An Assessment of Fisheries Species to Inform Time-of-Year Restrictions for North Carolina and South Carolina

National Centers for Coastal Ocean Science
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About this document

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For more information about this report and other available resources, please contact Kenneth Riley, Ph.D. at ken.riley@noaa.gov or visit https://coastalscience.noaa.gov/research/marine-spatial-ecology/.

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Executive Summary

Environmental windows or moratoria are used by federal and state regulators in resource management to temporarily reduce adverse environmental impacts associated with coastal development. Moratoria are seasonal restrictions on construction activities to protect migrations of fish, sensitive life stages of aquatic organisms, and threatened and endangered species. Broad categories of coastal development activities that may benefit from application of moratoria include, but are not limited to: pile driving, mining, dredging, fill, water impoundment, energy development, transportation infrastructure, water diversions, and sedimentation. A prominent concern among many is that the use of moratoria as a management tool can have significant cost implications (e.g., restricted work periods, prolonged projects) for the United States Army Corps of Engineers (USACE), Federal Highway Administration (FHA), private contractors, and state and local sponsors. This report responds to a vital need to use the best available science to inform environmental policies and standardize regulations for moratoria.

This publication provides a review of the life history and spatiotemporal distribution of 13 managed fish and crustacean species to protect associated fisheries and habitats and minimize negative impacts of coastal development. The life history reviews include recent biological data and distribution information. This report and associated data products (maps, infographics) are intended to help coastal managers make timely decisions regarding authorization of coastal development activities. The report can help normalize environmental reviews and mitigation of impacts to federally managed species, essential fish habitat (EFH), Endangered Species Act-listed species and their associated critical habitats. The NOAA National Marine Fisheries Service (NMFS) may use information in this document when developing conservation recommendations for specific actions to protect EFH under Section 305(b)(4)(A) of the Magnuson-Stevens Fishery Conservation and Management Act (MSA). The MSA also requires federal agencies to consult with the NMFS on all actions or proposed actions that are permitted, funded, or undertaken by the agency that may adversely affect EFH. Additionally, spatiotemporal information contained within this report may be used directly in environmental review and preparation of documents to satisfy the National Environmental Policy Act (NEPA).

It is our intention that the data used as a basis for this publication can bolster confidence among federal and state decision-makers for implementing meaningful and consistent moratoria while issuing permits for coastal development. The Sections and Appendix are organized in a logical sequence intended to provide: (1) an overview of coastal development activities and potential impacts to aquatic species, (2) review of environmental windows and construction moratoria, (3) complete life history reviews for estuarine-dependent species of finfish and crustaceans, and (4) management guidance for setting, managing, and monitoring moratoria in North Carolina and South Carolina.

NOAA provides this publication to inform decision makers and the public on activities that may affect federally managed species and possible conservation measures to protect healthy fish stocks and their habitat. Importantly, all maps within this document are intended to be viewed within a high-resolution Portable Document Format (PDF), so the intricacies of the maps can be observed. All spatial data used in this publication have been delivered to NMFS so maps may be further refined, and the map extent changed to visualize the data for decision-making purposes. For general trends in seasonal movements of species, spatiotemporal tables for each species provide adequate information on movements into various habitats used during certain time periods or seasons. The maps supplement the literature referenced throughout each descriptive section. Detailed maps highlight important habitats, fish passage and anadromous fish movements, and long-term surveys of fishery resources in North Carolina and South Carolina waters.

Table of Contents

List of Tables

List of Figures

List of Appendices

List of Abbreviations and Symbols

ACL	Annual catch limit
ASMFC	Atlantic State Marine Fisheries Commission
ATS	Atlantic Sturgeon
BMP	Best management practice
cm	Centimeter
CPUE	Catch per unit effort
CW	Carapace width
dB	Decibel
DO	Dissolved oxygen
DPS	Distinct population segment
EPA	United States Environmental Protection Agency
FL	Fork length
FMP	Fisheries management plan
Hz	Hertz
kg	Kilogram
km	Kilometer
kHz	Kilohertz
lbs	Pound
m	Meter
m/s	Meters per second
mg/l	Milligrams per liter
mi	Mile
mph	Miles per hour
MPA	Marine Protected Area
MT	Metric ton
NCDMF	North Carolina Division of Marine Fisheries
nm	Nautical mile
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
%	Percent
PSU	Practical salinity unit (salinity is unitless)
RMS	Root mean square
SAMFC	South Atlantic Marine Fisheries Council
SAV	Submerged aquatic vegetation
SBLL	Short-bottom longline
SCDNR	South Carolina Department of Natural Resources
SEFIS	Southeast Fishery-Independent Survey
SEL	Sound effects level
SERFS	Southeast Reef Fish Survey
SL	Standard length
TL	Total length
U.S.	United States
USACE	United States Army Corps of Engineers
yr	Year

Section 1: Rationale and Overview

1.1 Rationale

Commercial and recreational saltwater fishing in the United States of America (U.S.) generated more than $212 billion USD in sales in 2016 (NMFS 2016). In the South Atlantic region (North Carolina, South Carolina, Georgia, and Florida), the NOAA National Marine Fisheries Service (NMFS) estimates landings revenue is approximately $191 million (NMFS 2016). The region encompasses about 12% (1.34 million km^2 [517,377 mi^2]) of the U.S. Exclusive Economic Zone (EEZ; NMFS 2015b). Fisheries and associated coastal habitat are critical components and shared public trust resources of economic, cultural, and natural importance to these coastal states. Decades of building coastal infrastructure including activities in estuaries, coasts, and inlets such as dredging, filling, construction, surface hardening, nourishment, and dam building, have severely stressed many coastal habitats over time (Dahl 1990, Thayer et al. 2003, Alig et al. 2004). Potential fisheries habitat parameters affected by construction activities include but are not limited to temperature, salinity, dissolved oxygen (DO), total suspended solids, nutrients (i.e., nitrogen, phosphorus, silicate), depth, pH, water velocity and movement, and water clarity (SAFMC 1998, Deaton et al. 2010). Management plans and regulatory initiatives are important tools helping to balance ecosystem and infrastructure needs and services. Several important fisheries and fisheries habitats (e.g., estuarine-based nursery and spawning habitats) may be compromised as development stretches into ecologically important coastal systems (NCDEQ 2016). This document is a review of relevant fisheries species life stages and their associated habitats for management related to the timing and location of coastal development projects in North Carolina and South Carolina waters.

To protect marine and diadromous fish habitats, the Magnuson-Stevens Fishery Conservation and Management Act (MSA) set forth a new mandate for the NMFS and Regional Fishery Management Councils to identify and protect EFH for federally managed species. The MSA defines EFH as a tool to manage "…those waters and substrate necessary for fish spawning, breeding, feeding, or growth to maturity" (16 U.S.C. 1802(10)) (NMFS 2004, NMFS 2007). In this definition, necessary refers to habitats required to support a sustainable fishery and the managed species contribution to a healthy ecosystem, and covers a species' full life cycle (NMFS 2007). The EFH guidelines under 50 CFR 600.10 further interpret EFH as waters including aquatic areas and the associated physical, chemical, and biological parameters used by fish and may include historic areas when appropriate (NMFS 2007). EFH substrate types include sediment, hard bottom, structures underlying the waters, and the associated communities (NMFS 2007). The NMFS works closely with federal agencies and uses interagency coordination processes to fulfill EFH consultations for review of projects to minimize adverse impacts to EFH, and when unavoidable, mitigate the impact to EFH.

State and federal resource agencies often recommend coastal development projects not occur during the times of year when fish, shrimp, and crabs, and the associated habitats, are most vulnerable to construction operations. These restrictions are referenced as environmental windows, seasonal restrictions, time-of-year restrictions, or moratoria, depending on the state and agency. This publication will use the term *moratoria* since the proposed work focuses on North Carolina and South Carolina, and the agencies and cooperating partners use this term. As EFH occurs in state waters, where many in-water construction activities occur, each state offers some guidance for moratoria. In most cases, moratoria focus on impacts to eggs, larvae, and post larvae from entrainment associated with hydraulic dredging and the high concentrations of total suspended solids associated with dredging. While less common, moratoria also are used to address interference with migration or spawning from the noise and subsequent pressure waves associated with pile driving and to address impacts to prey infauna from physical disturbance of dredging, including sedimentation. Here, the term moratoria will encompass all the aforementioned activities. Requiring adherence to a moratorium can be costly if it limits competition between dredging companies, requires remobilization of construction equipment, or extends the project schedule. At the federal level, general guidelines are in place for evaluating the practicality of a moratorium based on project specific factors such as type of dredge, method of pile driving, waterway width, and construction proximity to habitat at certain times of year.

To understand and develop moratoria, consideration is given to the current state of fisheries and how in-water development activities impact managed stocks. The NMFS determines fish stock status (i.e., current condition of the stock relative to reference points) to assess when overfishing occurs (NMFS 2017). North Carolina and South Carolina management follow the same stock status listings based on stock assessments (SCDNR 2015, NCDEQ 2018). Overfishing is primarily resultant of fishing activities, which if unchecked, could be associated with many negative outcomes including a depleted stock (NMFS 2017). Management practices, such as annual catch limits and accountability measures, reduce the likelihood of overfishing. Habitat degradation, pollution, increased climate variability, and disease may also contribute to population decline and stocks classified as overfished (NMFS 2017). These factors may affect the ability of a stock to rebuild and recover. Table 1.1.1 gives the most current stock status in North Carolina and South Carolina for each of the species covered in this report based on recent stock assessments and recommendations of the respective management organization for each species, either the South Atlantic Fishery Management Council (SAFMC) or Atlantic States Marine Fisheries Commission (ASMFC).

Research Objectives

Over 75% of the economically important fisheries species in the southeast Atlantic coastal waters of the United States have estuarine life stages (Fox 1992). The characterization of a species as estuarine-dependent implies that the species has at least one critical life stage reliant upon estuarine habitats, whether it is a migration corridor, egg, larvae, and juvenile growth and recruitment areas, adult over-wintering, and spawning. Estuarine habitats are particularly vulnerable to natural disturbances and anthropogenic drivers including coastal development (Able 2005). Off the coast of North Carolina and South Carolina, 13 estuarine-dependent species (Table 1.1.1) were selected for extensive life history review according to fisheries importance, estuarine dependence, life stage sensitivity to coastal development, and management needs. This document provides an informational foundation to protect specific fisheries species and habitats from negative impacts of coastal development.

This publication provides a summary of the best available science on seasonal patterns of movement and habitat utilization for important fisheries species. This synthesis supports application of seasonal construction moratoria to protect EFH in North Carolina and South Carolina. By defining these spatiotemporal patterns for sensitive life stages, coastal managers can better understand and tailor management objectives to mitigate potential risks of lethal, sub-lethal, or behavioral impacts to the local species as a result of in-water construction activities. The major objectives are to: 1) provide an overview of coastal development activities and potential impacts to fisheries; 2) complete life history reviews for specified estuarine-dependent species with the most up-to-date data available for North Carolina and South Carolina; 3) define time of year and habitat used by various life stages of each species, and 4) provide baseline environmental information and maps coastal managers can use to implement construction moratoria for resource conservation. This synthesis will serve as a comprehensive reference for coastal manager decision-making concerning timing and placement of coastal development projects. Implementation plans for moratoria will ultimately consider the best available science, as well as tradeoffs, project-specific factors, and other vulnerable species (e.g., shorebirds, colonial seabirds, sea turtles, marine mammals).

Regulatory Authorities

There are 30 legal authorities and mandates that provide guidance for conservation of fisheries and habitat within the coastal waters of the United States. In 1996, amendments to the MSA emphasized the importance of habitat protection to healthy fisheries and strengthened the ability of federal entities to protect and conserve the habitat of marine, estuarine, and anadromous finfish, mollusks, and crustaceans through EFH protections. The River and Harbors Act of 1899, the Clean Water Act (CWA) of 1972, the National Environmental Policy Act (NEPA), the Endangered Species Act (ESA), and the Coastal Zone Management (CZMA) Act of 1972 are federal laws on avoidance and minimization of development impacts to fish habitat. These management measures require all federal agencies give proper consideration to the environment before undertaking any major federal action that may substantially affect EFH in state or federal waters. The USACE has broad responsibility to regulate the wetlands and waters of the United States pursuant to Section 404 of the CWA and Section 10 of the Rivers and Harbors Act. The USACE issues permits and other forms of authorization for projects that may impact EFH resources. Most non-federal dredging projects require a USACE Section 404/10 permit. Under Sections 301 and 502 of the CWA, any discharge of dredged or fill materials into waters of the United States, including wetlands, is forbidden unless authorized by a permit issued by the USACE pursuant to Section 404. Essentially, all discharges of fill or dredged material affecting the bottom elevation of a jurisdictional water of the United States require a permit from USACE. These permits are an essential part of protecting wetlands and weighing the tradeoffs of a coastal development project.

As part of the permitting process, the USACE is required to comply with NEPA, a law requiring review of projects for potential environmental effects that include, among others, impacts on social, cultural, and economic resources, as well as natural resources. Table 1.1.2 provides a summary of the potential impacts of dredging operations to some NEPA environments. NEPA requires compliance with the ESA (e.g., prevention of impacts to federally endangered species), which is administered by the U.S. Fish and Wildlife Service (USFWS) and the NMFS. Most moratoria have been in place for coastal projects since the induction of NEPA into law, but some are even more historic extending back 50 to 100 years (Suedel et al. 2008).

Table 1.1.1: An overview of stock status for the 13 managed species or species groups referenced in this report. Status reflects most recent stock assessment reports and management considerations determined by the Atlantic States Marine Fisheries Commission, South Atlantic Fishery Management Council, and cooperating state agencies in North Carolina and South Carolina. Overfishing occurs when the number of fish removed are greater than the number gained from reproducing fish in the population (NMFS 2017).

Stock Status:	**Overfishing**	**Overfished**		**Overfishing**	**Overfished**
White Shrimp (*Litopenaeus setiferus*)	Seasonal crop	Seasonal crop	Shortnose Sturgeon (*Acipenser brevirostrum*)	No[2]	Yes[2]
Brown Shrimp (*Farfantepenaeus aztecus*)	Seasonal crop	Seasonal crop	Atlantic Sturgeon (*Acipenser oxyrinchus*)	No[2]	Yes[2]
Pink Shrimp (*Farfantepenaeus duorarum*)	Seasonal crop	Seasonal crop	American Shad (*Alosa sapidissima*)	Unknown	Depleted[3]
Summer Flounder (*Paralichthys dentatus*)	Yes	No	River Herring (*Alosa aestivalis* and *Alosa pseudoharengus*)	Unknown	Depleted[3]
Gag (*Mycteroperca microlepis*)	No	No			
Blue Crab (*Callinectes sapidus*)	Yes	Yes			
Red Drum (*Sciaenops ocellatus*)	No	Unknown			
Southern Flounder (*Paralichthys lethostigma)*	Yes	Yes			

[1]All shrimp population sizes are determined by the number of shrimp entering the population each year (i.e., annual crop), which is driven by environmental conditions (e.g., amount of freshwater input and temporal variability in salinity).
[2]Federally Endangered Species under the Endangered Species Act. It is illegal to harvest or possess sturgeon.
[3]*Depleted* determination used instead of "overfished" or "overfishing" to indicate factors besides fishing have contributed to the decline, including habitat loss, predation, and climate variation.

Table 1.1.2: Examples of potential coastal development activities and considerations for each of the NEPA environments.

NEPA Environment	Potential Environmental Effect
Physical	Water quality, water depth, currents, erosion, underwater sound, bottom composition change
Ecological	Submerged aquatic vegetation, plankton, fish, shellfish
Social/cultural	Heritage, submerged archeological sites, public welfare
Economic	Increased developed infrastructure and industry for economic growth

Administered by NOAA, CZMA aims to balance competing land and water issues through state and territorial coastal management programs. CZMA safeguards coastal resources of national significance, which include any wetland, beach, dune, barrier island, reef, estuary, or fish and wildlife habitat. CZMA recognizes the value of habitat areas within the coastal zone and habitats sensitive to perturbation or disturbance. CZMA provides management measures for protection and restoration of coastal waters, while requiring NOAA to work in close conjunction with State and local authorities. A unique provision of the CZMA is that it affords state coastal programs substantial influence over federally authorized activities in offshore waters potentially affecting the state coastal zone (Lowry et al., 1994, Davis 2001, Davis et al. 2006).

In 1997, in response to MSA, North Carolina implemented the Fisheries Reform Act (FRA), assembled by a consortium of stakeholders, to promote healthy stocks, recovery of depleted stocks, and sustainable use of fisheries resources (NCDMF 1997). The North Carolina Division of Marine Fisheries and Marine Fisheries Commission have authority over marine and intertidal fisheries in waters up to 5.6 km (3.0 nm) offshore. The Coastal Habitat Protection Plan (CHPP) focuses on assessment and protection of all coastal habitat in North Carolina waters (Davis et al. 2006, NCDEQ 2016). The FRA requires preparation of Fishery Management Plans (FMPs) by the North Carolina Division of Marine Fisheries (NCDEQ 2016). The goal of all FMPs is to ensure the long-term viability of commercially and recreationally significant species and fisheries, with each plan including pertinent fishery information as well as habitat and water quality considerations consistent with the CHPP. This section of the FRA resembles the federal MSA. The MSA requires Regional Fishery Management Councils and the NMFS to amend federal FMPs to include provisions for the protection of EFH from federally authorized activities. Both the FRA and MSA have provisions to maintain high biodiversity increasing resiliency of aquatic and coastal systems by maintaining trophic levels, species interactions, and ecosystem services (NCDEQ 2016). Importantly, North Carolina also has interjurisdictional FMPs, for species with genetic stocks spanning multiple states (NCDEQ 2018).

South Carolina's Coastal Zone Management Program (CZMP) is administered through the South Carolina Department of Health and Environmental Control's Office of Ocean and Coastal Resource Management (DHEC-OCRM), and has direct permitting authority over any developments or alterations to marine and intertidal waters up to 5.6 km (3.0 nm) offshore (Critical Area Regulations, Chap. 30.1 to 30.18). Further authority is given to South Carolina CZMP to certify federally activities permitted or supported that might impact state waters (including federal activities beyond the 5.6 km limit) (Davis et. al. 2006). DHEC-OCRM also has the authority to protect the coastal environment and to promote the socioeconomic improvement of the coastal zone. The South Carolina Beach Front Management Act of 1988 requires scientific studies of coastal processes to occur before development occurs (including establishing building setback lines along the coast), bans future construction of seawalls, limits building size within the predicted erosion zone, and adopts a policy of retreat away from the erosional beach (Davis et al. 2006). The official Coastal Program document of the South Carolina CZMP, as amended and approved by the state legislature, contains the specific goals, objectives and policies necessary for staff review of development activities taking place in the coastal zone, including offshore waters. These activities include dredging, construction of artificial reefs, and wildlife and fisheries management. South Carolina will not approve activities deemed to have a significant negative impact on fisheries resources, on the stocks themselves or habitats, unless overriding socioeconomic considerations are justified (Davis et al. 2006, South Carolina Ocean Planning Work Group 2012).

Moratoria

The following review focuses on biogeographic considerations related to fisheries species whose habitats may be impacted by coastal development projects if they are conducted in an unsustainable manner (e.g., decreased flow from dammed area reduces spawning, recruitment). Coastal resiliency may be built by balancing tradeoffs and risks, and recognizing that altering the timing and in some cases, placement, of a coastal development project can protect fisheries while also allowing continued growth of coastal communities.

Moratoria are those times of the year (TOY) when dredging and disposal activities or pile driving cannot be carried out once regulatory thresholds indicate adverse impacts associated with the development activity are above critical levels. Moratoria were established over forty years ago, following the passage of NEPA, and are applied today to more than 80% of federal dredging operations (NRC 2001, Suedel et al. 2008). While the intent of moratoria are to act as a simple means of reducing risk to biological resources, unintended consequences have come about from these resource management efforts. A predominant concern is the substantial cost increase for dredging operations as moratoria may delay project deadlines (NRC 2001). Furthermore, project managers perceive moratoria as inconsistently applied, even for protection of identical resources in contiguous waterways (Reine et al. 1998). In an effort to provide spatiotemporal specificity for moratoria, this publication provides a review of technical foundations for specific moratoria across the United States, finding case studies with well-documented rationale. In any regulatory framework, review of the best available data are needed to formulate and add explanation to regulatory measures and actions.

Moratoria for North Carolina and South Carolina are similar in general principle, but are executed differently. Coastal managers from state and federal agencies in North Carolina have agreed upon moratoria to protect seasonal migrations of anadromous species as well as sensitive life states of estuarine-dependent species (Table 1.1.3). Coastal managers in South Carolina do not have formalized agreements for moratoria. Instead, state agencies and the NMFS recommend conservation measures to protect recruitment periods for larval fish, shrimp, and crabs. Coastal managers in South Carolina generally recommend that construction moratoria periods extend from February 1 through September 30. Spring and summer are considered peak recruitment periods and are highly regarded as the most important seasons for conservation.

Given that moratoria are intended to protect a specific resource of concern, restrictions may be placed in different locations at different times of year based on the spatiotemporal distribution of the resource. Scientific rigor, balancing economic gains and tradeoffs, and maintaining environmental and economic sustainability are taken into consideration for each proposed coastal development operation. This report is a compilation of the best life history and habitat information available to facilitate establishment of moratoria by regulatory agencies in North Carolina and South Carolina.

