2024

Fishery Management Plans

NC DIVISION OF MARINE FISHERIES | 3441 Arendell St. P.O. Box 769 Morehead City, NC 28557

2024

EASTERN OYSTER FISHERY MANAGEMENT PLAN AMENDMENT 5

NC Division of Marine fisheries

3441 Arendell St. P.O. Box 769
Morehead City, NC 28557

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

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Shellfish Advisory Committee

Oyster/Clam 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	Carter Witten
Dan Zapf		

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EXECUTIVE SUMMARY

*** This section is completed prior to final approval***

INTRODUCTION

This is Amendment 5 to the Oyster Fishery Management Plan (FMP). By law, each FMP must be reviewed at least once every five years (G.S. 113-182.1). The N.C. Division of Marine Fisheries (NCDMF) reviews each FMP annually and a comprehensive review is undertaken about every five years. The last comprehensive review of the plan (Amendment 4) was approved by the N.C. Marine Fisheries Commission (NCMFC) in 2018. FMPs are the ultimate product that brings all information and management considerations into one document. The NCDMF prepares FMPs for adoption by the 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. 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 Fishing Waters in accordance with 113-182.1. Until Amendment 5 is approved for management, Eastern Oysters are managed under Amendment 4 of the Oyster FMP (NCDMF 2018).

For more information about previous and current management, see the original Eastern Oyster FMP (NCDMF 2001) 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 (2018)
Revisions:	None
Supplements:	Supplement A (2010)
Information Updates:	None
Schedule Changes:	None
Next Comprehensive Review:	Five years after adoption of Amendment 5

Management Unit

The management unit of this FMP includes the Eastern Oyster *(Crassostrea virginica)* and its fisheries in all waters of coastal North Carolina.

Goal and Objectives

The goal of the N.C. Eastern Oyster FMP is to manage the oyster resource in such a way as to maintain 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 a sessile 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 indicated that 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 second 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 *Crassostrea virginica* (shaded line) as adapted from Bahr and Lanier (1981). Current research suggests the range of the Eastern Oyster does not extend south of the Caribbean Sea (Amaral and Simone 2014).

Eastern Oysters inhabit varied water temperatures that may range between 0 to 32 °C annually (Butler 1954). While their optimum salinity range varies between 14 and 28 ppt, oysters can tolerate extreme salinities (as low as 5 ppt and as high as 40 ppt) depending on temperature (Galtsoff 1964; Wallace 1966; Shumway 1996; Loosanoff 1965; Rybovich 2014). The distribution and survival of Eastern 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 below (pages 38-40).

North Carolina's oyster stocks are composed of both subtidal populations (below the mean low tide water level, up to 8 meters 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

Eastern 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 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).

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.

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 that 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 (i.e., 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).

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 only two to three months old, but a majority of young-of the-year oysters will not be sexually mature (Kennedy 1983; Galtsoff 1964). 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).

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 (Lillis et al. 2013; Hidu and Haskins 1971). 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 set in the intertidal zone where salinities are above 20 ppt whereas in subtidal areas they set when salinities are below 20 ppt (Mackin 1946; Loosonoff 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 reach 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 all 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 also under different environmental conditions (Godwin 1981; Puckett & Eggleston 2012; Kennedy & Breisch 1981; Roegner & Mann 1995).

Stock Unit

For the purposes of stock assessment, the unit stock is considered all Eastern Oysters occurring within North Carolina coastal waters.

Assessment Methodology

Data are not available to perform a traditional assessment, so it was not possible to estimate population size or fishing mortality rates. Currently, the only data representative of the stock are the commercial landings and associated effort. For this reason, the current assessment focuses on trends in catch rates in the commercial oyster fishery. These catch rates should not be considered an unbiased representation of trends in population size; fisheries-dependent data are often not proportional to population size due to several caveats and should be interpreted with caution if the interest is relative changes in the population.

The North Carolina commercial Eastern Oyster fishery is subject to trip limits, which could bias catch rates (Mike Wilberg, UMCES, pers. comm.; John Walter, NOAA Fisheries, pers. comm.); that is, the trip limits affect the amount of catch that is observed per unit effort—the true value of the variable cannot be observed. Here, a censored regression approach was attempted to calculate an index of relative abundance (numbers harvested per transaction) using data collected from a fishery with trip limits.

Data were obtained from the North Carolina Trip Ticket Program for 1994 through 2013. The censored response variable (catch per unit effort) was fit within a Generalized Additive Models for Location Scale and Shape (GAMLSS) framework using the 'gamlss.cens' (Stasinopoulos et al. 2014) and 'survival' (Therneau 2014) packages in R (R Core Team 2014). Catch rates were estimated for both hand harvest and mechanical harvest in each of the major water bodies from which Eastern Oysters are harvested where sufficient data were available. Data are summarized by fishing year (October through March for hand harvest and November through March for mechanical harvest). Only landings from public bottoms were examined.

Stock Status

There is insufficient data to conduct a traditional stock assessment for the Eastern Oyster in North Carolina; therefore, population size and the rate that oysters are removed from the population could not be determined. North Carolina commercial oyster landings have been in decline for most of the past century. This decline was likely initiated by overharvest and compounded by habitat disturbance, pollution, and biological and environmental stressors. Oysters are believed to be more vulnerable to overharvest because these other factors negatively impact their survival.

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 2001, 2003, 2008, 2010, 2014, 2017); all FMP documents are available on the DMF Fishery Management Plans website and commercial landings can be found in the License and Statistics Annual Report (NCDMF 2022) produced by the DMF which can be found on the DMF Fisheries Statistics page.

Commercial Fishery

HISTORICAL OVERVIEW

The Eastern 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 for oyster dredging in public bottom waters deeper than 8 feet throughout Pamlico and Roanoke sounds (Thorsen 1982). However, a loophole resulted in an influx of out-of-state fishermen flocking to North Carolina in 1889. Consequently, increased exploitation of oyster stocks with dredges and mechanical tongs led to a conflict between resident and out-of-state oystermen was 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 limited dredging in 1896 resulted in huge declines in oyster production and closing of many of the oyster canneries. In 1897 the dredging law was amended, allowing limited dredging, a longer dredging season, and more law enforcement, resulting in 677,239 bushels landed and 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 this peak, reaching 171,090 bushels in 1918. Around this time, the state recognized the value of recycling shell for the use of 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 harvests, additional state funding then 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, please see Appendix 1.

All oyster landings prior to 1931 were accomplished using hand methods and sail-powered oyster dredge boats. The 1940s saw the 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. Apart from 1987, the overall trend of oyster landings in North Carolina was that of gradual decline through 2000.

There appear to be several contributing factors which allowed for the continuing decline. 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 (Thorsen 1982; Chestnut 1951).

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, please refer to Amendment 4 of the Oyster FMP.

