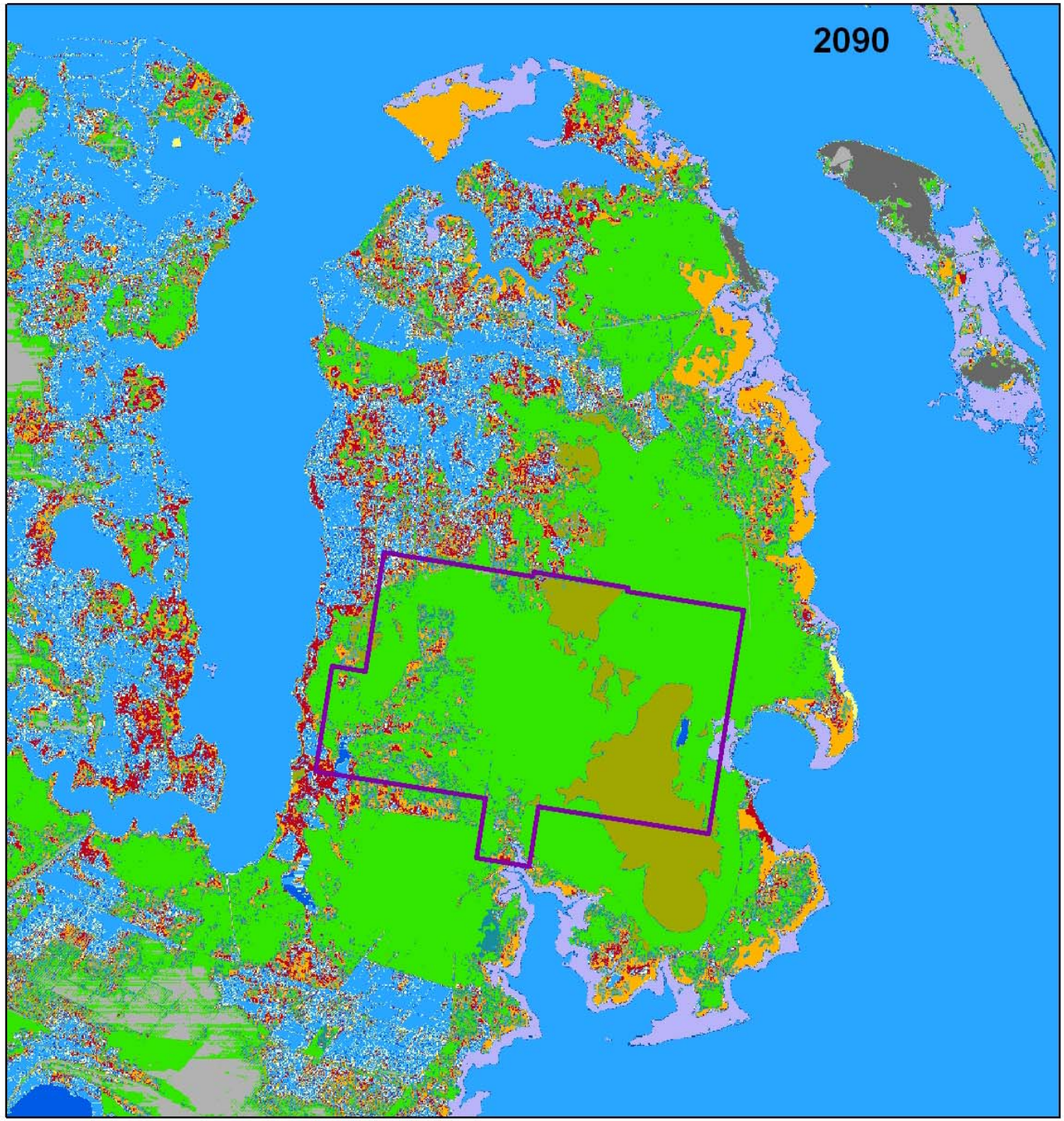
Air Force Dare County Bombing Range
Sea Level Rise Simulation

IPCC Scenario A1B Minimum: 0.13 m by 2100



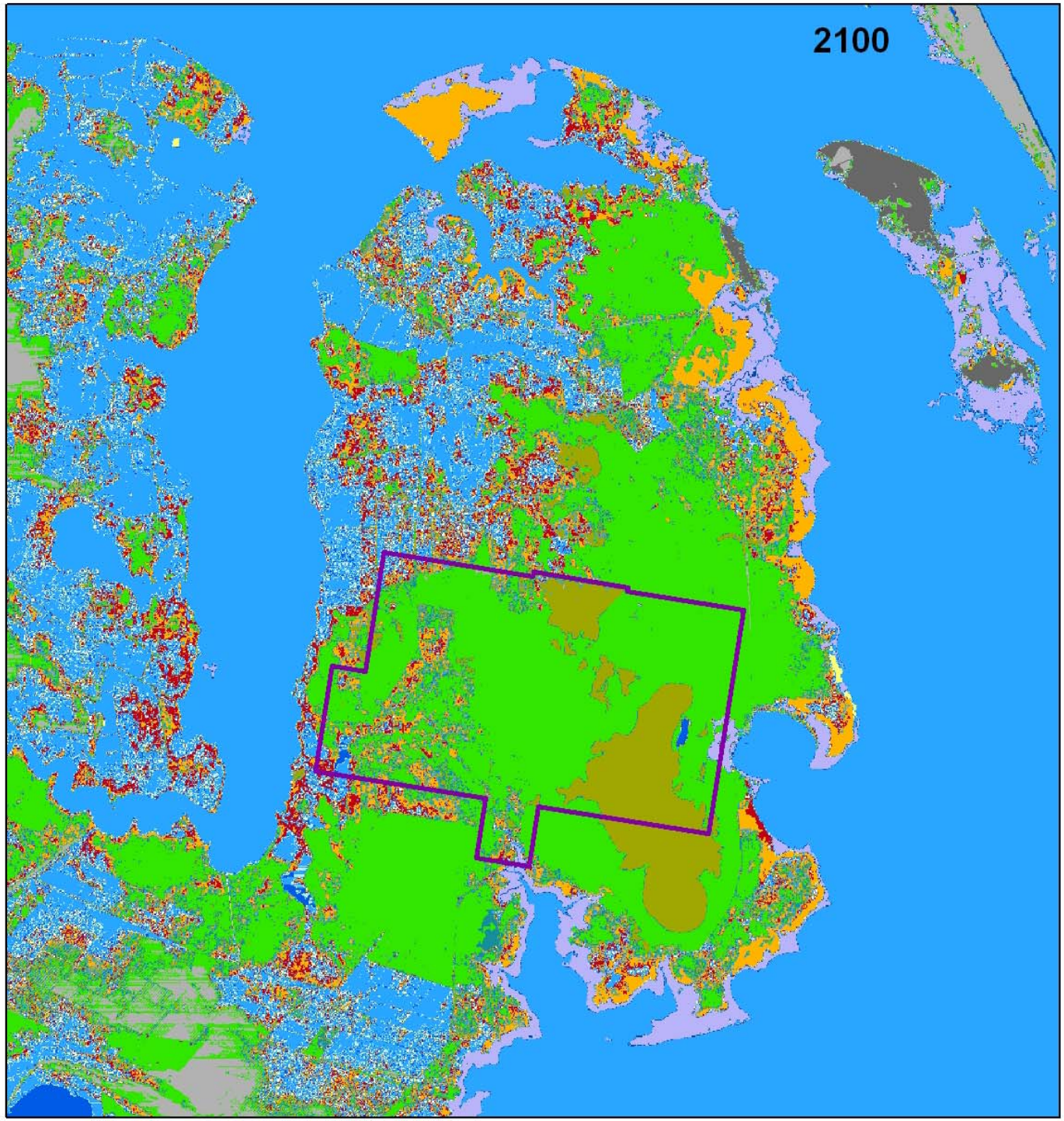
Air Force Dare County Bombing Range
Sea Level Rise Simulation

IPCC Scenario A1B Minimum: 0.13 m by 2100



Air Force Dare County Bombing Range
Sea Level Rise Simulation

IPCC Scenario A1B Minimum: 0.13 m by 2100



IPCC Scenario A1B Minimum: 0.13 m Rise by 2100
Air Force Dare County Bombing Range

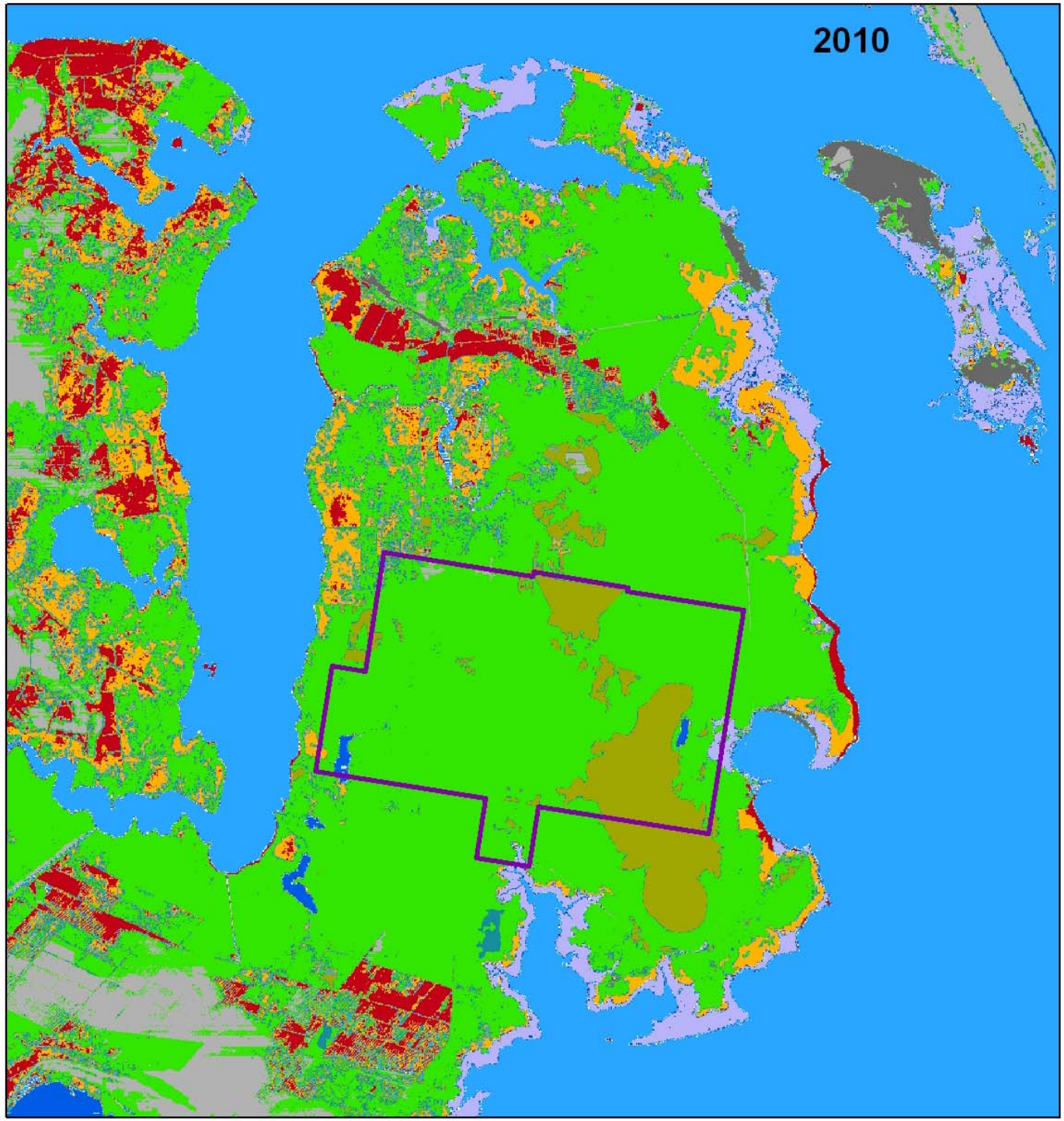
Land Cover Class (ha)	Year										
	1982	**2010**	**2020**	**2030**	**2040**	**2050**	**2060**	**2070**	**2080**	**2090**	**2100**
Undeveloped Upland	73	69	69	53	48	42	36	34	33	32	31
Forested Wetland	15,205	15,194	15,183	15,181	15,159	15,129	15,081	15,003	14,893	14,746	14,550
Inland Fresh Marsh	3,334	3,334	3,334	3,334	3,333	3,332	3,331	3,328	3,326	3,323	3,320
Marsh Transition	2	17	28	39	66	104	159	241	354	506	705
Salt Marsh	0	0	0	7	7	7	3	0	0	0	0
Tidal Flat	0	0	0	0	0	0	0	0	0	0	0
Inland Open Water	143	143	143	139	138	136	131	125	120	114	111
Estuarine Open Water	1	1	1	5	6	8	17	27	32	37	40
Brackish Marsh	109	109	109	109	109	109	109	109	109	109	109