1.2 Overview of Coastal Development and Fisheries Disturbances

The ocean presents a unique set of environmental conditions that dominate methods, equipment, support, and procedures employed in coastal and ocean development projects (Gerwick 2007). Coastal development can potentially negatively impact economically important and protected species unless proper management tools (e.g., fisheries management plans, stock assessments, environmental impact statements and environmental assessments, moratoria) are in place, ideally at the regional level (Table 1.2.1). For example, when impervious surfaces reach over 30% within a given watershed, the magnitude and frequency of runoff events increases and may lead to severe biological – both habitat and the species that depend upon them – degradation (Schueler 1994, Arnold and Gibbons 1996, Holland et al. 2004). These land modifications alter hydrologic patterns and flows, leading to potential deleterious effects on estuarine fish and crustacean habitats critical to proper development of certain life stages. On-land non-point source (NPS) activities such as mosquito control, wildlife management, flood control, agriculture, and silviculture activities can result in altered hydrology. NPS discharges are usually mitigated through implementation of Total Maximum Daily Loads (TMDLs), at the state level. Ditching, diking, draining, and impounding, dredging, fish passage blockage, beach nourishment, and in-water construction (e.g., bridge construction) are all activities leading to hydrologic changes impacting estuarine habitats and may require NMFS EFH consultation (ASMFC 2011). Figure 1.2.1 depicts locations in North Carolina for coastal storm damage reduction projects, beach nourishment projects, navigation dredging projects, and ocean disposal sites (i.e., dredged material disposal). Figures 1.2.2 and 1.2.3 show maps where dams and obstructions to fish passage occur in North Carolina. Scheduled release of water from dams and alteration of freshwater flows into estuarine areas may change temperature, salinity, and nutrient regimes and the overall area of estuarine habitats. Changes in salinity and temperature can have profound effects on estuarine fishes (Serafy et al. 1997), and salinity can dictate the abundance and distribution of organisms residing within these ecosystems (Holland et al. 1996).

Table 1.1.3: North Carolina Division of Coastal Management and North Carolina Wildlife Resources Commission (WRC) regional moratoria for in-water work for standard fish and anadromous fish (NCDEQ 2016). All dates are approximate and dependent on site-specific environmental conditions.

Region	Area	Standard fish moratorium period	Anadromous fish moratorium period
Southern	South Carolina border north through Onslow County	1 April – 30 September	1 February – 30 June
Central and Pamlico	Carteret County north through Long Shoal River, including the Neuse River basin above New Bern and all of Tar-Pamlico basin	1 April – 30 September	1 February – 30 September
Northern - Albemarle (sounds/tributaries)	North of Long Shoal River and including the Roanoke River basin	1 April – 30 September	15 February – 30 September (extended to 31 October east of Alligator River)
Northern - Outer Banks (sounds/tributaries)	North from Ocracoke Inlet in high energy, sandy estuaries	1 April – 30 September	N/A
Inlets	Shoals/channels dynamic	April 1 – 31 July	N/A
WRC		15 February – 30 September (Inland Primary Nursery Habitats)	15 February – 30 June*

*Depending on the river system and inland extent of the tributary, the anadromous fish moratoria may be adjusted to February 1.

The coastal counties in North Carolina that have undergone the greatest population change in the past 15 years are Brunswick, Pender, Camden, New Hanover, and Currituck. Growth during this time has increased from 76 to 139% in those counties, primarily the result of urban sprawl, as all are within commuting distance of municipalities such as Wilmington, North Carolina and Norfolk, Virginia. Since about 2005, there has been a shift to new residential waterfront development along the rivers and sounds rather than oceanfront areas of coastal counties, marketed as the "Inner Banks" (NCDEQ 2016). In 2008, sharply falling real estate prices and the recession led to a major slowdown in development. In 2014, signs of an improving economy were evident in some areas. Despite the low rate, population continues to increase in the coastal area, and in some areas has approximately doubled in size since 1990 (NCDEQ 2016). In coastal South Carolina, the largest population changes occurred in Horry and Beaufort counties, with an over 25% increase in population between 2000 and 2010 (U.S. Census Bureau 2010).

Another major activity for North Carolina and South Carolina coastal areas is the maintenance and stabilization of coastal inlets. Deepening of inlets as well as construction of groins and jetties alter hydrodynamic regimes and in turn, change habitat and the transport of larvae of estuarine-dependent organisms through inlets (Figure 1.2.1, Figure 1.2.4) (Miller et al. 1984, Miller 1988, ASMFC 2013). These inlet areas also act as critical corridors to all fishes, but particularly to species whose development spans more than one habitat type (e.g., diadromous, marine-spawning, estuarine-dependent) (NCDEQ 2016). The spatial and temporal interplay of factors triggering migration and the water conditions for successful migration determine the degree of corridor function (NCDEQ 2016). Many coastal development activities may alter the ecological capacity of ocean inlets and channels acting as essential corridors. BMPs recommend that maintenance of navigable waters and stabilization of shorelines are carefully timed and planned as to have the least impact to major fish corridor areas to avoid long-term population-level impacts on managed fisheries species. Proper utilization of moratoria can provide needed protection and minimize impacts of coastal development on important fisheries species; regionally based, scientifically sound guidance can advance coastal development moratoria, adding spatial and temporal specificity, potentially minimizing economic deficits to developers.

Adverse impacts to marine fisheries resources can result from suspension of fine grain sediments, lowered dissolved oxygen levels, impediments to migration, direct removal of important shelter, forage or spawning habitat, and direct mortality. In order to avoid or minimize some of these impacts, several conservation measures can be implemented including: 1) siting projects to avoid resources; 2) designing projects to minimize the area or size (e.g., minimizing the number of necessary piles on a bridge, pier, or dock); 3) using a particular construction technique (e.g., a clamshell dredge or dredge bucket); 4) real-time monitoring of the extent of turbidity plumes with permitted thresholds and contingency plans; 5) use of project sequencing (scheduling portions of a project at different times in different areas of the waterbody in order to minimize impacts to sensitive resources), and 6) use of time of year restrictions on in-water work (i.e., seasons when in-water work is not conducted to protect sensitive life stages) (Evans et al. 2011).

Detailed Assessment of Dredging Operations

A dredge is defined as a machine that scoops or suctions sediment from the bottom of waterways or is used to mine materials underwater (USACE 2015a). Dredging is the process of excavating sediment for navigation and docking facilities and sand for beach nourishment. More than 400 ports and 40,234 km (25,000 miles) of navigable channels are dredged throughout the

United States to keep vessel traffic operating efficiently (USACE 2015a). Most of North Carolina and South Carolina's estuarine waters are shallow habitats (e.g., wetlands, submerged aquatic vegetation, shell bottom) and consequently are most vulnerable to infill and subsequent dredging (NCDEQ 2016). Maintenance dredging is necessary to preserve water depths for commercial and recreational navigation (USACE 2015a). Dredging of estuarine inlets occurs at varying frequencies depending upon channel maintenance requirements for navigation or the need to protect oceanfront development (NCDEQ 2016). In some cases, inlet channels are relocated through extensive dredging to shift erosion patterns away from developed areas. Across the nation the USACE dredges approximately 191 to 229 million cubic meters (250 to 300 million cubic yards) of sediment annually (Suedel et al. 2008) for improved navigation of channels in ports and maintenance of ports once they are established (USACE 2015a). In North Carolina and South Carolina, shipping channels are dredged in ocean waters for accessing state ports or to obtain sand from designated borrow areas for nourishment (e.g., Morehead City Harbor, Wilmington Harbor, Charleston Harbor) (NCDEQ 2016). Dredging and dredge type have the potential to stress marine and aquatic biota both during dredging and dredge disposal (Suedel et al. 2008). Dredging can negatively affect fish spawning events and anadromous fish migrations and can also cause habitat destruction, detrimental levels of suspended sediment, and hydraulic entrainment of larvae, affecting vulnerable life stages of economically important crustaceans and fishes (Reine et al. 1998, Evans et al. 2011).

Dredging projects (Table 1.2.2) are performed with sidecast, hopper, clamshell, or pipeline dredges. Dredge type largely depends on the project size, location of work, and material disposal methods. Inlet dredging by the USACE is generally done by sidecast or hopper dredge (NCDEQ 2016). Materials dredged by sidecast are deposited on either side of the channel, while with a hopper dredge material is placed in a nearshore location (contours between 3.0 to 5.5 m or 10 to 18 ft), or in an EPA-designated ocean dredged material disposal site (NCDEQ 2016). Material dredged by hydraulic pipeline can be placed on nearby beaches or within confined upland diked disposal areas. Navigational dredging in inlets is allowed year-round by the USACE, but is subject to moratoria by state and federal agencies regarding timing of excavation, equipment presence, and spoil placement. For instance, contractors working in Wilmington Harbor, Morehead City Harbor, and Oregon Inlet are requested to refrain from using hopper dredges from December to March to avoid interactions with sea turtles (NCDEQ 2016, Emily Hughes, USACE, personal communication, June 8, 2016). Historically, dredging navigational channels for commerce through coastal North Carolina and South Carolina occurred with the passage of the Rivers and Harbors Act in 1937, establishing the creation of the Atlantic Intracoastal Waterway (AIWW) (USACE 2015b). The USACE is responsible for maintaining the AIWW, with a targeted maintained depth of 3.7 m (12 ft). There are now over 2,414 km (1,500 miles) of navigable channels in the AIWW, including 483 km (300 miles) in North Carolina, and 338 km (210 miles) in South Carolina.

Physical disturbance caused by dredging activities generally involves the generation of underwater sound leading to disruption of fish migration (e.g., anadromous fishes); suspension of sediment in the water column, which can impact fish and sensitive habitat; and hydraulic entrainment of larvae and juvenile fishes primarily through hopper dredges (Table 1.2.1). Underwater sound (i.e., pressure waves) may impact fish bioacoustics and disrupt certain behaviors (e.g., spawning, feeding) from occurring. In a survey of USACE dredging projects, physical disturbance of fish spawning activities was cited in 41% of reporting USACE Districts as the rationale for developing a moratoria period (Reine et al. 1998). Additionally, of the Districts surveyed, 68% (25 Districts) reported turbidity, suspended sediments, and sedimentation issues as a reason for moratoria.

Table 1.2.1: Coastal development activities and the associated impacts to the hydrology, physio-chemical environment, and fisheries. Adapted from Evans et al. (2011).

Coastal Development Activity	Potential Impact to Fisheries
Watershed development (e.g., increased impervious surfaces, nonpoint source pollution increases	• Increased levels of suspended sediment and turbidity • Eutrophication and increased algal levels • Egg smothering • Change in hydrologic characteristics • Impaired respiration and feeding and low dissolved oxygen • Impediments to passage for anadromous fish
Beach nourishment and shoreline protection	• Change in flow characteristics (e.g., longshore drift) • Increased sedimentation and turbidity • Smothering of eggs • Smothering of habitat (e.g., mud-flats, subtidal habitats, and intertidal zones) and habitat conversion or loss • Direct mortality
Dredging	• Change in flow characteristics • Loss of spawning habitat • Egg smothering • Impaired respiration and feeding • Direct mortality of vulnerable life stages • Benthic habitat alteration or loss • Impediments for anadromous fish migrations • Increased levels of suspended sediment and turbidity • Increased vulnerability of eggs to predation • Hypoxia • Entrainment

Table 1.2.1 continued: Coastal development activities and the associated impacts to the hydrology, physio-chemical environment, and fisheries. Adapted from Evans et al. (2011).

Coastal Development Activity	Potential Impact to Fisheries
Pile Driving	• Noise impact (i.e., stunning) • Increased levels of suspended sediment and turbidity • Substrate and water quality degradation due to increased levels of pollutants • Alteration in flow characteristics • Direct mortality • Impediments for anadromous fish migrations
Obstructions (Dams, Culverts, and Impoundments)	• Blockage of upstream migration for anadromous fishes • Decreases water flow rate, with potential adverse impacts on larval dispersion, recruitment, and survival

Entrainment, another concern for dredging projects, is defined as the direct uptake of aquatic organisms by the suction field generated at the hopper or cutterhead. Hydraulic dredging has been implicated in the entrainment of numerous commercial fish, shellfish, and threatened and endangered species. Both demersal and pelagic fish eggs and larvae are perceived to be susceptible to entrainment by suction dredges due to their inability to escape the suction field around the intake pipe. Maintenance dredging and disposal activities were the most common operations affected by moratoria. Although fewer dredging projects are conducted using hopper and mechanical dredges than with hydraulic pipeline dredges, a higher proportion of restrictions were identified for hopper (83%) and mechanical (85%) dredges than with pipeline (67%) dredges (Dickerson et al. 1998).

Fish species using dredged, poorly flushed waterbodies (e.g., channelized ditches, dead-end canals, enclosed marinas) have greater risk to exposure from degraded water quality such as low DO, high contaminant loading, extreme water temperatures, and rapid salinity changes (Chaillou and Weisburg 1996). In some cases, dredged waterbodies located at the headwaters of Primary Nursery Areas can augment critical nursery habitat for important fisheries species.

For dredging projects, BMPs are determined after impact assessment, examination of alternative practices, and appropriate stakeholder participation to be the most effective, practical, and sustainable means of achieving an environmental protection objective (Clarke et al. 2007). During active dredging projects operators often seek to reduce disturbances by modifying rate of operations, choosing the most effective dredge for the project (e.g., closed 13.8-cubic meter or 18.0-cubic yard bucket), reducing bucket ascent or descent speed to limit sediment loss, reducing over-dredging by bed leveling, limiting or prevent hopper/barge overflow, limiting fill of barges, restricting temporal aspects of operations, and providing spatial buffer zones between the dredging operation and sensitive habitats. To increase control of sediment during dredging, BMPs for engineering modifications include use of silt curtains, sheet piling, or bubble curtains, use of surface booms, and control of the ballast water.

Table 1.2.2: Dredge types, relative size, major uses, and sediment type used in North Carolina and South Carolina waters (USACE 2015a).

Dredge Type	Use	Sediment Type
MECHANICAL	Removing hard-packed material or debris. Working in confined areas.	
Bucket Ladder	Extremely accurate trench dredging and environmental applications.	Hard-packed material
Grab/Clamshell	Dredging in deep areas	Mud
Dragline	Mining operations	Hard substrate
Backhoe/Dipper	Extreme accuracy for trenching and widening channels. Precision work close to solid structures.	Sand, compact clay, and rock
HYDRAULIC	Large volume projects. Dredges are often ocean certified for working in exposed locations.	
Pipeline	Nourishment projects	Various materials
Cutterhead	Ideal for many dredging jobs, such as land reclamation and the construction of new port basins and canals.	Loosen up dense rock, soft rock, clay, silt, sand, and gravel
Dustpan	Beach reclamation in shallow water.	Sand and gravel
Hopper	Most commonly used for beach nourishment. In addition, dredging exposed harbors and shipping channels.	Loose, unconsolidated materials
Sidecasting	Especially designed to remove material from the bar channels of small coastal inlets.	Loose, unconsolidated materials

Erosion, Nourishment, and Shoreline Stabilization

Coastal communities face constant challenges from shoreline erosion caused by intense storms, wave erosion, and sea level rise. Shoreline erosional patterns can affect the hydrography within estuaries, cause sediment smothering, and baffle tidal currents that carry pelagic larvae into upper reaches of estuarine rivers (ASMFC 2007). Estuaries contain habitats important as nursery grounds for many important fishery species (Boehlert and Mundy 1988). Erosional processes have the potential to alter the freshwater flow into habitats essential for eggs, larvae, and juveniles, requiring certain salinities for proper development and survival. Another critical phase of estuarine-dependent life history patterns is the passage through narrow inlets or into mouths of estuaries that connect the ocean and estuarine habitats. Inlet passages to nursery habitats or out to the ocean in some cases, are few in number along much of the Atlantic coast of the United States and therefore serve as bottlenecks (i.e., congestion through the passage, or limited options for movement in and out of the estuary) to recruitment for many species (Reyier and Shenker 2007). Due to the dynamic nature of coastal shorelines, beach nourishment activities, and subsequent erosion, can result in increased sedimentation in estuaries, covering submerged aquatic vegetation (SAV) and other essential nearshore habitats (e.g., inlets, shell bottom) (Green 2002, DEP 2013). Moreover, the addition of sand to the shore can negatively affect nearshore hard bottom habitats through burial and sediment redistribution (Newell et. al. 2010). Whether erosion is human-induced or naturally occurring, nearshore habitats and inlet passages are consequently affected (ASFMC 2010). If sedimentation alters an inlet important for passage, size and age at maturity, a critical element of fish species life history (Roff 1982, Dieckmann and Heino 2007) may be impacted, resulting in variation in fish maturity scheduling directly impacting annual and lifetime reproductive outputs for fishery species (Midway and Scharf 2012). It is therefore recommended from a fisheries management perspective to protect inlets during those times of year when they act as corridors as to minimize impacts on recruitment for important fisheries species.

Shoreline stabilization projects may lead to significant adverse environmental impacts to the coastal ecosystems, but by incorporating BMPs into a project during the planning, design, construction, and post-construction phases, many of the adverse environmental impacts can be avoided and minimized (Rice 2009). Increasingly, BMPs recommend incorporating soft elements in shoreline stabilization projects to maintain the continuity of the natural land-water interface and reduce erosion. Hard stabilization of shorelines consists of modifications such as seawalls, bulkheads, revetments, riprap, sandbags, jetties, and groins (Figure 1.2.1, Figure 1.2.4). Often these stabilization techniques may lead to the eventual loss of the beach and its associated habitats (Rice 2009). When new hard stabilization is justified, BMPs include mitigation for loss of ecosystem services and habitat in the project design (Rice 2009). Probable mitigation measures include the removal of hard stabilization structures in other nearby locations, the relocation of buildings and structures that are impeding the natural landward migration of the beach system as sea levels rise, or the restoration of beaches where they have been historically lost to shoreline stabilization.

Soft stabilization (i.e., beach nourishment) provides several ecosystem services but can cause significant adverse environmental impacts. Large beach nourishment projects and those that frequently occur have well documented impacts on intertidal benthic communities (Rice 2009). Beach nourishment can lead to reduction in invertebrate populations with the most severe reductions and time to recovery at beaches nourished with sand in the spring and summer (Versar Inc. 2003, NCDEQ 2016). Hume and Pullen (1988) found turbidity to be a persistent problem after nourishment, reducing visibility seven years after project completion. Reilly and Bellis (1978) reported unusually high turbidity following nourishment in North Carolina, which was possibly correlated to a high content of clay balls in nourishment material. Sediment plumes occurring during nourishment can potentially damage important fish habitats. For instance, coral heads on reefs offshore of Miami Beach were still dying 14 years after impacts of a nourishment plume covered the corals (Bush et al. 1996). Similarly, Goldberg (1985) recorded high turbidity and burial of nearshore rocks seven years after another nourishment project was completed in south Florida.

BMPs call for the overall volume of fill material added to any beach in a nourishment episode not to exceed 50% of the projected annual net sediment transport for the beach, to minimize the magnitude of disturbance and prevent large-scale alterations to local coastal processes (Rice 2009). Dunes play an important role in erosion prevention and reduction on beaches after soft stabilization occurs. Planting native vegetation helps to trap natural windblown sediment in establishing new dunes (Rice 2009) and implementation of sand fencing can increase dune resiliency, and reduce the loss of nourished sediment. Emergency berms are considered beach fill projects with similar BMPs or conservation measures as a planned fill or dredge disposal project; the only difference is the level of planning and consultation involved (Rice 2009). Where a beach fill or dredged material disposal project is proposed, the new sediment must be compatible with the native sediment on the existing beach. Nourishment episodes are generally conducted after ecological monitoring (e.g., invertebrate, avian, fisheries, ESA-listed species) and indicate the beach ecosystem has recovered compared to control areas for a duration of one to three years in order to avoid permanent perturbations to local ecosystem (Table 1.2.3). BMPs recommend measured intervals and monitoring between episodic nourishment events to prevent long-term ecological impacts (Table 1.2.3). To facilitate the recovery of fill areas, Defeo et al. (2009) recommends repeated application of thin sediment layers, none thicker than 30 cm (11.8 in), for proper equilibration of the shoreline and to allow for recovery of benthic shoreline communities.

In instances when sand from channel dredging is not suitable or is insufficient for nourishment projects, sand can be mined or dredged from designated nearshore and offshore borrow sites (BOEM 2017). Shortages of sediment, when sand must be borrowed, may also arise from construction activities including harbors, groins, jetties, and seawalls; shoreline development; dredging of tidal inlets; damming of rivers; and beach nourishment (London et al. 1981, Kana 1988, NRC 1990, Green 2002). Physical recovery of borrow sites varies and is documented to range between 2 to 12 years, with some sites altered indefinitely (Table 1.2.4).

Sand borrow areas often refill with finer-grained silt and sand than the original sediment (NRC 1995, Van Dolah et al. 1998), making many borrow sites unusable for future nourishment projects, with alteration occurring in benthic species recruitment patterns (Van Dolah et al. 1992, Van Dolah et al. 1998, Jutte et al. 2001). Mining sand from tidal deltas or nearshore sandbars for nourishment projects modifies the sediment budget and may result in accelerated erosion from adjacent beaches (Wells and Peterson 1986). Removing or reducing these deltas from the system can exacerbate erosion due to the lack of source material for down current shorelines (Roessler 1998).

The ecological impacts of borrowing or disposing of sediment in the open ocean environment are similar to those from other dredging activities, including elevated turbidity around the project area. Recovery of benthic invertebrate communities as well as physical recovery of a project area are dependent upon dredging methods and site conditions (Table 1.2.4, Table 1.2.5). Studies in South Carolina indicated benthic communities appeared to recover more quickly where hopper dredges were used rather than pipeline dredges (Jutte et al. 2001). Van Dolah et al. (1998) observed significant changes in the species composition of recruited organisms over 12.5 years, predominately shifting from amphipods dominance to mollusks. The original species composition within the sand borrow area was never restored to its original state due to changes in substrate types during the observation period (Van Dolah et al. 1998). Borrow areas, where soft bottom habitat exists, are known to support seasonal aggregations of demersal fish, such as the overwintering area off the northern Outer Banks for juvenile Atlantic Sturgeon (Laney et al. 2007), or spawning areas or feeding grounds (e.g., inlet shoals used for Red Drum feeding and spawning) could disrupt or degrade ecological functions that these areas provide (Peterson et al. 1999).

Table 1.2.3: Reported biological recovery times at relevant nourished ocean beaches (Adapted from NCDEQ 2016). NC is North Carolina and SC is South Carolina.

