SCDNR
Shellfish Research Section

DNR

Five Year Report to the
Saltwater Recreational Fisheries Advisory Committee

October 1st 2009 – September 30th 2014

EXECUTIVE SUMMARY

Over the past 5 years, the Shellfish Research Section has received $143,684 from the Saltwater Recreational Fishing License (SRFL) funds. These funds have been used as match funds to leverage a further $430,000 of federal funds (75% federal: 25% non-federal match), specifically from Dingell-Johnson (DJ) Sport Fish Recreation Act Funds. The combination of these funding sources has provided critical support of Marine Resources Division temporary grant employee salaries, research and management activities within the Shellfish Research Section.

The primary mission of the SCDNR Shellfish Research Section is to research and monitor the status of estuarine and nearshore populations of recreationally, commercially and ecologically important species of shellfish in the state waters of South Carolina. The primary bivalve shellfish species of interest is the Eastern oyster, *Crassostrea virginica*, which is broadly recognized as a keystone species and 'ecosystem engineer'. The Eastern oyster generates extensive habitat on the shorelines of our estuaries and tidal creeks. This habitat provides foraging opportunities for fish and crustaceans when it is covered by water at high tide and for a number of shorebirds when it is uncovered at low tide. Much of the work conducted during this review period has involved the development and application of expertise in the creation of "living shorelines". The idea behind "living shorelines" is to create, maintain, and protect oyster reefs and associated saltmarshes along our shorelines as natural defenses to waves, boat wakes, and sea level rise. Other hardened, manmade structures, such as bulkheads, rip rap, and revetments, offer less of the ecological benefits provided by oyster reefs and salt marshes, such as supporting natural habitat for other organisms, trapping sediments to prevent erosion, and filtering and cleaning our estuarine waters.

The Shellfish Research Section is creating new "living shorelines" of oyster reefs using alternative substrates (concrete oyster castles and revitalized, concrete-coated crab traps) to protect eroding shorelines and increase the resiliency of our coastline to pressures from coastal development, increased boat traffic, sea level rise and climate change. These efforts have been implemented within the ACE Basin National Estuarine Research Reserve (NERR), the Charleston Harbor, and its surrounding watershed. The use of alternative substrates to build oyster reefs has expanded the diversity of habitat types in which oyster reef habitat restoration and enhancement can be implemented. Following the creation of new oyster reefs, the Shellfish Research Section monitors physical changes to the shoreline, such as erosion, accretion and sedimentation, and compares the biological diversity of recreationally-important finfish and crustaceans among the reef communities with those of natural habitats.

Since 2009 the Shellfish Research Section has addressed marine debris issues within our nearshore and estuarine waters, which NOAA recognizes as a high priority and emerging field of research. Staff have developed opportunities to engage the general public, as well as the recreational and commercial crab fisheries, by asking them to report and donate abandoned and unwanted crab traps that are then directed towards reef-building projects. Wherever possible, staff engage volunteers in the creation and monitoring of oysters reefs. Staff also continue to develop new technologies to increase the accuracy of efforts to map the distribution of oyster reefs statewide, including the utilization of low altitude, high resolution, helicopter-based aerial photography. Furthermore staff continue to explore research that facilitate improvements to in-state shellfish aquaculture, working directly with commercial growers to enhance operations through the use of triploid single oysters with proven and significant market value in other states.

Evaluation of the value of oyster reefs to other organisms.

Oyster reefs are broadly recognized as "ecosystem engineers" that form habitats that are complex in terms of their structure and that are utilized by numerous finfish, invertebrates, wading birds, and mammals. The three-dimensional structure of oyster reefs attracts greater numbers of resident and transient nektonic species (i.e., those that are capable of swimming against tides and currents in the water column) than sand or mud-bottom habitats. Nektonic species, such as fish and swimming crabs, are of particular interest as many of these species are recreationally, commercially and ecologically important. In South Carolina, oyster reefs are considered a priority habitat in the State Wildlife Action Plan (SWAP). The SWAP is a comprehensive plan that addresses those species that a state deems to have the greatest conservation need. Factors include rarity, threats, lack of management funding, and lack of data. Oyster reefs are primarily included in the SWAP due to their provision of habitat for a number of species of concern.