IPCC Scenario A1B Minimum: 0.13 m (0.43 feet) Rise by 2100
Dare County Peninsula and Surrounding Area

Land Cover Class (ha)	Year										
	1982	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
Developed Upland	2,301	2,276	2,269	2,266	2,261	2,253	2,242	2,226	2,205	2,184	2,162
Undeveloped Upland	36,370	31,939	24,413	23,764	21,942	20,977	20,235	19,559	18,912	18,278	17,703
Forested Wetland	107,632	99,481	100,024	98,049	96,601	93,631	90,210	86,374	82,370	78,587	75,023
Cypress Swamp	326	304	294	290	285	277	267	255	241	227	216
Inland Fresh Marsh	7,024	6,832	6,768	6,740	6,706	6,660	6,614	6,558	6,500	6,440	6,378
Tidal Fresh Marsh	39	37	37	37	37	36	36	35	33	28	24
Marsh Transition	3,916	16,603	15,441	18,754	16,687	20,670	24,884	29,422	34,148	38,641	42,860
Salt Marsh	111	326	8,242	7,596	8,112	7,320	5,710	2,570	287	274	264
Estuarine Beach	33	32	31	9	9	8	8	8	7	7	6
Tidal Flat	0	1	3	2	2,264	71	25	25	8	0	0
Ocean Beach	52	15	9	5	2	0	0	0	0	0	0
Inland Open Water	1,569	1,568	1,644	1,618	1,543	1,492	1,445	1,393	1,346	1,307	1,269
Riverine Tidal Water	46	46	24	23	16	12	8	6	4	3	2
Estuarine Open Water	1,288	1,311	1,565	1,608	4,295	7,350	9,076	12,328	14,697	14,783	14,850
Open Ocean	10	48	55	59	62	64	64	64	64	64	64
Brackish Marsh	9,351	9,253	9,258	9,261	9,265	9,270	9,275	9,282	9,290	9,299	9,307
Inland Shore	20	20	20	19	18	16	15	13	11	8	5
Tidal Swamp	158	154	149	146	142	137	132	126	121	116	113

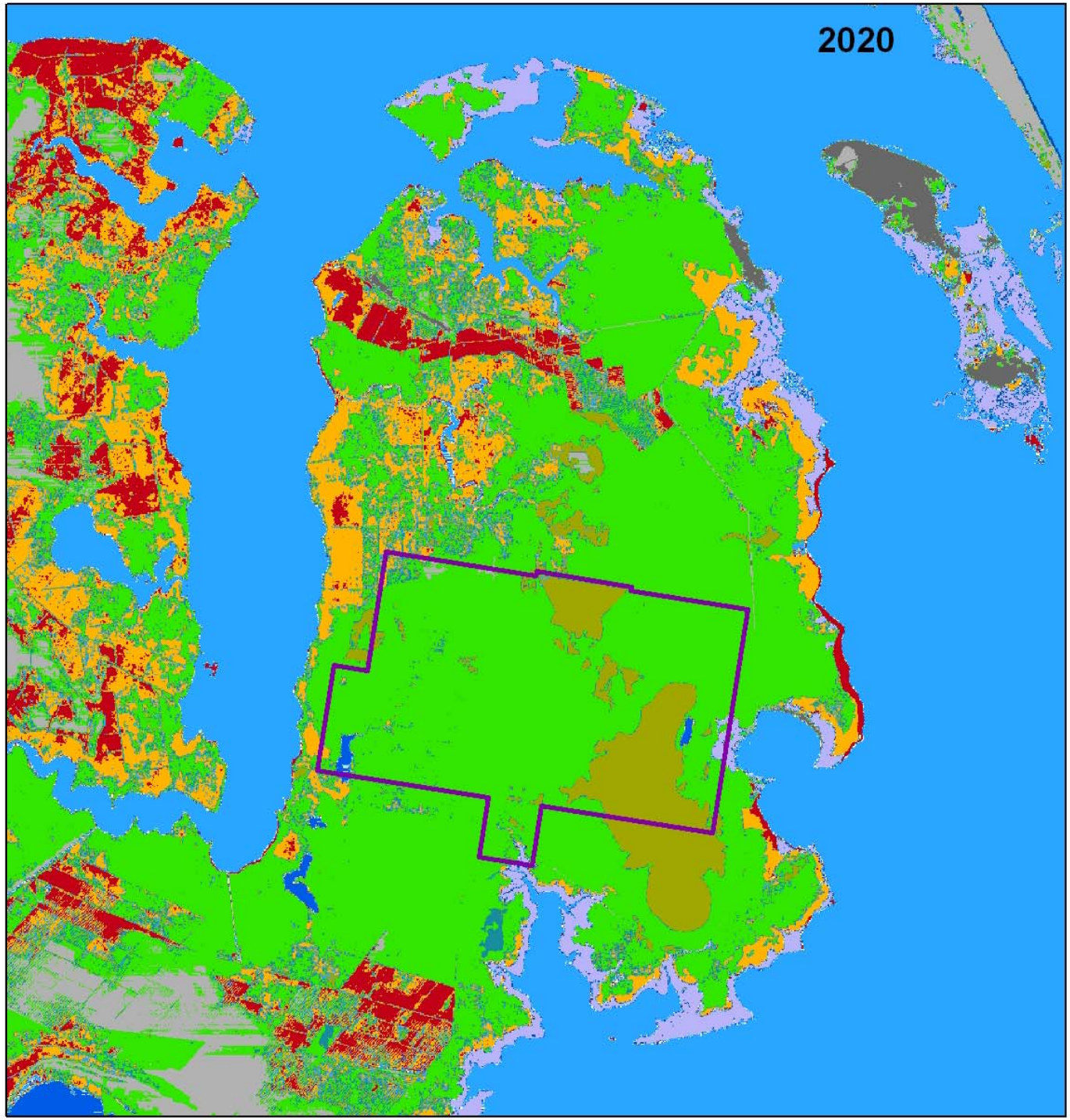
Air Force Dare County Bombing Range
Sea Level Rise Simulation

IPCC Scenario A1B Maximum: 0.7 m by 2100



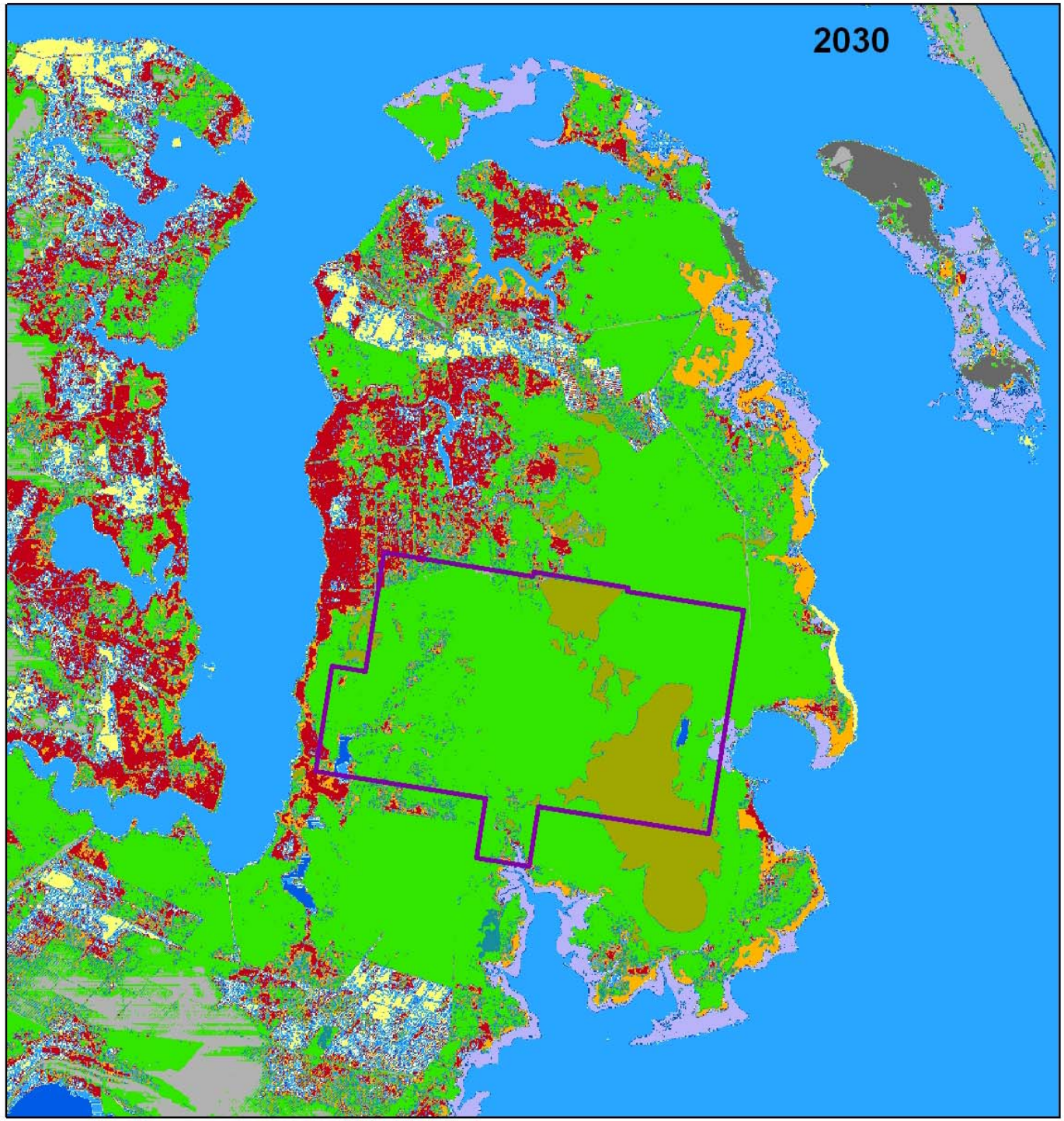
Air Force Dare County Bombing Range
Sea Level Rise Simulation