Location	**Biological recovery following beach nourishment**	**Reference**
Pea Island, NC	2 to 9 months for coquina clams and mole crabs.	Donoghue 1999
Atlantic Beach, NC	More than 3 months. Coquina clams in nearshore overwintering bottom killed initially by turbidity; delayed recruitment and repopulation; Haustoriid amphipods had not recovered after 3 months. Polychaete *S. squamata* recovered 15 to 30 days post nourishment.	Reilly and Bellis 1983
Atlantic Beach, NC	Densities of mole crabs and coquina clams were 86 to 99% lower than control sites, 5 to 10 weeks post-nourishment, during mid-summer.	Peterson et al. 2000
Bogue Banks, NC	Mole crabs recovered within months, coquina clams and amphipods failed to initiate recovery after one growing season. No follow up sampling.	Peterson et al. 2006
Bogue Banks, NC	On ebb tide delta, where sediment deposited, significant coarsening of sediment, and reductions in spionid polychaetes after 8 months	Bishop et al. 2006
North Topsail, NC	After 1 year, mole crab, coquina clam, and amphipod abundance remained significantly less than at control sites and body size was significantly smaller. Polychaetes increased in abundance.	Lindquist and Manning 2001
Bald Head, Caswell, and Oak Island, NC	Coquina clams, mole crabs > 1 year. Abundance declined 1 to 10 times from control. Most severe reductions and longest times of recovery due to season of project – greatest in spring and summer, except Oak Island coquina clams recovered within 1 year – timing of sand deposition allowed summer recruitment.	Versar, Inc. 2003
Folly Beach, SC	2 to 5 months, depending on benthic group and site, polychaetes recruiting earlier than mollusks.	Jutte et al. 1999
Hilton Head, SC	Density and diversity returned to levels similar to control sites in 6 months.	Van Dolah et al. 1992

Table 1.2.4: Reported biological recovery rates at sand borrow areas in North Carolina and South Carolina.

Location	Recovery Time	Reference
North Carolina	6 – 18 months	Posey and Alphin 2001
North Carolina	≤ 9 months	Posey and Alphin 2002
South Carolina	3 – 6 months	Van Dolah et al. 1992
South Carolina	2 – 12.5 years	Van Dolah et al. 1998
South Carolina	14 – 17 months	Jutte et al. 2001
South Carolina	3 – 6 months	Jutte et al. 2002

Table 1.2.5: Reported biological recovery rates at open water disposal sites. Recovery time at these sites ultimately depends on the frequency of disposal. SC stands for South Carolina.

Location	Recovery Time	Reference
Seewee Bay, SC	6 months	Van Dolah et al. 1979
Dawho River, SC	3 months	Van Dolah et al. 1984

Anadromous Fish Passage and Flow Obstructions

Dams have been constructed throughout North Carolina and South Carolina to provide flood control, hydropower generation, water supply, irrigation, navigation, recreation, fish and wildlife impoundments, debris and sediment control, and fire protection (NCDEQ 2016). Habitats upstream of a dam may become inaccessible to anadromous fish and habitats downstream receive altered surface water from upstream sources. Survival of anadromous species is threatened if passage to their historical spawning or nursery areas is obstructed by dams (Moser and Terra 1999). The majority of dams in North Carolina are in the upstream portions of estuaries, rivers, and streams. In the coastal plain, dams are most abundant in the upper reaches of the Cape Fear, Neuse, Tar-Pamlico, Roanoke, and Chowan watersheds (Figure 1.2.2, Figure 1.2.3). Over the past twenty years, a significant investment has been made in North Carolina to remove small low-head dams. In fact, the Quaker Neck Dam along the Neuse River was the first dam in the United States removed purely for environmental reasons. The removal of the Quaker Neck Dam and more recent fish passage and dam removal projects along the coastal plain of North Carolina have brought about a new era in river restoration. In South Carolina, many of the dams and impediments to fish passage are also in upstream portions of rivers and streams (Figure 1.2.4). There are currently three large-scale fish passage projects implemented in South Carolina including dam removal on the Congaree River, a fishway at the New Savannah Bluff Lock, and a development plan for restoration of the Santee River (USFWS 2001).

Removal of obstructions in coastal rivers has demonstrated almost immediate positive benefits for migratory species allowing migration and recolonization further upstream to reclaimed habitat (Hightower and Jackson 2000, Bowman and Hightower 2001, Burdick and Hightower 2006). Unfortunately, dam removal can also disrupt downstream aquatic communities by releasing a substantial amount of sediment and associated pollutants such as heavy metals, toxic chemicals, and nutrients. Further, dam removal provides opportunities for spread of nonindigenous aquatic species and can alter riverine food-web structure (Stanley and Doyle 2003).

Culverts are used in transportation projects as well as stormwater, flood control, and irrigation projects. Their purpose is to carry water under an embankment or roadway. Culverts are widely used by the North Carolina Department of Transportation, South Carolina Department of Transportation, and FHA. Circular culverts are common, but they can take many shapes and are constructed using a variety of materials. Culverts can significantly impede fish passage to upstream tributaries. They alter stream flows and the hydrology of riparian wetlands, affect water temperature and salinity, alter sediment transport, and can introduce contaminants. Based on analysis of North Carolina Department of Environmental Quality (NCDEQ) and North Carolina Department of Transportation (NCDOT) records, it is estimated that North Carolina loses an average of 500 acres of wetlands per year, mostly from road construction (NCDEQ 2016). The common reasons culverts become barriers to fish passage are excessive outlet drops, high water velocity within the culvert, turbulence within the culvert, accumulation of sediment and debris, and an inadequate water depth within the culvert (Bates et al. 2003). Fish passage criteria has been developed for culverts that accounts for culvert design, material, diameter, slope, roughness, and velocity to allow passage for a variety of species and sizes of fish (Bates et al. 2003). Two designs are popular among engineers and natural resource managers. Active channel culverts are sized to allow natural movement of the bedload and formation of a stable streambed inside the culvert. Hydraulic culvert designs balance the flow characteristics and hydraulics of the culvert and the swimming abilities of the target aquatic species.

Increasingly, transportation engineers are considering bridges to replace culverts when funding is available for improvements. In general, bridges become economical as stream size increases. Culverts are best when installed at the slope of a streambed or at less than 3% slope (Fitch 1996). When the stream gradient is greater than 5%, the cost of the culvert becomes comparable to the cost of a bridge (Robison 1999).

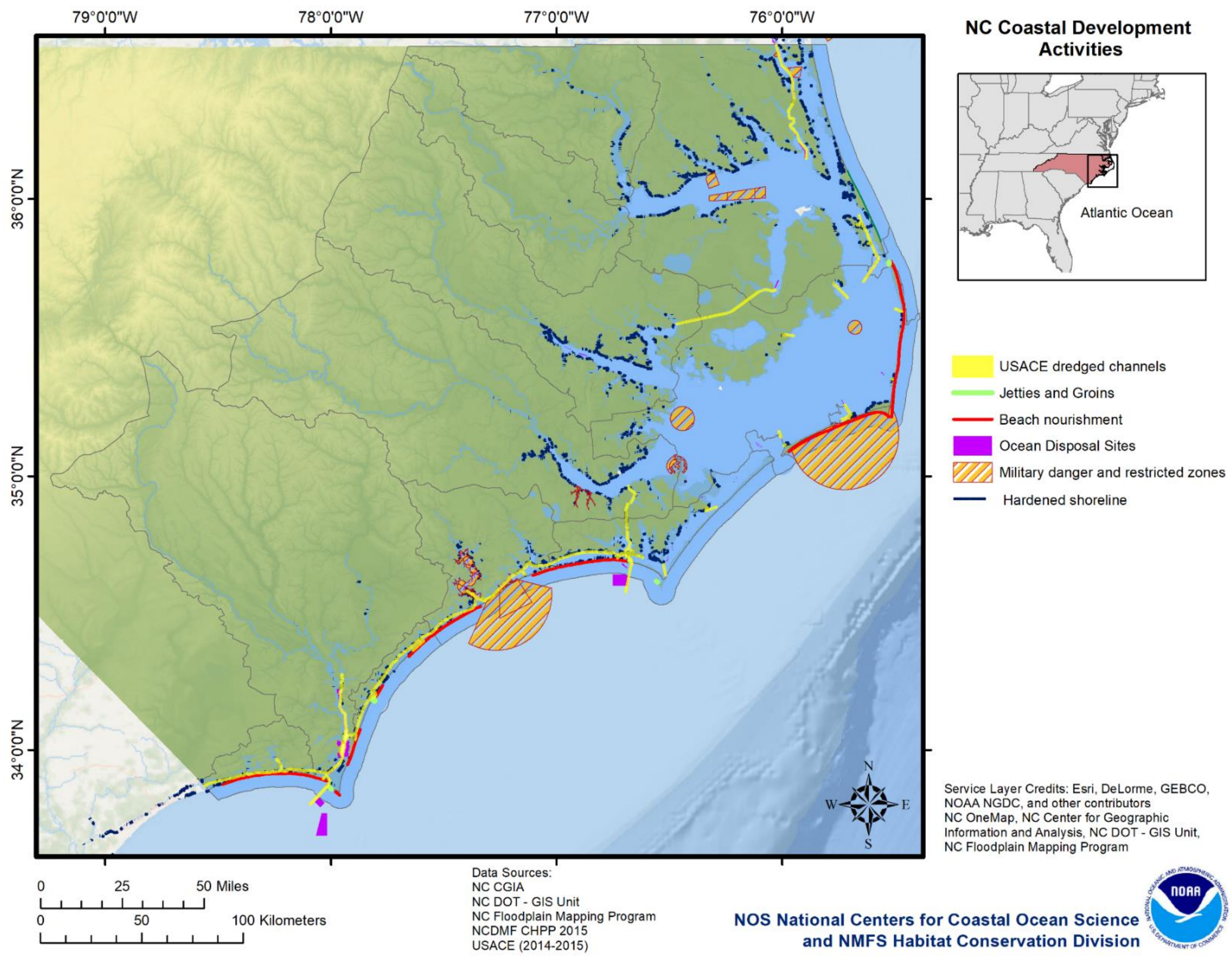

Figure 1.2.1: Various coastal development activities in North Carolina. These activities include any alteration of potential fish habitat and include USACE engineering projects; military zones including unexploded ordnance, dredged areas, ocean disposal sites, hardened shorelines, jetties, and groins; and areas prohibited from trawling and dredging.

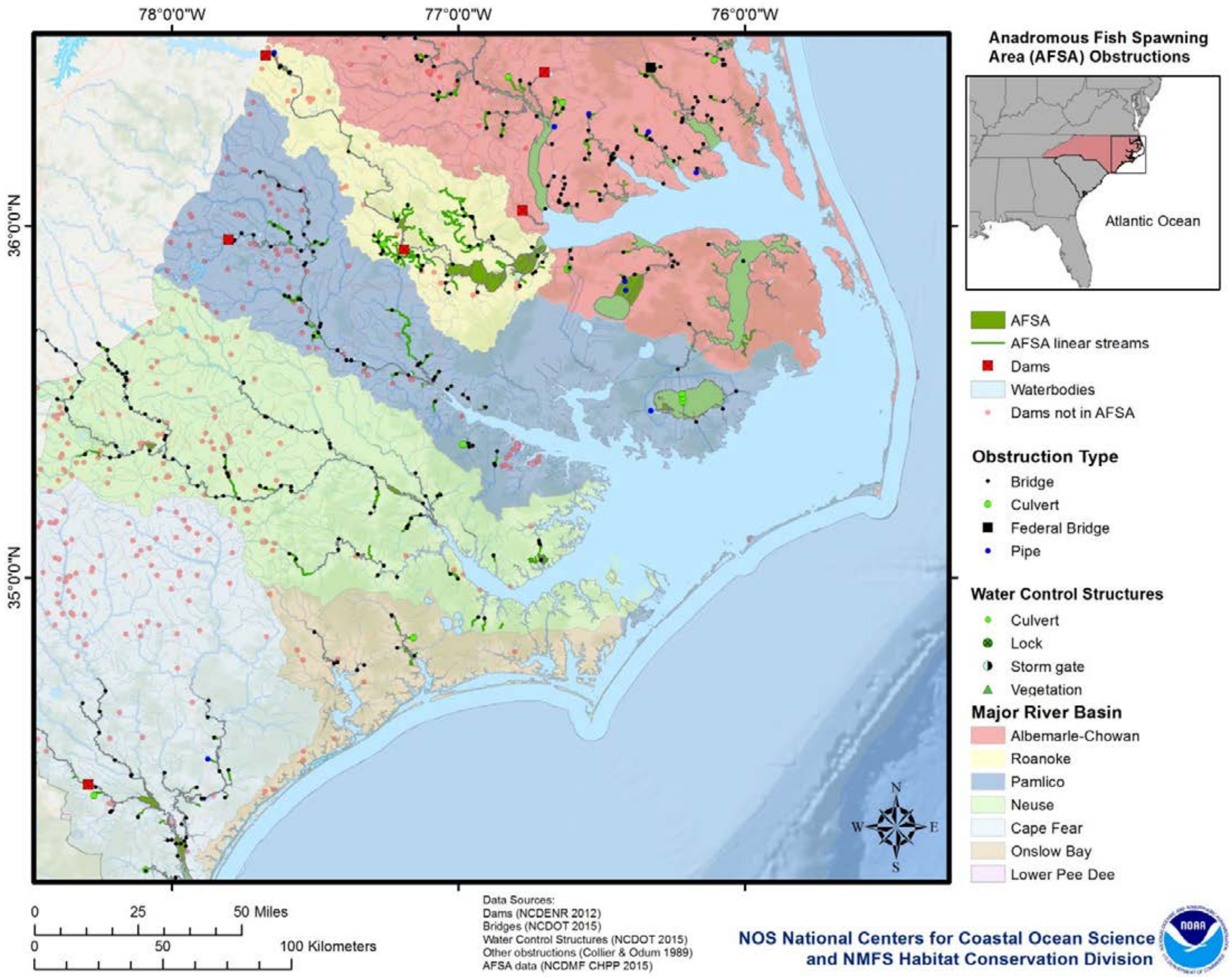

Figure 1.2.2: Anadromous Fish Spawning Areas (AFSA) and fish passage obstructions in northeastern coastal North Carolina.

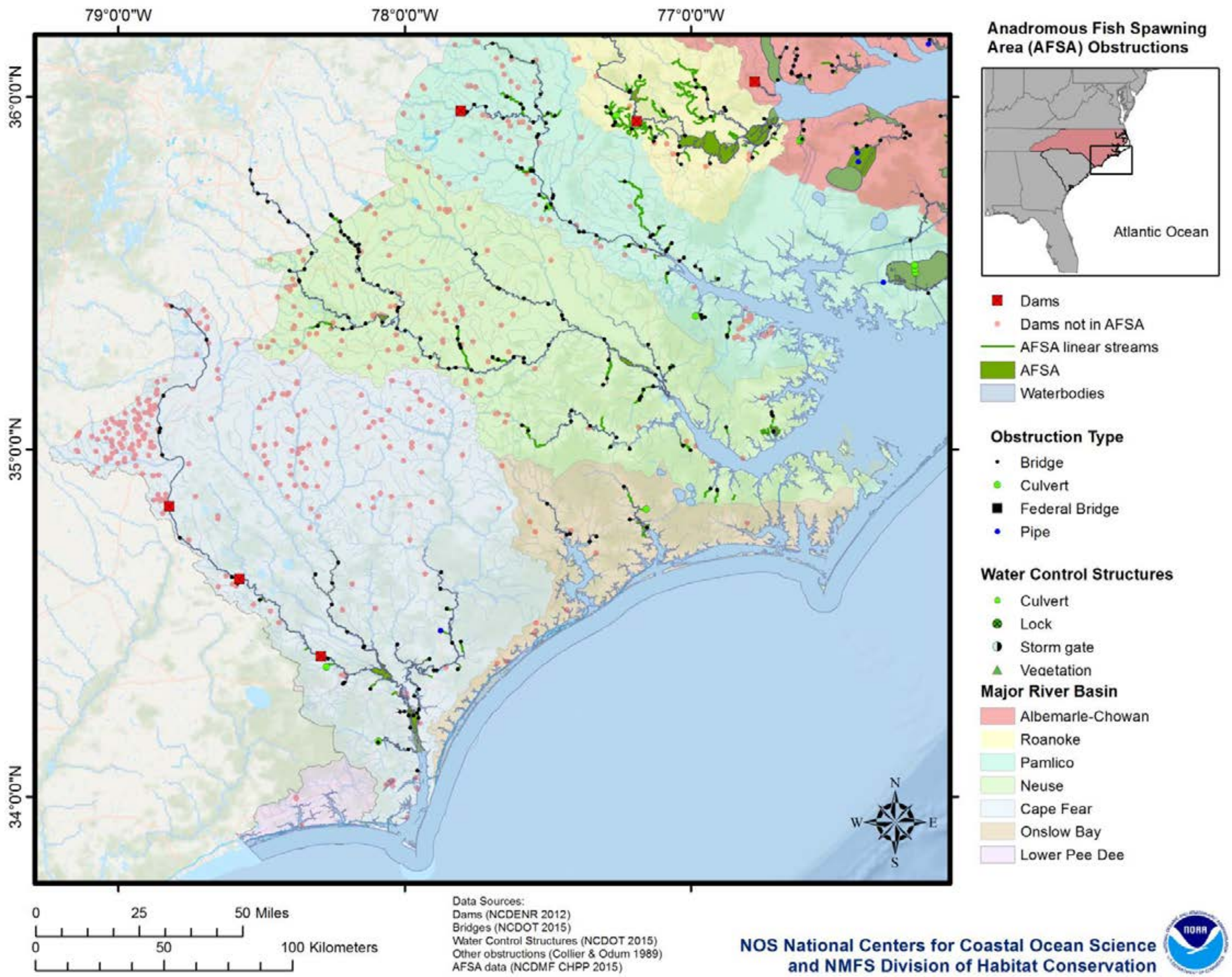

Figure 1.2.3: Anadromous Fish Spawning Areas (AFSA) and fish passage obstructions in southeastern North Carolina.

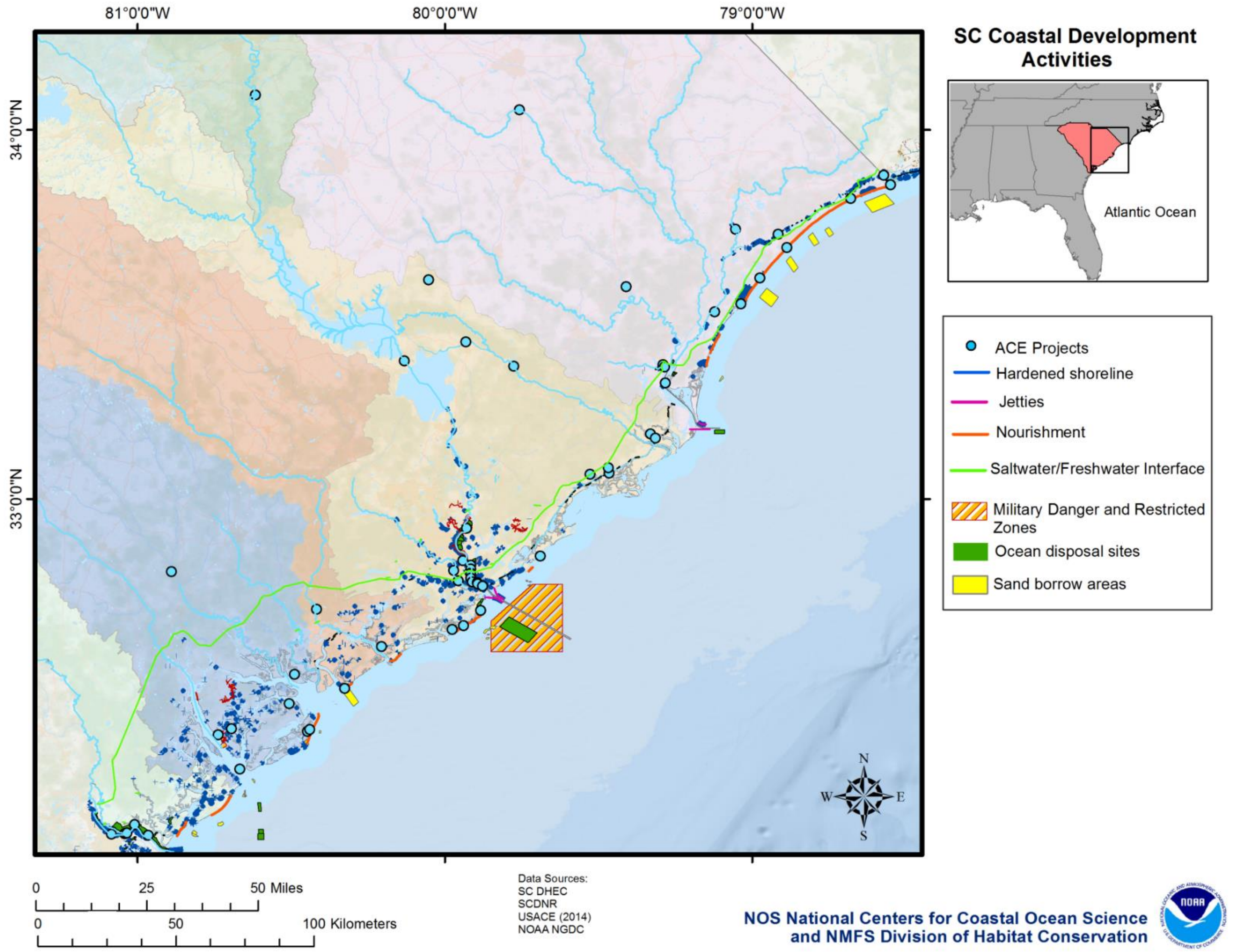

Figure 1.2.4: Various coastal development activities in South Carolina. These activities include any alteration of potential fish habitat and include USACE engineering projects; military zones including unexploded ordinance, dredged areas, ocean disposal sites, hardened shorelines, jetties; and area where beach nourishment has occurred.

Pile Installation

A pile driver is a mechanical device used to drive piles (poles) into substrate to provide foundational support for bridges, boardwalks, docks, or any other in-water structure. Piles are generally deep foundations typically put into place using excavation or drilling techniques, usually consisting of pre-stressed or poured concrete, steel, or timber (CADOT 2015). Pile foundations are used when the underlying soils are incapable of resisting the loads from the structure (CADOT 2015). Percussive pile driving is the operation of forcing a pile into the ground thereby displacing the soil mass across the cross section of the pile (Oestman et al. 2009). Piles are installed by a special pile driving device known as a pile hammer (Appendix A). The impact pile hammer may be suspended from the boom of a crawler crane, supported on a pile driver and carried on a barge for construction in water. Considerations for various types of hammers includes substrate type, depth, headroom, number of piles to drive, pile type and size, number of strikes per minute, and location of operation (nearshore, river, offshore). In some instances, it is possible to use non-impact pile driving equipment that does not produce as loud of a sound signature. This would include the use of vibratory hammers or push or press-in pile installation. The project engineer determines the feasibility of using non-impact pile driving equipment, with BMPs suggesting this approach is not an avoidance or minimization measure, unless the engineer has verified its feasibility (Oestman et al. 2009). The implications for this type (i.e., deep foundations) of coastal development for fisheries relates to sound, sound pressure waves, and particle movement occurring from the strike to the pile, resulting in transference of underwater sound. A detailed discussion of sound related to pile driving and the impacts on surrounding habitats is presented in Appendix A.