Table 1. North Carolina oyster landings in pounds of meat and bushels, 1880-2022. (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			

MECHANICAL HARVEST METHODS

Harvest of oysters by mechanical methods is accomplished almost exclusively with oyster dredges in North Carolina. 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 of the oyster landings were taken by dredge when compared to all hand methods (Figure 5). Chestnut (1955a) 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.

The mechanical oyster fishery is limited to Pamlico Sound with a maximum season beginning on the third Monday in November to 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 (Figures 4 & 5). There are currently four management areas for mechanical harvest in Pamlico Sound: Northern Dare, Northern Hyde, Pamlico River, and Neuse River (Figures 4 & 5). Throughout these areas, mechanical harvest is limited to 15 bushels per fishing operation in the open Sound and the Neuse and Pamlico Rivers. Conversely, some larger bays and tributaries are also open to mechanical harvest for a maximum of six weeks with a limit of 10 bushels per fishing operation. These areas and limitations are based on recommendations and criteria established in the original Oyster FMP (NCDMF 2001) and are designated in N.C. Marine Fisheries Commission Rule 15A NCAC 03R .0108.

In-season openings and closures of these areas are determined by management triggers. These triggers are based on the percentage of legal sized oysters in a management region. Biweekly monitoring by NCDMF gathers samples in bays and deep waters of Pamlico Sound across four management areas. Failure to meet the 26% legal-size threshold for two consecutive trigger sampling trips results in the 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 areas, 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 higher vertical relief (height) in these deep areas to be resilient to these negative water quality impacts from storm events (Lenihan 1999; Lenihan and Peterson 1998). 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 page 37 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.

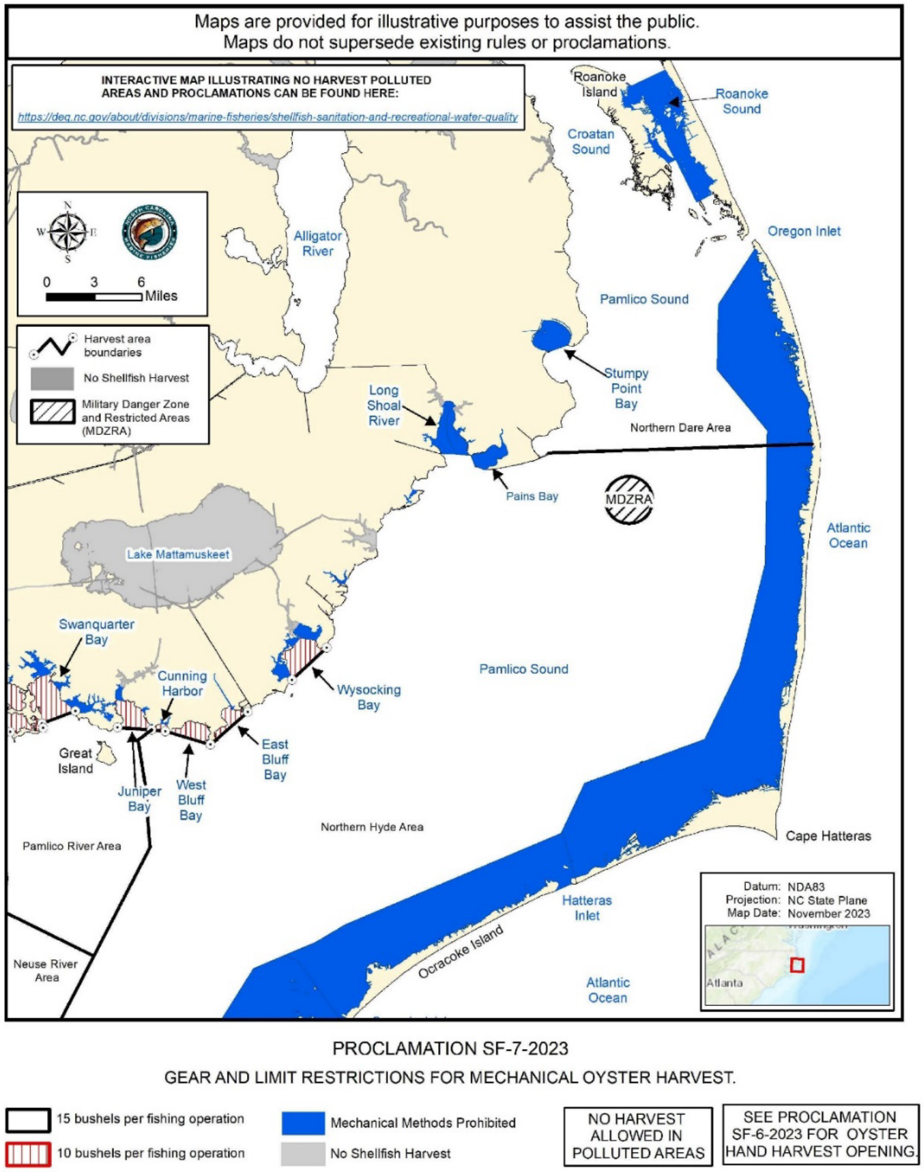

Figure 3. Mechanical gear and harvest restrictions in northern Pamlico Sound for North Carolina's Oyster Fishery.