IPCC Scenario A1B Maximum: 0.7 m by 2100



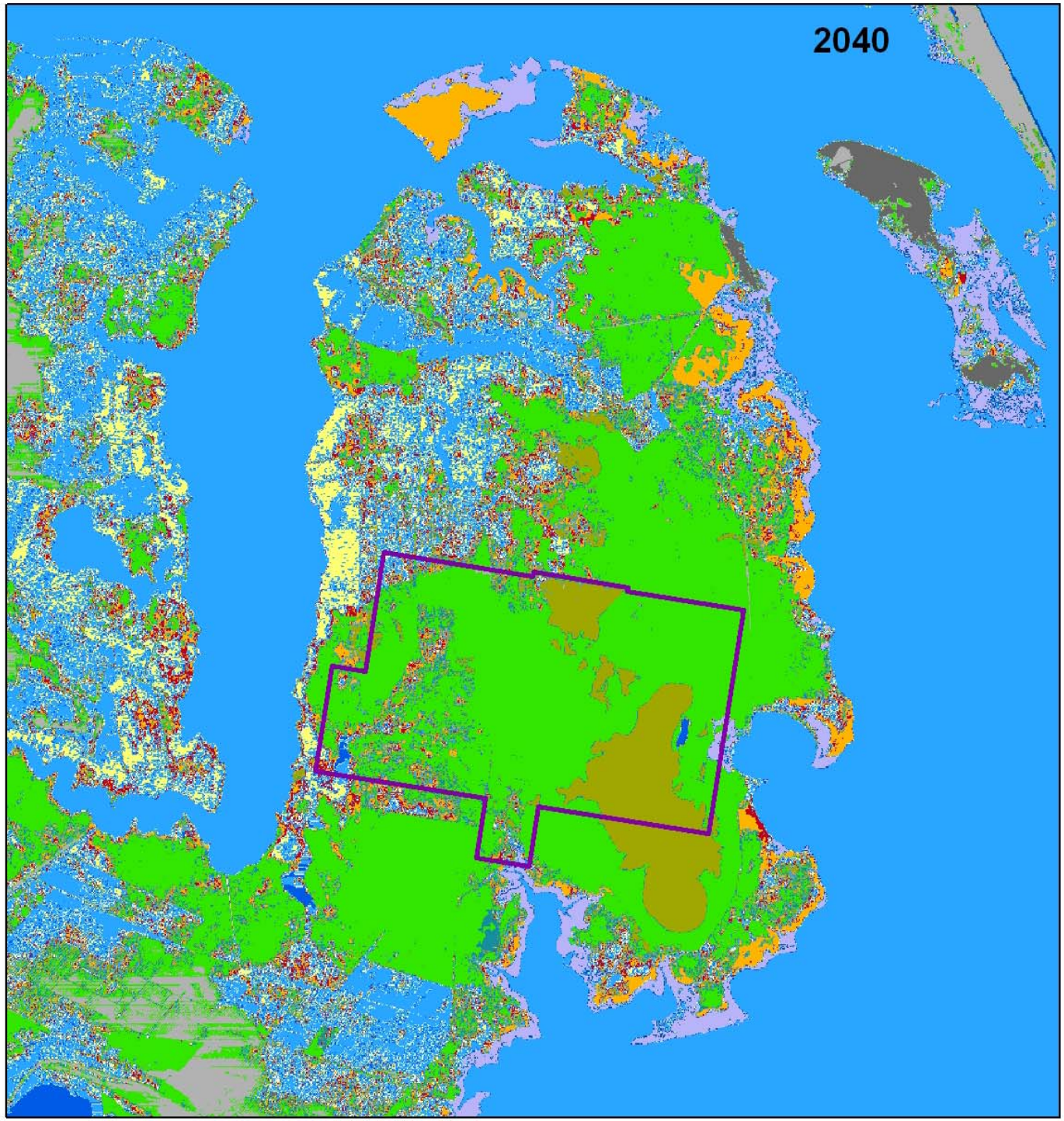
Air Force Dare County Bombing Range
Sea Level Rise Simulation

IPCC Scenario A1B Maximum: 0.7 m by 2100



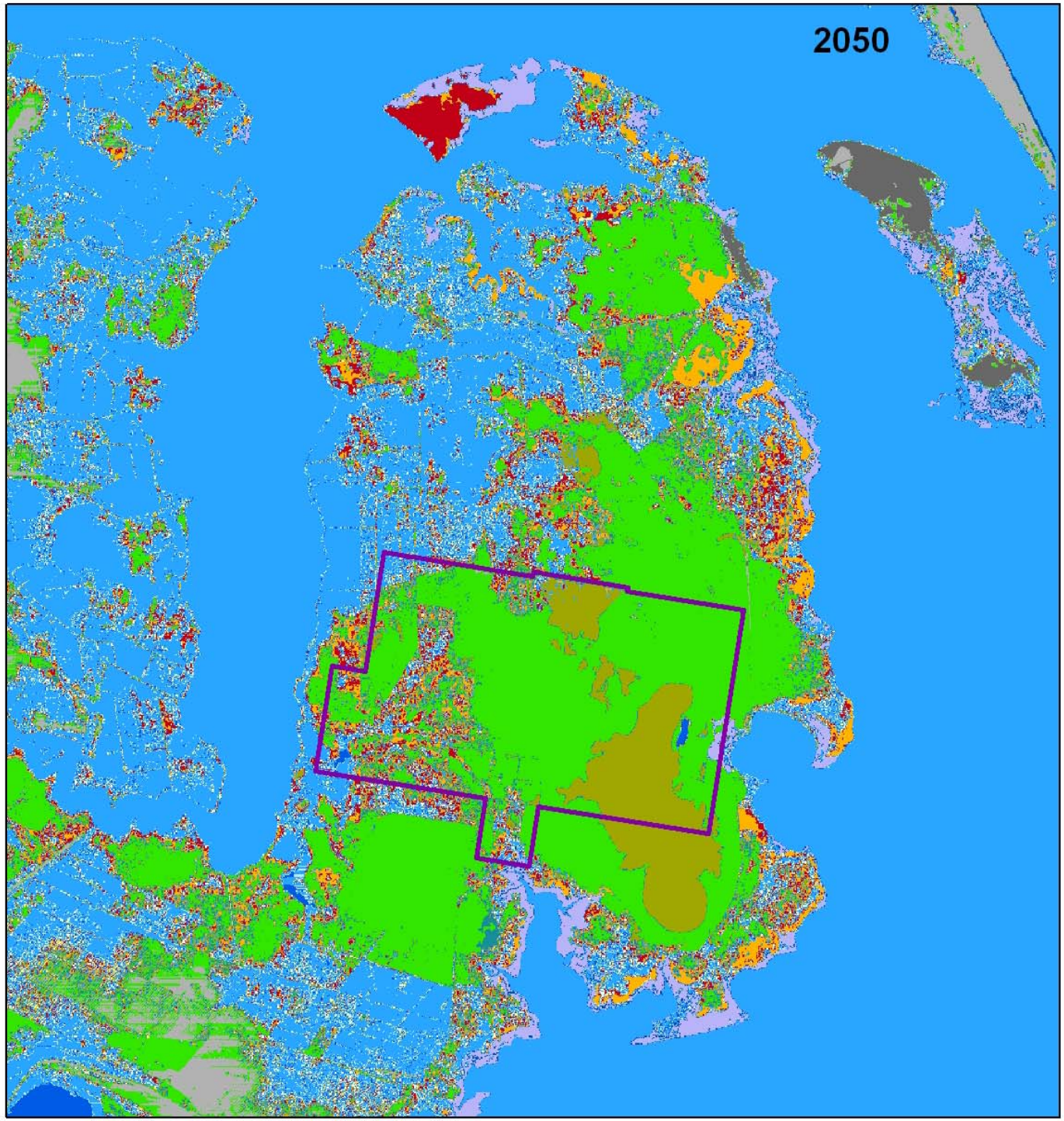
Air Force Dare County Bombing Range
Sea Level Rise Simulation

IPCC Scenario A1B Maximum: 0.7 m by 2100



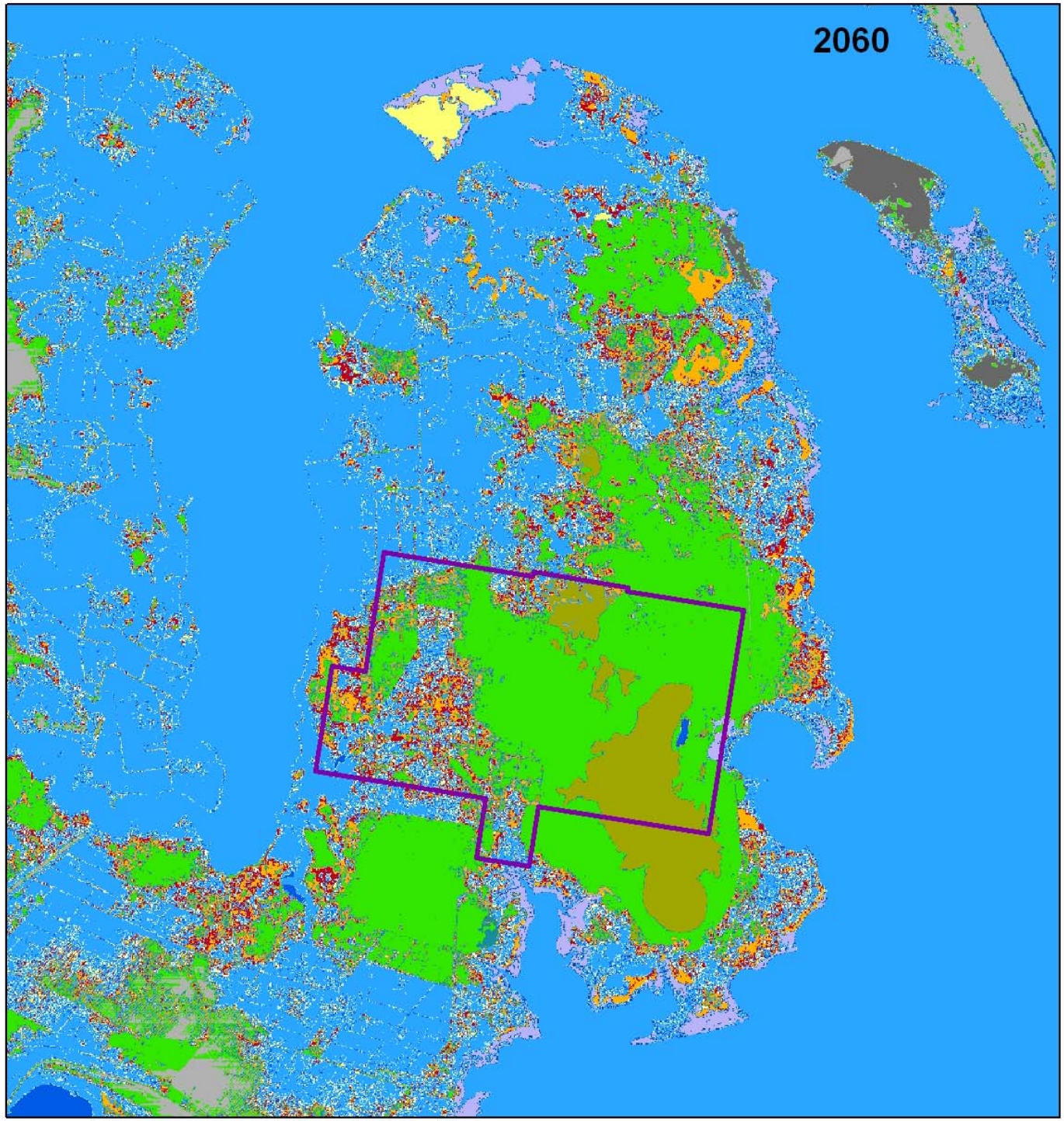
Air Force Dare County Bombing Range
Sea Level Rise Simulation