Sensory Biology, Fish Hearing, and Potential Impacts

Dredging, shoreline stabilization, dam construction, and pile installation all generate underwater sound during the development activity from the numerous machines used for such operations. Understanding how fish species are impacted physiologically and spatially establishes a basis for management. Fish bioacoustics is the study of hearing and sound communication by fishes (Popper 2005). Fishes possess two sensory systems that serve to detect sound – the ear (innervated by the 8th cranial nerve) and the lateral line (innervated by the lateralis nerves) (Popper et al. 1992, Popper 2005, Burgess et al. 2005). Together they are often referred to as the "octavolateralis system" (Popper et al. 1992, Popper 2005). The lateral line is used by fishes to detect nearby water (particle) motion, assisting the fish in maintaining their position in a school, avoiding predators, and finding prey (Coombs and Montgomery 1999, Burgess et al. 2005) while the ear is involved in detection of sound as well as the detection of angular acceleration and changes in the fish's position relative to gravity (Platt 1983, Popper et al. 2003, Popper 2003). The two inner ears of fish include three semicircular canals along with three fluid-filled sacs containing a sensory epithelium and a small calcium carbonate bony structure (i.e., otolith). The sensory epithelium has numerous hair cells that release a neurochemical signal when the hair cells are bent; this differential movement results in displacement of the sensory hairs. Excessive otolith movement may damage or shear off the sensory hairs (Burgess et al. 2005). The majority of fish species are known to detect sounds from below 50 Hz up to 2000 Hz (Popper and Fay 1993).

Fish can be categorized by the way they hear. All fish fall into two hearing categories: hearing generalists (e.g., Southern Flounder) and hearing specialists (e.g., clupeids) (Mann et al. 1997, 2001). The vast majority of fishes studied to date appear to be auditory generalists (Schellart and Popper 1992, Popper et al. 2003). Hearing generalists sense sound directly through their inner ear but also sense sound energy from the swim bladder. Hearing specialists are more complex (Popper and Hastings 2009). Many of the hearing specialists have evolved any one of a variety of different mechanisms to couple the swim bladder (or other gas-filled structure) to the ear. For clupeids, a gas-containing sphere (prootic bulla) connecting the swim bladder to the hearing system substantially lowers their hearing thresholds and extends the hearing bandwidth to higher frequencies up to several kHz (Webb et al. 2007). In hearing generalists, the lack of a swim bladder, or its lack of coupling to the ear, potentially results in the signal from the swim bladder attenuating before it gets to the ear. Consequently, these fishes detect little or none of the pressure component of the sound (Popper and Fay 1993). If the fish ear is sensitive to particle displacement, then it may detect the signal over a considerable distance from the source (Popper 2005). If the fish ear is not very sensitive to particle displacement, it will not detect the signal even as far as the transition point (Popper 2005).

Exposure to low levels of sound for a relatively long period of time, or exposure to higher levels of sound for shorter periods of time, may result in auditory tissue damage (damage to the sensory hair cells of the ear) or temporary hearing loss—referred to as a “temporary threshold shift” (TTS). The level and duration of exposure that cause auditory tissue damage and TTS vary widely and can be affected by factors such as repetition rate of the sound, pressure level, frequency, duration, size, and life history stage of the organism, and many other factors (Oestman et al. 2009). Peak sound pressure level and sound effects level (SEL) can affect hearing through auditory tissue damage or TTS. TTS will occur at lower levels than auditory tissue damage. Vulnerability to non-auditory tissue damage increases as the mass of the fish decreases meaning nonauditory tissue damage criteria differ depending on total fish mass (Oestman et al. 2009). Carlson et al. (2007) proposed separate peak and SEL interim criteria for auditory tissue damage and TTS for both hearing generalists and hearing specialists. By definition, hearing recovers after TTS. The extent (how many dB of hearing loss) of TTS depends on numerous variables. Recovery from TTS may occur minutes to days following exposure. Popper et al. (2005) found that both hearing specialists and generalists were able to recover from varying levels of substantial TTS in less than 18 hours post exposure. An additional possible effect on hearing from loud underwater sound is referred to as a “permanent threshold shift” (PTS) (Oestman et al. 2009). PTS is a permanent loss of hearing and is generally accompanied by death of the sensory hair cells of the ear. There is only a small body of peer-reviewed literature showing that exposure to extremely high sound pressure levels can destroy the sensory cells in fish ears (Enger 1981, Hastings et al. 1996, McCauley et al. 2003, Hastings and Popper 2005). Indirect impacts of hearing loss in fish may relate to the fish's reduced fitness, which may increase the animal's vulnerability to predators and result in the fish's inability or reduced success in locating prey, inability to communicate, or inability to sense their physical environment.

Key variables that appear to control the physical interaction of sound with fishes include the size of the fish relative to the wavelength of sound, mass of the fish, anatomical variation, and location of the fish in the water column relative to the sound source (Yelverton et al. 1975, Hastings and Popper 2005, Carlson et al. 2007). As described above, gas oscillations induced by high sound pressure levels can even cause the swim bladder in fishes to tear or rupture, as has been indicated in response to explosive stimuli in several reports (Gaspin 1975, Yelverton et al. 1975, Hastings and Popper 2005). Similar results have been seen from pile driving (Caltrans 2001, Caltrans 2004, Hastings and Popper 2005). Sound at sufficiently high pressure levels can generate bubbles from micronuclei in the blood and other tissues such as fat (ter Haar et al. 1982). Due to the particularly small diameter of fish blood vessels, if bubbles are forced to come out of solution at low frequencies, they could cause an embolus or clot and burst small capillaries. This also can occur in the eyes of fish, where tissue might have high levels of gas saturation (Turnpenny et al. 1994, Gisiner 1998). Traumatic brain injury can be caused by high-level transient sound; it is believed fish with swim bladders or other air bubbles near the ear could be susceptible to neurotrauma when exposed to high sound pressure levels (Hastings and Popper 2005). Whereas it is possible that some (although not all) species of fish would swim away from a sound source, thereby decreasing exposure to sound, larvae and eggs are often found at the mercy of currents or move slowly, leaving them more vulnerable to high sound pressure scenarios.

The evaluation of bioacoustic impacts to fish from in-water coastal activities, requires a clear understanding of construction methods, fish biology, and underwater acoustics. It is also important to recognize that the analysis of pile driving underwater sound on fish is not an exact science; it requires best professional judgment and BMPs based on scientific research and experience. Effects of sound on fish hearing and physiology likely will depend in part on the local environment, such as channel morphology, depth of water, or tidal conditions (Oestman et al. 2009).

Carlson et al. (2007) updated revised interim $SEL_{accumulated}$ criteria for hearing generalists as follows: non-auditory tissue damage occurs between 183 and 213 dB-$SEL_{accumulated}$, with a sliding scale based on fish mass between 0.5 and 200 g; auditory tissue damage occurs between 189 and 213 dB-$SEL_{accumulated}$, and TTS occurs at 185 dB-$SEL_{accumulated}$. Injury thresholds have now been simplified to 206 dB_{PEAK} and 189 dB-$SEL_{accumulated}$ (unless the fish is < 2g) for impact pile drivers (Carlson et al. 2007). For vibratory-hammers with continuous sound, the $SEL_{accumulated}$ injury threshold is between 187 and 220 dB (Popper et al. 2006). As a conservative measure, NMFS and USFWS use 150 dB_{RMS} as the threshold for behavioral effects to ESA-listed fish species (e.g., Atlantic Sturgeon and Shortnose Sturgeon) for most biological opinions evaluating pile driving. The NMFS and USFWS cite that sound pressure levels in excess of 150 dB_{RMS} can cause temporary behavioral changes (startle and stress) that could decrease an individual's ability to avoid predators (Oestman et al. 2009).

Specifically for pile driving, underwater sound propagation models need to be integrated with pile structural acoustics models to estimate received levels of sound pressure and particle velocity in the vicinity of pile driving operations. This will help to define the project action area and the region where acoustic impacts to fish may occur. The project action area is defined as all areas that are predicted to be affected directly and indirectly by the federal action, not merely the immediate area involved in the action (Oestman et al. 2009). With regard to underwater sound from pile driving, the NMFS considers the project action area to be the underwater area where peak pile driving noise is predicted to exceed the ambient noise level (i.e., distance needed for the peak sound pressure level generated by pile driving activities to attenuate to a level that is equal to the ambient noise level) (Oestman et al. 2009). A similar process is used to estimate the acoustic impact area, which is based on the distance at which pile driving sound attenuates to a level that equals an injury threshold. In general, if the injury thresholds are not predicted to be exceeded beyond 10 m from the pile, no further analysis is necessary and no injury to fish is indicated. If the thresholds are predicted to be exceeded beyond 10 m from the pile, the acoustic impact area needs to be determined (Figure 1.2.5) (Oestman et al. 2009).

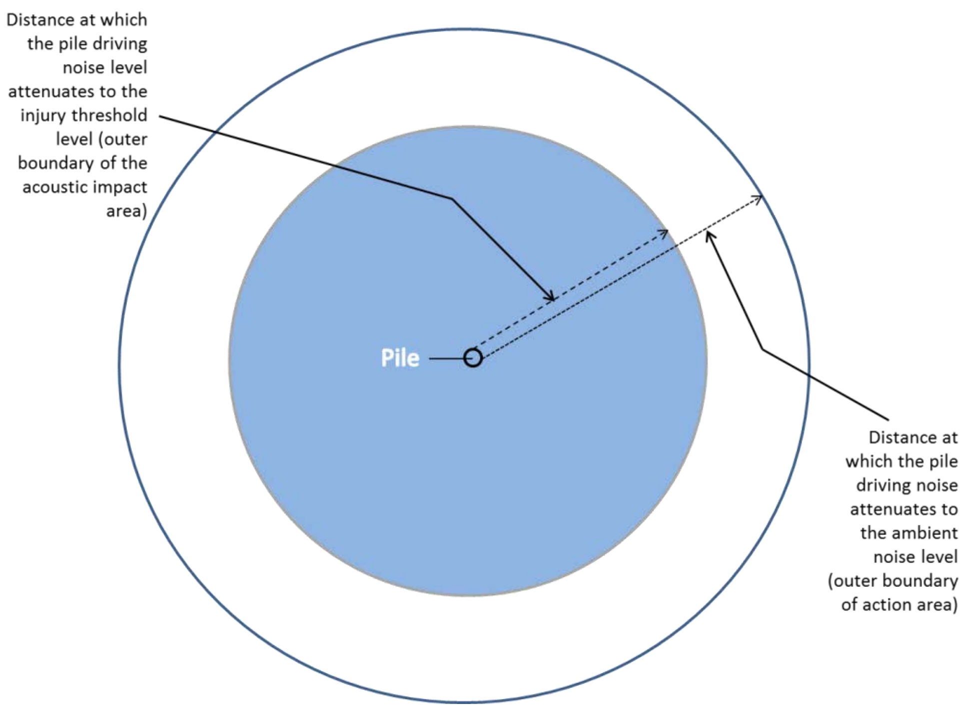

Figure 1.2.5: Defining the action area and the acoustic impact area for pile driving. Adapted from Oestman et al. 2009.

Sound Reduction Measures

Various engineering measures have been developed to reduce underwater sound generated by in-water development. For pile driving, these measures fall into two general categories: a) treatments that reduce the transmission of sound through the water, and b) treatments to reduce the sound generated by the pile during driving. The first category (a) includes simple unconfined air bubble curtains, multiple-stage unconfined air bubble curtains, confined air bubble curtains, and cofferdams. Use of the air bubble curtains during pile driving has reduced sounds substantially (Reyff 2009). Bubble curtains act as a barrier for the sound to pass through once the sound is radiated from the pile, and reduces the radiation of sound from the pile into the water by having the low-density bubbles very close to the pile (Oestman et al. 2009). Reyff (2009) reports that underwater sound tests were conducted with air bubble curtains with the air supplies turned on and off around a pile during driving. By using the curtain, the sound was reduced by 20 to 30 dBs close to the pile, which is where most fish injuries occur. Tests on other projects in shallower waters measured reductions of 10 to 20 dB (Reyff 2009). Noise reduction on the order of 40 to 50 dB is significant, and to put it into perspective, it is approximately the difference in sound pressure level between a busy city street (about 80 dB to 90 dB) and a quiet library (about 40 dB) (Wochner 2012). Areas with adverse effects on fish and marine mammals were estimated to decrease in size by up to 90% with the use of bubble curtains (Reyff 2009). Cofferdams are sometimes used during in-water and near-water pile driving. A cofferdam may be used for acoustic or non-acoustic reasons. Water-filled cofferdams provide only limited attenuation. Sometimes bubble curtains are used within a water-filled cofferdam if dewatering is not practical. Cofferdams that have been dewatered down to the mud line substantially reduce underwater pile driving sound. This is the best isolation that can be provided during pile driving (Oestman et al. 2009).

The second category includes alternative hammer types, such as vibratory hammers and oscillating, rotating, or press-in pile systems. The use of wood, nylon, and micarta pile caps also would fall in the second category. Vibratory hammers are often used on smaller piles. Although peak sound levels can be substantially less than those produced by impact hammers, the total energy imparted can be comparable to impact driving because the vibratory hammer operates continuously and may require more time to install the pile (Oestman et al. 2009). Other sound reduction systems utilize mechanisms for oscillating, rotating, or pressing in the pile (e.g., pile boring). These systems have limitations on pile size and type, and pile resistance. They are however, expected to generate substantially lower sound pressures than either impact or vibratory hammers. Pre-drilling the hole for the pile also can serve as a means to reduce the number of pile strikes needed to place a pile.

For dredging operations, submarine sound waves (i.e., any sound that interferes with communication, may cause damage to hearing, or diminishes the quality of the environment) varies by dredge type, movement of the dredge during operations, the waterbody depth and width, and type of sediment being dredged (WODA 2013, USACE 2015c). Dredging operations generally produce lower levels of sound energy, but may occur for prolonged periods of time than more intense construction activities (e.g., pile driving) (Nightengale and Simenstad 2001). These sounds have been documented to be continuous and at low frequencies (< 1000 Hz) (USACE 2015c). Dredge type influences sound, as cutterthead dredges have peak sounds at 100 to 110 dB up to ~500 m from the source; bucket dredges produce a repetitive sequence of sounds generated by winches, bucket impact with the substrate, bucket closing, and bucket emptying; hopper dredge hydraulically remove sediment through dragheads producing noise similar to that of a cutterhead dredge (USACE 2015c). Relatively deep offshore waters dredging may produce sound detectable at much greater distances than in shallow, estuarine environments (WODA 2013). Sound production from dredging activities is largely influence by sediment properties, as hard, cohesive and consolidated soils, require greater force to dislodge the material (Robinson et al. 2011). One major sound mitigation measure is to adequately maintain all dredging components on a regular basis (WODA 2013). Moreover, using a bucket dredge over a cutterhead or hopper dredge may reduce the consistent sound produced by the hydraulic dredge types. Using modeling approaches can also reduce risks related to dredging sound to fisheries species, by determining the best timing and dredge type to use for projects on a case-by-case basis.

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Section 2: Study Area

2.1 General Description of North Carolina and South Carolina

The scope of this project covers the spatiotemporal distribution of 13 fish and crustacean species that exhibit at least one estuarine-dependent life stage. North Carolina and South Carolina are located along the United States southeast coast (Figure 2.1.1). This coastal region is characterized by a gently sloping plain and large riverine estuaries, sounds, lagoons, and salt marshes. Prominent coastal rivers include the Roanoke, Neuse, Pamlico, and Cape Fear in North Carolina and Yadkin–Pee Dee, Edisto, Santee, and Savannah in South Carolina. Tributaries across the Carolinas drain vast expanses of palustrine, lacustrine, and riverine habitats from the eastern and central United States (Figure 2.1.2). These waters feed estuaries that transport and trap nutrients and sediment as the coastal region transitions from land to sea. Along the margin where estuaries mix with the ocean, North Carolina and South Carolina coastal areas are fringed by barrier islands, which play major hydrological and biological roles in estuarine processes (Mallin et al. 2000). North Carolina and South Carolina estuaries are among the most productive coastal ecosystems in the region. Their influence can be observed all along the outer coast eastward to the continental shelf and the Gulf Stream (i.e., a strong western boundary current of the north Atlantic subtropical gyre transporting significant amounts of warm water poleward) (Figure 2.1.2).

From the barrier islands, the continental shelf gradually deepens to approximately 50 to 60 m (164 to 197 ft) at the shelf break. The shelf is largely a soft-bottom system consisting of shallow (<1 m) relict sediments (i.e., medium and coarse sands with varying amounts of calcareous sands) overlying a series of sedimentary/calcareous lithofacies that outcrop to form rock-reef structures with up to 5 m (16 ft) relief. These hard bottom areas support a variety of associated fish communities (e.g., Snapper-Grouper complex) (Cahoon et al. 1990). From the shelf break seaward there is a rapid deepening, from approximately 50 km (31 miles) seaward of the North Carolina Capes, to about 100 km (62 miles) seaward from bays (Mallin et al. 2000). A topographic feature on the upper slope of the ocean bottom located about 145 km (90 miles) southeast of Charleston, South Carolina known as the "Charleston Bump," deflects the Gulf Stream eastward resulting in a quasi-permanent excursion of the Gulf Stream front downstream (Reddy and Raman 1994). Frequently observed features of the Gulf Stream in this region are warm-core folded-back filaments, or “shingles,” (Von Arx et al. 1955, Reddy and Raman 1994). Shingles oriented to the south are long, tongue-like extrusions of the Gulf Stream surface waters onto the shelf. Filaments occur frequently, 2 to 12 per month, on the North Carolina shelf (Pietrafesa 1983, Pietrafesa et al. 1994). Warm-core filaments are 100 to 300 km (62 to 186 miles) long and 10 to 50 km (6 to 31 miles) wide.

North Carolina

The North Carolina coast is framed by a chain of low-lying barrier islands extending from Virginia to the Cape Fear River Inlet (Figure 2.1.3). The predominantly flat and narrow barrier islands historically have been shaped by coastal forces such as waves, tidal currents, and winds. At geological time scales (>1000s of years), these barrier islands are ephemeral landforms dependent upon available sediment supply and sea level. At time scales relevant for coastal planning (decadal scales), the barrier islands exhibit continuous shoreline changes ranging from high erosion to high accretion. The northern part of the barrier islands, the Outer Banks, extends along a 322-km (200-mile) stretch of coastline adjacent to Albemarle-Pamlico Sound (Millan et al. 2000). The Albemarle-Pamlico Sound is the largest semi-enclosed estuarine system on the Atlantic Coast (Figure 2.1.1). It covers approximately 7,530 km^2 (2,907 mi^2) and has freshwater inputs from the Chowan, Roanoke, Tar-Pamlico, and Neuse Rivers (Figure 2.1.3). The Albemarle-Pamlico Sound extends southward to estuaries of moderate size including Core Sound, 264 km^2 (102 mi^2); Back Sound, 50 km^2 (19 mi^2); and Bogue Sound, 103 km^2 (40 mi^2). Moving south along the North Carolina coast and into South Carolina, estuaries constrict as a band of salt marshes, intersected by networks of tidal creeks, occupies areas between the mainland and barrier islands. A notable exception is the Cape Fear River, which flows directly into the Atlantic Ocean. Southwest of the Cape Fear River, dredging the Atlantic Intracoastal Waterway (AIWW) in the 1930s and maintenance activities have created an artificial extension of barrier islands in this region.

The North Carolina outer coast consists of a series of cuspate bays or coastal compartments, each with different spatial orientation and geologic character reflecting the adjacent continental shelf (McNinch and Luettich 2000, Riggs and Ames 2009). From north to south, three cuspate bays, Raleigh, Onslow, and Long, are defined by Cape Hatteras, Cape Lookout, and Cape Fear. These large capes and associated shoal complexes are prominent features extending to the continental shelf break. Frying Pan Shoals located off Cape Fear extends the farthest, approximately 48 km (30 mi). Cape-associated shoal complexes influence coastal circulation patterns. The shoal complexes are constantly changing. They shift under normal current regimes, but storm events are largely responsible for sediment transport, sand distribution, and shoal migration. A significant knowledge gap exists in understanding the role of cape-associated shoal complexes in the function and maintenance of North Carolina's barrier island system (Kalo and Schiavinato 2009).

Circulation along the nearshore, shallow coastal environment coupled with oceanic currents contribute to the unique biodiversity and ecology of the region. They are important drivers of finfish and crustacean larval dispersal and recruitment. Along the coast of North Carolina, currents within the nearshore environment are affected by shoreline morphology, depth, bathymetric features, and freshwater inputs. Coastal waters are greatly influenced by the Gulf Stream, which seasonally meanders to within 16 to 19 km (10 to 12 mi) off the coast of Cape Hatteras before turning northeast. The warm, north-flowing Gulf Stream mixes with the cool, south-flowing Labrador Current near Cape Hatteras, delineating mid and south Atlantic waters (Figure 2.1.2) (Menzel 1993). Salinity, temperature, oxygen, nutrients, light attenuation, and other environmental factors are all influenced by the Gulf Stream and Labrador Current.