More than 83 species of finfish and invertebrates are associated with intertidal Eastern oyster (*Crassostrea virginica*) reefs in South Carolina, including all 22 species managed by the Atlantic States Marine Fisheries Commission. In 2009, the South Atlantic Fishery Management Council designated oyster reefs as essential fish habitat. Species of recreational, commercial, and ecological importance that utilize oyster reef habitats include Atlantic croaker, spotted seatrout, red drum, spot, blue crab, stone crab, and penaeid shrimp. These species in turn provide prey for SAFMC-managed species such as Spanish mackerel, king mackerel, and cobia, as well as NOAA Fisheries-managed highly migratory species, such as sharks and billfishes. Furthermore, a number of prey species of southern flounder are associated with edge habitats, including oyster reefs. Small and intermediate sized fishes, such as gobies and blennies, are abundant in oyster reef-dominated ecosystems and are thought to attract larger pelagic predatory species, such as striped bass, bluefish, weakfish, southern flounder, sheepshead, and spotted seatrout. Other bottom-dwelling predators, such as the Atlantic blue crab (a South Carolina priority species for conservation) have also been shown to be strongly associated with oyster reefs.

To investigate the estuarine communities associated with oyster reefs constructed using alternative substrates, and to compare them to those associated with natural habitats, the Shellfish Research Section uses a drop net sampling technique developed by recent College of Charleston graduate student, Ryan Joyce. Drop nets are typically set up around paired study plots (i.e., a treatment plot containing an oyster reef constructed using an alternative substrate or a natural reef, and an adjacent control plot where there is no reef habitat) at low tide on the day prior to sampling. An example of these paired plots is shown *above left*.

On the first of two consecutive days, each net is suspended around a study plot on a series of metal poles and is held in brackets affixed to these poles fitted with cotter pins attached to a trigger line. At high tide the next morning, the trigger line is pulled, removing the cotter pins from the brackets allowing the net to fall, completely surrounding the study plot. Once the tide has ebbed away, dip netting sampling and visual inspection of the plot enables the collection of organisms contained within it, as shown in the image *right*.

This drop net sampling technique enables the collection, identification and enumeration of the nekton communities utilizing areas of interest at high tide. Without disturbing the habitat, it allows the sampling of intertidal areas that go dry at low tide, at which time the majority of swimming species leave the area. Nekton abundance was shown to be significantly higher on reef plots than control plots at three sites; a natural reef site in the Folly River, a bagged shell reef at Fort Johnson, and an oyster castle-based reef on the ICW near McClellanville. Nekton abundance also varied seasonally, with the greatest numbers of organisms occurring in summer compared to spring and fall. A total of 60 taxa were identified, 57 of which were identified to species, and reef plots contained a significantly higher total number of species than non-reef plots. Drop net sampling has been incorporated into a number of research projects supported by the Southeast Aquatic Resources Partnership (SARP, both NOAA and USWFS funds) and the State Wildlife Grant (SWG) Program and is being used to better our understanding of how the use of different habitats by different organisms changes over space and time.

As part of these sampling efforts, the Shellfish Research Section has documented several State Wildlife Action Plan (SWAP) priority conservation species in higher numbers on reefs than on adjacent control areas, including sheepshead, Atlantic croaker, silver perch and Atlantic blue crab, strongly suggesting that these species are using the reefs for habitat, refuge, or foraging opportunities. Researchers have also observed stocked spotted seatrout produced and released by the SCDNR using these reefs.

Addressing the issue of marine debris in nearshore waters.

The National Oceanic and Atmospheric Administration (NOAA) defines marine debris as "any persistent solid material that is manufactured or processed and directly or indirectly, intentionally or unintentionally, disposed of or abandoned into the marine environment or Great Lakes." The NOAA Marine Debris Program supports research into marine debris, its sources, and its impacts. The Shellfish Research Section is actively participating in such research projects by integrating its efforts with the NOAA Southeast Atlantic Marine Debris Initiative (SEA-MDI) and offering guidance to the development of strategic plans and collaborations focused on addressing marine debris issues. Shellfish Research Section projects predominantly focus on two forms of marine debris; abandoned crab traps and abandoned vessels.