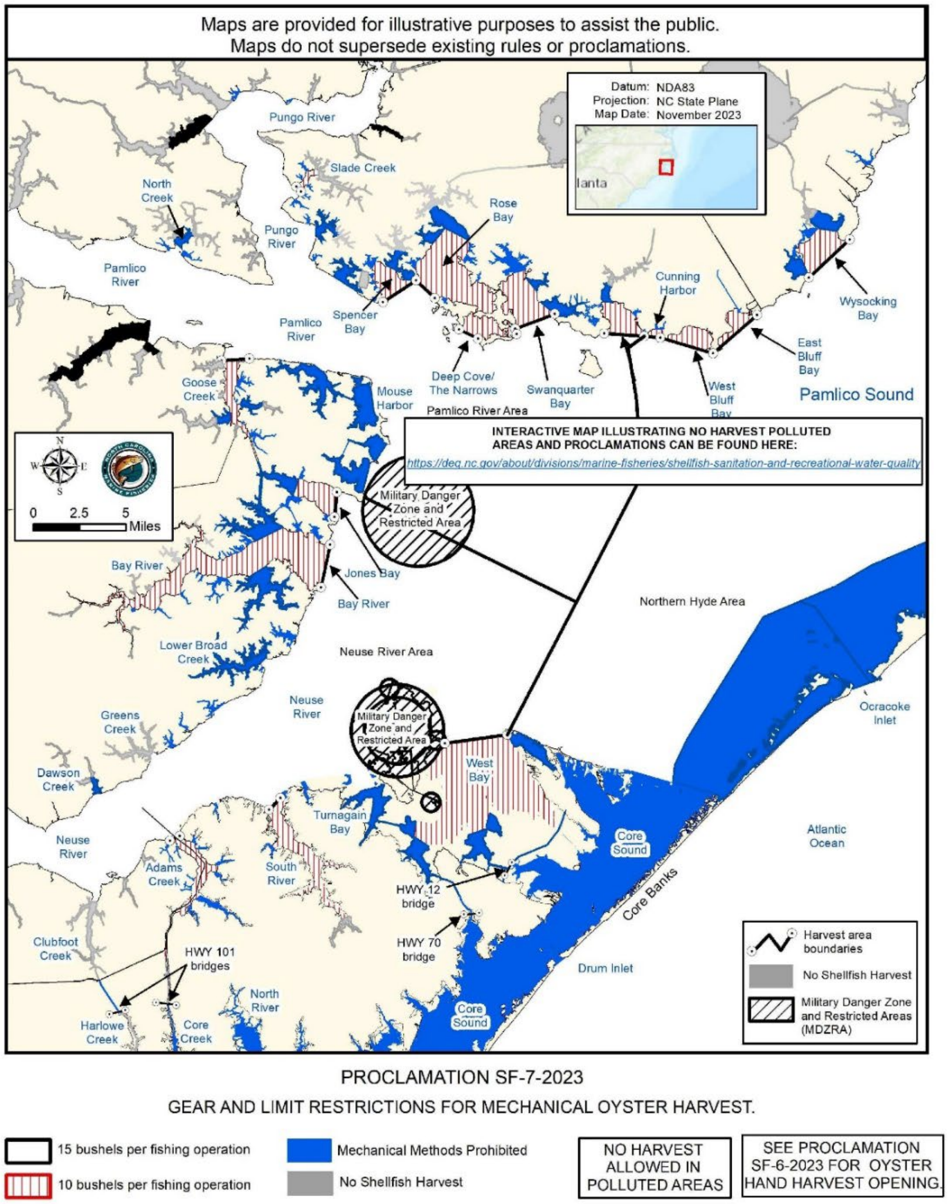

Figure 4. Mechanical gear and harvest restrictions in the western part of Pamlico Sound for North Carolina's Oyster Fishery.

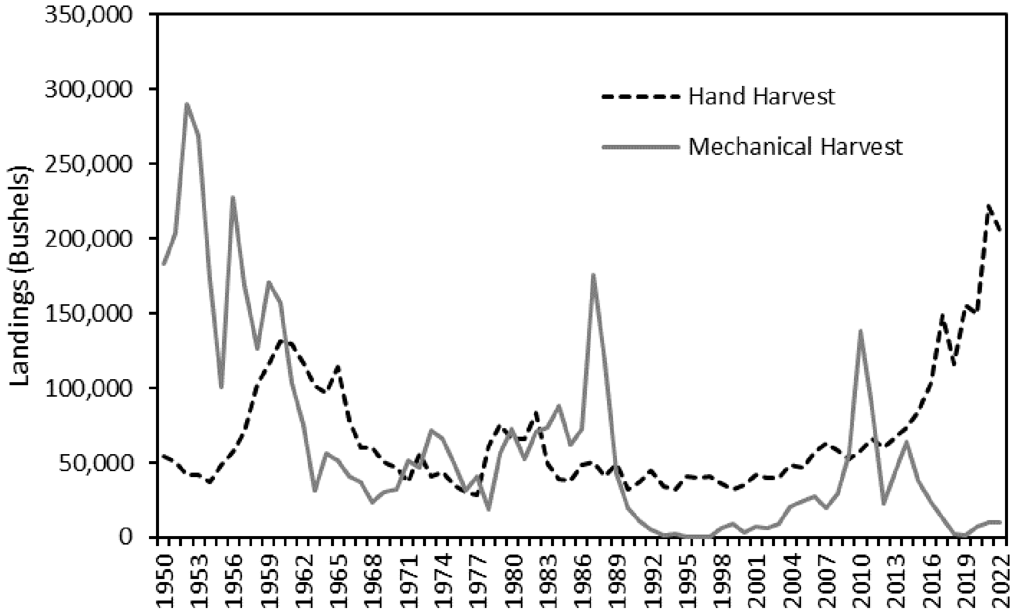

Figure 5. Commercial oyster landings by gear for public and private bottom, 1950-2022 (Chestnut and Davis 1975; National Marine Fisheries Service unpublished data; NCDMF Trip Ticket Program).

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 bays of Pamlico Sound and part of Roanoke Sound. The closures were accomplished under a framework established in the original Oyster FMP (NCDMF 2001). Another change was the 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 on mechanical harvest limits to allow for up to 20 bushels to be harvested per commercial fishing operation per day (NCDMF 2010). The bays around Pamlico Sound are opened for a six-week season normally from mid-November through December with a 10-bushel-per-commercial-fishing-operation-per-day harvest limit as adopted in the original Oyster FMP (NCDMF 2001).

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. The 2pm time limit on dredging resulted in harvesters culling their entire catch after 2pm rather than on-site, often depositing cultch where it could no longer function as oyster habitat. North Carolina has a rule (Marine Fisheries Commission Rule 15A NCAC 03K .0202) requiring culling on site. 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.

Additionally, some harvesters did not have vessels or dredges rigged for circular dredging patterns which work best with towing points over the side of the vessel or for short tows. As a result, restrictions were put in place to encourage circular dredging patterns and shorter tows to encourage culling between pickups. These restrictions include: 1) It is unlawful for the catch container (bag, cage) attached to a dredge to extend more than two feet 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.

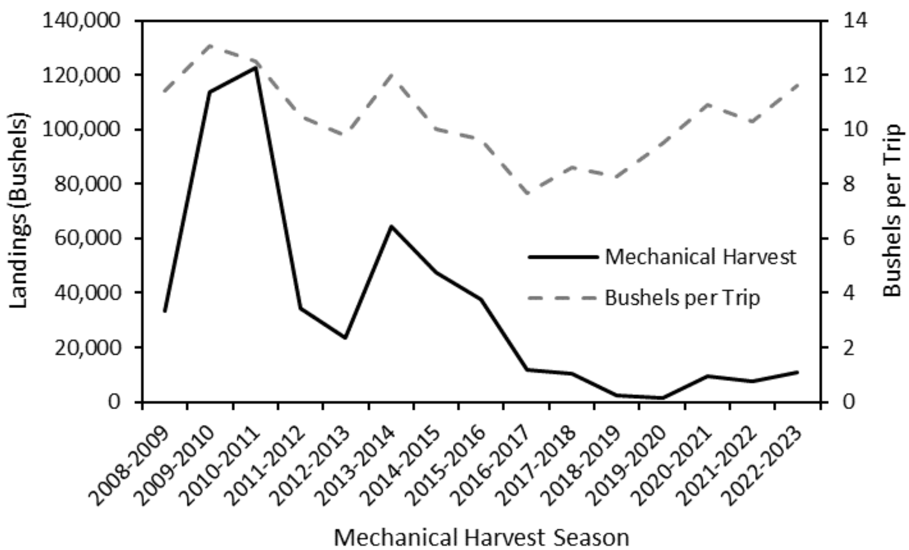

Figure 6. Mechanical harvest oyster landings by season 2008-09 through 2022-23. A monitoring system for determining the closure of mechanical harvest areas began in the 2010-11 season (NCDMF Trip Ticket Program).