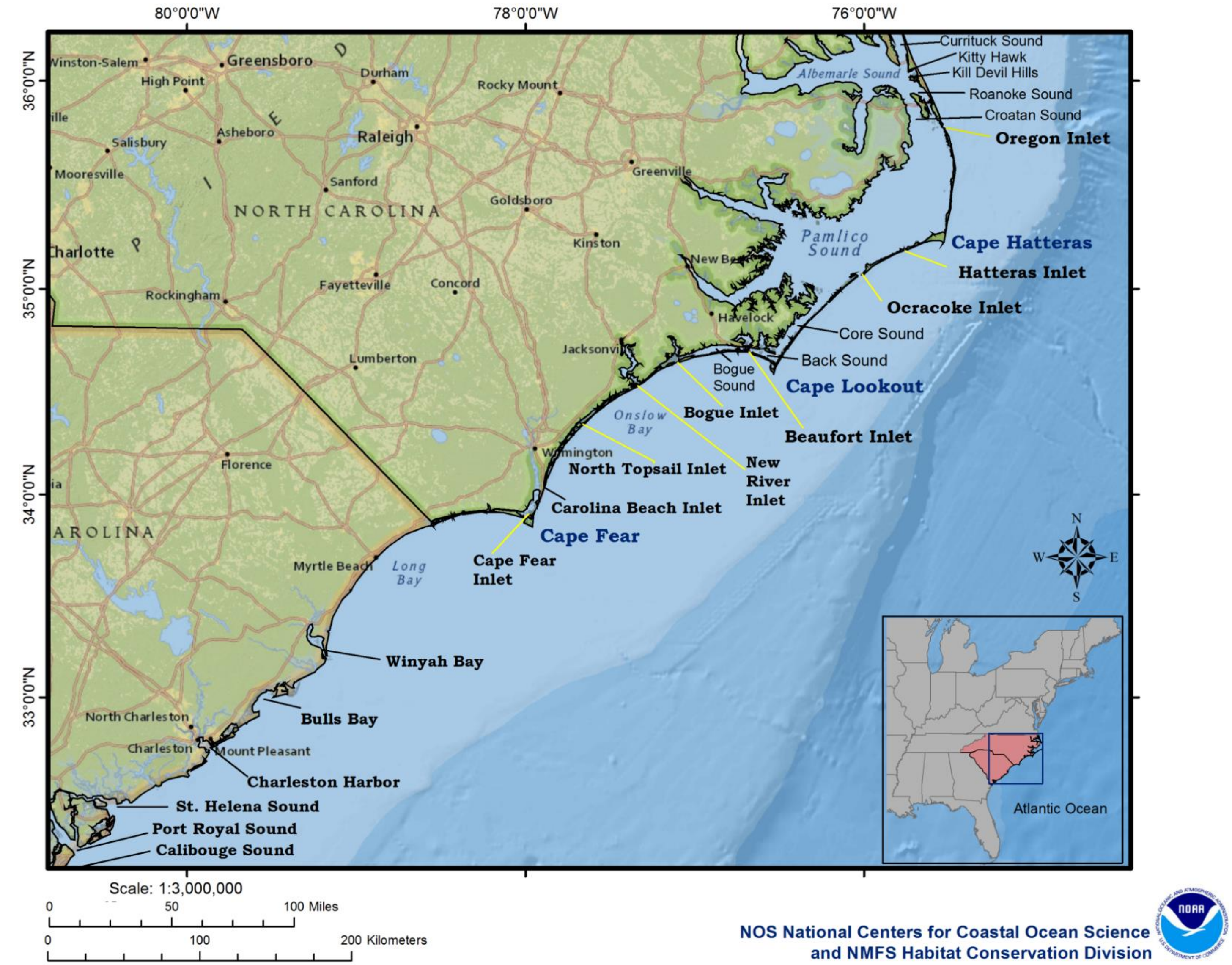

Figure 2.1.1: Inlets, capes, bays, and sounds of North Carolina and South Carolina. In South Carolina, many rivers drain directly into the ocean. North Carolina only has the Cape Fear River and New River flowing directly into the ocean, while all others flow into the sounds.

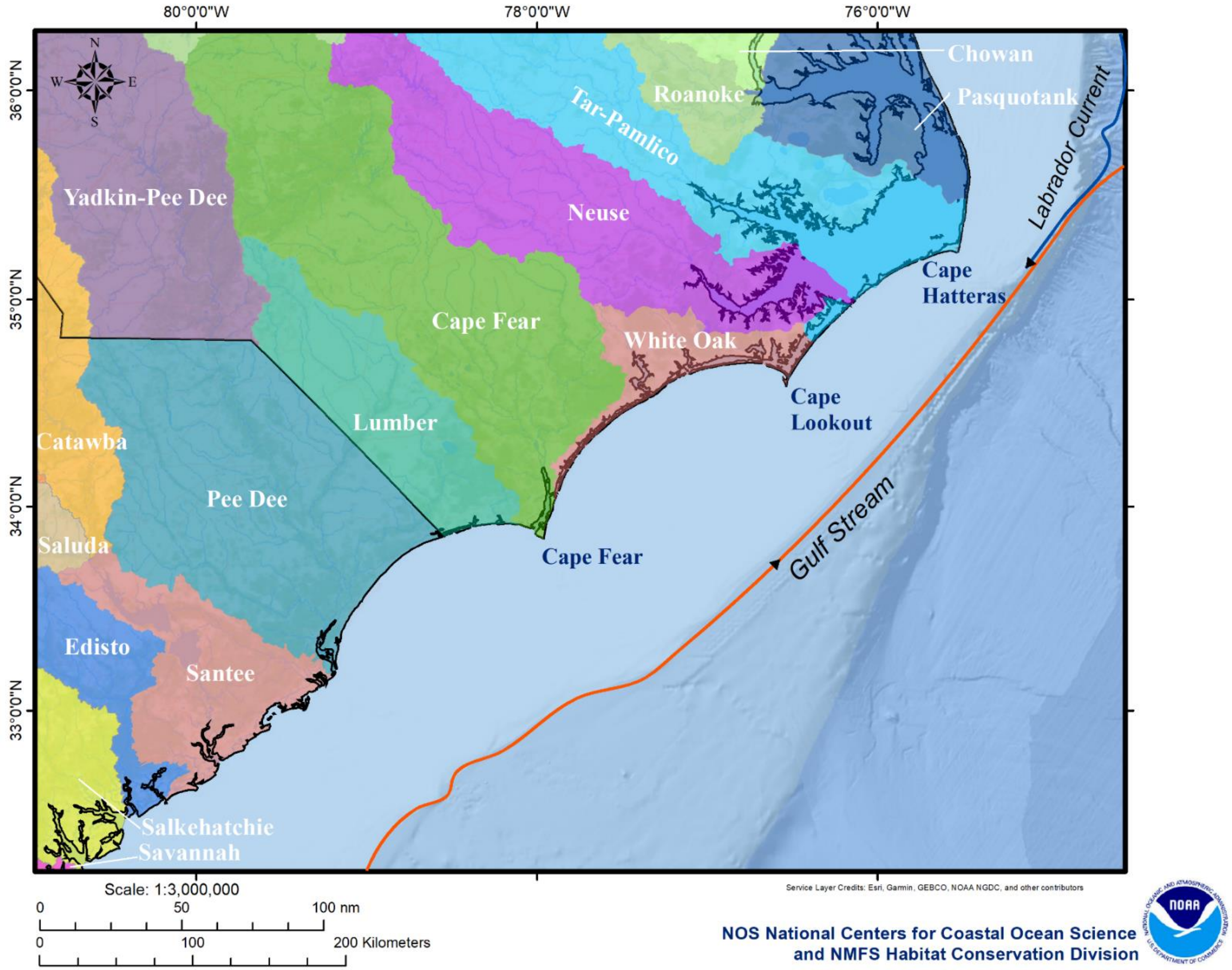

Figure 2.1.2: Watersheds across North Carolina and South Carolina. The Gulf Stream is highlighted by an orange line with an arrow indicating direction of flow. The Labrador Current is indicated by a blue line with an arrow indicating general direction of flow.

Figure 2.1.3: Detailed map of North Carolina river systems, sounds, inlets, and the land that encompasses the Outer Banks (outlined in yellow).

South Carolina

The coastal plain of South Carolina extends inland a distance ranging from 193 to 241 km (120 to 150 mi). It includes an area of more than 51,800 km^2 (20,000 mi^2) or nearly two-thirds of the State. This region is drained by the Pee Dee, Santee, and Savannah rivers as well as many smaller streams. Along the northern coastal region, Winyah Bay is the third largest estuary on the East coast. It is fed by the blackwater of the Waccamaw and Black rivers and Pee Dee River flowing from the Piedmont (Figure 2.1.1). The lower watershed sustains 498 km^2 (192 mi^2) of forested wetlands and 93 km^2 (36 mi^2) of tidal freshwater marshes. Adjoining Winyah Bay is North Inlet, a salt marsh estuary consisting of a meandering maze of high salinity tidal creeks. Further south lies the Santee River estuaries, formed from Piedmont drainages (Millan et al. 2000). The principal urbanized estuarine system in South Carolina is Charleston Harbor, fed by the coastal plain-derived Ashley and Wando rivers and the piedmont-derived Cooper River. Moving southwest, the lowland Stono River and Edisto River estuaries follow. Further down the coast, St. Helena Sound and the Broad River estuary are composed of numerous tidal creeks, islands, and salt marshes. In contrast to North Carolina, most large estuaries in South Carolina are open to the ocean. The continental shelf off South Carolina extends approximately 160 km (100 mi) and is broad and flat, with exception of the Charleston Bump, an area of rugged bottom topography. It is a deepwater bank that rises from depths of over 700 m (2300 ft). The Charleston Bump deflects the Gulf Stream offshore 30 to 40 km (18.6 to 24.8 mi) seaward of the shelf break (Pietrafesa et al. 1985). The deflection of the Gulf Stream at the Charleston Bump also sets up the Charleston Gyre, which is an eddy of warm Gulf Stream water that splits off the Stream at the Bump, and moves inshore. During periods of strong Gulf Stream flow, the Charleston Gyre is very prominent, and brings Gulf Stream water close to shore. This circulation, mixing, and upwelling bring nutrient rich, deep water to the surface and enrich significant fish habitat.

Special Consideration for Latitudinal Gradients from North Carolina to South Carolina

Latitudinal gradients and habitat characteristics can lead to temporal distinctions among species in North Carolina and South Carolina. Latitudinal gradients in temperature, salinity, and other environmental variables can affect migration, spawning, recruitment, and use of certain habitats. Variation in temperature across the Carolinas is influenced greatly by seasonal patterns in weather and climate. For example, coastal waters warm early in the spring off South Carolina (lower latitude) as compared to North Carolina (higher latitude). These environmental conditions lead to slight temporal differences (i.e., weeks) in life stage development and associated movements. White Shrimp are a well-known species exhibiting differences in spawning, habitat selection, growth, osmoregulation, movement, migration, and mortality because of water temperature differences (Muncy 1984). Shrimp early life stages may be staggered over time with larvae in warmer waters developing more rapidly and sooner than cooler waters. Similarly, latitudinal variation in life history has been noted for Summer Flounder. Large juveniles located north of Cape Hatteras demonstrate a north-south, inshore-offshore movement when they migrate from estuaries (Monaghan 1996). In contrast, Summer Flounder south of Cape Hatteras do not exhibit the same patterns in movement. Summer Flounder juveniles > 300 mm (11.8 in) TL rarely occupy estuaries south of Cape Hatteras, but larger fish are found around inlets and along coastal beaches (Packer et al. 1999).

Some habitat forms vary between states due to geological variations. Along the North Carolina Outer Banks, SAV occupies vast areas within the shallow estuaries and sounds. There is a clear absence of SAV in South Carolina. Often, shell bottom habitats in South Carolina are used as fish habitat in the absence of SAV for developmental stages of species discussed herein (e.g., juvenile Gag). The distinctive geography of the North Carolina coastline with large sounds and bays protected by barrier islands is much different from South Carolina's coastline, dominated by barrier islands, smaller estuaries, and tidal creek habitats. Many rivers in North Carolina flow into large sounds and bays. The Cape Fear River is the exception because if flows directly into the ocean. All coastal rivers in South Carolina flow directly into the ocean. This can lead to distinct differences in salinity in estuarine and inlet areas of North Carolina relative to South Carolina. In many cases, southeastern North Carolina is more closely related to the spatiotemporal distribution and movement of fishes in South Carolina waters (e.g., American Shad, River Herring). These distinct spatiotemporal differences in ecosystem characteristics are critical to timing and movement of various species' life stages into and out of estuarine environments, and when moratoria are most effective for conservation.

2.2 Habitat Categories

Fish habitat is defined as freshwater, estuarine, and marine areas supporting juvenile and adult populations of economically important fish species (commercial and recreational), as well as forage species important in the food chain (Lellis-Dibble et al. 2008). Essential Fish Habitat (EFH) are those waters and substrate necessary for fish to spawn, breed, feed, or grow to maturity (NMFS 2004). These habitats are essential because without these prime locations fish would not be able to survive (NMFS 2015). Land areas adjacent to and periodically flooded by riverine and coastal waters are also included within the fish habitat description. Fish occupy specific areas where conditions are suitable for growth and foraging, protection, and reproduction. A species' use of specific habitats depends upon various factors, including life stage, time of day, and tidal stage (NCDEQ 2016). Together these habitat areas form a functional and interconnected system that supports the fish from its earliest life stage until death. Within North Carolina and South Carolina's coastal zone, multiple habitat types were distinguished based on physical properties, ecological functions, and habitat requirements for living components including water column, shell bottom, SAV, wetlands, soft bottom, and hard bottom (Thayer et al. 2003). South Carolina does not have seagrass beds because of high freshwater input, high turbidity, and large tidal amplitude (vertical tide range) inhibit their occurrence (USACE 2014); rather juveniles (< 75 mm or 3 in) are found in high marsh areas with shell hash and mud bottoms (Thayer et al. 2003). Detailed documentation and descriptions of each habitat type can be found in the NMFS Our Living Oceans: Habitat (NMFS 2015), NOAA Coastal

Ocean Program's description of coastal habitats (Thayer et al. 2003), and the 2015 North Carolina Coastal Habitat Protection Plan Source document (NCDEQ 2016).

Most fish rely on a variety of habitats throughout their life cycle. The integrity of the entire system depends upon the health of areas and individual habitat types within the system. Certain conditions are necessary for proper development of particular life stages within each habitat. Here, we primarily focus on providing descriptions of estuarine habitats, but we have also included descriptions of offshore hard bottom habitats as they are important to some of the species reviewed (e.g., Gag).

Water Column

Water column habitat is defined by Street et al. (2005) as the water covering submerged surfaces (from the surface to the substrate) along with its physical, chemical, and biological characteristics. The biological constituents of the water column are intricately tied to the chemical and physical properties of the water column, including fish distribution (Street et al. 2005). As the medium through which all aquatic habitats are connected, the water column provides basic ecological roles and functions for organisms within, both by itself and by influencing the benthic community and sediments, and vice versa, through integrated events and processes such as resuspension, settlement, and absorption (Warwick 1993). The coastal aquatic ecosystem includes the river basins draining into the estuarine and marine systems (Figure 2.1.3). Within each river basin, characteristics change from the headwaters to the ocean, resulting in spatiotemporal differences in fish assemblages (NCDEQ 2016). For the discussion of fisheries habitats, four major ecosystems are connected via the water column: riverine, estuarine, shallow marine, and oceanic (NCDEQ 2016).

1. Riverine (above the salt wedge): Between headwater and head-of-tide; negligible salinity.
2. Estuarine: From the head-of-tide to a free connection with the open sea where seawater mixes with fresh water; variable salinity. Upper estuary describes where rivers enter estuary; Lower estuary describes where estuarine habitat meets the inlets
3. Shallow marine: Less than 200 m (656 ft) depth; between the estuarine and coastal boundary and the boundary of the U.S. Exclusive Economic Zone (EEZ).
4. Oceanic: Greater than 200 m (656 ft) depth; located within the U.S. EEZ.

Estuarine ecosystems are dynamic, lotic waters with a diverse array of substrates and high biodiversity of organisms. Estuarine habitats are generally characterized by zones of mixing of saltwater and freshwater (Cowardin et al. 1979). Estuaries have tidally- and wind-influenced tides, with the upstream and landward limit defined by the point where ocean-derived salts cause the water to have salinity 0.5 psu during the period of average annual low flow conditions (Cowardin et al. 1979). The seaward limit of estuaries is an imaginary line closing the mouth of a river, bay, or sound (Cowardin et al. 1979, Deaton et al. 2010). Typically, salinity and temperature are the two water column parameters that act as major cues for species movement, life stage range limits, and trigger spawning movements within and out of estuarine systems. These two parameters are discussed in more detail here, with the remainder of parameters given a brief description.

Salinity gradients are commonplace in estuaries as the freshwater meets the saltwater (Figure 2.2.1). Salinity zones within estuaries change with flow patterns, weather, and tidal flux. Salinity is generally lowest from December through spring, and highest from summer through early fall (Orlando et al. 1994). Estuarine salinity classifications based on NOAA mapping (Nelson 2015) are as follows:

a) 0.5 to 5 psu = low salinity
b) 5.0 to 15 psu = moderate salinity
c) 15 to 25 psu = high salinity
d) 25 to 30 psu = inlet salinity

Salinity and proximity to inlets are key factors in estuarine fish distribution (Ross and Epperly 1985, Noble and Monroe 1991, Szedlmayer and Able 1996). Some species, or species life stage, tolerate large variations in salinity, while others cannot. The presence or absence of species across salinity gradients has been used to determine biologically relevant salinity zones, habitat suitability, and describe EFH (Bulger et al. 1993, Rubek et al. 1998).

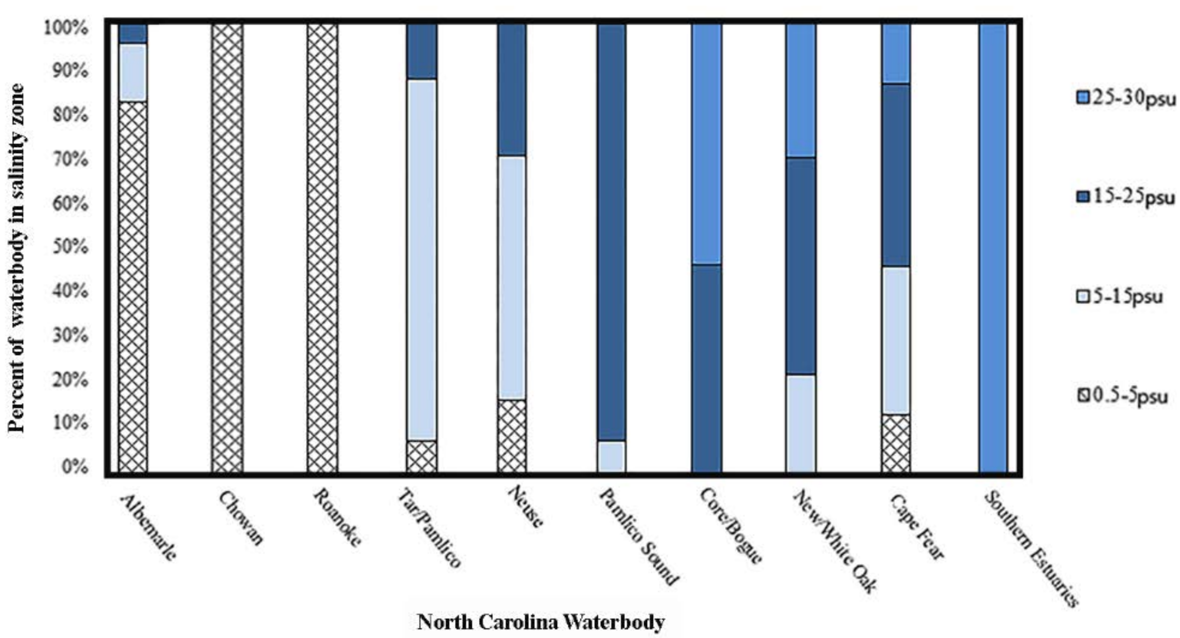

Figure 2.2.1: Estuarine salinity zones within North Carolina watersheds. Source: NOAA's 1:100,000 scale salinity mapping project (Coastal Ocean Resource Assessment Program).

Temporal and spatial variations and patterns in temperature in coastal waters affect fish distribution and function (NCDEQ 2016). Beginning in river systems, temperature increases from headwaters to estuaries, based on elevation, air temperature, shading, and velocity, acting as primary cues for anadromous fish spawning. The maximum temperature variation within North Carolina’s estuaries occurs seasonally, particularly due to spring flows (NCDEQ 2016). For example, the average monthly temperature in the Pamlico River ranges from 5 °C (41 °F) in January to 27 ºC (81 °F) in July and August (Copeland et al. 1984). Estuarine water temperature also responds to tidal changes (Peterson and Peterson 1979). Near ocean inlets, estuarine water temperatures rise with the incoming tide during winter, but during summer months, the incoming tide is relatively cooler (Peterson and Peterson 1979). Estuarine organisms that can tolerate a wide range of temperatures, still require adequate acclimation time (Nybakken and Bertness 2004). However, early life stages of certain species (e.g., Summer Flounder, Southern Flounder) have lower tolerances than adults and therefore may be more susceptible to extreme variations in temperature than juveniles or adults (Kennedy et al. 1974). These estuarine-dependent species in the near-shore ocean have a broader tolerance to temperature changes and therefore can tolerate greater extremes in these dynamic ecosystems (Reagan and Wingo 1985).

As with temperature, dissolved oxygen (DO) levels for survival and growth vary by organism, as some are more resilient in low DO conditions than others (e.g., Atlantic Blue Crab), and others are highly mobile and can avoid areas of low DO (e.g., fish) (NCDEQ 2016). Growth of actively swimming fish can be reduced at DO concentrations <6 mg/l, metabolism is reduced at 4.5 mg/l, and feeding can be reduced at 5.5 mg/l (Gray et al. 2002). The pH of water affects egg development, reproduction, and fish rate of DO absorption (Wilbur and Pentony 1999). Most fish require pH >5.0, with deviations potentially reducing diversity and reproduction (Wilbur and Pentony 1999). The pH of seawater ranges between 7.5 and 8.5, but is quite variable in estuaries with fluctuations occurring between day and night, with dense vegetation, and with the amount of mixing of fresh and saltwater (Nybakken and Bertness 2004, NCDEQ 2016). pH is also affected by hypoxia and eutrophication events, leaving to the acidification of subsurface coastal waters (Cai et al. 2011). Mean high water velocity and relatively deep water are important habitat variables to anadromous fish species during spawning and recruitment periods, while other estuarine-dependent species have larvae and juvenile stages that prefer relatively shallow areas with low mean water velocities (e.g., shallow, side-channel habitats) (Ross and Epperly 1985, Noble and Monroe 1991). Water clarity and light penetration through the water column may be reduced by TSS potentially affecting visibility of food for pelagic organisms (Bruton 1985), reducing reactive distance for visual feeders (Barrett et al. 1992, Gregory and Northcote 1993), volume of water searched, and feeding efficiency (Benfield and Minello 1996, Lindquist and Manning 2001). Moderately turbid waters may benefit small fish by offering protection from predators and increasing overall survival (Bruton 1985).