IPCC Scenario A1B Maximum: 0.7 m by 2100



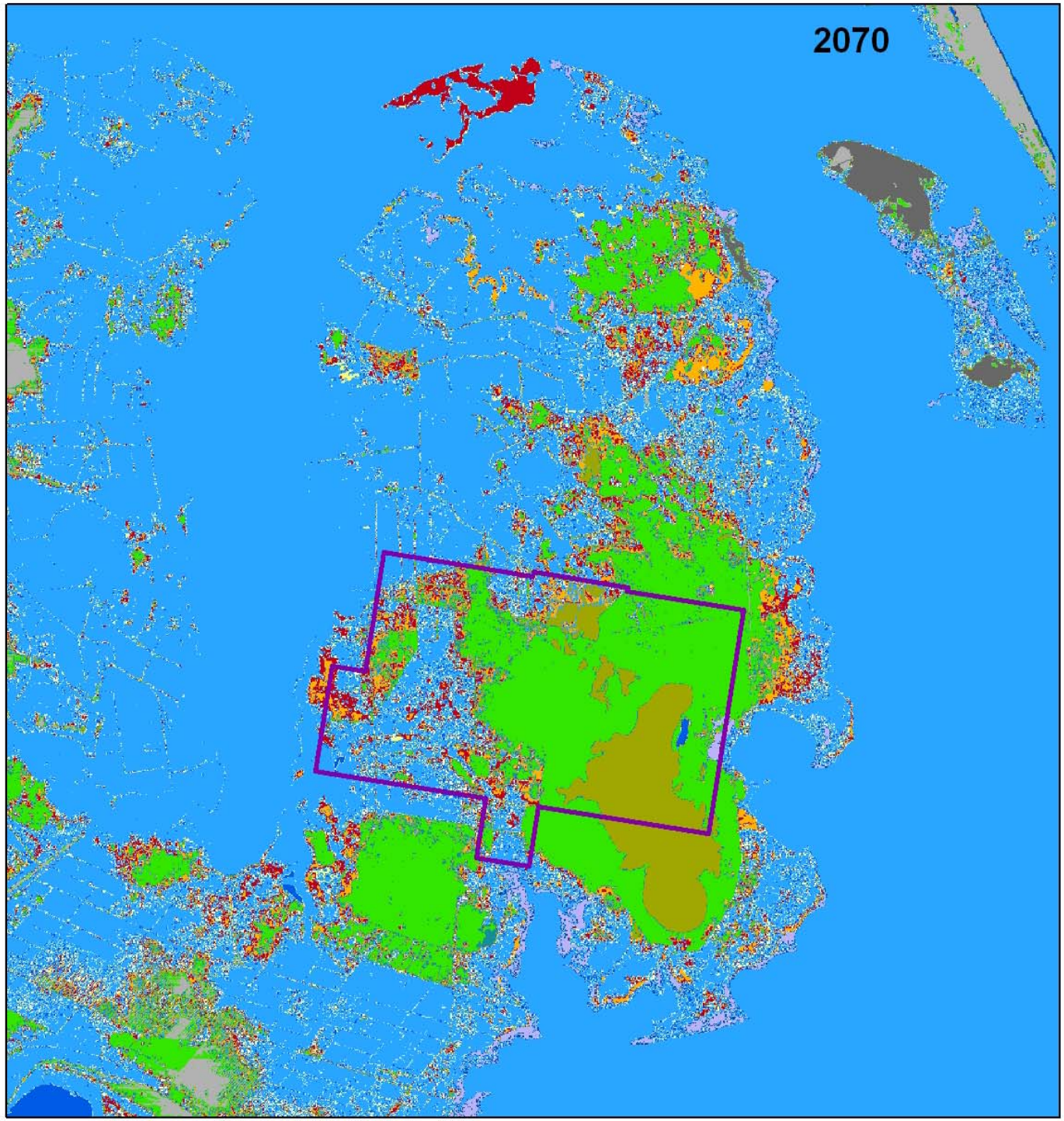
Air Force Dare County Bombing Range
Sea Level Rise Simulation

IPCC Scenario A1B Maximum: 0.7 m by 2100



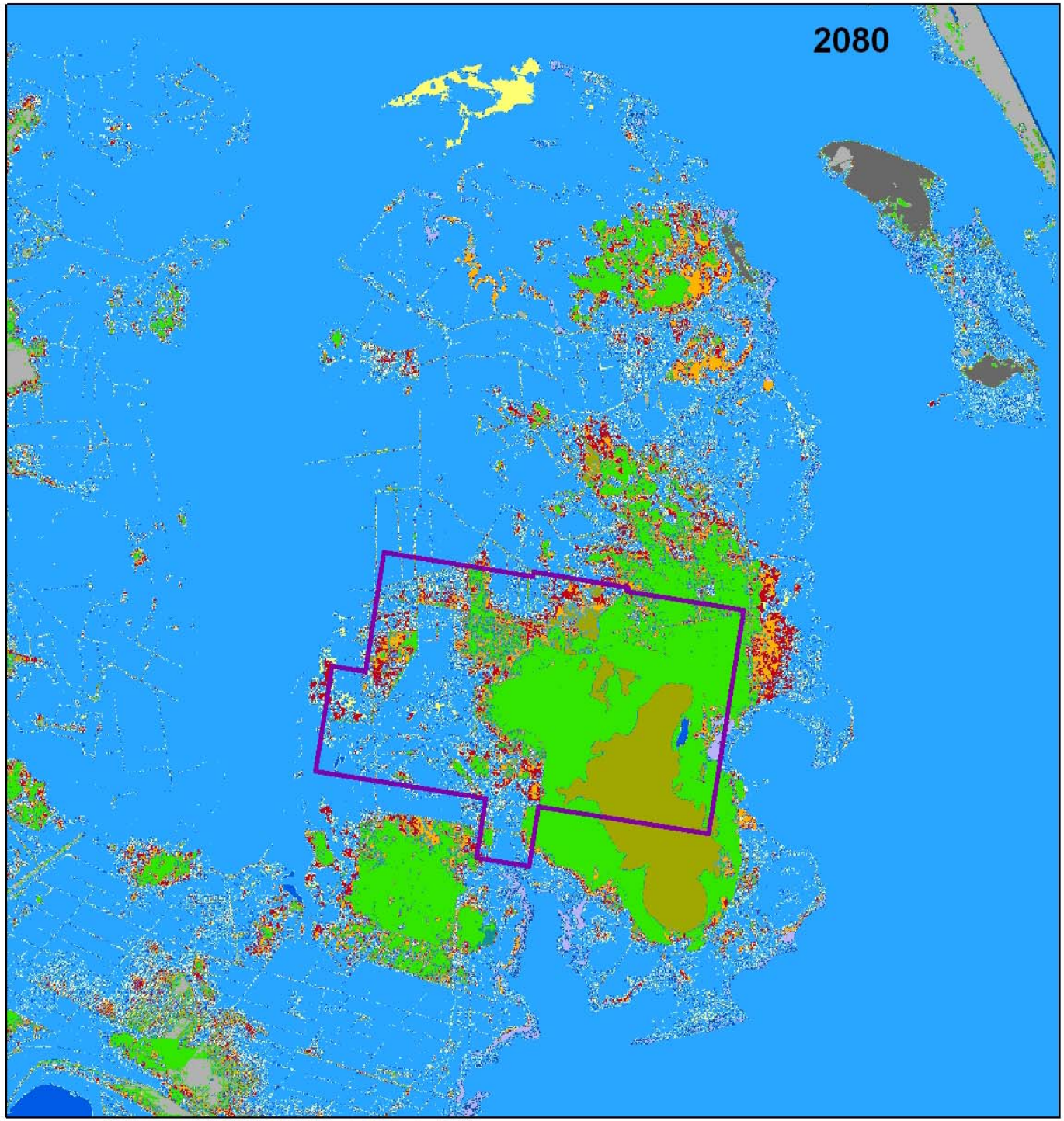
Air Force Dare County Bombing Range
Sea Level Rise Simulation

IPCC Scenario A1B Maximum: 0.7 m by 2100



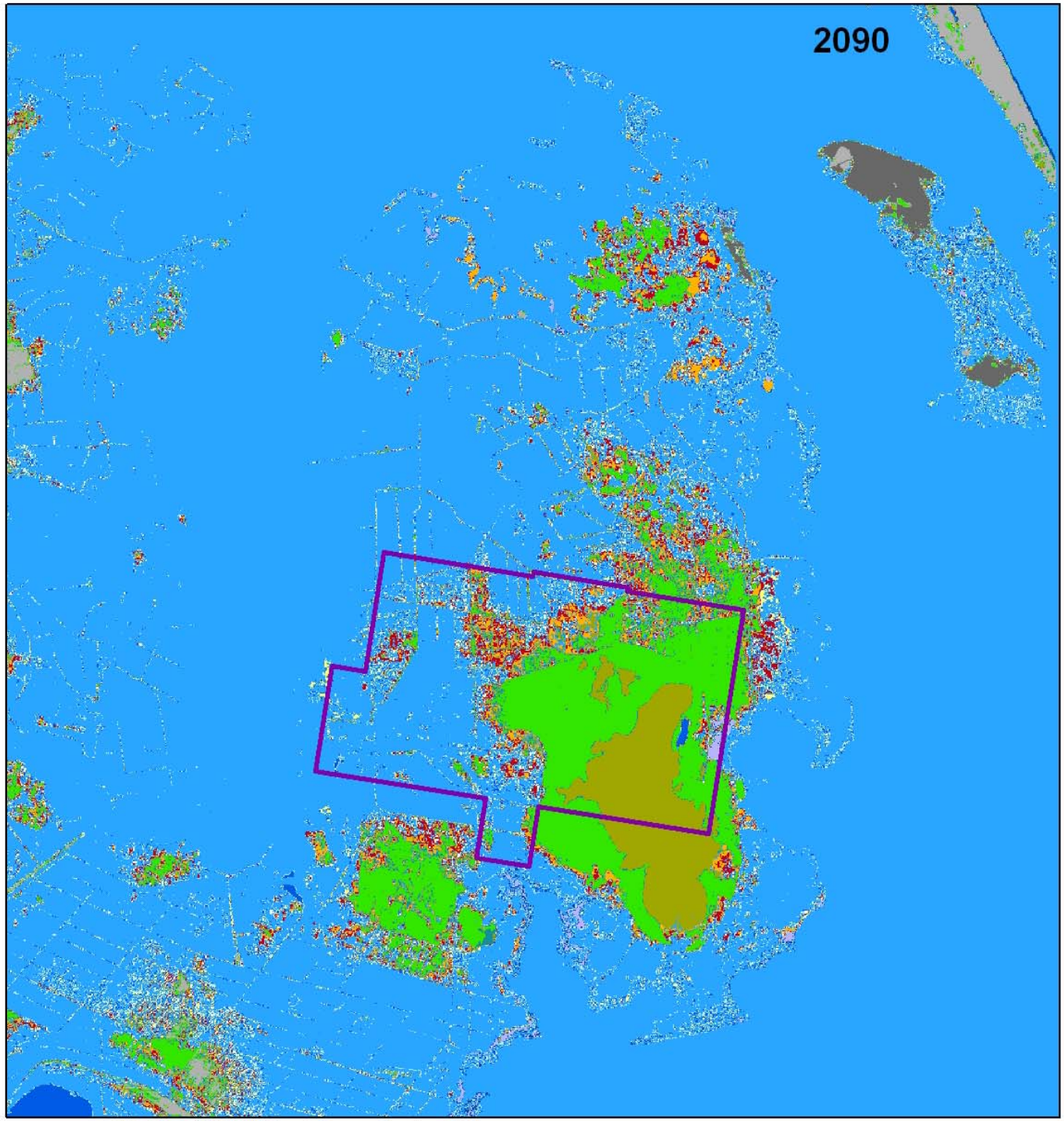
Air Force Dare County Bombing Range
Sea Level Rise Simulation

