Audubon | NORTH CAROLINA

CURRITUCK SOUND COALITION

Marsh Conservation Plan

DECEMBER 2021

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Currituck Sound Coalition Vision:
To increase community and ecosystem resilience to climate change and other threats through enhanced collaboration and partnership on nature-based initiatives.

Introduction and Summary

Nearly 200 years ago, the last of the inlets in the northern Outer Banks closed, severing Currituck Sound's direct connection to the Atlantic Ocean. Cut off from this influx of salt water, Currituck Sound began a transition to an oligohaline (very low salt content) water body. This globally rare ecosystem, with its shallow marshes pulsed by wind tides, has since become world-renowned for its abundant populations of birds, fish, and other wildlife.

Aerial view of oligohaline marshes at Donal C. O'Brien Jr. Sanctuary at Pine Island

An Essential Ecosystem

The marshes of Currituck Sound serve as important habitat for numerous terrestrial, aquatic, aerial, and amphibian species at all trophic levels. These highly productive wetlands also provide ecosystem services that benefit people. They act as buffers that protect communities along Currituck Sound from erosion caused by wind and waves. They reduce the impacts of flooding by slowing down and filtering stormwater as it flows through the wetland system. They also provide places of beauty and recreation, and play a critical role in preserving the cultural heritage of eastern North Carolina.

Together, we can chart a path to a healthier future for this unique and extraordinary place.

Marshes serve as habitat for fish and wildlife while also providing protection from storms, recreational opportunities, and many other benefits to coastal communities.

An Imperiled Treasure

The South Atlantic Coastal Plain has changed considerably over the last 100 years, with a growing human population affecting the biological diversity and environmental health of the region's landscapes and seascapes. Today, the marshes of Currituck Sound are increasingly at risk due to threats such as habitat loss and fragmentation, sea level rise, and proliferation of invasive aquatic plants—all of which may be exacerbated by climate change. Loss of marsh and submerged aquatic vegetation has led to population declines in birds and fish in the sound.

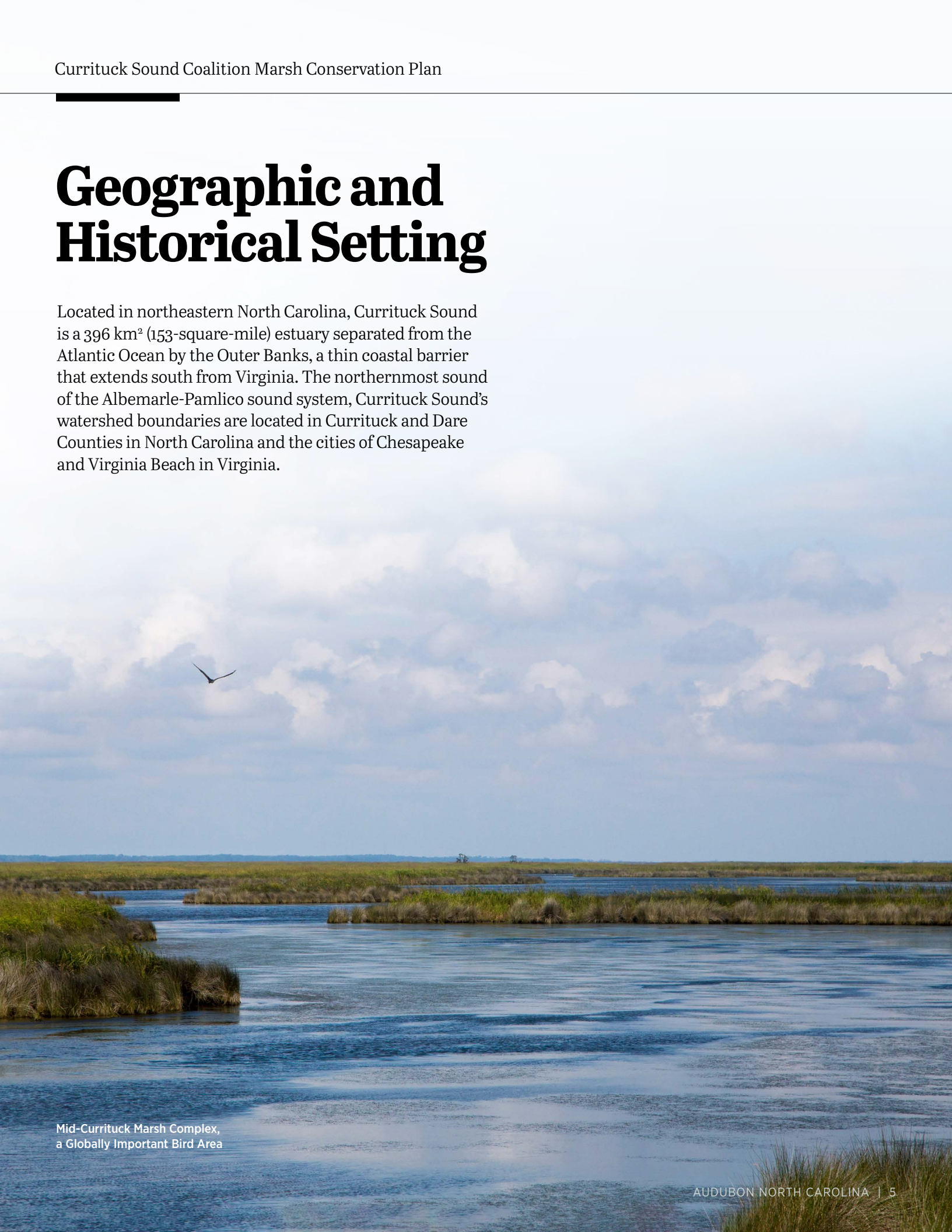
At the same time, these dynamic conditions have exposed gaps in our knowledge about best management practices for oligohaline marshes and the interconnections between marshes and other natural systems in the region. Sea levels are projected to rise 46 centimeters (1.5 feet) by 2050, and other effects of climate change are expected to increase stress on aquatic ecosystems and diminish their ability to support and maintain a balanced, adaptive, and diverse community of species in Currituck Sound. Without effective conservation action, the future of this important natural resource is in jeopardy.

A Collaborative Response

Recognizing that no one entity alone can effectively respond to the threats that face Currituck Sound, Audubon North Carolina (Audubon) convened the Currituck Sound Coalition (CSC) in 2019. The coalition is composed of 14 partners representing nonprofit organizations, academic institutions, local communities, and state and federal government agencies. With a range of expertise and experience, the coalition is uniquely positioned to tackle the challenges facing marshes in Currituck Sound through ecosystem restoration and conservation. Although we have diverse interests, we share a vision to increase community and ecosystem resilience to climate change and other threats through enhanced collaboration and partnership on nature-based initiatives. Our ability to work together will be critical to protecting and restoring the marshes in Currituck Sound to the benefit of the wildlife and people who depend on them. Together, we can chart a path to a healthier future for this unique and extraordinary place.

Geographic and Historical Setting

Located in northeastern North Carolina, Currituck Sound is a 396 km² (153-square-mile) estuary separated from the Atlantic Ocean by the Outer Banks, a thin coastal barrier that extends south from Virginia. The northernmost sound of the Albemarle-Pamlico sound system, Currituck Sound's watershed boundaries are located in Currituck and Dare Counties in North Carolina and the cities of Chesapeake and Virginia Beach in Virginia.



