APPENDIX 4: HABITAT ENHANCEMENT PROGRAMS

OVERVIEW

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

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

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

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

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

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

Terminology

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

CULTCH PLANTING PROGRAM

For over a century, NCDMF has worked to create cultch reefs to alleviate fishing pressure on North Carolina’s natural oyster reefs. Research has demonstrated the ability of cultch planted reefs to support significant oyster densities over time, with cultch sites hosting 9.6 times more oysters than natural subtidal reefs found throughout Pamlico Sound (Peters et al. 2017). Perhaps even more indicative of their effectiveness as a fisheries management strategy, North Carolina’s cultch reefs were found to have 4.5 times more legal sized oysters than on natural oyster reefs (Peters et al. 2017). Since its inception, over 21 million bushels of cultch material have been planted in the form of small-scale, low-relief, harvestable oyster reefs (Figure 1). The program has been a longstanding collaboration between the state government and local oyster harvesters to ensure cultch reefs are built in the best available locations for oyster recruitment.

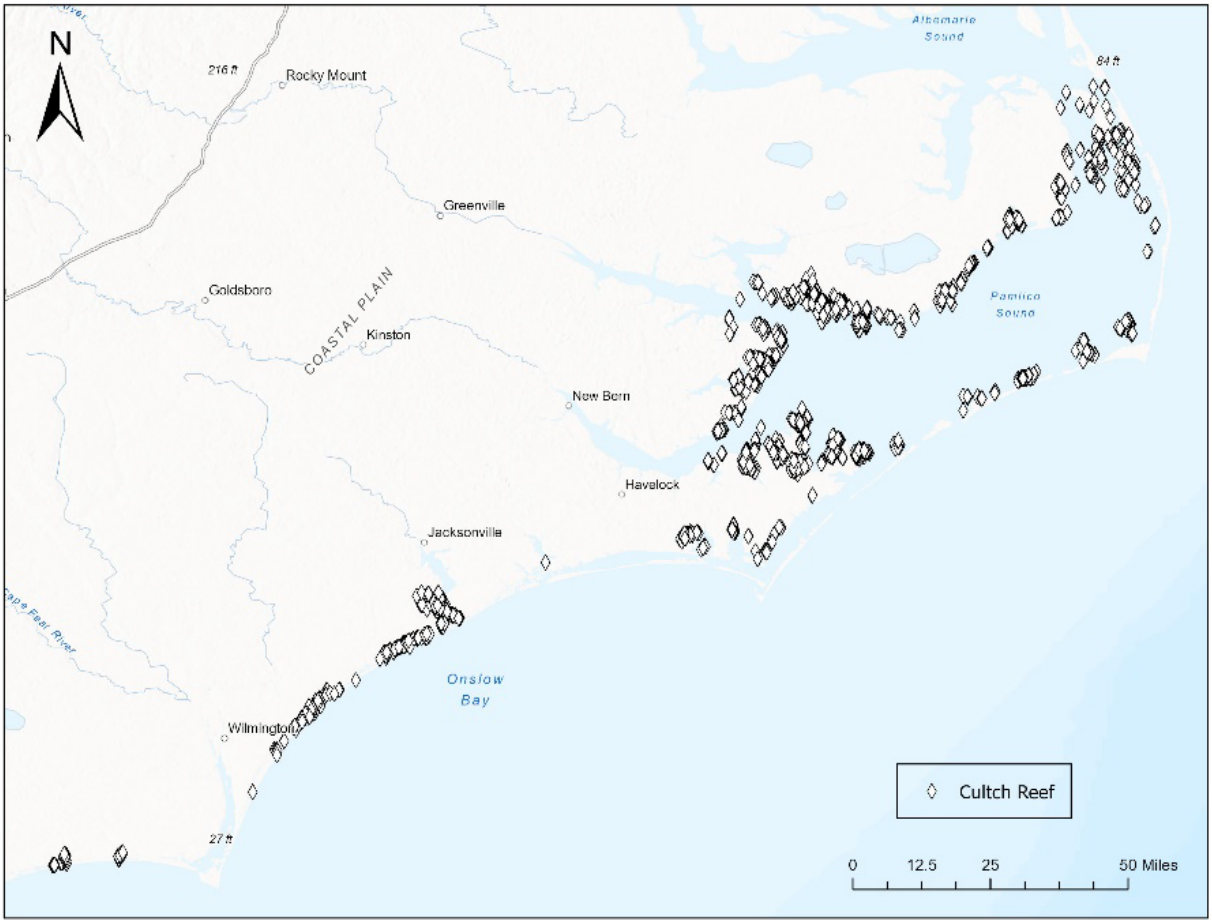

Figure 1: Map of cultch reefs from Dare County to the South Carolina border.

