COASTAL RECREATIONAL FISHING LICENSE
FINAL PERFORMANCE REPORT

Recipient**:** Dr. Jeffrey A. Buckel

Grant Award #: NCDENR Task Order #3210 (NCSU Project ID# 552267)

Grant Title: Marine Fisheries Fellowship Program

Grant Award Period: 7/1/2010-12/31/2015

Performance Reporting Period: 7/1/2010-12/31/2015

Project Costs:

Category	Expenditures
Personnel	$137,875
Fringe	$16,803
Travel	$2,330
Equipment	0
Supplies	$4,662
Construction	0
Contractual	0
Other	0
Total Direct	$161,670
Indirect	$24,250
TOTAL	$185,920

Total Cumulative Expenditures: $185,920

Total Remaining Balance: [$186,703 - $185,920=$783 (cost savings to project)]

Description of Work**:**

1) To provide an educational opportunity for a post-graduate student to spend one year working for the NCDMF.

2) To provide support for management priorities of the NCDMF on a substantive issue related to fisheries biology, management, stock assessment or coastal habitat identification and protection.

3) To enhance technology transfer from NCDMF and NCSG research to the user community in the most effective and efficient manners.

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Section 1 – Strategic Habitat Area Nomination for Region 2

Jennifer Weaver (2009-2011 Fellow)

(see Acknowledgements section for Jennifer Weaver's contribution to this document)

Strategic Habitat Area Nominations for Region 2: *The Pamlico Sound System in North Carolina*

FINAL

November 2011

Written by staff of Division of Marine Fisheries Habitat Section
Analysis conducted by Jen Weaver, NCSU fellow
Reviewed and endorsed by Strategic Habitat Area Regional Advisory Committee
Final approved by the Marine Fisheries Commission 11/4/2011

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ACKNOWLEDGEMENTS

Several DMF and NCSU staff played an important role in developing the process documented in this report. Jen Weaver (NCSU-Sea Grant fellow) performed the analysis and writing, with assistance from Scott Chappell (DMF), Anne Deaton (DMF), Katy West (DMF), Kevin Hart (DMF), and Jeff Buckel (NCSU). Scott, Anne, and Jen were also involved in fine-tuning the application of methods and presentation of information to the advisory committee. Ballingham Chepuri, from the DENR IT section, assisted with the creation of various map products for the analysis. Katy West, Kevin Hart, and Sean McKenna from the DMF Washington Regional Office, and Beth Burns and Lee Paramore from the DMF Wanchese office contributed additional information on fisheries species and habitat conditions due to their extensive experience in the region. Other contributions came from Maria Dunn and Bob Barwick (WRC staff), Tim Ellis (NCSU), Mike Marshall (DMF) and DMF staff on the Management Review Team. Jimmy Johnson (CHPP coordinator) was also present to ensure coordination of SHA work with other DENR activities. Finally, we thank the regional advisory committee members for laboring through the highly technical meetings needed to fully address the issue of Strategic Habitat Areas in Pamlico Sound region of North Carolina, and Pres Pate, for filling in for Mark Brinson, after his passing.

DEDICATION

This report is dedicated to Dr. Mark Brinson, who passed away suddenly while a member of the Region 2 Advisory Committee. He was also on the original SHA Process Advisory Committee and a long-standing member of the MFC's Habitat and Water Quality AC. His ideas and thoughts on identification of Strategic Habitat Areas greatly influenced the SHA Identification process. A thoughtful and engaged wetland ecologist, Mark was also cheerful, kind, professional, and a pleasure to work with. We'll miss him.

REGIONAL ADVISORY COMMITTEE

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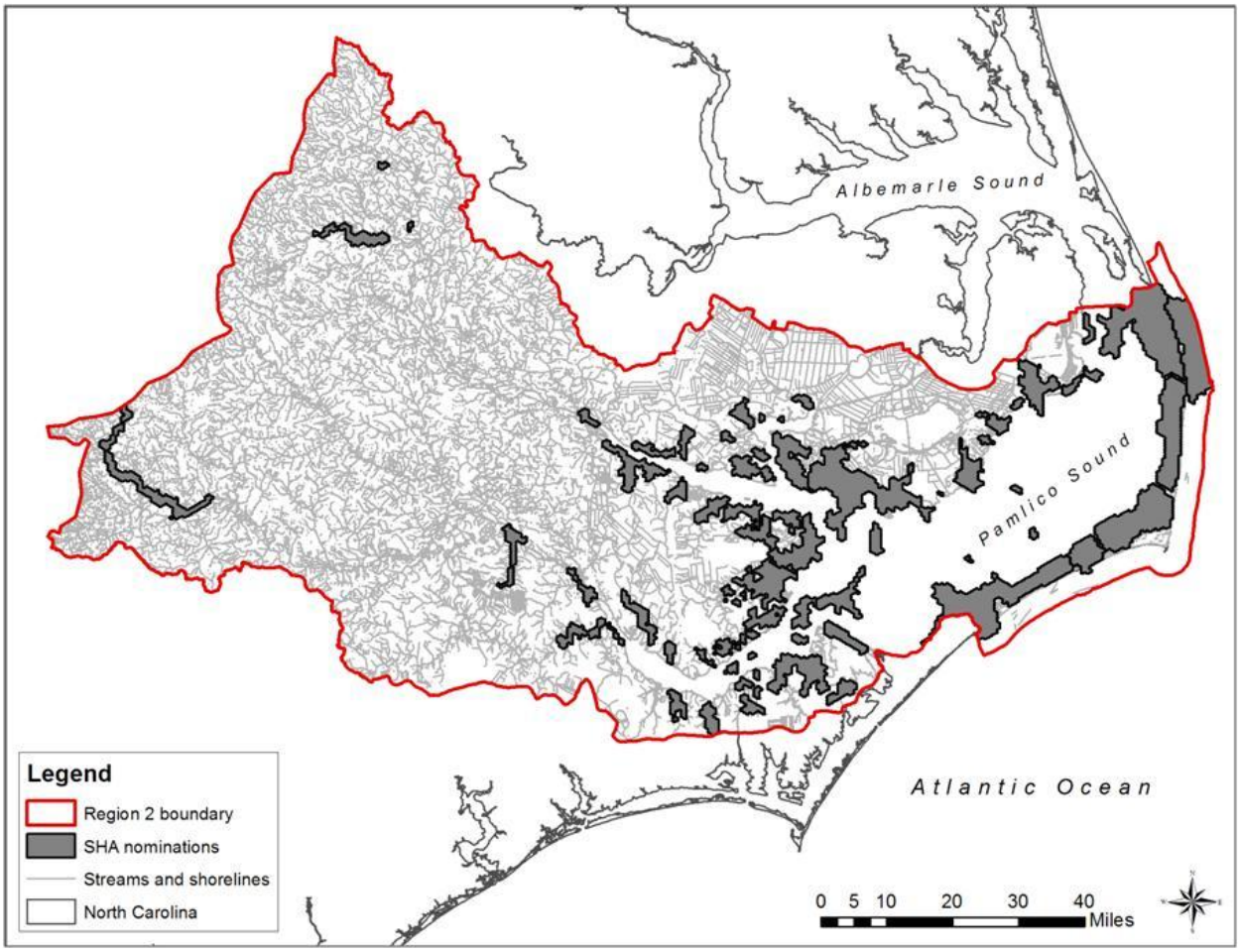
LIST OF ABBREVIATIONS

NAME	Abbreviation
CGIA	North Carolina Center for Geographic Information
CHPP	NC Coastal Habitat Protection Plan
COE	United States Army Corps of Engineers
DCM	North Carolina Division of Coastal Management
DEH-SS&RWQ	North Carolina Division of Environmental Health – Shellfish Sanitation and Recreational Water Quality section
DMF	North Carolina Division of Marine Fisheries
DOT	North Carolina Department of Transportation
DWQ	North Carolina Division of Water Quality
DWR	North Carolina Division of Water Resources
FWJ	North Carolina Fishing Water Jurisdictions
GIS	Geographical Information System
HU	Hydrologic unit
MARXAN	Site selection program
MFC	North Carolina Marine Fisheries Commission
NHD	National Hydrologic Dataset
NOAA	National Oceanographic and Atmospheric Administration
NRT	Natural resource targets
NWI	National Wetlands Inventory
NCSU	North Carolina State University
PCS	Potash Corporation of Saskatchewan Inc.
SAV	Submerged aquatic vegetation
SHA	Strategic Habitat Area
USACE	United States Army Corp of Engineers
VDEQ	Virginia Department of Environmental Quality
WRC	North Carolina Wildlife Resources Commission
WTP	Water treatment plant
WWTP	Waste water treatment plant

EXECUTIVE SUMMARY

Strategic Habitat Areas (SHA) represent priority habitat areas for protection due to their exceptional condition or imminent threat to their ecological functions supporting estuarine and coastal fish and shellfish species. Identification and designation of SHAs is a CHPP implementation action. The identification of SHAs was conducted in a two step process: 1) using GIS-based habitat and alteration data in a computerized site-selection analysis, and 2) verifying and modifying information based on input from a scientific advisory committee. Staff and the advisory committee specified representation levels for 31 unique habitat types, or natural resource targets. There were also 24 alteration factors that were represented geospatially (i.e., hydrologic alterations, water quality degradation, etc.). The site selection program MARXAN was used to select areas that met representation levels while limiting selection of highly altered sites. The scientific advisory committee then modified the computer results based on their unique knowledge and experience. The resulting SHA nominations for 67 discrete areas encompassed 11% of Region 2 and 26% of the focus area (open waters and riparian targets within 500 m of the shoreline). Approximately 11% of the selected SHAs are state or federally owned lands, managed for conservation, or are protected through PNA designations. The SHAs were corroborated with biological data, ecological designations, and specific knowledge of the area. The SHA nominations will be incorporated into conservation and restoration planning efforts.



Map 1. Region 2 SHA nominations.

INTRODUCTION

The identification and designation of Strategic Habitat Areas (SHAs) for marine and coastal fishery species is a critical component in the implementation of North Carolina's approved Coastal Habitat Protection Plan (CHPP). Strategic Habitat Areas were defined in the CHPP as, "specific locations of individual fish habitat or systems of habitats that have been identified to provide exceptional habitat functions or that are particularly at risk due to imminent threats, vulnerability, or rarity" (Street et al. 2005). Criteria for identifying SHAs were developed by an advisory committee of the Marine Fisheries Commission established in summer 2005. The committee developed a scientifically based process for identifying candidate areas for designation using biological data and the consensus of a regional expert panel (regional advisory committee). Their generic process is described in the MFC-approved guiding document entitled, "Process for Identification of Strategic Habitat Areas" (DMF 2006)." This document is often referred to as the SHA report or guiding document.

SHA designations will be based on regional analyses that identify optimally placed habitat areas of various ecological condition (exceptional or at risk). SHAs may include areas that have already been protected by other designations, as well as areas not currently recognized in any way. Thus, areas designated as SHA will require various site-specific regulatory and/or non-regulatory management actions that best address the threats affecting that site. A network of designated SHAs providing habitat connections throughout North Carolina's coastal waters should ensure that the complex life history needs of all species are met. Once SHAs are designated, resource managers may address priority fish habitat issues and take steps to prevent further alteration of the system as a whole. Thus, the necessary protections for some areas may go above and beyond current measures designed to protect habitat. In addition to regulatory changes, the nomination of SHAs can provide guidance for other conservation projects focused on conservation/acquisition, enhancement or restoration projects.

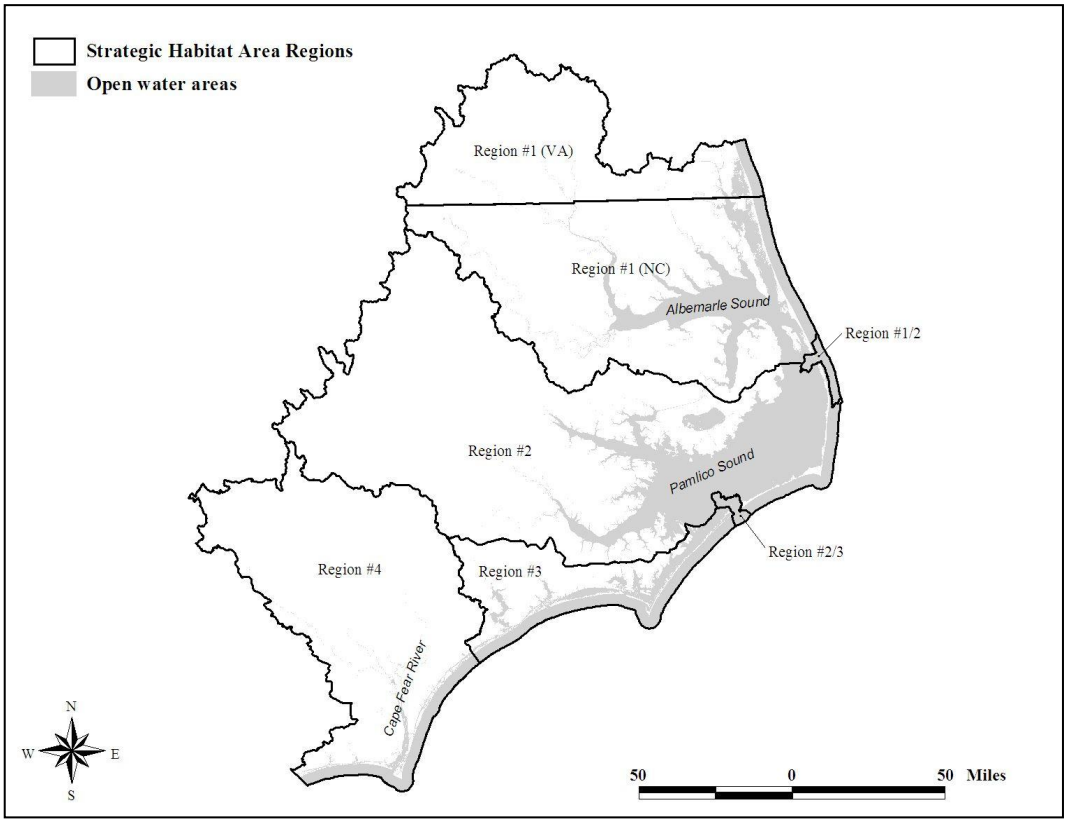
The identification of SHAs addresses the continuing degradation and loss of important habitats referenced in the CHPPs (Street et al. 2005, Deaton et al. 2010). The current rules and policies of the resource management agencies fail to adequately address the individually small but cumulatively large conversions and alterations of fish habitat for development and associated human activities (Street et al. 2005, Deaton et al. 2010). Eventually, resource management and conservation agencies must address the issue of cumulative impacts in terms of fisheries ecosystem integrity and threshold alteration levels (Deaton et al. 2010). The 2010 CHPP update included a recommendation to develop the tools for addressing cumulative impacts (Deaton et al. 2010). On a regional scale, the concept of managing ecosystems to avoid cumulative impacts is partially addressed by assessing the condition of natural resource targets based on the presence, extent, and influence of multiple alteration factors. Maintaining a healthy ecosystem, through focus on Strategic Habitat Areas, is based on the interdependent relationship between alteration factors, natural resource targets, and the spatial landscape. Averting threshold levels of cumulative alteration to SHAs could be accomplished with both regulatory and non-regulatory tools.

This report documents the selection of SHA candidates in Region 2, encompassing Pamlico Sound and its tributaries in eastern North Carolina, and follows the nomination report format specified in the guiding document (DMF 2006).

GEOGRAPHIC SCOPE OF REGION 2

Region 2 includes the waters and adjacent wetlands draining into and out of Pamlico Sound through both Oregon and Ocracoke Inlets to the adjoining coastal ocean (Map 2). It includes the sounds and tributaries of Pamlico Sound and the Tar-Pamlico and Neuse rivers up to the fall line separating Coastal Plains and Piedmont physiographic regions. The boundaries of the study area were based on the CHPP subregions of Pamlico Sound, Tar-Pamlico River, Neuse River, adjacent coastal ocean, Oregon Inlet and Ocracoke Inlet (Deaton et al. 2010). Region 2 (the Pamlico Sound system) and Region 1 (the Albemarle Sound

system) are interconnected by Oregon Inlet and Croatan and Roanoke Sounds. Because Oregon Inlet influences both systems, it was included in both Region 1 and 2. Together, the Albemarle-Pamlico Sound system comprises the second largest estuary in the United States.



Map 2. Regional boundaries for Strategic Habitat Area nominations.

Region 2 includes the Neuse and Tar-Pamlico river basins and subbasin 03-01-55 of the Pasquotank river basin (northern Pamlico Sound). The Neuse and Tar-Pamlico comprise the third and fourth largest river basins in the state and both drain to Pamlico Sound. The Neuse river basin is more developed, with the towns of Raleigh, Goldsboro, Kinston, New Bern and Havelock within its watershed. Growth in the Neuse river basin is projected to increase 44% from 2000 to 2020. Major communities in the Tar-Pamlico include Rocky Mount, Greenville, and Washington. Closer to the coastline, extensive lowlands have limited land use to rural fishing and farming communities, such as Stumpy Point, Engelhard, Bellhaven, Swanquarter, and Merimon. On the Outer Banks, fishing and tourism are the primary businesses. Both the Neuse and Tar-Pamlico river basins are classified as Nutrient Sensitive Waters (NSW). The primary stressor is excess nutrient loading derived primarily from nonpoint runoff associated with agriculture and development, as well as point source discharges. There are a few large industries in Region 2 that may also contribute to water quality degradation, such as Domtar, PCS, and Cherry Point Marine Corps. Fortunately, Region 2 is rich in protected conservation lands, primarily in the lower estuarine and marine portion, which help offset impacts from other land uses. These include Alligator River NWR, Mattamuskeet NWR, Swanquarter NWR, Cedar Island NWR, Cape Hatteras National Seashore, and other conservation lands.

Region 2 is 5,942,938 total acres in size. However analysis was limited to a ‘focus area’, consisting of surface waters and a 500 m wide margin of shoreline. This area is 2,405,413 acres in size. Within the Region 2 focus area, all six habitat types identified in the CHPP are present, including water column, soft

bottom, shell bottom, submerged aquatic vegetation, wetlands and hard bottom (Street et al. 2005, Deaton et al. 2010). The Pamlico Sound area was chosen as the second regional assessment site due to the importance of the sound and rivers to North Carolina's fisheries, prominent fishery stocks with a concern or depleted status (i.e., oysters, blue crabs, southern flounder, spotted seatrout), and growing concerns regarding accelerated development in western Pamlico Sound and tributary shorelines, sometimes referred to as "Inner Banks" development.

In Pamlico Sound proper, the salinities generally range from 15-25 ppt and the shoreline is characterized by eroding salt/brackish marsh (Deaton et al. 2010). The flushing rate in the Pamlico Sound system is relatively low (over 200 days) compared to more riverine-dominated estuaries in North Carolina (Basta et al. 1990). The flushing rate is influenced by the relative areas of water to land (Region 2 over 20% water) in conjunction with lunar and wind tides. At locations relatively isolated from inlets, the wind tides can have a greater effect on flushing than lunar tides (Reed et al. 2004, 2008). Salinity and circulation patterns are the key physical conditions affecting the species composition occurring in juvenile nursery habitat in Pamlico Sound (Ross and Epperly 1985, Noble and Monroe 1991).

The Pamlico Sound system is well known as a major contributor of fish and shellfish in North Carolina, and an extremely important area for commercial and recreational fishing. While comprising approximately 56% of the state's total coastal waters, landings in Pamlico Sound contribute 32% of the total commercial landings in state waters, and approximately 7% of the reported recreational landings in 2009 (DMF 2010a). Of these, blue crab, brown and white shrimp, southern flounder, and striped mullet are among the top species landed commercially. Atlantic croaker, spot, bluefish, and spotted sea trout are common recreational species caught. Seasonal occurrence of sea turtles adds to the diversity of life that utilizes Pamlico Sound. The disproportionately high productivity of the Pamlico System may be attributed to the extensive riverine and estuarine wetland communities, shallow nursery areas, diversity of habitats and salinity regimes, and relatively low development. Pamlico Sound has long been regarded as the fishing gem of the North Carolina coast. The Division of Marine Fisheries considers the traditionally important priority fishery species of Region 2 to include American oysters, blue crab, Penaeid shrimp, southern flounder, red drum, and spotted seatrout (DMF Management Review Team, pers. com., 2011). Shad and striped bass are important anadromous fishery species in the upper rivers. Listed species, such as sea turtles and Atlantic sturgeon are also priorities for the region.

Habitat features that contribute to the integrity and exceptional productivity of the Pamlico Sound system include extensive SAV beds behind the Outer Banks and along the rivers, intertidal and subtidal oyster rocks, and Primary Nursery Areas (PNAs), (DMF Management Review Team, pers. com., 2011). Maintaining conditions to sustain and enhance these habitats is critical for management of the priority species of the region. The most pressing threat to water quality in Region 2 appears to be non-point source pollution from "Inner Banks" development and agricultural drainage. Loss of wetland shoreline edge from erosion and shoreline stabilization is a concern, particularly considering that the rate of sea level rise is predicted to increase to a point that may exceed the ability of wetlands to migrate landward and upward. The Region 2 SHA assessment focused on identifying areas that support the DMF identified priority fishery species and sites that incorporate the aforementioned habitats in their most unaltered state.

METHODOLOGY

A guidance document was developed to direct the methods for identifying SHAs (DMF 2006). The SHA identification process consists of three main phases, each of which requires input from a regional expert panel. The first phase in the SHA process is to identify priority species and/or habitats, and build a GIS database of existing biological and anthropogenic use data layers for Pamlico Sound. Once data is assembled by DMF staff, the regional expert panel for Region 2 reviews the data layers to ensure that they have sufficient spatial coverage and are current enough to be included in the SHA selection process. In the second phase, the panel examines the priority fish species for the region and sets the amounts of

each biological feature that the final SHA network should include. The second phase of the process is running the site selection software MARXAN (Ball et al. 2009) to determine an initial configuration of SHA networks. Once the MARXAN modeling is complete, the third phase consists of an expert committee reviewing the MARXAN selections and using corroborating information and their own ecological knowledge to modify the boundaries of the SHA network and derive a final network of SHA nominations.

IDENTIFICATION OF PRIORITY SPECIES

Pamlico Sound is a focal point for the oyster, crab, and shrimp fisheries, and is an important area for southern flounder, red drum, and spotted seatrout. The 2010 CHPP states "The areas that contribute most to the integrity of the system are a category of habitat termed Strategic Habitat Area." In a general sense, the abundance and diversity of habitat such as shallow nursery areas, SAV and oyster beds is what sustains Pamlico Sound productivity (Katy West/DMF, pers. com., 2011). The Region 2 SHA assessment focused on identifying areas that support the fisheries and habitats identified as priorities by DMF and the AC and those sites that incorporate the aforementioned habitats in their most unaltered state.

NATURAL RESOURCE TARGETS

In this analysis, "Natural resource targets (NRTs)" are defined as the habitats or ecological functions that represent essential or unique components of the fisheries ecosystem. NRT's vary by region and should be chosen to differentiate between habitats that are used differently by fish species. To do this, priority species were grouped into anadromous species, shellfish, winter spawning estuarine fish and summer spawning estuarine fish based on common life history strategies (Table 1). Each habitat target was evaluated based on its value to these species' groups to determine representation levels for the analysis. Once identified, the use of habitat by each group of priority species is documented and used to set representation levels (the amount of a habitat to be included in the SHA network). In addition to the importance to priority species, the contribution of a habitat as a buffer to improve water quality was also considered when setting representation levels. After an initial value was set, representation levels were also adjusted based on the regional importance of a habitat type, quality of habitat data, and overall amount of habitat in a region. A comprehensive list of NRT's and the chosen representation level are listed in Table 1.

Table 1. List of natural resource targets and representation levels used in the analysis.

CHPP habitat type	Natural Resource Target	Total Acres in Region 2	Representation level (%)	Importance to Priority Species				
				Anadromous fish	Shellfish	Winter spawning est. fish	Summer spawning est. fish	Contribution to water quality
Polygon habitat types								
Hard bottom	Riverine hard bottom	1,135	100	X				
SAV	High salinity SAV	89,854	70		X	X	X	X
	Low salinity SAV	1,751	100			X	X	X
Shell bottom	Intertidal shell bottom	66	100		X	X	X	X
	Subtidal shell bottom	3,717	100		X	X	X	X
Riverine soft bottom	Riverine - lowest	1,456	60	X				
	Riverine - lower	10,408	0					
	Riverine - middle	1,048	0					
	Riverine - upper	121	0					
Deep Soft Bottom	Estuarine (>6ft)	983,218	0			X		
	Marine (>6ft)	189,231	0			X		
Shallow Soft Bottom	Estuarine (0-3ft)	82,883	30		X	X	X	
	Estuarine (3-6ft)	78,259	20		X	X	X	
	Estuarine (ND)	2,457	10			X		
	Marine (0-3ft)	16,438	20			X	X	
	Marine (3-6ft)	15,386	20			X	X	
	Intertidal marine	451	20			X	X	
	Lacustrine (ND)	46,642	10	X		X		
	Palustrine (ND)	1,755	0					

Table 1 cont. List of natural resource targets and representation levels used in the analysis.

CHPP habitat type	Natural Resource Target	Total Acres in Region 2	Representation level (%)	Importance to Priority Species				
				Anadromous fish	Shellfish	Winter spawning est. fish	Summer spawning est. fish	Contribution to water quality
Polygon habitat types								
Wetland	Non-riparian	121,173	0					X
	Emergent (estuarine and riparian)	104,333	0					X
	Forested (estuarine and riparian)	138,788	10	X				X
Wetland	Estuarine shrub/scrub	12,175	0					X
	Headwater	5,735	50					X
Upland	Low elevation upland	47,944	20					
Ecological Designation	Primary Nursery Area	12,163	100			X	X	
TOTAL AREA		1,968,587						
Line habitat types (all distance values are in miles)								
Hard bottom	Ocean Hard Bottom	30	0					
Water column	Streams (high elevation)	46	0					
	Streams (low elevation)	1,061	20	X				
	Streams (mid elevation)	266	20	X				
Shoreline	Non-wetland shoreline	1,296	20			X	X	
	Wetland edge	2,921	50	X		X	X	X
Fish groups	River Fish Group	54,520				X	X	
	Sound Fish Group	32,403				X	X	

Hard bottom

Two types of hard bottom habitats occur in Region 2: riverine hard bottom and ocean hard bottom. Ocean hard bottom was delineated based on the Southeast Area Monitoring and Assessment Program's reef-dependent fish collections from the 1990s (SEAMAP 2001) and Moser and Taylor (1995). Presence of hard bottom habitat was inferred based on the presence reef fish species in trawl samples. The survey coverage and design prevented the creation of polygon features representing hard bottom habitat; therefore, ocean hard bottom is represented as line features. Because of the scarcity of the data, the inferential nature of the data collected, and lack of use of these habitats by priority species, the representation level for ocean hard bottom was set to zero; though it was assumed some would be chosen incidentally.

Riverine hard bottom (i.e., rocky outcroppings) was present in middle and upper elevation sections of the Neuse and Tar Rivers. The general boundaries of the rocky outcrops were described by WRC staff (B. Wynne, R. Barwick, V. Stancil, and C. Waters) and delineated by DMF staff for inclusion in the assessment. These areas are important spawning substrate for anadromous fishes of the region and are relatively rare, so the representation level was set to 100% for this habitat type.

Submerged Aquatic Vegetation (SAV)

Submerged aquatic vegetation beds were mapped using aerial photography interpretation and transect data interpolation. Source data range in date of acquisition from the early 1980's to the very recent (Carroway and Priddy 1983; Ferguson and Wood 1994; ECSU 2002-2003-2006; DWQ 1998; DWQ 2005-2006-2007; DMF 1988-August 2009). With data up to 25 years old, significant changes in the distribution of SAV beds are likely to have occurred. Furthermore, the distribution of SAV habitat is likely more extensive than aerial observations suggest. For example, the growth of narrow fringing SAV beds and beds growing in organic stained water is difficult to discern from aerial photography (S. Chappell/DMF and J. Greene/DWQ, personal observation). Because of this, the extent of SAV habitat is likely underrepresented by the mapping data.

Mapped SAV was further differentiated into low (0-15 ppt) and high salinity (>15 ppt) beds, based on NOAA salinity classifications. Although SAV provides similar ecological services regardless of its location, salinity determines the fish species that are likely to be encountered in an SAV bed. Summertime measurements (which are considered the high salinity period) were used; therefore, the boundary helps capture the fluctuating boundary of both low and high salinity areas.

Large beds of high salinity SAV occur on the sound side of the outer banks. Such extensive beds of SAV are unique to region 2 and are important habitat for priority species. In addition, the presence of SAV indicates that water quality in an area is sufficient to support life, providing an implicit way to differentiate between qualities of areas in soft bottom habitats. In the context of other MARXAN inputs, a sensitive habitat such as SAV can help distinguish between otherwise similar habitats such as shallow estuarine soft bottom. Because of its regional importance and uniqueness, high salinity SAV targets were set relatively high (70%). Low salinity SAV is also important juvenile habitat for priority species, occupies less area, and is likely underrepresented in the data coverage since it is less visible in aerial photographs; therefore, the representation level was set to 100%.

Shell bottom

Shell bottom habitat in Region 2 was based on interpolated transect data collected by the DMF Bottom Mapping Program (DMF 1988-August 2009). The source data ranges from 1988 to August 2009, depending on the geographic area. The shell bottom target is defined as areas with at least 30% coverage of shell material (typically oysters) in water generally less than 12 feet deep. Shell bottom is subdivided into intertidal and subtidal by the Bottom Mapping Program.

Other sources of data were incorporated into the shell bottom target, including included cultch planting sites (DMF unpublished data, 1981-2008), historic Winslow-Ballance oyster reef footprints (Winslow 1889; Ballance 2004), oyster sanctuary boundaries (DMF unpublished data, 2010), and deep oyster reef profiles (USACE unpublished data, 2006-2007). The point data for cultch planting sites was converted to an area representing shell bottom based on the amount of cultch deployed (acres = bushels/8500). The additional shell bottom data was classified as subtidal shell bottom. Representation levels were set at 100% for both types of shell bottom habitat because they are regionally important as a resource and for maintaining water quality in Pamlico Sound.

Uplands

These areas were included because they are potential sites for marsh migration with sea level rise (Deaton et al. 2010). LIDAR elevation data (http://www.ncdot.org/it/gis/DataDistribution/ContourElevationData/, 2007) was used to delineate areas greater than 5 meters across adjacent to mapped NRT habitats less than 2ft above mean sea level. Non-wetland shorelines are also included in the category of uplands in the calculation of alteration scores. This linear target was created from the inverse of wetland shorelines selected by intersection the fishing water jurisdictions shoreline with the wetlands data. Both upland targets received a representation level of 20%. Non-wetland shoreline was assigned a representation level of 20% because these shorelines can be important habitat for some priority species.

Wetlands

Wetland targets were extracted from the NC Division of Coastal Management (DCM) wetland dataset (Sutter 1999). This dataset is a combination of National Wetland Inventory (NWI) maps (NWI 1981-1983), Natural Resource Conservation Service digital soil surveys, satellite imagery (1994) and hydrographic maps. Only contiguous wetlands within 90 meters of a stream or shoreline were included as a target for assessment. Wetlands of the following types are included in the region 2 analysis.

Estuarine/coastal wetlands
These wetlands are generally found along the margins of estuaries and sounds and sometimes exhibit tidal regimes. This group contains estuarine emergent wetland (salt/brackish marsh), estuarine shrub/scrub, and estuarine forest wetlands (including maritime swamp forests). Salt-brackish marsh occupy wetland areas at salinities from 0.5 to >35 ppt in North Carolina (Wiegert and Freeman 1990).

Riparian/riverine wetland
These wetlands are those in which hydrology is determined or heavily influenced by proximity to a perennial stream of any size or order. Overbank flow from the stream exerts considerable influence on their hydrology. The riverine or riparian wetlands (USACE mitigation type) include riparian emergent wetland (freshwater marsh) and riparian forested wetland (swamp forest and bottomland hardwood forests).

Non-riparian/flat-depressional wetland
These wetlands are generally not in direct proximity to surface water. While they may be either isolated from or hydrologically connected to surface water, the hydrology of depressional wetlands is primarily determined by groundwater discharge, overland runoff, and precipitation. The flat-depressional or non-riparian wetlands (USACE mitigation type) include non-riparian emergent wetland (freshwater marsh), non-riparian forested wetland (hardwood flat, pine flat, managed pineland), and non-riparian shrub/scrub wetland (pocosin).

Headwater wetland
These wetlands exist in the uppermost reaches of local watersheds upstream of perennial streams. Headwater systems may contain channels with intermittent flow, but the primary sources of water input are precipitation, overland runoff, and groundwater discharge rather than overbank flow from a stream.

Wetland edge

This target consists of the linear boundary of wetlands and open waters indicated on the fishing water jurisdiction coverage. The wetland edge target does not distinguish between marsh and forested edges. The inclusion of wetland edges was meant to minimize the selection of large areas of interior wetland (regardless of type), as well as capture an important ecotone within aquatic systems. Wetland shorelines are important habitats for juveniles of some priority species. Representation levels were set relatively high for the wetland edge target and lower for some wetland types under the assumption that those other riparian wetland habitat types would be captured with this target.

Wetlands were grouped into the following categories for the Region 2 analysis because they correspond to areas with similar usage by priority species: emergent wetland, forested wetland, headwater wetland, non-riparian wetland, and estuarine shrub/scrub wetland. Headwater and forested wetlands were assigned representation levels of 50 and 10 percent because of their function as spawning and nursery grounds for anadromous fish. Representation levels were not set for other wetland types, though it was assumed that adjacent wetlands would be captured as a function of wetland edge and other targets being met.

Creek/rivers and soft bottom habitats

Areas where there was no SAV, shell bottom, or other structured habitat were categorized as soft bottom or water column habitats. These targets were developed from a combination of DMF jurisdictional waters, NOAA bathymetric contour data, and National Wetland Inventory (NWI) open water classifications. Creeks and rivers are grouped under this heading because the process described here delineates riverine, estuarine, and marine systems for multiple targets. Creeks and rivers are considered a water column habitat for the purpose of alteration ratings because they have relatively high flushing rates compared to other soft bottom habitats.

The water column and soft bottom categories were further classified by system and depth category. The depth categories were 0-3ft, 3-6ft, >6 ft and no depth. These distinctions are important because they correspond to major differences in ecological function (i.e., shallow water nurseries). Depth data was derived from NOAA bathymetric charts (http://nauticalcharts.noaa.gov/mcd/Raster/Index.htm). The “no depth” category was assigned to channel-like hydrographic features adjoining more open waters, or where the bathymetric charts indicated no data. The delineation is valid where channel-like features are actually >3 ft deep. Unfortunately, these delineations may not have been consistently or completely applied. Soft bottom habitats are classified into riverine, lacustrine (lakes), estuarine, and marine systems.

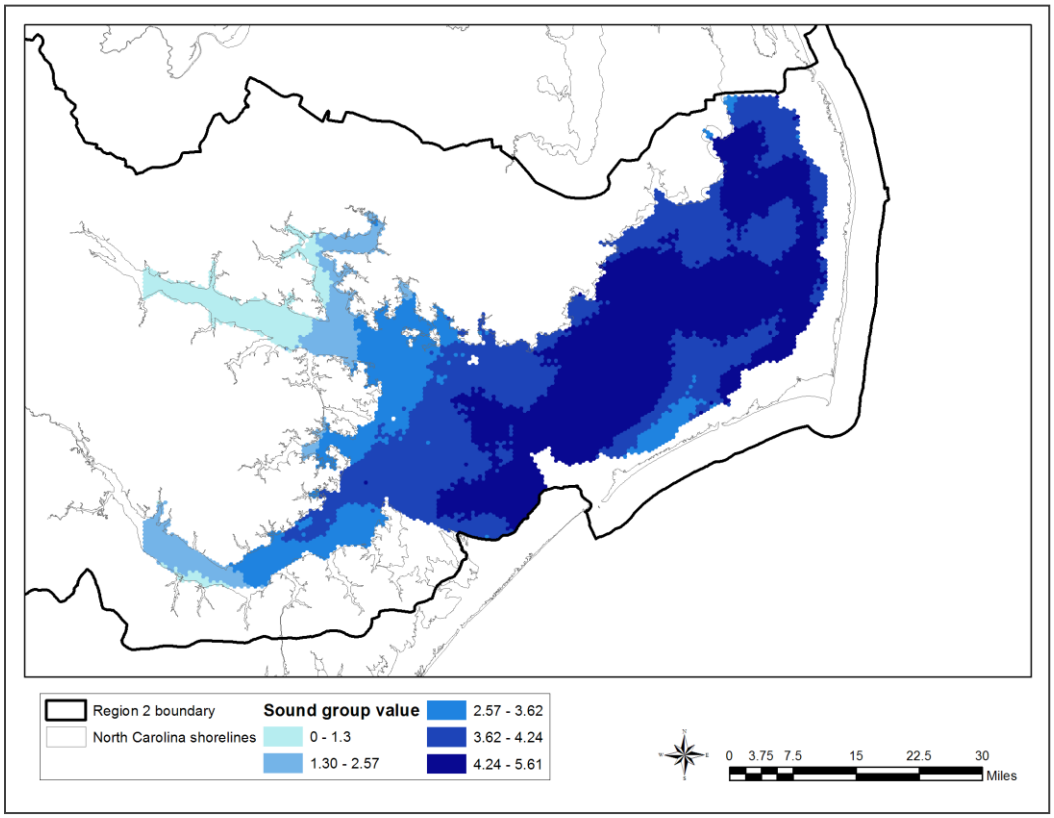
- **Riverine** systems were separated from low salinity estuarine systems based on a linear or meandering morphology and a substantial (unditched) drainage network upstream.
- The **marine** system includes subtidal and intertidal waters of the coastal ocean and Oregon, Ocracoke and Hatteras Inlets hydrologic units.
- The **estuarine** system includes all open waters and intertidal flats between riverine and marine systems. The estuarine system also includes pond-like features surrounded by estuarine wetlands. Large tidal creeks, isolated marsh pools, and some estuarine open waters are currently lumped together. The no depth estuarine soft bottom NRT represented tidal creeks. The boundary of estuarine wetlands was also used to differentiating the estuarine and riverine systems.
- **Lacustrine** systems (lakes) were classified as such by NWI and larger than 15 acres. Only lakes connected to riverine or estuarine systems by linear water features were included. A 30 meter threshold was applied to determine connectedness of lakes to adjacent water features.

Estuarine and marine intertidal flats were defined as areas below the mean high water line indicated on the fishing water jurisdiction coverage (DMF, unpub. data 2004). Marine intertidal flats were classified by NWI as unconsolidated shores within the marine system. A narrow band of intertidal habitat along the Atlantic Ocean was assumed.

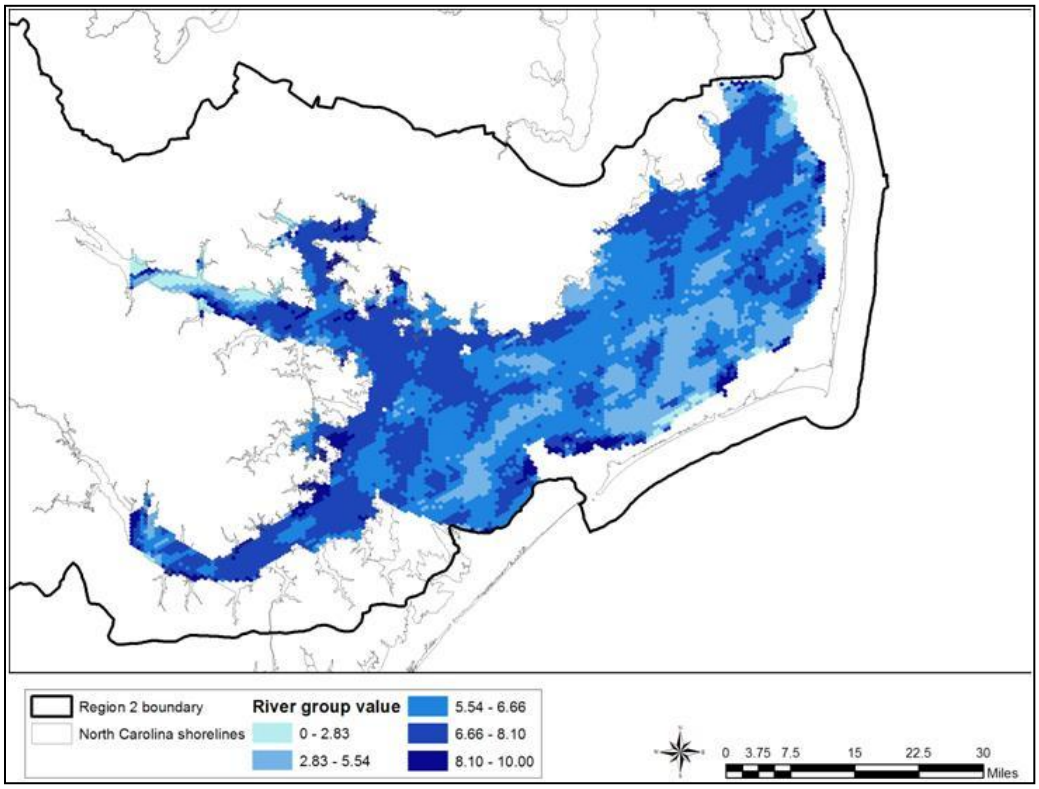
Marine systems were data poor regions for this analysis. Therefore, representation levels for marine systems were all set at 20% to capture a baseline amount of the ocean. Inlets were considered important because of their function in allowing migration in and out of the estuary, and were marked for inclusion in the final solution. Estuarine soft bottom is the most abundant target in the region. The shallower, nearshore areas were considered more important for fish species; therefore, representation levels were assigned proportional to depth group. Deep estuarine soft bottom was not assigned a representation level; the inclusion of a fish target provided the basis for selection of these areas. Riverine soft bottom habitat was further differentiated by position along the river (determined by elevation). The lowest category of riverine soft bottom habitat received a relatively high representation level because the corresponding areas are known overwintering grounds for important anadromous species. Other categories of riverine soft bottom were not considered especially important to any of the priority species groups and were therefore not targeted for consideration specifically in the SHA network; though a certain representation is assumed to be obtained incidentally in choosing adjacent targets.

Fish data

The inclusion of fish abundance data as a target was not possible in Region 1 due to the lack of adequate coverage by a survey with a stratified random survey design. In Region 2, trawl data (Program 195) from the deep waters of Pamlico Sound and the Neuse and Pamlico Rivers were used to identify a subset of areas within the deep soft bottom habitat of Pamlico Sound that might be of particular importance for fish abundance/productivity. Data from 1990- 2009 was used. Cluster analysis was used to divide resource species into two groups: one with higher abundance in the sound and one with higher abundance in the rivers (Figure 3a-b). Group abundance was summed for all species in a group at each survey point and averaged if more than one sample occurred in one geographic location. Kriging interpolation was used to create a surface of fish abundance for each group. Interpolated log of catch-per-unit-effort (CPUE) for each species group was assigned to hexagons that covered the main area of Pamlico Sound and the mouths of the Neuse and Pamlico Rivers. Details can be found in Appendix C (fish methods). Fish group representation levels were set at 20% for both fish groups, because they encompassed both summer and winter spawning estuarine fish groups.



Map 3a. Summed catch per unit effort of fish in the sound grouping using Program 195 data.



Map 3b. Summed catch per unit effort of fish in the river grouping using Program 195 data.

Streams

Small creeks and streams were represented using 1:100,000 scale data from the National Hydrologic Dataset (NHD), which represents a connected network of stream channels. The streams were clipped out of the open water features to leave a continuum from linear to polygon water features. Finer scale NHD data was not available for the entire region and the coarser scale data represented larger streams that fish more frequently use.

There are three basic linear water features based on elevation (1 arc-second National Elevation Dataset). Stream order was not used because it was not readily available and much of region 2 has flat topography and highly ditched hydrology. Three elevation zones were set based on natural breaks occurring from sea level up to the fall line of riverine channels. We also considered differentiating swamp waters from other linear water features, but the classifications from DWQ were incomplete. In future analysis, it may be helpful to include stream orders for linear water features in the middle and upper zones, and a swamp water classification for streams in the lower zone.

Habitat complexes/functional areas

Primary Nursery Area designations were included in the analysis as a NRT. PNAs are specific areas designated based on juvenile abundance surveys of five different species (spot, croaker, southern flounder, brown shrimp and blue crab). The designation represents areas with relatively high juvenile fish abundance and represents a subset of highly productive nursery areas. All PNAs in Region 2 were identified as Strategic Habitat Areas for inclusion in the SHA network.

Rare or listed species

Rare or listed species are not included in the MARXAN analysis as targets, but are taken into account indirectly through targeting of associated habitats, and during the second phase of the analysis using expert modification. Rare or listed species in this region include Atlantic sturgeon and sea turtles. Sturgeon habitat will be indirectly targeted through selection of riverine wetlands, streams, and soft and hard bottom. Green and loggerhead sea turtles are the most common listed species in Region 2. They tend to enter the sounds in the spring as they migrate north for the summer, and leave the sounds in the fall to migrate south for winter. Sea turtles are highly mobile, moving around as they feed opportunistically. Within Region 2, sea turtles are thought to be most abundant in eastern Pamlico Sound in water 10-20 ft deep, but can be found throughout the sound and lower rivers. Their habitat will be targeted indirectly through deep soft bottom and fish targets.

ALTERATION FACTORS

Alteration factors are human activities that impact the marine environment. The alteration factors used in the analysis are described in Table 2 and listed below. Factors included were evaluated for duplication with other factors. The advisory committee evaluated the data available on alteration factors and added some data that was not available in Region 1.

The natural resource targets of Region 2 were grouped into general habitat categories for the purpose of applying alteration factor ratings. For example, all wetland types are affected similarly by ditching and drainage; therefore, they form one habitat type for alteration. However, there were linear wetland features and polygon wetland features. In order to apply the equations presented in the SHA report (Appendix B), the linear features were converted into narrow polygon features. This conversion was also done for linear water features, unless noted below. The NRT groupings are listed and described below:

- Creeks/rivers – Polygon water column features for riverine hard and soft bottom NRTs. This category represents soft bottom under flowing water conditions.
- SAV – All categories of SAV
- Shell bottom – All categories of shell bottom

- Soft bottom, deep – All categories of estuarine and marine soft bottom >6ft deep. This category represents soft bottom under standing water conditions.
- Soft bottom, shallow – All categories of estuarine and marine soft bottom <6ft deep. This category represents soft bottom under standing water conditions.
- Uplands – Line features that were converted to polygons using a buffer 15 meters landward from non-wetland shorelines. The polygon target for low-elevation uplands was included in this basic habitat type for alteration.
- Wetland – Wetland edge was converted to polygons using a buffer 15 meters landward from wetland shorelines. Interior wetlands are polygon features >15 meters from wetland edge.
- Streams – Linear water column features converted to polygons using a 2.5 meter buffer. The size was based on the thinnest polygon water features, usually upper end of creeks or rivers.

Many other factors were considered, but were not included for various reasons. Among them were 2010 DWQ use support ratings, 2006 land cover data, stormwater outfalls, surface water intakes, silviculture operations, and beach nourishment. Their use was excluded for the following reasons:

- DWQ use support ratings were not used because we primarily needed aquatic life use support, which wasn't available in all locations.
- Coastal Change Analysis Program (CCAP) 2006 land cover data was not available until after the total alteration layer was completed.
- Stormwater outfall maps from DWQ and DEH-SS&RWQ were incomplete for the region; the DWQ data covers only municipalities and the DEH data covers only SA water shorelines.
- The GIS data for water intakes was extremely outdated, excludes certain areas and intakes under large minimum thresholds, and the NPDES sites covered major surface water intakes.
- Silviculture/forestry discharge not included because literature review in the CHPP indicated minor effect on habitat and water quality, the Advisory Committee felt the alterations to aquatic habitat were minor relative to other threats, and the activity was difficult to represent spatially (Deaton et al. 2010; Uphoff 2010).
- Dredge material disposal on beaches has occurred in the region (Deaton et al. 2010), but was not included in the alteration factors, since it was episodic and less frequent than beaches with long term storm protection projects.

Table 2. Alteration factor ratings used in the current MARXAN analysis. Note: X means no overlap or does not apply.

	Hydrology (water-based)								Water quality (land-based)											Physical (conversions)				
CHPP habitat (NRT groupings)	Culvert obstructed	Water control structures	Impounded	Channelized streams	Vertical shoreline stabilization	Dredged channels	Ditched/drained	Canals & boat basin	Industrial waste pond	Major NPDES	Minor NPDES & aquaculture	Marinas (>10 slips)	Animal operation (major)	Animal operations (minor)	Mining discharge	Military targets/ordinance	Developed land-use	Agricultural land-use	Prohibited shellfish harvest	Bottom disturbing fishing gear	Wetlands lost to development[5]	Wetlands lost to agriculture[6]	Riparian upland development	Riparian upland agriculture
Creeks, rivers	X	1	2	1	X	X	X	1	X	2	1	1	1	0.5	1	X	2	2	1	X	X	X	X	X
SAV	0.5	1	2	X	X	3	X	2	X	2	1	2	2	1	1	1	2	2	1	2	X	X	X	X
Shell bottom	X	X	X	X	X	3	X	1	X	1	1	2	1	0.5	1	1	2	1	1	2	X	X	X	X
Soft bottom, deep	0.5	1	2	X	X	1	X	1	3	2	1	1	1	0.5	1	1	1	1	0.5	1	X	X	X	X
Soft bottom, shallow	0.5	1	2	1	X	2	X	1	3	2	1	2	1	0.5	1	1	1	1	0.5	X	X	X	X	X
Non-wetland shoreline[3]	0.5	1	2	1	2	X	X	X	X	X	X	X	X	X	0	X	1	1	0	X	X	X	2	1
Wetland, riparian[1]	0.5	1	2	2	2	X	X	X	X	X	X	X	X	X	0	X	0	0	0	X	3	2	X	X
Wetland, interior[2]	0.5	1	2	X	X	X	2	X	X	X	X	X	X	X	0	X	0	0	0	X	2	1	X	X
Streams[4]	0.5	1	2	1	X	X	2	X	X	3	2	X	2	1	1	X	2	2	0	X	X	X	X	X

[1] 15 meter landward buffer from wetland edge

[2] Wetlands >15 meters from wetland edge

[3] 15 meter landward buffer from non-wetland shoreline + low-elevation uplands

[4] 2.5 meter buffer around stream

[5] Includes land use classes low, medium, high, and open space development

[6] Includes land use classes cropland, pastureland, and barren

Alteration factors are loosely categorized as affecting hydrology, physical structure of habitat or water quality in an area. The effect of alteration factors on natural resource targets is represented in various ways:

1. *Overlap of habitat area and alteration footprint* – This was done for alteration features whose effect could be accurately represented by a discrete area. Altered areas for these features were represented as the area of the intersection between the habitats present and alteration. This was done for channelized streams, dredged channels, ditched/drained, canals/boat basins, industrial waste pond, prohibited shellfish harvest, bottom disturbing fishing gear, habitats lost to development or agriculture, culverts and impoundments.
2. *Relative impact the alteration factor to a hydrologic unit* – This was done for alteration factors that were theorized to have watershed-level impacts, or if the data collection prevented a discrete area of impact from being delineated. To calculate this, the extent of an alteration factor (whether it be total area or the sum of point counts) is summed across a hydrologic unit and amount is relativized to the maximum value occurring in any hydrologic unit in the region. This includes vertical shoreline stabilization, NPDES, animal operations, aquaculture impacts, marinas, developed and agricultural land use, mining operations.

Hydrology alterations

Culverts
This factor identifies the watershed area (streams and wetlands) upstream from both documented and possible culvert location as altered. Altered areas were intersected with habitat present to identify altered areas. The culvert data was assembled from various sources, including Collier and Odum (1989), Moser and Terra (1999), and Department of Transportation (2003 data). In addition, possible culverts were located by creating a point where streams intersected roads with no bridge indicated on the DOT data.

Water control structures
This was applied to the stormwater gates around Lake Mattamuskeet (USFWS 2010). The designation was also applied to the dam on the Little River west of Goldsboro, which had breached, because the impacts were rated as similar by the advisory committee.

Impoundments
Impounded waters include all natural resource targets upstream from documented dam locations. The data sources for dam locations were Collier and Odum (1989), Moser and Terra (1999), Department of Transportation (2003 data), Division of Water Resources (2003 data), and USACE obstructions inventory (2009 data). The location of fish passage devices should be included and reviewed by appropriate committee members. Fish passage devices could make previously inaccessible waters partially accessible.

Channelized streams
Channelized streams are natural streambeds that were artificially straightened to enhance drainage and/or navigation. They differ from canals, which lack an original streambed and therefore, have little or no natural drainage. The specific location of channelization projects were visually estimated using the NHD for Region 2. Local Natural Resources Conservation Service (NRCS) staff was contacted, but no data was available (B. Chepuri/DMF, pers. com., 2010).

Vertical shoreline stabilization
Shoreline type data was extracted from the 1996 Environmental Sensitivity Index (ESI) maps produced by NOAA. Alteration was rated as the ratio of the linear distance of stabilized structures to the linear distance of shorelines in a watershed, scaled to the maximum in the region. Stabilized structures were defined as seawalls, corresponding to the ESI shoreline types of ‘exposed rocky shores’ and ‘sheltered artificial structures’. Riprap was not included as a stabilization structure because it functions as fish habitat (Waters and Thomas 2001).

Dredged channels
This factor includes areas dredged by the U.S. Army Corp of Engineers (USACE) on a regular basis. The source data originated from 2003. The map does not include channels dredged by the DWR or private channels dredged for deep-water access, though these areas may be included as canals and boat basins.

Ditched/Drained
Partially drained wetland areas were taken from the DCM wetland modifiers (applied to wetlands) and NHD ditched classification (applied to streams). The ditched classification was based on obvious linear and angular morphology. These data sources originated from the early 1990's. While this coverage has not been updated since the early 1990s, drainage projects in riparian wetlands have generally not been allowed since then so the data is likely pretty accurate.

Canals and boat basins
This alteration factor included obvious canals for navigation (very long and straight polygon features) or relatively short and straight, elongate polygons with no upstream hydrology (short, water access canals or boat basins). These features were digitized based on 1998 imagery and shoreline morphology. Some of the delineated boat basins could also overlap with marinas.

Water quality and land use alterations

Industrial waste ponds
This alteration factor was added to cover industrial waste pond located very close (<60 m) to other natural resource targets. The waste ponds were shown on the 1997 North Carolina Atlas and Gazetteer (Delorme 1997).

NPDES and aquaculture discharge
This factor was derived from NPDES sites locations provided by NCDWQ (2006 data). The impact of NPDES sites is difficult to quantify because the environmental impact of NPDES sites is variable and it is difficult to determine the area of influence for a point source without a detailed hydrologic model. We therefore decided to summarize NPDES sites by hydrologic unit to approximate the measure of alteration. NPDES sites are classified as major or minor based on the amount of discharge allowed per day. Sites discharging more than one million gallons per day were considered major. The number of major or minor NPDES within hydrologic units was then scaled by the maximum number occurring in the region, and the relative amount was used to calculate the relative severity of alteration. Note that major and minor NPDES were given different impact severities relative to habitat types (Table 2).

Current location and discharge data on large aquaculture operation was received from Division of Water Quality (A. Hodge/DWQ, pers. com., 2011.). Large aquaculture discharges were included with the minor NPDES factor because discharges from aquaculture facilities ranged from 54,236-435,363 gallons per day. However, aquaculture discharge is an untreated nutrient addition, and thus more concentrated than other minor NPDES.

Marinas
Wildlife Resources Commission and Shellfish Sanitation data on marina locations and slip numbers were combined to make one shapefile of all facilities with > 10 slips. The total number of slips at these facilities were aggregated per hydrologic unit and divided by the amount of shoreline (defined by the NRT wetland and non-wetland shoreline) in each hydrologic unit to create a slips/shoreline metric. This metric was scaled to the maximum value occurring in region 2, which was in Oriental (1021 slips; 0.012778 slips per meter of shoreline).

Animal operations
Locations and size of animal operations were obtained for poultry, swine and cattle operations. Swine and cattle operation information came from NC DENR's animal operations permits (DWQ, Non-

Discharge Compliance/Enforcement Section, available from NC Center for Geographic Information and Analysis on the internet at http://data.nconemap.com. Poultry data was downloaded from American Environmental Geographic Information System (AEGIS; available at http://www-geography.jsu.edu/ , downloaded 10/2009), which contains point locations of animal feeding operations identified through aerial photography. Each point location has an identifier giving the number of chicken houses at a site.

Animal operations were divided into major and minor based on the amount of nitrogen runoff generated by the operation. To do this, the amount of nitrogen production for each animal operation per year was calculated based on accepted values of nitrogen excreted per animal for each type of operation (McNaught et al. 2010). There are 554 swine operations, 3 cattle operations and 493 poultry operations in the study area. Values of nitrogen production per operation ranged from 0 to 470,274 lb N per year. The mean was 47,091; the distribution was heavily negatively skewed. The log-transformed distribution of N production is bimodal, with the mean of 9.5. This value was used to split animal operations into major (N production > 9.5) and minor (N production less than 9.5). All values greater than the mean were swine farms with the exception of one of the three cattle operations. Only one poultry farm is considered major, the rest are cattle and swine operations. The numbers of major and minor animal operations per hydrologic unit were calculated and the score for each hydrologic unit was scaled relative to the maximum number of each type of animal operation in region 2.

Mining discharge

Mining was included as an alteration factor because mining operations discharge fresh water into adjacent waterways. Freshwater discharge from mining operations was considered to have a low impact on soft bottom, shell bottom, SAV and water column habitats and received a rating of 1. Current data on mining discharge was acquired from the Division of Land Resources in August 2009. Location data was furnished with a column giving total acres in the mining operation. The impact of mine effluent on receiving hydrologic units was quantified using the acreage of the mining operation, under the assumption that the amount of water discharged was proportional to the size of the mining operation. To quantify the impact of mining discharge to adjacent habitats, the total acreage of mining operations in a hydrologic unit were summed. These values were then log transformed and scaled to the regional maximum (log value of 9.86) to get the relative extent for each hydrologic unit.

Military targets/ordnance

The military uses several areas in region 2 for training exercises, resulting in the accumulation of inactive ordnance at the site. Military designations in the area were considered an alteration because of anecdotal information regarding heavy metal contamination (A. Hodge/DWQ, pers. com., 2010). The alteration factor was rated low due to the mitigating effect of military areas as a refuge from trawling and a study finding no violations of EPA water quality standards in the areas (US Navy 2009). Several types of regulations exist in region 2, but only areas designated as prohibited and danger (no human entry allowed) were included in the alteration factor.

Developed land use

This factor was extracted from the 2001 National Land Cover Dataset using the low, medium and high intensity developed classifications. The total area of developed land-use within each 12-digit USGS hydrologic unit (HU) was calculated and scaled to the maximum proportion of developed land found in an HU in the region. A greater proportion of development within a HU suggests higher nutrient and chemical loadings from non-point development sources.

Agricultural land use

This factor was extracted from the 2001 National Land Cover Dataset using the cropland and pasture classifications. The total area of cropland within each 12-digit USGS hydrologic unit was calculated and scaled to the maximum proportion of developed land found in an HU in the region. A greater proportion of cropland within an HU suggests higher nutrient and chemical loadings from non-point agricultural sources.

Prohibited shellfish harvest
Areas prohibited to shellfish harvest due to high pathogenic microbe counts or automatic closures around wastewater treatment outfalls and marinas were included to represent non-point source alterations at spatial scales smaller than hydrologic units. The benefit of representing localized impacts was considered more important than minimizing the redundancy of similar alterations (i.e., NPDES, marinas, and developed land-use). In addition, the prohibited areas are documented alterations and not reliant upon inferred data. Only waters that fall under the category of prohibited harvest are included; conditionally approved harvesting waters were not included because they are considered restorable by NC Department of Environmental Health - Shellfish Sanitation.

Physical disturbance

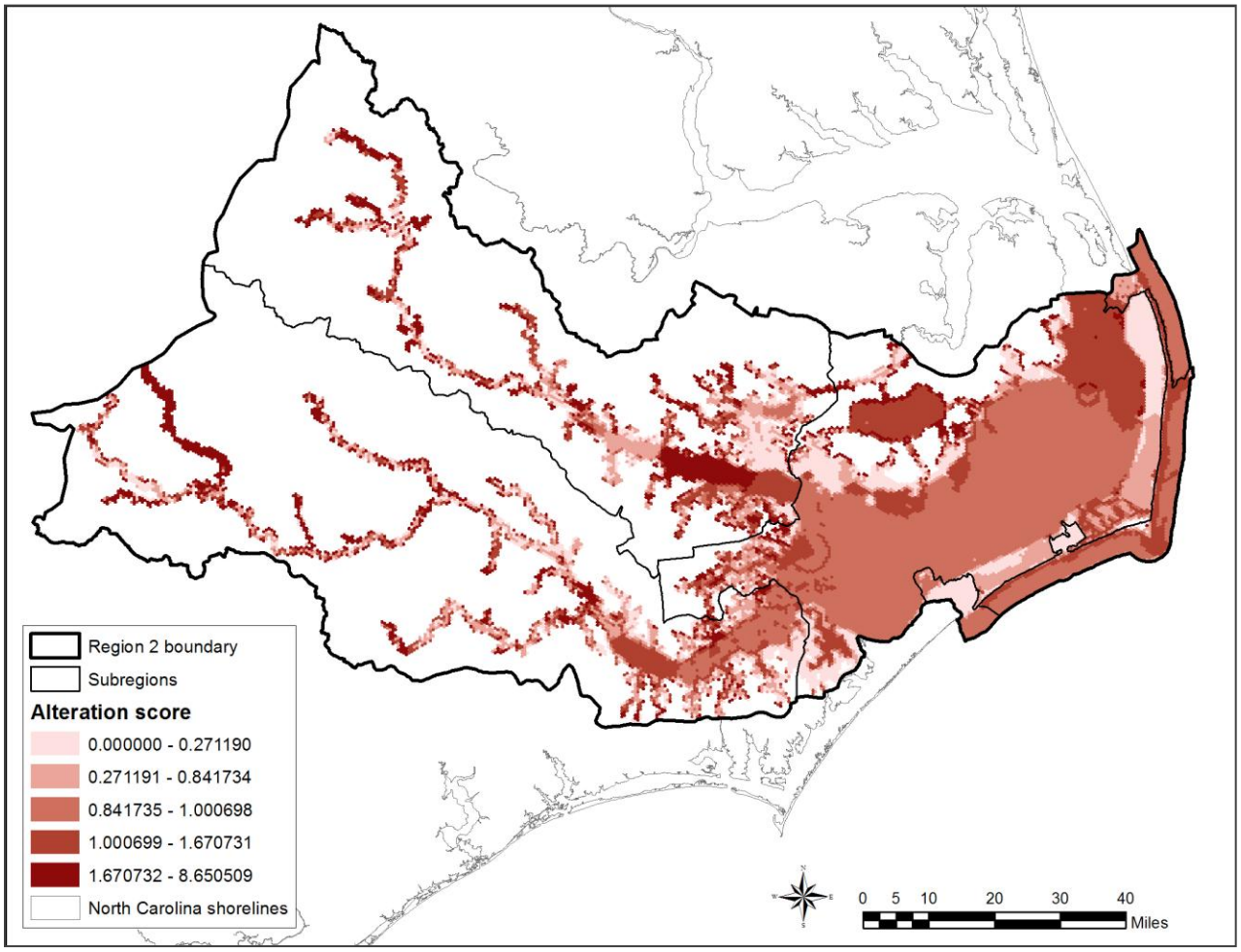
Trawling/dredging
The no trawling/no dredge coverage was created by DMF in accordance with 2004 MFC rules and provisions of the Shrimp Fisheries Management Plan (DMF 2006). Areas open to trawling or dredging and located in areas greater than 3ft deep were included in this alteration factor. Crab dredging areas were not included as 'no trawl' areas for the SHA process because dredging does not happen frequently or over a wide extent. The bottom disturbing gear factor was rated low in alteration because it represents only potential alteration within a very large area. Data on the frequency of trawling at specific locations is not available.

Converted wetlands
The area of wetland converted to other uses was incorporated as a metric of development in a region. This alteration factor was created by comparing wetland areas from the early 1990's (DCM data) to land use classifications from the 2001 National Land Cover data (NLC 2001) (30m resolution). The resulting maps show wetland areas that are now in some form of upland development, cropland, pastureland, or barren classification. The classifications for upland development included low, medium, high, and open space. The classifications for agriculture included cropland, pastureland, and barren. Cropland was only compared to forested wetlands because the classification accuracy differentiating salt marsh and cropland was low. Converted wetlands accurately reflect large shoreline developments where the shoreline has not greatly receded.

Converted uplands
This factor is specifically related to land uses within riparian upland areas. The land uses compared to converted wetlands were also used for converted upland shoreline. Similar to converted wetlands, converted upland shorelines accurately reflect large shoreline developments where the shoreline has not greatly receded. The land uses overlapping low elevation uplands were drawn from the CCAP 2006 dataset. The land use classifications for development included developed open space and various intensities of development. The land use classifications for agriculture include cultivated, pasture/hay, and bare land.

Total alteration/cumulative impacts

Each alteration factor was assigned a rating ranging from 0 (no impact) to 3 (high impact) for each habitat type it coincides with (Table 2). Habitat types were condensed to match the major CHPP habitat types. The factor ratings were guided by a modified version of a similar table in the CHPP (Street et al. 2005), which is based on literature reviews and expert opinion. Because multiple factors can contribute to the alteration within a region, we combined the alteration factors into a total alteration rating which quantitatively measure the amount of alteration to each hexagon in the region. Briefly, the alteration score weights the alteration severity by the amount of habitat impacted and combines the severity and impact scores into a total score by weighting the proportion of each habitat present in the hexagon. The alteration score for region 2 was created using a combination of ArcGIS models and R scripts and is described in detail in APPENDIX B). The resulting alteration layer is shown in Map 4.



Map 4. Alteration layer for Region 2. Higher values equate to greater degradation.

MARXAN ANALYSIS

The site selection software MARXAN (Ball and Possingham 2000) was used to identify an initial network of areas to be considered for SHA nomination. The use of MARXAN was recommended by a Duke University master's project (Smith 2005) and sequentially adopted as SHA methodology. The site-selection tool makes it possible to systematically consider multiple natural resource targets and various socio-economic factors represented as alterations. The computer program provides a way to select a network of areas (classified by hexagon units) with the least amount of alteration, which is helpful because specific information is not available on maximum tolerable alteration levels and specific minimum habitat sizes needed to maintain functional ecosystems (Stewart et al. 2003). Often, the results of site selection tools are used as a starting point from which to determine boundaries and are not considered a final output (e.g. Geselbracht et al. 2009). Final SHA nominations incorporate expert scientific knowledge to consider additional biological information and socio-economic factors that may not have been included in the MARXAN inputs.

The selection algorithm considers several sources of data and uses an iterative approach to consider multiple network configurations until it finds one that minimizes the area and cost of the network. MARXAN allows the user to input data on the distribution of conservation features (NRTs in the SHA process) and to define the desired amount of each conservation feature desired in the final reserve configuration. In addition, MARXAN allows the user to input a cost for each planning unit, which can vary based on the process objectives. The SHA process uses the alteration score of a hexagon as the cost under the assumption that alteration is equal to habitat degradation. This framework was designed so that

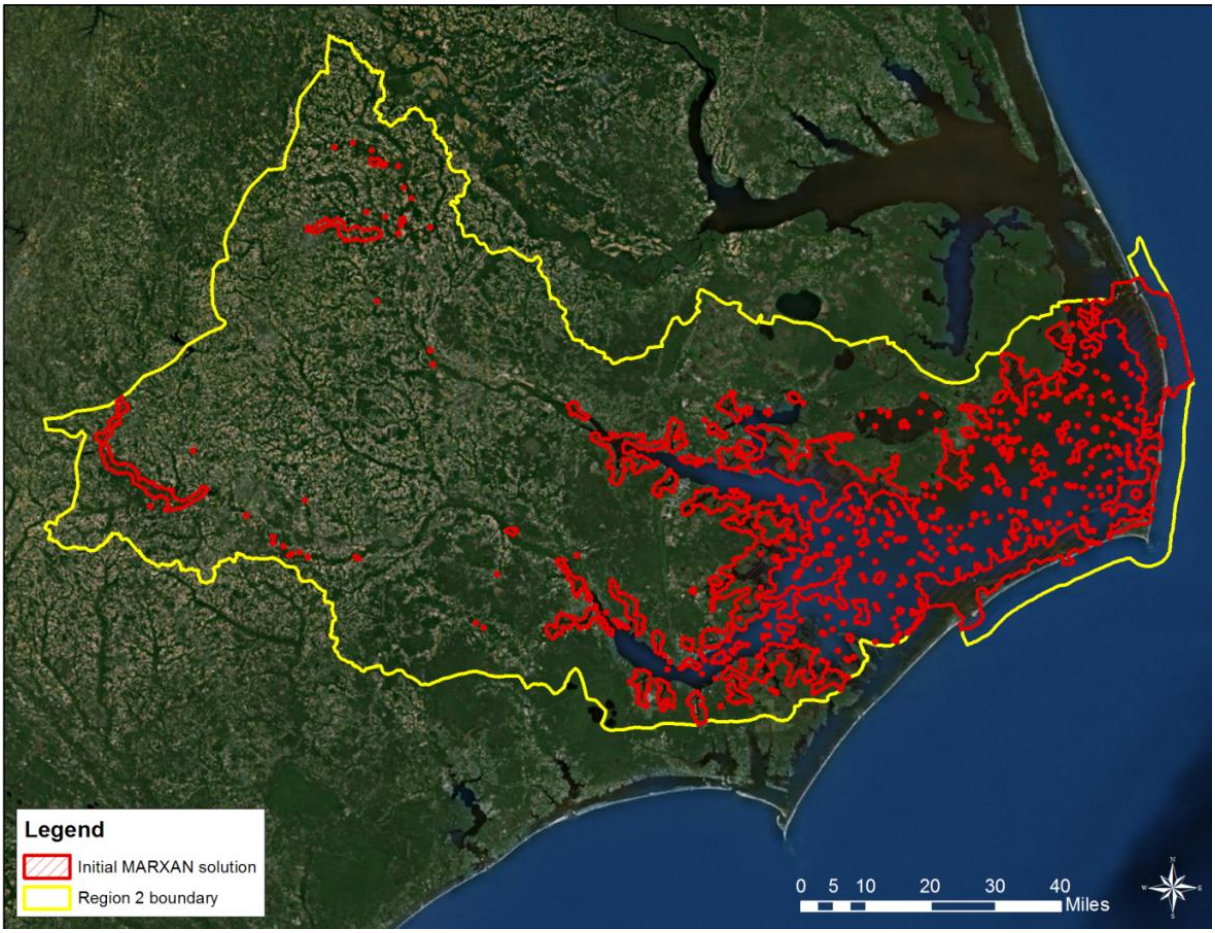
MARXAN would select a network of habitat areas that have the least amount of habitat degradation. In addition to the habitat and alteration inputs, MARXAN allows the user to input a boundary length modifier (BLM), which controls the length of border allowed by the solution. Raising the BLM increases the cost of spatially disparate solutions, forcing the program to select hexagons that are closer together.

A MARXAN analysis consists of a series of runs, each of which represents a solution found by the computer program. A grid of hexagons is laid over GIS habitat and alteration layers. The hexagons in this analysis were 124 acres in area, 880 m in diameter, and 440 in side length. Each run consists of a specified number of iterations. Each iteration considers a new reserve configuration of hexagons by calculating a cost that is based on the success of the program at meeting its targets, the reserve boundary length and the cost of the area considered. Iterations proceed until the change between iterations is minimal or a maximum amount is reached. The number of runs, iterations and BLM can all be specified in the MARXAN settings, and should be adjusted to attain an appropriate solution for each analysis. An informal sensitivity analysis was conducted for Region 2 (Appendix E), and it was decided to run each scenario for Region 2 500 times with 1,000,000 iterations per run. The BLM was adjusted to 0.001 in order to produce a solution which was driven by the difference in cost between runs. Lowering the BLM produced a solution that was relatively spatially aggregated in the rivers and along the shores of the sound, but resulted in many areas with three or fewer hexagons in Pamlico Sound. Areas composed of less than 3 adjacent hexagons were considered too small for management and removed from the solution considered in the corroboration stage. It was assumed that the advisory committee would add areas during the corroboration stage to make up for the area lost by eliminating these clusters.

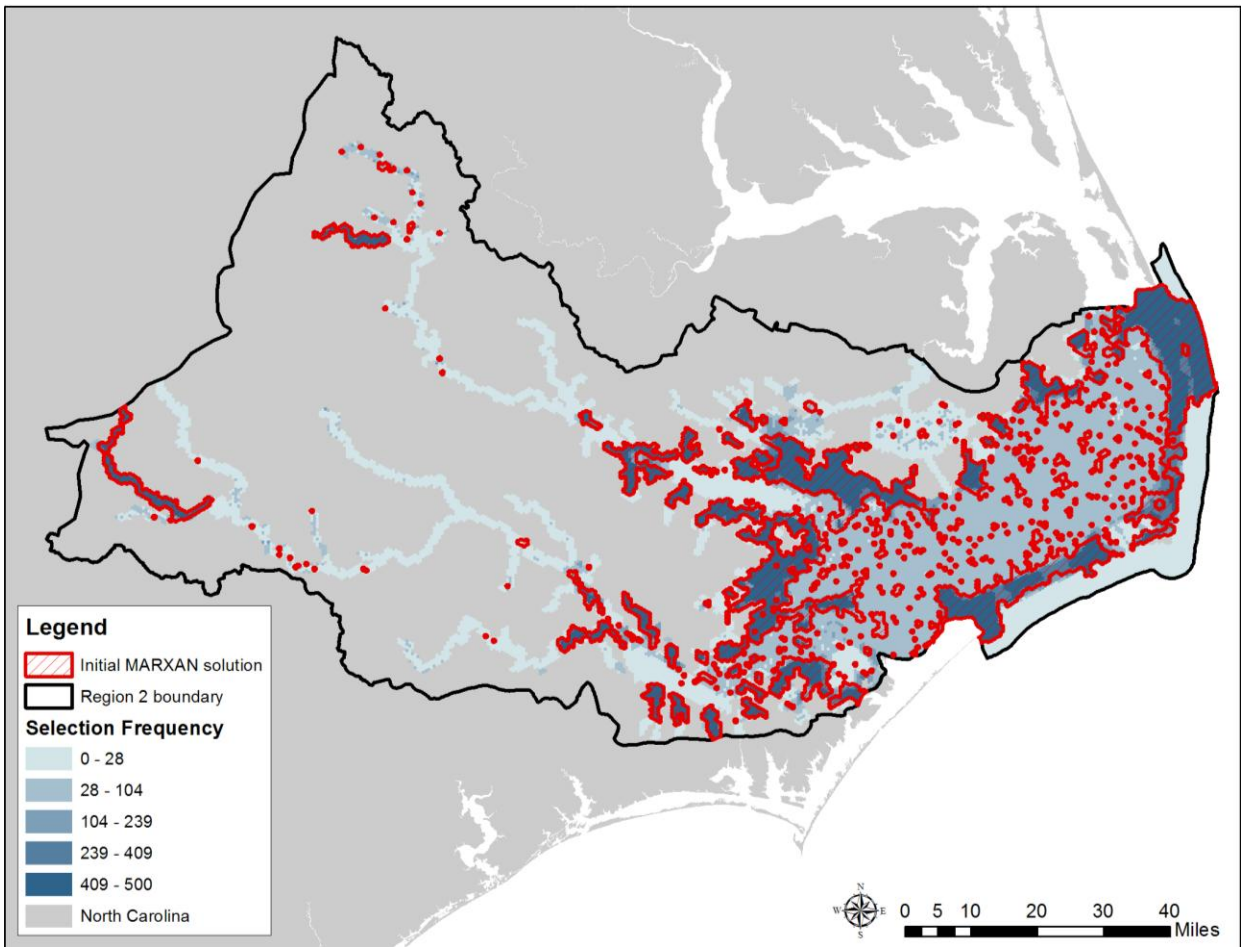
Once preliminary areas are identified by MARXAN, SHA selections are modified and refined by a regional expert panel using other known sources of quantitative or qualitative ecological or fishery information and professional knowledge (referred to as corroborating data). Public input was required to finalize identification and nomination of areas for eventual SHA designation.

MARXAN RESULTS

After the natural resource targets and total alteration layer were assembled, MARXAN was run at the specified representation levels for targets representing priority fisheries habitats (Table 1). Map 5 depicts the MARXAN selections. This resulted in a lot of small random selections within the sound being selected. These areas appear to have been selected at low frequencies to meet the deep soft bottom and fish categories (Map 6). High selection frequencies are an indication that an area was not erroneously chosen. In looking at the selection frequencies, it is important to note that the inlets, riverine hard bottom, shell bottom, MFC designated PNAs, and overlapping selections from Region 1 were tagged for 100% selection. The amount of each target captured in the MARXAN solution is shown in Table 4. The initial MARXAN solution met the representation goals for SAV, riverine hard bottom, shell bottom, wetland edge, PNAs, and fish numbers. However it overselected forested wetlands, estuarine and marine soft bottom, low elevation streams, low elevation uplands, and non-wetland shoreline. A large amount of non-riparian, emergent, and estuarine shrub/scrub wetland were also included with the solution, although they were set for a 0% representation level. These wetlands were set to 0% purposely, knowing that they would be represented through the selections of wetland edge and additional capture due to occurrence within a 124 acre hexagon. Overall, the MARXAN solution resulted in 213, 888 acres (275%) of polygon targets being selected, and 1,949 mi (113%) of line targets being selected. Selections appear to be strongly influenced by proximity to the tagged targets.



Map 5. MARXAN initial output.



Map 6. Initial MARXAN results overlaid with selection frequency.

CORROBORATION

The committee spent two meetings reviewing the initial MARXAN selections and making expert modifications, as needed. The SHA committee grouped individual selected hexagons into manageable polygons for the corroboration and identification process. Modifications to the MARXAN selected SHAs were made using an overlay of selected hexagon polygons on digital imagery. The SHA committee examined maps of both the selection frequency and alteration ratings for guidance during the manual selection phase. For each polygon or group of contiguous hexagons, the SHA committee reviewed data included within each polygon or group to confirm inclusion/exclusion as a SHA in a consistent and data based manner. This included examination of the alteration scores, selection frequencies, amount and type of targets present, habitat diversity and rarity, supporting biological data, existing ecological designations that were not included as NRTs (i.e. Anadromous Fish Spawning Areas, Significant Natural Heritage Areas) and connectivity with adjacent selections and protected areas. Known studies or information from committee members regarding habitat condition and fish utilization of specific areas were also included. Tables 4-7 and maps were used to review that information. The tables summarize information within the polygon, whereas the maps show spatially what is within and between the SHA selections.

Any modifications made were to be based on the following criteria:

- Habitats present – rare, vulnerable, diverse
- Occurrence of ecological designations
- Alteration factors and ratings
- Selection frequency
- Fish data/information available from DMF sampling or other research
- Fish abundance rank
- Water quality impairment status (5 categories)
- Regional importance of a functional area
- Size/isolation/connectivity/shape

The designations and biological data used in this phase of the analysis are listed in Table 3. These data are meant to support computer-selected areas and identify important areas omitted by the MARXAN analysis. Examples of omitted areas would be a bay that was rated as altered but still supports fish production or an oyster rock that consistently produces high catches relative to other areas. Ideally the regional expert panel would have local qualitative knowledge that further supported the area as having high fishery or habitat value. Areas with existing habitat designations that were not selected by MARXAN could also indicate areas that should be considered for manual addition to the list of proposed SHAs.

The committee used the data presented in Tables 4-7 and the supporting appendix maps to cut, extend, and/or consolidate MARXAN clusters within the focus area. Selected hexagons with fewer than three contiguous hexagons were excluded. The majority of these was in Pamlico Sound and selected due to slightly higher fish abundance data. Consolidations were based on avoiding what the group considered over-represented habitats (i.e., soft bottom >6 ft) and connecting similar contiguous areas or under-represented habitats. Some natural resource targets were also clipped out of MARXAN polygons. For example, deep soft bottom areas were removed in some areas of the Neuse and Tar rivers and coastal ocean waters lacking hard bottom resources. The primary reason for excluding much of the riverine or estuarine soft bottom (>6ft) was to prevent over-representation of this resilient habitat. However, riverine soft bottom (>6ft) was included in historically important areas for anadromous fish.

Where MARXAN selections only included a portion of a habitat area (such as half of an SAV bed), the group assessed whether that cutoff point made ecological sense, and if not, extended the SHA boundary to include whole habitat units. MARXAN selections that included developed low elevation uplands were removed. The AC also expanded polygons into some unselected areas that were known to be highly

productive for priority species or habitats. The visual assessment was conducted systematically around the region, starting in eastern Pamlico Sound, followed by western Pamlico Sound, Pamlico River, and Neuse River. Additional information and changes made to the selections were documented in Table 8.

Table 3. Ecological designations and biological data from DENR sampling programs that could be used as an indicator of aquatic habitat condition in Region 2.