Shell Bottom

For the purposes of this review, shell bottom habitat is defined as estuarine intertidal or subtidal substrate comprised of surface shell concentrations of living or dead oysters (*Crassostrea virginica*), hard clams (*Merceneria merceneria*), and other shellfish (Street et al. 2005) (Figure 2.2.2, Figure 2.2.3). Shell bottom habitat occurs in both North Carolina and South Carolina waters. Shell bottom can consist of fringing or patchy oyster reefs, surface aggregations of living shellfish, and shell accumulations (Coen et al. 1999, Coen and Grizzle 2007). Oysters are found throughout the North Carolina coast, from southeast Albemarle Sound to South Carolina, and in South Carolina from Long Bay to Calibogue Sound (Figure 2.2.2, Figure 2.2.3). In North Carolina, intertidal oyster reefs in the central and southern estuarine systems may be a few oysters thick, while subtidal oyster mounds in Pamlico Sound may be several meters tall (Lenihan and Peterson 1998). In the Albemarle-Pamlico estuarine system, oyster beds are concentrated in the lower portion of Pamlico Sound tributaries, along the western shore of Pamlico Sound, and behind the Outer Banks (Epperly and Ross 1986). South of Cape Lookout, subtidal oyster reefs occur in the New, Newport, and White Oak Rivers (NCDMF 2001). Extensive intertidal beds occur in the southern estuaries, with ample lunar tides (NCDEQ 2016). Plentiful shell hash exists in New River, eastern Bogue Sound, and stream and channel edges. In South Carolina, oyster reefs are most abundant in intertidal areas with some subtidal distribution to a depth of 2 to 3 m (6 to 9 feet). In contrast with oyster beds in Pamlico Sound, North Carolina, most oyster beds in South Carolina develop in areas with high salinities. Analyses of estuarine habitat productivity ratios indicate secondary production (organisms that consume primary producers) on oyster reefs is an order of magnitude greater than in *Spartina* marshes, soft bottom, SAV, and mangrove forests (English et al. 2009).

Shell bottom provides critical habitat for the ecologically and economically important finfish and shellfish discussed herein. The functional value of shell bottom for fish and shellfish includes aggregation of spawning stock and larvae and juvenile refuge from predators (Coen et al. 1999). Fish that utilize shell bottom can be classified into three categories: resident, facultative resident, and transient (Coen et al. 1999, Lowery and Paynter 2002, Coen and Grizzle 2007). Resident species use shell bottom as their primary habitat for breeding, feeding, and refuge. Facultative resident species are generally associated with structured habitats such as shell bottom, and depend on it for food. Transient species are wide-ranging, using shell bottom for refuge and foraging, but do not depend upon the habitat. While reef residents often dominate in abundance (e.g., juvenile Gag), transients are frequently the most diverse.

Submerged Aquatic Vegetation

SAV habitat includes marine, estuarine and riverine vascular plants that are rooted (NCDEQ 2016). SAV occurs in North Carolina, but is not a significant habitat in South Carolina waters. Regulatory ruling defines habitat to include areas where SAV is present, or areas where there is documentation or professional knowledge of its presence within the past ten growing seasons. Along the Atlantic coast, North Carolina supports more SAV (approximately 200,000 acres of SAV) than any other state, except for Florida (Funderburk et al. 1991, Sargent et al. 1995). The distribution, abundance, and density of SAV varies from year to year and seasonally (Thayer et al. 1984, Dawes et al. 1995, Fonseca et al. 1998, SAFMC 1998). Most habitat for SAV in coastal North Carolina occurs along the Outer Banks estuarine shoreline (Pamlico and Core/Bogue Sounds), with sparse coverage along the mainland shores (Figure 2.2.2) (Ferguson et al. 1989). Estuarine SAV occurs sporadically and in small patches south of Bogue Inlet to the South Carolina border (Ferguson and Wood 1994, NCDEQ 2016).

SAV is recognized as essential fish habitat (EFH) because of five interrelated features: primary production, structural complexity, modification of energy regimes, sediment and shoreline stabilization, and nutrient cycling (USACE 2014). Water quality enhancement and fish utilization are especially important ecosystem functions of SAV relevant to the enhancement of coastal fisheries. Many fish species occupy SAV at some point in their life cycles (Thayer et al. 1984), making the use of the critically important habitat contributing to species' refuge, spawning, nursery, foraging, and corridor needs (NCDEQ 2016). Because of the seasonal abundance patterns of SAV, refuge, and foraging habitat are provided almost year round for estuarine-dependent species (Steel 1991). Fish and invertebrates' use of SAV differs spatially and temporally due to distribution ranges, time of recruitment, and life histories (Nelson et al. 1991, Hovel et al. 2002, Heck et al. 2008). The SAFMC considers SAV as EFH for Brown, White, and Pink Shrimp, and species in the Snapper-Grouper Complex. Notable anadromous species utilizing SAV habitat are American Shad and River Herring (NCDEQ 2016). SAV habitats are also critical areas for Red Drum, particularly for one and two year old fish (SAFMC 1998, Thayer et al. 2003, Odell et al. 2017). Seagrass beds in shallow areas of estuarine rivers and mainland shorelines are also where many Red Drum reside during the summer.

Wetlands

Wetlands are among the most important, productive ecosystems on Earth, acting as essential breeding, rearing, and feeding grounds for many species of finfish and crustaceans (Mitsch and Gosselink 2015). Wetland habitats occur in both North Carolina and South Carolina, and are generally characterized as having water at or near the surface, and vegetation adapted to wet soils, and include swamp forest, bottomland hardwood, pocosin areas, and salt and brackish marshes (Figure 2.2.2, Figure 2.2.3) (Mitsch and Gosselink 2015). It is estimated that over 95% of the finfish and shellfish species commercially harvested in the United States are wetland-dependent (Feierabend and Zelazny 1987). In the southeast, fish and shellfish depending on coastal and estuarine wetlands comprise the majority of the commercial catch (Lellis-Dibble et al. 2008). Of fisheries in North Carolina, Penaeid shrimp and Red Drum are considered critically linked to the marsh edge (SAFMC 1998, Stunz et al. 2002). Expanses of vegetated shallow water habitat in freshwater wetlands provide food and cover for larval, juvenile and small organisms (Graff and Middleton 2001), and refuge from predators is provided by dense structures, shallow depth, and the expanse of water (Rozas and Odum 1987). Along with the shallow soft bottom and shell hash borders, salt/brackish marshes along the North Carolina and South Carolina coasts are probably the most recognizable nursery habitat for estuarine-dependent species. In eastern North Carolina, salt marsh communities can be found along 72,420 km (4,500 miles) of coastal shoreline, which encompasses 849,840 ha (2.1 million acres) of estuarine habitat (NCCF 2007, USACE 2014).

Soft Bottom

Soft bottom habitat is described by Street et al. (2005) as unconsolidated, non-vegetated sediment occurring in freshwater, estuarine, and marine systems, including subtidal bottom and shallow intertidal flats (Figure 2.2.2, Figure 2.2.3). Soft bottom habitat occurs in both North Carolina and South Carolina waters. The only requirement for the persistent soft bottom fish habitat is sediment supply. Environmental parameters (e.g., grain size, salinity, DO, flow conditions) affect the condition of soft bottom habitat and its inhabitants, but the habitat will persist regardless of colonization by organisms. Soft bottom covers ca. 90% (1.9 million acres) of 2.1 million acres of estuaries and coastal rivers in North Carolina (Riggs 2001). Soft bottom is in a constant state of flux, as other habitats expand or contract within these various ecosystems (NCDEQ 2016). Freshwater soft bottom habitat includes unvegetated shorelines, river, creek and lake bottoms; estuarine soft bottoms include intertidal flats and unvegetated shorelines; and marine soft bottom habitat includes intertidal beach areas and subtidal bottom (NCDEQ 2016). Unvegetated bottom within salt marshes may even act as a corridor by increasing faunal access to vegetated habitats (Zimmerman and Minello 1984).

The physio-chemical makeup of soft bottom habitats is based on the underlying geology, basin morphology, and related physical processes (Riggs 1996, Riggs and Ames 2003, NCDEQ 2016). North Carolina's Cape Lookout demarks geologically distinct northern and southern coastal regions where soft bottom sediment differs (Riggs 1996, Pilkey et al. 1998, Riggs and Ames 2003). In the coastal area north of Cape Hatteras, sediment formations are thick, slightly or unconsolidated muds, muddy sands, sands, and peat sediment lying in low sloping areas characterized by extensive systems of drowned river estuaries (e.g., Albemarle Sound), long barrier islands, and few inlets (NCDEQ 2016). In contrast, the coastal sediments south of Cape Hatteras are a thin and variable layer of surficial sands and mud overlying rock platforms. The area has a steeper sloping shoreline relative to the northern area, resulting in narrow estuaries (e.g., Topsail Sound, Stump Sound), short barrier islands, and numerous inlets (NCDEQ 2016).

Most coastal fishes in North Carolina use soft bottom. Estuary-dependent migratory species (e.g., Penaeid Shrimp) are common inhabitants of the estuarine soft bottom during summer and fall (Weinstein 1979, Epperly 1984, Noble and Monroe 1991, Ross 2003, NCDEQ 2016). Habitat use patterns by fishes on soft bottom are primarily related to season and ontogenetic stage (Walsh et al. 1999, Ross 2003). Fish that forage on estuarine soft bottom are predators of benthic invertebrates and include juvenile and adult flatfish, Red Drum, Atlantic Sturgeon, Shortnose Sturgeon, and Gag Grouper (Peterson and Peterson 1979, Bain 1997, Thorpe et al. 2004). Anadromous fishes require a corridor of soft bottom to reach upstream spawning areas and use soft bottom as nursery habitat as larvae move downstream in coastal rivers during spring and summer (NCDEQ 2016). Juvenile Atlantic Sturgeon are documented over nearshore subtidal bottom between Oregon Inlet and Kitty Hawk during winter months (Laney et al. 2007). Juvenile Red Drum are documented spawning on the west side of Pamlico Sound at the mouth of the Bay River and in estuarine channels near Ocracoke Inlet (Luczkovich et al. 1999, Luczkovich et al. 2008). The evidence for Blue Crabs spawning in soft bottom inlet areas warranted Crab Spawning Sanctuaries (Figure 2.2.4) (NCDMF 2004).

Hard Bottom

Hard bottom habitat is characterized by exposed areas of rock or consolidated sediments, set apart from contiguous unconsolidated sediments, possibly with a thin surface of live or dead biota, generally found beyond the estuarine ecosystem in oceanic waters (Figures 2.2.2, 2.2.3) (Street et al. 2005). Hard bottom habitat exists in both North Carolina and South Carolina waters. In addition to natural hard bottom areas, man-made structures such as artificial reefs, shipwrecks, jetties, and groins provide substrata for the development of hard bottom communities (Street et al. 2005). The North Carolina Department of Cultural Resources Underwater Archaeology Branch estimates >1,000 sunken vessels off the North Carolina coast dating back to the earliest period of European exploration. There are 50 artificial reefs in North Carolina that are managed by NCDMF; 29 are located in federal waters, 13 in state ocean waters, and 8 in estuarine waters (NCDEQ 2016). There are 49 artificial reefs in South Carolina managed by SCDNR (SCDNR 2006). There are two jetty systems and four groin systems along the North Carolina ocean shoreline. A single jetty is situated on the west side of Cape Lookout, while Masonboro Inlet has jetties on both sides. The groins are located on the south side of Oregon Inlet, off the former site of the Cape Hatteras Lighthouse, on the west side of Beaufort Inlet, and on the terminal end of Bald Head Island. In South Carolina, jetties occur off Folly Beach and Charleston Harbor (Figure 1.2.1, Figure 1.2.4).

Natural hard bottom habitat (i.e., live bottom) occurs in warm-temperate and subtropical areas of the South Atlantic Bight, but is less extensive in North Carolina as it is the northern end of its range (NCDEQ 2016). This habitat extends from the shoreline and nearshore (within NC's 5.6 km jurisdictional limit) to beyond the continental shelf edge (>200 m deep), commonly occurring in clusters (Figure 2.2.2) (SEAMAP-SA 2001). Hard bottoms, through the process of bioerosion, contribute substantial volumes of sand to sediment-starved sections of the North Carolina continental margin, (e.g., Onslow and Long Bays) (Riggs et al. 1996, Riggs et al. 1998). Although a number of attempts have been made, estimations of the total area of hard bottom are confounded due to the discontinuous or patchy nature of this habitat type (SAFMC 2009a). The SEAMAP-SA Deepwater Bottom Mapping Project identified 34 natural hard bottom sites in the waters off North Carolina, many of which are concentrated in Onslow Bay (Udouj 2007). Parker et al. (1983) estimated hard bottom accounts for approximately 14% (504,095 acres) of the substratum between 27 and 101 m depth from Cape Hatteras to Cape Fear, and 30% (1,829,321 acres) between Cape Fear and Cape Canaveral. Over 92% of the identified nearshore hard bottom is south of Cape Lookout, predominantly in the southern half of Onslow Bay and in northern Long Bay. Concentrations of nearshore hard bottom habitat occur seaward of inlets, such as Bogue, New River, New Topsail, Masonboro, Carolina Beach, Lockwood's Folly and Shallotte inlets (NCDEQ 2016). Cape Lookout and Cape Fear were included in Amendment 6 to the Coral, Coral Reefs, Live/Hard Bottom Habitats of the South Atlantic Region Fishery Management Plan establishing coral as an EFH Habitat Areas of Particular Concern (HAPC) (Figure 2.2.2) (SAFMC 2009b).

Surveys conducted by Lindeman and Snyder (1999) found that over 80% of the fish occupying this habitat were from early life stages and an estimated 34 fish species used it as a nursery area (Greene 2002). Species composition and abundance of algae, invertebrates, and reef fishes at hard bottom habitats in North Carolina and South Carolina vary with bottom water temperatures, ranging from approximately 11 to 27 °C (52 to 81 °F) over the continental shelf and shelf-edge due to the proximity of the Gulf Stream, with lower shelf habitat temperatures varying from 11 to 14 °C (52 to 58 °F), and nearshore habitats are typically cooler (SEAMAP

2001). Depths range from 17 to 27 m (54 to 90 ft) for live-bottom habitats, 55 to 110 m (180 to 360 ft) for the shelf-edge habitat, and from 110 to 183 m (360 to 600 ft) for the lower-shelf habitat (SAMFC 1998, SEAMAP 2001, Sedberry et al. 2001). Changes in water masses, seasonal fluctuations in water temperature, and light penetration may physically stress the hard bottom community in the Carolinas (Kirby-Smith 1989).

Nursery Habitats

Nursery habitats are not a physical habitat specifically, but a classification of habitats, which provide protection, foraging opportunities, and suitable environmental conditions for growth, development, and survival of fishes and crustaceans during early life history. Compared to other habitats, nursery habitats support greater contributions of juveniles to adult recruitment because of these attributes (Beck et al. 2001). Many estuarine and coastal ecosystems provide important nursery habitat. Failure to adequately protect these areas could result in a recruitment bottleneck to multiple fisheries. In North Carolina and South Carolina, some spatially explicit nursery areas are recognized by NMFS and the regional fishery management councils as EFH HAPC. These nursery areas identified through extensive surveys conducted by state agencies and granted special protection under state law (Table 2.2.1).

The North Carolina Division of Marine Fisheries (NCDMF) has designated about 595 km^2 (230 mi^2) of nursery areas throughout North Carolina (Figure 2.2.4). These areas generally comprise the upper reaches of tidal creeks and rivers and may include coastal wetlands, shell-bottom and soft subtidal bottom habitats. The NCDMF delineates nursery areas as either a Primary Nursery Area (PNA) or Secondary Nursery Area (SNA). PNAs are areas of the estuarine system where larval development occurs. These areas are located in the uppermost sections of a system where populations are uniformly early juveniles. SNAs are areas of the estuarine system where juvenile development occurs. Populations are usually composed of developing sub-adults of similar size, which have migrated from upstream PNA to the SNA located in the middle portion of the estuarine system. The North Carolina Wildlife Resources Commission (NCWRC) designates PNAs for inland waters under their jurisdiction. The NCWRC also designates Anadromous Fish Spawning Areas (ASFA) where evidence of anadromous fish spawning has been documented by direct observation of spawning, capture of ripe females, or capture of eggs or larvae.

South Carolina considers all major estuaries and tidal creek areas as nursery habitat (Figure 2.2.3). Long-term monitoring conducted by the South Carolina Department of Natural Resources (SCDNR) shows the value of tidal creeks as nursery habitat supporting a significantly higher abundance and biomass of finfish and crustaceans than observed at open water sites (Van Dolah et al. 2002). The State of South Carolina grants protection for nursery habitats by classifying them as Outstanding Resource Water. This designation indicates the waterbody constitutes an outstanding ecological resource. Such waters include: waters within national or state parks or wildlife refuges; waters supporting threatened or endangered species; waters under the National Wild and Scenic Rivers Act or South Carolina Scenic Rivers Act; waters known to be significant nursery areas for commercially important species or known to contain significant commercial or public shellfish resources; or waters used for or having significant value for scientific research and study (SCDHEC 2014).

Table 2.2.1: State regulations that designate areas that serve as nursery habitat and warrant special protection under state law. These areas are "state-designated nursery habitat" under the EFH or EFH-HAPC designations for penaeid shrimp, snapper-grouper species, and coastal migratory pelagic species.

State	Designation	Regulation
North Carolina		
	Inland Primary Nursery Areas	15A NCAC 10C .0503
	Primary Nursery Areas	15A NCAC 03R .0103
	Permanent Secondary Nursery Areas	15A NCAC 03R .0104
	Secondary Nursery Areas	15A NCAC 03R .0105
	Strategic Habitat Areas and Critical Habitat Areas	Coastal Habitat Protection Plan (NCDEQ 2016)
	Crab Spawning Sanctuaries	15A NCAC 03R .0110
	Oyster Sanctuaries	15A NCAC 03R .0117
	Outstanding Resource Waters	15A NCAC 02B .0225
South Carolina		
	Outstanding Resource Waters	DHEC R. 61-69
	Outstanding National Resource Waters	DHEC R. 61-68

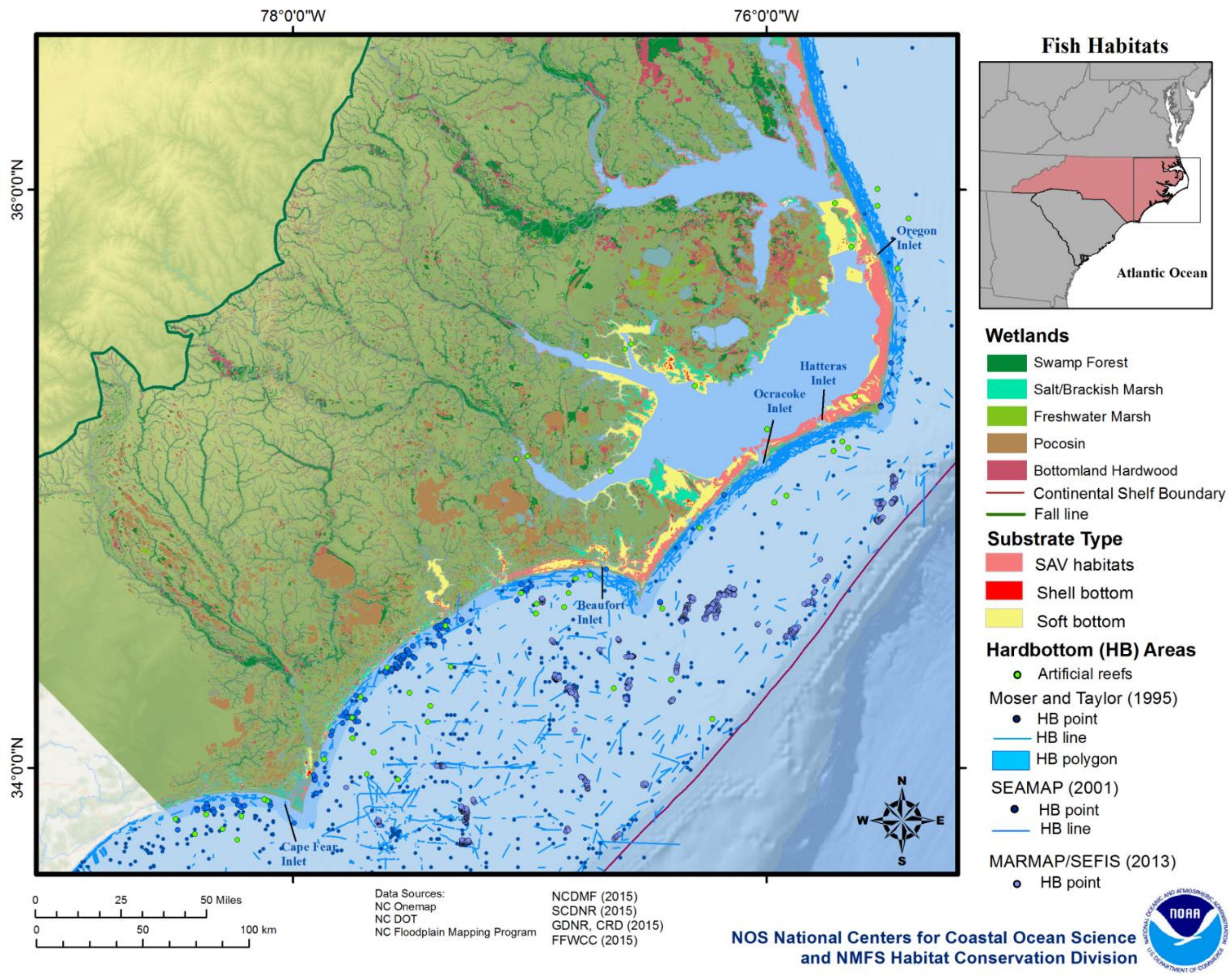

Figure 2.2.2: Various habitats used by fisheries species in coastal North Carolina. Hard bottom habitats are represented by blue points and lines scattered throughout the coastal ecosystem. Submerged aquatic vegetation (SAV) lines much of the Outer Banks, while soft and shell bottom comprise the remaining habitats.

