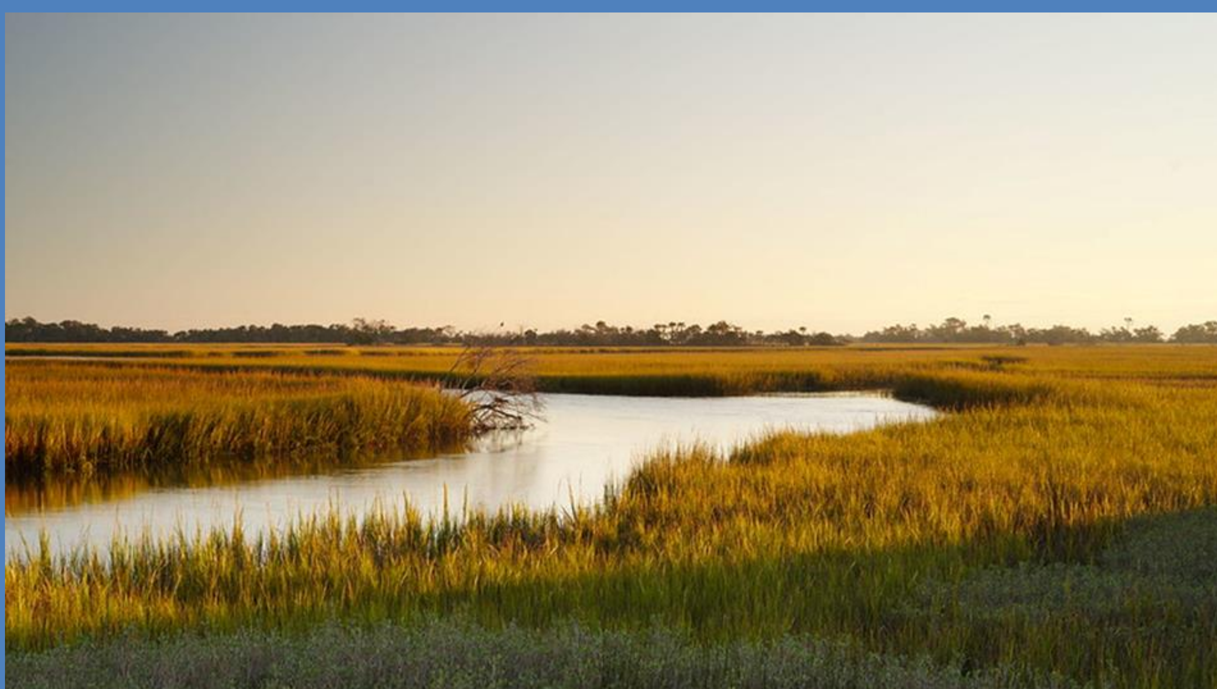
NORTH CAROLINA COASTAL HABITAT GREENHOUSE GAS INVENTORY



Salt marsh on Bald Head Island, North Carolina

Final Report

September 2023

Acknowledgements

We would like to acknowledge the contributions of our peer reviewers: Molly Bost, National Oceanic and Atmospheric Administration; Joanna Lyle, formerly with TNC; Katie Warnell, Duke University; Zac Cannizzo, National Oceanic and Atmospheric Administration; and Beverly Johnson, Bates College. Their feedback and guidance were invaluable.

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Executive Summary

This report presents a greenhouse gas (GHG) inventory for North Carolina's coastal wetlands: seagrass, emergent, and scrub-shrub.[1] This inventory demonstrates the extent to which these coastal wetlands remove GHGs and provide a carbon sink for the state, in addition to supporting other well-known benefits such as fisheries habitat and biodiversity. The GHG inventory of coastal wetlands has built on approaches used to prepare the State of North Carolina's GHG inventory, as well as the U.S. Environmental Protection Agency's Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2021. It is one of the first inventories developed in alignment with geographical regions as laid out in the state's Coastal Habitat Protection Plan (CHPP). The North Carolina GHG inventory for seagrass is one of the first of its kind in the U.S. and is also one of the first inventories to utilize salinity data to estimate methane emissions for emergent and scrub-shrub wetlands. The inventory presented here will be incorporated into the 2024 update of North Carolina's GHG inventory.

North Carolina has the largest extent of seagrass coverage along the U.S. Atlantic coast, measuring approximately 86,412 acres in 2021. The analysis shows that these high salinity seagrass habitats provided a net carbon sink to the state, although GHG removals decreased over time due to loss in seagrass coverage.[2] Overall, seagrass beds in 2021 sequestered approximately -0.055 million metric tons (MMT) CO_2 equivalent (CO_2e; -55.14 kilotons CO_2e) in the soils alone (a negative value denotes GHG removals).

The total acreage of emergent and scrub-shrub coastal wetlands in the state in 2021 was 308,659 acres, demonstrating a slight reduction in acreage since 1990. The analysis shows that from the period of 1990 to 2021, emergent and scrub-shrub coastal wetlands in North Carolina were a net carbon source, emitting 0.31 MMT CO_2e (307.0 kt CO_2e) in 2021, driven by naturally occurring methane emissions from lower salinity wetlands and loss of coastal wetlands to open water due to erosion driven by sea level rise and storm events.

North Carolina's coastal wetlands (emergent, scrub-shrub and seagrass) hold significant carbon stocks: 38.7 MMT C (141.9 MMT CO_2e) in the biomass and top meter of soil, equivalent to the emissions from 71.7 MMT of coal burned.[3] Avoiding degradation and conversion of coastal wetlands and restoring historic coastal wetlands habitat will help ensure these carbon stocks remain intact and that net annual carbon accumulation holds steady or increases.

Planned future improvements for the seagrass GHG inventory should include (1) incorporating new North Carolina-specific soil and biomass carbon accumulation rates; and 2) projecting GHG emissions through 2050 under two scenarios: a continuation of current trends, and achievement of the Coastal Habitat Protection Plan (CHPP) 2021 seagrass acreage goal. Planned future improvements for the coastal emergent and scrub-shrub wetlands inventory should include (1) using a nationally harmonized land cover representation that reconciles the National Ocean and Atmospheric Administration (NOAA) Coastal Change Analysis Program (C-CAP) data with the National Resource Inventory, Forest Inventory Analysis, and the National Land Cover Database; and (2) adding North Carolina-specific carbon accumulation rates.

Introduction

In 2018, the North Carolina Department of Environmental Quality (DEQ) began developing a state inventory of greenhouse gases (GHG), an economy-wide inventory that includes an accounting of GHG fluxes (i.e., emissions and removals) from natural and working lands (NWL)[4] within the "Land Use, Land Use Change, and Forestry (LULUCF)" sector. In the process of developing this inventory, the significance of NWL as major carbon sinks and their importance in helping mitigate climate change was evident to DEQ staff. While attending the US Climate Alliance and American Forests' Learning Lab in Washington, DC (July 2018), a workshop to support states in identifying and evaluating carbon mitigation strategies for NWL, DEQ representatives developed the framework for a plan to acknowledge and leverage the carbon sequestration benefits of these lands: the North Carolina Natural and Working Lands Action Plan.[5] The issuance of Executive Order 80 (EO 80) by Governor Roy Cooper in October 2018, which includes a goal of reducing statewide GHGs to 40% below 2005 levels by 2025, underscored the need to codify a plan for managing and enhancing NWLs to maximize their climate resilience and mitigation benefits. A North Carolina Natural and Working Lands (NC NWL) Stakeholder Group was convened, publishing their final plan in June 2020.

Recognized within the NWL Action Plan for their large per-unit-area carbon storage, North Carolina's wetlands cover 4.9 million acres of the state, with 95% of existing wetlands located in the state's coastal plain. However, lack of an available, state-specific breakdown of National Greenhouse Gas Inventory (NGGI) data for coastal wetlands precluded the inclusion of wetlands in the 2018 NC GHG Inventory. In 2021, the Environmental Protection Agency (EPA) made disaggregated coastal wetlands data (not including seagrass since these habitats are not yet included in the national inventory) available to states for incorporation into their own inventories, and NC incorporated these estimates into the state's 2022 GHG inventory update.

The North Carolina (NC) Coastal Habitats GHG Workgroup (Workgroup), under the auspices of the Coastal Habitats Subcommittee of the NC NWL Stakeholder Group, was formed to facilitate the development of a coastal wetland GHG inventory. The Workgroup's aim was to develop a refined coastal wetlands GHG inventory, using NGGI data as a starting point, that is readily assimilable into the sector-wide NC GHG inventory and incorporates NC-specific data to the maximum extent technically feasible.

In keeping with the NC GHG Inventory as a whole, the key uses of the Coastal Habitat GHG Inventory are to inform the public, identify the largest sectors contributing towards emissions and removals, and prioritize policy-making, as well as track progress on emission reduction commitments and goals. In addition, since the Coastal Habitat GHG Inventory builds on the Coastal Habitat Protection Plan (CHPP), it can be used to track the GHG mitigation impacts of CHPP goals, such as the goal of "protecting and restoring submerged aquatic vegetation (SAV) to reach an interim goal of 191,000 acres coastwide with specific targets by SAV waterbody regions."[6] The intended audiences are government officials, research and academic institutions, nonprofit organizations, businesses, and other stakeholders whose actions affect or could affect the net carbon accumulation rates of NC coastal habitats. The Coastal Habitats GHG inventory covers all of NC's seagrass as well as coastal emergent and shrub scrub wetlands. It does not include low-salinity SAV due to uncertainties in methane emission rates and in how the areal extent of low-salinity SAV has changed over time.

Practical and technical considerations led the Workgroup to pursue separate but parallel development of inventories for seagrass and for emergent and scrub-shrub coastal wetlands. This inventory covers NC's seagrass beds[7] and coastal emergent and scrub-shrub wetlands regions as presented in the CHPP 2021 Amendment[8] (Figure 1 and Figure 2).

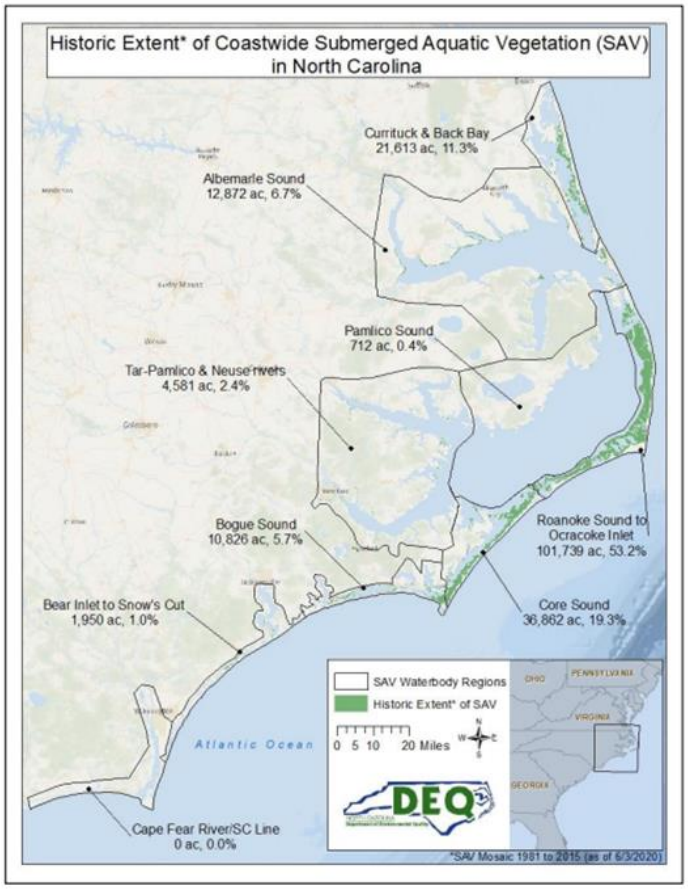

Figure 1. Known historic extent of submerged aquatic vegetation (SAV) mapped in NC, 1981 to 2015. Absence of SAV does not suggest actual absence, as surveys have not been conducted in all areas. Presence of SAV does not necessarily reflect its current status, as data dates to 1981.