Data type	Description	Data source/availability
Ecological designations	Anadromous Fish Spawning Areas	MFC designation
	Blue crab spawning sanctuaries	MFC designation
	Oyster sanctuaries	MFC designation
	Estuarine PNAs	MFC designation
	Inland PNAs	WRC designation
	Open shellfish harvesting waters	DEH-SS classification
	Significant Natural Heritage Areas (aquatic and terrestrial)	Natural Heritage Program designation
	Lands managed for conservation	One NC Naturally (DENR)
Species/ productivity data	Use support and biotic indices for fish and invertebrates (freshwater streams only) – index values	DWQ program
	Juvenile anadromous and freshwater fish	DMF program 100, 135
	Juvenile estuarine fish	DMF program 120, 915
	Adult estuarine fish	DMF program 195
	Shellfish densities	DMF program 635

OTHER CORROBORATING INFORMATION

Below is a partial list of written information that was provided by AC members and considered during corroboration. Complete citations are available in the Literature Cited section. Additional information in GIS format was also used.

Oyster larval dispersal:
Haase, A.T. 2009

Blue crab dispersal:
Eggleston D.B., N.B. Reyns, L.L. Etherington, G.R. Plaia, L. Xie. 2010.
Reyns, N.B., D.B. Eggleston, R.A. Luettich Jr. 2007.

Fish habitat utilization:
Spidel, M.R. 2009.
Smith, M.C. 2006.

Sea turtle distribution:
Keinath, J.A., J.A. Musik, and D.E. Barnard. 1996.
DMF. 2010b.

Military bombing ranges:
US Navy. 2009.
Sapp, Work, Haas, and Warren. 2010.

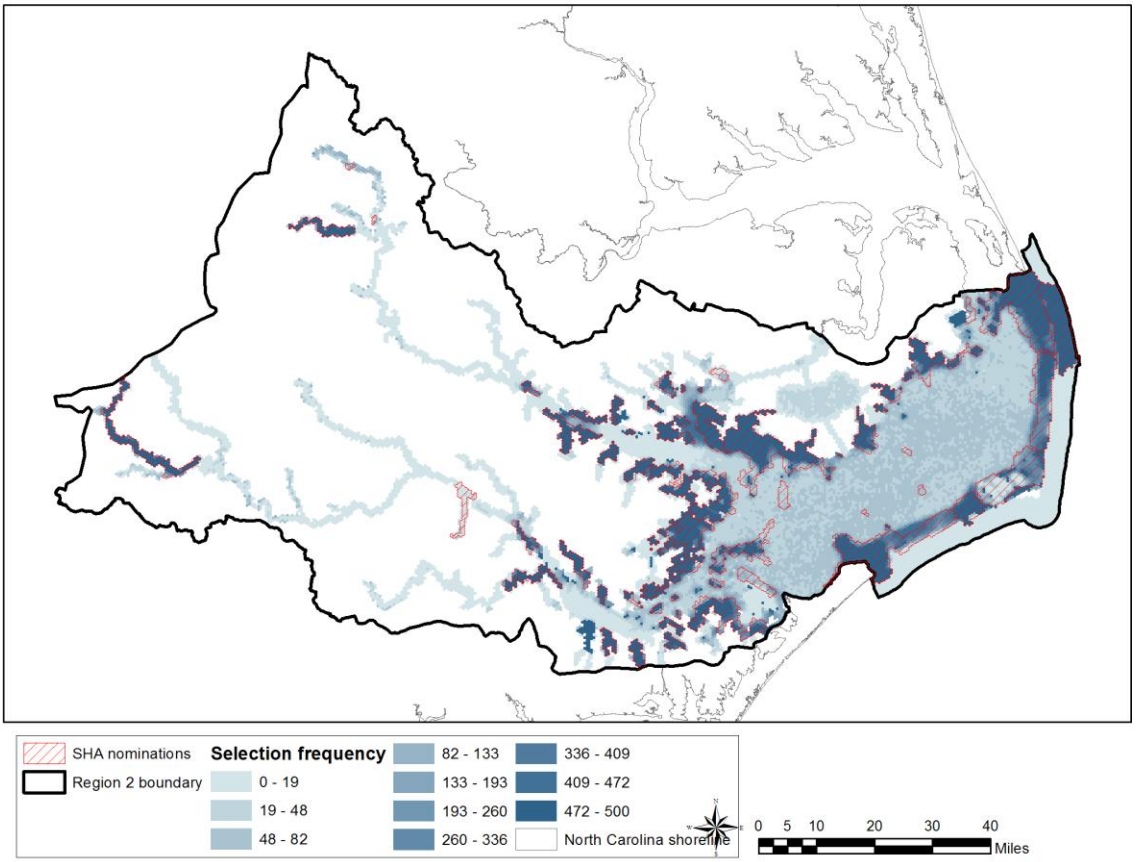
Sciaenid spawning activity:
Luczkovich, J.J., Pullinger, R.C.; S.E. Johnson, M.W. Sprague. 2008.

Effect of development and agriculture on organisms:
Uphoff. 2008.
Meyer, Luczkovich, Brinson, and West. 2010.

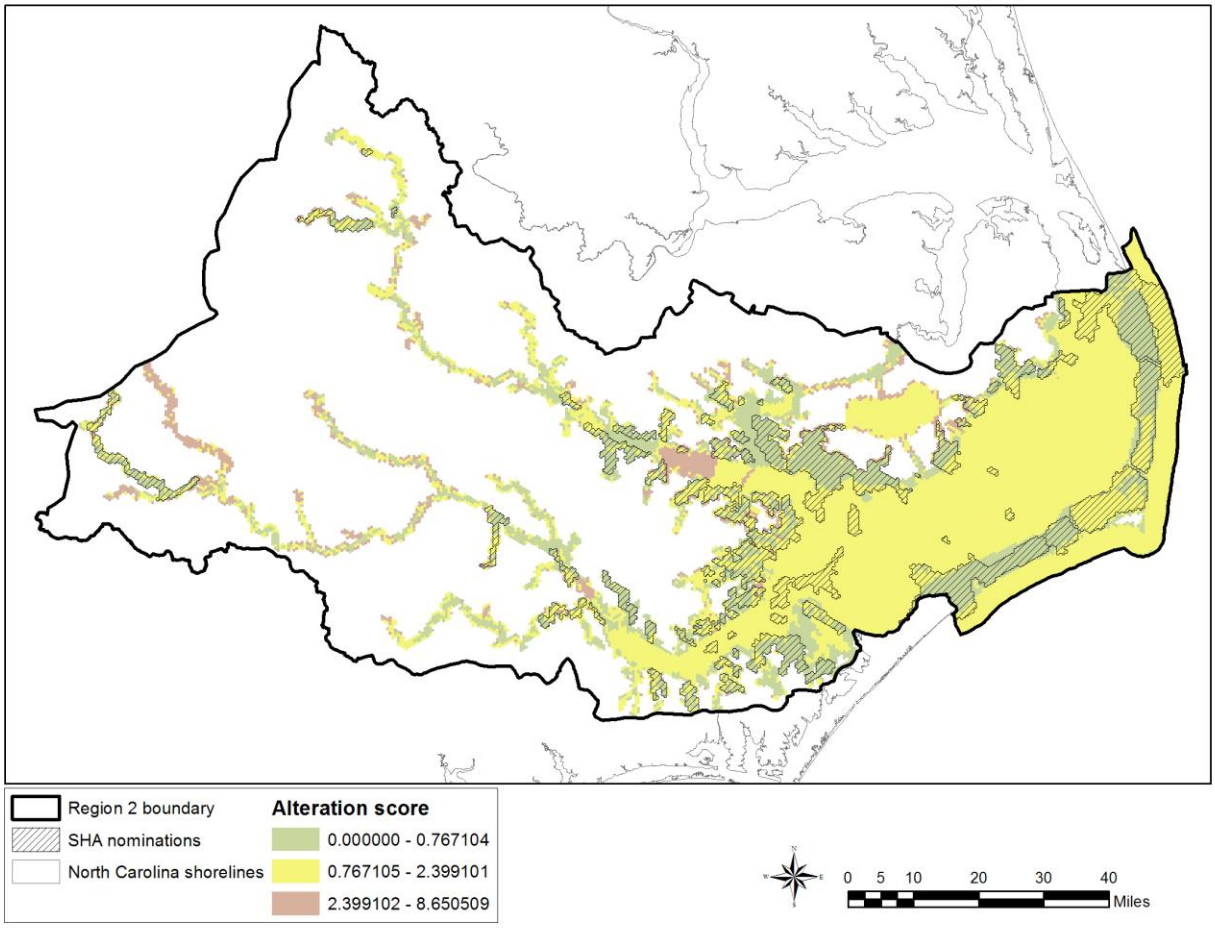
Water quality:
DWQ. 2010 Tar-Pamlico Basinwide plan.
DWQ . 2008. Neuse River Basinwide plan.

POST-CORROBORATION RESULTS

Corroboration led to an overall increase in the area selected as SHA, with selected target polygon acres increasing from 213,888 acres to 322,843 acres. Targets that increased substantially included high salinity SAV, forested wetland, and estuarine soft bottom of all depths. Targets that decreased included intertidal shell bottom, non-riparian wetland, lacustrine soft bottom, and low elevation uplands. After the AC completed the modifications, there were 67 discrete areas selected for nomination, totaling 631,820 acres of hexagons. This comprises 26% of the focus area or 10% of the total area within Region 2. Of that selected acreage, 308,545 acres and 1,924 miles consist of habitat targets. (Note that the acreage of PNAs was subtracted from the subtotal since PNA acreage is also accounted for the individual habitat targets). Acreage of selected targets is included in Table 4. Of the 308,545 acres selected for SHA nomination, 82% consist of submerged non-shoreline targets, and 18% consist of wetland or upland targets that may be adjacent to privately owned land (18% of 308,545 acres = 55,538 acres). Map 7 and 8 show the selection frequency and alteration scores of the post-corroboration SHAs. The majority of the areas that were not initially selected by MARXAN but were added by the AC had low selection frequency but low to medium alteration scores.



Map 7. SHA nominations after corroboration showing selection frequencies.

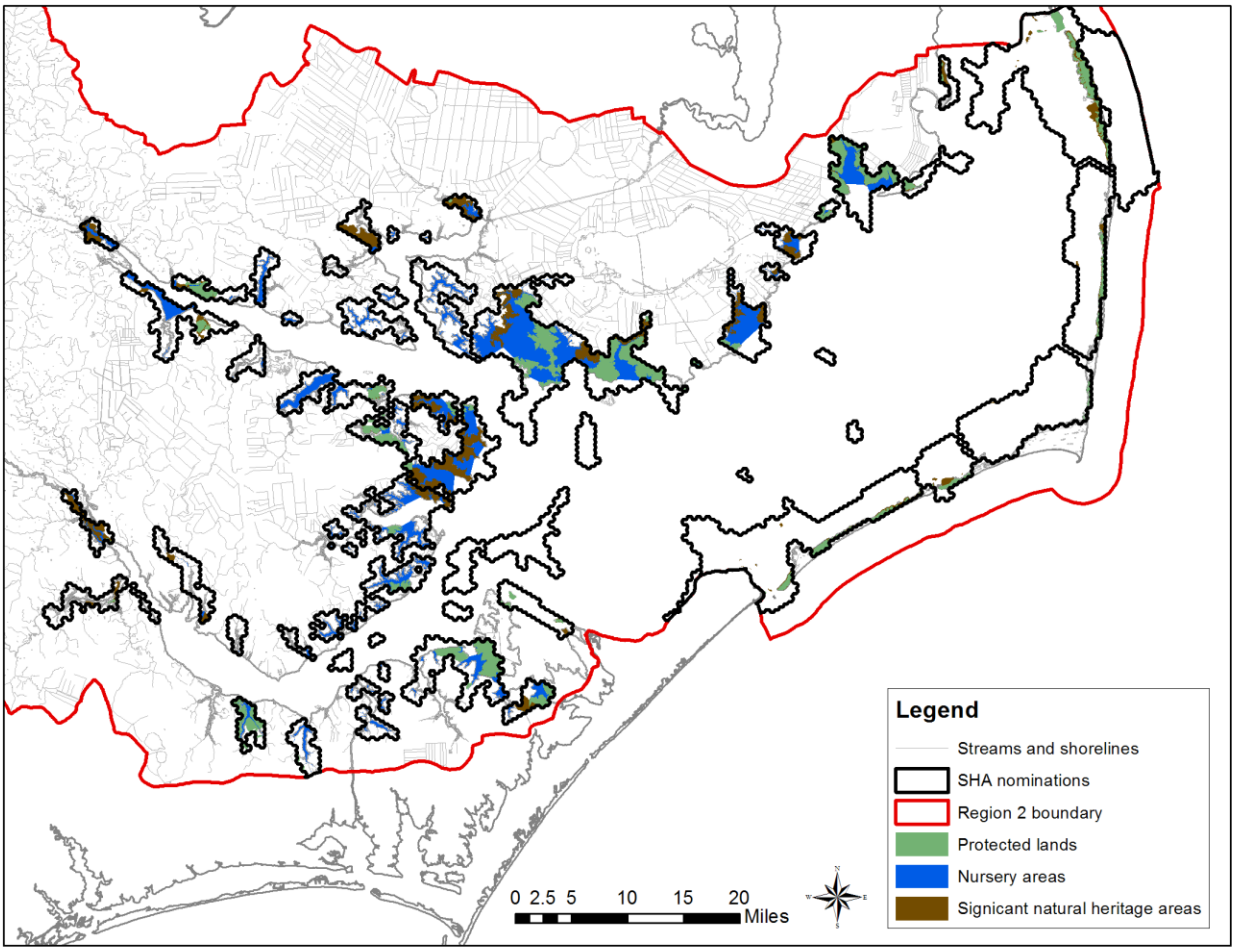


Map 8. Alteration score of post-corroboration SHA nominations. Management goals – target lowest scores (green) SHAs for protection/conservation, mid scores (yellow) for protection/enhancement, and highest scores (pink) SHAs for restoration.

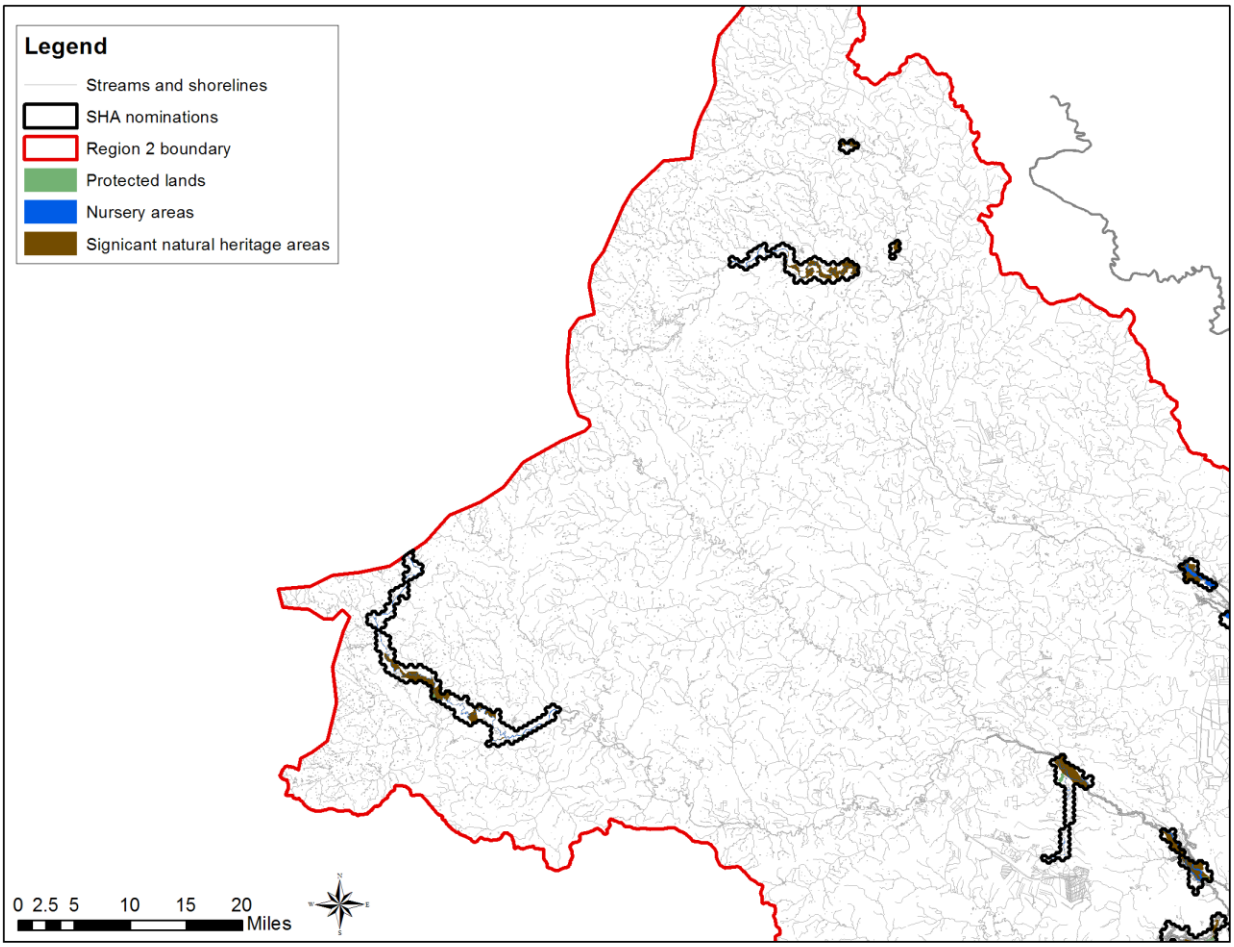
The final SHA selections form a network of priority areas for protection and enhancement ranging from the upstream watersheds of the Pamlico system to the grass beds and ebb tide deltas of the Outer Banks. Selections were concentrated along the eastern Pamlico Sound shoreline, lower estuary and upper headwaters of the Neuse and Pamlico rivers. Almost all of the high salinity SAV along the Outer Banks and low salinity SAV along the river tributaries was selected. The AC considered this appropriate since it is a critical habitat for the majority of the priority species, is a unique habitat feature of North Carolina that is known to contribute significantly to the diversity of fish life in the region, and is a habitat easily lost from physical disturbance (dredging) or water quality degradation. Along the Outer Banks, input from DMF staff indicated that fish and invertebrates were fairly uniformly distributed within the SAV, with no one area being more productive or higher quality than another, except possibly the grass beds in closest proximity to the inlets, since they can be the first structured habitat larval and juvenile fish encounter as they move in from the ocean. All mapped riverine hard bottom and some other upper areas of the Neuse and Tar were selected due to their importance as spawning areas for anadromous fish species. A few areas along the rivers were also selected. One area that was added through corroboration was Core, Village and Kidney creeks. WRC had documented that this area was one of the only areas on the Neuse or Tar-Pamlico that blueback herring were utilizing on a fairly consistent basis for spawning. Setting the representation level of PNAs at 100% encouraged MARXAN selection of other nearby targets, many of which were emergent or forested wetlands, and also soft bottom and shell bottom. The

PNAs are located in small bays and tidal creeks of the lower Neuse and Pamlico rivers and western Pamlico Sound shoreline. Concentrating SHAs around existing PNAs provides a buffer of protection and connectivity for juvenile fish movement to other estuarine habitats. Shell bottom was also set with high representation levels due to their ecological and fishery importance in the area, and current low abundance due to historical losses. Almost all mapped subtidal shell bottom was selected (95%), and approximately 75% of the intertidal oysters. SHAs selected over open water were due to occurrence of subtidal shell bottom, high fish abundance of river and sound groups, or a combination of both shell and fish. The mouths of the Neuse and Pamlico rivers appear particularly important for this.

Region 2 has an abundance of state and federally protected lands bordering coastal waters (Table 7, Maps 9a-b). Of the 631,820 acres of selected hexagons, 9% (58,701 a) occur on lands managed for conservation (state, federal, local), and 2% (14,298 a) are located in MFC designated PNAs. Some of the larger conservation lands on the western side of Pamlico Sound include Alligator River NWR, Swanquarter NWR, Cedar Island NWR, and Goose Creek Game Land, which together provide protection of low lying wetlands and water quality, particularly along the lower Neuse, Pamlico, and western Pamlico Sound shorelines. Much of the eastern side of Pamlico Sound is within Cape Hatteras National Seashore or Pea Island National Wildlife Refuge. SHAs within protected conservation lands are basically already protected from degradation associated with development. The remaining 88% (558,821 a) represent SHA nominations of various condition that are currently vulnerable to land and/or water based threats.



Map 9a. Post-corroboration SHA nominations, noting occurrence of state, federal, and private (land trust) conservation lands and MFC designated PNAs. Eastern portion of Region 2.



Map 9b. Post-corroboration SHA nominations, noting occurrence of state, federal, and private (land trust) conservation lands and MFC designated PNAs. Western portion of Region 2.

FINALIZING STRATEGIC HABITAT AREA POLYGONS

The SHA committee grouped individual selected hexagons into manageable polygons for the corroboration and identification process. The SHA committee also examined maps of both the selection frequency and alteration ratings for guidance during the manual selection phase. For each polygon or cluster of contiguous polygons, the SHA committee reviewed data included within each polygon or cluster to confirm inclusion/exclusion as a SHA in a consistent and data based manner. This included examination of the alteration scores, selection frequencies, habitat diversity and rarity, supporting biological data, and connectivity with adjacent selections and protected area. Tables 5-7 and maps were used to review that information. The tables summarize information within the cluster, whereas the maps show spatially what is within and between the clusters.

Table 4. Representation levels, target acres, and resulting amounts of natural resource targets.*

	Natural Resource Target Type	Acres in study area	Representation Level	Target Acres	Amount captured by MARXAN	% of target met	Amount selected after corroboration	% of target met
Hard Bottom	Riverine hard bottom	1,135	100	1,135	1,135	100	1,135	100
SAV	High salinity SAV	89,854	70	62,898	61,987	99	86,161	137
	Low salinity SAV	1,751	100	1,751	1,721	98	1,670	95
Shell Bottom	Intertidal shell bottom	66	100	66	64	97	49	74
	Subtidal shell bottom	3,717	100	3,717	3,593	97	3,540	95
Wetland	Non-riparian wetland	121,173	0	0	44,301		38,998	
	Emergent wetland	104,333	0	0	65,395		65,710	
	Forested wetland	138,788	10	13,879	25,688	185	27,109	195
	Estuarine shrub/scrub wetland	12,175	0	0	6,489		6,953	
	Headwater wetland	5,735	50	2,867	2,754	96	2,318	81
Riverine soft bottom	Riverine soft bottom - lowest elev.	1,456	60	874	872	100	783	90
	Riverine soft bottom - lower elev.	10,408	0	0	2,300		2,406	
	Riverine soft bottom – mid. elev.	1,048	0	0	7		7	
	Riverine soft bottom - upper elev.	121	0	0	0		0	
Shallow Soft Bottom	Estuarine soft bottom (0-3ft)	82,883	30	24,865	44,993	181	48,304	194
	Estuarine soft bottom (3-6ft)	78,259	20	15,652	37,786	241	43,430	277
	Estuarine soft bottom (ND)	2,457	10	246	1,589	647	1,725	702
	Marine soft bottom (0-3ft)	16,438	20	3,288	12,232	372	12,588	383
	Marine soft bottom (3-6ft)	15,386	20	3,077	12,678	412	12,693	412
	Intertidal marine soft bottom	451	20	90	451	500	451	500
	Lacustrine soft bottom (ND)	46,642	10	4,664	3,548	76	1,646	35
	Inlets		100	earmarked				
	Palustrine soft bottom (ND)	1,755	0	0	383		347	
Deep Soft Bottom	Estuarine soft bottom (>6ft)	983,218	0	0	13,904		118,556	
	Marine soft bottom (>6ft)	189,231	0	0	50,428		50,530	
Eco-desig	PNA	15,426	100	15,426	15,384	100	14,298	93
Upland	Low elevation upland	47,944	20	9,589	17,333	181	15,079	157
POLYGON TOTALS (acres)		1,493,124		77,770	213,888	275	322,843	415
Line targets	Wetland edge	2,921	50	1,461	1,428	98	1,467	100
	Non-wetland shoreline	1,296	20	259	521	201	457	176
	Ocean Hard Bottom	30	0	0	9		9	
	Streams (high elevation)	46	0	0	5		5	
	Streams (low elevation)	1,061	10	106	173	163	171	161
	Streams (middle elevation)	266	20	53	40	75	40	75
LINE TOTALS (miles)		4,217		1,720	1,949	113	1,924	112
Fish (numbers)	River Fish Group	54,520	20	10,904	9,893	91	8,954	82
	Sound Fish Group	32,403	20	6,481	5,371	83	4,798	74

*Gray boxes are target selections that exceeded the representation levels.

Table 5a. Alteration scores, selection frequencies, and amounts of targets within selected SHA polygons.

Parameter	Polygon number									
	1	2	4	7	14	15	17	19	20	21
Polygon Area	870	621	10,191	60,403	15,163	4,847	2,610	1,367	5,344	1,367
Mean alteration	1.52	0.63	1.17	0.63	0.45	0.67	0.46	1.94	1.30	0.36
Mean selection frequency	82	38	485	424	417	407	43	490	406	483
Emergent wetland				1,749	3,099	1,045	1,084	250	1,080	532
Estuarine shrub/scrub wetland				606	901	139	39	69	93	26
Estuarine soft bottom (>6ft)				13,348	2,976	258	248	146	1,028	
Estuarine soft bottom (3-6ft)				5,027	2,994	329	122	38	268	19
Estuarine soft bottom (ND)							263		0	
Estuarine soft bottom (0-3ft)				4,381	2,387	412	283	182	1,008	541
Forested wetland	329	165	1,470	46		268	163		44	
Headwater wetland										
High salinity SAV				18,744	0					
Intertidal marine soft bottom				451						
Intertidal shell bottom				13						0
Lacustrine soft bottom (ND)			21	748						
Low elevation upland				412	29	455	171	524	667	0
Low salinity SAV										
Marine soft bottom (>6ft)				4,054						
Marine soft bottom (3-6ft)				3,872						
Marine soft bottom (0-3ft)				4,280						
Non-riparian wetland	13	3	41	91	2,660	1,556	61	152	1,058	185
Palustrine soft bottom (ND)		1	20	26	2	0	7		2	
PNA					304			87	697	66
Riparian human impacted wetland			19							
Riverine hard bottom			366							
Riverine soft bottom (ND) - lower		18	2			88			11	
Riverine soft bottom (ND) - lowest										
Riverine soft bottom (ND) - middle										
Riverine soft bottom (ND) - upper										
Subtidal shell bottom				428	111	117		0	1	63

Table 5b. Alteration scores, selection frequencies, and amounts of targets within selected SHA polygons.

Parameter	Polygon number									
	27	38	40	41	42	43	44	47	49	51
Polygon Area	870	4,971	1,491	621	4,723	2,486	3,977	13,796	10,813	21,626
Mean alteration	1.00	0.81	0.96	0.80	0.32	0.89	0.87	0.53	0.71	0.97
Mean selection frequency	52	377	473	500	482	414	490	485	445	457
Emergent wetland		405	64	93	169	52	36	32	2,596	3,298
Estuarine shrub/scrub wetland		52	4		353		16	10	294	378
Estuarine soft bottom (>6ft)	870	2,656		52	92	1	347	2,197	3,452	2,248
Estuarine soft bottom (3-6ft)		649	110	81	232	0	258	881	2,211	1,520
Estuarine soft bottom (ND)			165						0	307
Estuarine soft bottom (0-3ft)		915	66	159	399		329	500	1,122	2,180
Forested wetland			55	3	666	1,225	394	1,101		211
Headwater wetland					132		10	9		156
High salinity SAV									4	
Intertidal marine soft bottom										
Intertidal shell bottom		11								
Lacustrine soft bottom (ND)										368
Low elevation upland			110	135	356	47	72	267	553	683
Low salinity SAV			0		22	1	4	489		142
Marine soft bottom (>6ft)										
Marine soft bottom (3-6ft)										
Marine soft bottom (0-3ft)										
Non-riparian wetland		106	39	15	385		72	88	359	2,510
Palustrine soft bottom (ND)		1		1		1	4	8	21	29
PNA				47	42		882		642	583
Riparian human impacted wetland				0	15	15		3		302
Riverine hard bottom										
Riverine soft bottom (ND) - lower			53			190	28	65	37	2
Riverine soft bottom (ND) - lowest						628		45		
Riverine soft bottom (ND) - middle										
Riverine soft bottom (ND) - upper										
Subtidal shell bottom		176	23	9					103	

Table 5c. Alteration scores, selection frequencies, and amounts of targets within selected SHA polygons.

Parameter	Polygon number									
	52	54	57	59	60	61	65	68	69	70
Polygon Area	60,900	870	497	1,119	17,276	4,101	4,474	39,274	5,096	18,891
Mean alteration	0.49	1.88	1.00	1.00	0.30	1.30	1.00	0.90	0.90	0.87
Mean selection frequency	410	500	61	57	495	500	46	194	424	425
Emergent wetland	17,629	83			2,500	159		576	1,876	5,547
Estuarine shrub/scrub wetland	335	34			196	51		144	90	250
Estuarine soft bottom (>6ft)	19,299	34	497	1,119	2,542	127	4,474	7,377	444	4,354
Estuarine soft bottom (3-6ft)	6,555	90			1,068	412		6,144	786	3,323
Estuarine soft bottom (ND)	286					17				210
Estuarine soft bottom (0-3ft)	6,729	165			2,432	339		2,001	596	2,877
Forested wetland	50	22			117	413			1	
Headwater wetland	24				26	1				
High salinity SAV	23				11			22,292	394	100
Intertidal marine soft bottom										
Intertidal shell bottom								10		
Lacustrine soft bottom (ND)						6			132	89
Low elevation upland	1,520	39			2,400	127		127		
Low salinity SAV		0			170	23				
Marine soft bottom (>6ft)								29		
Marine soft bottom (3-6ft)								38		
Marine soft bottom (0-3ft)								103		
Non-riparian wetland	6,293	215			5,005	500		15	347	1,412
Palustrine soft bottom (ND)	79				6	3		1		8
PNA	2,511	126			941	69			367	900
Riparian human impacted wetland									384	174
Riverine hard bottom										
Riverine soft bottom (ND) - lower	34					60				
Riverine soft bottom (ND) - lowest										
Riverine soft bottom (ND) - middle										
Riverine soft bottom (ND) - upper										
Subtidal shell bottom	1,386				167			84	1	326

Table 5d. Alteration scores, selection frequencies, and amounts of targets within selected SHA polygons.

Parameter	Polygon number									
	71	74	78	81	82	83	86	91	93	96
Polygon Area	7,582	12,304	20,383	1,243	621	4,474	11,683	1,740	7,581	7,333
Mean alteration		0.26	0.83	1.31	0.93	0.65	1.01	1.01	1.12	0.69
Mean selection frequency		450	471	500	471	400	281	313	468	78
Emergent wetland		81	3,905	131	44	264			259	637
Estuarine shrub/scrub wetland		75	346	25						73
Estuarine soft bottom (>6ft)		1,865	4,472	70			11,614	1,725	237	3,273
Estuarine soft bottom (3-6ft)		99	1,467	50	2				139	1,342
Estuarine soft bottom (ND)			61						5	
Estuarine soft bottom (0-3ft)		382	3,268	141	36				110	1,538
Forested wetland	2,946		80	9	25	2,114			1,445	
Headwater wetland			40			53			11	
High salinity SAV		3,555	575	0	0					449
Intertidal marine soft bottom										
Intertidal shell bottom		1								
Lacustrine soft bottom (ND)			170			58			13	
Low elevation upland	6	4	954	115	74	374			237	3
Low salinity SAV						17			342	
Marine soft bottom (>6ft)		1,780								
Marine soft bottom (3-6ft)		1,691								
Marine soft bottom (0-3ft)		2,468								
Non-riparian wetland	17	13	2,355	4	70	114			90	1
Palustrine soft bottom (ND)	5		2	1		0			15	2
PNA			1,574	98	30					
Riparian human impacted wetland	2		58	1		2			12	
Riverine hard bottom										
Riverine soft bottom (ND) - lower	213					639			767	
Riverine soft bottom (ND) - lowest	35					62				
Riverine soft bottom (ND) - middle										
Riverine soft bottom (ND) - upper										
Subtidal shell bottom		0	100				69	15		

Table 5e. Alteration scores, selection frequencies, and amounts of targets within selected SHA polygons.

Parameter	Polygon number									
	97	98	99	100	102	104	105	106	107	109
Polygon Area	20,756	2,610	1,491	5,966	621	1,864	1,616	746	5,220	3,853
Mean alteration	0.31	0.50	1.30	0.95	1.01	0.64	1.01	0.21	0.08	0.73
Mean selection frequency	408	500	500	499	431	293	386	362	358	492
Emergent wetland	7,140	151		403		168		48	2,504	505
Estuarine shrub/scrub wetland	761			23		9		5	115	70
Estuarine soft bottom (>6ft)	2,739		568	6	617	19	1,592		162	71
Estuarine soft bottom (3-6ft)	1,544	129	89	234		186			208	299
Estuarine soft bottom (ND)									112	
Estuarine soft bottom (0-3ft)	2,469	121	30	701		164		51	305	324
Forested wetland	180	115	1	264		105		75	7	144
Headwater wetland	1,126							29	23	163
High salinity SAV	49			9		0			235	2
Intertidal marine soft bottom										
Intertidal shell bottom										
Lacustrine soft bottom (ND)										
Low elevation upland	512	87	5	271		64		19	46	528
Low salinity SAV		32	190			5				
Marine soft bottom (>6ft)										
Marine soft bottom (3-6ft)										
Marine soft bottom (0-3ft)										
Non-riparian wetland	2,709	101		367		56		44	1,384	990
Palustrine soft bottom (ND)	3	0						1		5
PNA	489	8		620		4		25	117	334
Riparian human impacted wetland										
Riverine hard bottom										
Riverine soft bottom (ND) - lower		9				26				
Riverine soft bottom (ND) - lowest						12				
Riverine soft bottom (ND) - middle										
Riverine soft bottom (ND) - upper										
Subtidal shell bottom	41			0	4		24		0	0

Table 5f. Alteration scores, selection frequencies, and amounts of targets within selected SHA polygons.

Parameter	Polygon number								
	110	112	113	115	123	128	130	134	136
Polygon Area	2,983	4,971	5,841	56,550	36,167	2,113	8,451	7,954	8,079
Mean alteration	0.84	0.66	0.59	0.40	0.96	0.46	0.83	0.23	0.77
Mean selection frequency	491	500	488	391	490	471	490	454	452
Emergent wetland	214	153	217	1,016	35	70	552	588	1,217
Estuarine shrub/scrub wetland		14	3	347	46	16	125	19	122
Estuarine soft bottom (>6ft)	199		75	10,237		367	273	39	694
Estuarine soft bottom (3-6ft)	182	150	250	1,931		96	356	78	315
Estuarine soft bottom (ND)		110	4					44	140
Estuarine soft bottom (0-3ft)	361	304	315	2,902		309	893	44	1,455
Forested wetland	93	294	302			21	307	1,577	144
Headwater wetland	34	67	69			32	215	82	11
High salinity SAV	1			12,859					39
Intertidal marine soft bottom									
Intertidal shell bottom				10					
Lacustrine soft bottom (ND)					8				
Low elevation upland	214	194	147	85	104	273	704	167	728
Low salinity SAV		29	1			1	165	37	
Marine soft bottom (>6ft)				12,168	32,490				
Marine soft bottom (3-6ft)				6,718	343				
Marine soft bottom (0-3ft)				5,099	466				
Non-riparian wetland	153	174	489	4	15	643	3,025	1,279	963
Palustrine soft bottom (ND)			1				13	8	1
PNA	183	534	297			166	576		913
Riparian human impacted wetland	2	4					6	74	163
Riverine hard bottom									
Riverine soft bottom (ND) - lower			0					162	
Riverine soft bottom (ND) - lowest			0						
Riverine soft bottom (ND) - middle									
Riverine soft bottom (ND) - upper									
Subtidal shell bottom	2			151		23	0		1

Table 5g. Alteration scores, selection frequencies, and amounts of targets within selected SHA polygons.

Parameter	Polygon number							
	137	140	144	145	147	148	149	150
Polygon Area	6,339	22,371	497	31,941	373	249	124	2,859
Mean alteration	1.02	0.73	0.87	0.60	0.56	0.91	1.51	0.65
Mean selection frequency	330	477	500	354	500	500	500	89
Emergent wetland		129	26	949	43	148	26	131
Estuarine shrub/scrub wetland				432		41		204
Estuarine soft bottom (>6ft)	6,226		51	498	78		14	584
Estuarine soft bottom (3-6ft)			14	681	23	6	38	403
Estuarine soft bottom (ND)								
Estuarine soft bottom (0-3ft)			50	679	62	46	20	1,219
Forested wetland		10,110	7		3		0	
Headwater wetland		6						
High salinity SAV			8	26,812				
Intertidal marine soft bottom								
Intertidal shell bottom				4				
Lacustrine soft bottom (ND)		34						
Low elevation upland			20	380	60	0	12	
Low salinity SAV					1			
Marine soft bottom (>6ft)				9				
Marine soft bottom (3-6ft)				31				
Marine soft bottom (0-3ft)				171				
Non-riparian wetland		197	96	55	91	6		317
Palustrine soft bottom (ND)		62		9				
PNA			27		12	14	13	
Riparian human impacted wetland		34						
Riverine hard bottom		769						
Riverine soft bottom (ND) - lower								
Riverine soft bottom (ND) - lowest								
Riverine soft bottom (ND) - middle		7						
Riverine soft bottom (ND) - upper								
Subtidal shell bottom	113			1				

Table 6a. Proportion of ecological designations contained within selected SHA polygons.

Polygon ID	Area	Inland PNA	Primary Nursery Area	Secondary Nursery Area	Anadromous fish spawning area	Crab spawning sanctuary	Oyster Sanctuary	Artificial Reef	Outstanding Resource Waters	Significant Natural Heritage Area _A	Significant Natural Heritage Area _B	Significant Natural Heritage Area _C
1	870				0.71					0.71	0.86	
2	621				0.40					0.40		0.80
4	10,191	0.70			0.72					0.72		0.61
7	60,403					0.15	0.00			0.13	0.03	
14	15,163		0.25	0.39						0.07		0.61
15	4,847											0.62
17	2,610			0.67							0.71	0.38
19	1,367		0.82									0.55
20	5,344		0.70		0.02							0.51
21	1,367		0.27									0.91
27	870											
38	4,971											0.28
40	1,491											
41	621		1.00									
42	4,723	0.13		0.24	0.21						0.58	
43	2,486	0.80		0.20	0.35					0.15		0.75
44	3,977	0.81										
47	13,796			0.31	0.06							0.18
49	10,813		0.40	0.51	0.01						0.51	
51	21,626	0.14	0.17	0.09							0.23	
52	60,900		0.37	0.42	0.00		0.00		0.38	0.36	0.24	
54	870	1.00										
57	497											
59	1,119											
60	17,276		0.60	0.12								
61	4,101	0.12			0.06					0.03		
65	4,474								0.03			
68	39,274						0.00			0.00		
69	5,096		0.66	0.51							0.80	
70	18,891		0.38	0.53			0.01				0.69	
71	7,582	0.38									0.39	
74	12,304					0.44					0.06	0.08
78	20,383		0.60	0.26							0.13	
81	1,243		1.00									
82	621		0.80									

Table 6b. Proportion of ecological designations contained within selected SHA polygons.

Polygon ID	Area	Inland PNA	Primary Nursery Area	Secondary Nursery Area	Anadromous fish spawning area	Crab spawning sanctuary	Oyster Sanctuary	Artificial Reef	Outstanding Resource Waters	Significant Natural Heritage Area _A	Significant Natural Heritage Area _B	Significant Natural Heritage Area _C
83	4,474				0.61					0.17	0.83	
86	11,683											
91	1,740											
93	7,581										0.05	0.13
96	7,333										0.27	0.07
97	20,756		0.23				0.01				0.22	
98	2,610		0.05		0.14							
99	1,491											
100	5,966		0.88	0.08	0.25							
102	621											
104	1,864		0.13	0.27	0.13							
105	1,616											
106	746		0.33									
107	5,220		0.14							0.40	0.31	
109	3,853		0.81									
110	2,983		0.75	0.08								
112	4,971	0.85										0.05
113	5,841		0.60	0.23								
115	56,550					0.20	0.00		0.14	0.04	0.10	
123	36,167							0.00		0.06		
128	2,113	0.47										
130	8,451	0.07	0.66	0.07								
134	7,954			0.06	0.11						0.06	0.02
136	8,079		0.77	0.25								
137	6,339											
140	22,371	0.61			0.64					0.02	0.34	0.05
144	497		1.00									
145	31,941										0.14	
147	373		1.00									
148	249		1.00								1.00	
149	124		1.00									
150	2,859											0.52

Table 7a. Acres of state and federal conservation lands within selected SHA polygons.

Polygon ID	Acres of overlap
4	**36**
Upper Coastal Plain Research Station (State)	36
7	**4,495**
Cape Hatteras National Seashore (Federal)	885
Pea Island National Wildlife Refuge (Federal)	3,553
WRC Island C 05-06 (State)	56
14	**6,431**
Alligator River National Wildlife Refuge (Federal)	5,258
Dare County Air Force Range (Federal)	23
Gull Rock Game Land (State)	1,150
17	**81**
Pungo River Game Land (State)	81
21	**732**
Gull Rock Game Land (State)	732
38	**613**
Alligator River National Wildlife Refuge (Federal)	613
42	**1,526**
Goose Creek (State)	1,526
43	**5**
North Carolina Estuarium (Local)	5
44	**8**
Historic Bath State Historic Site (State)	8
47	**630**
Nevil’s Creek (Land Trust)	516
Nevil's Creek (CLT) Preserve (Private)	115
49	**574**
Gull Rock Game Land (State)	574
51	**3,382**
Goose Creek Game Land (State)	3,382
52	**18,205**
Gull Rock Game Land (State)	595
Mattamuskeet National Wildlife Refuge (Federal)	3
Swanquarter National Wildlife Refuge - Swanquarter Wilderness (Federal)	4,696
Swanquarter National Wildlife Refuge (Federal)	12,911
68	**350**
Buxton Woods Coastal Reserve (State)	0
Cape Hatteras National Seashore (Federal)	350
69	**390**
Goose Creek Game Land (State)	390

Table 7b. Acres of state and federal conservation lands within selected SHA polygons.

Polygon ID	Acres of overlap
70	**2278.90**
(Land Trust)	8.75
Goose Creek Game Land (State)	784.06
Hobucken Marshes (CLT) Preserve (Private)	12.51
Prohibited - near Brant Island (Federal - Navy)	1473.58
74	**629.90**
Cape Hatteras National Seashore (Federal)	629.90
78	**556.15**
(Land Trust)	69.90
Hobucken Marshes (CLT) Preserve (Private)	53.91
Lampe-Woodard Tract (Land Trust)	432.34
83	**111.60**
Bellair Plantation (CLT) Preserve (Private)	13.94
Bellair Plantation (Land Trust)	16.49
Neuse River Game Land (State)	81.17
87	**3.17**
Neuse River Game Land (State)	3.17
93	**75.38**
Brices Creek (Land Trust)	61.31
Croatan National Forest (Federal)	9.45
Sawmill (NCDOT) Wetland Mitigation Site (State)	4.62
96	**704.99**
Cedar Island National Wildlife Refuge (Federal)	160.72
Marine Corps Air Station Cherry Point - Piney Island (Federal)	444.71
Prohibited - vicinity of Piney Island (Federal - Navy)	99.56
97	**5218.38**
Carteret County Game Land (State)	1420.35
Marine Corps Air Station Cherry Point - Piney Island (Federal)	3372.81
Prohibited - vicinity of Piney Island (Federal - Navy)	309.47
Turnagain Bay (CLT) Preserve (Private)	115.75
107	**1341.55**
Cedar Island National Wildlife Refuge (Federal)	1341.55
112	**3475.31**
Croatan National Forest (Federal)	1379.52
Marine Corps Air Station Cherry Point - Main Air Station (Federal)	1542.26
Restricted - vicinity of Cherry Point (Federal - Navy)	553.53
113	**224.03**
Croatan National Forest (Federal)	224.03

Table 7c. Acres of state and federal conservation lands within selected SHA polygons.

Polygon ID	Acres of overlap
115	**2637.02**
Cape Hatteras National Seashore (Federal)	2572.17
Cape Lookout National Seashore (Federal)	64.85
123	**456.77**
Cape Hatteras National Seashore (Federal)	40.83
Pea Island National Wildlife Refuge (Federal)	415.94
134	**27.63**
Neuse River Game Land (State)	27.63
136	**750.70**
(Conservation Group)	750.70
140	**420.77**
(Land Trust)	35.13
Howell Woods (Other Public)	189.97
Howell Woods Environmental Learning Center (State)	189.95
Montgomery Laurel Bluffs (TLC) Preserve (Private)	2.86
Popular Creek Bluffs (Land Trust)	2.86
145	**1620.24**
Cape Hatteras National Seashore (Federal)	1620.24
148	**203.88**
Gull Rock Game Land (State)	203.88
(blank)	
(blank)	
71	**143.08**
Core Creek (Land Trust)	143.08
150	**364.08**
Alligator River National Wildlife Refuge (Federal)	364.08
Grand Total	**58701.16**

Table 8a. Documentation of expert modifications to MARXAN clusters within focus area.

Nom. ID	Change	Ecological Reason
All	add any PNAs not selected by MARXAN	selected 100%
All	remove hexagons with developed low elevation uplands with no targets	
3-Jan	keep as is	
4	combine with 5 - now 4	
5-7	keep as is	
8	extend to include all SAV	
9	delete	
10	keep, add to 38	
11	join to 122	productive shell bottom
12	delete	Stumpy Bay - not as productive as other areas to the south
13	join to 122	productive shell bottom- oyster sanc
14	keep	Long Shoal River
15	eliminate Bellhaven (1 hex)	developed
16	combine with 140	
17	add up river to campground and tribs	unique brackish marsh
18	delete	Mattamuskeet, not good for blue crab
19	keep	Middleton Anchorage
20	add 3 hex to include Charles Rock?	Far Creek and productive oyster bottom
21-22	keep	natural rock
23-26	delete	
27	change to fit shoal	
28-37	delete	
38	combine with 10	
39	keep	
40	eliminate Jack's Creek	Jacks -bad habitat, no shellfish. Pungo Creek good
41	keep	
42	eliminate 4 hex of ag, expand west to get east side of Broad Creek	
43	eliminate hex over Washington	Chocowinity, includes downtown Washngton, good striper fishing
44	exclude Back Creek, trim developed hex	Bath Creek, muddy, detrital, developed, low DO
45	combine with 140	
46	delete	developed shoreline
47-48	keep as is	47-48 - AFSA
49	keep, connect to Mattemuskeet - up to flapgates	
50	make part of 140	
51	remove mitigation ponds, add Little creek and main part of South Creek	51-57 - productive PNAs, NCPC tract?
52	extend to include areas of high fish abundance	
53	keep	
54	trim to IPNA, eliminate Bayview	
55	keep as is	
56	keep as is	lots of SAV
57	keep as is	boaters guide shows wreck
58	reduced in size (cut fingers) and combined with Ocracoke	
59	remove 2 hex, clip to fit shoal	

Table 8b. Documentation of expert modifications to MARXAN clusters within focus area.

Nom. ID	Change	Ecological Reason
58	reduced in size (cut fingers) and combined with Ocracoke	
59	remove 2 hex, clip to fit shoal	
60	keep as is	
61	eliminate PCS, trimmed SE corner	
62	combine with 140	
63	add 13 hex S to oyster reef. Rose Bay to almost Brandt Island Shoal	record level of oysters 2010-11. Last 2 seasons - Dermo, not this year
64	delete	
65	join with 77, label as 65	Upper Middle Ground
66	add snowed creek & remove 3 polygons of impoundment	
67	keep as is	hammock island - diverse- Reid
68	removed Buxton, keep rest	diverse
69	remove impoundment hexs without stream edges	
70 - 71	keep as is	
72	delete	
73	remove impoundment on west side, fix hole in feature	
74	include Hatteras point (NPS)	
75	delete	
76	combine with 86 & label as 86	
77	join with 65- label 65	Upper Middle Ground
78	trim XS	Vandemere, heavily fished
79	combine with 90	
80	delete	
81	keep as is	
82	remove 5 hex on west side, clip to creek, split into 2 & rename E	
83	keep as is	
84-85	delete	fish only
86	add 76 to 86	
87	keep as is	
88	add adjacent creek from 82, cut significantly, remove inland hex	
89	combine with Ocracoke	
90	combine with 79	
91	keep	good drum fishing & oysters
92	delete	
93	remove 3 hex - no targets; add 1 hex to get entire river	
94	keep	
95	delete	not priority habitat
96	add point to the west (tip of land) to wetland edge	pristine, Raccoon Island - cultch oysters, better than West Bay
97	keep	little development, canal into Turnagain - good fishing
98	keep	Beard's Creek, SAV, eels

Table 8c. Documentation of expert modifications to MARXAN clusters within focus area.

Nom. ID	Change	Ecological Reason
99	remove 8 hex, New Bern, ponds, interchange	hi altered, but SAV present
100	exclude Oriental, trim to remove excess hex, split into 2	
101	remove hex with airport	
102	keep	
103	delete	no PNA, altered, ferry route
104	trim west and extend main branch to Neuse R	Dawson's Creek, no hardened shoreline, better than adj creeks
105	keep	oysters, tarpon, drum
106	keep	
107	exclude ditches, remove SE portion to exclude canal, keep creek next to it - good for Flounder	quality marshes, drains Open Grounds
108-109	keep	
110	2 polys out, cut in half (no way to cut out water without excluding shore	Adams Creek, SNA
111	delete - Slocum Creek	sediment contamination, no benthos, mullet, stripers
112	Hancock Creek - keep, eliminate 1 hex that's not hydrologically connected	speckled trout, red drum, IPNA
113	keep	good shrimping
114	keep, re-examine with Region 3	intertidal oysters
115	extend to shoreline, add SAV and wetlands	
116	delete everything north of ferry	
117	combine with 74 - Hatteras Inlet	
118	combine with 74 - Hatteras Inlet	
119	delete - combine with OBX SAV	also artificial reef
120	connected both parts, cut boundary b/t 120 & 68 at Avon channel - combine with 8. all SAV, excluding channels	to exclude navigation channel
121	delete	
122	add 11 & 13 to 122	productive, Crab Hole, shell bottom ~ 12 ft deep, crab trawling/dredging allowed
123	keep - R1 selection	
124	delete - Stumpy Bay	silty
125	cut off 2 hex	
126	add 2 hex on E side & 8 on W side of island, add marsh on W side - Straits b/t 126 & Great Island & bay W of Great Island	good oyster habitat
127	remove open water, cut farms	open water no different than surrounding areas; includes artificial reef
128	trim small polys	Jordan Creek
129	remove open water	
130	keep	good system - North Creek
131	cut deep water river crossing	Blounts Bay
132	remove 1 open water hex	
133	keep	
134	keep	Goose Creek

Table 8d. Documentation of expert modifications to MARXAN clusters within focus area.

Nom. ID	Change	Ecological Reason
135	add 1 hex to river, remove from mouth, remove NW creek, west part, exclude area w/ houses and ramp	ramp, shrimp trawling
136	eliminate developed/farm areas; split into smaller by length, keep impoundments, add shoreline	were mapped as wetlands but weren't
137	trim to oyster bed	136 &137 red drum hot spot
138	add shoreline around mouth	SAV and good fish habitat
139	keep	
140	add 16, 50, 45, 62	includes Neuse River hard bottom
141	included adj creek hex	no wetlands upstream
142	combine with 4	
143-145	no change	
146	Duck Creek - added then removed	
147	added - Flax Pond	PNA
150	added shoreline north of Stumpy Pt Bay	Eggleston - important blue crab settlement area under certain weather conditions

FINAL STRATEGIC HABITAT AREA NOMINATIONS

Based on public comments received at the October 11, 2011 public meeting (Appendix F), no changes were made to the proposed SHAs, with the exception of a slight modification of boundaries within SHA # 93 to exclude a section of urbanized shoreline in New Bern. The MFC approved the SHA nominations at their November 3, 2011 meeting. Strategic Habitat Area units are described below (numbering is not sequential) beginning in the Outer Banks and moving counter-clockwise around the region. Strategic Habitat Areas with average alteration scores less than 1.0 and selection frequencies greater than 300 (on a scale of 0–500) represent sites with the least extent of alteration and high ecosystem value. In some cases, areas without these criteria were still selected as SHAs due to other outstanding features.

The following is a list of final SHA nominations grouped by region. Maps 10.1 through 10.20 follow showing the location of each SHA.

OUTER BANKS

SHA #115: Ocracoke Inlet system (Map 10.1)

Description – Ocracoke Inlet, flats, banks, and channels behind the inlet – Ocracoke Island
Acres – 56,550
Prominent habitats – High salinity SAV, inlet, shallow and deep estuarine and marine soft bottom, emergent wetlands, intertidal shell bottom, subtidal shell bottom
Ecological designations – CSS, SNHA, ORW
Conservation Lands – Cape Hatteras National Seashore
Fish data – yes
Prominent alterations present – some residential/seasonal development (Ocracoke), multi-slip docking, trawling
Avg. total alteration score – 0.63
Avg. selection frequency – 424

SHA #57: Pamlico Sound Fish Area 1(Map 10.1)

Description – good fish data, inside of Ocracoke Inlet
Acres – 497
Prominent habitats – estuarine soft bottom > 6 ft, good fish data
Ecological designations –
Conservation Lands –
Fish data – yes
Prominent alterations present –
Avg. total alteration score – 1.0
Avg. selection frequency – 61

SHA #74: Hatteras Inlet system (Map 10.2)

Description – Hatteras Inlet, flats, banks, and channels behind the inlet – Hatteras area, Hatteras village excluded
Acres – 12,304
Prominent habitats – High salinity SAV, inlet, intertidal flats, shallow and deep estuarine soft bottom
Ecological designations – CSS, SNHA
Conservation Lands – Cape Hatteras National Seashore
Fish data – yes
Prominent alterations present – some multi-slip docking, trawling, residential development (Hatteras), trawling
Avg. total alteration score – 0.26
Avg. selection frequency – 450

SHA #59: Pamlico Sound Fish Area 2 (Map 10.2)

Description –good fish data, inside of Hatteras Inlet
Acres – 1,119
Prominent habitats – marine soft bottom, good fish data
Ecological designations –
Conservation Lands –
Fish data – yes
Prominent alterations present – trawling
Avg. total alteration score – 1.00
Avg. selection frequency – 57

SHA #68: Eastern Pamlico Sound, behind Cape Hatteras (Map 10.3)

Description – grass flats, shallow bottom behind the Outer Banks, Buxton – Frisco area
Acres – 39,274
Prominent habitats – High salinity SAV, soft bottom < 6 ft, emergent wetlands, intertidal shell bottom, subtidal shell bottom
Ecological designations –
Conservation Lands – Cape Hatteras National Seashore, Buxton Woods Coastal Reserve
Fish data – yes
Prominent alterations present – minimal, some marinas, residential development (Buxton and Frisco), trawling
Avg. total alteration score – 0.09
Avg. selection frequency – 194

SHA #145: Eastern Pamlico Sound, northern Hatteras Island (Map 10.4)

Description – high salinity SAV, shallow bottom behind the Outer Banks, Rodanthe, Waves, Salvo, Avon area
Acres – 31,941
Prominent habitats – High salinity SAV, shallow soft bottom < 6ft, emergent wetlands
Ecological designations – SNHA, CSS
Conservation Lands – Cape Hatteras National Seashore
Fish data – yes
Prominent alterations present – residential and seasonal development (Salvo, Avon), trawling
Avg. total alteration score –0.60
Avg. selection frequency – 354

SHA #7: Oregon Inlet system (Map 10.5)

Description – Oregon Inlet, flats, banks, and channels behind the inlet (Oldhouse and Davis channels)
Acres – 60,403
Prominent habitats – High salinity SAV, subtidal shell bottom, intertidal flats, intertidal shell bottom, soft bottom > 6 ft, inlet, tidal marsh
Ecological designations – Crab Spawning Sanctuary (CSS), Significant Natural Heritage Areas (SNHA),
Conservation Lands – Pea Island National Wildlife Refuge (NWR), Cape Hatteras National Seashore (NS), WRC managed island (C 05-06)
Fish data – yes
Prominent alterations present – minimal, trawling and dredging allowed in portions of area
Avg. total alteration score – 0.63
Avg. selection frequency – 424

SHA #123: Ocean, Platt Shoals (Map 10.5)

Description – nearshore Ocean adjacent to Oregon Inlet, Pea Island NWR
Acres – 36,137
Prominent habitats – marine soft bottom
Ecological designations –
Conservation Lands – Cape Hatteras National Seashore, Pea Island NWR
Fish data – yes
Prominent alterations present –
Avg. total alteration score – 0.96
Avg. selection frequency – 490

MAINLAND SHORELINE

SHA #150: Northwest Pamlico Shoreline (Map 10.5)

Description – western Pamlico Sound, north of Stumpy Point
Acres – 2,859
Prominent habitats – soft bottom 0-3 ft, > 6 ft, emergent and non-riparian wetlands
Ecological designations – SNHA
Conservation Lands – Alligator River NWR
Fish data – yes
Prominent alterations present –
Avg. total alteration score – 0.65
Avg. selection frequency – 89

Notes – recruitment area for blue crab larvae under certain weather conditions (Eggleston)

SHA #38: Parched Corn Bay (Map 10.6)

Description – western Pamlico Sound bay, just south of Stumpy Point
Acres – 4,971
Prominent habitats – soft bottom > 6 ft, soft bottom 0-3 ft, subtidal shell bottom
Ecological designations – SNHA
Conservation Lands – Alligator River NWR
Fish data – yes
Prominent alterations present – trawling, minor NPDES
Avg. total alteration score – 0.81
Avg. selection frequency – 377

SHA # 14: Long Shoal River (Map 10.6)

Description – Long Shoal River, Pains Bay, Pamlico Sound
Acres – 15,163
Prominent habitats – emergent wetland, subtidal shell bottom, shallow – deep soft bottom
Ecological designations – PNA, SNA, SNHA
Conservation Lands – Alligator River NWR, Gull Rock Game Land, Dare County Air Force Range
Fish data – yes
Prominent alterations present – canals, wetlands lost to development, some bottom trawling, minor developed and agriculture land use
Avg. total alteration score – 0.45
Avg. selection frequency – 417

SHA # 21: Otter Creek (Map 10.6)

Description – bay and creek north of Engelhard, south of Long Shoal River, Juniper Swamp Point
Acres – 1,367
Prominent habitats – emergent wetlands, subtidal shell bottom, and shallow soft bottom 0-3 ft
Ecological designations – PNA, SNHA
Conservation Lands – Gull Rock Game Land
Fish data – no
Prominent alterations present – agriculture, minor NPDES
Avg. total alteration score – 0.36
Avg. selection frequency – 483

SHA #20: Far Creek (Map 10.6)

Description – embayment and creek near Engelhard, Gibbs Point, connected to Mattamuskeet draining canal
Acres – 5,344
Prominent habitats – emergent wetlands, soft bottom 0-3 ft, soft bottom > 6 ft, non-riparian wetlands, subtidal shell
Ecological designations – PNA, AFSA, SNHA
Conservation Lands –
Fish data – yes
Prominent alterations present – agriculture, canals and ditching, bottom disturbing gear, minor NPDES
Avg. total alteration score – 1.3
Avg. selection frequency – 406

SHA # 19: Middleton Creek (Map 10.7)

Description – embayment and creek near Middleton
Acres – 1,367
Prominent habitats – low elevation uplands, emergent wetlands, soft bottom 0-3 ft, non-riparian wetlands
Ecological designations – PNA
Conservation Lands –
Fish data – yes
Prominent alterations present – agriculture, canal and culverts, bottom disturbing gear, minor NPDES
Avg. total alteration score – 1.94
Avg. selection frequency – 490

SHA #49: Wysocking Bay (Map 10.7)

Description – large embayment southeast of Lake Mattamuskeet
Acres – 10,813
Prominent habitats – emergent wetlands, estuarine soft bottom, shallow to deep, low elevation uplands, subtidal shell bottom
Ecological designations – PNA, SPNA, AFSA, SNHA
Conservation Lands – Gull Rock Game Land
Fish data – yes
Prominent alterations present – culvert, bottom disturbing gear, minor NPDES
Avg. total alteration score – 0.71
Avg. selection frequency – 445

SHA #148: East Bluff Bay (Map 10.7)

Description – Embayment south of Wysocking Bay and near Outfall Canal
Acres – 249
Prominent habitats – emergent wetlands, soft bottom 0-3 ft.
Ecological designations – PNA, SNHA
Conservation Lands – Gull rock Game Land
Fish data – no
Prominent alterations present – minimal, bottom disturbing gear
Avg. total alteration score – 0.91
Avg. selection frequency – 500

SHA #27: Pamlico Sound Fish Area 3 (Map 10.7)

Description – soft bottom with good fish data
Acres – 870
Prominent habitats – soft bottom > 6 ft.
Ecological designations –
Conservation Lands –
Fish data – yes
Prominent alterations present – bottom disturbing gear
Avg. total alteration score – 1.0
Avg. selection frequency – 52

PAMLICO RIVER MOUTH

SHA # 52: Swanquarter Bays (Map 10.8)

Description – Swanquarter, Rose, Juniper Bays, near Swanquarter, hydrologically connects with Lake Mattamuskeet via Rose Bay Canal
Acres – 60,900
Prominent habitats – estuarine soft bottom, emergent wetlands, soft bottom 0- 6 ft., non-riparian wetland, subtidal shell bottom, high salinity SAV
Ecological designations – PNA, SNA, ORW, SNHA
Conservation Lands – Gull Rock Gameland, Mattamuskeet NWR, Swanquarter NWR
Fish data – yes
Prominent alterations present – agriculture, ditching, bottom disturbing gear
Avg. total alteration score – 0.49
Avg. selection frequency – 410
Notes –good fish data in river

SHA #60: southeast Pungo River (Map 10.8)

Description – Slade and Fortescue creeks and Abel Bay
Acres – 17,276
Prominent habitats –Non-riparian wetlands, emergent wetlands, shallow to deep soft bottom, low elevation uplands, subtidal shell bottom, low salinity SAV, high salinity SAV
Ecological designations – PNA, SNA
Conservation Lands –
Fish data – yes
Prominent alterations present – agriculture, wetlands lost to development, ditched, bottom disturbing gear
Avg. total alteration score – 0.3
Avg. selection frequency – 495

SHA #69: Goose Creek Game Land 1 (Map 10.8)

Description – creeks and bays at south tip of Pamlico River, including Oyster Creek, Middle Prong, and some impoundments
Acres – 5,096
Prominent habitats – emergent wetlands, wetland edge, soft bottom 0-3 and 3-6 ft, high salinity SAV
Ecological designations – PNA, SNA, SNHA
Conservation Lands – Goose Creek Game Land
Fish data – yes
Prominent alterations present – drained, bottom disturbing gear
Avg. total alteration score – 0.9
Avg. selection frequency – 424

SHA #70: Goose Creek Game Land 2 (Map 10.8)

Description – Big Porpoise, Middle and Jones bays south of Pamlico River mouth; near Hobucken
Acres – 18,891
Prominent habitats – emergent wetlands, soft bottom 0-> 6 ft, subtidal shell bottom, high salinity SAV
Ecological designations – PNA, SNA, oyster sanctuary, SNHA
Conservation Lands – Goose Creek Game Land, Hobucken Marshes Preserve, military prohibited Brandt Island
Fish data – yes
Prominent alterations present – drained, military activities, bottom disturbing gear

Avg. total alteration score – 0.87
Avg. selection frequency – 425

SHA #65: Upper Middle Ground (Map 10.8)

Description – Subtidal oyster reefs with good fishing off Pamlico River
Acres – 4,474
Prominent habitats – soft bottom, subtidal shell bottom
Ecological designations – ORW
Conservation Lands –
Fish data – yes
Prominent alterations present – bottom disturbing gear
Avg. total alteration score – 1.0
Avg. selection frequency – 46
Notes – oyster reefs and large red drum (per M. Marshall)

PAMLICO RIVER

SHA #130: southwest Pungo River (Map 10.9)

Description – creeks along lower and west of Pungo River and Pamlico River, includes North Creek, Wades Point and Pamlico Beach
Acres – 8,451
Prominent habitats – non-riparian wetlands, soft bottom 0-3 ft., low elevation uplands, emergent wetland, low salinity SAV.
Ecological designations – IPNA, PNA, SNA
Conservation Lands –
Fish data – yes
Prominent alterations present –
Avg. total alteration score –0.83
Avg. selection frequency – 490
Notes – healthy system

SHA #128: Jordan Creek (Map 10.9)

Description – Jordan Creek off Pungo River
Acres – 2,113
Prominent habitats – Non-riparian wetlands, soft bottom 0- >6, subtidal shell bottom
Ecological designations – IPNA
Conservation Lands –
Fish data – yes
Prominent alterations present – agriculture, culvert, wetlands lost to development and agriculture, bottom disturbing gear, minor animal operations
Avg. total alteration score – 0.46
Avg. selection frequency – 471

SHA #40 : Pungo Creek (Map 10.9)

Description – mid- Pungo Creek, west of Hwy. 99
Acres – 1,491
Prominent habitats – soft bottom, subtidal shell bottom
Ecological designations –

Conservation Lands –
Fish data – no
Prominent alterations present – agriculture, bottom disturbing fishing gear, wetlands lost to development
Avg. total alteration score –0.96
Avg. selection frequency – 473

SHA #15: Pantego Creek (Map #10.9)

Description – Pantego Creek off Pungo River
Acres – 4,847
Prominent habitats – non-riparian wetlands, emergent wetlands
Ecological designations – SNHA
Conservation Lands –
Fish data – yes
Prominent alterations present – agriculture, minor NPDES, major animal operation, bottom disturbing gear
Avg. total alteration score – 0.67
Avg. selection frequency – 407

SHA #41: Tooley's Point (Map 10.9)

Description – bay and lower Dowry Creek by Tooley's Point near Bellhaven
Acres – 621
Prominent habitats – soft bottom 0-3 ft, low elevation upland
Ecological designations – PNA
Conservation Lands –
Fish data – yes
Prominent alterations present – bottom disturbing gear, minor NPDES, multi-slip docks
Avg. total alteration score –0.8
Avg. selection frequency – 500

SHA #147: Haystack Point (Map 10.9)

Description – Flax Pond by Haystack Point, west of Upper Dowry Creek off Pungo River
Acres – 373
Prominent habitats – non-riparian wetland, soft bottom > 6 ft., soft bottom 0-3 ft., low elevation upland
Ecological designations – PNA
Conservation Lands –
Fish data – yes
Prominent alterations present – bottom disturbing gear, shoreline stabilization, minor NPDES
Avg. total alteration score –0.56
Avg. selection frequency – 500

SHA # 17: Upper Pungo River (Map 10.9)

Description – Upper Pungo to Hwy 264 and Hwy 45
Acres – 2,610
Prominent habitats – emergent wetlands, soft bottom 0-3, soft bottom > 6, low salinity SAV
Ecological designations – SNA, SNHA
Conservation Lands – Pungo River Game Land
Fish data – yes
Prominent alterations present – agriculture, bottom disturbing gear
Avg. total alteration score – 0.46

Avg. selection frequency – 43

SHA #51: South and Goose Creeks (Map 10.10)

Description – South, Bond, Goose, Eastham and Campbell creeks, south side of Pamlico River, southeast of PCS, near Aurora
Acres – 21,626
Prominent habitats – wetland edge, emergent wetland, non-riparian wetland, low salinity SAV
Ecological designations – IPNA, PNA, SNA, SNHA
Conservation Lands – Goose Creek Game Land
Fish data – yes
Prominent alterations present – drained, minor NPDES, bottom disturbing gear
Avg. total alteration score – 0.97
Avg. selection frequency – 457

SHA #61: Durham Creek (Map 10.10)

Description – Durham Creek, south side of Pamlico River, west of PCS
Acres – 4,101
Prominent habitats – non-riparian wetlands, forested wetlands, soft bottom 3-6 ft
Ecological designations – PNA, IPNA, AFSA, SNHA
Conservation Lands –
Fish data – yes
Prominent alterations present – major NPDES, bottom disturbing gear
Avg. total alteration score – 1.30
Avg. selection frequency – 500

SHA # 54: Mixon Creek (Map 10.10)

Description – Mixon Creek west of Gum Point near Bayview
Acres – 870
Prominent habitats – non-riparian wetlands, soft bottom 0-3
Ecological designations – IPNA
Conservation Lands –
Fish data – yes
Prominent alterations present – major NPDES
Avg. total alteration score – 1.88
Avg. selection frequency – 500

SHA #44: Bath Creek (Map 10.11)

Description – Bath Creek
Acres – 3,977
Prominent habitats – forested wetlands, soft bottom >6 ft, soft bottom 0-3 ft
Ecological designations – IPNA
Conservation Lands – Bath State Historic Site
Fish data – yes
Prominent alterations present – agriculture, residential development along shoreline, wetlands lost to development, bottom disturbing fishing gear
Avg. total alteration score – 0.87
Avg. selection frequency – 490

SHA #42: Goose Creek State Park (Map 10.11)

Description – Duck, Little Goose, and Broad creeks along Pamlico River shoreline, west of Bath
Acres – 4,723
Prominent habitats – forested wetlands, soft bottom 0-3 ft, low elevation upland, low salinity SAV
Ecological designations – IPNA, SNA, AFSA, SNHA
Conservation Lands – Goose Creek State Park
Fish data – yes
Prominent alterations present – relatively minor, some agriculture, bottom disturbing fishing gear
Avg. total alteration score – 0.32
Avg. selection frequency – 482

SHA #47: Blount's Bay (Map 10.11)

Description – Blount's Bay and Blount's Creek off Pamlico River, just south of Chocowinity.
Acres – 13,796
Prominent habitats – soft bottom > 6ft, forested wetland, low salinity SAV, soft bottom 0-3ft
Ecological designations – SNA, AFSA, SNHA
Conservation Lands – Nevil's Creek Land Trust and Preserve
Fish data – yes
Prominent alterations present – agriculture and residential development, obstruction, bottom disturbing gear
Avg. total alteration score – 0.53
Avg. selection frequency – 485

SHA # 43: Upper Pamlico River, Washington (Map 10.11)

Description – Upper Pamlico River north of Chocowinity Bay, up to Tranters Creek
Acres – 2,486
Prominent habitats – forested wetlands
Ecological designations – IPNA, SNA, AFSA, SNHA
Conservation Lands –
Fish data – no
Prominent alterations present – developed north shore, minor NPDES, bridges
Avg. total alteration score – 0.89
Avg. selection frequency – 414
Notes – good striper fishing, especially around bridge pilings

SHA # 2: Lower Fishing Creek (Map 10.12)

Description – Fishing Creek – upper Tar River, just above Tarboro
Acres – 621
Prominent habitats – forested wetland, riverine soft bottom
Ecological designations – AFSA, SNHA
Conservation Lands –
Fish data – no
Prominent alterations present – agriculture, culvert (road bisects), wetlands lost to agriculture
Avg. total alteration score – 0.63
Avg. selection frequency – 38
Notes – Check on why – fairly close to Tarboro or major highways, low selection freq

SHA #4: Tar River, Rocky Mount (Map 10.12)

Description – Tar River just below Rocky Mills Dam
Acres – 10,191
Prominent habitats – forested wetland, riverine rocky bottom, wetland edge
Ecological designations – IPNA, AFSA, SNHA
Conservation Lands –
Fish data – yes, WRC
Prominent alterations present – agriculture and developed (Rocky Mount), dam, impoundment, major NPDES, hog lagoon,
Avg. total alteration score – 1.17
Avg. selection frequency – 485

SHA # 1: Upper Fishing Creek (Map 10.12)

Description – Fishing Creek – upper Tar River, above Tarboro, on Halifax/Edgecombe county line
Acres – 870
Prominent habitats – forested wetland, riverine stream, mid elevation
Ecological designations – AFSA, SNHA
Conservation Lands –
Fish data – no
Prominent alterations present – agriculture (forestry), minor NPDES
Avg. total alteration score – 1.52
Avg. selection frequency – 82
Notes – American shad use for spawning (B.Wynne, WRC, personal communication)

PAMLICO-NEUSE BAYS

SHA #78: Bay River (Map 10.13)

Description – Bay River and adjacent bays and creeks including Bear, Gale, Vandemere creeks and Bonner Bay; Near Vandemere
Acres – 20383
Prominent habitats – soft bottom 0-3 and >6 ft, emergent wetland, non-riparian wetland, subtidal shell bottom, high salinity SAV
Ecological designations – PNA, SNA, SNHA
Conservation Lands – Hobucken Marshes Preserve, Lampe-Woodard tract land trust
Fish data – yes
Prominent alterations present – agriculture, drained, bottom disturbing gear
Avg. total alteration score – 0.83
Avg. selection frequency – 471

SHA #81: Chapel Creek (Map 10.13)

Description – Chapel Creek in upper Bay River
Acres – 1,243
Prominent habitats – soft bottom, emergent wetland
Ecological designations – PNA
Conservation Lands –
Fish data – no
Prominent alterations present – agriculture, drained, obstructions, animal operations
Avg. total alteration score – 1.31

Avg. selection frequency – 100

SHA #144: Moore Bay (Map 10.13)

Description – creek feeding into Moore Bay on upper south side of Bay River
Acres – 497
Prominent habitats – non-riparian wetlands, soft bottom 0-3 and >6 ft
Ecological designations – PNA
Conservation Lands –
Fish data – no
Prominent alterations present – agriculture, drained, bottom disturbing gear
Avg. total alteration score – 0.87
Avg. selection frequency – 500

SHA #149: Upper Bay River (Map 10.13)

Description – single hex in upper Bay River – PNA
Acres – 124
Prominent habitats – non-riparian wetlands, soft bottom 0-3 and >6 ft
Ecological designations – PNA
Conservation Lands –
Fish data – no
Prominent alterations present – agriculture, drained, bottom disturbing gear
Avg. total alteration score – 1.51
Avg. selection frequency – 500

SHA #82: Mason Bay (Map 10.13)

Description – creek feeding into Mason Bay on upper south side of Bay River
Acres – 621
Prominent habitats – low elevation upland, non-riparian wetland, emergent wetland
Ecological designations – PNA
Conservation Lands –
Fish data – no
Prominent alterations present – agriculture, drained, major animal operation
Avg. total alteration score – 0.93
Avg. selection frequency – 471

NEUSE RIVER

SHA # 137: Neuse Mouth 1 (Map 10.14)

Description – subtidal oyster reefs in mouth of Neuse River
Acres – 6,339
Prominent habitats – subtidal shell bottom, soft bottom > 6 ft
Ecological designations –
Conservation Lands –
Fish data – yes
Prominent alterations present – bottom disturbing gear
Avg. total alteration score – 1.02
Avg. selection frequency – 330

SHA # 86: Neuse Mouth 2 (Map 10.14)

Description – just outside Neuse mouth
Acres – 11,683
Prominent habitats – good fish data, shell bottom, soft bottom >6 ft
Ecological designations –
Conservation Lands –
Fish data – yes
Prominent alterations present – bottom disturbing gear
Avg. total alteration score –1.01
Avg. selection frequency – 281

SHA #91: Neuse Oyster Rock 3 (Map 10.14)

Description – subtidal oyster reef, center of Neuse, west of Rattan Bay
Acres – 1,725
Prominent habitats – subtidal oyster reefs, soft bottom > 6ft
Ecological designations –
Conservation Lands –
Fish data – yes
Prominent alterations present –
Avg. total alteration score – 1.01
Avg. selection frequency – 313
Notes – good drum fishing and oysters

SHA # 96: West Bay (Map 10.14)

Description – mouth of West Bay
Acres – 7,333
Prominent habitats – shallow to deep soft bottom, high salinity SAV
Ecological designations – SNHA
Conservation Lands – Cedar Island NWR, Piney Island, military prohibited area (BT-11)
Fish data – yes
Prominent alterations present – bottom disturbing gear
Avg. total alteration score – 0.69
Avg. selection frequency – 78

SHA #97: Turnagain Bay area (Map 10.15)

Description – Turnagain Bay, upper South River, west side of Long Bay
Acres – 20,756
Prominent habitats – emergent wetland, soft bottom >6ft, non-riparian wetland, headwater wetland, some high salinity SAV and subtidal shell bottom
Ecological designations – PNA, oyster sanctuary, SNHA
Conservation Lands – Carteret County Game Land, Turnagain Bay Preserve, Piney Island Marine Corps land, military prohibited area (BT-11)
Fish data – yes
Prominent alterations present – agriculture, bottom disturbing gear
Avg. total alteration score –0.31
Avg. selection frequency – 408

SHA # 107: West Thorofare Bay (Map 10.15)

Description – West Thorofare, upper Long Bay, Cedar Island
Acres – 5,220
Prominent habitats – Emergent wetlands, non-riparian wetlands, high salinity SAV
Ecological designations – PNA, SNHA
Conservation Lands – Cedar Island NWR
Fish data – no
Prominent alterations present – agriculture, drained
Avg. total alteration score – 0.08
Avg. selection frequency – 358
Notes – connects to Thorofare Bay, good shrimping area

SHA #106: Sandy Point (Map 10.15)

Description – Neuse shoal between Adams and South River
Acres – 746
Prominent habitats – forested wetland, emergent wetland
Ecological designations – PNA
Conservation Lands –
Fish data – no
Prominent alterations present – agriculture, wetlands lost to agriculture and development
Avg. total alteration score – 0.21
Avg. selection frequency – 362

SHA #109: Back Creek (Map 10.15)

Description – Back Creek, tributary of Adams Creek, headwaters in Open Grounds Farm
Acres – 3,853
Prominent habitats – non-riparian wetland, low elevation upland, emergent wetland
Ecological designations – PNA
Conservation Lands –
Fish data – no
Prominent alterations present – agriculture, bottom disturbing gear, drained
Avg. total alteration score – 0.73
Avg. selection frequency – 492

SHA # 110: Adams Creek (Map 10.15)

Description – Adams Creek mouth and side tributary near Merimon
Acres – 2,983
Prominent habitats – soft bottom 0-3 ft, emergent wetlands, low elevation upland
Ecological designations – PNA, SNA
Conservation Lands –
Fish data –
Prominent alterations present – agriculture, bottom disturbing gear, wetlands lost to development
Avg. total alteration score – 0.84
Avg. selection frequency – 491

SHA #136: Broad Creek (Map 10.16)

Description – Broad Creek, north mouth of Neuse River
Acres – 8,079

Prominent habitats – soft bottom 0-3 ft, emergent wetland, high salinity SAV
Ecological designations – PNA, SNA
Conservation Lands – NGO owned tract
Fish data – yes
Prominent alterations present – drained, obstruction, bottom disturbing gear, multi-slip docking, minor NPDES
Avg. total alteration score – 0.77
Avg. selection frequency – 452

SHA #100: Green Creek (Map 10.16)

Description – Green, Whittaker, Pierce, and Orchard creeks at Oriental
Acres – 5,966
Prominent habitats – soft bottom 0-3 ft, emergent wetlands
Ecological designations – PNA, SNA, AFSA
Conservation Lands –
Fish data – yes
Prominent alterations present – agriculture, multi-slip docking, drained
Avg. total alteration score – 0.95
Avg. selection frequency – 499

SHA # 105: Neuse Oyster Rock 1 (Map 10.17)

Description – subtidal oyster reef, center of Neuse opposite Adams Creek
Acres – 1,616
Prominent habitats – subtidal shell bottom, soft bottom > 6ft
Ecological designations –
Conservation Lands –
Fish data – yes
Prominent alterations present – bottom disturbing gear
Avg. total alteration score –1.01
Avg. selection frequency – 386

SHA #102: Neuse Oyster Rock 2 (Map 10.17)

Description – subtidal oyster reef, center of Neuse near South Creek

Acres – 621
Prominent habitats – subtidal shell bottom, soft bottom > 6ft
Ecological designations –
Conservation Lands –
Fish data – yes
Prominent alterations present – bottom disturbing gear
Avg. total alteration score – 1.01
Avg. selection frequency – 431

SHA #104: Dawson Creek (Map 10.17)

Description – Dawson Creek, between Minnesott Beach and Oriental
Acres – 1,864
Prominent habitats – soft bottom > 6 ft, emergent wetlands, soft bottom 0-3 ft
Ecological designations – PNA, SNA, AFSA
Conservation Lands –

Fish data – yes
Prominent alterations present – agriculture, bottom disturbing gear
Avg. total alteration score – 0.64
Avg. selection frequency – 293

SHA # 98: Beard's Creek (Map 10.17)

Description – Beards Creek near Arapahoe
Acres – 2,610
Prominent habitats – emergent wetlands, low salinity SAV
Ecological designations – PNA, AFSA
Conservation Lands –
Fish data – yes
Prominent alterations present – agriculture, development along shore, multi-slip docking facilities, minor NPDES, bottom disturbing gear
Avg. total alteration score – 0.50
Avg. selection frequency – 500

SHA #113: Clubfoot Creek (Map 10.17)

Description – Clubfoot Creek, connected to Harlowe Creek (tributary of Newport River) via canal
Acres – 5,841
Prominent habitats – non-riparian wetland, soft bottom 0- ft, forested wetland, some low salinity SAV
Ecological designations – PNA, SNA
Conservation Lands – Croatan National Forest
Fish data – no
Prominent alterations present – agriculture and development, obstruction, wetlands lost to agriculture
Avg. total alteration score – 0.59
Avg. selection frequency – 488

SHA #112: Hancock Creek (Map 10.17)

Description – Hancock Creek, south side of Neuse, near Cherry Point
Acres – 4,971
Prominent habitats – soft bottom 0-3 ft, forested wetland, low elevation upland, low salinity SAV
Ecological designations – IPNA, SNHA
Conservation Lands – Croatan National Forest
Fish data – no
Prominent alterations present – development, obstructions, wetlands lost to development
Avg. total alteration score – 0.66
Avg. selection frequency – 500
Notes – metal contamination but not as bad as Slocum; lot of recreational fishing for speckled trout, red drum, striped bass