Recent Trends and Impacts to Mechanical Harvest

In the past two decades the mechanical oyster fishery has experienced two relative peaks—the 2009 and 2014 seasons (Figures 6 & 7).

During the early 2009-2010 mechanical harvest oyster season, the Great Island Narrows area between Great Island and the mainland in Hyde County experienced intensive oyster harvest. NCDMF staff observed ~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. Staff investigation indicated that substantial shell damage was occurring on 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.

The closure of oyster harvest areas in the Gulf of Mexico following the Deepwater Horizon oil spill generated greater market demand and resulted in North Carolina's mechanical harvest season opening earlier on November 1st in 2010. Supplement A to the N.C. Oyster FMP Amendment 2 (adopted November 3, 2010) provided for a variable mechanical harvest limit of up to 20 bushels per day was put in place for November 18-24 and March 16-31 and 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. Effort in the Neuse River area appeared to be much lower after the re-opening.

In August 2011, Hurricane Irene had major impacts on the mechanical harvest areas. Sedimentation or strong currents likely buried or displaced the 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. Sampling of oyster sizes has made it clear that oyster growth during the harvest season is essential to sustain acceptable harvest levels.

Prior to the 2012-13 mechanical harvest season, NCDMF oyster sampling indicated an apparent, severe low dissolved oxygen event occurred in the Neuse River that caused virtually 100 percent mortality of the oyster resources at 18 feet 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 although 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, 2013 based on failure to meet the 26% trigger although effort was much reduced since early January. The 2012-2013 mechanical harvest oyster landings declined further to 23,566 bushels (Table 1).

There was little evidence of any 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, and when oyster harvests began to decline in the western sound in early February, 20 to 25 boats moved to Dare County to finish the season. The remaining productive areas in the Neuse River closed on February 28, 2014 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, 2014. The overall result was a significant 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 (Table 1).

HAND HARVEST METHODS

In North Carolina, hand harvest methods for the oyster fishery currently include hand tongs, hand rakes, and by hand. 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 begins on October 15 each year with commercial harvest limited to Monday through Friday each week. The season typically continues until closed by rule on March 31 although some locations may close early due to perceived excessive harvest or pollution concerns. Brunswick County is the only area frequently closed early due to excessive harvest, and typically is closed by proclamation on March 15 annually.

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 (Figure 5). 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 that affected subtidal oyster beds in the northern part of the state.

These higher and more consistent landings come primarily from intertidal oyster reefs between Core Sound and the South Carolina state line. Hand harvest from this southern region is a significant amount of the overall oyster landings even though the area only accounts for five percent of the total shellfish harvest area open in the state. The southern portion of the coast from Core Sound south to the North Carolina-South Carolina border (Coastal Fishing Waters in Brunswick, New Hanover, Pender, Onslow, and portions of Carteret counties) currently operates under a harvest limit of five bushels per person per day, not to exceed 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 five-bushels-per-person-not to-exceed-10-bushels-per-vessel-per-day limit until the 2009-10 season. At that time Amendment 2 to the N.C. 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 is 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 each hand harvester working alone with the opportunity to take 10 bushels each day. The rationale for that 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 8). In 2005, that 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, that percentage has remained under 5%.

Hand-harvest oyster landings generally increased from 1994 to 2017 (Figure 7). This is likely due to increased effort as reflected by the number of trips mirroring the trend in landings (Figure 7). Hand harvest landings peaked in 2017 at 61,574 bushels, and despite some decline, have remained steady around 41,000 annual 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. The Division will re-examine the issue to assess participation and effort in the hand harvest oyster fishery.

A pilot program to monitor intertidal oyster reefs was developed and implemented by the Division. While this program is not currently used to manage the hand harvest fishery, information collected by this sampling program could be used in future management.

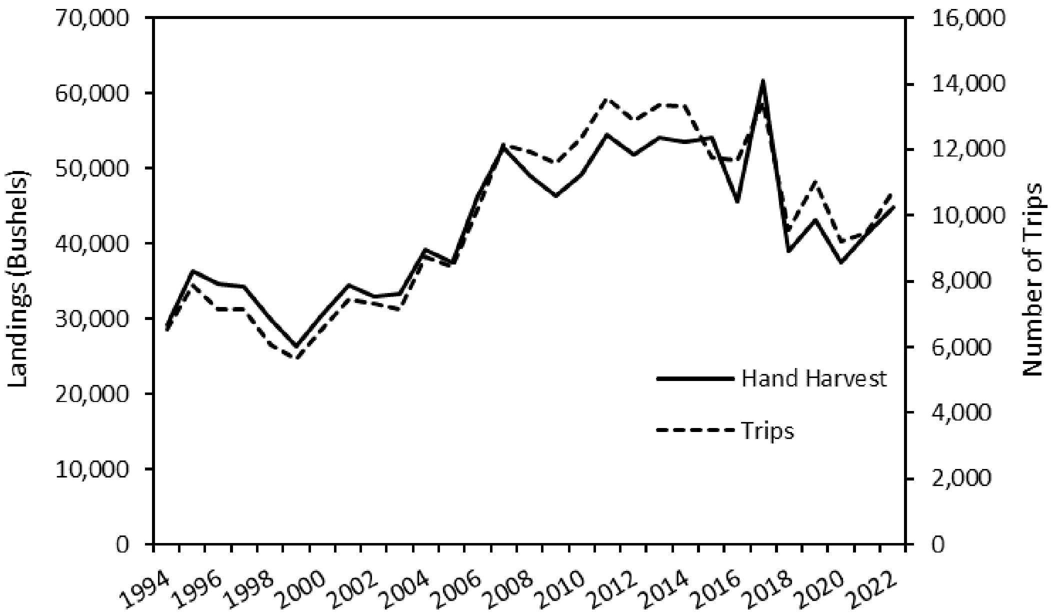

Figure 7. Hand harvest from public bottom oyster landings and trips 1994-2022 (NCDMF Trip Ticket Program).