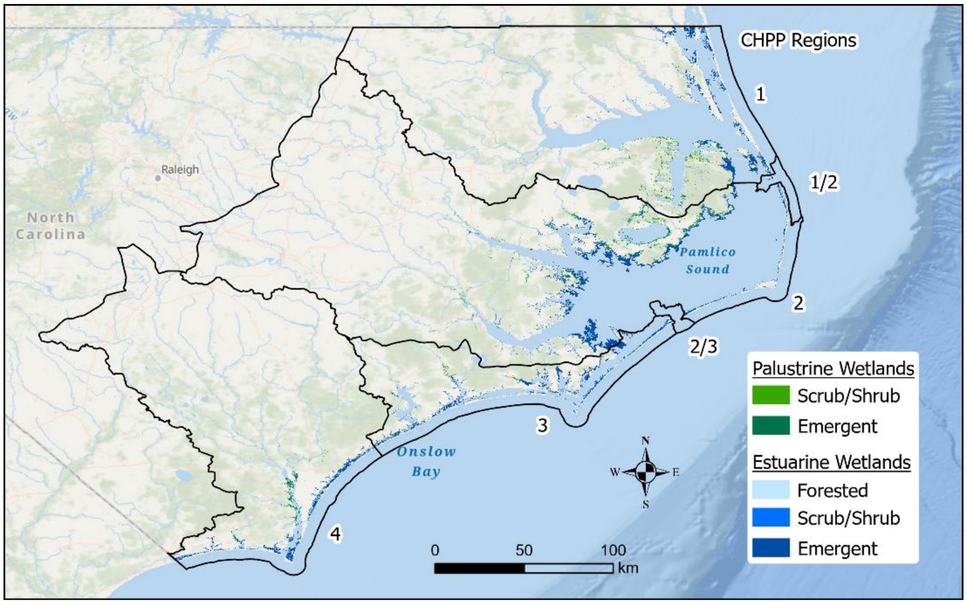

Figure 2. Distribution of coastal wetlands, differentiated by salinity and wetland type, within North Carolina's Coastal Plain with Coastal Habitat Protection Plan (CHPP) regions overlaid. Wetland extent derived from NOAA's 2016 Coastal Change Analysis Program (C-CAP) data. Only palustrine wetlands within the mean higher high water – spring tide extent are shown.

GHG inventories are a critical tool in addressing the climate crisis, as they provide a standardized means of tracking GHG emissions and removals and allow managers and policymakers to understand current trends as well as develop strategies to reach emissions reduction targets. Recognizing this imperative, since 1997, the United Nations Framework Convention on Climate Change (UNFCCC) has required that participating nations, including the United States, produce annual GHG inventories of anthropogenic emissions. The Intergovernmental Panel on Climate Change (IPCC) issues guidance for developing these inventories along three tiers, with Tier 1 being the most basic method and Tiers 2 and 3 incorporating national and more refined model-based data. Tiers 2 and 3 are sometimes referred to as higher tier methods and are generally considered to be more accurate on condition that adequate data are available to develop, evaluate and apply a higher tier method. Over time, as more data becomes available, GHG inventories can move up the tiers.

The EPA's Inventory of U.S. Greenhouse Gas Emissions and Sinks (NGGI) is the annual reporting of GHG emissions and removals resulting from socioeconomic activity and natural processes that are anthropogenically influenced. Within the LULUCF section of the NGGI, emissions and removals of GHG from land use, including natural and working lands, are tracked. Since 2017, the NGGI has incorporated coastal wetlands into the LULUCF section of the inventory following guidance from the 2013 IPCC Wetlands Supplement.[9] This inventory includes Tier 1 and 2 emission factor data and the activity data from NOAA's C-CAP landcover dataset. Across all the sectors included within the NGGI, the land sector is the only net carbon sink, offsetting U.S. emissions by over 700 million metric tons CO_2e per year, roughly 12% of gross national emissions.[10]

To support states with their own GHG inventories, the EPA developed the State Inventory Tool (SIT[11]), which strives to replicate the same methodologies and data as the NGGI to estimate state GHG emissions and removals. Most states lack the resources required to independently produce their own estimates of the complex carbon cycling occurring within their NWL and, as such, the content of inventories they may produce are dictated by what is available through the SIT.[12] Thus, the release of disaggregated, state-level NGGI data for coastal wetlands by the EPA in 2021 represented the first opportunity for North Carolina, a state with a wealth of coastal wetland resources, to account for removals provided by these habitats in future iterations of the North Carolina GHG Inventory.

Like other carbon sink subsectors included in the NC GHG Inventory, one of the intended uses of a GHG inventory is to better understand current trends and track progress toward emission reduction commitments and goals. In this context, EO80 includes the goal of a 40% net reduction in state net emissions between 2005 and 2025. After GHG inventories for seagrass and emergent and scrub-shrub wetlands have been added to the NC GHG Inventory, future actions to prevent further loss, conserve and restore these ecosystems could support emissions reduction goals.

This interim report contributes to the implementation of the CHPP[13] Recommended Actions 4.2, 4.5, 5.17, 8.1, 8.2, and 8.3 (Appendix E), as well as NWL Plan recommendations 3.1.2, 3.1.3, 3.1.4, 3.6.1, and 3.6.2 (Appendix F).

Development of this Interim Report has relied on approaches used to prepare the State of North Carolina's GHG inventory, as well as the U.S. EPA's Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2021. The North Carolina GHG inventory for seagrass is one of the first of its kind in the United States.

Key Partners and Contributors to Date

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U.S. Environmental Protection Agency: Phil Colarusso

NOAA National Centers of Coastal Ocean Science: Carolyn Currin

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NC Coastal Wetlands: Estimates of GHG Emissions and Removals

High Salinity Seagrass Meadows

Methodology and Time-Series Consistency

GHG emissions and removals were calculated using high salinity seagrass mapping surveys grouped by CHPP region from 2007, 2013, and 2020 (Table 1).[14] Area estimates for years between these survey dates were linearly interpolated. Since there are no empirically derived coefficients that explicitly differentiate carbon sequestration rates between patchy and continuous meadows in NC, we assumed one rate for both cover categories.[15] In 2020, seagrass areas in the Bear Inlet to Snow's Cut region were not able to be determined; therefore, total seagrass areas and associated removals between 2014 and 2021 do not include this region and values presented are an underestimate of current conditions. The IPCC Tier 1 value,[16] -0.43 metric tons (t) C ha^{-1} yr^{-1} (-0.17 t C $acre^{-1}$ yr^{-1}), was applied to calculate seagrass soil carbon accumulation. A negative value denotes carbon removal. This default rate is similar to that calculated for *Zostera marina* meadows in neighboring coastal Virginia by Oreska et. al[17] of -0.42 t C ha^{-1} yr^{-1} (-0.169 t C $acre^{-1}$ yr^{-1}), which includes methane and nitrous oxide emissions. Under IPCC GHG guidance, biomass carbon stocks are not accounted for unless regionally specific Tier 2 or Tier 3 data are available; therefore, biomass is not included in this analysis.

Table 1. Seagrass area (acres) across North Carolina CHPP regions between 1990 and 2021.

CHPP Region	1990		2005		2017	2018	2019	2020	2021
Roanoke Sound to Ocracoke Inlet	33,515		33,515		29,298	28,818	28,338	27,858	27,378
Core Sound	8,573		8,573		7,152	6,797	6,441	6,086	5,731
Bogue Sound	2,411		2,411		1,943	1,922	1,902	1,882	1,862
Bear Inlet to Snow's Cut	192		192		no data	no data	no data	no data	no data
Total area	**110,433**		**110,433**		**94,869**	**92,755**	**90,640**	**88,526**	**86,412**

From the period of 1990 to 2021, seagrass along the coast of North Carolina were a net carbon sink, with GHG removals decreasing slightly over time due to loss in seagrass coverage (Table 2). In 2021, this habitat sequestered approximately –55.14 kt CO_2e[18] in the soils alone.

Table 2. Greenhouse gas emissions and removals for seagrass in North Carolina in kilotons[19] (kt) CO_2e

Carbon Pool	***1990***		***2005***		***2017***	***2018***	***2019***	***2020***	***2021***
Soil C flux	-70.46		-69.85		-60.53	-59.18	-57.83	-56.49	-55.14

Uncertainty

An uncertainty analysis was performed using the Tier 1 soil carbon accumulation rate and associated 95% confidence interval. No uncertainty estimate was provided for the activity data;[20] therefore, an uncertainty of 15% was applied based on expert judgment. Associated combined uncertainties (total seagrass) for years 1990 and 2021 are included in Table 3 and Table 4.

Table 3. Approach 1 quantitative combined uncertainty emissions estimates for C stock changes and activity data in 1990 occurring within seagrass remaining seagrass (kt CO_2e and percent).

Source	Gas	1990 (kt CO_2e)	Uncertainty Range Relative to Flux Estimate (kt CO_2 Eq.)		(%)	
			Lower Bound	Upper Bound	Lower Bound	Upper Bound
Soil C Stock Change	CO_2	(70.5)	(51.6)	(89.3)	-26.7	26.7
Total Flux	**CO_2**	**(70.5)**	**(50.3)**	**(90.6)**	**-28.6**	**28.6**

Table 4. Approach 1 quantitative combined uncertainty emissions estimates for C stock changes and activity data in 2021 occurring within seagrass remaining seagrass (kt CO_2e and percent).

Source	Gas	2021 (kt CO_2e)	Uncertainty Range Relative to Flux Estimate (kt CO_2 Eq.)		Uncertainty Range Relative to Flux Estimate (%)	
			Lower Bound	Upper Bound	Lower Bound	Upper Bound
Soil C Stock Change	CO_2	(55.1)	(40.4)	(69.9)	-26.7	26.7
Total Flux	**CO_2**	**(55.1)**	**(39.4)**	**(70.6)**	**-28.6**	**28.6**

QA/QC and Verification

Quality assurance/quality control (QA/QC) and verification of soil C accumulation rates were conducted by the IPCC and were subject to internal assessments. Activity data for mapping seagrass in 2007 and 2013 was provided by the North Carolina Department of Environmental Quality and underwent internal QA/QC and verification.