Mid-Currituck Marsh Complex, a Globally Important Bird Area

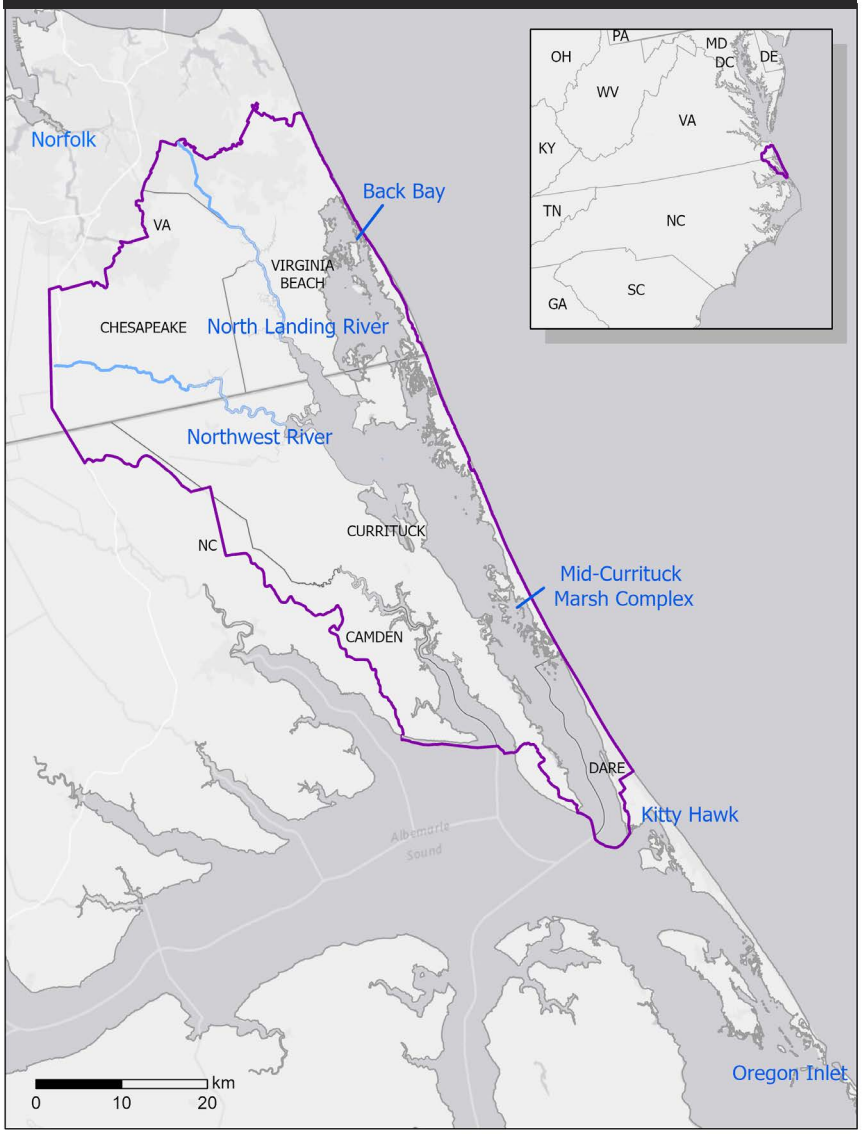
Between three and eight miles wide, Currituck Sound extends 60 km (37 miles) north to south from Back Bay in Virginia to the sound's confluence with Albemarle Sound in North Carolina (Eagleson 1994). Its depth averages 1.5 meters (5 feet) with a general maximum depth of 4 meters (13.1 feet) (Caldwell 2001), although deeper "holes" exist locally. Freshwater inputs include the North Landing River and Northwest River which originate in the Great Dismal Swamp of North Carolina and Virginia; however, the sound lacks a major source of fluvial sediment (Rideout 1990). Oregon Inlet, located approximately 72 km (45 miles) from its southern end, is the nearest connection to the Atlantic Ocean. In the past, several inlets have periodically connected Currituck Sound with the ocean (Fisher 1962; Robinson and McBride 2006; Mallinson, et al. 2008).

The Currituck Sound region was home to Algonquian-speaking Indigenous people, and served as fishing and hunting grounds for the Weapemeoc Tribe (Malvasi 2010) at the time of the arrival of the first English settlers. After the last inlet in the northern Outer Banks closed naturally in 1828, the sound began converting to an oligohaline system. Through all these changes, it has remained a critical component of the ecological and cultural heritage of eastern North Carolina.

The geologic setting of Currituck Sound places it in North Carolina's Northern Coastal Province as defined by Riggs and Ames (2003). The region is characterized by gentle topographic slopes, relatively few slow-draining streams, a long uninterrupted coastal barrier, and an estuary with minimal astronomical tides and little saltwater exchange. Inland alterations to hydrology (e.g., flood control, power generation reservoirs, deforestation, and urban development), coupled with siltation of aquatic ecosystems, have altered natural habitat connectivity and water quality in the sound (USFWS 2008).

The estuary's day-to-day water level is influenced primarily by wind rather than lunar tides. Its shorelines support marshes dominated by big cordgrass (*Spartina cynosuroides*), black needlerush (*Juncus roemarianus*), and common reed (*Phragmites australis*). Fringing marsh makes up much of the western (mainland) and eastern (coastal barrier) shorelines of the sound while marsh islands are locally extensive. One notable area is the mid-Currituck marsh complex, which, at approximately 2,428 hectares (6,000 acres), is the largest marsh complex in Currituck Sound. Several other marsh complexes are located in the northern part of Currituck Sound and are mostly associated with Mackay Island and Currituck National Wildlife Refuges. The marshes in Currituck Sound provide a host of ecosystem services including protection from storm events, sinks for nutrients and sediment, and critical habitat for a variety of aquatic and avian taxa.

CURRITUCK SOUND COALITION PLANNING AREA



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The Currituck Sound Coalition

The Currituck Sound Coalition (CSC) is composed of 14 partners representing non-profit organizations, academic institutions, local communities, and state and federal government agencies. In addition to leading independent projects in northeastern North Carolina, members work together voluntarily on ecosystem restoration and conservation initiatives in the Currituck Sound region.

ALBEMARLE-PAMLICO NATIONAL ESTUARY PARTNERSHIP

AUDUBON NORTH CAROLINA

CHOWAN UNIVERSITY

COASTAL STUDIES INSTITUTE

CURRITUCK COUNTY

DUCKS UNLIMITED

NATIONAL WILDLIFE REFUGE ASSOCIATION

NORTH CAROLINA COASTAL FEDERATION

NORTH CAROLINA COASTAL RESERVE AND NATIONAL ESTUARINE RESEARCH RESERVE

NORTH CAROLINA SEA GRANT

NORTH CAROLINA WILDLIFE RESOURCES COMMISSION

THE NATURE CONSERVANCY

TOWN OF DUCK

U.S. FISH AND WILDLIFE SERVICE

Coalition Vision and Goals

The Currituck Sound Coalition was formed in October 2019 by Audubon to foster collaboration among diverse partners on ecosystem restoration and conservation in Currituck Sound. The purpose of the CSC is to:

- **Leverage the expertise, knowledge, and networks of partner members** to advance shared conservation goals and priorities in Currituck Sound, and
- **Demonstrate broad-based, durable support** to funders and decision makers for investments in protecting and restoring natural systems in Currituck Sound.

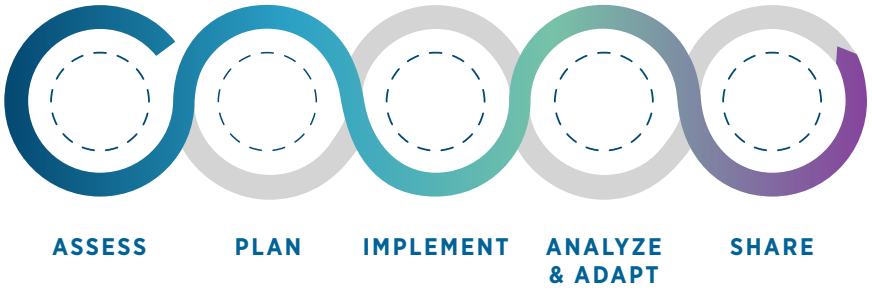
Our shared vision is to increase community and ecosystem resilience to climate change and other threats through enhanced collaboration and partnership on nature-based initiatives. Among our first priorities as a coalition was the development of this conservation plan, which serves as a starting point in an ongoing process of collaborative conservation planning and action.

Process Overview

In 2019, Audubon received funding from the North Carolina Environmental Enhancement Grant Program to support the coalition in developing a marsh conservation plan for Currituck Sound. A working group was formed to lead the planning process with partner members from the Albemarle-Pamlico National Estuary Partnership, Audubon, Currituck County, Chowan University, North Carolina Sea Grant, the Town of Duck, and The Nature Conservancy. Starting in mid-2020, the working group met regularly to engage the coalition partner members in development of the Currituck Sound Coalition Marsh Conservation Plan.

The CSC followed two widely recognized conservation planning frameworks to guide the planning process, including the Open Standards for the Practice of Conservation. These frameworks steered the group's efforts to understand the current status of marshes, the challenges they face, and other information necessary to develop conservation strategies through a facilitated, open, and participatory process. The following sections outline the major steps of the planning process.

PROJECT MANAGEMENT CYCLE | The Open Standards for the Practice of Conservation provide a set of best practices for successful conservation projects, organized into a five-step management cycle.



PLANNING GOALS

The CSC identified three primary goals for the marsh conservation plan:

1 **Build a shared understanding** of the threats to marshes and other conservation targets in northeastern North Carolina.