IPCC Scenario A1B Maximum: 0.7 m by 2100



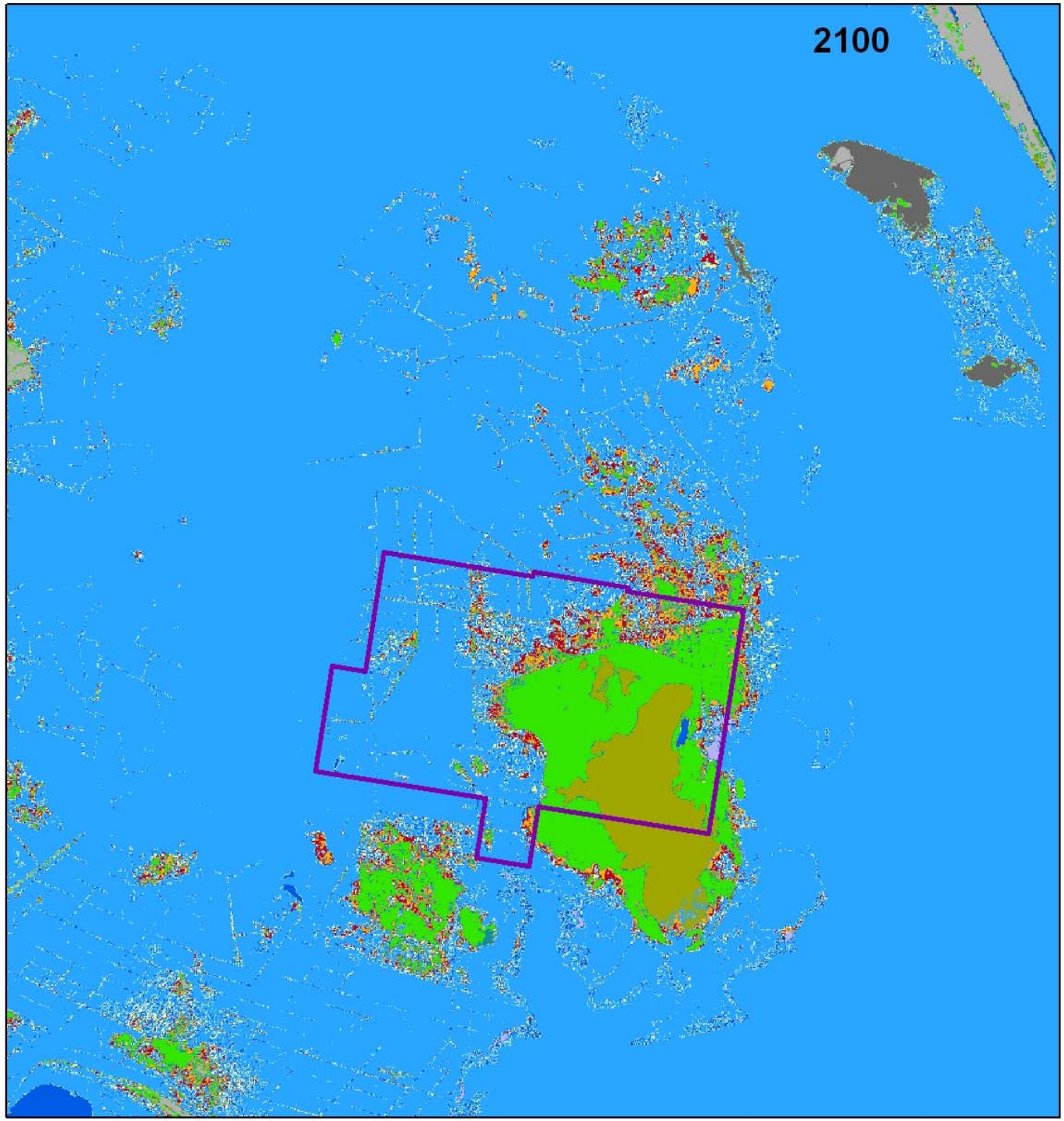
Air Force Dare County Bombing Range
Sea Level Rise Simulation

IPCC Scenario A1B Maximum: 0.7 m by 2100



Air Force Dare County Bombing Range
Sea Level Rise Simulation

IPCC Scenario A1B Maximum: 0.7 m by 2100



IPCC Scenario A1B Maximum 0.7 m (2.3 feet) Rise by 2100
Air Force Dare County Bombing Range

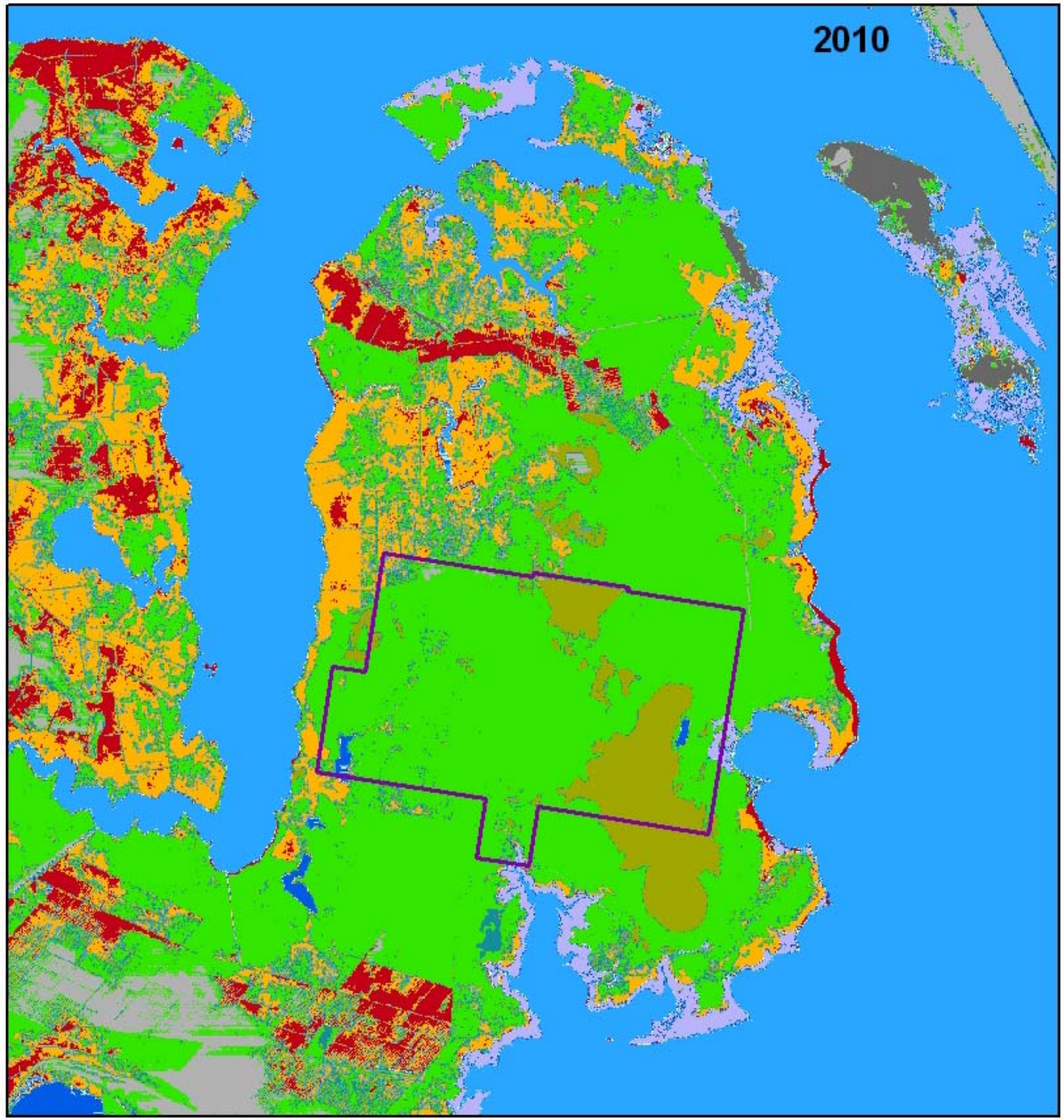
Land Cover Class (ha)	Year										
	1982	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
Undeveloped Upland	73	68	68	35	29	26	18	14	9	6	4
Forested Wetland	15,205	15,147	15,071	14,874	14,187	12,833	10,957	9,358	8,108	6,894	5,775
Inland Fresh Marsh	3,334	3,333	3,331	3,325	3,312	3,286	3,206	3,074	2,881	2,719	2,559
Marsh Transition	2	63	142	235	706	1,383	1,963	1,737	1,448	1,379	1,280
Salt Marsh	0	2	2	143	237	708	1,387	1,969	1,742	1,450	1,380
Tidal Flat	143	142	142	0	47	19	112	273	501	417	287
Inland Open Water	0	0	0	124	110	95	81	70	66	63	62
Estuarine Open Water	1	2	2	22	132	412	1,042	2,278	4,025	5,856	7,439
Brackish Marsh	109	108	108	108	107	105	100	94	89	85	80

IPCC Scenario A1B Maximum: 0.7 m Rise by 2100
Dare County Peninsula and Surrounding Area

Land Cover Class (ha)	Year										
	1982	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
Developed Upland	2,276	2,258	2,238	2,194	2,126	2,049	1,955	1,866	1,782	1,696	1,611
Undeveloped Upland	31,939	22,663	21,141	18,590	16,925	15,449	13,653	11,808	9,901	7,944	6,071
Forested Wetland	99,481	93,178	86,519	77,951	65,322	53,508	40,904	31,499	24,223	18,248	13,640
Cypress Swamp	304	279	259	226	194	169	133	100	74	59	50
Inland Fresh Marsh	6,832	6,653	6,539	6,394	6,140	5,853	5,499	5,177	4,872	4,628	4,367
Tidal Fresh Marsh	37	36	35	26	10	2	0	0	0	0	0
Marsh Transition	16,603	19,412	27,748	15,030	18,271	17,140	17,930	14,127	11,287	9,420	7,597
Salt Marsh	326	13,493	13,576	24,268	11,708	15,196	14,750	16,405	14,285	11,405	9,779
Estuarine Beach	32	8	8	7	6	4	3	2	2	1	1
Tidal Flat	1	16	8	7,414	10,376	1,144	2,491	1,887	2,724	2,664	1,602
Ocean Beach	15	0	0	0	0	0	0	0	0	0	0
Inland Open Water	1,568	1,577	1,529	1,348	1,238	1,149	1,059	1,014	997	987	984
Riverine Tidal Water	46	20	17	3	1	0	0	0	0	0	0
Estuarine Open Water	1,311	1,738	1,783	8,090	29,450	50,414	64,320	79,709	95,290	109,634	122,093
Open Ocean	48	64	64	64	64	65	65	65	66	66	67
Brackish Marsh	9,253	8,701	8,647	8,526	8,322	8,028	7,429	6,552	4,724	3,482	2,380
Inland Shore	20	17	14	9	2	0	0	0	0	0	0
Tidal Swamp	154	132	119	106	92	77	56	35	20	11	4

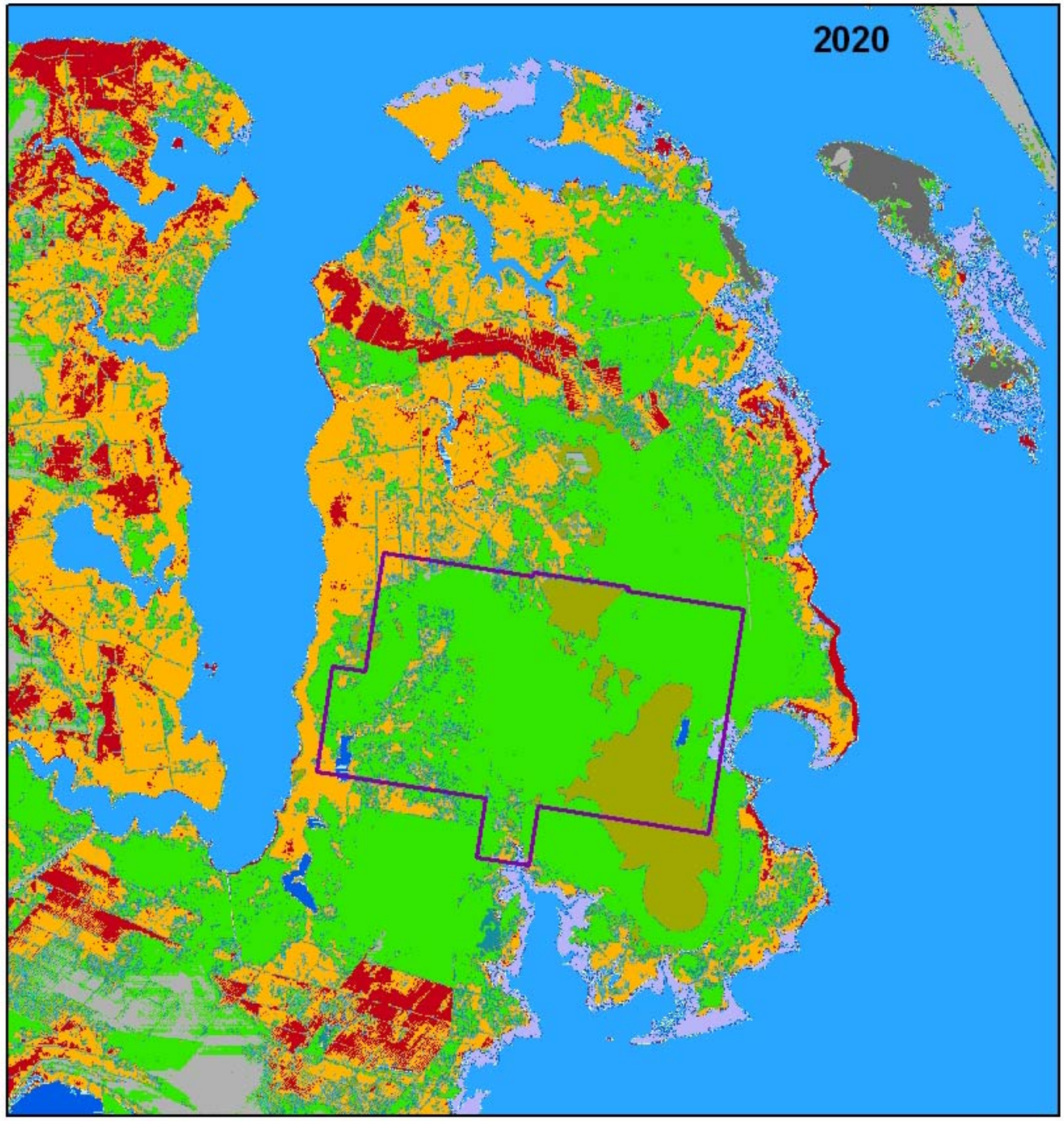
Air Force Dare County Bombing Range
Sea Level Rise Simulation