Planned Improvements[21]

Planned future improvements for the seagrass GHG inventory include 1) incorporating new North Carolina-specific soil carbon accumulation rates; and 2) projecting GHG emissions through 2050 under two scenarios: a continuation of current trends, and achievement of the CHPP 2021 seagrass acreage goal.

Emergent and Scrub-shrub Wetlands

The LULUCF Coastal Wetlands section of the NGGI defines coastal wetlands as “land-use that includes land covered or saturated for all or part of the year other than those occurring within estuarine water bodies.” The emergent and scrub-shrub coastal wetlands section for this North Carolina Coastal Wetland GHG Inventory is modeled on the NGGI, which has included coastal wetlands (excluding seagrass) within its LULUCF section since 2017. Aligning with the NGGI, the Coastal Wetland section recognizes both Vegetated Wetlands and Unvegetated Open Water Wetlands as Coastal Wetlands.

Coastal Wetland Type and Aerial Extent

The coastal wetland types used in the Coastal Wetland section are the same as those used in the NGGI: estuarine and palustrine emergent and scrub-shrub wetlands. Estuarine wetlands are those with salinities greater than or equal to 0.5 practical salinity units (PSU). To refine the estuarine salinity range to better account for CH_4 emissions in lower salinity wetlands, each estuarine wetland category was subdivided into two salinity categories: low salinity (less than 18 PSU) and high salinity (greater than or equal to 18 PSU) based on a salinity data layer from the North Carolina Wildlife Resources Commission. Palustrine wetlands are those with salinities less than 0.5 PSU. Only palustrine wetlands within the mean higher high water – spring tide extent (MHHWS) are considered to be coastal wetlands and included in the inventory.

The aerial extent of these coastal wetland types is derived from the same national land-use representation system used by the NGGI for coastal wetlands: the C-CAP spatial dataset. The

"Agriculture, Forestry and Other Land Use" (AFOLU) NGGI land-use representation system uses three databases to track land management in the United States, classifying lands into one of 36 IPCC land-use categories; however, the C-CAP data have not yet been harmonized with these datasets. This lack of harmonization results in significant areas of overlap between palustrine coastal wetlands and other land-use categories (especially forests). To avoid double-counting, it is not recommended to include palustrine coastal wetlands as a separate category in the North Carolina GHG inventory at this time. Separate results tables for estuarine wetlands only are provided below to include in the state GHG inventory.

Since only five image dates are currently available for the C-CAP dataset, areas were interpolated by taking the acreage difference between each C-CAP year for each coastal wetland type, dividing by the number of years between the image dates, and adding that value to areas for all years between those image dates. For the period between 1990 and 1995, the same yearly change determined between 1996 and 2001 was used. For the period between 2017 and 2021, the same yearly change determined between 2010 and 2016 was used. Acreages of coastal wetland types are extrapolated from 1990 through 2021 (Table 5).[22] Conversions between Vegetated Coastal Wetlands and Unvegetated Open Waters, both considered Coastal Wetlands, informed calculations of GHG fluxes between 1990 and 2021; total areas and those not including palustrine wetlands are in Table 6 and Table 7, respectively. Area changes in Lands converted to Vegetated Coastal Wetlands are in Table 8.

Table 5. Area in acres of Coastal Wetlands Remaining Coastal Wetlands.

Wetland Category	**Salinity (PSU)**	**1990**		**2005**		**2017**	**2018**	**2019**	**2020**	**2021**
Palustrine Scrub/Shrub Wetland	< 0.5	30,014		42,551		31,663	28,984	26,304	23,624	20,945
Palustrine Emergent Wetland	< 0.5	36,613		45,238		40,053	39,519	38,984	38,449	37,915
Estuarine Scrub/Shrub Wetland	0.5-18	4,280		5,111		4,181	3,954	3,728	3,501	3,274
	≥ 18	896		946		825	794	763	732	701
Estuarine Emergent Wetland	0.5-18	165,792		169,068		165,874	165,218	164,561	163,904	163,248
	≥ 18	82,719		84,403		83,293	83,114	82,935	82,755	82,576
TOTAL		**320,313**		**347,317**		**325,890**	**321,582**	**317,274**	**312,967**	**308,659**

Table 6. Area in acres of all Vegetated Coastal Wetlands Remaining Vegetated Coastal Wetlands, Vegetated Coastal Wetlands Converted to Open Water, and Unvegetated Open Water Coastal Wetlands Converted to Vegetated Coastal Wetlands.

Conversion Type (Acres)	**1990**		**2005**		**2017**	**2018**	**2019**	**2020**	**2021**
Vegetated Coastal Wetlands Remaining Vegetated Coastal Wetlands	320,313		347,317		325,890	321,582	317,274	312,967	308,659
Vegetated Coastal Wetlands Converted to Unvegetated Open Water Coastal Wetlands	97		191		269	269	269	269	269
Unvegetated Open Water Coastal Wetlands Converted to Vegetated Coastal Wetlands	53		125		340	340	340	340	340

Table 7. Area in acres of only estuarine wetlands in Vegetated Coastal Wetlands Remaining Vegetated Coastal Wetlands, Vegetated Coastal Wetlands Converted to Open Water, and Unvegetated Open Water Coastal Wetlands Converted to Vegetated Coastal Wetlands.

Conversion Type (Acres)	**1990**		**2005**		**2017**	**2018**	**2019**	**2020**	**2021**
Vegetated Coastal Wetlands Remaining Vegetated Coastal Wetlands	253,687		259,528		254,173	253,080	251,986	250,893	249,799
Vegetated Coastal Wetlands Converted to Unvegetated Open Water Coastal Wetlands	88		135		43	43	43	43	34
Unvegetated Open Water Coastal Wetlands Converted to Vegetated Coastal Wetlands	12		17		260	260	260	260	260

Table 8. Area in acres of Land Converted to Vegetated Coastal Wetlands.

Converted from	**Converted to**	**1990**		**2005**		**2017**	**2018**	**2019**	**2020**	**2021**
Settlement	Palustrine Scrub/Shrub Wetland	0		0		2	2	2	2	2
Settlement	Palustrine Emergent Wetland	0		0		8	8	8	8	8
Settlement	Estuarine Scrub/Shrub Wetland, <18 PSU	0		0		2	2	2	2	2
Settlement	Estuarine Scrub/Shrub Wetland, ≥18 PSU	0		0		0	0	0	0	0
Settlement	Estuarine Emergent Wetland, <18 PSU	0		0		25	25	25	25	25
Settlement	Estuarine Emergent Wetland, ≥18 PSU	0		0		8	8	8	8	8
Cultivated	Palustrine Scrub/Shrub Wetland	0		0		2	2	2	2	2
Cultivated	Palustrine Emergent Wetland	0		0		4	4	4	4	4

Cultivated	Estuarine Scrub/Shrub Wetland, <18 PSU	0	0	0	0	0	0	0
Cultivated	Estuarine Scrub/Shrub Wetland, ≥18 PSU	0	0	0	0	0	0	0
Cultivated	Estuarine Emergent Wetland, <18 PSU	0	0	15	15	15	15	15
Cultivated	Estuarine Emergent Wetland, ≥18 PSU	0	0	4	4	4	4	4
Grassland	Palustrine Scrub/Shrub Wetland	0	0	0	0	0	0	0
Grassland	Palustrine Emergent Wetland	0	0	19	19	19	19	19
Grassland	Estuarine Scrub/Shrub Wetland, <18 PSU	0	0	0	0	0	0	0
Grassland	Estuarine Scrub/Shrub Wetland, ≥18 PSU	0	0	0	0	0	0	0
Grassland	Estuarine Emergent Wetland, <18 PSU	0	0	1	1	1	1	1
Grassland	Estuarine Emergent Wetland, ≥18 PSU	0	0	0	0	0	0	0
Forest	Palustrine Scrub/Shrub Wetland	791	806	108	108	108	108	108
Forest	Palustrine Emergent Wetland	740	1,206	387	387	387	387	387
Forest	Estuarine Scrub/Shrub Wetland, <18 PSU	0	0	0	0	0	0	0
Forest	Estuarine Scrub/Shrub Wetland, ≥18 PSU	0	0	0	0	0	0	0
Forest	Estuarine Emergent Wetland, <18 PSU	0	0	0	0	0	0	0
Forest	Estuarine Emergent Wetland, ≥18 PSU	0	0	0	0	0	0	0
Other	Palustrine Scrub/Shrub Wetland	0	399	3	3	3	3	3
Other	Palustrine Emergent Wetland	0	0	8	8	8	8	8
Other	Estuarine Scrub/Shrub Wetland, <18 PSU	0	0	2	2	2	2	2
Other	Estuarine Scrub/Shrub Wetland, ≥18 PSU	0	0	5	5	5	5	5
Other	Estuarine Emergent Wetland, <18 PSU	1	1	8	8	8	8	8
Other	Estuarine Emergent Wetland, ≥18 PSU	65	0	16	16	16	16	16

Coastal Wetlands Carbon Stocks and Fluxes

The NC emergent and scrub-shrub Coastal Wetland section calculates emissions and removals of CO_2 and CH_4 from the following four source/sink subsectors:

Carbon flux and CH_4 emissions from Vegetated Coastal Wetlands Remaining Vegetated Coastal Wetlands

Carbon flux from Vegetated Coastal Wetlands Converted to Open Water Coastal Wetland

Carbon flux from Open Water Coastal Wetland Converted to Vegetated Wetlands

Carbon flux and CH_4 emissions from Lands Converted to Vegetated Coastal Wetlands

Within Vegetated Coastal Wetlands, carbon is stored in the soils, above- and belowground biomass and dead organic matter (DOM). For as long as soils remain inundated and undisturbed, Vegetated Coastal Wetlands will continue to sequester carbon. However, carbon stored in soils and biomass of Vegetated Coastal Wetlands is released when converted to Unvegetated Open Water Coastal Wetlands. The amount of carbon stored in the top one meter (3.28 ft) of soil that is released to the atmosphere is assumed to be 100%, but this is a subject of ongoing research. Conversely, when Unvegetated Open Water Coastal Wetlands are converted to Vegetated Coastal Wetlands through restoration or natural processes (e.g., flooding of previously nontidal land), carbon will be sequestered in soils and biomass. Methane emissions are assumed from all palustrine wetland classes and from estuarine wetlands with salinity less than 18 PSU. As per IPCC guidance, N_2O emissions are only calculated when aquacultural activities are present; however, the NOAA dataset used in the NGGI to calculate N_2O emissions from aquaculture yields at the national level is not currently disaggregated at the state level. In 2021, emergent and scrub-shrub coastal wetlands emitted 0.06 MMT CO_2e when all wetlands are included and sequestered -0.0009 MMT CO_2e when only estuarine wetlands are included. Emission factors used in this analysis are included in Table 9. Carbon fluxes from Coastal Wetlands Remaining Coastal Wetlands with and without palustrine coastal wetlands are summarized in Table 10 and Table 11, respectively. Carbon fluxes from lands converted to Vegetated Coastal Wetlands are summarized in Table 12 for all coastal wetlands and Table 13 for only estuarine wetlands.