2 **Study, protect, and restore** marshes and marsh migration corridors in northeastern North Carolina and southern Virginia.

3 **Increase regional collaboration** among CSC partners and watershed stakeholders on marsh restoration and resilience efforts.

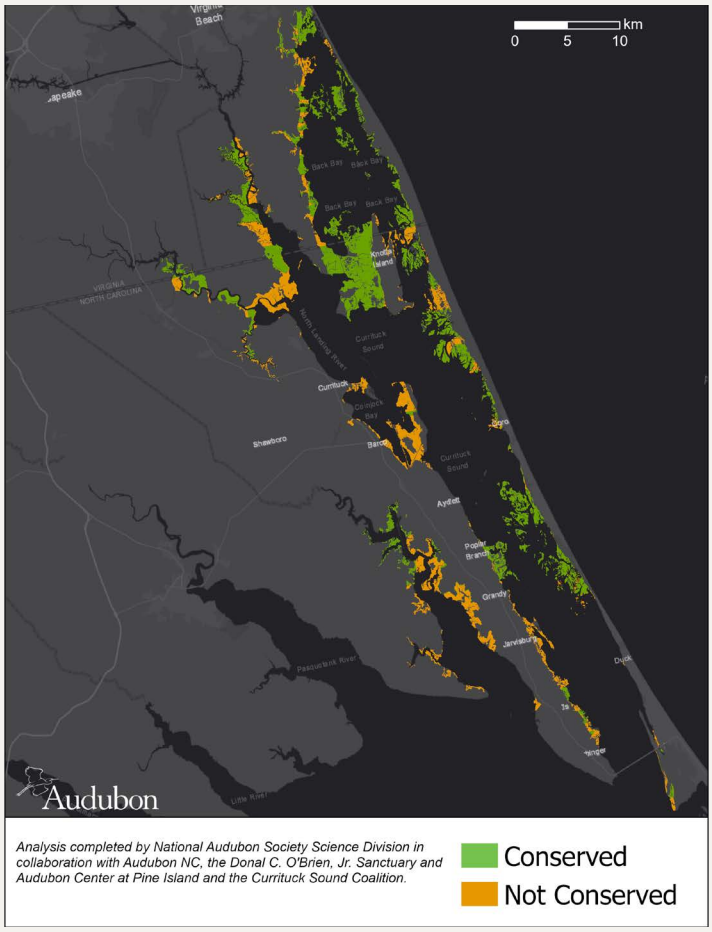
Current Status

Primary Conservation Target: Marshes

As climate change exacerbates sea level rise, flooding, and storms, marshes and other wetlands will play a critical role in protecting people and property and ensuring the survival of coastal wildlife. Of the nearly 142 km² (35,000 acres) of marshes in the planning area, 86 km² (21,194 acres)are currently protected by conservation organizations, easements, or other land protection incentives or regulations (Figure A).

According to the NOAA Coastal Change Analysis Program (C-CAP), the net extent of all wetlands in the planning area declined by 13.31 km² (3,289 acres) from 1996 to 2010. While certain types of wetlands (such as those dominated by shrubs) experienced measurable increases during that time, the decrease in forested wetlands was larger than any gains. Upland migration can help to offset marsh loss in the coming decades; nevertheless, this process will also have implications for other wetland types in the region, many of which will be affected by the same challenges facing marshes.

FIGURE A | CONSERVATION STATUS OF MARSHES IN CURRITUCK SOUND



Marshes on Currituck Sound

Secondary Conservation Targets

While marshes are the primary focus of this conservation plan, the coalition identified additional conservation targets that are closely linked to marsh health. Secondary conservation targets include submerged aquatic vegetation (SAV), water quality, fisheries, and birds.

Submerged Aquatic Vegetation

Rooted aquatic plants that grow underwater in Currituck Sound provide habitat for fish and birds, reduce storm impacts by attenuating wave energy, enhance water quality, and sequester carbon (Biarrieta 2020). Data describing the distribution and overall health of submerged aquatic vegetation (SAV) in the sound are available as far back as the early 1980s, with more recent surveys led by Elizabeth City State University and the Albemarle-Pamlico National Estuary Partnership. Due to variations in data collection and processing methods, it is difficult to directly compare trends in abundance based on these fairly limited datasets.

SAV species present in Currituck Sound include native widgeon grass, wild celery, redhead grass, bushy pondweed, and the invasive Eurasian watermilfoil (Biarrieta 2020). Statewide SAV monitoring is led by the Albemarle-Pamlico National Estuary Partnership (APNEP); however, wind and turbidity inhibit SAV monitoring using aerial surveys in the low-salinity waters of Currituck Sound. To date, APNEP has published two maps of SAV in the high-salinity portions of the Albemarle-Pamlico estuary from the years 2012-2014 and 2006-2008. Currituck Sound was not included in the 2012-2014 aerial surveys due to the challenges referenced above.

Submerged aquatic vegetation serves as a nursery and food source for aquatic life, including blue crab. It also helps to improve water quality, attenuate wave energy, and stabilize marsh shorelines.

Water Quality

Changes in the geomorphology of the coast in northeastern North Carolina over time—in particular the closing of inlets connecting Currituck Sound to the Atlantic Ocean—have resulted in significant shifts in the sound's hydrological regime. In a 2011 study, the U.S. Army Corps of Engineers identified four primary threats to water quality in Currituck Sound: nutrient loading associated with agricultural and urban runoff and septic wastewater contamination; increased turbidity; saltwater intrusion; and increased pollution from draining basins in Virginia (USACE 2011). In 2014, Currituck Sound was listed on the 303d list as impaired for Enterococcus. The state does not conduct ambient water quality sampling in Currituck Sound, North Landing River, or Northwest River watersheds (DEQ DWR Pasquotank Basin Plan 2021), but two existing studies using the Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST) and Spatially Referenced Regressions on Watershed Attributes (SPARROW) models can provide guidance to target localized surface-water quality sampling and implementation of best management practices which improve water quality (NCDEQ 2021).

Fisheries

Oligohaline marshes in Currituck Sound support habitat for numerous commercially valuable fisheries including Atlantic croaker, striped bass, southern flounder, red drum, spotted sea trout, and blue crab (USACE 2011). Submerged aquatic vegetation provides critical habitat for juvenile and adult fish in Currituck Sound. The North Carolina Division of Marine Fisheries (NCDMF) has developed Fisheries Management Plans for many of the species in Currituck Sound. The most valuable commercial fisheries in Currituck Sound based on NCDMF data from 1990 to 2008 are blue crab and paralichthid flounder (CZR 2009).

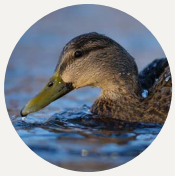
Sunrise from the nature trail at Currituck Banks Reserve.

Birds

Currituck Sound is among the most important places for birds in the world, and could serve as a stronghold for species as climate changes. Migratory waterfowl are an integral part of the ecosystem and cultural heritage in Currituck Sound. Population size and behavior of migratory waterfowl such as the American Black Duck have been monitored since the early 1950s (NCWRC 1964). Historically, waterfowl hunting has been a significant recreational and economic activity in Currituck Sound. Waterfowl populations have experienced declines across the region since the early 1900s due at least in part to fluctuations in SAV extent over that time period (Biarrieta 2020).

In addition to waterfowl, Currituck Sound hosts other locally and regionally significant marsh birds such as herons, ibis, rails, and egrets, as well as raptors and songbirds (USACE 2011). Numerous investigations and monitoring efforts shed light on population trends and behavior of these species in northeastern North Carolina. Federally listed species such as the threatened Eastern Black Rail and the endangered Red-cockaded Woodpecker have also been found in Currituck Sound. The Eastern Black Rail is a priority species for numerous conservation entities along the Atlantic Flyway and has been detected as recently as 2015 in the region (Wilson et al. 2016). Ongoing investigations related to birds include studies of nesting behavior of King Rails at Mackay Island National Wildlife Refuge and Tree Swallows at Pine Island Sanctuary, led by East Carolina University and Davidson College, respectively. Audubon North Carolina leads annual secretive marsh bird surveys at Pine Island Sanctuary.