SHA # 134: Goose Creek (Map 10.18)

Description – Goose and Upper Broad creeks just east of Fairfield Harbour
Acres – 7,954
Prominent habitats – forested wetland, non-riparian wetland, low salinity SAV
Ecological designations – SNA, AFSA, SNHA
Conservation Lands – Neuse River Game Land
Fish data – yes
Prominent alterations present – agriculture, development, wetlands lost to agriculture and development,

bottom disturbing gear
Avg. total alteration score – 0.23
Avg. selection frequency – 454

SHA # 99: Neuse shoreline, James City (Map 10.18)

Description – 1,491
Acres – 1,491
Prominent habitats – soft bottom >6 ft, low salinity SAV
Ecological designations –
Conservation Lands –
Fish data – no
Prominent alterations present – development, bottom disturbing gear
Avg. total alteration score – 1.3
Avg. selection frequency – 500
Notes – high bluff shoreline

SHA #93: Trent River (Map 10.18)

Description – Trent River
Acres – 7,581
Prominent habitats – forested wetland, riverine soft bottom, low salinity SAV
Ecological designations – SNHA
Conservation Lands – Brice's Creek Land Trust, Croatan National Forest, Sawmill Wetland Mitigation Site
Fish data – no
Prominent alterations present – development, multi-slip docking, minor NPDES, bottom disturbing gear, wetlands lost to development
Avg. total alteration score – 1.12
Avg. selection frequency – 468

SHA # 83: Upper Neuse 1 (Map 10.19)

Description – Upper Neuse just upstream of New Bern, adjacent to Weyerhauser and including Hog Island, Hwy. 43 crosses it
Acres – 4,474
Prominent habitats – forested wetland, riverine soft bottom
Ecological designations – SNA, SNHA
Conservation Lands – Bellair Plantation Preserve and Land Trust, Neuse River Game Land
Fish data – yes, WRC
Prominent alterations present – development, major NPDES, wetlands lost to development
Avg. total alteration score – 0.65
Avg. selection frequency – 400
Notes: inland and anadromous spp, juvenile herring; pers. com., J. Homan, WRC

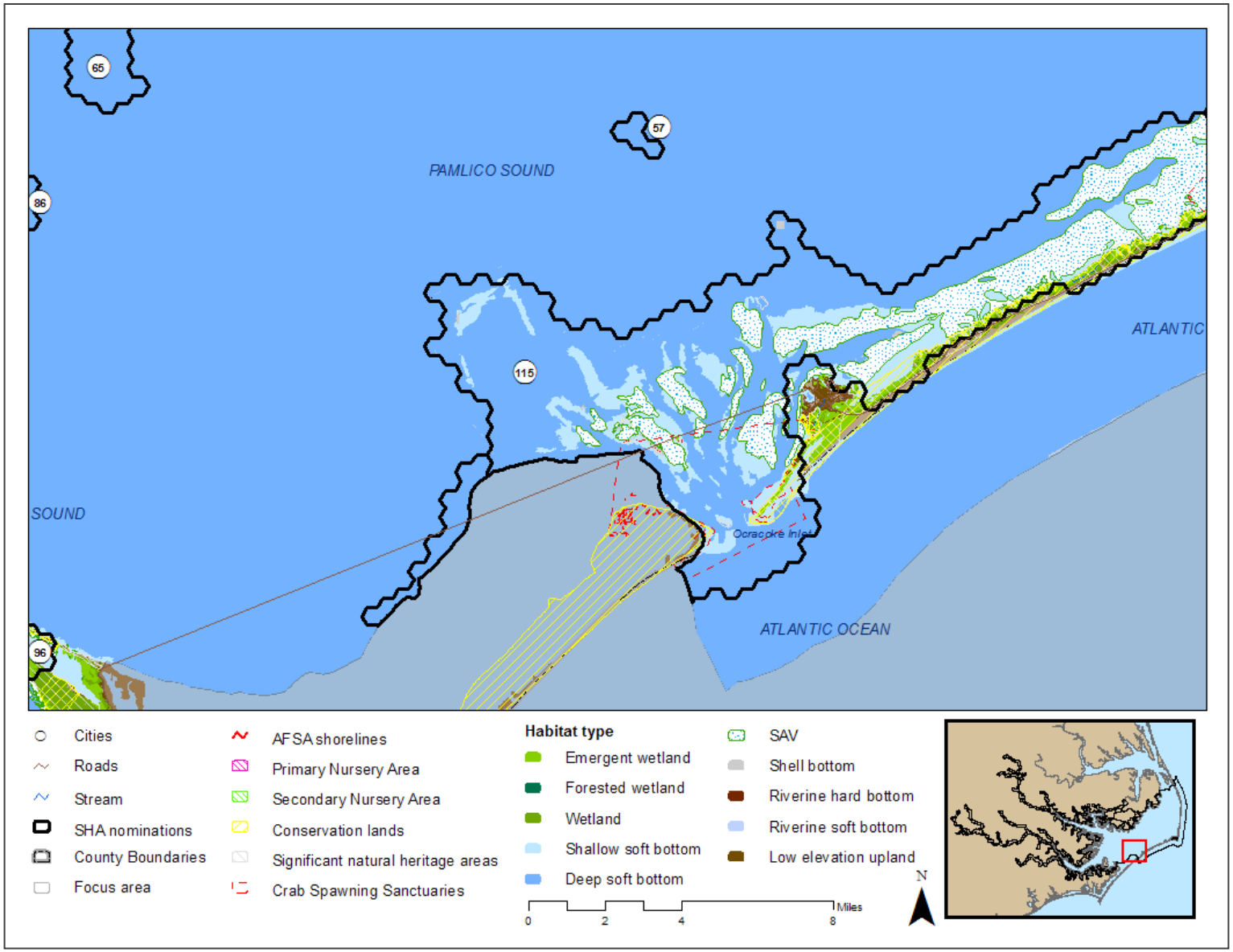
SHA #71: Riverine Upper Neuse 2 (Map 10.19)

Description – Pitch Kettle, Village, Core, Kidney creeks, further upstream than #83
Acres – 7,582
Prominent habitats – forested wetland, riverine soft bottom
Ecological designations – IPNA, AFSA, SNHA
Conservation Lands –
Fish data –yes, WRC

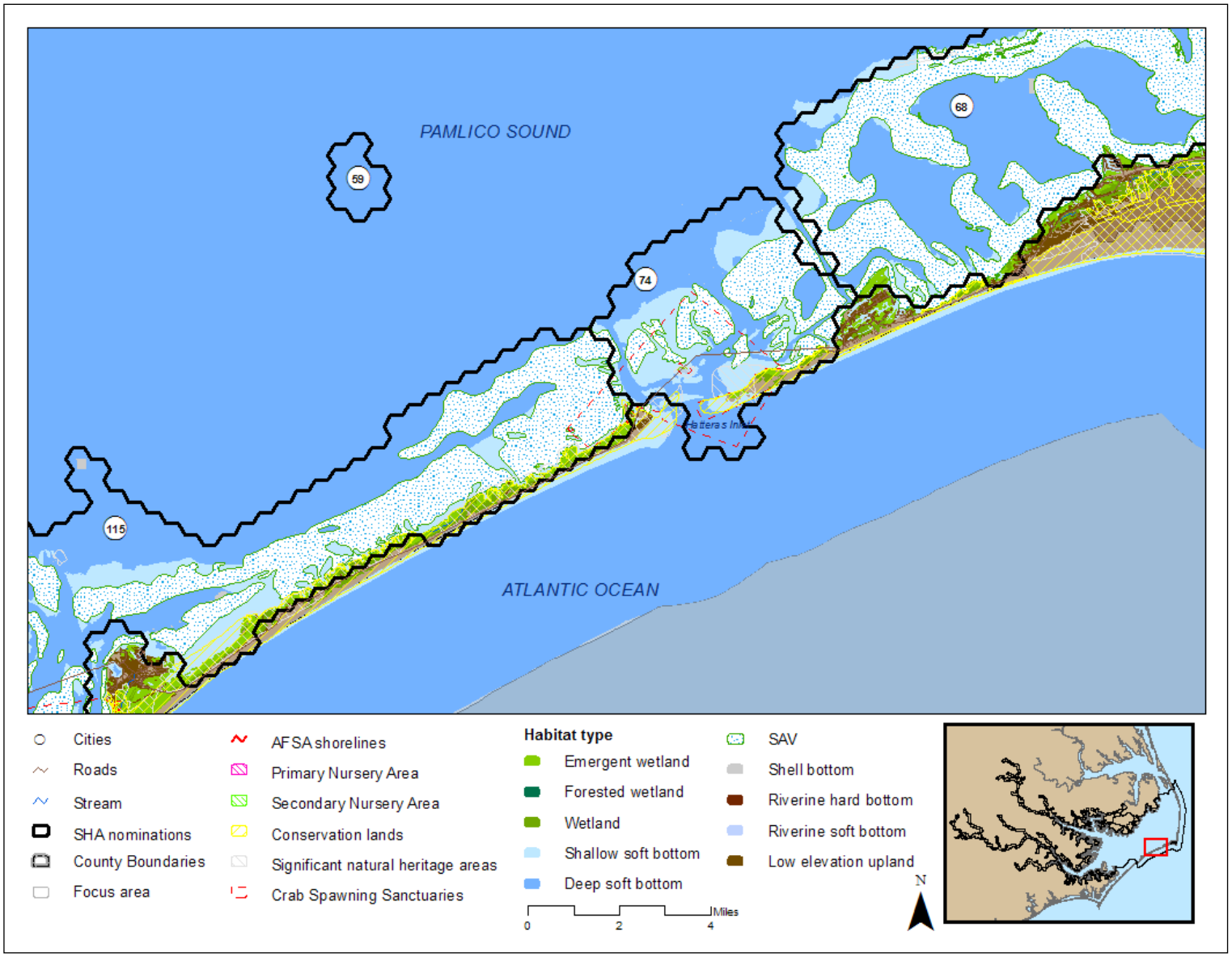
Prominent alterations present – agriculture, major animal operation, wetlands lost to development
Avg. total alteration score – 0.37
Avg. selection frequency – 20
Notes –Pitch Kettle used by hickory shad, Core, Village and Kidney creeks have relatively more and consistent use by juvenile blueback herring than anywhere else in Neuse or Tar. (B. Wynne, WRC, personal communication)

SHA # 140: Riverine Upper Neuse 3 (Map 10.20)

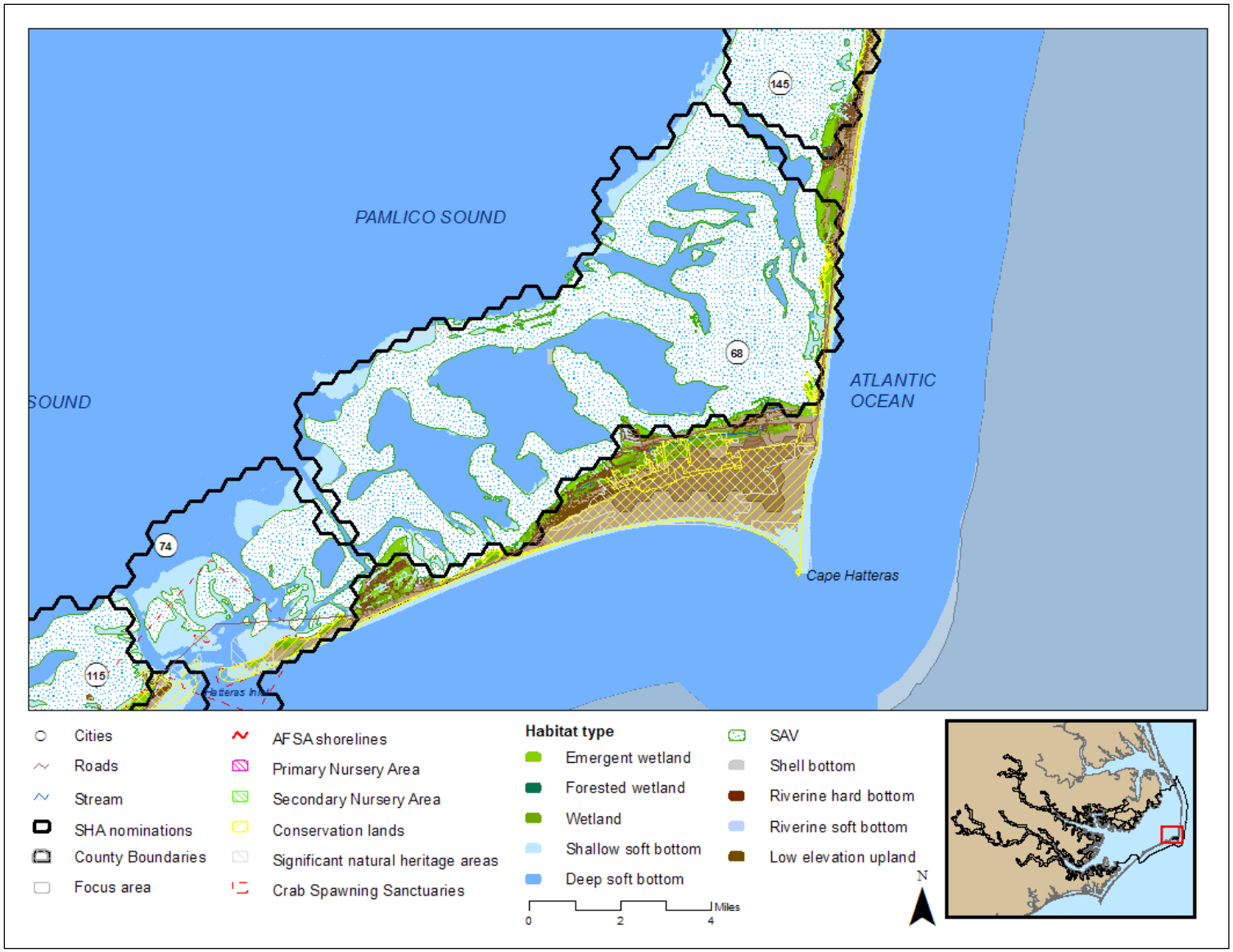
Description – Rocky bottom area of upper Neuse, upstream of former Quaker Neck dam, Goldsboro
Acres – 22,371
Prominent habitats – forested wetland, riverine soft bottom, riverine hard bottom
Ecological designations – IPNA, AFSA, SNHA
Conservation Lands – Poplar Creek Bluffs Land Trust, Montgomery Laurel Bluffs Preserve, Land Trust
Fish data – yes, WRC
Prominent alterations present – agriculture, development, NPDES, animal operations
Avg. total alteration score – 0.73
Avg. selection frequency – 477
Notes: - major spawning area for American shad, hickory shad and striped bass, pers. comm., Justin Homan, WRC



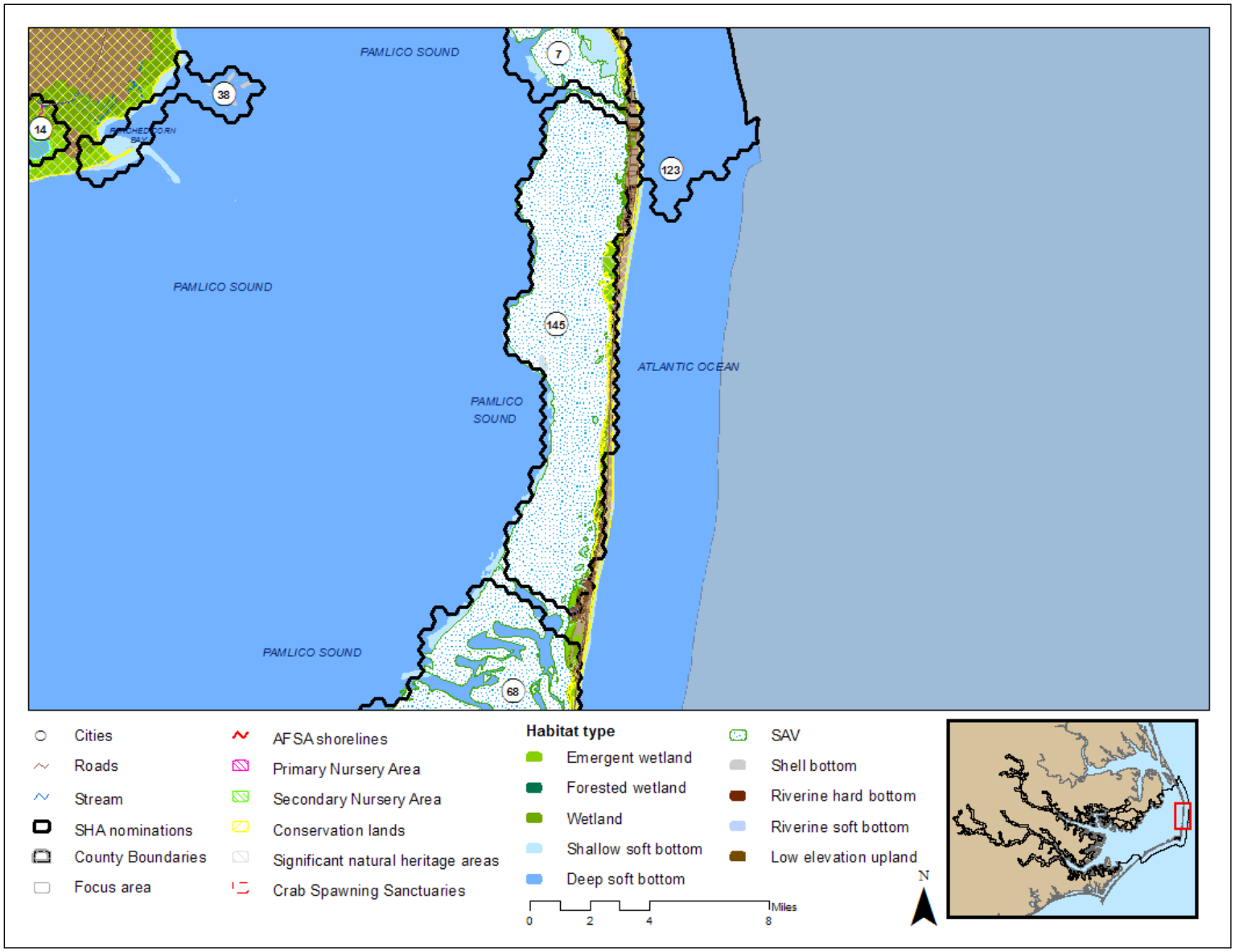
Map 10.1. Region 2 Strategic Habitat Areas (SHAs): Ocracoke Inlet and Pamlico Sound (SHAs 115 & 57).



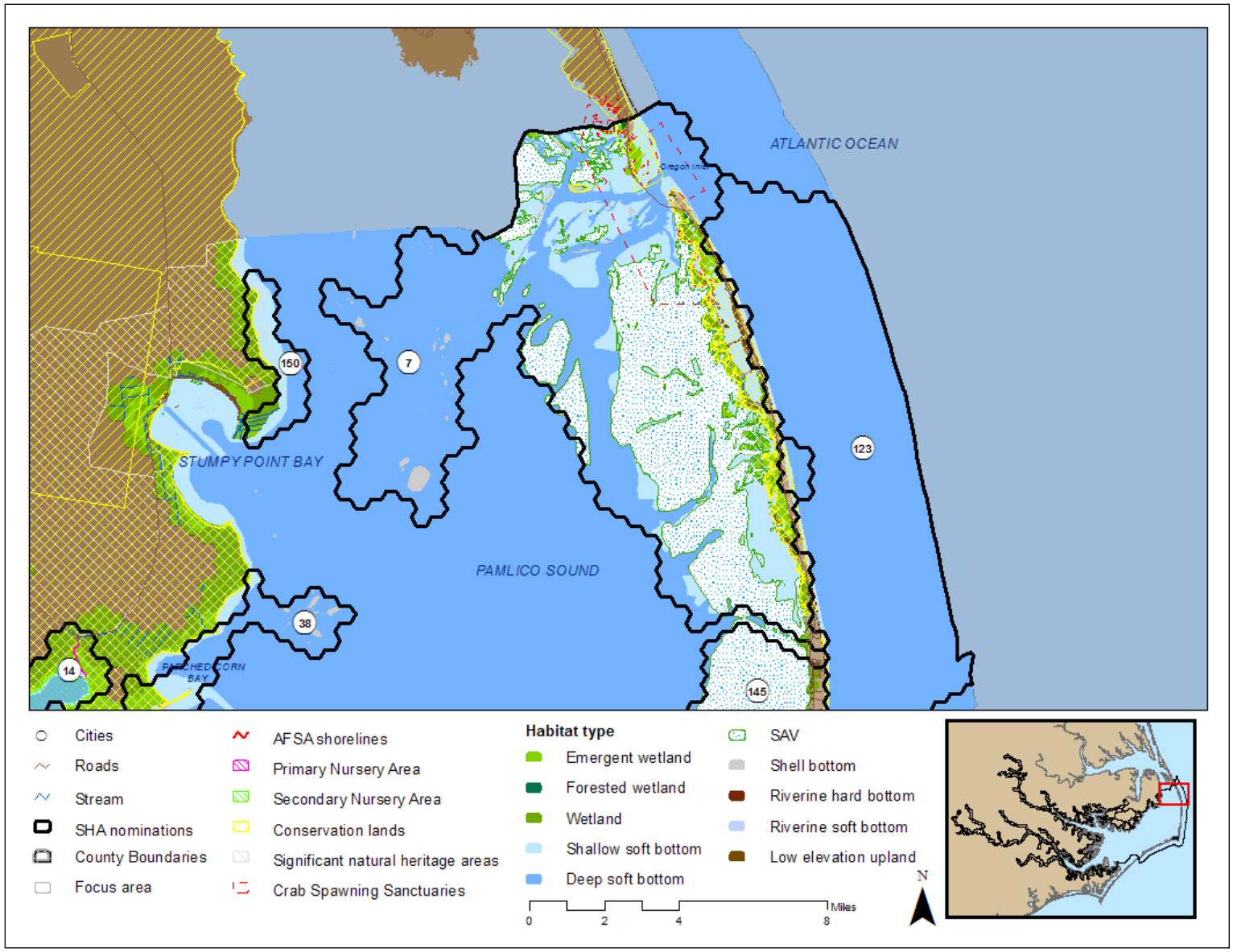
Map 10.2. Region 2 Strategic Habitat Areas (SHAs): Hatteras Inlet and Pamlico Sound (SHAs 74 & 59).



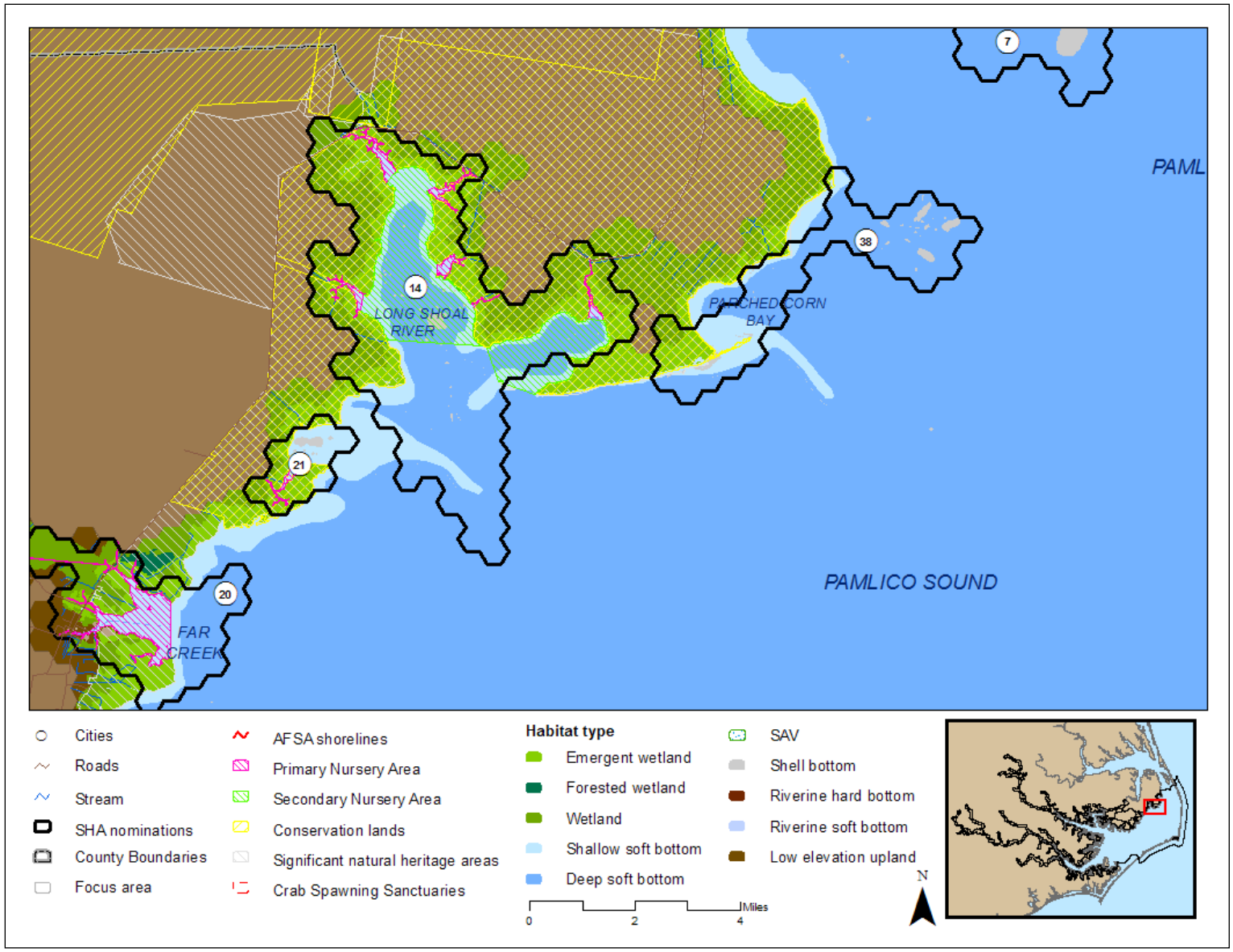
Map 10.3. Region 2 Strategic Habitat Areas (SHAs): Eastern Pamlico Sound, Hatteras Inlet (SHAs 68 & 74).



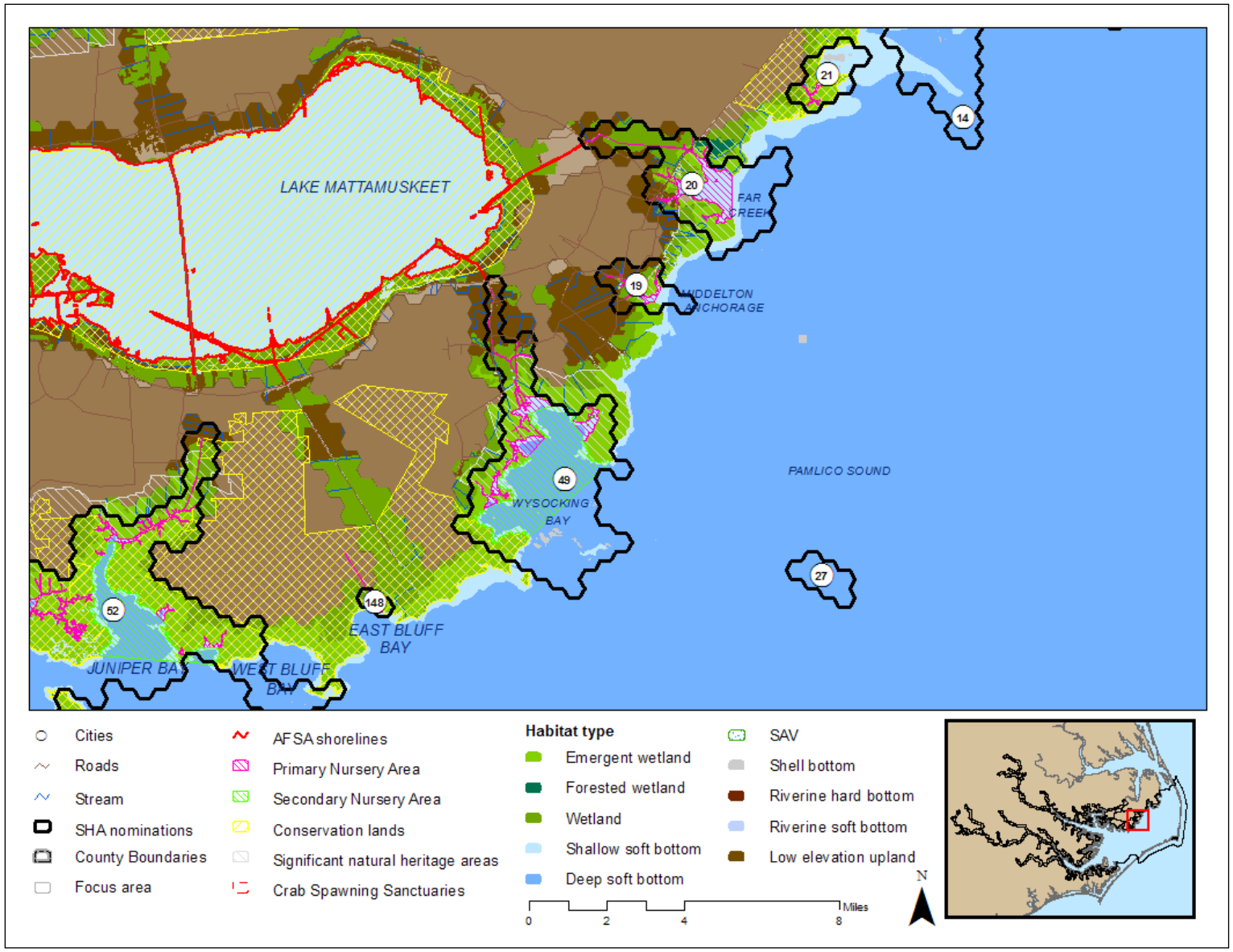
Map 10.4. Region 2 Strategic Habitat Areas (SHAs): Eastern Pamlico Sound (SHA 145).



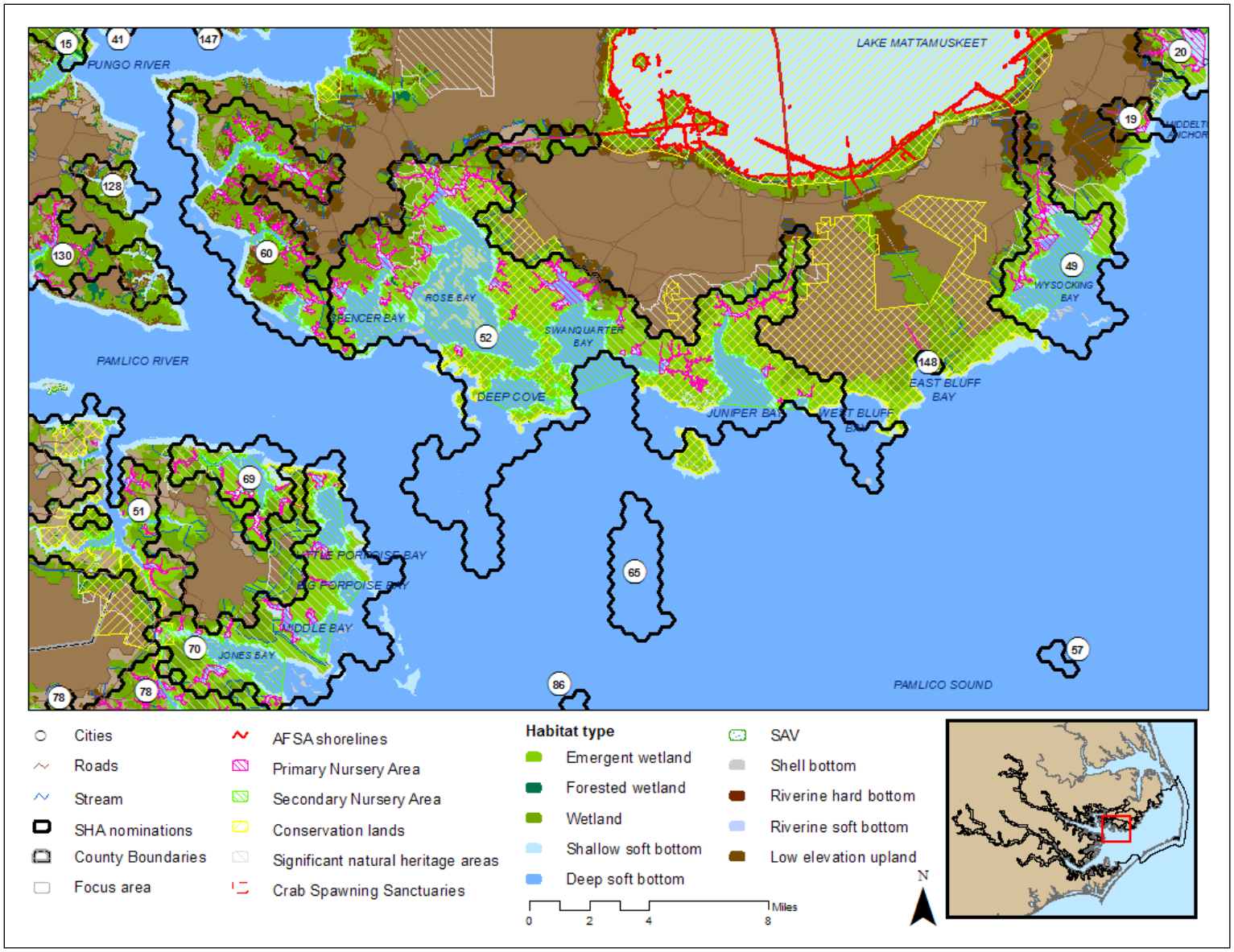
Map 10.5. Region 2 Strategic Habitat Areas (SHAs): Eastern Pamlico Sound (SHAs 123, 7, & 150).



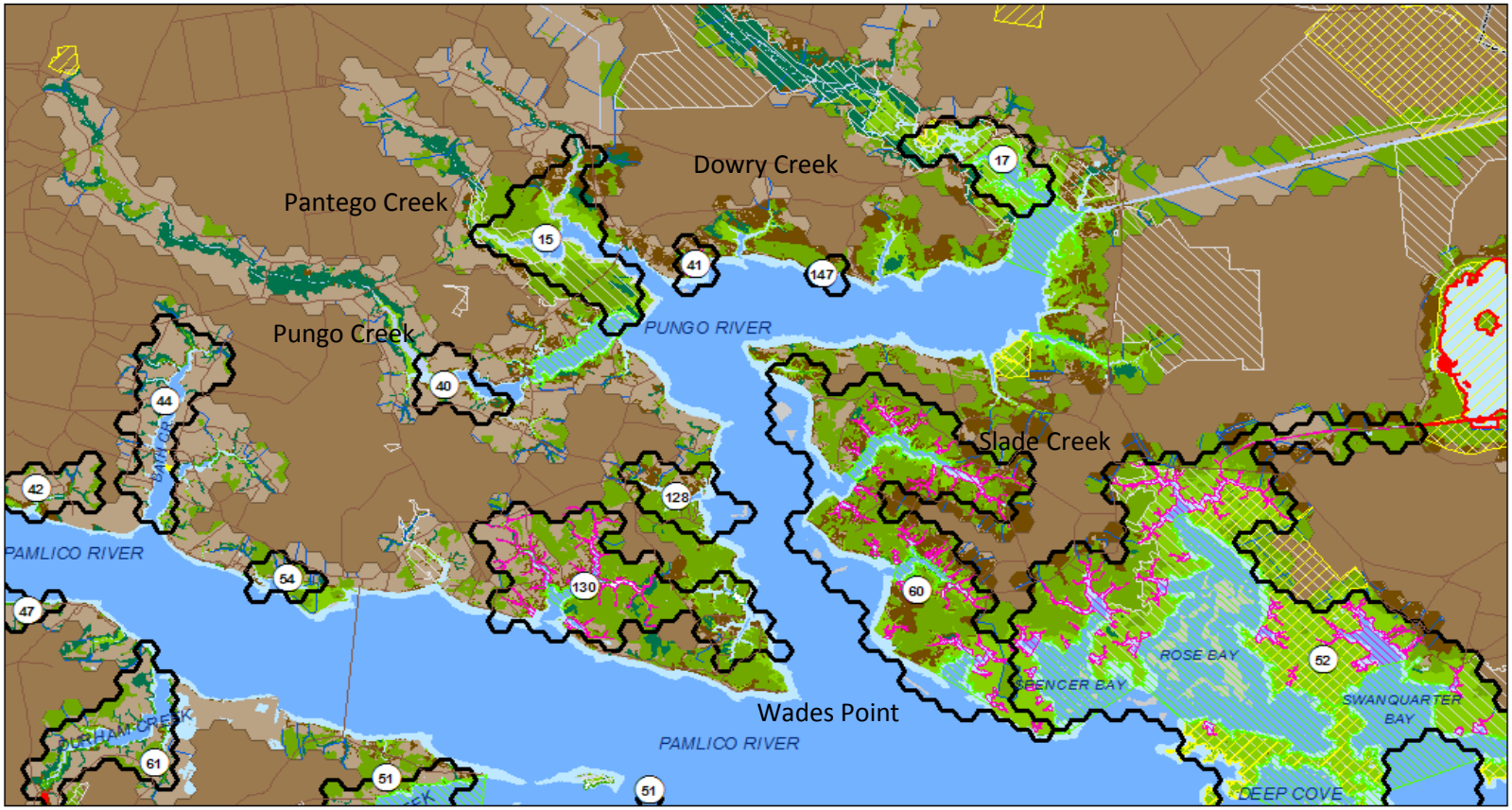
Map 10.6. Region 2 Strategic Habitat Areas (SHAs): Northwestern Pamlico Sound, Long Shoal River area (SHAs 38, 14, 21, & 20).



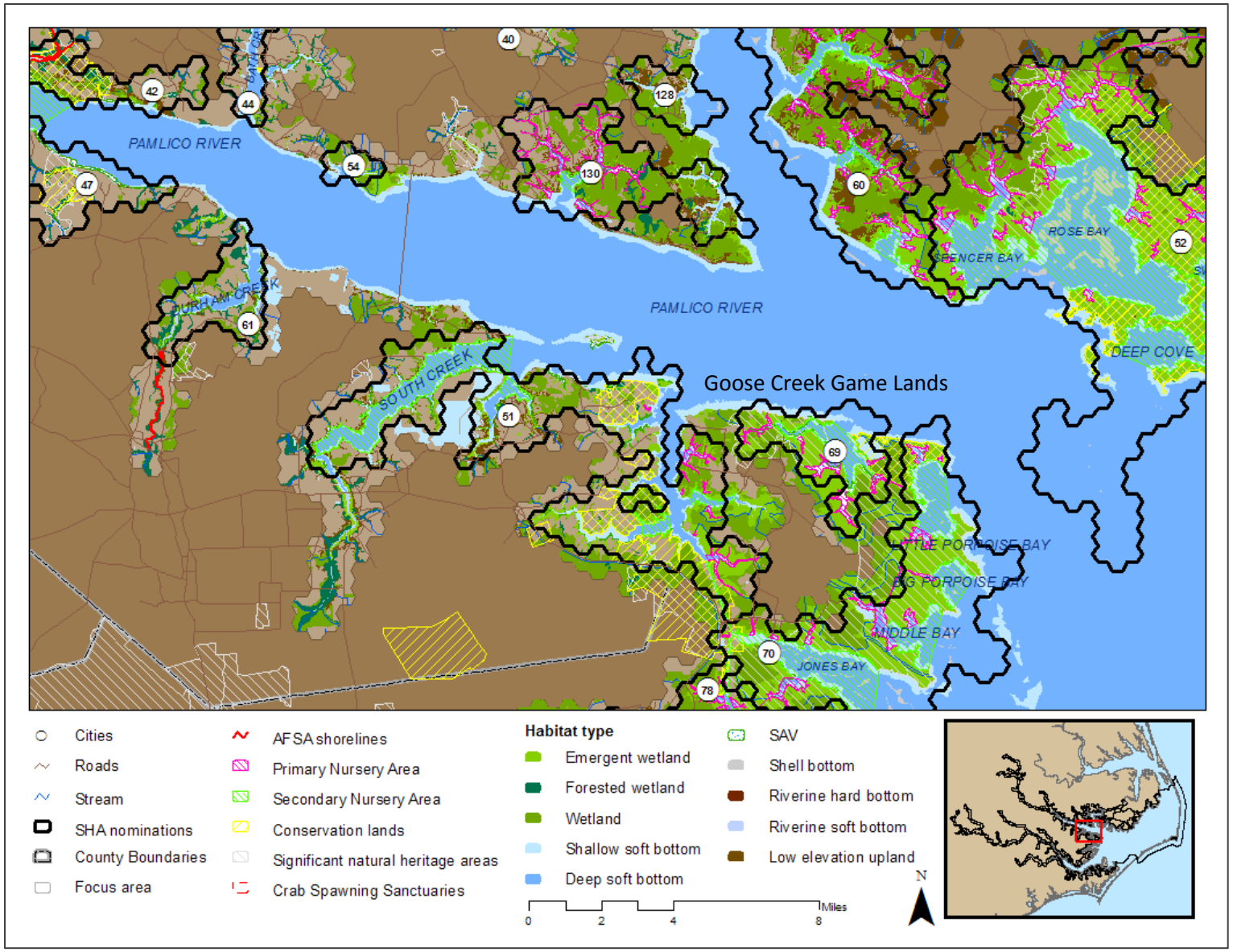
Map 10.7. Region 2 Strategic Habitat Areas (SHAs): Western Pamlico Sound bays, Wysocking Bay area (SHAs 19, 49, 148, & 27).



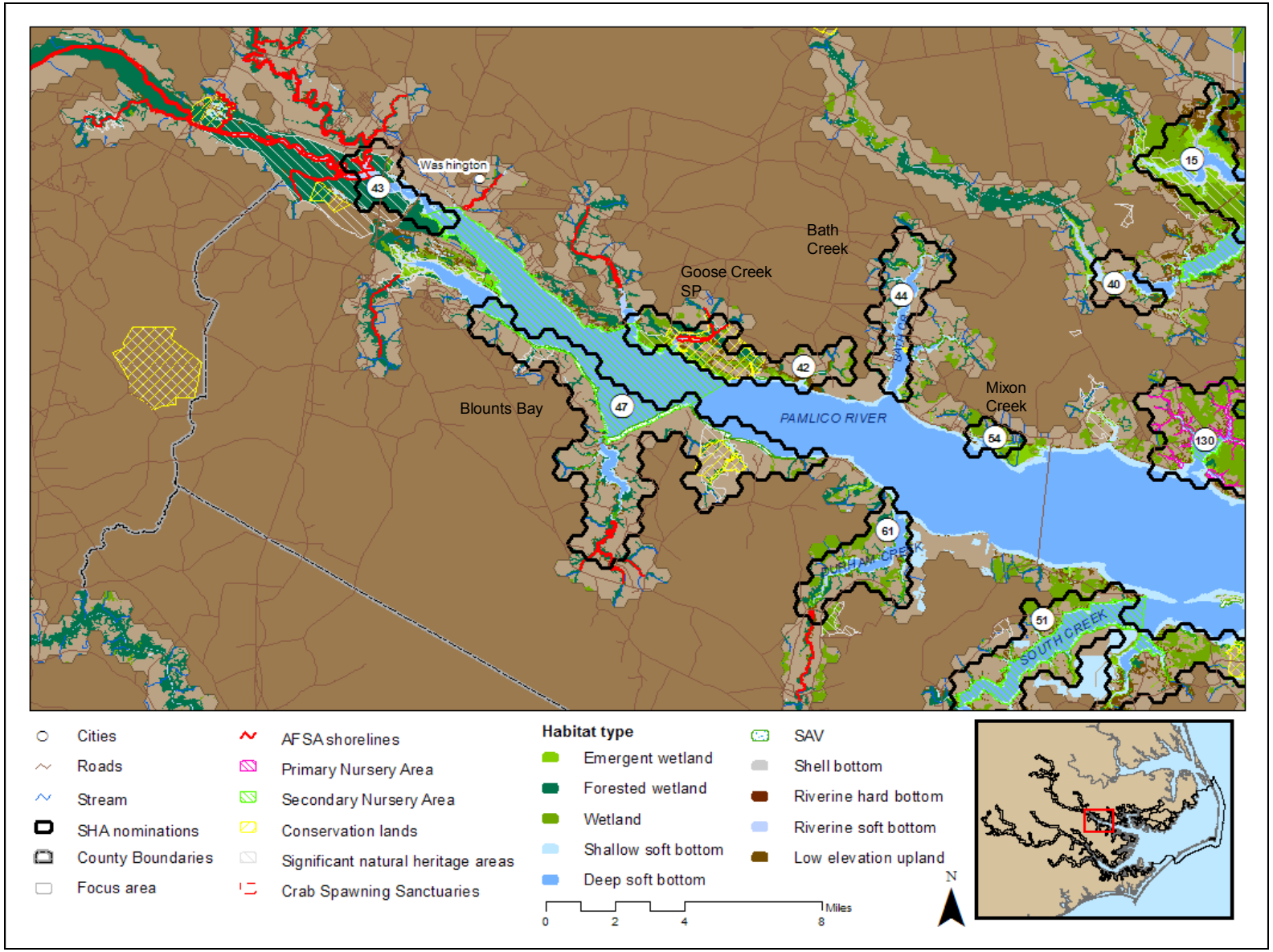
Map 10.8. Region 2 Strategic Habitat Areas (SHAs): Pamlico River mouth and bays, including Juniper, Swanquarter, Rose, Porpoise, and Jones bays (SHAs 52, 60, 69, 70, 65, & 57).



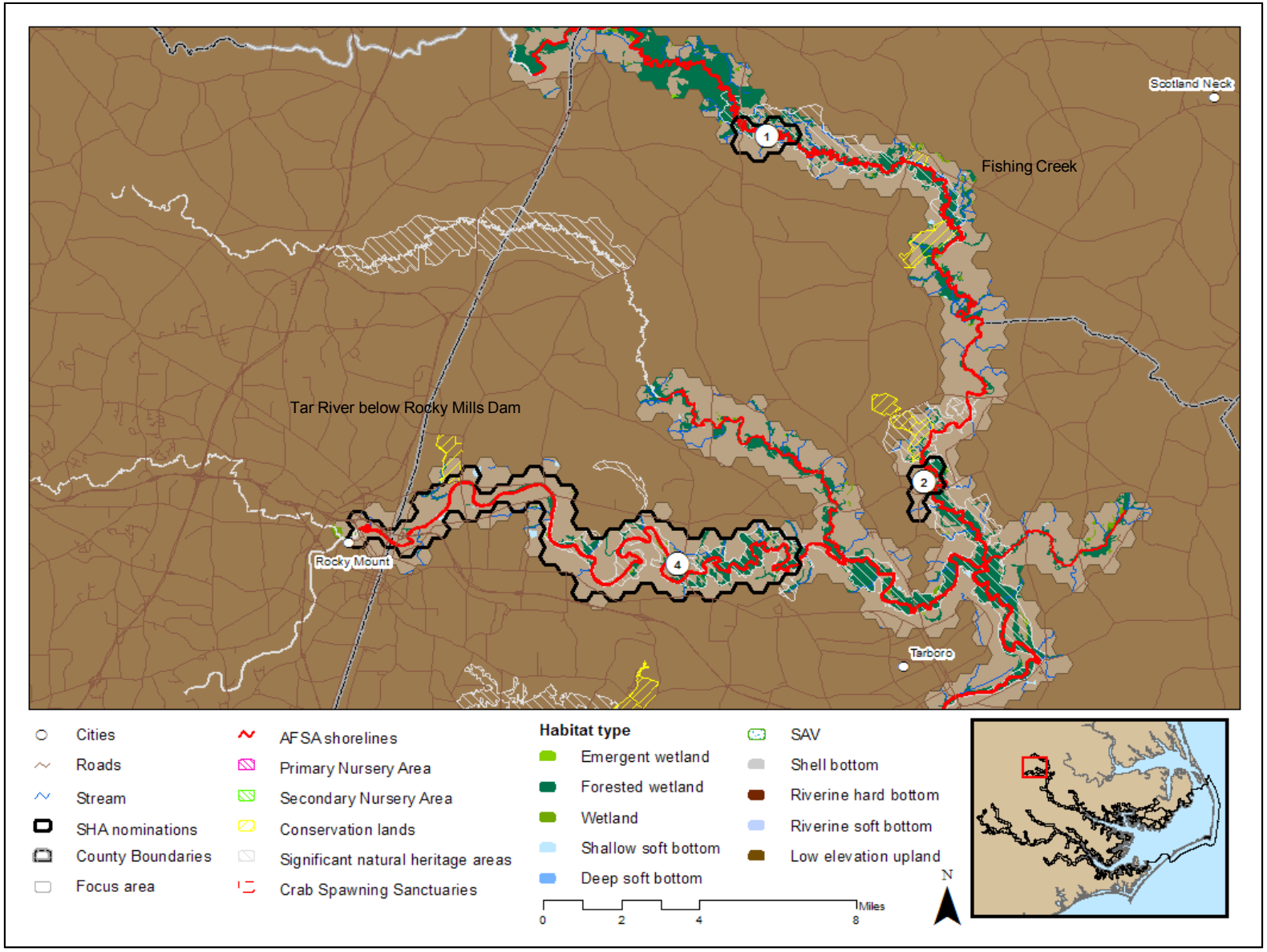
Map 10.9. Region 2 Strategic Habitat Areas (SHAs): Pungo and lower Pamlico rivers, including Pungo, Pantego, Downy, and Slade creeks (SHAs 60, 130, 128, 40, 15, 41, 147, 17, & 54).



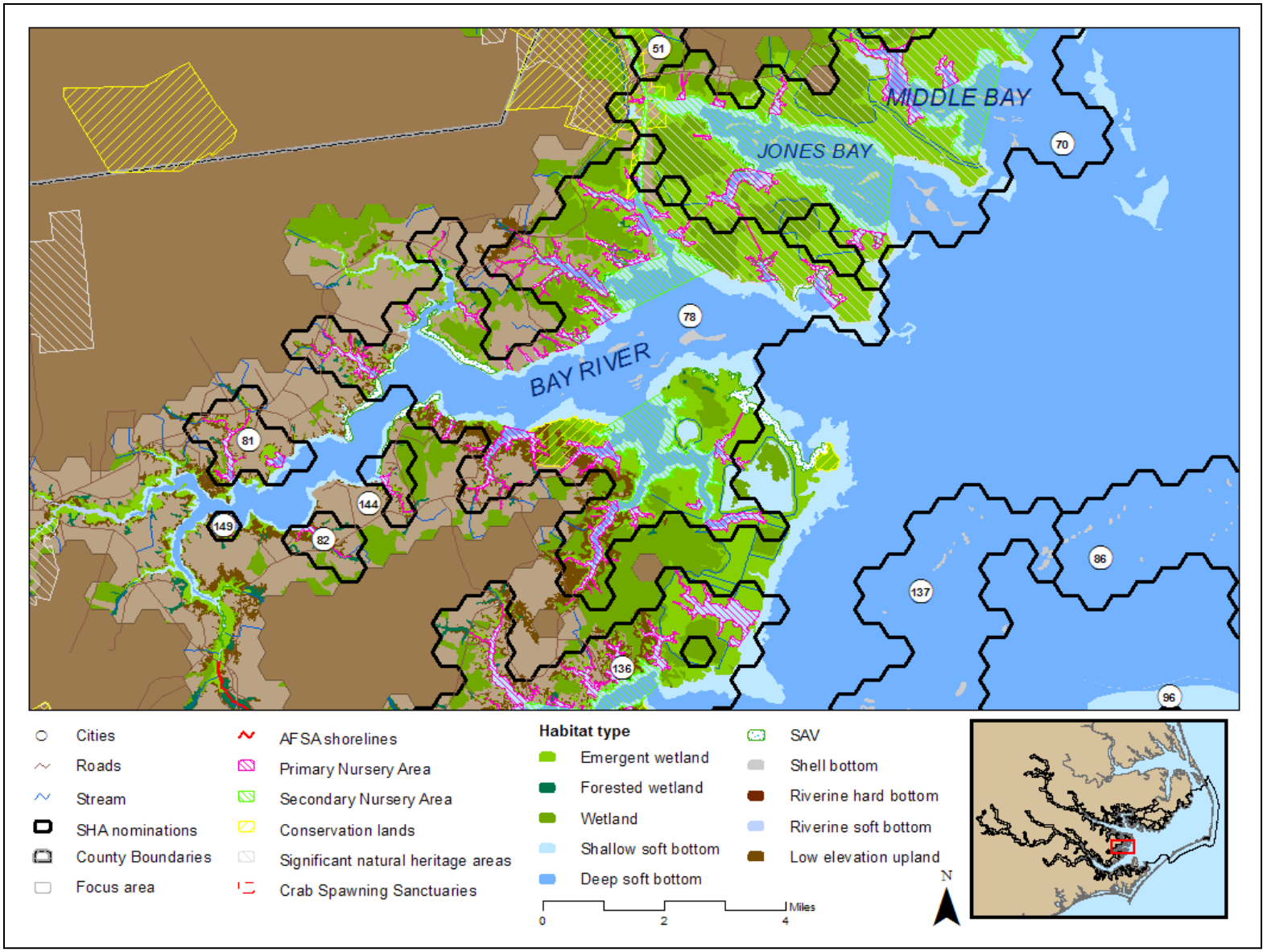
Map 10.10. Region 2 Strategic Habitat Areas (SHAs): Pamlico River, South Creek area (SHAs 51, 61, 44, & 54).



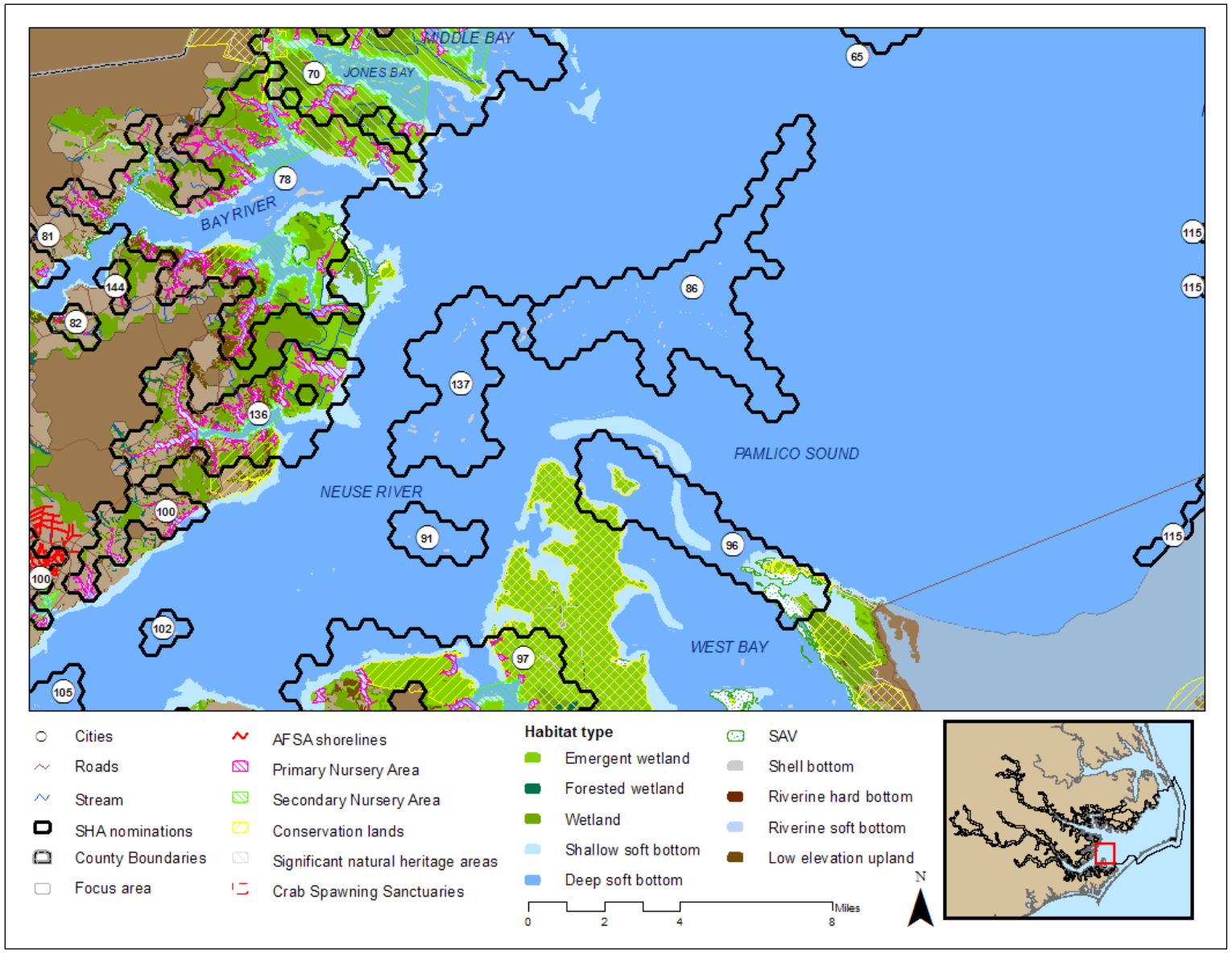
Map 10.11. Region 2 Strategic Habitat Areas (SHAs): Pamlico River near Washington, including Blount's Bay, Bath Creek, and Goose Creek State Park (SHAs 44, 42, 47, & 43).



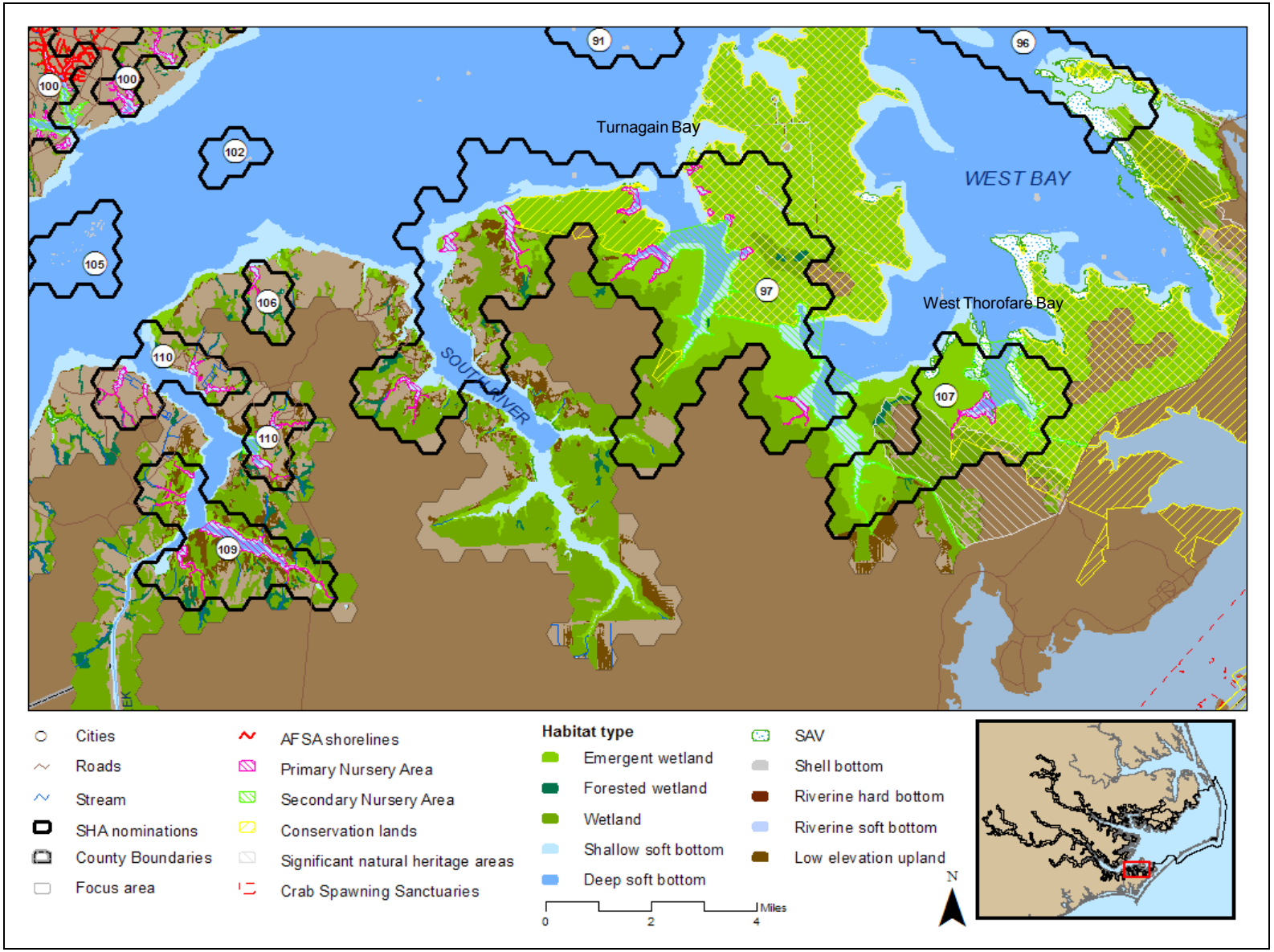
Map 10.12. Region 2 Strategic Habitat Areas (SHAs): Upper Pamlico River near Rocky Mount (SHAs 2, 4, & 1).



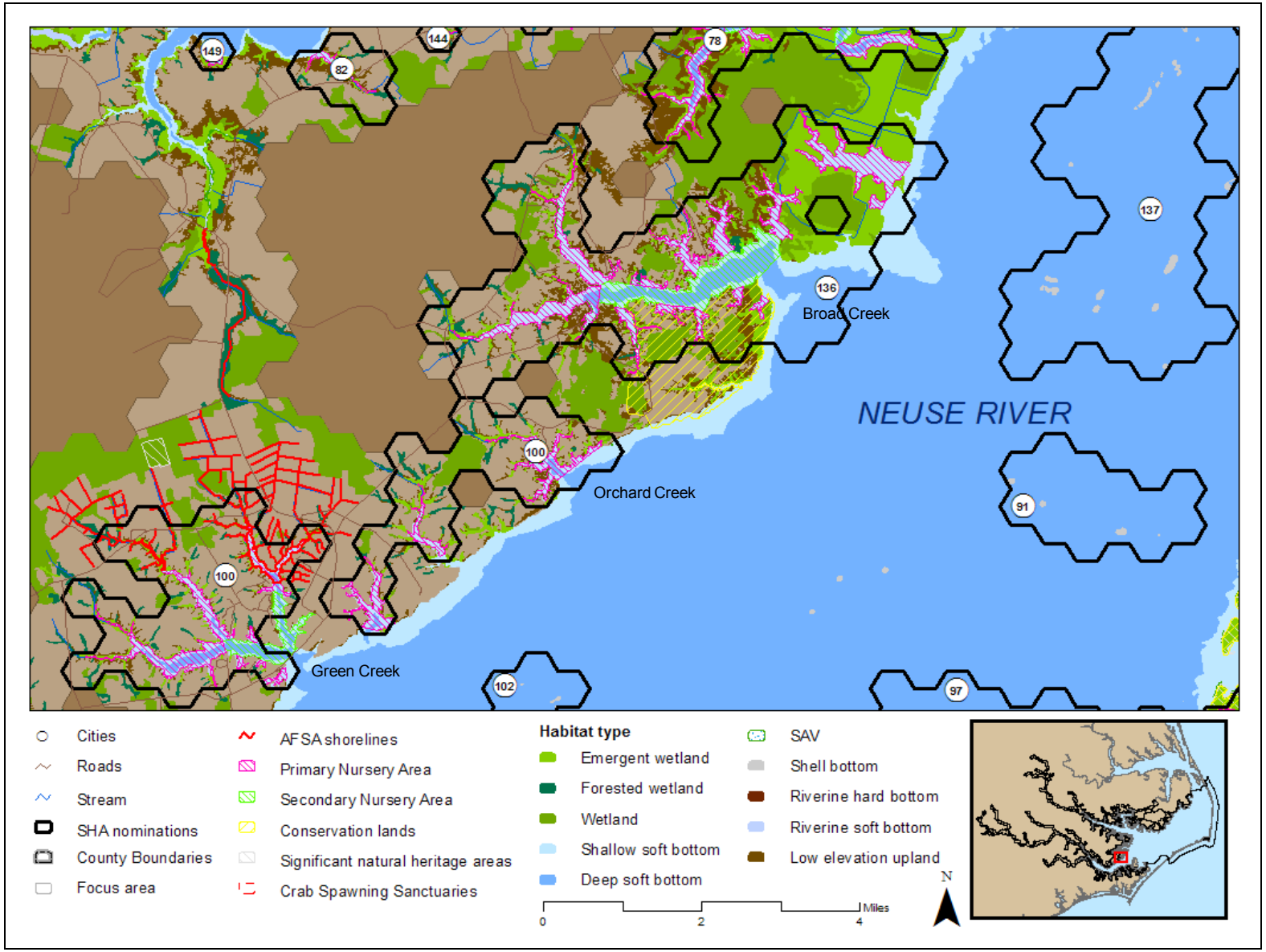
Map 10.13. Region 2 Strategic Habitat Areas (SHAs): Neuse River bays (SHAs 78, 81, 144, 149, & 82).



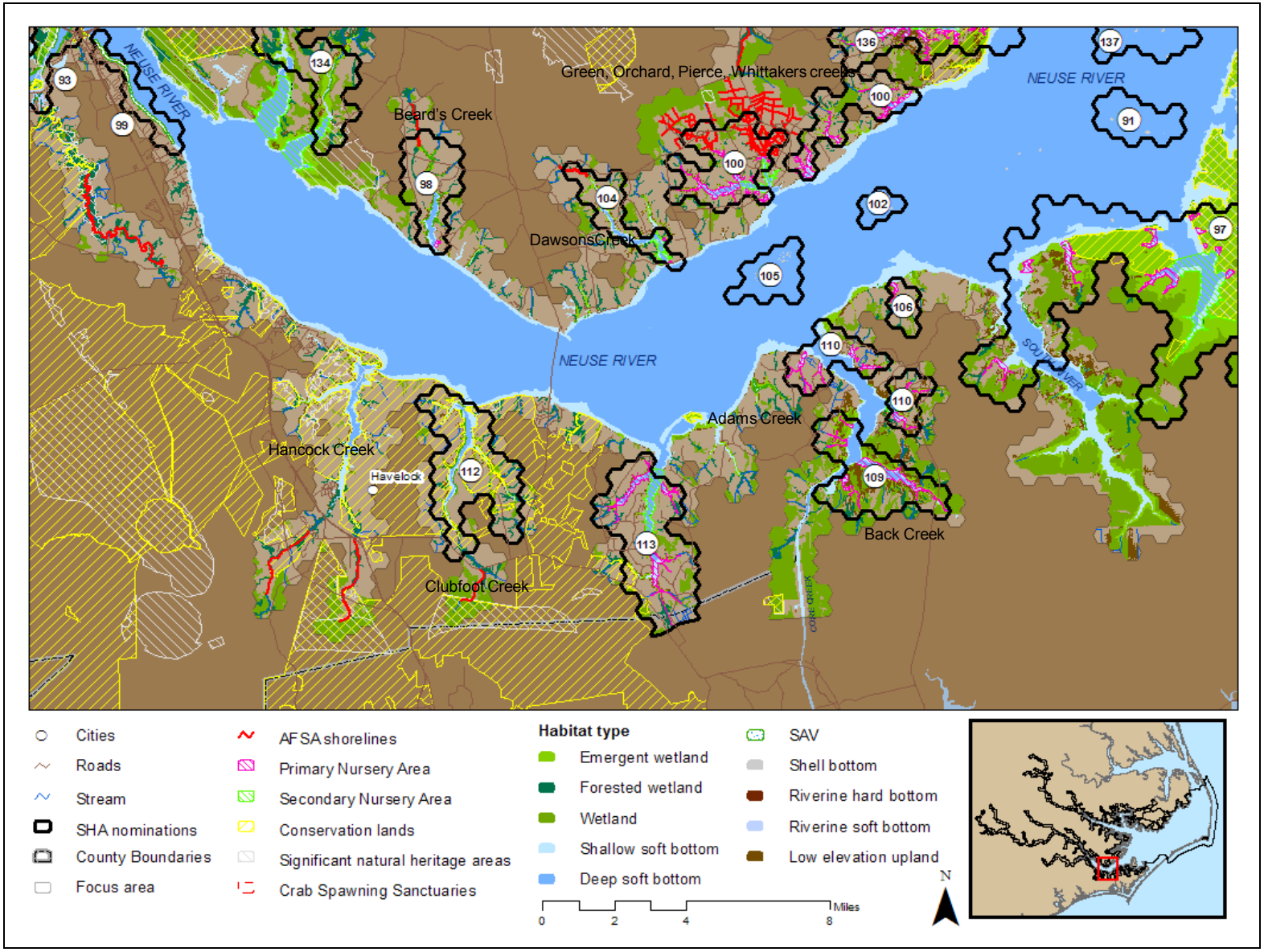
Map 10.14. Region 2 Strategic Habitat Areas (SHAs): Neuse River mouth (SHAs 137, 86, 91, & 96).



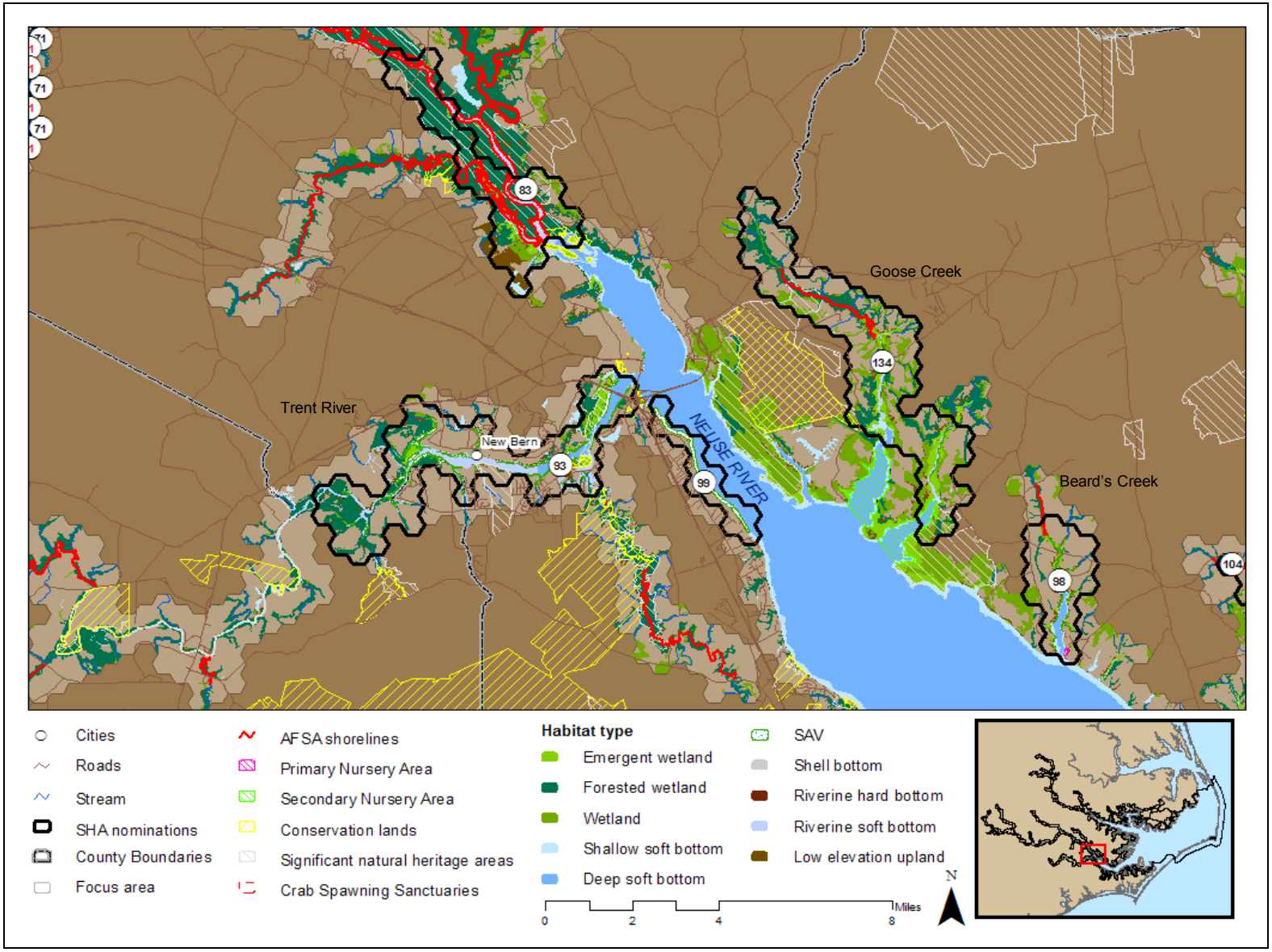
Map 10.15. Region 2 Strategic Habitat Areas (SHAs): Lower Neuse River, South River, West Bay (SHAs 97, 107, 106, 109, & 110).



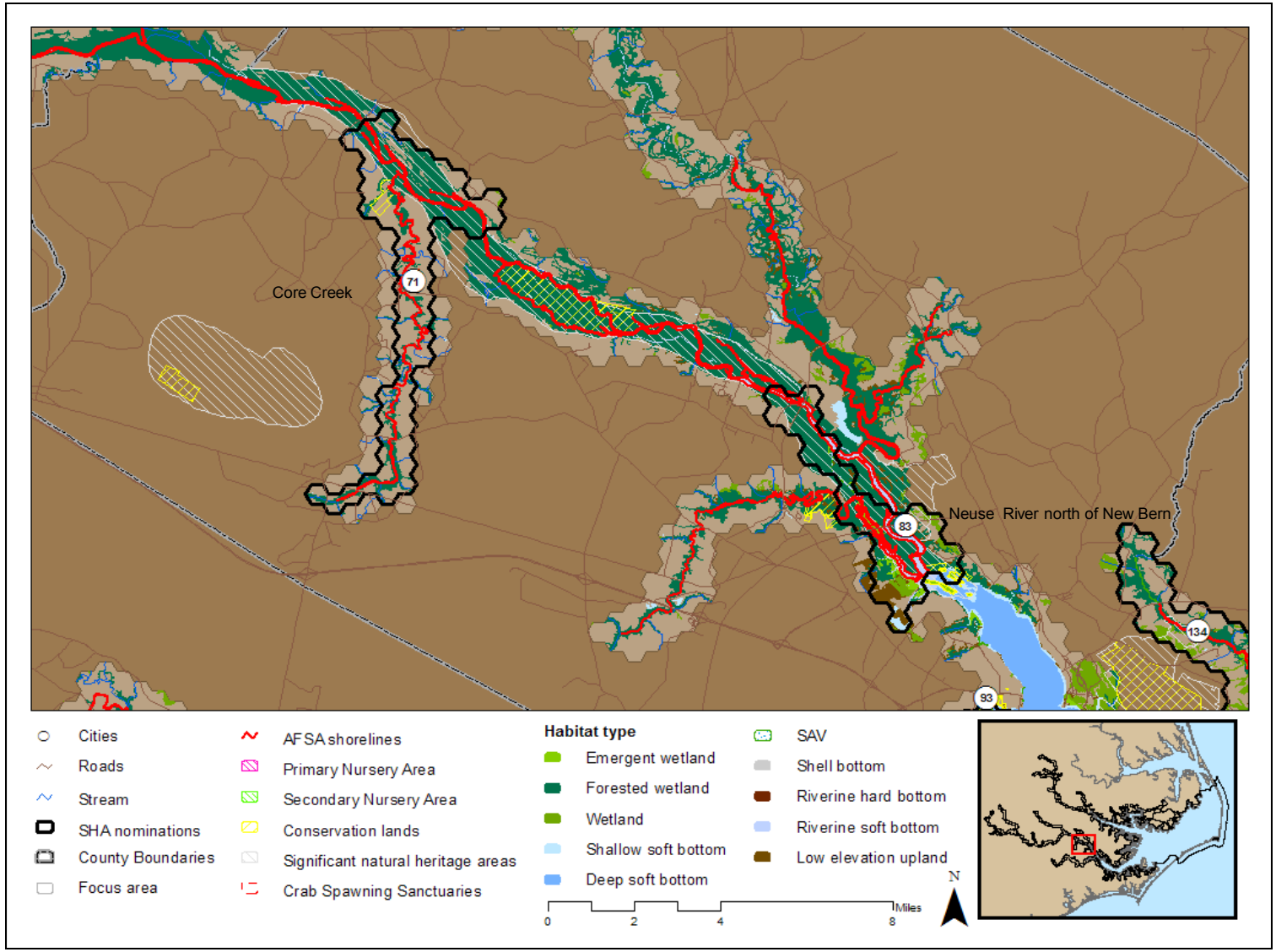
Map 10.16. Region 2 Strategic Habitat Areas (SHAs): Lower Neuse River and Broad, Orchard, and Green creeks (SHAs 136 & 100).



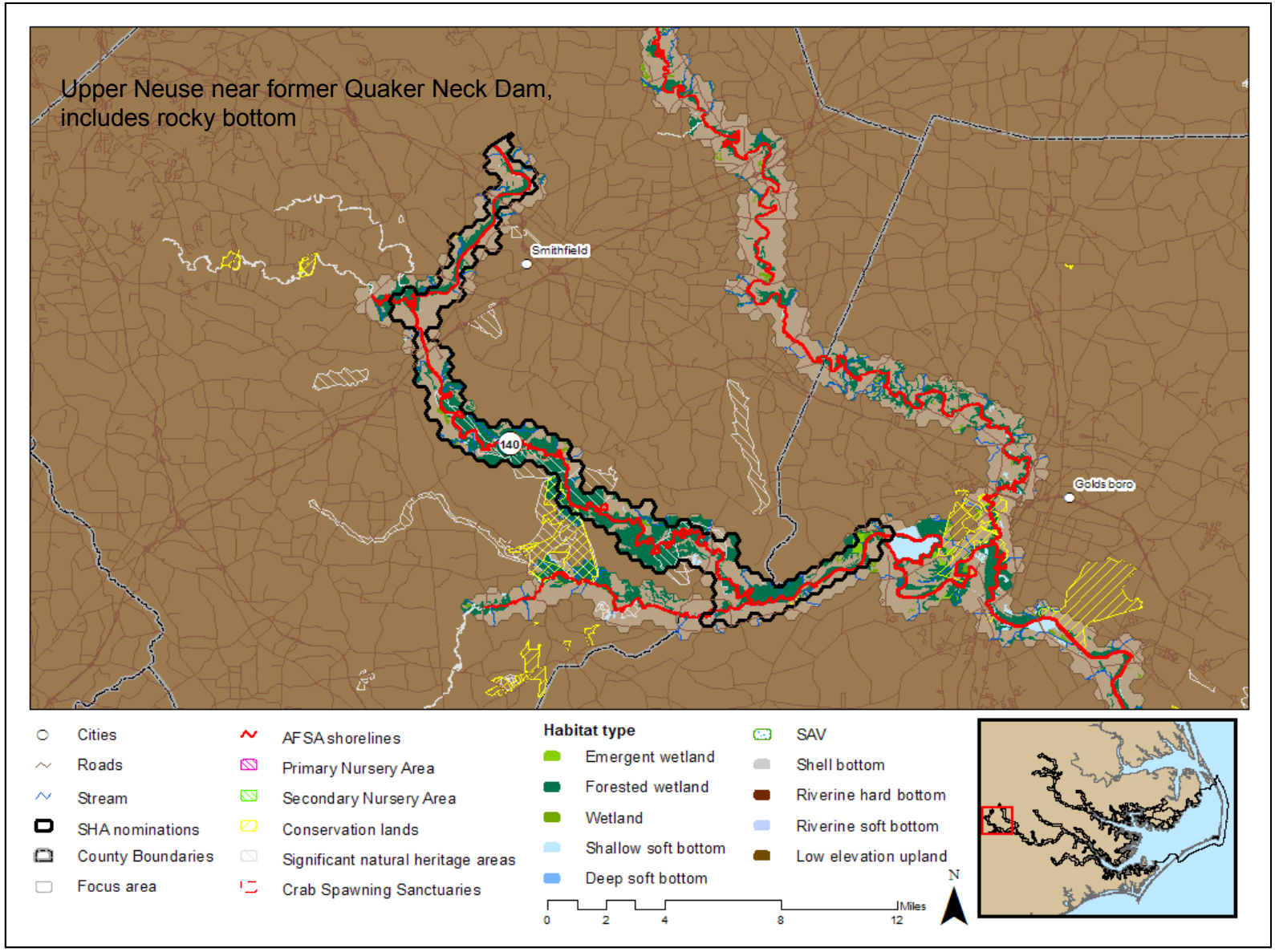
Map 10.17. Region 2 Strategic Habitat Areas (SHAs): Mid Neuse River including Dawson's, Adams, Hancock, and Clubfoot creeks (SHAs 105, 102, 104, 98, 113, & 112).



Map 10.18. Region 2 Strategic Habitat Areas (SHAs): Neuse River, New Bern area, including Trent River (SHAs 134, 99, & 93).



Map 10.19. Region 2 Strategic Habitat Areas (SHAs): Upper Neuse River and Core Creek (SHAs 83 & 71).



Map 10.20. Region 2 Strategic Habitat Areas (SHAs): Upper Neuse River, Goldsboro area (SHA 140).