<u>Program History: The First 100 years of Cultch Planting</u>

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

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

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

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

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

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

Monitoring efforts to quantify the performance of cultch sites was typically limited to a three-year period post-construction. NCDMF would survey each cultch planting site to observe trends in population demographics (annual recruitment, size frequency, and population density). However, monitoring of cultch planting sites beyond 3 years was not conducted due to funding and staffing limitations. Initial cultch reef sampling was conducted using imperfect methodology, including small sample sizes, variable sampling intervals, and uncertain area estimates covered by the dredge, all of which made estimating densities and size class distributions difficult and not standardized.

Modern Cultch Planting Program: 2020 – Present

NCDMF currently plants between 300,000 and 400,000 bushels of cultch material annually, covering over approximately 40 acres of undeveloped inshore bottom. Proposed cultch reef locations undergo rigorous site selection each winter before planting begins in the spring. This process is critical to ensure reefs will perform as intended and cultivate oysters for local oystermen, while not disrupting other important habitats. In 2020 NCDMF hired the first biologist dedicated solely to the Cultch Planting Program with the aim to update and standardize the site selection and sampling processes.

Several geospatial analytical tools are used when selecting initial locations for cultch planting. A Habitat Suitability Index (HSI) determines candidate sites based on biological and ecological factors. The HSI is used in tandem with a broadscale multiyear permit from the US Army Corps of Engineers (Nationwide 27). This permit restricts cultch material from being planted in areas with Submerged Aquatic Vegetation (SAV) or existing natural shellfish populations so as to prevent the destruction of important established habitat. Desirable areas found within the constraints of the Nationwide 27 and HSI are then considered depending on logistic variables such as distance from cultch material stockpile sites. Staff review and further ground truthing are conducted to ensures permit compliance and physical suitability of the proposed site. Public surveys are also sent to commercial fishermen for solicit public input and comment.

Data from the Cultch Program are captured in three monitoring programs: P-600 (cultch planting), P-610 (spatfall evaluation), and P-627 (trigger sampling). P-600 records the locations and the type and amount of material planted annually across the state. This is used to update the public facing interactive cultch map to allow for commercial oystermen to find the cultch reefs. P-610 monitors cultch enhanced reefs for three years post planting. Hydraulic tongs are used to collect random point samples. The oysters are counted and measured to determine spat recruitment rates and mortality metrics. P-627 trigger sampling occurs in the fall and lasts for the duration of the commercial oyster mechanical harvest season. A pre-season sample is taken as a baseline for mechanical harvest areas in the Pamlico Sound. Once the season is open, monitoring occurs throughout the season to ensure legal catch does not fall below an allowable threshold. For further details on P-627 (trigger sampling), please refer to Supplement A and Appendix 2 (Mechanical Oyster Harvest Management Issue Paper).

The goals defined by internal documentation for the Cultch Planting Program are highly generalized. These main goals are 1) to provide suitable substrate for the attachment of natural oyster larvae, and 2) to increase oyster production. The Cultch Planting Program relieves harvest pressure from degraded natural reefs by developing permanent and routinely managed areas. However, the current regulations and trip ticket data do not differentiate between oysters caught on cultch sites from oysters harvested on natural reefs. Apart from an annual survey inquiring commercial oystermen about their preferences and use of cultch sites, estimates of how much is harvested from cultch sites are conservative.

Table 2. Bushels and acres planted per year by county for the cultch program from 2010-2022.

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

With the growth of the Cultch Planting Program in the last decade, there is potential for the Cultch Program to become an integral strategy of the oyster fishery management plan. An example strategy for the Cultch Program is further outlined below with a proposed rotational harvest management plan. However, throughout the course of the Cultch Program's history, the acquisition and deployment of materials has been limited by funding resources, which has been inconsistent. In order to effectively integrate and anchor the Cultch Program in its entirety as a management strategy, consistent funding would be required for the Division to utilize it as a continued adaptive management tool.