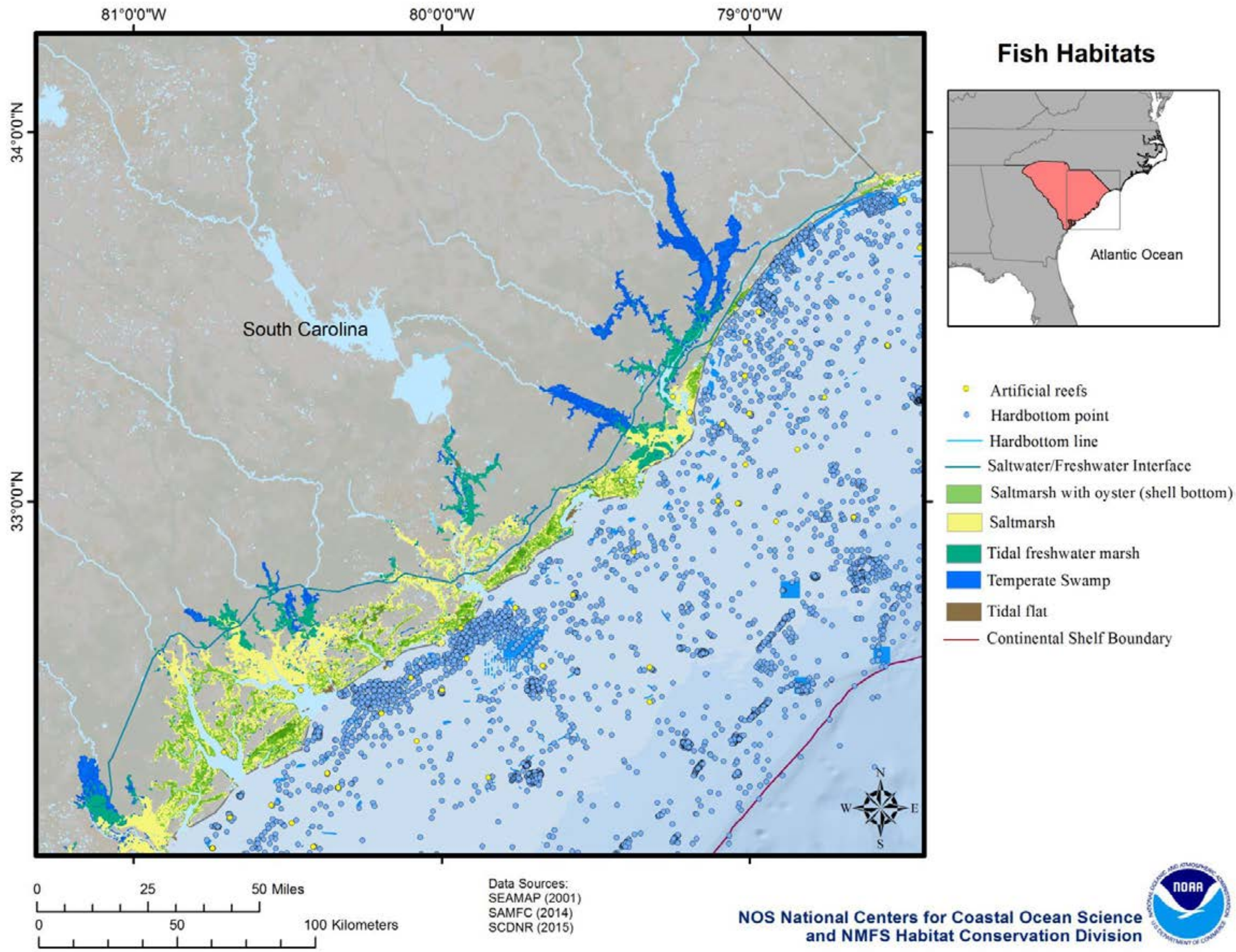

Figure 2.2.3: Fisheries habitats in the coastal and offshore waters off the South Carolina coast. Blue dots and lines in the ocean represent hard bottom habitat. Saltmarsh habitat with oysters and shell bottom habitat are prevalent from along the coastal area.

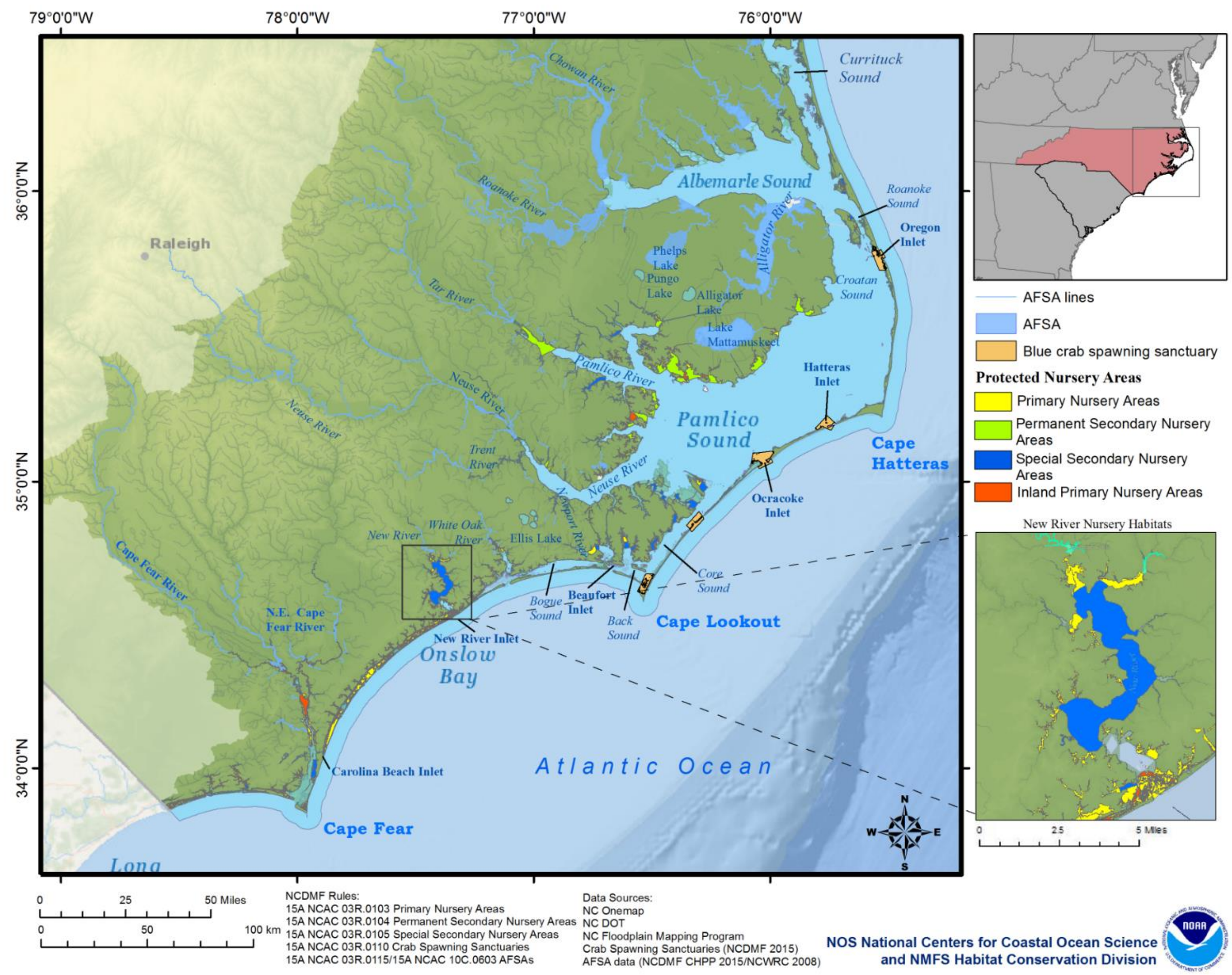

Figure 2.2.4: Designated nursery habitats for important fisheries species in coastal North Carolina. Each designation has various rules and restrictions that govern the use of those areas.

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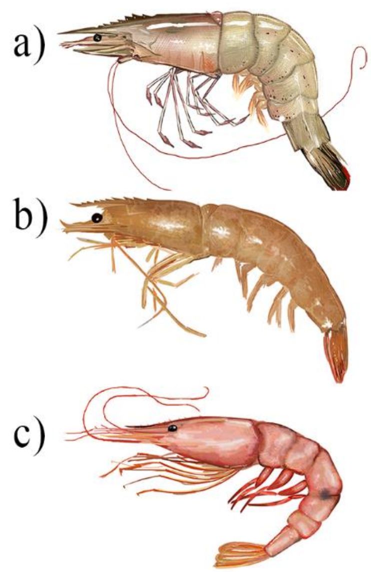
Section 3: Species Review

3.1 Penaeid Shrimp

a) White Shrimp (*Litopenaeus setiferus*, Linnaeus, 1767) (top)

b) Brown Shrimp (*Farfantepenaeus aztecus*, Ives, 1891) (middle)

c) Pink Shrimp (*Farfantepenaeus duorarum*, Burkenroad, 1939) (bottom)



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General Information

Penaeid Shrimp are the most well-known and ubiquitous shrimp species of the southeastern United States (SAFMC 2012, DeLancey 2015). Penaeid Shrimp are a relatively large group, containing White Shrimp (*L. setiferus*), Brown shrimp (*F. aztecus*), and Pink Shrimp (*F. duorarum*) as well as smaller species common in shallow, southeastern United States coastal waters (DeLancey 2015). The lifecycle of these three species are similar, as all adults spawn offshore and eggs are hatched into free-swimming larvae (Figure 3.1.1) (SAFMC 2012). Moreover, all three species have 12 larval stages before developing into postlarvae (SAFMC 2012).

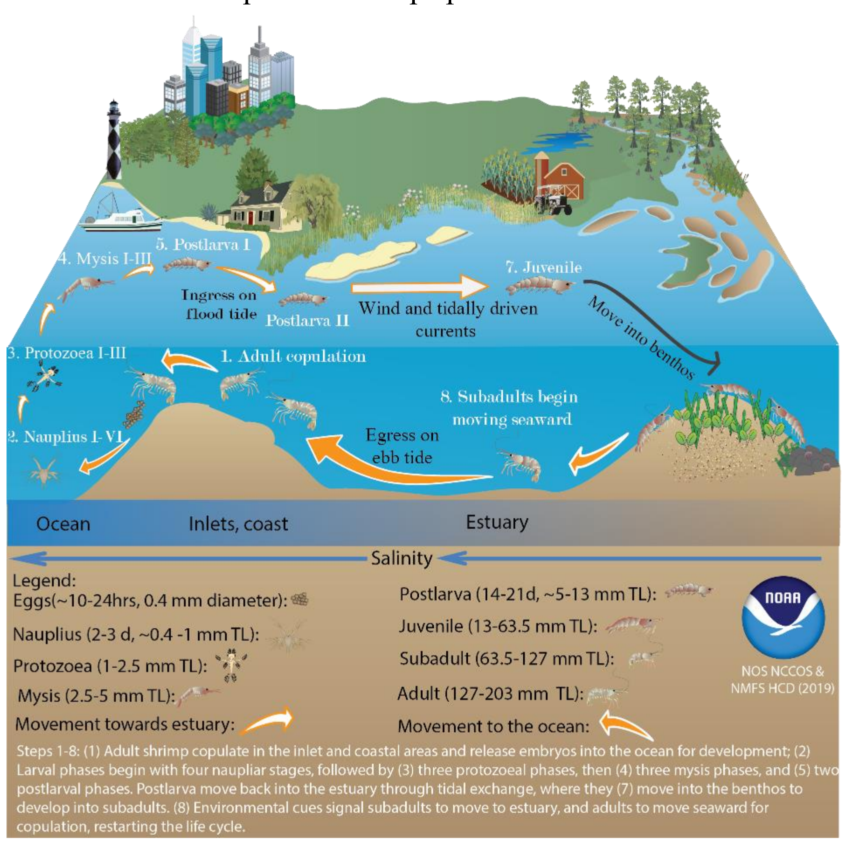

Figure 3.1.1: Life cycle of the White Shrimp, Brown Shrimp, and Pink Shrimp in North Carolina and South Carolina.

South Atlantic landings of shrimp from 1978-2011 were 7% Pink Shrimp, 34% Brown Shrimp, and 59% White Shrimp (Whitaker and DeLancey 2013). Along the

Atlantic coast, White Shrimp range from Fire Island, New York to St. Lucie Inlet in Florida (Steele 2002, SAFMC 2012). They are most commonly found off the continental shelf at depths less than 27 m (89 ft) in North Carolina, South Carolina, Georgia, and northeast Florida waters (SAFMC 1996a, SAFMC 2012). Along the Atlantic coast Brown Shrimp range from Martha's Vineyard, Massachusetts to the Florida Keys (SAFMC 2012, NCDMF 2015). Although the range of Brown Shrimp extends to Massachusetts, breeding populations most likely do not range northward of North Carolina (SAFMC 1996b). Brown Shrimp are most abundant in water depths less than 54.9 m (180 ft), and are less tolerant of low salinities and high temperatures relative to the White Shrimp (McMillen-Jackson and Bert 2003). The highest abundance of Brown Shrimp occurs in the Gulf of Mexico, but Brown Shrimp also support major commercial fisheries in North Carolina and South Carolina (NCDMF 2015). Pink Shrimp range from southern Chesapeake Bay to the Florida Keys along the Atlantic coast, with relatively high abundances in southwestern Florida and the Pamlico Sound, North Carolina (Steele 2002, SAFMC 2012).

Economically, White Shrimp, Brown Shrimp, and Pink Shrimp are important fisheries in the South Atlantic Region (North Carolina, South Carolina, Georgia, and Florida) and are considered annual crops (NCDMF 2015). The North Carolina shrimp fishery shows annual variation because of changes in environmental conditions, with total landings from 1994 to 2017 averaging 3,286 MT per year (7,244,330 lbs per year) (NCDMF 2018). In 2017, 6,302 MT (13,892,730 lbs) of shrimp were landed setting record high landings of the 24-year time series. Total landings increased 5.3% from 2016 to 2017 (NCDMF 2018). Examining harvest by North Carolina waterbody type, on average 74.36 % were estuarine, while 25.64% were ocean-based of the 1994-2017 landings (NCDMF 2017).

In South Carolina, shrimp trawlers dominate commercial operations. Trawling is only allowed in the ocean, except for short periods during fall when trawlers work in the lower areas of Winyah and North Santee Bays. Most shrimpers trawl within three or four miles of the beach. White Shrimp typically produces the largest catch with landings ranging from 688.1 to 3962.6 MT (1.5 to 8.7 million lbs). Comercial landings for Brown Shrimp during good years range from 589.7 to 907.2 MT (1.3 to 2.0 million lbs); however, historically landings have ranged from 589.7 to 3,084.4 MT (1.3 to 6.8 million lbs) (Whitaker and Kingsley-Smith 2014). Total landings revenue in 2011 for South Carolina's shrimp industry was approximately $7 million dollars with about 1,315.4 MT (2.9 million lbs) landed (NMFS 2014).

Annual crops of White Shrimp are strongly influenced by seasonal weather conditions. While commercial fishers have long recognized this phenomena, researchers are continually working to investigate the influence of weather on shrimp harvests as well as their life history. In North Carolina and South Carolina, small White Shrimp overwinter in estuaries and the ocean and are the primary spring spawning stock. When winter water temperatures drop below 7.7 °C (45.9 °F) for seven days or more, most of the overwintering broodstock experiences high mortality. In January 2018, South Carolina experienced abnormally low temperatures. State resource managers immediately closed state waters to shrimp trawling and requested the same in federal waters (those waters > 3 nm or 6 km from the South Carolina's shore) in order to protect the surviving shrimp (SCDNR 2018). Following severe winters, the roe shrimp (i.e., White Shrimp that have recently completed the spawning process) harvest is usually less than 22.7 MT (50,000 lbs), and with such a small spawning stock, fall commercial landings are also low (Whitaker and Kingsley-Smith 2014).

Life History

In general, Penaeid Shrimp go through the same life stages (egg→nauplius→protozoea→ mysis→postlarva→juvenile→subadult→adult) (Figure 3.1.1). Spawning usually occurs in the ocean, with distances from shore ranging from near beaches to several kilometers offshore (Whitaker and Kingsley-Smith 2014). Spawning occurs before individuals reach 12 months of age (NCDMF 2015). Shrimp are dioecious (separate sexes) and females generally grow larger than males (NCDMF 2015). Shrimp are highly fecund with females expelling between 500,000 to 1,000,000 eggs during one spawning period (Perez-Farfante 1969, Whitaker and Kingsley-Smith 2014, NCDMF 2015). White Shrimp copulation is limited to hard-shelled individuals with the male depositing a spermatophore onto the female thelycum (Muncy 1984). Fertilization of eggs takes place when the female expels ova and spermatozoa simultaneously, directly following mating (Muncy 1984). Grooved shrimp (i.e., Pink and Brown Shrimp) mate when females are soft and the sperm is stored under ventral plates, affording females the opportunity to hold eggs instead of releasing them immediately after copulation. Once hatching occurs, all three species go through multiple larval stages before developing into postlarvae (SAFMC 2012). Duration of the larval period is dependent upon temperature, food, and habitat characteristics (SAFMC 2012) and varies from species to species.

Eggs hatch into elongated (0.3 mm or 0.01 in) planktonic nauplii within 10 to 24 hours of fertilization (Klima et al. 1982, Whitaker and Kingsley-Smith 2014). Nauplii are non-feeding and are carried by prevailing currents and wind as they go through the six naupliar molts (24-36 hours) to become free-swimming protozoea (Muncy 1984). Protozoea grow from about 1 mm to 2.5 mm (0.01 to 0.04 in) through the three protozoeal molts before attaining the first mysid stage. The three mysid stages are still in oceanic waters with legs and antennae developing (DeLancey 2015). Post-larval individuals now morphologically appear as small shrimp (2-3 weeks post-hatching). During the second post-larval stage, ingress into estuaries begins as individuals ride the flood tides in, become active, and then once ebb tide arrives settle to the bottom (DeLancey 2015). The inshore, estuarine period of the Penaeid Shrimp life cycle is perhaps the most critical as it is a time of rapid growth (SAFMC 2012). Post-larval shrimp settle out in the shallow water nursery grounds (< 2 m or 7 ft depth) of the upper ends of salt marsh tidal creeks (Figure 3.1.2, Figure 3.1.3, Figure 3.1.4, Figure 3.1.5) (Whitaker and Kingsley-Smith 2014). Postlarvae will remain in the nursery habitat for about two to three months, growing into juveniles. After reaching sub-adult sizes seaward migration is initiated (Figure 3.1.6). It is hypothesized that as shrimp increase in size they seek higher more stable salinities in the lower estuary because of a decrease in the ability to osmoregulate (Bishop et al. 1980).