Crab traps can become abandoned (or 'derelict') as a result of their deliberate disposal in the environment, from broken buoy lines, or due to their accidental displacement by storms and large tides. Abandoned crab traps result in the mortality of both target and non-target species (often referred to as 'ghost fishing mortality'), exacerbate user group conflicts, and cause visual pollution and damage to sensitive habitats, such as submerged aquatic vegetation (SAV) or non-vegetated live bottom.

At least 23 species of finfish and 5 species of invertebrates have been observed in blue crab traps, highlighting the lack of selectivity of this type of fishing gear and therefore its propensity to generate bycatch (i.e., the collection of non-target species). Recreationally-important fish species included among these taxa were black drum and southern flounder, both of which are listed as South Carolina priority species for conservation in the State Wildlife Action Plan (SWAP), although in general mortality rates of these finfish species as bycatch in abandoned traps are low.

In contrast, however, recent studies and observations by researchers at the Marine Resources Research Institute and collaborating institutions have documented that the mortality of the diamondback terrapin as a result of its capture in crab traps can on occasion by considerable (see image *right*).

In addition to countering the negative effects of abandoned crab traps in the environment, a number of recent Shellfish Research Section projects have effectively used concrete-coated, abandoned and donated crab traps as substrate for oyster reef habitat restoration and enhancement activities. Recreational and commercial fishers, and other members of the general public, are asked to report abandoned crab traps that they observe in our waterways. Several individuals and organizations have also collaborated to directly donate unwanted traps as substrate for oyster reef-building projects. Recently staff have utilized smartphone application technology (specifically the Marine Debris Tracker app) to make it easier for engaged participants to report their observations of marine debris.

Since 2009 the Shellfish Research Section has gathered information on the location of more than 500 abandoned crab traps in our state waters through outreach activities. Staff have also received and recovered over 800 donated and abandoned traps for reef-building projects. The photo to the left shows a typical crab trap reef immediately after construction, while the photo *below right* from Bears Bluff on Wadmalaw Island shows the high rates of settlement and growth of oysters on these substrates that lead to the rapid development of reef habitat in approximately one year following the placement of the revitalized crabs on the shoreline. Revitalized crab traps are a highly effective substrate for establishing oyster reefs in “pluff mud” areas where more traditional, heavier substrates are not suitable, thereby expanding the diversity of habitats over which oyster reef restoration and enhancement efforts can be implemented.

Beyond the work with abandoned and unwanted crab traps, the Shellfish Research Section is also addressing marine debris issues through a recent collaboration with SCDHEC, South Carolina Sea Grant Consortium, and the City of Charleston, with funding from the NOAA Marine Debris Program. This project will enable researchers to identify, prioritize, and remove abandoned vessels from the Charleston Harbor watershed. Following these removals, Shellfish Research Section staff will use funding from the State Wildlife Grant Program to establish crab trap-based oyster reefs within the impacted footprints left following vessel removal on intertidal shorelines.

Restoration and enhancement of oyster reef habitat using alternative substrates to create living shorelines and increase coastal resiliency.

Populations of the Eastern oyster, *Crassostrea virginica*, the dominant species of oyster found in South Carolina, have declined along much of the Mid-Atlantic coast of the United States during the last century due to over-harvesting, reductions in water quality, negative impacts on habitat quality, diseases within the oysters themselves, broader scale environmental changes in the ecosystem, and the interactions among these factors. The Nature Conservancy recently estimated that more than 85% of oysters worldwide have disappeared and recent estimates of the population of oysters in the Chesapeake Bay, which once supported vibrant wild fisheries in Virginia and Maryland, suggest that they now exist at <1% of historical levels. These declines in oyster populations have led to considerable efforts coastwide to direct resources towards oyster reef restoration and enhancement projects with a variety of goals, including the resurrection of commercial fisheries and the restoration of ecological services. Although oysters in South Carolina have not been as extensively exploited as the oyster populations in the mid-Atlantic States, the rapid pace of coastal development has created numerous threats to tidal creek habitats, where oysters are common in South Carolina. This increase in development has had inevitable undesirable impacts involving increased runoff from the land, the introduction of pollutants to our waterways, impacts from dredging, and the creation of manmade channels through marshes.

