DRAFT, 2025

North Carolina
Eastern Oyster
Fishery Management Plan Amendment 5

North Carolina Division of Marine Fisheries

North Carolina Department of Environmental Quality
North Carolina Division of Marine Fisheries
3441 Arendell Street
P. O. Box 769
Morehead City, NC 28557

This document may be cited as:

NCDMF (North Carolina Division of Marine Fisheries). 2025. North Carolina Oyster Fishery Management Plan, Amendment 5. North Carolina Division of Marine Fisheries, Morehead City, North Carolina. 138 p.

Disclaimer: Data in this Fishery Management Plan may have changed since publication based on updates to source documents.

ACKNOWLEDGMENTS

Amendment 5 to the North Carolina (NC) Eastern Oyster Fishery Management Plan (FMP) was developed by the NC Department of Environmental Quality (NCDEQ), Division of Marine Fisheries (NCDMF) under the auspices of the NC Marine Fisheries Commission (NCMFC) with the advice of the Shellfish Advisory Committee (AC). Deserving special recognition are the members of the Shellfish/Crustacean AC and the NCDMF Plan Development Team (PDT) who contributed their time and knowledge to this effort.

Shellfish Advisory Committee

Barry Martee Hodowanic
Herman (Wayne) Dunbar
Perry Allen McMahon
Brassai Marie Mustin
Thomas Edward Newman III
Brandon Joel Puckett
Abby Elizabeth Williams

Eastern Oyster Plan Development Team

Greg Allen	Brooke Anderson	Alan Bianchi
Jacob Boyd	Clay Caroon	Anne Deaton
Charlie Deaton	Lorena de la Garza (Clam Co-Lead)	Jeffrey Dobbs (Clam Co-Lead)
Joe Facendola (Oyster Co-Lead)	Corrin Flora	Daniel Ipock
Casey Knight	Cara Kowalchyk	Melinda Lambert
Christopher Lee	Chearin Lewis	Tina Moore (Mentor)
Doug Munroe	Sara Pace	Bennett Paradis (Oyster Co-Lead)
Lee Paramore	Blaine Parker	Jason Peters
Steve Poland	Jason Rock	Brandi Salmon
Catherine J Schlick	Chris Stewart	Andrew Valmassoi
Jason Walsh	Meredith Whitten	Abby Williams
Carter Witten	Dan Zapf	

The following NCDMF staff were also invaluable in assisting with the development of this document and providing administrative support: Kathy Rawls, Mike Loeffler, Catherine Blum, Laura Lee, Barbie Byrd, Deborah Manley, Mike Griffin, and Patricia Smith.

Table of Contents

List of Tables

List of Figures

EXECUTIVE SUMMARY

The Eastern Oyster is a commercially and recreationally important molluscan shellfish harvested from North Carolina's estuarine waters. In fact, the oyster fishery was the first regulated fishery in North Carolina. Hand harvest and mechanical dredges are the primary commercial methods for harvesting oysters, while hand harvest methods are the sole means used in the recreational fishery.

Stock status, including population size, rate of removals and sustainable harvest metrics, is unknown due to insufficient data to conduct a traditional stock assessment. Data available for the stock include commercial landings and fishing effort (i.e., trips) reported to the Trip Ticket Program, biological data collected from the commercial catch, and voluntary responses to an annual recreational survey. Commercial landings trends reflect population abundance to an extent, but other factors like market demand, regulations, changes in effort, closures from rainfall events, and gear technology also affect harvest. Recreational landings and fishing effort in North Carolina is currently unknown and cannot be quantified from the voluntary recreational survey.

The mechanical oyster fishery is limited to subtidal open water regions of Pamlico Sound and its surrounding bays. To balance the value of oysters as both a fishery resource and essential habitat for oysters and other estuarine species, a three-tiered management strategy is proposed for the Pamlico Sound oyster mechanical harvest management. The first tier prioritizes the ecological value of oysters with the designation of Deep-water Oyster Recovery Areas (DORAs) at the mouth of the Pamlico and Neuse rivers that will be closed to mechanical harvest. The closures protect 81% of the identified deep-water oyster habitat, preventing further height loss and damage to recovering oyster reefs. The second tier is a Cultch Supported Harvest strategy that incorporates industry input to guide NCDMF sampling locations to assess the percentage of legal-sized oysters. This approach uses data to set fixed season lengths by proclamation, which may only be extended, balancing habitat and fishery value and providing harvesters with greater certainty on the season length. Additionally, the NCDMF's extensive cultch planting program will continue to support the fishery by replenishing material lost through mechanical harvesting. To evaluate the effectiveness of the second tier, an adaptive management framework is included to evaluate fixed season lengths if participation in the mechanical harvest fishery changes by more than 25%. The third tier is the Rotational Cultch Site strategy, which uses rotational openings for 10-acre planting sites across four management areas in Pamlico Sound to further strengthen the integration of the NCDMF's Cultch Planting Program into management of the oyster fishery, prioritizing the fishery value of these sites.

Identification of a strategy to quantify recreational harvest continues as a need outlined in Amendment 5. The number of recreational shellfish harvesters in North Carolina is currently unknown, which prevents reliable estimates of total recreational harvest of shellfish. Because there is no license or permit required for recreational shellfish harvest, there is no mechanism for communicating with recreational harvesters regarding human health and safety information related to shellfish harvest like there is for commercial harvesters when they acquire their license. Instituting a recreational shellfish license or permit provides a mechanism for distributing human health and safety information and allows the NCDMF to quantify the number of recreational shellfish harvesters to aid in future stock assessments. This issue is shared with the Hard Clam FMP Amendment 3.

The goal of Amendment 5 to the N.C. Eastern Oyster FMP is to manage the oyster resource in such a way as to enhance oyster populations that provide long-term harvest and continue to offer protection and ecological benefits to North Carolina's estuaries. The following objectives will be used to achieve this goal: use the best available biological, environmental, habitat, fishery, social, and economic data to effectively monitor and manage the oyster fishery and its environmental role, support and implement the restoration and protection of oyster populations as both a fishery resource and an important estuarine habitat through the actions of the Cultch Planting and Oyster Sanctuary programs, coordinate with DEQ and stakeholders to implement actions that protect habitat and environmental quality consistent with the Coastal Habitat Protection Plan (CHPP) recommendations, manage oyster harvesting gear use to minimize damage to habitat, and promote stewardship of the resource through public outreach to increase public awareness regarding the ecological value of oysters and encourage stakeholder involvement in fishery management and habitat enhancement activities. To meet the goal and objectives of Amendment 5, the N.C. Marine Fisheries Commission (NCMFC) selected their preferred management options at their March 2025 business meeting as follows:

Mechanical Oyster Harvest

1. Deep-Water Oyster Recovery Areas
   - Adopt the proposed Pamlico and Neuse River Deep-water Oyster Recovery Areas (DORAs), which are bound by existing navigational aids as presented to the NC MFC regional Advisory Committees, to protect deep subtidal oyster reefs from continued physical disturbance by mechanical gear. These areas will be closed to mechanical oyster dredging and monitoring efforts will be used to evaluate the effectiveness of closure within the next FMP amendment. The DORAs cover 681 acres of potential oyster habitat (500 acres in Pamlico River and 180 acres in Neuse River), which represents approximately 81% of the vulnerable deep-water oyster habitat. (Appendix 2)

2. Cultch Supported Harvest Management
   - Adopt the Cultch Supported Harvest strategy outlined in Appendix 2, which would set the season length based on pre-season sampling aided by industry input on sampling locations with the 10 bushel per day and 15 bushel per day areas considered separately.

3. Rotational Harvest Cultch Sites
   - Adopt the inclusion of Rotational Harvest Cultch Sites strategy outlined in Appendix 2. This strategy would create a rotating series of readily available cultch areas available to harvest for the full extent of the mechanical season length each year with the intent of reducing harvest pressure on natural reefs.

4. Adaptive Management
    - Adopt the proposed adaptive management framework to allow for modification of set season length based on changes to participation in the fishery (Appendix 2).

Recreational Harvest

- Support the DMF to further explore potential options and develop a solution to estimate recreational shellfish participation and landings, with the intent to move towards a stock assessment and stock level management for both hard clams and oysters; and to establish a mechanism to provide all recreational shellfish harvesters with Shellfish Sanitation and Recreational Water Quality health and safety information outside of the FMP process.

Additionally, the following management measures from the previous FMP are carried forward into Amendment 5:

- A daily limit of two bushels of oysters per person with a maximum of four bushels of oysters per vessel off public bottom for Shellfish License holders statewide.
- A six-week opening timeframe for mechanical harvest in deep bays to begin on the Monday of the week prior to Thanksgiving week through the Friday after Thanksgiving. Reopen two weeks before Christmas for the remainder of the six-week season.
- A 15-bushel hand/mechanical harvest limit in Pamlico Sound mechanical harvest areas outside the bays, 10-bushel hand/mechanical harvest limit in the bays, and 10-bushel hand harvest limit in the Mechanical Methods Prohibited area along the Outer Banks of Pamlico Sound. Areas as defined and adopted in Amendment 2 of the Oyster FMP.

INTRODUCTION

This is Amendment 5 to the Oyster Fishery Management Plan (FMP). FMPs are the ultimate product that brings all information and management considerations into one document. The North Carolina Division of Marine Fisheries (NCDMF) prepares FMPs for adoption by the North Carolina Marine Fisheries Commission (NCMFC) for all commercially and recreationally significant species or fisheries that comprise state marine or estuarine resources. The goal of these plans is to ensure long-term viability of these fisheries. By law, each FMP must be reviewed at least once every five years (G.S. 113-182.1). The NCDMF reviews each FMP annually and a comprehensive review is undertaken approximately every five years. The last comprehensive review of the plan (Amendment 4) was approved by the NCMFC in 2018. All management authority for the North Carolina Eastern Oyster fishery is vested in the State of North Carolina. The NCMFC adopts rules and policies and implements management measures for the Eastern Oyster fishery in Coastal and Joint Fishing Waters in accordance with G.S. 113-182.1. Until Amendment 5 is approved for management, Eastern Oysters are managed under Amendment 4 of the Oyster FMP (NCDMF 2018).

There are insufficient data to conduct a traditional stock assessment to determine population size and the rate of removals for the eastern oyster in North Carolina. Without a stock assessment, management is focused on habitat protection and enhancement measures that maintain harvestable oyster populations.

For more information about previous and current management, see the original Eastern Oyster FMP (NCDMF 2001b) and the previous amendments, all of which are available on the North Carolina Division of Marine Fisheries Fishery Management website.

Fishery Management Plan History

Original FMP Adoption:	2001
Amendments:	Amendment 1 (2003)
	Amendment 2 (2008)
	Amendment 3 (2013)
	Amendment 4 (2017)
Revisions:	None
Supplements:	Supplement A (2010)
Information Updates:	None
Schedule Changes:	None
Next Comprehensive Review:	Five years after adoption of Amendment 5

Past versions or revisions of the Oyster FMP (NCDMF 2003, 2008, 2013, 2017) are available on the NCDMF website at: https://www.deq.nc.gov/about/Divisions/marine-fisheries/managing-fisheries/fishery-management-plans

Management Unit

The management unit of this FMP includes the Eastern Oyster *(Crassostrea virginica)* and its fisheries in all public coastal fishing waters of North Carolina. This FMP pertains only to oysters from wild stocks and does not address managing farmed oysters originating from private aquaculture leases and franchises.

Goal and Objectives

The goal of the N.C. Eastern Oyster FMP is to manage the oyster resource in such a way as to enhance oyster populations that provide long-term harvest and continue to offer protection and ecological benefits to North Carolina's estuaries. To achieve this goal, it is recommended that the following objectives be met:

- Use the best available biological, environmental, habitat, fishery, social, and economic data to effectively monitor and manage the oyster fishery and its environmental role.
- Support and implement the restoration and protection of oyster populations as both a fishery resource and an important estuarine habitat through the actions of the Cultch Planting and Oyster Sanctuary programs.
- Coordinate with DEQ and stakeholders to implement actions that protect habitat and environmental quality consistent with the Coastal Habitat Protection Plan (CHPP) recommendations.
- Manage oyster harvesting gear use to minimize damage to habitat.
- Promote stewardship of the resource through public outreach to increase public awareness regarding the ecological value of oysters and encourage stakeholder involvement in fishery management and habitat enhancement activities.

DESCRIPTION OF THE STOCK

Biological Profile

DISTRIBUTION

The Eastern Oyster (*Crassostrea virginica*) is an immobile filter feeding bivalve mollusk occurring naturally along the western Atlantic Ocean from the Gulf of St. Lawrence to the Gulf of Mexico (Figure 1; Bahr and Lanier 1981; Carlton and Mann 1996; Jenkins et al. 1997; MacKenzie et al. 1997). Recent research suggests several related oyster species are distributed throughout the Caribbean and coastal South America; however, the Eastern Oyster’s southern range extends only to the northern Yucatan Peninsula Caribbean (Gaffney 2005; Amaral and Simone 2014).

Initial molecular analysis indicates North Carolina's stock is part of the Atlantic coast stock, which extends from Maine to Key Biscayne, Florida (ASMFC 1988). Additional genetic analyses suggest a population division occurs in the Mid-Atlantic region, subdividing the Atlantic coast stock into northern and southern groups (Wakefield and Gaffney 1996; Hoover and Gaffney 2005; Varney and Gaffney 2008). North Carolina represents a transition zone within the Atlantic stock of Eastern Oyster, with a shift between northern and southern types occurring approximately at the southern boundary of the Pamlico Sound (Sackett 2002).

Figure 1. Distribution of the Eastern Oyster (*Crassostrea virginica*) represented by the red line (adapted from Bahr and Lanier 1981; Amaral and Simone 2014).

Eastern Oysters (hereafter, "oysters") inhabit waters across a wide range of temperatures (0 to 32°C; Butler 1954). Though oysters can also tolerate extreme salinities (as low as 5 ppt and as high as 40 ppt) depending on temperature, their optimum salinity range is 14 and 28 ppt (Galtsoff 1964; Wallace 1966; Shumway 1996; Loosanoff 1965; Rybovich 2014). The distribution and survival of oysters is further influenced by abiotic factors such as oxygenation, flow, and tide (Stanley and Sellers 1986; Roegner and Mann 1995; Kennedy et al. 1996; Lenihan 1999), as well as biotic factors such as disease, bioeroders, and predation (Barnes et al. 2010; Johnson and Smee 2012; Pollack et al. 2012; Dunn et al. 2014). More information on the impacts of introduced pathogens and native bioeroders may be found in the Biological Stressors section.

North Carolina's oysters are composed of both subtidal populations (below the mean low tide water level, up to 26 ft deep) and intertidal populations (between the mean high and low tide levels; MacKenzie et al. 1997). Throughout the Croatan, Roanoke, and Pamlico sounds, oyster resources are almost exclusively subtidal. This region is primarily influenced by wind-driven tides, with intertidal oysters found occasionally near the inlets. Scattered subtidal populations may be found in larger systems farther south (Newport, White Oak, and New River systems). Conversely, intertidal populations are predominantly observed south of Cape Lookout and throughout estuaries extending to the state's southern border. The horse or crested oyster (*Ostrea equestris*) may be confused with small Eastern Oysters and can be locally abundant in both intertidal and subtidal habitats in southeastern North Carolina (Markwith et al. 2009).

MORPHOLOGY

Oyster bodies (meats) have a small foot, a relatively small adductor muscle, fillibranch gills with interlamellar junctions, and lack a siphon (Galtsoff 1964). The interior of the Eastern Oyster shell contains a purple-pigmented adductor muscle scar that does differentiate Eastern Oysters from other similar species within its range (Figure 2). The left valve is generally more cupped than the right that is normally found on top, and there is no gap between the shells when the valves are completely closed (Figure 2; Yonge 1960; Galtsoff 1964). Shell morphology can vary greatly depending on substrate and habitat conditions. For instance, oysters grown in subtidal and lower salinity environments tend to have thick, rounded shells with visible radial ridges (Stanley and Sellers 1986). In the presence of predators, oysters may allocate more energy to shell growth, resulting in thicker and heavier shells (Johnson and Smee 2012; Lord and Whitlatch 2012). Shell thickness has also been found to correlate with latitude and water temperature along the Atlantic coast, with warmer southern locations having oysters with thicker shells than colder northern locations (Lord and Whitlatch 2014).

REPRODUCTION AND RECRUITMENT

Oysters are typically hermaphroditic, as they first develop and spawn as males in the first few years and may ultimately develop as females as individuals get larger and older (Galtsoff 1964; Kennedy 1983). Oysters may change sexes once each year when the gonad is undifferentiated (Thompson et al. 1996). Research suggests natural oyster populations maintain balanced sex ratios (Kennedy 1983). However, certain environmental conditions, such as limited food availability and extreme salinity gradients, have been attributed to skewing sex ratios to high abundances of males (Bahr and Hillman 1967; Davis and Hillman 1971; Powell et al. 2013). The sex of nearby oysters may also influence individual oyster sex determination (Smith 1949; Menzel 1951). Age or size selective mortality (e.g., from disease or harvest pressure) can alter oyster population demographics and result in a local shift from male to female majority (Harding et al. 2012).

Figure 2. Left and right valves of a subtidal Eastern Oyster from Stump Sound, North Carolina, illustrating the purple pigmented adductor muscle scar in the interior of the cupped left valve, and radial ridges on the exterior of the right valve.

The formation of eggs and sperm is initially stimulated by increasing water temperatures during the spring (Galtsoff 1964; Kennedy et al. 1996). In North Carolina, oyster broadcast spawning peaks twice, once in June at 20°C, with a second spawning event in August at 25°C (Chestnut 1954). Salinities greater than 10 ppt are also typically required for mass spawning (Breuer 1962). Gonads may be developed in oysters at two to three months old, but most of these sub-adult oysters will not be sexually mature (Galtsoff 1964; Kennedy 1983). Fecundity estimates range from 2 million eggs for a 4-cm (1.5 in) oyster to 45 million for an oyster 7 cm (2.8 in) in length (Kennedy et al. 1996). These estimates range widely as oysters can spawn several times per season and gonads may expand into other tissues (Kennedy et al. 1996). However, it’s accepted that larger oysters allocate greater energy towards egg production and therefore have increased fecundity (Kennedy et al. 1996). For instance, oysters collected from North Carolina’s no-take sanctuaries have demonstrated that fecundity increases exponentially with size, reaching the highest levels in May (Mroch et al. 2012; see Appendix 4 for further information on NC’s Oyster Sanctuaries).

Under normal conditions, male oysters spawn first in response to various physical stimuli and environmental conditions. Female oysters are stimulated to spawn specifically by the presence of oyster sperm. Fertilization must take place shortly thereafter in the surrounding waters, or the unfertilized eggs lose their viability. Fertilized eggs develop into a free-swimming larva, which can migrate vertically in the water column in response to temperature and salinity changes (Hopkins 1931; Galtsoff 1964). Oyster larvae have also been documented to travel up to 30 miles, with dispersion strongly dependent on prevailing winds (Bahr and Lanier 1981; Andrews 1983). Patterns of larval distribution in North Carolina estuaries remain relatively unstudied; however, predictive models of Pamlico Sound larval dispersal from oyster sanctuaries have been developed (Haase et al. 2012).

An oyster larva may visit several sites before it cements itself to the substrate (Kennedy et al. 1996). Several environmental factors, including light, salinity, temperature, acoustic signature, and current velocity may influence the setting of larvae (Hidu and Haskins 1971; Lillis et al. 2013). Oyster larvae also respond positively to a protein on the surface of oyster shells as well as other recently set spat (Kennedy et al. 1996). Larval oysters tend to settle in the intertidal zone where salinities are above 20 ppt whereas in subtidal areas they settle when salinities are below 20 ppt (Mackin 1946; Loosanoff 1952; Menzel 1955). Generally, spatfall is higher in intertidal areas and in areas boasting salinities in the upper range of tolerance (Bahr and Lanier 1981).

Chestnut (1954) reported recruitment peaks generally occurring in June, the latter part of August, and possibly another peak in October. Ortega et al. (1990) found recruitment in western Pamlico Sound to be continuous, concentrated in one or two peaks depending on the year and location. Generally, peaks occurred in June (lesser) and September–October (greater). Munden (1975) reported that spat monitors located in Morehead City and Wilmington did not show a decline in availability of spat during the summer of 1972 until September.

GROWTH

Oyster growth is highest during the first six months after settling and gradually declines throughout the life of the oyster (Galtsoff 1964). Seasonally, adult oysters grow most rapidly during spring and fall in North Carolina. Shell growth was found to cease when water temperatures reached 28°C and slowed when temperatures decreased to 5°C (Chestnut 1954). Ortega et al. (1990) examined data from 1979–1989 and found that spat from western Pamlico Sound sites attained lengths of 10–40 mm during the first year and reached marketable size (76 mm) by the end of three years. Varying growth rates have been observed between and within different regions of North Carolina and under different environmental conditions (Godwin 1981; Kennedy and Breisch 1981; Roegner and Mann 1995; Puckett and Eggleston 2012).

Stock Unit

For the purposes of this fishery management plan, the unit stock is considered to be all wild oysters occurring within North Carolina coastal fishing waters, excluding oysters produced via private aquaculture leases or franchises.

Assessment Methodology

Data are not available to perform a traditional assessment, so it was not possible to estimate population size or fishing mortality rates.

Stock Status

Data limitations prevent the NCDMF from conducting an Eastern Oyster stock assessment and calculating sustainable harvest metrics. Data available for the stock include commercial landings and fishing effort (i.e., trips) reported to the Trip Ticket Program, biological data collected from the commercial catch, and voluntary responses to an annual recreational survey. For information on the methodology used in previous stock assessment attempts, see Amendment 4 of the Oyster FMP.

While the oyster is managed by 18 other states along the Atlantic Coast and Gulf of Mexico, it is worth noting that only Louisiana, Maryland, and Virginia have complete stock assessments. Louisiana’s most recent stock assessment in 2023 utilized 1,700 dredge samples and 1,000 diver quadrat samples collected during summer months. Their results suggested a 118% year-over-year increase in the stock of oysters, with most of the stock occurring in the west. Maryland conducts a stock assessment within the northern region of Chesapeake Bay and its tributaries (north of Smith Island, following the state-boundary); while Virginia’s stock assessment of oysters includes the southern portion of the Chesapeake and its tributaries, including the James River. Maryland’s stock assessment, which involves a stage-structured model integrated with various fishery-independent data, recently reported increases in their adult and spat populations but regional overfishing occurring within the fishery (MDDNR 2021). The Virginia Marine Resources Commission and the Virginia Institute of Marine Science collect data during the fall using tongs to extract samples of one square-meter (See graphic summaries on the Virginia Oyster Stock Assessment and Replenishment Archive - VOSARA). The most recent evaluation found the oyster stock in the southern Chesapeake was at its best condition in a generation, extending the fishery season for the first time since 1987. In addition to a stock assessment, Virginia employs a rotational harvest management system for the oyster.

In the absence of a formal stock assessment, Delaware and New Jersey use other metrics to inform their management strategies. Delaware conducts a population survey to set quotas; New Jersey does an annual assessment of Delaware Bay. For more information on how other states manage their fisheries, see Appendix 5.

The NCDMF partnered with researchers at North Carolina State University and The Nature Conservancy to design statistically robust fishery-independent population survey methodologies for oysters in North Carolina to inform a potential future stock assessment. While methods have been developed, NCDMF does not currently have the staff or equipment resources to implement the recommended sampling programs.

DESCRIPTION OF THE FISHERY

Additional in-depth analyses and discussion of North Carolina’s commercial oyster fishery can be found in earlier versions of the Oyster FMP, Revisions, Amendment 1, Amendment 2, Supplement 2A, Amendment 3, and Amendment 4 (NCDMF 2001b, 2003, 2008, 2010, 2014, 2017); all FMP documents are available on the NCDMF Fishery Management Plans website and commercial landings can be found in the License and

Statistics Annual Report (NCDMF 2022) produced by the NCDMF and available on the NCDMF Fisheries Statistics website.

Commercial Fishery

HISTORICAL OVERVIEW

The oyster fishery was the first regulated fishery in North Carolina, with laws limiting gear to hand methods only and prohibiting oysters from being sold out of state until 1872 (Thorsen 1982). Prior to 1880, New Bern and Wilmington were the state's major oyster markets, while Beaufort and Washington were also sites for significant oyster trade. Despite dredging methods being blamed for overharvesting in other states, North Carolina adopted a law in 1887 allowing oyster dredging in public bottom waters deeper than 8 ft throughout Pamlico and Roanoke sounds (Thorsen 1982). However, a loophole resulted in an influx of out-of-state fishers flocking to North Carolina in 1889. Consequently, increased exploitation of oyster with dredges and mechanical tongs led to a conflict between resident and out-of-state oystermen known as the “Oyster Wars”.

In response to the conflict, a law prohibiting oyster harvest by non-residents was passed and enforced in 1891. Attempts to return to hand-harvest-only management from 1892 to 1895 and to limit dredging in 1896 resulted in huge declines in oyster production and the subsequent closing of many oyster canneries. In 1897 the dredging law was amended, allowing limited dredging, a longer dredging season, and more law enforcement. These changes resulted in 677,239 bushels landed and the reopening of the canneries. Landings reached their highest level in 1902 at 806,363 bushels (Table 1).

However, oyster landings saw a drastic decline soon after the 1902 peak, reaching 171,090 bushels in 1918. Around this time, the state recognized the value of recycling shells for rebuilding oyster beds. From 1915 to 1920, the state began funding the Cultch Planting Program, resulting in 10,000–12,000 bushels of shell being planted each year for the aimed benefit of the fishery. After initial success and apparent rebound in harvest, additional state funding allowed the program to scale up and plant around 100,000 bushels of seed oysters and substrate in the early 1920s. Harvest statistics show a rebound in landings from 1923 to around 1931. For a more comprehensive history of the Cultch Program, see Appendix 1.

All oyster landings prior to 1931 were accomplished using hand methods and sail-powered oyster dredge boats. The 1940s saw restrictions on powerboats lifted, likely due to heightened demand and the price of oysters during World War II. The distinction between power and sailboat dredging disappeared altogether by 1955.

Throughout the remainder of the 20th century, oyster landings fluctuated between 650,000 to less than 50,000 bushels per year. Even with the switch from sailboat to power dredging, the overall trend of oyster landings in North Carolina was that of gradual decline through 2000 with a notable exception in 1987. There are several factors contributing to the continued decline in landings. For instance, taking oysters for personal consumption was allowed year-round until 1966, which may have been exacerbated by the fact that hand gear for oyster harvest has been largely unregulated in shallow subtidal (hand tongs) and intertidal areas (hand rakes and by hand). Furthermore, a lack of adequate enforcement seemed to allow the harvest and sale of undersize oysters; it was not until 1981 that the three-inch size limit was applied throughout the state (Chestnut 1951; Thorsen 1982). Modern commercial shellfishing continues in North Carolina and these fisheries include mechanical dredging and hand harvest methods, which are further detailed in the following sections. For a more thorough history of the oyster fishery including changes in regulations for commercial gear, length of seasons, and openings and closures of bays, refer to Amendment 4 of the Oyster FMP (NCDMF 2017)

MECHANICAL HARVEST METHODS

Harvest of oysters by mechanical methods is accomplished almost exclusively with oyster dredges in North Carolina (Figure 3). The dredge itself is a metal frame with a chain mesh acting as a net, collecting oysters or other shellfish while a boat tows it along the bottom. Other mechanical gear used for harvesting oysters include patent tongs and power rakes. NCDMF commercial fishery statistics indicate prior to 1960, most oyster landings were taken by dredge when compared to all hand methods (Figure 4). Chestnut (1955) reported that 90% of oysters landed in North Carolina prior to 1960 came from Pamlico Sound, suggesting that harvest in Pamlico Sound was largely dependent on dredging.

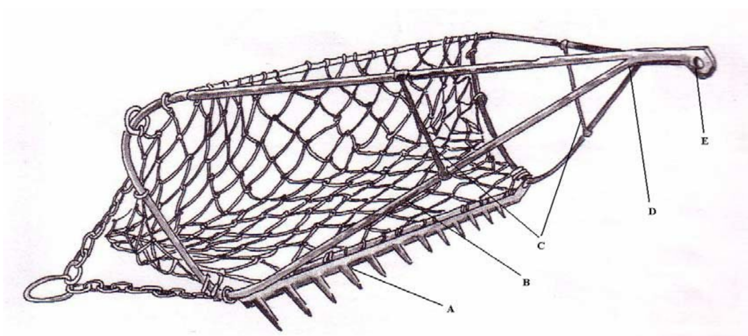

Figure 3. Sketched illustration of a dredge used in North Carolina's mechanical oyster fishery (from Shefi 2007, adapted from Heddeen 1986).

Table 1. North Carolina commercial oyster landings in pounds of meat and bushels (Bu.), 1880–2022. (Source: Chestnut and Davis 1975; National Marine Fisheries Service unpublished data; NCDMF Trip Ticket Program).

Year	Pounds	Bu. (x1,000)	Year	Pounds	Bu. (x1,000)	Year	Pounds	Bu. (x1,000)
1880	938,400	134	1959	1,311,000	287	1992	293,956	50
1887	1,175,650	168	1960	1,216,200	289	1993	223,136	35
1888	1,129,960	161	1961	1,209,100	233	1994	183,704	35
1889	5,528,942	790	1962	961,400	192	1995	220,661	42
1890	4,456,075	637	1963	694,000	133	1996	210,931	40
1897	4,740,675	677	1964	727,700	153	1997	218,970	41
1902	5,645,928	807	1965	863,700	166	1998	224,214	42
1908	4,159,320	594	1966	626,200	119	1999	216,831	41
1910	1,834,058	262	1967	514,900	98	2000	203,427	38
1918	1,197,630	171	1968	402,600	84	2001	258,086	49
1923	3,089,146	441	1969	370,300	80	2002	243,775	46
1927	2,397,750	343	1970	382,500	79	2003	261,043	49
1928	2,286,610	327	1971	423,400	88	2004	367,961	70
1929	2,828,420	404	1972	470,112	103	2005	378,014	71
1930	2,205,674	537	1973	548,351	112	2006	447,889	85
1931	1,500,571	353	1974	558,821	109	2007	441,415	83
1932	1,201,356	275	1975	424,831	84	2008	466,176	88
1934	1,160,700	271	1976	333,315	61	2009	573,630	108
1936	2,480,500	651	1977	365,714	69	2010	1,040,407	197
1937	1,940,900	457	1978	449,544	84	2011	800,543	151
1938	1,426,900	334	1979	665,439	132	2012	440,063	83
1939	1,055,600	313	1980	723,099	139	2013	586,625	111
1940	690,400	204	1981	550,502	119	2014	727,775	138
1945	1,707,100	586	1982	611,998	155	2015	648,444	123
1950	1,322,100	238	1983	724,509	123	2016	668,423	126
1951	1,531,900	253	1984	724,557	128	2017	852,848	161
1952	1,620,900	331	1985	545,439	100	2018	625,278	118
1953	1,525,300	310	1986	745,548	120	2019	832,708	157
1954	998,400	210	1987	1,425,584	226	2020	829,106	157
1955	731,000	150	1988	913,100	157	2021	1,227,347	232
1956	1,318,000	285	1989	529,858	92	2022	1,142,911	216
1957	1,086,500	239	1990	328,850	52			
1958	1,041,500	228	1991	319,040	48			

The current mechanical oyster fishery is limited to greater Pamlico Sound and adjacent bays and tributaries, including the Neuse and Pamlico rivers, with a maximum season beginning on the Monday of the week prior to Thanksgiving week, which is typically the third Monday in November, and running through March 31. Mechanical harvest gear is restricted to the deeper portions (more than 6 ft) of the Sound, including deeper areas of rivers and bays (see Appendix 2, Figures 2.8 & 2.9). There are currently four oyster management areas for mechanical harvest: Northern Dare, Northern Hyde, Pamlico River, and Neuse River (see Appendix 2, Figure 2.3). Throughout these areas, mechanical harvest is limited to 15 bushels per fishing operation in the open sound and the Neuse and Pamlico rivers. Conversely, mechanical harvest in some larger bays and tributaries is limited to 10 bushels per fishing operation. These areas and limitations are based on recommendations and criteria established in the original Oyster FMP (NCDMF 2001b) with areas prohibited to take oysters by mechanical methods are designated in the N.C. Marine Fisheries Commission Rule 15A NCAC 03R .0108.

In-season openings and closures of these four areas are determined by management triggers. These triggers are management area specific and based on the percentage of legal sized oysters (≥3 in) from samples collected during NCDMF biweekly monitoring across the four management areas. Failure to meet the 26% legal-size threshold for two consecutive trigger sampling trips results in closure of an area. The specifics of the trigger sampling protocol are outlined in further detail in Supplement A to the Oyster FMP (NCDMF 2010). The trigger sampling as it applies to the season length is further discussed in Appendix 2 (the Mechanical Oyster Harvest Management Issue Paper).

In areas open to mechanical harvest, oysters may be impacted by hurricanes, low dissolved oxygen events, or extreme temperatures. These impacts may only allow harvest for a few weeks before the management trigger is reached. Furthermore, poor water quality from storm events has disproportionately affected the deep-water oyster reefs in the Neuse River and Pamlico River areas of western Pamlico Sound. These reefs have suffered large die offs compared to oyster reefs in the shallow bays or the eastern portion of Pamlico Sound, closer to Oregon Inlet. These reefs have been in poor condition since 2017 and have likely not supported any significant mechanical harvest.

Research has shown oyster reefs need high vertical relief (height) in these deep areas to be resilient to negative water quality impacts from storm events (Lenihan and Peterson 1998; Lenihan 1999). However, mechanical harvest reduces the ability of natural oyster reefs in deep water to gain and maintain height as dredging actively removes valuable shell bottom habitat (see Threats and Alterations for further information). As a result of these influences affecting oyster condition within the fishery and current trigger sampling protocol, the actual mechanical harvest season for oysters is highly variable. This variability in season length and area openings is often viewed negatively by commercial harvesters.

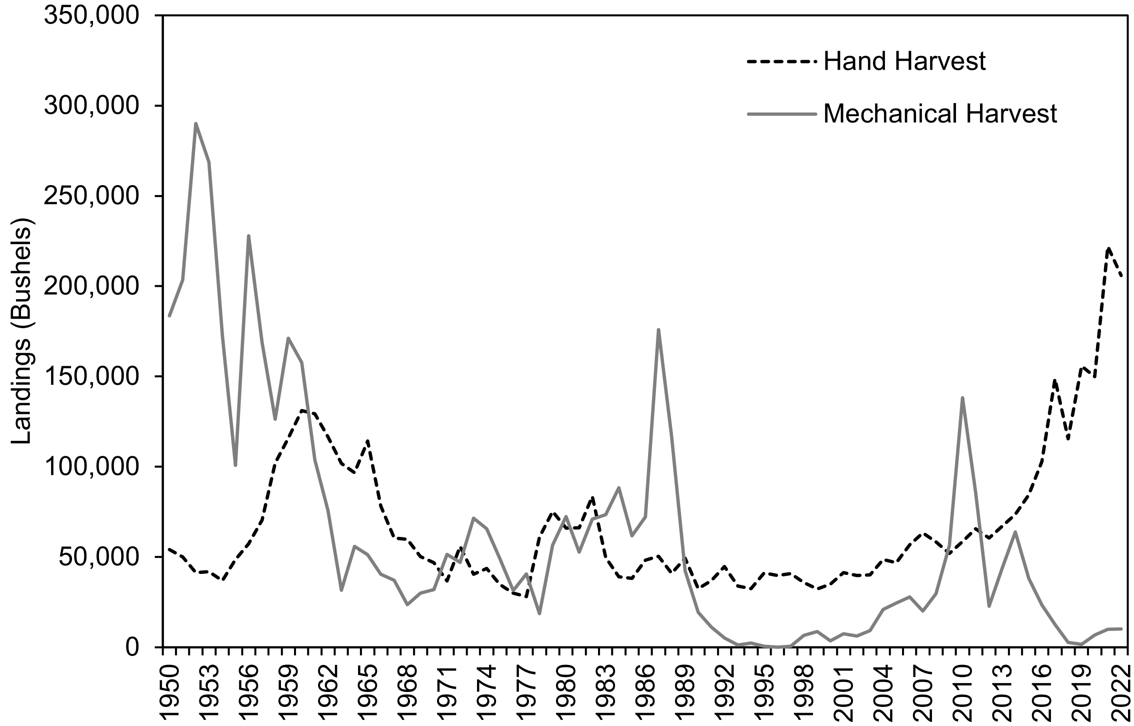

Figure 4. Commercial oyster landings by gear, 1950–2022. Landings for both gear types include both public (wild) and private bottom (farmed oysters). Landings data for farmed oysters are included in this figure as historically it contributed an insignificant portion of the overall oyster landings, and prior to 2010 the distinction between wild and farmed was not recorded in landings data. (Sources: Chestnut and Davis 1975; National Marine Fisheries Service unpublished data; NCDMF Trip Ticket Program).

Recent Changes to Mechanical Harvest Methods

The most recent changes in mechanical harvest gear management included closing off 30,000 acres to mechanical gear by closing the upper portions of the Pamlico Sound bays and part of Roanoke Sound. The closures were accomplished under a framework established in the original Eastern Oyster FMP (NCDMF 2001b). Another change was reduction of the mechanical harvest limit to match the hand harvest limit set in the remaining areas of Pamlico Sound as outlined in Amendment 2 (NCDMF 2008). Supplement A to the Oyster FMP established a trigger-monitoring system for determining the closure of mechanical harvest areas and changed the management strategy for mechanical harvest limits to allow up to 20 bushels to be harvested per commercial fishing operation per day (NCDMF 2010). The bays around Pamlico Sound can be opened for a potential maximum six-week season beginning mid-November with a 10-bushel-per-commercial-fishing-operation-per-day harvest limit as adopted in the original Oyster FMP (NCDMF 2001b).

From 2009 to 2012, many inexperienced oyster dredgers came into the fishery and several new restrictions were required to maintain traditionally accepted harvest and culling techniques. One of these restrictions was a 2 PM time limit on dredging; this limit resulted in harvesters culling their entire catch after 2 PM rather than on-site, often depositing cultch where it could no longer function as oyster habitat. Additionally, during this time, many vessels were not rigged with towing points over the side of the vessel that work best for circular dredging patterns or for short tows. As a result, restrictions were put in place between the Adoption of Supplement A and before the development of the Oyster FMP Amendment 3 in 2014. The purpose of these restrictions was to encourage circular dredging patterns, which are viewed as less damaging to oyster reef habitat, and shorter tows, which encourage culling onsite and between each deployment of the gear. These restrictions include the following: 1) It is unlawful for the catch container (bag, cage) attached to a dredge to extend more than 2 ft in any direction from the tooth bar; and 2) it is unlawful to tow a dredge unless the point where the tow line or cable is in the water is on the port or starboard side of the vessel forward of the transom. The North Carolina Marine Fisheries Commission established additional measures to further protect oyster habitat, such as Rule 15A NCAC 03K .0202, which requires that oysters be culled on site. As a result of this rule, it is unlawful to possess more than five bushels of unculled catch onboard a vessel. Only material on the culling tray is exempt from culling restrictions. It is unlawful to possess unculled catch or culled cultch material while underway and not engaged in mechanical harvesting.

Trends and Impacts to Mechanical Harvest

In the past two decades, the mechanical oyster fishery has experienced two relative peaks, one during 2009–2010 and 2010–2011, and another during 2014–2015 (Figure 5). During the 2009–2010 mechanical harvest oyster season, the Great Island Narrows area between Great Island and mainland Hyde County experienced intensive oyster harvest. NCDMF staff observed approximately 50 oyster dredge boats intensively working in this small area with some returning with new crews to fish the 15-bushel limit twice in one day. Further investigation indicated substantial shell damage was occurring to the remaining oysters and the area was closed after six weeks of harvest. Deeper waters of western Pamlico Sound and areas of Middle Ground also contributed to increased landings in the 2009–2010 and 2010–2011 seasons.

Fishing effort in 2010 was influenced by an increase in market demand due to the closure of oyster harvest areas in the Gulf of Mexico following the Deepwater Horizon oil spill. In response to this market demand, the North Carolina's mechanical harvest season opened earlier than usual, on November 1, 2010. Supplement A to the Eastern Oyster FMP Amendment 2 (adopted November 3, 2010) provided for a variable mechanical harvest limit of up to 20 bushels per day from November 18–24, 2010, and March 16–31, 2011, which likely increased landings. The Neuse River area was closed to dredging from January 7 to February 14, 2011, because samples failed to meet the minimum 26% legal size criterion set in Supplement A (NCDMF 2010). Effort in the Neuse River area appeared to be much lower after the re-opening of the area to oyster harvest in February 2011.

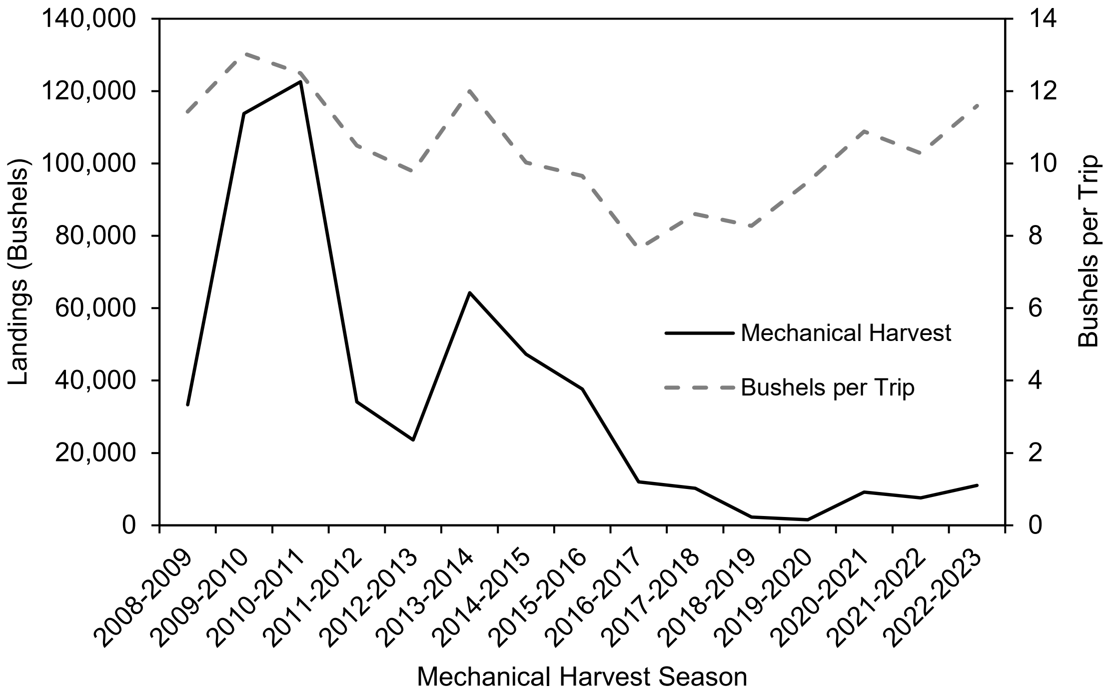

Figure 5. Mechanical harvest oyster landings on public bottom by season 2008–2009 through 2022–23. A monitoring system for determining the closure of mechanical harvest areas began in the 2010–11 season (Source: NCDMF Trip Ticket Program).

In August 2011, Hurricane Irene had major impacts on mechanical harvest areas. Sedimentation or strong currents likely buried or displaced oyster resources on the Middle Ground following the storm. Many of the deeper water oyster resources located near Brant Island Shoal also suffered significant damage caused by detritus covering and killing oyster beds. Oysters in the Neuse and Pamlico rivers did not show any of the typical growth patterns in the following months, which likely had a pronounced effect on the mechanical harvest season in 2011–2012. The mechanical harvest area in western Pamlico Sound was closed on January 2, 2012.

Prior to the 2012–2013 mechanical harvest season, NCDMF oyster sampling indicated an apparent severely low dissolved oxygen event in the Neuse River that caused virtually 100 percent mortality of the oyster resources at 18 ft or greater depths. A few oyster rocks in shallower waters between Maw Point Shoal and Light House Shoal were spared as well as some NCDMF oyster habitat enhancement projects in other shallow areas. The Pamlico River area also had not recovered from the effects of Hurricane Irene at this time. The Neuse River area was available for mechanical harvest until the adjacent bays closed on December 21; however, there was no harvest activity in the river during the time it was open. The Pamlico River area closed to mechanical harvest on February 1 based on failure to meet the 26% trigger even though effort was much reduced since early January. The 2012–2013 mechanical harvest oyster landings declined further to 23,566 bushels (Figure 5).

There was little evidence of recovery of the Neuse River oyster resources prior to the 2013–2014 season but the Pamlico River area appeared to be recovering, and growth indicators were good during the season. The Dare County area in northern Pamlico Sound also supported some significant mechanical harvest activity throughout the season. When oyster harvests began to decline in the western sound in early February, 20 to 25 boats moved east to Dare County to finish the season. The remaining productive areas in the Neuse River closed on February 28 and most of the harvesters left the Pamlico River area by mid-February. Mechanical harvest in Dare County continued until the season ended on March 31. The overall result was a notable increase in mechanical harvest oyster landings with 64,274 bushels for the season.

After the peak in 2013–2014, mechanical oyster harvest declined steadily, reaching lows reminiscent of the mid-1990s. Hurricane Florence in 2018 severely damaged coastal infrastructure, vessels, and habitat. These impacts, along with the world-wide COVID pandemic, are likely responsible for low harvest between 2018 and 2020. Since then, mechanical harvest landings have rebounded slightly to 11,061 bushels in the 2022–2023 season (Figure 5).

Overall, participation in the mechanical oyster fishery has declined rapidly since 2010 according to trip ticket data (Figure 6). There was a high of 503 participants in 2010, wherein 74.8% of landings (bushels) were brought in by the top quartile (25%) of participants (Figures 6 & 7). Between 2012 and 2016, participation declined and fluctuated around 200 fishers (Figure 6). During the same period, the top quartile of participants contributed 62–70% of total landings (Figure 7). However, in the last five years (2018–2023) there were 60 or fewer participants in the mechanical oyster fishery, and the top quartile of participants contributed 48–61% of bushels landed (Figures 6 & 7).