Table 9. Emission factors used in the calculations of emissions and removals.

Wetland Category	**Salinity Range (PSU)**	**soil C accum. rate[23] (t C acre^{-1} yr^{-1})**	**Aboveground biomass[24 25] (t C acre^{-1})**	**Belowground biomass[26] (t C acre^{-1})**	**Total biomass (t C acre^{-1})**	**soil C top 1m[27] (t C acre^{-1})**	**CH_4 [21] (kg acre^{-1} yr^{-1})**
Palustrine Scrub/Shrub	< 0.5	0.623	1.28	1.48	2.76	109.27	78.39
Palustrine Emergent	< 0.5	0.623	1.28	1.48	2.76	109.27	78.39
Estuarine Scrub/Shrub Wetland	0.5 - 18	0.332	1.23	2.60	3.84	109.27	78.39
	≥ 18	0.332	1.23	2.60	3.84	109.27	0
Estuarine Emergent Wetland	0.5 - 18	0.332	1.25	2.65	3.90	109.27	78.39
	≥ 18	0.332	1.23	2.60	3.84	109.27	0

Table 10. Emissions and Removals from ***all Coastal Wetlands Remaining Coastal Wetlands*** *in North Carolina (****MMT*** ***CO_2e****). Removals are represented by negative values (in parentheses). Emissions are represented as positive values. Values denoted by a '+' represent a flux that is less than ± 0.0005 MMT CO_2e.*

Land Use/Carbon Pool	1990		2005		2017	2018	2019	2020	2021
Vegetated Coastal Wetlands Remaining Vegetated Coastal Wetlands	**0.04**		**0.1**		**0.2**	**0.2**	**0.2**	**0.2**	**0.2**
Biomass C Flux	(0.02)		(0.03)		0.05	0.05	0.05	0.05	0.05
Soil C Flux	(0.5)		(0.4)		(0.4)	(0.4)	(0.4)	(0.3)	(0.3)
Net CH_4 flux	0.5		0.6		0.5	0.5	0.5	0.5	0.5

Vegetated Coastal Wetlands Converted to Unvegetated Open Water Coastal Wetlands	**0.04**	**0.08**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**
Biomass C Flux	0.001	0.002	0.003	0.003	0.003	0.003	0.003
Dead Organic Matter C Flux	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Soil C Flux	0.04	0.08	0.1	0.1	0.1	0.1	0.1
Unvegetated Open Water Coastal Wetlands Converted to Vegetated Coastal Wetlands	**(0.001)**	**(0.001)**	**(0.002)**	**(0.002)**	**(0.002)**	**(0.002)**	**(0.002)**
Biomass C Flux	(0.001)	(0.001)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
Dead Organic Matter C Flux	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Soil C Flux	(+)	(+)	(0.0005)	(0.0005)	(0.0005)	(0.0005)	(0.0005)
Net N_2O Flux from Aquaculture in Coastal Wetlands	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**
Total Biomass C Flux	**(0.02)**	**(0.02)**	**0.05**	**0.05**	**0.05**	**0.05**	**0.05**
Total Dead Organic Matter C	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Total Soil C Flux	**(0.4)**	**(0.3)**	**(0.3)**	**(0.3)**	**(0.2)**	**(0.2)**	**(0.2)**
Total CH_4 Flux	**0.5**	**0.6**	**0.5**	**0.5**	**0.5**	**0.5**	**0.5**
Total N_2O Flux	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**
Total CO_2e Flux	**0.08**	**0.2**	**0.3**	**0.3**	**0.3**	**0.3**	**0.3**

Table 11. Emissions and Removals from ***Estuarine Coastal Wetlands Remaining Coastal Wetlands in North Carolina*** *(**MMT CO_2e**). Removals are represented by negative values (in parentheses). Emissions are represented as positive values. Values denoted by a '+' represent a flux that is less than ± 0.0005 MMT CO_2e.*

Land Use/Carbon Pool	**1990**	**2005**	**2017**	**2018**	**2019**	**2020**	**2021**
Vegetated Coastal Wetlands Remaining Vegetated Coastal Wetlands	**0.06**	**0.06**	**0.08**	**0.08**	**0.08**	**0.08**	**0.08**
Biomass C Flux	(0.004)	(0.01)	0.02	0.02	0.02	0.02	0.02
Soil C Flux	(0.3)	(0.3)	(0.3)	(0.3)	(0.3)	(0.3)	(0.3)
Net CH_4 flux	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Vegetated Coastal Wetlands Converted to Unvegetated Open Water Coastal Wetlands	**0.04**	**0.06**	**0.02**	**0.02**	**0.02**	**0.02**	**0.02**
Biomass C Flux	0.001	0.002	0.001	0.001	0.001	0.001	0.001
Dead Organic Matter C Flux	0	0	0	0	0	0	0

Soil C Flux	0.04		0.05		0.02	0.02	0.02	0.02	0.02
Unvegetated Open Water Coastal Wetlands Converted to Vegetated Coastal Wetlands	**(+)**		**(+)**		**(0.004)**	**(0.004)**	**(0.004)**	**(0.004)**	**(0.004)**
Biomass C Flux	(+)		(+)		(0.004)	(0.004)	(0.004)	(0.004)	(0.004)
Dead Organic Matter C Flux	0		0		0	0	0	0	0
Soil C Flux	(+)		(+)		(+)	(+)	(+)	(+)	(+)
Net N_2O Flux from Aquaculture in Coastal Wetlands	**ND**		**ND**		**ND**	**ND**	**ND**	**ND**	**ND**
Total Biomass C Flux	**(0.003)**		**(0.009)**		**0.01**	**0.01**	**0.01**	**0.01**	**0.01**
Total Dead Organic Matter C	**0.0**		**0.0**		**0**	**0**	**0**	**0**	**0**
Total Soil C Flux	**(0.3)**		**(0.3)**		**(0.3)**	**(0.3)**	**(0.3)**	**(0.3)**	**(0.3)**
Total CH_4 Flux	**0.4**		**0.4**		**0.4**	**0.4**	**0.4**	**0.4**	**0.4**
Total N_2O Flux	**ND**		**ND**		**ND**	**ND**	**ND**	**ND**	**ND**
Total CO_2e Flux	**0.1**		**0.1**		**0.09**	**0.09**	**0.09)**	**0.09**	**0.09**

Table 12. Emissions and Removals from Land Converted to **All** *Coastal Wetlands in North Carolina (MMT CO_2e). Removals are represented by negative values (in parentheses). Emissions are represented as positive values. Values denoted by a '+' represent a flux that is less than ± 0.0005 MMT CO_2e.*

Land Use/Flux	**1990**		**2005**		**2017**	**2018**	**2019**	**2020**	**2021**
Cropland Converted to Vegetated Coastal Wetlands	**0**		**0**		**+**	**+**	**+**	**+**	**+**
Biomass C Stock	0		0		(+)	(+)	(+)	(+)	(+)
Soil C Stock	0		0		(+)	(+)	(+)	(+)	(+)
Net CH_4 flux	0		0		0.0006	0.0007	0.0007	0.0008	0.0009
Forest Land Converted to Vegetated Coastal Wetlands	**0.2**		**0.3**		**0.1**	**0.1**	**0.1**	**0.1**	**0.1**
Biomass C Stock	0.2		0.2		0.1	0.1	0.1	0.1	0.1
Dead Organic Matter C Flux	0.02		0.03		0.01	0.01	0.01	0.01	0.01
Soil C Stock	(0.07)		(0.08)		(0.05)	(0.05)	(0.05)	(0.05)	(0.05)
Net CH_4 flux	0.07		0.07		0.05	0.05	0.05	0.04	0.04
Grassland Converted to Vegetated Coastal Wetlands	**0**		**0**		**(+)**	**(+)**	**(+)**	**(+)**	**(+)**
Biomass C Stock	0		0		(+)	(+)	(+)	(+)	(+)
Soil C Stock	0		0		(+)	(+)	(+)	(+)	(+)

Net CH_4 flux	0	0	+	+	+	+	+
Other Land Converted to Vegetated Coastal Wetlands	**(0.003)**	**(0.005)**	**(0.001)**	**(0.001)**	**(0.001)**	**(0.001)**	**(0.001)**
Biomass C Stock	(0.001)	(0.004)	(0.0006)	(0.0006)	(0.0006)	(0.0006)	(0.0006)
Soil C Stock	(0.002)	(0.006)	(0.005)	(0.005)	(0.005)	(0.005)	(0.004)
Net CH_4 flux	+	0.004	0.005	0.005	0.005	0.005	0.004
Settlements Converted to Vegetated Coastal Wetlands	**0**	**0**	**(0.0005)**	**(0.0005)**	**(0.0005)**	**(0.0005)**	**(0.0004)**
Biomass C Stock	0	0	(0.0006)	(0.0006)	(0.0006)	(0.0006)	(0.0006)
Soil C Stock	0	0	(0.0005)	(0.0005)	(0.0005)	(0.0006)	(0.0007)
Net CH_4 flux	0	0	0.0006	0.0007	0.0007	0.0008	0.0009
Total Biomass Flux	**0.2**	**0.2**	**0.05**	**0.05**	**0.05**	**0.05**	**0.05**
Total Dead Organic Matter Flux	**0.02**	**0.03**	**0.01**	**0.01**	**0.01**	**0.01**	**0.01**
Total Soil C Flux	**(0.07)**	**(0.08)**	**(0.06)**	**(0.06)**	**(0.05)**	**(0.05)**	**(0.05)**
Total CH_4 Flux	**0.07**	**0.08**	**0.06**	**0.05**	**0.05**	**0.05**	**0.05**
Total CO_2e Flux	**0.2**	**0.2**	**0.06**	**0.06**	**0.06**	**0.06**	**0.06**

Table 13. Emissions and Removals from Land Converted to ***Estuarine*** *Coastal Wetlands in North Carolina (MMT CO_2e). Removals are represented by negative values (in parentheses). Emissions are represented as positive values. Values denoted by a '+' represent a flux that is less than ± 0.0005 MMT CO_2e.*

Land Use/Flux	1990	2005	2017	2018	2019	2020	2021
Cropland Converted to Vegetated Coastal Wetlands	**0**	**0**	**(+)**	**(+)**	**(+)**	**(+)**	**(+)**
Biomass C Stock	0	0	(+)	(+)	(+)	(+)	(+)
Soil C Stock	0	0	(+)	(+)	(+)	(+)	(+)
Net CH_4 flux	0	0	+	+	+	+	+
Forest Land Converted to Vegetated Coastal Wetlands	**0**	**0**	**+**	**+**	**+**	**+**	**+**
Biomass C Stock	0	0	+	+	+	+	+
Dead Organic Matter C Flux	0	0	+	+	+	+	+
Soil C Stock	0	0	(+)	(+)	(+)	(+)	(+)
Net CH_4 flux	0	0	+	+	+	+	+
Grassland Converted to Vegetated Coastal Wetlands	**0**	**0**	**+**	**+**	**+**	**+**	**+**