More than 95% (over 2,100 acres) of the South Carolina oyster populations are intertidal, meaning that they are exposed to air at low tide, but covered by the water at high tide. Oysters settle on each others' shell, and as more generations of oysters combine to form reefs, more spaces are formed within the reef that provide shelter and refuge for other organisms. Unlike subtidal oysters, which are continuously covered by water, intertidal populations form natural breakwaters that trap sediments and protect fringing marshes from erosion, waves and boat wakes. This close spatial relationship between intertidal oyster reefs and the adjacent marshes is clearly shown in the image *above* taken in the fall of 2013 in the Folly River.

This shoreline protection attribute of intertidal oysters has resulted in their consideration as an alternative to hardened, engineered structures, such as bulkheads and revetments, and their installation as "living shorelines". These "living shorelines" create habitat for other organisms, trap sediment, and clean the water. They are therefore viewed by many as a preferred strategy for enhancing coastal resiliency and reducing losses of shorelines through erosion which is predicted to increase under scenarios of future global climate change-driven sea level rise. Recent oyster reef habitat restoration and enhancement efforts by the Shellfish Research Section,

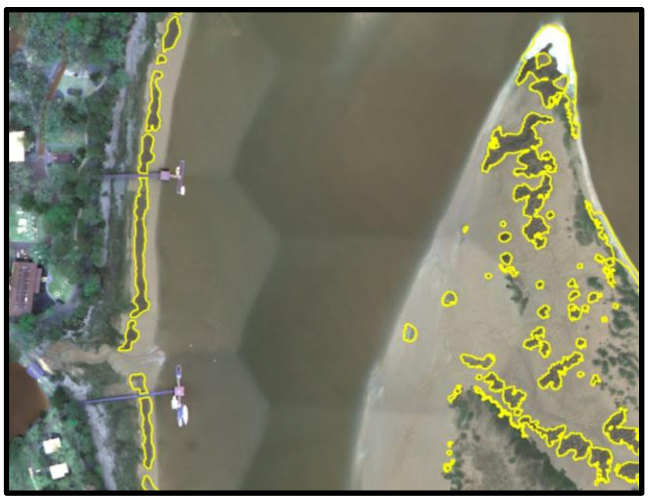
through funding from the NERRS Science Collaborative as well as other sources, have implemented a variety of oyster reef shoreline protection techniques at sites within the ACE Basin NERR where eroding shorelines are impacted by wind-driven waves. New reefs have been created in the Edisto River, where human communities are situated, at sites supporting critical habitat for species of special concern, and in areas associated manmade cuts through marsh islands along the Atlantic Intracoastal Waterway (such as that at Fenwick Cut in the image *left*). Marshes along these manmade cuts lack the hard substrate needed for oyster recruitment and therefore also lack the stabilization created by subsequent oyster reef growth, and thus are actively eroding, leaving bare shelves of mud and degraded water quality. Rates of erosion in such areas are often further increased by heavy boat traffic.

In areas where wild oysters are abundant, restoration approaches based upon the provision of suitable substrate on which larvae can settle are highly effective. Expertise within the Shellfish Research Section is being used to match restoration and enhancement strategies (oyster castles, crab traps, loose shell and bagged shell) to site characteristics, such as sediment type, slope, and wave energy. More specifically, sites that experience higher wave energy, and therefore also tend to be dominated by firmer, sandier sediments, lend themselves to substrates that are heavier, such as oyster castles and bagged oyster shell. In sheltered areas that are dominated by fine sediments, where bagged or loose shell would be less appropriate due to the silting over and sinking of the substrate, making it less accessible for settling oyster larvae, concrete-coated abandoned and unwanted crab traps are being used as reef-building substrates.

The combination of restoration and enhancement approaches that use natural and alternative substrates to create new oyster reefs can effectively create living shorelines in a diversity of environments thereby increasing coastal resiliency. Since 2009, the Shellfish Research Section has used alternative substrates (oyster castles and crab traps) to create more than 2,200 ft of living shoreline, engaging more than 150 volunteers over more than 800 volunteer hours. Engaging these volunteers in all stages of the project, including site selection, reef-building, and monitoring, creates future stewards of these critical natural resources.