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APPENDIX A: DATA/INFORMATION DIRECTORY

Regional (SHA) GIS File Structure on K:\fish\chpp\SHA related\Region 2\Inputs and outputs\[1]

1. R2_hydrologic_units
2. R2_sha_nominations
3. R2_subregions
4. R2_subregions_oregon_inlet_cut

Alteration factors

Alteration (The following is Jen Weaver's geodatabase containing the modified alteration files used in the analysis):

1. Conversions
    a. conv_by_hex
    b. trawling_updated
    c. uplands_to_ag
    d. uplands_to_dev
    e. wetlands_to_ag
    f. wetlands_to_dev
2. land_based
    a. anop_by_huc
    b. lu_by_huc
    c. marinas_over_10
    d. NPDES_by_huc
    e. Prohibited_shellfish_areas
    f. Slips_per_m_hu
    g. Waste_ponds
3. water_based
    a. canal_bb
    b. culvert_obstructed
    c. ditch_lines_focusarea
    d. drained
    e. dredged
    f. impounded
    g. mpra_danger_restricted
    h. seawalls
    i. storm_gate_obstructed
    j. water_based_merge
4. alt_habitat
5. hexagons
6. huc_boundaries
7. mines_per_hu
8. streams_by_hex

[1] Files include only themes created specifically for SHA region 2 – other data sources can be clipped to SHA region from the coast-wide GIS (K:\Fish\Chpp\Coastwide data\).

Alteration tools (The following are ArcGIS version 10.0 custom toolboxes created by Jen Weaver that contain the GIS models used to create the alteration data layers listed above. Duplicate toolboxes are available for ArcGIS version 9.3.1 in the same folder (labeled 'Alteration tools 93')).

1. Alteration habitat processing
    a. Make riparian uplands
    b. Make riparian wetlands
    c. Make streams
2. Data processing
    a. Aggregate marinas by HU
    b. Aggregate point features by HU
    c. Calculate marinas per shoreline
3. Extent calculation
    a. Land-based extent
    b. Physical conversions extent
    c. Water-based extent

The following alteration files were created by Scott Chappell and may or may not have been used in the final analysis:

1. R2_altered_lulc_agri_by_nrt_polygons
2. R2_altered_lulc_dev_by_nrt_polygons
3. R2_altered_riparian_wetlands_lost_to_lulc_agri
4. R2_altered_riparian_wetlands_lost_to_lulc_dev
5. R2_animal_operations
6. R2_aquaculture_2009
7. R2_bottom_disturbing_fishing_gear
8. R2_canals_boat_basins
9. R2_canals_ditches_nhd
10. R2_converted_low_elevation_uplands
11. R2_culverts
12. R2_damsR2_ind_munic_waste_ponds
13. R2_lulc2001_by_hu
14. R2_NC_railroads
15. R2_NPDES_sites_hu
16. R2_nwi_impoudment
17. R2_possible_channelized_streams
18. R2_riparian_low_high_elv_uplands_lost_to_lulc_agri
19. R2_riparian_low_high_elv_uplands_lost_to_lulc_dev
20. R2_storm_gates_FWS
21. R2_upstream_impediments

Corroborating information

The following files were created by Scott Chappell and may or may not have been used in the final analysis.

1. 915_biodiversity_bysample
2. Biodiversity_pooled_spm
3. Prg120_biodiversity_nonnull
4. Prg120_cpue_all_onemin_trawls_nonnull
5. Prg120_pna_spp_nonnull
6. Prg915_abund_SpatialJoin

7. R2_corroboration_Oct2010_metadata
8. R2_dwq_impaired_waters_2010

MARXAN files

The following files were created by Scott Chappell and may or may not have been used in the final analysis.

1. R2_corroboration_Dec2010
2. R2_hexagons
3. R2_hexagons_focusarea
4. R2_MARXAN_clusters_Dec2010
5. R2_stage1_nominations_Dec2010

Natural Resource Targets

The following files were created by Scott Chappell and may or may not have been used in the final analysis.

1. R2_connected_wetlands
2. R2_intertidal_flats
3. R2_marine_intertidal_flats
4. R2_nrt_lines
5. R2_nrt_lines_focus_area
6. R2_nrt_polygons_focus_area
7. R2_riverine_estuarine_marine
8. R2_riverine hard bottom
9. R2_USACE_ReefBottoms

Final things (The following is Jen Weaver's geodatabase containing final SHA files):

1. Alterations
    a. R2_alteration_score
2. Boundaries
    a. map_index
    b. North_Carolina
    c. R2_boundary
    d. R2_focus_area_boundary
    e. R2_hexagons
    f. R2_hexagons_focus_area
    g. R2_hexagons_focusarea_habitatonly
    h. R2_hydrologic_units
    i. R2_subregional_index
    j. R2_subregions
    k. SHA_regions
3. Corroboration
    a. Corroboration_hex
    b. Hex_points_with_habitats
    c. SHA_nominations
4. Fish_data
    a. fish_values
    b. p120_all_cpue
    c. p120_biodiversity_pna

   d. p195_fall_points
   e. p1915_abundant_species_CPUE
   f. p915_biodiversity
5. Habitats
   a. alteration_habitat_types
   b. PNAs
   c. R2_nrt_lines
   d. R2_nrt_lines_focus_area
   e. R2_nrt_polys
6. MARXAN
   a. MARXAN_output
   b. MARXAN_solution
   c. pu
   d. puvsp_habitats
   e. puvsp_lines
   f. puvsp_PNA
7. GP_2_abund
8. GP_3_abund
9. R2_waterbody_names
10. R2_waterbody_namesAnno
11. R2_waterbody_namesAnno2

R2_corroboration_Dec2010

Unit_id	Description	Coastwide	Region2 only
Area	Acres		
Ipna	Inland Primary Nursery Area	X	
Pna	Primary Nursery Area	X	
Sna	Permanent Secondary Nursery Area	X	
Afsa	Anadromous Fish Spawning Area	X	
Css	Crab Spawning Sanctuary	X	
Os	Oyster Sanctuary	X	
Ar	Artificial Reef	X	
Hb	Hard bottom (point)	X	
Orw	Outstanding Resource Waters	X	
Hydrounit	Hydrologic Units	X	
Snha_a	Significant Natural Heritage Areas (national)	X	
Snha_b	Significant Natural Heritage Areas (state)	X	
Snha_c	Significant Natural Heritage Areas (regional)	X	
Shoreline	Shoreline hexagons	X	
R1_sha	R1 SHA nominations		X
Pna_locked	PNA hexagon	X	
Canal_bb	Canals and boat basins		X
Culvert	Culvert obstructed		X
Impounded	Impounded		X
Lock	Lock obstructed		X
Dredged	Dredged	X	

Unit_id	Description	Coastwide	Region2 only
Drained	Drained	X	
Military	Military impacts/ordinance	X	
Seawall	Vertical shoreline stabilization	X	
Wet_dev	Wetlands converted to development		X
Bottom_gea	Bottom disturbing fishing gear		X
Wet_ag	Wetlands converted to agriculture		X
Up_dev	Riparian uplands converted to development		X
Up_ag	Riparian uplands converted to agriculture		X
Waste_pond	Industrial waste pond		X
Shellfish	Shellfish closures	X	
Maj_npdes	Major NPDES	X	
Min_npdes	Minor NPDES	X	
Docks	Marinas and docks	X	
Maj_anop	Major Animal operations		X
Min_anop	Minor Animal operations		X
Cost_10_8	Total alteration		X
Eew	Estuarine emergent wetland	X	
Efw	Estuarine forested wetland	X	
Ehiw	Estuarine human impacted wetland	X	
Essw	Estuarine shrub/scrub wetland	X	
Esb6	Estuarine soft bottom (>6ft)		X
Esb03	Estuarine soft bottom (0-3ft)		X
Esb36	Estuarine soft bottom (3-6ft)		X
Esbnd	Estuarine soft bottom (ND)		X
Hw	Headwater wetland	X	
Hssav	High salinity SAV		X
Imsb	Intertidal marine soft bottom		X
Isbhd	Intertidal shell bottom (high density)	X	
Isbld	Intertidal shell bottom (low density)	X	
Lsbnb	Lacustrine soft bottmo (ND)		X
Leu	Low elevation uplands		X
Lssav	Low salinity SAV		X
Msb6	Marine soft bottom (>6ft)		X
Msb03	Marine soft bottom (0-3ft)		X
Msb36	Marine soft bottom (3-6ft)		X
New	Non-riparian emergent wetland	X	
Nfw	Non-riparian forested wetland	X	
Nhiw	Non-riparian human impacted wetland	X	
Nssw	Non-riparian shrub/scrub wetland	X	
Psbnd	Palustrine soft bottom (ND)	X	
Rew	Riverine emergent wetland	X	
Rfw	Riverine forested wetland	X	

Unit_id	Description	Coastwide	Region2 only
Rhiw	Riverine human impacted wetland	X	
Rhb	Riverine hard bottom		X
Rsb6	Riverine soft bottom (>6ft)		X
Rsb03	Riverine soft bottom(0-3ft)		X
Rsb36	Riverine soft bottom (3-6ft)		X
Rsbndl	Riverine soft bottom (ND) - lower		X
Rsbndm	Riverine soft bottom (ND) - middle elevation		X
Rsbndu	Riverine soft bottom (ND) - Upper		X
Ssbhd	Subtidal shell bottom (high density)	X	
Ssbld	Subtidal shell bottom (low density)	X	
We	Wetland edge	X	
Ns	Non-wetland shore	X	
She	Streams-high elevation		X
Sle	Streams-low elevation		X
Sme	Streams-middle elevation		X
Hbp	Hard bottom (possible)	X	
Sfg	Sound fish group (program 195)		X
Rfg	River fish group (program 195)		X
PNA_ac	PNA (acres)	X	
Selnom1	Scenario 1 nominations		X
SelFreq1	Scenario 1 frequencies		X
SelNom2	Scenario 2 nominations		X
SelFreq2	Scenario 2 frequencies		X
SelNom3	Scenario 3 nominations		X
SelFreq3	Scenario 3 frequencies		X
SelNom4	Scenario 4 nominations		X
SelFreq4	Scenario 4 frequencies		X
SelNom5	Scenario 5 nominations		X
SelFreq5	Scenario 5 frequencies		X
P915_richness	Program 915 fish species richness (avg)		X
P915_Diversity	Program 915 fish species diversity (avg)		X
P915_N	Program 915 sample size		X
P915_abund	Program 915 fish abundance (avg)		X
P120_richness	Program 120 fish species richness (avg)		X
P120_diversity	Program 120 fish species diversity (avg)		X
P120N	Program 120 sample size		X
AvgOfSou_flndr	Program 120 flounder abundance (avg)		X
AvgOfBl_crab	Program 120 crab abundance (avg)		X
AvgOfBrn_shrimp	Program 120 shrimp abundance (avg)		X
AvgOfSpot	Program 120 spot abundance (avg)		X
AvgOfAtl_croak	Program 120 croaker abundance (avg)		X

APPENDIX B: CALCULATING TOTAL ALTERATION

Alteration scores are calculated for each hexagon and take three things into account:

1) **S**everity of an alteration factor/threat to each natural resource target (**S** rating).
2) **E**xtent that an alteration factor/threat affects each natural resource target (**E** rating)
3) **P**ortion of total natural resource targets in hexagon consisting of natural resource target X (**P** rating).

Severity (S) ratings in Table 2 were based on the individual habitat ratings for each threat listed in the threats table of the CHPP (Street et al. 2005, p. 486) and approved by the MFC, CRC, EMC, and DENR in 2004. This rating ranges from 0 (no impact) to 3 (high impact) and estimates the potential impact of each alteration factor for each habitat type. For water-based factors, such as trawling or dredging, the rating in the CHPP (Street et al. 2005, p. 486) was directly applied. For land-based alteration factors (i.e., land use/land cover), an adjusted S rating is applied to all hexagons within a hydrologic unit (HU). This adjusted S rating scales the intensity of activity to the maximum occurring within the region. To do this, first the relative intensity of the alteration is computed for each HU within the region by dividing by the maximum value occurring in the region. These values are then multiplied by the severity ratings given in Table 2 to get the adjusted severity for each particular alteration/habitat combination in each hexagon. An example is shown in table B-1. For example, if the severity rating for agricultural land use on SAV habitats is 2, and the hexagon lies within an HU with 40% cropland coverage where the maximum percent cover in the study area is 50 (0.80 intensity of alteration), the resulting S rating for that hexagon would be 2 x 0.80 = 1.60 (Table B-1).

Table B-1. Examples of calculating the adjusted S (severity) value for land-based factors.

Hexagon	% crop cover	Scaled intensity	Adjusted S in SAV
A	0	0	2 x 0 = 0
B	40	0.8	2 x 0.8 = 1.60
C	50 (maximum value)	1.0	2 x 1 = 2

Extent (E) ratings were determined by calculating the percent of the habitat within the hexagon that is affected by the factor. For water-based factors, such as dredging, the threat may only overlap with a portion of the habitat present. For land-based alteration factors, the E rating is simply 1 (complete overlap) for hexagons fully within a hydrologic unit.

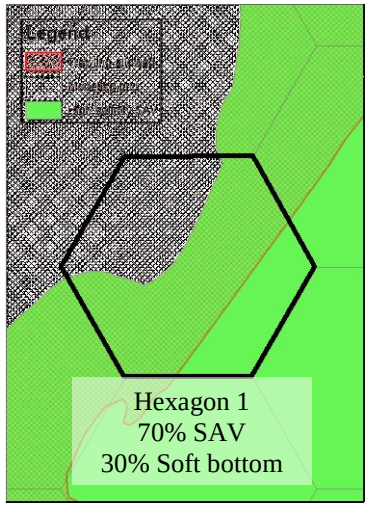

Figure B-1. Calculation of E rating for hexagon-based (water-based) alteration factors. Trawling (e.g., trawling, dredging).

Portion (P) ratings are calculated as [Acres of habitat X / Acres of all natural resource targets present within the hexagon].

The total alteration of each habitat in a hexagon with one alteration factor is determined by multiplying S, E and P ratings: **Habitat X weight rating = S x E x P** (Figure B-1).

For example: a hexagon has one alteration factor – trawling, and contains 70 acres of SAV and 30 acres of subtidal soft bottom (Figure B-1, Table B-2). Within the 70 acres of SAV, trawling is allowed over 60% (E=0.6). The S rating of trawling on SAV is 2 (moderate) and the portion of SAV among targets in the hexagon is 70% or 0.7. The final rating for SAV would be S (2) x E (0.6) x P (0.7) = 0.84. Within the 30 acres of soft bottom, trawling is allowed over 100% (E = 1). The portion (P) of the soft bottom among targets in the hexagon is 30% or 0.3. The S rating for trawling on soft bottom is 1. The final rating for soft bottom is S(1) x E(1) x P(0.3) = 0.3. The total alteration of the hexagon would be 1.14 (0.84 + 0.30).

Table B-2. Calculation of hexagon alteration with only one alteration factor, but which occurs in some portion of two habitat types. S=severity, E=extent, P=portion

Hexagon#	Natural Resource Target	Total area (acres)	$S_{trawling}$	$E_{trawling}$	P	S x E x P	Total weight
Hexagon1	SAV	70	2	0.60	0.70	0.84	1.14
	Soft bottom	30	1	1.00	0.30	0.30	

Where more than one factor is present within a hexagon, the weight for each habitat (all factors) is

determined by summing the S x E of each factor and multiplying by the percent of that habitat comprising the targets (P). The habitat alterations are summed to obtain one total alteration value for each cell (Table B-3).

Table B-3. Example of calculations to determine total alteration level of one hexagon with multiple alterations and habitats occur.

		S x E values				
Factor type	**Factors**	**Soft bottom**	**SAV**	**Wetlands**	**Shell bottom**	**Water lines**
Water-based	Culverts	0	0	2x0.2	0	2x0.5
	Dams/ impoundments	0	0	0	0	0
	Ditching/drainage/ channelization	0	0	2x0.2	0	0
	Forestry	0	0	0	0	0
	Boating activity	1x0.4	1x0.2	0	1x0.3	0
	Bottom trawling	1x0.5	2x0.5	0	2x0.2	0
	Navigation channels and inlet dredging	1x0.2	2x0.1	0	2x0.2	0
	Clam kicking	1x0.1	0	0	0	0
	Ports	0	0	0	0	0
	Conditionally approved closed	0	0	0	0	0
	Conditionally approved open	0	0	0	0	0
	Permanent closures	0	0	0	0	0
Land-based	Construction activities	0.02	0.04	0.06	0.04	0.1
	Cropland	0.1	0.2	0.2	0.1	0.5
	Development	0.06	0.18	0.06	0.18	0.45
Sum		1.38	1.82	1.12	1.42	2.05
Fraction of targets (P)		0.25	0.25	0.25	0.25	0.50
Sum x P		0.345	0.455	0.28	0.355	1.025
Total alteration for Hexagon 1		**2.46**				

PROCESSING DETAILS

For the region 2 analysis, the alteration calculations were completed using a combination of ArcGIS tools and R scripts. This approach was useful because it allowed the alteration scores to be quickly recalculated as changes were made throughout the SHA process. While the processing models and scripts are currently specific to the data found in this region, they could easily be adapted for the analyses in the following regions. Future changes could also include coding the alteration processing to be completely done in ArcGIS using the Python language.

All processing tools and data are provided in the alteration folder. This folder has four subfolders labeled data, docs, output, scripts, and scratch. It also includes the Alteration tools toolbox, which contains all of the ArcGIS tools described below. The process began by building a geodatabase of alteration data layers. Some manipulation was required to create the input layers for the alteration score. Tools were created using ArcGIS ModelBuilder with ArcGIS version 9.3.1. ModelBuilder allows the user to string together multiple tools and then execute them as a single process. The benefit to this approach was that it made the process transparent and easy to repeat.

The first step in creating the alteration score is to create the alterations habitat dataset. This is stored in the field ALT_HABITA in the following steps. Below is a table showing the relationship between NRT types for Region 2 and the habitat types for alteration.

Alteration habitat type	**NRT types**
Creeks/rivers	Riverine hard and soft bottom
Deep soft bottom	All estuarine and marine soft bottom deeper than 6 feet
Interior wetland	All wetlands that are greater than 15 m from a shoreline
Riparian wetland	All wetlands within 15 m of a shoreline
SAV	Low and high salinity SAV
Shallow soft bottom	Soft bottom less than 6 feet in depth
Shell bottom	Subtidal and intertidal shell bottom
Stream	Polygons 4m in diameter centered on stream lines
Upland	Low elevation upland and land within 15 m of a non-wetland shoreline that is not identified as an NRT

It is assumed that a dataset of NRT habitat types has the ALT_HABITA field populated before the alteration score calculations can begin. Begin by dissolving the NRT polygons by ALT_HABITA to get a feature class of alteration habitats (hereafter referred to as alt_habitat). The following describes the tools provided in the alterations toolbox. It is divided into three toolsets, which are numbered and in all caps below. Tool names are in bold, under the corresponding toolset. In order to run the tools, double click on the name. Right clicking and choosing 'edit' will allow you to see the full process diagram, which can be helpful if things need to be adjusted for future analysis.

1. DATA PROCESSING

These are miscellaneous tools that were used to create some of the inputs to alteration factors. They can be reused if need be but are provided more for convenience. Currently the tools are set to the input and output files that were used in the Region 2 analysis.

Aggregate point features by HU

Assigns the frequency of a point feature to the corresponding hydrologic unit in a polygon feature class of hydrologic units. Needs a HU feature class and the point feature to aggregate. Allows the user to choose the field or fields to aggregate. The output file contains the frequency of these fields and is named to match the names of the input fields the tool aggregates. The model is currently set for the animal operations layer, but it could be used for NPDES or any other point file as well.

Aggregate marines by HU

Counts the number of slips at marinas in each hydrologic unit and joins the result to a shapefile of hydrologic units. A marina is defined as a facility with greater than 10 slips. The output is currently a feature class marinas_by_huc2 that is located in the alterations geodatabase under the land_based feature set.

Calculate marinas per shoreline

Calculates the 'marinas per shoreline metric' by calculating the number of slips per linear unit of shoreline for each hydrologic unit and joining it to the hydrologic unit feature class. This tool uses the results of the previous tool (Aggregate marinas by HU) as inputs. The output has the number of slips per meter of shoeline in a HU in the field 'slips_per_m'.

2. ALTERATION HABITAT PROCESSING

These tools are all used in the initial steps of the alteration score calculation to manipulate the input features to make them compatible with the manner in which alteration scores are calculated. For example, the stream lines are converted to small polygons 4 meters in width centered on the stream line to calculate the overlap with most alteration factors. These tools manipulate the alterations habitat feature class, which is created by dissolving the NRT polygons by the field ALT_HABITA. It must have the attribute field 'ALT_HABITA', which contains the habitat type for alteration, for these tools to be effective. While not necessary, it is best to do these in the order they are presented below.

Make streams
Creates a streams polygon by adding a 2 m buffer to the steam lines in the study area and adds them to the NRT polygons shapefile.

Inputs: nrt polygons (with ALT_HABITAT attribute)
nrt lines (with field EDGE, one of which is 'Stream')
Output: updated alt_habitat polygon file with "ALT_HABITAT" for the streams polygons labeled "STREAM"

Make riparian wetlands
This tool identifies and labels wetland areas within 15 m of a wetland shoreline as riparian. Prior to this all ALT_HABITAT was listed as interior wetlands for all wetlands.

Inputs: nrt lines file, or any file with wetland edges labeled with the attribute 'EDGE= Wetland'
Alt_habitat polygons with all wetlands labeled as 'ALT_HABITA = interior wetlands'
Ouput: updated alt_habitat polygon file with riparian uplands included and labeled as 'Riparian wetland'

Make riparian uplands
This tool identifies all upland land within 15 m of a non-wetland shoreline not already in the polygon file as upland. THIS NEEDS TO BE RUN LAST.
Inputs: nrt line shapefile, with the wetland edge labeled as EDGE = Non-wetland
alteration habitat shapefile, all polygons should have a value assigned for ALT_HABITA at this point
Output: updated alteration habitat shapefile with the additional riparian uplands labeled as 'upland'

3. EXTENT CALCULATION

These tools calculate the extent files needed as the inputs for the R scripts. Outputs are saved as DBF tables and currently written to a folder called 'data'. Field maps are given below for all of the output tables. Currently they are organized by the aspect of habitat they affect; therefore, there is a separate tool for land-based, physical, and water-based alterations. This was done for this version because it was thought that the alteration scores were calculated the same way for each group of alterations. This ended up not being true. In future versions, it might make sense to rearrange these for the purpose of alteration score calculation. These tools can be executed from the dialog box (by double clicking on the tool name). At this point, the alterations habitat file is assumed to be named alt_habitat and located in the alteration geodatabase.

Land-based extent
This tool joins the land-based alterations to a hydrologic unit file to create a master table of alterations by hydrologic unit. Shellfish sanitation areas and wasteponds are kept separate because they are not extrapolated to the hydrologic unit for the purpose of the alteration calculations. It also creates a table giving the amount of each hydrologic unit in each hexagon; which is used to calculate the land-based alteration scores for hexagons that cross hydrologic unit boundaries.

Inputs:

1. Each land based alteration factor aggregated by HU. All of these are polygon feature classes except for the mines per HU input, which is a geodatabase table.
2. Polygon feature class of wastepond locations
3. Alteration habitats feature class
4. Hexagon boundaries, with hexagon ID
5. Hydrologic unit boundaries

Output: The following tables are output as DBFs:

1. hu_alt_factors_table.dbf: gives the amount of each alteration factor present by hydrologic unit

NC_VA_HU	12 digit hydrologic unit code
hu_area	Are of the hydrologic unit in square meters
maj_NPDES	Number of major NPDES sites per HU
min_NPDES	Number of minor NPDES sites per HU
maj_anop	Number of major animal operations sites per HU
min_anop	Number of minor animal operations sites per HU
dev_prop	Proportion of HU in developed land use
agri_prop	Proportion of HU in agriculatural land use
mines	Log transformed total area of mining operations in the HU
marinas	Number of slips per meter of shoreline for each HU

2. hu_by_hex.dbf: gives the areas of each hydrologic unit in each hexagon and the max area of a hydrologic unit in each hexagon. This is used to calculate scores for hexagons that cover hydrologic unit boundaries.

NC_VA_HU	12 digit hydrologic unit code
hu_area	Are of the hydrologic unit in square meters
maj_NPDES	Number of major NPDES sites per HU
min_NPDES	Number of minor NPDES sites per HU
maj_anop	Number of major animal operations sites per HU
min_anop	Number of minor animal operations sites per HU
dev_prop	Proportion of HU in developed land use
agri_prop	Proportion of HU in agriculatural land use
mines	Log transformed total area of mining operations in the HU
marinas	Number of slips per meter of shoreline for each HU

3. Wasteponds_by_hex_table.dbf: gives the area of waste ponds x habitat intersection for each hexagon

ALT_HABITA	Habitat type for alteration
ID	Hexagon ID
Shape_Leng	ArcGIS generated value for perimeter length
Shape_Area	ArcGIS generated value for shape area; area of waste pond/habitat overlap in square meters

4. shellfish_by_hex.dbf: gives the area of each hexagon that is comprised of closed shellfish waters and the habitats it intersects

ALT_HABITA	Habitat type for alteration
ID	Hexagon ID
Shape_Leng	ArcGIS generated value for perimeter length
Shape_Area	ArcGIS generated value for shape area; area of closed shellfish area/habitat overlap in square meters

Physical conversions extent

This tool combines the physical alterations into one feature class giving the presence/absence of each alteration and the area affected within each hexagon.

Inputs:

1. Alterations habitat feature class
2. Hexagons feature class, with hexagons labeled with a unique ID number (ID)
3. Polygon feature classes giving the areas affected by each of the 5 physical conversions:
    a. Upland converted to agriculture
    b. Upland converted to developed
    c. Wetland converted to agriculture
    d. Wetland converted to developed
    e. Trawling

Output:

Conv_by_hex.dbf: Each line represents a unique combination of hexagon, habitat, and alteration. The output is a table gives presence (1) or absence (0) of each alteration factor for each area described in the table. The field Shape_Area gives the area of each polygon overlap feature.

ID	Hexagon ID
ALT_HABITA	Alteration habitat type
wet_dev bottom_gea wet_ag up_dev up_ag	Identifies the alteration present. 1 for presence and 0 for absence.
Shape_Leng	ArcGIS generated value for perimeter length
Shape_Area	ArcGIS generated value for shape area
alt_area	Area of alteration/habitat overlap in square meters; should match Shape_Area

Water-based extent

Note: this makes the habitat per hexagon and lines per hexagon tables that are used in all of the following R scripts.

Inputs:

1. Polygon feature classes of the areas affected by water-based alteration factors:
    a. Ditches
    b. Drained wetland areas
    c. Dredged areas
    d. Storm gate obstructed areas
    e. Impounded areas
    f. Culvert obstructed areas
    g. Canals and boat basins
    h. Military areas
2. Line feature classes of areas affected by water-based alteration factors:
    a. Seawalls feature class
    b. Ditch lines feature class
3. Alteration habitats feature class
4. Hexagons feature class
5. NRT lines file

Outputs:

1. hab_alt_by_hex_table.dbf - Each line represents a unique combination of hexagon, habitat, and alteration. The output is a table gives presence (1) or absence (0) of each alteration factor for each area described in the table. The field Shape_Area gives the area of each polygon overlap feature.

ALT_HABITA	Habitat type for alteration
canal_bb culvert impounded lock dredged drained military	Identifies the alteration present. 1 for presence and 0 for absence.
ID	Hexagon ID
Shape_Area	Area of alteration/habitat combination in m^2

2. streams_by_hex_table.dbf – gives a list of the streams found in each hexagon, the length of the stream (Shape_leng)

ID	Hexagon ID
Shape_Leng	Length of stream feature, in meters
ID_1	Repeats the ID for ditches
ditch	1 for ditched streams, 0 otherwise
Shape_Le_1	Length of the ditch, if present
Prop_ditch	Proportion of ditched stream in each hexagon

3. seawalls_by_hex_table.dbf: Gives the amount of seawalls in each hexagon

EDGE	Type of line feature; should be Non-wetland for all
ID_1	Hexagon ID
Shape_Leng	Length of stream in hexagon, in meters
wall_len	Length of seawall in hexagon, in meters

4. shoreline_by_hex_table.dbf: lists the shorelines found in each hexagon

EDGE	Wetland or Non-wetland
ID_1	Hexagon ID
Shoreline	Length of shoreline in m

5. hab_by_hex_table.dbf

ALT_HABITA	Habitat type for alteration
ID	Hexagon ID
Shape_Leng	ArcGIS generated value for perimeter length
Shape_Area	ArcGIS generated value for shape area
hab_area	Habitat area in m^2; should match Shape_Area

R Tools for use in calculating alterations

These take the outputs of the previous steps (in ArcGIS) and use them to combine the severity, extent and portion into the alteration score for each hexagon. There are three separate scripts to calculate the severity x extent ratings: one each for the physical, water-based, and land-based alteration groups. The outputs from these scripts are then combined into the total alteration score in one final script (alteration

scores.r). Input and output file locations are in the top portions of all scripts and can be easily changed to match where the data is stored. All scripts require a csv file of the severity ratings in order to calculate the severities for each alteration/habitat combination in each hexagon. This file gives the severity (0-3) for each alteration/habitat combination. Alterations and habitats that do not overlap are assigned a value of 0 for the purpose of calculating the scores. The alteration severity file for region 2 is located at docs/alt_factor_ratings_final.csv. Column names are alteration factors and row names are alteration habitat types. Names are case sensitive and must match those that are in the output tables from the Arc scripts. Columns do not have to be in any particular order; the scripts will select the correct ones.

Each script file has two sections: a top section labeled inputs and a lower portion labeled calculations. In order to use these for different files, it will be necessary to open them and change the directories listed under the inputs section to match the correct file locations. The working directory needs to be set to the alteration folder. The output directory is where the outputs of the script will be placed (currently the folder 'output'). All files except for the csv of habitat severities are outputs of the ArcGIS tools described in the previous sections. Each input section contains a list of the alterations included in each script (found at line 9). In order to add other alterations in future analyses, these lists would need to be amended with the field names of the new alterations. Corresponding columns would need to be added to the alterations by habitat tables (hu_alt_factors.dbf, conv_by_hex.dbf or hab_alt_by_hex_table.dbf) giving the extent of each alteration in each hydrologic unit or hexagon and consistent with their current format. In addition, the severity for new alterations would need to be added to the alteration severity file.

Water based severity extent calculation.r

Input files:

1) Table listing the area-based alterations x habitat combinations per hexagon. Needs to have the fields:
    a. ALT_HABITA – alteration habitat type, must be one of the following: "Creeks/rivers", "Deep soft bottom", "Interior wetland", "Riparian wetland", "SAV" , "Shallow soft bottom", "Shell bottom", "STREAM", "upland"
    b. ID – unique hexagon identifier
    c. Shape_Leng – assigned for each feature class in arcGIS
    d. Shape_Area – assigned for each feature class in arcGIS; area of habitat in each hexagon
    e. alt_area - area of habitat intersection the by alteration factor in each hexagon
    f. Fields for any polygon based alterations considered. Currently I have these:
        i. "canal_bb" "culvert" "impounded" "lock" "dredged" "drained" "military"
        ii. each row gives the presence/absence (1/0) of one specific factor for each hexagon
        iii. each hexagon has multiple rows, one for each habitat type x factor combination

2) Table giving amount of each polygon habitat in each hexagon with the following fields:
    a. ALT_HABITA – alteration habitat type
    b. ID - unique hexagon identifier
    c. Shape_Leng - assigned for each feature class in arcGIS
    d. Shape_Area - assigned for each feature class in arcGIS
    e. hab_area – same as shape area

3) Alteration severity table
    a. Rows – habitat types (ALT_HABITA)
    b. Columns – alterations(must match names used in the alt file, are case sensitive as well
    c. Matrix of alteration x severity makes up the table

4) Raw file for length of seawalls by hexagon
    a. EDGE – identifier giving shoreline type, either "Wetland or "Non-Wetland"
    b. ID_1 – unique hexagon identifier

   c. wall_len – length of seawall in hexagon

5) Length of streams with an amount ditched attribute. Necessary attributes:
   a. ID – hexagon identifier
   b. prop_ditch – proportion of stream ditched per hexagon (calculated in the arc script)

6) Length of shorelines in each hexagon
   a. EDGE – identifier giving shoreline type, either "Wetland or "Non-Wetland"
   b. ID_1 – unique hexagon identifier
   c. Shoreline – length of shoreline

Output: Severity multiplied by extent for all water based factors for each hexagon, in dbf and csv form: wbse.csv and wbse.dbf

Land based severity extent calculations.r
Input files:

1) Table of factors for each hydrologic unit (hu_alt_factors_table.dbf):
   a. NC_VA_HU – 12 digit hydrologic unit ID
   b. hu_area – area of hydrologic unit in meters
   c. Shape_Leng - assigned for each feature class in ArcGIS
   d. Shape_Area - assigned for each feature class in ArcGIS
   e. Currently the *unscaled* values for the affected amount for each HU:
      i. maj_NPDES – number of sites per HU
      ii. min_NPDES – number of sites per hu (includes aquaculture facilities)
      iii. docks - # of slips in marinas per m shoreline for each HU
      iv. maj_anop – number of sites per HU
      v. min_anop – number of sites per HU
      vi. dev_prop – proportion of area of each HU in developed land use class
      vii. agri_prop – proportion of area of each HU in agricultural land use class
      viii. mines – log of the area of mining operations present in each HU
2) Table giving amount of each polygon habitat in each hexagon (.dbf)
   a. ALT_HABITA – alteration habitat type
   b. ID - unique hexagon identifier
   c. Shape_Leng - assigned for each feature class in arcGIS
   d. Shape_Area - assigned for each feature class in arcGIS
   e. hab_area – area of habitat in meters; same as shape area
3) Table identifying which HU a hexagon is in (if a hexagon has more than one HU it will have more than one line):
   a. ID – hexagon ID
   b. NC_VA_HU – hydrologic unit
   c. hu_area – area of hydrologic unit
   d. Shape_Leng - assigned for each feature class in arcGIS
   e. Shape_Area - assigned for each feature class in arcGIS – area of hexagon in corresponding hydrologic unit
   f. FREQUENCY- number of HU's a hexagon intersects
   g. MAX_Shape_ - maximum area of hexagon in one HU
4) Alteration severity table:
   a. Rows – habitat types (ALT_HABITA)
   b. Columns – alterations(must match names used in the alt file, are case sensitive as well
   c. Matrix of alteration x severity makes up the table
5) wasteponds_by_hex_table.dbf - intersection of waste ponds with habitats in the study area
   a. ALT_HABITA – alteration habitat type
   b. ID – hexagon ID

   c. Shape_Leng - assigned for each feature class in arcGIS
   d. Shape_Area - assigned for each feature class in arcGIS (area in meters of the intersection)
6) shellfish_by_hex.dbf – intersection of closed shellfish areas with habitats in the study area
   a. ALT_HABITA – alteration habitat type
   b. ID – hexagon ID
   c. Shape_Leng - assigned for each feature class in arcGIS
   d. Shape_Area - assigned for each feature class in arcGIS (area in meters of the intersection)

Output file: lbse.csv

Physical conversion severity extent calculations.r
Input files:
1) Alteration severity table
2) Physical conversions by hexagon table (conv_by_hex.dbf)
   a. Each row represents a single combination of hexagon, habitat, and alteration. The hexagons are labeled in the field 'ID', the habitat is labeled in the field 'ALT_HABITA', and the alteration is designated by a 1 in the appropriate column. The field Shape_Area gives the area (in square meters) of the overlap for each row. The following alterations are currently included:
      i. wet_dev –wetlands converted to developed land use
      ii. bottom_gea – bottom disturbing gear
      iii. wet_ag – wetlands converted to agricultural land use
      iv. up_dev- uplands converted to developed land use
      v. up_ag- uplands converted to agricultural land use
3) Table giving amount of each polygon habitat in each hexagon (hab_by_hex_table.dbf)
   a. ALT_HABITA – alteration habitat type
   b. ID - unique hexagon identifier
   c. Shape_Leng - assigned for each feature class in arcGIS
   d. Shape_Area - assigned for each feature class in arcGIS
   e. hab_area – area of habitat in meters; same as shape area

Output file: cbse.csv

Alteration scores.r
Combines the output of the previous three scripts to make the overall output
All inputs and outputs go to a folder called data in the working directory
Inputs:
1) wbse.csv – severity by extent for water-based alterations
2) cbse.csv – severity by extent for physical conversions alterations
3) lbse.csv – severity by extent for land-based alterations. Note: this is already aggregated so that there's one row per hexagon whereas the other two severity by extent files are not.

4) Table giving amount of each polygon habitat in each hexagon (hab_by_hex_table.dbf)
   a. ALT_HABITA – alteration habitat type
   b. ID - unique hexagon identifier
   c. Shape_Leng - assigned for each feature class in arcGIS
   d. Shape_Area - assigned for each feature class in arcGIS
   e. hab_area – same as shape area
5) Length of shorelines in each hexagon ("data/lines_by_hex_table.dbf")
   a. EDGE – identifier giving shoreline type, either "Wetland or "Non-Wetland"
   b. ID_1 – unique hexagon identifier
   c. Shoreline – length of shoreline

Outputs (all of these currently go to the data folder):

1) alt_scores.csv, alt_scores.dbf - combined alteration scores for all hexagons. Includes hexagon ID [ID] and total alteration scores [r2_alt_sco]
2) pu.dat - Input file formatted for MARXAN (tab delimited and labeled correctly)
3) ind_scores.dbf - alteration scores broken down by alteration factor by hexagon. One line per hex gives the s x e x p for each alteration factor for each hexagon

APPENDIX C: INCORPORATION OF FISH ABUNDANCE DATA INTO THE MARXAN MODELING PROCESS

Fish abundance is important to include in the SHA designation process because it can reflect factors not otherwise included in the analysis that affect habitat quality. Fish abundance data was incorporated as corroborating data in the Region 1 nomination process because NCDMF's fishery independent sampling programs do not always follow a stratified random sampling design and lack the spatial coverage necessary for inclusion as a SHA target (NCDMF 2009). Unlike Region 1, fishery independent survey data with comprehensive spatial coverage is available for Region 2. Geographically, a large amount of the total area of Region 2 is the main body of Pamlico Sound, which shows little variability in habitat type or alteration score. Incorporating fish data into the MARXAN modeling process may provide an objective way to include abundance data and identify areas that are more important to fish production in an otherwise monotonous seascape.

The goal of this analysis was to create a data layer of fish abundance to use as an input to MARXAN. Specifically, it was thought that some areas labeled as 'estuarine soft bottom' could be more productive than others due to physical characteristics not captured by habitat data, such as currents or geographic location.

In order to create a data layer that could be incorporated into the MARXAN analysis, multivariate statistical techniques were used to identify groups of species that show similar patterns of occurrence based on abundance trends in Pamlico Sound and the lower portions of the major rivers. Multivariate statistical techniques were selected for the analysis because they allow for the incorporation of all species captured and reduce the amount of new data added into the modeling process, compared to adding all species separately. The resulting layers include species that are not recreationally or commercially fished, and may be important prey species for priority fish species. In addition, because they are not subject to direct fishing pressure, abundance of non-fished species may reflect true differences in habitat quality better than fished species. Once species groups were identified, geostatistical methods were used to create surfaces representing abundance of fish groups for the extent of the deep soft bottom habitats in region 2.

Methods

Fish were collected as part of the Pamlico Sound Survey (DMF program 195), which is a biannual trawl survey covering Pamlico Sound and the Neuse, Pamlico and Pungo Rivers. Samples were collected using a double rigged demersal mongoose trawl with 20 minute tows at 2.5 knots. All species are counted and measured; lengths and individual weights are recorded for a subset of more commonly occurring species. Sampling for the Pamlico Sound Survey usually occurs on the second and third week of June and September of each year, though sampling can often run longer due to weather delays. Survey methods have been consistent since 1991. Data collected from 1991 – 2008 samples were used for this analysis. Within each sampling period, 52-54 samples were collected. The sampling area is divided into seven strata, each with a minimum number of samples (in parentheses): Neuse River (5), Pamlico River (5), Pungo River (3), Pamlico Sound East (3 shallow, 3 deep) and Pamlico Sound West (3 shallow, 3 deep).

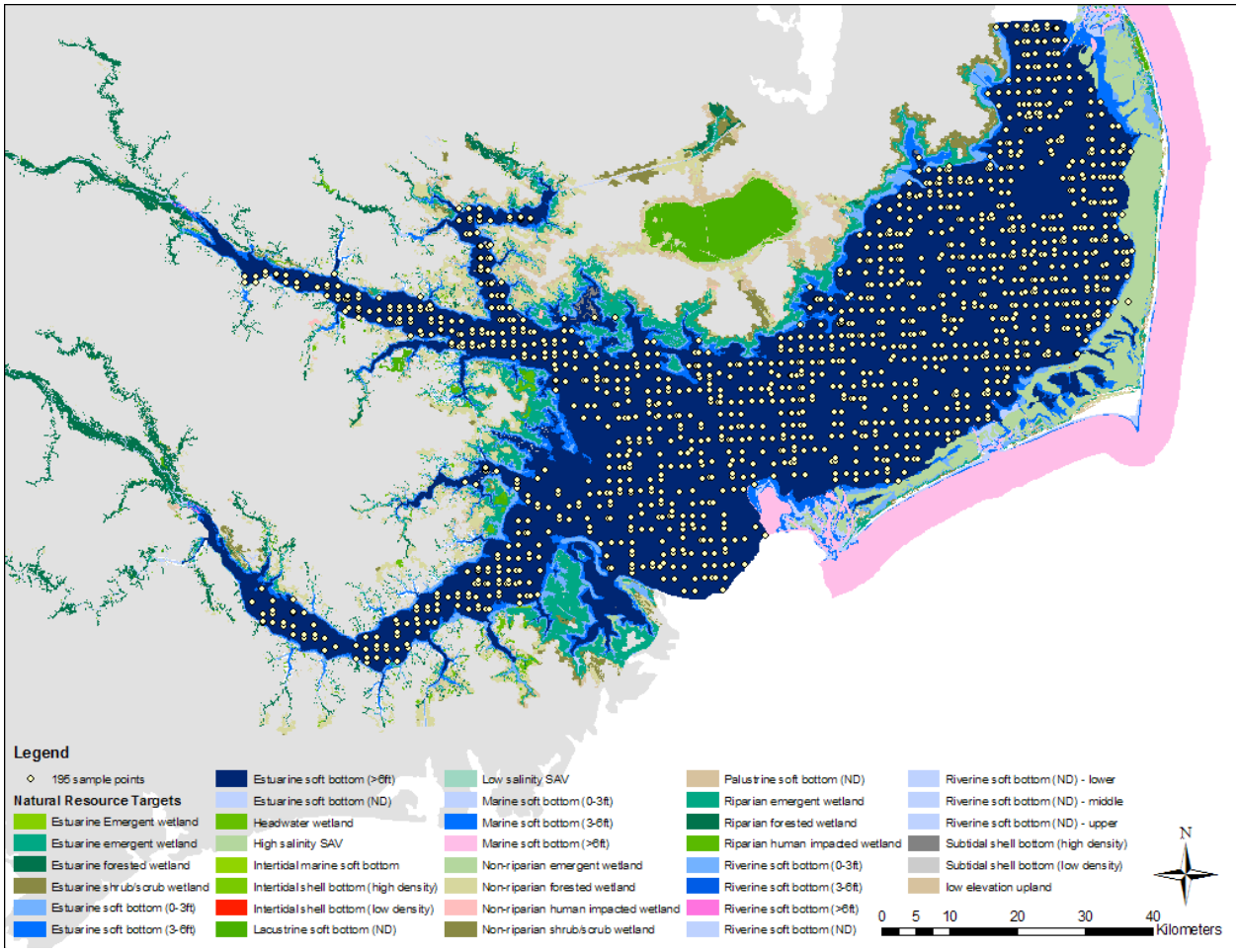

Figure 1: Map of program 195 sampling sites in region 2

Preliminary analyses and previous studies indicated a seasonal difference in estuarine fish assemblages (Ross & Epperly 1985), so analyses were done separately for fall and spring samples. After examining the results, the priority species identified for the Region 2 analysis were found mostly to occur in the fall samples, so analyses were focused on fall sampling data. Data were filtered to remove incomplete records or points with erroneous geographic coordinates. After filtering, the dataset consisted of 991 samples. Species that did not occur in more than 5% of the samples were removed, leaving 49 possible species to consider for community analysis.

Heirarchical cluster analysis was used to identify species with similar trends in abundance. Cluster analysis forms groups out of input units in a manner that minimized dissimalirity among the data. The process begins as the least dissimilar species are joined together to form a group. Once a group has been formed, dissimilarities are recalculated and a new grouping is made. This continues until all of the units of analysis have been joined into one group. The resulting structure is shown in a dendrogram, which displays the group associations relative to the amount of information lost by forming each connection. The less information lost, the more alike the group members are. Following the approach of Shertzer & Williams (2008), a double square root transformation was used, which reduces the effect of large abundances on similarity between sites and transforms the abundances into nearly presence/absence (McCune and Grace 2002). Bray-Curtis dissimilarity (Sorenson distance) was used to compute dissimilarity as it has been proven to give interpretable results in ecological studies and has been widely

applied to studies of fish assemblages (Shertzer & Williams 2008). All analyses were performed in PC-ORD (McCune and Mefford 1999), using the hierarchical clustering function.

Interpolation

Kriging interpolation was used to create a continuous surface of fish abundance values. Kriging differs from simpler interpolation methods because it accounts for error around observed points instead of creating surface that reflects the exact measured abundance at each location. Surfaces were created using the geostatistical analyst toolset in ArcGIS 9.3 (ArcGIS, Version 9.3; ESRI, Redlands, CA, USA), which allows the user to interactively fit and examine different models. Abundance for all group members was summed, and the natural logarithm of the summed abundance of all species for each group was used as the input for interpolation. Universal kriging was applied for each dataset because it allows for detrending. Total abundance was log transformed to meet the assumptions of the Kriging, which assumes a Gaussian error structure among the dependent variable. Anisotropy was present in both datasets, and modeled accordingly. Cross validation was used to examine the resulting model fits and to compare between models. The mapped results were also examined to ensure that the resulting models were appropriate. A raster of predicted values for each fish group across the study area was created, and used as the basis for the MARXAN input layer.

Creation of MARXAN input data

In order to get an input layer for use in MARXAN, the resulting grids were clipped to the extent of habitats labeled as estuarine deep soft bottom. Values were assigned to each hexagon for each fish group by identifying the value for each fish surface at the centroid of each hexagon in the planning unit. To derive a representation level for each fish group, the total amount in the study area was summed, and the desired percentage of the total was set as the representation level for each fish group.

Results

Outputs from the cluster analysis indicated that there data were split into two major groups (Figure 2). One consisted mostly of rare and incidental species that were not of interest to this project. The other group was split into four subgroups, two of which contained the species most important for the SHA process. It was decided to use these groups as the basis for creating a data layer of fish abundance. The spatial data indicates that one group is widely abundant throughout both the sound and the rivers, while the other is abundant only in Pamlico Sound.

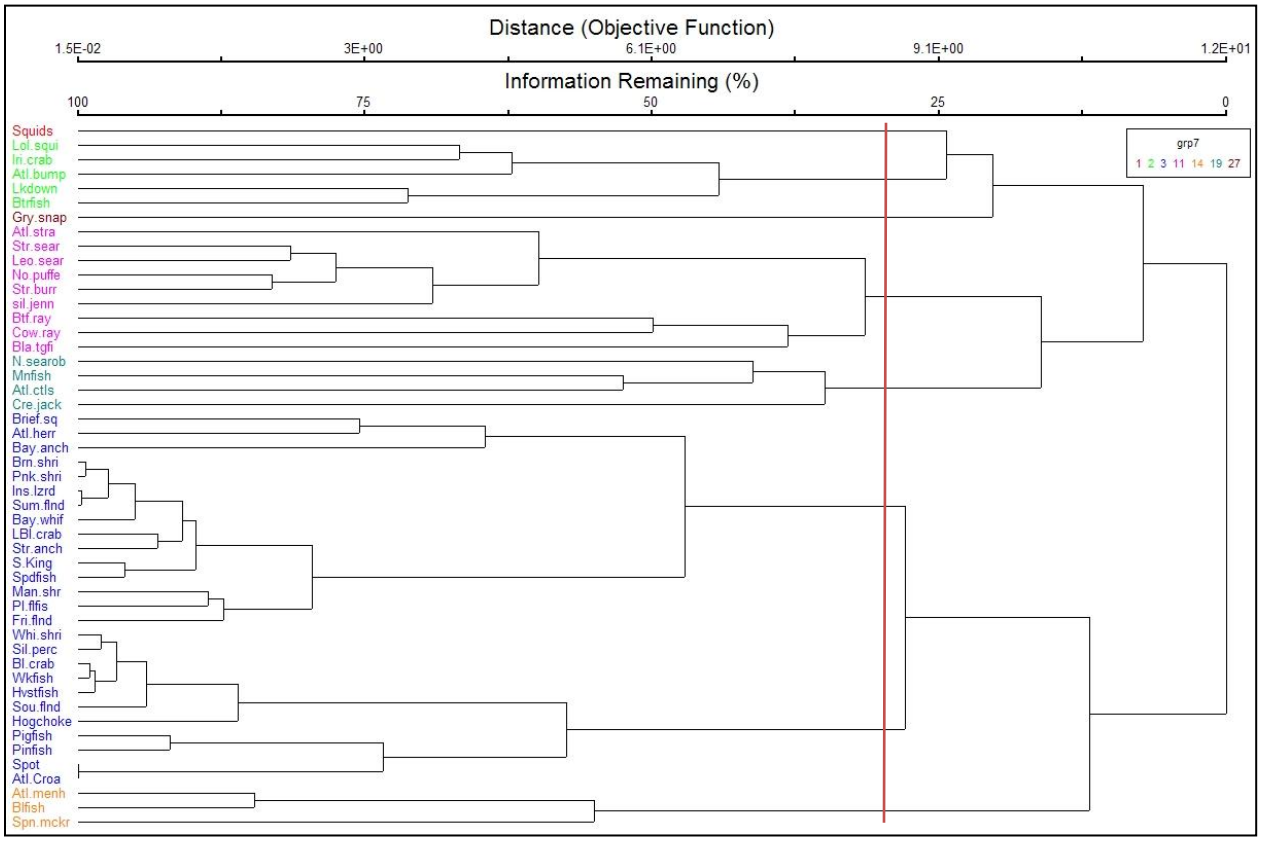

Figure 2: Output dendrogram from cluster analysis. Red line indicates where the tree was cut into groups.

Table 1. Species composition of the two fish abundance groups

Group 2 (River)	Spot, Croaker, Pinfish, Pigfish, Hogchoker, Southern flounder, Harvestfish, Weakfish, Blue crab, Silver perch, White Shrimp
Group 3 (Sound)	Fringed flounder, Planehead filefish, Mantis shrimp, Spadefish, Southern kingfish, Striped anchovy, Lesser Blue Crab, Bay whiff, Summer flounder, Inshore lizardfish, Pink shrimp, Brown shrimp

Interpolation was conducted for each of the two groups separately. Input parameters are shown in table 2. The interpolated surface for this group was fit using universal Kriging with a third order trend, which provided the best fit based on visual examination of the diagnostic plots. Abundance for the river group was highly variable, making the model difficult to fit. The model underpredicts the higher abundances and overpredicts the lower abundances, which is a common result of Kriging interpolation. Because kriging interpolation is dependent on correctly capturing the error structure, it is important that the prediction errors match the variability in the input dataset. Standardized mean prediction error was low (0.0292) indicating that overall the model was unbiased. QQ plots of the standard errors indicate that they are normally distributed, and similar to those from the observed data (standardized RMS 1.089). Average standard error (4.093) is higher than RMS (1.911), indicating that the model overestimates variability compared to the observed values. This can be seen in the predicted values, a few of which are far outside of the range of the observed data. The output interpolation map is more variable than the sound group because of the selection of a third order trend (figure 3). There are some extreme predictions at the edges of the map, outside of the area that was actually sampled. These were eliminated in the final layer by restricting the range of the output values to between 0 and 10. The range of input values was 0-9.05.

The sound group interpolation was fit with a first order trend, and is a better fit than the river group. There is still a general trend to overpredict points of low abundance and underpredict areas with high

abundance. Mean standard prediction error is close to zero (-0.019), indicating that the model is unbiased. Prediction errors appear to be normally distributed and average standard error (0.878) is similar to RMS (0.9718), indicating that modeled variability is similar to observed variability. The resulting surface has low abundance in upper reaches of the rivers, higher abundance in the middle of the sound, and some areas of extremely high abundance on the eastern edge of the sound that are probably prediction error. The range of the predicted values is -0.4 to 5.7, which is comparable to the input data points (0-5.61). Values below zero were converted to zeroes for the purpose of the MARXAN analysis.

Table 2. Input specifications for kriging interpolation of both fish groups

	Sound Group	River Group
Method	Universal Kriging	Universal Kriging
Output type	Prediction	Prediction
Trend type	1	3
Neighbors to include	5	5
Include at least	2	2
Sector type	Four and 45 degree	Four and 45 degree
Angle	43.78	47.41
Major semiaxis	54350.985	123575.29
Minor semiaxis	37261.222	68941.32
Trend removal	Global polynomial interpolation	Local polynomial interpolation
Power	1	1
Variogram	Semivariogram	Semivariogram
Number of lags	12	12
Lag size	4770.3	10883
Nugget	0.675114554	1.303
Measurement error	0	0
Model type	Spherical	Spherical
Range	54350.985	123575.29
Anisotropy	Yes	Yes
Minor range	37621.222	68941.32
Direction	43.78	47.41
Partial sill	0.532	0.398

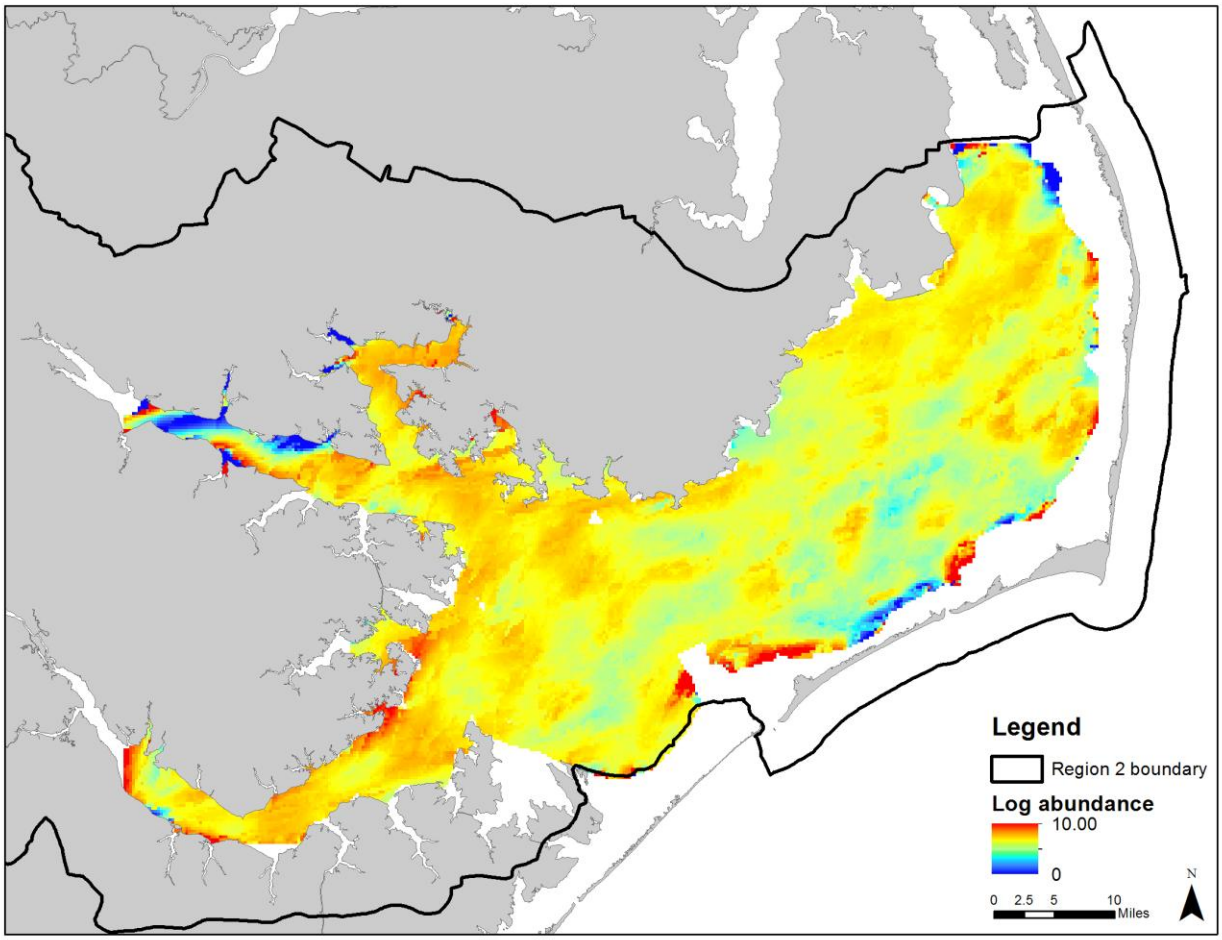

Figure 3: River group interpolation

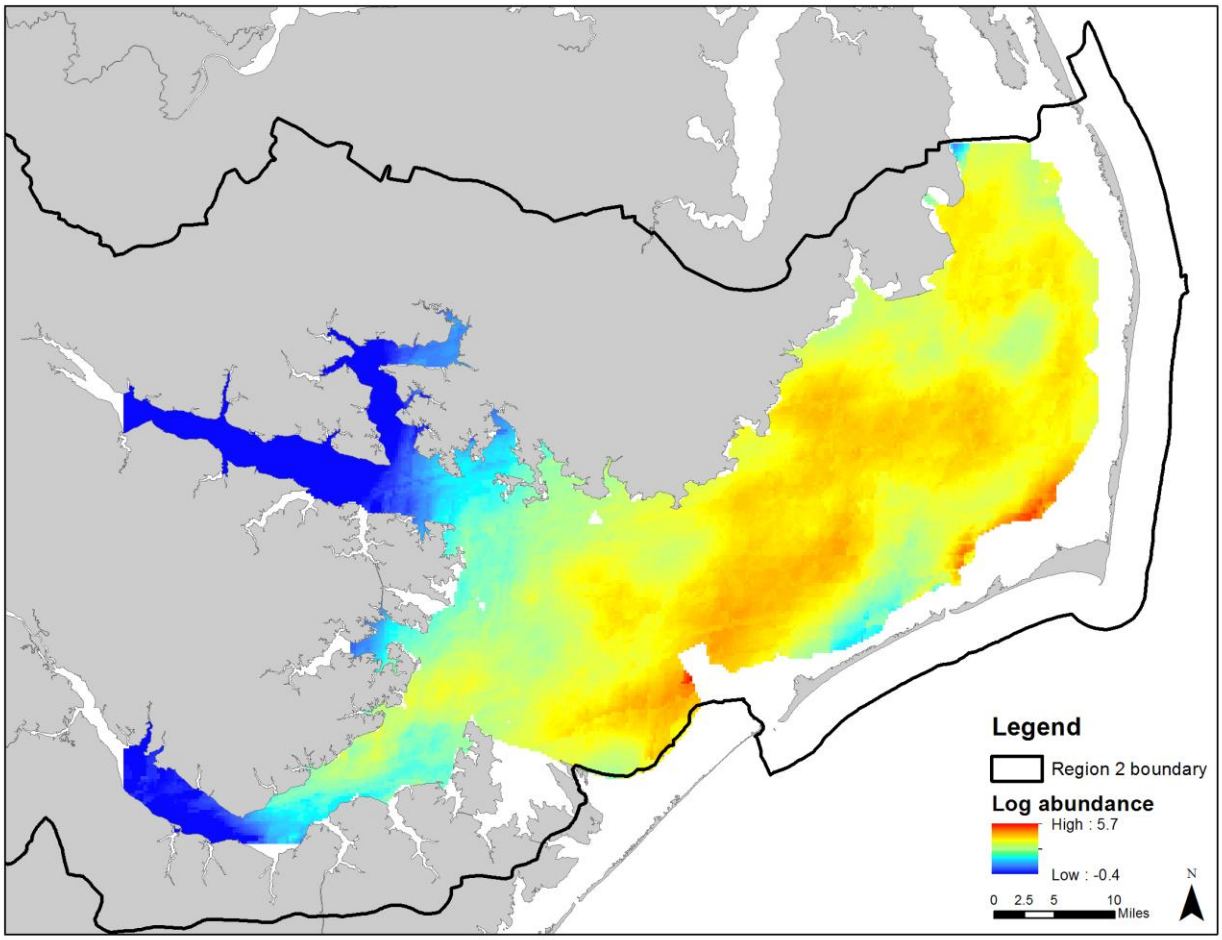

Figure 4: Sound group interpolation

Discussion

Abundance data is highly variable and hard to model. While not perfect, the method used to create the fish data layer provides a way to incorporate fish abundance into the MARXAN planning process, and to visualize the trends in fish abundance throughout the region. Other options for creating a layer in MARXAN would include creating habitat models of either presence/absence or predicted CPUE. However, these are more time-intensive to produce and require having comprehensive coverage of abiotic variables for the study area, which were not available. Interpolation presents a second option for creating a surface layer of fish abundance, and is relatively easy to create using the tools available in the Geostatistical Analyst (ESRI 2009). Bahn and McGill (2007) argue that, due to the importance of spatial structure and presence of autocorrelation in determining species distribution, interpolation can outperform niche-based modeling at larger scales.

The development of a fish group layer allowed the SHA advisory committee to examine available fishery independent data as part of the MARXAN planning process. The inclusion of the fish values in the MARXAN selection process forced the program to select areas in the middle of the sound as part of the MARXAN solution. While many of these areas were eliminated because they were isolated and small by the committee during selection, the committee did choose certain areas as fish hostpots near the mouths of the Neuse and Pamlico Rivers and across some of the shoal areas adjacent to shoreline features.

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ESRI. 2009. ArcGIS Desktop: Release 9.3. Redlands, CA: Environmental Systems Research Institute.

McCune, B. and Grace, J.B. 2002. *Analysis of Ecological Communities*. MjM Software Design: Gleneden Beach, OR.

McCune, B. and M. J. Mefford. 2006. PC-ORD. Multivariate Analysis of Ecological Data. Version 5.13 MjM Software, Gleneden Beach, Oregon, U.S.A.

North Carolina Division of Marine Fisheries (NCDMF). 2009. *Strategic Habitat Area Nominations for Region #1: Albemarle Sound to Northeastern Coastal Ocean of North Carolina*. North Carolina Division of Marine Fisheries: Morehead City, NC, 91 pp.

Ross, S.W. & Epperly, S.P. 1985. Utilization of shallow estuarine nursery areas by fishes in Pamlico Sound and adjacent tributaries, North Carolina. *Fish Community Ecology in Estuaries and Coastal Lagoons: Towards an Ecosystem Integration* 207-232.

Shertzer, K.W. & Williams, E.H. 2008. Fish assemblages and indicator species: reef fishes off the southeastern United States. *Fishery Bulletin* **106**, 257-269.

APPENDIX D: PREPARING THE MARXAN FILES

The MARXAN documentation and good practices handbook are both comprehensive and can assist in designing and carrying out an analysis. As the documentation is quite thorough, the intent of this appendix is to give specific details about this analysis and not a complete set of instructions for using MARXAN. For this analysis, the program was used in its stand-alone form and the input files prepared using ArcGIS, Excel and R. User interfaces such as Zonae Cogito (Watts et al.) are available for users that are less familiar with ArcGIS.

MARXAN version 2.1.1 was used for this analysis. There is currently no official user's manual for this version and some differences exist between it and the previous versions. The accompanying README text file explains the major changes. The biggest difference is in the format of the species vs. planning unit file and is described below. Formatting of the input files seems consistent with the formats described in the MARXAN with zones handbook (Watts et al. 2008), which I used to crossreference formatting questions.

MARXAN requires four data files and an input file in order to run. They are all text files (either tab or comma delimited) that have been renamed with the extension .dat. The file names can be changed but they must have the correct extension for MARXAN to work properly. There are a specific set of column names that are required for each file. They must be present and match the descriptions given in the handbook in order for MARXAN to read the input files.

1) Species file (spec.dat) – This contains information on all conservation features in the analysis. It assigns each conservation feature (NRT) a unique numerical id, which is uses to relate to the other MARXAN input files, and gives the target amounts (or proportion) for each conservation feature in the final solution, and assigns each conservation feature a species protection factor. In addition, it can contain a name for each conservation feature. For Region 2, this was made in Excel and exported to a csv.

   Example species file:

id	target	name	spf
1	0	Emergent_wetland	100
2	0	Est_shrubscrub_wet	100
3	0	Est_soft_bottom_deep	100
4	100625213.3	Est_soft_bottom_shallow	100
5	63340840.9	Est_soft_bottom_mid	100
6	994230.1102	Est_soft_bottom_ND	100
7	56165054.07	Forested_wet	100
8	11604155.83	Headwater_wet	100

2) Planning units file (pu.dat) – this is a list giving the planning units in the study area, their cost, and their status. Alteration score was used as the cost. We assigned planning units defined as inlets and Region 1 SHA nominations to have a status of '2', which means they must be included in the final solution. Other options for status are to include a planning unit in the initial solution, or to exclude a planning unit from the final solution. This was created in ArcGIS by joining the alteration score to the planning units shapefile, and exported to a csv.

   Example planning unit file:

id	cost	status
1	0	0

2	0	0
3	1.024817	0
4	1.160994	0
5	0.767445	0
6	1.091048	0
7	1.115639	0
8	0.140693	0
9	1.189066	0
10	0.737211	0
11	1.385543	0

3) Boundary file (bound.dat) – This gives the length of the boundary between adjacent files. It is in the format of id1, id2, and amount. For the region 2 analysis it was created in ArcGIS, using the tool 'Make Boundary file' in the SHA tools toolbox. This tool requires a layer file of the planning units as an input. The input layer file must have a field called 'MarxID' and the workspace should be set to the default geodatabase. The tool outputs a DBF file, which can be converted to a csv using Excel.

Example boundary file:

id1	id2	boundary
1	3	440
1	4	440
1	19140	440
2	3	440
2	5	440
2	6	440
2	19140	440
3	4	440

4) Planning units vs. Species file (puvspr.dat) – This file gives the amount of each conservation feature in each planning unit. MARXAN version 2.1.1 differs from previous MARXAN in that it will only read the long format, where each combination of planning unit and conservation feature is in a separate row. Previous versions of MARXAN were configured to accept this table in the wide format, where each planning unit was a row and the conservation features were the columns. The MARXAN software comes with a utility (convert_mtx.exe) to convert records from the long to wide format and vice versa. The file needs to be ordered by the planning unit, and then species ID. This file was made in ArcGIS by intersecting the planning unit with the polygon (r2_nrt_polygons) and line (r2_nrt_lines) habitat shapefiles. Fish group values were obtained by identifying the value at each hexagon centroid. These three tables were exported as DBFs, concatenated and then sorted by planning unit and then species in Excel.

Example planning unit vs species file.

Species	pu	amount
7	1	3032.72
7	2	34301.95
7	3	182339.9

29	3	69.95
32	3	251.47
33	3	583.5
7	4	92544.15
33	4	818.69

5) The input file (input.dat) – Sets the MARXAN specifications for the analysis. MARXAN comes with an executable called InEdit.exe. that guides the user through all of the MARXAN options and generates the input file.

MARXAN resources:

Watts, M. E., R.R. Stewart, D. Segan, L. Kircher: Using the Zonae Cogito Decision Support System, a Manual.pdf (1288KB)

Marxan

Ball, I.R., and H.P. Possingham, 2000. MARXAN (V1.8.2): Marine Reserve Design Using Spatially Explicit Annealing, a Manual.
Game, E.T. and H.S. Grantham, 2008. Marxan User Manual: For Marxan version 1.8.10. University of Queensland, St. Lucia, Queensland, Australia, and Pacific Marine Analysis and Research Association, Vancouver, British Columbia, Canada.

Marxan with Zones

Watts, M.E., C.K. Klein, R. R. Stewart, I. R. Ball, and H. P. Possingham. 2008. Marxan with Zones (V1.0.1): Conservation Zoning using Spatially Explicit Annealing, a Manual.

APPENDIX E: SENSITIVITY ANALYSIS

MARXAN allows the user customize the selection algorithm by adjusting several parameters. In order to ensure a robust analysis, these parameters should be calibrated for each analysis to ensure that MARXAN is meeting the objectives of the project (Ardron et al. 2008). Calibration involves running the analysis with a range of values and examining the outputs. Two parameters were examined in this sensitivity analysis: the number of runs and the boundary length modifier (BLM).

Number of runs

MARXAN is an iterative program that proceeds for a user defined number of runs and returns the best solution it found across all runs. Each run will continue for a user-defined number of iterations, in each of which a different solution is considered. MARXAN compares solutions by calculating a score for each potential configuration of reserves. For each run, the program continues to evaluate new solutions until the program ceases to find new solutions with lower scores, or the number of iterations is reached. The assumption behind this is MARXAN will find the best solution, or something very close to it, in the user-defined number of runs. There is no guarantee that this solution will be the best solution of all possible for the analysis. As the number of runs is increased, it is more likely that MARXAN will find a better solution. The total number of runs for the previous SHA region was set at 100 because processing time was quite lengthy; however, in this analysis a newer version of MARXAN was used and the extent of the data that was included for MARXAN analysis was decreased by only including hexagons in the focus area. These changes greatly decreased the processing time, allowing for the addition of number of runs in this analysis.

In this analysis the distribution of scores across all MARXAN runs for an analysis with 100 runs and an analysis with 500 runs were examined, specifically with respect to the lower scores. The score for each run is given in the MARXAN output tables ending in '_sum.txt'.

Upon inspecting the initial solutions with 100 runs, the scores of the best solutions were sometimes much lower than that of the second best solutions, leading to a distribution that is truncated at lower scores (Figure 1). This indicates that MARXAN might not be finding the best solution possible, and could, in fact be finding a local minimum instead of a global minimum. The distribution of scores that result from an analysis with 500 runs is more robust among lower scores, indicating that MARXAN is finding similar solutions across runs. MARXAN is, therefore, more likely converging to the best solution to the problem across all of the runs. Increasing the number of runs only resulted in a moderate increase in processing time (~ 5 minutes compared to ~ 2 minutes for 100 runs). Based on these results, the number of runs was set to 500 for the rest of the analysis.

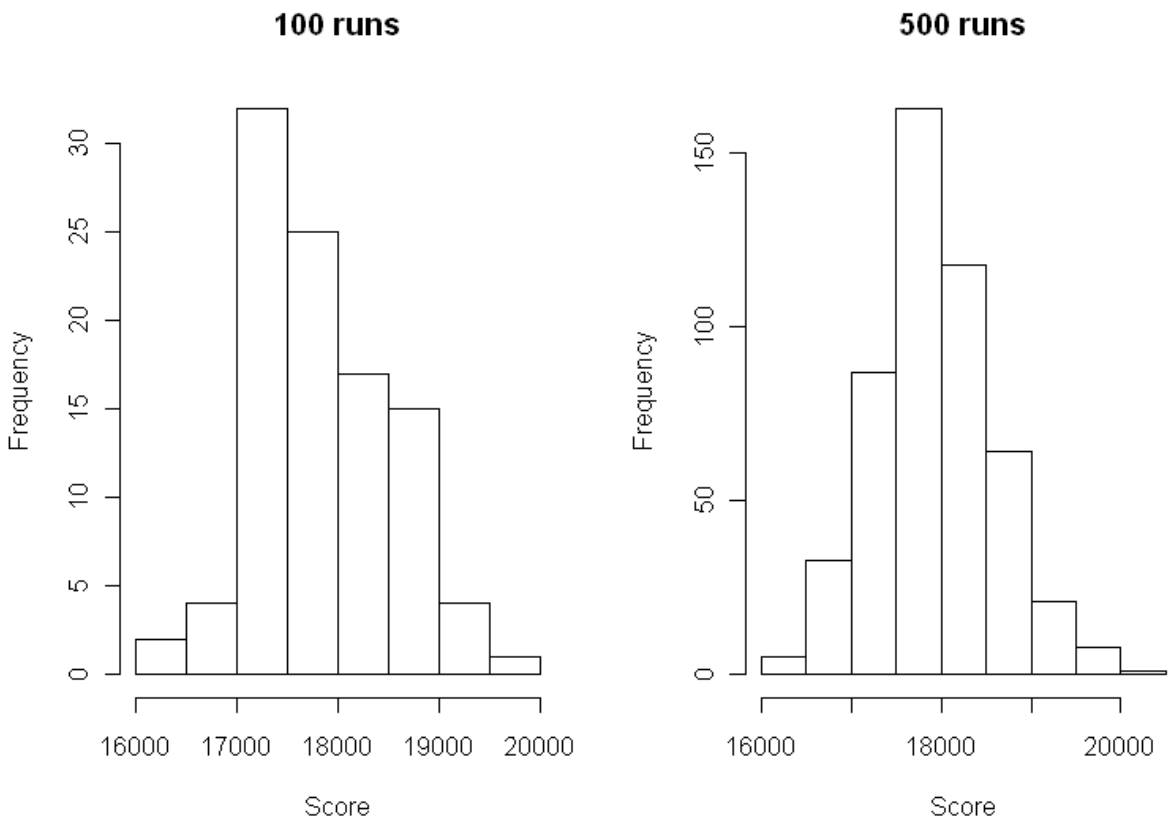

Figure 5: Distribution of scores for MARXAN analysis using 100 and 500 runs

Boundary Length Modifier

MARXAN computes an objective score for each potential solution that is the sum of three components: a cost component that sums the cost of the planning units included, a species protection component that computes a penalty for not reaching species representation goals, and a boundary length component that penalizes a solution for being more spread out (having more boundary length). The total score for each run is the sum of all three components; therefore, the components all need to be on a similar scale in order for the solution to consider all three factors in the solution. If the components are not scaled, the program will be selecting solutions based on changes in one component and not the others.

Each component has a parameter that can be adjusted to adjust its scale. The species component is based on a species penalty factor that is assigned to each species. The boundary term is the sum of the boundary length multiplied by a boundary length modifier (BLM), which should be adjusted based on the units of the analysis. The cost can be adjusted by rescaling the units of the cost score. I examined the influence of the three different parameters on the MARXAN solutions in order to ensure that the MARXAN analysis was equally considering all three parameters. In order to assess the contribution of each component to the final score, scatterplots were created to visualize the relationship between the total score and each component across all 500 runs. Values for the score, cost, boundary length and species penalty were taken from the MARXAN summary output table (ending in _sum.txt) created at the end of each analysis. In addition, maps of the best solution and selection frequency were examined to visualize the spatial arrangement of the solutions produced at each setting.

Boundary length factors into the equation by summing the length of the boundary of each solution and multiplying it by a boundary length modifier. The boundary length modifier (BLM) can take on any value and should be adjusted to scale the boundary length to the other terms in the score equation. For example, an analysis in which the boundary lengths are expressed in meters would require a BLM that is

one thousandth that of an analysis that expresses the same boundaries in kilometers in order to yield the same scores. The BLM for SHA analysis was originally set to 0.01 based on visual examination of results. This analysis examined the effect of lowering the BLM on the relationship between the overall score and its components, and the spatial configuration of the final solution. BLMs of 0.001 and 0.005 were considered, in addition to the original value of 0.01.

At the initial BLM of 0.01, there was a strong correlation between boundary length and score for each run and no correlation between cost and score (Figure 3). This indicates that the MARXAN selections are being driven by differences in boundary length and not in overall cost. The expanses of open water connecting the shorelines of the Neuse and Pamlico River support this conclusion (Figure 2). Decreasing the BLM yielded a solution that was more spatially separated and had more numerous small areas in the solution network. At a BLM of 0.005, the scatterplots indicate that there is a still a tight relationship between the BLM and the total score (Figure 5). Lowering the BLM again to 0.001 the relationship between the score and the BLM is not as strict and there is a positive relationship between the cost and score, indicating that changes in score correlate to changes in cost (Figure 7). As expected, the solution is more fragmented than at higher BLMs. Fragmentation was more pronounced in Pamlico Sound, where the solution produced many isolated areas compose of three or fewer clusters in response to the fish group targets. Shoreline areas remained relatively aggregated; suggesting that the extra boundary length allowed was used to add areas in the sound that were based on the fish targets. The relationship between SPF and total cost indicates that not all representation levels were met in all analyses. Upon further examination, these targets were not far from being met, so it was decided not to base decisions on this factor, as modifications would likely change the representation of habitat types in the proposed SHA network during corroboration.

Based on this information, the advisory group decided to use the solution with a BLM of 0.001 as the basis for the corroboration phase of the analysis, but to only consider clusters that were greater than 3 hexagons as potential SHAs.