Biomass C Stock	0	0	(+)	(+)	(+)	(+)	(+)
Soil C Stock	0	0	(+)	(+)	(+)	(+)	(+)
Net CH_4 flux	0	0	+	+	+	+	+
Other Land Converted to Vegetated Coastal Wetlands	**(0.003)**	**(0.001)**	**(0.001)**	**(0.001)**	**(0.0006)**	**(0.0006)**	**(0.0006)**
Biomass C Stock	(0.001)	(+)	(+)	(+)	(+)	(+)	(+)
Soil C Stock	(0.002)	(0.001)	(0.001)	(0.0005)	(+)	(+)	(+)
Net CH_4 flux	+	+	+	+	+	+	+
Settlements Converted to Vegetated Coastal Wetlands	**0**	**0**	**(+)**	**(+)**	**(+)**	**(+)**	**(+)**
Biomass C Stock	0	0	(0.0005)	(0.0005)	(0.0005)	(0.0005)	(0.0005)
Soil C Stock	0	0	(+)	(+)	(+)	(+)	(0.0005)
Net CH_4 flux	0	0	+	0.0005	0.0005	0.0006	0.0007
Total Biomass Flux	**(0.001)**	**(+)**	**(0.001)**	**(0.001)**	**(0.001)**	**(0.001)**	**(0.001)**
Total Dead Organic Matter Flux	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Total Soil C Flux	**(0.002)**	**(0.001)**	**(0.001)**	**(0.001)**	**(0.001)**	**(0.001)**	**(0.001)**
Total CH_4 Flux	**+**	**+**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**
Total CO_2e Flux	**(0.003)**	**(0.001)**	**(0.001)**	**(0.001)**	**(0.001)**	**(0.001)**	**(0.001)**

Data Sources and Uncertainty

Coastal wetland acreage data was derived from the NOAA C-CAP dataset, which has an overall uncertainty of 15%. Wetland type-specific estimates of aboveground biomass, root-to-shoot ratio, soil carbon stocks in the top meter, and annual soil carbon accumulation rates were derived from Byrd et al. (2018[28] and 2020[20]), 2013 IPCC Wetlands Supplement, Holmquist et al. (2018),[29] and Lu and Megonigal (2017),[30] respectively. These estimates of aboveground biomass, root-to-shoot ratio, and annual soil carbon accumulation rates, all specific to the warm temperate climate zone, have uncertainties associated with the methodologies of the syntheses from which they were derived. The methane emission factor is the Tier 1 default value from the 2013 IPCC Wetland Supplement and likely has a larger uncertainty than Tiers 2 or 3. The NOAA C-CAP wetland classification scheme employs a salinity breakpoint of 0.5 PSU to differentiate palustrine and estuarine wetlands. As such, differentiating oligohaline and mesohaline estuarine wetlands, which typically emit CH_4 (methanogenesis typically occurs at <18 PSU), from polyhaline estuarine wetland, which typically do not, is not possible with NOAA C-CAP data. Instead, salinity data from the NC Wildlife Resources Commission was used to categorize estuarine wetlands into a low salinity class (less than 18 PSU), for which CH_4 emissions were estimated, and a high salinity class (greater than or equal to 18 PSU), for which no CH_4 emissions were included.

Planned Improvements

Coastal Wetlands are not currently incorporated into the NGGI Land Representation analysis, and it is acknowledged within the NGGI that there is need to harmonize C-CAP data with the three layers currently used to compile NGGI land representation, which includes the U.S. Department of Agriculture (USDA) National Resource Inventory (NRI), the USDA Forest Service (USFS) Forest Inventory and Analysis (FIA) database, and the Multi-Resolution Land Characteristics Consortium (MRLC) National Land Cover Dataset (NLCD). As such, there are discrepancies in the total reported area of palustrine wetlands within C-CAP and the Land Representation, which likely results in double-counting. For that reason, it is recommended that only the estuarine wetlands are added to the North Carolina Greenhouse Gas Inventory at this time, and palustrine wetlands are excluded to avoid double-counting. Work is underway to refine emission factors for North Carolina so that they are more regionally specific.

Technical Appendices

A. Acronyms

- CCAP - Coastal Change Analysis Program
- CHPP – Coastal Habitat Protection Plan
- EO 80 - Executive Order 80
- FIA - Forest Inventory Analysis
- LULUCF - Land Use, Land Use Change, and Forestry
- NLCD - National Land Cover Database
- NC – North Carolina
- NCDEQ – North Carolina Department of Environmental Quality
- NCDMF – North Carolina Division of Marine Fisheries
- NGGI - National Greenhouse Gas Inventory
- NWL – Natural and working lands
- SAV - submerged aquatic vegetation
- SIT - State Inventory Tool

B. Technical Background on Selected Issues

Methodology for 2007, 2013, and 2020 Seagrass Surveys

The coastal waters of North Carolina are a large and biophysically complex ecosystem characterized by a persistent salinity gradient and populated with seagrass species that have affinities for different salinity environments.[31] Like other large estuarine systems in the United States (e.g., Chesapeake Bay), the species composition and structure of the seagrass communities are organized along the salinity gradient with a larger taxonomic biodiversity of meadow and canopy forming species (5 – 8 species) found in oligohaline and mesohaline (low salinity) waters and only three meadow forming species of seagrass growing in polyhaline (high salinity) environments. Each of these seagrass community types have species with different life histories and display widely varying spatial and temporal dynamics in distribution and abundance. The inventory presented in this report includes only estimates for the aerial coverage of the high salinity seagrass species: *Zostera marina, Halodule wrightii,* and *Ruppia maritima*. The geographic area encompassed by this inventory comprises the shallow waters of eastern Pamlico Sound beginning at the Highway 64 bridge connecting Roanoke Island to Nags Head (Roanoke Sound) south through Core Sound, Back Sound, lower North River, Bogue Sound and the interior waterways and lagoons between the mouth of the White Oak River inside Bogue Inlet south to Snows Cut just south of Masonboro Sound.

Four aerial photographic surveys were used to assemble the inventory. Three of the surveys were conducted under the auspices of the Albemarle Pamlico National Estuary Partnership and covered the area between Roanoke Sound and Bogue Sound where the largest proportion of the seagrass acreage occurs in NC[32]). Survey 1 was conducted in two phases: phase 1 in May/June 2006, including aerial surveys of Bogue and Back Sounds between Barden Inlet and Bogue Inlet and phase 2 in October 2007 between Roanoke Island and Barden Inlet. Survey 2 included the area between Roanoke Sound and

Bogue Inlet in May 2013. During Survey 2, atmospheric conditions in a large portion of Core Sound rendered the aerial imagery unusable for mapping seagrass aerial extent. Survey 3 included the area between Roanoke Sound and Bogue Inlet conducted in May and June 2020.

Details of the methodologies used in these aerial surveys and the results are provided in Field et al. (2021). Briefly, aerial images were captured with an Intergraph Z/I Digital Mapping Camera (DMC) (Bands = red, green, blue, near infrared). For Survey 1, images along the mainland and Outer Banks of Bogue Sound and Back Sound, and the mainland side of Core Sound north to Atlantic were acquired on May 31 and June 1, 2006 with a 0.3 m pixel size resolution (phase 1). All other areas in the survey area were collected on October 12, 14, and 15, 2007 with a 1.0 m pixel size resolution (phase 2). For Survey 2, all aerial images were acquired at a 0.3 m pixel size resolution. Images along the Outer Banks of Pamlico Sound from Ocracoke Inlet to Roanoke Sound were collected on May 30, 2013. Images along the mainland and Outer Banks of Bogue Sound and Back Sound were collected on May 27, 2013. For Survey 3 all images were acquired at a 0.3 m pixel size resolution. Images along the mainland and Outer Banks of Bogue, Back, Core and Pamlico Sound were collected on May 16, June 1, and October 14, 2020.

Coincidental with each of these surveys, APNEP and the NC Division of Marine Fisheries (NCDMF) coordinated boat-based and in-water field monitoring within several weeks of aerial image acquisition to verify benthic seagrass signatures, facilitate image interpretation, and conduct quantitative visual assessments of the species composition and cover of seagrass at randomly selected points.

For analyses, the imagery obtained in surveys 1, 2 and 3 were digitized in ArcGIS according to procedures described in Rohmann and Monaco (2005) and classified into three categories: continuous seagrass, patchy seagrass and unvegetated. Continuous seagrass was defined as areas covering 70% or greater of the substrate that may contain unvegetated or sparsely vegetated areas that are smaller than the minimum mapping unit (MMU = 0.2 ha). Patchy seagrass was defined as discontinuous meadows covering more than 10% but less than 70% of the substrate. These areas were diffuse and irregular consisting of isolated patches that are below the MMU. Areas with less than 10% seagrass were considered beyond the level of detection of the imagery used and thus were assigned the unvegetated category. For this inventory, the continuous and patchy categories were combined to calculate the total aerial extent of seagrass.

Survey 4 covered the area from Bogue Inlet south to Snows Cut and consisted of three separate aerial photographic acquisitions of seagrass extent. The first acquisition was conducted in October 2007 as part of the Survey 1, Phase 2 project referenced above for the APNEP region from Roanoke Island to Barden's Inlet. Since this was a multi-agency effort (SAV Partnership) to map all seagrass in coastal waters, the methodology and imagery resolution were the same as described above. The 2007 survey extended only to Snows Cut, since the Cape Fear River is considered the southernmost extent of seagrass in NC. Results found minimal seagrass present south of Mason's Inlet.

The NCDMF contracted the NC Department of Transportation (NCDOT) to acquire aerial photography for the area south of Bogue Inlet to approximately Mason's Inlet again in May 2015 and May 2021. In 2015, aircraft height was 10,000 ft for a final imagery product with a 1 ft pixel size. In 2021, aircraft height averaged 11,300 ft for final imagery products with 0.5 ft and 1 ft pixel resolution.

Delineation of seagrass was conducted following the same protocol and classifications as done for the APNEP region. For this study the MMU was approximately 0.2 ha for either 1) a contiguous seagrass bed, or 2) multiple patches, that when combined, are at least 15 m across on the longest axis and are within 15 m of each other. The results of the 2007 and 2015 mapping events for Survey Area 3 were included in the CHPP (DEQ 2021) and links to GIS data for the mapping events are available on the NCDMF Spatial Interface.[33] While this area represents only a small portion of the seagrass inventory in NC, change in extent and species composition at the southern distributional limit can be a valuable indicator.

Status of a GHG inventory for low salinity SAV regions

The Workgroup initially hoped to develop a GHG inventory for low salinity SAV regions (SAV Regions 1, 2, 3 in Table 4.5 below). However, it became clear that this was not feasible due to due to uncertainties in methane emission rates and in how the areal extent of low-salinity SAV has changed over time.

Table 4.5. The known historical extent of mapped submerged aquatic vegetation (SAV) in NC, 1981-2015.