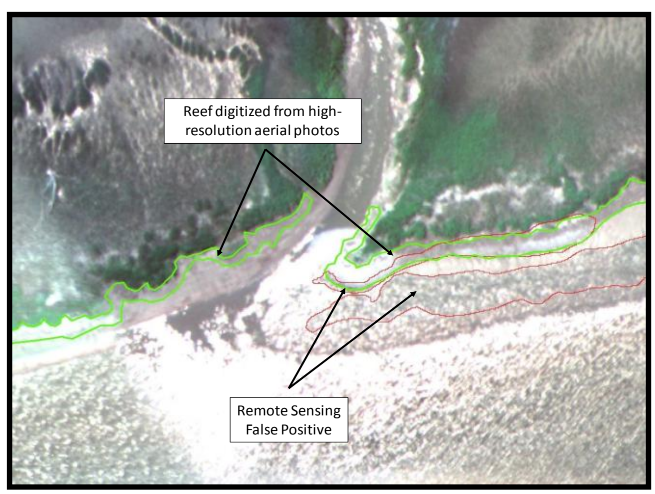
Determination of the current and historical distribution of oysters statewide.

For both research and the management of oyster reef resources throughout the coastal region of South Carolina, it is critical to be able to describe both the current and historical distributions of oysters and to create mechanisms for detecting future changes in these resources. Efforts to map oyster reefs in South Carolina were first conducted in 1890-1891 through the John D. Battle Intertidal Oyster Survey. This survey was commissioned by the U.S. Fish Commission aboard a U.S Navy steamer, the Fish Hawk. It collected hydrographic data and delineated oyster beds by recording the locations and lengths of accessible fringing reefs, but did not include information on the oysters located in smaller tidal creeks and on mud flats. Acreages were totaled over large, pre-determined areas, but were not recorded for individual oyster reefs, and acreages were determined based only on estimates of oyster bed width rather than direct measurements. In the 1980s (1980-1986) further surveys were conducted by hand-drawing reefs onto USGS topographic maps, which were enlarged in scale for use in the field, using known points as reference. These field maps were then transferred by hand to Mylar maps and then to digital format for use in GIS software. Reefs on large mud flats were not individually measured; however, the locations and extents of the flats were drawn on the maps.

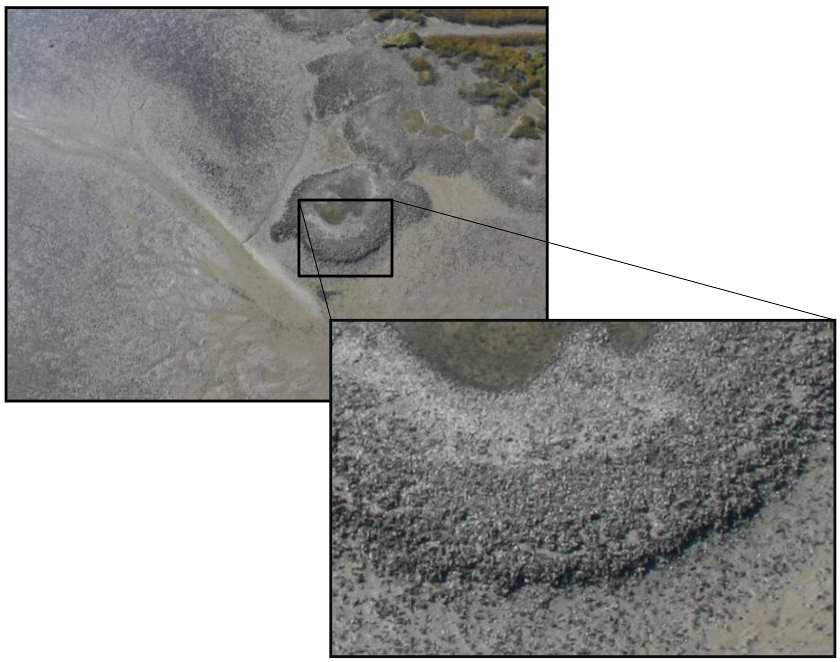


In 2003-2006, in collaboration with the US Geological Survey, NOAA Coastal Services Center and Photo Science, Inc., the SCDNR secured a substantial federal grant to collect high quality aerial imagery of the South Carolina coastal zone. Using this imagery, the outlines of oyster reefs were drawn onto digital maps using a combination of manual and automated techniques (such as Feature Analyst™, as shown in the image *left* in which oyster reefs are identified and delineated in yellow). On-the-ground assessments by boat showed that the software correctly identified the presence of oyster reefs more than 84% of the time.