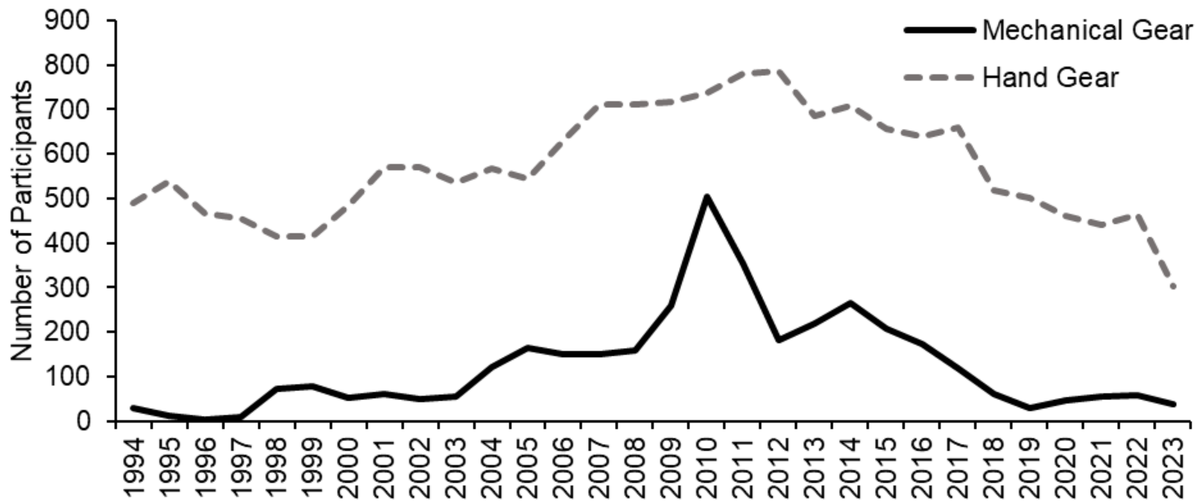

Figure 6. Participation in North Carolina's wild oyster fisheries between 1994 and 2023. Two separate fisheries are distinguished by the two types of gear that may be used to harvest oysters from wild populations: mechanical (dredge) and hand gear (rakes, tongs, etc.). For additional data, see NCDMF License and Statistic's Annual Report.

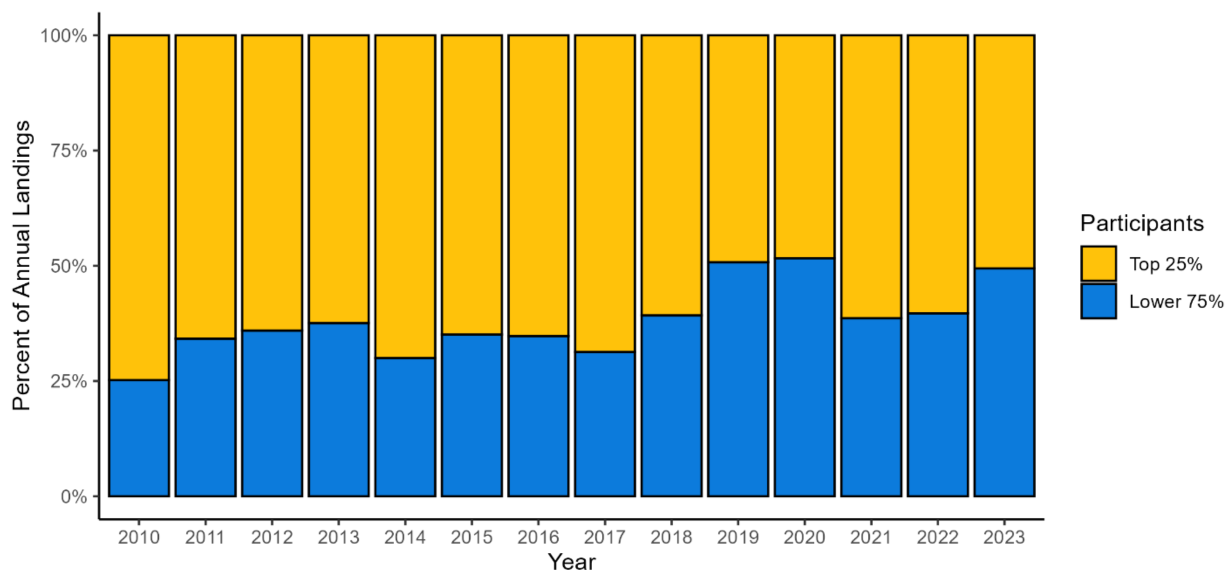

Figure 7. Relative contribution to annual landings from public bottom (wild harvest) by the top quartile of participants in North Carolina's mechanical oyster fishery, 2010–2023 (Source: NCDMF Trip Ticket Program).

HAND-HARVEST METHODS

In North Carolina, hand harvest methods include hand tongs, hand rakes, and by hand (Figure 8). Hand tongs are generally used in shallow subtidal areas. Hand rakes and actual picking up by hand are normally used in intertidal areas. Some specialized uses of rakes and modified tongs occur in subtidal areas. Hand-harvest methods are allowed in all areas found suitable for shellfish harvest by the Shellfish Sanitation and Recreational Water Quality Section of the NCDMF.

The hand-harvest season for commercial and recreational harvest is October 15 through March 31 each year (15A NCAC 03K .0201 (a)). Commercial harvest is limited to Monday through Friday each week. Some locations may close early due to perceived excessive harvest or pollution concerns. Brunswick County is the only area that frequently closes early due to excessive harvest and typically is closed by proclamation on March 15 annually.

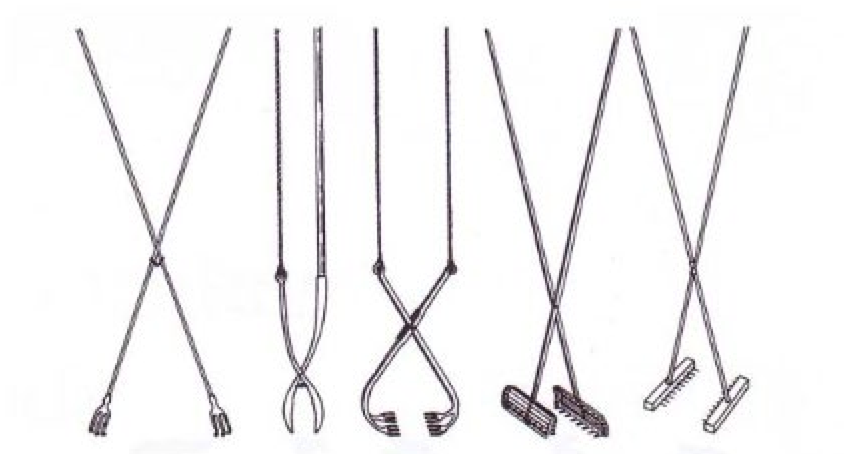

Figure 8. An illustration of several different designs for hand tongs and rakes that may be used for harvesting oysters (from Shafi 2007, reproduced from von Brandt 1964).

Since the 1990s, hand harvest has accounted for most of the commercial landings each season and has been the dominant harvest gear for oysters in North Carolina (See Appendix 3: Intertidal Oyster Harvest Management Information Paper). This trend may be the result of hand harvest landings being less variable than mechanical harvest landings. For instance, southern intertidal oyster resources did not suffer the same long-term mortality from Dermo, an easily transmittable parasitic disease, that affected subtidal oyster beds in the northern part of the state (for more information, see Biological Stressors section).

These higher and more consistent hand-harvest landings come primarily from intertidal oyster reefs between Core Sound and the North Carolina-South Carolina state line (Coastal Fishing Waters in Brunswick, New Hanover, Pender, Onslow, and portions of Carteret counties). This trend is despite the fact that this southern portion of the coast only accounts for five percent of the total area open to shellfish harvest in the state. Additionally, the harvest limit in this area is five bushels per person per day, not exceeding

10 bushels per vessel per day for Standard and Retired Commercial Fishing License holders.

Oyster harvest areas north of Core Sound also operated under the 5 bushels per person per vessel (not to exceed 10 bushels per vessel) per day limit until the 2009–2010 season. At that time, Amendment 2 to the Eastern Oyster FMP changed the limit in that area to 10 bushels per fishing operation in typical hand-harvest waterbodies including bays, small rivers, and shallow sounds designated by proclamation. A 15-bushel limit has since been specified for Pamlico Sound, Neuse and Pamlico rivers, and Croatan Sound, but oysters in these areas are seldom harvested by hand methods. The practical application of the 10-bushels-per-fishing-operation limit results in hand harvesters working alone with the opportunity to take 10 bushels each day. The rationale for the change was to encourage hand harvesting by making mechanical and hand-harvest limits the same in areas where they overlap. The increased limit was justified because hand-harvest oyster resources in the northern area are widely dispersed and much more difficult to locate than in the southern area making excessive harvest less likely.

Hand-harvest oyster landings from areas north of Core Sound accounted for less than 2% of total hand-harvest landings prior to 2005 (Figure 9). In 2005, the percentage began to climb, reaching a peak near 11% in 2009. The highest percentages occurred in 2015 and 2017, with landings north of Core Sound reaching almost 20% of the total hand-harvest landings. Since 2019, the percentage has remained under 5%.

Across the state, hand-harvest oyster landings generally increased from 1994 to 2017 (Figure 10). This is likely due to increased effort as reflected by the number of trips, mirroring the trend in landings (Figure 9). Hand harvest landings peaked in 2017 at 61,574 bushels, and despite some decline, have remained steady around 41,000 bushels since 2017.

In response to the concern of increasing participation and declining bushels landed per trip in the hand harvest oyster fishery, the Marine Fisheries Commission limited Shellfish License holders to two bushels of oysters per person per day and no more than four bushels per vessel statewide as part of Amendment 4 in October 2017. After Amendment 4 implementation, participation and landings in the hand harvest fishery declined.

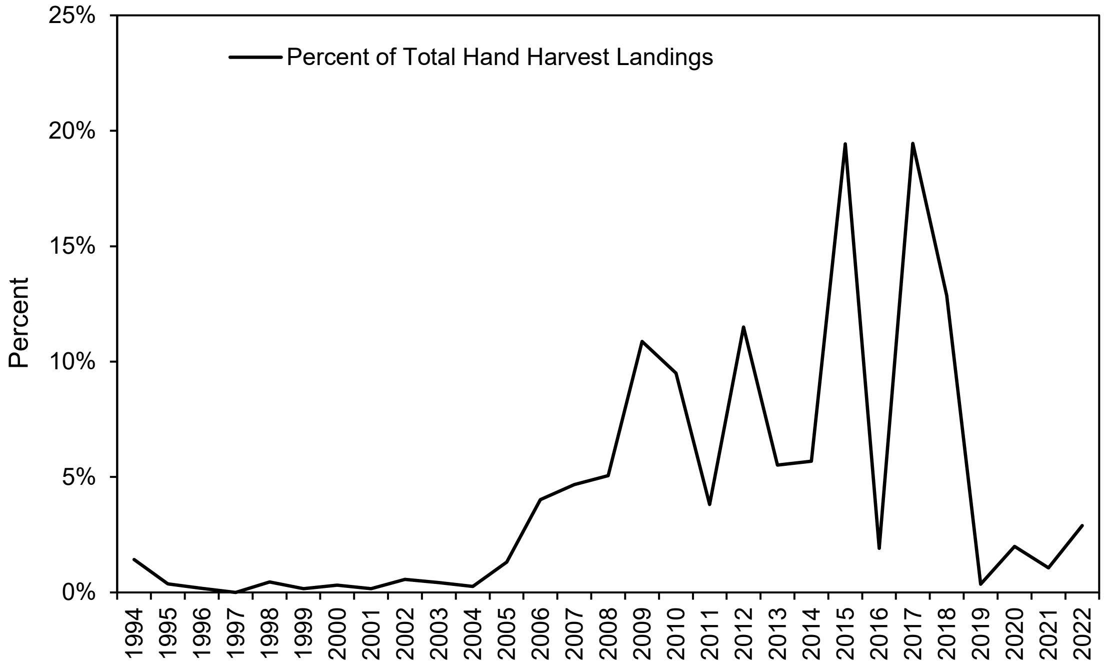

Figure 9. Public bottom commercial hand harvest oyster landings north of Core Sound as a percentage of total public bottom hand harvest oyster landings, 1994–2022 (Source: NCDMF Trip Ticket Program).

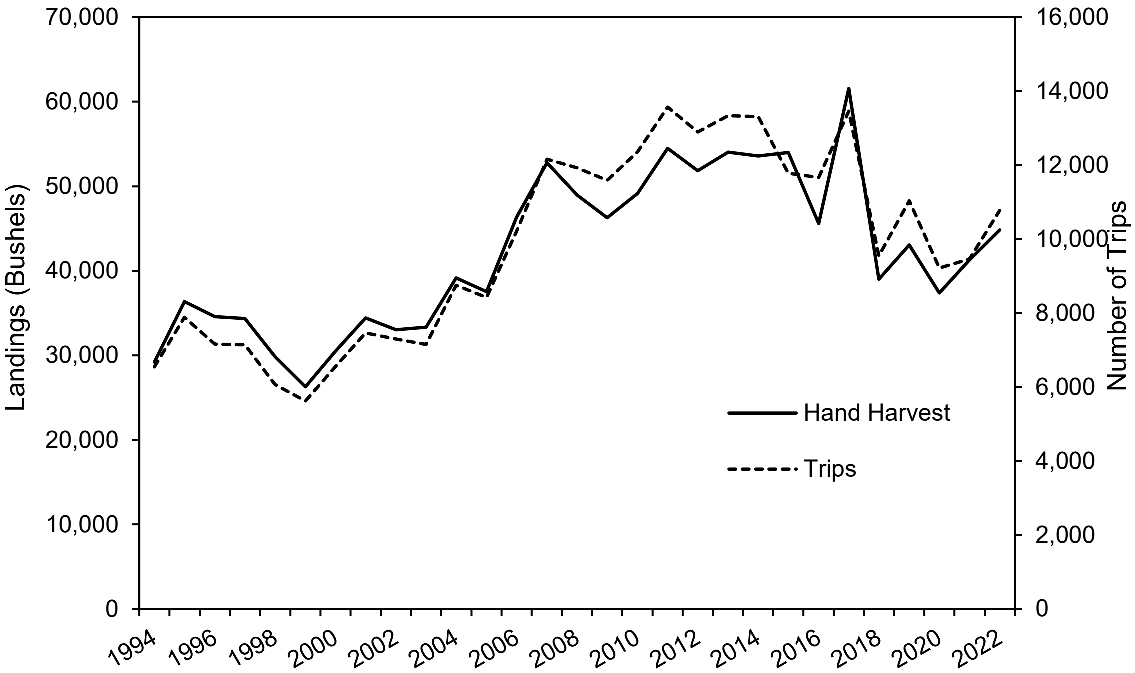

Figure 10. Commercial oyster hand harvest landings and number of dedicated trips in public bottom waters of North Carolina, 1994–2022. (Source: NCDMF Trip Ticket Program).

Recreational Fishery

Oysters are commonly harvested recreationally in North Carolina from October to March by hand, rake, and hand tongs. The limit allowed for personal consumption is one bushel of oysters per person per day, not to exceed two bushels per vessel with a minimum shell length of 3-inches. The NCDMF has limited data on recreational oyster fishing, including the number of participants and the extent of their economic activity. Efforts to accurately quantify the impact of recreational fishing on shellfish (mollusks and crustaceans) have been met with limited success in North Carolina. The NCDMF collects data on recreational fishing in conjunction with the Marine Recreational Information Program (MRIP). However, MRIP collects information on finfish only. The Marine Recreational Fishery Statistics Survey (MRFSS), which was a survey used prior to 2008, reported that more than one million recreational fishing trips targeted shellfish in 1991 in the state; however, estimates of shellfish harvest were not reported.

Based on recommendations by the original Oyster and Hard Clam FMPs, House Bill 1427 was introduced before the general assembly in 2004 to establish a recreational shellfish license on a three-year trial basis (NCDMF 2001b). However, House Bill 1427 was not passed. In the same year, House Bill 831 sought to create a saltwater fishing license requiring individuals recreationally fishing for finfish and shellfish to obtain a license, but this bill did not pass. The state legislature revisited the issue in 2005 and passed a bill to create the Coastal Recreational Fishing License (CRFL). When CRFL was implemented in 2007, it was only required when harvesting finfish and did not include shellfish.

To fill this data gap, the NCDMF implemented a Saltwater Activity Mail Survey during November 2010 to collect monthly data on the harvest of crabs, oysters, clams, and scallops from the CRFL pool. The survey sample initially included approximately 650 randomly selected CRFL holders that held a valid license for at least one day during the survey period and answered “yes” to the harvest of at least one of the following species: crabs, oysters, clams, or scallops. In September 2014, the sample size doubled to approximately 1,300 CRFL holders. The Saltwater Activity Mail survey continued through July 2023 and is set to resume in 2025.

Each survey sent to selected CRFL holders included an explanation letter outlining methods to return the paper survey or to fill it out online. The survey obtained information on the number of trips taken during the survey period, average length of the trip, average party size, number of species kept and discarded, gear used, location information (water access), waterbody, and county of harvest. Data from this survey were limited in scope but could potentially be used to estimate catch and effort in the recreational shellfish fishery for those people who purchased a CRFL license. One limitation, however, is that the survey did not have the means to include individuals who fish exclusively for shellfish as they would not need to purchase a CRFL.

Furthermore, some recreational fishers may purchase a commercial shellfish license over a CRFL because the license is easy to obtain (available to any NC resident), is relatively inexpensive ($50), and allows fishers to harvest more shellfish than the recreational limits allow. Additionally, the Recreational Commercial Gear License (RCGL) allows recreational fisherman to use limited amounts of commercial gear to harvest seafood for personal consumption. In both cases for commercial license holders and RCGL holders, shellfish that are kept for personal consumption and not sold to a seafood dealer will not be captured in landings data recorded by the North Carolina Trip Ticket Program (NCTTP).

With the limited data collected from the optional CRFL survey, some information about recreational effort has been collected. For instance, recreational oyster harvest was reported from 92 waterbodies throughout coastal North Carolina, with Topsail Sound, Pamlico Sound, Bogue Sound, and Masonboro Sound including more than 100 reported trips. The same survey revealed 70% of reported oyster harvesting effort originated from private residence, private boat ramp, or shore. Given only 28% of reported effort originated at public access locations, intercept-oriented surveys are less than ideal. Recreational oyster harvesting effort and catch were both concentrated between October and March, accounting for over 84% of reported trips. Conversely, some individuals reported recreational harvest of oysters during summer months despite state-imposed restrictions on harvest during this time. This suggests unfamiliarity with state regulations.

Given North Carolina's shellfish fisheries are exclusively under state jurisdiction, a lack of recreational shellfish harvest data makes it extremely difficult to address potential management issues such as harvest limits, size limits, and gear restrictions for this fishery. There are currently no data on demographics, perceptions, or expenditures of recreational oyster harvesters in the state. Consequently, there are no data available to conduct an economic impact assessment of recreational oyster harvesting. Due to the widespread accessibility of intertidal oysters along North Carolina's coast, the potential impact of recreational harvest on stock status could be significant. Furthermore, collecting recreational data would fill data gaps that may be necessary for completion of a comprehensive stock assessment. For additional background regarding this issue, please refer to Appendix 1.

PRIVATE CULTURE

In North Carolina, a shellfish lease or franchise are mechanisms through which individuals or entities can gain exclusive rights to grow and harvest shellfish from designated areas of public trust waters. Some shellfish leases are held by commercial fishers to supplement their income from public harvest areas. Other shellfish leases are held by individuals and corporations looking to augment other sources of income; to be engaged in a sustainable business opportunity; or to maintain an attachment to cultural maritime heritage. The NCDMF does not differentiate between clam, oyster, bay scallop, and mussel leases, thereby allowing shellfish growers to grow out multiple species simultaneously as their efforts and individual management strategy allows. Oysters commercially landed from shellfish leases or franchises (designated as private bottom landings) are considered by the NCDMF as farm raised.

Landings from farmed raised oysters have shown a consistent upward trend since around 2014, surpassing wild harvest landings since 2017 (Figure 11). This shift marked a notable change in the primary methods and scale of production, with farm-raised oysters becoming a dominant component of overall oyster landings in the state. This growth was facilitated by advancements in aquaculture technology, increased investment in oyster farming infrastructure, and favorable market conditions for farmed oysters. Additionally, initiatives supporting aquaculture and the expansion of shellfish leasing programs further contributed to the industry's expansion during this period.

Since 1994, North Carolina has seen a significant increase in private shellfish aquaculture participation. Additionally, changes to common practices among private oyster cultures and the termination of the relay program have reduced reliance on wild shellfish among private leases. As such, addressing issues specific to aquaculture has expanded beyond the intended scope of the Fishery Management Plan. Therefore, Amendment 5 of the Oyster FMP will only focus on managing wild oyster populations. For additional details on private culture of shellfish, including the application process, statutes, rules, proclamations, contact, and other helpful resources, please visit the Shellfish Lease and Franchise program website.

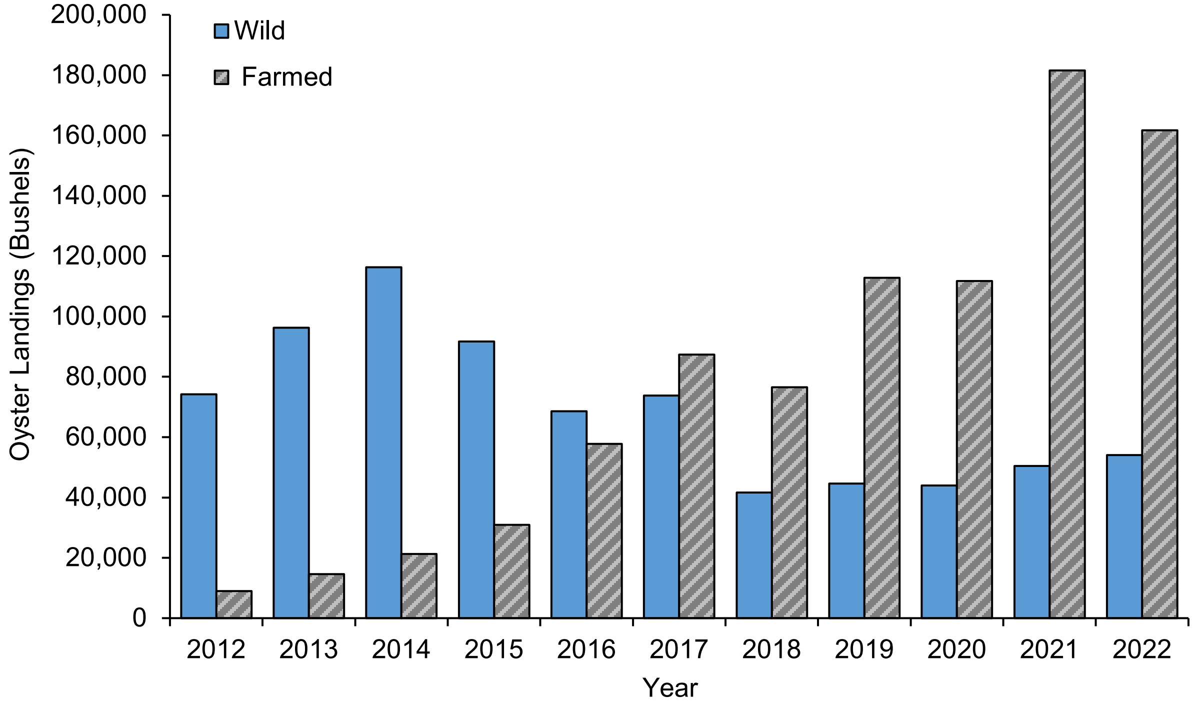

Figure 11 Annual commercial landings of wild harvest and farm-raised (aquaculture) oysters in North Carolina. Wild harvest includes oysters landed by either mechanical (dredge) or hand (e.g., tong, rakes) methods on public bottom.

Summary of Economic Impact

In 2022, oysters were the third most commercially important species in the state (NCDMF 2022). As a species landed primarily during the winter months, oysters provide income to commercial fishers at a time when other species may not be present in harvestable amounts. The expenditures and income within the commercial fishing industry as well as those by consumers of seafood create additional indirect economic benefits throughout the state. Each dollar earned and spent generates additional impact by stimulating other industries, fostering jobs, income, and business sales. The NCDMF estimates the extent of these impacts using a commercial fishing economic impact model that uses information from socioeconomic surveys of commercial fishers and seafood dealers in North Carolina, economic multipliers found in *Fisheries Economics of the United States, 2020,* and IMPLAN economic impact modeling software. In 2022, the wild harvest commercial oyster fishery in North Carolina supported an estimated 636 full-time and part time jobs, $3.5 million in income, and $7.7 million in sales impacts (Table 2).

Table 2. A summary of the economic impact of the commercial wild harvest oyster fishery on public bottom over the last ten years in North Carolina, 2013–2022. (Source: NCDMF Fisheries Economics Program)

			Estimated Economic Impacts			
Year	Trips[1]	Bushels landed[1]	Ex-vessel value (in thousands)[1]	Jobs[2,3]	Income impacts (in thousands)[3]	Sales impacts (in thousands)[3]
2022	11,620	54,342	$2,574	636	$3,526	$7,666
2021	10,328	50,416	$2,516	612	$3,459	$8,474
2020	9,831	44,080	$2,211	611	$3,400	$7,336
2019	11,190	44,567	$2,261	635	$3,651	$8,384
2018	9,880	41,611	$2,105	671	$3,282	$7,190
2017	14,985	73,809	$3,776	923	$5,587	$12,417
2016	14,295	68,573	$3,618	957	$5,315	$11,577
2015	15,748	91,689	$4,222	1,008	$6,061	$13,587
2014	18,951	116,330	$5,058	1,158	$7,562	$17,375
2013	17,013	96,258	$3,817	1,031	$5,533	$12,502

[1]As reported by the North Carolina Division of Marine Fisheries (NCDMF) Trip Ticket Program.
[2]Represents both full-time and part-time jobs.
[3]Economic impacts calculated using the NCDMF commercial fishing economic impact model.

RECENT ECONOMIC TRENDS

The inflation-adjusted value of North Carolina oysters increased in the early 2010s, reaching a peak of about $6.7 million in 2010. Since then, the value of the wild oyster fishery has trended downwards (Figure 12). The nominal ex-vessel price per bushel for oysters exhibited an overall steady increase from 1994 to 2022. When corrected for inflation the price per bushel for oysters has increased by $10 over the last thirty years.

In the 2000s the proportion of landings by mechanical versus hand harvest was consistent before reaching a peak in 2010 when it made up 74% of landings (Figure 13). Since then, mechanical harvest has steadily decreased, comprising a small percentage of total landings. This decrease in mechanical landings is likely a result of changes in licensing requirements for mechanical harvest and waterbody closures from management actions, as well as greater participation in the private lease aquaculture program. While many water bodies have accounted for a steady portion of the overall harvest value, the oyster fishery in Pamlico Sound has decreased in market share from 34% in 2004 down to 16% in 2022. Conversely, Topsail Sound, Masonboro Sound, and Newport River have increased their market shares in the same time span.

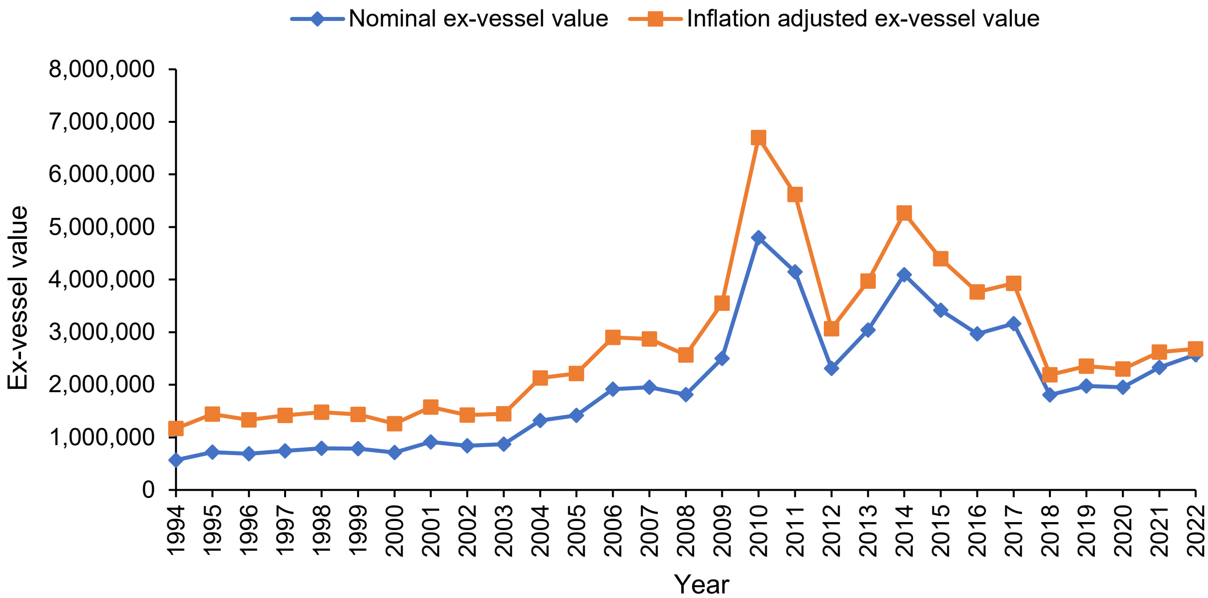

Figure 12. Annual ex-vessel value within North Carolina's wild oyster fisheries, 1994–2022. Inflation adjusted values are in 2023 dollars (Source: NCDMF Trip Ticket Program).

The NCDMF tracks commercial catches of all fishers in the state when the catch is sold to a commercial seafood dealer. Data suggests the oyster fishery expanded from 2004 to 2010, when it peaked at 1,148 participants. However, between 2010 and 2018 there was a significant decrease in participation, but the number of participants has been relatively consistent since 2018. The number of commercial hand harvest and mechanical harvest trips landing oysters exhibited decreasing trends since 2017 with a large decrease in trips in the last year of the data set. Mechanical harvest has seen a considerable downward trend since 2014 and has stayed consistently low since 2018.

As is the case for all commercial fisheries in the state, oyster fishers may only sell their catch to licensed seafood dealers. From 2004 to 2022, the number of seafood dealers who deal in oysters fluctuated between 120 and 170, with a decreasing trend in the last few years. Many seafood dealers are likely oyster fishers who also hold a dealer license, who can vertically integrate their commercial fishing business by both catching and selling a seafood product to wholesalers or consumers.

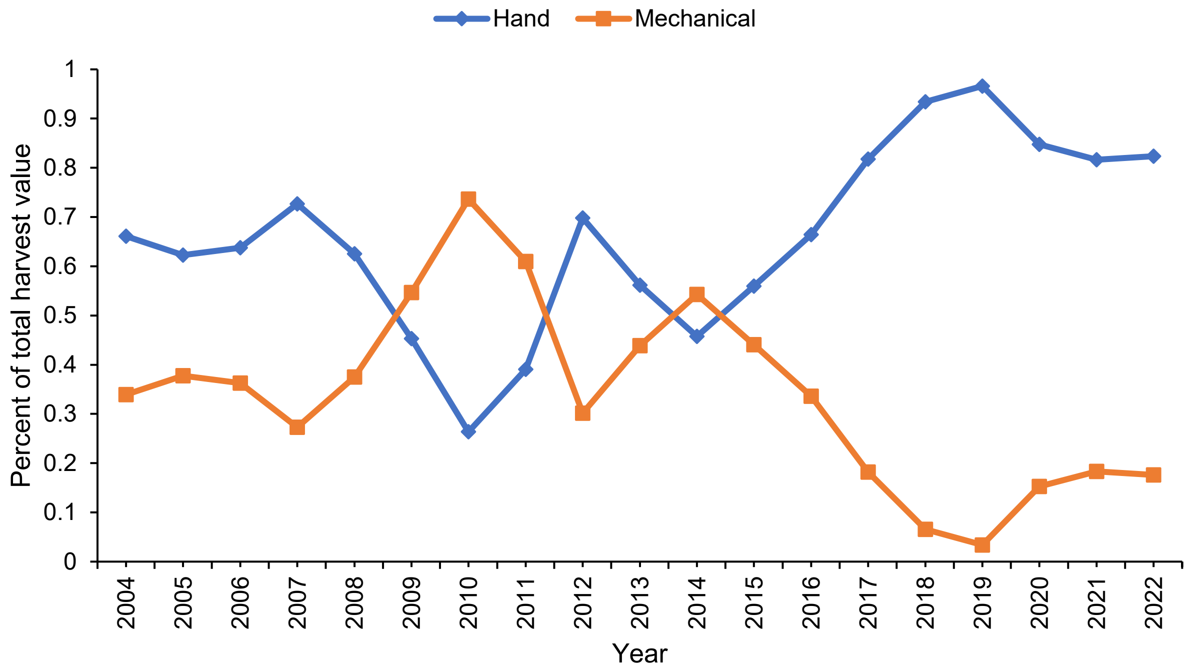

Figure 13. Annual percent of total landings value by gear types used in North Carolina's hand and mechanical oyster fisheries, 2004–2022 (Source: NCDMF Trip Ticket Program).

SOCIAL IMPORTANCE OF THE FISHERY

The NCDMF Fisheries Economics Program has conducted a series of in-depth interview-style surveys with commercial fishers along the coast since 1999. This information is used for fishery management plans, tracking the status of the industry, and informing management of fisher perceptions on potential management strategies. The most recent surveys were collected in 2017. For an in-depth look into responses, see Amendment 4 of the Eastern Oyster FMP (NCDMF 2017). A summary of survey responses from 168 commercial fishers active in the oyster fishery across 58 different communities along North Carolina's coast is provided in this Amendment.

As of the 2017 survey, the greatest number of commercial oyster fishers lived in Sneads Ferry, followed by Newport, Beaufort, and Wilmington. Active participants in the oyster fishery were characterized as white males, with an average age of 50 and 28 years of commercial fishing experience. On average, commercial fishing accounted for 68% of the personal income for these fishers, and 46% reported commercial fishing was their sole source of personal income. Most (77%) commercial fishers that targeted oysters fished year-round. Respondents indicated commercial fishing held extremely high historical and economic importance within their communities.

The most important issue to these fishers was low prices for seafood, which is also related to competition from imported seafood. Another key issue for oyster fishers was coastal development. With several areas of coastal North Carolina having undergone intense development in recent decades, associated water quality impairments have often impacted opening/closure of shellfish areas. Additionally, coastal development is associated with losing working waterfronts, another top five concern of respondents. Conversely, the bottom ranked issues according to 168 commercial oyster harvesters were keeping up with rule changes/proclamations, overfishing, bag limits, size limits and quotas.

ECOSYSTEM PROTECTION AND IMPACT

This section primarily focuses on the role of oysters as habitat, though it also addresses the impacts of the fishery on habitat and other ecosystem services of oyster reefs. The benefits and impacts discussed below refer to "shell bottom" and "oyster reefs" interchangeably, and includes both intertidal and subtidal habitats, consisting of fringing or patch oyster reefs, surface aggregations of living shellfish, and/or shell accumulations. This section includes overviews of the Coastal Habitat Protection Plan (CHPP) and NCDMF's Habitat & Enhancement Shellfish Rehabilitation Programs, both of which aim to protect and enhance oyster reef habitat throughout the state.

Coastal Habitat Protection Plan

In the 1990s, addressing habitat and water quality degradation was recognized by resource managers, fishers, the public, and the legislature as a critical component for improving and sustaining fish stocks, as well as the coastal ecosystem. When the Fisheries Reform Act (FRA) of 1997 (G.S. 143B-279.8) was passed, it required developing Coastal Habitat Protection Plans (CHPPs). The legislative goal of the CHPP is "…the long-term enhancement of coastal fisheries associated with coastal habitats." The FRA specifies the CHPP will identify threats and recommend management actions to protect and restore coastal habitats critical to North Carolina's coastal fishery resources. The plans are updated every five years and must be adopted by the North Carolina Coastal Resources Commission (CRC), North Carolina Environmental Management Commission (EMC), and NCMFC to ensure consistency among commissions as well as their supporting DEQ agencies. The 2021 CHPP Amendment is the most recent update to the CHPP, building upon the 2016 CHPP source document.

The NCMFC's CHPP includes four overarching goals for the protection of coastal habitat: 1) improve the effectiveness of existing rules and programs protecting coastal fish habitats; 2) identify and delineate strategic coastal habitats; 3) enhance habitat and protect it from physical impacts; and 4) enhance and protect water quality. The CHPP is an interagency plan with its goals and actions carried out by several state agencies. For instance, while NCDMF has the capacity to recommend management decisions towards meeting the goals described above pertaining to coastal habitat, the Division of Water Quality enforces policies concerning water quality issues described in the CHPP. Overall, achieving the goals set by the CHPP to protect North Carolina's coastal resources involves managers and policy makers from several state agencies making recommendations and enforcing regulations.

The CHPP identifies bottom disturbing fishing gear, including oyster dredges, as having the potential to be highly destructive towards oyster reefs. As such, the NCMFC has recommended the following actions: protect habitat from adverse fishing gear effects and protect and restore important fish habitat functions from damage associated with activities such as dredging (NCDEQ 2016). This recommendation is cited as a specific objective within this Amendment of the Eastern Oyster FMP, and is explored further in Appendix 2, the Mechanical Oyster Harvest Issue Paper. Furthermore, the complexity of managing the oyster resource as both a fishery and essential estuarine habitat is reason for establishing an ongoing and sustained interconnectedness between the Eastern Oyster FMP and the CHPP.

ESSENTIAL HABITAT

In estuarine ecosystems worldwide, oyster reefs play a vital role in creating habitat for diverse communities in estuarine habitats. As prolific filter feeders, dense oyster assemblages can affect phytoplankton dynamics and water quality, which in turn aids submerged aquatic vegetation (SAV) and reduces excessive nutrient loading that could otherwise lead to hypoxic conditions (Thayer et al. 1978; Newell 1988; Everett et al. 1995; Newell and Koch 2004; Carroll et al. 2008; Wall et al. 2008). Such an impact on water quality also provides direct and indirect benefit to humans in the form of ecosystem services. For instance, oyster reefs serve as habitat for a variety of economically important species while also stabilizing sediment along coastlines. With successive generations building upon shells left by their predecessors, oyster reefs add spatial complexity to the benthos, creating colonization space, refuge, and foraging substrate for many species (Arve 1960; Bahr and Lanier 1981; Zimmerman et al. 1989; Lenihan and Peterson 1998). As water quality and healthy, diverse oyster reefs benefit coastal communities, NCDMF recognizes the economic importance of oyster reef habitat. Combining the ecosystem services provided by oysters, the estimated value of North Carolina's oyster reefs is $2,200 to $40,200 per acre annually (Grabowski et al. 2012).

Studies have shown shell bottom supports a greater abundance and/or diversity of finfish and crustaceans than unstructured soft bottom (Grabowski and Peterson 2007; Nevins et al. 2013). The structural complexity and emergent structure of these reefs offer various benefits to inhabitants, including refuge and foraging opportunities (Coen et al. 1999; Grabowski et al. 2005; Lenihan et al. 2001; Peterson et al. 2003). The reef structures themselves impact the flow of currents, thereby offering enhanced deposition of food for benthic fauna (Grabowski 2002; Kelaher 2003). Additionally, tertiary production of nektonic organisms is found to be more than double on oyster reefs than from *Spartina* marshes, soft bottom, and SAV, indicating the importance of this habitat for higher order consumers (English et al. 2009).

In North Carolina, over 70 species of fish and crustaceans have been documented using natural and restored oyster reefs (Table 3; ASMFC 2007; Coen et al. 1999; Grabowski et al. 2005; Lenihan et al. 2001; Peterson et al. 2003). The list includes 12 species managed by the Atlantic State Marine Fisheries Commission and seven species managed by the South Atlantic Fishery Management Council, highlighting the importance of this habitat for recreational and commercial fisheries. Many of the state's economically important fishery species are estuarine dependent at some point in their life cycles as oyster reefs serve as nursery habitat for numerous marine and estuarine species during key phases of their life cycles (Ross and Epperly 1985; Pierson and Eggleston 2014). Fish that utilize oyster reefs can be classified into three groups: residents, facultative residents, and transients. Residents depend on oyster reefs for breeding, feeding, and shelter. Facultative residents primarily use the reefs for food. Transients, on the other hand, visit the reefs for food and shelter but do not rely on them long-term (NCDEQ 2016).

Oyster reefs also host large abundances of small forage fishes and crustaceans, such as pinfish, gobies, grass shrimp, and mud crabs, which are important prey for larger recreationally and commercially important fishes (Minello 1999; Posey et al. 1999; Plunket and La Peyre 2005; ASMFC 2007). The structural complexity of oyster reefs provides safe refuge from disturbance events, thereby offering stability to both shell-bottom and soft-bottom habitats. A diversity of invertebrates and microalgae that have key food web roles inhabit these microenvironments, such as polychaetes, crabs, clams, and amphipods, and those species rely on the interstitial spaces in the shell matrix of oyster reefs to improve survival from foraging by predators like oyster toadfish, blue crabs, and birds (NCDEQ 2016).

An in-depth discussion of fish species' usage of oyster reef habitats is available in Amendment 4 to the Eastern Oyster FMP (NCDMF 2017) and Chapter 3 of the 2016 CHPP (NCDEQ 2016).

WATER QUALITY

Oyster habitat offers a variety of direct and indirect ecosystem services related to water quality. The filtering activities of oysters and other suspension feeding bivalves remove particulate matter, phytoplankton, and microbes from the water column (Prins et al. 1997; Coen et al. 1999; Wetz et al. 2002; Cressman et al. 2003; Nelson et al. 2004; Porter et al. 2004; Grizzle et al. 2006; Coen et al. 2007; Wall et al. 2008). Adult oysters have been reported to filter as high as 10 L per hour per gram of dry tissue weight (Jordan 1987). Because non-degraded oyster reefs contain high densities of filter-feeding bivalves, they can modify water quality in shallow waters by their intense filtration. Even small-scale additions of oysters to tidal creeks can reduce total suspended solids (TSS) and chlorophyll-a concentrations downstream of transplanted reefs (Nelson et al. 2004).

Oyster reefs also provide a key ecosystem service by removing nutrients, especially nitrogen, from the water column (Piehler and Smyth 2011; Kellogg et al. 2013). Nitrogen (N) and phosphorous (P) in biodeposits can become buried or removed via bacterially mediated nitrification-denitrification (Newell et al. 2002; Porter et al. 2004; Newell et al. 2005). In North Carolina, Smyth et al. (2013) found that rates of denitrification by oyster reefs were like that of SAV and marsh, and highest in the summer and fall when oyster filtration is greatest. The dollar benefit of the nitrogen removal service provided by oyster reefs was estimated to be $2,969 per acre per year (2011 dollars; $4,135 per acre per year in 2023 dollars).

Table 3. List of all observed and known estuarine species that have been surveyed on oyster reefs or are known to use oyster reefs as habitat in North Carolina

Common name	Scientific name	Common name	Scientific name
Anchovy, Bay	*Anchoa mitchilli*	Mullet, Striped *†‡	*Mugil spp.*
Bass, Striped *†‡	*Morone saxatilis*	Needlefish, Houndfish	*Tylosurus crocodilus*
Blenny, Feather	*Hypsoblennius hentz*	Perch, Sand	*Diplectrum formosum*
Blenny, Striped	*Chasmodes bosquianus*	Perch, Silver	*Bairdiella chrysoura*
Bluefish **	*Pomatomus saltatrix*	Pigfish	*Orthopristis chrysoptera*
Bumper, Atlantic	*Chloroscombrus chrysurus*	Pinfish	*Lagodon rhomboides*
Butterfish	*Peprilus triacanthus*	Pinfish, Spottail	*Diplodus holbrooki*
Clam, Hard	*Mercenaria mercenaria*	Pompano	*Trachinotus carolinus*
Cobia **	*Rachycentron canadum*	Sea Bass, Black **	*Centropristis striata*
Crab, Blue *†‡	*Callinectes sapidus*	Sea Bass, Rock	*Centropristis philadelphica*
Crab, Florida Stone	*Menippe mercenaria*	Searobins, Prionotus	*Prionotus spp.*
Crabs, Spider	*Majidae spp.*	Seatrout, Spotted *‡	*Cynoscion nebulosus*
Croaker, Atlantic **	*Micropogonias undulatus*	Shad, Threadfin	*Dorosoma petenense*
Dogfish, Smooth	*Mustelus canis*	Shark, Atlantic Sharpnose	*Rhizoprionodon terraenovae*
Dogfish, Spiny **	*Squalus acanthias*	Shark, Blacktip	*Carcharhinus limbatus*
Drum, Black **	*Pogonias cromis*	Shark, Finetooth	*Carcharhinus isodon*
Drum, Red *	*Sciaenops ocellatus*	Sheepshead *	*Archosargus probatocephalus*
Eel, American **†	*Anguilla rostrata*	Shrimp, Palaemonidae *	*Palaemonetes spp.*
Eel, Conger	*Conger oceanicus*	Shrimp, Penaeidae *	*Farfantepenaeus spp.* *Litopenaeus spp.*
Filefish, Planehead	*Stephanolepis hispidus*	Silverside, Atlantic	*Menidia menidia*
Filefish, Pygmy	*Monacanthus setifer*	Silverside, Inland	*Menidia beryllina*
Flounder, Gulf	*Paralichthys albigutta*	Silverside, Rough	*Membras martinica*
Flounder, Southern *†‡	*Paralichthys lethostigma*	Skate, Clearnose	*Raja eglanteria*
Flounder, Summer **‡	*Paralichthys dentatus*	Skilletfish	*Gobiesox strumosus*
Goby, Naked	*Gobiosoma bosc*	Snapper, Grey	*Lutjanus griseus*
Grouper, Gag	*Mycteroperca microlepis*	Spadefish, Atlantic	*Chaetodipterus faber*
Harvestfish	*Peprilus alepidotus*	Spot **	*Leiostomus xanthurus*
Herring, Atlantic Thread	*Opisthonema oglinum*	Stingray, Bullnose	*Myliobatis freminvillei*
Herring, Blueback*†	*Alosa aestivalis*	Stingray, Cownose	*Rhinoptera bonasus*
Jack, Bar	*Caranx ruber*	Stingray, Southern	*Dasyatis americana*
Jack, Crevalle	*Caranx hippos*	Tarpon	*Megalops atlanticus*
Killifish	*Fundulus spp.*	Tautog **	*Tautoga onitis*
Lizardfish, Inshore	*Synodus foetens*	Toadfish, Oyster	*Opsanus tau*
Lookdown	*Selene vomer*	Triggerfish, Grey	*Balistes capriscus*
Mackerel, Spanish**	*Scomberomorus maculatus*	Weakfish **	*Cynoscion regalis*
Menhaden, Atlantic **	*Brevoortia tyrannus*		

*NCDMF state managed species
** ASMFC federally managed species
† Most recent stock assessment suggests population is overfished as of 2025
‡ Most recent stock assessment suggests overfishing is occurring as of 2025

Habitat and Enhancement Programs

In 2007, a National Oceanic and Atmospheric Administration biological review team found that east coast oyster harvest was 2 percent of peak historical volume, and suggested oyster restoration and enhancement efforts are "necessary to sustain populations" (EOBRT 2007). One example in North Carolina is the Neuse River Estuary, which has experienced widespread loss of oyster habitat, as oyster beds have been "displaced downstream roughly 10–15 miles" since the late 1940s (Jones and Sholar 1981; Steel 1991). Natural expansion of healthy oyster reefs is not expected in this area because adjacent bottom lacks attachment substrate (Lenihan 1999; Lenihan and Peterson 1998).