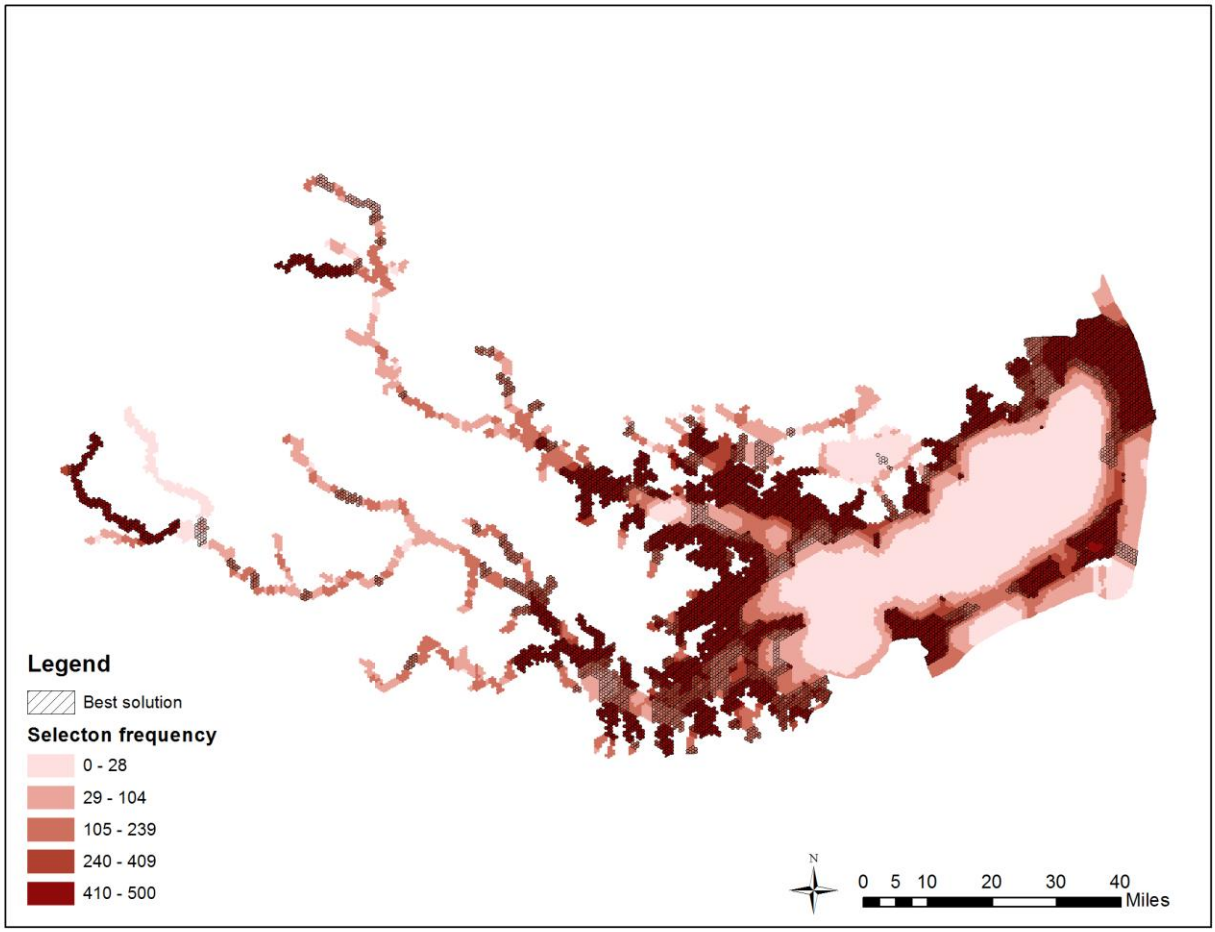

Figure 6: BLM 0.01

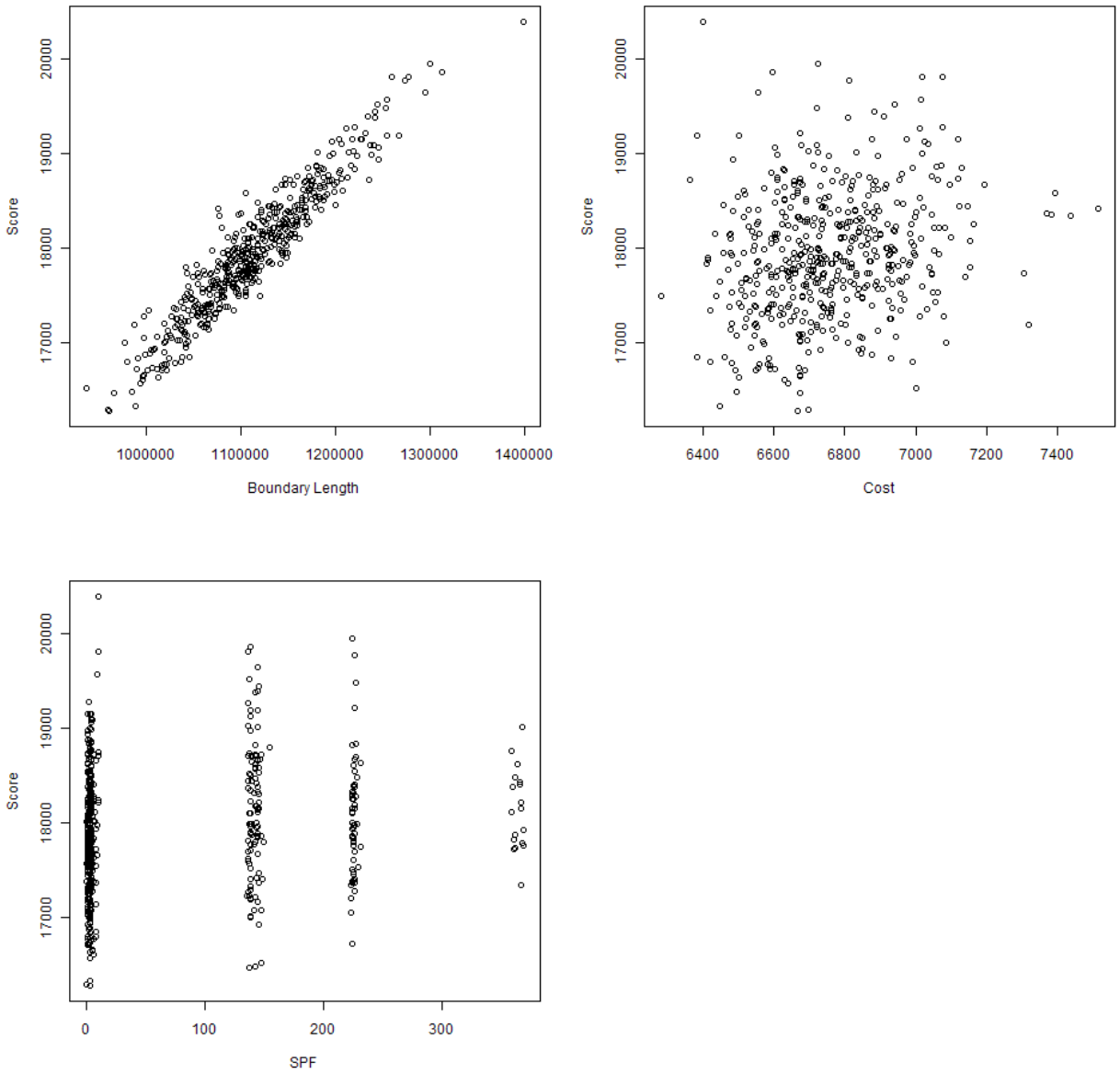

Figure 7: Correlation graphs for initial setup, BLM = 0.01 and 500 runs

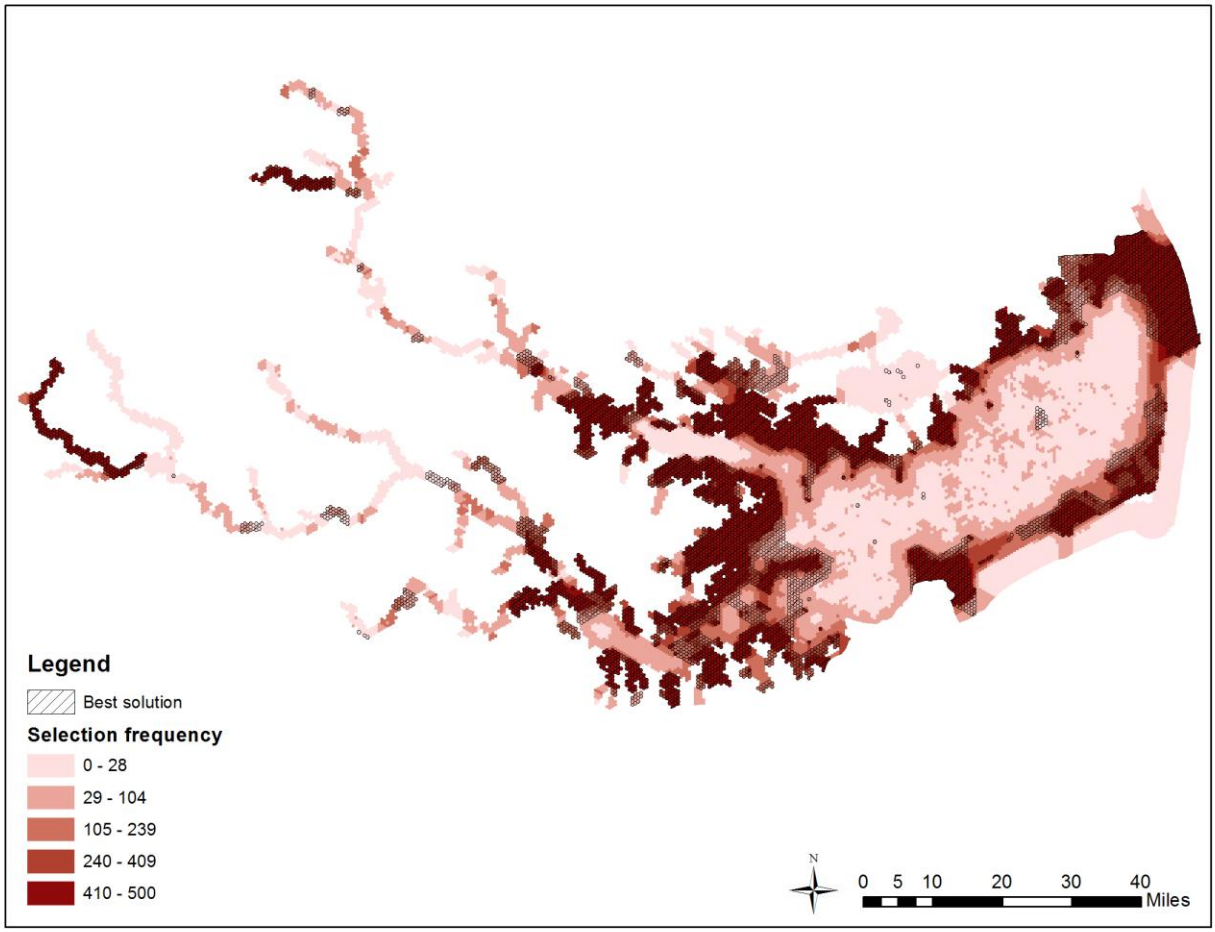

Figure 8: BLM of 0.005

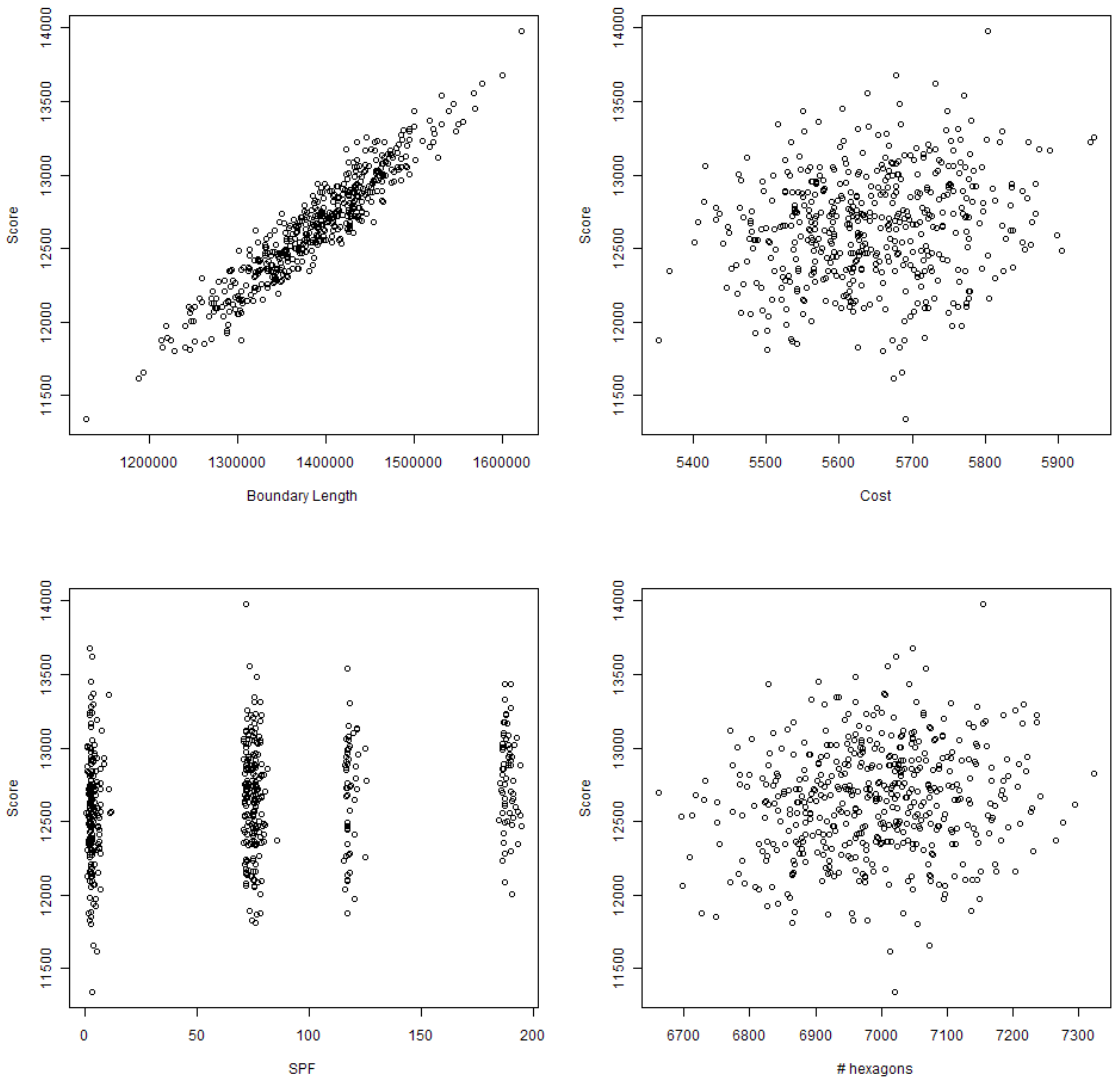

Figure 9: BLM 0.005

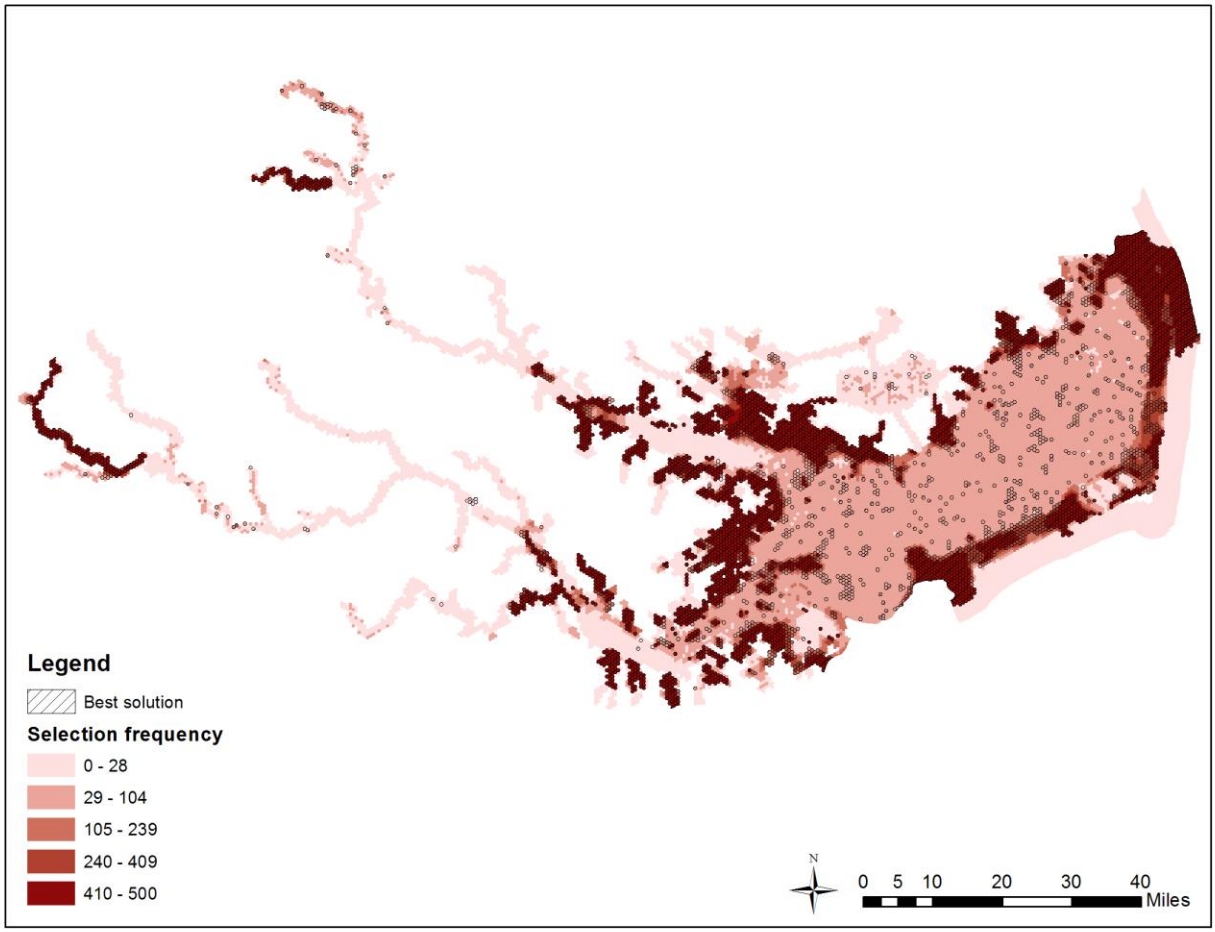

Figure 10: BLM 0.001

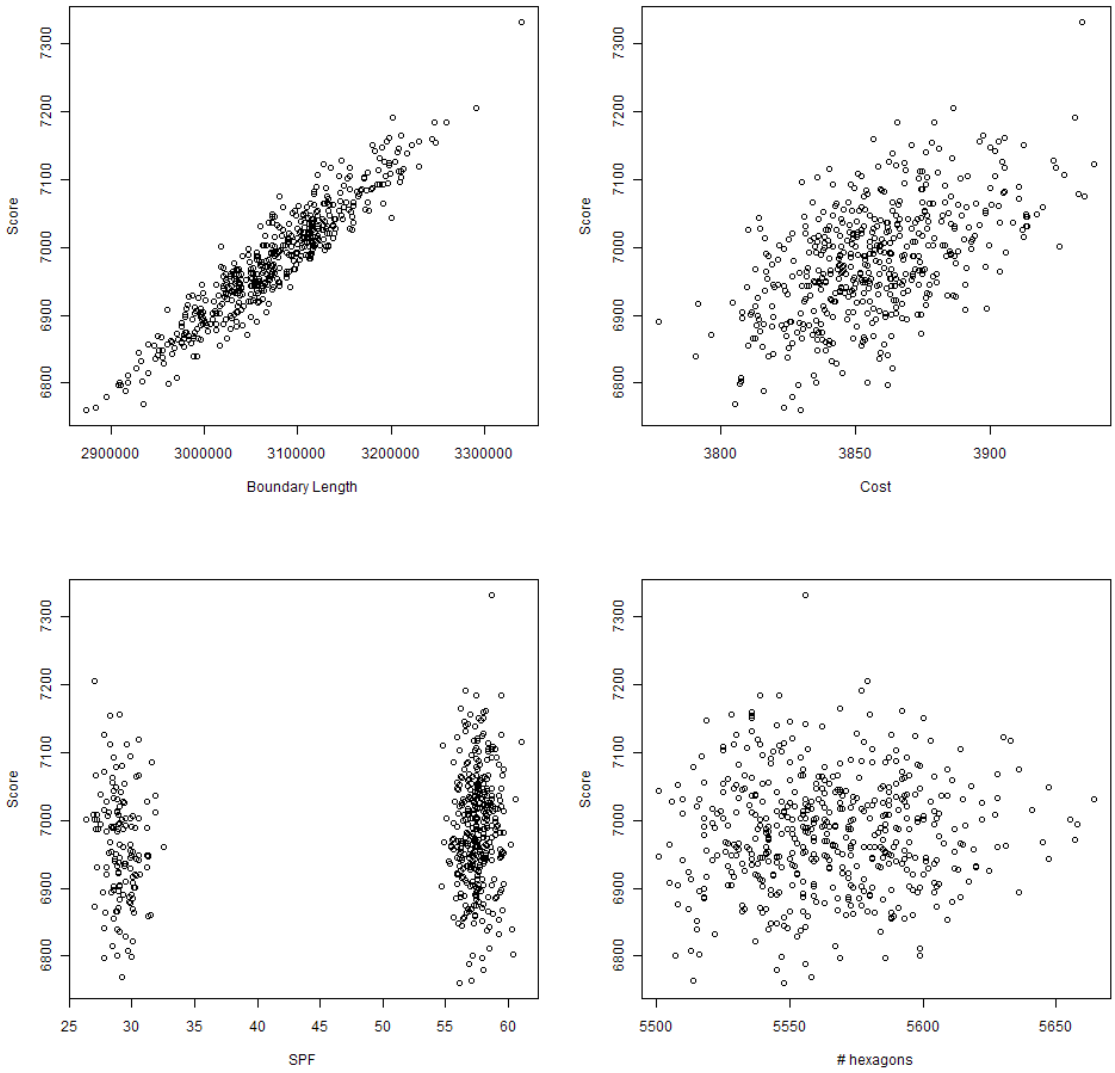

Figure 11: BLM 0.001

Reference

Ardron, J.A., Possingham, H.P., Klein, C.J. (eds) 2008. Marxan Good Practices Handbook. External review version; 17 May 2008. Pacific Marine Analysis and Research Association, Vancouver, BC, Canada. 155 pages. www.pacmara.org

APPENDIX F: PUBLIC MEETING COMMENTS

A public meeting was held on October 11, 2011. Eight members of the public attended, in additional to agency staff. The memo below summarizes the comments. Following the meeting, written comments were received from Mazie Smith, Hyde County manager. A Hyde County representative also spoke at the MFC meeting reiterating their written comments that they were concerned with any potential regulations that may result later due to SHA designations, and the effect of regulations on their economy. The SHA Advisory Committee discussed the comments and had no objections to adjusting the SHA boundary in the vicinity of the Trent River, where it included urbanized areas of New Bern, but felt the areas selected in Hyde County and elsewhere were appropriate. The meeting memo below summarizes the public comments.

MEMORANDUM

TO: N.C. Marine Fisheries Commission (MFC)
Strategic Habitat Area Region 2 Advisory Committee
Louis Daniel

FROM: Anne Deaton

DATE: November 1, 2012

SUBJECT: Public Meeting – input on Strategic Habitat Area (SHA) Region 2

A public meeting was held on Tuesday, October 11, 2011 at 6:00 pm at the Washington Regional Office located at 943 Washington Square Mall. The following staff attended:

Staff: Anne Deaton, Kevin Hart, Christine Jensen, Jimmy Johnson

Eight people, in addition to staff, attended the meeting.

The meeting began with Anne Deaton reviewing the process/method used and showed the areas selected for Strategic Habitat Area (SHA) nomination. She summarized what habitats and alterations were considered in the assessment and the prominent features within the selected SHAs. Division of Marine Fisheries (DMF) staff emphasized that the Strategic Habitat Area assessment was an ecological evaluation that was not considering management needs at this point, but was simply identifying a network of priority high quality habitat areas - the best of the best habitats. The evaluation was conducted following a process established by the DMF and an advisory committee. A separate advisory committee, with local research knowledge was used to review the methods, input data, and results of this assessment. Field groundtruthing will be conducted following this to confirm condition within the SHAs and consider if any conservation measures are needed. Once North Carolina's entire coast has been evaluated (approximately half remains to be done), management measures may be considered but will involve extensive public stakeholder involvement. The driving reason for conducting SHA analyses is because scientific literature indicates that protecting a network of priority habitat areas is an effective means of enhancing sustainable fisheries.

The habitats in the SHAs along the Outer Banks contain large beds of seagrass, intertidal flats, oyster beds, and wetlands. The areas on the mainland consist primarily of embayments identified designated as Primary Nursery Areas, and also containing some oyster beds, wetlands, shallow soft bottom, and some low elevation uplands. Some areas were also designated as Anadromous Fish Spawning Area and provide a connection to Lake Mattamuskeet. Some subtidal shell bottom at the mouth of the rivers were included. Selections on the rivers were concentrated in the lower estuarine waters and in the headwaters. Some mid river tributaries on the rivers due to habitats and known anadromous fish use.

It was pointed out that many of the areas selected were within an existing federal or state property and already protected from land use activities, or contained fisheries designations, such as Primary Nursery Areas, where rules are already in place to provide protection from bottom disturbance. There was discussion on what could be done to benefit such areas. It was pointed out that some may only need the existing protections to remain in place. Water quality affecting habitat condition was mentioned as the primary concern for the region.

Some of the comments were positive, while some had concern. Some of the points raised:

- There was a concern that such a large area of Hyde County was selected and that it might result in fishing restrictions. Did not like being a "target" and did not want further fishing restrictions.
- Others mentioned that the selection of a large amount of area in Hyde County was a recognition of the significance and uniqueness of the area.
- One person said he was glad that a lot of wetland areas in Hyde County seemed to have been included because they are so important to many resources.
- The SHA areas should be used to protect and maintain these high quality habitats, to sustain fisheries, and not restrict fisheries.
- The SHAs represent aquatic assets that the area needs to support the fishing and tourism industries.
- SHA areas along the northeast side of Trent River include some developed areas and should consider removing.
- Low elevation uplands adjacent to wetlands should be considered for protection to allow migration of wetlands as sea level rises.

The SHA Advisory Committee will consider all the comments and make adjustments if found necessary before finalizing.

Board of Commissioners
Sharon Spencer, Chair
Anson Byrd, Vice-chair
Darlene Styron
Barry Swindell
Dick Tunnell

COUNTY OF HYDE

30 Oyster Creek Road
PO Box 188
SWAN QUARTER, NORTH CAROLINA 27885
Phone: 252-926-4400
Fax: 252-926-3701

Mazie Swindell Smith
County Manager

Fred Holscher
County Attorney

October, 24 2011

W. Robert Bizzell
Chairman, Marine Fisheries Commission
N.C. Division of Marine Fisheries
3441 Arendell Street
Morehead City, NC 28557

Dear Mr. Bizzell,

Based on recommendations from staffers in the Hyde County Office of Economic Development and Planning, the Hyde County Board of Commissioners passed a resolution on October 17th formally opposing regulatory action in the Strategic Habitat Area (SHA) waters of the Pamlico Sound and the Atlantic Ocean. A copy of the resolution is attached. The Commissioners request that this resolution be entered into the record of the November 2011 Marine Fisheries Commission meeting.

The commissioners agreed with the scientific findings in the proposed SHA area, and acknowledged the waters are relatively free of pollution and that fish stocks are exceptional. The findings seem to indicate that no regulatory action is needed. The commissioners are concerned however that the SHA designation will lead to additional regulations for fishermen, resulting in significant loss of income and jobs for the county. Fishing, both commercial and recreational, is part of our heritage, our culture and our very way of life, and fishing-related industries account for a large portion of our workforce, along with farming and agriculture. It is the belief of the Board that any additional regulatory action -- over and above what our citizens already must follow -- would cause severe, negative consequences on both the fishing and farming industries.

Because of the potential impact to our local economy, any consideration to changes in management of our waters should come only after citizen input. The commissioners want to be active participants in the decision-making process for any regulations which impact our citizens. We thank you in advance for ensuring that we are given that opportunity.

Respectfully,

Mazie Smith, Hyde County Manager

Cc: Senator Stan White
Representative Tim Spear

"On the journey toward progress down the road less traveled..."

A RESOLUTION OF THE HYDE COUNTY BOARD OF COMMISSIONERS OPPOSING REGULATORY ACTION IN THE STRATEGIC HABITAT AREA OF THE PAMLICO SOUND AND ATLANTIC OCEAN

WHEREAS, the N.C. Division of Marine Fisheries has proposed a Strategic Habitat Area (SHA) in waters of the Pamlico Sound and Atlantic Ocean with much of the designated area surrounding mainland Hyde and Ocracoke; and

WHEREAS, the County of Hyde has a 300-year history of commercial fishing in proposed SHA waters with targeted species of shrimp, oysters, crabs, southern flounder, red drum, speckled trout and androgynous fish; and

WHEREAS, the County of Hyde is one of the most economically distressed in the state and relies heavily on income from fishing and further regulations would be detrimental to the economy and heritage of the county; and

WHEREAS, DMF studies show waters surrounding the county are relatively free of pollution and water quality alteration factors, and therefore should warrant no further regulatory action towards fishermen;

WHEREAS, a large quantity of land in Hyde County is already federally protected and access to natural resources should not be further limited; and

NOW THEREFORE BE IT RESOLVED, BY THE BOARD OF COMMISSIONERS OF THE COUNTY OF HYDE:

That the County of Hyde opposes further fisheries regulations in the proposed Strategic Habitat Area waters of the Pamlico Sound. The county supports DMF findings that the proposed SHA areas are ideal habitats for marine life and fish stocks. However, the county does not want SHA designation to further restrict access to marine resources, as commercial and recreational fishing are industries of significant economic importance in Hyde County.

Adopted this date OCTOBER 17, 2011 at THE GOVERNMENT CENTER, SWAN QUARTER, North Carolina.

Sharon P. Spencer
(Signature of Chief Executive Officer)

Chair, Hyde County Board of Commissioners
(Title)

ATTEST:

Marie Smith
Clerk (Seal)

Section 2 - Effect of demography on spatial distribution: movement patterns of Albemarle Sound-Roanoke River stock of striped bass (*Morone saxatilis*) in relation to their recovery

Jody Callihan (2011-2012 Fellow)

Effect of demography on spatial distribution: movement patterns of the Albemarle Sound–Roanoke River stock of Striped Bass (*Morone saxatilis*) in relation to their recovery

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Charlton H. Godwin[2]
Jeffrey A. Buckel[3]

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Morehead City, North Carolina 28557

Abstract—We analyzed tag returns from a long-term tagging program to evaluate the movement patterns of the Albemarle Sound–Roanoke River (AR) stock of Striped Bass (*Morone saxatilis*) during a period of stock recovery in 1991–2008. The AR stock was found to increase its movement outside the Albemarle Sound estuary (from <4% to 15–31%) as it recovered from 1991 to 2008. Analysis with multinomial logistic regression where recapture area was modeled as a function of fish size and stock abundance indicated that Striped Bass from the AR stock exhibit a strong size-dependent emigration pattern. Larger (older) adults >600 mm in total length (TL) were much more likely to emigrate to ocean habitats (after spawning) than were smaller adults (350–600 mm TL), which mostly remained in inshore estuarine habitats. Smaller adults showed evidence of density-dependent movement and were recaptured only in adjacent estuarine systems, the Pamlico Sound and lower Chesapeake Bay, during periods of increased stock abundance. Assessment and management strategies for the AR stock of Striped Bass could be improved by accounting for movement (and hence harvest) outside the currently assumed stock boundary. More broadly, this study illustrates that changes in the demographics, such as size structure and total abundance, within fish populations can result in major shifts in their distribution and that long-term tagging data are useful in detection of such population-level changes in movement patterns.

Manuscript submitted 18 April 2013.
Manuscript accepted 12 February 2014.
Fish. Bull. 112:131–143 (2014).
doi:10.7755/FB.112.2-3.3

The views and opinions expressed or implied in this article are those of the author (or authors) and do not necessarily reflect the position of the National Marine Fisheries Service, NOAA.

The demographics of fish populations can be important in shaping their movement patterns. Numerous species have been shown to increase their distributional range or movement distances as population abundance increases (Swain and Wade, 1993; Brodie et al., 1998; Overholtz, 2002; Abesamis and Russ, 2005; Dunning et al., 2006), a response presumably due to density-dependent mechanisms (e.g., intraspecific competition for food or the saturation of optimal habitats) (MacCall, 1990). In addition, changes in movement patterns with ontogenetic changes in fish are common because habitat requirements change as species age (Werner and Gilliam, 1984; Dahlgren and Eggleston, 2000).

The demographics of fish populations are continually shifting for reasons that include changes in fishing pressure and the natural environment (e.g., recruitment variation) that can alter age structure and abundance (Longhurst, 2002; Berkeley et al., 2004; Hutchings and Baum, 2005) and in turn cause population-level changes in movement patterns. Understanding if and how population-level movements (and distribution) change over time is of particular importance for exploited fishery species because such changes can pose challenges for assessment and management techniques, for which stock boundaries are often assumed to be static and not dynamic (Winters and Wheeler, 1985; Hammer and Zimmermann, 2005; Link et al., 2011).

Striped Bass (*Morone saxatilis*) occur throughout the East Coast of the United States and have supported important fisheries there for centuries (Merriman, 1941). Tagging studies clearly have shown that spawning populations (or stocks) of Striped Bass in the mid-Atlantic region, which includes the Hudson River, Delaware River, and Chesapeake Bay, generally exhibit an anadromous life-history strategy and undergo extensive seasonal migrations. After spawning in the freshwater portion of their respective estuaries, many adults emigrate to Atlantic

Ocean waters from New Jersey to Maine in early summer, move south in the fall to overwintering habitats in coastal waters from New Jersey to Cape Lookout in North Carolina, then return to their natal estuary in subsequent springs to spawn (Boreman and Lewis, 1987; Waldman et al., 1990; Dorazio et al., 1994; Welsh et al., 2007). In contrast, the Albemarle Sound–Roanoke River (AR) stock of Striped Bass, hereafter referred to as the "AR stock," has historically been viewed as a nonmigratory stock, and most fish are believed to remain in their natal estuarine system, the Albemarle Sound estuary, throughout their lives (Merriman, 1941; Hassler et al.[1]). Indeed, in the most extensive tagging study to date on the AR stock by Hassler et al.[1], virtually all (99%) of the 2428 returns of the 9220 adults tagged in the Roanoke River during the springs of 1959–77, occurred within the Albemarle Sound estuary. The few returns that occurred outside Albemarle Sound (<1% of the total) were from an adjacent estuary (Pamlico Sound); remarkably, no returns were from ocean waters (Hassler et al.[1]).

These differences in migration patterns may have been due to differences in life-history strategies (nonanadromous vs. anadromous) between the AR stock and more northerly stocks, or it could have been a result of a historic lack of larger, older fish (>600 mm in total length [TL]) in the AR stock because of high harvest levels. Differences in life-history strategy would be perplexing given that these stocks occur in the same zoogeographic province (mid-Atlantic coast of the United States) and given that some of them are in close latitudinal proximity (e.g., the AR and Chesapeake Bay stocks). In 1988, the North Carolina Division of Marine Fisheries (NCDMF) began a cooperative tagging program with the North Carolina Wildlife Resources Commission (NCWRC) to address this question and to further investigate the migration dynamics of the AR stock of Striped Bass.

Much of the past work of tagging individuals from the AR stock was done when Striped Bass were at low levels of abundance and overfished (NCDMF and NCWRC[2]). In more recent years (1991–2008), the AR stock, as well as the Chesapeake Bay stock (Richards and Rago, 1999), made a dramatic recovery from their depleted state in the late 1970s and 1980s. The estimated total abundance of the AR stock nearly doubled during the 1990s, increasing from 1.0 to 1.9 million fish, and remained at high levels (>1.8 million fish) throughout the 2000s (NCDMF and NCWRC[2]). In addition, the age and size structure of the stock expanded as larger (>600 mm TL) and older (age 9+) fish became more prevalent as the stock recovered (NCDMF and NCWRC[2]). The recovery of the AR stock was a result of a combination of factors, namely more stringent fishing regulations that increased development to older age classes and improvements in environmental conditions that enhanced spawning habitat and recruitment of young Striped Bass (e.g., regulated river flows that were more conducive for the transport and survival of eggs and larvae) (Rulifson and Manooch, 1990; NCDMF and NCWRC[2]).

For this study, we first addressed the following question: Have Striped Bass of the AR stock increased their movement outside of the Albemarle Sound estuary since population rebuilding in the 1990s? After showing that the movement of the AR stock out of the estuary has indeed increased, we then related recapture locations of tagged individuals to both fish size and total annual stock abundance (density) in an effort to explain this increase in emigration over the past 2 decades (1991–2008). Lastly, we discuss the management implications of this increased movement given the stock is currently considered to be resident.

Materials and methods

Fish tagging

During the springs of 1991–2008, 42,534 adult Striped Bass from the AR stock (mostly >350 mm TL; Fig. 1) were tagged and released on their well-described spawning grounds (Hassler et al.[1]) ~200 km upstream of the mouth of the Roanoke River in North Carolina (Fig. 2A). During weekly sampling events throughout April and May, Striped Bass were collected with an electrofishing boat and transported to a tagging vessel, where they were held in a "live well" until processing. Fish in good condition were measured (TL to the nearest millimeter), weighed (to the nearest gram), and sex was determined by expression of gonadal products. The fish were then tagged just above the posterior tip of the pelvic fin with a Floy (model FM-84[3]) internal anchor tag (Floy Tag, Inc., Seattle, WA). Fish were immediately released after tagging. The streamer of the tags indicated a "reward" (US $5 or a baseball cap) would be offered for reporting information on recaptured Striped Bass (e.g., recovery date and location, and tag number)

[1] Hassler, W. W., N. L. Hill, and J. T. Brown. 1981. The status and abundance of striped bass, Morone saxatilis, in the Roanoke River and Albemarle Sound, North Carolina, 1956–1980. North Carolina Department of Natural Resources and Community Development, Division of Marine Fisheries, Special Scientific Report 38, 156 p. [Available from the Division of Marine Fisheries, 3441 Arendell St., Morehead City, NC 28557.

[2] NCDMF (North Carolina Division of Marine Fisheries) and NCWRC (North Carolina Wildlife Resources Commission). 2013. Amendment I to the North Carolina Estuarine Striped Bass Fishery Management Plan, 420 p + appendices. North Carolina Division of Marine Fisheries, North Carolina Department of Environment and Natural Resources, Morehead City, NC. [Available from http://portal.ncdenr.org/c/document_library/get_file?uuid=d3fdf967-82d5-4653-8b79-20247c5ed5ad&groupId=38337, accessed January 2014.]

[3] Mention of trade names of commercial companies is for identification purposes only and does not imply endorsement by the National Marine Fisheries Service, NOAA.

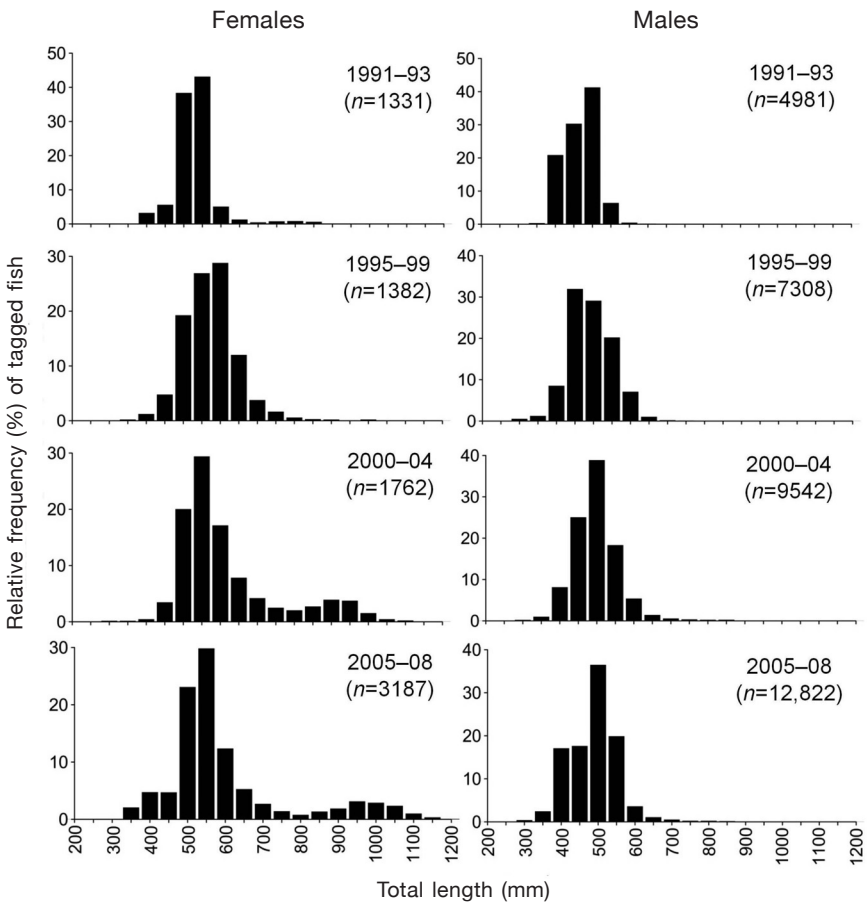

Figure 1

Size distributions of tagged Striped Bass (*Morone saxatilis*) by time period and sex. Fish were collected by electrofishing during spring in the Roanoke River. Note that sex was determined for nearly all (>99%) tagged fish. Data from 1994 were excluded because few fish (n=9) were tagged that year.

to the NCDMF, whose contact information was printed on the tag.

Data analysis

We used multinomial logistic regression to evaluate the effects of fish size and stock abundance on the recapture location (i.e., to evaluate the movements) of Striped Bass of the AR stock. For this analysis, recapture locations of tagged fish were assigned to 1 of 4 broad geographic areas: 1) the Albemarle Sound estuary, 2) the Pamlico Sound estuary, 3) ocean waters of North Carolina, or 4) northern coastal waters from Virginia to Massachusetts (Fig. 2B). Therefore, recapture area constituted a multicategory response variable. Explanatory variables were fish size (TL at tagging) and total annual abundance of the AR stock (1991–2008). Annual abundance estimates (of age 1+ fish) were obtained from a statistical catch-at-age model from the most recent AR stock assessment (NCDMF and NCWRC[2]) and served as a proxy for the annual densities of conspecifics (AR stock only) with which tagged Striped Bass were expected to interact each year. Sex was not included as an explanatory variable because it was confounded with fish size beyond 800 mm TL because all but 4 tag returns from this size range were from females. However, across smaller sizes (400–800 mm TL), over which sexes were more equally represented, similar-size males and females were generally recaptured in the same areas, indicating that movements differed little between sexes.

For the purpose of our analyses, we included only tag returns that occurred after the first 2 weeks but within the first calendar year at liberty. By restricting returns to those returns that occurred within the first calendar year at liberty (on or before 31 December), movement between tagging and recapture loca-

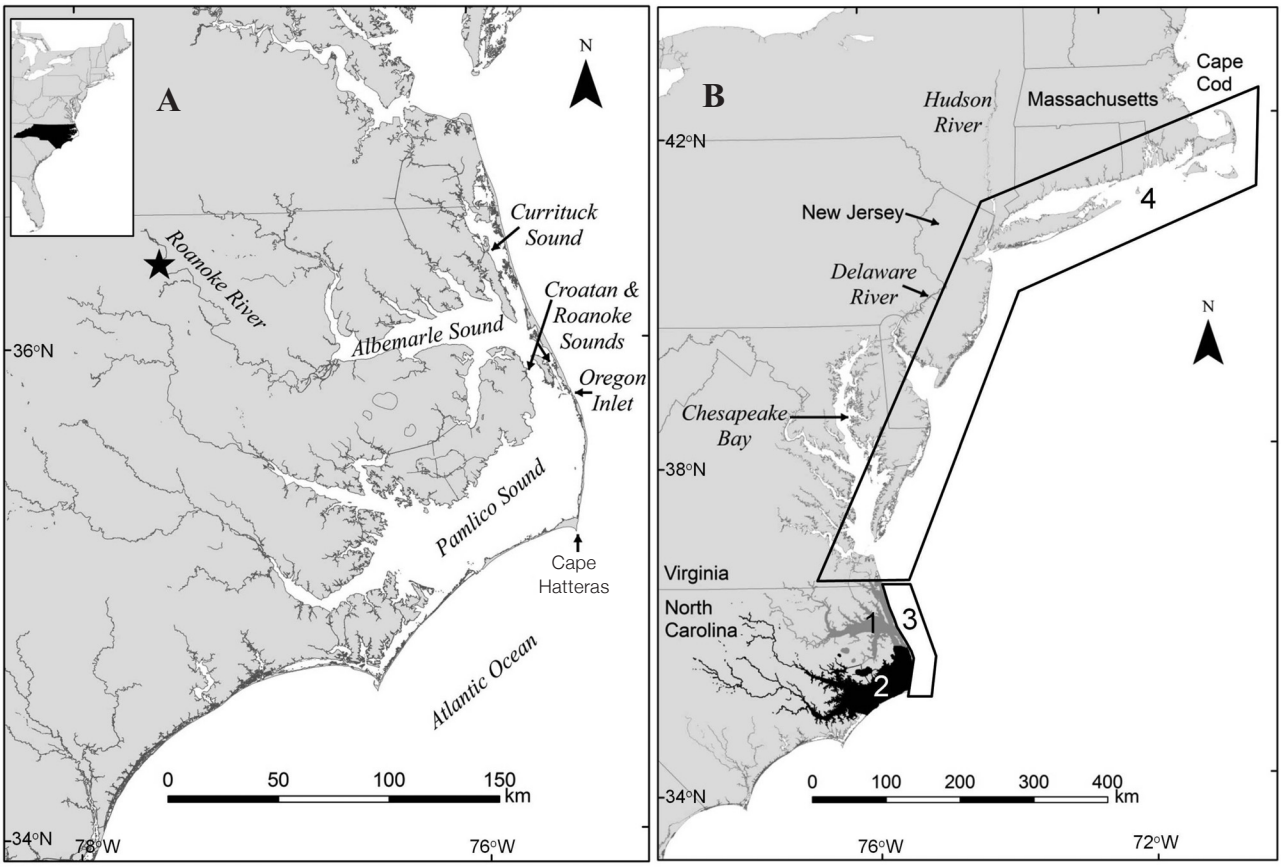

Figure 2

(A) Capture and release location (represented by the star in the upper Roanoke River) of tagged Striped Bass (*Morone saxatilis*) during the period of 1991–2008 and reference map for waterbodies in coastal North Carolina. **(B)** Geographic areas of recapture used in data analyses: 1) Albemarle Sound estuary (area shaded in gray), 2) Pamlico Sound estuary (area shaded in black), 3) North Carolina ocean waters (box 3), and 4) northern coastal waters (box 4).

tions could be known to occur during a given year. This restriction allowed movements (recapture area) to be directly related to stock abundance, which was estimated on an annual basis (i.e., each calendar year) from 1991 to 2008, the terminal year in the assessment. In addition, restriction of returns to a relatively short time period at liberty (<9 months) minimized the opportunity for growth between tagging and recapture, thereby ensuring that fish lengths at tagging (the size variable used in our analyses) were representative of the size of fish when movement occurred.

To reach another recapture area (outside the Albemarle Sound estuary), tagged fish would have had to travel a considerable distance (>300 km) from their release site in the upper Roanoke River. Therefore, to reduce the likelihood of underestimation of fish movement, we excluded tag returns from the first 14 days at liberty, affording tagged fish a more realistic period of time to complete movement or migration to another system. Indeed, the earliest tag return from outside the Albemarle Sound estuary (in North Carolina ocean waters) occurred at 16 days after tagging, providing justification for our 14-day exclusion window. Finally, data from 1994 were excluded from analyses because of reduced tagging efforts in that year (only 9 fish were tagged and 1 returned).

To determine which explanatory variables affected movements of Striped Bass and to assess their relative importance, we used an information-theoretic approach. A multinomial logistic regression model was run for each of the 5 possible combinations of explanatory variables: 1) length, abundance, length×abundance (interaction model), 2) length and abundance, 3) length only, 4) abundance only, and 5) intercept only (no effects model). Akaike's information criterion (AIC) values were obtained for each candidate model. We considered the model with the lowest AIC value as the most parsimonious or "best," but we also computed additional diagnostics, Akaike differences (Δ_i) and Akaike weights (w_i), to assess how other models performed in comparison to this single best model (Burnham and Anderson, 2002). The first of these other diagnostics was calculated as

$$\Delta_i = AIC_i - AIC_{min},$$

where AIC_i = the AIC value of a given model (i); and
AIC_{min} = the AIC value of the best model (minimum AIC).

As a general guideline, models with Δ_i close to zero have considerable empirical support, models with Δ_i of 4–7 have much less support, and models with Δ_i of 9–14 have little support (Anderson, 2008). The following equation was used to calculate w_i values:

$$w_i = \frac{\exp\left(-\frac{1}{2}\Delta_i\right)}{\sum_{r=1}^{R}\exp\left(-\frac{1}{2}\Delta_r\right)}.$$

Note that R refers to the set of models being evaluated. Values of w_i can be interpreted as the probability that a particular model (i) is the best model for the data set given that one of the models must be selected as the best (Anderson, 2008).

We based our inferences on parameter estimates from the model (i.e., on the combination of explanatory variables) deemed most parsimonious from AIC diagnostics. For example, if the third model (length effect only) was determined to be the best model, values of the parameters (i.e., regression coefficients) that represented the effect of fish length were used to calculate the predicted relative probability of Striped Bass being recovered in each recapture area as a function of their size at tagging. We assessed the fit of the best model through the use of both Pearson and deviance goodness-of-fit tests. Because explanatory variables were continuous, it was necessary to group data for these tests (Agresti, 1996). For this purpose, we used 100-mm bins and abundance bins of 0.1 million fish. All statistical analyses were performed in SAS, vers. 9.1.3 (SAS Institute, Inc., Cary, NC) with α =0.05.

Results

Tag return summary

From 1991 to 2008, 1197 tagged Striped Bass were reported as having been recaptured within their first 9 months at liberty (late April–December); analyses conducted for this study were based on data from these individuals. Hook-and-line (recreational) anglers accounted for a majority (84%) of tag returns. Although most returns (80%) were from fish 400–600 mm TL (at tagging), fish lengths ranged from 287 to 1105 mm TL. Moreover, nearly all tag returns (154 of 156) of larger Striped Bass (>600 mm TL) were from years in which stock abundance exceeded 1.5 million fish (Table 1).

Temporal recapture trends

The AR stock of Striped Bass increased their movement outside of the Albemarle Sound estuary as the

Table 1

Number of tag returns of Striped Bass (*Morone saxatilis*) per combination of total annual stock abundance (millions of fish) and interval of total length (TL) at tagging. Annual abundance estimates (1991–2008) of Albemarle Sound–Roanoke River Striped Bass were obtained from a statistical catch-at-age model (NCDMF and NCWRC[2]). Only those tag returns occurring after the first 2 weeks but within the first calendar year at liberty were included in data analyses and are enumerated here. "–"=no tag returns for that year.

Abundance (millions)	Year	Number of returns per size (mm TL) interval							
		<400	400–499	500–599	600–699	700–799	800–899	900–999	>1000
1.035	1993	–	37	15	–	–	–	–	–
1.101	1991	10	17	5	–	–	–	–	–
1.104	1992	2	48	7	1	1	–	–	–
1.388	1995	–	4	17	–	–	–	–	–
1.518	2005	1	68	36	7	2	–	6	–
1.569	1996	4	7	13	1	–	–	–	–
1.673	2004	–	17	8	–	1	3	1	–
1.752	1997	6	38	28	4	1	–	–	–
1.803	2006	–	54	80	6	5	3	9	3
1.828	2003	7	20	36	7	2	1	3	–
1.829	2001	1	35	38	12	2	2	–	–
1.836	2000	1	29	16	4	2	–	–	–
1.860	2002	2	27	39	4	7	1	–	1
1.877	1998	4	41	23	7	3	–	–	–
1.895	2008	38	42	13	3	–	3	5	6
1.907	1999	1	29	17	5	1	–	–	–
2.051	2007	–	19	40	11	3	1	5	2

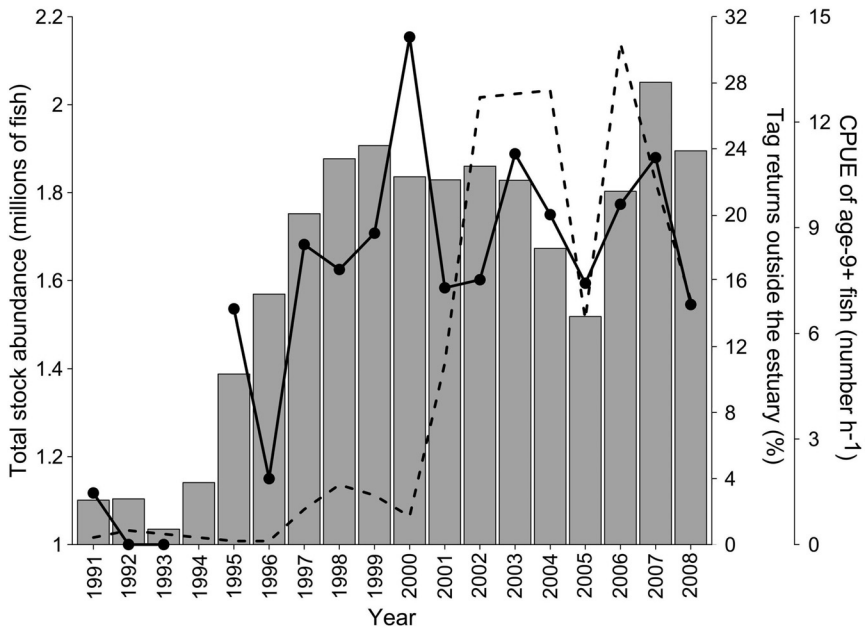

Figure 3

Time series for the period of 1991–2008 of the following trends of the Albemarle Sound–Roanoke River stock of Striped Bass (*Morone saxatilis*): 1) total annual abundance (millions of fish; gray bars) of the stock (age 1+ fish) estimated from a statistical catch-at-age model (NCDMF and NCWRC[2]), 2) annual percentage of tag returns (solid line) that occurred outside the Albemarle Sound estuary from Striped Bass tagged and released on the spawning grounds in the upper Roanoke River, and 3) catch per unit of effort for fish (number h^{-1}) age 9+ (>700 mm in total length) (dashed line) in annual spring electrofishing surveys on the Roanoke River spawning grounds.

population rebuilt over the past 2 decades (1991–2008). In the early 1990s, few tag returns occurred outside the Albemarle Sound estuary: <4% annually across the years of 1991–96, with the exception of 1995 (Fig. 3). However, as the stock increased in abundance and its age structure expanded, returns from regions outside the Albemarle Sound estuary increased considerably and ranged from 15% to 31% annually during the years of 1997–2008 (Fig. 3).

Effects of fish size and stock abundance on recapture area

Fish size and stock abundance affected recapture area. The best multinomial logistic regression model included the main effects of both fish length and stock abundance but not their interaction (Table 2). Goodness-of-fit tests indicated this model fitted the sample data well (Pearson goodness of fit, χ^2=117, degrees of freedom=126, P=0.70; deviance goodness of fit, χ^2=104, degrees of freedom=126, P=0.93). Although the best model showed that recapture area depended on both fish size and stock abundance, AIC diagnostics across the suite of models indicated that fish length exerted a much stronger effect than abundance. Specifically, the model that included only fish length had moderate empirical support (Δ_i=3.8, w_i=0.12), but the model that included stock abundance alone had very little support (Δ_i=462.2, w_i=0) (Table 2).

Striped Bass of the AR stock exhibit a strong size-dependent migration pattern, whereby both the incidence of emigration and the distance emigrants move increase with fish size. The best model predicted that the probability of emigration from (i.e., recapture outside) the Albemarle Sound estuary increased dramatically with fish size. Specifically, the probability of recapture within Albemarle Sound declined sharply (from values >90%) beyond 600 mm TL, the size at which recapture probabilities began to increase in other areas, such as Pamlico Sound and ocean waters (Fig. 4). The model predicted that Striped Bass 700–800 mm TL in length were most likely to be recaptured in ocean waters of North Carolina (Fig. 4C) and that the largest fish (>850 mm TL) were most likely to be recaptured in the northern coastal region (Fig. 4D).

Empirical tag return data supported the movement pattern indicated by the best model. Nearly all (92%) of the tag returns of smaller fish (<600 mm TL;

Table 2

Diagnostics with Akaike's information criterion (AIC) for candidate multinomial logistic regression models that relate the recapture area (Albemarle Sound estuary, Pamlico Sound estuary, North Carolina ocean waters, or northern coastal waters from Virginia to Massachusetts) of tagged Striped Bass (*Morone saxatilis*) to fish length and total annual stock abundance for the years 1991–2008. Each model represents a different combination of these explanatory variables. Note that Δ_i=Akaike's differences and w_i=Akaike's weights, where lower values of Δ_i and higher values of w_i indicate greater relative empirical support for a model.

Model	AIC	Δ_i	w_i
Length + abundance	1003.2	0.0	0.80
Length only	1007.0	3.8	0.12
Length + abundance + length *x* abundance	1007.8	4.6	0.08
Abundance only	1465.4	462.2	0.0
Intercept only	1496.1	492.9	0.0

n=1040) occurred within the Albemarle Sound estuary (Fig. 5A). Yet, only 47% of returns of fish 600–799 mm TL (*n*=102) and 2% of returns of fish >800 mm TL (*n*=55) occurred in Albemarle Sound; most tag returns of these larger fish occurred in ocean waters (Fig. 5, B and C). Interestingly, the majority (78%) of tag returns of the largest fish in this study (800–1105 mm TL) occurred in distant coastal waters from New Jersey to Cape Cod, 780 to 1250 km from the release site (Fig. 5C).

Stock abundance also affected the areas in which Striped Bass were recaptured. The best model predicted a slight increase (~5%) in recapture of small Striped Bass (<600 mm TL) in the Pamlico Sound region as stock abundance increased from 1 to 2 million fish (Fig. 4B). This trend also was evident in empirical tag return data. Returns from the Pamlico Sound estuary, ~6% of all returns, occurred only during years in which stock abundance exceeded 1.4 million fish. There were no returns from the Pamlico Sound estuary during years of lower abundance (1.0–1.1 million fish) (Fig. 6).

Discussion

Continuous tagging over a 20-year period, a length of effort that is rare in most fisheries, allowed us to determine the strong effect of fish size and relatively smaller effect of stock abundance on a fish stock's spatial distribution. Multiple stocks of Striped Bass co-occur along the East Coast of the United States during nonspawning periods. Therefore, by tagging fish on their natal spawning grounds (when stocks are separated), we were able to investigate stock-specific movements and spatial distribution—information that could otherwise not have been resolved with approaches such as fisheries-independent surveys (e.g., trawl surveys). In this section, we provide further details on the effects of fish size and stock abundance on the spatial distribution of the AR stock of Striped Bass and on the implications for management of Striped Bass.

Effects of fish size on recapture area

The increase in tag returns of the AR stock from regions outside its natal estuary over the past 2 decades was largely due to expansion of the age and size structure of the stock as it recovered. The majority of returns (67%) that occurred outside the Albemarle Sound estuary during the stock recovery period were from ocean waters. Model results and empirical data both showed the probability of Striped Bass being recaptured in ocean waters increased dramatically with fish size beyond 600 mm TL, to the point where the largest individuals (>800 mm TL) were almost exclusively captured in ocean waters. Therefore, it is not surprising that returns from ocean waters increased over the past 2 decades as more fish from this largest size class (which was the class most likely to emigrate to ocean habitats) became available for tagging and recapture as the age and size structure of the AR stock expanded.

The strong size-dependent emigration pattern of Striped Bass revealed by this study helps explain the lack of recaptures in ocean waters by Hassler et al.[1], who also focused on the AR stock. To collect fish for tagging, Hassler et al.[1] primarily used small-mesh (<150 mm stretched) gill nets that likely selected for smaller fish. Indeed, of the 2428 returns in their study, most (86%) were from fish 400–550 mm TL at tagging, and only 2 returns (<0.1%) were from fish >800 mm TL at tagging. Moreover, the vast majority (88%) of tag returns in their study occurred within the first year at liberty. Therefore, given the small sizes of tagged fish and short-term nature of returns (i.e., small tagged fish did not have time to grow into larger size categories because of high har-

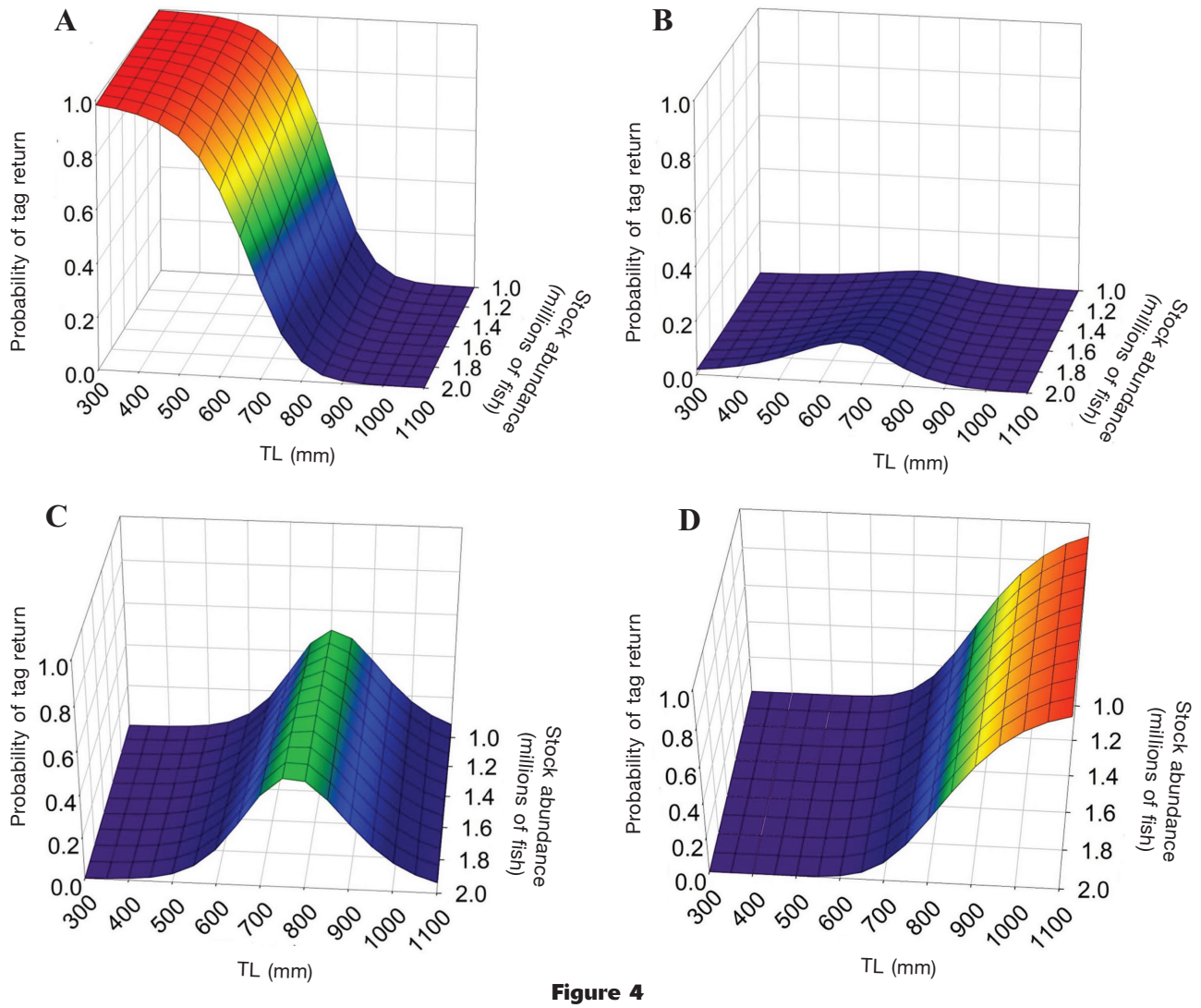

Figure 4

Predicted probabilities of tag returns in each recapture area as a function of total length (TL) and annual total stock abundance (millions of fish) of Striped Bass (*Morone saxatilis*) during the period of 1991–2008. We used the following 4 recapture areas **(A)** Albemarle Sound estuary, **(B)** Pamlico Sound estuary, **(C)** North Carolina ocean waters, and **(D)** northern coastal waters (for locations, see the map in Fig. 2B). Probabilities are based on parameter estimates from the most parsimonious multinomial logistic regression model that related the recapture area of Striped Bass to TL and stock abundance. Cooler and warmer colors represent low and high tag return probabilities, respectively, as follows: (0.0, ■; 0.2, ■; 0.4, ■; 0.6, ■; 0.8, ■; 1.0, ■). Note that tag return probabilities sum to 1.0 (across recapture areas) for a given combination of TL and stock abundance.

vest), the lack of ocean recaptures by Hassler et al.[1] is not surprising. Nearly all fish recaptured in their study (>99%) were smaller than the size at which appreciable ocean emigration occurs (>800 mm TL), as indicated in our study.

Although other factors, such as prey availability and susceptibility to predation, may be involved, water temperature appears to be a salient factor in explanation of the size-dependent migration and distribution patterns of the AR stock. A change in temperature preferences with fish size has been hypothesized to be the main driver of the size-dependent emigration pattern observed previously for other stocks of Striped Bass (Coutant, 1985), especially the Chesapeake stock (Dorazio et al., 1994; Secor and Piccoli, 2007).

Decreases in temperature optima with fish size can be explained by bioenergetic principles. Specifically, the temperature threshold beyond which the increase in total metabolic load starts to become stressful (i.e., the point at which the scope for activity and growth begins

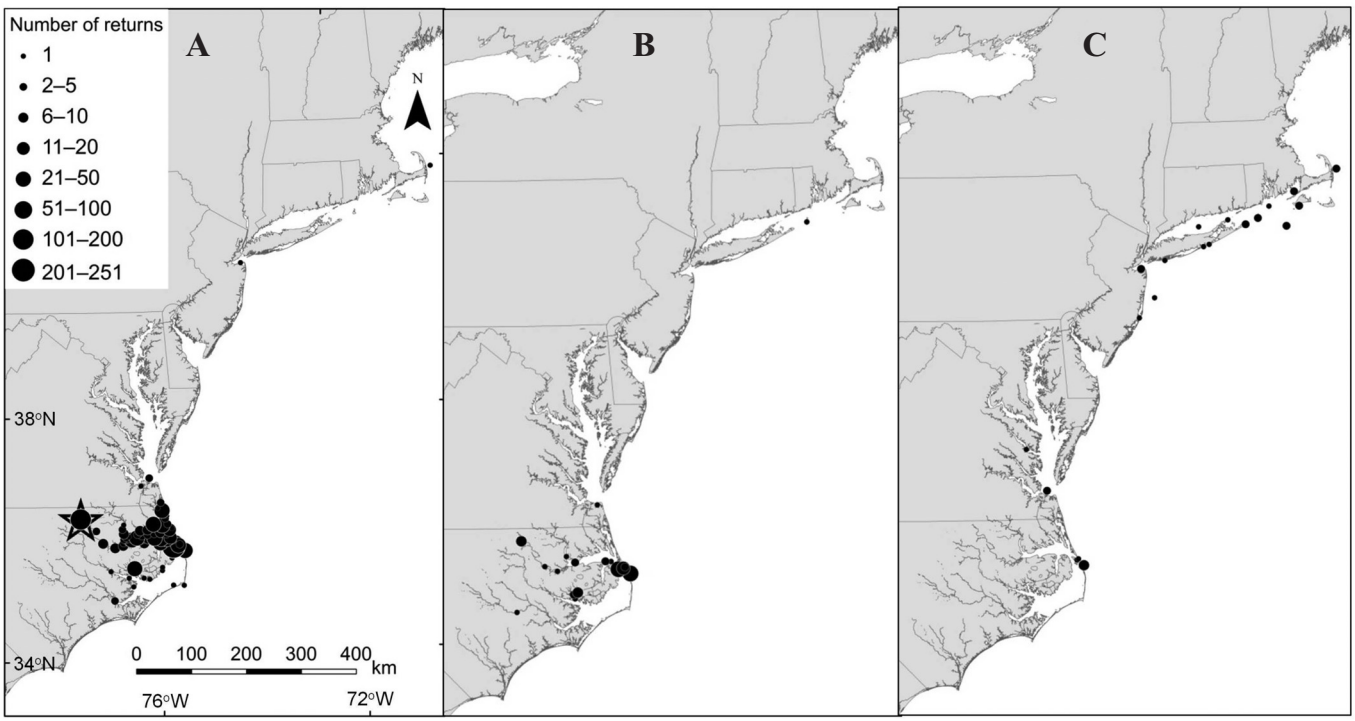

Figure 5

Tag return locations of Striped Bass (*Morone saxatilis*) along the eastern seaboard of the United States by length group (data pooled across years): **(A)** fish 287–599 mm in total length (TL) (n=1020 returns), **(B)** fish 600–799 mm TL (n=101 returns), and **(C)** fish 800–1105 mm TL (n=55 returns). Bubble sizes represent the number of tag returns from each location (within each length group). The star in panel A denotes the location where Striped Bass were tagged and released during annual spring electrofishing surveys conducted in the Roanoke River in 1991–2008. Only those tag returns that occurred after the first 2 weeks but within the first calendar year at liberty were included in analyses and are shown. The location of 21 tag returns (of the 1197 total) could be assigned only to 1 of the 4 broad geographic recapture areas (shown in Fig. 2B) and are, therefore, not shown.

to decline) occurs at progressively lower temperatures as fish size increases because larger individuals have a greater total metabolic demand than smaller individuals on the basis of body size alone (Hartman and Brandt, 1995). Therefore, after spawning, most large Striped Bass may emigrate, as we found, to cooler northern ocean habitats, which would provide a metabolic reprieve, rather than spend their summers in warm estuarine waters.

Interestingly, Striped Bass of the AR stock in the intermediate size range of 700–850 mm TL, were mainly recaptured in ocean waters off North Carolina, from the Oregon Inlet north to the border of North Carolina and Virginia. No Striped Bass were recaptured in ocean waters south of Cape Hatteras, where summer temperatures (>26°C; http://www.ndbc.noaa.gov, Station#41036) are similar to summer temperatures in Albemarle Sound. Therefore, nearby ocean waters may provide an adequate thermal refuge (23–26°C; http://www.ndbc.noaa.gov, Station#44100) during summer for Striped Bass in the size range of 700–850 mm TL. One intriguing question is whether the size at which the onset of ocean emigration occurs will shift to a smaller size as inshore estuarine waters, which already approach 30°C in summer (http://waterdata.usgs.gov, Gage#0208114150), are expected to continue warming under current projections for climate change (IPCC, 2007). Continuation of the long-term tagging program on the AR stock of Striped Bass could help address this question.

Previous research on northern stocks of Striped Bass has provided evidence for diverse lifetime migration patterns: some members of a given population reside in freshwater or estuarine environments throughout their life (resident contingent) and others are more exploratory and engage in large-scale coastal migrations (migratory contingent) (Clark, 1968; Secor, 1999). There is particularly strong evidence for this "contingent" behavior in Striped Bass in the Hudson River (Secor and Piccoli, 1996; Secor et al., 2001; Zlokovitz et al., 2003). Our study, however, provides little indication of this phenomenon in the AR stock of Striped Bass. If contingent behavior had been prevalent, one would have expected that some large fish would have remained and been recaptured in the Albemarle Sound after spawning. Yet, of the 50 fish exceeding 855 mm TL that were recovered in our study, none were recaptured within Albemarle Sound and, instead, all were taken in the ocean. It is possible that contingent behavior is not

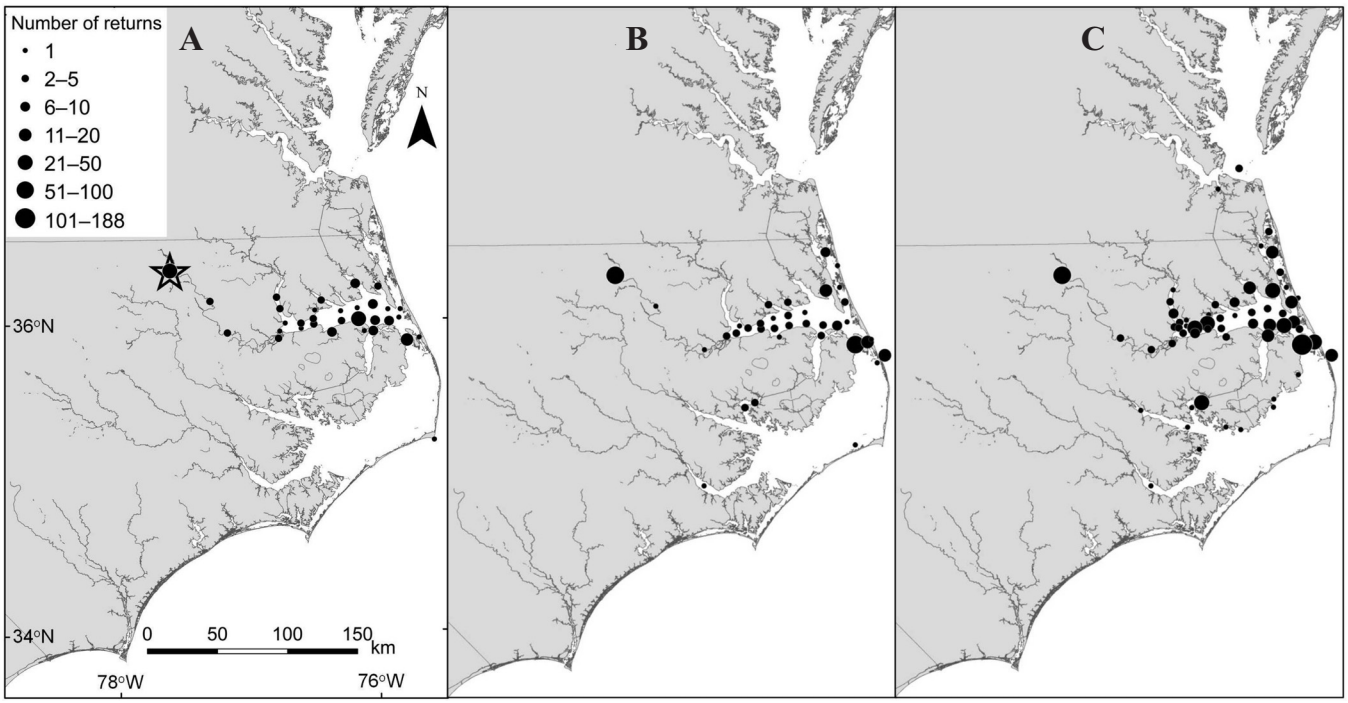

Figure 6

Tag return locations of Striped Bass (*Morone saxatilis*) <600 mm in total length in North Carolina and Virginia coastal waters by stock abundance in the year of release: **(A)** annual abundance values of 1.0–1.1 million fish (n=138 returns), **(B)** annual abundance values of 1.4–1.7 million fish (n=169 returns), and **(C)** annual abundance values of 1.8–2.0 million fish (n=713 returns). Bubble sizes represent the number of tag returns from each location (within each abundance group) as indicated in the legend. The star in panel A denotes the location where Striped Bass were tagged and released during annual spring electrofishing surveys in the Roanoke River in 1991–2008. Only those tag returns that occurred after the first 2 weeks but within the end of the first calendar year at liberty were included in analyses and are shown. The location of 20 tag returns (of the 1040 total) could be assigned to only 1 of the 4 broad geographic recapture areas (shown in Fig. 2B) and are, therefore, not shown.

beneficial, and, therefore, it does not manifest in the AR stock because of high inshore water temperatures during summer that would be unsuitable for "resident" fish once they attain a large size. The possibility for latitudinal differences in the frequency of contingent behavior in Striped Bass and other fishes warrants future investigation.

Effects of stock abundance on recapture area

Stock abundance in the year of release was included in the best model explaining where Striped Bass were recaptured. This effect was primarily a result of smaller Striped Bass being recaptured in the adjacent estuarine systems of Pamlico Sound and lower Chesapeake Bay only in the years of highest abundance (Fig. 6C). Also, evidence of recapture patterns within the Albemarle Sound estuary were indicative of a density effect. Namely, tag returns were much more common in the eastern portions of Albemarle Sound, particularly in Currituck Sound (6% vs. 1% of returns) and Croatan and Roanoke sounds (32% vs. 6%), during years in which stock abundance exceeded 1.4 million fish in contrast to years when it was below this level (Fig. 6). Therefore, although adults generally may remain inshore until they reach larger sizes (>600 mm TL), the distances they disperse *within* estuarine habitats, after spawning, tend to increase with the abundance of conspecifics, presumably because of density-dependent mechanisms. These movements likely are important ecologically to prey of Striped Bass because the smallest size groups (<600 mm TL) are the most numerous in this population (i.e., predation effects may change with stock abundance). Future research should investigate these possibilities and better isolate the effects of density by controlling for environmental covariates, such as the abundance of competitor species and changing habitat suitability, as suggested by Shepherd and Litvak (2004).

Management implications

Results from this study have important implications for the management of Striped Bass along the East Coast of the United States. With current assessment strategies, Striped Bass from the AR stock are assumed not to contribute to the Atlantic Ocean mixed stock

fishery (ASMFC[4]). However, this study revealed that some members of the AR stock, those fish surviving to sizes >800 mm TL, are indeed migratory and, therefore, unequivocally contribute to (i.e., are harvested by) the mixed stock fishery of the Atlantic coast. Because management benchmarks for the mixed stock fishery, such as the threshold fishing mortality (F_{MSY}=0.41; ASMFC[4]), currently are based on data from Chesapeake, Hudson, and Delaware stocks that are potentially more productive than the AR stock, it is possible that the mixed stock fishery could affect the AR stock disproportionately. Accordingly, future research should establish the productivity of the AR stock of Striped Bass in relation to other stocks. If the AR stock is found to be less productive, then future work also should determine the implementation costs of more stringent fishing regulations in the mixed stock fishery, namely the amount and value of harvest that would be lost from more productive stocks (Chaput, 2004; Crozier et al., 2004; Hilborn et al., 2004).

Results from this study also have implications for the assessment and management of Striped Bass within North Carolina. Currently, landings of Striped Bass outside the Albemarle Sound estuary (region 1; Fig. 2B) are not included in the AR stock assessment (NCDMF and NCWRC[2]). Stock status is based on the estimate of fishing mortality ($F_{threshold}$=0.27) for fully recruited Striped Bass of age 4–6 and 400–600 mm TL, a size group for which fish were found in this study to increase their movement to adjacent estuarine systems outside the stock boundary as they increased in abundance. Therefore, by not including fish that move to and are harvested in adjacent systems, the AR stock assessment underestimates fishing mortality. Accordingly, future research should examine the sensitivity of fishing mortality estimates from the AR stock assessment to additional landings of age-4–6 Striped Bass of AR origin outside the Albemarle Sound estuary.

Caveats

It is important to note that the analyses in this study indicate the probability of recapture location; movements are inferred from these data. Fishermen behavior (e.g., spatiotemporal differences in fishing effort or size targeting because of regulations and economic value) can affect and potentially bias tag returns and inferences about movement patterns (Hilborn, 1990; Gillanders et al., 2001). The size-dependent migration pattern that we observed could be due to differences in selectivity between ocean and estuarine fisheries; that is, small tagged fish could have migrated to the ocean but not been caught in the fishery. However, fisheries-independent data indicate that it is predominantly the large Striped Bass of the AR stock that migrate to ocean waters. In a mobile telemetry study, Haeseker et al. (1996) searched the Albemarle Sound during summer (May–August) for the presence of 26 telemetered Striped Bass (all but 1 fish <600 mm TL) that participated in the April Roanoke River spawning run. They relocated 25 (96%) of these fish in the Albemarle Sound at least 1 month after spawning, providing evidence that smaller Striped Bass mostly remain in the estuary after spawning. Furthermore, in an ongoing telemetry study, 163 Striped Bass ranging in length from 445 to 1146 mm TL (mean=580 mm TL) were telemetered in the Roanoke River during spring, beginning in 2011, by Harris and Hightower.[5] Most large fish in their study (15 of the18 individuals >900 mm TL at tagging) have been detected by coastal receiver arrays in Massachusetts, New York, New Jersey, Delaware, and Virginia, but no smaller individuals have been detected in these northern ocean waters (Harris and Hightower[5]). Hence, results from these fisheries-independent telemetry studies corroborate the strong size-dependent emigration pattern of the AR stock of Striped Bass that we inferred from tag recaptures in our study.

A limitation of our study was that nearly all tag returns (99%) from larger fish (>600 mm TL) occurred during years of higher stock abundance (>1.5 million fish). Therefore, it is possible that the observed ocean emigration of larger fish was due in part to the higher abundance of similar size conspecifics (i.e., density-dependent mechanisms). However, ocean emigration of the AR stock of Striped Bass appears to be a size-dependent phenomenon related to bioenergetics as described and is probably largely independent of ambient population density or abundance. Two lines of evidence support this notion. First, data on large Striped Bass (>600 mm TL) across the more restricted range of annual values of stock abundance (1.5–2.0 million fish) indicate that density had little effect (an increase <3%) on the probability of large fish being recaptured in ocean waters. Second, just as we found in our study, Dorazio et al. (1994) found a strong size-dependent emigration pattern for the Chesapeake Bay stock: most fish >800 mm TL were recovered in northern ocean waters from New Jersey to Maine. Their study occurred in 1988–91, years when the Chesapeake Bay stock was at relatively low abundance levels and still rebuilding, demonstrating that substantial ocean emigration of large fish, albeit from a different stock, still occurs at low densities.

[4] ASMFC (Atlantic States Marine Fisheries Commission). 2003. Amendment 6 to the Interstate Fishery Management Plan for Atlantic Striped Bass. Fishery Management Report No. 41 of the Atlantic States Marine Fisheries Commission, 63 p. [Available from http://www.asmfc.org/uploads/file/sbAmendment6.pdf.]

[5] Harris, J. E., and J. E. Hightower. 2013. Unpubl. data. North Carolina Cooperative Fish and Wildlife Research Unit, U. S. Geological Survey, and Department of Applied Ecology, North Carolina State Univ., Raleigh, NC 27695.

Conclusions

Our study revealed major changes in the movements and associated distribution of a fish stock as it recovered from a depleted state. During the early phases of rebuilding, the stock was largely confined to its natal estuary but dramatically expanded its distribution, and degree of anadromy, as recovery continued. This major shift in distribution was due to changes in the demographics—namely size structure and total abundance—of the stock as it recovered. Size structure has received little attention in the fisheries literature in regard to its effects on stock distribution but appears to be important.

Although the recovery of Striped Bass often is regarded as one of the few success stories in fisheries management (Richards and Rago, 1999), many global fish stocks are either currently experiencing rebuilding or have recently recovered, for example, nearly one-third of the 166 stocks examined worldwide by Worm et al. (2009). It is possible that the spatial dynamics of these and other rebuilding stocks will differ from their depleted state. For instance, as stocks recover and more individuals are allowed to reach larger sizes (e.g., through a reduction in fishing mortality; Berkeley et al., 2004), the spatial distribution of stocks may shift or expand because larger, older fish often have different migratory behaviors and habitat preferences than smaller, younger individuals (Heifetz and Fujioka, 1991; Macpherson and Duarte, 1991; Shepherd et al., 2006; Grüss et al., 2011). Such changes in the movement and distribution of fish populations can have important consequences for stock assessments, as argued previously, and also affect ecosystem dynamics (e.g., as predators move into new areas, they can exert top-down changes in community structure; Casini et al., 2012). Therefore, resource managers should be aware of potential changes in the movement and distribution of recovering fish stocks and account for them accordingly if they manifest. As indicated in our study, long-term tagging and monitoring data are useful for detection of population-level changes in the movement and distribution of fishes.

Acknowledgments

We thank the many individuals from the NCDMF and North Carolina Wildlife Resources Commission who collected and tagged Striped Bass and also compiled and processed tag return data. We also are grateful to the many fishermen who provided tag return information. Analyses for this study were completed while J. Callihan was a Marine Fisheries Management Fellow supported by NCDMF (Coastal Recreational Fisheries License fund award no. 3210) and North Carolina Sea Grant award E/GS-6. The manuscript was improved by comments from J. Harris, J. Finn, P. McGrath, and R. Laney.

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Section 3 – Growth and mortality of hatchery-reared striped bass stocked into nonnatal systems

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North American Journal of Fisheries Management
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/ujfm20

Growth and Mortality of Hatchery-Reared Striped Bass Stocked into Nonnatal Systems

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Published online: 30 Oct 2014.

To cite this article: Jody L. Callihan, Charlton H. Godwin, Kevin J. Dockendorf & Jeffrey A. Buckel (2014) Growth and Mortality of Hatchery-Reared Striped Bass Stocked into Nonnatal Systems, North American Journal of Fisheries Management, 34:6, 1131-1139, DOI: 10.1080/02755947.2014.951805

To link to this article: http://dx.doi.org/10.1080/02755947.2014.951805

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North American Journal of Fisheries Management 34:1131–1139, 2014
© American Fisheries Society 2014
ISSN: 0275-5947 print / 1548-8675 online
DOI: 10.1080/02755947.2014.951805

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Abstract
Cross-stocking involves the use of fish from nonnatal sources to augment populations. This practice may not be effective, especially if fish from different populations are not well adapted to the environmental conditions of the areas intended for enhancement. Yet, the ecological consequences of cross-stocking have received little attention, particularly in coastal environments. We used tag return data (1990–2010) from an ongoing stock enhancement program to compare the growth and mortality of hatchery-reared Striped Bass *Morone saxatilis* of Roanoke River origin between their natal (Albemarle Sound estuary) and two nonnatal systems (Tar-Pamlico and Neuse rivers) in North Carolina. Despite their Roanoke River origin, stocked juveniles exhibited high fidelity (>90%) to nonnatal systems and similarly high growth as in their natal habitat (von Bertalanffy *K* values were statistically similar among systems and ranged from 0.54 to 0.61). However, time-at-liberty estimators of total mortality (*Z*) indicated stocked Striped Bass experienced significantly higher mortality in nonnatal (*Z* values, 0.48–0.51) versus natal (*Z* = 0.33) systems. Therefore, while cross-stocking may not contribute to stock rebuilding, it appeared to be an effective management tool for supporting local put-and-take fisheries for this recreationally and commercially important species.