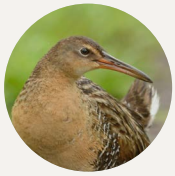
Oligohaline Priority Bird Species



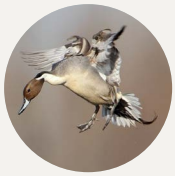
American Black Duck

Black Rail

Clapper Rail

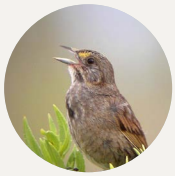


King Rail



Northern Pintail

Saltmarsh Sparrow



Seaside Sparrow

Conservation Challenges

The CSC working group conducted a situation analysis for the coalition's primary conservation target, oligohaline marshes, to explore the current state of marshes and the challenges they face in Currituck Sound. Challenges to Currituck Sound marshes involve processes that directly decrease marsh areal extent, diminish the ability of marshes to persist in a changing environment, and/or degrade the ecosystem services that marshes provide. While the impacts of some challenges are well understood (Table 1), others require further analysis to understand their effects on marshes in Currituck Sound (Table 2).

« **A situation analysis** is an assessment that identifies and considers the key challenges affecting a conservation target, including direct threats, indirect threats, and opportunities for intervention.

TABLE 1 | CHALLENGES WITH KNOWN IMPACTS TO MARSHES IN CURRITUCK SOUND

CHALLENGE	DESCRIPTION
Sea Level Rise	The Currituck Sound region experiences one of the highest rates of relative sea level rise along the Atlantic East Coast (City of Virginia Beach 2020) due to a high rate of geologic subsidence and shifts in the position and speed of the Gulf Stream (NCCRC Science Panel 2015). For example, sea level rise in the Town of Duck, North Carolina has averaged 4.6cm (1.8 inches) per decade since 1978 (NC Climate Report 2020). Over time, marshes that cannot accrete vertically to keep pace with sea level rise will either shrink in size, with the former marsh area becoming open water, or transgress inland in a process known as marsh migration (Fagherazzi et al. 2019). The extent of marsh migration and its success in maintaining a healthy marsh ecosystem are complicated by a variety of factors that include the slope and topography of the land's surface and the presence of development that blocks the process.
Erosion	Based on analysis of aerial and satellite imagery, the U.S. Army Corps of Engineers reported that Currituck Sound is losing approximately 28 hectares (70 acres) of marsh each year (USACE 2011). Wind and wave erosion at the marsh-sound boundary are major processes contributing to this problem. Continued sea level rise is expected to exacerbate the loss of fringing marsh and marsh islands due to erosion.
Invasive Species	Several invasive species are known to exist in Currituck Sound marshes including plants (common reed and alligator weed), invertebrates (red swamp crayfish), and mammals (nutria). Three of these taxa are considered high priority, and the fourth (nutria) medium priority, with respect to their potential ecological and economic impact and management difficulty (NCANSMPC 2015). Numerous other invasive species are potentially present, or could easily be introduced, but are undocumented at this time. The presence of invasive species in marshes is known to alter habitat structure, decrease biodiversity, change nutrient cycling and productivity, and modify food webs (Zedler and Kercher 2004).
Lack of Sediment Delivered to the Marsh Surface	The survival of coastal wetlands threatened with sea level rise depends on their ability to maintain surface elevation (Callaway et al. 1996) through some combination of organic matter accumulation and mineral sediment deposition. Unfortunately, Currituck Sound lacks a significant source of mineral sediment due to 1) the absence of a major stream system that delivers sediment to the sound, and 2) development that has altered natural coastal sediment flux (Miselis and Lorenzo-Trueba 2017).

TABLE 2 | CHALLENGES REQUIRING FURTHER STUDY TO ASSESS IMPACTS TO MARSHES IN CURRITUCK SOUND

CHALLENGE	DESCRIPTION
Altered Hydrology	An area's hydrology, and more specifically hydroperiod (the frequency and duration of flooding) is the single most important factor in determining wetland function (Mitsch and Gosselink, 2015). It controls the growth and species composition of wetlands (Todd et al. 2010), as well as directly affects ecological processes such as productivity, germination, decomposition, nutrient dynamics, and vegetative reproduction. Thus, changes in hydrology (e.g., due to land use change, development, agricultural practices) can have a negative impact on wetland function.
Declining Water Quality	A major benefit of wetlands in general, and marshes in particular, is their ability to absorb and breakdown pollutants. However, there is a limit to their capacity to provide this important service. At elevated levels, the concentration of a pollutant can degrade a marsh and become toxic to nearby communities. Examples of pollutants that, at high levels, can negatively impact marshes include: sediment, fertilizer, human sewage, animal waste, road chemicals, pesticides, and heavy metals (EPA 2001).
Loss of Biodiversity	Oligohaline marshes such as those in Currituck Sound are characterized by low salinity, and as a result are capable of supporting a relatively large number of plant species. Loss of plant diversity can degrade ecosystem function and diminish the services they provide (Cardinale et al. 2011). Marsh plant diversity is positively related to primary productivity, nutrient retention, and ecosystem resiliency/stability (Zedler et al. 2001). Moreover, marsh plant diversity can affect higher trophic levels and allow for a more complex food web. Loss of biodiversity in marshes is often related to fragmentation, changes in hydrology, and introduction of non-native species.
Saltwater Intrusion	As sea levels rise, saltwater moves inland through a process called saltwater intrusion (White and Kaplan 2017). Freshwater wetlands, and marshes in particular, will be the first to experience saltwater intrusion. In general, three scenarios are possible: 1) marsh plants adapted to low salinities may not be able to survive and are replaced by saltmarsh plants, 2) salt stress causes low salinity marsh plants to be outcompeted by an invasive species like common reed (*Phragmites australis*), 3) the rate of sea level rise and saltwater intrusion is such that the low salinity marsh dies off and the area becomes open water.
Storm Activity	Coastal wetlands are valued for their ability to provide protection from storm events. However, these wetlands are often adversely affected by wind and wave related erosion, deposition of wrack and/or large volumes of sediment, and negative physiochemical reactions of wetland plants to prolonged increases in water level and salinities (Morton and Barras 2011). Increases in storm intensity can lead to mechanical removal of marsh plants and increased stress on remaining vegetation, resulting in loss of wetland function. During the 20-year period from 1999 through 2018, NCEI recorded 57 hurricane and tropical storms across 27 separate days which impacted the Outer Banks with extreme winds (Outer Banks Regional Hazard Mitigation Plan 2020). The 2020 North Carolina Risk Assessment and Resilience Plan concluded that rising sea levels coupled with more intense coastal storms will almost certainly increase storm surge, flooding, and erosion in the state.

Drivers of Conservation Challenges

Drivers represent the key underlying causes of conservation challenges. Just like the habitats that make up the Currituck Sound ecosystem, the challenges to Currituck Sound's marshes and their drivers are interrelated. The synergies that exist among challenges and drivers often create positive feedbacks.

Climate Change
The principal driver of the challenges to marshes identified in Currituck Sound is climate change. Fundamentally, climate change either directly or indirectly influences many of the challenges listed above through increased temperatures and carbon dioxide concentrations (Erwin 2009), changes in precipitation patterns (Pearl et al. 2019), and enhanced storm activity (Knutson et al. 2021).

Land-use Changes
Development and land-use change resulting in loss of green space represent another major driver of marsh loss. Between 2010 and 2019, the human populations in Currituck and Dare Counties increased 17.9 and 9.1 percent respectively (U.S. Census Bureau 2019a, 2019b). More recently, a booming real estate market has spurred several large development projects along the Currituck County mainland (Nielson 2019; Stevens 2021) and both residential and lot/land sales on the Outer Banks (OBAR 2021) have increased dramatically. Between April 2020 and April 2021 residential sales increased 183 percent and 122 percent in Corolla and Duck respectively. Development in natural areas reduces the space available for marshes to move as sea levels rise, and can create physical barriers to upland migration.

Stormwater Management
Stormwater management practices are another important driver of challenges relating to water quality, hydrology, and invasive species (EPA 1996). Effective stormwater management reduces the "pulse" associated with surface water runoff from storm events and limits the amount of pollutants delivered directly to streams by allowing stormwater to soak in and percolate through the soils.

Development can affect both the quantity and quality of water by changing the natural flow of stormwater runoff in a watershed. Development often removes beneficial vegetation and replaces it with impervious materials such as driveways, parking lots, and roads, thereby reducing evapotranspiration and infiltration rates. In addition, clearing and grading can remove surface depressions that store rainfall, and agricultural practices such as ditching and draining can dramatically alter drainage patterns. The low gradients found in the Currituck Sound region create poorly drained soils, and agricultural drainage contributes surface and subsurface water, as well as soluble salts, to the sound.