To improve and preserve the diverse ecosystem functions provided by oyster reef habitat, restoration is essential in North Carolina. In recognition of this need, NCDMF's Habitat and Enhancement Section coordinates ongoing habitat enhancement activities to improve statewide oyster populations and subsequently enhance the ecosystem services they provide. These efforts began with the Cultch Planting program in 1915 with the goal to rebuild oyster beds on public bottom by planting shells for substrate, thereby creating state-subsidized harvest areas for the fishery. Since the 1980s, over 2,000 cultch sites have been planted throughout North Carolina's coastline, with each area ranging in size from 0.5 to 10 acres. Estimates by NCDMF biologists indicate that each acre of cultch material can support and yield 368 bushels of oysters.

Additionally, NCDMF's Habitat & Enhancement Section oversees the construction of no-take reserves with the goal of creating and maintaining a self-sustaining network of subtidal oyster reefs. Protected oyster sanctuaries have the potential to supply approximately 65 times more larvae per square meter than non-protected reefs (Puckett and Eggleston 2012; Peters et al. 2017). This heightened reproductive output potential further benefits naturally occurring reefs and cultch sites as wind patterns distribute oyster larvae to historical oyster fishing areas for grow-out and future harvest (Haase et al. 2012; Puckett et al. 2014). A 20-acre protected oyster reef could provide an annual commercial fish value of $33,370 and have a larval oyster supply functionally equivalent to 1,300 acres of non-protected oyster reef (adapted from Grabowski et al. 2012; Peters 2014; Peters et al. 2017). Oyster Sanctuaries also provide recreational hook-and-line fishing and diving opportunities for the public. Sanctuary and cultch sites are planned with the aim of improving larval connectivity within the network of restoration sites. To date there are 17 sanctuaries (Figure 4.2), and a total of 789 acres of protected habitat placed in effect by proclamation (see Appendix 4 for more information on Enhancement Programs).

Secondary to improving oyster populations, enhancement programs also provide valuable reef habitat for many estuarine species (Table 3). Both cultch sites and sanctuaries offer oysters and other species refuge from hypoxia events via the construction of high relief habitat using alternative substrates. Additionally, artificial reefs may serve as nursery habitat to commercially valuable finfish. The estimated commercial fish value supported by a hectare of oyster reef is $4,123 annually (Grabowski et al. 2012). Peterson et al. (2003) conducted a meta-analysis that indicated every 10 m^2 of newly constructed oyster reef in the southeast United States is expected to yield an additional 2.6 kg of fish production per year for the lifetime of the reef.

For a more comprehensive history of NCDMF's oyster habitat enhancement efforts and detailed methodologies employed by the cultch and sanctuary programs (site selection, monitoring, and analysis), please refer to Appendix 4.

Threats and Alterations

Oysters are unique in their status as an ecosystem engineer in that they not only have a disproportionate impact on their surrounding environment, but they are also a global commodity. Declining oyster populations have been observed, especially on sub-tidal reefs along the US East Coast (Rothschild et al. 1994; Hargis and Haven 1988; NCDMF 2001b; EOBRT 2007). The declining trend has been noted for oyster harvest in North Carolina (Street et al. 2005; Deaton et al. 2010).

The primary threats to oyster habitat in North Carolina are physical disturbance (e.g., harvesting) and water quality degradation (e.g., bacterial contamination and eutrophication). Other potential threats such as sedimentation, and in-water development have the potential to impact oyster habitat, and those threats are discussed in Amendment 4 to the Oyster FMP (2017) and in the CHPP (2016), but they are omitted here to provide a focus on the most widespread and long-term threats to oyster habitat across North Carolina. Notably, of these threats, only hand-harvest and bottom-disturbing gear are directly within the control of the NCMFC. However, the NCMFC can encourage progress on other issues through collaboration with the EMC and CRC through its role in developing the CHPP.

Physical Disturbance From Harvest Methods

Of the factors affecting the condition and distribution of oyster habitat, oyster harvest has had the greatest impact. Winslow (1889) and Chestnut (1955) reported finding formerly productive areas in Pamlico Sound where intensive oyster harvesting made further harvest and recovery of the oyster rocks impossible. Heavily fished oyster reefs lose vertical profile and are more likely to be affected by sedimentation and anoxia, which can suffocate live oysters and inhibit recruitment (Kennedy and Breisch 1981; Lenihan and Peterson 1998; Lenihan et al. 1999). Anecdotal accounts also indicate significant negative impacts occurred to oyster rocks in areas before they were closed to mechanical harvest of clams. In fact, current fisheries regulations prohibit the use of mechanical gear for the harvest of shellfish in SAV beds, Primary Nursery Areas, and live oyster beds outside of designated mechanical harvest areas because of the destructive capacity of the gear. Further discussion of the impacts of mechanical harvest is included in [Appendix 2].

Intensive hand harvest methods can also be destructive to oyster rocks. The harvest of clams or oysters by tonging or raking on intertidal oyster beds causes damage to not only living oysters but also the cohesive shell structure of the reef (Lenihan and Peterson 1998). This destruction has been an issue where oysters and hard clams co-exist, primarily around the inlets in the northern part of the state and on intertidal oyster beds in the south (DMF Oyster FMP 2001). Studies by Noble (1996) and Lenihan et al. (1999) quantified the effects of oyster and clam harvesting on oyster rocks, finding that the density of live adult oysters was significantly reduced where clam harvesting occurred, but that oyster harvesting had little effect on clam populations. Further discussion of the impacts of hand harvest is included in Appendix 3.

BIOLOGICAL STRESSORS

Introduced Species

Nuisance and non-native aquatic species have been accidentally or intentionally introduced to North Carolina waters through river systems, created waterways like the Intracoastal Waterway (IWW), discharged ballast water, out-of-state vessels, and the sale of live fish and shellfish for bait or aquaculture. Oysters were impacted by the introduction of the Dermo parasite and the pathogen *Haplosporidium nelson* (MSX) via introduced Pacific oysters in 1988 (*Crassostrea gigas*; NCDMF 2001b). However, infection rates of MSX within oysters have drastically declined since 1989 and further sampling for MSX was discontinued in 1996 (for more information, please see Amendment 4). Intentional introductions of non-native species are covered under state laws and rules of several commissions. Permits are required for introducing, transferring, holding, and selling as bait any imported marine and estuarine species. Applicants must provide certification to ensure the organisms being moved are disease free and no additional macroscopic or microscopic organisms are present. The Fisheries Director may hold public meetings concerning these applications to help determine whether to issue the permit.

There is much debate and uncertainty regarding the introduction of non-native oysters for the purpose of rebuilding complex reef habitat, enhancing water filtration, and preserving the fishery (Andrews 1980; NCDMF 2001b; Richards and Ticco 2002). Concerns of introduction include long-term survival of introduced species, competition with native oysters, unknown reef-building attributes, cross-fertilization reducing larval viability, and unintentional introduction of non-native pests (NCDMF 2008). Testing of the Pacific oyster and the Suminoe oyster (*Crassostrea ariakensis*) was carried out by researchers in North Carolina to assess their potential use (NCDMF 2008). Pacific oysters were found to be too thin to resist predation by native oyster drills and boring worms and Suminoe oysters were found to be susceptible to a parasitic protist in high salinities (DeBrosse and Allen 1996; Richards and Ticco 2002). In 2009, the US Army Corps of Engineers issued a Record of Decision to disallow the introduction of the Suminoe oyster and instead encouraged enhanced restoration and aquaculture using native oysters.

Dermo Disease

The oyster parasite (*Perkinsus marinus)*, also known as Dermo disease, is a protist that causes tissue degradation resulting in reduced growth, poor condition, diminished reproductive capacity, and ultimately mortality resulting from tissue lysis and occlusion of hemolymph vessels in infected oysters (Ray and Chandler 1955; Haskin et al. 1966; Ford and Figueras 1988; Ford and Tripp 1996). Oysters become more susceptible to parasitism and disease during extended periods of high salinity and temperature (VIMS 2002; La Peyre et al. 2006; NCDMF 2008), dissolved oxygen, sediment loading, and anthropogenic pollution (Barber 1987; Kennedy et al. 1996; Lenihan et al. 1999).

Research on experimental subtidal oyster reefs in the Neuse River estuary found oysters located at the base of reefs had the highest Dermo prevalence, infection intensity, and mortality, while oysters located at the crest of reefs were much less susceptible to parasitism and Dermo-related mortality (Lenihan et al. 1999). Dermo infection was responsible for large-scale oyster mortalities in North Carolina during the late 1980s to mid-1990s (NCDMF 2008).

In 1989, the NCDMF began diagnosing Dermo infections and by 1991, a formal annual monitoring program was in place. Samples with moderate and high categories of infection intensity are expected to have mortality rates that considerably affect harvest if optimum conditions for parasitic growth and dispersal continue to persist. Results of the NCDMF monitoring program indicated that North Carolina appears to have some overwintering infections during mild years, although few samples were taken during winter months. Infection levels were high in the early 90s, and mortality of a smaller size class of oysters was observed. Infection intensity dropped between the mid-1990s to the mid-2000s.

Staff observed in southern estuaries during late summer months that moderate and high Dermo infection levels did not reduce oyster populations. It is suspected that small, high salinity estuaries may inhibit mortality by flushing out parasites at a higher rate or by exceeding the salinity tolerance of the Dermo parasite, allowing for a higher survival rate compared to Pamlico Sound. The link between low dissolved oxygen, increased availability of iron, and increased parasite activity may also be a factor in the different mortality rates as the smaller, high salinity estuaries are less prone to low dissolved oxygen events than Pamlico Sound (Leffler et al. 1998). Dermo infection intensity levels since 2005 have remained low and have likely not resulted in large scale mortality events, resulting in NCDMF discontinuing the routine annual monitoring program in 2017 (NCDMF unpublished data).

Other Harmful microbes

In addition to Dermo, there are various environmental pathogens that can impact shellfish and those that consume shellfish. Pathogens of most notable concern are *Vibrio* and Neurotoxic Shellfish Poisoning (NSP). Although the pathogen, *Haplosporidium nelson* (MSX), can also be of concern, infection rates of MSX in North Carolina oysters have drastically declined since 1989 and are currently not considered a major concern (for more information, please see Amendment 4 (NCDMF 2017).

Vibrio spp. are salt-loving bacteria that inhabit coastal waters throughout the world and can be ubiquitous in areas open to shellfish harvest. *Vibrio* can be found in North Carolina's coastal waters year-round but are more abundant during the warmer summer months (Pfeffer et al. 2003; Blackwell and Oliver, 2008). While they are not usually associated with pollution that typically triggers shellfish closures, filter-feeders can accumulate high concentrations of *Vibrio*. These bacteria can pose a public health risk as they may cause gastrointestinal illness from the consumption of raw or undercooked shellfish. People with underlying health conditions such as liver disease, diabetes, cancer, or weakened immune systems are at a higher risk of infection and can potentially experience life-threatening illness from *Vibrio*. For this reason, it is not advised to consume raw shellfish in the warm-water months. Humans can also contract *Vibrio* infections through open wounds on the skin and contact with brackish or saltwater.

Neurotoxic Shellfish Poisoning is a disease caused by consumption of molluscan shellfish contaminated with brevetoxins primarily produced by the dinoflagellate, *Karenia brevis*. Blooms of *K. brevis*, sometime referred to as Florida red tide, occur frequently along the Gulf of Mexico (Watkins et al. 2008). Red Tide events have been documented to cause impacts to shellfish fisheries in North Carolina (NCDMF 2001a).

For more detailed information on these environmental pathogens, see Amendment 2 of the Hard Clam FMP (NCDMF 2017). The NCDMF has a contingency plan in place as required by the FDA, including a monitoring program and management plan. The purpose is to ensure quick response to any harmful algal species within State waters that may threaten the health and safety of shellfish consumers. The plan also details the system to provide early warning of any potential issues, actions to be taken to protect public health and steps to reopen areas to harvest (Shellfish Sanitation and Recreational Water Quality Section Marine Biotoxin Contingency Plan 2022).

Boring Sponge

The boring sponge (*Cliona spp.*) is a bioeroder of calcified skeletons such as corals and oyster reefs. These sponges can chemically etch out canal systems within oyster reefs, as well as incrust and smother them which can cause mortality by weakening the shell. Once the oyster reef has been compromised, there is a loss of substrate, reduction in vertical relief, and loss of structural integrity. Boring sponges are linked to salinity gradients with some species found in high salinity waters while other species are found in low to mid-range salinities but typically are not found in waters with less than 10 ppt salinity. Intertidal oysters have some refuge from boring sponges.

Lindquist et al. (2012) examined the distribution and abundance of oyster reef bioerosion by *Cliona* in North Carolina. The study examined levels of boring sponge infestations across salinity gradients in multiple oyster habitats from New River through the southern portions of Pamlico Sound, finding that higher salinity areas, with a mean salinity of 20 ppt or greater, were infested by the high salinity tolerant boring sponge *Cliona celata*. As salinities increased, infestations increased and subtidal reefs disappeared (Lindquist et al. 2012), and freshets that occurred in White Oak River and New River prior to initial surveys demonstrated resilience of boring sponges to low salinity events. Sample sites in both areas had no active infestations but gemmules were observed; sampling seven to eight months later found moderate to high levels of active sponge infestation. Bioeroding polychaete *Polydora* worms were also more abundant in lower salinity areas and less abundant in higher salinities (Lindquist et al. 2012).

WATER QUALITY THREATS

Marine bivalves, including oysters, have been shown to accumulate chemical contaminants, such as hydrocarbons and heavy metals, in high concentrations. Reductions in growth and increased mortality have been observed in soft-shelled clams (*Mya arenaria*) following oil spill pollution events (Appeldoorn 1981). Impaired larval development, increased respiration, reduction in shell thickness, inhibition of shell growth, and general emaciation of tissues have been attributed to adult bivalve exposure to heavy metal contamination (Roesijadi 1996). High concentrations of organic contaminates also result in impairment of physiological mechanisms, histopathological disorders, and loss of reproductive potential in bivalves (Capuzzo 1996). As shellfish can easily accumulate chemical pollutants in their tissues, consumption of impaired shellfish creates a health risk. Subsequently, shellfish closures occur due to chemical contamination, commonly associated with industry, marinas, and runoff.

Delivery of inorganic pollutants, organic contaminants, and harmful microbes to waterways occurs via both point and non-point sources. Accumulation of harmful agents in the water column subjects oyster populations to the adverse effects listed above. Point sources have identifiable origins and include the National Pollution Discharge Elimination System (NPDES) wastewater discharges. Although wastewater discharges are treated, mechanical failure allows contaminated sewage to reach shellfish growing waters triggering an area to be closed to harvest.

Non-point sources of microbial contamination include runoff from animal agriculture operations and urban development. Animal agriculture produces waste with fecal bacteria, runoff from pastures, concentrated animal feeding operations (CAFOs), and land where CAFO waste has been applied as manure, all of which can be transported to surface waters and subsequently lead to shellfish restrictions (Burkholder et al. 2007; Wolfson and Harrigan 2010; Hribar 2010). Impervious surfaces (e.g., roads, roofs, parking lots) facilitate runoff and microbe transportation, facilitating significant water quality degradation in neighboring watersheds (Holland et al. 2004). For instance, in New Hanover County, an analysis of the impact of urban development showed that just 10–20% impervious cover in an area impairs water quality (Mallin et al. 2000). In North Carolina, CAFOs primarily house swine and poultry with a majority located in the coastal plain portions of the Cape Fear and Neuse basins; however, both occur in all basins across the coastal plain (NCDWR 2023a).

Low Oxygen

Point and non-point sources (developed and agricultural lands) are also sources of increased nutrient loads, which fuel phytoplankton growth and increase the strength and frequency of algal blooms. The eventual bacterial decomposition of these blooms results in depletion of dissolved oxygen to levels that can be dangerous to shellfish, particularly in warm, deep waters. Increased eutrophication leads to decreased oxygen levels (hypoxia and anoxia), which North Carolina’s estuaries are already prone to because of salinity stratification and high summertime water temperatures (Buzzelli et al. 2002). Low-oxygen events degrade the usability of subtidal oyster reef habitats for fish (Eby and Crowder 2002) and cause high rates of oyster mortality in the deeper (4–6 m) estuarine waters (Lenihan and Peterson 1998; Powers et al. 2009; Johnson et al. 2009). State action to limit nutrient loading from urban and agricultural lands is critical for reducing hypoxia impacts to estuarine habitat and resources, including oysters and the reefs they create (NCDWR 2023b).

Shellfish Sanitation

North Carolina is part of the National Shellfish Sanitation Program (NSSP). The NSSP is administered by the U.S. Food and Drug Administration. The NSSP is based on public health principles and controls and is designed to prevent human illness associated with the consumption of shellfish. Sanitary controls are established over all phases of the growing, harvesting, shucking, packing and distribution of fresh and fresh-frozen shellfish. Shellfish Sanitation and Marine Patrol are the primary Sections of NCDMF responsible for North Carolina's compliance with the NSSP.

The Shellfish Sanitation Section classifies shellfish growing areas and recommends closures and re-openings to the Director that are implemented by proclamation. The entire North Carolina coast is divided into a series of management units referred to as Growing Areas. Each Growing Area is individually managed to determine which portions of the area are suitable for shellfish harvest, and which need to be closed to harvest. Data collected and used in classifying Growing Areas includes actual and potential pollution sources, rainfall and runoff impacts, physical hydrodynamic patterns, and bacteriological water quality.

Shellfish growing waters can be classified as "Approved", "Conditionally Approved", "Restricted", or "Prohibited". Approved areas are consistently open to harvest, while Prohibited areas are off limits for shellfish harvest. Conditionally Approved areas can be open to harvest under certain conditions, such as dry weather when stormwater runoff is not having an impact on surrounding water quality, and Restricted waters can be used for harvest at certain times as long as the shellfish are subjected to further cleansing before they are made available for consumption. For a map of both temporary and permanent closures, please visit the Interactive Shellfish Closure Map on NCDMF's Shellfish Sanitation website. Additional information can be found under Current Polluted Area Proclamations.

Climate Change

Along the southeastern coastline, models suggest the intensity of hurricanes is likely to increase with warming temperatures, which will result in increased heavy precipitation from hurricanes (Kunkel et al. 2020). Additionally, it is likely the frequency of severe thunderstorms and annual total precipitation in North Carolina will increase. The expected increase in heavy precipitation events will lead to increased runoff, which will result in an increase in chemical and microbial pollutants transferred to oyster habitats. Recent research has provided evidence that negative impacts from increased precipitation and pollutant delivery to estuaries have already begun in North Carolina (Paerl et al. 2019; Kunkel et al. 2020).

For instance, Paerl et al. (2020) investigated the impact of tropical cyclones on nutrient delivery and algal bloom occurrences in the Neuse River Estuary and Pamlico Sound. They found high-discharge storm events, such as high-rainfall tropical cyclones, can double annual nutrient loadings to the estuary, leading to increased nutrients and dissolved organic carbon. Phytoplankton response to moderate storm events is immediate, while during high-rainfall events like Hurricanes Floyd (1999), Matthew

(2016), and Florence (2018), phytoplankton growth is diverted downstream to Pamlico Sound, where it can persist for weeks. Additionally, increased organic matter and phytoplankton biomass from heavy rainfall events contribute to oxygen depletion, exacerbating hypoxic and anoxic conditions in the Neuse River and Pamlico Sound.

Additionally, warming water temperatures caused by climate change may benefit growth rates for pathogens that can negatively impact oyster resources. For instance, increased water temperatures have been linked to increasing abundance of *Vibrio* over the past 60 years and may increase in frequency and length as temperatures rise (Vezzulli et al. 2016). Rising water temperatures threaten to increase this risk, potentially through longer periods of the year.

To reduce the negative impacts of climate change on the oyster fishery, it will be important for state agencies to implement policies that encourage the use of agriculture, forestry, and urban stormwater best management practices (BMPs) to reduce the amount of runoff reaching North Carolina’s estuaries. This need, among others, has been emphasized in the CHPP as recommended actions to improve water quality (NCDEQ 2016, 2021). While the MFC has little direct control over such actions to mitigate the impacts of increased runoff, it can continue to support them through its role in developing and approving the CHPP.

Protected Species

A “protected species” is defined as any organism whose population is protected by federal or state statute due to the risk of extinction. In North Carolina, these species are primarily protected by the following federal statues: the Marine Mammal Protection Act (MMPA), Endangered Species Act (ESA), and the Migratory Bird Treaty Act. The primary marine mammal that occurs in North Carolina estuaries is the common bottlenose dolphin (*Tursiops truncatus*; Hayes 2018) though the West Indian Manatee (*Trichechus manatus*) seasonally occurs during warm water months (Cummings et al. 2014). The NMFS has designated oyster fisheries as Category III, with no known gear interactions with marine mammals. More information on the MMPA List of Fisheries and fisheries categorizations can be found on the National Oceanic and Atmospheric Administration (NOAA) MMPA website.

North Carolina estuaries are also home to multiple ESA-listed species including the Green Sea Turtle (*Chelonia mydas*), Kemp’s Ridley Sea Turtle (*Lepidochelys kempii*), Loggerhead Sea Turtle (*Caretta caretta*), Leatherback Sea Turtle (*Dermochelys coriacea*), Hawksbill Sea Turtle (*Eretmochelys imbricata)*, Atlantic Sturgeon (*Acipenser oxyrinchus*), and Shortnose Sturgeon (*Acipenser brevirostrum*). These species are unlikely to be impacted as harvest methods employed largely exclude any potential for direct interactions. Due to the lack of recorded interactions and the unlikelihood of any interactions between these ESA-listed species and the oyster industry, it can be assumed any potential impacts of oyster harvest on protected species populations would be indirect and at the ecosystem-level.

A diverse array of migratory bird species occurs in North Carolina estuaries (Potter et al. 2006). Little evidence exists to suggest birds are directly impacted by oyster harvest.

However, as oysters are a primary prey species of the American Oystercatcher (*Haematopus palliatus;* Tuckwell and Nol 1997), oyster harvest may result in secondary interactions with the species. For example, overharvest of oyster reefs has been found, in some cases, to contribute to a decrease in overall reproductive success of nearby nesting Oystercatchers (Thibault et al. 2010).

FINAL AMENDMENT 5 MANAGEMENT STRATEGY

The NCMFC selected management measures

APPENDIX 1: RECREATIONAL SHELLFISH HARVEST ISSUE PAPER

Option 1: Recreational Harvest

b. Support the NCDMF to further explore potential options and develop a solution to estimate recreational shellfish participation and landings, with the intent to move towards a stock assessment and stock level management for both hard clams and oysters; and to establish a mechanism to provide all recreational shellfish harvesters with SSRWQ health and safety information outside of the FMP process.

APPENDIX 2: MECHANICAL OYSTER HARVEST MANAGEMENT ISSUE PAPER

Option 1: Deep-water Oyster Recovery Areas (DORAs)

b. Adopt the proposed Pamlico and Neuse River Deep-water Oyster Recovery Areas (DORAs), which are bound by existing navigational aids as presented to the NC MFC Advisory Committees, to protect deep subtidal oyster reefs from continued physical disturbance by mechanical gear. These areas will be closed to mechanical oyster dredging and monitoring efforts will be used to evaluate the effectiveness of closure within the next FMP amendment. The DORAs cover 681 acres of potential oyster habitat (500 acres in Pamlico River and 180 acres in Neuse River), which represents approximately 81% of the vulnerable deep-water oyster habitat.

Option 2: Cultch Supported Harvest

b. Adopt the Cultch Supported Harvest strategy outlined in Appendix 2, which would set the season length based on pre-season sampling aided by industry input on sampling locations with the 10 bushel per day and 15 bushel per day areas considered separately.

Option 3: Rotational Cultch Site Strategy

b. Adopt the inclusion of Rotational Harvest Cultch Sites strategy outlined in Appendix 2. This strategy would create a rotating series of readily available cultch areas available to harvest for the full extent of the mechanical season length each year with the intent of reducing harvest pressure on natural reefs.

Option 4: Adaptive Management

b. Adopt the proposed adaptive management framework to allow for modification of set season length based on changes to participation in the fishery.

MANAGEMENT FROM PREVIOUS PLANS

The following management measures from the previous FMP are carried forward into Amendment 5.

- A daily limit of two bushels of oysters per person with a maximum of four bushels of oysters per vessel off public bottom for Shellfish License holders statewide.
- A six-week opening timeframe for mechanical harvest in deep bays to begin on the Monday of the week prior to Thanksgiving week through the Friday after Thanksgiving. Reopen two weeks before Christmas for the remainder of the six-week season.
- A 15-bushel hand/mechanical harvest limit in Pamlico Sound mechanical harvest areas outside the bays, 10-bushel hand/mechanical harvest limit in the bays, and 10-bushel hand harvest limit in the Mechanical Methods Prohibited area along the Outer Banks of Pamlico Sound. Areas as defined and adopted in Amendment 2 of the Oyster FMP (NCDMF 2008).

RESEARCH NEEDS

The research recommendations listed below are offered by the NCDMF to improve future management strategies for the Eastern Oyster fishery. They are considered high priority as they will help to better understand the oyster fishery and meet the goal and objectives of the FMP. A more comprehensive list of research recommendations is provided in the Annual FMP Review and NCDMF Research Priorities documents.

- Improve the reliability of estimating recreational harvest.
- Develop regional juvenile and adult abundance indices or methods to monitor abundance of the oyster population (fisheries-independent).
- Establish and monitor sentinel sites for shell bottom habitat condition; develop shell bottom metrics to monitor.
- Develop a program to monitor oyster reef height, area, and condition.
- Explore water quality data sources (e.g.., NOAA, U.S. Geological Survey, FerryMon, Shellfish Growing Areas and Recreational Water Quality programs, meteorology sources) and their use in analyses that incorporates environmental variables that can impact regional population dynamics.

APPENDICES

Appendix 1: Recreational Shellfish Harvest Issue Paper

ISSUE

The number of recreational shellfish harvesters in North Carolina is currently unknown, which prevents reliable estimates of total recreational harvest of shellfish. Additionally, commercial harvesters are provided with human health and safety information regarding shellfish harvest when acquiring their license; however, there is currently no mechanism for reaching and educating recreational harvesters.

ORIGINATION

The North Carolina Division of Marine Fisheries (NCDMF) Oyster/Clam Plan Development Team (PDT).

BACKGROUND

Despite the importance of the commercial shellfish fisheries (molluscan and crustacean) to the state, limited data exist on recreational shellfish harvest. Currently, the NCDMF has limited data on recreational shellfish harvesting, including the number of participants and the extent of their economic activity. Collection of recreational shellfish harvest data, in addition to existing commercial landings data available through the North Carolina Trip Ticket Program (NCTTP) would provide a better estimate of total fishing mortality, relative abundance, and improve knowledge of variation in abundance caused by a combination of fishing effort and environmental changes. A more accurate account of landings allows managers to examine the proportional harvest of recreational and commercial fisheries to make better decisions on management strategies for both harvest sectors. It is imperative to collect high quality recreational harvest data to address potential management issues such as harvest limits, size limits, and gear restrictions. Collection of this data is crucial to completing a stock assessment and moving to stock level management of Oyster and Hard Clam.

Efforts to accurately quantify the impact of recreational fishing on shellfish have had limited success in North Carolina. The NCDMF collects data on recreational fishing in conjunction with the federal government's Marine Recreational Information Program (MRIP). However, MRIP collects information on finfish only.

Participation in recreational shellfishing in North Carolina has not been assessed for over 30 years. In 1991, a phone survey was conducted by the Marine Recreational Fisheries Statistics Survey (MRFSS), precursor to the MRIP, and it indicated that 3% of households in coastal North Carolina participated in recreational shellfishing, compared to an average of approximately 7% for finfish at that time (D. Mumford, NCDMF, personal communication). In 1991, MRFSS reported that in the state more than one million recreational fishing trips targeted shellfish. However, data on actual shellfish harvest estimates were not reported. The current extent of coastal households in North Carolina that recreationally harvest shellfish is unknown at this time.

The Marine Fisheries Commission in the original Bay Scallop, Hard Clam, and Oyster FMPs recommended developing a mechanism to obtain data on recreational harvest of shellfish (DMF 2007). The need for a mechanism to be able to accurately quantify recreational effort and harvest has been a consistent area of concern in all subsequent North Carolina shellfish and crustacean FMPs. The Hard Clam Fisheries Management Plan FMP (NCDMF 2001a) and Eastern Oyster FMP (NCDMF 2001b) supported adoption of a mechanism to provide data on recreational shellfish harvest. As a result, House Bill 1427 was introduced before the General Assembly in 2003 to establish a recreational shellfish license. This license would have been for shellfish only and would have been instituted on a trial basis for three years. However, the bill was never passed. In 2004, House Bill 831 did pass a saltwater fishing license mandating those individuals recreationally fishing for both finfish and shellfish to obtain a license. However, the state legislature revisited the issue in 2005 and replaced the saltwater fishing license with the Coastal Recreational Fishing License (CRFL). The CRFL, which was implemented January 1, 2007, is only required when targeting finfish. When the CRFL legislation was originally drafted in 2007, it also included shellfish. However, the inclusion of shellfish was removed from the draft bill was removed before it was finally legislated.

To fill this data gap, the NCDMF implemented a Saltwater Activity Mail Survey during November 2010 to collect monthly data on the harvest of crabs, oysters, clams, and scallops from the CRFL pool. The survey sample initially included approximately 650 randomly selected CRFL holders that held a valid license for at least one day during the survey period and answered “yes” to the harvest of at least one of the following species: crabs, oysters, clams, or scallops. In September 2014, the sample size doubled to approximately 1,300 CRFL holders. The Saltwater Activity Mail survey continued through July 2023 and is set to resume in 2025.

Each survey sent to selected CRFL holders included an explanation letter outlining methods to return the paper survey or to fill it out online. Those that did not respond by the end of the month were sent a second copy of the survey. The survey obtained information on the number of trips taken during the survey period, average length of the trip, average party size, number of species kept and discarded, gear used, location information (water access), waterbody, and county of harvest. Despite good response rates, few responses contained oyster and clam activity. One limitation to the survey, however, is that the survey did not have the means to include individuals who fish exclusively for shellfish as they would not need to purchase a CRFL. So, while the data are a useful representation of shellfish harvest by CRFL holders, they do not cover the entire population of potential recreational shellfish harvesters and probably represent a minimum estimate of effort and harvest.

The Fisheries Reform Act of 1997 (FRA) created a Recreational Commercial Gear License (RCGL) to allow recreational fisherman to use limited amounts of commercial gear to harvest recreational limits of seafood for personal consumption; however, shellfish gear (including hand, rakes, and tongs) was not authorized under this license. Since these gears are not covered by RCGL, recreational shellfishers can use these gears to harvest recreational bag limits of oysters and clams without a license. Therefore, recreational harvest data are not captured by past RCGL surveys.

Some recreational fishers may purchase a commercial shellfish license rather than a CRFL because the license is easy to obtain (available to any NC resident), is relatively inexpensive ($50.00), and allows fishers to harvest more shellfish than allowed under recreational limits. The NCTTP only captures landings from fishers who sell their catch to certified seafood dealers. Identifying and surveying individuals who purchase a commercial shellfish license but do not have any record of landings within the NCTTP could be used to determine if the license is indeed being used for recreational purposes. This is also true for fishers who buy a Standard Commercial Fishing License (SCFL) with a shellfish endorsement but do not have any reported landings of shellfish. Even though this approach limits the sampling universe to only recreational fishers who bought a commercial license, it would provide some information on recreational shellfish harvest occurring that is not constrained by recreational limits. The shellfish harvest survey provides the ability to characterize recreational shellfish harvest but still has limitations for estimating the total recreational harvest of shellfish.

With the limited data collected from the optional CRFL survey, some information about recreational effort has been collected. For instance, recreational oyster harvest was reported from 92 waterbodies throughout coastal North Carolina, with Topsail, Pamlico, Bogue, and Masonboro sounds all including more than 100 reported trips. The same survey revealed 70% of recreational oyster harvest effort originated from private residences, private boat ramps, or from shore. Given only 28% of reported effort originated at public access locations, intercept-oriented surveys are less than ideal. Recreational oyster harvest effort and catch were concentrated between October and March, accounting for over 84% of reported trips. Conversely, some individuals reported recreational harvest of oysters during summer months despite state-imposed restrictions on harvest during this time. This suggests unfamiliarity with state regulations such as season and area closures.

Another concern of not having a license requirement for recreational shellfish harvest is the inability to easily communicate health and safety concerns of this harvest to recreational participants. The Shellfish Sanitation and Recreational Water Quality Section (SSRWQ) within the NCDMF is responsible for ensuring all shellfish (oysters, clams, mussels) harvested or processed within North Carolina are safe for human consumption. To ensure shellfish are being harvested from areas free of contaminants, the SSRWQ conducts pollution source assessments around shellfish growing areas, direct water quality sampling, hydrographic studies at point source discharges of pollution, and studies of the impacts of stormwater runoff on water quality. The SSRWQ also conducts inspections and certifications of shellfish dealer facilities, as well as providing training for commercial harvesters and dealers, to ensure that shellfish are handled, stored, processed, and transported in a manner that keeps them safe for consumption.

To help keep the public informed of safe harvest areas and safe harvesting and handling practices, the SSRWQ produces several publicly available informational resources, including the following:

- Prohibited Shellfish Harvest Boundaries – SSRWQ establishes permanent closure boundaries that prohibit the harvest of shellfish in areas where there may be consistent contamination exceeding the standards for safe human consumption. These permanently closed areas are described and established via proclamation.
- Polluted Area Proclamations and Temporary Closure Maps – In addition to the permanently closed areas described above, studies have found that water quality in certain areas can be negatively impacted by stormwater runoff, and shellfish can become temporarily unsafe for harvest under certain conditions. SSRWQ has developed management plans describing rainfall thresholds that can generate negative impacts and require temporary closures of these impacted areas. Temporary closures are put in place via proclamation and shown visually on the NCDMF website through a web map updated as closed areas change.
- Articles and Fact Sheets on Safe Handling Practices – Temperature abuse or improper handling practices can render shellfish unsafe to eat. To provide the public with information on how to safely store and handle shellfish, SSRWQ has prepared articles, fact sheets, and pamphlets available through the NCDMF website.
- Information on *Vibrio* Bacteria – *Vibrio* bacteria are naturally occurring bacteria that can be found in North Carolina waters and can cause severe illness in certain susceptible populations if consumed or through exposure to open wounds. Notably, these bacteria can proliferate within harvested shellfish even after they've been removed from the water, if the shellfish are held in warm/hot temperatures for extended periods of time. Proper handling/cooling of harvested shellfish is a critical step towards avoiding illness. SSRWQ has made available pamphlets and articles describing risks associated with these types of bacteria, and best practices for shellfish handling.

Although commercial harvesters, dealers, and shellfish lease/franchise holders are provided with all this information when acquiring their license, getting their dealer certification, or acquiring/renewing their lease, there is no mechanism for reaching and educating recreational harvesters unless they actively seek out information.

AUTHORITY

N.C. General Statute

113-134	Rules.
113-169.2	Shellfish license for NC residents without a SCFL.,
113-174.2	Coastal Recreational Fishing License.
113-182	Regulation of fishing and fisheries.
113-182.1	Fishery Management Plans.

113-201	Legislative findings and declaration of policy; authority of Marine Fisheries Commission.
113-221.1	Proclamation; emergency review.
143B-289.52	Marine Fisheries Commission – powers and duties.

Session Law 2023-137

<u>N.C. Marine Fisheries Commission Rule (15A NCAC)</u>

03O.0101	PROCEDURES AND REQUIREMENTS TO OBTAIN LICENSES, ENDORSEMENTS AND COMMERCIAL FISHING VESSEL REGISTRATION
03O.0107	LISENCE REPLACEMENT AND FEES
03O.0501	PROCEDURES AND REQUIREMENTS TO OBTAIN PERMITS
03O.0502	PERMIT CONDITIONS; GENERAL
03O.0506	SPECIAL PERMIT REQUIRED FOR SPECIFIC MANAGEMENT PURPOSES

DISCUSSION

Given North Carolina's shellfish fisheries are exclusively under state jurisdiction, lack of recreational shellfish harvest data makes addressing potential management issues such as harvest limits, size limits, and gear restrictions difficult. There are no data on demographics, perceptions, or expenditures of recreational shellfish harvesters in the state. Consequently, there is no data available to conduct an economic impact assessment of recreational oyster harvesting. Due to widespread accessibility of intertidal oysters and clams along North Carolina's coast, the potential impact of recreational harvest could be significant.

License requirements for recreational shellfish harvesting varies by state along the United States east coast (Table 1.1). Most states require some type of license while in Maine, Massachusetts, New York, and Connecticut individual towns and cities require a license to recreationally harvest shellfish. North Carolina and Virginia are the only states without some form of license, local permitting, or residency requirements.

There are multiple avenues the NCDMF and NCMFC could pursue to better assess the population of recreational shellfish harvesters. One solution is to include shellfish as part of the CRFL. This can be accomplished by three different methods. The first is to require the existing CRFL to recreationally harvest both finfish and shellfish. The second would be to create a separate shellfish only CRFL. This license would only give a recreational angler access to the allowed shellfish species and would exclude finfish harvest. This would allow fishery access to recreational anglers who are only interested in harvesting shellfish, and the cost could be set at a lower price than a standard CRFL. The third option would be to require the existing CRFL and create an additional recreational shellfish endorsement. The endorsement would be applied to the CRFL and would indicate the angler is licensed to recreationally harvest both finfish and shellfish. One drawback to these three options is it would require legislation to change the CRFL.

Table 1. 1. Recreational shellfish harvest license requirements for east coast states.

State	License Requirements
Maine	No state license, towns have local restrictions and permits
New Hampshire	State license
Massachusetts	No state license, towns have local restrictions and permits
Rhode Island	Required for non-residents
Connecticut	No state license, towns have local restrictions and permits
New York	No state license, towns have local restrictions and permits, also has residency requirements
New Jersey	State license
Delaware	State license
Maryland	None, must be state resident
Virginia	None
North Carolina	None
South Carolina	State license
Georgia	State license and free permit
Florida	State license

Another solution is to develop a recreational shellfish permit. The NCMFC has the authority to implement a permit to help manage estuarine and coastal resources and can set a maximum fee of up to $100 (although most permits are free of charge). A permit could function similar to a license. Recreational anglers would be required to have the permit to participate in the recreational shellfish fishery. A nominal fee for the permit would discourage participants from only obtaining the permit because it was free, helping to constrain the sampling universe.

The options above would provide NCDMF with a complete pool of recreational shellfish harvesters. That list could then be used as a survey frame to help estimate effort and harvest in the fishery. Having a list of the population of recreational shellfish harvesters is useful for distributing shellfish area closure proclamations and maps. If shellfish species are added to the existing CRFL, the activity survey conducted during CRFL sale would still be needed to identify fishers who are involved in recreational shellfishing. These fishers would then receive additional surveys to estimate effort and harvest in the recreational shellfish fishery.

Another way to obtain data on recreational shellfish activity would be through the MRIP. The MRIP does capture some non-finfish activity, but those data are broad and not available to shellfish at the species level and MRIP agents rarely encounter those types of recreational fishing trips. Most recreational shellfishing effort is by coastal residents using private docks and access points as opposed to public access points. Because MRIP is a nationwide program, any changes to methodology designed to intercept more recreational shellfishing activity would need to undergo extensive review process and if implemented could take away from intercepts in other target fisheries.

Personal consumption by participants holding commercial fishing licenses (either a SCFL with a shellfish endorsement or a Shellfish license without a SCFL) would not be covered under any type of recreational shellfish license or permit. In the fall of 2023, the North Carolina General Assembly passed Session Law 2023-137. Section 6 of this legislation requires anyone holding a commercial fishing license who is engaged in a commercial fishing operation to report all fish (including shellfish) harvested to NCDMF, regardless of if the fish are sold or kept for personal consumption. Currently, this legislation is effective December 1, 2025. The NCDMF is working on draft rules to implement this law and to develop the reporting mechanism for these participants. Implementation of this law should fill this data gap.

Implementing a licensing or permitting requirement for recreational shellfish harvesters would give the NCDMF the opportunity to inform participants of where to find information on harvest closure boundaries, where to sign up to receive polluted area proclamations or to access temporary closure maps, and where to find information on safe handling practices, particularly as it relates to *Vibrio* bacteria.

To pursue any of these solutions, significant time and effort will be needed to assess internal program and resource capabilities and limitations. Any legislative changes require a specific process and are ultimately out of NCDMF or NCMFC control. Given these constraints, the NCDMF recommends exploring potential options and solutions outside of the FMP process.

Option 1: Recreational Harvest

a. Status Quo
   - Does not provide reliable estimates of recreational shellfish harvest or effort.
   - Does not provide a mechanism to ensure recreational shellfish harvesters are provided with SSRWQ health and safety information and links to harvest area closures.

b. Support the NCDMF to further explore potential options and develop a solution to estimate recreational shellfish participation and landings, with the intent to move towards a stock assessment and stock level management for both hard clams and oysters; and to establish a mechanism to provide all recreational shellfish harvesters with SSRWQ health and safety information outside of the FMP process.

RECOMMENDATIONS

The DMF recommends that the NCMFC support the NCDMF to further explore potential options and develop a solution to quantify recreational shellfish participation and landings, with the intent to move towards a stock assessment and stock level management for both hard clams and oysters; and to establish a mechanism to provide all recreational shellfish harvesters with SSRWQ health and safety information outside of the FMP process.

Advisory Committee Recommendations and Public Comment: see *Appendix 7*

NCMFC Selected Management Options

Option 1: Recreational Harvest

b. Support the DMF to further explore potential options and develop a solution to estimate recreational shellfish participation and landings, and to establish a mechanism to provide all recreational shellfish harvesters with Shellfish Sanitation and Recreational Water Quality health and safety information outside of the FMP process.

Appendix 2: Mechanical Oyster Harvest Management Issue Paper

ISSUE

Addressing management for the mechanical fishery for subtidal oysters in Pamlico Sound, North Carolina.

ORIGINATION

The Coastal Habitat Protection Plan as adopted by the North Carolina Marine Fisheries Commission, and the Division of Marine Fisheries.

BACKGROUND

The North Carolina Eastern Oyster Fishery Management Plan (FMP) Amendment 5 focuses on management of wild oysters, and this issue paper does not include farm raised or private cultured oysters.

North Carolina's wild oysters are composed of both intertidal (exposed to air during portions of the tidal cycle) and subtidal (continuously submerged) populations. In North Carolina, commercial oyster harvest through mechanical means is primarily achieved using oyster dredges and is limited to subtidal oyster reefs in specific areas of Pamlico Sound and adjacent bays and tributaries. Although some hand harvest of subtidal oysters does occur, the primary harvest method for oysters in these areas has been mechanical gear (Figure 2.1). While mechanical harvest gear like oyster dredges may offer an efficient means of harvesting oysters, their use requires careful management and consideration of their potential negative impacts on both oysters and habitat. The North Carolina Marine Fisheries Commission's (NCMFC) Coastal Habitat Protection Plan (CHPP) identifies bottom disturbing fishing gear, including oyster dredges, as having the potential to be highly destructive towards oyster reefs. The NCMFC has set a goal to “Enhance and protect habitats from adverse physical impacts” and recommended the following actions: protect habitat from adverse fishing gear effects and protect and restore important fish habitat functions from damage associated with activities such as dredging (NCDEQ 2016).

Currently, large scale abundance estimates or a traditional stock assessment for the Eastern Oyster in North Carolina is not possible. Without a stock assessment the Division of Marine Fisheries (hereafter, DMF) is unable to assign a stock status or determine sustainable harvest limits. Oysters pose a unique management problem as they are simultaneously a stock that is harvested as a fishery resource, and the essential habitat for that same fishery resource. Oysters need suitable hard substrate (cultch) for juvenile oyster (spat) to settle on and grow. Shells of living or dead oysters provide the appropriate hard substrate for juvenile oysters to settle on, creating self-sustaining oyster reefs. If living oysters or dead shell material is removed from a reef through fishery effort at a rate faster than it can naturally replenish, both the oyster resource and habitat required for oysters to successfully reproduce will eventually disappear. An approach to manage oyster fisheries that considers this balance of shell gain and loss (Shell Budget Model) has been developed and employed in the Gulf of Mexico (Soniat et al. 2022; Soniat 2016).

The current mechanical oyster fishery is limited to only the subtidal open water regions of the greater Pamlico Sound as well as specified subtidal regions of its surrounding bays. A key component for mechanical oyster harvest management is to balance the value of utilizing oysters as a fishery resource while maintaining their role as an essential habitat for themselves and a wide range of estuarine species. To minimize damage to oyster habitat from mechanical harvest, decreases in bushel limits and larger area or seasonal closures implemented via fishery monitoring have been established through time. Dredges are subject to weight and size restrictions and are required to be towed from the side of the vessel to mitigate habitat impacts by not removing excess cultch material and sub-legal oysters from their areas of origin. To limit excessive effort impacts, mechanical harvest is only allowed from sunrise to 2:00 PM Monday through Friday. To ensure excess reef material and undersized oysters are not removed from their respective reefs, culling of cultch material and undersized oysters must occur at the harvest location with a 5% culling tolerance. Additionally, extensive cultch planting efforts have occurred in mechanical harvest areas to mitigate harvest impacts to oyster reefs by adding cultch material.

The first oyster harvest limits for the mechanical fishery were introduced in 1947 at 75 bushels per vessel per day, remaining in effect until 1984. From then until 1989, the daily limit was lowered to 50 bushels per vessel. In 1989, the daily limit for commercial operations was capped at 50 bushels per vessel, but with added flexibility for the director to set lower limits as needed. In 1990, the bushel limit was dropped to 20 then further reduced to 15 bushels due to declining populations attributed to Dermo disease. The 2001 Oyster FMP changed the criteria for where mechanical harvest would be allowed in the bays of Pamlico Sound (NCDMF 2001b). The 2008 Amendment 2 to the Oyster FMP outlined a strategy for Pamlico Sound and its tributaries, setting a 15-bushel limit per commercial fishing operation in open waters of the sound, and limiting harvest in the bays to a six total possible week season with a daily limit of 10 bushels per vessel (NCDMF 2008). In 2010, Supplement A to Amendment 2 of the Oyster FMP established the trigger for closing areas to mechanical harvest when sampling indicates the number of legal-sized oysters in the area has declined below the threshold (NCDMF 2010). Additionally, this management strategy was re-adopted in Amendment 4 in 2016 (NCDMF 2016). Beginning in 2017, the six-week open period for bays was split into two potential open periods. The first begins on the Monday of the week prior to Thanksgiving and runs through the Friday after Thanksgiving. The second opening of the bays could begin two weeks before Christmas and remain open for the remaining four weeks. For more detailed information on the management history of the Pamlico Sound mechanical oyster fishery see the previous Eastern Oyster Fishery Management Plan, Amendments, and Supplement.

The mechanical harvest season has the potential to occur between the Monday of the week prior to Thanksgiving week, which is typically the third Monday in November, to 31 March in areas designated open to mechanical harvest; however, the actual season length is ultimately determined by a harvest monitoring program. In bays where harvest is allowed, the season is capped to a total of six possible weeks. If the area in which the bay is located is closed due to harvest monitoring the season may be shorter than six weeks.