Rotational Harvest Management

A Rotational Harvest Management (RHM) plan would be a viable strategy for using the Cultch Planting Program as a management tool to relieve harvest pressure on natural reefs. This strategy considers spatial distribution, adequate reef size, regular monitoring and reef maintenance, as well as regular enforced opening and closure by proclamation. The RHM reefs can be built strategically around Pamlico Sound in mechanical harvest areas and located near oyster sanctuaries to reap the benefits of their brood stock production. The reefs would be permanent fixtures approximately 10 acres in size, which differs from the previous strategy of building many small temporary reefs approximately 1-5 acres in size. Reefs can be opened and closed to harvest in a cyclical manner via proclamation, in a manner that always allows for some reefs to remain open (Table 1). Regular side-scan imaging will occur so that, while closed, reefs can be re-enhanced with material to mitigate damage from harvest or other forces such as impacts from hurricanes or sedimentation. Closure will persist for one to two years, or long enough for oyster populations to recover from harvest. Harvester education is one additional consideration and will be critical to ensure successful implementation of this RHM plan.

Table 1 Proposed calendar of Rotational Harvest Management reef building and management strategy.

Task	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029
Build 4 sites.	■	■	■	■	■					
Open 2020 sites.					■					■
Open 2021 sites.						■				
Close 2020 sites.						■				
Open 2022 sites.							■			
Close 2021 sites.							■			
Open 2023 sites.								■		
Close 2022 sites.								■		
Open 2024 sites.									■	
Close 2023 sites									■	
Close 2024 sites.										■

Cultch reefs successfully hosted 4.5-times more legal oysters than natural reefs where no restoration effort had occurred (reference—Peters?). On average, cultch sites had 27 legal oysters (≥3 inches) per square meter (Peters et al. 2017). With 27 legal oysters/m^2 on cultch material, a conservative estimate suggests that one acre of harvestable cultch reef should yield approximately 368 bushels of legal oysters (300 oysters/bushel). Estimating the number of oysters produced over the lifespan of a cultch reef proves difficult, as reefs take several years for oysters to mature, may be harvested multiple times during their lifespan, and may only last five years.

Table 2. Acres of harvestable oysters per year.

	Planted Acres	Acres with Harvestable Oysters
Year 1	40	0
Year 2	40	0
Year 3	40	40
Year 4	40	80
Year 5	40	120
Year 6*	40	120

In the above example, oysters are not large enough for harvest until year three (from the year one sites). In year four, both year one and two sites are producing legal sized oysters. In year five, sites from years one-three produce oysters for harvest (120 acres). In year six, sites from year one may no longer exist, but sites two-four are producing. In this simplified scheme, the total habitat area available for annual harvest never exceeds 120 acres, but since habitats are available for harvest in years' prior, the harvested acreage is cumulative. Year six is not included in the oyster production estimates below.

At a cumulative 240 acres of harvested area, 88,320 bushels of oysters are estimated to be available to the fishery for harvest over the five-year period, given 27 legal oysters per square meter. Not considering the fish production value, water filtration value, or other ecosystem service value of the habitat, the market value of oysters provided by 200 acres of constructed habitat over five years is estimated to be $6,624,000 at $75 per bushel. Typical investment for NCDMF to construct 40 acres using 250,000 bushels is approximately $795,000 ($1.90/bushel for limestone marl and $1.25/bushel to deploy). Based on reef demographics in published literature and construction cost estimates, the five-year investment cost of $3,975,000 is met with a direct return potential of $6,624,000; a ~167% return in harvest value alone.

It is important to recognize that this return on investment is only realized if the reefs are entirely exploited during the five-year period. History has taught us that harvest trends more closely follow patterns of socioeconomics and can be correlated to market, regulatory, and environmental factors, more so than biological productivity. Therefore, it is important to draw a clear distinction between annual harvest levels and reef productivity or success. Regardless of harvest levels and subsequent annual market value, oyster reefs developed by cultch planting have indirect and likely immeasurable monetary value, providing water filtration, fish production (recreational and commercial), and other ecosystem benefits which positively impact tourism and overall environmental health.