For some parts of the state, tidal or weather conditions at the time that that area was flown resulted in imagery that was challenging to interpret (such as the rather 'washed out' imagery shown right) which led to the mis-identification of reef vs. non-reef habitat using automated editing. Some of these errors are classified as "false positives" in which the automated editing tools identified areas as being reefs when in fact these are not reefs. Such areas are being corrected by digitizing these reefs manually using high resolution aerial photos captured using helicopter-based technology.



Helicopter-based photography is especially useful for surveying fringing reefs and patch reefs that are located on mud flats, as these can be challenging to access by boat. Such areas can support significant amounts of harvestable resource that previously has not been captured in assessments or surveys. Annual assessments of South Carolina state shellfish grounds (SSGs), i.e., those that are opened periodically to commercial harvesting, are used to make management decisions in terms of the need to close ground to enable them to recover. These assessments are typically conducted by boat; however, the condition of parts of these areas, particularly those with extensive flats and shallow tidal creeks can be difficult to assess by boat. Since 2011, therefore, low altitude (250-500ft), high resolution (20 Megapixel) helicopter imagery has been used to complement on-the-ground efforts and to improve the mapping accuracy of oyster resources statewide. An example of the high resolution nature of this imagery is shown *below*.



Since these efforts began, SSGs have been prioritized for helicopter-based surveys based on their contribution to the overall harvest, with the goal of surveying the 20 top SSGs at least once every 5 years. Since 2011, approximately 65 flight hours have surveyed 22 SSGs, collecting imagery for more than 600 miles of shoreline and more than 650 acres of oyster reefs. The high resolution nature of these photographs is such that areas that have been heavily harvested are clearly visible from the imagery. Helicopter-based imagery has also been used to refine the boundaries of culture permit areas (formerly leases; areas managed by private individuals or companies under contract with the SCDNR). Acreage reassessments in 2010 tripled the estimate of oyster reef acreage within culture permit areas, which in 2009-2010 comprised \$1.4M of the total value of oyster resources harvested in the state (\$1.79M). Imagery-based techniques have been used to more accurately determine the costs to the permittees (\$5 per acre) and inform the husbandry requirements (planting of 50 bushels of shell or other SCDNR-approved material per acre) of these active harvest areas. Furthermore, capturing this imagery represents an independent, long-term record of the status of these critically important natural resources. Ultimately one of our goals is to enable mapping efforts to identify areas of change, or more precisely loss, so that efforts can be directed to address those losses through protection, restoration and enhancement.

A collaboration with industry to improve South Carolina shellfish aquaculture through the use of sterile triploid native oysters.

The productive estuarine waters, extensive intertidal habitats and high levels of natural recruitment (i.e., addition of the new generation of baby oysters to a reef) in South Carolina produce dense clusters of oysters that support a valuable fishery resource that is actively harvested both recreationally and commercially in support of a vibrant "oyster roast" market. [An example of these typical intertidal cluster oysters in the Folly River is shown *below left*.]

While intertidal cluster oysters have consistently represented the dominant harvested oyster resource in South Carolina, additional subtidal beds were also historically heavily exploited using bottom dredges in many parts of the state. Commercial oysterman Steve Flowers, for example, dredged as many as 1000 bushels in a single day from the Edisto area, while other industry members harvested seed from St. Pierre Creek and the Wando River for replanting.

The wild single (as opposed to intertidal cluster) oyster resource in South Carolina has, however, now largely disappeared. Considerable economic potential therefore exists for the aquaculture production of locally-derived single oysters raised from hatchery seed to supply the lucrative half-shell market. In South Carolina between 2004 and 2009, for example, wholesale prices for wild stock single oysters ranged from 30¢ and 60¢ each. Maximizing the economic potential of single oysters will depend on 3 main factors: 1) the optimization of grow-out techniques e.g., determination of which grow-out methods, be it on-bottom bags, floating bags, cages etc., is best suited to a particular area; 2) the development of husbandry practices to produce a high quality, marketable single oyster e.g., how often the oysters need to be handled and cleaned; and 3) the evaluation of the merits (increased survival, growth, meat yields and disease resistance) of triploid oysters on which the majority of single oyster aquaculture in other regions is now based.