Annual landings from mechanical harvest in North Carolina have declined significantly since a peak in 2010. The 2010–2011 landings peak reflects the highest participation and landings in the mechanical oyster fishery between 1994 and 2021. During the 2010–2011 oyster season, high market demand caused by the closure of harvest areas in the Gulf of Mexico from the Deepwater Horizon oil spill drew a large amount of effort and participation into the North Carolina mechanical harvest oyster fishery. Landings in this fishery are strongly tied to participation and effort, and declining trends in participation mirror landings trends (Figures 2.1 & 2.2). Prior to 2012, mechanical harvest of oysters only required a Shellfish Commercial License. This license is not capped to a total number of participants, unlike the Standard/Retired Commercial Fishing License (SCFL/RSCFL) and is potentially available at a relatively low cost to all residents of the state. The large and rapid increase in effort in the mechanical fishery observed leading up to the 2010–2011 harvest season was primarily driven by new entrants into the fishery obtaining a Shellfish Commercial License. In response to this, a SCFL/RSCLF has been required to participate in this fishery since the 2011–2012 season.

Weather and water quality events have also directly influenced effort and landings in the mechanical oyster fishery. After major hurricanes, low dissolved oxygen events, or extreme temperature events, the oyster resource in the mechanical harvest areas may only sustain harvest for a few weeks before NCDMF closes areas to mechanical harvest. The actual length of time mechanical harvest for oysters can occur each year in North Carolina is determined by the monitoring program and is variable depending on the status of the oyster resource and fishery effort.

The current harvest monitoring program which serves as a habitat protection framework to manage fishery effort in the Pamlico Sound mechanical oyster fishery was developed as Supplement A to Amendment 2 of the Oyster FMP and has been in place since 2010. In this framework, the sound is divided into four Management Areas based on geographic region: the Neuse River Area, Pamlico River Area, Northern Hyde Area, and Northern Dare Area (Figure 2.3). The NCDMF samples oyster reefs in each management area once before the opening of the mechanical harvest season, and then biweekly once mechanical harvest is open. Sampling sites are chosen based on the current (or previously known) presence of commercial harvesting in the area. Areas are selected where commercial harvest occurs with the goal of assessing localized depletion and addressing habitat protection concerns. A threshold of 26% legal-size live oysters (3 inches shell length or greater) in pooled samples for each sampling event and Management Area was established as the management trigger. In developing this management framework, the effect of the effort required to harvest a limit of legal oysters on reef habitat was considered. When an area oyster population reaches 26% or lower legal oysters, it was determined that impacts to reef habitat through the removal of shell material outweighed the fishery benefit from harvest. If the pooled samples collected across a management area for a sampling event show 26% or less legal oysters, the management trigger is tripped for that area. If two consecutive sampling events result in the management trigger being tripped, the entire management area is closed to mechanical harvest. An area may re-open if two additional consecutive sampling events show above 26% legal oysters.

There is no minimum threshold for percent legal in the initial opening of an area to mechanical harvest. A management area will open even if pre-season sampling shows the area is below the 26% legal threshold. Biweekly sampling begins the first week of the mechanical harvest season, meaning areas that start below the 26% legal threshold can take three weeks to trip the management trigger twice before closing.

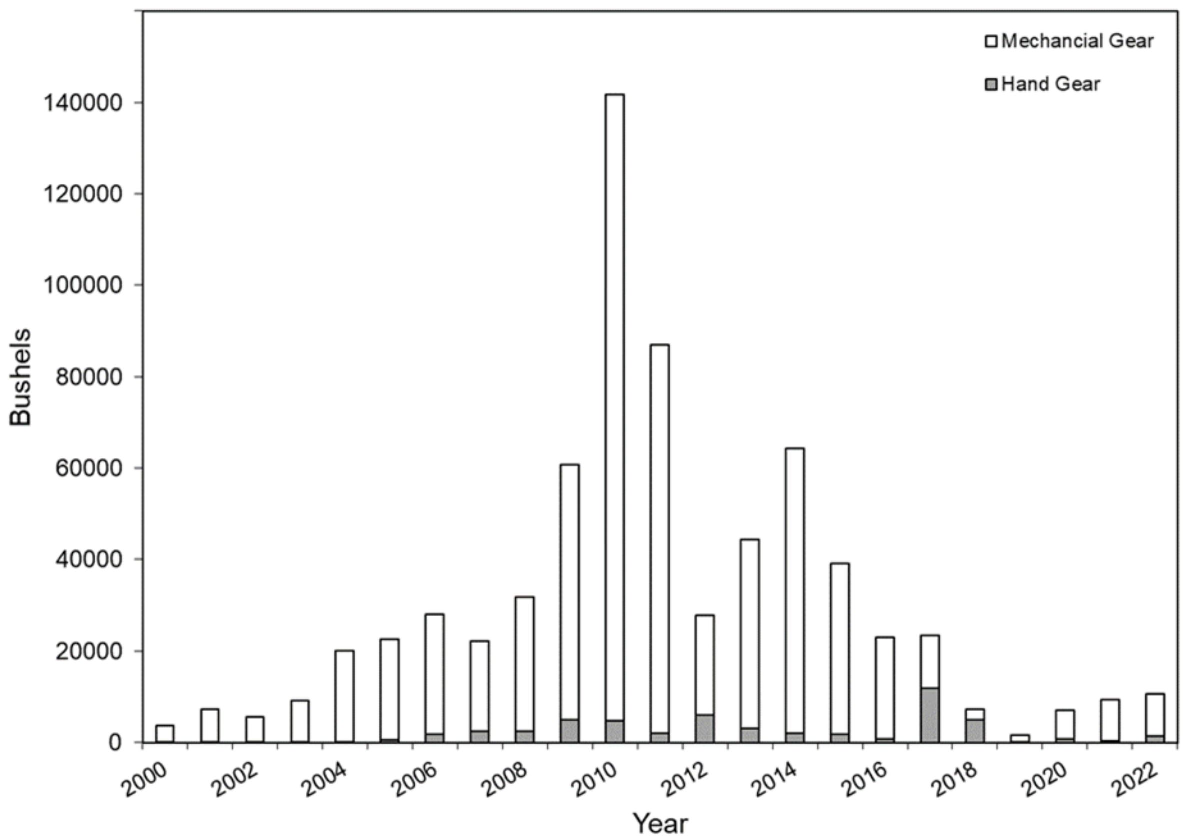

Figure 2.1. Commercial landings of wild oysters from greater Pamlico Sound, adjacent bays and tributaries in North Carolina from 2000 to 2022, showing annual landings in bushels harvested by hand gear (rakes, tongs, hand) as dark gray bars and mechanical gear (dredges) as white bars.

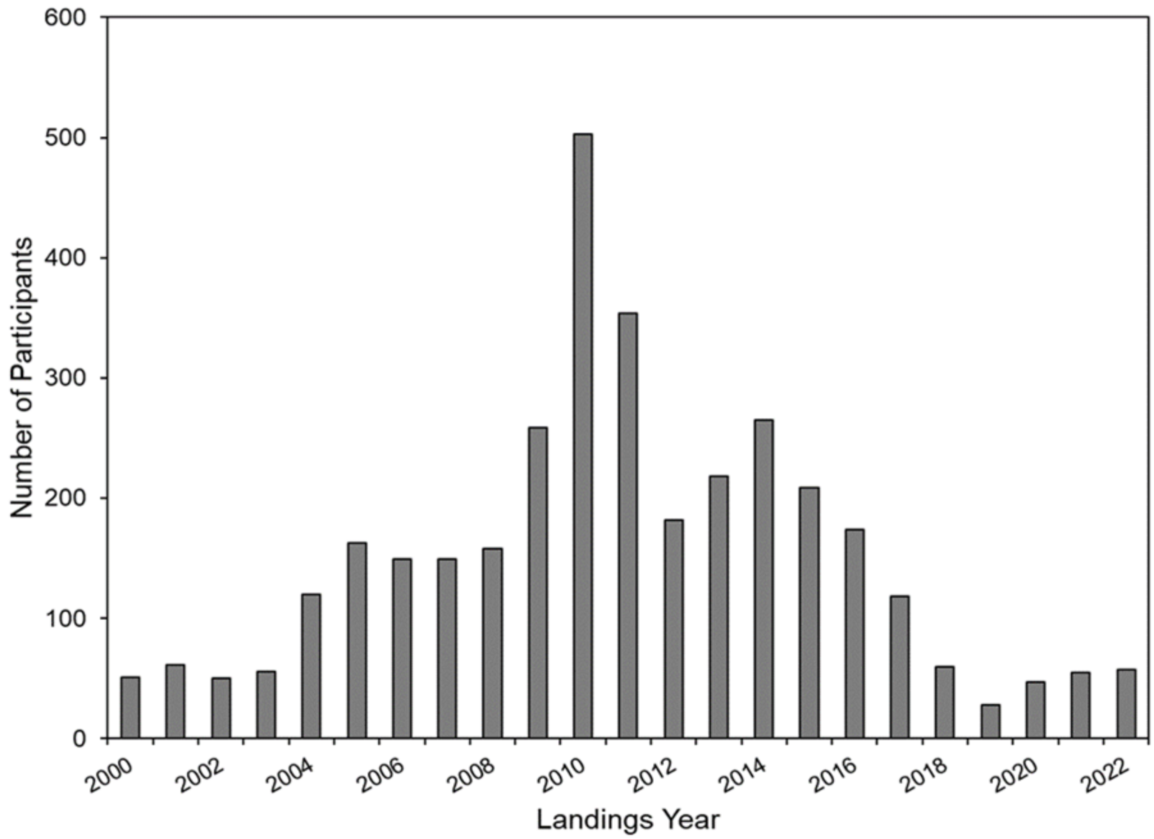

Figure 2.2. Annual number of participants with landings of wild oyster using mechanical gear, 2000–2022.

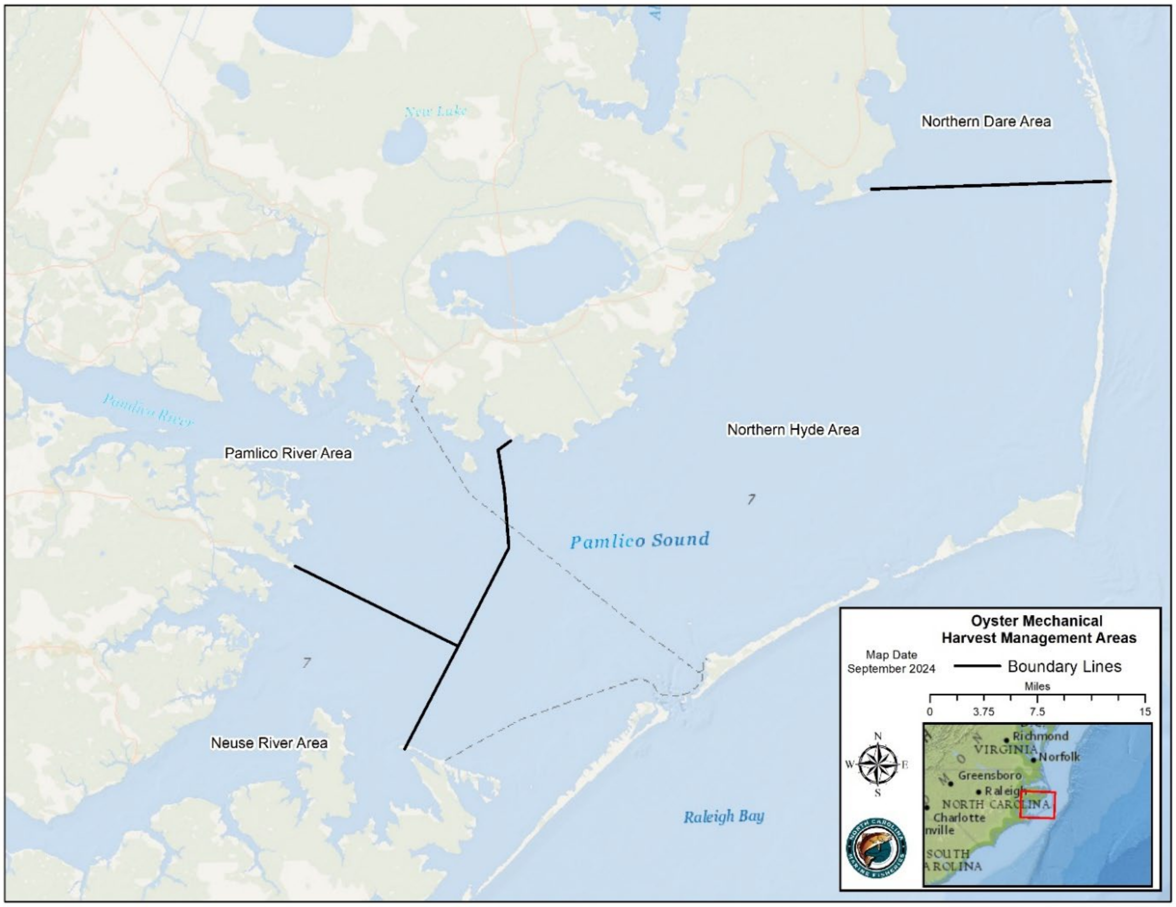

Figure 2.3. Pamlico Sound Oyster Mechanical Harvest Management Areas from south to north: the Neuse River Area, Pamlico River Area, Northern Hyde Area, and Northern Dare Area.

Oyster mortality from Hurricane Irene in 2011 and a low dissolved oxygen event in 2012 resulted in the 2012–2013 mechanical harvest season being closed by the management trigger months shorter than in previous seasons. In 2018, Hurricane Florence caused significant damage to the Pamlico Sound oyster resource, and Hurricane Dorian in 2019 further impacted oysters in Western Pamlico Sound. Over the last five years since these storm events, the mechanical harvest trigger has taken on average three weeks into the mechanical harvest season to be tripped across all management areas (Table 2.1). As the oyster resource recovered, mechanical harvest closures have occurred later in the potential season for the Neuse and Pamlico River Management Areas in recent years. The longer time taken to trip the management trigger in the Neuse and Pamlico River Areas is driven by higher populations of oysters in the 10 bushel-per-day bays, which are capped at a six-week total possible season. While the deep-water regions and bays of a Management Area are not treated separately for the calculation of the management trigger, the deep-water reefs (>5 m) sampled in the Pamlico and Neuse River Areas were found to have very few legal sized oysters during harvest monitoring in recent years.

When the bays are examined separately from the deep waters, they have averaged above the management trigger (Table 2.2).

Table 2.1. The number of open weeks into the mechanical harvest season before the 26% legal management trigger tripped for each Mechanical Harvest Management Area by oyster season years.

Mechanical Harvest Management Area	2019–20	2020–21	2021–22	2022–23	2023–24
Dare Management Area	1	10	3	3	2
Hyde Management Area	4	1	3	3	3
Pamlico Management Area	1	2	6	6	6
Neuse Management Area	1	1	6	6	6

Table 2.2. Percentage of legal sized (3-inch shell length or greater) live oysters sampled during the first harvest monitoring program sampling event each year for the Pamlico and Neuse Management Areas by deep-water areas (>5 m) and bays.

Management Areas	2019–20	2020–21	2021–22	2022–23	2023–24
Pamlico Management Area Deep	13%	0%	0%	0%	0%
Pamlico Management Area Bays	44%	45%	49%	18%	41%
Neuse Management Area Deep	0%	0%	0%	0%	0%
Neuse Management Area Bays	8%	26%	33%	28%	39%

The NCDMF has one of the longest running and expansive oyster restoration and enhancement programs in the United States. North Carolina's Cultch Planting Program began in 1915 to replace shell material removed by harvest. Since its inception, over 21 million bushels of cultch material have been planted in the form of small-scale, low-relief, harvestable oyster reefs. Today, the NCDMF Cultch Planting Program creates oyster reefs that provide both habitat restoration and alleviation of public harvest pressure from natural reefs. Over the last ten years, 624 acres of harvestable oyster reefs have been created on public bottom through this program, with the ongoing goal of creating an additional 50 acres per year into the future. In addition, 789 acres of protected oyster reef have been permitted and constructed across 17 separate no-take Oyster Sanctuaries in Pamlico Sound. For more detailed information about these two programs see Appendix 4: Habitat Enhancement Programs. In areas open to mechanical harvest, cultch planting efforts have been focused primarily in the bays of the Neuse and Pamlico River Areas as well as in the eastern portion of the sound in the Dare and Hyde areas (Figure 2.4).

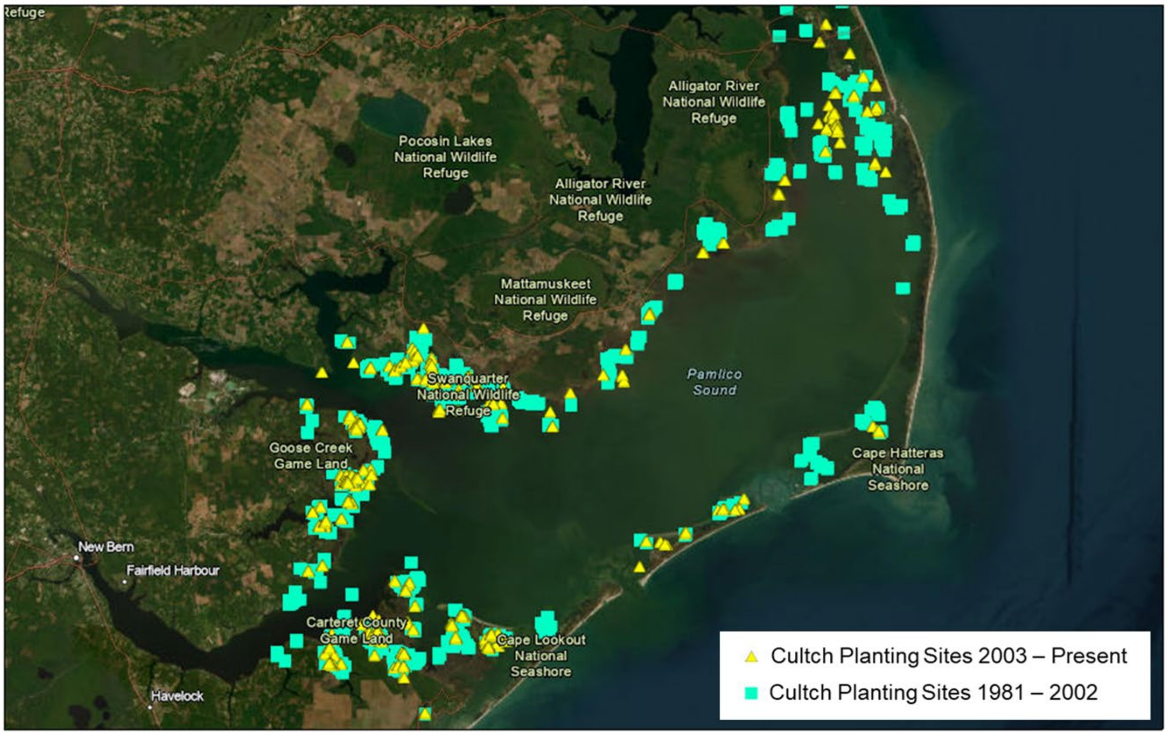

Figure 2.4. Map of cultch planting sites in the greater Pamlico Sound, 1981 to present.

Between 2000 and 2022, a total of 2,167,638 bushels of cultch material were planted in the mechanical harvest areas of Pamlico Sound, and 452,112 bushels of oyster were mechanically harvested. This resulted in 4.8 times more bushels of cultch being planted than oysters mechanically harvested over this time. Since 2018, 36 times more bushels of cultch have been planted compared to bushels of oysters commercially harvested and removed (Figure 2.5). The return in commercial harvest per unit of cultch planted in North Carolina remains unknown and likely varies across different planting sites. The impact of cultch plantings on oyster landings is not immediate, as it typically takes between one and three years after planting for new cultch material to yield legal-sized oysters. While some cultch planting sites have relatively short lifespans, others have been observed to continue yielding harvests for decades. Current management of oyster harvest in North Carolina does not distinguish between harvest from constructed cultch planted reefs and wild naturally occurring reefs.

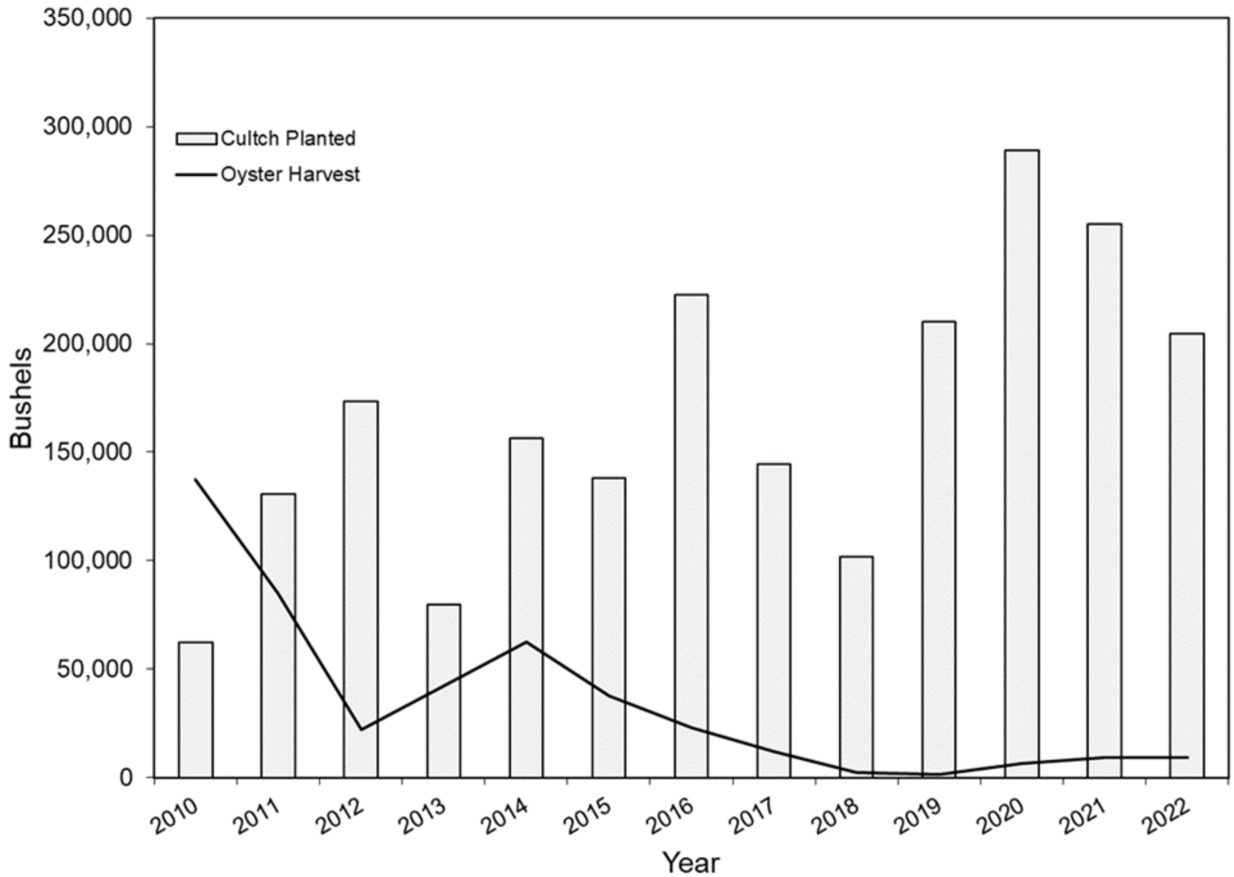

Figure 2.5. Annual bushels of cultch planted (shown as light gray bars) and bushels of oysters mechanically harvested (shown as black line) from the mechanical harvest areas of Pamlico Sound.

AUTHORITY

N.C. General Statute

113-134 Rules.
113-182 Regulation of fishing and fisheries.
113-182.1 Fishery Management Plans.
113-201 Legislative findings and declaration of policy; authority of Marine Fisheries Commission.
113-221.1 Proclamation; emergency review.
143B-289.52 Marine Fisheries Commission – powers and duties.

N.C. Marine Fisheries Commission Rules (15A NCAC)

03K .0201 Oyster Harvest Management

DISCUSSION

The existing mechanical harvest management strategy for oysters in Pamlico Sound aims to monitor in real time the habitat conditions of oyster reefs where mechanical harvest is actively occurring, and then close broad management areas once the condition of the oyster resource reaches a point where the effort required to harvest legal oysters causes excessive damage to the reef habitat. When this reactive management strategy was developed and adopted in 2010, participation in this fishery was approximately five times greater than participation has been in recent years. This drop in participation has often made it problematic for NCDMF staff to find areas where there is active fishing activity to sample, particularly in the bays of the Neuse and Pamlico River Areas. When active mechanical harvest areas are not encountered by staff, knowledge of past harvesting areas or localized areas of current oyster abundance are chosen for trigger sampling locations using their best judgment. Additionally, during pre-season sampling events, or when areas are either closed due to the management trigger being tripped or the break in the 6-week season for the bays and there is no mechanical harvest occurring, staff are again required to make judgment call decisions on where to sample. Given the sometimes-varying conditions between oyster reefs in the region, mechanical harvesters may view sampling locations selected by the NCDMF as not representative of areas they fish.

While the potential mechanical harvest season for oysters could run from November through March, the actual season length allowed in each Management Area is ultimately dictated by results of the trigger sampling and opened or closed via proclamation. With fluctuations in the oyster resource due to storm events, the season length for a given area may vary widely between years. If sampling indicates the management trigger has tripped, a proclamation is issued closing that area effective no sooner than 72 hours from issuance. After impacts from multiple hurricanes, the mechanical harvest season in the Pamlico and Neuse River Management Areas was only open to mechanical harvest for 10 days in the 2019–2020 season, yet in the 2021–2022 season it was open eight weeks. At the opening of each mechanical harvest season, harvesters are unaware of how long each area will be open and rely on monitoring proclamations for closures. This uncertainty and variability in season length is often viewed unfavorably by harvesters.

The current management trigger uses the percentage of live legal sized oysters as a metric to determine fishery effort impact on oyster reef habitat. While this has been a proactive approach to close mechanical harvest at a point that ensures cultch material and live oysters remain on reefs, it does not consider oyster abundance when triggering area openings or closures. If an area that was being sampled had very few (low oyster abundance) but very large (high percent legal) oysters, the management trigger would not be tripped and remain open to harvest. However, with such a low abundance of oysters, this area may be vulnerable to overharvesting, and damage to the habitat from the effort required to harvest would be high. Conversely, if an area has a healthy and abundant mature oyster population that is experiencing a period of high recruitment (heavy spat set), the relatively high number of spat counted in the live oyster sample would drive down the percentage of legal live oysters and trip the management trigger. The trigger sampling program is designed to monitor impacts from the mechanical fishery as a habitat protection measure and does not currently allow for the estimation of oyster population or abundance.

The Neuse River, Pamlico River, and Northern Hyde Management Areas all contain bays that are capped at a total possible six-week season and are limited to 10 bushels per vessel a day. The condition of the oyster resource in the bays is often significantly different than what is found in the deep open water areas of the management area. The bays and deep portions of the management areas are not considered separately during calculation of the management trigger, or during management area closures from the results of trigger sampling. In recent years, bays in the Pamlico and Neuse River Management Areas have had oyster resources to sustain the full six-week possible season, while there have been few legal oysters found in the deeper areas. The entire management area remained open due to the greater abundance of legal oysters in the bays, leaving the deeper portions of the management area vulnerable to damage from potential dredge effort. The deep-water reefs and shallow reefs in the bays were likely impacted differently from storm events, with oysters in the bays not suffering the mass mortality observed in those found in deeper portions of western Pamlico Sound (Table 2.2).

Historically deep-water reefs of western Pamlico Sound were reported to reach up to 13 feet (4 m) in height. In the Neuse River, high relief deep-water oyster reefs were shown to suffer mass mortality at water depths greater than 16.4 ft (below 5 meters) due to low oxygen, while low relief reefs in shallow waters (between 9.8 to 13 ft in depth) did not experience such die offs (Lenihan and Peterson 1998). The historical mounded structure of reefs in Pamlico Sound provided increased habitat complexity for a wide variety of invertebrates and fish and the upper portion of the mounds provided refuge for benthic organisms when lower portions of the reef were hypoxic. Research has shown that oysters at the base of subtidal reefs have a greater proportion of oyster mortality, significantly lower abundance of associated organisms, and higher incidence of disease occurrence, compared to the crest of reefs (Lenihan and Peterson 1998; Lenihan et al 1999). The survival and recovery of deep-water oyster reefs is contingent on their ability to gain vertical height.

Mechanical oyster harvest using dredges significantly impacts subtidal oyster reefs by reducing their vertical relief, which leads to several negative habitat effects (Lenihan and

Peterson 1998; Lenihan et al. 1999). This harvest method causes the scattering of shells and oysters into less suitable substrates, destabilizing the reef structure and increasing its vulnerability to storm damage. The process also decreases the reef's resistance to disease. The removal of live and dead oysters, along with portions of the upper shell layers, leads to a reduction in the potential number of spawning adults (spawning stock biomass) and diminishes the area available for oyster larvae settlement. Furthermore, newly settled oysters are subjected to lower oxygen levels and increased sedimentation due to the reduced depth in the water column. Additionally, it reduces the availability of small spaces within the reef that serve as crucial refuge and foraging areas for juvenile fish. For more information on the ecosystem importance of oyster reefs see the Ecosystem Protection and Impact section of this current FMP, Amendment 4 to the Eastern Oyster FMP (NCDMF 2017) and Chapter 3 of the 2016 CHPP (NCDEQ 2016).

To investigate the impacts of mechanical harvest methods on oyster reef heights, NCDMF and the University of North Carolina Institute of Marine Science researchers created restored reefs in the Neuse River in 1993, which were experimentally harvested in 1995 and 1996 (Lenihan and Peterson 1998, 2004). The 1995 experimental dredge harvest (designed to approximate the minimum seasonal dredge effort a reef would experience) removed an average of 11.4 in of height from the reefs that were 3.28-ft tall (Lenihan and Peterson 1998). The 1996 experimental harvest included dredge, tong, and diver hand harvest methods, which reduced the heights of the 3.3-ft reefs by averages of 13.2 in., 9 in., and 2.4 in., respectively, illustrating that dredge harvest has the greatest impact to reef height out of the harvest methods examined (Lenihan and Peterson 2004). While oyster growth rates can vary based on site conditions, Oysters monitored by NCDMF cultch planted reefs in the Greater Pamlico Sound take approximately three years to reach 3 in in shell length. Considering this observed oyster growth rate, it could take approximately 12 years for an oyster reef in this area to re-grow 1 ft of height.

In Pamlico Sound, changes in abundance of historic oyster reefs since the 1880s were documented by Ballance (2004). Using new technologies to locate subtidal reefs reported by Winslow (1889), Ballance (2004) found many formerly productive high-profile reefs now consisting of low-profile shell rubble, low density reefs, or buried reefs. Ballance (2004) also found the larger shallow reefs had less live oysters, which he attributed to the ease of locating those reefs by fishers. Similarly, Lenihan and Peterson (1998) re-surveyed natural oyster reefs in the deeper (>16.4 ft depth) portions of the Neuse River Estuary that had been marked in an 1868 US Coast and Geodetic Survey, finding that reefs that were 5.9 to 7.9 ft tall in 1868 were only 1 to 3 feet tall in 1993, and that no reefs in the 1993 survey were taller than 4 feet. Lenihan and Peterson (1998) reported that it was "probable that reduction in reef heights in the Neuse River estuary is due to decades of fishery-related disturbances caused by oyster dredging" and suggested reefs in heavily fished North Carolina waters would need to be restored every 3–4 years.

The NCDMF oyster restoration and enhancement program has focused significant effort into creating cultch reefs in areas open to mechanical oyster harvest in Pamlico Sound, with the volume of cultch material planted into the sound greatly exceeding the volume of oysters commercially harvested. Cultch plantings form low relief harvestable reefs and are not planted over areas of existing oyster to prevent the destruction of present natural populations of shellfish. No cultch planting or oyster restoration has been documented in the deeper portions of the sound to restore the historic high-relief reefs found at the mouth of the Pamlico and Neuse rivers. The NCDMF cultch planting efforts have been focused in the bays surrounding the western Pamlico Sound and the area between Stumpy Point and Oregon Inlet and have likely supported a significant portion of the fishery effort. While landings from cultch planted reefs are not currently separated from wild reefs in Trip Ticket landings, NCDMF sampling and harvester feedback indicates cultch reefs are used for harvest areas. Since 2018, 36 times more bushels of cultch have been planted compared to bushels of oysters commercially harvested and removed. Given this large disparity and the distribution of cultch planting sites in Pamlico Sound, the current harvest management approach, which does not differentiate between cultch and wild reefs, is not best using the cultch planting program.

To maintain long-term harvestable oyster populations in Pamlico Sound, a three-tiered approach is proposed for Pamlico Sound oyster mechanical harvest management to balance the value of oysters as both a fishery resource and essential habitat. Tier 1 of this approach is to protect highly degraded and threatened oyster habitats by establishing Deep-water Oyster Recovery Areas (DORAs). Meanwhile, Tiers 2 and 3 modify current management strategies that place equal or greater value on the oyster resource with continued Cultch Supported Harvest and the creation of a series of Rotational Cultch Sites, respectively.

Deep-water Oyster Recovery Areas (Tier 1)

The remnant deep-water natural oyster reefs in the Pamlico and Neuse rivers have been recognized by the NCMFC as a habitat requiring protection due to their ecological importance and vulnerability. These reefs have suffered from excessive historical harvest, disease outbreak, and mass mortality from water quality impacts. Sites which contain these deep-water natural oyster reefs have been nominated by the NCMFC as Strategic Habitat Areas for the Pamlico Sound System (Figure 2.6) (NCDMF 2011). Strategic Habitat Areas (SHAs) are priority habitats identified for protection because of their exceptional condition or the imminent threats to their ecological functions, which support estuarine and coastal fish and shellfish species. Additionally, the NCMFC has directed the NCDMF to develop habitat protection measures through the adoption of the CHPP. Goal 3 of the 2016 CHPP is to “enhance and protect habitats from adverse physical impacts”, which includes reducing the impacts of mobile bottom disturbing fishing gear, the negative effects of which are described in Section 8.1.1 of the 2016 CHPP. Under Goal 3, the relevant recommended actions are 3.3 “Protect habitat from adverse fishing gear effects through improved compliance” and 3.8 “Develop coordinated policies including management adaptations and guidelines to increase resiliency of fish habitat to ecosystem changes." (NCDEQ 2016)

Monitoring of the oyster resource in this area has indicated that these reefs have likely not supported much fishery effort between the 2018–19 and 2023–24 oyster seasons, due to few live or legal oysters sampled during NCDMF efforts. Past and present permit restrictions do not allow for the enhancement of deep-water reefs in Pamlico Sound with cultch. However, if future permitting could be secured to enhance or restore these deep-water reefs, low-relief cultch plantings would likely not be sufficient to quickly restore the reef height needed, and large high relief materials would need to be employed. The use of large materials such as boulders may prevent any future mechanical harvest of these sites once restored. To meet the NCMFC goals adopted in the CHPP and recognize the nomination of these areas as SHAs, Tier 1 proposes Deep-water Oyster Recovery Areas (DORAs) where mechanical harvest would not be opened. The long-term goal of DORAs would be to allow deep-water oyster reefs to grow and accumulate living oysters and dead shell material to gain the height necessary to better function as habitat and therefore be resilient to low dissolved oxygen events. Mechanical harvest can quickly remove oysters and shell material at a faster rate than it can naturally replenish, potentially resulting in no net vertical growth of any mechanically harvested reefs in these areas.

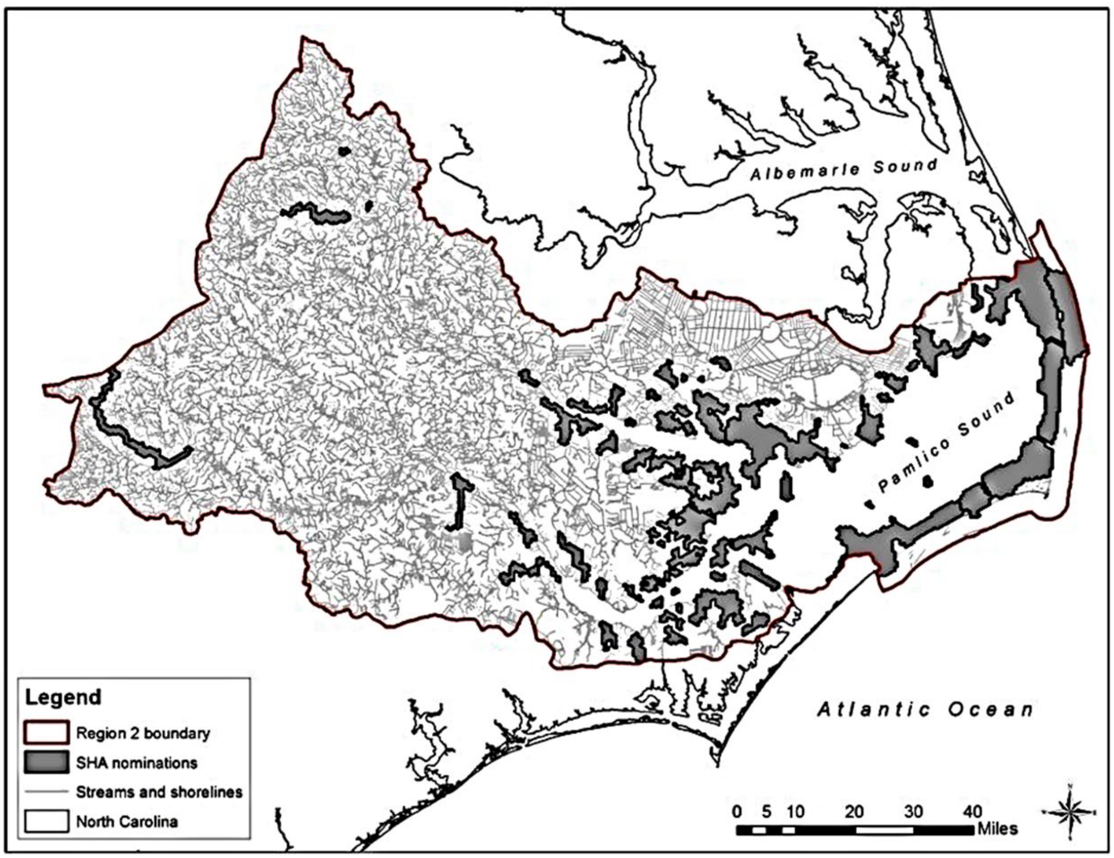

Figure 2.6. NCMFC nominated Strategic Habitat Areas (SHAs) for the Pamlico Sound Watershed (SHA Region 2), note the SHA areas in the mouth of the Neuse and Pamlico Rivers that encompass deep-water oyster reefs. (from NCDMF 2011)

Oyster habitat in Pamlico Sound, including both cultch planting sites and natural shell bottom, has been mapped across a long time period. Potential oyster habitat has been identified in areas deeper than 16.4 feet (5 meters), which is the depth at which oyster reefs are known to suffer mortality during low-oxygen events (Figure 2.7).

Using existing navigation aids (such as lights, buoys, and beacons) as boundary reference points for ease of compliance and enforcement, a total of 91,158 acres of deep-water area have been identified where oyster reefs are vulnerable to low-oxygen events. This area is divided into 29,561 acres in the Pamlico River and 61,597 acres in the Neuse River. However, within these larger areas, only about 845 acres represent potential oyster habitat—600 acres in the Pamlico River and 245 acres in the Neuse River—making up just 0.9% of the total identified deep-water area (2% in Pamlico River, 0.4% in Neuse River).

To protect the identified deep-water oyster reefs while minimizing areas that do not contain potential oyster habitat, two options are proposed for Designated Oyster Restoration Areas (DORAs) in both the Pamlico River and Neuse River (DORA options 1.b and 1.c, Figures 2.8 and 2.9). The two proposed DORA options do not include any known cultch planting sites and cover oyster reefs deeper than 16.4 ft (5 m) that have successfully re-grown oysters since the 2018–19 low-oxygen mortality event. These reefs are monitored by NCDMF and have oysters documented during the 2024–25 oyster season with shell lengths of at least 3 inches.

The larger DORA options (Management Option 1.b) cover 681 acres of potential oyster habitat (500 acres in Pamlico River and 180 acres in Neuse River), which represents approximately 81% of the vulnerable deep-water oyster habitat. The smaller DORA options (Management Option 1.c) cover 271 acres of potential habitat (200 acres in Pamlico River and 71 acres in Neuse River), which represents only approximately 32% of the vulnerable habitat.

The strategy of Deep-water Oyster Recovery Areas prioritizes the habitat value of these oyster reefs over the potential fishery resource they could provide, allowing reefs to not lose any gained shell volume and vertical height to fishery effort. The structural relief provided by oyster reefs plays a crucial role in the estuarine ecosystem. As the deep-water reefs located in DORAs recover, they would increase in habitat complexity from gaining height and more interstitial spaces. This complexity allows the reefs to function better as habitat for oysters and the numerous other commercially important species which rely on them. Oysters are viewed as ecosystem engineers, and for a more complete review on the significant role oyster reefs play in enhancing estuarine biodiversity, supporting fish production, improving water quality, and influencing hydrodynamic processes, see Chapter 3 of the 2016 CHPP (NCDEQ 2016).

Harvest may be allowed in the future if reefs recover to a point which a regulated harvest can be sustained. Subsequent Oyster FMPs can evaluate the success of the DORA approach by monitoring reef metrics such as height, rugosity, total area, and oyster demographics. Determination of successful recovery and developing sustainable harvest strategies would occur in a future FMP. Future sustainable harvest is defined as a level of harvest that would not result in a net loss of reef height through time and maintain reef height gained through DORA implementation.

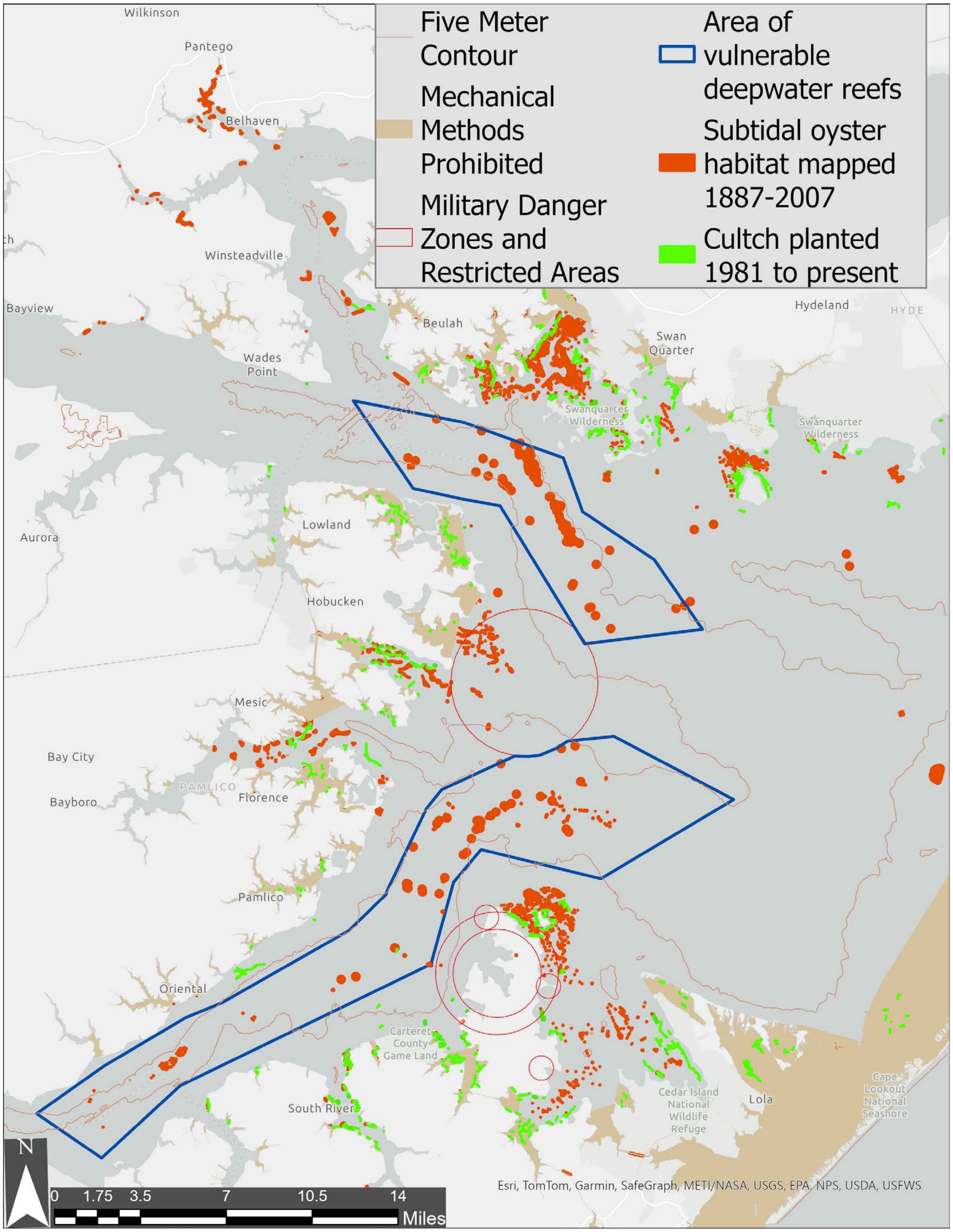

Figure 2.7. All known potential subtidal oyster habitat, including natural shell (red), and cultch planted sites (green), in western Pamlico Sound. All available historic and current data sources were used to illustrate potential locations for oyster reefs. Existing navigational markers were used to create boundaries around nearly all the identified vulnerable deep-water oyster habitat (blue polygons).