Due to practical constraints such as costs, hatchery proximity, or difficulties obtaining natal broodstock (for imperiled populations), stocking programs may use fish from nonnatal sources for population enhancement (Lichatowich et al. 1999; Rulifson and Laney 1999; St. Pierre 1999). This practice of stocking fish in nonnatal systems is referred to as "cross-stocking" (Murphy 1990; Rulifson and Laney 1999; Norton et al. 2000). While there are obvious genetic concerns with this approach (e.g., outbreeding depression: Blankenship and Leber 1995; Bulak et al. 2004; Ward 2006), few studies have evaluated the ecological consequences of cross-stocking in coastal environments. For example, fish populations often develop beneficial local adaptations to

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Received March 11, 2014; accepted July 16, 2014

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their natal habitat such as unique bioenergetic properties that allow them to maximize growth in their natal area (Conover 1990; Conover et al. 1997). Therefore, individuals of those populations may not grow and survive as well when placed in nonnatal systems. Clearly, for any stocking program to be successful and contribute to fisheries and/or rebuild populations, stocked fish must exhibit favorable growth and survival and also demonstrate high fidelity to the areas targeted for enhancement (Rimmer and Russell 1998; Jenkins et al. 2004; Hervas et al. 2010).

Striped Bass *Morone saxatilis* have been extensively cross-stocked in North America during the past century (Harrell et al. 1990; Woodroffe 2011). The first hatchery for this species was built in the 1880s along the Roanoke River in North Carolina, which comprises the largest spawning run of Striped Bass south of the Chesapeake Bay (Worth 1884). Accordingly, Roanoke River broodstock have served as a major source of hatchery-reared Striped Bass stocked into North Carolina waters and along the U.S. eastern seaboard. The current paradigm suggests that Roanoke River Striped Bass are a resident population that generally remains in their natal estuary (Albemarle Sound) throughout their lives, making only local spawning migrations during spring to their freshwater spawning grounds on the upper Roanoke River (Hassler et al. 1981). However, a recent study by Callihan et al. (2014) revealed that some members of this population, mainly larger and older fish (TL > 850 mm, age > 10), are indeed migratory and engage in seasonal coastwide migrations (north in the summer, south in the fall–winter).

In our study, we used tag return data from a stock enhancement program to estimate and compare the growth and mortality of hatchery-reared Striped Bass of Roanoke River origin between their natal (Albemarle Sound estuary, including the Roanoke River) and two nonnatal systems (the Tar-Pamlico and Neuse rivers) in North Carolina. Roanoke River adults served as the sole source of broodstock from 1980 to 2010 to produce juvenile Striped Bass that were stocked into North Carolina coastal waters. Therefore, this data set of tag returns afforded a unique opportunity to compare the growth and mortality of a recreationally and commercially important fish species between its natal and nonnatal habitats. As such, our study provides an important example of the effectiveness of cross-stocking as a management tool for coastal fish populations.

METHODS

Study area.—Our study focused on three systems in coastal North Carolina: (1) the Albemarle Sound estuary, (2) the Tar-Pamlico River, and (3) the Neuse River (Figure 1). These systems exhibit similar temperatures (annual range, 5–30°C) and bathymetry (mean depth, ~4 m at midtide: NOAA 1990), but their salinity regimes differ markedly. The Albemarle Sound is fresh to oligohaline (salinities < 5‰) as high flows from the Roanoke and Chowan rivers dominate the system relative to marine waters derived from a single, distant ocean inlet (Oregon Inlet) (Figure 1). Meanwhile, due to their close proximity to multiple inlets and lower river flows, salinities are higher in the Tar-Pamlico and Neuse rivers, especially near the mouths of these coastal rivers, where salinities can reach 15–20‰ (Epperly and Ross 1986; Orlando et al. 1994).

Stocking program.—While hatchery-reared Striped Bass of Roanoke River origin have been stocked as juveniles into the coastal waters of North Carolina for decades (Rulifson and Laney 1999), only since 1980 have fish been tagged by the North Carolina Division of Marine Fisheries (NCDMF) to permit an evaluation of stocking efforts. During this period (i.e., post-1980), broodstock were collected on the Roanoke River spawning grounds in spring (April–May), transported to the Watha State Fish Hatchery (Figure 1), and spawned in indoor tanks. One-week-old larvae were then transported to the Edenton National Fish Hatchery (Figure 1) and placed in outdoor (~1 acre [0.4 ha]) ponds. This grow-out phase lasted through late fall (November–December), at which time juveniles were harvested from the ponds for stocking purposes. Striped Bass were stocked in the Tar-Pamlico and Neuse rivers during the following 1.5 months, and ~10,000 fish were released during each stocking event (total numbers stocked varied across years, see Table 1). Tagged fish (~3,000 per system) were released with ~7,000 untagged counterparts in early to mid-December; the mean release date across years was December 11 and ranged from December 6 to 19. One stocking event occurred in Albemarle Sound each year from 1990 to 1996, and all stocked fish were tagged (Table 1). Striped Bass were stocked at the same location in each system (Figure 1) across years. The external tags indicated that a "reward" (US$5 or a baseball cap) would be offered for reporting information on recaptured Striped Bass to the NCDMF; contact information for NCDMF was printed on the tag.

For the purposes of this study, we analyzed tag returns from Striped Bass stocked during the years 1990–2003 (Table 1). Multiple tag types have been used since the inception of the tagging program and included Carlin disk, cinch-up spaghetti, and model FM-84 internal anchor tags. Sprankle et al. (1996) found that internal anchor tags had much higher annual retention rates in Striped Bass (85%) than spaghetti tags (62%). Therefore, to maintain consistency and not bias growth and mortality estimates (the latter of which were based on mean time at liberty) we only used data from fish tagged with internal anchor tags: 1990 and onwards for the Albemarle Sound, and after 1992 and 1993 for the Neuse and Tar-Pamlico rivers, respectively. In addition, due to a change in hatchery procedures (fish densities in grow-out ponds were decreased and food rations increased), juveniles produced after 2003 were larger (mean TL = 164 mm, range = 145–183 mm) at the time of stocking than those from earlier years (mean TL = 127 mm, range = 122–132 mm). Accordingly, we excluded tag returns from fish released after 2003 to ensure that size at release was similar among systems.

Growth estimation.—Striped Bass exhibited high fidelity to their stocking system, which allowed us to estimate system-specific growth and mortality. In other studies, tagged Striped

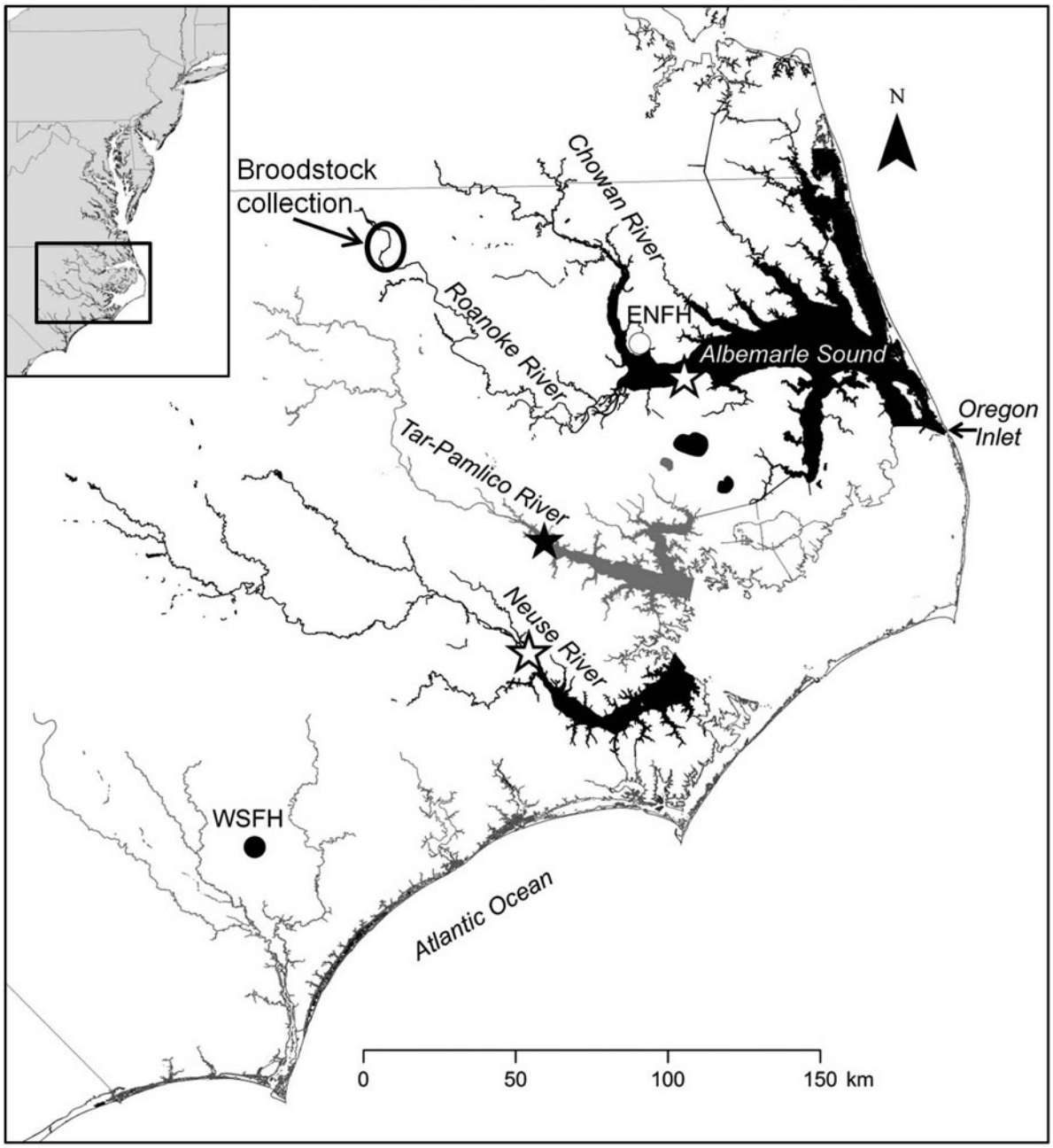

FIGURE 1. Coastal North Carolina study area for assessment of growth and mortality of hatchery-reared Striped Bass, showing the Albemarle Sound estuary (shaded in black, which includes the Roanoke and Chowan rivers), Tar-Pamlico River (shaded in gray), and Neuse River (shaded in black). Stars indicate stocking locations in each system. ENFH = the Edenton National Fish Hatchery, WSFH = the Watha State Fish Hatchery.

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Bass have been reported by fishers in coastal waters from North Carolina to Maine (Dorazio et al. 1994; Welsh et al. 2007; Callihan et al. 2014); thus, Striped Bass fisheries (and potential tag recovery locations) occur along the entire eastern seaboard of North America. Yet, the majority (>90%) of tag returns of stocked fish was from the same river system in which fish were initially released. Specifically, 91% of tag returns (479 of 527) from fish stocked in the Tar-Pamlico River occurred in that system; values for the Albemarle Sound and Neuse River were similarly high at 94% (442 of 472) and 96% (582 of 605), respectively (the boundaries for each system are shown in Figure 1). Therefore, growth and mortality estimates for fish released into a given system should incorporate and reflect any effects of system-specific conditions.

System-specific growth was estimated using the von Bertalanffy (VB) growth model. We were able to estimate growth

TABLE 1. Annual number of juvenile Striped Bass stocked and tagged in each system. Fish were released into the Tar-Pamlico and Neuse rivers during multiple stocking events (~10,000 fish per event) in late fall (November–December); one stocking event per year occurred in Albemarle Sound and all stocked fish were tagged. The total number (and percent) of tag returns from each release year (through the end of the study reporting period on December 31, 2010) are also provided. Data are only shown for those release years included in statistical analyses (1990–2003).

	Albemarle Sound			Tar-Pamlico River			Neuse River		
Release year	Number stocked	Number tagged	Number of returns	Number stocked	Number tagged	Number of returns	Number stocked	Number tagged	Number of returns
1990	2,000	2,000	60 (3.0%)						
1991	2,994	2,994	292 (9.8%)						
1992	2,465	2,465	83 (3.4%)				116,820	2,527	129 (5.1%)
1993	2,180	2,180	23 (1.1%)	118,600	2,204	37 (1.7%)			
1994	2,481	2,481	2 (0.1%)	183,254	2,320	27 (1.1%)	79,933	2,212	7 (0.3%)
1995	2,498	2,498	14 (0.6%)	140,972	2,497	51 (2.0%)			
1996	2,490	2,490	2 (0.1%)				100,760	4,998	122 (2.4%)
1997				24,031	4,865	114 (2.3%)			
1998							83,195	2,500	73 (2.9%)
1999				17,954	2,750	118 (4.3%)			
2000							108,000	2,900	37 (1.3%)
2001				37,000	3,000	30 (1.0%)			
2002							147,654	2,960	18 (0.6%)
2003				159,996	3,000	21 (0.7%)			
Total	17,108	17,108	476 (2.8%)	681,807	20,636	398 (1.9%)	636,362	18,097	386 (2.1%)

parameters (K: the Brody growth coefficient, and L_∞: the asymptotic length; Jennings et al. 2001) using size-at-age data because the age of recaptured fish was known. Fish age was calculated as the time between the spawn date in the hatchery and the recapture date reported by fishers. Because the exact spawn date was known for most, but not all release batches (79%, or 11 of 14), we used the mean spawn date across years (April 28; range, April 18 to May 10) to calculate fish age. While most recapture lengths (97%, 584 of 600) were reported by recreational or commercial fishers, some returns ($n = 16$) were made during scientific surveys by the NCDMF and North Carolina Wildlife Resources Commission (NCWRC), which allowed us to assess the reliability of our growth data. In the case of multiple recaptures (1.4% of all returns), only lengths from the terminal recapture were used as in Patterson et al. (2001) to ensure statistical independence such that data from a given fish was included only once in analyses. We modeled length at recapture as a function of fish age. In these models, the mean size (127 mm TL) and age (227 d) at stocking was used as a data point and the t_0 parameter was constrained to zero. We used nonlinear least squares to fit VB models to the observed data; residuals were normally distributed and not heteroscedastic. Likelihood ratio (LR) tests were used to compare growth curves and parameters among systems (Kimura 1980).

The Albemarle–Roanoke stock of Striped Bass was declared to be fully recovered in 1997 (ASMFC 1998). Therefore, stocking was discontinued in Albemarle Sound in 1997, but continued in other coastal systems (Tar-Pamlico and Neuse rivers) due to the low abundance levels and truncated age structure of those populations (NCDMF and NCWRC 2013). Consequently, most Striped Bass at liberty during the later years of this study (2000s) were those stocked in the Tar-Pamlico and Neuse rivers. It is possible that large-scale (i.e., statewide) environmental conditions (e.g., temperature) differed between earlier years (1990s) and later years (2000s), which could confound growth comparisons among systems (because fish in Albemarle Sound were only exposed to earlier-year conditions). To explore this potential issue, we examined whether growth trends based on all data (release years, 1990–2003) persisted when analyses were restricted to a common time period over which releases occurred in all systems (1992–1996) (Table 1).

Mortality estimation.—Because the fate of recaptured fish was not known in our study (i.e., whether they were harvested or released by fishers), we did not estimate mortality using traditional approaches such as the Brownie model (Brownie et al. 1985), which require this information and estimate survival based on dead recoveries. The assumption that all recovered fish are dead, when in fact many are released alive after being caught, can result in overestimates of the mortality rate (Smith et. al 2000), especially when catch and release is common, as is the case in Striped Bass fisheries. Instead, we estimated the total instantaneous mortality rate (Z) of Striped Bass using time-at-liberty (TAL) estimators that were originally developed by Gulland (1955) and Chapman (1961), and largely ignored until McGarvey (2009) recently renewed this approach.

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The basic premise of the TAL approach is that, in a fish population experiencing higher mortality, there should be fewer tagged individuals at liberty for long periods than in a population experiencing lower mortality (i.e., mortality is inversely proportional to TAL) (McGarvey 2009). Using this rationale, Chapman (1961) developed the following equations (for a finite sample of tag returns) to estimate Z (assumed to be constant over time) and its SE:

$$\hat{Z}_{\text{Chapman}} = \left(\frac{n_r - 1}{n_r}\right)\frac{1}{\bar{\tau}},\ \text{SE}\left(\hat{Z}_{\text{Chapman}}\right) = \frac{\hat{Z}_{\text{Chapman}}}{\sqrt{n_r - 2}},$$

where n_r = the number of tag returns from fish released in a given system and $\bar{\tau}$ = the mean TAL of fish released in a given system.

We used the above equations to estimate Z of Striped Bass stocked into each system. Estimates of Z were made for each annual stocking by system, with the exception of 1994 and 1996 in the Albemarle Sound and 1994 in the Neuse River due to low sample sizes (Table 1). As recommended by McGarvey et al. (2009), we excluded multiple recaptures from our analyses. In addition, we only included TAL data from hook-and-line recaptures (not gill nets and pound nets) so that gear type did not confound mortality comparisons. For example, many recaptures from Albemarle Sound were from commercial gill nets (140-mm stretched mesh) that are inefficient at capturing old, large fish. Using these data could bias mortality estimates (shorter TALs, higher Z values) relative to other systems (Tar-Pamlico and Neuse rivers) where gill-net recaptures were rare. Furthermore, because the TAL approach requires a sufficiently long period to estimate Z such that most tagged fish would have died (McGarvey 2009), or their tags would have fallen out, we only included TAL data for Striped Bass released from 1990 to 2000 because the maximum TAL observed in the database was 10 years (the database included returns reported through December 31, 2010, up to 20 years after tagging). We assumed tag loss (which is a component of Z estimated via the TAL approach: McGarvey 2009) was constant across systems and did not confound among-system comparisons of mortality. Finally, the TAL approach does not require information on reporting rates and is therefore insensitive to differences in reporting rates among systems; this is a major advantage of the approach (McGarvey 2009; McGarvey et al. 2009).

To simulate differences in mortality, we used the standard exponential decay model for fish mortality (Jennings et al. 2001) to project the decline of 100,000 stocked fish over time in each system based on data pooled across years within each system. We pooled data because Z values were consistent across release years within each system (see Results). To test statistical significance, we compared mean TALs among systems (data pooled within each system across years) using a one-way ANOVA. For this analysis, a data transformation (ln transformed) was necessary to meet the assumptions of homogeneity of variance and normality of residuals. The significance levels of pairwise mean comparisons (among systems) were assessed using Tukey-adjusted P-values. Statistical tests were performed in Statistical Analysis System (SAS, version 9.1.3) using $\alpha = 0.05$.

RESULTS

Growth

On average, Striped Bass were more than 400 mm at age 2 and 500 mm at age 3 across systems, and therefore exceeded the minimum size limit for recreational and commercial harvest (457 mm TL, 1991–present) during their second year of life (Figure 2). Growth curves for Striped Bass from the Tar-Pamlico and Neuse rivers were statistically indistinguishable from one another (LR test: $P = 0.50$), but each differed from the Albemarle Sound fish (LR tests: P-values < 0.0001). This difference in growth curves was due to the slightly higher L_∞ values in the Tar-Pamlico (657 mm) and Neuse (636 mm) rivers versus the Albemarle Sound (582 mm) (LR tests: P-values < 0.0001) as K values were similar (0.54–0.61) and did not significantly differ among systems (LR test: $P = 0.12$) (Figure 2).

Growth parameters and trends were similar when data were restricted to 1992–1996 releases only. That is, K values were similar among systems (0.52–0.62), and L_∞ values were slightly higher in the Tar-Pamlico (595 mm) and Neuse (665 mm) rivers than in Albemarle Sound (565 mm).

Mortality

Stocked Striped Bass were at liberty for much shorter periods in the Tar-Pamlico and Neuse rivers than in Albemarle Sound. For instance, only 6% of returns in the Tar-Pamlico and Neuse rivers occurred beyond 4 years at liberty, whereas returns beyond 4 years were fairly common (24%) in the Albemarle Sound (Figure 3). The ANOVA confirmed this trend as mean TALs were significantly lower (P-values < 0.0001) in the Tar-Pamlico (2.0 years) and Neuse (2.1 years) rivers than in the Albemarle Sound (3.0 years). Mean TALS did not differ between the Tar-Pamlico and Neuse rivers (ANOVA: $P = 0.34$).

Total mortality of Striped Bass was consistently higher in the Tar-Pamlico and Neuse rivers than in the Albemarle Sound regardless of release year. In the Albemarle Sound, Z values ranged from 0.27 to 0.39 across release years 1990–1995 (Figure 4). In the Tar-Pamlico and Neuse rivers, Z values exceeded 0.4 and ranged from 0.42 to 0.65, with the exception of one release year (1994 in the Tar-Pamlico River) (Figure 4). During 3 years (1992, 1993, and 1995), fish from the same batch (raised together in the hatchery) were stocked into two different systems 1 d apart. These fish showed the same trend in mortality among systems; that is, higher Z values in the Tar-Pamlico (1993, 1995) and Neuse (1992) rivers than in the Albemarle Sound (Figure 4).

Overall, system-specific Z values, calculated from data pooled across release years, were higher in nonnatal systems, the Tar-Pamlico ($Z = 0.51$, SE $= 0.03$) and Neuse ($Z = 0.48$, SE $= 0.03$) rivers, than in the natal system, Albemarle Sound

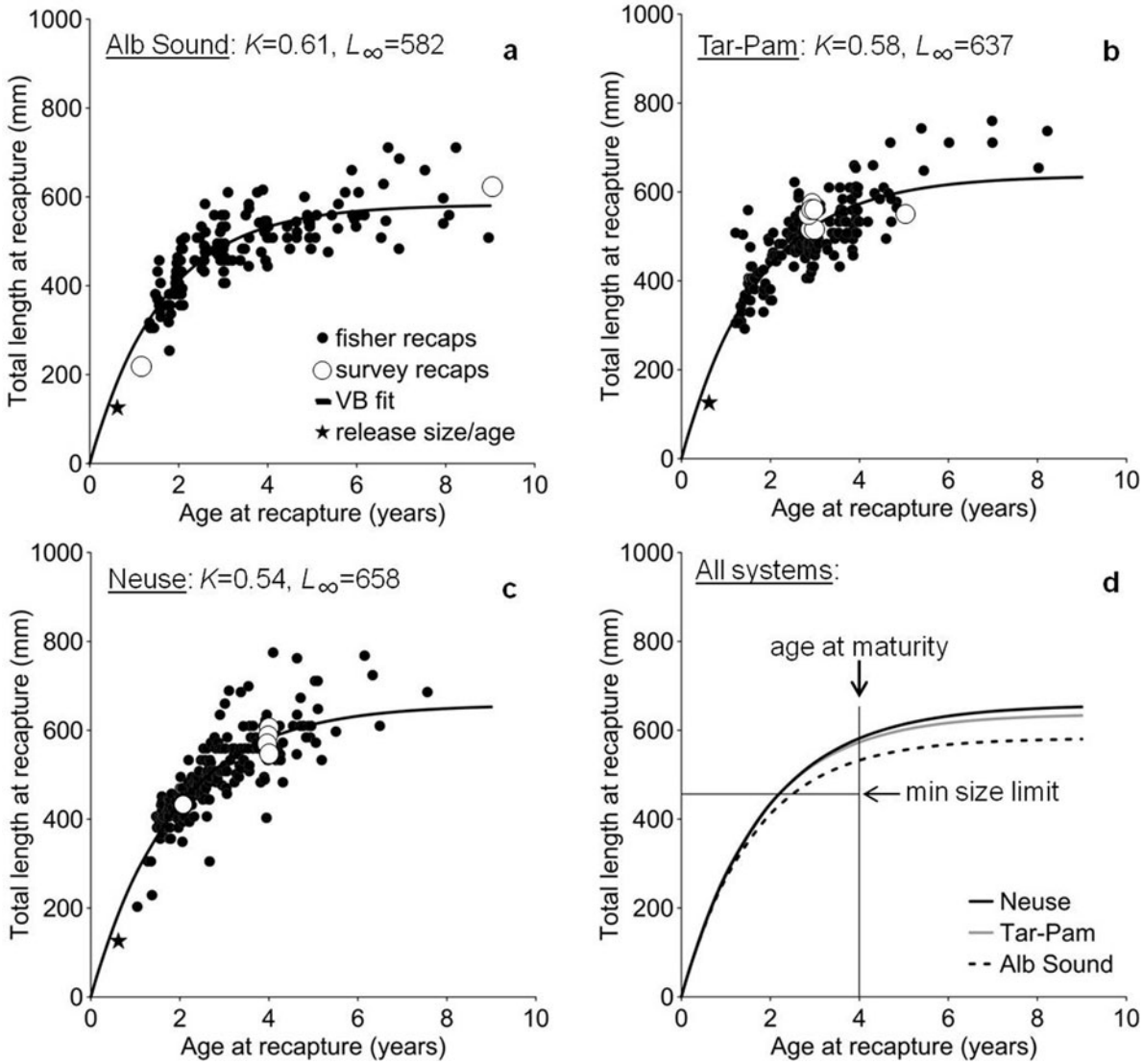

FIGURE 2. (**a**–**c**) System-specific growth of hatchery-reared Striped Bass released into the wild. Growth parameters (K, L_∞) were obtained by fitting the von Bertalanffy (VB) growth model to size-at-age data from tag returns of fish stocked into each system. Black dots show lengths reported from fishers, white dots show lengths of recaptured fish measured in scientific surveys, black stars indicate the mean size and age at release, and the thick black line is the VB growth model fitted to observed data. (**d**) Mean growth curves estimated for each system in relation to the current minimum size limit and known age at maturity (age 4: Olsen and Rulifson 1992; Boyd 2011). Alb Sound = the Albemarle Sound estuary, Tar-Pam = the Tar-Pamlico River, Neuse = the Neuse River (see Figure 1 for system boundaries).

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($Z = 0.33$, SE = 0.02). Based on these Z estimates, the exponential decay model indicated that twice as many stocked Striped Bass would survive to maturity (age 4) in the Albemarle Sound (26,317 fish) than would in the Tar-Pamlico and Neuse rivers: 13,252 and 14,517 fish, respectively.

DISCUSSION

Our study demonstrated that cross-stocking can be an effective management tool, at least in supporting put-and-take type fisheries. Despite their Roanoke River origin, stocked Striped Bass exhibited high fidelity (>90%) to nonnatal systems (the Tar-Pamlico and Neuse rivers) and contributed to local fisheries, because they grew just as quickly as they did in their natal system, reaching legal catchable size by age 2, and were caught by fishers. However, total mortality was significantly higher in nonnatal versus natal systems, the causes of which are unknown. These results will help guide future research initiatives and management efforts to enhance Striped Bass populations in North Carolina's southern coastal rivers.

Fishery-dependent tag return data are not always reliable for the purpose of growth estimation. For example, Støttrup et al. (2002) found that return data from commercial fishers suggested a lack of growth during the summer

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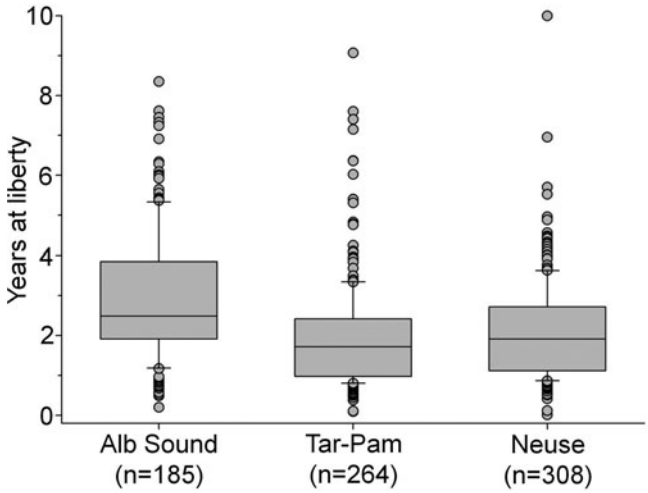

FIGURE 3. System-specific times at liberty for Striped Bass tagged and released during 1990–2000. Sample sizes refer to the number of tag returns reported through December 31, 2010, from fish released in each system. See Figure 1 for system boundaries and Figure 2 for definitions of abbreviations.

growing season for juvenile Turbot *Psetta maxima* stocked along the coast of Denmark (there was no relationship between reported recapture lengths and TAL). Yet, growth was positive, as would be expected, based on recaptures of stocked fish made during scientific surveys (Støttrup et al. 2002). In our study, the VB growth model provided a good fit to recapture lengths at age. Moreover, the lengths of Striped Bass recaptured during scientific surveys agreed with the mean growth curves for each system (which were largely derived from fishery-dependent data) (Figure 2a–c), providing evidence that size information from fishers was reliable.

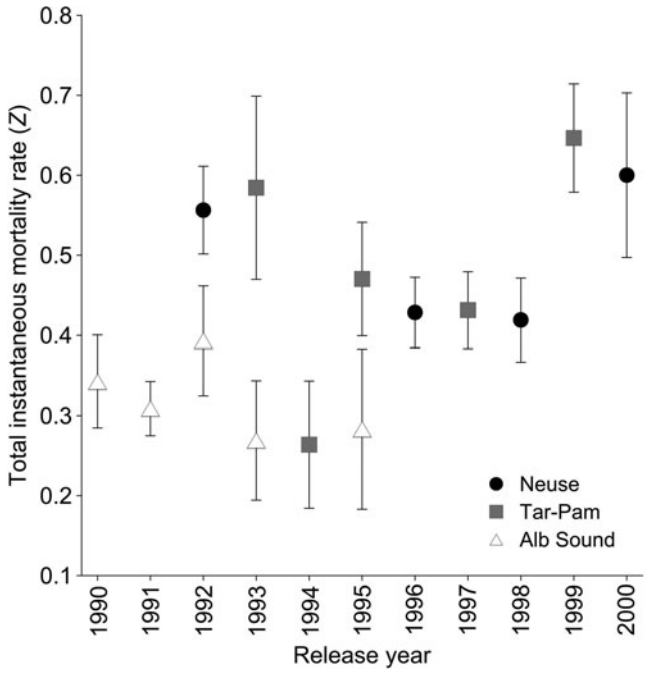

FIGURE 4. Mortality rate estimates of tagged Striped Bass by release year. Note that in some years (1992, 1993, and 1995), Striped Bass were stocked into multiple systems. Symbols (triangles, filled circles, and squares) represent the mean estimates of Z for each release year by system combination. Mean estimates of Z and their SEs (illustrated as vertical error bars) were determined via the time-at-liberty approach (McGarvey 2009). See Figure 2 for definitions of abbreviations.

Although our analyses indicated L_∞ was significantly higher in nonnatal versus natal systems, this result may be a statistical artifact of low sample sizes. Because Striped Bass experienced higher mortality in the Tar-Pamlico and Neuse rivers, there were few tag returns from fish older than age 6 in these systems. The few data points for fish > age 6 in the Tar-Pamlico and Neuse rivers lie above the mean growth curve for those systems (Figure 2). Therefore, L_∞ values were probably overestimated for the Tar-Pamlico and Neuse systems and in actuality were more similar to those for the Albemarle Sound, which would agree with size-at-age data for Striped Bass < 6 years old (size at age was similar among systems for those ages). It is also possible the higher L_∞ values for the Tar-Pamlico and Neuse systems were partly due to the inherent negative correlation between L_∞ and K (Pilling et al. 2002). Although not significantly different, K values were lower (and L_∞ values higher) for the Tar-Pamlico and Neuse systems relative to that of Albemarle Sound (Figure 2).

While we can only speculate why the growth of Striped Bass was similar among systems (possibly due to similar water temperatures), our growth results have important management implications. Stocked Striped Bass grew rapidly and exceeded the current minimum size limit (457 mm TL) between the ages of 2 and 3 across systems. Most Roanoke River Striped Bass do not mature until age 4. By age 4, more than 93% of Roanoke River females were found to be mature compared with only 29–44% at age 3 (Olsen and Rulifson 1992; Boyd 2011). Therefore, fishing pressure on immature fish could be limiting the ability of the stocking program to enhance Striped Bass populations in southern coastal rivers within North Carolina, at least in the Tar-Pamlico and Neuse rivers where harvest is still permitted, especially if the higher mortality we observed in those systems was due to fishing mortality.

As with growth patterns, we cannot discern the underlying reasons for the higher total mortality of Striped Bass in nonnatal relative to natal systems. Roanoke River Striped Bass may exhibit a more exploratory foraging behavior (a heritable trait in fish: Bell 2009; Wisenden et al. 2011) if there are fewer predators in their oligohaline natal estuary (Albemarle Sound). If so, Roanoke River fish may suffer greater predation mortality when they are transplanted into more saline systems (Tar-Pamlico and Neuse rivers) that contain more marine predators. There are several other biotic and/or abiotic explanations for differences in mortality, but we do not speculate further. Our mortality results provide important baseline data for North Carolina's collaborative (NCWRC and NCDMF) Striped Bass stock enhancement program. As of 2012, this program began using local (river-specific) broodstock to produce juveniles, which

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were then stocked into the same system from which their parents (broodstock) were obtained. Therefore, our data will permit comparisons between these two alternative stocking methods (cross-stocking versus using local fish) to determine which is the most successful and cost-effective approach. For instance, the additional costs and logistics of raising and maintaining locally sourced fish may be justifiable if juveniles from local (natal) broodstock exhibit higher survival in the Tar-Pamlico and Neuse rivers (e.g., due to local adaptations).

In addition to providing important baseline data to evaluate the efficiency of different stocking methods, our results will allow mangers to more precisely estimate fishing mortality levels. The current status of Striped Bass stocks in the Tar-Pamlico and Neuse rivers is considered to be "unknown, but of concern" due to the lack of precise stock assessment data from these two systems (NCDMF and NCWRC 2013). Cohort-based catch curves have been used to estimate Z values for each river system (stock) in prior assessments, but the results were deemed too imprecise for management purposes (NCDMF and NCWRC 2013). The SEs of Z values estimated via catch curves approached or exceeded the mean values of Z, as proportional standard errors (PSEs) were, on average, 98% and 72% in the Tar-Pamlico and Neuse rivers, respectively, for the same release years (cohorts) analyzed in our study (1992–2000) (NCDMF and NCWRC 2013). These imprecise estimates of Z were likely due to a truncated age structure (few age-classes on the descending limb of the catch curve), indicative of high total mortality, which limited the effectiveness of the catch-curve method. The approach we used resulted in more precise estimates of Z: mean PSEs for the Tar-Pamlico and Neuse rivers were 12% and 17%, respectively, based on year-specific Z values and 6% for both systems based upon data pooled across release years. Accordingly, our Z estimates and approach should provide a better (more precise) evaluation of stock status of Striped Bass in the Tar-Pamlico and Neuse rivers. For example, an independent estimate of the instantaneous natural mortality rate (e.g., $M = 0.15$: NCDMF and NCWRC 2013) could be subtracted from our Z estimates to obtain fishing mortality rates (F) for each river system. In doing so, it should be noted that our Z values are overestimates in the absolute sense due to tag loss (McGarvey et al. 2009). However, this bias is minimal and at most, the values for Z in our study were overestimated by 0.02–0.16 based on available estimates of annual tag loss rates in Striped Bass (2% to 15%) from double-tagging studies (Waldman et al. 1991; Sprankle et al. 1996).

Although we used data from multiple release batches (release years), this did not bias our study inferences on mortality and growth. Across release years, Z values were consistently higher in nonnatal (Tar-Pamlico and Neuse rivers) versus natal systems (Albemarle Sound), clearly demonstrating that "batch effects" did not confound among-system comparisons of mortality. Nor did "batch effects" confound growth comparisons. Striped Bass were only released in nonnatal systems after 1996. However, growth trends calculated from the entire data set (release years 1990–2003) persisted when analyses were restricted to the common time period of release across all systems (1992–1996), indicating the differing release years among systems did not confound among-system comparisons of growth.

In conclusion, our study demonstrated that cross-stocking can be an effective management tool for Striped Bass populations in coastal North Carolina, at least in terms of supporting put-and-take type fisheries and possibly for stock rebuilding. Current research, which is being conducted on the degree of Striped Bass natural reproduction in the Tar-Pamlico and Neuse rivers (i.e., the relative contributions of stocked versus wild fish), will provide further insight into the type of fishery that can be achieved with stocking. For example, if spawning success is poor due to a lack of suitable habitat, stocked fish may not successfully reproduce in these systems and therefore only support a put-and-take type fishery. In a broader context, as one of the few studies investigating the ecological consequences of cross-stocking in coastal fish populations, our findings provide an important reference for managers considering this approach, which may be the only stock enhancement option available in some cases, especially for severely depleted populations in which adult broodstock are rare and difficult to obtain. Still, it is important to bear in mind that the effectiveness (and potential genetic effects) of cross-stocking may vary widely among species and largely depend on population structure and specifically *where* within a species' range source fish are procured from. For instance, juveniles from more distant source populations may perform poorly relative to those from nearby (adjacent) systems whose environmental conditions are more similar to the natal habitat.

ACKNOWLEDGMENTS

We thank the many individuals from the NCDMF and NCWRC who were involved in the hatchery-production and tagging of juvenile Striped Bass. We thank Jeff Evans (NCWRC) for providing data on spawning dates and Stephen Jackson (U.S. Fish and Wildlife Service) for length-at-release data. We are also grateful to the many fishers who provided tag return information and the NCDMF personnel who processed and compiled these data. Analyses for this study were completed while J. L. Callihan was a Marine Fisheries Management Fellow supported by NCDMF (Coastal Recreational Fisheries License fund award 3210) and North Carolina Sea Grant award E/GS-6.

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Section 4 – A river herring runs through it: evaluating culverts for river herring passage in the Albemarle Sound watershed of North Carolina

Ernie Hain (2013-2014 Fellow)

(Ernie Hain's fellowship was less than one year as he took a job with NC DMF in 2014)

A river herring runs through it: evaluating culverts for river herring passage in the Albemarle Sound watershed of North Carolina

Ernie Hain, Lindsey Staszak, and Jeffrey A. Buckel

Abstract

Blueback herring *Alosa aestivalis* and alewife *A. pseudoharengus*, collectively known as river herring, saw a significant decline in population abundances beginning in the late 1970's. Despite reductions and moratoriums on take, population abundances remain a small percentage of historic values, and both species are designated as a Species of Concern by NOAA Fisheries. In North Carolina, road culverts may impede upstream migration, resulting in an effective loss of spawning habitat. Ideal culvert design for river herring passage is currently unknown. However, culverts can impede migration by increasing flow velocity beyond the maximum swimming speeds of the fish. Using data collected by the NC Division of Marine Fisheries, we identified 17 culverts in the Albemarle Sound watershed that are potential barriers to river herring migration. We used FishXing software, developed by the US Forest Service, to evaluate the ability of river herring to pass through these 8 of these culverts. By modeling the culvert hydraulics across a range of expected stream discharges, we were able to predict factors that impede passage for each culvert. In collaboration with NC Division of Marine Fisheries, we are currently sampling below and above culverts, to verify our passage predictions during the 2014 spring migration. Results of this study will benefit the NC Division of Marine Fisheries by enabling managers to advise and prioritize culvert construction and replacement projects in order to aid this historically important fishery.

Introduction

The spawning migrations and habitat of blueback herring *Alosa aestivalis* and alewife *A. pseudoharengus*, collectively known as river herring, have been identified as a research priority for the NC Division of Marine Fisheries. River herring are anadromous fishes that spawn in rivers along the Atlantic coast of North America. In North Carolina, the Chowan River and Albemarle Sound are the historic center of the river herring fishery. Beginning in the 1970's, severe declines in landings were observed throughout the river herring range. This decline continued in the Chowan River fishery until 2007, when a moratorium on river herring was established.

Despite the moratorium in North Carolina, and similar moratoriums in other states throughout the range, river herring populations have remained at historically low levels. Several potential causes of decline have been identified, including habitat loss, overfishing, bycatch, predation, and barriers to migration. Habitat loss may be related to changes in water quality, land use, and hydrologic function; all of which may impact adults in coastal/estuarine habitats as well as spawners, larvae, and juveniles in freshwater habitats. While dams are common in many parts of the river herring range, in North Carolina, many dams have already been removed, and most that remain are further inland than river herring are currently migrating. However other potential barriers do exist, such as log jams and culverts.
Culverts are a common and relatively inexpensive road construction method for crossing streams. Construction techniques for culverts can vary in their shape, length, dimension, material, and

installation.

In this study, we have identified culverts in the Albemarle Sound watershed that river herring are likely to encounter during their spawning migration. Using a US Forest Service product called FishXing, we have assessed the ability of river herring to pass through these different culverts. Predictions are currently being validated in the field.

Methods

NCDMF has previously conducted an assessment of culverts in the Albemarle Sound watershed, identifying the lowest culvert in each tributary (as well as many further upstream), taking basic measurements of the culverts, and identifying those that appeared impassable. We developed a spatially explicit dataset, linking DMF river herring and culvert data to hydrologic and landscape data, including data from the National Hydrography Dataset, NCDOT high resolution roads and bridges, National Inventory of Dams, USGS hydrologic boundaries, National Land Cover Database, and USDA-NRCS soils. Using this dataset, we created a new Python script that uses data within an ArcGIS framework to identify all sample sites that are either near or upstream of a culvert. Using this script, we have identified 17 sites near or upstream of culverts where river herring presence has been observed during the previous 5 spawning seasons (2008-2013). NCDMF does not sample all river systems every year. In order to validate our predictions of culvert passage, NCDMF chose 8 of the 17 potential culverts to sample during the 2014 spring migration.

In order to assess the ability of river herring to pass through culverts, we used software developed by the US Forest Service's Aquatic Organism Passage Program. The software is called FishXing (Version 3 Beta), and is intended "to assist engineers, hydrologists, and fish biologists in the evaluation and design of culverts for fish passage." The software is well supported and available for free download (http://www.stream.fs.fed.us/fishxing/software.html).

The FishXing software requires four categories of inputs (fish information, culvert information, fish passage flows, and tailwater methods) in order to calculate potential passage for a given culvert. The required fish information includes fish length, maximum swim speed with an affiliated exhaustion time, max leap speed, and minimum water depth that the fish can swim through. We used the average fish length recorded in the DMF database (2008 – present), and fish depth as the minimum water depth (fish that are not fully submerged cannot obtain optimal swimming performance). For maximum swim speeds and time to exhaustion, we used the optimal ground speed obtained from Castro-Santos (2005), which were equal to 3.89 ft/s and 151.41 s respectively. Culvert information (shape, size, material, etc.) was previously collected by the DMF culvert assessment. Fish passage flows determine the range of flows for which FishXing will calculate passage. Minimum (7-day mean low-flow that occurs on average once in 2 years) and maximum (maximum instantaneous flow that occurs on average once in 2 years) were estimated using regression equations developed by the USGS' National Streamflow Statistics Program. The tailwater information is used to calculate the elevation of the tailwater using one of three separate tailwater methods. One of these methods (user defined rating curve) was not possible to use

given our available data. We calculated each of the remaining two methods; 1) constant tailwater method, which assumes that the tailwater elevation does not change with flow, and 2) channel cross-section method, which calculates a rating curve based on the shape and roughness of the tailwater cross section.

Normally, as part of the river herring adult spawning area program (program 150), adult river herring are sampled with gill nets or herring baskets at road crossings. When running ripe females are observed, sampling gear is moved upstream to the next road crossing. In order to verify that river herring are or are not passing through a given culvert, DMF has agreed to slightly alter their sampling protocol by placing gear first on the downstream side of each culvert, then upon observing river herring, moving the gear to the upstream side of the culvert. Using this altered protocol allows us to isolate the culvert as the potential blockage, as opposed to a log jam or other unknown barrier that may occur between a culvert and the next upstream road crossing.

Results

Results from the constant tailwater and tailwater cross section methods produced similar results, although there was variation. FishXing calculates passage for all flows between the minimum and maximum entered. Percent of flows passable ranged from 15.3% to 100% for the constant tailwater method and 0% to 100% for the tailwater cross section method. Using the constant tailwater method, all culverts were passable during certain flows, although three sites were passable at less than 50% of flows. Only two sites were passable at less than 50% of flows using the tailwater cross section method. However, of these two sites, Killem Swamp was not passable at any flows, and BBQ Swamp was only passable at 4.4% of flows.
The most common barriers to passage were insufficient depth barriers, which occurred at low flows, and velocity barriers, which occurred at high flows. Leap barriers, where fish have to jump out of the water to enter the culvert, also occurred at two culverts (Killem Swamp and Flat Swamp). Only one site (Flat Swamp) had no barriers at any flows. This site was 100% passable using both tailwater methods.

Discussion

Currently, we have developed a product for identifying culverts that are potential barriers, identified those potential culverts that occur within the DMF sampling regime, and have produced *a priori* predictions of river herring passage in eight of those culverts, which are currently being field validated. This work supports a river herring research priority as the recent NOAA (2013) endangered species listing decision for river herring identified dams and other barriers as the highest ranked threat for both river herring species and across all identified stocks. Thus, management of river herring in North Carolina must consider the impact that barriers are having on river herring populations. Any barrier potentially limits the upstream migration of river herring, thereby isolated potentially large areas of otherwise suitable spawning habitat. The DMF has identified culverts as a common potential barrier to river herring migration. However, until now, very little was known about the criteria that enables river herring to pass through culverts. We have provided a sound approach to identifying and assessing

culverts for river herring passage using freely available software and data sets. Results of our work will enable DMF to assess more culverts in the future, provide informed consultation to the NC DOT or other agencies involved in new culvert installation, and prioritize culverts for removal and/or replacement.

Leveraged Funds

This work provided clear questions that could be addressed with NC DMF's spawning and nursery area survey. Ernie Hain, Lindsey Staszak (NCDMF river herring biologist), and Jeff Buckel were awarded a Coastal Recreational Fishing License grant to examine these questions that followed from Ernie Hain's fellowship.

Section 5 – Reducing sea turtle bycatch in the Pamlico Sound southern flounder fishery by expanding no-fishing zones around inlet corridors

Liza Hoos (2014-2015 Fellow)

REDUCING SEA TURTLE BYCATCH IN THE PAMLICO SOUND SOUTHERN FLOUNDER FISHERY BY EXPANDING NO-FISHING ZONES AROUND INLET CORRIDORS

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1. INTRODUCTION

1.1 BACKGROUND

The southern flounder fishery is the most economically important estuarine finfish fishery in North Carolina [1]. A large portion of this species' landings is caught using large-mesh gillnets, a gear-type known to have high rates of sea turtle bycatch [2]. The North Carolina Division of Marine Fisheries (DMF) has implemented various adaptive management measures since 1999 to reduce sea turtle bycatch in large-mesh gillnets in the Pamlico Sound, where the largest portion of NC southern flounder are caught [1, 3]. Since 2000, the deep-water portions of the Pamlico Sound as well as three inlet corridors into the sound have been closed to large-mesh gill nets during the southern flounder fishing season (September - December) in order to reduce the number of interactions between the fishery and sea turtles [4]. In past years the fishing season has often been closed or shortened in order to stay below authorized sea turtle incidental take levels, causing fishermen to forego a significant source of income [2]. Managers at DMF want to determine if expanding the area closed to fishing around the Pamlico Sound inlet corridors could be an effective way of reducing sea turtle bycatch in the flounder fishery, thereby allowing the fishery to operate more days of the year.

2. METHODS

2.1 DATA SOURCE

Due to the high number of interactions between the southern flounder gillnet fishery and endangered sea turtles on the Pamlico Sound, DMF has had to apply for an Incidental Take Permit (ITP) under the Endangered Species Act and implement management measures to reduce sea turtle takes since the year 2000. As part of the management plan implemented under the ITP, DMF closes the deep water portions of the Pamlico Sound to gill netting each year from September to December, and has established an observer program (DMF Program 466) with a goal of 10% observer coverage of the large mesh gillnet fishery during the flounder season [3]. The areas of the Pamlico Sound near the Outer Banks that are open to gillnetting from September to December each year are referred to as the Shallow Water Gillnet Restricted Areas

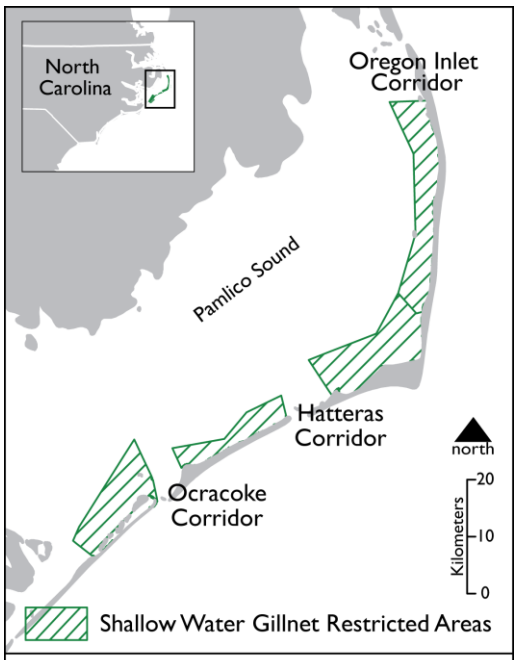

Figure 1. Areas where gillnetting is allowed from September to December

(SWGNRAs; Figure 1).

Program 466 uses a fishery-dependent sampling design, in which observers go out with commercial, large and small mesh gillnet fishermen and record the location, catch, and gear used along with many environmental variables. For this study, we used data collected by observers between 2003 and 2014, during the months of September through December. To prepare this dataset for use in our analysis, all records collected at locations outside of the Shallow Water Gillnet Restricted Areas were discarded. Due to the relatively small size of the dataset and number of observed sea turtle interactions, we did not distinguish between the three sea turtle species observed in this fishery (green, Kemps ridley, and loggerhead). We deleted records where it appeared there had been data entry errors, for instance if the coordinates were on land, or if records had net lengths greater than 3000 yards/soak times greater than 3 days. We were left with 1945 records (fishing events), and 121 sea turtle takes (Figure 2). Net lengths and soak times averaged around 1000 yards and 1 day, respectively.

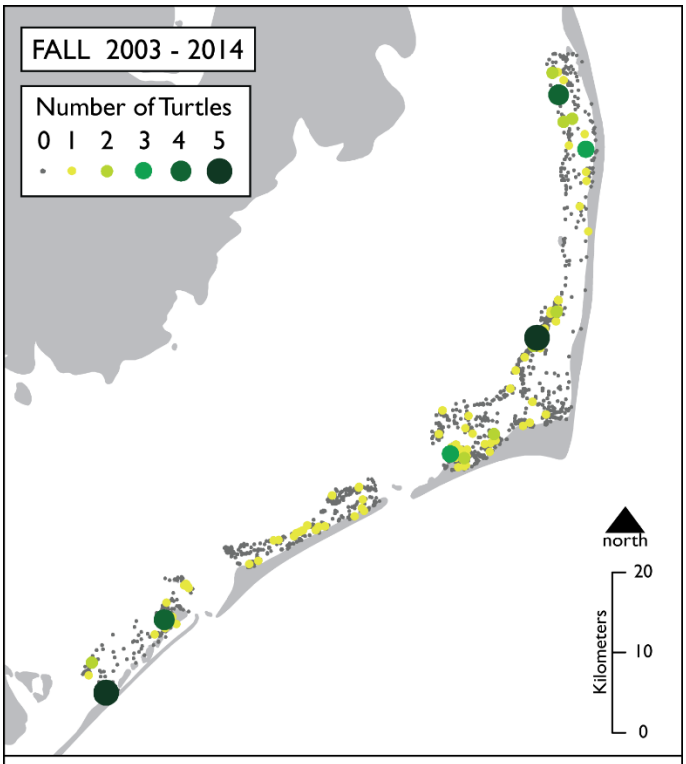

Figure 2. Sea turtle bycatch in the southern flounder large-mesh gill net fishery from September to December, 2003 to 2014. Co--ordinates are recorded by fishery observers. For this study, we used only records within the shallow water gill net areas.

2.2 MAPS

2.2A MAP TYPES AND PARAMETERS

In order to determine whether sea turtle takes were occurring near the inlet corridors, two general types of maps were created: point maps and grid maps. On the point maps, the parameter's value is shown at the latitude/longitude coordinate where the fishing event took place. On the grid maps, the value of the relevant parameter was summed up for all records within 2000X2000 yard grid cells over a given time step. Grid cells within the SWGNRAs that did not contain any records from the Program 466 dataset were removed from the map.

The parameters displayed on these maps are:

1. Number of sea turtles
    - Point maps - display the number of sea turtles caught during each fishing event over a given time period.
    - Grid maps - display the number of sea turtles caught within a grid cell over a given time period.

2. Fishing effort
    - Grid maps - display fishing effort summed up across all points within a grid over a given time period. Fishing effort was calculated as the product of net length (yards) and the amount of time gear was fished (days) at each location.

3. Bycatch per unit effort (BPUE)
    - Grid maps - display the number of sea turtles caught per unit of effort. BPUE is calculated as the sum of all sea turtles caught divided by the sum of all effort within a grid cell over a given time period. These maps are essentially created by dividing the number of sea turtles maps by the effort maps.

2.2B MAP SYMBOLOGY

For all three parameters (number of sea turtles, fishing effort, and sea turtle BPUE) the data are heavily skewed, with the largest portion of values falling at the low end of the range (at or close to zero). Although it would be preferable to display each parameter by dividing the range of values into equal intervals, representing the data in this way would hide some of the variations in values at the lower end of the range, and make it difficult to identify areas with values higher than the mean/median value of the parameter. A manual classification scheme was devised to best convey the finer scale differences in values at the bottom of the range for each parameter.

2.2C TEMPORAL RESOLUTION

We created maps of the Program 466 data for the months that the southern flounder fishery operates in the SWGNRAs: from September through December, which is referred to as "fall" in all figures. We also created maps for each individual month during the southern flounder season – September, October, and November. No maps were made for the month of December alone due to the low number of observations and lack of sea turtle interactions during this month. Due to inter-annual variability in catch and effort, we created fall and monthly maps using data from 3-year intervals (2003 – 2005, 2006 – 2008, 2009 – 2011, and 2012 – 2014) in addition to maps created from the full dataset (2003 – 2014).

2.3 PREDICTING THE EFFECT OF EXPANDING PAMLICO SOUND INLET CORRIDORS ON CATCH OF SEA TURTLES & SOUTHERN FLOUNDER

2.3A SELECTING NEW CORRIDOR BOUNDARIES

We used the grid maps to identify spatial and temporal clusters of high BPUE values near existing corridor boundaries. The location of the expanded corridor boundary lines were then selected based the location of these clusters and proximity to geographic markers, such as bays, points, and islands. This was done in order to increase the ease of enforceability of the new boundaries.

2.3B CALCULATING FISHING EFFORT DISPLACEMENT

We explored the effect of expanding the corridors boundaries on the number of sea turtle takes and southern flounder catch. We calculated the percent change in sea turtle bycatch and southern flounder catch assuming that all effort in the expanded inlet corridors would not have occurred within those boundaries from 2003 – 2014 under different scenarios of displacement of fishing effort. New effort under each effort displacement scenario was calculated at each individual fishing site (latitude/longitude coordinate), and new turtle/flounder catch estimates were calculated by multiplying the new effort by the original catch per unit effort estimates. In this modeling exercise we assumed that displaced effort would only be reallocated to fishing sites within the same SWGNRA.

2.3C EFFORT DISPLACEMENT SCENARIOS

1. No redistribution: All displaced effort is eliminated completely, e.g. all effort that occurred within in the proposed expanded corridor boundaries is removed and not reallocated to other fishing sites.
2. Even redistribution: All displaced effort is shifted into areas where fishing is allowed within the affected SWGNRA, and is redistributed evenly across known fishing sites.
3. Proportional redistribution: All displaced effort is shifted into areas where fishing is allowed within the affected SWGNRA, and is redistributed across known fishing sites proportionally to recorded effort in that location (i.e. sites with high effort would get allocated a larger percentage of displaced effort).
4. Inverse distance weighted redistribution: All displaced effort is shifted into areas where fishing is allowed within the affected SWGNRA, and is redistributed across known fishing sites in an inverse distance weighted manner from the new closed area boundaries

(i.e. more of the effort is reallocated to fishing sites in close proximity to the closed areas).

2.3D TEMPORAL RESOLUTION

We conducted the analysis over the months that the southern flounder fishery operates in the SWGNRA – from September through December, referred to as "fall" in all figures. We also conducted the analysis for individual months during the southern flounder season – September, October, and November. December was excluded from the individual monthly analysis due to the low number of observations and lack of sea turtle interactions during this month.

2.4 GETIS–ORD GI* HOTSPOT ANALYSIS

Due to the ambiguity introduced into the analysis by the selection of the search radius *d* (see equation 1), the Getis-Ord Gi* hot spot analysis was not used as a basis for determining corridor expansions, but we have included a description of the technique here for reference. We also discuss some of the drawbacks of this technique in section 3.3, as hot spot analysis is often used in the spatial analysis of fisheries data [5-7].

The tool *Hot Spot Analysis (Getis-Ord Gi*)* from the Spatial Analyst toolbox in ArcMap can be used to identify statistically significant clusters (e.g. hot spots) of sea turtle bycatch. This tool calculates the Getis-Ord Gi* statistic for each feature in a dataset. In our case the features are gillnet hauls observed as part of Program 466, and the value in question is sea turtle BPUE at

$$G_i^*(d) = \frac{\sum_{j=1}^{n} W_{ij}(d) x_j}{\sum_{j=1}^{n} x_j}$$

Equation 1. Getis-Ord Gi statistic, Where xj is the BPUE value for each point location j, Wij(d) is the spatial weight between feature I and all features j within the specified search radius d, and n is the total number of features.*

each fishing site.

For each feature (j), the statistic compares the average BPUE across all other features within a specified search radius (*d*) around the feature in question to the average BPUE across all fishing records across the entire study area (SWGNRAs 1 through 4). The results are then converted to z-scores to determine statistical significance [8]. For more information on the Getis-Ord Gi* sta-

tistic and tool please see - Ord, J. K. and A. Getis (1995) and the ArcGIS Desktop Help webpage[1] for this tool.

3. RESULTS & DISCUSSION

3.1 MAPS

The maps created using the methodology described in section 2.2 are contained in sections 1 and 2 of the appendix, pages 2 – 24. Effort and sea turtle bycatch shift throughout the season and as well as vary from year to year. Clusters of high bycatch per unit effort values tend to occur near Hatteras Island, as well as south of Oregon Inlet and behind Portsmouth Island (southwest of the Ocracoke Corridor).

Figures 3 – 5 below show the distribution of the program 466 data, divided into the bins used to display these data on the maps.

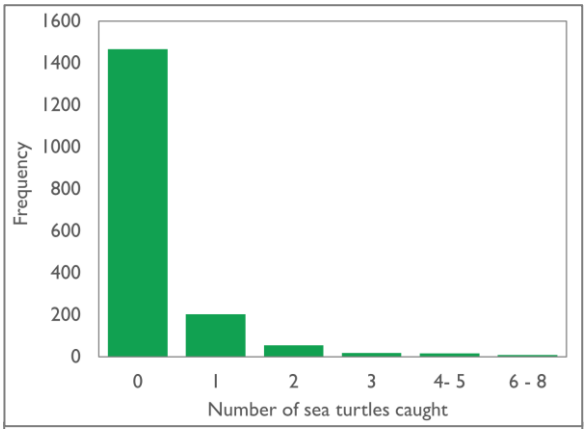

Figure 3. Frequency distribution of the number of sea turtles caught per grid cell on all maps in appendices A and B. Data are divided using the same classes displayed on the maps.

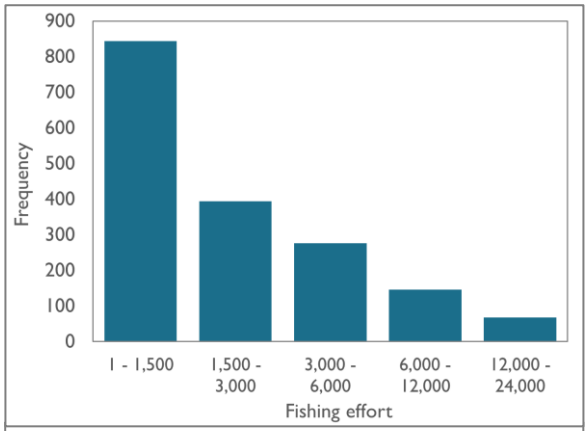

Figure 4. Frequency distribution of total fishing effort per grid cell on all maps in appendices A and B. Data are divided using the same classes displayed on the maps.

[1] http://desktop.arcgis.com/en/desktop/latest/tools/spatial-statistics-toolbox/hot-spot-analysis.htm

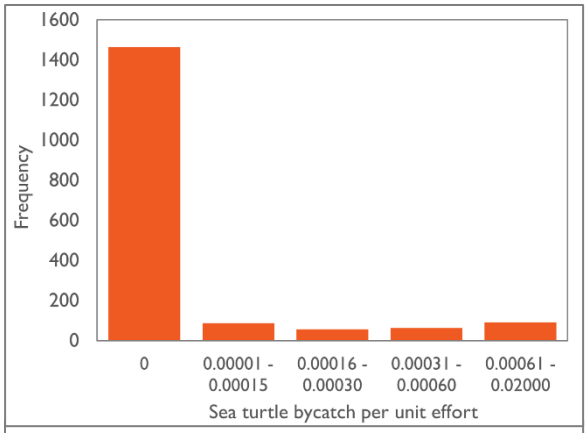

Figure 5. Frequency distribution of sea turtle bycatch per unity effort per grid cell on all maps in appendices A and B. Data are divided using the same classes displayed on the maps.

3.2 PREDICTING THE EFFECT OF EXPANDING PAMLICO SOUND INLET CORRIDORS ON CATCH OF SEA TURTLES & SOUTHERN FLOUNDER

3.2A PROPOSED CORRIDOR EXPANSIONS

Based on the clusters of high BPUE values shown on Appendix Figures 9 – 12, we decided to analyze the effect of:

1. Expanding Oregon Inlet Corridor to the south.
2. Expanding Hatteras Corridor to the northeast.
3. Expanding Ocracoke Corridor to the southwest.

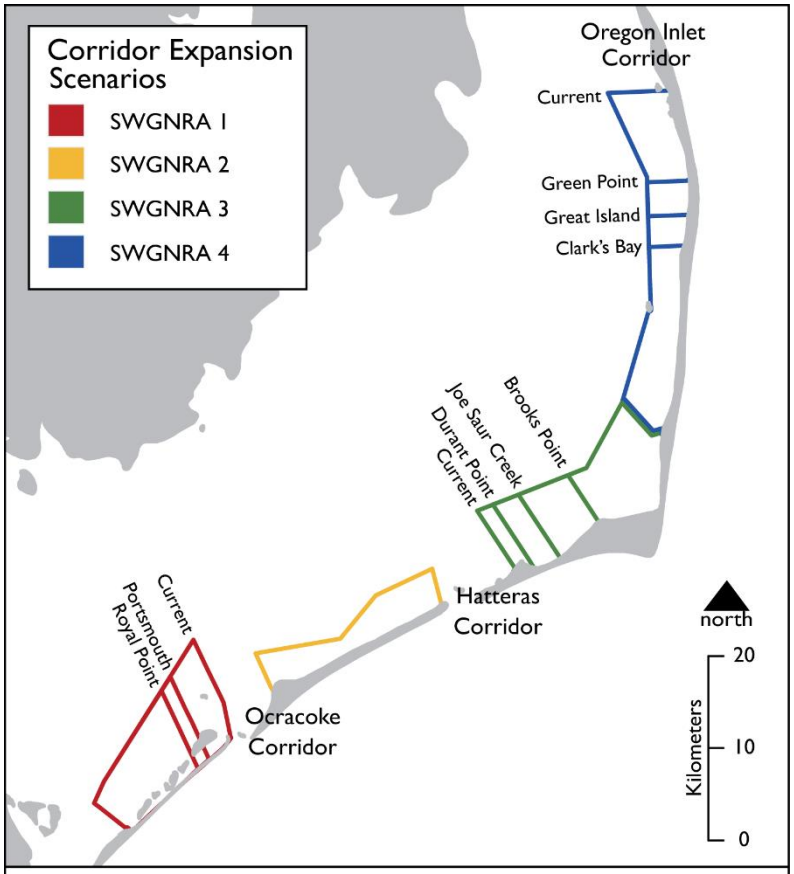

Figure 6. Proposed boundaries of expanded inlet corridors into Pamlico Sound.

Geographic markers were then selected to delineate new corridor boundary lines, such that portions of the high BPUE value areas near the inlet corridors would be included in the expanded corridors. Multiple potential boundary lines were chosen for each expansion scenario. Table 1 contains a list of the geographic markers (and coordinates) selected to delineate the expanded corridor boundary lines for each of the proposed corridor expansions, which are also shown on Figure 6. The new boundary lines start at the geographic marker and extend to the outer edge (towards mainland) of the SWGNRA, parallel to the current boundary line.

Table 1. Corridor expansion scenario names, geographic markers, and coordinates.				
Corridor	**Scenario Name**	**Geographic Marker**	**Latitude**	**Longitude**
Oregon Inlet Corridor	Oreg_Green	Green Point	35.597	-75.472
	Oreg_Great	Great Island	35.531	-75.482
	Oreg_Clarks	Clark's Bay	35.531	-75.482
Hatteras Corridor	Hatt_Durant	Durant Point	35.233	-75.681
	Hatt_JoeSaur	Joe Saur Creek	35.229	-75.639
	Hatt_Brooks	Brooks Point	35.269	-75.596
Ocracoke Corridor	Ocra_Portsmouth	Portsmouth Island/Evergreen Slough	35.069	-76.076
	Ocra_Royal	Royal Point	35.053	-76.088

The potential corridor expansion boundaries shown in Figure 6 were overlaid on maps of sea turtle BPUE and southern flounder catch per unit effort (Appendix Figures 33 & 34). The southern flounder maps were created using the same methodology as is described in section 2.2 for sea turtles.

3.2B CORRIDOR EXPANSION'S EFFECT ON SEA TURTLE & FLOUNDER CATCH ESTIMATES

The results of the effort redistribution analysis are contained in a series of tables in section 3 of the appendix. There are three types of tables. The first two types were created for both sea turtles and flounder:

1. Table type 1 shows the absolute (number of individuals) change in catch in each of the different effort redistribution scenarios (columns) described in section 2.4C, for each of the different corridor expansion scenarios (rows) shown in Figure 6.
2. Table type 2 shows the relative (percent) change in catch in each of the different effort redistribution scenarios (columns) described in section 2.4C, for each of the different corridor expansion scenarios (rows) shown in Figure 6.

The third type of table was created only for sea turtles:

3. Table type 3 quantifies the efficiency of each corridor expansion scenario in terms of the reduction in sea turtle takes relative to the amount of area closed to fishing, the amount of effort displaced, and the change in southern flounder catch. Only the results of effort redistribution scenarios 3 and 4 are displayed because these are "worst case" scenarios (meaning that pre- and post-corridor expansion effort remains the same), and the assumptions in these scenarios (that effort would redistribute either to areas where effort was concentrated previously, or as close to the new corridor boundaries as possible) seem the most plausible. Many studies in other fisheries have shown that displaced fish-

ing effort often concentrates near the borders of newly closed areas/marine protected areas [9-11].

The results in each table are color coded based on the assumption that the desired outcome of expanding the inlet corridors is a reduction in sea turtle takes, and no change in southern flounder catch rates. For each effort redistribution scenario column, the corridor expansion scenario with the most desirable outcome is highlighted in red or purple (for sea turtles and southern flounder, respectively). These colors correspond to the color scheme used to represent BPUE in Appendix Figures 33 and 34. The corridor expansion scenario with the least desirable outcome is highlighted in dark grey. The rest of the cells in each column are highlighted in varying shades of either red/purple or grey depending on where the cell's value falls on the range between the highest and lowest values in that column. Cells with no color fall near the middle of the range.

The results in these tables show that while it might initially seem beneficial to close an area based solely on the number of sea turtle takes that have historically occurred in an area (i.e. effort redistribution scenario 1), the redistribution of displaced effort may lead to different results. For example, the prediction for effort redistribution scenario 1 in the fall shows a 25.6% reduction in sea turtle takes in corridor expansion scenario Hatt_Brooks (Appendix Tables 2 and 3). However, once the cost of redistributing displaced effort is taken into account, there is either a much smaller reduction (9.1%) or anywhere from a 9.1 – 16.5% predicted *increase* in sea turtle bycatch that results from closing that area, depending on the effort redistribution scenario (Appendix Table 3).

The third type of table for each species in each season can be used in determining which corridor expansion scenario will result in the greatest reduction in sea turtle catch for smallest amount of forfeited fishing opportunity. For instance, corridor expansion scenario Oreg_Clarks resulted in the largest decrease in sea turtle takes under effort redistribution scenarios 3 and 4 in the fall (Appendix Table 4). It makes sense that this corridor expansion scenario would be the most effective at reducing sea turtle takes given that it is the scenario with the most additional area closed to gill netting (86 square km; Appendix Table 4). However, this doesn't necessarily translate into being the best or most efficient management solution, since it would mean closing a large portion of the SWGNRA 4 to gillnetting. The most efficient corridor expansion scenario (when considering all three ratios under both effort redistribution scenarios 3 and 4) is Oreg_Great, even though this expansion doesn't result in the largest reduction in sea turtle bycatch (Appendix Table 4).

These tables reveal that it would actually be a more effective management solution to only close certain corridors for a portion of the season. The greatest reduction in sea turtles that results

from expanding any corridor for the entire length of the southern flounder season would only save between a maximum of 13 or 15 sea turtles (Oreg_Great & Oreg_Clark) in either the 3rd or 4th effort redistribution scenarios (Appendix Table 4). Alternatively, expanding the Hatteras Corridor to the Brooks Point boundary line (Hatt_Brooks) for just the month of September leads to a predicted reduction in the number of sea turtle takes by 17 or 18 in scenarios 3 and 4, respectively (Appendix Table 9). Additionally, the Hatt_Brooks corridor expansion scenario in September also has a high number of sea turtles caught relative to the change in flounder catch (last two columns of Appendix Table 9), with only a 2% increase in the number of flounder caught (Appendix Table 11).

The table types 1 and 2 for southern flounder could aid in deciding on the pros and cons of a corridor expansion in terms of the impact of each corridor expansion scenario on catch rates of southern flounder. There is predicted to be a relatively small change in the amount of southern flounder caught in effort redistribution scenarios 3 and 4 for all proposed boundaries and for all months. In most scenarios the predicted change is within the range of 1 to 3%, with a maximum change of an 8.7% decrease in southern flounder catch occurring for the Hatt_Brooks corridor expansion in effort redistribution scenario 4 in November (Appendix Table 24).

It is important to point out that the true number of sea turtle takes and southern flounder catch in the commercial fishery within the SWGNRAs is higher than presented in these tables, as observers only attended a small percentage (7-10%) of commercial gill net trips taken during the time period examined.

3.3 GETIS–ORD GI* HOTSPOT ANALYSIS

As mentioned in section 2.4, the Getis-Ord Gi* hot spot analysis was not used to determine which corridors to expand. The main reason for deciding against this technique was the ambiguity introduced into the results when specifying the search radius *d*. For example, a small search radius would include fewer points in each calculation, e.g. only the fishing locations within a very close proximity to the feature in question. This could result the designation of hotspots only in areas where high BPUE values are very tightly clustered, and overlook areas that have equally high BPUE values that are more dispersed, but may still be important for management purposes. There is little guidance in the literature regarding the selection of an appropriate search radius. It has been suggested that the search radius be specified based on knowledge of the system being studied and the underlying spatial processes, however the decision is ultimately subjective [12].

Figure 7 illustrates how changing the search radius *d* can significantly impact the location of identified hot spots. At smaller search radii (*d* =1000m or 2000m) there appear to be many statistically significant clusters of high BPUE values. Of particular significance (because it is close to

an inlet corridor) is the hotspot to the northeast of the Hatteras Corridor. This hotspot then disappears when larger search radii are used (d >4000m). In addition to affecting the location of hot spots, the selection of the search radius also affects the size and level of confidence with which this technique predicts each hot spot.

There have been alternative techniques suggested for the identification of hot spots that are less susceptible to the issue described above. One such technique was developed by Bartolino et. al (2011), and uses cumulative relative frequency distribution curves to identify hot spots, and should be more objective than the Getis-Ord Gi* statistic [12-14].

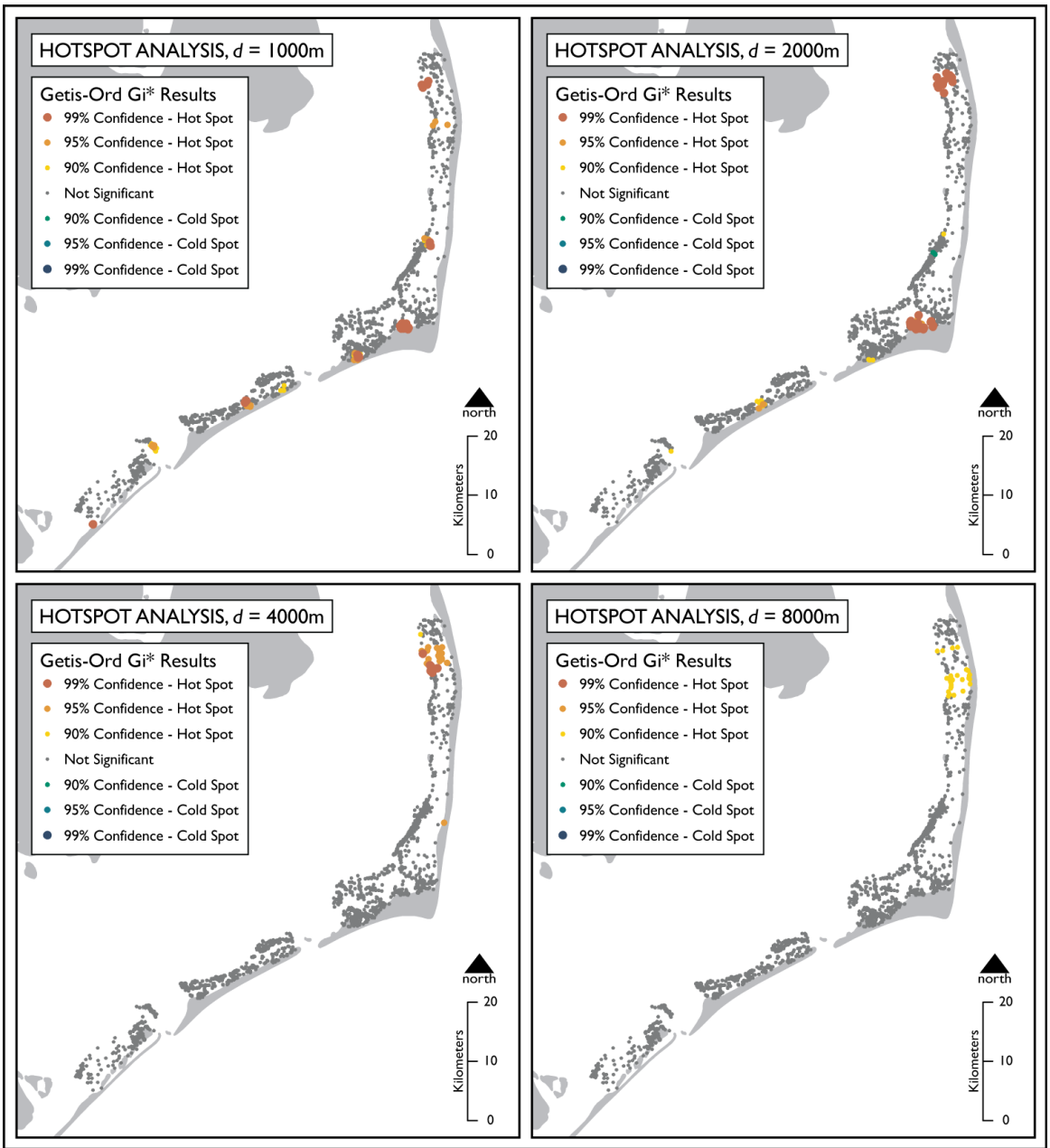

Figure 7. Results of the Getis-Ord Gi* Hot Spot analysis from September through December using varying distances for the search radius *d*. Results are expressed in percent confidence that locations are a hot spot or cold spot.

SUMMARY

- Based on data collected by observers in DMF Program 466, there do appear to be areas of high sea turtle bycatch located within the SWGNRAs, near the Pamlico Sound inlet corridors.

- Although Getis-Ord Gi* hotspot analysis is commonly used in analyzing environmental and fisheries spatial data, the subjectivity of this type of analysis led us to base the delineation of new inlet corridor boundaries solely on visual inspection of BPUE maps.
- Simulating effort redistribution under different scenarios of inlet corridor expansion revealed that this could be an effective way of reducing sea turtle bycatch in the southern flounder large-mesh gill net fishery without heavily impacting current catch rates of southern flounder.
- Expanding the corridors for just September is actually more effective at reducing sea turtle takes in most scenarios than expanding the corridors for the entire fall.

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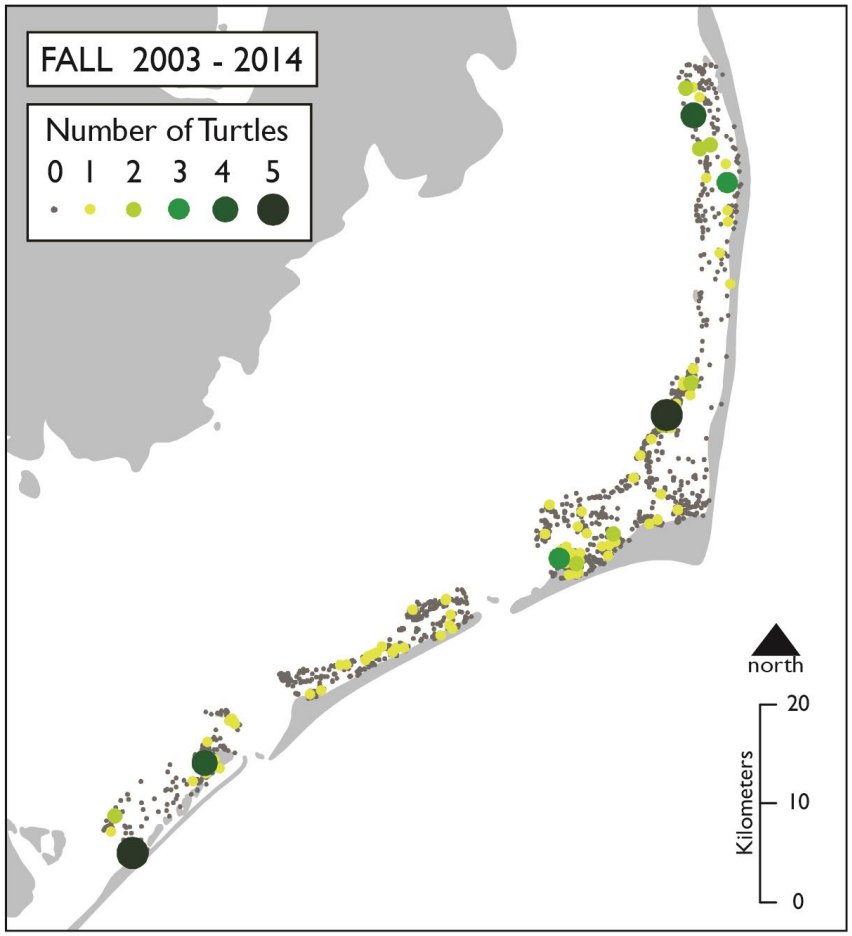
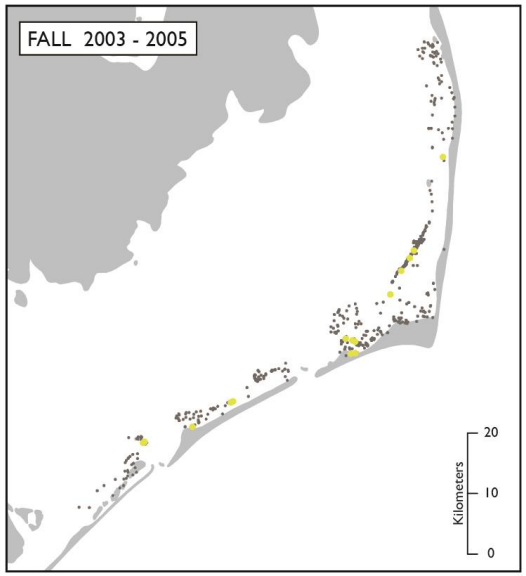
REDUCING SEA TURTLE BYCATCH IN THE PAMLICO SOUND SOUTHERN FLOUNDER FISHERY BY EXPANDING NO-FISHING ZONES AROUND INLET CORRIDORS

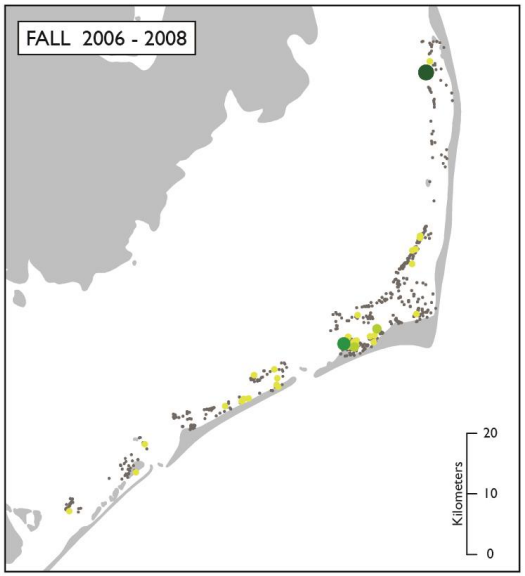
APPENDIX

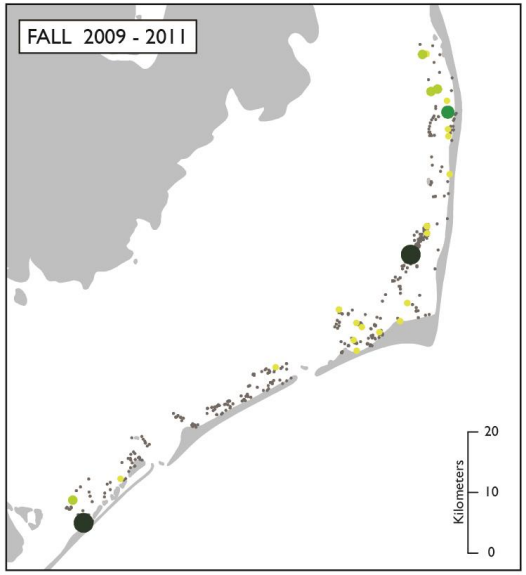
SECTION 1

Point maps of sea turtle bycatch, and grid maps of fishing effort and sea turtle bycatch per unit effort recorded by observers in Program 466 (2003 – 2014) in the Shallow Water Gillnet Restricted Areas (SWGNRAs) in Pamlico Sound, divided into 3-year bins (2003 – 2005; 2006 – 2008; 2009 – 2011; 2012 – 2014).