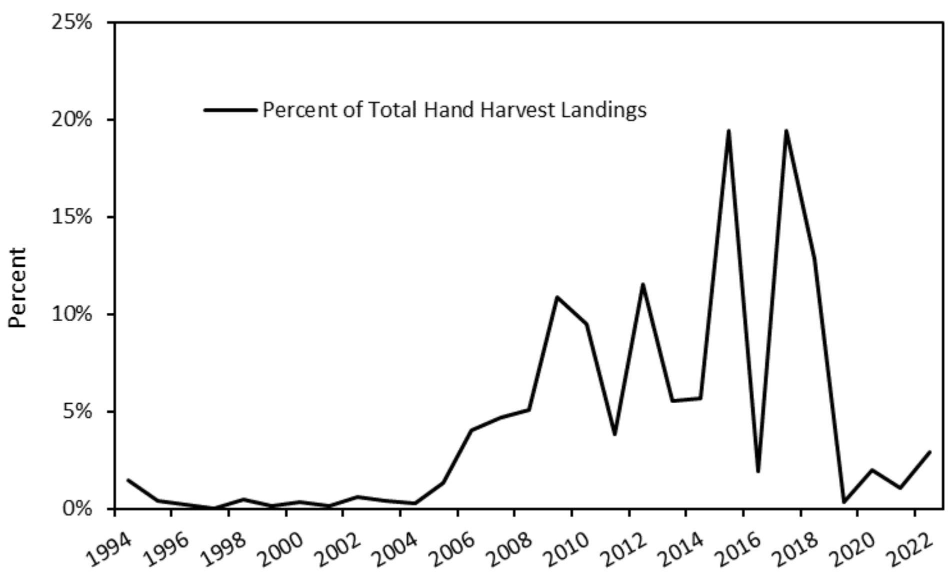

Figure 8. Public bottom hand harvest oyster landings north of Core Sound as a percentage of total public bottom hand harvest oyster landings, 1994-2022 (NCDMF Trip Ticket Program).

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, not to exceed two bushels per vessel with a minimum shell length of 3-inches.

Currently, 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 federal government's Marine Recreational Information Program (MRIP). However, MRIP collects information on finfish only. The Marine Recreational Fishery Statistics Survey (MRFSS) reported that in the state, more than one million recreational fishing trips targeted shellfish in 1991; however, data on actual shellfish harvest estimates 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 with the purpose to establish a recreational shellfish license on a three-year trial basis. However, House Bill 1427 was not passed. Similarly, House Bill 831 (2004) sought to create a saltwater fishing license requiring individuals recreationally fishing for *both* finfish and shellfish to obtain a license. The state legislature revisited the issue in 2005 and replaced the saltwater fishing license with 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 overcome this data gap, NCDMF implemented an optional shellfish survey during November 2010 to collect monthly data on the harvest of crabs, oysters, clams, and scallops from the CRFL license pool. The survey sample is made up of approximately 1,300 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. The survey aims to obtain 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. While data from this survey could be of potential use for estimating recreational catch and effort of shellfish, there are limitations regarding the representative population of recreational shellfish harvesters. For instance, the supplementary CRFL survey does not include individuals who fish exclusively for shellfish as they would not need to purchase a CRFL.

Furthermore, some recreational fishermen 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 fishermen 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 Trip Ticket Program.

With the limited data collected from the optional CRFL survey, some pieces of information about recreational efforts have been captured. For instance, recreational oyster harvest was reported from 92 waterbodies throughout coastal North Carolina, with Topsail Sound, Pamlico Sound, Bogue Sound, and Masonboro Sound all boasting more than 100 reported trips. The same survey revealed that 70% of reported oyster harvesting effort originated from private residence, private boat ramp, or shore. Given that 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 the summer months despite state-imposed restrictions on harvest during this time. This suggests unfamiliarity with state regulations.

Given that 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 is 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 could be significant. Furthermore, collecting recreational data would improve data gaps that may be necessary for a comprehensive stock assessment strategy. 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. Today some shellfish leases are held by commercial fishermen 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 or 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 9). This shift marked a notable change in the primary methods of 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 the participation of private shellfish aquaculture. Additionally, changes to common practices among private oyster cultures and the termination of the relay program have declined 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.

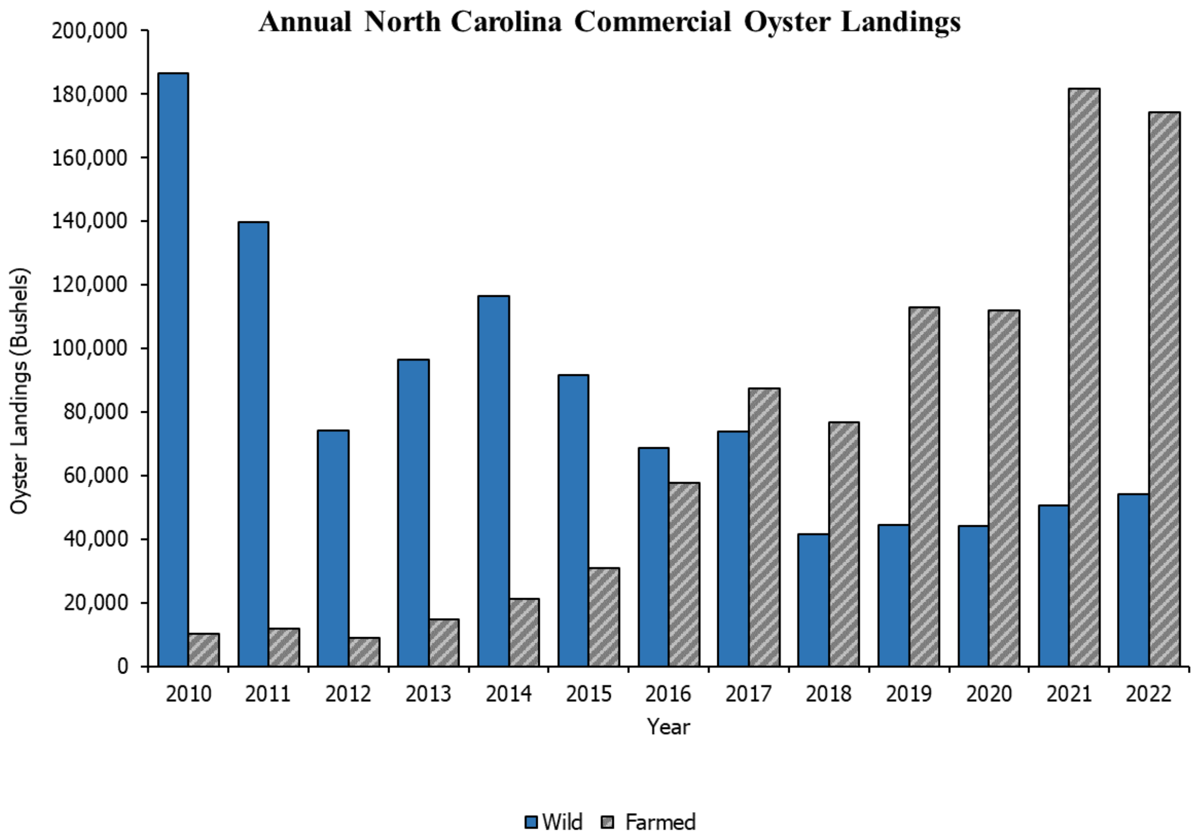

Figure 9. Commercial Annual Landings of Wild Harvest and Farm-Raised Oysters in North Carolina. This graph depicts the yearly commercial landings of both wild harvest and farm-raised oysters in North Carolina.