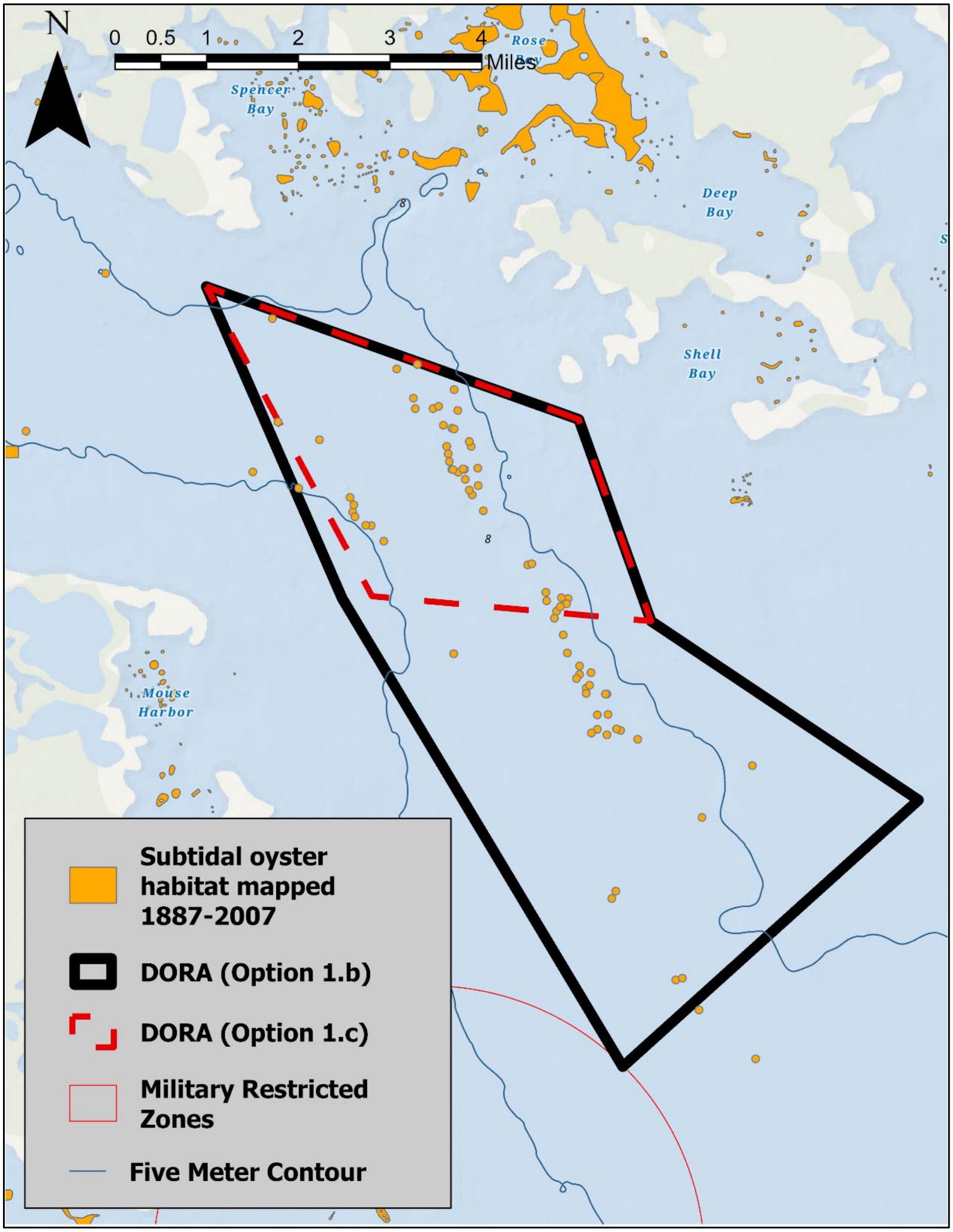

Figure 2.8. Two potential options for DORAs containing documented potential oyster habitat in the mouth of the Pamlico River. Proposed boundaries are delineated with already existing buoys and markers. The 5-meter contour line is shown to illustrate areas of oyster habitat located at this depth or below and vulnerable to low oxygen events. DORA Option 1.b represents a larger DORA than Option 1.c.

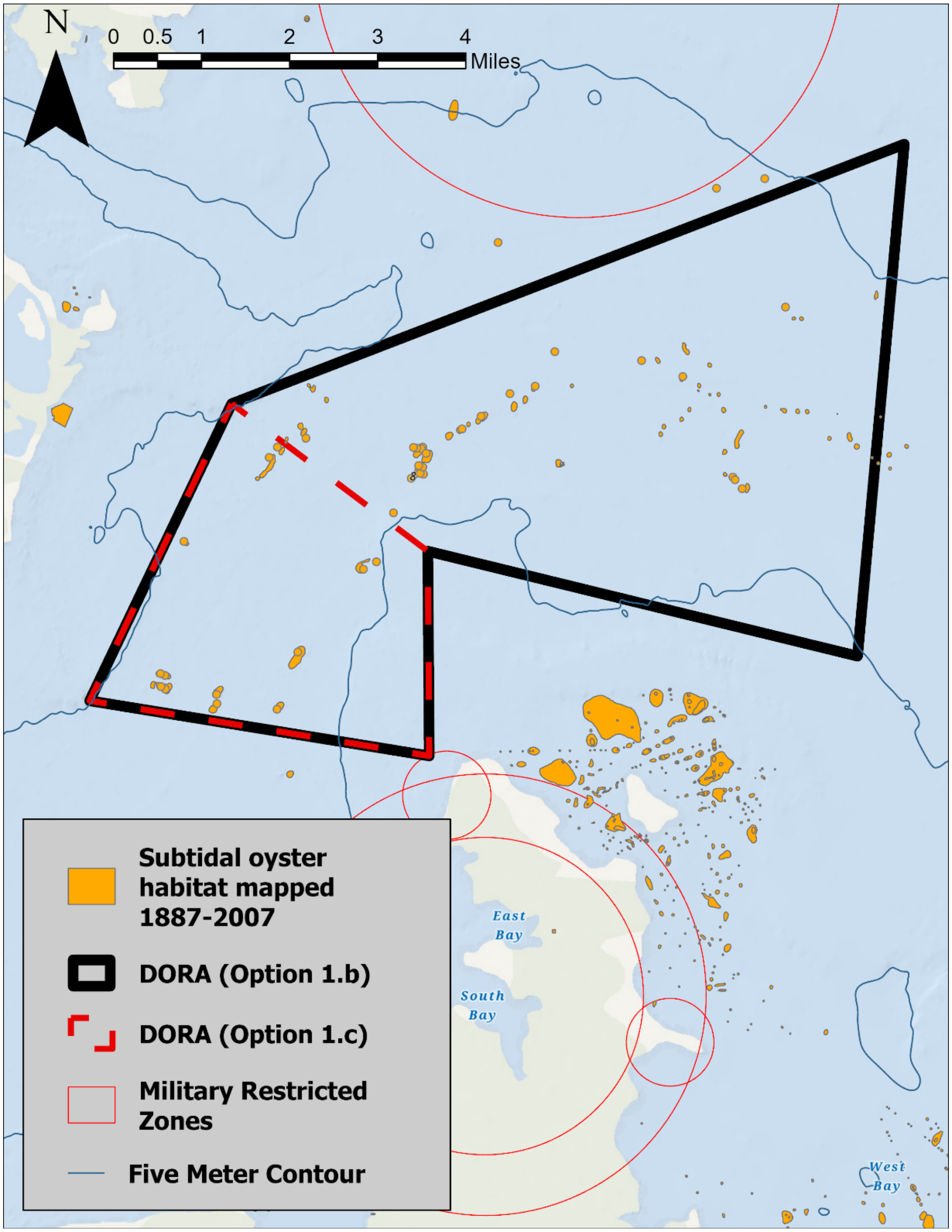

Figure 2.9. Two potential options for DORAs containing documented potential oyster habitat in the mouth of the Neuse River. Proposed boundaries are delineated with already existing buoys and markers. The 5-meter contour line is shown to illustrate areas of oyster habitat located at this depth or below and vulnerable to low oxygen events. DORA Option 1.b represents a larger DORA than Option 1.c.

The Cultch Planting Program operates under the U.S. Army Corps of Engineers Nationwide 27 permit. Currently, this permit is renewed every five years and grants the state 200 acres combined of acceptable inland water for oyster restoration. This permit restricts reef material to low relief sites, and from being planted in areas with existing natural shellfish populations to prevent destruction of important established habitat. For more information on the Cultch Planting Program see Appendix 4: Habitat & Enhancement Oyster Programs Information Paper. Past and present permit restrictions do not allow for the enhancement of deep-water reefs in Pamlico Sound with cultch. However, if future permitting could be secured to enhance or restore these deep-water reefs, low-relief cultch plantings would likely not be sufficient to quickly restore the reef height needed, and large high relief materials would need to be employed. The use of large materials such as boulders may prevent any future mechanical harvest of these sites once restored.

Cultch Supported Harvest (Tier 2)

Significant cultch planting effort has gone into creating harvestable reefs and replenishing cultch material lost in areas open to mechanical harvest in Pamlico Sound. Cultch planting has been central to Pamlico Sound oyster management, with some planted reefs over 40 years old and still producing harvestable oysters. Over time, extensive cultch planting initiatives have blurred the distinction between 'natural' reefs and those created by the NCDMF. The proposed Cultch Supported Harvest strategy would cover the portions of the Neuse and Pamlico River Management Areas not designated as DORAs and the entire Northern Dare and Northern Hyde Management Areas (Figure 2.3), but exclude rotational cultch areas proposed under Tier 3. Cultch planting effort will continue in these areas as long as the cultch planting program remains funded and operational. Cultch Supported Harvest Areas will be subject to the previously established bushel limits (15 bushels per day open water, 10 bushels per day bays; Figures 2.10 & 2.11) and the bays will continue to be capped to a total six-week possible season. This strategy would replace the current reactive approach of the mechanical harvest monitoring program established in 2010. The primary changes from previous management to the proposed strategy are that season length will be predetermined and based on NCDMF pre-season sampling of the oyster resource in these areas, and the 10-bushel per day bays and 15-bushel per day deep areas will be considered differently for each management area. This change eliminates the unpredictability in mechanical harvest season length experienced by harvesters and considers differences in oyster mortality experienced at varying depths of Pamlico Sound.

Past trigger sampling data can be used to analyze the relationship between the condition of the oyster resource during pre-season sampling and the number of weeks of mechanical harvesting that occurred before the sampling reached the management trigger, which is defined as two consecutive sampling events with less than 26% legal-sized oysters. Harvest rates are driven by effort in the fishery, and steep declines have been observed since implementation of the trigger sampling program in 2010. Effort after the 2016–2017 season has stabilized at a relatively low level, and data from that point forward can be considered representative of the current mechanical fishery. Any significant changes in effort and/or participation in the future would require adaptive management to address.

Using trigger sampling data from the oyster mechanical harvest seasons between November 2017 and March 2023, the pre-season condition (percent legal oyster) of each management area was compared to the number of weeks it took for the management trigger to trip and close mechanical harvest in that area (Figure 2.12). This relationship was used to assign potential season lengths for starting conditions by area (10-bushel bays, 15-bushel deep). The two samples with the lowest percent legal oyster per management area were dropped before calculating the overall percentage legal, then compared to how long it took for two consecutive sampling events to be at 26% legal or less (current trigger to close a management area). Dropping the sites in poorest condition, which may not have been used by harvesters, prevents those sites from impacting the overall area pre-season condition. However, the typical difference when these sites were dropped was an increase of less than five percent for legal oysters. Proposed maximum season lengths in the 10-bushel per day bays reflect that these areas are capped to a six-week possible season, and 18 total possible weeks for the 15-bushel per day areas to reflect the end of the possible mechanical harvest season on March 31.

The proposed season lengths (Table 2.3) underestimated the actual time it took to trip the current management trigger two times by an average of two days across the entire period examined (Figure 2.13). The proposed season lengths have a minimum threshold for opening of 10% legal; if an area is less than 10% legal, mechanical harvest will not open. Using a minimum threshold of 10% would have resulted in openings not occurring in two areas under current management between 2017 and 2023.

Table 2.3. Proposed weeks of oyster mechanical harvest for 10-bushel (bay) and 15-bushel limit (open water) management areas based on the starting condition percentage of live legal oysters calculated from pre-season samples.

	Weeks of Mechanical Harvest Season	
Starting Condition	10 bushel per day areas	15 bushel per day areas
<10%	0	0
10–14%	2	2
15–19%	3	3
20–24%	4	4
25–29%	5	5
30–34%	6	6
35–39%	6	8
40–44%	6	10
45–49%	6	13
50–54%	6	16
>55%	6	18

Pre-season sampling would occur prior to the mechanical harvest season for all four management areas. At least ten sites would be sampled per management area (with potentially more if resources allowed). As with previous trigger sampling, the percentage of legal live oysters for each management area would be calculated for samples pooled for each management area, with the 10 bushel per day and 15 bushel per day areas considered separately. The bottom 20% of sites sampled with the lowest percent legal for each management area would be dropped from calculating the pre-season percentages. This would prevent errant sites with poor oyster resources that would likely not be fished by mechanical harvesters from impacting potential season length.

Once pre-season sampling occurred, the season length for each management area for the 10 bushel per day and 15 bushel per day areas would be determined by using Table 2.3, which shows the corresponding number of weeks of mechanical harvest to be allowed based on pre-season conditions present in each area. Any areas in the 10-bushel bays would continue to follow the split open period of the six-week possible season (the first opening on Monday of the week prior to Thanksgiving through the Friday after Thanksgiving, and the second opening on the Monday two weeks before Christmas) as adopted in Amendment 4 of the Oyster FMP (NCDMF 2017).

Better sampling of mechanical harvest areas that fishers actively oyster or plan to oyster, encourages participation from the industry to direct division staff to sampling locations used to determine season length. Currently, the Cultch Planting Program mails out an annual survey to commercial license holders who have had oyster landings over the past three years to solicit feedback and input on cultch planting locations. Part of this proposed management strategy would include a dedicated e-mail address or phone line for harvesters to report sites they feel are productive and likely to be fished in the upcoming season. Participation from commercial stakeholders will be critical for the implementation of this strategy. Without input from mechanical harvesters, the NCDMF will rely on knowledge of prior fishing activity and known locations of oyster resources. As a result, pre-season sampling locations may not be representative of potential in-season harvest locations.

After initial season lengths have been determined, a proclamation will be issued establishing the mechanical season length by area. After the mechanical harvest season begins, one in-season sampling event will occur to potentially extend mechanical harvest for each area. Harvesters will be encouraged to report areas they are actively harvesting to the dedicated e-mail address or phone line mentioned above to inform in-season sampling locations. In-season sampling will occur prior to the midpoint of the proclaimed season for all four management areas. At least ten sites will be sampled per management area. Like pre-season sampling, the percentage of legal live oysters for each management area will be calculated for samples pooled for each management area, with the 10 bushel per day and 15 bushel per day areas considered separately. The bottom 20% of sites sampled with the lowest percent legal for each management area would be dropped from calculating the pre-season percentages.

Once in-season sampling occurs, Table 2.3 would again be used to determine if the initial fixed season would be extended via proclamation. First, the number of weeks left in the initial fixed season for an area would be calculated. Next, Table 2.3 would be consulted using the in-season sampling to determine the potential number of weeks to extend the season. The number of weeks left in the proclaimed season at the time of sampling would be subtracted from the number of weeks identified based on oyster condition in Table 2.3. If the number of weeks is greater than zero, that number of weeks would be added to the mechanical harvest season, and an additional proclamation extending the mechanical harvest season for that area would be issued. Mechanical harvest in the 10-bushel bay areas is capped at a total possible six weeks, so the season cannot be extended in these areas beyond a total of six weeks. Mechanical harvest in the 15-bushel areas cannot be extended past March 31. See Table 2.4 for steps and examples.

If pre-season sampling results in a management area not opening to mechanical harvest due to not meeting the 10% legal oyster threshold for opening, in-season sampling would still occur by January 15 of that mechanical harvest season. Any additional industry input received from harvesters would be used to inform sampling locations. If the in-season sampling event results in a percent legal of 10% or above, Table 2.3 would be used to determine the number of weeks of mechanical harvest allowed via proclamation.

In summary, the Cultch Supported Harvest Areas strategy places equal value on the fishery and habitat value of oysters in these areas. The amount of cultch material planted in these areas has exceeded the amount of oyster harvested since 2010, and many of these plantings have formed oyster reefs that have persisted for decades. Given the long history of cultch planting in North Carolina, many older cultch plantings in Pamlico Sound are considered “naturalized” and may be hard to distinguish from wild reefs. The purpose of setting season lengths in these areas is to protect oyster habitat from excessive damage caused by harvest, and to maintain substrate for juvenile oysters to recruit. The cultch planting program will continue to supplement oyster populations in these areas by providing hard substrate.

Rotational Cultch Sites (Tier 3)

The Cultch Planting Program has implemented a reef building strategy in Pamlico Sound to create large 10-acre cultch planting sites in areas open to mechanical harvest, with the goal of having at least 16 sites planted by 2026. Rotational cultch sites will be distributed across the sound with at least four planned for each management area. As of 2024, 13 large sites have been constructed with two management areas having at least four sites built already (Figure 2.14). To improve access to consistent oyster resources, a new fishery management approach is proposed for these large cultch sites. Currently, cultch sites have been made available to harvest as soon as they are planted, but typically it takes three ‘years’ (i.e., three 12-month cycles) for a new cultch site to produce legal oysters. The proposed management strategy for a Rotational Cultch Site is to not allow harvest for three years after initial construction, and then open harvest on the fourth year. After one season of harvest, the site would then be closed for the following three years. Immediately after the harvest season, the site would be evaluated by the NCDMF to determine if additional cultch material is needed. Sites would open and close via proclamation on a four-year rotational schedule. Additional sites are planned for each management area to enable contingency based substitutions of rotational sites for potentially more successful sites. The goal would be to have at least one large rotational cultch site open per management area each season. Rotational Cultch Sites would not be subject to the season lengths set for Cultch Supported Harvest Areas. The large open sites in a management area would open to mechanical harvest on the Monday of the week prior to Thanksgiving week, which is typically the third Monday of November, and close on March 31. Rotational Cultch Sites would be limited to 10 or 15 bushels per day per vessel based on the harvest limit in the waterbody that each site is located within. This strategy focuses on the fishery value of these reefs and gives harvesters relatively open access to these cultch plantings.

Without a stock assessment or metrics of abundance for oysters in Pamlico Sound, management focuses on protecting oyster habitat and cultch planting to restore hard substrate ensures ongoing populations of harvestable oysters. The proposed three tier approach seeks to balance the habitat and fishery values of oysters in Pamlico Sound. Deep-water Oyster Recovery Areas (Tier 1) protect reefs where continued shell loss prevents remnant natural reefs from recovering. The habitat value of these areas is prioritized over their potential function as a harvestable fishery resource. Cultch Supported Harvest Areas (Tier 2) aim to allow harvest but prevent damage to oyster habitat through excessive removal of cultch material. Effort is limited by setting season lengths by management area according to conditions of the oyster resource. Additionally, cultch planting in these areas helps mitigate substrate loss via oyster harvest. Rotational Cultch Sites (Tier 3) are constructed with the goal of supporting the mechanical harvest oyster fishery. The fishery value of these sites is prioritized. Sites will be evaluated at the end of the harvest season and replenished with cultch before being allowed to re-grow harvestable sized oysters. The NCDMF will modify sampling and data collection protocols to better incorporate an abundance of indices into future management to be addressed in a subsequent fishery management plan.

Adaptive management

The fixed mechanical season lengths for Cultch Supported Harvest developed in this issue paper used fishery monitoring data for the five oyster mechanical harvest seasons between November 2018 and March 2023. On average, 93 participants landed oysters with mechanical gear between 2018 and 2023. Any large changes in effort would potentially result in fixed season lengths becoming either inadequate to provide protection to the oyster resource with increased participation in the fishery, or too restrictive with decreased fishery participation. If the three-year running average of participants in the mechanical oyster fishery changes by more than 25% (i.e., less than 70 or more than 116 participants), adaptive management would be triggered to re-evaluate the fixed season lengths outlined in Table 2.3. Effort and landings data as well as division mechanical harvest season sampling data will be used to assess the effectiveness of adopted fixed season lengths in relation to the condition of the oyster resource. If adaptive management is triggered, season lengths may be lengthened, shortened, or maintained as previously adopted. For example, if participation dropped to a 3-year average of 65 participants and in-season sampling of management areas consistently results in 2 additional weeks of mechanical harvest being added to the initial proclaimed season length, Table 2.3 can be modified to extend the season length to reflect this change.

Adaptive Management Framework

A three-year running average of the number of participants with landings in the wild mechanical oyster fishery of less than 70 or greater than 116 (calculated during annual FMP Update), triggers the examination of oyster sampling data and potential adjustment to fixed season lengths (Table 2.3) for Cultch Supported Harvest management strategy.

Table 2.4. Steps used to determine mechanical harvest season lengths in the proposed Cultch Supported Harvest management strategy. Examples are provided to demonstrate how the initial proclaimed season length may be extended (Example 1) or how the initial proclaimed season may remain the same (Example 2).

Step	Example 1	Example 2
1. Pre-season Industry Reports	Receive reports from fishers about locations of sites in the 10-bushel areas of Pamlico Management Area	Receive reports from fishers about location of sites in the 15-bushel area of Dare Management Area
2. Pre-season Sampling	NCDMF sampling including areas reported by fishers. Pre-season condition 25% legal.	NCDMF sampling including areas reported by fishers. Pre-season condition 40% legal.
3. Set Season Length (See Table 2.3)	25% legal = 5 weeks. Mechanical harvest season set via proclamation for 5 weeks in 10 bushel/day areas of Pamlico Management Area	40% legal = 10 weeks. Mechanical harvest season set via proclamation for 10 weeks in 15 bushel/day area of Dare Management Area
4. In-season Industry Reports	Reports from fishers about specific locations in the 10 bushel/day areas.	No additional reports from fishers
5. In-season Sampling	NCDMF in-season sampling occurs 2 weeks into the proclaimed 5-week season targeting areas reported by fishers. In-season condition = 20%	NCDMF in-season sampling occurs 5 weeks into the proclaimed 10-week season using initial fisher reports and prior experience. In-season condition = 24%
6. Evaluate Season Length (See Table 2.3)	20% legal = 4 weeks 4 weeks - 3 weeks (amount of season left) = 2 additional weeks In-season sampling shows 2 additional weeks may be added to the initial 5 week proclaimed season for this area for a total of 7 weeks	24% legal = 4 Weeks 4 weeks – 5 weeks (amount of season left) = -1 weeks. The number of additional weeks from the in-season evaluation is less than 0.
7. Modify Season (If needed)	New proclamation issued to extend the initial set harvest season by 1 week.	The initial proclaimed harvest season remains. No change.

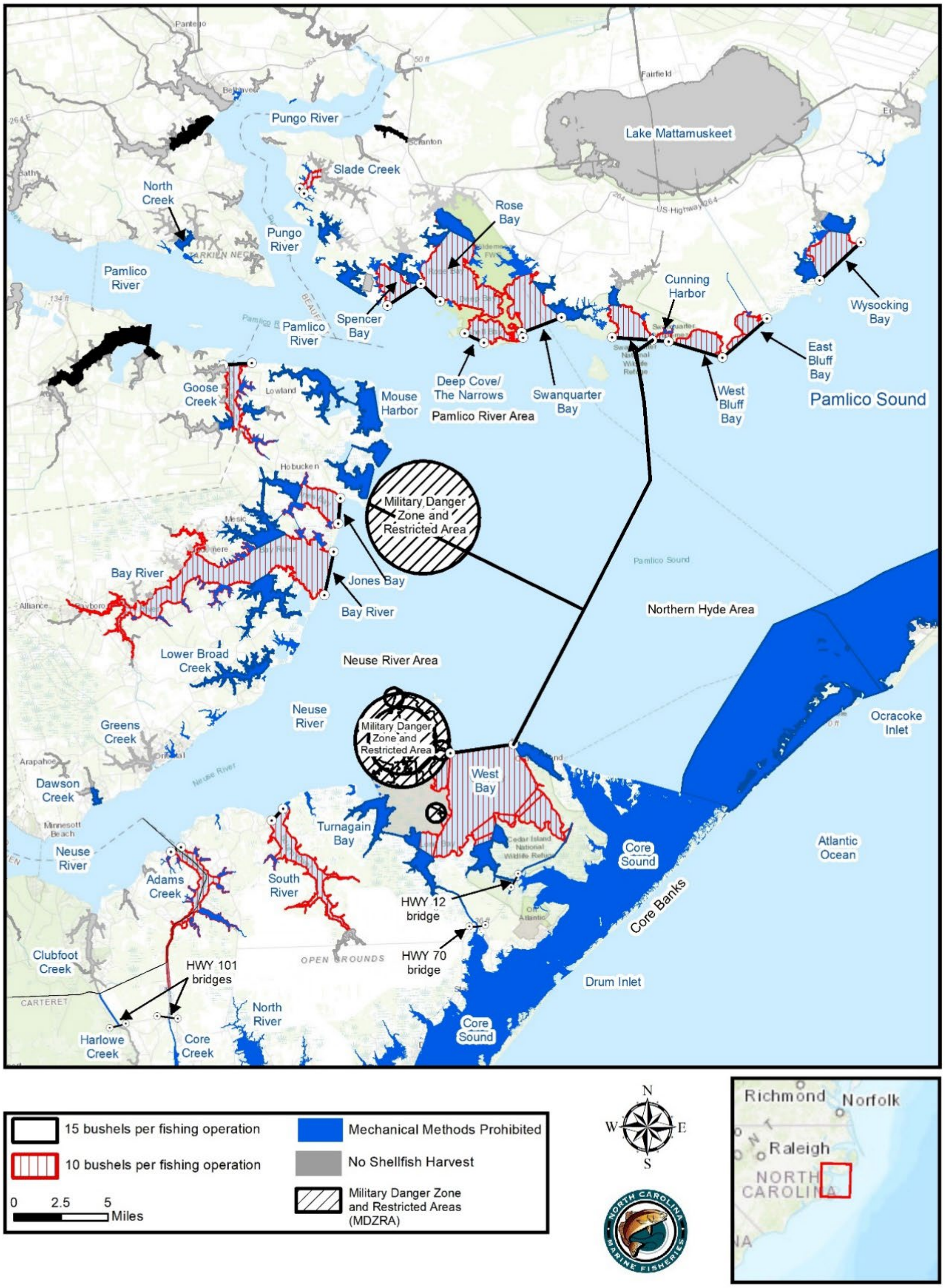

Figure 2.10. Bushel limits for bays and deep-water areas of western Pamlico Sound.

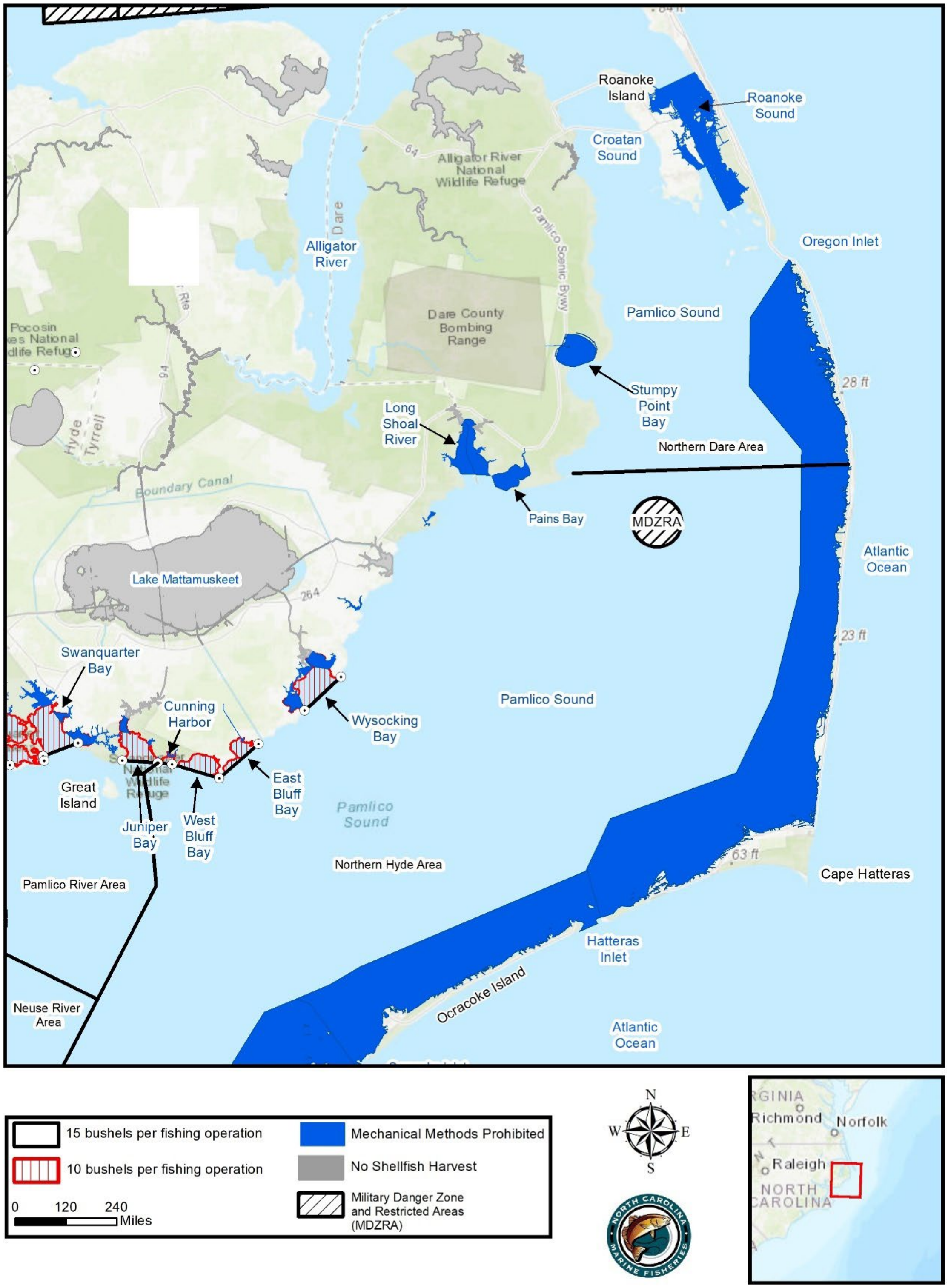

Figure 2.11. Bushel limits for bays and deep-water areas of eastern Pamlico Sound.

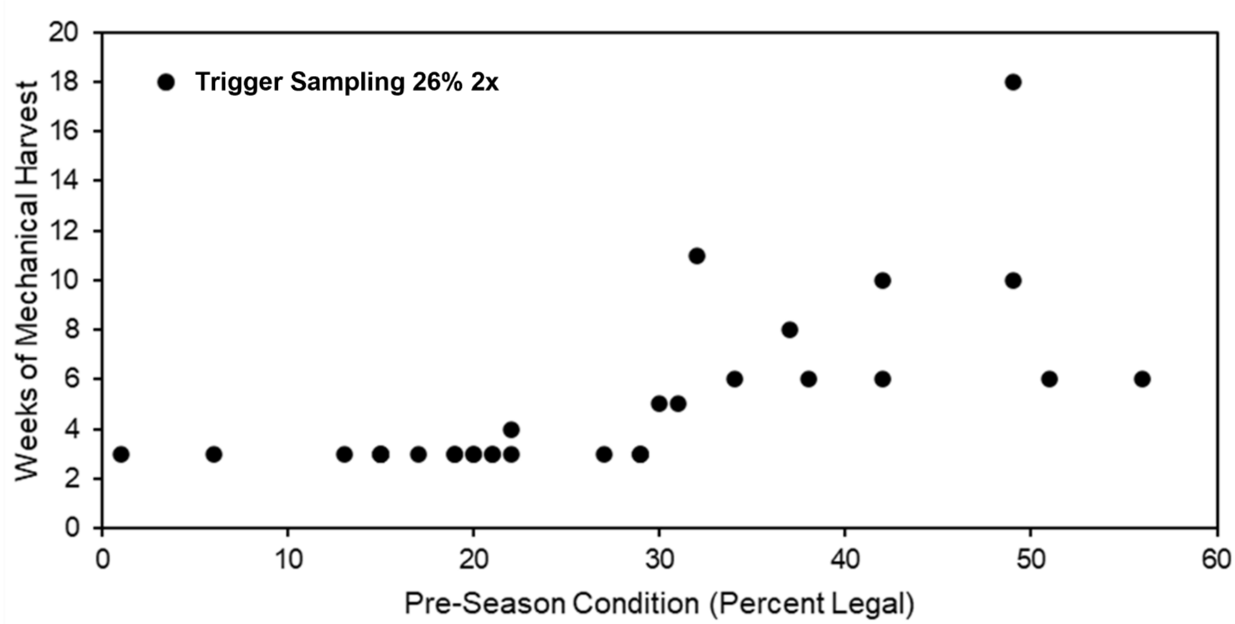

Figure 2.12. Pre-season condition (percent legal) of oysters in management areas sampled during mechanical harvest monitoring compared to the number of weeks it took for the management trigger to trip in that area from 2017 to 2023. The management trigger is 26% legal or less for two consecutive sampling events (26% 2x). The two lowest percent legal samples per area were dropped before calculating the pre-season condition of that area.

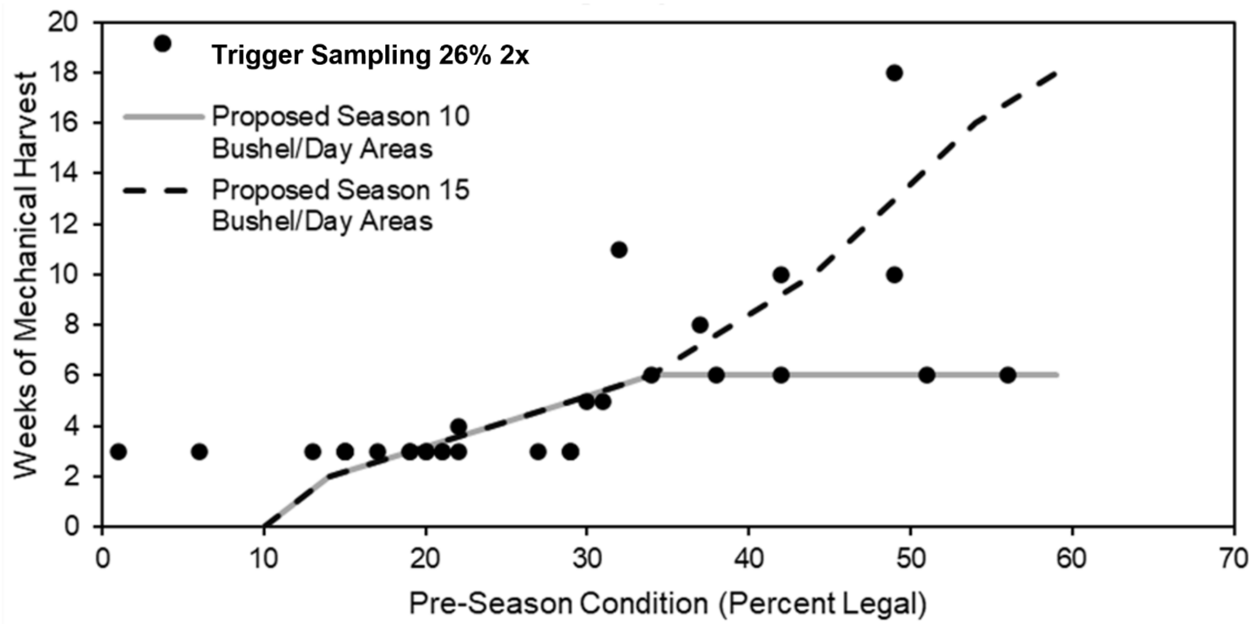

Figure 2.13. Pre-season condition (percent legal) of oysters in management areas sampled during mechanical harvest monitoring compared to the number of weeks it took for the management trigger to trip in that area from 2017 to 2023. The management trigger is 26% legal or less for two consecutive sampling events (26% 2x). The two lowest percent legal samples per area were dropped before calculating the pre-season condition of that area. The light gray line shows the proposed season length for the 10 bushel/day areas, and the dashed black line shows the proposed season length for the 15 bushel/day areas.

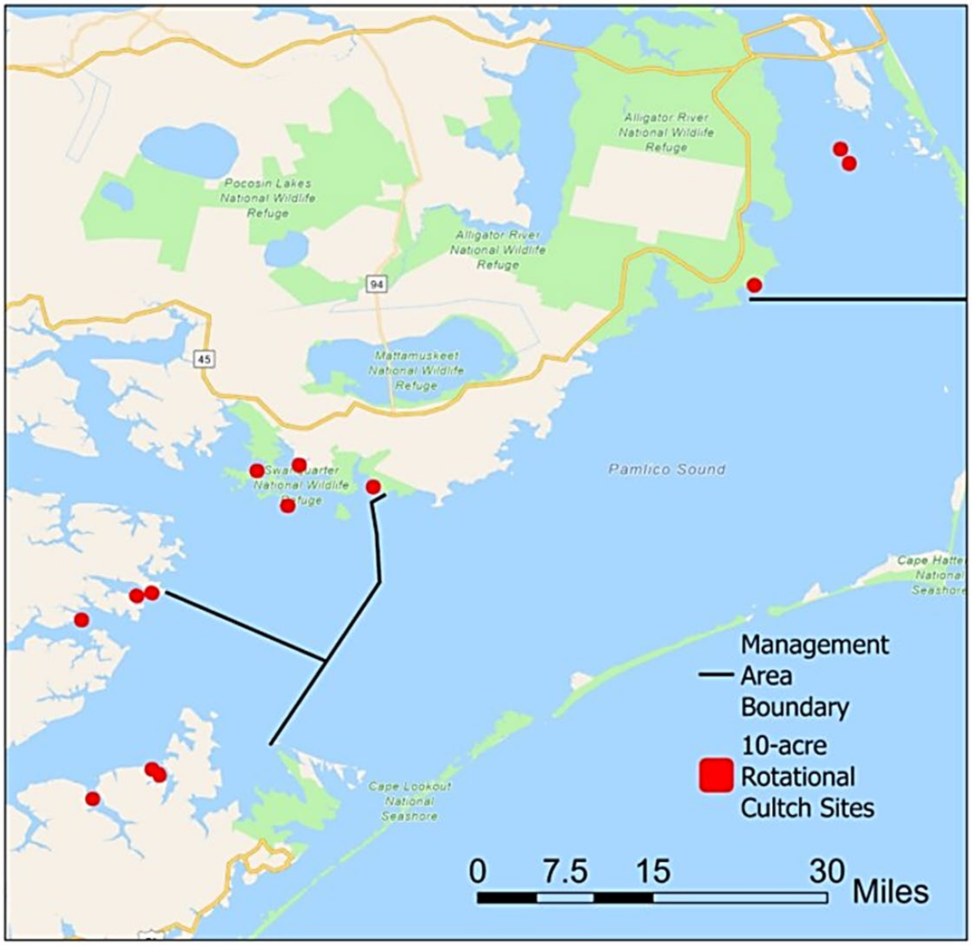

Figure 2.14. Locations of Rotational Cultch Sites that were constructed through 2024.

MANAGEMENT OPTIONS

Option 1: Deep-water Oyster Recovery Areas (DORAs)

a. Status Quo (do not support)
   - Does not protect any deep-water (>5 m) oyster reefs in Pamlico Sound from mechanical harvest methods which reduce reef height.
   - Does not allow deep-water (>5 m) oyster reefs in Pamlico Sound to gain height and resiliency from negative water quality impacts.

b. Adopt Deep-water Oyster Recovery Areas (DORAs larger option)
   - Protects 81% (681 acres: 500 acres in Pamlico River and 180 acres in Neuse River) of identified deep-water (>5 m) oyster reefs in Pamlico Sound from mechanical harvest methods that reduce reef height
   - Allow protected deep-water (>5 m) oyster reefs in Pamlico Sound to gain height and resiliency from negative water quality impacts.

  - Does not allow harvest in all areas of western Pamlico Sound which may periodically have harvestable oyster resource.

c. Adopt Deep-water Oyster Recovery Areas (DORAs smaller option)
  - Protects 32% (271 acres: 200 acres in Pamlico River and 71 acres in Neuse River) of identified deep-water (>5 m) oyster reefs in Pamlico Sound from mechanical harvest methods which reduce reef height.
  - Allow deep-water (>5 m) oyster reefs in Pamlico Sound to gain height and resiliency from negative water quality impacts.
  - Does not allow harvest in all areas of western Pamlico Sound which may periodically have harvestable oyster resource.
  - Allows for harvest in areas of western Pamlico Sound which may periodically have harvestable oyster resource

Option 2: Cultch Supported Harvest

a. Status Quo (maintain current trigger sampling approach)
  - Uncertainty and variability in season length annually.
  - Does not provide a standardized opportunity for industry to provide input into management sampling locations.
  - Maintains current habitat protection measures in the mechanical oyster fishery.

b. Adopt Proposed Cultch Supported Harvest Strategy
  - Provides more certainty in annual season length by area.
  - Incorporates industry input into management sampling locations for pre and in-season sampling.
  - Provides habitat protection measures in the mechanical oyster fishery.

Option 3: Rotational Cultch Sites

a. Status Quo (maintain current cultch site management)
  - All cultch planting sites are open to harvest of legal-size oysters.
  - No differentiation in management of wild and cultch planting sites.
  - Does not formalize NCDMF cultch planting efforts into an adopted fishery management strategy.

b. Adopt Rotational Cultch Site Strategy
  - Some cultch sites would be closed to harvest on a rotational schedule.
  - The fishery value of these cultch planting sites is prioritized.
  - Formalizes NCDMF cultch planting efforts into an adopted fishery management strategy.

Option 4: Adaptive Management

a. Do not support Adaptive Management
   - Does not allow for changes in set season length based on changes in fishery participation.

b. Adopt Adaptive Management (only applies if the proposed Cultch Supported Harvest Strategy is adopted)
   - Allows for modification of set season length based on changes to fishery participation.

RECOMMENDATIONS

The DMF recommends the following options:

Option 1. Deep-water Oyster Recovery Areas (DORAs)

b. Adopt Deep-water Oyster Recovery Areas (DORAs larger option)

Option 2. Cultch Supported Harvest

b. Adopt the proposed Cultch Supported Harvest strategy as described in the Issue Paper.

Option 3. Rotational Cultch Sites

b. Adopt the proposed Rotational Cultch Site strategy as described in the Issue Paper.

Option 4. Adaptive Management

b. Adopt the proposed adaptive management framework.

Advisory Committee Recommendations and Public Comment: see *Appendix 7*

NCMFC Selected Management Options

Option 1: Deep-water Oyster Recovery Areas (DORAs)

b. Adopt the proposed Pamlico and Neuse River Deep-water Oyster Recovery Areas (DORAs), which are bound by existing navigational aids as presented to the NC MFC regional Advisory Committees, to protect deep subtidal oyster reefs from continued physical disturbance by mechanical gear. These areas will be closed to mechanical oyster dredging and monitoring efforts will be used to evaluate the effectiveness of closure within the next FMP amendment. The DORAs cover 681 acres of potential oyster habitat (500 acres in Pamlico River and 180 acres in

Neuse River), which represents approximately 81% of the vulnerable deep-water oyster habitat.

Option 2: Cultch Supported Harvest

b. Adopt the Cultch Supported Harvest strategy outlined in Appendix 2, which would set the season length based on pre-season sampling aided by industry input on sampling locations with the 10 bushel per day and 15 bushel per day areas considered separately.

Option 3: Rotational Cultch Site Strategy

b. Adopt the inclusion of Rotational Harvest Cultch Sites strategy outlined in Appendix 2. This strategy would create a rotating series of readily available cultch areas available to harvest for the full extent of the mechanical season length each year with the intent of reducing harvest pressure on natural reefs.

Option 4: Adaptive Management

b. Adopt the proposed adaptive management framework to allow for modification of set season length based on changes to participation in the fishery.

Appendix 3: Intertidal Oyster Harvest Management Information Paper

ISSUE

Addressing management needs for intertidal oysters in North Carolina.

ORIGINATION

The Division of Marine Fisheries and the North Carolina Marine Fisheries Commission (NCMFC) selected management strategies from the Eastern Oyster Fishery Management Plan (FMP) Amendment 4.

BACKGROUND

The North Carolina Eastern Oyster FMP Amendment 5 is focused on management of wild oysters, and this information paper does not pertain to farm raised or private cultured oysters.

North Carolina's wild oysters are composed of both intertidal (exposed to air during portions of the tidal cycle) and subtidal (continuously submerged) populations. Oyster populations in the southern region of the state (Onslow, Pender, New Hanover, and Brunswick counties) are primarily intertidal reefs. There is currently not a stock assessment or fishery independent sampling program for intertidal oysters in the state.

Commercial harvest of oysters in North Carolina requires a Standard or Retired Commercial Fishing License (SCFL, RSCFL) with a shellfish endorsement, or a commercial Shellfish License. The number of SCFL/RSCFL available within the state is capped, limiting the total potential participation from these license holders. The commercial Shellfish License, however, is not limited to a maximum number of participants and is available at a much lower cost than the SCFL or RSCFL to any resident of the state. Harvest is limited to hand methods from Core Sound south to the NC/SC state line, with harvesters walking onto exposed oyster reefs to manually collect legal sized (3 in shell length or greater) oysters. Exposed intertidal oyster reefs are easily accessible to harvest by hand and are vulnerable to impacts from harvest pressure.

The southern region of North Carolina contributes consistently to the overall public landings of oysters within the state (Figure 3.1). From 1994 to 2022, the southern region produced 51% of the state's total wild oyster landings, accounting for between 20% and 91% of the annual harvest. Although this region covers only 5.7% of the state's total coastal waterbody area, it has contributed more than half of the total oyster landings since 1994.

The North Carolina Eastern Oyster FMP Amendment 4 examined increasing landings and participation from commercial Shellfish License holders with decreasing catch per unit effort (average bushels landed per trip), and the potential of effectively open entry on a finite fishery resource via the commercial Shellfish License as management issues (NCDMF 2017). For more information see the following issue papers in Amendment 4 of the Eastern Oyster FMP: Assessing and Mitigating Harvest Effort Impacts on Oyster

Resources in the Southern Region and Consider Elimination of the Shellfish License and Require All Shellfish Harvesters to Have a SCFL or RSCFL. To address these concerns, the Marine Fisheries Commission (MFC) adopted specific management strategies. One of these strategies was the reduction of the daily oyster harvest limit for commercial Shellfish License holders from five bushels to two. This strategy was implemented in October of the 2017–2018 season with an allowance for up to four bushels per vessel per day if two or more Shellfish License holders were on board the vessel. In Amendment 4 of the Eastern Oyster FMP, the NCMFC also recommended excluding oysters harvested from public bottoms as eligible for harvest with the commercial Shellfish License. The elimination of oysters from the commercial Shellfish License requires legislative action and has yet to occur. They also proposed the development of a fishery independent sampling program for intertidal oysters in the southern region.