Scenario 1.5 m Rise by 2100



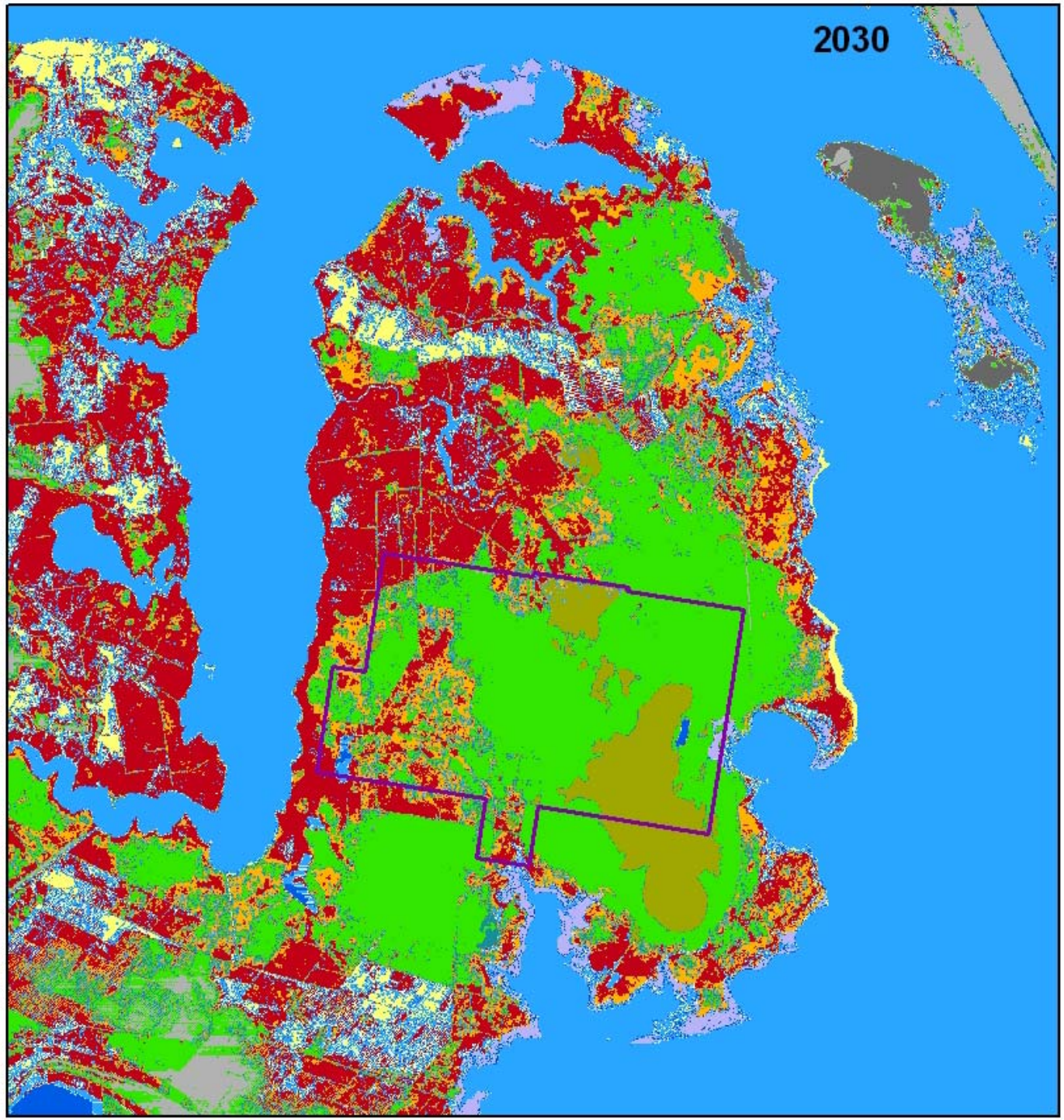
Air Force Dare County Bombing Range
Sea Level Rise Simulation

Scenario 1.5 m Rise by 2100



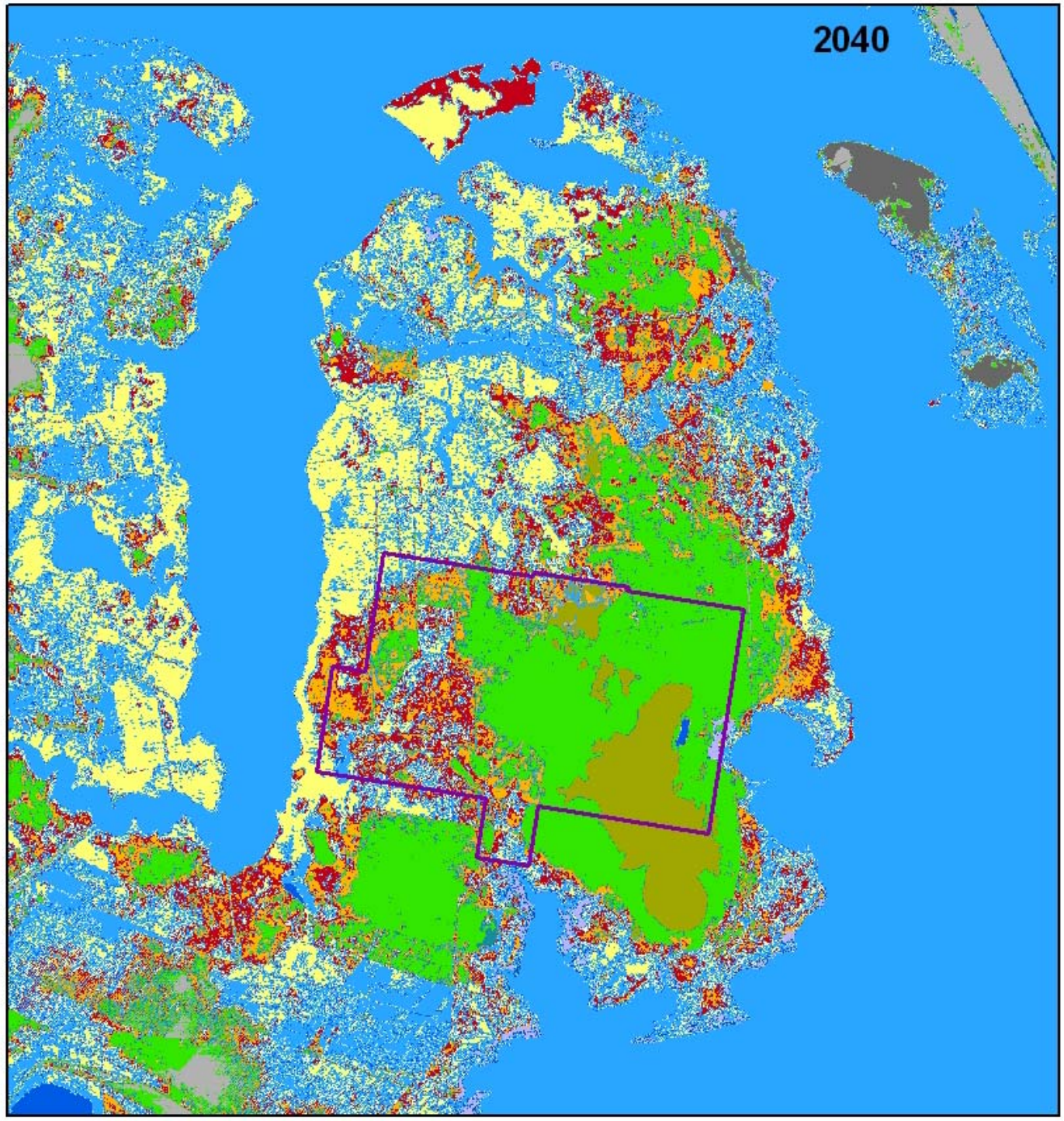
Air Force Dare County Bombing Range
Sea Level Rise Simulation

Scenario 1.5 m Rise by 2100



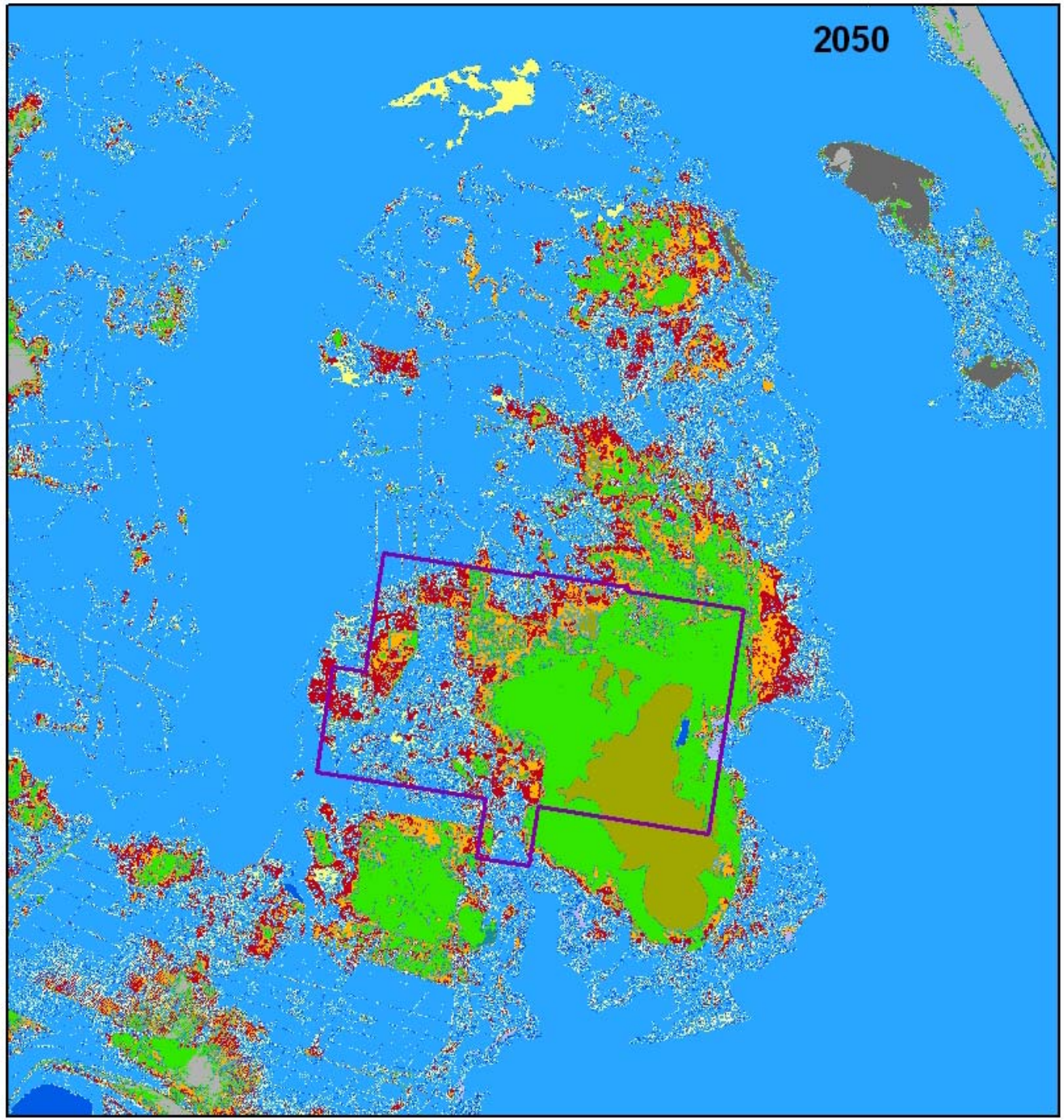
Air Force Dare County Bombing Range
Sea Level Rise Simulation