Summary of Economic Impact

In 2022, oysters were the third most commercially important species in the state. As a species landed primarily during the winter months, oysters provide income to commercial fishermen at a time when other species are not present in harvestable amounts. The expenditures and income within the commercial fishing industry as well as those by consumers of seafood produce 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. NCDMF estimates the extent of these impacts using a commercial fishing economic impact model which utilizes information from socioeconomic surveys of commercial fishermen 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 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 oyster fishery over the last ten years in North Carolina, 2013-2022. 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	1008	$6,061	$13,587
2014	18,951	116,330	$5,058	1158	$7,562	$17,375
2013	17,013	96,258	$3,817	1031	$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 nominal value (the value that is not adjusted for inflation) of North Carolina oyster increased in the early 2010s, reaching a peak of about $6.7 million in 2010. Since then, the value of the oyster fishery has been trending downwards (Figure 10). 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.

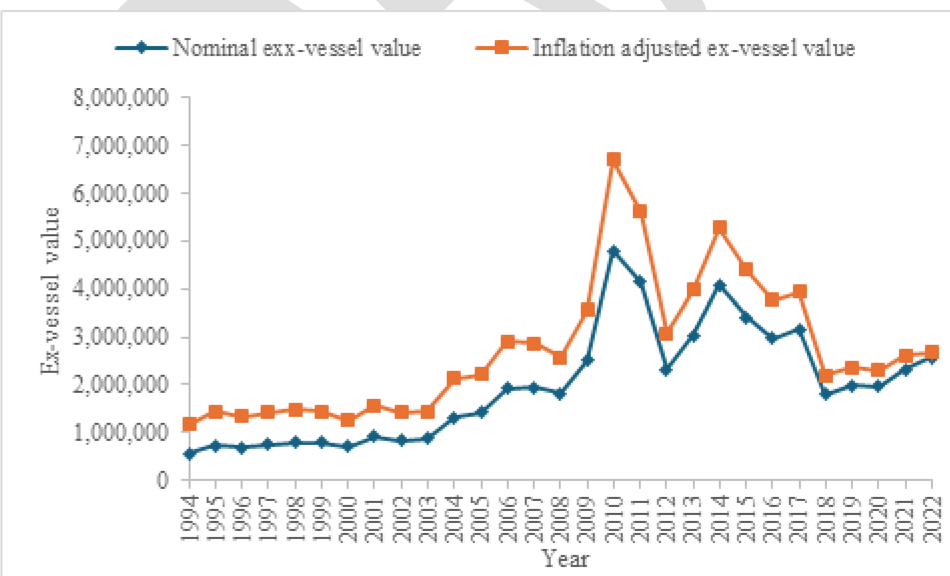

Figure 101. Annual ex-vessel value of oysters in North Carolina, 1994-2022. Inflation adjusted values are in 2023 dollars. NCDMF Trip Ticket Program.

In the 2000s the proportion of landings by mechanical harvest was consistent before reaching a peak in 2010 when it made up 74% of landings (Figure 11). Since then, mechanical harvest has steadily decreased to comprise a small percentage of total landings. This decrease in mechanical landings is likely a result of fewer water bodies being open to mechanical harvest 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 the Pamlico Sound has seen a variable decrease in market share from 34% in 2004 down to 16% in 2022. Conversely, Topsail Sound, Masonboro Sound, and Newport River have seen significant increases in their market shares in the same time span.

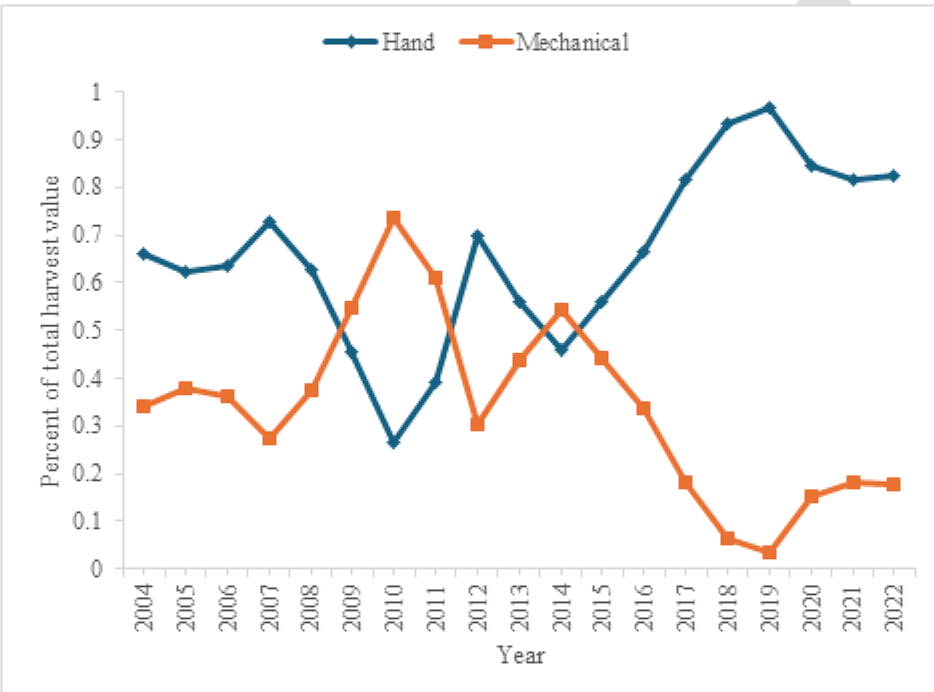

Figure 112. Annual percent of total landings value by gear type used to harvest oysters, 2004-2022. NCDMF Trip Ticket Program

The NCDMF keeps track of the commercial catches of all fishermen in the state. Information is captured for each trip when the catch is sold to a commercial seafood dealer. Data suggests that the oyster fishery was expanding from 2004 to 2010, when it peaked at 1,148 participants. However, between 2010 and 2018 there was a general decrease in the number of participants but 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 in all commercial fisheries in the state, oyster fishermen may only sell their catch to licensed seafood dealers. Between 2004 to 2022, dealers who deal in oysters fluctuated between 120 and 170, with a decreasing trend in the last few years. Many of these seafood dealers are likely oyster fishermen holding a seafood dealers license, who can vertically integrate their commercial fishing business by both catching and selling a seafood product to wholesalers or consumers.