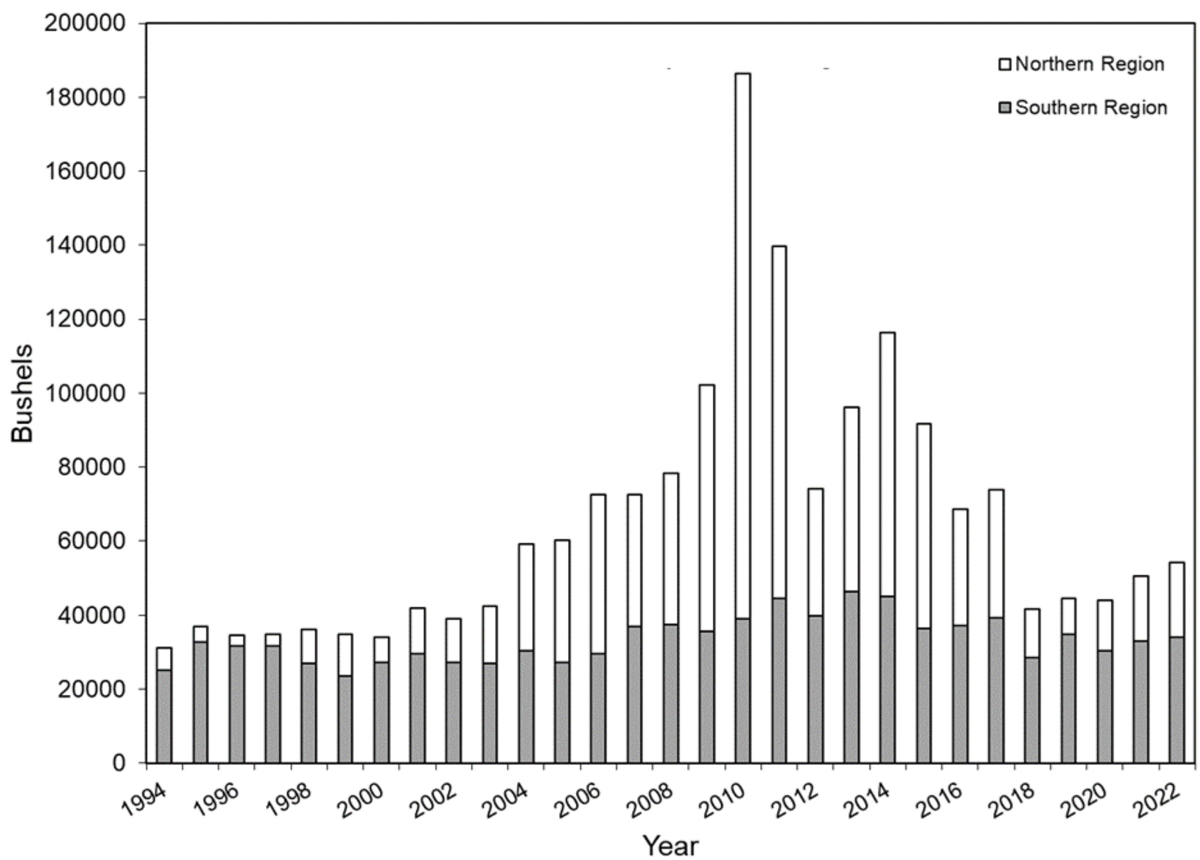

Figure 3.1. Commercial landings of oysters from public bottom in North Carolina from 1994 to 2022, showing annual landings in bushels from the southern region (waterbodies south of Bogue Sound; gray bars) and the northern region (white bars).

Commercial oyster fishery effort in the southern region experienced a period of growth between 2000 and 2014, with the total amount of trips nearly doubling during that time (Figure 3.2). The increase in participation was primarily driven by increasing participation from harvesters with commercial Shellfish Licenses, with a 388% increase in trips by commercial Shellfish License holders over that period. The number of trips made by Shellfish License holders declined sharply in 2018. This coincides with NCDMF enacting the bushel reduction limit for Shellfish License holders as recommended by the MFC.

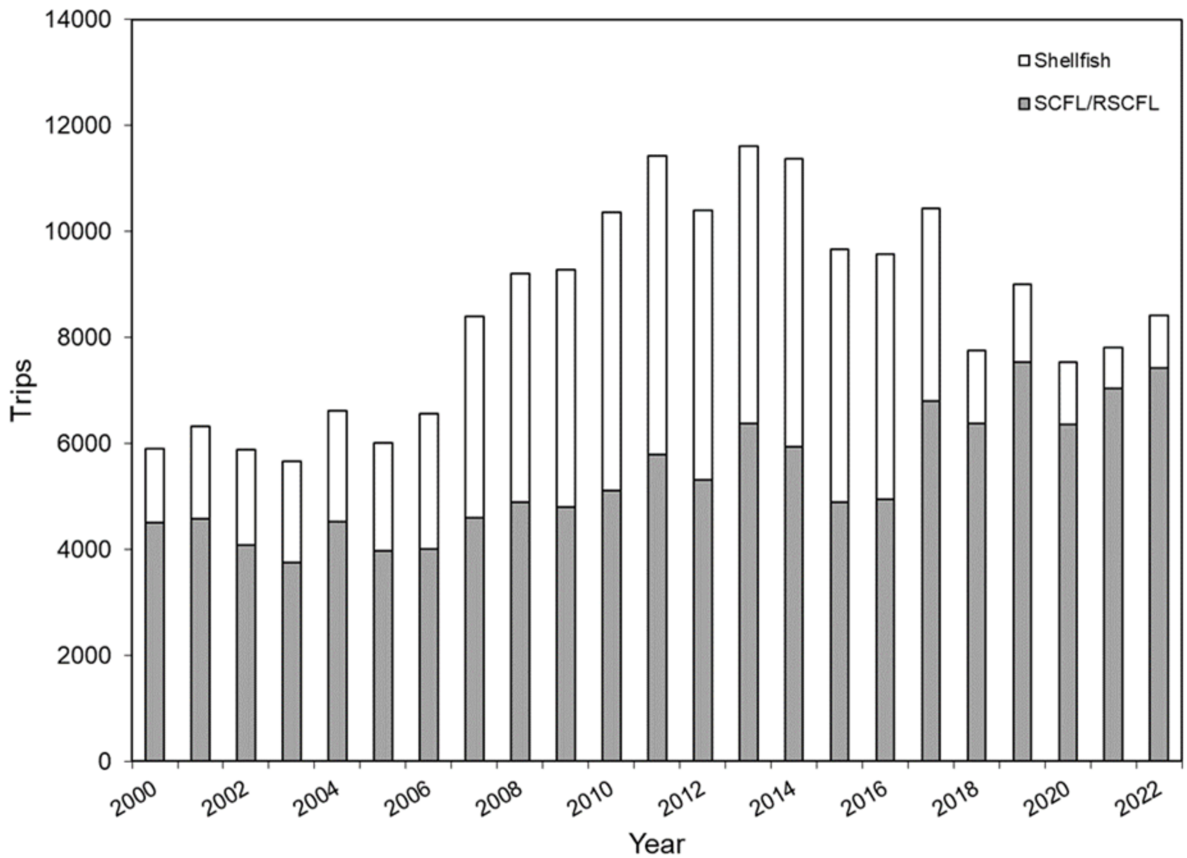

Figure 3.2. Commercial oyster fishing effort in trips for the southern region (waterbodies south of Bogue Sound) from 2000 to 2022, showing trips made by Shellfish License holders (white bars) and SCFL/RSCFL holders (gray bars).

Because there is currently no independent sampling or stock assessment for intertidal oysters in the southern region of North Carolina, one way to gauge the health of oysters is by assessing the average catch-per-unit-effort (CPUE) of commercial fishing trips. This is measured by the average annual number of bushels landed per fishing trip, as recorded in the NC Trip Ticket Program (NCTTP). Since 1994, all commercially harvested oysters in North Carolina must be reported through the NCTTP. However, it is important to interpret CPUE data from commercial fisheries cautiously because factors like regulations, market demand, and weather all influence fishing behavior and catch levels. In the case of oysters, if declines in average number of bushels landed while fishers are expending the same amount of effort (trips) are observed, this may indicate that the resource cannot sustain the amount of harvest pressure occurring. However, without fisheries independent data to provide information about oyster abundance or population structure, it is impossible to verify if trends in fisheries dependent data are reflective of the oyster population.

From 2000 to 2006, the average number of bushels landed per trip by SCFL/RSCFL holders in the southern region remained relatively close to the trip limit of five bushels, averaging 4.6 bushels per trip (Figure 3.3). However, starting in 2007, the average annual bushel amount landed per trip began to decline, reaching 3.7 bushels per trip by 2010. Between 2008 and 2017, the average annual bushel amount fluctuated but remained below four bushels per trip. Beginning in 2018 after the bushel limit for Shellfish License holders was reduced by management action implemented via Amendment 4, there was an increase in the average annual bushels per trip, reaching an average of 4.6 bushels per trip by 2023.

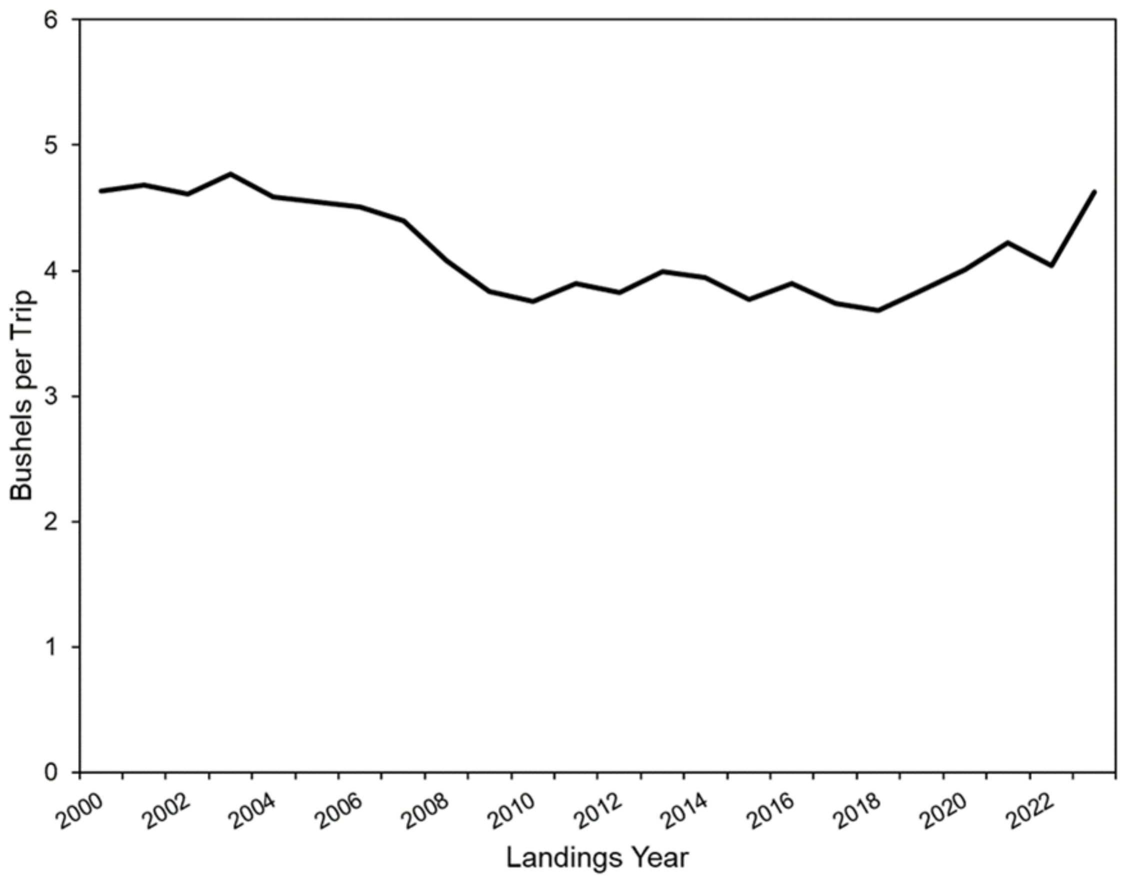

Figure 3.3. The catch-per-unit-effort (CPUE) for oyster commercial harvest in the southern region (waterbodies south of Bogue Sound) from 2000 to 2023. The black line represents the average annual bushel amount landed per trip by SCFL/RSCFL holders.

Four waterbodies, Lockwood Folly River, Shallotte River, Masonboro Sound, and Topsail Sound contributed 68% of the region's total commercial oyster landings from public bottom since 1994 and are representative of the intertidal hand harvest fishery in the region. Since 2000, landings trends from these areas fluctuated annually. Topsail and Masonboro sounds showed increasing landings until a decline in 2014; however, Lockwood Folly and Shallotte rivers were more variable. (Figures 3.4 – 3.7). Yearly changes in landings from these water bodies generally reflect the number of participants in the fishery (Figures 3.4 – 3.7). Like the rest of the southern region, generally increasing numbers of Shellfish License holders participated in the fishery until 2018. Despite variation in participation and landings across the region, the number of bushels landed per commercial trip decreased between 2000 and 2010. This decrease in CPUE was concurrent with the overall increase in participation and effort in the oyster fishery for these waterbodies, with lowest average bushels per trip landed during periods of highest participation (Figures 3.4 – 3.8). Lockwood Folly and Shallotte rivers both showed an increased annual average bushels per trip in recent years as participation decreased, while Masonboro and Topsail Sounds showed relatively flat trends in bushels per trip.

The NCDMF Shellfish Rehabilitation Program conducts annual efforts to plant cultch (material suitable for oyster spat settlement, such as oyster shell or limestone marl) in coastal waterbody areas across the state. Cultch reefs are created in waters open to shellfishing to improve oyster recruitment and increase biomass in areas where suitable substrate is otherwise limited. For more information on the NCDMF's cultch planting program see Appendix 4: Habitat Enhancement Programs. The quantity of material planted each year varies considerably based on availability and funding. Between 2000 and 2022, a total of 1,054,243 bushels of cultch material were planted, and 744,311 bushels of oyster were commercially harvested across the entire southern region of the state (Figure 3.9). The return in commercial harvest per unit of cultch planted remains unknown and likely varies across different planting sites. The impact of cultch plantings on oyster landings is not immediate, as it typically takes between one and three years after planting for new cultch material to yield legal-sized oysters. While some cultch planting sites have relatively short lifespans, others have been observed to continue yielding harvests for decades.

The existing management strategy in the southern region relies on the NCDMF Director's authority to close the oyster season before March 31 by proclamation. In the Pamlico Sound mechanical oyster fishery, a mechanical harvest monitoring program is used to regulate fishing activity to protect oyster habitat during the harvest season. For additional information see Appendix 2: Mechanical Oyster Harvest Management Issue Paper. Currently, no harvest monitoring program or closure trigger exists for hand harvest areas. In Brunswick County, waterbodies close to oyster harvest on March 15 due to concerns stemming from excessive harvest pressure in past years.

Intertidal oyster reefs in the southern region are also readily accessible to recreational harvesters. However, the extent of recreational shellfish harvesting compared to commercial harvesting is currently unknown. There is no established mechanism for accurately quantifying the number of recreational shellfish harvesters in North Carolina, which limits the NCDMF's ability to estimate total recreational shellfish harvest in the southern region. For further details, please refer to Appendix 1: Recreational Shellfish Harvest Issue Paper.

In 2024, the NCDMF implemented a pilot fishery independent sampling program to monitor the intertidal oyster resource. Fifteen sentinel sites have been proposed across the southern region of the state to represent the intertidal oyster population. Sites include areas both open and closed to shellfish harvest. These sentinel sites will be surveyed using UAS (uncrewed aerial systems; drones), allowing for high-resolution repeated mapping, as well as traditional sampling for biological and water quality data. Sampling is planned to occur before and after the open harvest season, allowing development of fishery independent indices and assessment of fishing impacts on the oyster resource.

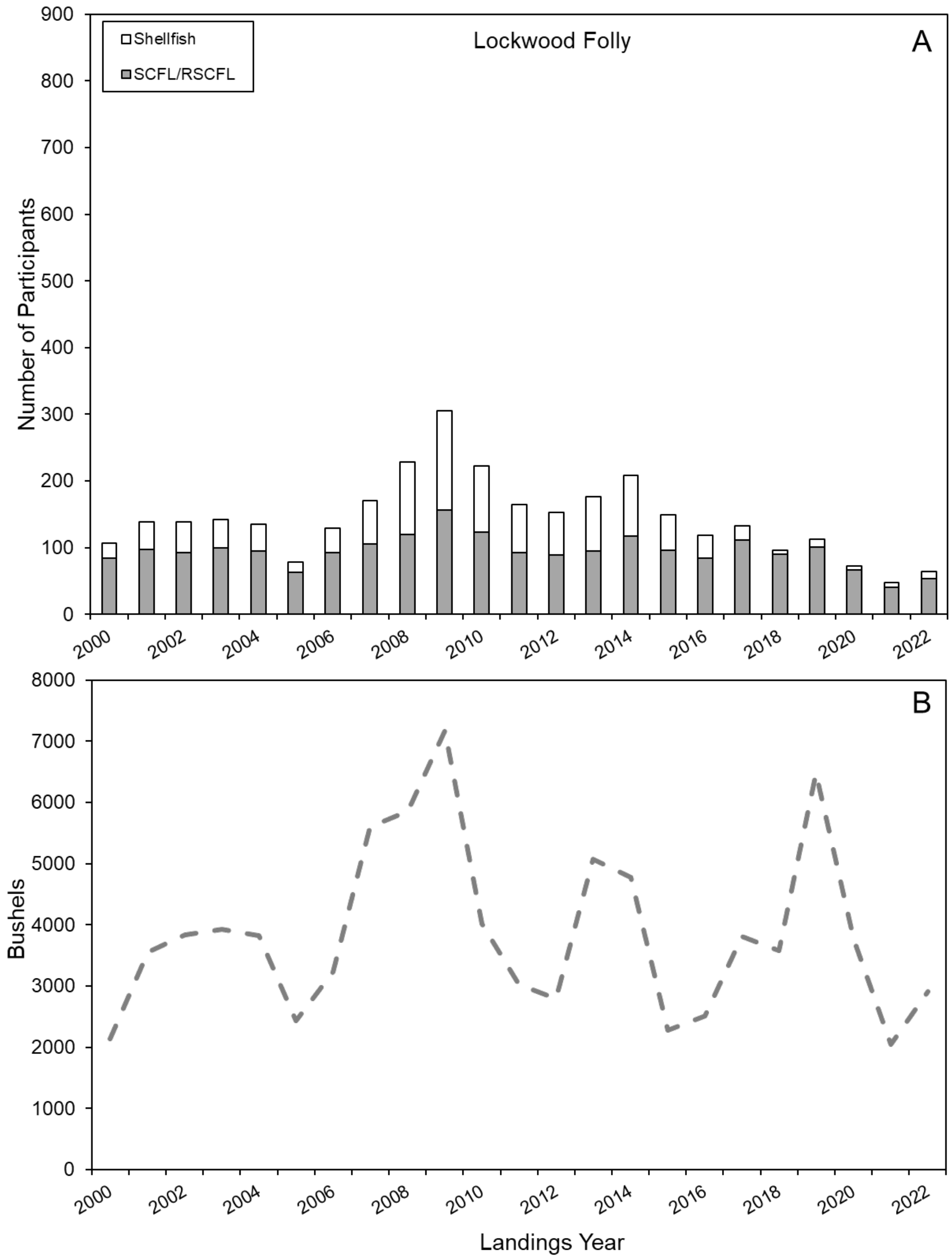

Figure 3.4. (A) Annual number of participants with oyster landings for Lockwood Folly River, from 2000 to 2022, by license type for Shellfish Licenses (white bars) and SCFL/RSCFL (gray bars). (B) Annual commercial landings of oysters in bushels for the Lockwood Folly River from 2000 to 2022.

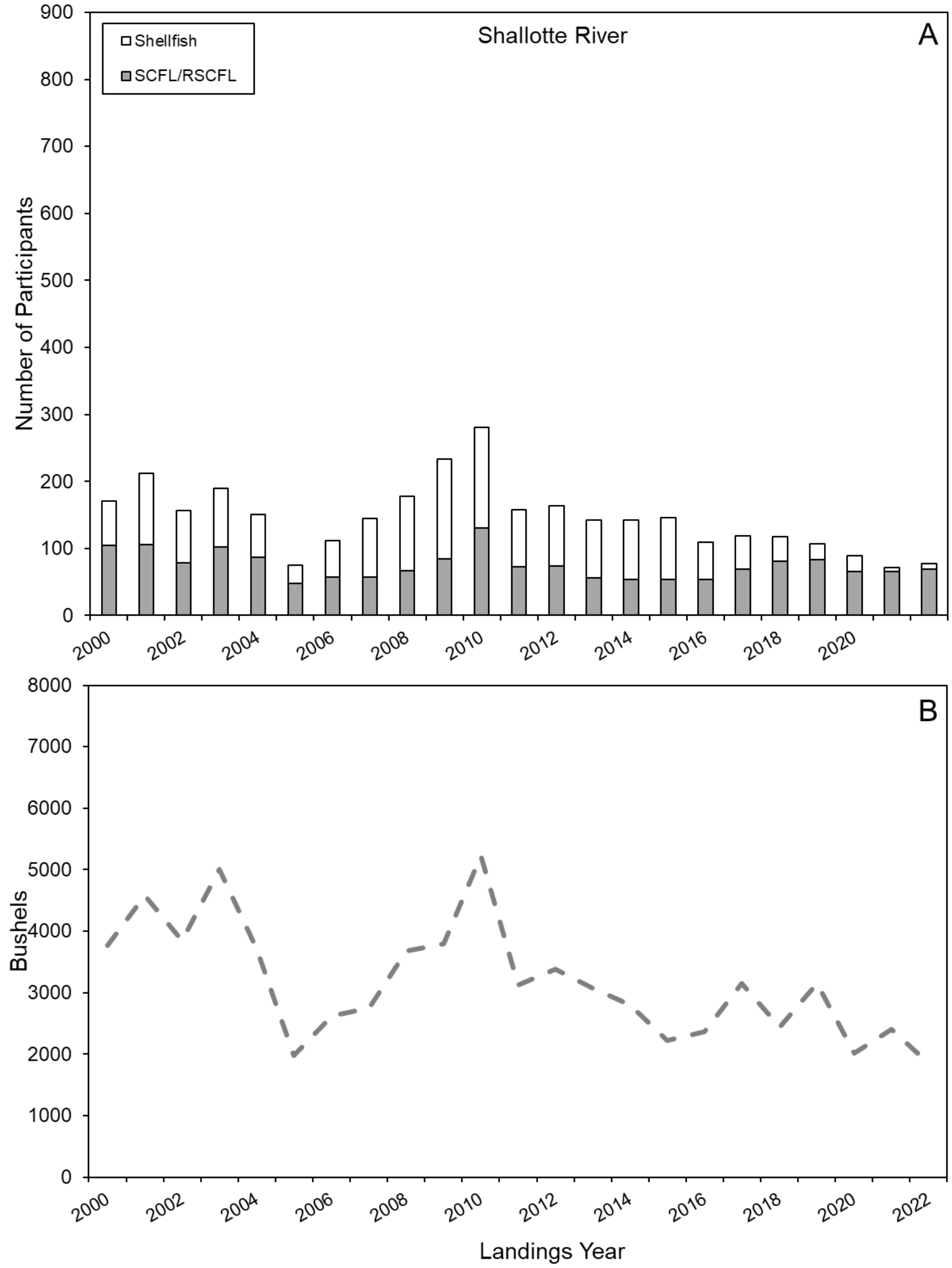

Figure 3.5. (A) Annual number of participants with oyster landings for Shallotte River, the entire bar height shows total number of participants, with the proportion of participants with Shellfish Licenses shown as white, and the proportion with SCFL/RSCFL shown as grey. (B) Total commercial landings of oyster in bushels by year for the Shallotte River.

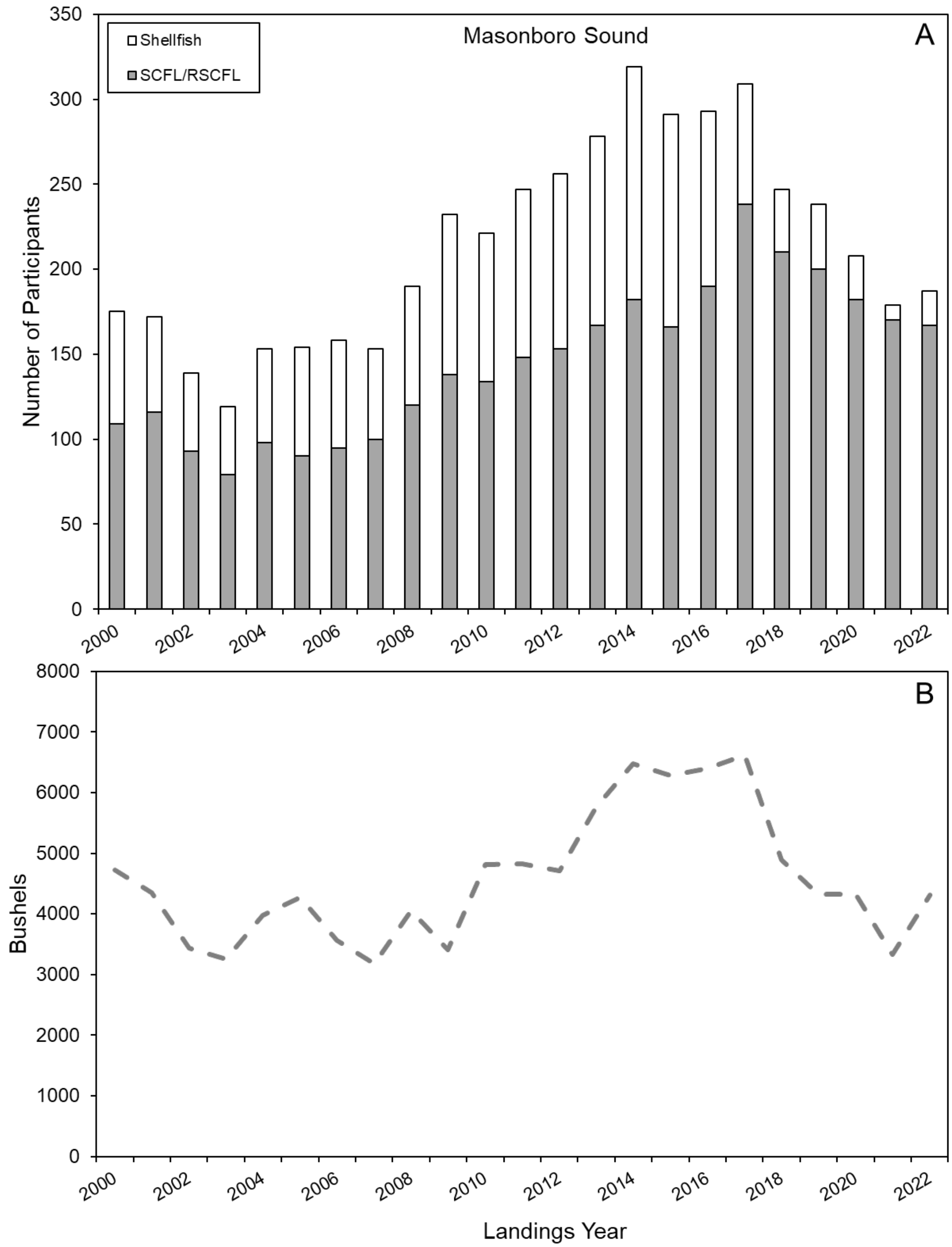

Figure 3.6. (A) Annual number of participants with oyster landings for Masonboro Sound, the entire bar shows total number of participants, with the proportion of participants with Shellfish Licenses shown as white, and the proportion with SCFL/RSCFL shown as grey. (B) Total commercial landings of oyster in bushels by year for Masonboro Sound.

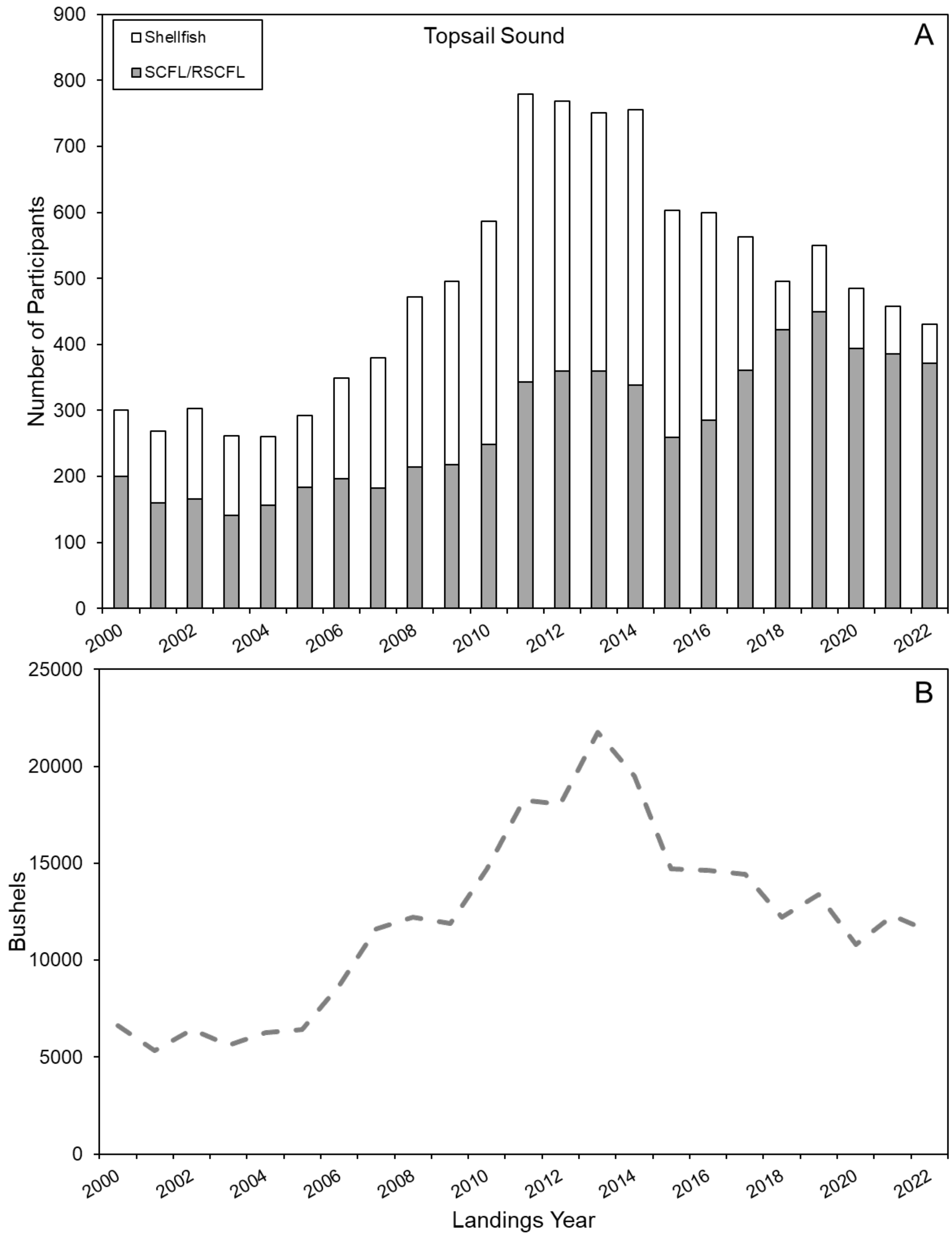

Figure 3.7. (A) Annual number of participants with oyster landings for Topsail Sound, the entire bar height shows total number of participants, with the proportion of participants with Shellfish Licenses shown as white, and the proportion with SCFL/RSCFL shown as grey. (B) Total commercial landings of oyster in bushels by year for Topsail Sound.

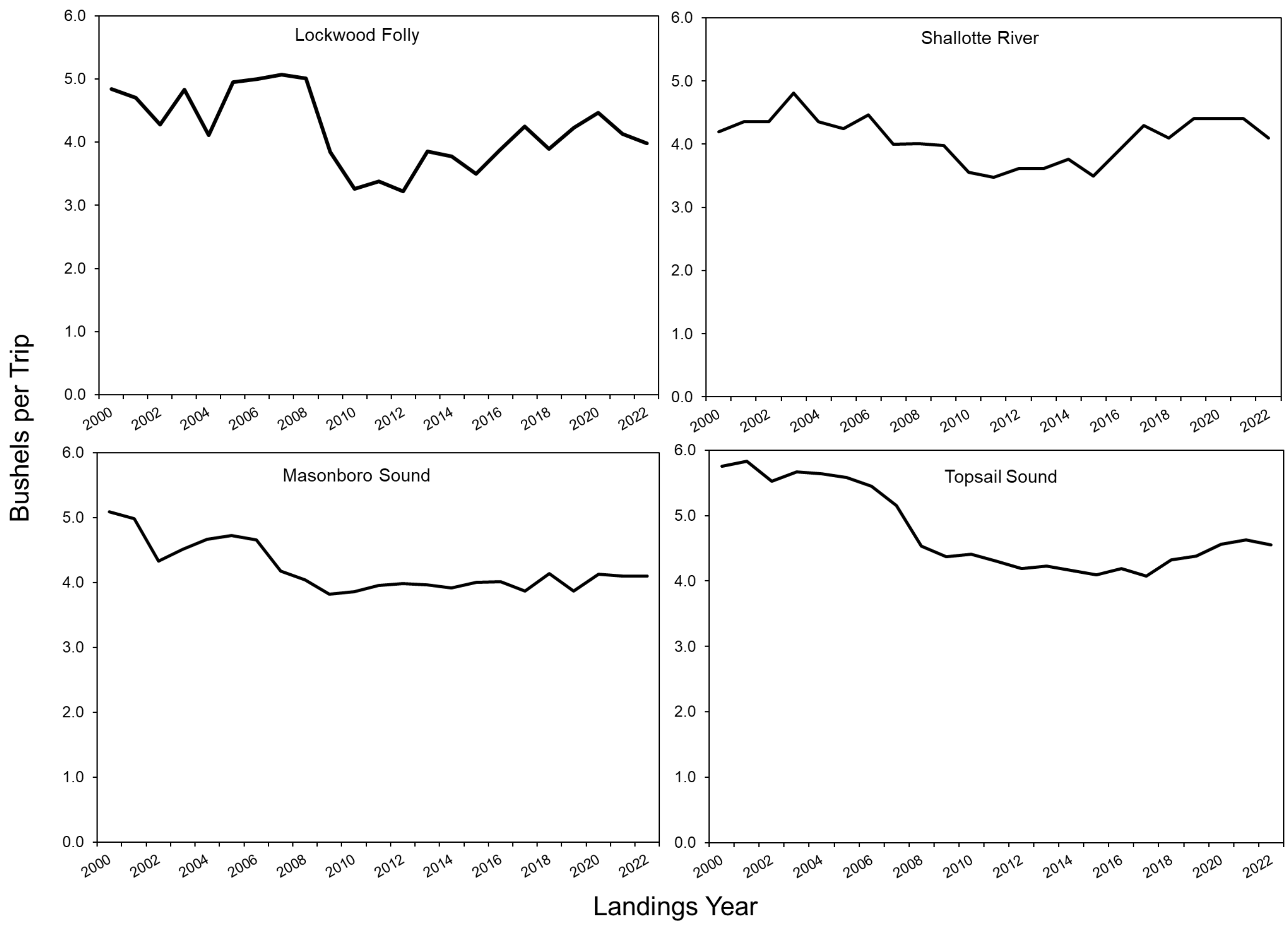

Figure 3.8. The catch-per-unit-effort (CPUE) for oyster commercial harvest in Lockwood Folly River, Shallotte River, Masonboro Sound, and Topsail Sound from 2000 to 2022. The black line represents the average annual bushel amount landed per trip for SCFL/RSCFL holders, separated by waterbody into individual panels.

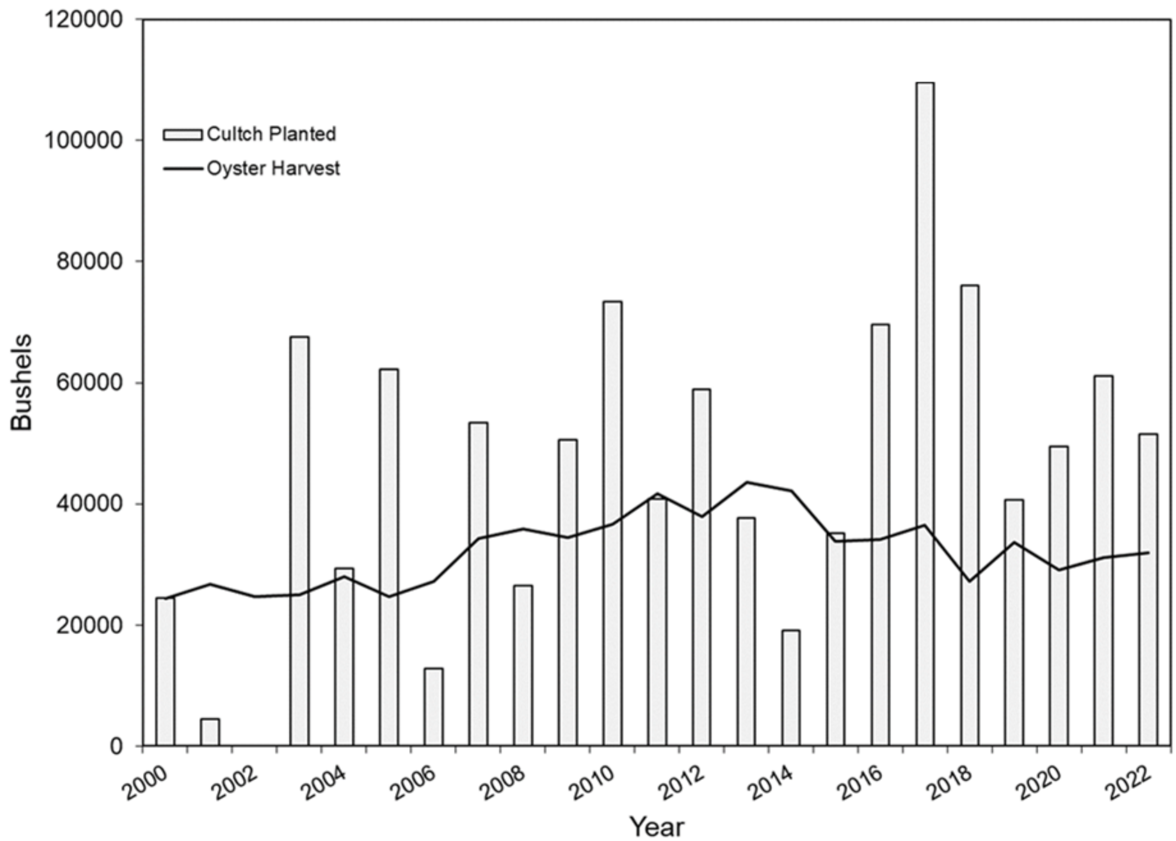

Figure 3.9. Annual bushels of cultch planted (gray bars) and commercially harvested oysters (as black line) for the southern region (waterbodies south of Bogue Sound).

AUTHORITY

<u>N.C. General Statute</u>

113 134	Rules
113 182	Regulation of fishing and fisheries
113-201	Legislative findings and declaration of policy; authority of Marine Fisheries Commission.
113221.1	Proclamations; emergency review
143B-289.52	Marine Fisheries Commission – powers and duties.

<u>N.C. Rule</u>

North Carolina Marine Fisheries Commission Rules (15A NCAC)

03K .0201	Open Season and Possession Limit
03K .0202	Size Limit and Culling Tolerance

DISCUSSION

Landings in the intertidal hand harvest commercial oyster fishery in the southern region of North Carolina tend to generally follow trends in effort/participation, with periods of higher participation resulting in greater landings. Without fishery independent indices of oyster abundance, it is unclear whether fluctuations in oyster abundance influence or are influenced by effort in the fishery. Trends in CPUE indicate that periods of greater effort/participation result in lower annual average bushels landed per trip (Figures 3.2 & 3.3). This may be interpreted as when the oyster resource can support the amount of harvest pressure exerted, fishers are able to easily land a full limit of oysters each trip. As the oyster resource becomes impacted by additional harvest pressure, it becomes harder for all fishers to land a full limit each trip, and the average number of bushels landed per trip decreases. Because exposed intertidal oysters are relatively easy to find and harvest, reefs in the southern region are at risk of suffering impacts due to harvest pressure. To prevent excessive damage to these reefs, a minimum size limit of 3 inches was established. This rule ensures smaller mature oysters are left unharvested and can remain as breeding stock or sites for future oyster recruitment. As reefs become depleted of legal sized oysters during the harvest season and greater effort is required to find legal oysters, fishers generally move to more productive areas. As participation in the fishery increases, harvesters may have trouble finding areas with legal oysters and be willing to exert more effort to thoroughly harvest one reef, causing greater damage to the resource.

Considering the rising effort and declining CPUE observed in the southern region before development of the Oyster FMP Amendment 4 in 2015, the NCMFC chose management strategies focused on curbing the increase in effort from Shellfish License holders. This sector of the oyster fishery is potentially open to all state residents and was experiencing rapid growth. To limit landings and effort from the Shellfish License holders, in October of 2017 the bushel limit was reduced from five bushels per day to two only for those license holders. After this was implemented, the number of trips made by Shellfish License holders in the region quickly dropped, resulting in a lower overall effort (Figure 3.2). Some Shellfish License holder participants transitioned to a SCFL, resulting in a slight increase in average SCFL/RSCFL trips and participants from 2018 onward when compared to years prior to the limit reduction. In all four waterbodies examined, number of participants with Shellfish Licenses dropped notedly after 2017 (Figures 3.4 – 3.7). This management approach appeared to have the desired effect on the region, decreasing overall commercial oyster effort (Figure 3.2). Additionally, CPUE for the region increased in the years following 2017 (Figure 3.3). When CPUE is examined on a waterbody scale, Lockwood Folly and Shallotte Rivers show increasing trends, while CPUE in Masonboro and Topsail Sounds has remained relatively consistent (Figure 3.8), indicating effort may remain elevated despite some reduction in participation.

In the southern region, 1.42 times more bushels of cultch material have been planted compared to bushels of oysters commercially harvested between 2000 and 2022. While the cultch planting program in this region is not designed to function as direct replacement for oysters harvested in this region, the goal is to at least mitigate the amount of shell removed by commercial harvest and provide adequate substrate for oyster spat to settle. On a regional scale, the cultch planting program has been able to keep up with or exceed the amount of shell removed from the system via harvest overall. However, due to logistical constraints the cultch material is not distributed across all waterbodies, creating localized cultch surpluses and deficits when compared to harvest amounts. Recent cultch planting locations in the southern region have been limited to areas near one of two current cultch stockpile locations, Mile Hammock Bay (Onslow County), or Morris Landing (Onslow County). With deployment of the R/V Oyster Creek for the 2024 cultch planting season, cultch planting efforts in the southern region can be extended to sites in Pender, New Hanover, and Brunswick counties. Cultch planting efforts statewide are reliant on continued funding.

With implementation of the fishery independent sentinel site monitoring program for intertidal oysters in the southern region, the NCDMF will be able to use trends in oyster abundance and changes in demographics to inform future management options. This program will need several years of data collection before indices can be created and trends can be used to inform management decisions. Management strategies informed by this new program can be developed in a future amendment to the Eastern Oyster FMP.

Appendix 4: Habitat & Enhancement Oyster Programs Information Paper

ISSUE

Provide further context behind current shellfish rehabilitation programs to be used in leveraging management strategies regarding subtidal oysters in Pamlico Sound, North Carolina.

ORIGINATION

The Blue-Ribbon Advisory Council on Oysters (BRACO, 1995), the North Carolina Division of Marine Fisheries (NCDMF) Oyster/Clam Plan Development Team (PDT).

BACKGROUND

The North Carolina Eastern Oyster FMP Amendment 5 is focused on management of wild oysters, and this information paper does not pertain to farm raised or private cultured oysters.

Oyster reefs can be likened to coral reefs as successive generations build on top of the calcium carbonate remains left by their predecessors. This process adds spatial complexity to the oyster reef habitat, creating colonization space, refuge, and foraging substrate for many economically important fishes and invertebrates in these estuarine environments (Arve 1960; Bahr and Lanier 1981; Zimmerman et al. 1989; Lenihan and Peterson 1998). Furthermore, as prolific filter feeders, reefs with dense oyster assemblages can affect phytoplankton dynamics and water quality, which can be beneficial to submerged aquatic vegetation (SAV) and reduces excessive nutrient loading that could otherwise lead to hypoxic conditions (Thayer et al. 1978; Newell 1988, Everett et al. 1995; Newell and Koch 2004; Carroll et al. 2008; Wall et al. 2008). Oyster reefs may also offer a degree of shoreline stabilization, protecting coastline habitats such as marshes (Coen et al. 2007). In sum, oyster reefs offer an array of ecosystem services that directly benefit the coastal communities living alongside them. The annual value of the services provided by oyster reefs has been estimated to be between $10,325 and $99,421 per hectare (Grabowski et al. 2012).

However, as a result of heightened demand, decades of intensive pressure from harmful fishing practices diminished oyster habitat, resulting in an 85% loss of oyster reef habitat worldwide (Rothschild et al. 1994; Lenihan and Peterson 1998). Additional anthropogenic stressors including increased nutrient runoff, declining water quality, and increased sediment loads have exacerbated the decline of oyster reefs (Lenihan and Peterson 1998). In North Carolina, historical data show a decline in oysters and decreased water quality following the introduction of the oyster dredge (Marshall 1995). Such harvesting practices result in the removal of vital oyster shell substrate, which serves as the foundation for subsequent generations, leaving many remaining populations functionally extinct (Gross and Smyth 1946; Rothschild et al. 1994; Kirby 2004; Beck et al. 2011). As subtidal oyster populations have declined, so has the quality and availability of shell and hard bottom substrate, limiting the ability of oyster larvae to settle and build upon degraded reefs.

In response to rapid global declines and subsequent low harvest rates, resource managers and researchers identified habitat restoration as the best management practice to combat reef loss from harmful harvesting practices (Brown et al. 2013). Subtidal oyster restoration often involves replenishing settlement substrate removed during harvest, protection of broodstock from harvest (e.g., no-take reserves), or a combination of both (Coen and Luckenbach 2000; Powers et al. 2009; Schulte et al. 2009).

In North Carolina, state officials recognized early on the importance of restoration in the face of a declining fishery. In response to rapidly declining harvests, the Fisheries Commission Board began the Cultch Planting Program in 1915 to rebuild oysters by planting shells for substrate (cultch) and seed oysters on sites that would later be available for harvest. The North Carolina Division of Marine Fisheries (NCDMF) oversees the Cultch Planting Program as it continues today as one of the oldest and most extensive oyster restoration efforts in the country.

In 1996, the NCDMF sought to integrate no-take reserves into restoration efforts via establishment of the Oyster Sanctuary Program. The primary goal was to improve oyster sustainability by developing a large, self-sustaining network of no-take reserves that support oyster brood stock and ultimately supply wild harvest reefs and cultch sites with viable larvae. North Carolina has 17 protected oyster reefs encompassing 789 acres within the Oyster Sanctuary Network throughout Pamlico Sound. The goal of creating a self-sustaining network of oyster larvae “sources” and “sinks” illustrates how NCDMF’s Sanctuary and Cultch Programs serve as complements to one another in its shellfish rehabilitation strategy.

Among the management strategies implemented within the oyster fishery, NCDMF also recognizes the effectiveness and importance of continued habitat restoration efforts. Today these supplementary strategies are carried out by NCDMF's Habitat and Enhancement Section. Together the Cultch and Sanctuary programs help NCDMF achieve its goal of promoting sustainable fisheries by creating oyster habitat. The benefits of these programs are multifaceted as they not only promote an improved oyster stock, but also restore vital ecosystem services including water filtration, increased fish and macroinvertebrate habitat provisions, and food web diversity (Peterson et al. 2003). The Cultch and Sanctuary programs use data-driven approaches to determine subsequent enhancement projects with the aimed benefit of improving oyster habitat throughout North Carolina’s estuaries. This information paper provides detailed information on the history and current methodologies for site selection and monitoring protocols for both programs.