Salinity Zone	SAV Region #	SAV Region Name	Historic Extent* (ac)	Percent of Historical Extent* (%)
Low	1	Currituck and Back Bay	21,613	11.3
Low	2	Albemarle Sound	12,872	6.7
Low	3	Tar-Pamlico & Neuse rivers	4,581	2.4
High	4	Pamlico Sound	712	0.4
High	5	Roanoke Sound to Ocracoke Inlet	101,739	53.2
High	6	Core Sound	36,862	19.3
High	7	Bogue Sound	10,826	5.7
High	8	Bear Inlet to Snow's Cut	1,950	1.0
High/Low	9	Cape Fear River to SC line	0	0.0
Total			**191,155**	100.0

*SAV Mosaic 1981 to 2015 (as of 6/3/2020)

Figure B1. Known historical extent of mapped submerged aquatic vegetation in North Carolina as presented in the CHPP 2021 Amendment, Table 4.5.[34]

As an initial step toward developing a GHG inventory for low-salinity SAV regions, a literature review was conducted that focused on: a) carbon accumulation/emission rates for low-salinity SAV habitats (sediment, methane, and biomass contributions), including literature from other states, regions of the U.S. (e.g., Gulf of Mexico) and beyond that might be relevant to North Carolina; b) using low-salinity SAV species as a proxy for salinity; and c) any information on low-salinity SAV species distribution in North Carolina or other U.S. states, as applicable, or any approaches to model/infer distributions that would be applicable to NC.

Based on the literature review and expert judgement, the Workgroup developed a set of key issues to consider in any future effort to develop a GHG Inventory for low-salinity SAV:

1. Low-salinity SAV survey/mapping data is quite limited, so start with the best-mapped areas, such as Currituck Sound.[35]
2. Build on related initiatives pertaining to low-salinity SAV, such as NRCS's Coastal Zone Soil Survey (CZSS) of the Alligator River and Currituck Sound areas of the Albemarle, preliminary samples taken around the Swan Quarter and Rose Bay areas of the Pamlico, and Lake Mattamuskeet, as described above.

3. Build on studies from other areas such as the Mississippi River Delta Plan[36] that estimate GHG inventories or blue carbon stocks across salinity gradients.
4. Assess the extent to which the results of research on methane emissions from freshwater wetlands are useful in estimating methane emissions from low-salinity SAV.

A review of seagrass surveys prior to 1990

Calculations of net carbon accumulation rates prior to 2007 have been hindered by the absence of reliable estimates of the seagrass area for any of the high salinity regions presented in the CHPP 2021 Amendment, Table 4.5 (see Figure B1 above).

The Workgroup determined that the most relevant earlier seagrass survey is the one conducted by R.J. Carraway and L. J. Priddy.[37] In 1983, they produced 40 maps of seagrass beds totaling 19,458 acres from Bogue Inlet to Ocracoke Inlet.

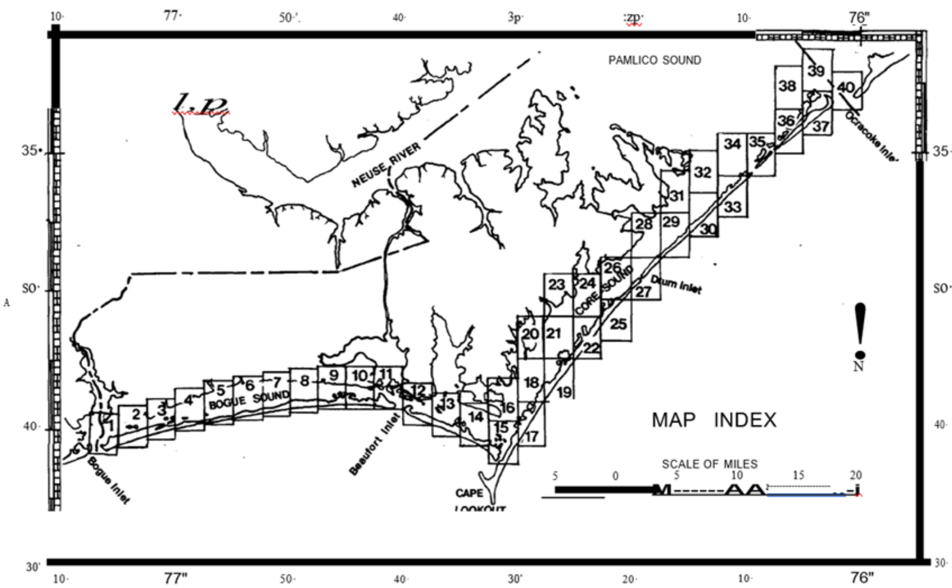

Figure B2. Index of mapped seagrass areas by Carraway & Priddy (1983).[38]

These maps were based on conventional aerial photography flown May 12-22, 1981, coupled with ground truthing. At the time, the authors described the results as “most satisfactory.” Seagrass beds were mapped onto USGS 7 ½ minute series quadrangle sheets. Seagrass beds were divided into three density classes: scattered (<20% of the bottom area within the bed), moderate (20-75%), and dense (>75%). An index of mapped areas is shown above (Figure B2).

In 2023, Workgroup member Don Field compiled the Carraway and Priddy photography and shapefiles of seagrass aerial extent for Bogue and Back Sounds. He then compared them with APNEP surveys for 2007, 2013 and 2020. To do this comparison, he clipped out the Carraway and Priddy 1981 data for the region from Bogue Sound to Back Sound. The 1981 Carraway and Priddy shapefile did not cover some portions of the sounds (e.g., the Straits or North River). Therefore, to make a valid comparison of the areas, data for the Straits and North River were clipped out of the coverages for the APNEP surveys in

2006, 2013 and 2020. As a result, the data below (Table B1) for 2006, 2013 and 2020 do not correspond to the CHPP data for the Bogue Sound region (note: the CHPP Bogue Sound region extends roughly from the White Oak River to Back Sound). However, the data provide an interesting comparison of the change in seagrass coverage over time for this particular area and explicit footprint, and could be useful as a benchmark for consideration of future seagrass protection and restoration initiatives.

Table B1. Estimated seagrass acreage mapped in Bogue and Back Sounds in four surveys between 1981 and 2020.

Year	Acreage
1981	5,126
2006	4,668
2013	4,020
2020	3,849

C. Planned Improvements

The sections below detail planned improvements for both seagrass and emergent and scrub-shrub wetlands in future iterations of the GHG inventory.

Incorporate findings and methodologies from USDA/NRCS Coastal Zone Soil Survey and Blue Carbon Mapping

The Coastal Zone Soil Survey (CZSS) is a nationwide effort by the Soil and Plant Science Division of the Natural Resources Conservation Service to study and inventory the marsh and subaqueous soils of the coastal United States. Soil cores are collected based on geomorphological position, prevalence of SAV, and areas where more detailed soils information is requested. These cores are then sampled for traditional soil properties along with additional chemical analysis such as carbon content by weight, electrical conductivity to determine presence of salts, and incubated pH by horizon.

Sampling and mapping soil properties by horizon allows the CZSS team to project soil types and associated properties across repetitive geomorphological features, known as landforms. This is a tried-and-true practice used in subaerial soil survey techniques for over 120 years. Once completed, the user would have access to a public database (via Web Soil Survey) with information such as: how much carbon is stored in the soils in the Albemarle-Pamlico Sound; what soils and areas are best suited for SAV restoration; where would one have the best substrate to produce oysters; what soils have the potential to produce acid sulfate if dredged and oxidized; and even how much carbon has been lost due to coastal erosion.

Initial work has begun in the Alligator River and Currituck Sound areas of the Albemarle along with some preliminary samples taken around the Swanquarter and Rose Bay areas of the Pamlico. The first project area to be mapped would be Currituck Sound with an estimated completion date set for late 2025 or early 2026, depending on staffing levels, funding, and equipment availability.

Other projects in the vicinity include Lake Mattamuskeet. Field sampling was completed in mid-2022 with the final product set for publication to Web Soil Survey in Fall 2023. This project collected simple water chemistry data along with characterization data for the soils of the lake. The Lake Mattamuskeet CZSS will be the first published subaqueous soil survey in the southeastern United States and provides an example of what CZSS can do. The data produced and soils map provided from this project will inform management and land use decisions in the lake, and ultimately with the restoration of the lake itself.

Incorporate carbon accumulation research for Core Sound by Antonio Rodríguez, Brent McKee, Yasamin Sharifi, and Lillian Cooper (University of North Carolina at Chapel Hill, Institute of Marine Sciences)

Extensive seagrass meadows along the North Carolina coast may hold great potential for long-term burial of organic carbon in bed sediments; however, efforts to assess and manage North Carolina's seagrass beds as a potentially valuable blue carbon sink are hindered by a lack of basic data about carbon burial dynamics in these systems specifically. In particular, little is known about the rates of carbon burial and the total size of the carbon stock (inventory) that have formed locally over the past millennia. This lack of local data forces any assessment of the North Carolina seagrass carbon inventory to rely on values found in other environmental settings, often with differing species compositions, depositional conditions, and site characteristics. The effects of these varying factors on the carbon burial capacity of different seagrass species are also understudied and poorly understood. As a result, current seagrass blue carbon inventories in North Carolina draw from the wide range of carbon burial rates and stock sizes reported in the global literature but cannot account for these naturally occurring variations when translating these values to local sites. Local seagrass blue carbon inventories are therefore at risk of over- or underestimating the organic carbon burial capacity of North Carolina seagrass beds.

Work at UNC Chapel Hill's Institute of Marine Sciences, in collaboration with APNEP, measures the seagrass carbon stock in Back and Core Sounds through sampling surface sediment at approximately 200 sites. Analysis of these samples in conjunction with other metrics gathered by APNEP facilitates a greater understanding of how local carbon stock varies in response to both environmental conditions and meadow characteristics. Accounting for these factors will allow a more precise, data-driven inventory than previously possible. Preliminary findings based on analysis of these surface samples indicate that temperate Zostera and Halodule beds in North Carolina may hold significantly less carbon stores than global mean values reported for other seagrass species, with local seagrass meadows containing a mean organic carbon stock of approximately 4,200 g C per cubic meter.

Additional components of this work assess local rates of carbon accumulation over time and depth. Quantifying carbon accumulation rates, rather than only considering stocks, is critical for assessing the contribution of North Carolina seagrass beds to offsetting anthropogenic emissions and determining their efficiency as blue carbon sinks over decadal to centennial time scales. Results will also determine the ability of seagrass beds to accrete vertically at rates commensurate with sea-level rise. Seagrass beds that cannot keep pace with accelerating sea-level will become light-limited, ultimately transitioning to unvegetated sandflats that are not sustainable carbon sinks. Full findings will provide the first empirical reports of both carbon stocks and carbon accumulation rates in natural seagrass beds in North Carolina. Results will advance the field of blue carbon science by improving measuring methodology and expanding the available dataset for creating carbon inventories of North American seagrass.

Project GHG emissions from seagrass through 2050

GHG projections would cover two scenarios:

1. The GHG impact of a continuation of current trends in seagrass area, based on APNEP and DMF surveys, and;
2. The GHG impact of achieving by 2050 the seagrass portion of the CHPP 2021 goal of "protecting and restoring submerged aquatic vegetation (SAV) to reach an interim goal of 191,000 acres coastwide with specific targets by SAV waterbody regions."