OYSTER SANCTUARY PROGRAM

Overview

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

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

Various research projects and analyses have been conducted to quantify the intended performance of North Carolina's oyster sanctuaries as larvae production sites and their overall economic benefit to the state. It has been estimated that 1 out of every 4 larvae settling on commercially harvested oyster reefs (natural or cultch) in Pamlico Sound originated from an oyster sanctuary (Peters et al. 2017). Furthermore, an independent economic analysis estimated that for every dollar invested in oyster sanctuaries, there was $4 return in the form of economic opportunity or ecosystem services (RTI International 2016). By 2026, the Oyster Sanctuary Program will be comprised of 17 sanctuary sites, totaling 789 permitted acres. With an additional 140,000 tons of marl limestone and granite planned for Maw Point and Brant Island combined, there will be over 373,000 tons of aggregate material used for the creation of protected oyster reef habitat in Pamlico Sound by 2026 (Figure 1; Table 3).

Legislation and Rules

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

In the 2014 legislative session, the North Carolina General Assembly established the Senator Jean Preston Oyster Sanctuary Network (Figure 1). This was done "to enhance shellfish habitats within the Albemarle and Pamlico Sounds and their tributaries to benefit fisheries, water quality, and the economy…achieved through the establishment of a network of oyster sanctuaries, harvestable enhancement sites, and coordinated support for the development of shellfish aquaculture."