Terminology

While the state of North Carolina has been creating artificial reefs since the 1970s, not all reefs serve the same purpose. Of the 72 artificial reefs, only 17 are oyster sanctuaries. It is important to distinguish that while all artificial reef habitat is considered “reef,” not all reefs are considered “sanctuary.” The term “oyster sanctuary” refers to reefs protected from oyster harvest and some bottom disturbing gears through North Carolina Marine Fisheries Commission (NCMFC) rule 15A NCAC 03K .0209. It is also important to consider that created habitat within sanctuary boundaries always exists as a collection of separate reef habitat patches. Therefore, sanctuaries are sometimes referred to as reef sites. In most cases concerning reef sites managed by the Oyster Sanctuary Program, the entire reef site authorized by state and federal permits is protected from oyster harvest. Therefore, the terms “reef,” “sanctuary,” and “reef site” are often used interchangeably. Conversely, the term “cultch site” refers to any site where a thin layer of material (recycled shell or marl limestone #4) has been laid out with the intention of creating oyster habitat open to harvest.

Site Selection Methodology

The NCDMF’s Shellfish Rehabilitation program aims to incorporate sound science into both the Cultch and Sanctuary programs to maximize cost-effectiveness of material acquisition and oyster production. Data from shellfish monitoring efforts and historical environmental data are incorporated into the site selection process. This approach utilizes a habitat suitability index (HSI) model, which considers several environmental variables that influence oyster survivability.

When building an HSI model for Pamlico Sound, for instance, the waterbody is divided into approximately 6,000 individual one square kilometer squares. Each square receives a value for the variables used in the model. The variables are weighted and averaged to calculate a total score that indicates the relative habitat suitability for oysters. Variables may either be “exclusionary” or “threshold” layers. Exclusionary variables are binary (the square may be assigned a 0 or 1) and include variables such as depth, shellfish lease areas, and military exclusion zones. Threshold variables are scaled on an optimum and include salinity, dissolved oxygen, and larval dispersal patterns. For more information on the methodology used in the first iteration of the HSI for Pamlico Sound, refer to Puckett et al. (2018).

The HSI is used in tandem with a broadscale multiyear permit from the US Army Corps of Engineers (Nationwide 27). The Nationwide 27 (NW 27) is renewed every five years and grants the state 200 acres combined of acceptable inland water for oyster restoration. This permit restricts reef material from being planted in areas with Submerged Aquatic Vegetation (SAV) or existing natural shellfish populations to prevent destruction of important established habitat. Desirable areas found within the constraints of the NW 27 and HSI are then considered depending on logistic variables such as distance from cultch material stockpile sites. Staff further ground-truth proposed sites to ensure permit compliance and physical suitability for cultch planting. Surveys are also sent to commercial fishers to solicit public input and comment.

CULTCH PLANTING PROGRAM

For over a century, the NCDMF has worked to create cultch reefs to alleviate fishing pressure on North Carolina’s natural oyster reefs. Research has demonstrated the ability of cultch planted reefs to support significant oyster densities over time, with cultch sites hosting 9.6 times more oysters than natural subtidal reefs found throughout Pamlico Sound (Peters et al. 2017). Perhaps even more indicative of their effectiveness as a fisheries management strategy, North Carolina’s cultch reefs were found to have 4.5 times more legal sized oysters than on natural oyster reefs (Peters et al. 2017). Since its inception, over 21 million bushels of cultch material have been planted in the form of small-scale, low-relief, harvestable oyster reefs (Figure 4.1). The program has been a longstanding collaboration between state government and local oyster harvesters to ensure cultch reefs are built in the best available locations for oyster recruitment.

Program History: The First 100 years of Cultch Planting

The Cultch Program began with state funding to plant up to 12,000 bushels of shell each year from 1915 to 1920. After initial success and apparent rebound in harvests, additional state funding allowed the program to scale up and plant around 100,000 bushels of seed oysters and substrate in the early 1920s. Harvest statistics show a rebound in landings from 1923 to 1931 with landings ranging from 326,659 to 441,307 bushels. However, harvest numbers began to decline between 1932 and 1934, reaching a low of 271,192 bushels. The state then doubled its efforts, planting 825,000 bushels of seed oysters and 78,567 bushels of shell in the largest oyster enhancement project at the time. These planted areas were closed until 1936. Upon reopening those areas, oyster harvest more than doubled to 651,050 bushels in 1936.

However, in the following decade, no significant investments were made to rebuild the oyster stock with the events of World War II. During this period, harvest declined significantly until the end of the War in 1945. Soon after, Governor Cherry created a special oyster commission in 1946. The legislation resulting from the commission's recommendations contained landmark changes in oyster management, including appropriated funds and several provisions for supporting the renewed oyster enhancement effort—the Shellfish Rehabilitation Program (later named the Cultch Planting Program). Among these provisions were the following: 1) a continuation of large-scale planting shell and seed oyster planting efforts; 2) an oyster tax to support the program; 3) a requirement that 50% of the shell from shucking operations be contributed to the program; and 4) a $0.50 per bushel tax on shell stock shipped out-of-state. The first ten years of the program saw 838,000 bushels of shell and 350,734 bushels of seed oysters planted.

By the mid-1950s, appropriated funds had been exhausted while the shell tax collection had not increased. Furthermore, up until this point fishers had been employed to carry out enhancement activities, putting additional financial stress on the program. Harvest numbers fluctuated from 149,489 to 331,472 bushels during this time. To alleviate costs, the state purchased a 40-foot wooden barge and began deploying material on its own in 1954. In 1956, a request for an $80,000 annual appropriation was approved by the N.C. General Assembly, allowing oyster enhancement efforts to increase to 500,000 bushels per year. Oyster harvest remained greater than 200,000 bushels each year until 1962. A state report would later conclude that fluctuating harvest numbers were likely the result of repeated severe hurricanes, which would have negated most oyster rehabilitation efforts conducted since 1947 (Munden 1981).

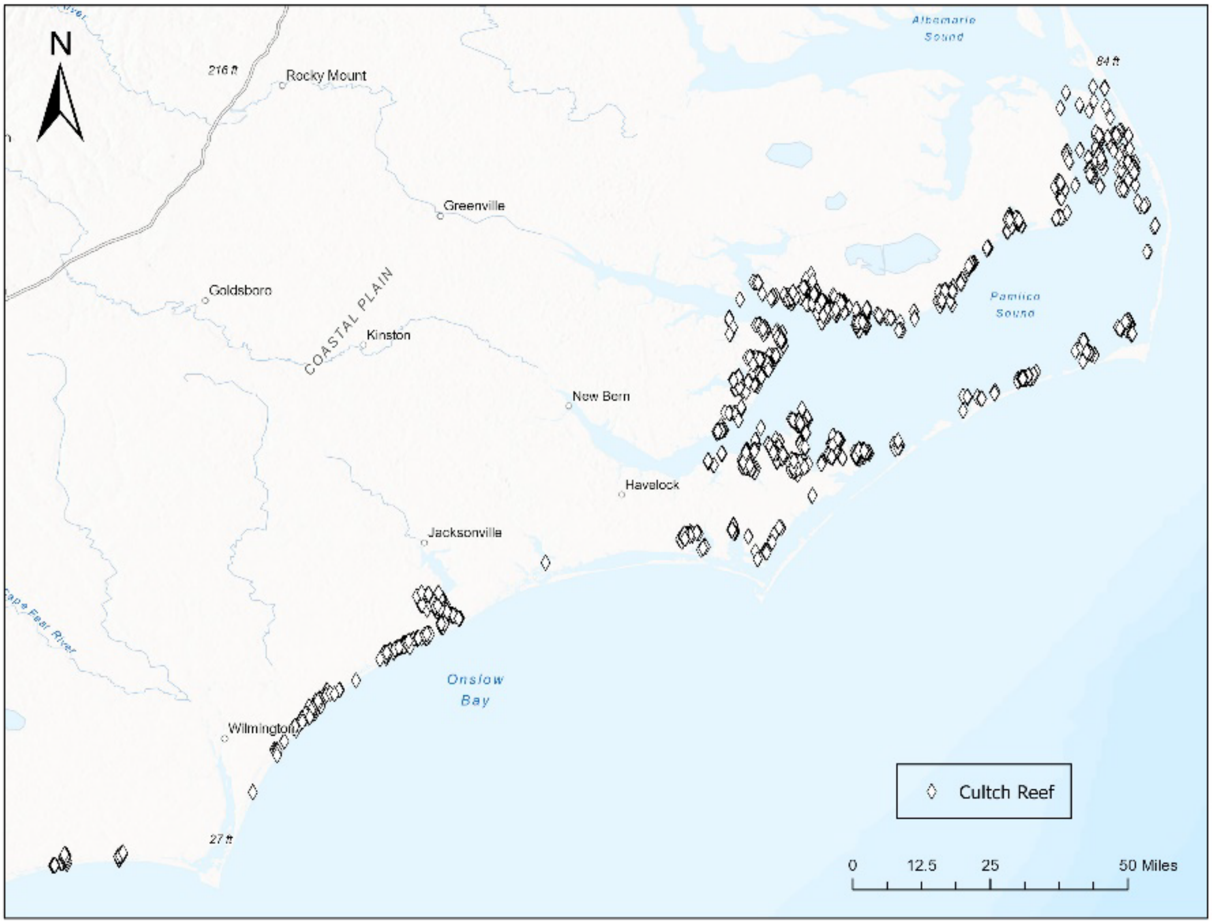

Figure 4.1. Map of cultch reefs planted between 1981–2022 from Dare County to the South Carolina border.

In the 1970s, new approaches and strategies to rebuild the oyster stock were undertaken with the state budget increasing appropriations for enhancement activities several times throughout the decade. For instance, the Cultch Program began acquiring its own barges and equipment and hired support staff for the next few decades. Additionally, the program received a grant from the Coastal Plains Regional Commission in 1980 along with state appropriations that allowed it to pay for its operations, including the procurement of two large surplus military landing crafts that were repurposed to deploy shells. In the following two years, more than 700,000 bushels of substrate were planted. During this period, oyster harvest peaked in 1987 at 226,283 bushels before declining significantly, not exceeding 100,000 bushels through 2008. Meanwhile, continued state appropriations allowed the program to deploy 250,000 bushels of substrate each year until 1997.

In 1998, the legislature revised the Cultch Program, namely by appropriating an annual budget of approximately $300,000 for purchasing and transporting cultch material. This equated to planting 30–40 acres of harvestable oyster reefs each year. In fiscal year 2015–2016, funds for cultch increased to approximately $600,000; then increased again in fiscal year 2016–2017 to $900,000. In recent years, annual appropriations for the program have increased to over $1 million in some years to cover the cost of substrate, staffing, and vessels. Increases in appropriations resulted in substantial increases in annual deployments and investments in much needed modernization and improved efficiencies of fleet equipment.

The approach and methodology used by managers for cultch planting have remained consistent since 1998. Planting sites were selected based on input from local fishers, historical production, and environmental criteria (bottom substrate type, salinity, currents, and historical production). These variables were used to weigh possible effects of fishing operations in the area before deciding on a new cultch planting site. While NCDMF vessel crews typically deploy shell and small marl limestone (4) rock, other methods were explored with varying levels of success, such as hiring fishers to gather and transplant seed oysters and hiring marine contractors for deployments. Additionally, managers experimented with site size in an effort to maximize deployment efficiency and fishery impact. The result meant fewer total sites planted per year but saw an improvement in integrity and effectiveness of cultch reefs as large as 10 acres.

Monitoring efforts to quantify the performance of cultch sites was typically limited to a three-year period post-construction. The NCDMF would survey each cultch planting site to observe trends in population demographics (annual recruitment, size frequency, and population density). However, monitoring of cultch planting sites beyond three years was not conducted due to resource limitations. Initial cultch reef sampling was conducted using imperfect methodology, including small sample sizes, variable sampling intervals, and uncertain area estimates covered by the dredge, all of which made estimating densities and size class distribution difficult and not standardized.

Modern Cultch Planting Program: 2020 – Present

The goals defined by internal Cultch Planting Program documentation are as follows: 1) to provide suitable substrate for the attachment of natural oyster larvae, and 2) to increase oyster production. The Cultch Planting Program relieves harvest pressure from degraded natural reefs by developing permanent and routinely managed areas. In 2020, NCDMF hired the first biologist dedicated solely to the Cultch Planting Program with an objective to update and standardize site selection and sampling processes. The NCDMF currently plants between 300,000 and 400,000 bushels of cultch material annually, covering over approximately 40 acres of undeveloped inshore bottom (Table 4.1).

Data from the Cultch Planting Program are divided into three monitoring programs: P600 (cultch planting), P610 (spatfall evaluation), and P627 (trigger sampling). P600 records location, type, and amount of material planted annually across the state. This is used to update the public facing interactive cultch map, allowing commercial oystermen to find cultch reefs. The current Nationwide 27 Permit limits materials that can be used for cultch planting to oyster shell, crushed concrete, and limestone marl. Of these materials, limestone marl is readily available and cheapest.

Recycled oyster shells are a well-known valuable resource for oyster restoration but remain in short supply in the state. Other states, including Virginia and Maryland, have legislative-backed shell recycling programs that offer tax credits and incentives to businesses in exchange for oyster shells. Growing demand has increased the price of oyster shell and subsequently resulted in shell being exported out of North Carolina. Without sufficient incentives or funding, shell has become a rare resource for restoration efforts, further limiting cultch planting efforts to marl and concrete materials.

P610 monitors cultch enhanced reefs for three years post-planting. Hydraulic tongs are used to collect random point samples within a cultch site. The oysters are counted and measured to determine spat recruitment rates and mortality metrics. The data collected under P610 provides insight into oyster spat recruitment and once analyzed could be incorporated into a future state oyster stock assessment.

Peer-reviewed research has also independently quantified oyster recruitment on cultch sites. For instance, cultch reefs successfully hosted 4.5-times more legal oysters than natural reefs where no restoration effort had occurred (Peters et al. 2017). On average, cultch sites had 27 legal oysters (≥3 inches) per square meter (Peters et al. 2017). With 27 legal oysters/m^2 on cultch material, a conservative estimate suggests that one acre of harvestable cultch reef should yield approximately 368 bushels of legal oysters (300 oysters/bushel).

P627 trigger sampling occurs in the fall and lasts the duration of the commercial oyster mechanical harvest season. Pre-season sampling serves as a baseline for mechanical harvest areas in the Pamlico Sound. Once the season is open, monitoring occurs throughout the season to ensure the legal catch does not fall below an allowable threshold. For further details on P627 (trigger sampling), refer to Supplement A and Appendix 2 (Mechanical Oyster Harvest Management Issue Paper). Methodology for P627 is subject to change regardless of selected management strategies following adoption of Amendment 5 to the Eastern Oyster FMP.

Cultch for Future Management

Throughout the course of the Cultch Planting Program's history, the acquisition and deployment of materials has been limited by funding, which has been inconsistent. Yet, with growth of the program in the last decade, there is potential for the Cultch Program to become an integral strategy to meet the goal and objectives of the Eastern Oyster FMP. An example strategy for the Cultch Program is further outlined in Appendix 2: Mechanical Oyster Harvest Management Issue Paper, specifically with a proposed rotational harvest management plan. It is worth noting that Virginia utilizes a rotational harvest system as a management strategy in tandem with oyster restoration efforts.

Additionally, with monitoring of cultch sites post-construction, useful oyster metrics can be analyzed and used for development of a stock assessment in the future. However, the utility of data collected from cultch sites can be further maximized if harvest locations on trip tickets are categorized as cultch or natural reefs. However, consistent funding is required to effectively integrate and anchor the Cultch Program as an effective long-term management strategy.

OYSTER SANCTUARY PROGRAM

Overview

The 1995 Blue-Ribbon Advisory Council on Oysters highlighted the importance of restoring North Carolina's oyster population in Pamlico Sound. Accordingly, the NCDMF responded by incorporating no-take marine reserves into its oyster restoration efforts with the creation of the Oyster Sanctuary Program. No-take marine reserves support increased size and density of target species—for oysters a larger size equates to greater reproductive output (Duran and Castilla 1989; Coen et al. 2007; Lester et al. 2009). The aim of NCDMF's protected subtidal oyster sanctuaries is to supplement larvae to decimated natural oyster reefs and cultch sites throughout Pamlico Sound via the "spillover effect" created by these protected areas with heightened reproductive output (Peters et al. 2017). Secondary objectives of the sanctuaries are to increase the impact of environmental services provided by oysters, and to provide North Carolina residents with relatively accessible recreational fishing and diving opportunities.

The creation and preservation of oyster sanctuaries represent both a long-term, large-scale ecological restoration project as well as a long-term fisheries investment to the state of North Carolina. The network of sanctuaries provides ecosystem services that improve the quality of habitat throughout Pamlico Sound. Sanctuary sites offer nursery habitat for other species, increasing their abundance for commercial and recreational fishing; provide refuge and forage habitat for marine life; form travel corridors for transient finfish; and increase water filtration, reducing turbidity and excess nutrients in the estuary. The impacts of sanctuary sites expand far beyond their boundaries as brood stock populations supplement the growth of natural reefs and cultch sites. Furthermore, the necessity of oyster sanctuary construction falls within Recommendation 3.1 in the NC Coastal Habitat Protection Plan source document – "Greatly expand habitat restoration, including creation of subtidal oyster reef no-take sanctuaries" (NCDEQ 2016).

Table 4.1. Bushels (bu.) and acres planted per year by county for the cultch program, 2010–2022.

County		2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	Total
Brunswick	bu.	3,447	24,509	6,294	9,403	4,991	4,053	5,470	-	-	-	-	-	-	58,167
	acres	0.3	0.9	0.7	1.8	1.0	0.7	3.2	-	-	-	-	-	-	8.5
Carteret	bu.	53,741	5,470	93,943	23,440	43,756	48,889	81,725	-	35,234	46,112	88,857	70,576	13,276	593,909
	acres	17.8	2.7	20.1	5.4	11.5	10.5	13.6	-	5.9	12.0	11.4	7.3	1.0	119.2
Dare	bu.	41,501	71,226	39,156	37,856	32,428	22,829	48,251	70,516	43,257	80,342	50,359	55,057	71,120	663,898
	acres	2.8	7.0	4.2	2.7	3.8	2.5	4.7	6.0	4.2	8.0	4.1	9.8	10.0	69.8
Hyde	bu.	32,104	44,071	62,324	46,908	108,261	48,889	114,583	73,832	21,179	76,992	85,423	62,100	79,863	856,529
	acres	6.2	9.1	6.3	9.5	10.8	5.7	12.8	7.9	1.8	8.4	9.9	6.7	10.0	105.1
New Hanover	bu.	2,611	2,244	-	8,385	-	4,059	-	-	-	-	-	-	-	17,299
	acres	1.2	0.4	-	5.2	-	2.8	-	-	-	-	-	-	-	9.6
Onslow	bu.	65,176	21,198	50,960	19,800	14,119	27,073	82,996	109,634	56,444	40,696	49,524	64,916	90,767	692,300
	acres	48.7	2.0	32.5	12.7	8.1	11.6	41.3	24.2	12.6	23.6	7.2	9.0	11.0	244.5
Pamlico	bu.	14,372	35,738	22,002	11,885	28,863	54,479	91,815	79,331	38,676	47,696	80,162	84,656	53,625	643,300
	acres	4.8	8.3	5.1	2.6	3.7	8.0	12.9	10.1	6.7	6.2	9.9	6.7	10.0	95.0
Pender	bu.	-	-	-	-	-	-	3,687	-	-	-	-	-	-	3,687
	acres	-	-	-	-	-	-	1.6	-	-	-	-	-	-	1.6
Total	bu.	212,952	204,456	274,679	157,677	232,418	210,271	428,527	332,313	183,680	291,838	354,322	337,305	308,651	**3,529,089**
	acres	81.8	30.4	68.9	39.9	38.9	41.8	90.1	48.2	31.2	58.2	42.5	39.5	42.0	**653.4**

Various research projects and analyses have been conducted to quantify the intended performance of North Carolina's oyster sanctuaries as larvae production sites and their overall economic benefit to the state. It has been estimated that one out of every four larvae settled on commercially harvested oyster reefs (natural or cultch) in Pamlico Sound originated from an oyster sanctuary (Peters et al. 2017). Furthermore, an independent economic analysis estimated that for every dollar invested in oyster sanctuaries, there was $4 return in the form of economic opportunity or ecosystem services (RTI International 2016). By 2026, the Oyster Sanctuary Program will be comprised of 17 sanctuary sites, totaling 789 permitted acres. With an additional 140,000 tons of marl limestone and granite planned for deployment at Maw Point and Brant Island combined, there will be over 373,000 tons of aggregate material used for the creation of protected oyster reef habitat in Pamlico Sound by 2026 (Figure 4.2; Table 4.2).

Legislation and Rules

As part of the 2008 Oyster Fishery Management Plan Amendment 2, the NCMFC moved the protection of oyster sanctuaries from proclamation into rules 15A NCAC 03K .0209 and 03R .0117, Oyster Sanctuaries, which in effect prohibits the harvest of oysters and use of trawls, long haul seines, and swipe nets in sanctuary boundaries, thereby promoting growth and enhancing survivability of large oysters within the sanctuary sites. Oyster sanctuaries under construction but not yet incorporated into 15A NCAC 03R.0117 can be protected under Rule 15A NCAC 03H .0103 and 03K. 103 through proclamation authority.

In the 2014 legislative session, the North Carolina General Assembly established the Senator Jean Preston Oyster Sanctuary Network (Figure 4.2). This was done "to enhance shellfish habitats within the Albemarle and Pamlico Sounds and their tributaries to benefit fisheries, water quality, and the economy…achieved through the establishment of a network of oyster sanctuaries, harvestable enhancement sites, and coordinated support for the development of shellfish aquaculture."

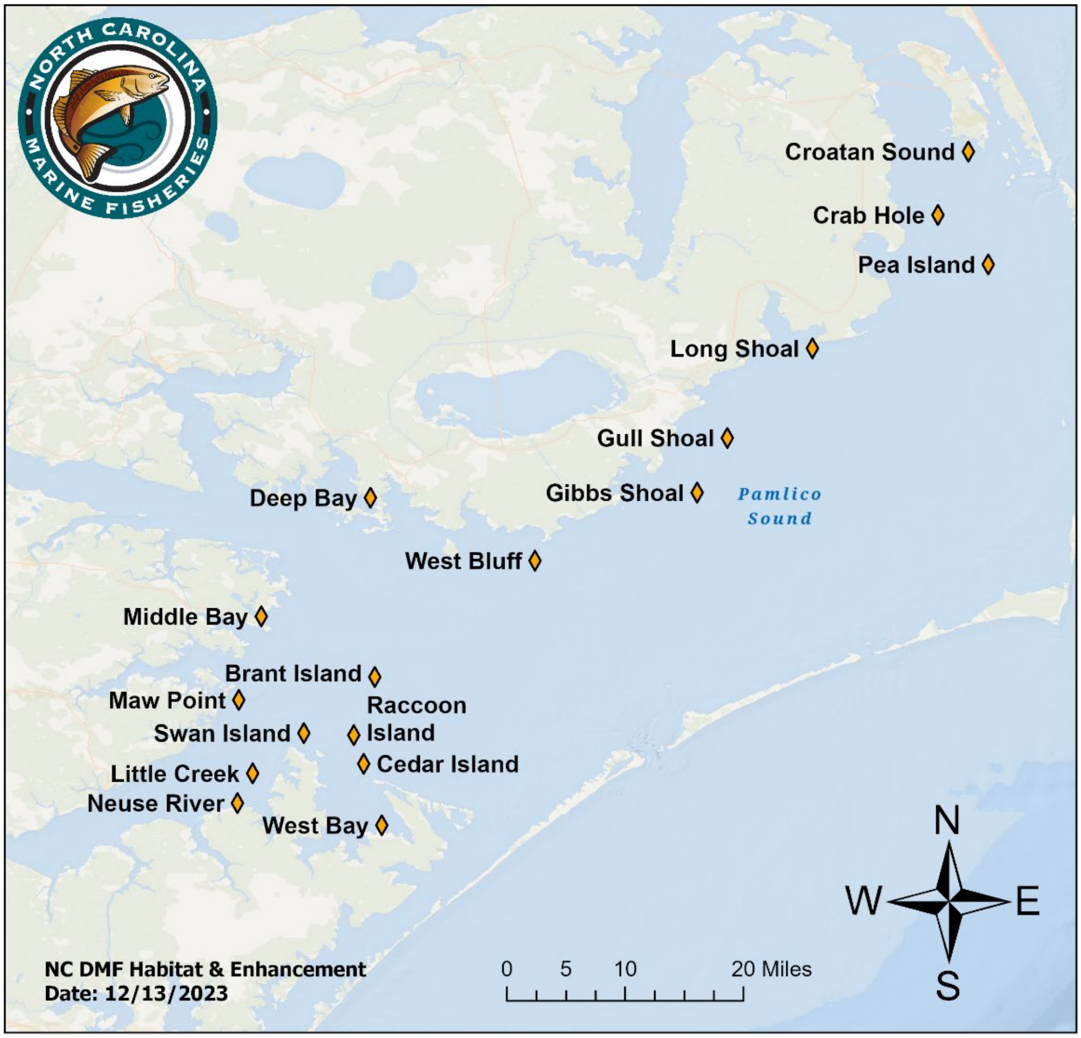

Figure 4.2. Jean Preston Oyster Sanctuary Network, Pamlico Sound, NC.

Table 4.2. A comprehensive list of North Carolina's Oyster Sanctuaries (OS) found throughout Pamlico Sound. Permit area refers to the total protected boundary area delineated by rule or proclamation. Developed habitat area includes material footprints and surrounding unconsolidated soft bottom, whereas habitat footprint area refers to the cumulative total area of reef patches only, not to include unconsolidated soft bottom. For example, Croatan Sound Oyster Sanctuary has 3.10 acres of habitat within the overall boundary of 7.73 acres, meaning 4.63 acres of the site do not have habitat material present, but harvest is prohibited within the entire site.

OS Name	Permit Area (Acres)	Developed Habitat (Acres)	Habitat Footprint (Acres)	Aggregate Material (Tons)	Year Established	Most Recent Addition	Materials
Croatan Sound	7.73	7.73	3.10	2,093	1996	2013	Marl, Reef Balls, Clam Shell, Oyster Shell
Deep Bay	17.20	17.20	4.15	1,749	1996	2014	Marl, Reef Balls, Clam Shell, Oyster Shell
West Bay	6.57	6.57	2.27	2,329	1996	2014	Marl, Reef Balls
Crab Hole	30.52	30.52	13.26	36,489	2003	2009	Marl
Middle Bay	4.59	4.59	0.27	900	2004	2004	Marl
Neuse River	11.21	11.21	3.55	7,357	2005	2008	Marl
West Bluff	29.42	9.97	2.82	10,162	2005	2013	Marl, Reef Balls
Gibbs Shoal	54.69	54.69	8.19	22,447	2009	2013	Marl, Reef Balls
Long Shoal	10.01	6.79	1.13	2,173	2013	2013	Reef Balls
Raccoon Island	9.97	9.97	1.61	1,824	2013	2016	Crushed Concrete, Consolidated Concrete, Reef Balls
Pea Island	46.36	33.9	2.62	3,420	2015	2015	Crushed Concrete, Consolidated Concrete, Reef Balls
Little Creek	20.71	20.71	6.14	5,700	2016	2016	Marl, Crushed Concrete, Basalt, Reef Balls, Granite, Consolidated Concrete
Swan Island	80.32	62.6	10.93	55,000	2017	2021	Marl, Granite
Cedar Island	75.01	70.32	12.43	51,800	2021	2022	Marl, Crushed Concrete
Gull Shoal	158.40	TBD	TBD	36,000	2022	TBD	TBD
Maw Point	126.66	TBD	TBD	TBD	2024	2024	Marl
Brant Island	99.26	TBD	TBD	TBD	2024	2024	Crushed Concrete, Granite
Total	**788.63**	**346.77**	**72.47**	**239,443**			

Funding History

Initially, oyster sanctuaries were built by NCDMF's Artificial Reef Program, which provided funding for materials, and the Shellfish Program, which deployed materials. In 2002, relief money was available from a National Marine Fisheries Service (NMFS) grant for Hurricane Floyd damages. The NCDMF has continued to expand the Oyster Sanctuary Program via funding and collaboration with the North Carolina General Assembly, The Nature Conservancy, National Oceanic and Atmospheric Administration (NOAA), National Estuarine Counsel, Coastal Recreational Fishing Licenses, North Carolina Coastal Federation, and other mitigation sources. These funds have been used to cover material purchasing and deployment costs.

Beginning in 2017, and still in effect through 2026, NCDMF entered a partnership agreement with North Carolina Coastal Federation (NCCF) to significantly increase funding availability and deployment efficiency for the construction of multi-year sanctuary projects. From 2017 to 2020, Swan Island (OS-15) was constructed in southern Pamlico Sound encompassing 80 acres. In 2021, NCDMF and NCCF began construction of Cedar Island (OS-16) within a 75-acre site. The most recent plans for further construction include two large sites, both 100+ acres – Maw Point (OS-18) and Brant Island Shoal (OS-19). Funding for these two sites was acquired through a successful NOAA proposal submitted by NCCF.

Additionally, North Carolina's Division of Mitigation Services undertook the task of funding, planning, and constructing an oyster sanctuary site at Gull Shoal (OS-17). Details of this project do not fall under NCDMF supervision; however, it will be incorporated into the OS Network and the NCDMF plans to take over monitoring efforts after five years of post-construction.

Sanctuary Site Selection

Historically, oyster sanctuary construction and site selection were largely dependent upon where historic oyster reefs once existed. By 2014 the Oyster Sanctuary Program placed greater emphasis on establishing a connected oyster network in Pamlico Sound, stemming from research and hydrological models on currents and wind patterns that drive distribution of oyster larvae (Xie & Eggleston 1999; Puckett et al. 2014). To ensure larval connectivity and to further safeguard subtidal oyster populations, new sanctuary sites are selected based on a habitat suitability index (HSI) model for Pamlico Sound. This model weights environmental and biological variables, including dissolved oxygen, salinity, bottom substrate type, tidal flow, larval transport, wave action, and prevailing wind data to determine ideal locations conducive to building long-lasting and effective sanctuaries (Puckett et al. 2018). Planning and logistic constraints are also considered to narrow down potential sites. After determining several areas with high suitability scores, site investigations ground-truth bathymetric and environmental conditions and check for existing oysters or SAV.

Reef Design & Construction

The Oyster Sanctuary Program has utilized various materials to create artificial subtidal oyster reefs, including marl limestone rock, crushed concrete, crushed granite, reef balls, recycled concrete pipe, basalt, and a variety of recycled shell materials. Aggregate materials (marl, concrete, granite, basalt) are large in diameter to deter attempts to illegally dredge sanctuary reefs. Material selection for new sanctuary mounds is both opportunistic and cost dependent. Materials are secured by program staff or by outside partnerships. Environmental factors are taken into consideration for material selection as well. For instance, higher salinity sites may be built with granite or crushed concrete as these materials may be less susceptible to “pest” species such as boring sponge, which may otherwise inhibit sustained oyster growth.

The NCDMF oyster sanctuary reefs have been constructed with the goal of providing vertical relief and structural complexity to oyster populations. Vertical relief and structural complexity contribute to increased flow speed, which enhances mixing of the water column and thus food availability for oysters (Butman et al. 1994). Conversely, oysters on low vertical relief reefs are exposed to greater sedimentation and increased exposure to low dissolved oxygen events (Lenihan and Peterson, 1998; Lenihan 1999). Up until 2017, sanctuaries were designed with clusters of high-relief mounds 3–6 ft in height. More recently, Swan Island, Cedar Island, Maw Point, and Brant Island oyster sanctuaries were designed with parallel ridges arranged in a grid-like pattern. These ridges are approximately 200–250 ft long, 30–40 ft wide, with a height of 4–6 ft (Figure 4.3). This approach increases the efficiency of the permitted areas and may improve the long-term integrity of reef habitat.

Sanctuary material deployments are designed around project objectives and vary widely according to project specifics, such as material type and size, site location, material quantity, funding, sea conditions, etc. As of 2017, reef enhancements are completed by Habitat and Enhancement staff using NC state vessels and with the assistance of contractors. All reef construction activities are subject to local, state, and federal permitting agencies. Any deployment activity must fall within permitted boundaries and environmental restrictions.

Monitoring and Analyses

Each year biologists and technicians conduct SCUBA surveys at each sanctuary across Pamlico Sound to quantify the performance of each site and the materials used in construction. Performance metrics include the following: 1) oyster population and density metrics; 2) material performance as bottom substrate; and 3) material stability over time. Annual monitoring efforts began in 2007, and apart from a few data gaps, have yielded a rare long-term data set on a large scale, long-term ecological restoration project.

Measuring oyster density and size frequencies are some of the most effective ways to assess oyster reef performance (Baggett et al. 2015). NCDMF divers collect random samples for each material type within each sanctuary to measure density and population structure. Insights from oyster population metrics provide insight into material selection and improve site selection for future projects. Side scan sonar of sanctuaries every few years provides further insight into the stability of deployed materials at each sanctuary. For instance, reefs built with recycled shell can persist if heavily colonized by oysters, and oyster growth and recruitment rates exceed mortality and shell degradation. However, constructed shell reefs rapidly degrade if not heavily colonized by oysters and are prone to being displaced in areas of heavy currents (Powell et al. 2006). Heavier and larger materials offer several advantages including long-term persistence and cost-effectiveness.

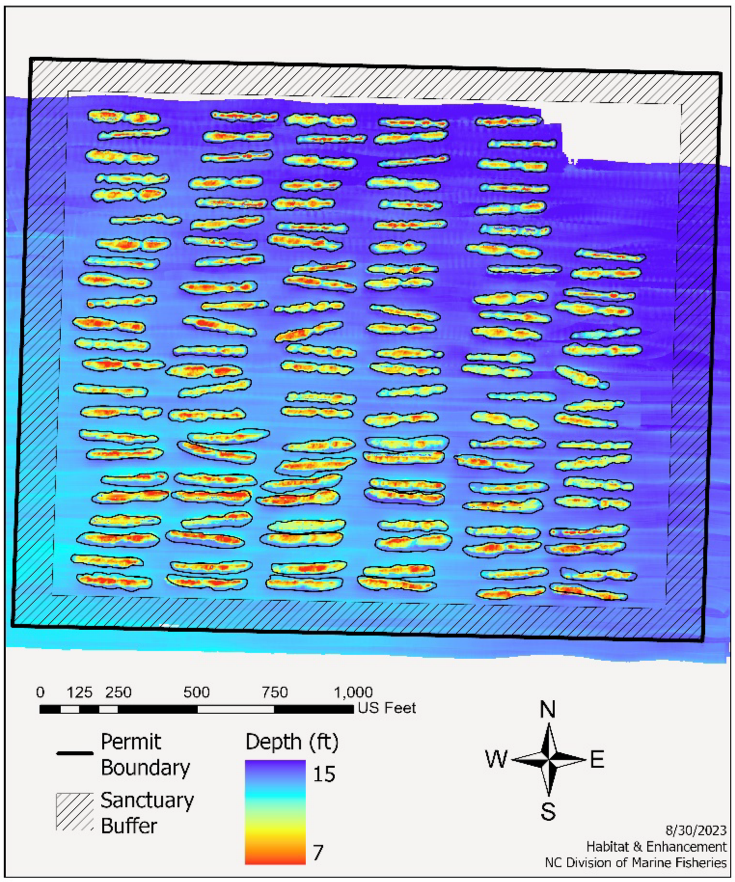

Figure 4.3. The side scan view of Cedar Island Oyster Sanctuary located in Pamlico Sound, North Carolina. The construction of the sanctuary began in 2021, using marl limestone rip rap and crushed concrete in a grid design with parallel ridges.

Data from sanctuary monitoring in 2023 suggest North Carolina's oyster sanctuaries had an average total density of 1,333 oysters/m^2 and an average legal density of 127 oysters/m^2. These estimates, along with those from independent peer-reviewed studies, verify and quantify the effectiveness of the Oyster Sanctuary Program. For instance, total oyster density at sanctuary sites was 72 times greater than natural reefs open to harvest, and 7.5 times higher than restored harvested (cultch) areas (Peters et al. 2017). This trend extended to legal oyster density (>75mm), as sanctuary sites demonstrated 27 times greater density than natural harvested reefs and six times greater density than restored harvested reefs (Peters et al. 2017). The potential larval output per m^2 of sanctuary sites was significantly higher than at natural reefs (700 times greater) and cultch areas (four times), illustrating the high potential for larval spillover as intended in the design of the Oyster Sanctuary Network (Peters et al. 2017).

Appendix 5: Eastern Oyster Management & Stock Status in Other States

Eastern Oyster management & stock status in other states. Fishery type is categorized as either recreational (Rec.') or commercial (Com.'); Mechanical gear type abbreviated as 'Mech.'; bushels abbreviated as 'bu.'.

State	Fishery	License Issued by	Gear	Daily Trip Limit	Season	Size Limit	Stock Assessment	Management
ME	Rec.	Town	Hand	1 peck/person	Nov 1 – Apr 30	2.5"	No	Co-managed towns may further restrict harvest via shellfish control ordinance. Oyster habitat restoration program.
	Com.	State	-	-				
NH	Rec.	State (resident only)	Hand	0.2 bu./person	1 Sep – Jun 30	None	No	Managed by towns and municipalities.
	Com.	No Wild Harvest	-	-				
MA	Rec. & Com.	Town	Hand	Consult Town Regs	Consult Town Regs	3"	No	Managed by towns and municipalities.
RI	Rec.	License for Non-residents	Hand	0.5–1 peck (varies by area)	15 Sep – 15 May	3"	No	Managed in state shellfish management areas and closed spawner sanctuaries. Habitat restoration program.
	Com.	State	Hand	3 bu./person, 6 bu./vessel	Fixed Season Varies by Management Area			
CT	Rec.	Town	Hand	Between 24 oysters to 0.5 bu./person (varies by town)	Year round, exceptions by town	3"	No	Habitat restoration. Allows seed oyster harvest for relay and sale.
	Com.	State	Hand, Mech.	Seed Oyster Harvest Fishery Only	20 Sep – 20 Jul			
NY	Rec.	Town	Hand, Sail power	0.5 bu.	1st Monday Nov – 31 Mar	3"	No	Habitat restoration.

State	Fishery	License Issued by	Gear	Daily Trip Limit	Season	Size Limit	Stock Assessment	Management
	Com.	State	Hand, Sail power	None				
NJ	Rec.	State	Hand	150 (total mollusks)	Year round (no Sunday harvest)	3"	Yes (Delaware Bay Only)	Annual assessment for Delaware Bay. Quota set by dredge survey of six management areas. 2024 stock status, thresholds and reference points from times series 1989 onward. 224 grids sampled to determine 2023 stock status. >100sq miles of area. Partnership with Rutgers.
	Com.	State	Tong, Dredge	Quota for Delaware Bay (Direct Market Fishery)	Apr – Nov			
DE	Com.	State	Dredge	Quota set by Dept Fish & Wildlife (split between license holders)	Set by Dept Fish & Wildlife (2024 split: 1 Apr – 31 May & 2 Sep – 31 Dec)	2.75"	Population Survey	Survey used to set landings quota. 2% of population as target set in 2018. Limited entry into oyster fishery. Rec harvest prohibited.
MD	Rec.	None (resident only)	Hand	100 oysters	1 Oct – 31 Mar (M–Sat, before noon)	3"	Yes	Stage-structured model with various integrated sources (buy ticket data, MDDNR surveys, oyster/shell planting data, bottom mapping, etc.) to estimate sustainable fishing reference points. MD area of Chesapeake ~1,500 sq miles.
	Com.	State	Hand	12 bu./person, 24 bu./vessel	1 Oct – 31 Mar (M–F)			
			Power Dredge	10 bu./person, 20 bu./vessel	1 Nov – 31 Mar (M–F)			
			Sail Dredge	100 bu./person, 100 bu./vessel				

State	Fishery	License Issued by	Gear	Daily Trip Limit	Season	Size Limit	Stock Assessment	Management
VA	Rec.	None	Hand	1 bu./vessel	1 Oct – 31 Mar (M–F until 3:00 pm)	3"	Yes	Virginia Oyster Stock Assessment and Replenishment. Partnership with VIMS and VMRC. Assessment Program and Restoration activities for Chesapeake Bay. Managed and surveyed by individual public oyster reefs. Virginia Public Oyster Grounds, 243,000 acres (380 sq miles) Fishing mortality limited by area using season length and fishing times.
	Com.	State	Hand	8 bu./person, 16 bu./vessel	Season length varies by areas, time allowed to fish varies by season			
			Hand Tong	14 bu./person, 28 bu./vessel				
			Mech.	8 bu./person, 16 bu./vessel				
NC	Rec.	None	Hand	1 bu.	1 Oct – 31 Mar	3"	No	Oyster restoration and enhancement programs in closed sanctuaries and public shellfish grounds. Mechanical harvest monitoring to close harvest when trigger falls below 26% legal by area.
	Com.	State	Hand	3–15 bu. (varies by license, area)	1 Oct – 31 Mar (Brunswick Co., Mar 15) (Mon–Sat)			
			Mech.	10 or 15 bu. (varies by area)	3rd Monday in Nov until closure by management trigger (M–F)			
SC	Rec.	State	Hand	2 bu., no more than 4 bu. per seven-day pd.	1 Oct – 27 May	None	No	Restoration and enhancement on public shellfish grounds.
	Com.	State	Hand, Mech.	None				

State	Fishery	License Issued by	Gear	Daily Trip Limit	Season	Size Limit	Stock Assessment	Management
GA	Rec.	State	Hand	2 bu./person, 6 bu./vessel	1 Oct – 27 May	3"	No	Restoration and enhancement.
	Com.		Hand	None		2"		
FL	Rec.	State	Hand	120 lbs. per person/vessel	1 Sep – 31 May or 1 Oct – Jun 30, depending on County	3"	No	Restoration and enhancement.
	Com.		Hand Tong	1200 lbs. per person/vessel				
AL	Rec.	None	Hand	100 oysters	1 Oct – 30 April (M–F until 2 pm)	3"	No	Reefs are assessed annually by divers to determine if management changes are needed. Enhancement program funded by the sale of oyster tags.
	Com.	State	Hand, Mech.	6 sacks				
MS	Rec.	State	Hand	3 sacks per week	1 Oct – 31 Mar	3"	No	Restoration and enhancement.
	Com.	State	Hand, Mech.	15 sacks, quotas by area				
LA	Rec.	State	Hand	2 sacks	Wed after Labor Day to 30 Apr	3"	Yes	over 1,700 dredge samples and 1,000 diver quadrat samples used to inform fishery independent portion of stock assessment. 2,656 sq. miles of oyster ground. Shell Recycling and restoration and enhancement programs.
	Com.	State	Hand, Mech.	5–30 sacks per vessel (varies by region)				
TX	Rec.	State	Hand	220 lbs.	1 Nov – 30 April	3"	No	Restoration and enhancement. Area and season closures determined by monitoring and a traffic light approach.
	Com.	State	Hand, Mech.	330 lbs.	1 Nov – 30 April (M–F until 3:30 pm)			

Appendix 6: Eastern Oyster Fishery Management Plan Advisory Committee Workshop Summary

ISSUE

Summarize input received from stakeholders from the Oyster & Clam Fishery Management Plans Advisory Committee Workshop.

ORIGINATION

The North Carolina Division of Marine Fisheries (NCDMF).

BACKGROUND

The Oyster and Clam Fishery Management Plans (FMPs) Advisory Committee (AC) met for a three-day workshop on July 15, 16, and 17, 2024, at Craven Community College in New Bern. As these two fisheries share considerable overlap in their ecology and management, the FMPs are being revised simultaneously though written separately. The purpose of the workshop was for the AC to assist NCDMF staff in evaluating management issues and options included in the draft documents of Amendment 5 to the Eastern Oyster FMP and Amendment 3 to the Hard Clam FMP. The NCDMF sought to solicit feedback and input on the impacts of management options on the oyster and clam resources and user groups. It is important to note the aim of the AC workshop was to receive input from committee members based on their experiences, expertise, and sector relationships, not to build a consensus among AC members or to recommend specific management strategies.

For the Eastern Oyster FMP, NCDMF staff presented overviews of the base plan (life history, stock assessment, description of the fisheries, habitat impacts), Habitat and Enhancement information paper, intertidal hand harvest information paper, mechanical harvest issue paper, and recreational shellfish harvest issue paper. Each presentation was followed by an opportunity for the AC to ask clarifying questions and discuss the content and management options presented. Below is a summary of the input and subsequent discussions for each of the Eastern Oyster FMP Amendment 5 information and issue papers. These ideas represent the management options the AC suggested be considered. NCDMF staff explored these options and incorporated many of them directly into the relevant information and issue papers.

DISCUSSION

Base Plan

AC members suggested adding more information to the stock assessment section within the base plan. Discussion revolved around comparing management of Eastern Oysters in other states along the Atlantic coast and Gulf of Mexico. At the time of the workshop, a table summarizing management strategies, gear, season length, limits, and stock assessment status of other states was available as an appendix. However, members of the AC expressed their interest in having a paragraph summary of information pertaining to the status of stock assessment completion in other states, including methodologies and findings.

In the description of the fishery, the AC brought up that on many trip tickets, oysters may be an opportunistically harvested species rather than the target. To this point, the AC suggested including an economic analysis of the landings brought in by the top 30 participants compared to all other participants. The AC was curious about discerning where the fishing effort of full-time oystermen is directed. Furthermore, the AC suggested an economic analysis of landings from specific areas would better contextualize the potential impact of large-scale closures as suggested in the initial draft of the mechanical harvest issue paper.

An analysis of trip ticket data was added to the base plan illustrating relative landings contribution of the top 25% of participants in the oyster mechanical fishery. These data, along with the number of participants from 2010 to 2023, were added to the Mechanical Harvest section. It is important to note that Trip Ticket data are assigned to major water bodies (e.g., Pamlico Sound, Neuse River), but not at a finer detail to allow for spatial analysis on fishing effort by top contributors.

The AC emphasized the importance of water quality and its importance to the oyster fishery. Because water quality issues are explored extensively in the Coastal Habitat Protection Plan and enforced by the Division of Water Resources, the AC suggested strengthening the tie to the CHPP in the base plan. The AC also brought up the difficulty of reporting shellfish die-offs. AC members from the commercial shellfish sector expressed interest in developing a mechanism for anonymous reporting of observed die-offs. Currently, there is a way to report fish kills, but no easy, online mechanism to report shellfish die-offs.

The AC suggested the table of fish species found on oyster reefs should include the current stock status of each species to further stress the indirect benefits of oyster reefs on other fisheries.

Throughout the workshop, the importance of geospatial data was highlighted. Members of the AC wished to see all available historical and modern mapping data of naturally occurring oyster reefs. When discussing the cost of resources needed to map Pamlico Sound, the AC recommended that exploring novel mapping methods should be added to the list of research needs.

Habitat and Enhancement Programs

The AC suggested including more information on the weighting and scaling of variables used in the Habitat Suitability Index model to clarify why certain areas scored higher when planning cultch and sanctuary sites. On this topic, the AC sought more detail on the Army Corps permit used for planning cultch planting as it constrains where material can be planted.

As it pertains to the cultch planting program, the AC suggested elaborating on the status of the state's shell supply, including why the resource might be shipped to other states.

AC members highlighted that further detail on this topic would lay out the framework put in place by other states for keeping shell resources in-state.