(From top) Live oaks killed by rising seas and erosion at the Pine Island Audubon Sanctuary; marsh view from Town of Duck

Knowledge Gaps

A first step in identifying and filling gaps in information consisted of compiling previous environmental assessments of Currituck Sound and using them as a baseline for comparing to current conditions. We consulted assessments from peer-reviewed literature, coastal planning and conservation prioritization efforts by the State of North Carolina and local communities, and documentation of declines of coastal wetlands and seagrass in the region.

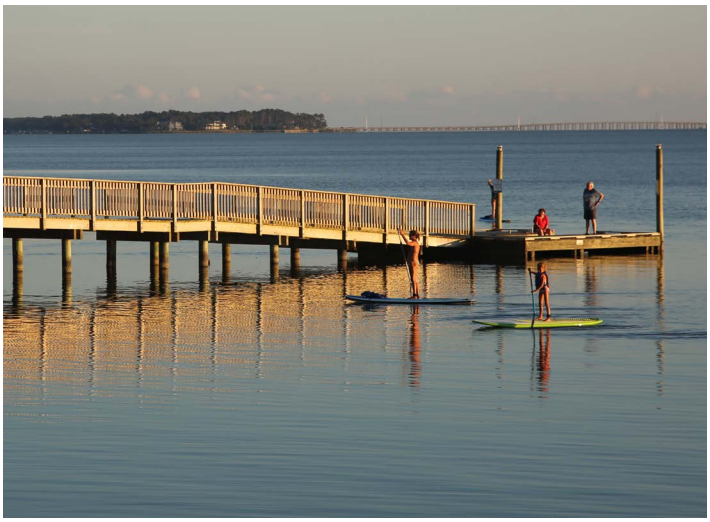
Coalition partners identified seven specific areas where knowledge gaps exist and additional work is needed to improve our understanding and ability to protect Currituck Sound marshes. By their nature, many of these areas overlap and information gained in one area will increase our understanding in others.

Local Rates of Wetland Accretion

A critical question for coastal managers is, "To what extent can wetlands accrete vertically and keep pace with rising sea level?" To answer this question fundamental research is needed to define characteristics specific to Currituck Sound marshes. These are called biogeomorphic properties and include species present, productivity, decomposition, above-ground and below-ground biomass, surface accretion, compaction, and local subsidence. Although these metrics are well documented in other oligohaline marshes, site-specific data is necessary for successful marsh management and restoration (Reed et al. 2008). A key component of this effort should involve establishing surface elevation tables–marker horizons (SET-MH) (Lynch et al. 2015) in different marsh types throughout Currituck Sound to complement the existing network of SETs in North Carolina.

Economic Impact

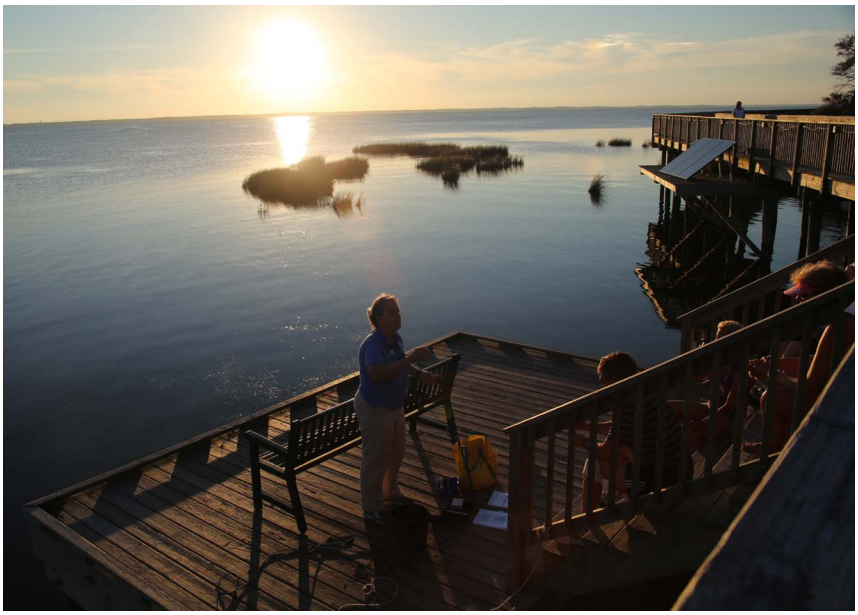
The marshes in Currituck Sound provide a range of ecosystem services that support and maintain ecological processes as well as an important tourism economy and a growing year-round population. Providing quantitative economic data on the value of these marshes can bolster support and funding for efforts to protect, conserve, and restore them. As an example, the Albemarle-Pamlico National Estuary Partnership recently funded a study that estimates market and non-market economic losses from declines in submerged aquatic vegetation in the Albemarle-Pamlico estuary (Sutherland et al. 2021).



(From top) Coastal Studies Institute and Audubon staff install surface elevation table (SET) markers to monitor marsh elevation dynamics over time in marshes near the mainland; in the Town of Duck, outdoor recreation and tourism contribute to the local economy

Ecosystem Feedbacks

Currituck Sound consists of open-water and benthic habitats, SAV communities, oligohaline marshes, swamps, and adjacent uplands that are interconnected. Any one habitat type is interdependent on the health and processes occurring in adjacent habitats. For example, SAV can slow wave energy and inhibit erosion in an adjacent marsh, but may also reduce the amount of sediment reaching the marsh platform. On the other hand, marshes can filter water-column sediments to improve light penetration and promote SAV growth. The two adjacent habitats are dependent on each other; however, details of these types of connections are not well understood.



(From top) An educator leads a talk on the marsh ecology in the Town of Duck; Pine Island Audubon Sanctuary's living shoreline project will help build stronger, more resilient marshes through natural processes.

Long-Term Monitoring and Modeling

Another critical question for coastal managers is, "How do Currituck Sound marshes change in type, character, area, and health through time?" Ongoing monitoring and spatial analyses are needed to keep track of changes in species diversity (including invasive species), structure (e.g., stem height and density), and marsh spatial extent. The latter requires precise mapping of wetland-upland boundaries and marsh types based on dominant vegetation. In addition, predictive modeling is necessary to inform management and planning for processes such as marsh loss and marsh migration.

Management Best Practices

Marsh management often involves practices such as prescribed burning (Venne et al. 2016), water-level control (Mitchell et al. 2006), and removal of invasive species (Hazelton et al. 2014). These activities are undertaken to promote plant diversity and habitat quality for upper trophic levels, and to maintain marsh areal extent. Nevertheless, the scientific literature is mixed on the benefits of these actions (e.g., Theuerkauf et al. 2017). Non-native *Phragmites australis* is prevalent in Currituck Sound, but guidance on the ecological impact and management of this species remains a significant gap. Further research is needed to determine the most appropriate marsh management practices for specific sites, and to adapt our management practices to incorporate climate change and sea level rise.

Physiochemical Regime

Physical parameters and processes in Currituck Sound are poorly documented (Kozak 2016). Detailed information is lacking on bathymetry, wind-wave-current interactions, sediment resuspension, turbidity, and other water quality variables (e.g., temperature, salinity, dissolved oxygen, nutrients, and pH). Many of these parameters are related to each other, and all are influenced by wind events and storm activity. A better understanding of the parameters and processes associated with the transport, erosion, and deposition of sediment within and around marshes in Currituck Sound is needed to maintain the health, stability, and persistence of these wetlands.

Restoration Best Practices

Marsh loss in Currituck Sound is largely due to two processes: 1) lateral erosion occurring at the marsh-sound boundary (USACE 2011), and 2) marsh breakup due to insufficient accretion with rising sea level (Cahoon et al 2019). Potential actions to address these processes involve a combination of living shorelines (Currin 2019), submerged sills (Gittman et al. 2011), and thin-layer placement of sediment (VanZomeren and Piercy 2020). Although these techniques have been successfully used in other ecosystems, research is needed to determine the efficacy and most appropriate sites in Currituck Sound.

Conservation Strategies

The coalition identified a set of five near-term strategies to address the threats facing marshes in Currituck Sound. Since the health of marshes is closely tied to other conservation targets in the region, these strategies are likely to have system-wide benefits for natural systems and communities alike.

Homes occupy a narrow strip of the Outer Banks wedged between the Atlantic Ocean and Currituck Sound near the Pine Island Audubon Sanctuary.