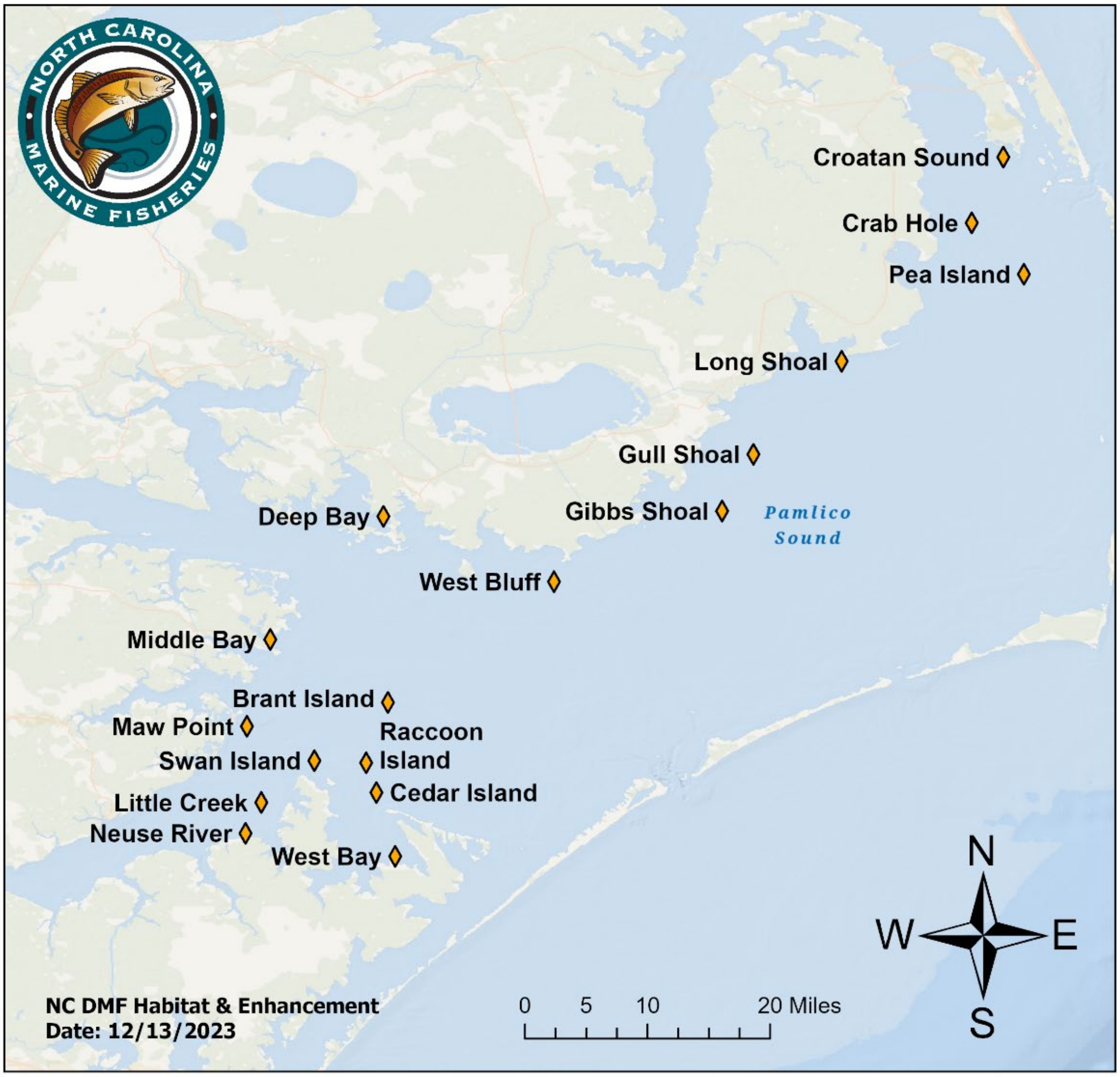

Figure 2. Jean Preston Oyster Sanctuary Network, Pamlico Sound, NC.

Table 3. A comprehensive list of North Carolina's Oyster Sanctuaries found throughout Pamlico Sound. Permit area refers to the total protected boundary area delineated by rule or proclamation. Developed habitat area includes material footprints and surrounding unconsolidated soft bottom; whereas habitat footprint area- refers to the cumulative total area of reef patches only, not to include unconsolidated soft bottom. For example, Croatan Sound Oyster Sanctuary has 3.10 acres of habitat within the overall boundary of 7.73 acres, meaning 4.63 acres of the site do not have habitat material present, but harvest is prohibited within the entire site.

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

Funding History

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

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

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

Sanctuary Site Selection

Historically, oyster sanctuary construction and site selection were largely dependent upon where historic oyster reefs once existed. As the program and funding availability grew, more scientific approaches were integrated into site selection. For instance, by 2014 the Program placed greater emphasis on establishing a connected oyster network in Pamlico Sound, stemming from research and hydrological models on the currents and wind patterns that drive the distribution of oyster larvae (Xie & Eggleston 1999; Puckett et al. 2014). To ensure larval connectivity and to further safeguard subtidal oyster populations, new sanctuary sites are selected based on a habitat suitability index (HSI) model. The site selection model takes into account dissolved oxygen, salinity, bottom substrate type, tidal flow, larval transport, wave action, and prevailing wind data to determine ideal locations conducive to building long-lasting and effective sanctuaries (Puckett et al. 2018). After determining several areas with high suitability scores, site investigations ground-truth bathymetric and environmental conditions and check for any existing oysters or subaquatic vegetation (SAV).