The cultch planting program also conducts monitoring of oyster spat recruitment on newly constructed reefs. The AC emphasized the importance of this dataset and its potential contribution to a future stock assessment. The AC expressed interest in that dataset being analyzed and reported within the next FMP iteration.

Mechanical Oyster Harvest

For areas in Pamlico Sound that are subject to in-season management triggers, the AC felt strongly about including more information about current trigger sampling methods. The NCDMF plans to revamp trigger sampling methodology regardless of which management strategies are selected in Amendment 5. To this end, the AC supported revisiting the trigger sampling procedure, though they were made aware that this effort was not tied to adoption of Amendment 5.

As it pertains to the large-scale, rotational harvest site proposed in this issue paper, AC members were largely supportive of formalizing the cultch program as a management strategy and expressed the desire for increased planting efforts.

Additionally, during discussion of cultch sites, the AC pointed out there is currently no easy way to distinguish where oysters had been harvested in landings data. The AC expressed interest in assigning location codes to harvest areas and including a field for reporting if oysters were harvested at a cultch site or natural reef as part of data collection efforts.

Another approach outlined in this issue paper was to establish deep-water closure areas. AC members recognized the importance of vertical relief for the growth of oyster reefs, however, there was no consensus for the recommended extent of these closure areas. While some believed these deep-water areas are still harvestable, albeit about once every eight years, others believed extensive closures are necessary to counter the impacts of mechanical gear on natural reefs.

Intertidal Oyster Harvest

No proposed management changes to the intertidal oyster hand harvest industry were brought to the AC workshop. Rather the draft of this information paper further highlighted the same data gaps described in other Amendment 5 issue papers. Currently, there is no approved methodology for assessing important oyster metrics along intertidal habitats, which prevents completion of a stock assessment. Members of the AC recognized the importance of filling current data gaps related to North Carolina's oyster resource. As fishery independent data is required for a stock assessment, the AC emphasized the importance of researching intertidal sentinel sites. Currently, the NCDMF is working to establish and monitor sentinel sites to estimate oyster metrics in intertidal areas in the southern part of the state. Additionally, the AC suggested another research priority in southern cultch sites whereby alternative materials be tested for oyster recruitment as marl limestone has demonstrated limited recruitment for commercial oyster harvest. Due to limited shell availability, other materials besides marl should be considered for future cultch planting efforts.

Recreational Shellfish Harvest

AC members recognized the potential widespread impact of recreational shellfish collection, particularly with high tourism occurring along the coast and harvest efforts have mostly been undocumented. The AC workshop further highlighted the importance of understanding this impact as recreational harvest estimates would be necessary for completion of a stock assessment. AC members recognized the potential scale of recreational harvest and the importance of filling the data gap. As such, the AC voiced their support for taking steps to collect these data, either through a survey or temporary permit, until a recreational license could be put in place. Additionally, the AC identified having such a system in place would improve public education of safe harvest practices and reduce consumption during warm months. Listing public health as a concern furthered the discussion on the potential economic impact *Vibrio* cases might have on North Carolina's shellfish fisheries. Ultimately, the AC agreed that a nominal permit would be a great step before a license to promote education and to collect recreational data.

Appendix 7: Summary Of Management Recommendations and Comment

Table 7.1. Summary of management recommendations from NCDMF, the Northern, Southern, Shellfish & Crustacean, and Habitat & Water Quality Advisory Committees (AC).

	NCDMF	Northern AC	Southern AC	Shellfish & Crustacean AC	Habitat & Water Quality AC
Appendix 1: Recreational Shellfish Harvest					
Recreational License or Permit for Shellfish	Support the MFC to task the DMF with exploring options outside of the FMP process for developing a solution to quantify recreational shellfish participation and landings, and to create a mechanism for providing recreational participants with SSRWQ health and safety information.	Support the MFC to task the DMF with exploring options outside of the FMP process for developing a solution to quantify recreational shellfish participation and landings, and to create a mechanism for providing recreational participants with SSRWQ health and safety information.	Support the MFC to task the DMF with exploring options outside of the FMP process for developing a solution to quantify recreational shellfish participation and landings, and to create a mechanism for providing recreational participants with SSRWQ health and safety information.	Support the MFC to task the DMF with exploring options outside of the FMP process for developing a solution to quantify recreational shellfish participation and landings, and to create a mechanism for providing recreational participants with SSRWQ health and safety information.	Support the MFC to task the DMF with exploring options outside of the FMP process for developing a solution to quantify recreational shellfish participation and landings, and to create a mechanism for providing recreational participants with SSRWQ health and safety information.
Appendix 2: Mechanical Oyster Harvest					
Deep Water Recovery Areas (DORAs)	Adopt the proposed Pamlico and Neuse River DORAs which are bound by existing navigational aids as presented to the regional ACs.	Recommended maintaining status quo and did not support adopting DORAs as a management strategy because of the unknown advantages and known disadvantages to the commercial industry.	Supported a significantly narrower approach to DORAs with the purpose of evaluating the effectiveness of the closures before considering closing the majority of the area.	Recommended maintaining status quo and did not support adopting DORAs as a management strategy.	Adopt the proposed Pamlico and Neuse River DORAs which are bound by existing navigational aids as presented to the regional ACs.

Cultch Supported Harvest	Adopt the Cultch Supported Harvest strategy outlined in the issue paper.	Adopt the Cultch Supported Harvest strategy outlined in the issue paper. with the intent to streamline and adapt the trigger sampling procedure.	Adopt the Cultch Supported Harvest strategy outlined in the issue paper.	Adopt the Cultch Supported Harvest strategy outlined in the issue paper.	Adopt the Cultch Supported Harvest strategy outlined in the issue paper.
Adaptive Management to Cultch Supported Harvest	Adopt the proposed adaptive management framework.	Adopt the proposed adaptive management framework.	Adopt the proposed adaptive management framework.	Adopt the proposed adaptive management framework.	Adopt the proposed adaptive management framework.
Rotational Harvest Cultch Sites	Adopt the inclusion of Rotational Harvest Cultch sites as a management strategy as described in the issue paper.	Adopt the inclusion of Rotational Harvest Cultch sites as a management strategy as described in the issue paper.	Adopt the inclusion of Rotational Harvest Cultch sites as a management strategy as described in the issue paper.	Adopt the inclusion of Rotational Harvest Cultch sites as a management strategy as described in the issue paper.	Adopt the inclusion of Rotational Harvest Cultch sites as a management strategy as described in the issue paper.

Online Eastern Oyster Amendment 5 Public Questionnaire

The online Eastern Oyster Amendment 5 Public Questionnaire opened on December 11, 2024, and closed January 15, 2025. In total, the questionnaire had 8 participants, 6 of which left comments pertaining specifically to the draft of Amendment 5 to the Eastern Oyster Fishery Management Plan.

Comments to the open response questionnaire were mixed when it came to implementing deep water recovery areas (DORAs) in Pamlico Sound. Three responders voiced their opposition to closure areas. Both cited that die-offs occur in these areas as a result of hurricanes and water quality issues, and that oyster production is cyclical in these areas. One additional commentor also advocated against closure of large areas but suggested being amenable to a smaller closure area. One of these responders requested additional cultch planting and suggested improved involvement of local oystermen for future site selection.

One responder for both plans suggested stocking clams and oysters to help rebuild natural populations while allowing for continued traditional harvest methods. The same responder also expressed opposition to further public water leases and advocated for stricter labeling of farmed shellfish.

Another responder expressed the need for regulations that promote sustainable practices, specifically aquaculture and protecting wild shellfish populations from bottom disturbing gear.

REFERENCES

Amaral, V. S. D., and L. R. L. Simone. 2014. Revision of genus *Crassostrea* (Bivalvia: Ostreidae) of Brazil. Journal of the Marine Biological Association of the United Kingdom 94:811–836.

Andrews, J. D. 1980. A Review of Introductions of Exotic Oysters and Biological Planning for New Importations. Marine Fisheries Review 42(12):1–11.

Andrews, J. D. 1983. *Minchinia nelsoni* (MSX) infections in the James River seed-oyster area and their expulsion in spring. Estuarine, Coastal and Shelf Science 16(3):255–269.

Appeldoorn, R. S. 1981. Response of soft-shell clam (*Mya arenaria*) growth to onset and abatement of pollution. Journal of Shellfish Research 1(1):41–49.

Arve, J. 1960. Preliminary report on attracting fish by oyster-shell plantings in Chincoteague Bay, Maryland. Chesapeake Science 1(1):58–65.

ASMFC (Atlantic States Marine Fisheries Commission). 1988. A procedural plan to control interjurisdictional transfers and introductions of shellfish. Atlantic States Marine Fisheries Commission, Washington, D.C. 58 p.

ASMFC. 2007. The importance of habitat created by shellfish and shell beds along the Atlantic coast of the U.S. Prepared by Coen LD, Grizzle R, with contributions by Lowery J, Paynter KT Jr. Atlantic States Marine Fisheries Commission, Washington, D.C., p 1–116

Baggett, L. P., S.P. Powers, R.D. Brumbaugh, L. D. Coen, B. M. Deangelis, J. K. Greene, B. T. Hancock, S. M. Morlock, B. L. Allen, D. L. Breitburg, and D. Bushek. 2015. Guidelines for evaluating performance of oyster habitat restoration. Restoration Ecology 23:737–745.

Bahr, L. M., and R. E. Hillman. 1967. Effects of repeated shell damage on gametogenesis in the American oyster *Crassostrea virginica* (Gmelin). Proceedings of the National Shellfisheries Association 57:59–62.

Bahr, L. M., and W. P. Lanier. 1981. The ecology of intertidal oyster reefs of the South Atlantic Coast: a community profile. U.S. Fish and Wildlife Service, Office of Biological Services, Washington, D.C. FWS/OBS-81/15,105 p.

Ballance, E. S. 2004. Using Winslow's 1886 NC oyster bed survey and GIS to guide future restoration projects. North Carolina Sea Grant.

Barber, B. J. 1987. Influence of stress on disease susceptibility. Pages 82–85 *in* W. S. Fisher and A. J. Figueras, editors. Marine Bivalve Pathology. Maryland Sea Grant Publication, University of Maryland, College Park, Maryland.

Barnes, B. B., M. W. Luckenbach, and P. R. Kingsley-Smith. 2010. Oyster reef community interactions: The effect of resident fauna on oyster (*Crassostrea* spp.) larval recruitment. *Journal of Experimental* Marine Biology and Ecology 391(1–2):169–177.

Beck, M. W., R. D. Brumbaugh, L. Airoldi, A. Carranza, L. D. Coen, C. Crawford, O. Defeo, G. J. Edgar, B. Hancock, M. C. Kay, H. S. Lenihan, M. W. Luckenbach, C. L. Toropova, G. Zhang, and X. Guo. 2011. Oyster reefs at risk and recommendations for conservation, restoration, and management. BioScience 61:107–116.

Blackwell, K. D., and J. D. Oliver. 2008. The ecology of *Vibrio vulnificus, Vibrio cholerae*, and *Vibrio parahaemolyticus* in North Carolina Estuaries. Journal of Microbiology 46:146–153.

Breuer, J. P. 1962. An ecological survey of the lower Laguna Madre of Texas, 1953–1959. Publications of the Institute of Marine Science, University of Texas. 8(15):3–183.

Brown, L. A., J. N. Furlong, M. K. Brown, and K. Peyre. 2013. Oyster reef restoration in the northern Gulf of Mexico: effect of artificial substrate and age on nekton and benthic macroinvertebrate assemblage use. Restoration Ecology 22(2):214–222.

Burkholder, J. M., G. M. Hallegraeff, G. Melia, A. Cohen, H. A. Bowers, D. W. Oldach, M. W. Parrow, M. J. Sullivan, P. V. Zimba, E. H. Allen, C. A. Kinder, and M. A. Mallin. 2007. Phytoplankton and bacterial assemblages in ballast water of U.S. military ships as a function of port of origin, voyage time, and ocean exchange practices. Harmful Algae 6(4):486–518.

Butler, P. A. 1954. Summary of our knowledge of the oyster in the Gulf of Mexico. Fishery Bulletin of the Fish and Wildlife Service 55:479–489.

Buzzelli, C. P., R. A. Luettich, Jr., S. P. Powers, C. H. Peterson, J. E. McNinch, J. L. Pinckney, and H. W. Paerl. 2002. Estimating the spatial extent of bottom-water hypoxia and habitat degradation in a shallow estuary. Marine Ecology Progress Series 230:103–112.

Capuzzo. J. M. 1996. Biological effects of contaminants on shellfish populations in coastal habitat: case history of New Bedford, MA. Pages 457–466 *in* K. Sherman, editor. Marine Ecosystem Management: The Northeast Shellfish. Blackwell Science. Cambridge, Massachusetts.

Carlton, J. T., and R. Mann, 1996. Transfers and worldwide distributions. Pages 691–706 *in* V. S., Kennedy, R. I. E. Newell, and A. F. Eble, editors. The Eastern Oyster, *Crassostrea virginica*. Maryland Sea Grant Publication, University of Maryland, College Park, Maryland.

Carroll J. C., C. J. Gobler, B. P. Peterson. 2008. Resource limitation of eelgrass in New York estuaries; light limitation and nutrient stress alleviation by hard clams. Marine Ecology Progress Series 369:39–50.

Chestnut, A. F. 1951. The oyster and other molluscs in North Carolina. Pages 141–190 *in* H. F. Taylor, editor. Survey of Marine Fisheries of North Carolina. University of North Carolina Press, Chapel Hill, NC.

Chestnut, A. F. 1954. A preliminary report of the mollusc studies conducted by the University of North Carolina Institute of Fisheries Research, 1948–1954. University of North Carolina, Institute of Fisheries Research. 39 p.

Chestnut, A. F. 1955. A report of the mollusc studies conducted by the University of North Carolina Institute of Fisheries Research, 1948–1954. University of North Carolina, Institute of Fisheries Research, 66 p.

Chestnut, A. F., and H. S. Davis. 1975. Synopsis of Marine Fisheries of North Carolina. Part I: Statistical Information, 1880–1973. University of North Carolina Sea Grant Publication, UNC-SG-75-12, 425 p.

Coen, L. D., M. W. Luckenbach, and D. L. Breitburg. 1999. The role of oyster reefs as essential fish habitat: a review of current knowledge and some new perspectives. American Fisheries Society Symposium 22:438–454.

Coen L. D., R. D. Brumbaugh, D. Bushek, R. Grizzle, M. W. Luckenbach, M. H. Posey, S. P. Powers, and S. G. Tolley. 2007. Ecosystem services related to oyster restoration. Marine Ecology Progress Series 341:303–307.

Cressman, K. A., M. H. Posey, M. A. Mallin, L. A. Leonard, and T. D. Alphin. 2003. Effects of oyster reefs on water quality in a tidal creek estuary. Journal of Shellfish Research 22:753–762.

Cummings, E. W., D. A. Pabst, J. E. Blum, S. G. Barco, S. J. Davis, V. G. Thayer, N. Adimey, and W.A. McLellan. 2014. Spatial and temporal patterns of habitat use and mortality of the Florida manatee (*Trichechus manatus latirostris*) in the mid-Atlantic states of North Carolina and Virginia from 1991 to 2012. Aquatic Mammals 40(2):126–138. https://doi.org/10.1578/AM.40.2.2014.126

Davis, N. W., and R. E. Hillman. 1971. Effect of artificial shell damage on sex determination in oysters (Abstract). Proceedings of the National Shellfisheries Association 61:2.

Deaton, A. S., W. S. Chappell, K. Hart, J. O'Neal, and B. Boutin. 2010. North Carolina Coastal Habitat Protection Plan. North Carolina Department of Environment and Natural Resources, Division of Marine Fisheries. 639 p.

DeBrosse, G. A., and K. S. Allen. 1996. The suitability of land-based evaluations of *Crassostrea gigas* (Thunberg, 1793) as an indicator of performance in the field. Journal of Shellfish Research 15:291–295

Dunn, R. P., D. B. Eggleston, and N. Lindquist. 2014. Effects of substrate type on demographic rates of Eastern Oyster (*Crassostrea virginica*). Journal of Shellfish Research 33(1):177–185.

Duran, L. R., and J. C. Castilla. 1989. Variation and persistence of the middle rocky intertidal community of central Chile, with and without human harvesting. Marine Biology 103:555–562.

Eby, L. A., and L. B. Crowder. 2002. Hypoxia-based habitat compression in the Neuse River Estuary: context-dependent shifts in behavioral avoidance thresholds. Canadian Journal of Fisheries and Aquatic Sciences 59:952–965.

English, E. P. P., C. H. Voss, and C. M. 2009. Ecology and Economics of Compensatory Restoration. NOAA Coastal Response Research Center (CRRC), New Hampshire. 193 p.

EOBRT (Eastern Oyster Biological Review Team). 2007. Status review of the Eastern Oyster (*Crassostrea virginica*). Report to the National Marine Fisheries Service, Northeast Regional Office.

Everett, R. A., G. M. Ruiz, and J. T. Carlton. 1995. Effect of oyster mariculture on submerged aquatic vegetation: an experimental test in a Pacific Northwest estuary. Marine Ecology Progress Series 125(1–3):205–217.

Ford, S. E., and A. J. Figueras. 1988. Effects of sublethal infection by the parasite *Haplosporidium nelsoni* (MSX) on gametogenesis, spawning, and sex ratios of oysters in Delaware Bay, USA. Diseases of Aquatic Organisms 4(2):121–133.

Ford, S. E., and M. R. Tripp. 1996. Diseases and defense mechanisms. Pages 581–660 *in* V. S. Kennedy, R. I. E., Newell, and A. F. Eble, editors. The Eastern Oyster *Crassostrea virginica*. Maryland Sea Grant Publication, University of Maryland, College Park, Maryland.

Gaffney, P. M. 2005. Congressional hearing testimony and personal communication to NOAA Eastern Oyster Biological Review Team 8/9/05.

Galtsoff, P. S. 1964. The American oyster, *Crassostrea virginica* (Gmelin). Fishery Bulletin of the Fish and Wildlife Service 64:1–480.

Godwin, W. F. 1981. Development of a mechanical seed oyster relaying program in North Carolina. NC Department of Natural Resources and Community Development, Division of Marine Fisheries, Special Scientific Report No. 35. 91 p.

Grabowski, J. H. 2002. The influence of trophic interactions, habitat complexity, and landscape setting on community dynamics and restoration of oyster reefs. Doctoral dissertation. University of North Carolina at Chapel Hill.

Grabowski, J. H., and C. H. Peterson. 2007. Restoring oyster reefs to recover ecosystem services. Theoretical Ecology Series 4: 281–298.

Grabowski, J. H., A. R. Hughes, D. L. Kimbro, and M. A. Dolan. 2005. How habitat setting influences restored oyster reef communities. Ecology 86:1926–1935.

Grabowski, J. L., R. D. Brumbaugh, R. F. Conrad, A. G. Keeler, J. J. Opaluch, C. H. Peterson, M. F. Piehler, S. P. Powers, and A. R. Smyth. 2012. Economic valuation of ecosystem services provided by oyster reefs. BioScience 62(10): 900–909.

Grizzle, R. E., J. K. Greene, M. W. Luckenbach, and L. D. Coen. 2006. A new in-situ method for measuring seston uptake by suspension-feeding bivalve molluscs. Journal of Shellfish Research 25:643–650.

Gross, F., and J. C. Smyth. 1946. The decline of oyster populations. Nature 147:540–542.

Haase, A. T., D. B. Eggleston, R. A. Luettich, R. J. Weaver, and B. J. Puckett. 2012. Estuarine circulation and predicted oyster larval dispersal among a network of reserves. Estuarine, Coastal and Shelf Science 101:33–43.

Harding, J. M., E. N. Powell, R. Mann, and M. J. Southworth. 2012. Variations in Eastern Oyster (*Crassostrea virginica*) sex-ratios from three Virginia estuaries: protandry, growth and demographics. Journal of the Marine Biological Association of the United Kingdom 92:1–13.

Hargis, W. J., Jr., and D. S. Haven. 1988. The imperiled oyster industry of Virginia: a critical analysis with recommendations for restoration. Special Reports in Applied Marine Science and Ocean Engineering No. 290. Virginia Institute of Marine Science, College of William and Mary. DOI: 10.21220/V5JF2K

Haskin, H. H., L. A. Stauber, and J. A. Mackin. 1966. *Minchinia nelsoni* n. sp. (Haplosporida, Haplosporidiidae): causative agent of the Delaware Bay oyster epizootic. Science 153(3742):1414–1416. DOI: 10.1126/science.153.3742.141

Hayes, S. A., E. Josephson, K. Maze-Foley, and P. E. Rosel. 2018. US Atlantic and Gulf of Mexico Marine Mammal Stock Assessments – 2017: (second edition). National Marine Fisheries Service, NOAA Technical Memorandum NMFS-NE-245, Woods Hole, Massachusetts. 378 p.

Hidu, H., and H. H. Haskin. 1971. Setting of the American oyster related to environmental factors and larval behavior. Proceedings of the National Shellfisheries Association 61:35–50.

Hedeen, R. A. 1986. The Oyster: Life and Lore of the Celebrated Bivalve. Tidewater Publishers. Centreville, Maryland.

Holland, A. F., D. M. Sanger, C. P. Gawle, S. B. Lerberg, M. S. Santiago, G. H. M. Riekerk, L. E. Zimmerman, and G. I. Scott. 2004. Linkages between tidal creek ecosystems and the landscape and demographic attributes of their watersheds. Journal of Experimental Marine Biology and Ecology 298:151–178.

Hoover, C. A., and P. M. Gaffney. 2005. Geographic variation in nuclear genes of the Eastern Oyster, *Crassostrea virginica* Gmelin. Journal of Shellfish Research. 24(1):103–112.

Hopkins, A. E. 1931. Factors influencing the spawning and setting of oysters in Galveston Bay, Texas. Bulletin of the U.S. Bureau of Fisheries. 47(3):57–83.

Hribar, C. 2010. Concentrated Animal Feeding Operations and Their Impact on Communities.

Jenkins, J. B., A. Morrison, and C. L. MacKenzie, Jr. 1997. The molluscan fisheries of the Canadian Maritimes. Pages 15–44 *in* C. L. MacKenzie, Jr., V. G. Burrell, Jr., A. Rosenfield, and W. L. Hobart, editors. The history, present condition, and future of the molluscan fisheries of North and Central America and Europe, Vol. 1. Atlantic and Gulf Coasts. U.S. Department of Commerce, NOAA Technical Report 127, 234 p.

Johnson K. D., and D. I. Smee. 2012. Size matters for risk assessment and resource allocation in bivalves. Marine Ecology Progress Series 462:103–110.

Jones, R. A., and T. M. Sholar. 1981. The effects of freshwater discharge on estuarine nursery areas of Pamlico Sound. NC Department of Natural Resources and Community Development, Division of Marine Fisheries, Completion Report Project. CEIP 79–11.

Jordan, S. J. 1987. Sedimentation and remineralization associated with biodeposition by the American oyster *Crassostrea virginica* (Gmelin). Doctoral dissertation. University of Maryland, College Park.

Kelaher, B. P. 2003. Changes in habitat complexity negatively affect diverse gastropod assemblages in coralline algal turf. Oecologia 135:431–441.

Kellogg, L. M., J. C. Cornwell, M. S., Owens, and K. T. Paynter. 2013. Denitrification and nutrient assimilation on a restored oyster reef. Marine Ecology Progress Series 480(22):1–19.

Kennedy, V. S., and L. L. Breisch. 1981. Maryland's Oysters: Research and Management. Maryland Sea Grant Publication, University of Maryland, College Park, Maryland. Publication Number UM-SG-TS-81-04.

Kennedy, V. S. 1983. Sex ratios in oysters, emphasizing *Crassostrea virginica* from Chesapeake Bay, Maryland. Veliger 25:329–338.

Kennedy, V. S., R. I. E. Newell, and A. F. Ebele, editors. 1996. The Eastern Oyster, *Crassostrea virginica*. Maryland Sea Grant Publication, University of Maryland, College Park, Maryland.

Kirbym, M. X. 2004. Fishing down the coast: historical expansion and collapse of oyster fisheries along continental margins. Proceedings of the National Academy of Sciences of the United States of America. 101:13096–13099.

Kunkel, K. E., T. R. Karl, M. F. Squires, X. Yin, S. T. Stegall, and D. R. Easterling. 2020. Precipitation extremes: trends and relationships with average precipitation and precipitable water in the contiguous United States. Journal of Applied Meteorology and Climatology 59(1):125–142.

La Peyre, M., S. Casas, and J. La Peyre. 2006. Salinity effects on viability, metabolic activity and proliferation of three *Perkinsus* Species. Diseases of Aquatic Organisms 71(1):59–74.

Leffler, M., J. Greer, G. Mackiernan, and K. Folk. 1998. Restoring Oysters to U.S. Coastal Waters: A National Commitment. National Sea Grant College Program, UM-SG-TS-98-03, 21 p. https://repository.library.noaa.gov/view/noaa/42200/noaa_42200_DS1.pdf

Lenihan, H. S. 1999. Physical-biological coupling on oyster reefs: how habitat structure influences individual performance. Ecological Monographs 69(3):251–275.

Lenihan, H.S., and C.H. Peterson. 1998. How habitat degradation through fishery disturbance enhances impacts of hypoxia on oyster reefs. Ecological Applications 8:128–140.

Lenihan, H. S., and C. H. Peterson. 2004. Conserving oyster reef habitat by switching from dredging and tonging to diver-harvesting. Fishery Bulletin 102(2):298–305.

Lenihan, H. S., F. Micheli, S. W. Shelton, and C. H. Peterson. 1999. The influence of multiple environmental stressors on susceptibility to parasites: an experimental determination with oysters. Limnology and Oceanography 44:910–924.

Lenihan, H. S., C. H. Peterson, J. E. Byers, J. H. Grabowski, and G. W. Thayer. 2001. Cascading of habitat degradation: oyster reefs invaded by refugee fishes escaping stress. Ecological Applications 11(3):764–782.

Lester, S. E., B. S. Halpern, K. Grorud-Colvert, J. Lubchenco, B. I. Ruttenberg, S. D. Gaines, S. Airamé, and R. R. Warner. 2009. Biological effects within no-take marine reserves: a global synthesis. Marine Ecology Progress Series 384:33–46.

Lillis, A., D. B. Eggleston, and D. R. Bohnenstiehl. 2013. Oyster larvae settle in response to habitat-associated underwater sounds. PLoS ONE 8(10):e79337.

Lindquist, N., A. Tyler, D. Cessna, and S. Fegley. 2012. Quantifying boring sponge abundance, biomass and bioerosion rates in North Carolina oyster reefs. North Carolina Sea Grant Fishery Resource Grant Final Report, Raleigh, NC.

Loosanoff, V. L. 1952. Behavior of oysters in water of low salinity. Proceedings of the National Shellfish Association, 1952 Convention Addresses, pages 135–151.

Loosanoff, V. L. 1965. The American or Eastern Oyster. U.S. Fish and Wildlife Service, Circular 205.

Lord, J. P., and R. B. Whitlatch. 2012. Inducible defenses in the Eastern Oyster *Crassostrea virginica* (Gmelin) in response to the presence of the predatory oyster drill *Urosalpinx cinerea* (Say) in Long Island Sound. Marine Biology 159(6):1177–1182.

Lord, J. P., and R. B. Whitlatch. 2014. Latitudinal patterns of shell thickness and metabolism in the Eastern Oyster *Crassostrea virginica* along the east coast of North America. Marine Biology 161(7):1487–1497.

MacKenzie, C. L., Jr., V. G, Burrell, Jr., A. Rosenfield, and W. L. Hobart, editors. 1997. The history, present condition, and future of the molluscan fisheries of North and Central America and Europe. NOAA Technical Report NMFS 127.

Mackin, J. G. 1946. A study of oyster strike on the seaside of Virginia. Commission of Fisheries, Virginia, No. 25.

Mallin, M. A., K. E. Williams, E. C. Esham, and R. P. Lowe. 2000. Effect of human development on bacteriological water quality in coastal watersheds. Ecological Applications 10(4): 1047–1056.

Markwith, A. L., M. H. Posey, and T. D. Alphin. 2009. Distribution and life history characteristics of *Ostreola equestris*. Journal of Shellfish Research 28(3):713.

Marshall, M. D. 1995. North Carolina Oyster Restoration and Fishery Management Plan. North Carolina Division of Marine Fisheries and the North Carolina Blue Ribbon Advisory Council on Oysters, Morehead City, N.C.116 p.

Menzel, R. W. 1955. Some phases of the biology of *Ostrea equestris* and a comparison with *Crassostrea virginica* (Gmelin). Publications of the Institute of Marine Science, University of Texas 4:69–153.

Menzel, R. W. 1951. Early sexual development and growth of the American oyster in Louisiana waters. Science 113:719–721.

Minello, T. J. 1999. Nekton densities in shallow estuarine habitats of Texas and Louisiana and the identification of essential fish habitat. American Fisheries Society Symposium 22, p. 43–75.

Mroch, R. M., III, D. B. Eggleston, and B. J. Puckett. 2012. Spatiotemporal variation in oyster fecundity and reproductive output in a network of no-take reserves. Journal of Shellfish Research 31(4):1091–1101.

Munden, F. H. 1975. Rehabilitation of Pamlico Sound oyster producing grounds damaged or destroyed by Hurricane Ginger. N.C. Dept. of Natural and Economic Resources, Division of Marine Fisheries, Special Scientific Report No. 27. 34 p.

Munden, F. H. 1981. A review of the North Carolina Oyster Rehabilitation Program *in* Proceedings of the North American Oyster Workshop, Special Publication No. 1, Louisiana State University, p. 138–152.

NCDEQ (North Carolina Department of Environmental Quality). 2016. North Carolina Coastal Habitat Protection Plan Source Document. Morehead City, NC. Division of Marine Fisheries. 475 p.

NCDMF (North Carolina Division of Marine Fisheries). 2001a. North Carolina Hard Clam Fishery Management Plan. North Carolina Department of Environment and Natural Resources. North Carolina Division of Marine Fisheries, PO Box 769, Morehead City, NC.

NCDMF. 2001b. North Carolina Oyster Fishery Management Plan. North Carolina Department of Environment and Natural Resources. North Carolina Division of Marine Fisheries, PO Box 769, Morehead City, NC.

NCDMF. 2008. North Carolina Oyster Fishery Management Plan Amendment 2. North Carolina Department of Environment and Natural Resources. North Carolina Division of Marine Fisheries, PO Box 769, Morehead City, NC.

NCDMF. 2010. Supplement A to Amendment 2 of the NC Oyster Fishery Management Plan. North Carolina Department of Environment and Natural Resources. North Carolina Division of Marine Fisheries, PO Box 769, Morehead City, NC.

NCDMF. 2011. Strategic Habitat Area Nominations for Pamlico Sound System, North Carolina (Region 2). North Carolina Department of Environment and Natural Resources. North Carolina Division of Marine Fisheries, PO Box 769, Morehead City, NC.

NCDMF. 2013. North Carolina Oyster Fishery Management Plan Amendment 3. North Carolina Department of Environment and Natural Resources. North Carolina Division of Marine Fisheries, PO Box 769, Morehead City, NC.

NCDMF. 2017. North Carolina Oyster Fishery Management Plan Amendment 4. North Carolina Department of Environment and Natural Resources. North Carolina Division of Marine Fisheries, PO Box 769, Morehead City, NC.

NCDWR (North Carolina Division of Water Resources). 2023a. Animal Operation Permits Map. 2023. Raleigh, North Carolina. N.C. Department of Environmental Quality. Raleigh, NC.

NCDWR. 2023b. Nonpoint Source Planning Branch (2023). 20-Year Neuse and Tar-Pamlico Nutrient Management Strategy Retrospective: An Analysis of Implementation and Recommendations for Adaptive Management. N.C. Department of Environmental Quality. Raleigh, NC.

Nelson, K. A., L. A. Leonard, M. H. Posey, T. D. Alphin, and M. A. Mallin. 2004. Using transplanted oyster (*Crassostrea virginica*) beds to improve water quality in small tidal creeks: a pilot study. Journal of Experimental Marine Biology and Ecology 298:347–368.

Nevins, J., J. Pollack, and G. Stunz. 2013. Characterizing the pristine oyster reef community of Sabine Lake estuary relative to surrounding marsh edge and non-vegetated bottom habitats. 22nd Biennial Conference of the Coastal and Estuarine Research Federation (CERF 2013).

Newell, R. I. E. 1988. Ecological changes in the Chesapeake Bay: are they the result of overharvesting the American oyster? Pages 536–546 *in* M. P. Lynch and E. C. Krome, editors. Understanding the estuary: advances in Chesapeake Bay research. Chesapeake Bay Research Consortium, Baltimore, MD. Publication 129.

Newell R. I. E., and E. W. Koch. 2004. Modeling seagrass density and distribution in response to changes in turbidity stemming from bivalve filtration and seagrass sediment stabilization. Estuaries 27:793–806.

Newell, R. I. E., J. C. Cornwell, and M. S. Owens. 2002. Influence of simulated bivalve biodeposition and microphytobenthos on sediment nitrogen dynamics: a laboratory study. Limnology and Oceanography 47(5):1367–1379.

Newell, R. I. E., T. R. Fisher, R. R. Holyoke, and J. C. Cornwell. 2005. Influence of eastern oysters on nitrogen and phosphorus regeneration in Chesapeake Bay, USA. Pages 93–120 *in* R. F. Dame and S. Olenin, editors. The Comparative Roles of Suspension Feeders in Ecosystems: Proceedings of the NATO Advanced Research Workshop on The Comparative Roles of Suspension-Feeders in Ecosystems Nida, Lithuania 4–9 October 2003. Springer, The Netherlands.

NOAA (National Oceanic and Atmospheric Administration). *Fisheries Economics of the United States, 2020.* 2023. National Marine Fisheries Service. U.S. Dept. Commerce, NOAA Tech. Memo. NMFS-F/SPO-236B.

Noble, E. 1996. Report to the Oyster, Clam, and Scallop Committee on Ward Creek Field Investigation by Resource Enhancement Staff. North Carolina Department of Environment and Natural Resources. Division of Marine Fisheries, Unpublished Report. 8 p.

Ortega, S., J. P. Sutherland and C. H. Peterson. 1990. Environmental determination of oyster success in the Pamlico Sound. Albemarle-Pamlico Estuarine Study, North Carolina Department of Environment, Health, and Natural Resources and United States Environmental Protection Agency. Report 90-08, 29 p.

Paerl, H. W., N.S. Hall, A. G. Hounshell, R. A. Luettich, Jr., K. L. Rossignol, C. L. Osburn, and J. Bales. 2019. Recent increase in catastrophic tropical cyclone flooding in coastal North Carolina, USA: Long-term observations suggest a regime shift. Scientific Reports 9(1):10620.

Paerl, H. W., N. S. Hall, A. G. Hounshell, K. L. Rossignol, M. A. Barnard, R. A. Luettich, J. C. Rudolph, C. L. Osburn, J. Bales, and L. W. Harding. 2020. Recent increases of rainfall and flooding from tropical cyclones (TCs) in North Carolina (USA): implications for organic matter and nutrient cycling in coastal watersheds. Biogeochemistry 150:197–216.

Peters J. W. 2014. Oyster demographic rates in sub-tidal fished areas: recruitment, growth, mortality, and potential larval output. Master’s Thesis. North Carolina State University, Raleigh, NC.

Peters J. W., D. B. Eggleston, B. J. Puckett, and S. J. Theuerkauf. 2017. Oyster demographics in harvested reefs vs. no-take reserves: implications for larval spillover and restoration success. Frontiers in Marine Science 4:326.

Peterson, C. H., J. H. Grabowski, and S. P. Powers. 2003. Estimated enhancement of fish production resulting from restoring oyster reef habitat: Quantitative valuation. Marine Ecology Progress Series 264:249–264.

Pfeffer, C. S., M. F. Hite, and J. D. Oliver. 2003. Ecology of *Vibrio vulnificus* in estuarine waters of eastern North Carolina. Applied and Environmental Microbiology 69(6):3526–3531.

Piehler, M. F., and A. R. Smyth. 2011. Habitat-specific distinctions in estuarine denitrification affect both ecosystem function and services. Ecosphere 2(1):1–17.

Pierson, K. J., and D. B. Eggleston. 2014. Response of estuarine fish to large-scale oyster reef restoration. Transactions of the American Fisheries Society 143(1):273–288.

Plunket, J., and M. K. La Peyre. 2005. Oyster beds as fish and macroinvertebrate habitat in Barataria Bay, Louisiana. Bulletin of Marine Science 77(1):155–164.

Pollack, J., S. M. Ray, B. Lebreton, B. Blomberg, and S. Rikard. 2012. Patchiness of dermo (*Perkinsus marinus*) disease foci in the Aransas – Copano, Texas estuarine system. Journal of Shellfish Research 31:333.

Porter, E. T., J. C. Cornwell, and L. P. Sanford. 2004. Effect of oysters *Crassostrea virginica* and bottom shear velocity on benthic-pelagic coupling and estuarine water quality. Marine Ecology Progress Series 271:61–75.

Posey, M. H., T. D. Alphin, C. M Powell, and E. Towsend. 1999. Use of oyster reefs as habitat for epibenthic fish and decapods. Pages 229–238 *in* M. W. Luckenbach, R. Mann, and J. A. Wesson, editors. Oyster Reef Habitat Restoration: A Synopsis and Synthesis of Approaches. Virginia Institute of Marine Science Press, Gloucester Point, VA.

Potter, E. F., J. F. Parnell, R. P. Teulings, and R. Davis. 2006. Birds of the Carolinas. The University of North Carolina Press, Chapel Hill, NC.

Powell, E., J. M. Morson, K. A. Ashton-Alcox, and Y. Kim. 2013. Accommodation of the sex-ratio in Eastern Oysters *Crassostrea virginica* to variation in growth and mortality across the estuarine salinity gradient. Journal of the Marine Biological Association of the United Kingdom 93:533–555.

Powell E.N., J. N. Kraeuter, K.A. Ashton-Alcox. 2006. How long does oyster shell last on an oyster reef? Estuarine, Coastal and Shelf Science 69:531–542.

Powers, S. P., C. H. Peterson, J. H. Grabowski, and H. S. Lenihan. 2009. Success of constructed oyster reefs in no harvest sanctuaries: implications for restoration. Marine Ecology Progress Series 389:159–170.

Prins, T. C., A. C. Smaal, and R. Dame. 1997. A review of the feedbacks between bivalve grazing and ecosystem processes. Aquatic Ecology 31:349–359.

Puckett, B. J., and D. B. Eggleston. 2012. Oyster demographics in a network of no-take reserves: recruitment, growth, survival, and density dependence. Marine and Coastal Fisheries 4(1):605–627.

Puckett, B. J., D. B. Eggleston, P. C. Kerr, and R. A. Luettich Jr. 2014. Larval dispersal and population connectivity among a network of marine reserves. Fisheries Oceanography 23(4):342–361.

Puckett, B. J., S. J. Theuerkauf, D. B. Eggleston, R. Guajardo, C. Hardy, J. Gao, and R. A. Luettich. 2018. Integrating larval dispersal, permitting, and logistical factors within a validated habitat suitability index for oyster restoration. Frontiers of Marine Science 5:76.

Ray, S. M., and A. C. Chandler. 1955. Parasitological reviews: *Dermocystidium marinum*, a parasite of oysters. Experimental Parasitology 4:172–200.

Richards, W. R., and P. C. Ticco. 2002. The Suminoe oyster, *Crassostrea ariakensis*. Virginia Sea Grant/University of Virginia – Charlottesville, Charlottesville, VA, VSG-02-23, 6 p.

Roegner, G. C., and R. Mann. 1995. Early recruitment and growth of the American oyster *Crassostrea virginica* with respect to tidal zonation and season. Marine Ecology Progress Series 117:91–101.

Roesijadi, G. 1996. Metallothionein and its role in toxic metal regulation. Comparative Biochemistry and Physiology 113(2):117–123.

Ross, S. W., and S. P. Epperly. 1985. Utilization of shallow estuarine nursery areas by fishes in Pamlico Sound and adjacent tributaries, North Carolina. Pages 207–232 *in* A. Yanez-Arancibia, editor. Fish community ecology in estuaries and coastal lagoons: towards an ecosystem integration. Universidad Nacional Autonoma de Mexico Press, Mexico City.

Rothschild, B. J., J. S. Ault, P. Goulletquer, and M. Héral. 1994. Decline of the Chesapeake Bay oyster population: a century of habitat destruction and overfishing. Marine Ecology Program Series 111:29–39.

Rybovich, M. M. 2014. Growth and mortality of spat, seed, and market-sized oysters (*Crassostrea virginica*) in low salinities and high temperatures. Master's thesis. Louisiana State University, Baton Rouge. 65 p.

Sackett, R. E. 2002. Characterization of North Carolina *Crassostrea virginica* population structure based on mtDNA haplotype variation. Master's thesis. University of North Carolina at Wilmington. 57 p.

Schulte, D. M., R. P. Burke, and R. N. Lipcius. 2009. Unprecedented restoration of native oyster metapopulation. Science 325:1124–1128.

Shefi, D. 2007. The development of cutters in relation to the South Australian oyster industry: an amalgamation of two parallel developing industries. Department of Archaeology, Flinders University, Adelaide, South Australia.

Shumway, S. E. 1996. Natural environmental factors. Pages 467–513 *in* V. S. Kennedy, R. I. E. Newell, and A. F. Eble, editors. The Eastern Oyster *Crassostrea virginica*. Maryland Sea Grant Publication, University of Maryland, College Park, Maryland.

Smith, R. O. 1949. Summary of oyster farming experiments in South Carolina 1939–1940. U.S. Fish and Wildlife Service Special Scientific Report 63:1–20.

Smyth, A. R., N. R. Geraldi, and M. F. Piehler. 2013. Oyster-mediated benthic-pelagic coupling modifies nitrogen pools and processes. Marine Ecology Progress Series 493:23–30.

Soniat, T. M. 2016. Synopsis of the fifth annual Louisiana oyster stock assessment workshop. New Orleans, LA: University of New Orleans.

Soniat, T. M., E. N. Powell, N. A. Cooper, S. M. Pace, and L.K. Solinger. 2022. Predicting oyster harvests at maximum sustained yield: application of cultch and stock benchmarks to depleted public oyster reefs in the northern Gulf of Mexico. Journal of Shellfish Research 40(3):429–449.

Stanley, J. G., and M. A. Sellers. 1986. Species profiles: Life histories and environmental requirements of coastal fishes and invertebrates (Gulf of Mexico) – American oyster. U.S. Fish and Wildlife Service Biological Report. 82(11.64). U.S. Army Corps of Engineers, TR EL-82-4. 25 p.

Steel, J. 1991. Albemarle-Pamlico Estuarine System, Technical Analysis of Status and Trends. APES Report No. 90-01. North Carolina Department of Environment and Natural Resources, Raleigh, NC.

Street, M. W., A. S. Deaton, W. S. Chappell, and P. D. Mooreside. 2005. North Carolina Coastal Habitat Protection Plan. North Carolina Department of Environment and Natural Resources. Division of Marine Fisheries. Morehead City, North Carolina. 656 p.

Thayer, G. W., H. H. Stuart, W. J. Kenworthy, J. F. Ustach, and A. B. Hall. 1978. Habitat values of salt marshes, mangroves, and seagrasses for aquatic organisms. Pages 235–247 *in* P. E. Greeson, J. R. Clark, and J. E. Clark, editors. Wetland Functions and Values: The State of Our Understanding. American Water Resource Association, Minneapolis, MN.

Thibault, J. M., F.J. Sanders, and P.G. Jodice. 2010. Parental attendance and brood success in American Oystercatchers in South Carolina. Waterbirds 33(4):511–517.

Thompson, R. J., R. I. E. Newell, V. S. Kennedy, and R. Mann. 1996. Reproductive processes and early development. Pages 335–370 *in* V. S. Kennedy, R. I. E. Newell and A. F. Eble, editors. The Eastern Oyster *Crassostrea virginica*. Maryland Sea Grant Publication, University of Maryland, College Park, Maryland.

Thorsen, B. D. 1982. Origins and early development of the North Carolina Division of Commercial Fisheries 1822–1925. Master's thesis, East Carolina University, Greenville, N.C. 151 p.

Tuckwell, J., and E. Nol 1997. Foraging behaviour of American oystercatchers in response to declining prey densities. Canadian Journal of Zoology 75(2):170–181. https://doi.org/10.1139/z97-024

Varney, R. L., and P. M., Gaffney. 2008. Assessment of population structure in *Crassostrea virginica* throughout the species range using single nucleotide polymorphisms. Journal of Shellfish Research 27:1061.

Vezzulli, L., C. Grande, P. C. Reid, P. Hélaouët, M. Edwards, M. G. Höfle, I. Brettar, R. R. Colwell, and C. Pruzzo. 2016. Climate influence on Vibrio and associated human diseases during the past half-century in the coastal North Atlantic. Proceedings of the National Academy of Sciences 113(34): E5062–E5071.

VIMS (Virginia Institute of Marine Science). 2002. Oyster Diseases of the Chesapeake Bay: Dermo and MSX Fact Sheet. 4 p.

Von Brandt, A. 1964. Fishing catching methods of the world. Fishing News Books Ltd. Surrey, England.

Wakefield J. R., and P. M. Gaffney. 1996. DGGE reveals additional population structure in American oyster (*Crassostrea virginica*) populations. Journal of Shellfish Research 15:513.

Wall, C. C., B. J. Peterson, and C. J. Gobler. 2008. Facilitation of seagrass *Zostera marina* productivity by suspension-feeding bivalves. Marine Ecology Progress Series 357:165–174.

Wallace, D. H. 1966. Oysters in the estuarine environment. A symposium of estuarine fisheries. American Fisheries Society, Special Publication. 3:68–73.

Watkins, S. M., A. Reich, L. E. Fleming, and R. Hammond. 2008. Neurotoxic Shellfish Poisoning. Marine Drugs 6(3):431–455.

Wetz, M. S., A. J. Lewitus, E. T. Koepfler, and K. C. Hayes. 2002. Impact of the Eastern oyster *Crassostrea virginica* on microbial community structure in a salt marsh estuary. Aquatic Microbial Ecology 28:87–97.

Winslow, F. 1889. Report on the sounds and estuaries of North Carolina, with reference to oyster culture. United States Coast and Geodetic Survey, Bulletin No. 10, 135 p. federal laws. U.S. Department. of Commerce, NOAA, National Marine Fisheries Service, 106 p.

Wolfson, L., and T. Harrigan. 2010. Cows, Streams, and *E. coli*: What everyone needs to know. Michigan State University Extension E, 3101.

Yonge, C. M. 1960. Oysters. Willmer Brothers and Haran, Ltd., Birkenhead, England.

Xie, L., and D. B. Eggleston. 1999. Computer simulation of wind-induced estuarine circulation pattern and estuary-shelf exchange processes: the potential role of wind forcing on larval transport. Estuarine, Coastal and Shelf Science 49:221–234.

Zimmerman, R., T. J. Minello, T. Baumer, and M. Castiglione. 1989. Oyster reef as habitat for estuarine macrofauna. National Marine Fisheries Service, NOAA Technical Memorandum NMFS-SEFC-249. Galveston, Texas.