SOCIAL IMPORTANCE OF THE FISHERY

The NCDMF Fisheries Economics Program has been conducting a series of in-depth interview-style surveys with commercial fishermen 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 these responses, please see Amendment 4 of the Oyster FMP. Below is a summary of the survey responses from 168 commercial fishermen active in the oyster fishery across 58 different communities along North Carolina's coast.

The largest number of commercial oyster fishermen 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 fishermen, and 46% reported that commercial fishing was their sole source of personal income. The majority (77%) of commercial fishermen that targeted oysters fished all year long. The respondents indicated that commercial fishing held extremely high historical importance and economic importance within their communities.

The most important issue to these fishermen was low prices for seafood which are also related to competition from imported seafood. Another key issue for oyster fishermen was development of the coast. Several areas of coastal North Carolina have undergone intense development in recent decades. Water quality impairments are often associated with coastal development, which greatly impact 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

In estuarine ecosystems worldwide, oyster reefs play a vital role in creating habitat for diverse communities in estuarine habitats. For instance, 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). Furthermore, as successive generations build 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).

However, 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. Population declines of oysters have been observed, especially on sub-tidal reefs along the US East Coast (Rothschild et al. 1994; Hargis and Haven 1988; NCDMF 2001; Rothschild et al. 1994). In 2007, a National Oceanic and Atmospheric Administration biological review team found that current east coast oyster harvest is 2 percent of peak historical volume (EOBRT 2007). Oyster harvest in North Carolina has shown a similar trend of decline (Street et al. 2005; Deaton et al. 2010).

This section primarily focuses on the role of oysters as habitat, though it also addresses the impacts of the fishery on habitat provision 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. Also in this section are overviews of the Coastal Habitat Protection Plan 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, fishermen, 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 of 1997 (FRA; 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 that the CHPP will identify threats and recommend management actions to protect and restore coastal habitats critical to NC’s coastal fishery resources. The plans are updated every five years and must be adopted by the NC Coastal Resources (CRC), the NC Environmental Management (EMC), and the NC Marine Fisheries (MFC) Commissions to ensure consistency among commissions as well as their supporting NC Department of Environmental Quality (DEQ) agencies. The 2021 CHPP Amendment is the most recent update to the CHPP, building upon the 2016 CHPP source document.

Ecosystem services are the direct and indirect benefits that healthy ecosystems may provide humans. With their role as filter feeders, high densities of oyster reefs have the potential to drastically improve water quality conditions. Additionally, oyster reefs serve as habitat for a variety of economically important species while also stabilizing sediment along coastlines. As each of these functions of oyster reefs benefit coastal living communities, NCDMF recognizes the economic importance of oyster reef habitat. Combining these ecosystem services provided by oysters, the estimated value of North Carolina’s oyster reefs at $2,200 to $40,200 per acre annually (Grabowski et al. 2012). The following sections provide an overview of each of these functions and services provided by oyster reefs.

ESSENTIAL HABITAT

Studies have shown that 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; Kehaler 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 ASMFC-managed and seven

SAFMC-managed species, 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 (Pierson and Eggleston 2014; Ross and Epperly 1985). Estuarine fish can be grouped into three categories: estuary-dependent species, permanent resident species, and seasonal migrant species (Deaton et al. 2010; Street et al. 2005). The most abundant on oyster reefs are estuary-dependent species, which inhabit the estuary as larvae. This group includes species that spawn offshore as well as species that spawn in the estuary.

Table 3. List of all observed and known estuarine species which have been surveyed on oyster reefs or are known to utilize oyster reefs as habitat in North Carolina (Coen et al. 1999; Deaton et al. 2010; Grabowski et al. 2005; Lenihan et al. 2001; Lowery and Paynter 2002; NCDMF Prg.118 unpub. Data; Peterson et al. 2003; Street et al. 2005; ASMFC 2007).

Common name	Scientific name	Common name	Scientific name
Anchovy, Bay	*Anchoa mitchilli*	Mullets	*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*		

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 (ASMFC 2007; Minello 1999; Plunket and La Peyre 2005; Posey et al. 1999). 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 roles in the food webs inhabit these microenvironments. Soft bottoms offer refuge for clams and polychaete worms while larger, mobile invertebrates such as horshoe crabs, whelks, tulip snails, moon snails, shrimp and hermit crabs live on the surface of soft bottoms. Most of soft bottom species listed above also inhabit shell bottoms; however, shell bottom support additional benthic macroinvertebrates, including mud crabs, pea crab, barnacles, soft-shelled clams, mussels, anemones, hydroids, bryozoans, flatworms, and sponges (Deaton et al. 2010; Street et al. 2005). Fiddler crabs use intertidal flats and submerged flats, and shallow bottoms support blue crab and other crustaceans and shellfish.

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

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 (Cressman et al. 2003; Grizzle et al. 2006; Porter et al. 2004; Prins et al. 1997; Coen et al. 2007; Coen et al. 1999; Nelson et al. 2004; Wall et al. 2008; Wetz et al. 2002). Adult oysters have been reported to filter as high as 10 L h-1g-1 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 (Kellogg 2013; Piehler and Smyth 2011). Nitrogen (N) and phosphorous (P) in biodeposits can become buried or removed via bacterially mediated nitrification-denitrification (Newell et al. 2002; Newell et al. 2005; Porter et al. 2004). 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).

Habitat & Enhancement Programs

In 2007, a National Oceanic and Atmospheric Administration biological review team found that current east coast oyster harvest is 2 percent of peak historical volume and suggested that oyster restoration and enhancement efforts are “necessary to sustain populations” (EOBRT 2007). In North Carolina, the Neuse River Estuary 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, and any shell that is sloughed from an existing reef might be subject to deep water hypoxia and sediment burial, where reef establishment is unlikely (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-subsidizing 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 DMF biologists indicate that each acre of cultch material can support and yield 368 bushels of oysters.

Most of the Cultch Planting Program’s effort has occurred in the shallow bays, along the northern shorelines and the Crab Hole area south of Wanchese. Fishery management strategies have not distinguished between natural reefs and cultch planted reefs in Pamlico Sound. The Division is seeking to develop new strategies which will better integrate the cultch planting program with the management of the mechanical fishery. Possible new management could be developed to focus harvest effort on cultch planted reefs. This could help restore and protect the deep-water natural oyster resources in western Pamlico Sound, offer greater certainty to commercial harvesters on season length and area openings that are focused on harvesting cultch planted reefs, and allow the division to prioritize collecting the data we need for a potential future stock assessment.