Reef Design & Construction

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

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

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

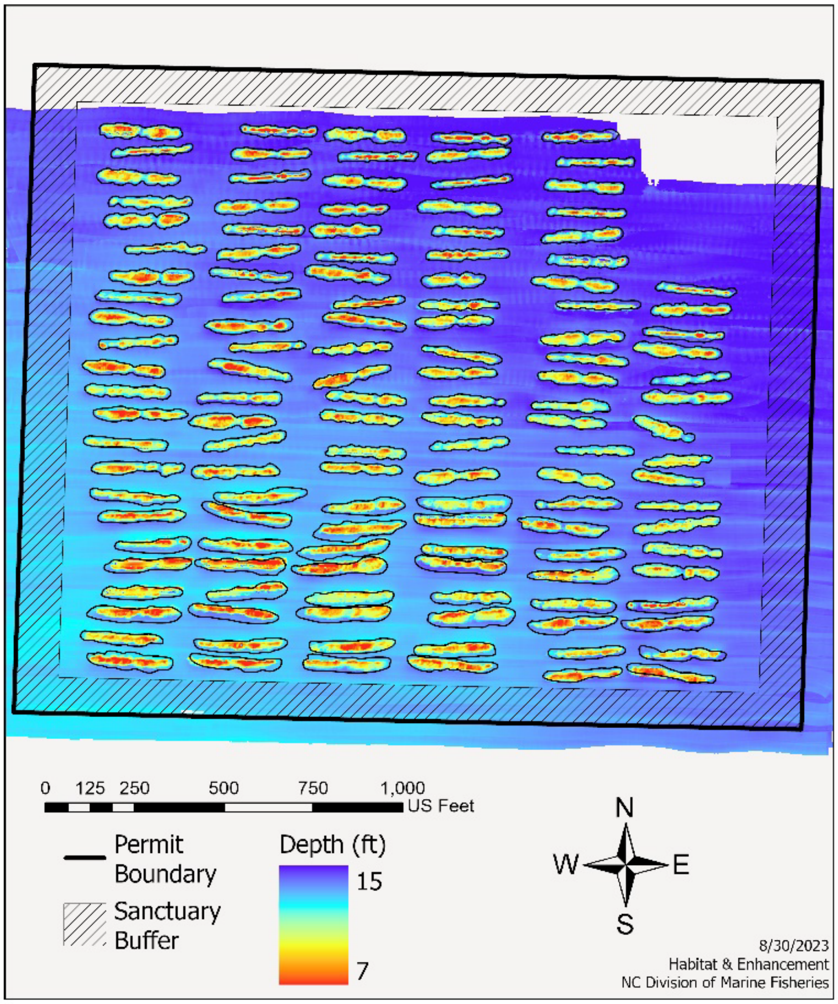

Figure 3. Side scan view of Cedar Island Oyster Sanctuary located in Pamlico Sound, North Carolina. Construction of the sanctuary began in 2021, using marl limestone rip rap and crushed concrete in a grid design with parallel ridges.

Monitoring and Analyses

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

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

Data from sanctuary monitoring in 2023 suggest that North Carolina's oyster sanctuaries had an average total density of 1333 oysters/m^2 and an average legal density of 127 oysters/m^2 . These estimates, along with those from independent peer-reviewed studies, verify and quantify the effectiveness of the Sanctuary Program. For instance, total oyster density at sanctuary sites was 72 times greater than natural reefs open to harvest, and 7.5 times higher than restored harvested (cultch) areas (Peters et al. 2017). This trend extended to legal oyster density (>75mm), as sanctuary sites demonstrated 27 times greater density than natural harvested reefs and 6 times greater density than restored harvested reefs (Peters et al. 2017). The potential larval output per m^2 of sanctuary sites was also significantly higher than at natural reefs (700 times greater) and cultch areas (4 times), illustrating the high potential for larval spillover as intended in the design of the Oyster Sanctuary Network (Peters et al. 2017).

References

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

Baggett LP, Powers SP, Brumbaugh RD, Coen LD, Deangelis BM, Greene JK, et al. (2015). Guidelines for evaluating performance of oyster habitat restoration. Restor. Ecol. 23, 737–745.

Bahr LM, Lanier WP (1981). The ecology of intertidal oyster reefs of the south Atlantic coast: a community profile. FWS/OBS/81.15. US Fish & Wildlife Service, Washington, DC.

Beck MW, Brumbaugh RD, Airoldi L, Carranza A, Coen LD, Crawford C, Defeo O, Edgar GJ, Hancock B, Kay MC, Lenihan HS, Luckenbach MW, Toropova CL, Zhang G, Guo X. (2011). Oyster reefs at risk and recommendations for conservation, restoration, and management. BioScience. 61: 107-116.

Carroll JC, Gobler CJ, Peterson BP (2008). Resource limitation of eelgrass in New York estuaries; light limitation and nutrient stress alleviation by hard clams. Marine Ecology Progress Series 369: 39–50.

Carter KS (2000). The More Things Change...: Oysters, Public Policy, and Species Decline in the Pamlico Sound, 1880-1900. In: Microbehavior and Macroresults: Proceedings of the Tenth Biennial Conference of the International Institute of Fisheries Economics and Trade, July 10-14, 2000, Corvallis, Oregon, USA.

Coen LD, Brumbaugh RD, Bushek D, Grizzle R, Luckenbach MW, Posey MH, et al. (2007). Ecosystem services related to oyster restoration. Mar. Ecol. Prog. Ser. 341, 303–307.

Dame R & Libes S (1993). Oyster reefs and nutrient retention in tidal creeks. Journal of Experimental Marine Biology and Ecology, 171(2), 251-258.

DeAlteris, JT (1988). The geomorphic development of Wreck Shoal, a subtidal oyster reef of the James River, Virginia. Estuaries, 11:240–249.