Reconcile NOAA C-CAP Land Representation for Intertidal Wetlands with NRI, FIA, and NLCD

Coastal Wetlands are not currently incorporated into the NGGI Land Representation analysis, which currently includes the USDA, the NRI, the USDA USFS FIA database, and the MRLC NLCD datasets. It is acknowledged within the NGGI that there is need to harmonize C-CAP data with these three layers. The aerial extent of coastal wetland types is 308,659 acres[39] (C-CAP), which encompasses North Carolina's entire Coastal Plain (Figure 2). Of the three databases, FIA and NRI are prioritized to inform NGGI land representation, with NLCD data only used in instances where NRI and FIA data are missing for a given area. The NGGI states that "FIA is the main database for forest statistics, and consequently, the NRI and NLCD are adjusted to achieve consistency with FIA estimates of Forest Land." Further, the NGGI acknowledges that "some lands within the LULUCF sector can be classified into one or more categories due to multiple uses that meet the criteria of more than one definition. However, a ranking priority has been developed for assignment priority in these cases. The ranking process is from highest to lowest priority in the following order: Settlements > Cropland > Forest Land > Grassland > Wetlands > Other Land."

Because the C-CAP land use product has yet to be incorporated into the land representation analysis for the NGGI's LULUCF section, there are recognized discrepancies between the C-CAP product and wetland areas provided by NRI, FIA, and NLCD that need to be reconciled in future iterations of the inventory. More specifically, due to the current ranking framework for lands that can be classified into one or more categories, only a subset of all C-CAP classified wetlands in North Carolina are classified as Coastal Wetlands in the NGGI. An obvious concern identified by the North Carolina Coastal Habitat GHG Workgroup was the potential for double counting of lands classified by NGGI and SIT as Forest Land and by NOAA C-CAP as Wetland, given that coastal wetland acreages from NOAA C-CAP data have yet to be integrated into NGGI land representation.

Conducting the spatial analyses to identify areas of overlap and identify a suitable remedy was therefore made a priority. Attempts were made to access FIA spatial layers from USFS' online database but were found to be unavailable. An independently compiled (non-USFS source) approximation of FIA's Forest Land inventory for North Carolina's Coastal Plain region was acquired from a reputable *ArcGIS Online* repository and compared to C-CAP Wetland coverage as a first step in assessing the potential for spatial overlap. Extensive overlap was evident (Figure C1). Seeking official FIA spatial layers with which to conduct our spatial analyses, a request was sent to the USFS FIA program office. We were informed that FIA sampling plot locations are "fuzzed" to protect the privacy of private landowners and, thus, publicly available FIA data are not spatially explicit. Fortunately, one of the senior analysts with whom we corresponded had coincidentally conducted analyses capable of providing quantitative estimates of FIA Forest Land – C-CAP Wetland spatial overlap in the North Carolina Coastal Plain.

We were informed that, while there was no overlap between C-CAP classified Estuarine Wetlands (classes 16-18) and FIA classified Forest Land, there was appreciable (>85%) overlap across all C-CAP Palustrine Wetland classes and FIA classified Forest Land (Table 10). Therefore, we recommend that the

North Carolina Greenhouse Gas Inventory incorporate the results for estuarine wetlands from this report but exclude the results for palustrine wetlands. This will avoid double-counting of areas that are classified as palustrine wetlands in C-CAP and forest land by FIA, but will result in undercounting methane emissions from these systems (soil methane emissions are not accounted for under the Forest land sector). Work on a national harmonized land cover dataset is in progress and should be available in the next few years; when it is available, it will be possible to add palustrine wetlands to the North Carolina Greenhouse Gas Inventory without creating double-counting issues due to overlaps.

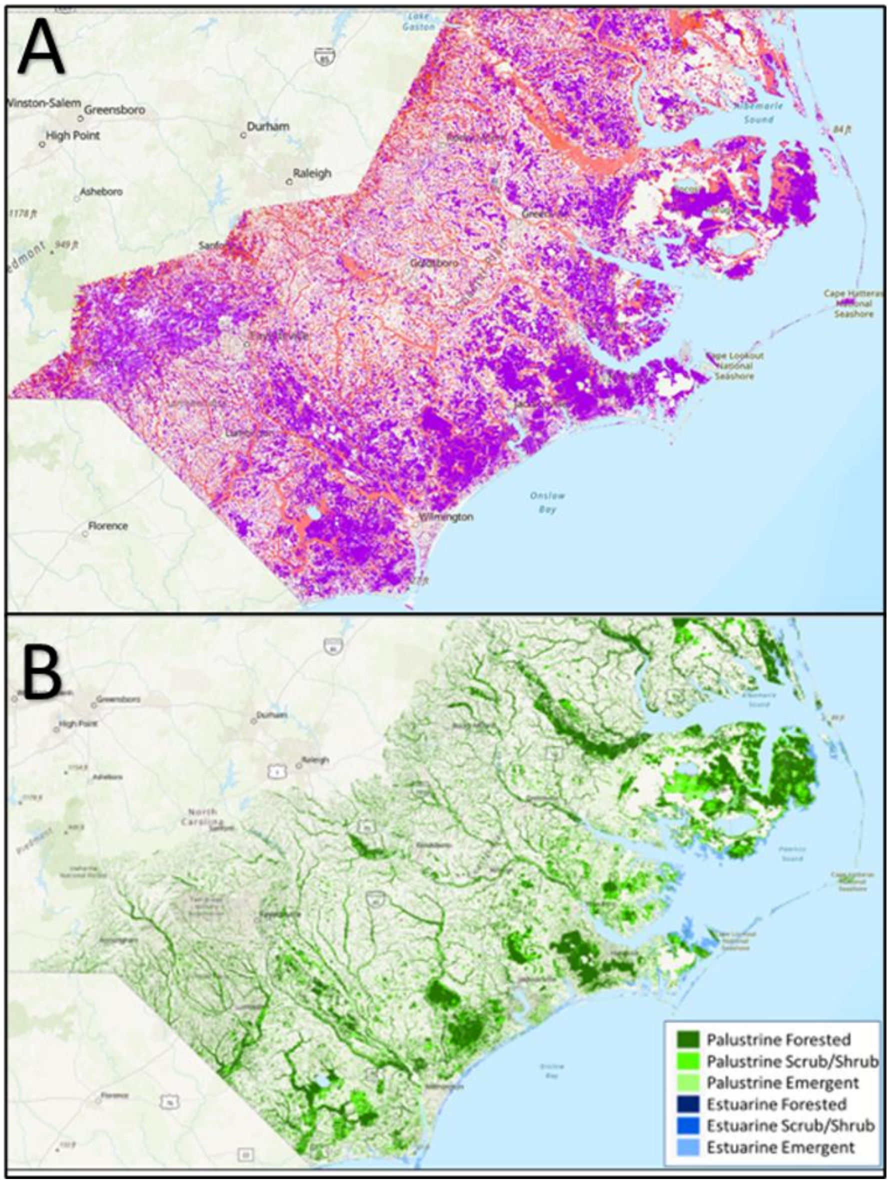

Figure C1. Maps showing (A) an approximation of FIA classified Forest Lands in North Carolina's Coastal Plain compiled from best available data sources and (B) NOAA C-CAP coverage of Wetland (land classes 13-18) in North Carolina's Coastal Plain.

Table C1. Acres of overlap between lands classified as Forested Lands within the NGGI land representation and C-CAP classified Coastal Wetlands in North Carolina, total C-CAP wetland acreage by wetland class, and percentage of C-CAP acreage by wetland class overlapping with NGGI classified forest lands.

Wetland Class	Acreage of NC FIA Forest and C-CAP	Total C-CAP Wetland Acreage	Percentage of Total Acreage
Palustrine Forested	2,713,054	3,069,690	88.4
Palustrine Scrub/Shrub	867,669	1,008,552	86.0
Palustrine Emergent	276,212	272,932	100*

*Value exceeds 100%, likely attributable to pixel resolution and rounding

Develop Regional Carbon Accumulation Rate Estimates

Data on wetland carbon fluxes used in this inventory are based on nationally derived values based on climate zones and, thus, are not NC or regionally specific. Carbon fluxes can vary appreciably by region, variability that is not currently captured in this inventory. The use of state- or region-specific GHG flux values could improve the accuracy of the inventory. There has been considerable field-based research on wetland carbon stocks and flux conducted in North Carolina that could inform the development of the state-specific stocks and fluxes. However, these data are largely disaggregated. The Smithsonian Environmental Research Institute's Coastal Carbon Research Coordination Network, a consortium of biogeochemists, ecologists, pedologists, and coastal land managers, works to improve access to coastal wetland carbon data. Their Coastal Carbon Data Clearinghouse aggregates standardized coastal wetland carbon data, which, with sufficient state- or region-specific data could inform place-specific GHG flux values to inform state GHG inventories.

At present, North Carolina is underrepresented in the Coastal Carbon Data Clearinghouse. Recent analyses by Holmquist and colleagues (2021)[40] identified shortcomings in the quality, quantity, spatial coverage, and habitat coverage of coastal wetland carbon data from North Carolina (Figure C2). Additional funding to facilitate the inclusion of previously collected data into the Coastal Carbon Data Clearinghouse was recently acquired; Reide Corbett at East Carolina University is leading this effort. The addition of North Carolina data to the Clearinghouse and ongoing work by the Smithsonian to model carbon accumulation rates should allow the use of more North Carolina-specific coastal wetland carbon data in future iterations of this inventory.