Strategies

1 Conserve and expand marsh migration corridors

Our first strategy focuses on protecting existing marshes and critical migration corridors that may support future marsh. We will begin by exploring conservation projects and funding opportunities in the locations prioritized in this plan. We will also seek to protect likely future marshlands, especially those with high flood risk reduction benefits and habitat value, as well as a strong potential to benefit from conservation intervention. For example, hardened structures like bulkheads can be replaced with living shorelines in conjunction with protection of adjacent upland areas to accommodate future marsh migration.

2 Restore and enhance degraded marshes

Our second strategy focuses on interventions to restore and enhance the quality of vulnerable or degraded marshes. Certain restoration techniques, like living shorelines and invasive species removal, have been proven to enhance degraded saltmarshes and are widely practiced across coastal North Carolina. Further implementation is needed to explore the efficacy of these approaches in the oligohaline marshes of Currituck Sound. Other techniques, like thin layer sediment application to help marshes keep pace with sea level rise, are more novel in North Carolina. By fortifying marshes that are currently degraded, we can make them more resilient to sea level rise by improving their ability to accrete vertically or migrate upslope.

3 Address knowledge gaps through research and monitoring to inform adaptive marsh management

This strategy seeks to fill data gaps by expanding monitoring efforts to better understand erosion trends, sediment supply and transport, water quality, and wildlife populations. Preservation and restoration of wetland functions can be difficult because wetlands depend on a complex interface of hydrologic regimes to maintain water, vegetation, and animal complexes and processes. These functions are difficult to monitor and have been historically under-studied in low-salinity systems such as Currituck Sound. Research will also focus on the efficacy of conservation actions and shed light on topics such as the interactions between marshes and other conservation targets, e.g., submerged and emergent vegetation.

4 Strengthen community use and appreciation of natural areas, especially marshes

This strategy seeks to elevate the importance of marsh protection in land use and hazard mitigation planning and through engagement of local stakeholders and decision makers in partner-led initiatives. The coalition seeks to expand local support for conservation action by educating the public about the benefits of natural infrastructure—an approach to accommodating traditional infrastructure needs in a way that mimics nature and is more resilient in the face of climate change—through demonstration projects and other initiatives.

5 Enhance marsh habitat connectivity and ecosystem function

Our final strategy focuses on coordinating management of marshes and other conservation targets (including fisheries, SAV, birds and water quality) across coalition partner members to maximize the impact of our conservation actions. This includes developing and sharing best management practices for conservation actions that impact multiple targets such as prescribed burns.

Conservation Status and Marsh Migration Space

The Nature Conservancy's analysis of marsh migration space was used to explore potential future conservation priorities in the Currituck Sound region (Strategy 1). There are approximately 13,375 hectares (33,050 acres) of migration space available under 46cm (1.5 feet) of sea level rise in the study area (Figure C). Data describing current and future characteristics of migration space—such as land use, flood risk, and demographics—was summarized in 25-km² grids and within county and/or township boundaries (Figure C). Of the total migration space, 9,683 hectares (23,926 acres) or 72 percent is already protected (Figure B). Of the unprotected migration space, approximately 14 percent is currently in use for agriculture and the remainder is considered natural land cover (wetlands, forests, grasslands, etc.). Development was excluded from the migration space analysis.

FIGURE B | CONSERVATION STATUS OF MARSH MIGRATION SPACE UNDER 46 CM (1.5 FEET) OF SEA LEVEL RISE

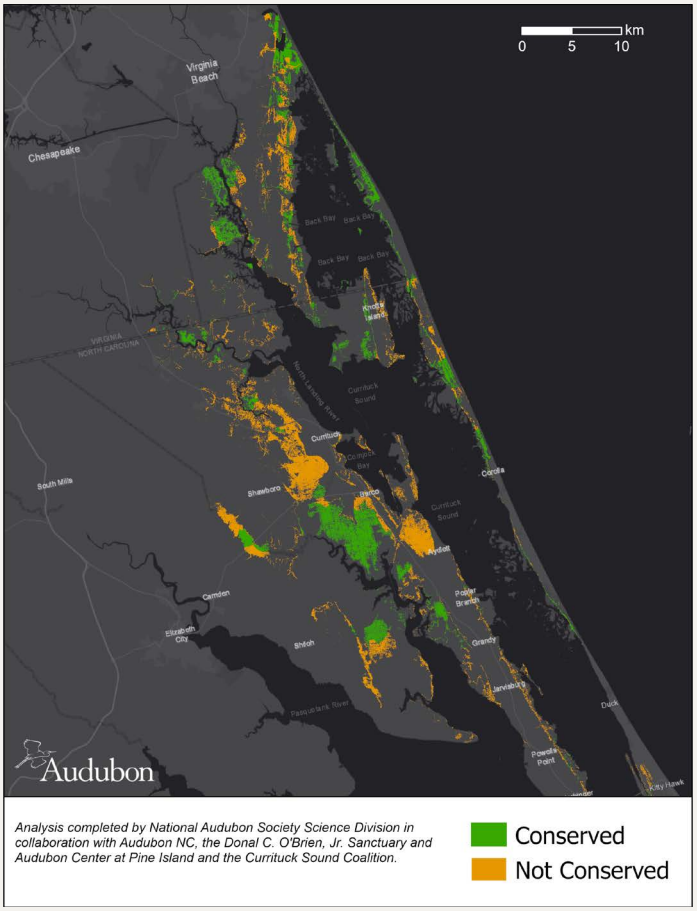
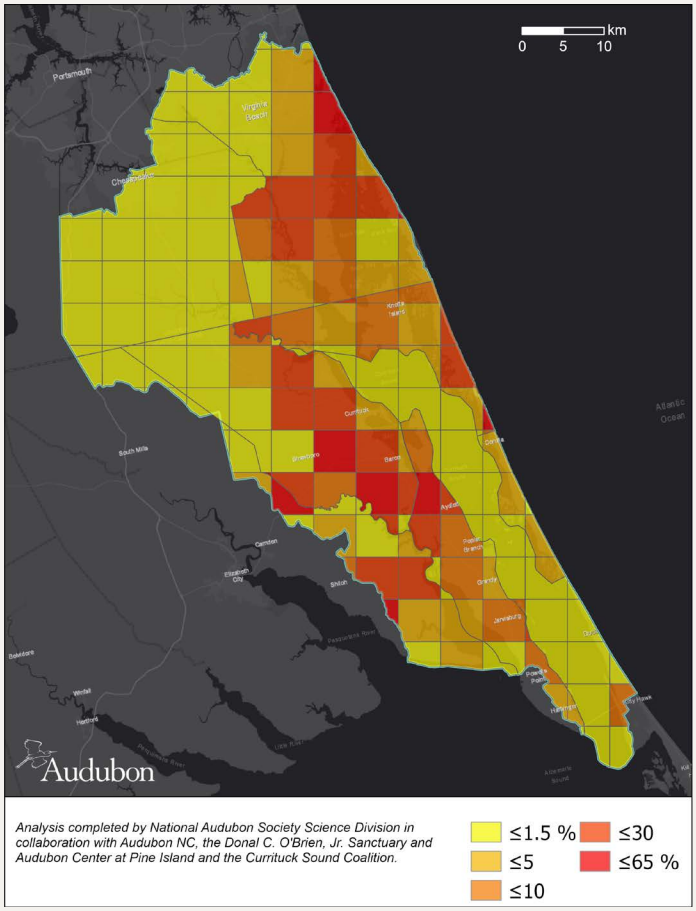


FIGURE C | AVAILABILITY OF MARSH MIGRATION SPACE BY 25-KM² PARCELS



Restoration Scenarios

Restoration of degraded marshes can help ensure the long-term survival of this critical habitat across northeastern North Carolina (Strategy 2). The National Audubon Society's Science Team collaborated with the CSC to assess marsh vulnerability and explore restoration priorities under two distinct scenarios (Figures D and E). The results are available for public use in the Currituck Sound Marsh Restoration Assessment Web App.

The CSC identified and ranked the relative importance of a set of 11 existing data layers for restoration project siting, such as vulnerability to sea level rise, historic increase in surface water, and distance to hardened shorelines. The assessment is based on 46 centimeters (1.5 feet) of projected sea level rise, which follows NOAA model forecasts for mid-century in the Currituck Sound region. For reference, NOAA projects that 80.7 percent of current marsh in the planning area would be inundated under 61 cm (2 feet) of sea level rise. The restoration assessment web app is a screening tool to identify potential high-priority areas for restoration and requires further groundtruthing of restoration needs with local stakeholders and partners. Certain datasets were not available for use in the assessment, including habitat value, shoreline change based on historical imagery, and sediment flux. The CSC seeks to fill these data gaps and update the web app accordingly.