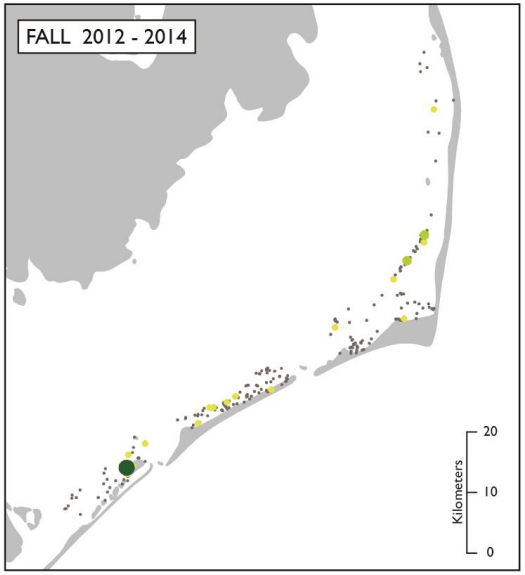


Figure 1. Number of sea turtles caught in Program 466 during fall (September - December) between 2003 - 2014.

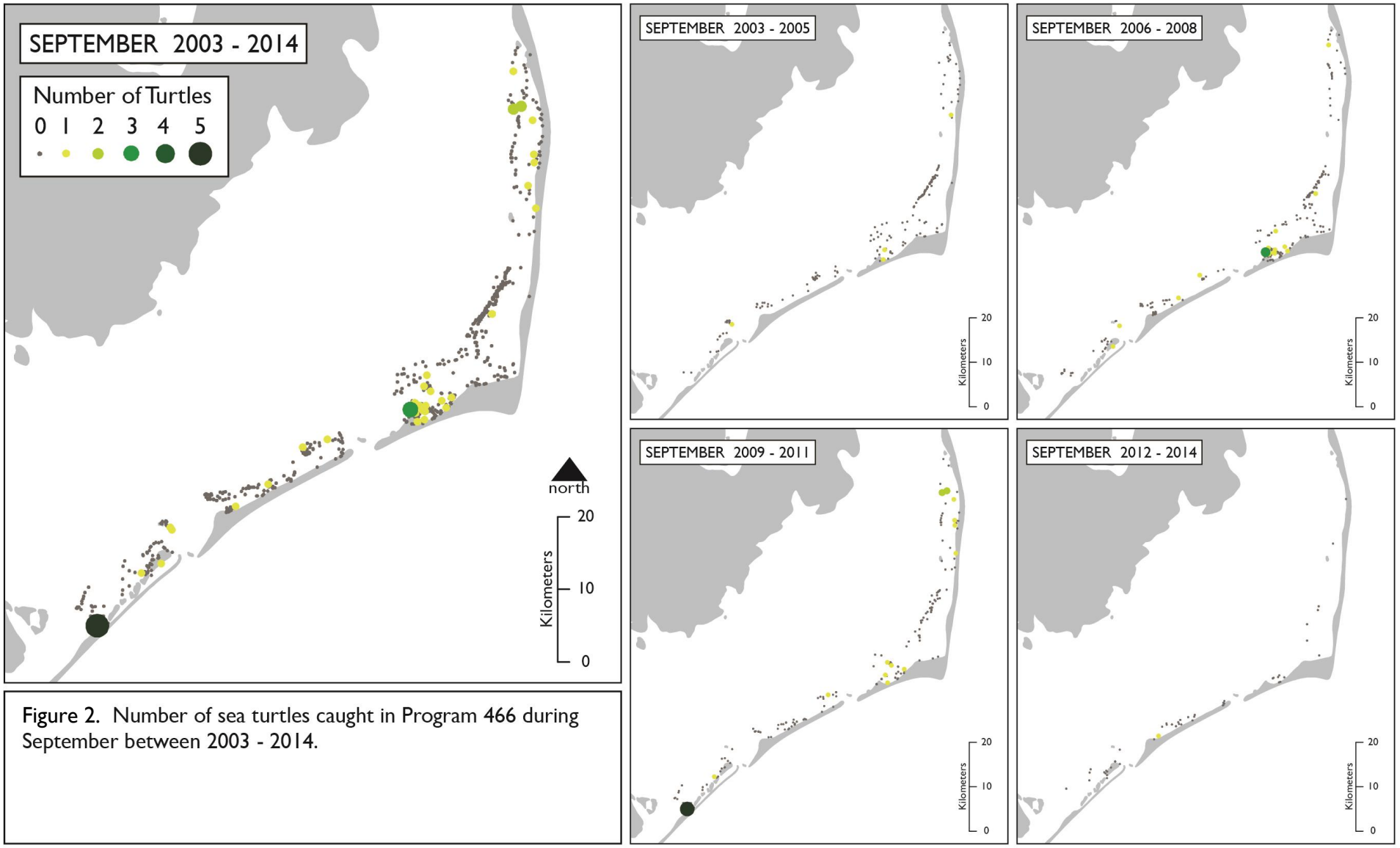
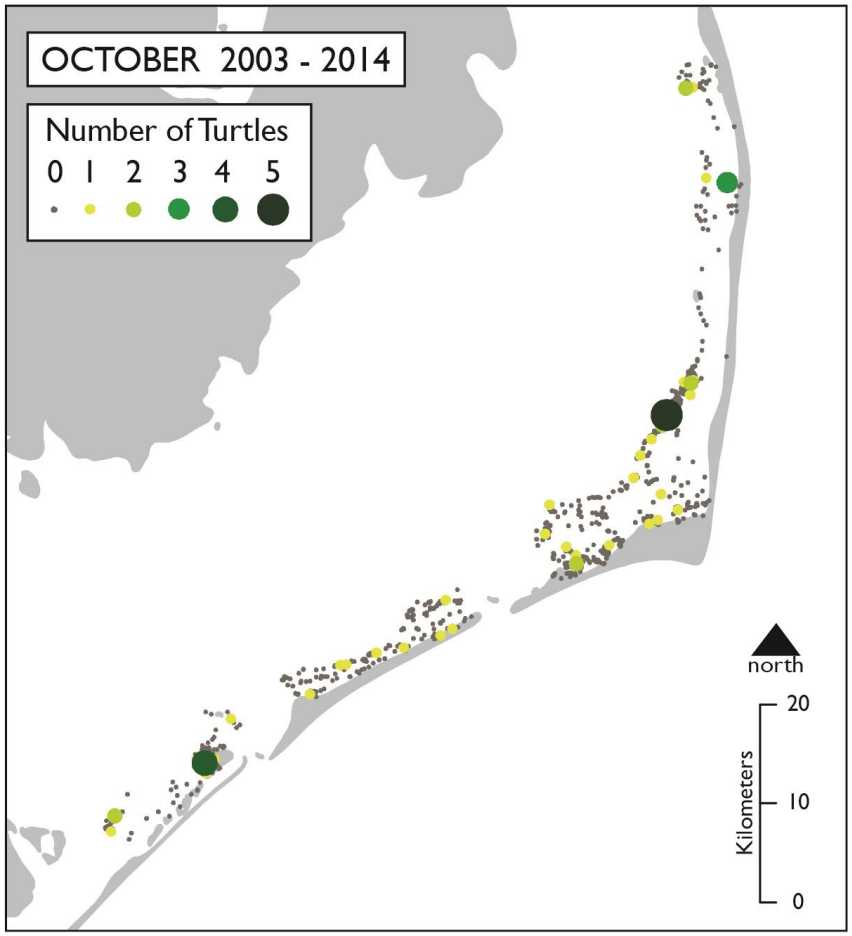
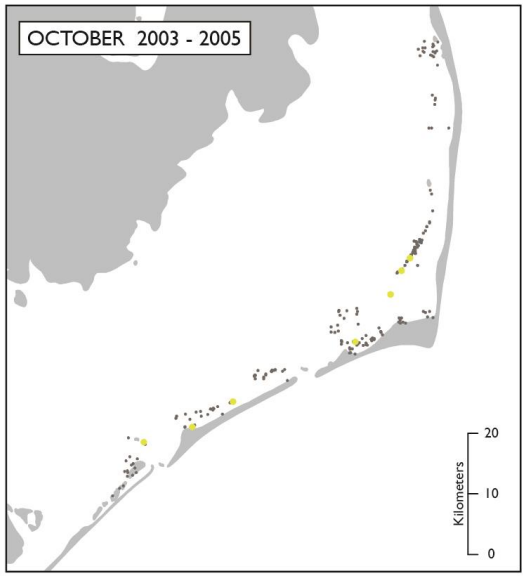
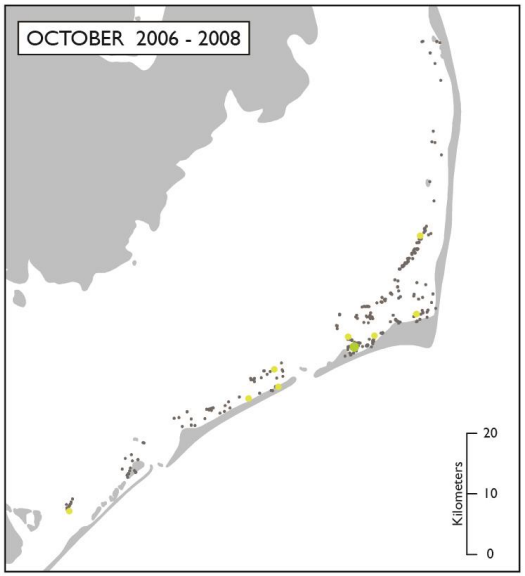
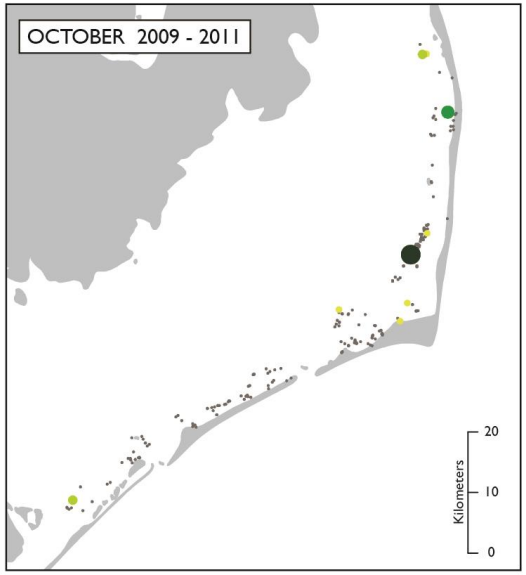


Figure 2. Number of sea turtles caught in Program 466 during September between 2003 - 2014.









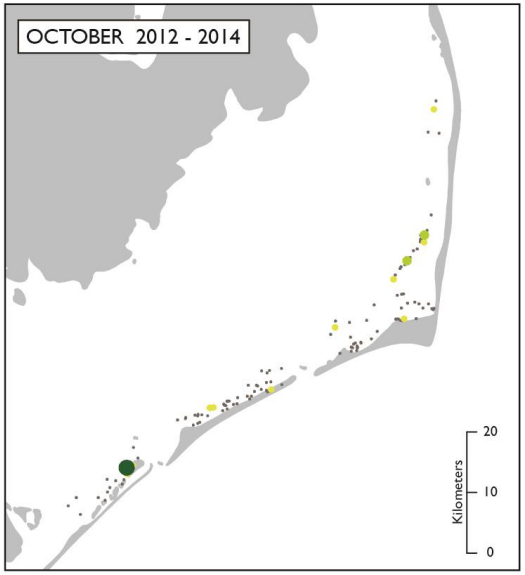
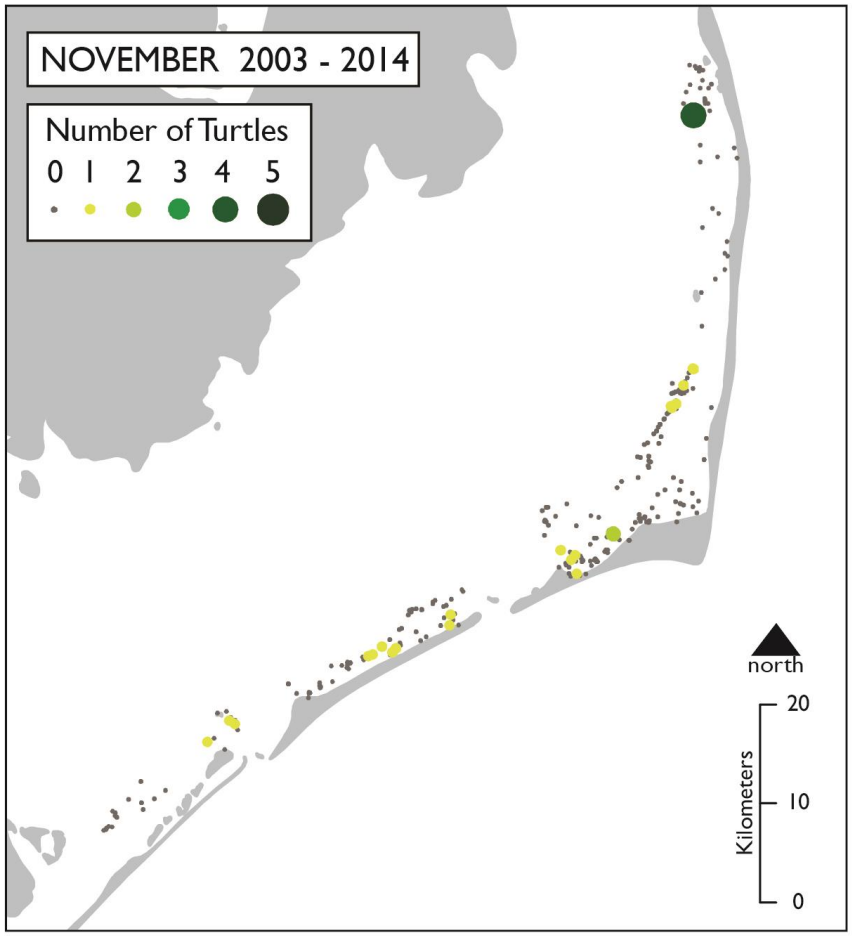
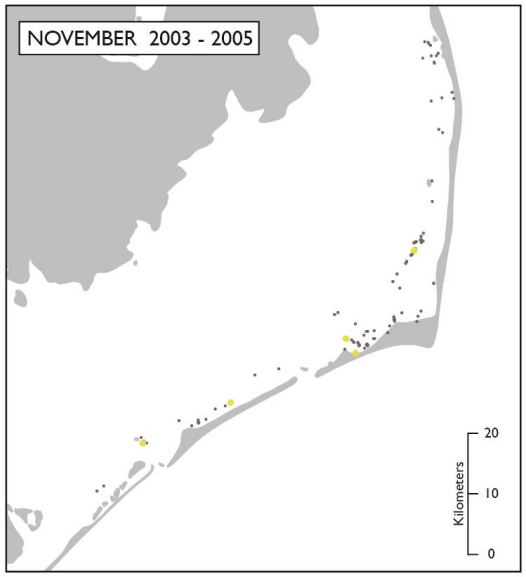
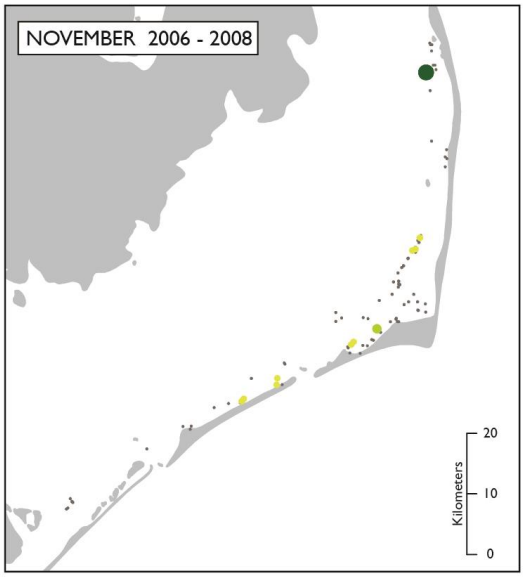
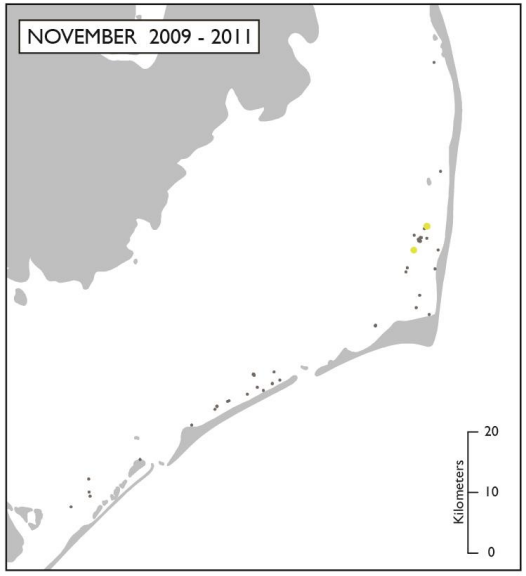


Figure 3. Number of sea turtles caught in Program 466 during October between 2003 - 2014.









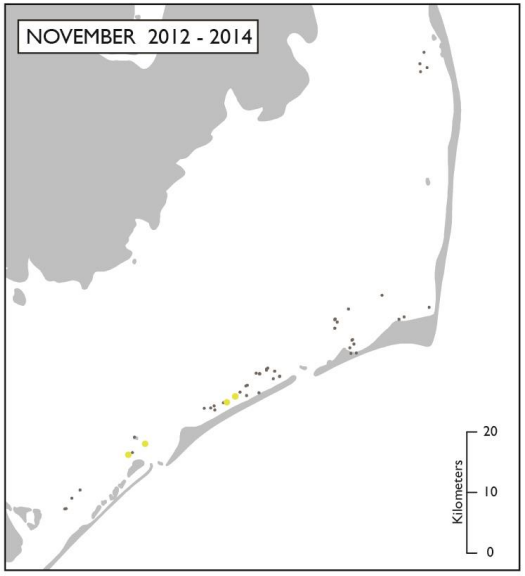
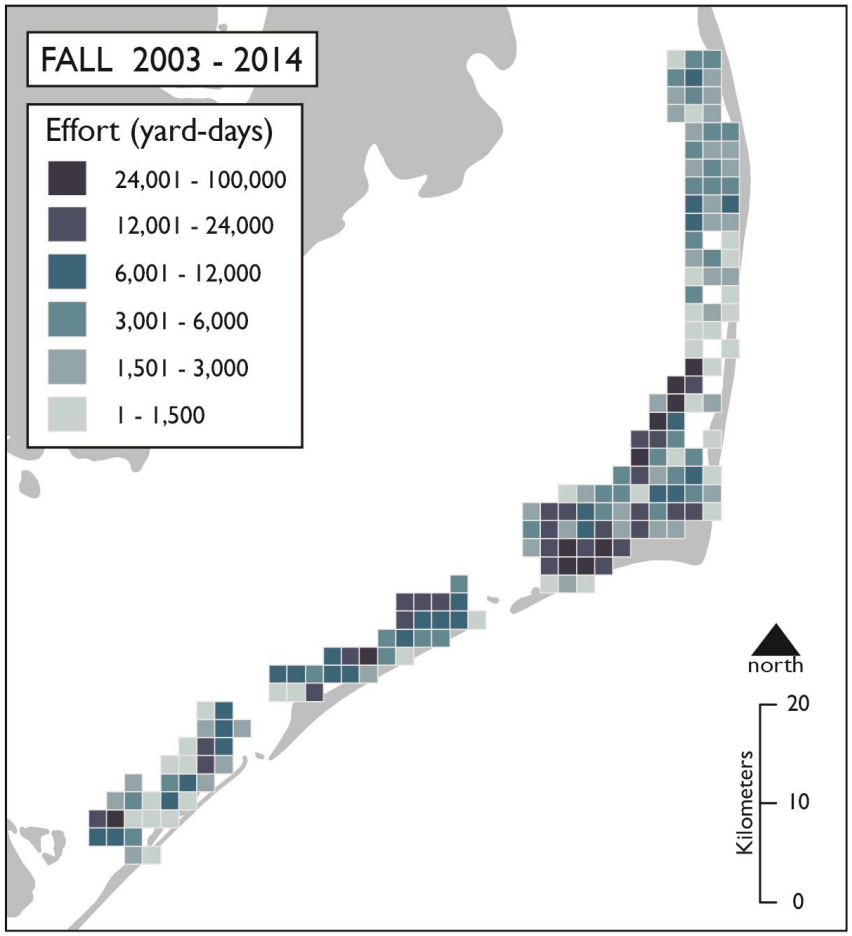
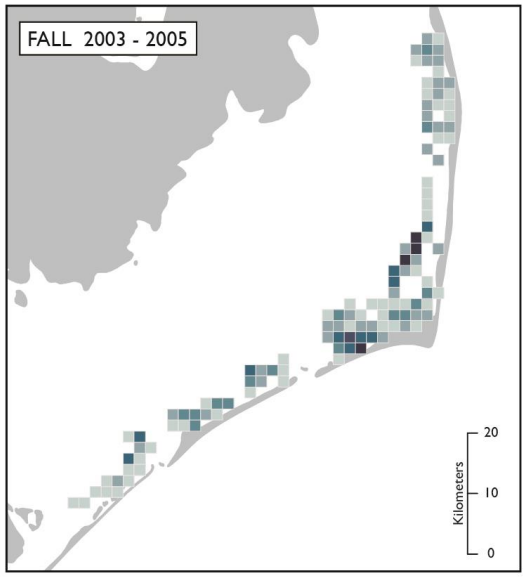
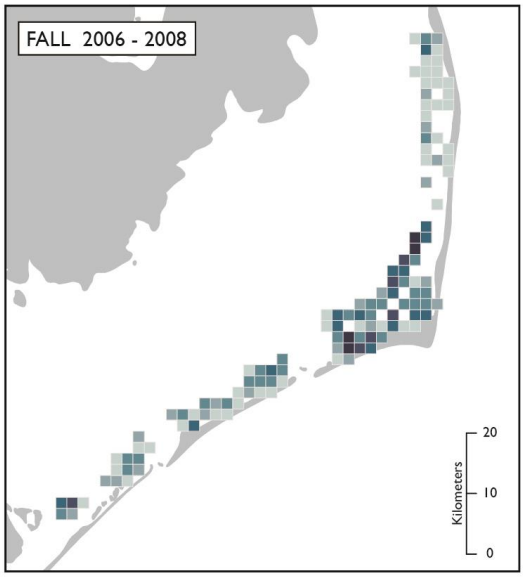
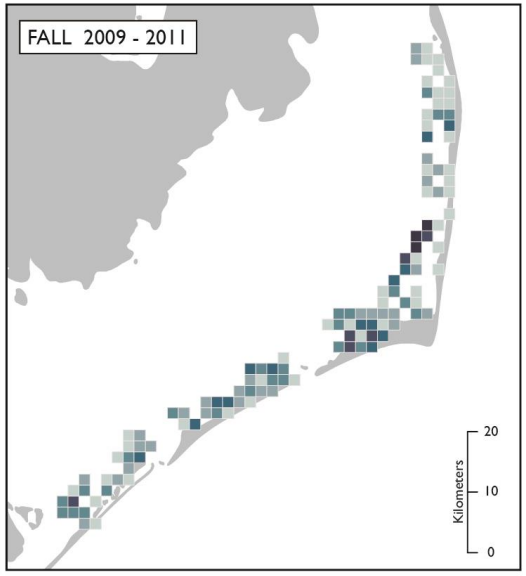


Figure 4. Number of sea turtles caught in Program 466 during November between 2003 - 2014.









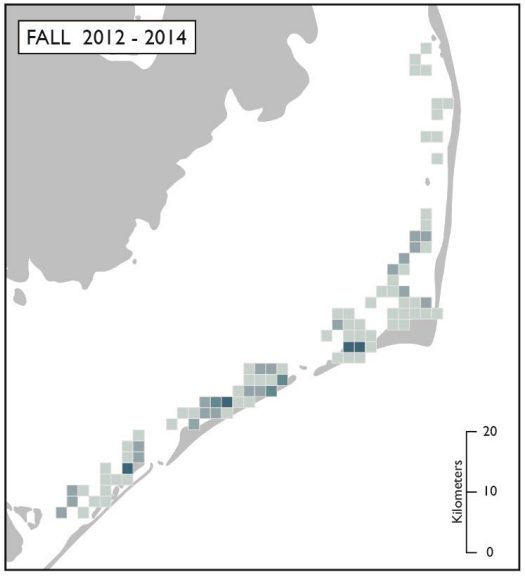
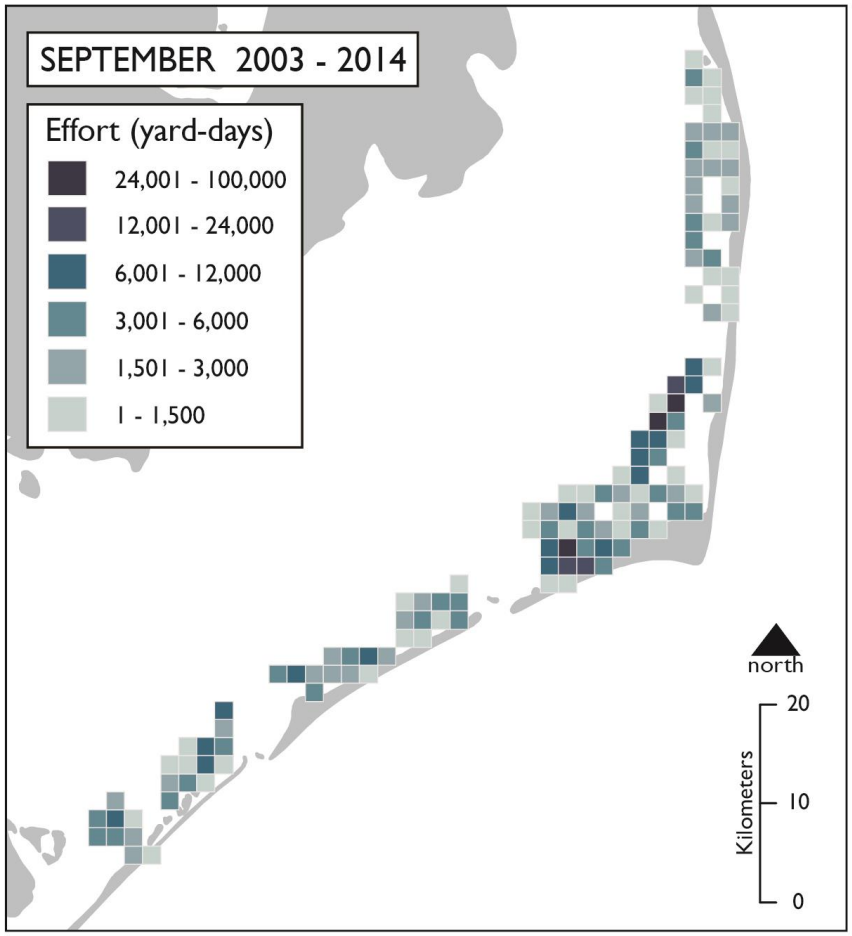
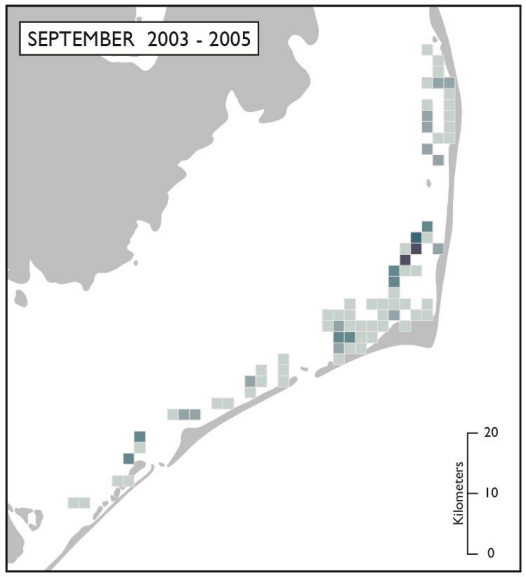
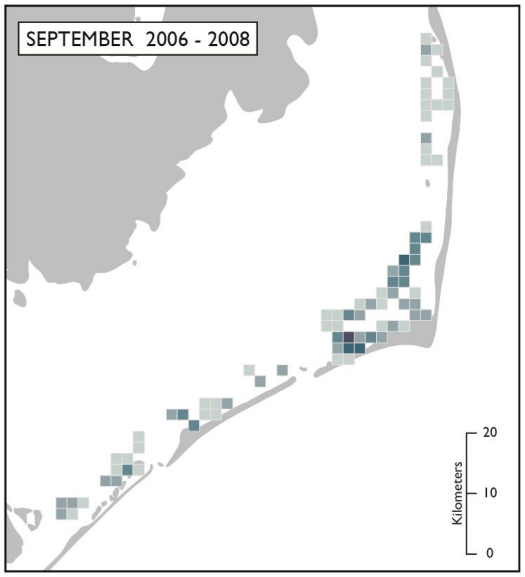
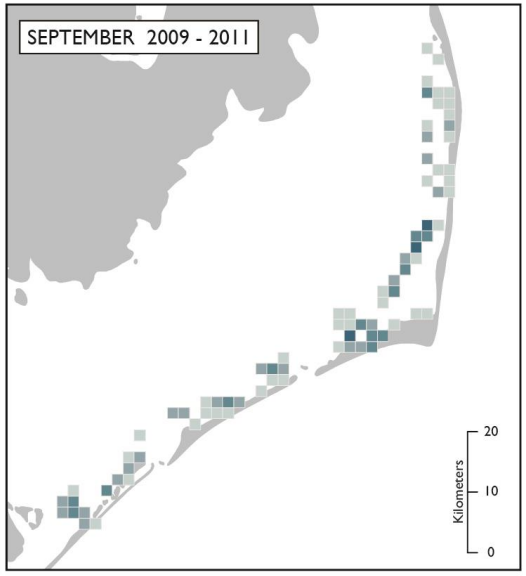


Figure 5. Fishing effort in Program 466 summed up across all records located within each grid cell during fall (September - December) between 2003 - 2014. Effort is calculated as the product of net length (yards) and the amount of time gear was fished (days) at each location.









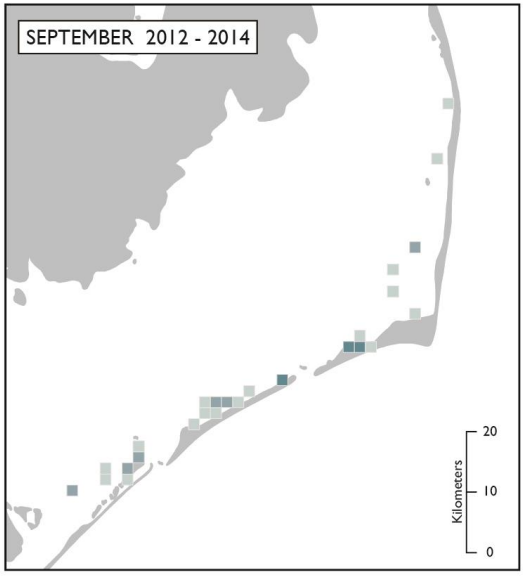
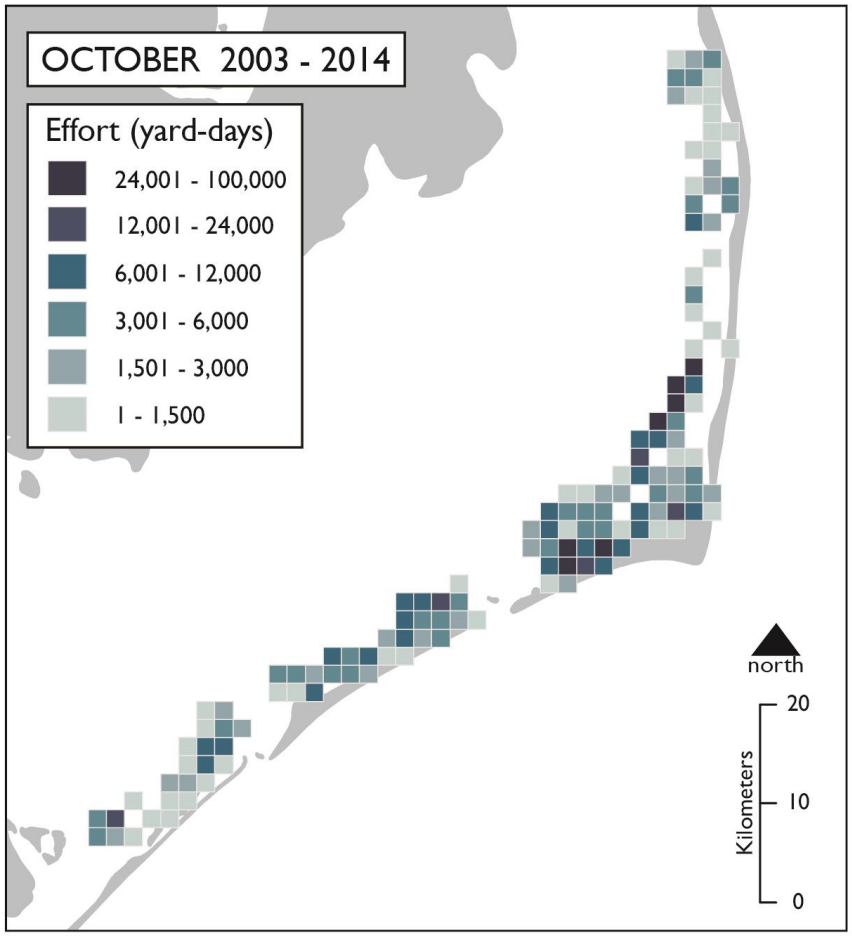
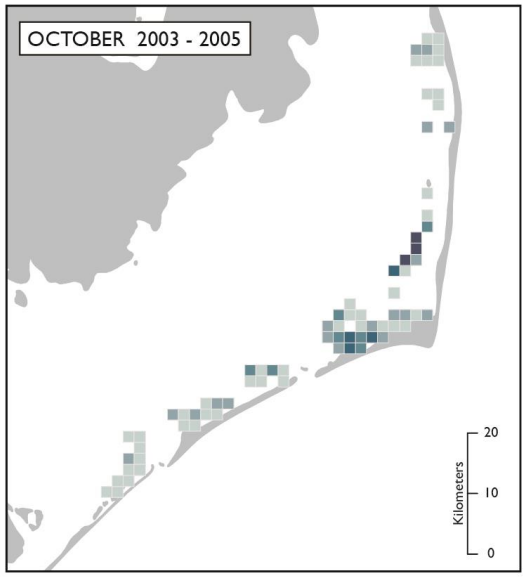
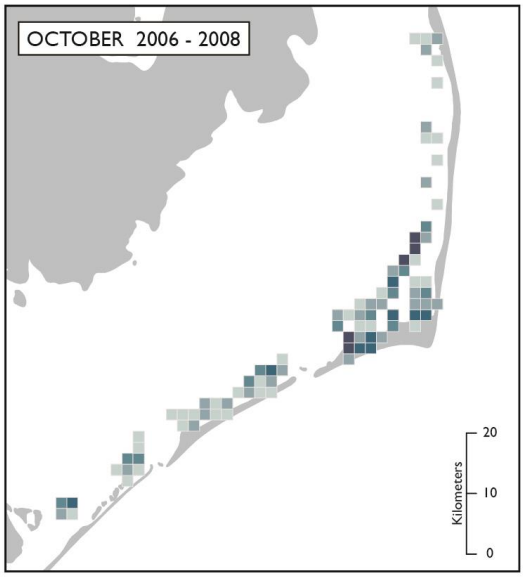
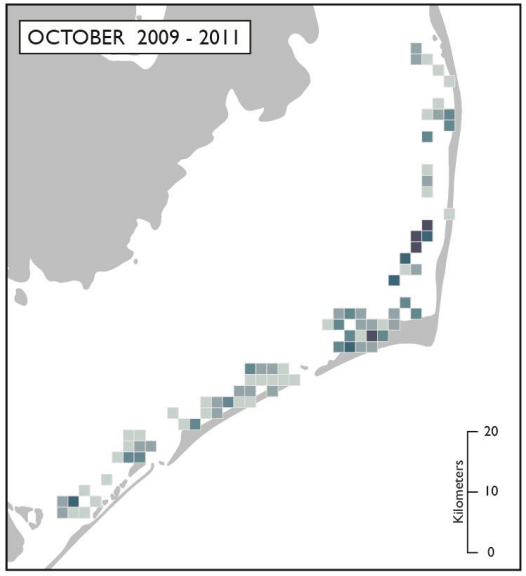


Figure 6. Fishing effort in Program 466 summed up across all records located within each grid cell during September between 2003 - 2014. Effort is calculated as the product of net length (yards) and the amount of time gear was fished (days) at each location.









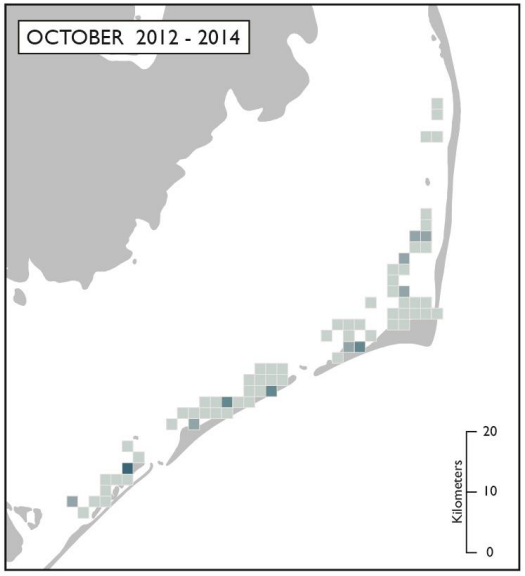
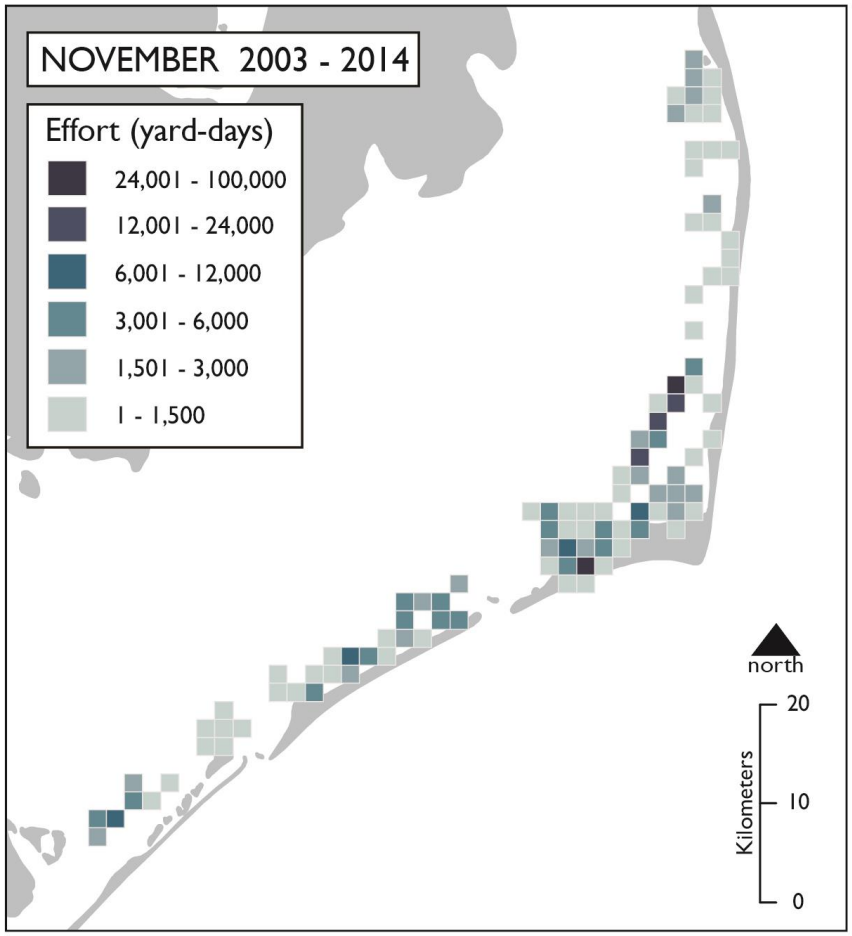
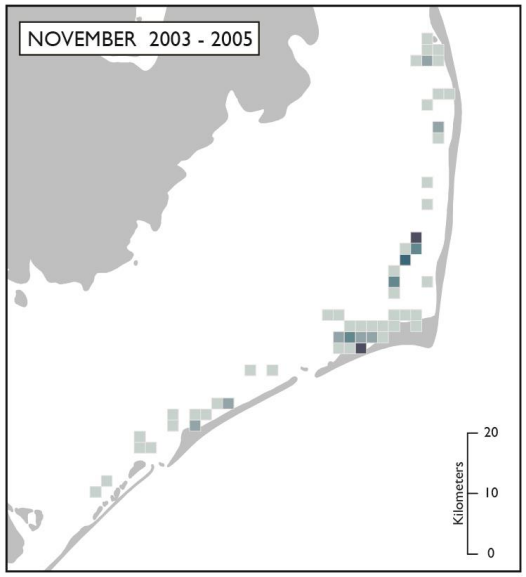
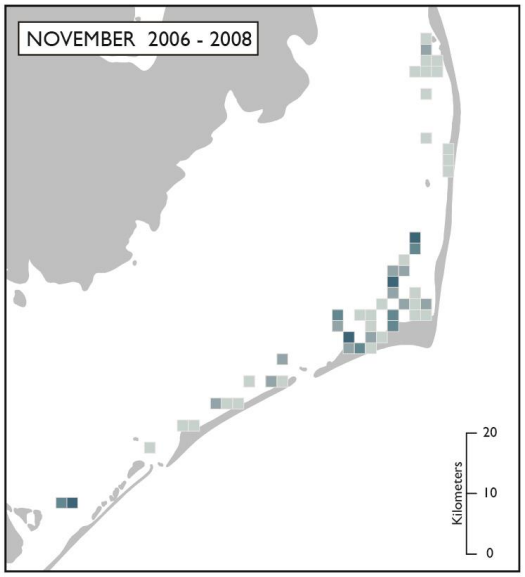
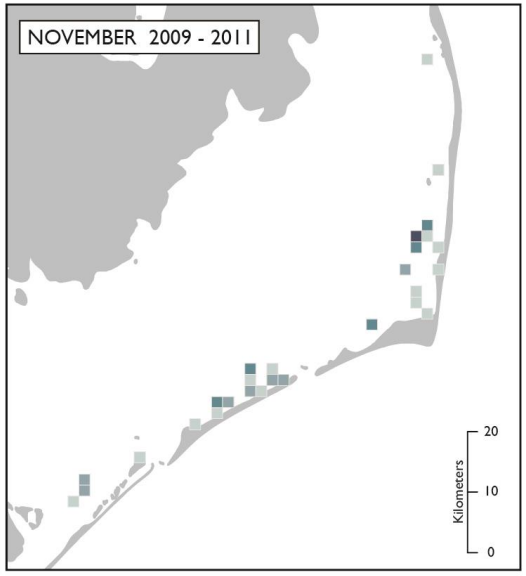


Figure 7. Fishing effort in Program 466 summed up across all records located within each grid cell during October between 2003 - 2014. Effort is calculated as the product of net length (yards) and the amount of time gear was fished (days) at each location.









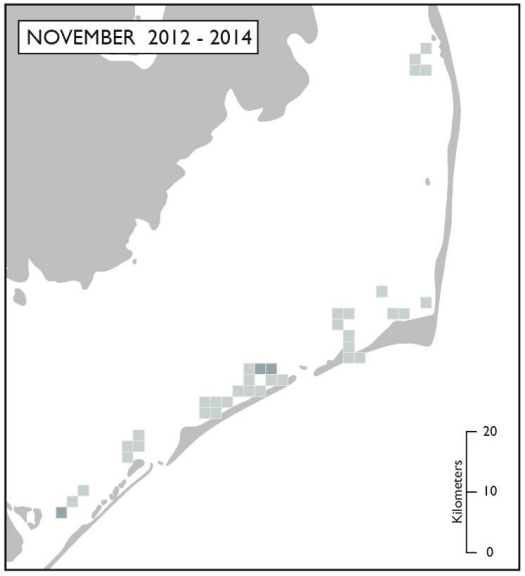
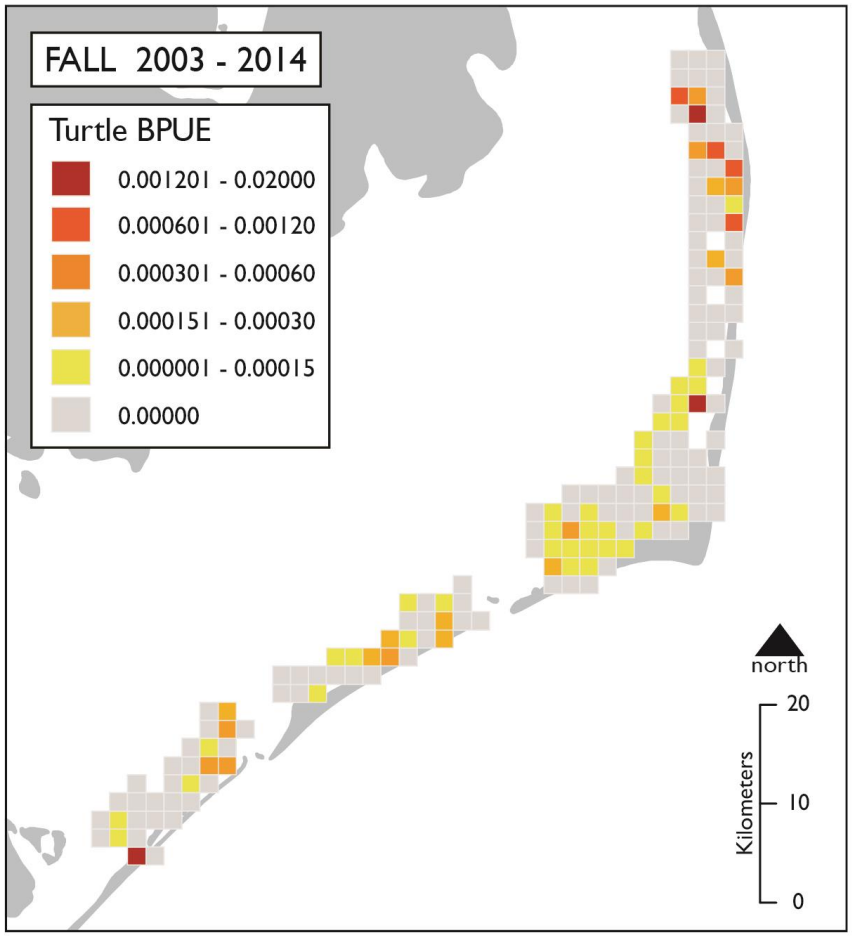
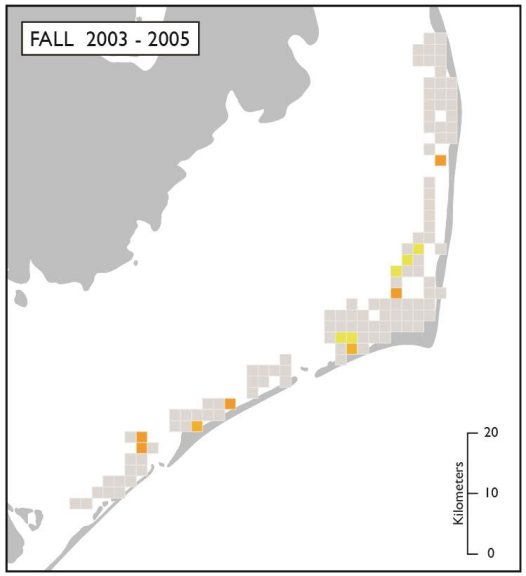
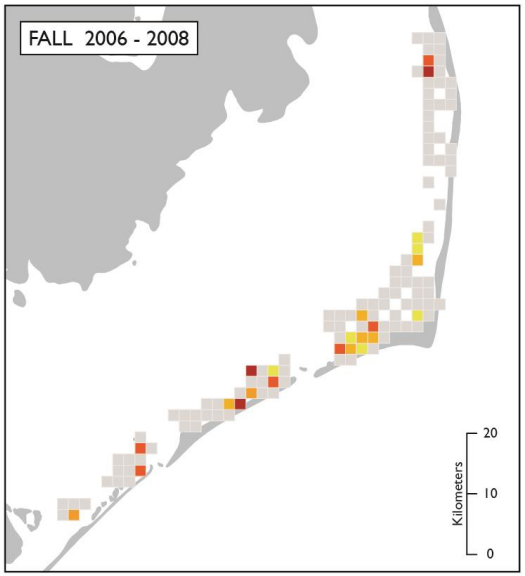
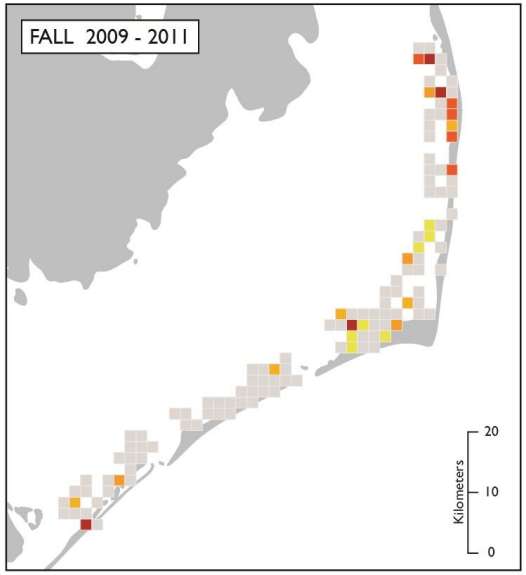


Figure 8. Fishing effort in Program 466 summed up across all records located within each grid cell during November between 2003 - 2014. Effort is calculated as the product of net length (yards) and the amount of time gear was fished (days) at each location.









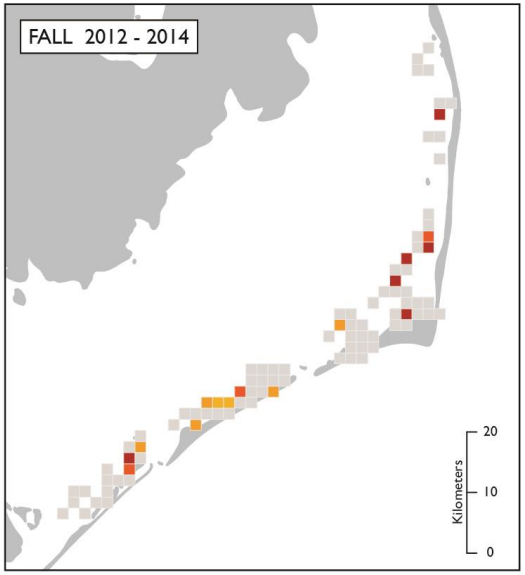
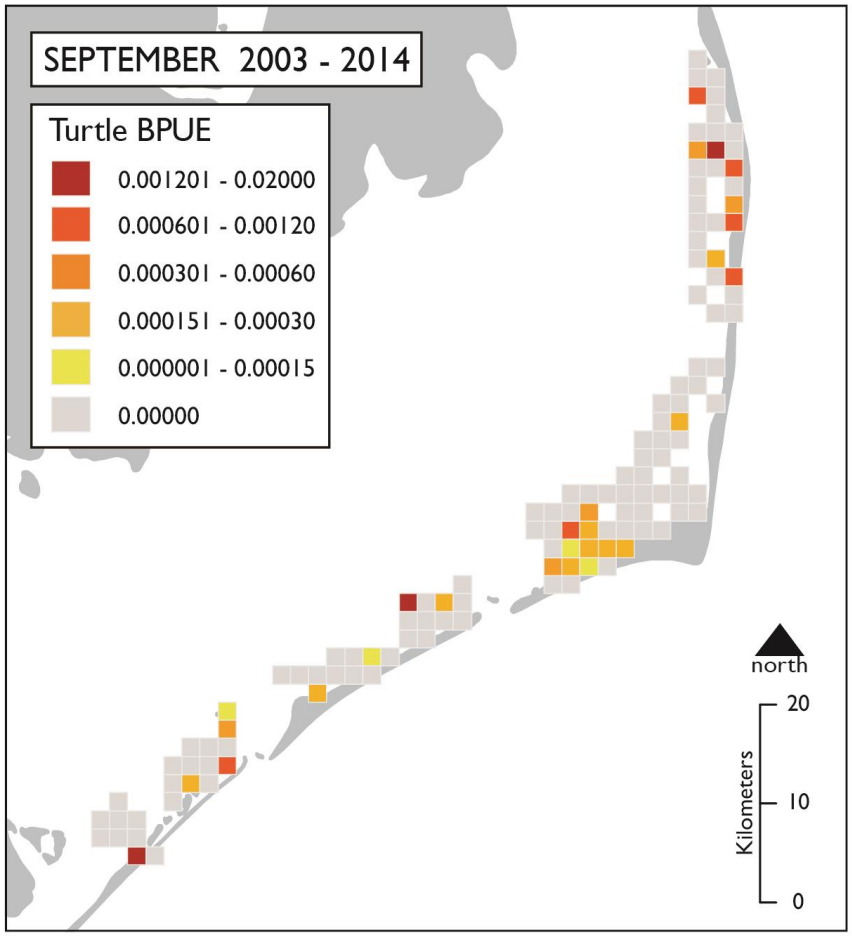
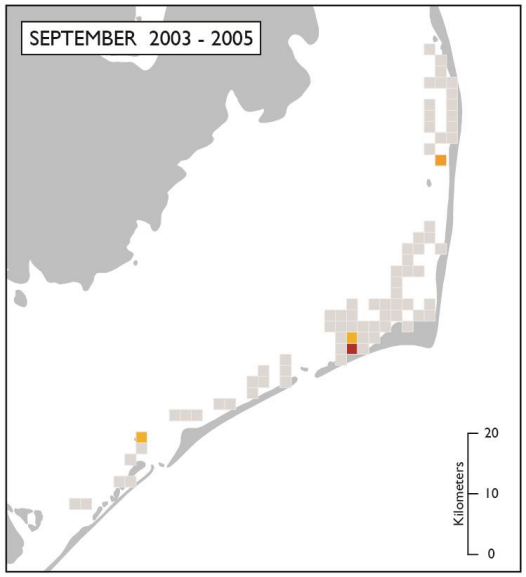
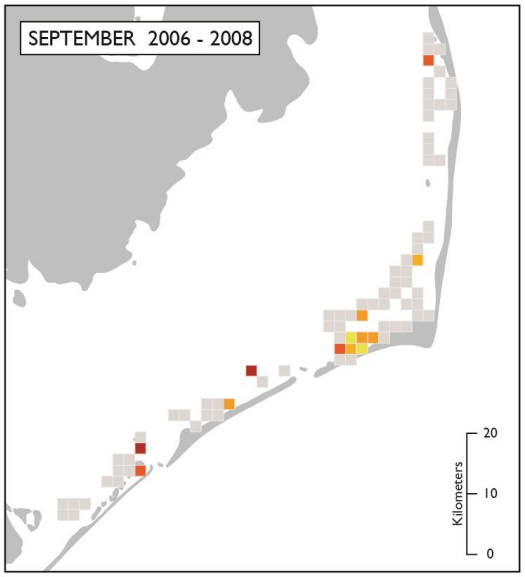
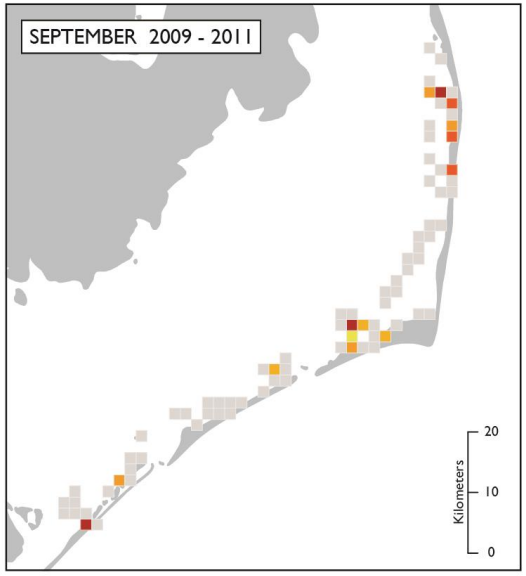


Figure 9. Number of sea turtles caught in Program 466 summed up across all records located within each grid cell during fall (September - December) between 2003 - 2014.









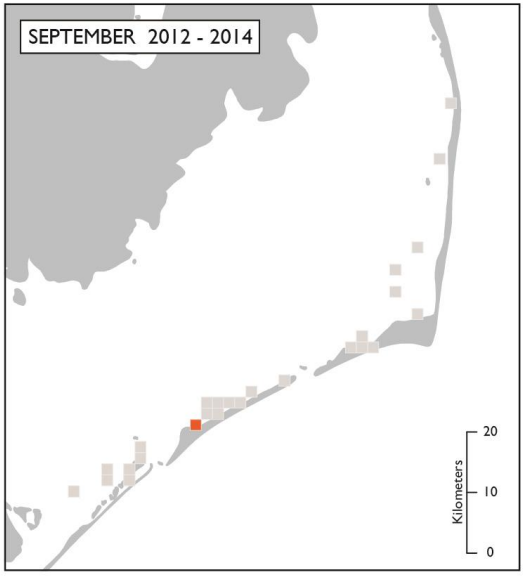


Figure 10. Number of sea turtles caught in Program 466 summed up across all records located within each grid cell during September between 2003 - 2014.

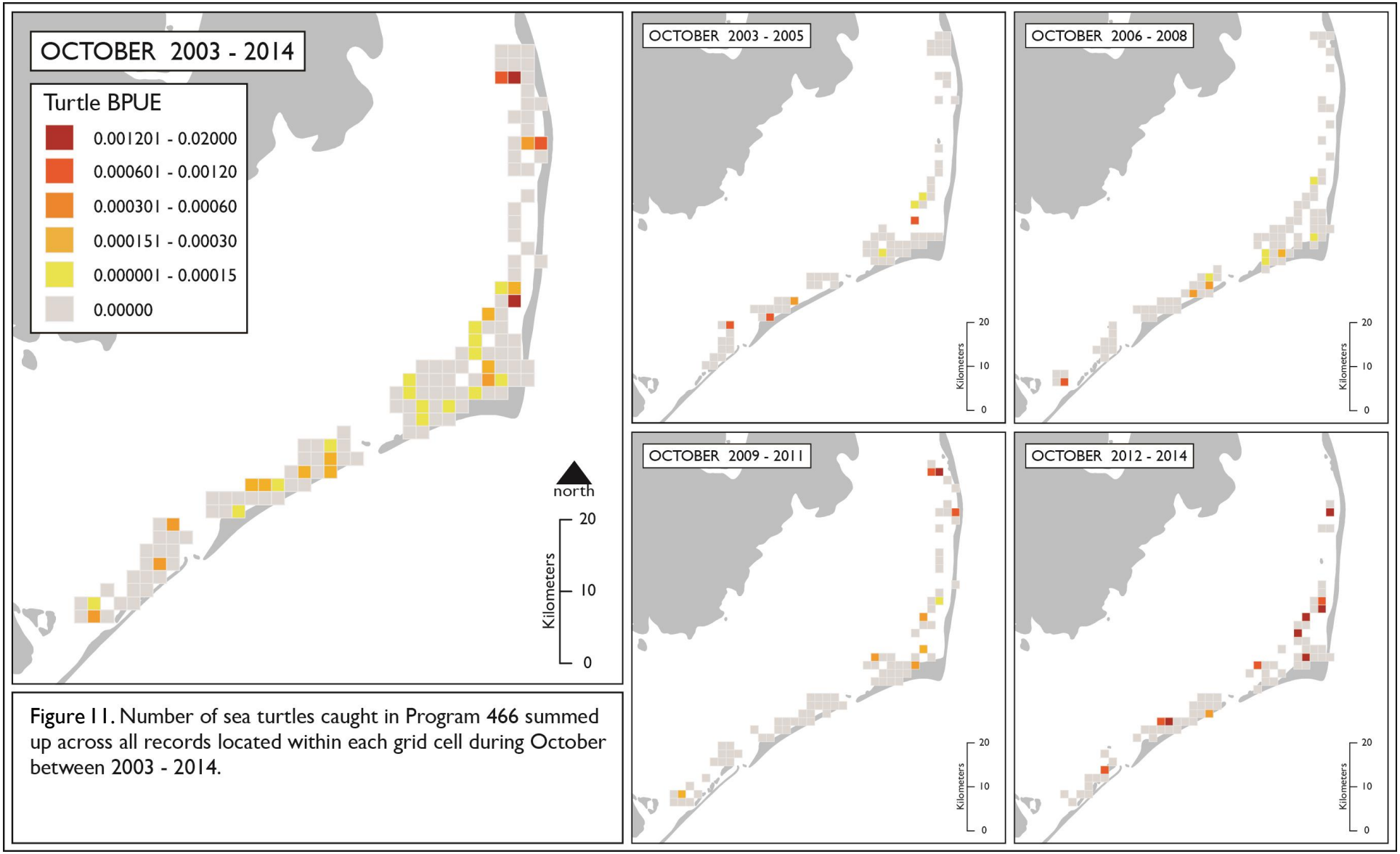
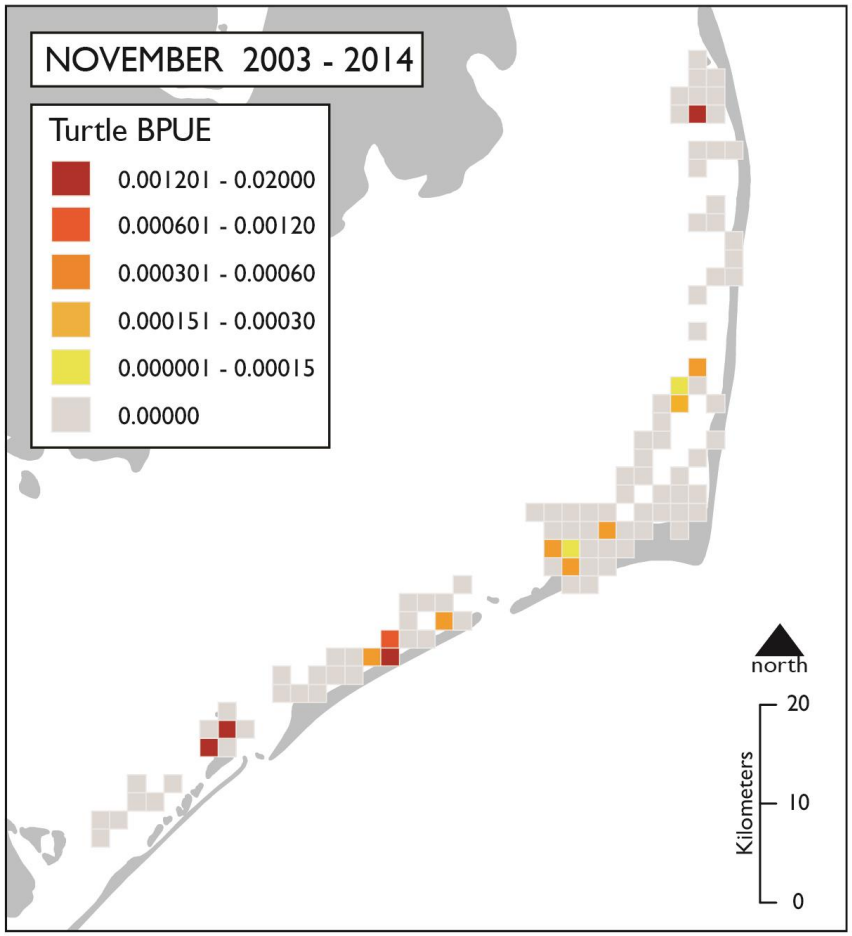
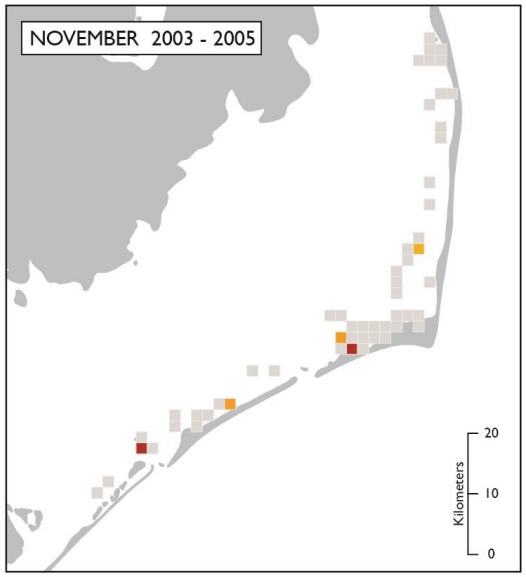
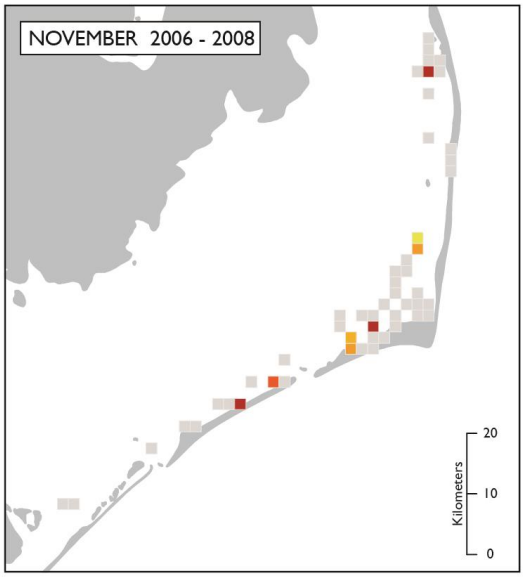
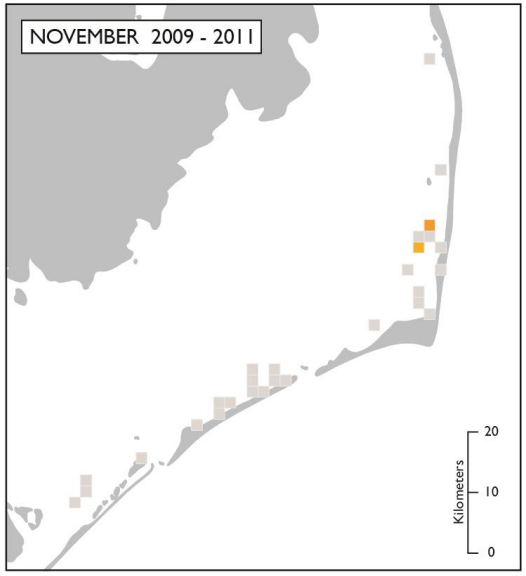


Figure 11. Number of sea turtles caught in Program 466 summed up across all records located within each grid cell during October between 2003 - 2014.









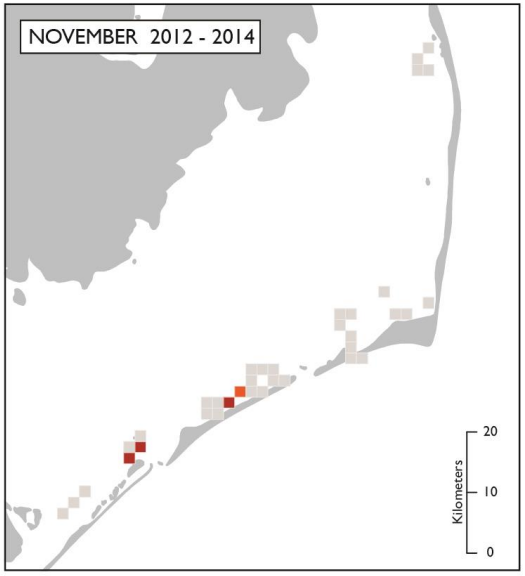


Figure 12. Number of sea turtles caught in Program 466 summed up across all records located within each grid cell during November between 2003 - 2014.

SECTION 2

Grid maps with side by side comparisons of sea turtle bycatch and grid maps of fishing effort, and sea turtle bycatch per unit effort recorded by observers in Program 466 (2003 – 2014) in the Shallow Water Gillnet Restricted Areas (SWGNRAs) in Pamlico Sound, divided into 3-year bins (2003 – 2005; 2006 – 2008; 2009 – 2011; 2012 – 2014).

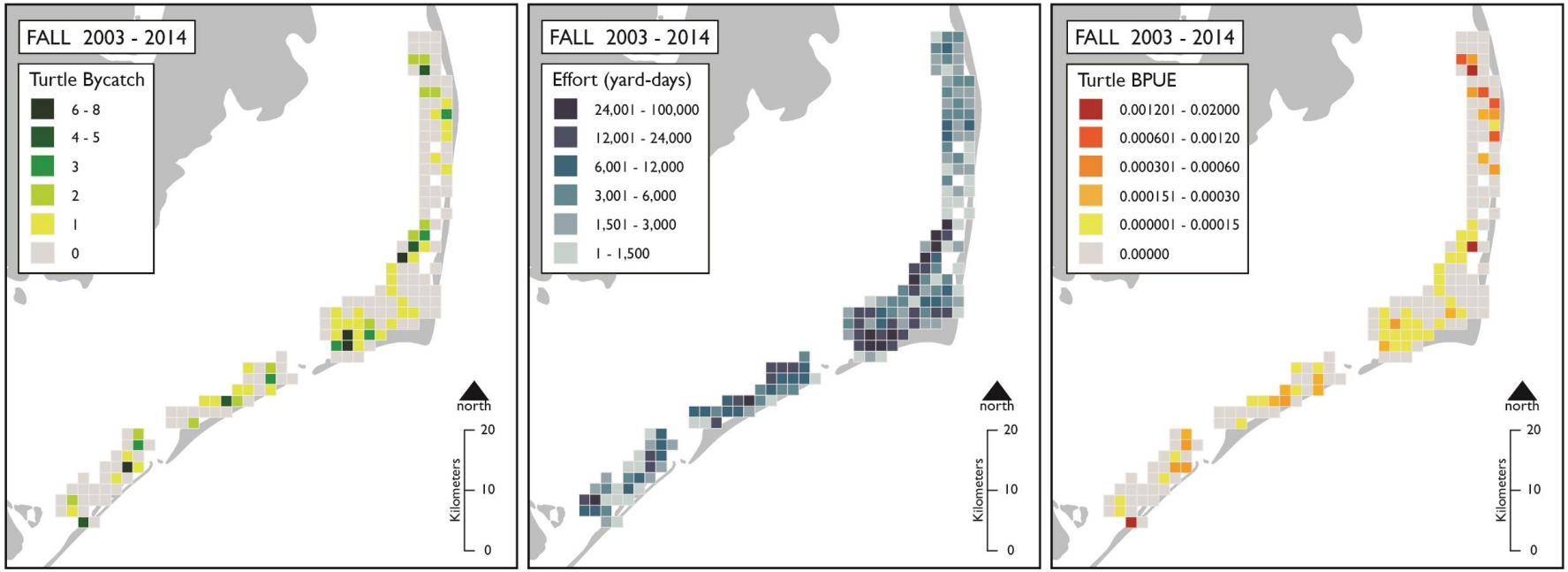


Figure 13. Sea turtle bycatch, fishing effort, and bycatch per unit effort recorded by DMF Program 466 observers during fall (September to December) 2003 - 2014.

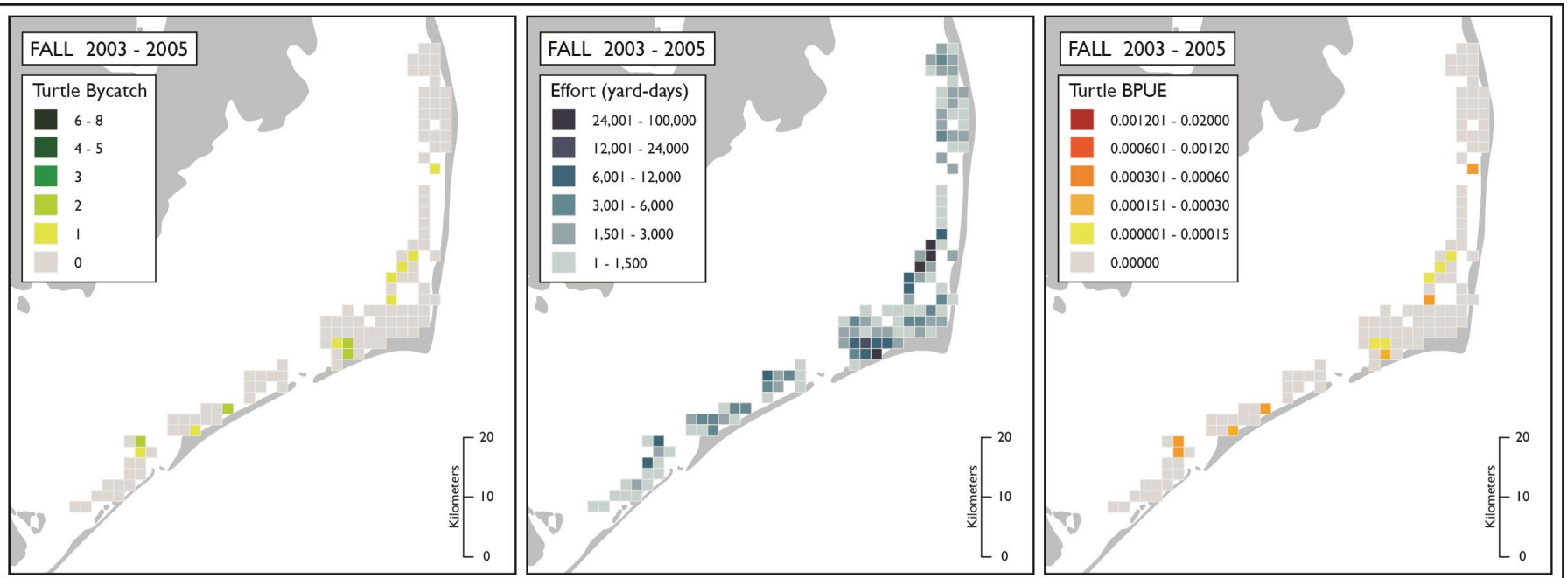


Figure 14. Sea turtle bycatch, fishing effort, and bycatch per unit effort recorded by DMF Program 466 observers during fall (September - December) 2003 - 2005.

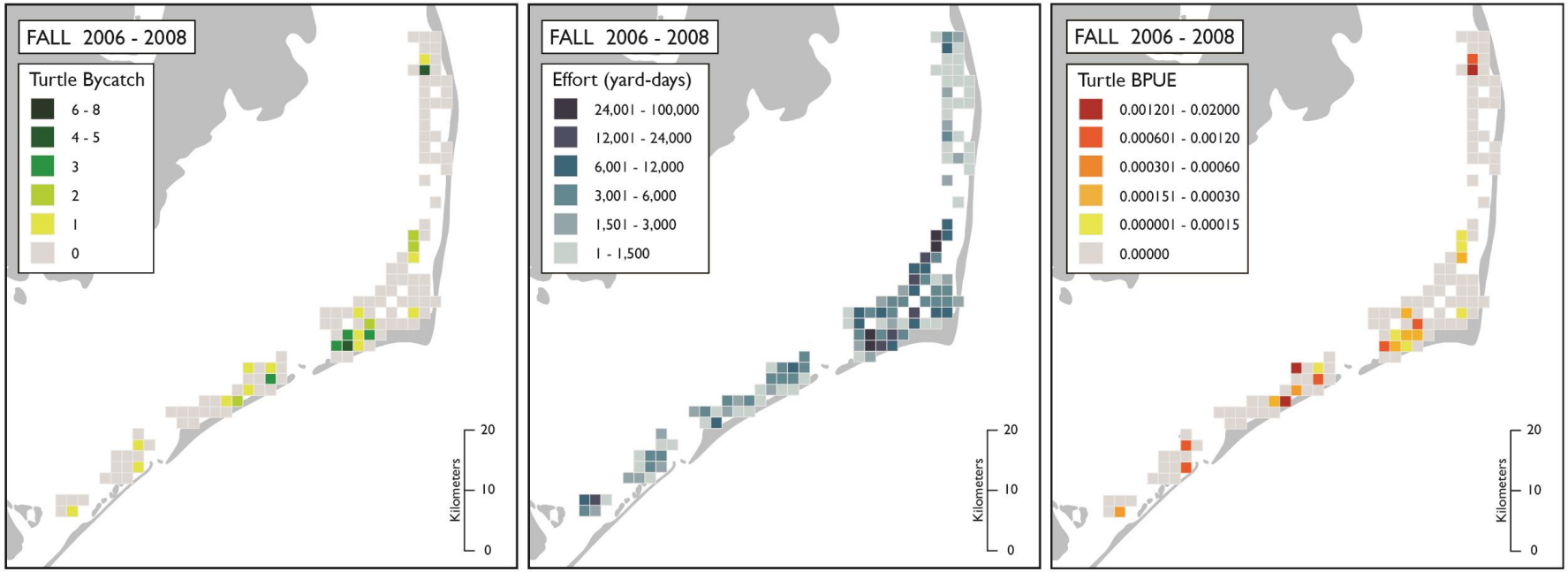


Figure 15. Sea turtle bycatch, fishing effort, and bycatch per unit effort recorded by DMF Program 466 observers during fall (September to December) 2003 - 2014.

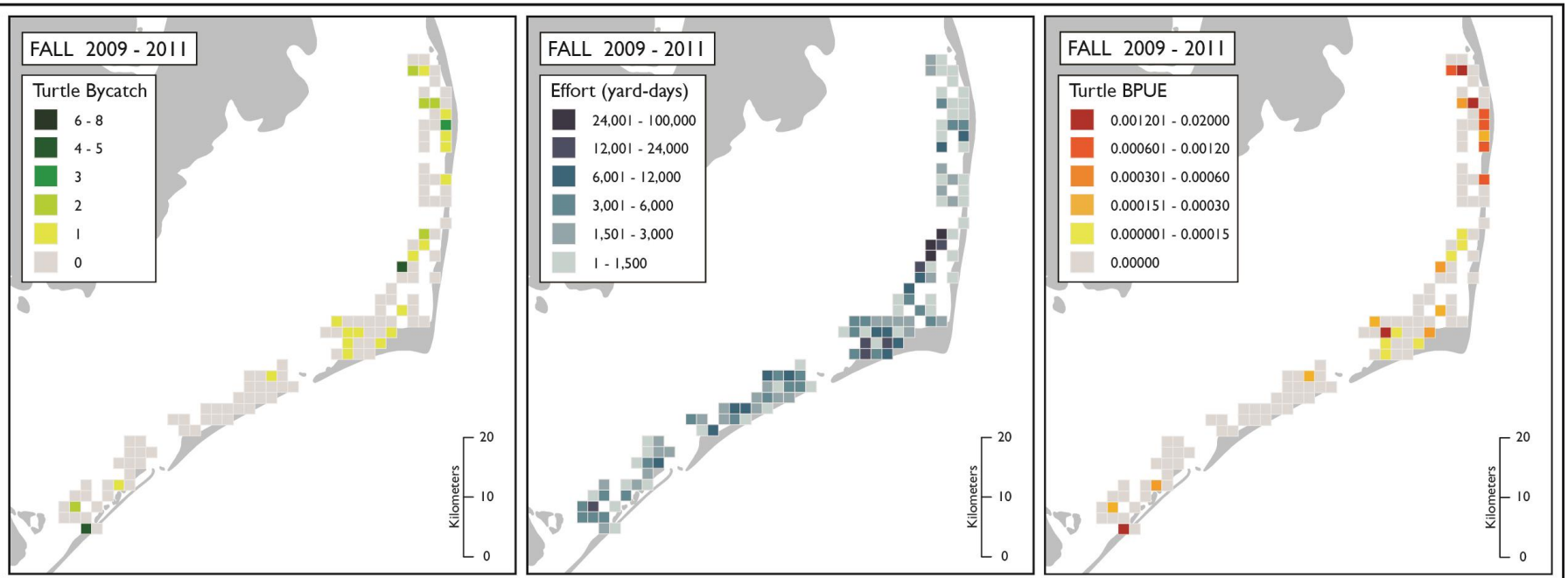


Figure 16. Sea turtle bycatch, fishing effort, and bycatch per unit effort recorded by DMF Program 466 observers during fall (September - December) 2003 - 2005.