Scenario 1.5 m Rise by 2100



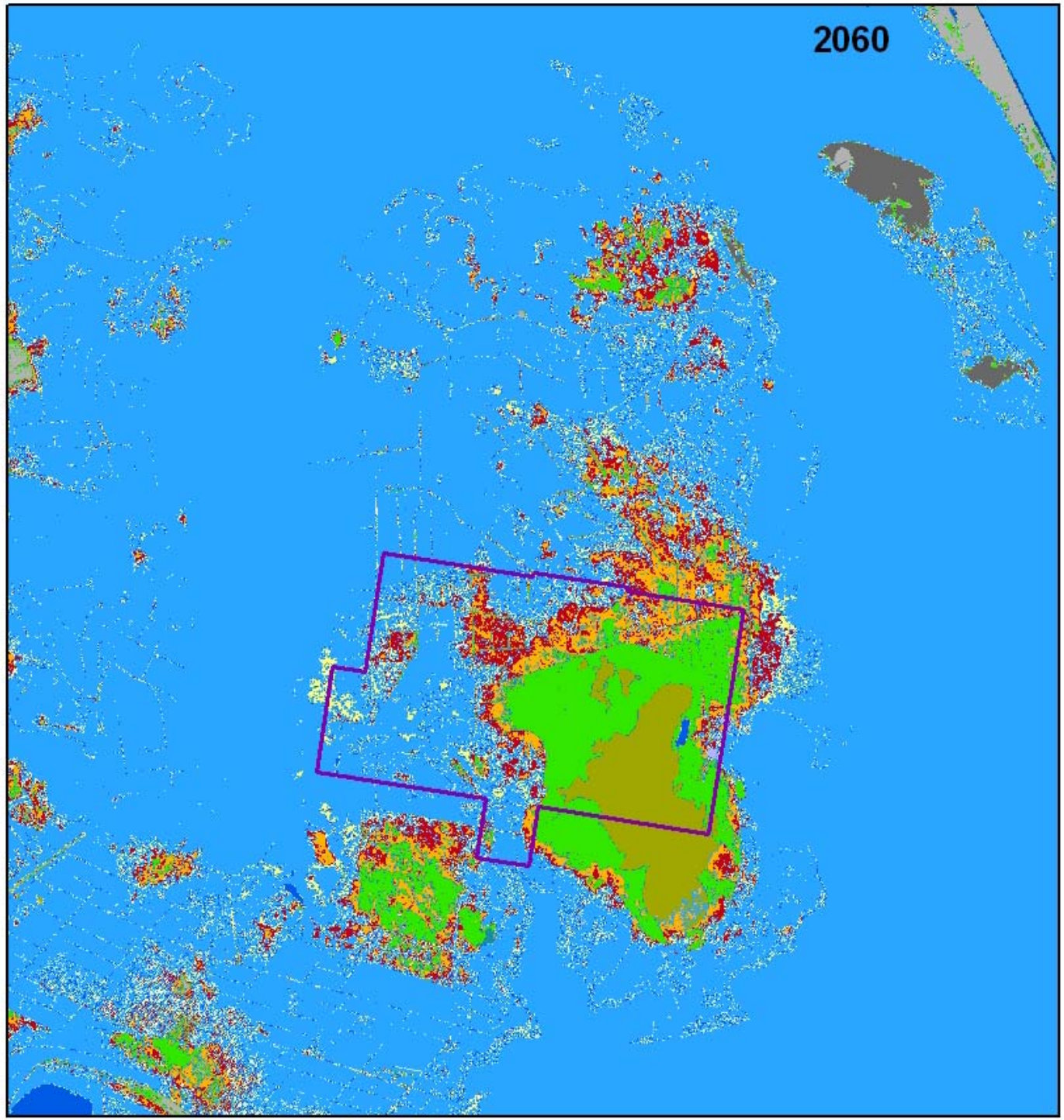
Air Force Dare County Bombing Range
Sea Level Rise Simulation

Scenario 1.5 m Rise by 2100



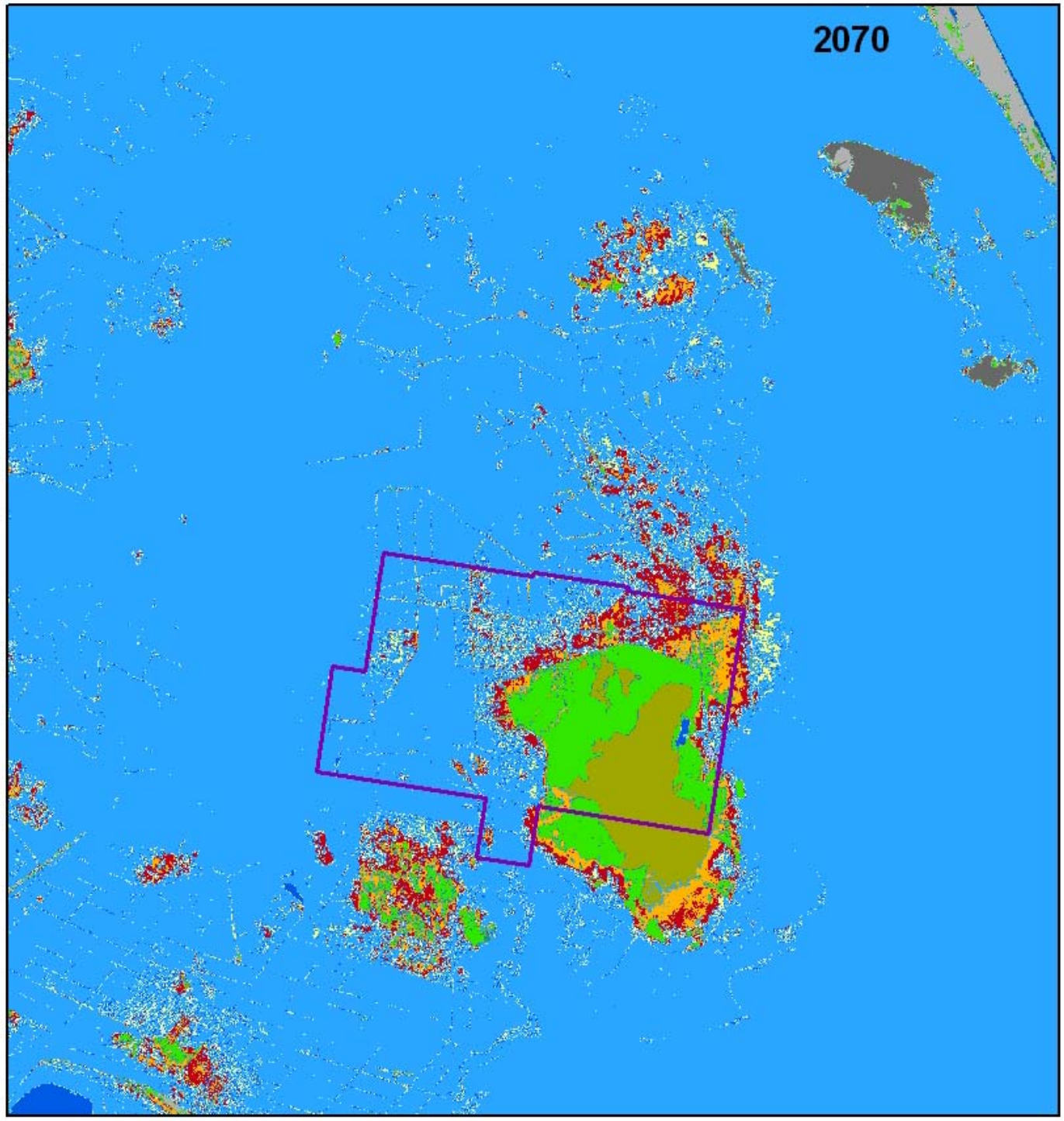
Air Force Dare County
Bombing Range
Sea Level Rise Simulation

Scenario 1.5 m Rise by 2100



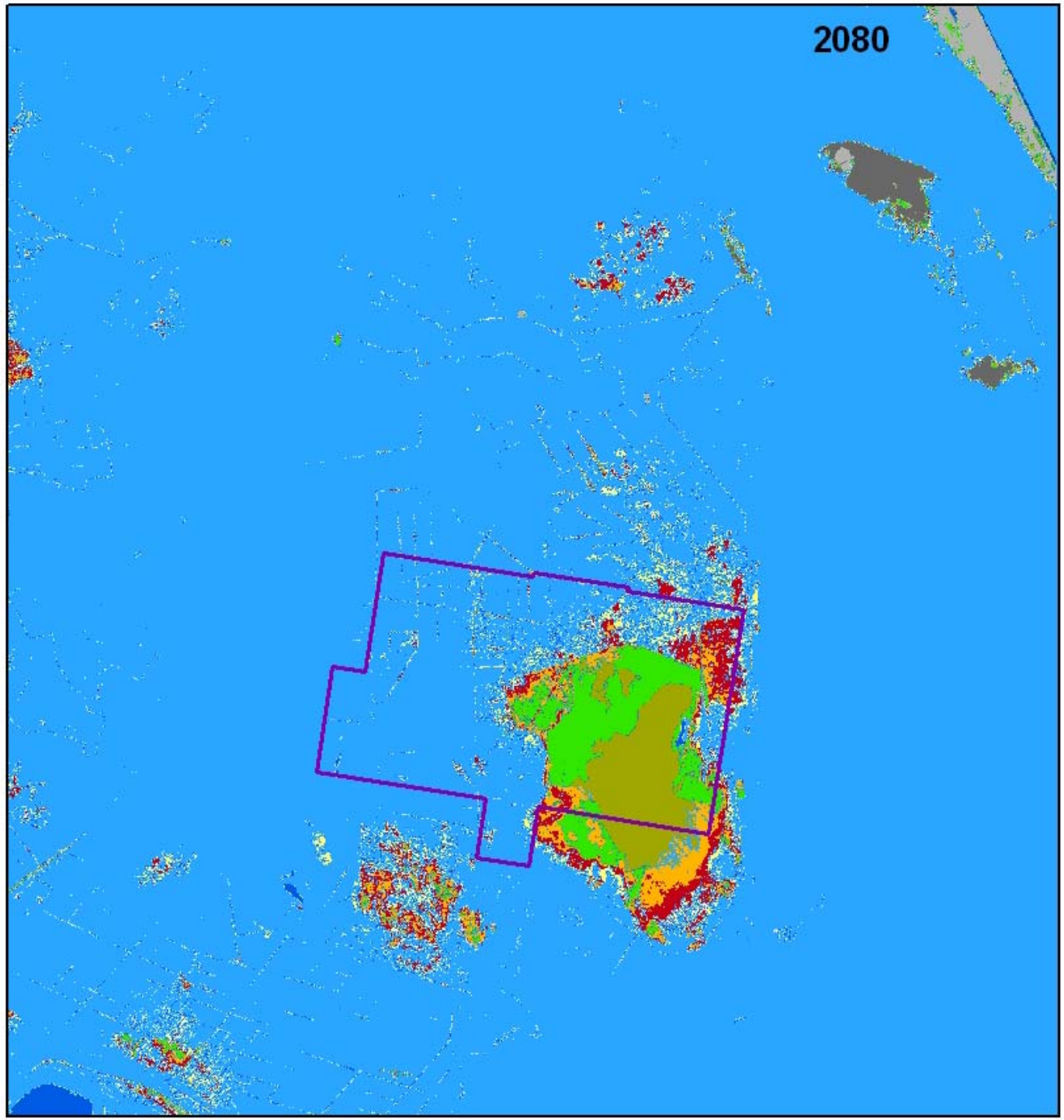
Air Force Dare County
Bombing Range
Sea Level Rise Simulation