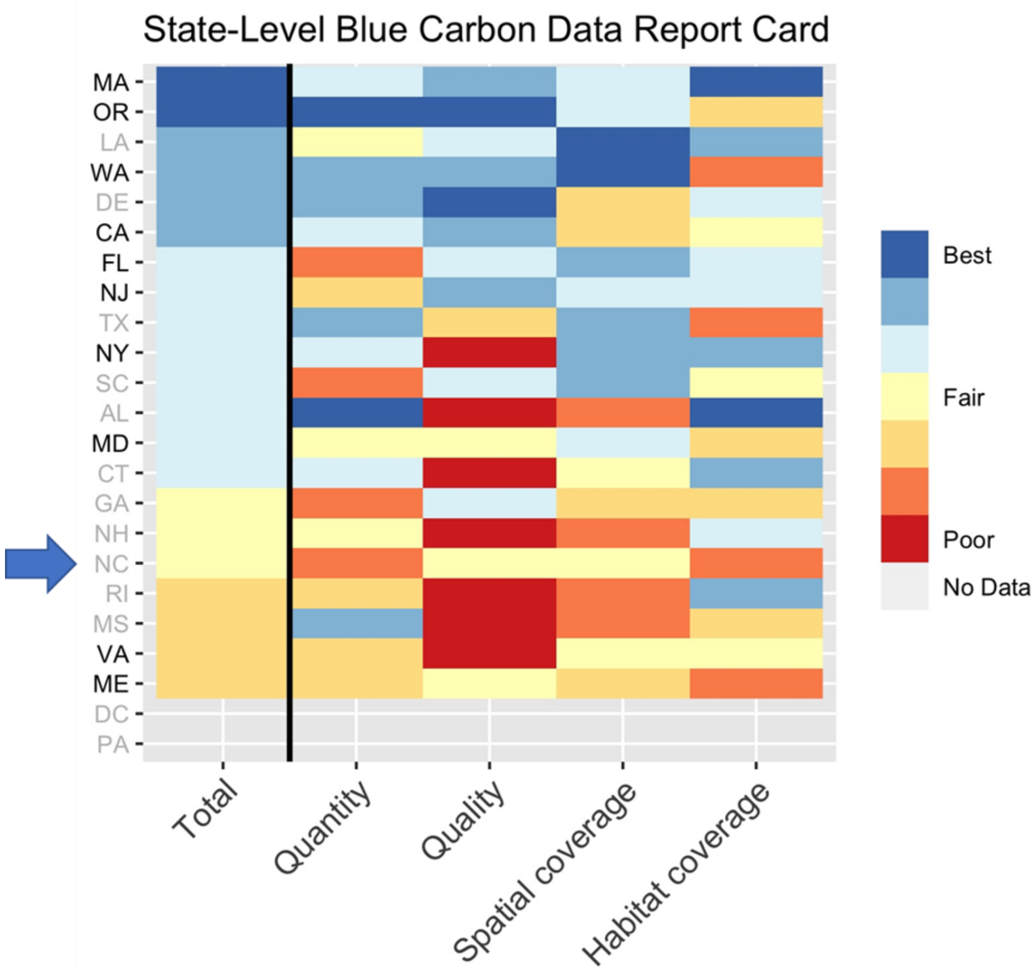

Figure C2. State Level Report Card showing rankings of all coastal states and the District of Columbia along four metrics: quantity, quality, spatial coverage, and habitat coverage for focal states selected by Pew (black) and other coastal states in CONUS (grey).[41] They are ordered top to bottom by their composite rank, calculated as the average of the other four rankings.

D. NC Coastal Habitat Protection Plan (CHPP) Recommended Actions

This interim report contributes to the implementation of CHPP Recommended Actions 4.2, 4.5, 5.17, 8.1, 8.2, and 8.3:

- **4.2**: By 2022, DEQ will commit to protecting and restoring SAV to reach an interim goal of 191,000 acres coastwide with specific targets by SAV waterbody regions
- **4.5**: By 2023, DEQ will develop and implement a full-scale assessment program to conduct coastwide SAV mapping and monitoring at regular intervals (≤ 5 years).
- **5.17**: By 2022, DEQ should support efforts to incorporate coastal wetlands into NC's Greenhouse Gas (GHG) Inventory.

- **8.1**: By 2022, convene interagency workgroups of DEQ agency staff, academics, and subject matter experts by coastal habitat type (i.e., water column, shell bottom, SAV, wetlands, hard bottom, and soft bottom) to define indicator metrics and identify data gaps and monitoring needs for the ability to determine long-term status and trends of coastal habitats and the estuarine ecosystem.
- **8.2**: By 2026, develop a document determined by the workgroups to communicate the ecosystem conditions of NC to the public.
- **8.3**: By 2023, DWR will evaluate and prioritize estuarine ambient monitoring system sites to address gaps in spatial, habitat, or parameter coverage.

E. NC Natural and Working Lands Action Plan Recommendations

The interim report contributes to the implementation of NWL Plan recommendations 3.1.2, 3.1.3, 3.1.4, 3.6.1, and 3.6.2:

- **3.1.2**: Facilitate voluntary landowner participation in carbon offsets and ecosystem service markets
- **3.1.3**: Build a natural and working lands solutions toolbox
- **3.1.4**: Integrate climate adaptation and resiliency strategies into local comprehensive plans
- **3.6.1**: Protect coastal habitats
- **3.6.2**: Restore coastal habitats

[1] Based on the Federal Geographic Data Committee: Classification of Wetlands and Deepwater Habitats of the United States as defined at the Class level (Figure 1)

[2] D. Field, J. Kenworthy, and D. Carpenter, "Metric Report: Extent of Submerged Aquatic Vegetation in High-Salinity Estuarine Waters" (Albemarle-Pamlico National Estuary Partnership, 2021), https://apnep.nc.gov/documents/files/metric-report-extent-submerged-aquatic-vegetation-high-salinity-estuarine-waters/open.

[3] U.S. Environmental Protection Agency, "Greenhouse Gas Equivalencies Calculator," accessed April 2023, https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator.

[4] North Carolina uses the following definition for NWL, modelled after California's 2030 Natural and Working Land Climate Change Implementation Plan: "Forests, woodlands, grasslands, shrubland, wetlands, riparian areas, rangeland, farmland, coastal areas, and greenspaces within urban and built environments (including the urban forest and street trees in the public right-of-way)"

[5] North Carolina Department of Environmental Quality and North Carolina Department of Natural and Cultural Resources, "North Carolina Natural and Working Lands Action Plan" (2020), https://files.nc.gov/ncdeq/climate-change/natural-working-lands/NWL-Action-Plan-FINAL---Copy.pdf.

[6] North Carolina Department of Environmental Quality, "North Carolina Coastal Habitat Protection Plan" (2021 Amendment), https://www.deq.nc.gov/marine-fisheries/coastal-habitat-protection-plan/north-carolina-coastal-habitat-protection-plan-2021-amendment/open.

[7] This report uses high salinity submerged aquatic vegetation (SAV), high salinity seagrass, and seagrass interchangeably to refer to three high salinity seagrass species: *Zostera marina* (eelgrass), *Halodule wrightii* (shoal grass), and *Ruppia maritima* (widgeon grass). Figure 1 depicts the historic extent of both high- and low-salinity submerged aquatic vegetation; however, this report only examines the three true seagrass species named above.

[8] North Carolina Department of Environmental Quality, "North Carolina CHPP."

[9] Intergovernmental Panel on Climate Change, "2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands" (2014), https://www.ipcc-nggip.iges.or.jp/public/wetlands/.

[10] United States Climate Alliance, "Natural and Working Lands," United States Climate Alliance, https://usclimatealliance.org/policy-priorities/natural-working-lands/.

[11] United States Environmental Protection Agency, "State Inventory and Projection Tool," https://www.epa.gov/statelocalenergy/state-inventory-and-projection-tool#:~:text=What%20is%20the%20State%20Inventory,or%20complete%20a%20new%20inventory.

[12] The U.S. EPA's State Inventory Tool does not include coastal wetlands.

[13] Developing Coastal Habitat Protection Plans (CHPPs) were required in the Fisheries Reform Act of 1997 (FRA; G.S. 143B-279.8). The legislative goal of the CHPP is "…the long-term enhancement of coastal fisheries associated with coastal habitats." North Carolina Department of Environmental Quality, "North Carolina CHPP."

[14] Field, Kenworthy, and Carpenter, "Metric Report: Extent of Submerged Aquatic Vegetation in High-Salinity Estuarine Waters." Also see Appendix.

[15] Intergovernmental Panel on Climate Change, "2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands."

[16] Ibid.

[17] M.P.J. Oreska et al., "The greenhouse gas offset potential from seagrass restoration," *Scientific Reports* 10, no. 1 (2020): 7325, https://doi.org/10.1038/s41598-020-64094-1.

[18] CO_2 equivalents are calculated by multiplying the molecular weight of CO_2 (44) and dividing by the molecular weight of C (12)

[19] One kiloton is equal to 1,000 tons.

[20] Activity data refers to area change over time.

[21] More detailed descriptions are provided in the Technical Appendix.

[22] The UNFCCC requires that the reporting tables include data from 1990, 2005, and the five most recent years.

[23] Smithsonian Environmental Research Center, Coastal Wetland NGGI Public Data, https://github.com/Smithsonian/Coastal-Wetland-NGGI-Data-Public.

[24] K.B. Byrd et al., “A remote sensing-based model of tidal marsh aboveground carbon stocks for the conterminous United States,” *ISPRS Journal of Photogrammetry and Remote Sensing* 139 (2018): 255-71, 10.1016/j.isprsjprs.2018.03.019.

[25] K.B. Byrd et al., “Corrigendum to "A remote sensing-based model of tidal marsh aboveground carbon stocks for the conterminous United States" [ISPRS J. Photogram. Rem. Sens.139 (2018) 255-271],” *ISPRS Journal of Photogrammetry and Remote Sensing* 166 (2020): 63-67, http://pubs.usgs.gov/publication/70211960.

[26] Intergovernmental Panel on Climate Change, “2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands.”

[27] J.R. Holmquist et al., “Accuracy and Precision of Tidal Wetland Soil Carbon Mapping in the Conterminous United States,” *Scientific Reports* 8, no. 1 (2018): 9478, https://doi.org/10.1038/s41598-018-26948-7.

[28] Byrd et al., “Remote sensing-based model of tidal marsh.”

[29] Holmquist et al., “Accuracy and Precision of Tidal Wetland Soil Carbon Mapping in the Conterminous United States.”

[30] X. Lu et al., “Increasing Methane Emissions From Natural Land Ecosystems due to Sea-Level Rise,” *Journal of Geophysical Research: Biogeosciences* 123, no. 5 (2018): 1756-68, https://doi.org/10.1029/2017JG004273.

[31] A. Bartenfelder et al., “The Abundance and Persistence of Temperate and Tropical Seagrasses at Their Edge-of-Range in the Western Atlantic Ocean,” *Frontiers in Marine Science* 9 (2022), https://www.frontiersin.org/articles/10.3389/fmars.2022.917237.

[32] Field, Kenworthy, and Carpenter, “Metric Report: Extent of Submerged Aquatic Vegetation in High-Salinity Estuarine Waters.”

[33] North Carolina Department of Marine Fisheries, North Carolina Marine Fisheries Spatial Interface, https://fisheries-ncdenr.opendata.arcgis.com/.

[34] North Carolina Department of Environmental Quality, “North Carolina CHPP.”

[35] G.J. Davis and M.M. Brinson, “A survey of submersed aquatic vegetation of the Currituck Sound and the western Albemarle-Pamlico estuarine system” (East Carolina University, 1990), https://apnep.nc.gov/documents/files/apes/survey-sav-currituck-sound-and-western-ap-estuarine-system/open.

[36] E.R. Hillmann et al., “Estuarine submerged aquatic vegetation habitat provides organic carbon storage across a shifting landscape,” *Science of The Total Environment* 717 (2020): 137217, https://www.sciencedirect.com/science/article/pii/S0048969720307270.

[37] R.J. Carraway and L.J. Priddy, “Mapping of submerged grass beds in Core and Bogue Sounds, Carteret County, North Carolina by conventional aerial photography,” (1983), https://repository.library.noaa.gov/view/noaa/1538.

[38] Ibid.

[39] National Oceanic and Atmospheric Administration Office for Coastal Management, Coastal Change Analysis Program (C-CAP) Regional Land Cover, https://coast.noaa.gov/digitalcoast/data/ccapregional.html.

[40] J. Holmquist, J. Wolfe, and P. Megonigal, “Coastal Carbon Research Network Blue Carbon Inventory” (Smithsonian Environmental Research Center, 2021), https://smithsonian.github.io/CCRCN-Pew-Project/s.

[41] Ibid.