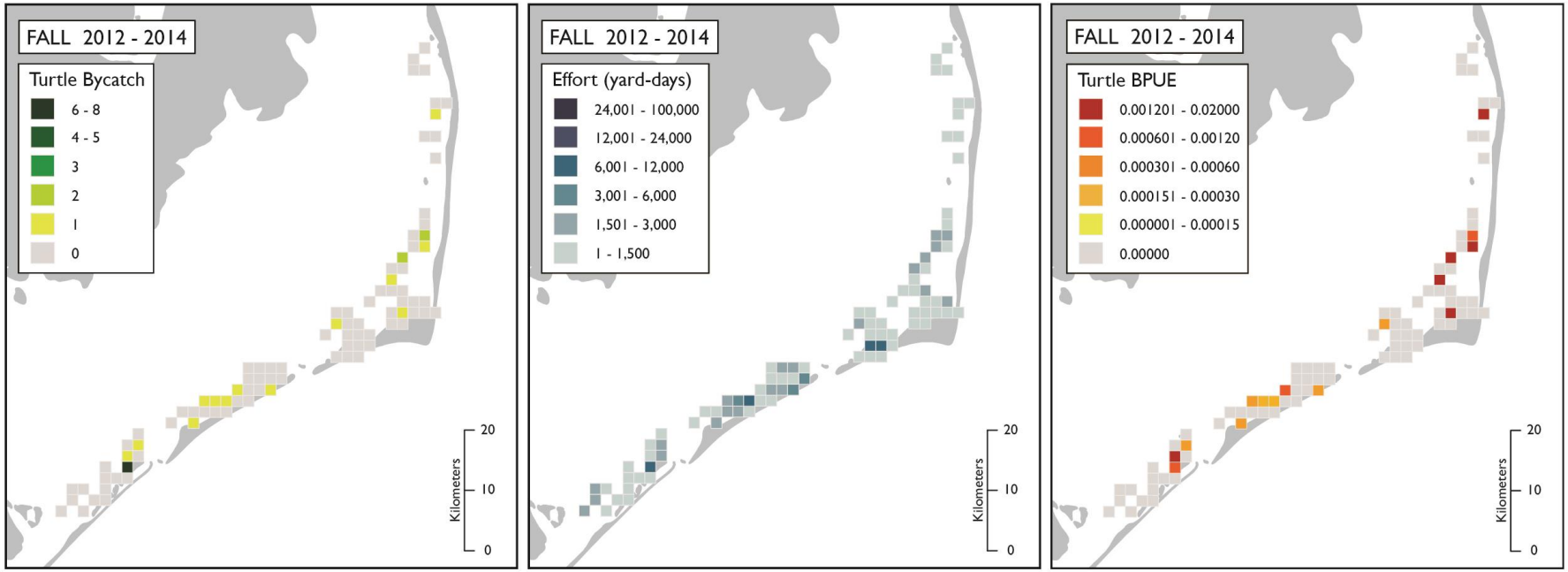


Figure 17. Sea turtle bycatch, fishing effort, and bycatch per unit effort recorded by DMF Program 466 observers during fall (September to December) 2003 - 2014.

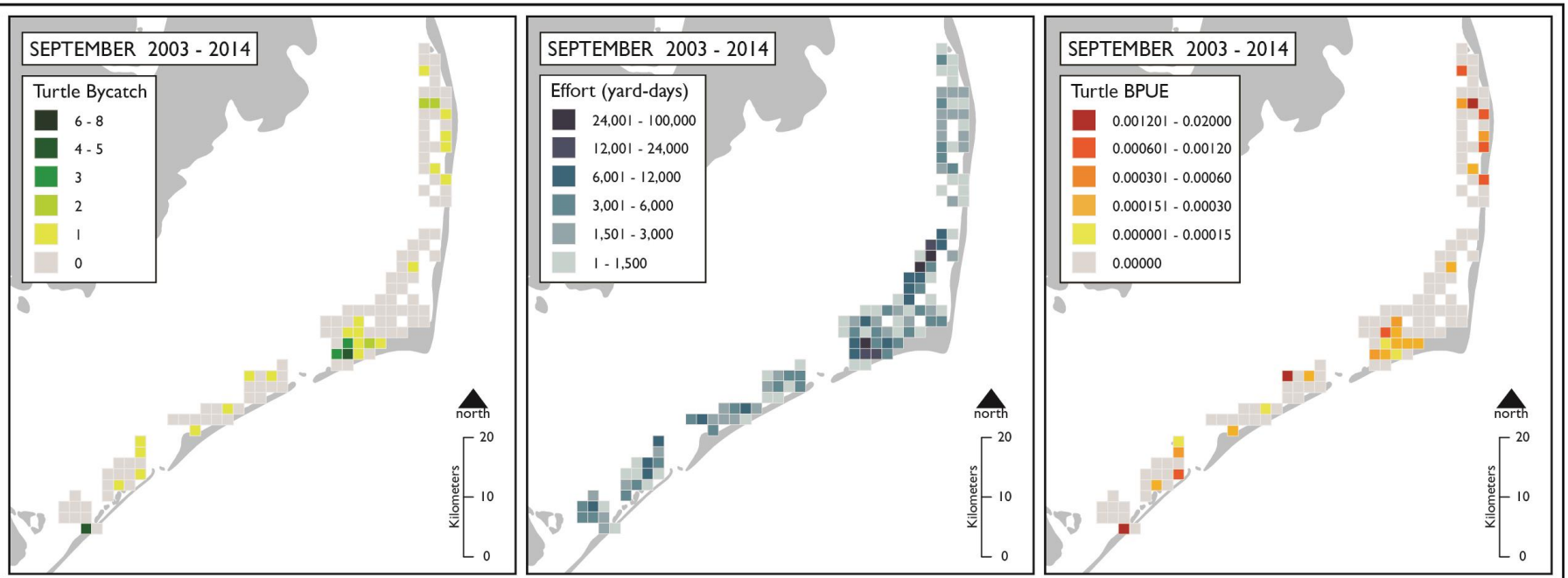


Figure 18. Sea turtle bycatch, fishing effort, and bycatch per unit effort recorded by DMF Program 466 observers during fall (September - December) 2003 - 2005.

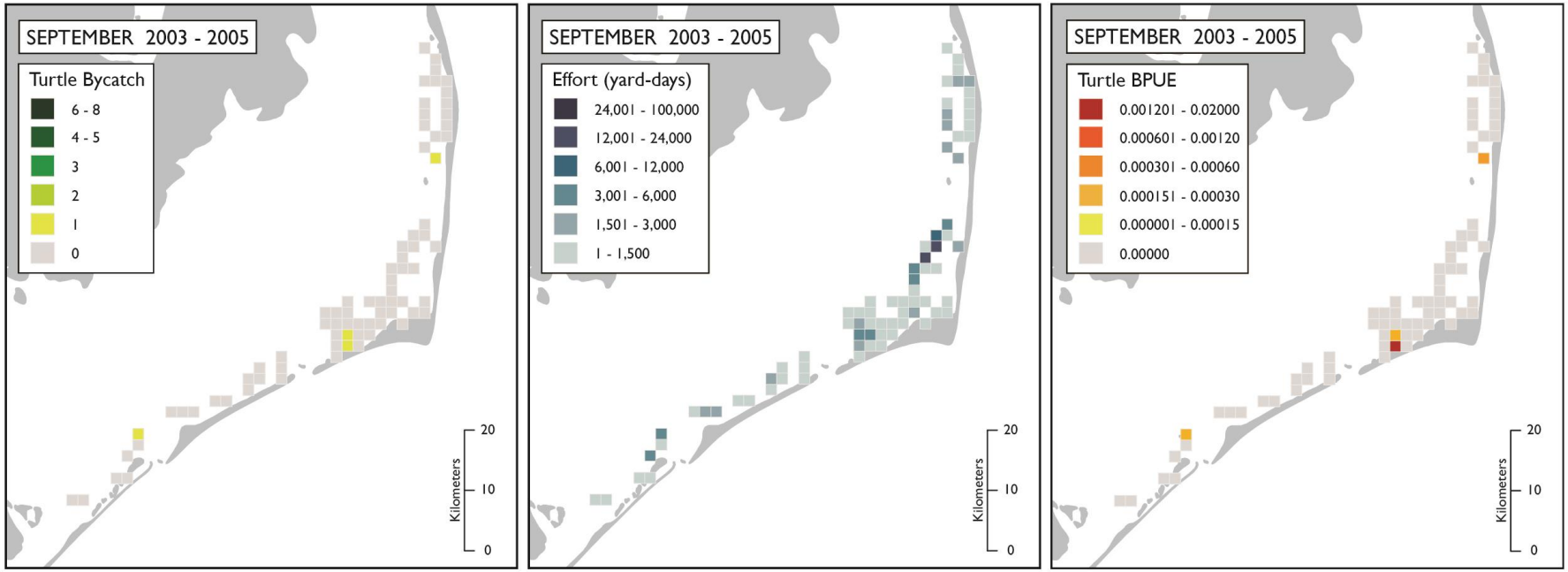


Figure 19. Sea turtle bycatch, fishing effort, and bycatch per unit effort recorded by DMF Program 466 observers during fall (September to December) 2003 - 2014.

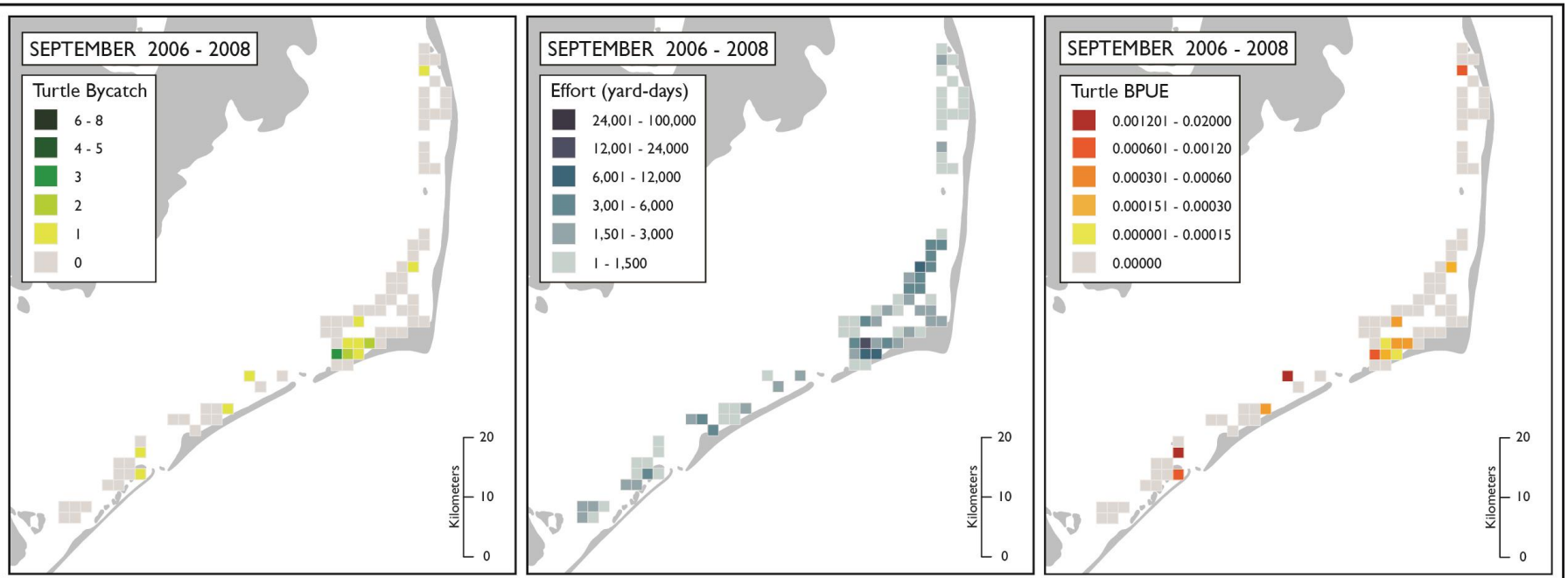


Figure 20. Sea turtle bycatch, fishing effort, and bycatch per unit effort recorded by DMF Program 466 observers during fall (September - December) 2003 - 2005.

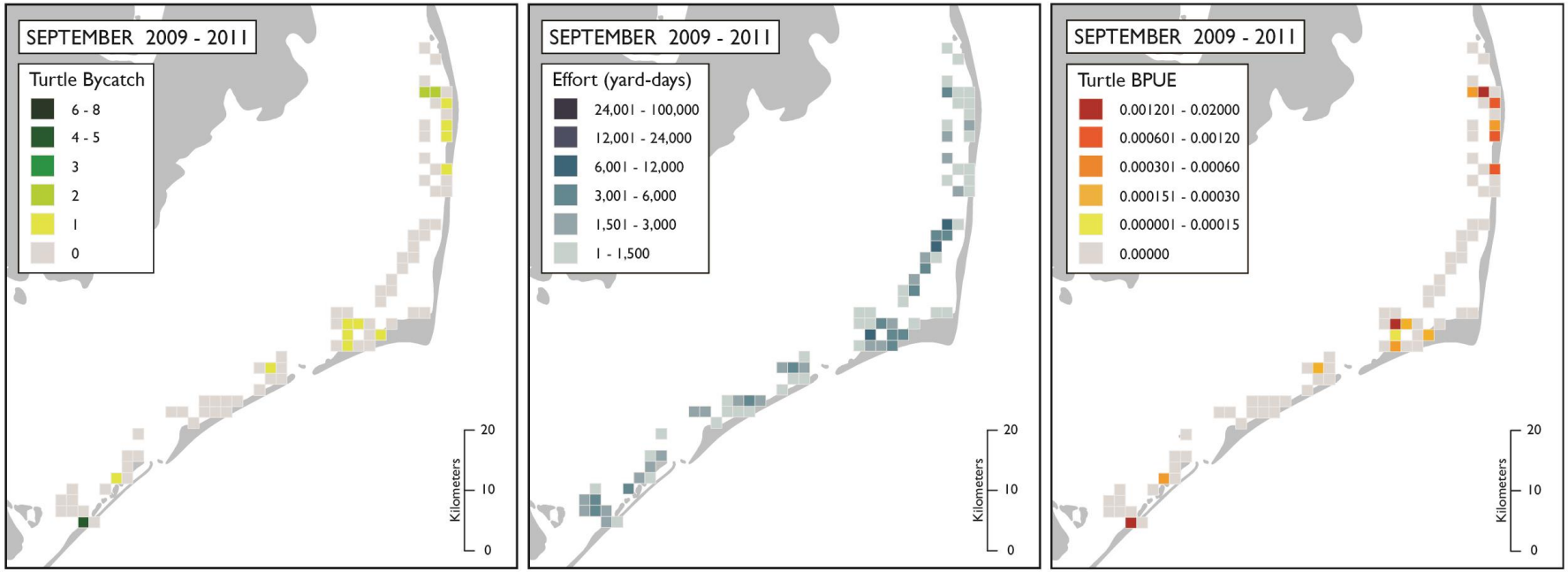


Figure 21. Sea turtle bycatch, fishing effort, and bycatch per unit effort recorded by DMF Program 466 observers during fall (September to December) 2003 - 2014.

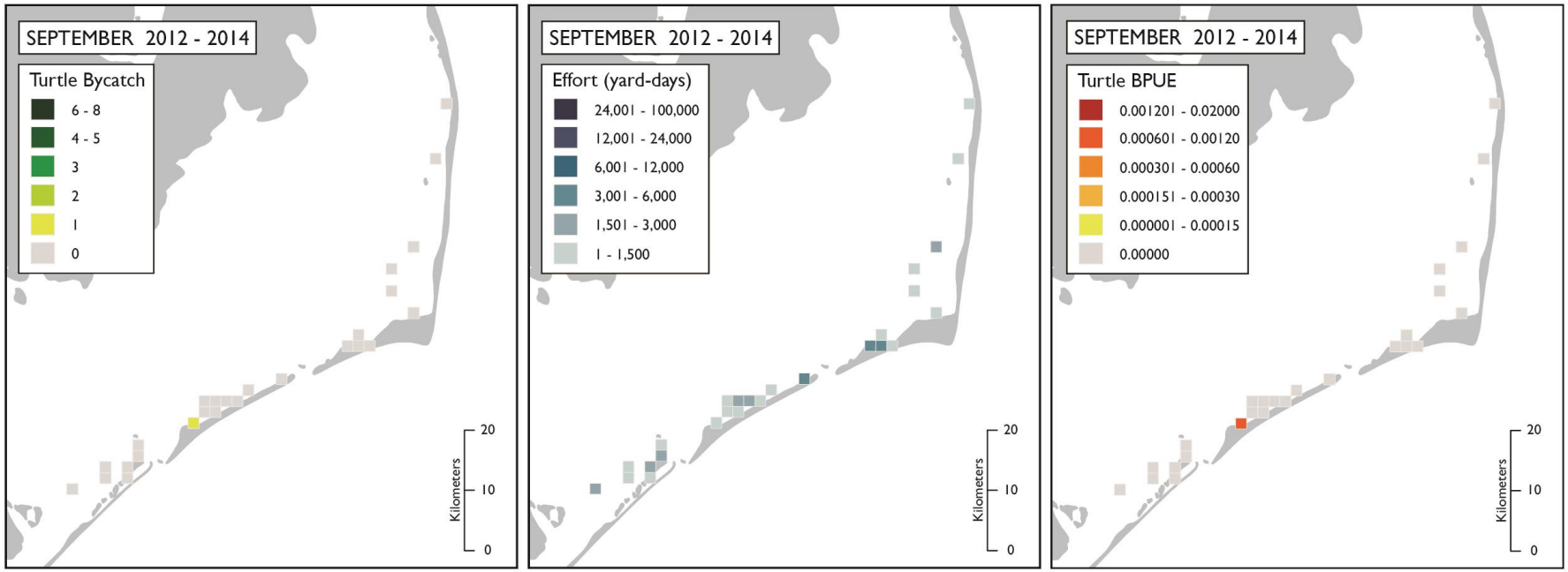


Figure 22. Sea turtle bycatch, fishing effort, and bycatch per unit effort recorded by DMF Program 466 observers during fall (September - December) 2003 - 2005.

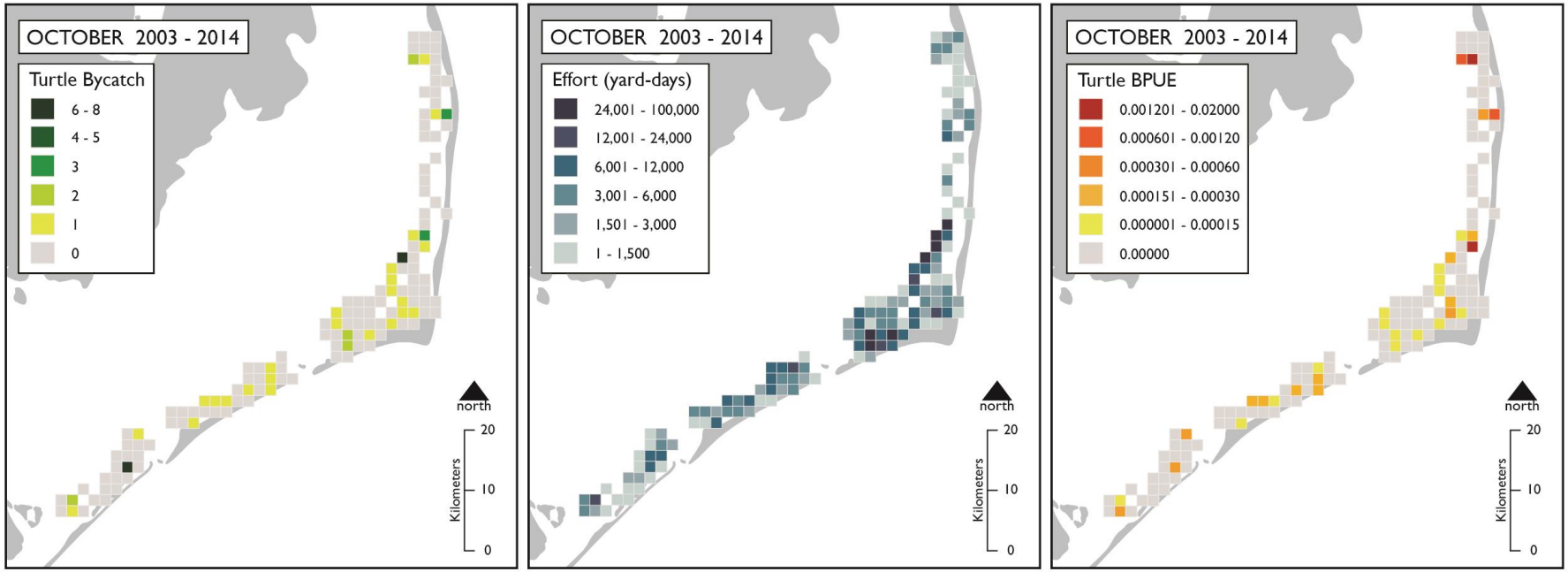


Figure 23. Sea turtle bycatch, fishing effort, and bycatch per unit effort recorded by DMF Program 466 observers during fall (September to December) 2003 - 2014.

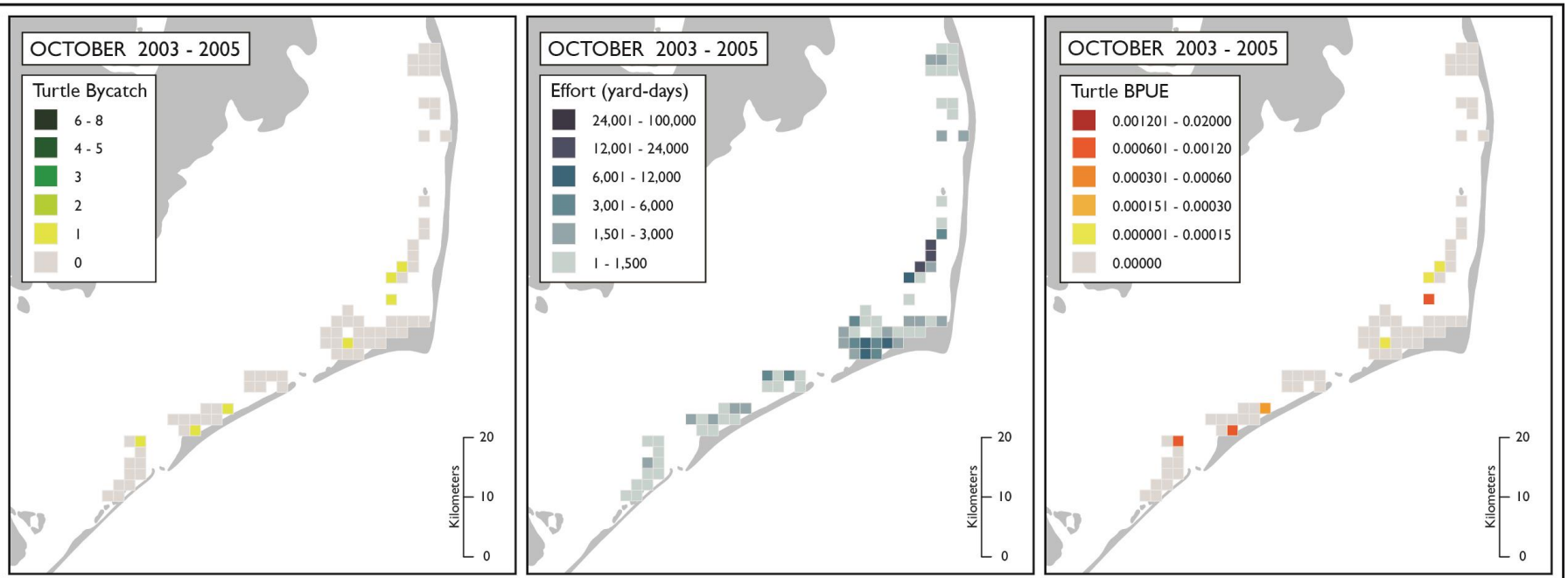


Figure 24. Sea turtle bycatch, fishing effort, and bycatch per unit effort recorded by DMF Program 466 observers during fall (September - December) 2003 - 2005.

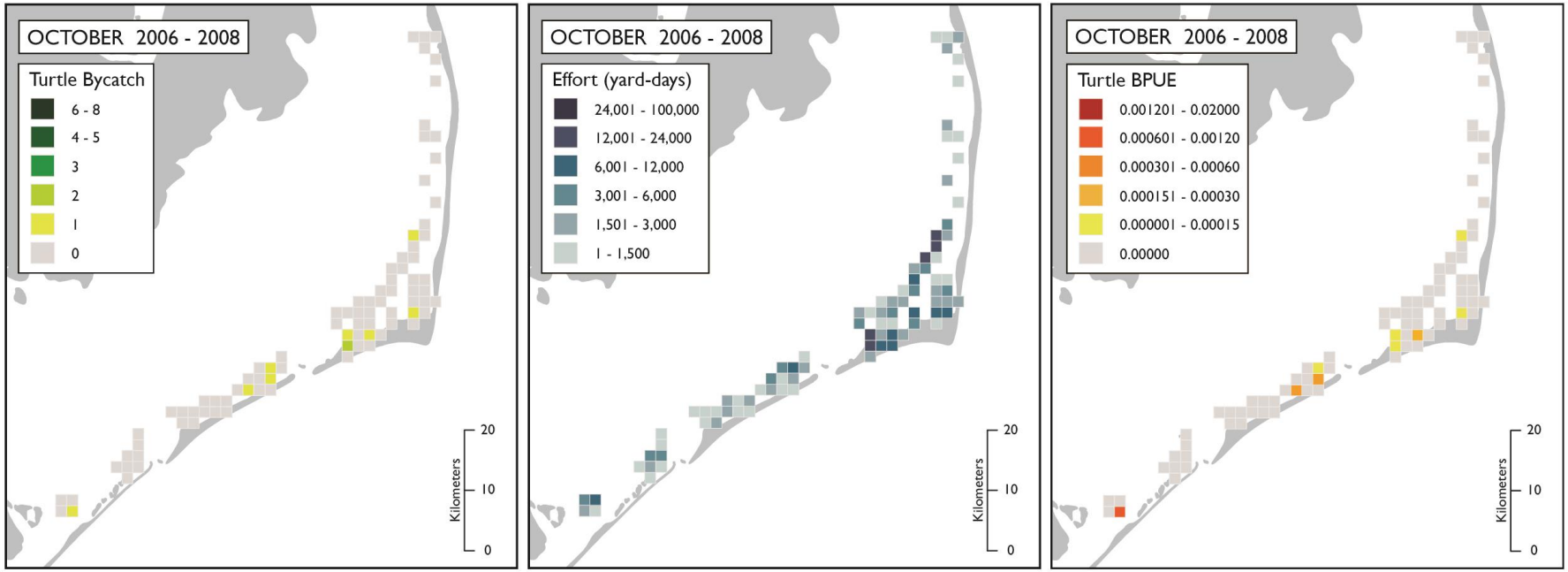


Figure 25. Sea turtle bycatch, fishing effort, and bycatch per unit effort recorded by DMF Program 466 observers during fall (September to December) 2003 - 2014.

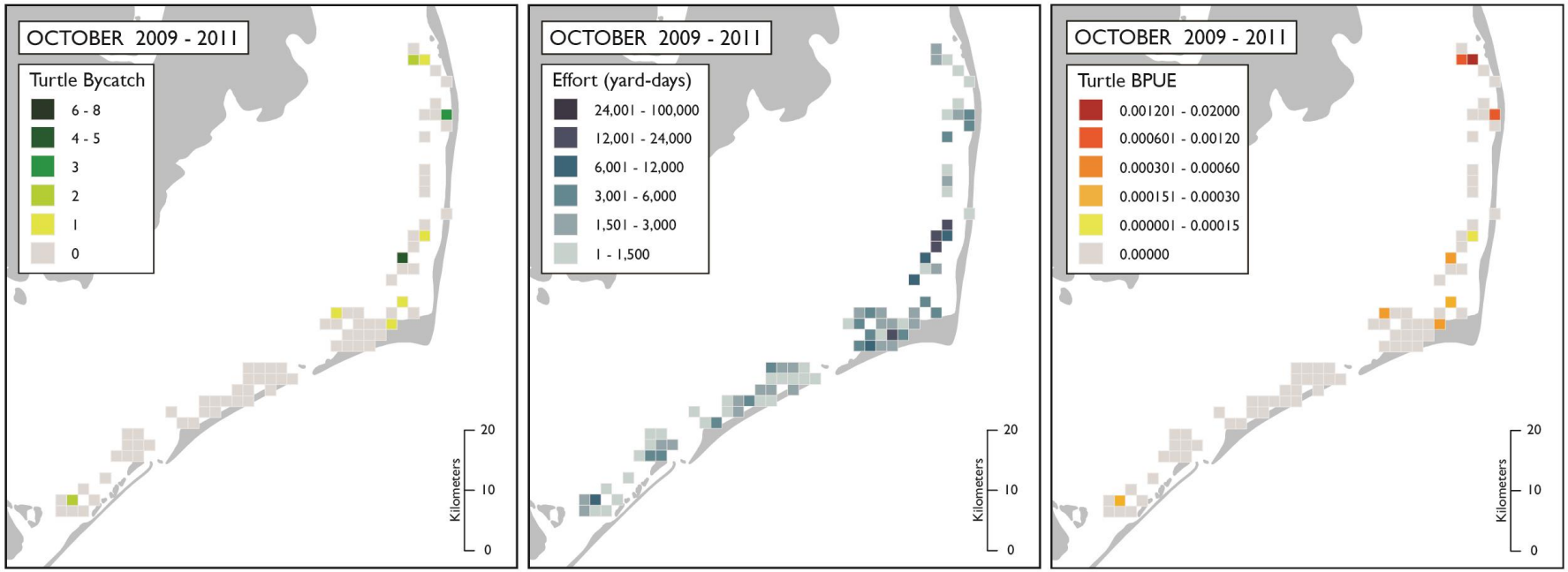


Figure 26. Sea turtle bycatch, fishing effort, and bycatch per unit effort recorded by DMF Program 466 observers during fall (September - December) 2003 - 2005.

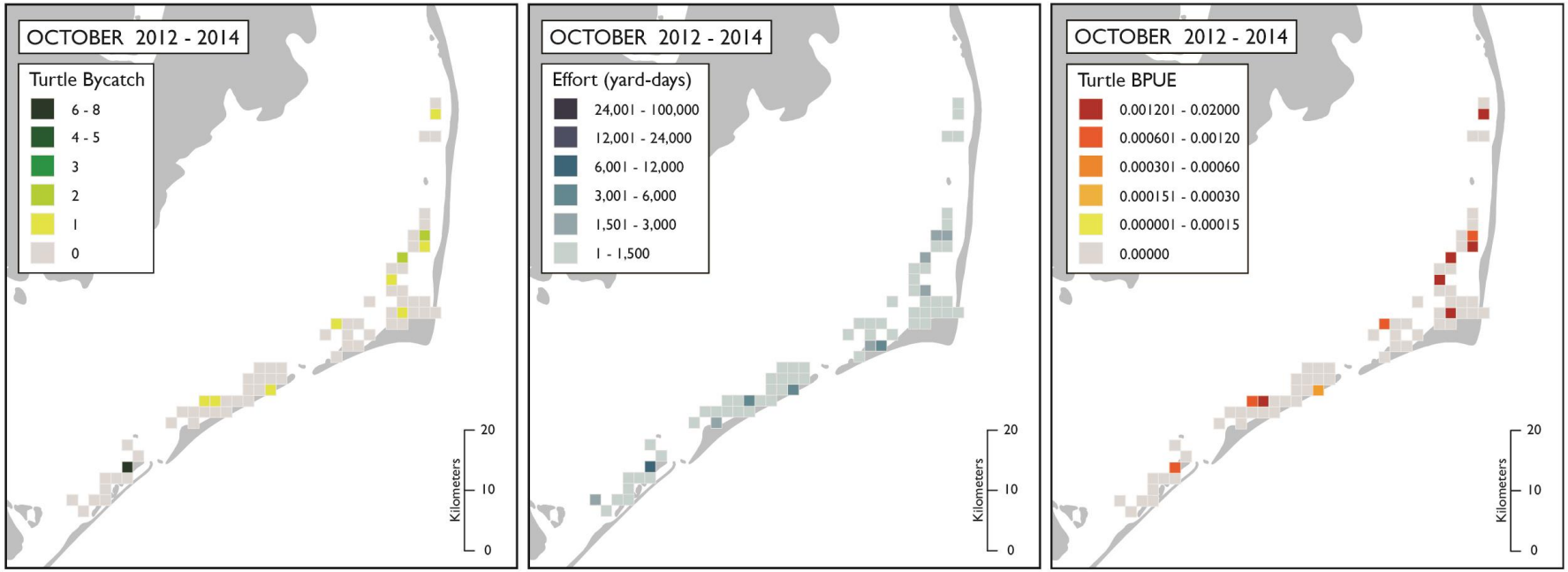


Figure 27. Sea turtle bycatch, fishing effort, and bycatch per unit effort recorded by DMF Program 466 observers during fall (September to December) 2003 - 2014.

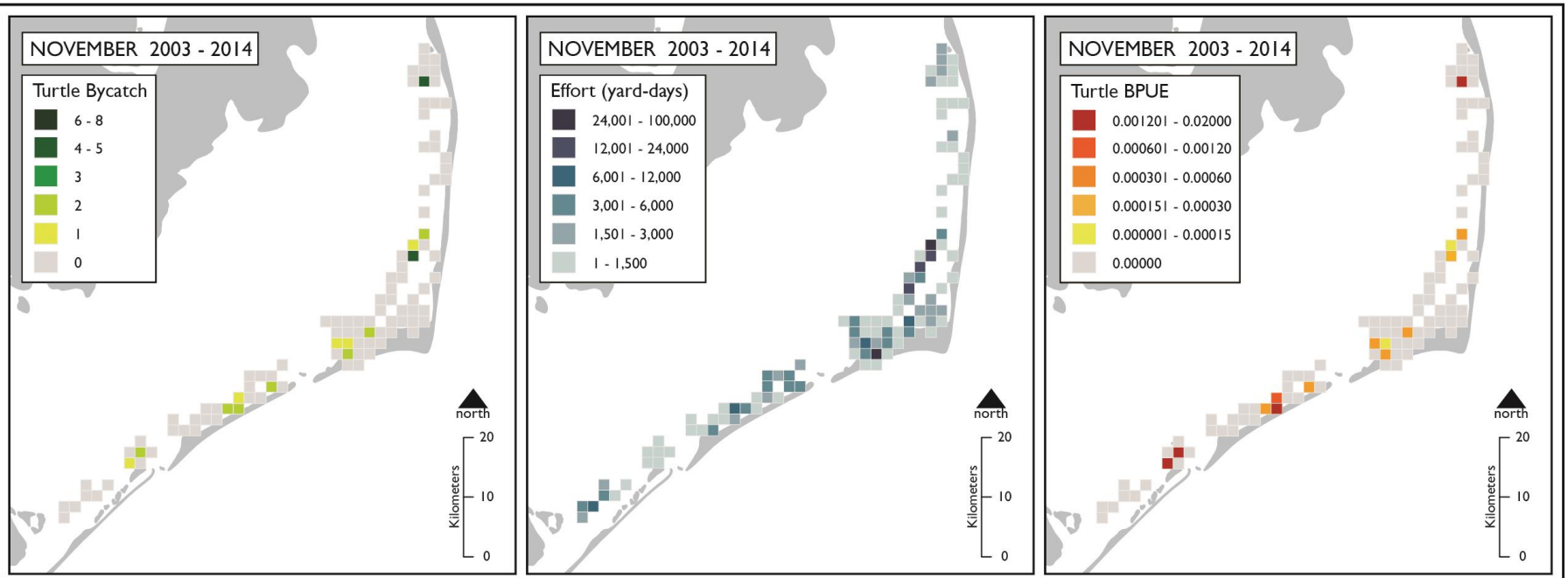


Figure 28. Sea turtle bycatch, fishing effort, and bycatch per unit effort recorded by DMF Program 466 observers during fall (September - December) 2003 - 2005.

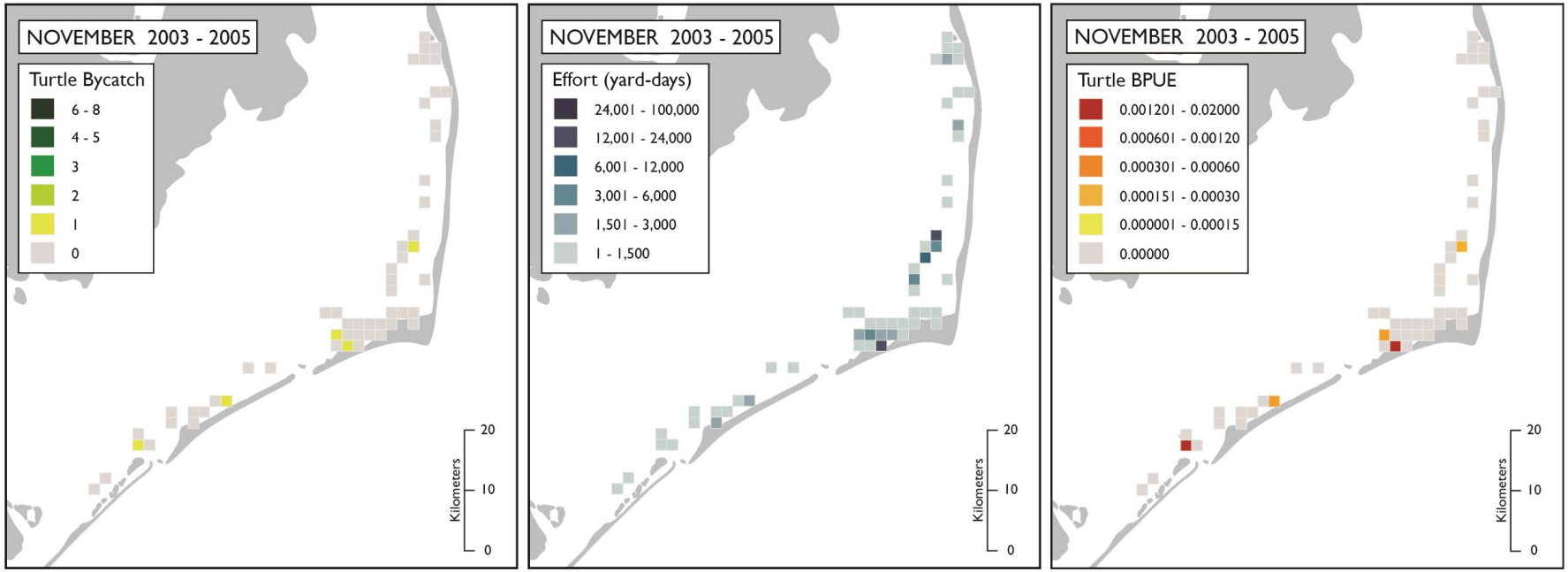


Figure 29. Sea turtle bycatch, fishing effort, and bycatch per unit effort recorded by DMF Program 466 observers during fall (September to December) 2003 - 2014.

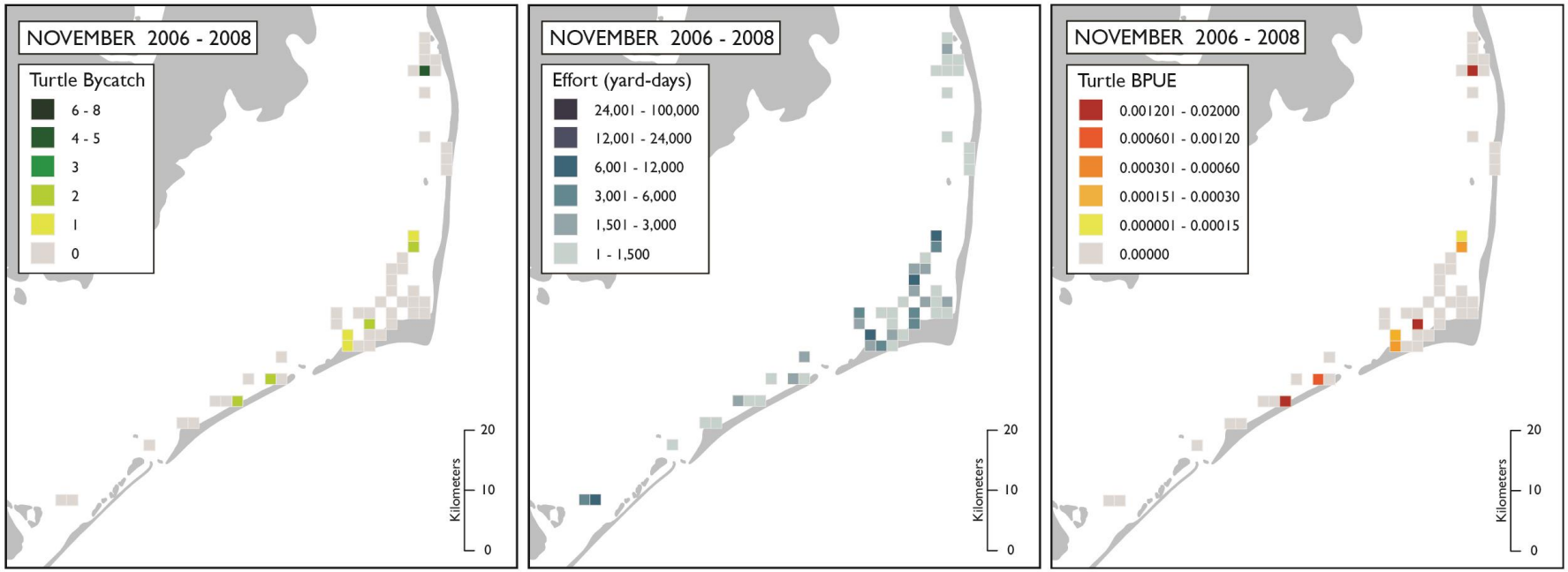


Figure 30. Sea turtle bycatch, fishing effort, and bycatch per unit effort recorded by DMF Program 466 observers during fall (September - December) 2003 - 2005.

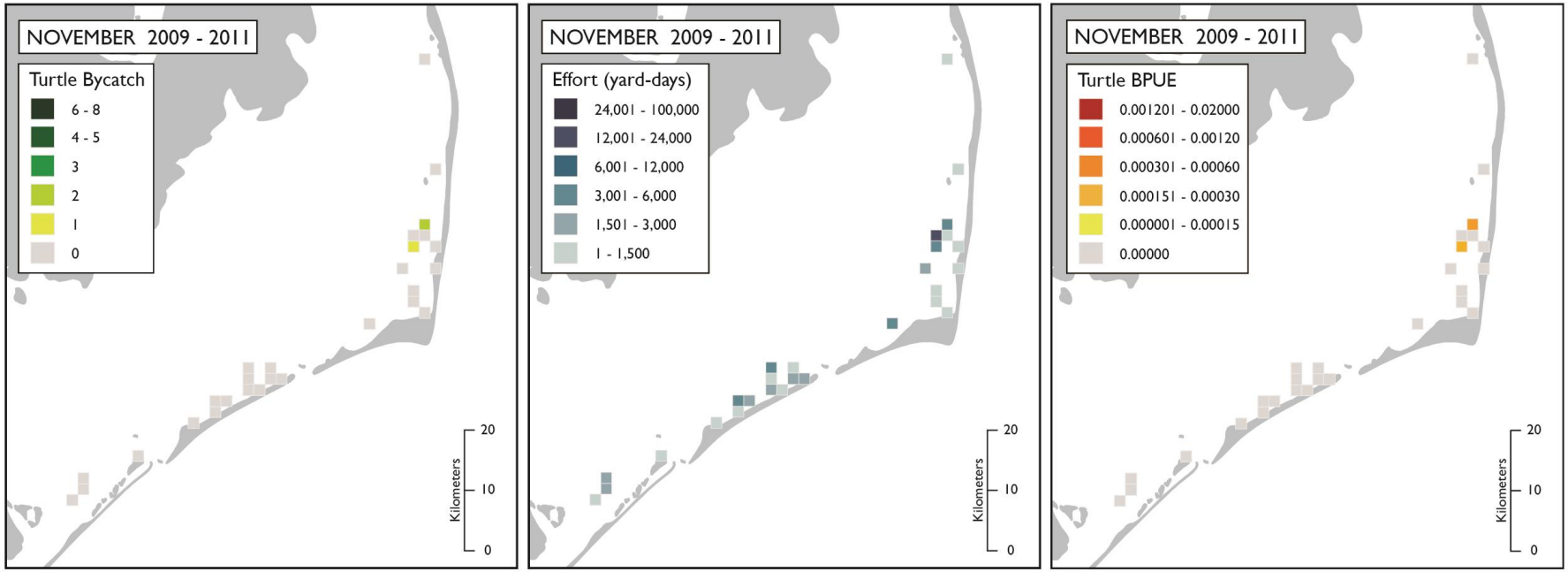


Figure 31. Sea turtle bycatch, fishing effort, and bycatch per unit effort recorded by DMF Program 466 observers during fall (September to December) 2003 - 2014.

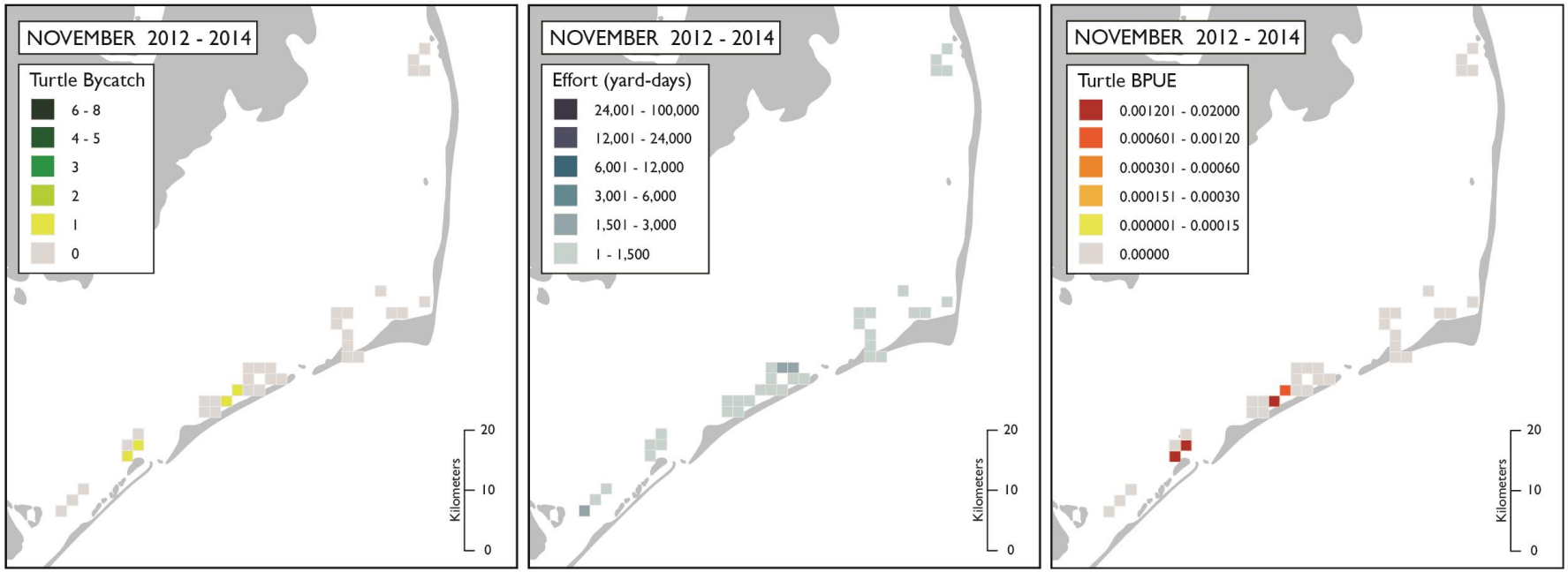


Figure 32. Sea turtle bycatch, fishing effort, and bycatch per unit effort recorded by DMF Program 466 observers during fall (September - December) 2003 - 2005.

SECTION 3

Proposed corridor expansion scenarios overlaid onto grid maps of sea turtle bycatch per unit effort and southern flounder bycatch per unit effort recorded by observers in Program 466 (2003 – 2014). Tables with the observed and predicted number of sea turtles and southern flounder caught under different effort redistribution and corridor expansion scenarios. See section 3.2B in the body of the report for more details on interpreting these tables.

Table 1. Corridor expansion scenario names, geographic markers, and coordinates.

Corridor	Scenario Name	Geographic Marker	Latitude	Longitude
Oregon Inlet Corridor	Oreg_Green	Green Point	35.597	-75.472
	Oreg_Great	Great Island	35.531	-75.482
	Oreg_Clarks	Clark's Bay	35.531	-75.482
Hatteras Corridor	Hatt_Durant	Durant Point	35.233	-75.681
	Hatt_JoeSaur	Joe Saur Creek	35.229	-75.639
	Hatt_Brooks	Brooks Point	35.269	-75.596
Ocracoke Corridor	Ocra_Portsmouth	Portsmouth Island/Evergreen Slough	35.069	-76.076
	Ocra_Royal	Royal Point	35.053	-76.088

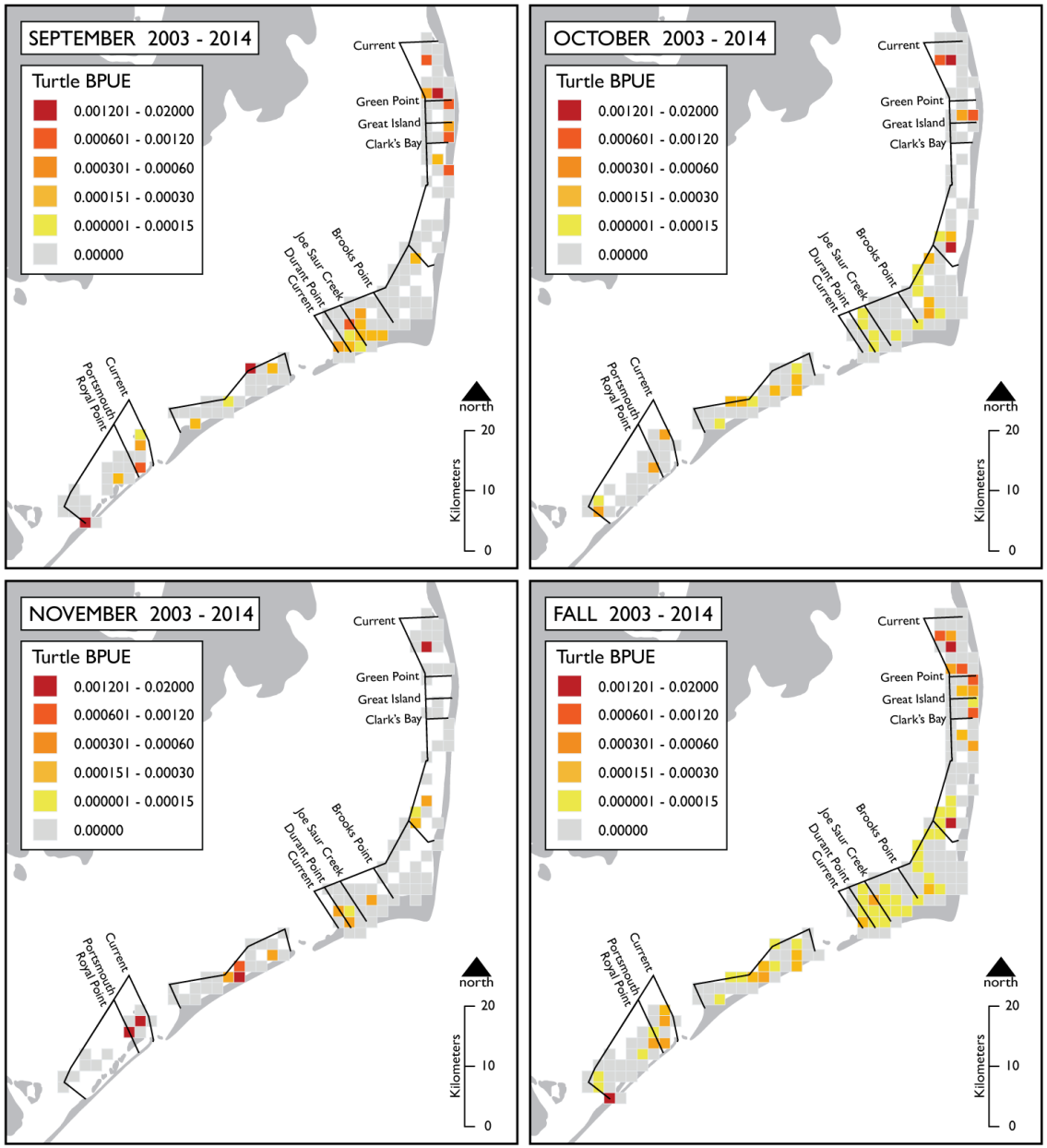


Figure 33. Proposed boundaries of expanded inlet corridors into Pamlico Sound overlaid on top of sea turtle catch per unit effort.

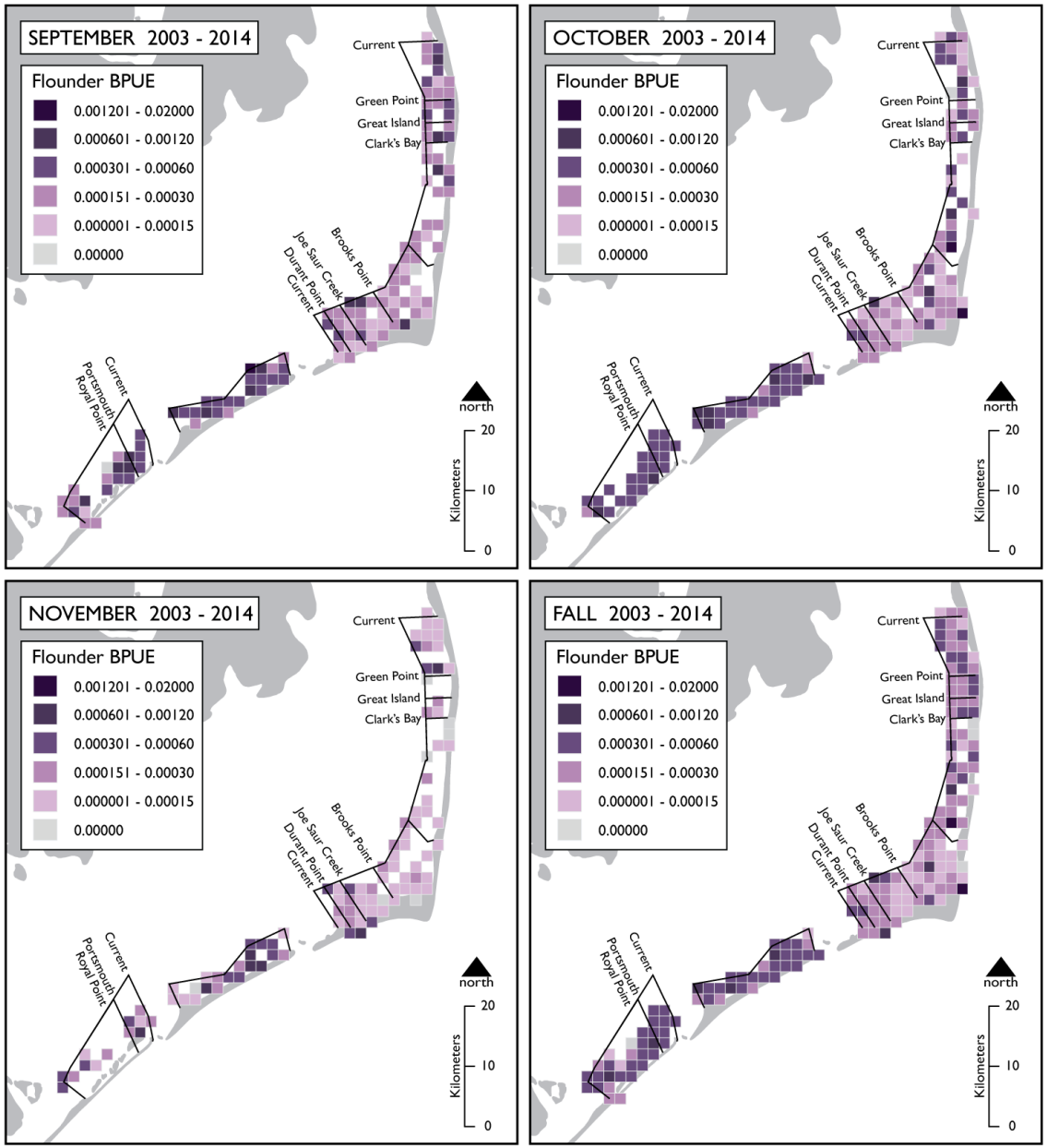


Figure 34. Proposed boundaries of expanded inlet corridors into Pamlico Sound overlaid on top of southern flounder catch per unit effort.

Table 2. Observed and predicted number of sea turtles caught during fall from 2003 - 2014 under different effort redistribution & corridor expansion scenarios in the Pamlico Sound Shallow Water Gillnet Restricted Areas.

FALL - SEA TURTLES	Corridor Expansion Scenarios	Scenario 0	Scenario 1	Scenario 2	Scenario 3	Scenario 4
		No corridor expansion (current scenario)	Effort not redistributed	Effort redistributed evenly	Effort redistributed based on previous distribution of effort	Effort redistributed based on distance to closed area boundary
	Oreg_Green	121	109	116	113	119
	Oreg_Great	121	104	112	108	108
	Oreg_Clarks	121	102	113	108	106
	Hatt_Durant	121	116	120	118	123
	Hatt_JoeSaur	121	99	127	114	131
	Hatt_Brooks	121	90	132	110	141
	Ocra_Portsmouth	121	113	116	118	115
	Ocra_Royal	121	108	111	114	109

Table 3. Percent change in the observed and predicted number of sea turtles caught during fall from 2003 - 2014 under different effort redistribution & corridor expansion scenarios in the Pamlico Sound Shallow Water Gillnet Restricted Areas.

FALL - SEA TURTLES	Corridor Expansion Scenarios	Scenario 0	Scenario 1	Scenario 2	Scenario 3	Scenario 4
		No corridor expansion (current scenario)	Effort not redistributed	Effort redistributed evenly	Effort redistributed based on previous distribution of effort	Effort redistributed based on distance to closed area boundary
	Oreg_Green	0%	-9.9%	-4.1%	-6.6%	-1.7%
	Oreg_Great	0%	-14.0%	-7.4%	-10.7%	-10.7%
	Oreg_Clarks	0%	-15.7%	-6.6%	-10.7%	-12.4%
	Hatt_Durant	0%	-4.1%	-0.8%	-2.5%	1.7%
	Hatt_JoeSaur	0%	-18.2%	5.0%	-5.8%	8.3%
	Hatt_Brooks	0%	-25.6%	9.1%	-9.1%	16.5%
	Ocra_Portsmouth	0%	-6.6%	-4.1%	-2.5%	-5.0%
	Ocra_Royal	0%	-10.7%	-8.3%	-5.8%	-9.9%

Table 4. Analysis of the efficiency of different corridor expansion scenarios under effort redistribution scenarios #3 & #4 during fall between 2003 - 2014 in the Pamlico Sound Shallow Water Gillnet Restricted Areas.

	Corridor Expansion Scenarios	Expansion Area (km^2)	Effort displaced (yard-days)	Reduction in the number of sea turtles caught		Ratio of sea turtles caught to area closed		Ratio of sea turtles caught to effort displaced		Ratio of sea turtles caught to change in flounder catch	
				Scenario 3	Scenario 4	Scenario 3	Scenario 4	Scenario 3	Scenario 4	Scenario 3	Scenario 4
FALL - SEA TURTLES	Oreg_Green	55	60425	8	2	0.15	0.04	0.00013	0.00003	0.07	0.08
	Oreg_Great	72	80837	13	13	0.18	0.18	0.00016	0.00016	0.08	0.12
	Oreg_Clarks	86	114651	13	15	0.15	0.17	0.00011	0.00013	0.04	0.01
	Hatt_Durant	13	40487	3	-2	0.22	-0.15	0.00007	-0.00005	0.00	0.00
	Hatt_JoeSaur	39	290730	7	-10	0.18	-0.26	0.00002	-0.00003	0.01	-0.05
	Hatt_Brooks	79	424954	11	-20	0.14	-0.25	0.00003	-0.00005	0.06	-0.04
	Ocra_Portsmouth	39	47210	3	6	0.08	0.15	0.00006	0.00013	0.13	0.01
	Ocra_Royal	53	71232	7	12	0.13	0.23	0.00010	0.00017	0.01	0.12

Table 5. Observed and predicted number of flounder caught during fall from 2003 - 2014 under different effort redistribution & corridor expansion scenarios in the Pamlico Sound Shallow Water Gillnet Restricted Areas.

FALL - FLOUNDER		Scenario 0	Scenario 1	Scenario 2	Scenario 3	Scenario 4
	Corridor Expansion Scenarios	**No corridor expansion (current scenario)**	**Effort not redistributed**	**Effort redistributed evenly**	**Effort redistributed based on previous distribution of effort**	**Effort redistributed based on distance to closed area boundary**
	Oreg_Green	52718	50843	52833	52598	52693
	Oreg_Great	52718	50219	52822	52558	52826
	Oreg_Clarks	52718	49117	52754	52372	51110
	Hatt_Durant	52718	51182	52205	52089	52234
	Hatt_JoeSaur	52718	45262	52619	51603	52516
	Hatt_Brooks	52718	42955	54199	52891	53217
	Ocra_Portsmouth	52718	50303	52947	52695	53594
	Ocra_Royal	52718	48451	52039	51649	52815

Table 6. Percent change in the observed and predicted number of flounder caught during fall from 2003 - 2014 under different effort redistribution & corridor expansion scenarios in the Pamlico Sound Shallow Water Gillnet Restricted Areas.

FALL - FLOUNDER	Corridor Expansion Scenarios	Scenario 0	Scenario 1	Scenario 2	Scenario 3	Scenario 4
		No Closure (current scenario)	Effort not redistributed	Effort redistributed evenly	Effort redistributed based on previous distribution of effort	Effort redistributed based on distance to closed area boundary
	Oreg_Green	0%	-3.6%	0.2%	-0.2%	0.0%
	Oreg_Great	0%	-4.7%	0.2%	-0.3%	0.2%
	Oreg_Clarks	0%	-6.8%	0.1%	-0.7%	-3.1%
	Hatt_Durant	0%	-2.9%	-1.0%	-1.2%	-0.9%
	Hatt_JoeSaur	0%	-14.1%	-0.2%	-2.1%	-0.4%
	Hatt_Brooks	0%	-18.5%	2.8%	0.3%	0.9%
	Ocra_Portsmouth	0%	-4.6%	0.4%	0.0%	1.7%
	Ocra_Royal	0%	-8.1%	-1.3%	-2.0%	0.2%

Table 7. Observed and predicted number of sea turtles caught during September from 2003 - 2014 under different effort redistribution & corridor expansion scenarios in the Pamlico Sound Shallow Water Gillnet Restricted Areas.

SEPTEMBER - SEA TURTLES	Corridor Expansion Scenarios	Scenario 0	Scenario 1	Scenario 2	Scenario 3	Scenario 4
		No corridor expansion (current scenario)	Effort not redistributed	Effort redistributed evenly	Effort redistributed based on previous distribution of effort	Effort redistributed based on distance to closed area boundary
	Oreg_Green	42	37	38	38	39
	Oreg_Great	42	36	38	38	39
	Oreg_Clarks	42	34	35	35	36
	Hatt_Durant	42	38	39	39	41
	Hatt_JoeSaur	42	30	36	34	53
	Hatt_Brooks	42	24	26	25	24
	Ocra_Portsmouth	42	39	40	41	39
	Ocra_Royal	42	39	41	43	39

Table 8. Percent change in the observed and predicted number of sea turtles caught during September from 2003 - 2014 under different effort redistribution & corridor expansion scenarios in the Pamlico Sound Shallow Water Gillnet Restricted Areas.

SEPTEMBER - SEA TURTLES		Scenario 0	Scenario 1	Scenario 2	Scenario 3	Scenario 4
	Corridor Expansion Scenarios	**No corridor expansion (current scenario)**	**Effort not redistributed**	**Effort redistributed evenly**	**Effort redistributed based on previous distribution of effort**	**Effort redistributed based on distance to closed area boundary**
	Oreg_Green	0%	-11.9%	-9.5%	-9.5%	-7.1%
	Oreg_Great	0%	-14.3%	-9.5%	-9.5%	-7.1%
	Oreg_Clarks	0%	-19.0%	-16.7%	-16.7%	-14.3%
	Hatt_Durant	0%	-9.5%	-7.1%	-7.1%	-2.4%
	Hatt_JoeSaur	0%	-28.6%	-14.3%	-19.0%	26.2%
	Hatt_Brooks	0%	-42.9%	-38.1%	-40.5%	-42.9%
	Ocra_Portsmouth	0%	-7.1%	-4.8%	-2.4%	-7.1%
	Ocra_Royal	0%	-7.1%	-2.4%	2.4%	-7.1%

Table 9. Analysis of the efficiency of different corridor expansion scenarios under effort redistribution scenarios #3 & #4 during September between 2003 - 2014 in the Pamlico Sound Shallow Water Gillnet Restricted Areas.

SEPTEMBER - SEA TURTLES	Corridor Expansion Scenarios	Expansion Area (km^2)	Effort displaced (yard-days)	Reduction in the number of sea turtles caught		Ratio of sea turtles caught to area closed		Ratio of sea turtles caught to effort displaced		Ratio of sea turtles caught to change in flounder catch	
				Scenario 3	Scenario 4	Scenario 3	Scenario 4	Scenario 3	Scenario 4	Scenario 3	Scenario 4
	Oreg_Green	55	21760	4	3	0.07	0.05	0.00018	0.00014	0.08	0.02
	Oreg_Great	72	30872	4	3	0.06	0.04	0.00013	0.00010	0.03	0.03
	Oreg_Clarks	86	42316	7	6	0.08	0.07	0.00017	0.00014	0.02	0.01
	Hatt_Durant	13	15642	3	1	0.22	0.07	0.00019	0.00006	0.02	0.01
	Hatt_JoeSaur	39	94483	8	-11	0.21	-0.28	0.00008	-0.00012	0.10	-0.03
	Hatt_Brooks	79	130380	17	18	0.21	0.23	0.00013	0.00014	0.18	0.05
	Ocra_Portsmouth	39	18651	1	3	0.03	0.08	0.00005	0.00016	0.01	0.01
	Ocra_Royal	53	26613	-1	3	-0.02	0.06	-0.00004	0.00011	0.00	0.02

Table 10. Observed and predicted number of flounder caught during September from 2003 - 2014 under different effort redistribution & corridor expansion scenarios in the Pamlico Sound Shallow Water Gillnet Restricted Areas.

SEPTEMBER - FLOUNDER		Scenario 0	Scenario 1	Scenario 2	Scenario 3	Scenario 4
	Corridor Expansion Scenarios	**No corridor expansion (current scenario)**	**Effort not redistributed**	**Effort redistributed evenly**	**Effort redistributed based on previous distribution of effort**	**Effort redistributed based on distance to closed area boundary**
	Oreg_Green	17132	16457	17249	17079	17263
	Oreg_Great	17132	16123	17145	16977	17220
	Oreg_Clarks	17132	15691	16989	16790	16451
	Hatt_Durant	17132	16588	16983	16948	16961
	Hatt_JoeSaur	17132	14937	17496	17216	17466
	Hatt_Brooks	17132	14077	17536	17229	17483
	Ocra_Portsmouth	17132	16085	17110	16976	17663
	Ocra_Royal	17132	15336	16553	16386	16952

Table 11. Percent change in the observed and predicted number of flounder caught during September from 2003 - 2014 under different effort redistribution & corridor expansion scenarios in the Pamlico Sound Shallow Water Gillnet Restricted Areas.

SEPTEMBER - FLOUNDER		Scenario 0	Scenario 1	Scenario 2	Scenario 3	Scenario 4
	Corridor Expansion Scenarios	**No Closure (current scenario)**	**Effort not redistributed**	**Effort redistributed evenly**	**Effort redistributed based on previous distribution of effort**	**Effort redistributed based on distance to closed area boundary**
	Oreg_Green	0%	-3.9%	0.7%	-0.3%	0.8%
	Oreg_Great	0%	-5.9%	0.1%	-0.9%	0.5%
	Oreg_Clarks	0%	-8.4%	-0.8%	-2.0%	-4.0%
	Hatt_Durant	0%	-3.2%	-0.9%	-1.1%	-1.0%
	Hatt_JoeSaur	0%	-12.8%	2.1%	0.5%	1.9%
	Hatt_Brooks	0%	-17.8%	2.4%	0.6%	2.0%
	Ocra_Portsmouth	0%	-6.1%	-0.1%	-0.9%	3.1%
	Ocra_Royal	0%	-10.5%	-3.4%	-4.4%	-1.1%

Table 12. Observed and predicted number of sea turtles caught during October from 2003 - 2014 under different effort redistribution & corridor expansion scenarios in the Pamlico Sound Shallow Water Gillnet Restricted Areas.

OCTOBER - SEA TURTLES	Corridor Expansion Scenarios	Scenario 0	Scenario 1	Scenario 2	Scenario 3	Scenario 4
		No corridor expansion (current scenario)	Effort not redistributed	Effort redistributed evenly	Effort redistributed based on previous distribution of effort	Effort redistributed based on distance to closed area boundary
	Oreg_Green	52	49	53	51	59
	Oreg_Great	52	45	50	46	45
	Oreg_Clarks	52	45	53	47	45
	Hatt_Durant	52	51	54	52	54
	Hatt_JoeSaur	52	46	65	54	49
	Hatt_Brooks	52	45	83	61	90
	Ocra_Portsmouth	52	50	52	53	51
	Ocra_Royal	52	45	47	48	45

Table 13. Percent change in the observed and predicted number of sea turtles caught during October from 2003 - 2014 under different effort redistribution & corridor expansion scenarios in the Pamlico Sound Shallow Water Gillnet Restricted Areas.

OCTOBER - SEA TURTLES	Corridor Expansion Scenarios	Scenario 0	Scenario 1	Scenario 2	Scenario 3	Scenario 4
		No corridor expansion (current scenario)	Effort not redistributed	Effort redistributed evenly	Effort redistributed based on previous distribution of effort	Effort redistributed based on distance to closed area boundary
	Oreg_Green	0%	-5.8%	1.9%	-1.9%	13.5%
	Oreg_Great	0%	-13.5%	-3.8%	-11.5%	-13.5%
	Oreg_Clarks	0%	-13.5%	1.9%	-9.6%	-13.5%
	Hatt_Durant	0%	-1.9%	3.8%	0.0%	3.8%
	Hatt_JoeSaur	0%	-11.5%	25.0%	3.8%	-5.8%
	Hatt_Brooks	0%	-13.5%	59.6%	17.3%	73.1%
	Ocra_Portsmouth	0%	-3.8%	0.0%	1.9%	-1.9%
	Ocra_Royal	0%	-13.5%	-9.6%	-7.7%	-13.5%

Table 14. Analysis of the efficiency of different corridor expansion scenarios under effort redistribution scenarios #3 & #4 during October between 2003 - 2014 in the Pamlico Sound Shallow Water Gillnet Restricted Areas.

OCTOBER - SEA TURTLES	Corridor Expansion Scenarios	Expansion Area (km^2)	Effort displaced (yard-days)	Reduction in the number of sea turtles caught		Ratio of sea turtles caught to area closed		Ratio of sea turtles caught to effort displaced		Ratio of sea turtles caught to change in flounder catch	
				Scenario 3	Scenario 4	Scenario 3	Scenario 4	Scenario 3	Scenario 4	Scenario 3	Scenario 4
	Oreg_Green	55	25820	1	-7	0.02	-0.13	0.00004	-0.00027	0.03	-0.03
	Oreg_Great	72	34732	6	7	0.08	0.10	0.00017	0.00020	1.20	0.05
	Oreg_Clarks	86	53502	5	7	0.06	0.08	0.00009	0.00013	0.04	0.06
	Hatt_Durant	13	22367	0	-2	0.00	-0.15	0.00000	-0.00009	0.00	-0.01
	Hatt_JoeSaur	39	139822	-2	3	-0.05	0.08	-0.00001	0.00002	0.00	0.01
	Hatt_Brooks	79	213436	-9	-38	-0.11	-0.48	-0.00004	-0.00018	-0.01	-0.04
	Ocra_Portsmouth	39	23160	-1	1	-0.03	0.03	-0.00004	0.00004	0.00	0.00
	Ocra_Royal	53	39218	4	7	0.08	0.13	0.00010	0.00018	0.13	0.03

Table 15. Observed and predicted number of flounder caught during October from 2003 - 2014 under different effort redistribution & corridor expansion scenarios in the Pamlico Sound Shallow Water Gillnet Restricted Areas.

OCTOBER - FLOUNDER	Corridor Expansion Scenarios	Scenario 0	Scenario 1	Scenario 2	Scenario 3	Scenario 4
		No corridor expansion (current scenario)	Effort not redistributed	Effort redistributed evenly	Effort redistributed based on previous distribution of effort	Effort redistributed based on distance to closed area boundary
	Oreg_Green	28734	27809	28754	28699	28469
	Oreg_Great	28734	27525	28821	28729	28579
	Oreg_Clarks	28734	26966	29013	28864	28607
	Hatt_Durant	28734	27777	28427	28348	28389
	Hatt_JoeSaur	28734	24623	28689	28114	28283
	Hatt_Brooks	28734	23387	30211	29359	29686
	Ocra_Portsmouth	28734	27595	28975	28980	29057
	Ocra_Royal	28734	26492	28759	28703	28968

Table 16. Percent change in the observed and predicted number of flounder caught during October from 2003 - 2014 under different effort redistribution & corridor expansion scenarios in the Pamlico Sound Shallow Water Gillnet Restricted Areas.

OCTOBER - FLOUNDER		Scenario 0	Scenario 1	Scenario 2	Scenario 3	Scenario 4
	Corridor Expansion Scenarios	**No Closure (current scenario)**	**Effort not redistributed**	**Effort redistributed evenly**	**Effort redistributed based on previous distribution of effort**	**Effort redistributed based on distance to closed area boundary**
	Oreg_Green	0%	-3.2%	0.1%	-0.1%	-0.9%
	Oreg_Great	0%	-4.2%	0.3%	0.0%	-0.5%
	Oreg_Clarks	0%	-6.2%	1.0%	0.5%	-0.4%
	Hatt_Durant	0%	-3.3%	-1.1%	-1.3%	-1.2%
	Hatt_JoeSaur	0%	-14.3%	-0.2%	-2.2%	-1.6%
	Hatt_Brooks	0%	-18.6%	5.1%	2.2%	3.3%
	Ocra_Portsmouth	0%	-4.0%	0.8%	0.9%	1.1%
	Ocra_Royal	0%	-7.8%	0.1%	-0.1%	0.8%

Table 17. Observed and predicted number of sea turtles caught during November from 2003 - 2014 under different effort redistribution & corridor expansion scenarios in the Pamlico Sound Shallow Water Gillnet Restricted Areas.

NOVEMBER - SEA TURTLES	Corridor Expansion Scenarios	Scenario 0	Scenario 1	Scenario 2	Scenario 3	Scenario 4
		No corridor expansion (current scenario)	Effort not redistributed	Effort redistributed evenly	Effort redistributed based on previous distribution of effort	Effort redistributed based on distance to closed area boundary
	Oreg_Green	27	23	24	24	23
	Oreg_Great	27	23	24	24	23
	Oreg_Clarks	27	23	24	24	23
	Hatt_Durant	27	27	27	27	27
	Hatt_JoeSaur	27	23	26	26	25
	Hatt_Brooks	27	21	24	24	21
	Ocra_Portsmouth	27	24	24	24	24
	Ocra_Royal	27	24	24	24	24

Table 18. Percent change in the observed and predicted number of sea turtles caught during November from 2003 - 2014 under different effort redistribution & corridor expansion scenarios in the Pamlico Sound Shallow Water Gillnet Restricted Areas.

NOVEMBER - SEA TURTLES		Scenario 0	Scenario 1	Scenario 2	Scenario 3	Scenario 4
	Corridor Expansion Scenarios	**No corridor expansion (current scenario)**	**Effort not redistributed**	**Effort redistributed evenly**	**Effort redistributed based on previous distribution of effort**	**Effort redistributed based on distance to closed area boundary**
	Oreg_Green	0%	-14.8%	-11.1%	-11.1%	-14.8%
	Oreg_Great	0%	-14.8%	-11.1%	-11.1%	-14.8%
	Oreg_Clarks	0%	-14.8%	-11.1%	-11.1%	-14.8%
	Hatt_Durant	0%	0.0%	0.0%	0.0%	0.0%
	Hatt_JoeSaur	0%	-14.8%	-3.7%	-3.7%	-7.4%
	Hatt_Brooks	0%	-22.2%	-11.1%	-11.1%	-22.2%
	Ocra_Portsmouth	0%	-11.1%	-11.1%	-11.1%	-11.1%
	Ocra_Royal	0%	-11.1%	-11.1%	-11.1%	-11.1%

Table 14. Analysis of the efficiency of different corridor expansion scenarios under effort redistribution scenarios #3 & #4 during October between 2003 - 2014 in the Pamlico Sound Shallow Water Gillnet Restricted Areas.

	Corridor Expansion Scenarios	Expansion Area (km^2)	Effort displaced (yard-days)	Reduction in the number of sea turtles caught		Ratio of sea turtles caught to area closed		Ratio of sea turtles caught to effort displaced		Ratio of sea turtles caught to change in flounder catch	
				Scenario 3	Scenario 4	Scenario 3	Scenario 4	Scenario 3	Scenario 4	Scenario 3	Scenario 4
OCTOBER - SEA TURTLES	Oreg_Green	55	25820	1	-7	0.02	-0.13	0.00004	-0.00027	0.03	-0.03
	Oreg_Great	72	34732	6	7	0.08	0.10	0.00017	0.00020	1.20	0.05
	Oreg_Clarks	86	53502	5	7	0.06	0.08	0.00009	0.00013	0.04	0.06
	Hatt_Durant	13	22367	0	-2	0.00	-0.15	0.00000	-0.00009	0.00	-0.01
	Hatt_JoeSaur	39	139822	-2	3	-0.05	0.08	-0.00001	0.00002	0.00	0.01
	Hatt_Brooks	79	213436	-9	-38	-0.11	-0.48	-0.00004	-0.00018	-0.01	-0.04
	Ocra_Portsmouth	39	23160	-1	1	-0.03	0.03	-0.00004	0.00004	0.00	0.00
	Ocra_Royal	53	39218	4	7	0.08	0.13	0.00010	0.00018	0.13	0.03

Table 20. Observed and predicted number of flounder caught during November from 2003 - 2014 under different effort redistribution & corridor expansion scenarios in the Pamlico Sound Shallow Water Gillnet Restricted Areas.

NOVEMBER - FLOUNDER		Scenario 0	Scenario 1	Scenario 2	Scenario 3	Scenario 4
	Corridor Expansion Scenarios	**No corridor expansion (current scenario)**	**Effort not redistributed**	**Effort redistributed evenly**	**Effort redistributed based on previous distribution of effort**	**Effort redistributed based on distance to closed area boundary**
	Oreg_Green	6829	6554	6786	6766	6579
	Oreg_Great	6829	6554	6794	6770	6792
	Oreg_Clarks	6829	6443	6745	6701	6472
	Hatt_Durant	6829	6794	6835	6832	6860
	Hatt_JoeSaur	6829	5679	6480	6365	6569
	Hatt_Brooks	6829	5473	6566	6384	6237
	Ocra_Portsmouth	6829	6600	6832	6790	6800
	Ocra_Royal	6829	6600	6832	6790	6793

Table 21. Percent change in the observed and predicted number of flounder caught during November from 2003 - 2014 under different effort redistribution & corridor expansion scenarios in the Pamlico Sound Shallow Water Gillnet Restricted Areas.

NOVEMBER - FLOUNDER		Scenario 0	Scenario 1	Scenario 2	Scenario 3	Scenario 4
	Corridor Expansion Scenarios	**No Closure (current scenario)**	**Effort not redistributed**	**Effort redistributed evenly**	**Effort redistributed based on previous distribution of effort**	**Effort redistributed based on distance to closed area boundary**
	Oreg_Green	0%	-4.0%	-0.6%	-0.9%	-3.7%
	Oreg_Great	0%	-4.0%	-0.5%	-0.9%	-0.5%
	Oreg_Clarks	0%	-5.7%	-1.2%	-1.9%	-5.2%
	Hatt_Durant	0%	-0.5%	0.1%	0.0%	0.5%
	Hatt_JoeSaur	0%	-16.8%	-5.1%	-6.8%	-3.8%
	Hatt_Brooks	0%	-19.9%	-3.9%	-6.5%	-8.7%
	Ocra_Portsmouth	0%	-3.4%	0.0%	-0.6%	-0.4%
	Ocra_Royal	0%	-3.4%	0.0%	-0.6%	-0.5%