The first restoration scenario prioritized large, degraded estuarine emergent marsh complexes with limited migration space (Figure D). Restoration solutions under this scenario include fortifying existing marshes in place using nature-based techniques such as living shorelines and thin-layer sediment application. In the second scenario, large marsh complexes that are degraded and have migration space available were prioritized for restoration (Figure E). An example of a restoration solution in this scenario might include restoration of the upland edge of the marsh to enable migration. In this scenario, the area that will become marsh in the future should be prioritized for protection. Differences in marsh restoration priorities under the two scenarios are most evident on the mainland side of the sound (Figure F, Appendix).

FIGURE D | MARSH RESTORATION SCENARIO 1

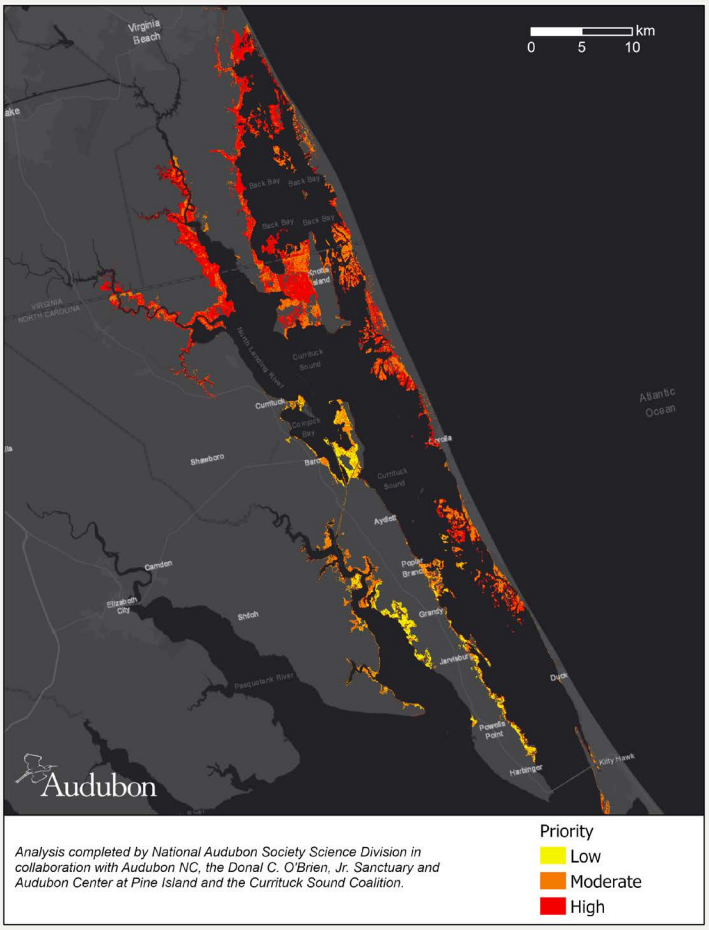
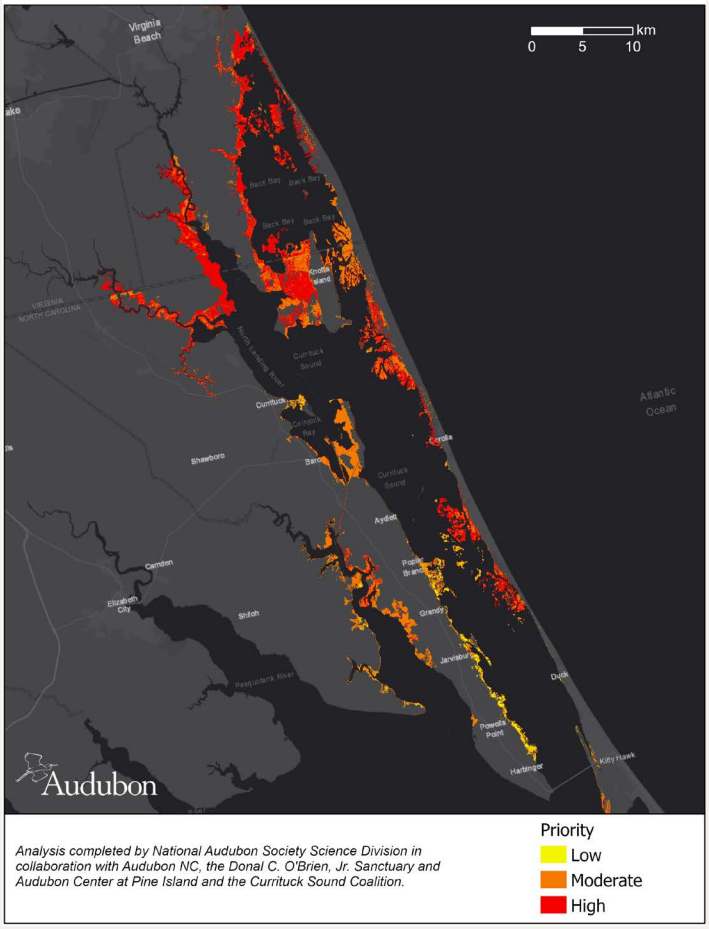


FIGURE E | MARSH RESTORATION SCENARIO 2



Integrating Project Opportunities with Strategies

Partner Project Opportunities

The Currituck Sound Coalition partners are actively collaborating to secure funding for implementation of projects, research, and other initiatives that advance the strategies in this plan. To date, the coalition partners have identified 14 relevant conservation projects and research initiatives that reduce the impacts of threats to marshes in Currituck Sound, while also benefiting multiple conservation targets.

TABLE 5 | CURRITUCK SOUND COALITION PARTNER PROJECTS

PROJECT NAME	LEAD PARTNER	STRATEGY	STATUS
Annual Secretive Marsh Bird Surveys at Pine Island	Audubon	3 & 5	Active
Currituck County Watershed Protection Plan	Currituck County	1 & 5	Proposed
Currituck Sound Sediment Dynamics Study	Coastal Studies Institute, Audubon, Chowan University, North Carolina Sea Grant	3	Proposed
Currituck Sound Water Quality Monitoring	U.S. Army Corps of Engineers	3	Completed
Drone Shoreline Monitoring	Elizabeth City State University and Audubon	3	Active
FWS Invasive Management Program	U.S. Fish and Wildlife Service	2	Active
King Rail Research at Mackay Island Reserve	U.S. Fish and Wildlife Service	3 & 5	Active
Live Oak Point Living Shoreline Demonstration Project	U.S. Fish and Wildlife Service	2 & 4	Proposed
Marsh Vegetation Monitoring at Pine Island	Chowan University, Audubon, North Carolina Coastal Reserve and National Estuarine Research Reserve, North Carolina Sea Grant	3	Completed
NC SET Community of Practice	North Carolina Coastal Reserve and National Estuarine Research Reserve, NC Sea Grant, NOAA National Centers for Coastal Ocean Science, and others	3	Active
North River Game Land Expansion	North Carolina Wildlife Resources Commission and Ducks Unlimited	1	Completed
North River Wetland Protection	The Nature Conservancy	1	Completed
Pine Island Sanctuary Marsh Restoration Project	Audubon, Elizabeth City State University, CSC partners	2	Active
Town of Duck Living Shoreline	Town of Duck	2 & 4	Active

Plan Implementation

Clapper Rail

The strategies detailed in the Currituck Sound Marsh Conservation Plan are intended to yield near-term benefits for marshes in northeastern North Carolina. While a significant amount of work is already underway to advance these strategies, additional funding and collaboration will be necessary to ensure that the goals of this plan are achieved at a pace and scale sufficient to address challenges facing marshes.

As a result, the plan will be revisited every three years by the Currituck Sound Coalition to update the status of partner projects, fill in research gaps with new information, identify additional collaboration opportunities, and refine conservation strategies as needed and appropriate. The coalition will continue to meet at least twice per year to foster collaboration on this plan and other initiatives that benefit natural systems in the Currituck Sound region, and the wildlife and communities that depend on them.

Join Us!