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

Durham CL (2009). Spatial Dynamics in an Estuarine System: Modeling Biophysical Components and Interactions to Advance Blue Crab Fishery Management. MS Thesis, North Carolina State University, Raleigh, NC.

Epperly SP and Ross SW. (1986). Characterization of the North Carolina Pamlico-Albemarle Estuarine Complex. Report No. NMFS-SEFC-175, National Oceanic and Atmospheric Administration, Beaufort, NC.

Everett RA, Ruiz GM, Carlton JT. (1995). Effect of oyster mariculture on submerged aquatic vegetation: An experimental test in a Pacific Northwest estuary. Marine Ecology Progress Series 125: 205–217.

Grabowski JH, Brumbaugh RD, Conrad RF, Keeler AG, Opaluch JJ, Peterson CH, Piehler MF, Powers SP, Smyth AR (2012). Economic valuation of ecosystem services provided by oyster reefs. BioScience. 62: 900-909.

Gross F and Smyth JC (1946). The decline of oyster populations. Nature 147, 540–542.

Hughes TP, Baird AH, Dinsdale EA, Moltshcaniwskyj NA, Pratchett MS, Tanner JE, Willis BL (2000) Supply-side ecology works both ways: the link between benthic adults, fecundity, and larval recruits. Ecology 81:2241–2249.

Jackson, JBC, Kirby MX, Berger WH, Bjorndal KA and others. (2001). Historical overfishing and the recent collapse of coastal ecosystems. Science 293: 629–638.

Kirby MX (2004). Fishing down the coast: historical expansion and collapse of oyster fisheries along continental margins. PNAS USA. 101, 13096–13099.

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

Lenihan HS and Peterson CH (1998). How habitat degradation through fishery disturbance enhances impacts of hypoxia on oyster reefs. Ecological Applications 8: 128–140.

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

Newell RIE and Koch EW (2004). Modeling seagrass density and distribution in response to changes in turbidity stemming from bivalve filtration and seagrass sediment stabilization. Estuaries 27: 793–806.

Peters JW, Eggleston DB, Puckett BJ, Theuerkauf SJ (2017). Oyster demographic in harvested reefs vs. no-take reserves: implications for larval spillover and restoration success. Frontiers in Marine Science 4:326.

Powell EN, Kraeuter JN, Ashton-Alcox, KA. (2006). How long does oyster shell last on an oyster reef? Estuarine, Coastal and Shelf Science. 69:531–542.

Puckett BJ, Eggleston DB, Kerr PC, and Luettich R (2014). Larval dispersal and population connectivity among a network of marine reserves. Fisheries Oceanography. 23, 342-361.

Puckett BJ, Theuerkauf SJ, Eggleston DB, Guajardo R, Hardy C, Gao J, Luettich RA (2018). Integrating larval dispersal, permitting, and logistical factors within a validated habitat suitability index for oyster restoration (2018). Frontiers of Marine Science 5:76.

Rothschild BJ, Ault JS, Goulletquer P, Héral M. 1994. Decline of the Chesapeake Bay oyster population: A century of habitat destruction and overfishing. Marine Ecology Progress Series 111: 29–39.

Smith GF, Bruce DG, Roach EB, Hansen A, Newell RIE, McManus AM (2005). Assessment of recent habitat conditions of eastern oyster Crassostrea virginica bars in mesohaline Chesapeake Bay. North American Journal of Fisheries Management. 25: 1569–1590.

Thayer GW, Stuart HH, Kenworthy WJ, Ustach JF, Hall AB. (1978). Habitat values of salt marshes, mangroves, and seagrasses for aquatic organisms. Pages 235–247 in

Greeson PE, Clark JR, Clark JE, eds. Wetland Functions and Values: The State of Our Understanding. American Water Resource Association.

Wall CC, Peterson BJ, Gobler CJ (2008). Facilitation of seagrass Zostera marina productivity by suspension-feeding bivalves. Marine Ecology Progress Series 357: 165–174.

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

Zimmerman R, Minello TJ, Baumer T, and Castiglione M (1989). Oyster reef as habitat for estuarine macrofauna. Technical Memorandum NMFS-SEFC-249. National Oceanic and Atmospheric Administration, Washington, D.C., US.