Scenario 1.5 m Rise by 2100



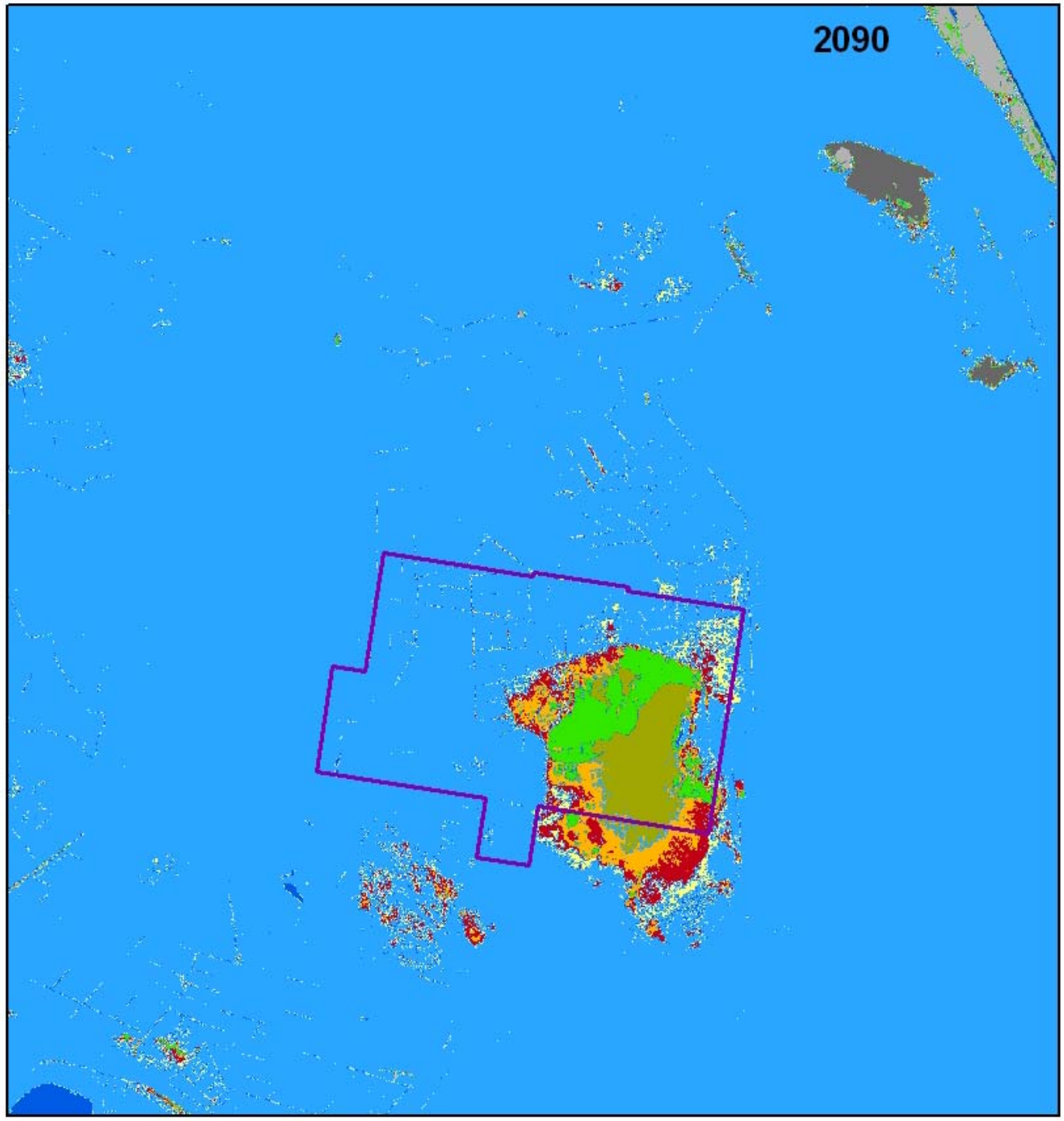
Air Force Dare County Bombing Range
Sea Level Rise Simulation

Scenario 1.5 m Rise by 2100



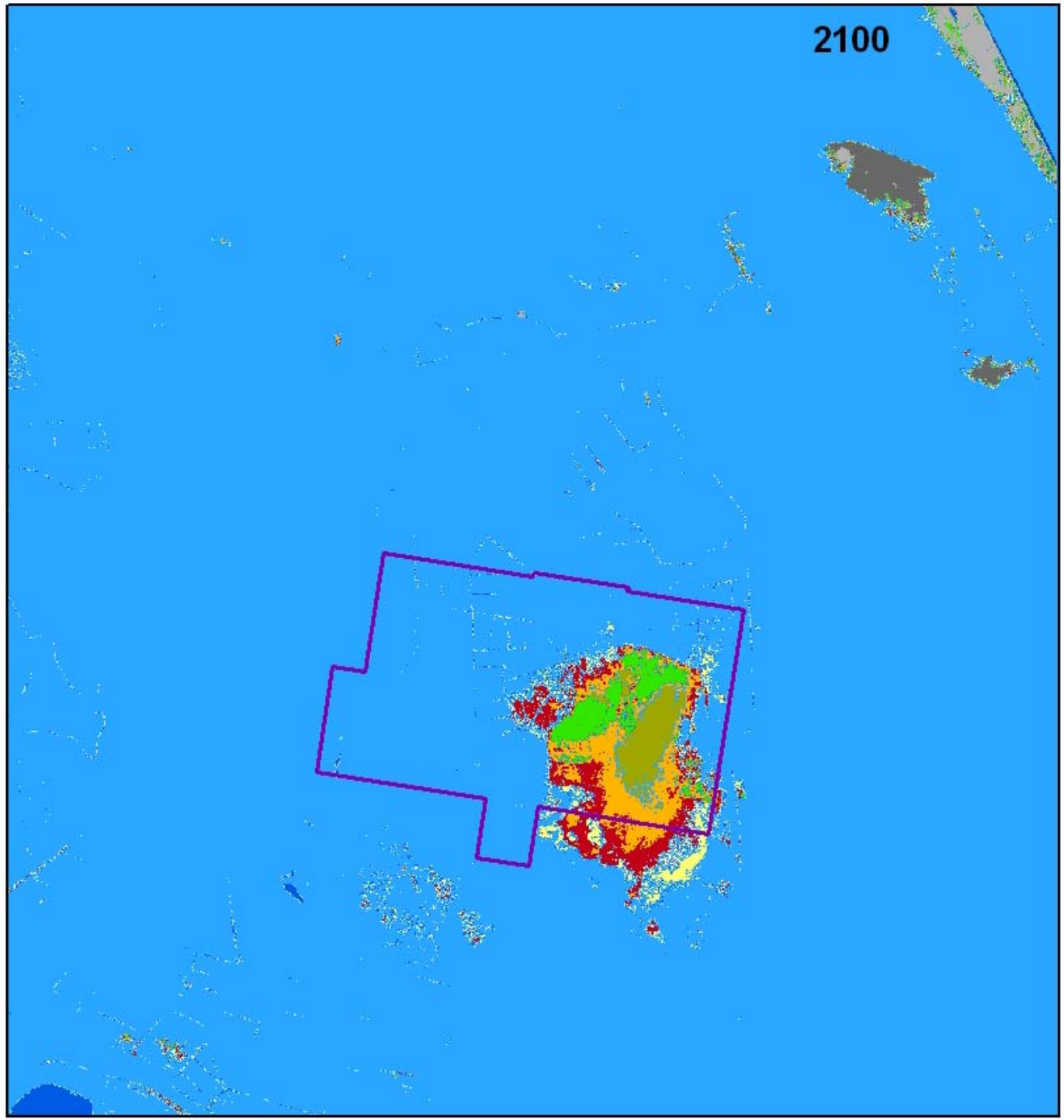
Air Force Dare County Bombing Range
Sea Level Rise Simulation

Scenario 1.5 m Rise by 2100



Air Force Dare County Bombing Range
Sea Level Rise Simulation

Scenario 1.5 m Rise by 2100



Eustatic Sea Level Rise Scenario: 1.5m (4.92 feet) Rise by 2100
Air Force Dare County Bombing Range

Land Cover Class (ha)	Year										
	1982	**2010**	**2020**	**2030**	**2040**	**2050**	**2060**	**2070**	**2080**	**2090**	**2100**
Undeveloped Upland	73	67	54	25	13	6	3	2	1	0	0
Forested Wetland	15,205	14,954	14,229	11,995	9,296	7,371	5,264	3,938	3,008	2,179	1,370
Inland Fresh Marsh	3,334	3,327	3,312	3,255	3,055	2,770	2,511	2,453	2,383	2,173	1,485
Marsh Transition	2	264	1,016	2,321	2,912	2,216	2,369	1,385	1,002	1,039	1,498
Salt Marsh	0	4	6	1,024	2,331	2,919	2,232	2,401	1,407	1,008	1,039
Tidal Flat	143	141	141	1	497	912	1,246	800	1,134	667	466
Inland Open Water	0	0	0	91	71	64	59	58	44	33	21
Estuarine Open Water	1	3	4	58	606	2,529	5,119	7,799	9,881	11,766	12,988
Brackish Marsh	109	107	104	97	87	79	63	30	7	1	0

Eustatic Sea Level Rise Scenario: 1.5m Rise by 2100
Dare County Peninsula and Surrounding Area

Land Cover Class (ha)	Year										
	1982	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
Developed Upland	2,301	2,276	2,216	2,137	2,015	1,871	1,741	1,578	1,439	1,321	1,214
Undeveloped Upland	36,370	31,939	20,071	17,343	13,853	11,205	8,513	5,219	2,937	1,957	1,607
Forested Wetland	107,632	99,481	80,655	65,918	48,536	31,876	20,936	11,783	6,914	4,296	2,582
Cypress Swamp	326	304	239	196	154	99	63	46	29	4	0
Inland Fresh Marsh	7,024	6,832	6,420	6,098	5,677	5,144	4,710	4,257	3,847	3,277	2,643
Tidal Fresh Marsh	39	37	30	10	1	0	0	0	0	0	0
Marsh Transition	3,916	16,603	34,741	52,422	24,171	21,479	14,923	13,353	7,778	4,307	2,812
Salt Marsh	111	326	13,951	14,550	50,778	25,452	22,820	16,168	13,865	7,887	4,314
Estuarine Beach	33	32	7	6	3	2	1	1	1	1	1
Tidal Flat	0	1	16	8	7,671	31,645	7,134	6,620	4,301	4,616	2,545
Ocean Beach	52	15	0	0	0	0	0	0	0	1	3
Inland Open Water	1,569	1,568	1,503	1,460	1,144	1,022	987	974	970	954	940
Riverine Tidal Water	46	46	16	15	0	0	0	0	0	0	0
Estuarine Open Water	1,288	1,311	1,806	1,886	9,098	36,054	86,075	109,434	127,937	141,525	151,500
Open Ocean	10	48	64	64	65	65	66	67	68	70	74
Brackish Marsh	9,351	9,253	8,392	8,041	7,017	4,302	2,266	746	159	29	11
Inland Shore	20	20	12	2	0	0	0	0	0	0	0
Tidal Swamp	158	154	107	89	63	30	11	1	0	0	0

Specific sea level rise mitigation strategies that the US Fish and Wildlife Service and Nature Conservancy have recommended include:

- Conducting a hydrologic assessment and management plan
- Installing tide gates adjacent to the sound and river and gated culverts in interior ditches so that brackish water does not flow inland through them,
- Establishing salt tolerant cypress trees and other vegetation in areas that are expected to become brackish wetlands,
- Construction oyster shell reefs and re-establishing brackish marshes along the Dare County peninsula in eroded areas where it is absent and areas that are likely to become wetlands in the future,
- Creating corridors that run from the shoreline inland which could facilitate habitat migration,
- Establishing submerged aquatic vegetation beds offshore to reduce shoreline erosion.

Restoration Challenges for Atlantic white-cedar

- Seed germination and seedling establishment under altered surface hydrology
- Lack of wildland fire for natural stand replacement
- Hardwood competition (aerial hardwood herbicide application)
- Tide driven saltwater intrusion and overwash from storm events
- Wind damage from increased severity and frequency of storm events