If you care about the future of Currituck Sound and the wildlife and communities of coastal North Carolina, we welcome you to join the conversation and support our efforts to protect the wildlife, ecosystems, and vital environmental benefits for communities throughout the region. **For more information on how you can help, please contact us at csc@audubon.org**

Appendix

TABLE 4 | EXISTING LAND USE AND RESILIENCY PLANS THAT INCLUDE GOALS AND OBJECTIVES RELEVANT TO MARSH CONSERVATION IN CURRITUCK SOUND

PLAN TITLE	DATE	DESCRIPTION
Draft Comprehensive Conservation Plan and Environmental Assessment - Currituck NWR	January 2006	A plan to guide the management of Currituck National Wildlife Refuge in Currituck County, North Carolina that outlines programs and corresponding resource needs for 15 years as mandated by the National Wildlife Refuge Improvement Act of 1997.
Mackay Island NWR Comprehensive Conservation Plan	November 2008	A plan to guide the management of Mackay Island National Wildlife Refuge in Currituck County, North Carolina and Virginia Beach, Virginia that outlines programs and corresponding resource needs for 15 years as mandated by the National Wildlife Refuge Improvement Act of 1997.
Town of Southern Shores Land Use Plan	August 2012	The Town of Southern Shores' fifth land use plan in accordance with Coastal Area Management Act requirements.
Comprehensive Conservation and Management Plan	2012-2022	A resources management plan by the Albemarle-Pamlico National Estuary Partnership.
Green Sea Blueway Greenway Management Plan	June 2015	A plan to steward the Green Sea area's natural, cultural, and recreational resources.
NC Coastal Habitat Protection Plan	2016	A resource and guide created by the Department of Environmental Quality to assist the Marine Fisheries, Environmental Management, and Coastal Resources Commissions in development of goals and recommendations for protecting fisheries habitat in North Carolina.
Imagine Currituck 2040 Vision Plan	Spring/ Summer 2019	A plan to replace the 2006 Currituck County Land Use Plan and satisfy the Coastal Area Management Act requiring each of the 20 coastal counties in North Carolina to produce and adopt a local land use plan that sets forth policies for growth.
Virginia Beach Sea Level Rise Policy Response Report	December 2019	A range of policy action items developed in an effort to provide future guidelines while fostering resilience in city-wide practices.
Town of Duck Coastal Hazards Infrastructure Vulnerability Assessment	February 2020	Developed by the Program for the Study of Developed Shorelines at Western Carolina University in partnership with the Town of Duck, this study assesses the extent to which public resources are susceptible to harm from hazards or climate change impacts.
Natural and Working Lands Action Plan	June 2020	A plan to identify and create opportunities and outline specific projects for North Carolina's natural and working lands that sequester carbon, build ecosystem and community resilience, provide ecosystem benefits, and enhance the economy.
NC Climate Risk Assessment and Resilience Plan	June 2020	A plan directed by Executive Order 80 and led by the North Carolina Department of Environmental Quality and statewide stakeholders to develop resilience strategies to adapt to climate change.
Outer Banks Hazard Mitigation Plan	June 2020	A hazard mitigation plan for the Outer Banks Region; also an eligibility requirement for FEMA hazard mitigation funding.
Town of Duck Comprehensive & Land Use Plan	August 2020	A plan prepared and adopted in accordance with Coastal Area Management Act requirements.
Draft 2021 Pasquotank River Basin Water Resources Plan	2021	A plan required under North Carolina General Statute 143-215.8B that identifies areas in need of additional protection, restoration, or preservation to ensure that waters of the state are meeting their designated use.

FIGURE F |
COMPARISON OF MARSH RESTORATION SCENARIOS

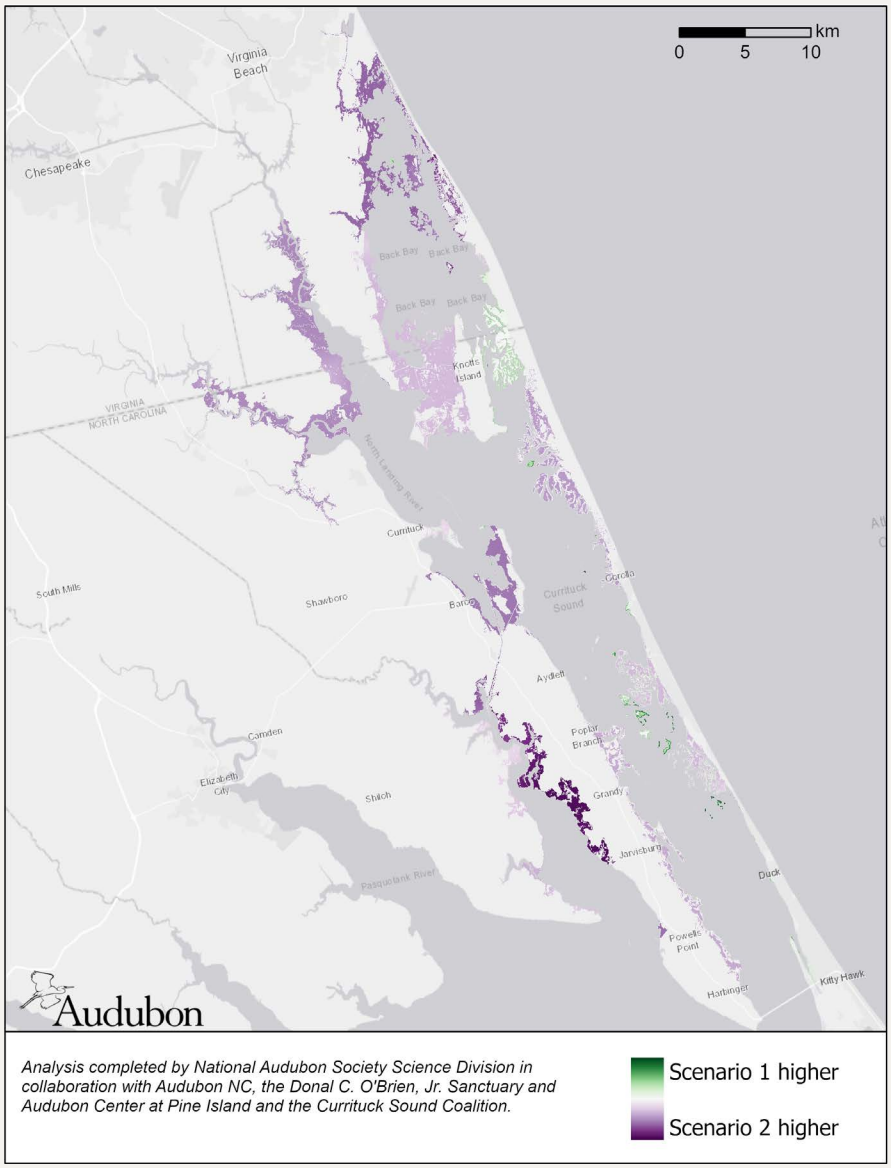


FIGURE DATA SOURCES—more information available on the Currituck Sound Marsh Restoration Assessment Web App

Figure A.
- U.S. Fish & Wildlife Service National Wetlands Inventory
- North Carolina Heritage Program (2019)
- Virginia Department of Conservation and Recreation (2019)
- The Nature Conservancy (TNC) and Currituck County GIS (2019)

Figure B.
- The Nature Conservancy Resilient Coastal Sites for Conservation in the South Atlantic (2019) – Citation: Anderson, M.G. and Barnett, A. 2019. Resilient Coastal Sites for Conservation in the South Atlantic US. The Nature Conservancy, Eastern Conservation Science.
- North Carolina Heritage Program (2019)
- Virginia Department of Conservation and Recreation (2019)
- The Nature Conservancy (TNC) and Currituck County GIS (2019)

Figure C.
- The Nature Conservancy Resilient Coastal Sites for Conservation in the South Atlantic (2019)

Figures D, E, & F.
- The Nature Conservancy Resilient Coastal Sites for Conservation in the South Atlantic (2019)
- Global Surface Water – Citation: Jean-Francois Pekel, Andrew Cottam, Noel Gorelick, Alan S. Belward, High-resolution mapping of global surface water and its long-term changes. Nature 540, 418-422 (2016). (doi:10.1038/nature20584)
- North Carolina Division of Marine Fisheries
- NOAA Office for Coastal Management
- NOAA Environmental Sensitivity Index
- Virginia Institute of Marine Science

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PROJECT TEAM

Funding Source

North Carolina Environmental Enhancement Grant Program

Plan Leads

Albemarle-Pamlico National Estuary Partnership
Audubon North Carolina
Chowan University
Currituck County
North Carolina Sea Grant
The Nature Conservancy

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North Carolina Coastal Federation
North Carolina Coastal Reserve and National Estuarine Research Reserve
North Carolina Sea Grant
North Carolina Wildlife Resources Commission
The Nature Conservancy
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