Several studies have demonstrated that triploid oysters (i.e., those that possess an extra set of chromosomes in their cells and are sterile) exhibit higher survival and growth rates than normal diploid oysters, primarily through reduced investments of energy in reproduction. This reduces the time taken for the oysters to reach market size. Sterility, or the inability to reproduce, in triploid shellfish leads to extended periods of growth and more 'year-round' marketability in terms of meat quality, particularly in the summer months, due to greatly reduced gonadal development. Summer condition is perhaps less of an issue in South Carolina where harvesting is typically prohibited from mid-May to mid-September. This prohibited harvest is an historical management policy of the SCDNR to protect the resource during times of reproduction and to protect human health from *Vibrio* concerns during periods of higher water temperatures. Nevertheless, triploidy in oysters has been suggested to confer greater tissue weight both before and after spawning. Furthermore, triploids are capable of alleviating disease pressure through higher growth rates which allows these oysters to reach market size prior to significant mortalities during the second year of disease exposure. South Carolina oysters appear to have naturally high resistance to disease; however, mortality events have been reported in association with excessively hot, dry summers.

With funding from the South Carolina Sea Grant Consortium, in 2010-2012 the Shellfish Research Section conducted the first evaluation of the performance of "naturally mated" (as opposed to those produced by chemical alteration) triploid native oysters in coastal South Carolina waters. Staff worked directly with members of the commercial shellfish industry at locations from Whale Creek near Murrells Inlet in the north to the May River in the south. Triploid oysters produced by crossing diploid (fertile) South Carolina (SC) females with tetraploid Virginia (VA) males (possessing four sets of chromosomes in each of their adult cells) were compared alongside both a diploid SC-SC line and a diploid SC-VA line (both produced using SC females, but differing in the geographic origin of their male counterparts). All three lines were produced using South Carolina broodstock ripened at the Island Fresh Seafood, Inc. hatchery on Yonges Island in January-April 2011 and crosses were completed at the Virginia Institute of Marine Sciences (VIMS) Aquaculture Genetics and Breeding Technology Center (ABC) in Gloucester Point, VA in mid-April 2011. Oyster seed were verified as disease-free prior to importation into South Carolina and inspected for any "hitch-hikers" prior to exposure to open state waters, both of which are standard practices for SCDNR in order to prevent risks to our natural resources through the transmission of disease and negative impacts from the introduction non-indigenous, invasive species associated with imported oysters.

Oysters were nurseried in a floating upwelling system prior to being transferred to floating bags (*right*) once they reached >10mm in shell height. This nursery period lasted from June 2011 to September 2011, whereupon oysters were transferred to commercial oyster grow sites. Commercial growers used a variety of grow-out apparatus such as floating bags, subtidal cages, intertidal on-bottom bags, and intertidal rack-and-bag systems. Samples of oysters from each line for all grow-out sites were measured immediately prior to leaving the nursery, and both one month and quarterly following set up at the commercial grow-out sites to compare growth between the different oyster lines. Overall, the triploid oysters grew faster in terms of both shell height and tissue weight than the diploid oysters, although at certain sites even the diploids reached a high proportion (>80%) of marketable sized oysters (>3") in less than a year of grow-out. For example, at the May River site, the average shell heights of the three lines in May 2012 ranged between 89 and 93mm.

Having experienced the growth advantage of triploid oysters, primarily through their participation in this study, several growers in the state have since imported additional triploid seed from licensed operations in the Gulf of Mexico and mid-Atlantic region. South Carolina-based shellfish hatchery operators are also exploring the steps needed to gain access to the patented and proprietary technology needed to develop their own tetraploid broodstock. Once a hatchery is licensed to maintain tetraploids it can produce triploid seed without the reliance on importation of oysters from out of state. The connections between industry and researchers made as a result of this study were critical in enabling the South Carolina shellfish industry to move forward with triploid oyster production.