Additionally, NCDMF’s Habitat & Enhancement oversees the construction of no-take reserves with the goal of creating and maintaining a self-sustaining network subtidal oyster reefs. Protected oyster sanctuaries have the potential to supply ~65 times more larvae per square meter than non-protected reefs (Peters 2017; Puckett and Eggleston 2012). 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 line fishing and diving opportunities for the public. Sanctuary and cultch sites are planned with the aim to improve larval connectivity within the network of restoration sites. To date there are 17 sanctuaries, and a total of 789 acres of protected habitat placed in effect by proclamation.

Secondary to improving oyster populations, these enhancement programs also provide valuable reef habitat for many estuarine species (Table 3). Both cultch sites and sanctuaries offer oysters and other species from hypoxia events via the construction of high relief habitat using alternative substrates. Additionally, these 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 that every 10 m^2 of newly constructed oyster reef in the southeast United States is expected to yield a benefit of 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

The primary threats to oyster habitat in North Carolina are physical disturbance (i.e. harvesting) and water quality degradation (i.e. 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 MFC. However, the MFC can encourage progress on the other issues discussed here 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. Both Chestnut (1955) and Winslow (1889) 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 that significant negative impacts occurred to oyster rocks prior to closure and marking of areas closed to the mechanical harvest of clams, and current fisheries regulations prohibit the use of mechanical gear in SAV beds and live oyster beds 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 and Micheli (2000) quantified the effects of oyster and clam harvest 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

The accidental or intentional introduction of nuisance and non-native aquatic species can enter North Carolina waters through river systems, created waterways like the ICW, 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*) (DMF 2001). However, infection rates of MSX within oysters have drastically declined since 1989 and further sampling for MSX was discontinued by 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 (Richards and Ticco 2002; Andrews 1980; DMF 2001). 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 (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 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 (Ford and Figueras 1988; Ford and Tripp 1996; Haskin et al. 1966; Ray and Chandler 1955). Oysters become more susceptible during extended periods of high salinity and temperature (DMF 2008; La Peyre et al. 2006; VIMS 2002) as well as low dissolved oxygen, sediment loading, and anthropogenic pollution, increase the susceptibility of oysters to parasitism and disease (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 mortally, 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 (DMF 2008).

In 1989, DMF 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. North Carolina appears to have some overwintering infections during mild years, although few samples are taken during winter months. Infection levels were high in the early 90's and mortality of a smaller size class of oysters was observed. Infection intensity dropped between the mid-1990's to the mid-2000's.

Staff observed in southern estuaries during late summer 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 the Pamlico Sound (Leffler et al. 1998). Dermo infection intensity levels since 2005 have remained low; however, prevalence appears to be increasing (DMF 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), and *Haplosporidium nelson* (MSX). In North Carolina oysters, infection rates of MSX have drastically declined since 1989 and are currently not considered a major concern (for more information, please see Amendment 4).

Vibrio spp. are salt-loving bacteria that inhabit coastal waters throughout the world and can be ubiquitous in open shellfish growing areas. *Vibrio* can be found in North Carolina's coastal waters year-round but are more abundant during the warmer summer months (Blackwell and Oliver, 2008; Pfeffer et al. 2003). 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*, called Florida red tide, occur frequently along the Gulf of Mexico (Watkins et al.

2008). Green gill disease in shellfish comes from the single-celled alga called *Haslea ostrearia.* This is a blue-green diatom found in the coastal waters of North Carolina.

For more detailed information on these environmental pathogens, see Amendment 2 of the Hard Clam FMP. 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 of 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. They 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 the low to mid-range salinities but typically are not found in waters with less than 10 ppt. Intertidal oysters have some refuge from boring sponge.

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 the resilience of boring sponges to low salinity events. Sample sites in both areas had no active infestations but gemmules were observed, and sampling seven to eight months later found moderate to high levels of active sponge infestation. Bioeroding polychaete *Polydora* worms were also more abundant in the lower salinity areas and less abundant in areas where salinities were higher (Lindquist et al. 2012).

Water Quality Threats

Marine bivalves, including oysters, have been shown to accumulate chemical contaminates, such as hydrocarbons and heavy metals, in high concentrations. Reductions in growth and increased mortality have been observed in soft-shelled clams (*M. 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 can create 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. The accumulation of such harmful agents in the water column subjects oyster populations to the adverse effects listed above. Point sources have identifiable origins and include National Pollution Discharge Elimination System (NPDES) wastewater discharges. Although wastewater discharges are treated, mechanical failure can allow contaminated sewage to reach shellfish growing waters, thereby 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 (Wolfson and Harrigan 2010; Burkholder et al. 2007; 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, most 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 (DWR 2023a).

HYPOXIA

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 a depletion of dissolved oxygen 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 can already be prone to because of salinity stratification and high summertime water temperatures (Buzzelli et al. 2002). These 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 (4-6m) waters of the estuaries (Lenihan and Peterson 1998; Powers et al. 2009; Johnson et al. 2009). Increased 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 (DWR 2023b).

SHELLFISH SANITATION

North Carolina is part of the National Shellfish Sanitation Program. 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 that are referred to as Growing

Areas. Each of these Growing Areas 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 include 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 DMF’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 that the frequency of severe thunderstorms and the annual total precipitation in NC 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 (Kunkel et al. 2020; Paerl et al. 2019).

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 that 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 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 potentially increase in frequency and length as temperatures rise (Vezzulli et al. 2016). and 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. 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 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 NOAA's MMPA website.

North Carolina estuaries are also home to multiple ESA-listed species including Atlantic Sturgeon (*Acipenser oxyrinchus*), Shortnose Sturgeon (*Acipenser brevirostrum*), and five species of sea turtle. These species are unlikely to be impacted by oyster harvest, as the timing of the season (i.e., October – March) and harvest methods employed largely exclude any potential for any direct interactions. Due to the lack of recorded interactions and the unlikelihood of any interactions between these ESA-listed species and the oyster industry, there is little to no extant literature. As such, it can be assumed that any potential impacts of oyster harvest on protected species populations would be primarily indirect and at the ecosystem-level.

North Carolina is home to a diverse array of migratory bird species (Potter et al. 2006). Little evidence exists to suggest that most species of 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 the overall reproductive success of nearby nesting Oystercatchers (Thibault et al. 2010).

FINAL AMENDMENT 5 MANAGEMENT STRATEGY

****Section will be completed when the MFC selects preferred management and prior to DEQ secretary and legislative committees review****

RESEARCH NEEDS

The research recommendations listed below are offered by the division to improve future management strategies of the eastern oyster fishery. They are considered high priority as they will help to better understand the eastern 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 DMF 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 (i.e., National Oceanic and Atmospheric Administration—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
Appendix 2: Mechanical Oyster Harvest Management Issue Paper
Appendix 3: Hand Oyster Harvest Management Issue Paper
Appendix 4: Habitat Enhancement Programs (Information Paper)

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