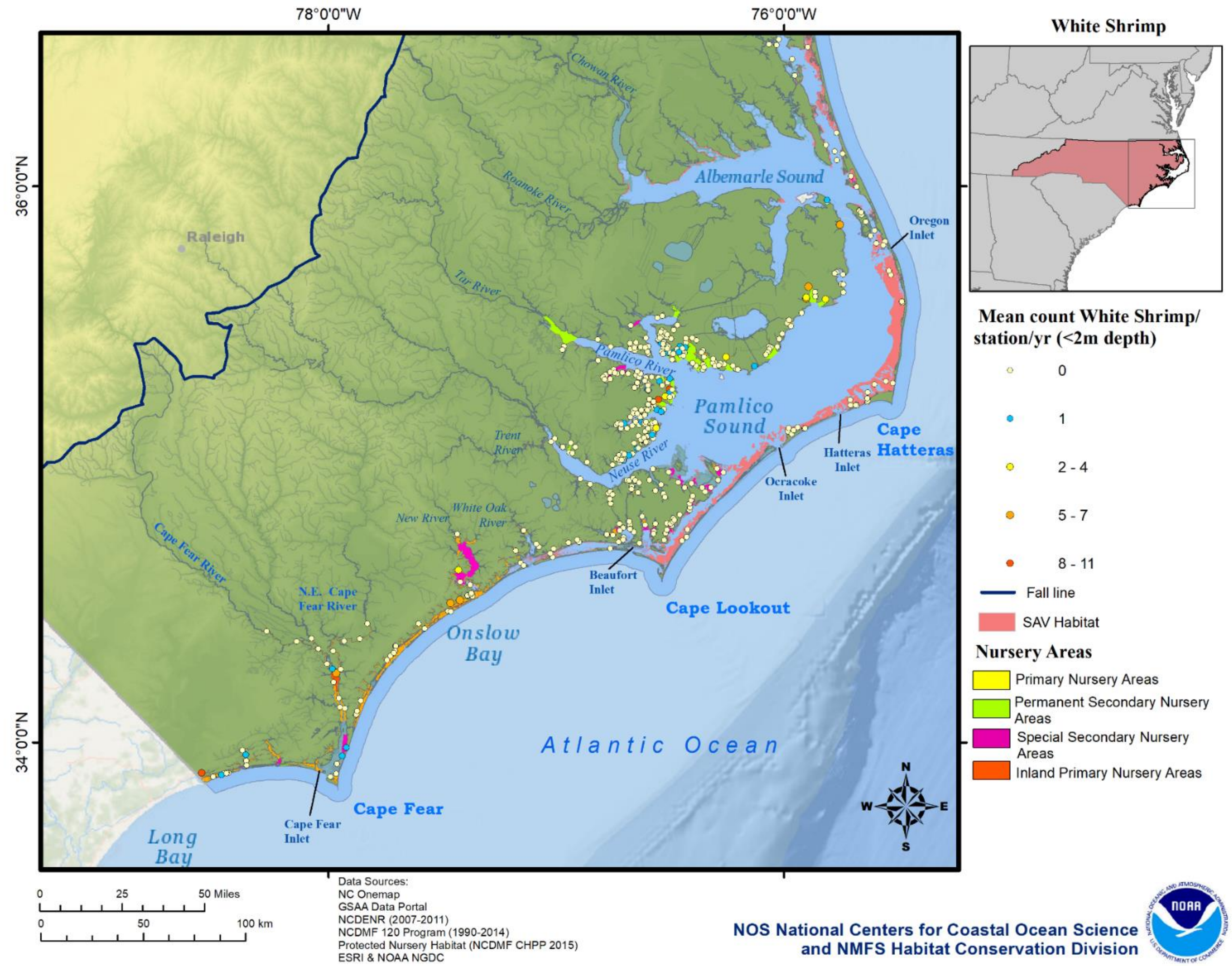

Figure 3.1.2: Abundance of White Shrimp in shallow water habitats (< 2 m depth) in coastal North Carolina (1990-2014). Shrimp nursery habitats (as defined by NCDMF) are shown to indicate areas of high recruitment. The mean number of White Shrimp/station/year in the fishery independent surveys (Program 120) was 0.33. Commercial catches are indicated by various colors of counties, and group all three commercial shrimp species together

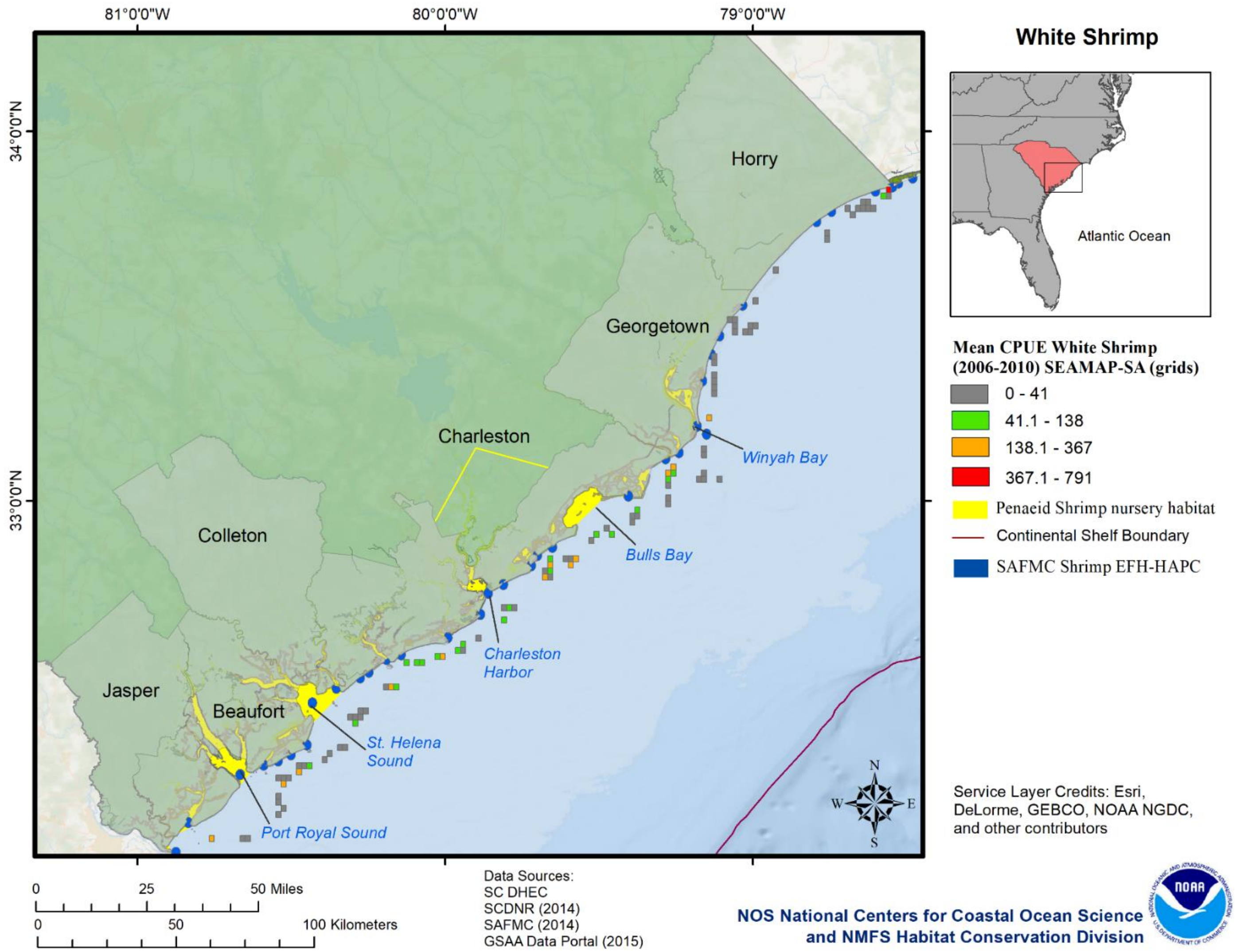

Figure 3.1.3: Abundance of White Shrimp in shallow water habitats in coastal South Carolina (2006-2010). Shrimp nursery habitats (as defined by SAMFC) are shown to indicate areas of high recruitment. Areas which meet the criteria for EFH or HAPCs for Penaeid shrimp include all coastal inlets, all identified nursery habitat of particular importance to shrimp (i.e., all SC coastal sounds and tidal creeks), and state-identified overwintering areas.

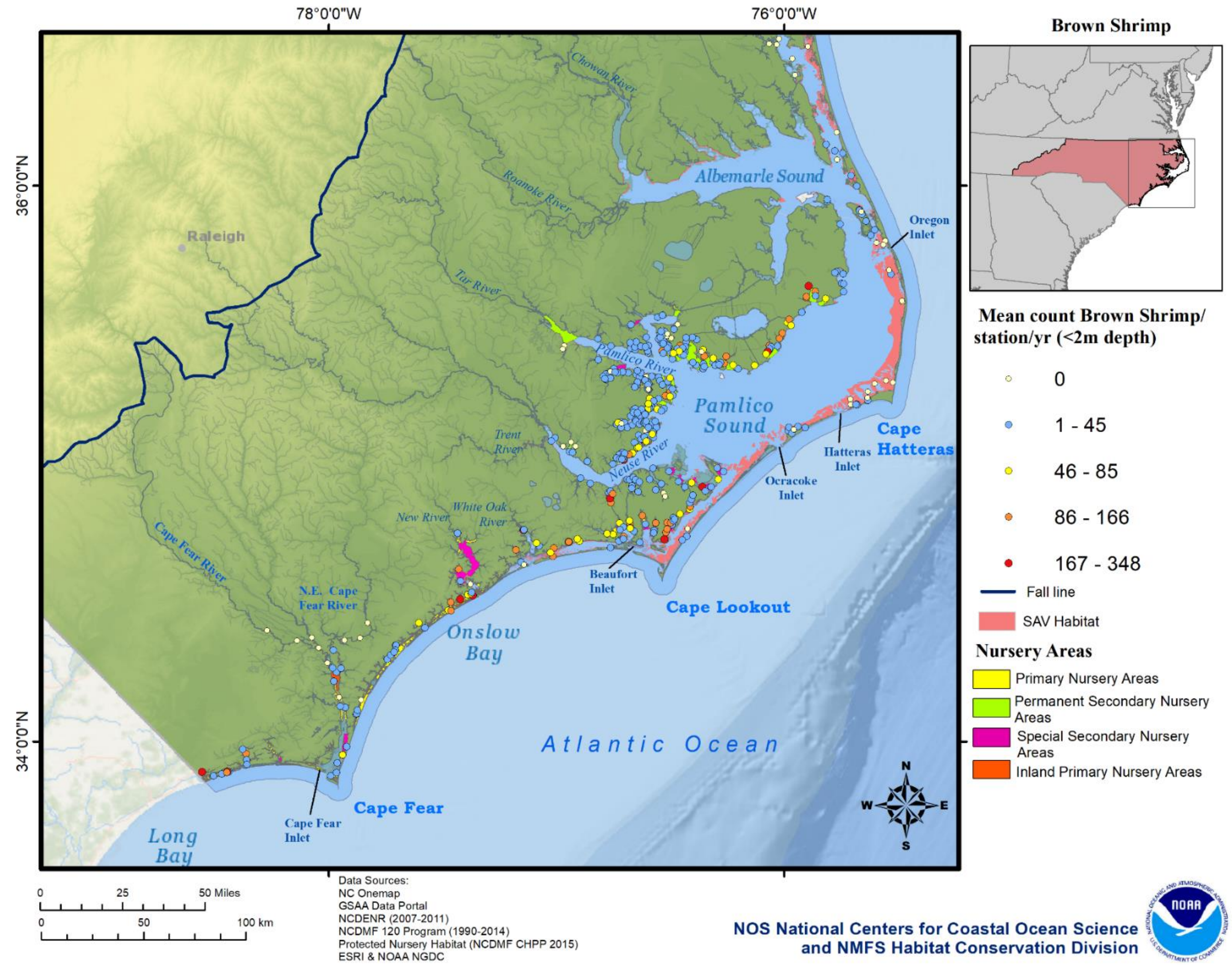

Figure 3.1.4: Abundance of Brown Shrimp in shallow water habitats (<2 m depth) in coastal North Carolina (1990-2014). Shrimp nursery habitats (as defined by NCDMF) are shown to indicate areas of high recruitment. Various nursery areas and habitats are also shown on the map to denote other important shrimp habitat characteristics.

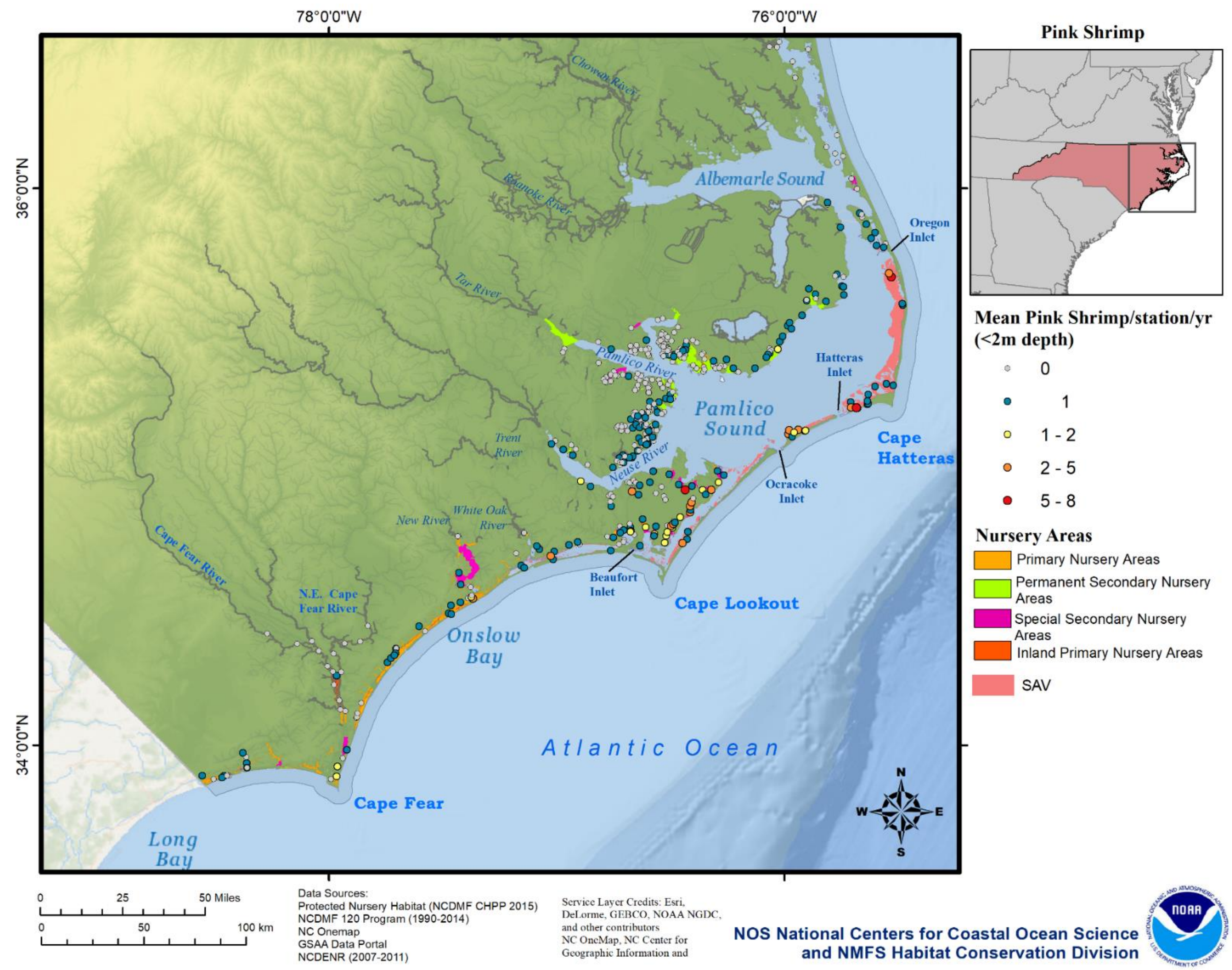

Figure 3.1.5: Abundance of Pink Shrimp in shallow water habitats (<2 m depth) in coastal North Carolina (1990-2014). Shrimp nursery habitats (as defined by NCDMF) are shown to indicate areas of high recruitment. NCDMF Program 120 data indicate preferred areas in and around SAV. Commercial Penaeid Shrimp catches are indicated by various colors of counties.

White Shrimp: Spawning usually occurs at ocean depths greater than 9.1 m (30 ft) from March to June (Table 3.1.1) (NCDMF 2015). White Shrimp can potentially spawn more than once a year (Nance et al. 2010), but may only spawn once in North Carolina waters (Williams 1965). After two to three weeks post-hatch, tidal currents bring postlarvae into the estuaries where they become benthic (Figure 3.1.1) (Perez-Farfante 1969). White Shrimp have a relatively long recruitment period (for South Carolina usually early May through August with peaks in late May and early June). Post-larval White Shrimp enter estuaries in North Carolina from June through September (McKenzie 1981). Once juveniles reach lengths of 20 to 31 mm (0.8 to 1.2 in).Total Length (TL), movement from shallow marshes to deeper creeks, rivers, bays, and sounds ensues (Figure 3.1.6) (NCDMF 2015). Adult White Shrimp (i.e., roe shrimp) migrate out of estuaries in April (if the winter is mild), May, and June (the primary spawning season), making a valuable spring fishery in southern North Carolina, South Carolina, and Georgia (Table 3.1.1) (Lam et al. 1989, NCDMF 2015). This season is lacking in the central and northern portions of North Carolina. Large White Shrimp (≥ 120 mm or 4.7 in TL) that are the offspring of the spring spawn, emigrate out of estuaries into commercial fishing areas from August to January, when the largest landings occur and is often referred to as the fall fishery (Lam et al. 1989). The spring fishery is comprised of spawning stock, whereas the fall fishery consists of young-of-year recruits (Lam et al. 1989).

Table 3.1.1: General temporal and spatial distribution of White Shrimp (*L. setiferus*) life stages in three habitats (estuary = 0 – 25 psu, inlets/coast = 25 – 35 psu, and ocean = >35 psu) in North Carolina and South Carolina waters. Peak events refer to time period when the greatest densities of individuals at various life stages (spawning, egg, larvae and postlarvae, and juveniles) are present within the specified habitat.

Estuary		**Q$_1$= Winter**			**Q$_2$=Spring**			**Q$_3$=Summer**			**Q$_4$=Fall**		
Inlets/ coasts / **Ocean**	**Life Stage**	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
White Shrimp (*Litopenaeus setiferus*)	Spawning Adults												
	Egg												
	Larvae/ postlarvae												
	Juveniles												

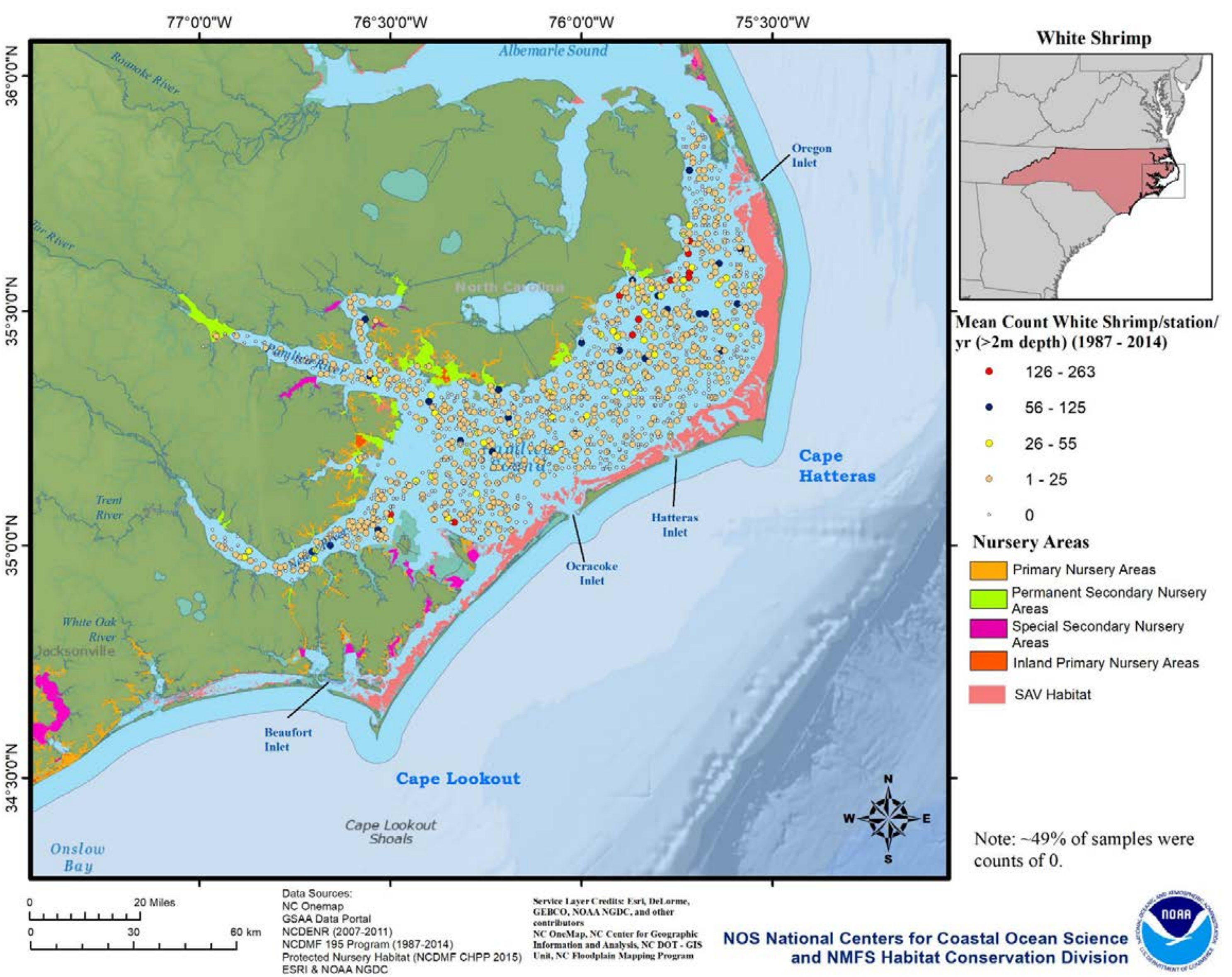

Figure 3.1.6: Abundance of White Shrimp in deepwater habitats (>2 m depth) in coastal North Carolina (1987-2014) within the North Carolina Division of Marine Fisheries fishery independent Pamlico Sound survey.

Brown Shrimp: Both female and male Brown Shrimp reach sexual maturity around 140 mm (5.5 in) TL and spawn in either deep oceanic water (>13.7 m or 45 ft) or coastal areas around 6 to 10.7 m (19.6 to 35.1 ft) depth (Renfro 1964, Cook and Linder 1970) (Figure 3.1.1). Although there is still uncertainty in location of spawning stocks, time of spawning, or migration of larvae, it is known that postlarvae enter the estuaries with warming water temperatures in late winter and early spring and appear to come in large pulses, unlike White Shrimp. Timing of Brown Shrimp spawning is likely in October and November based on mature males and females found in trawler catches in South Carolina (Table 3.1.2) (SAFMC 1996). There is also the documentation of influx of postlarvae into estuaries during February and March, and possibly April depending on environmental conditions (Cook and Lindner 1970, NCDMF 2015). For instance, Brown Shrimp stocks in southern North Carolina (e.g., New River South) and South Carolina have declined over the last few years, most likely resulting from warmer winters limiting larval recruitment of Brown Shrimp in these areas. It takes Brown Shrimp 10 -17 days to complete the larval life stages, and grow into postlarvae about 8 -14 mm (0.3 to 0.6 in) TL. Initial entrance into the estuaries is on a flood tide, with wind driven currents pushing them to the upper reaches of estuaries in North Carolina and spring tides acting as the driver in South Carolina (Figure 3.1.4) (Williams 1955, 1965). Brown Shrimp juveniles and adults appear to overwinter in offshore bottom sediments and have a maximum life span of 18 months (NCDMF 2015). As they increase in size, adults move to deeper, more saline waters before moving out to sea in late fall (Figure 3.1.7, Figure 3.1.8) (NCDMF 2015).

Table 3.1.2: General temporal and spatial distribution of Brown Shrimp (*F. aztecus*) life stages in three habitats (estuary = 0 – 25 psu, inlets/coast = 25 – 35 psu, and ocean = >35 psu) in North Carolina and South Carolina waters. Peak events refer to time periods when the greatest densities of individuals during various life stages (spawning, egg, larvae and postlarvae, and juveniles) are present within the specified habitat.

Estuary			**Q_1= Winter**			**Q_2=Spring**			**Q_3=Summer**			**Q_4=Fall**		
Inlets/ coasts		**Life Stage**	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Ocean														
Brown Shrimp (*Farfantepenaeus aztecus*)		Spawning Adults												
		Egg												
		Larvae/ postlarvae												
		Juveniles												

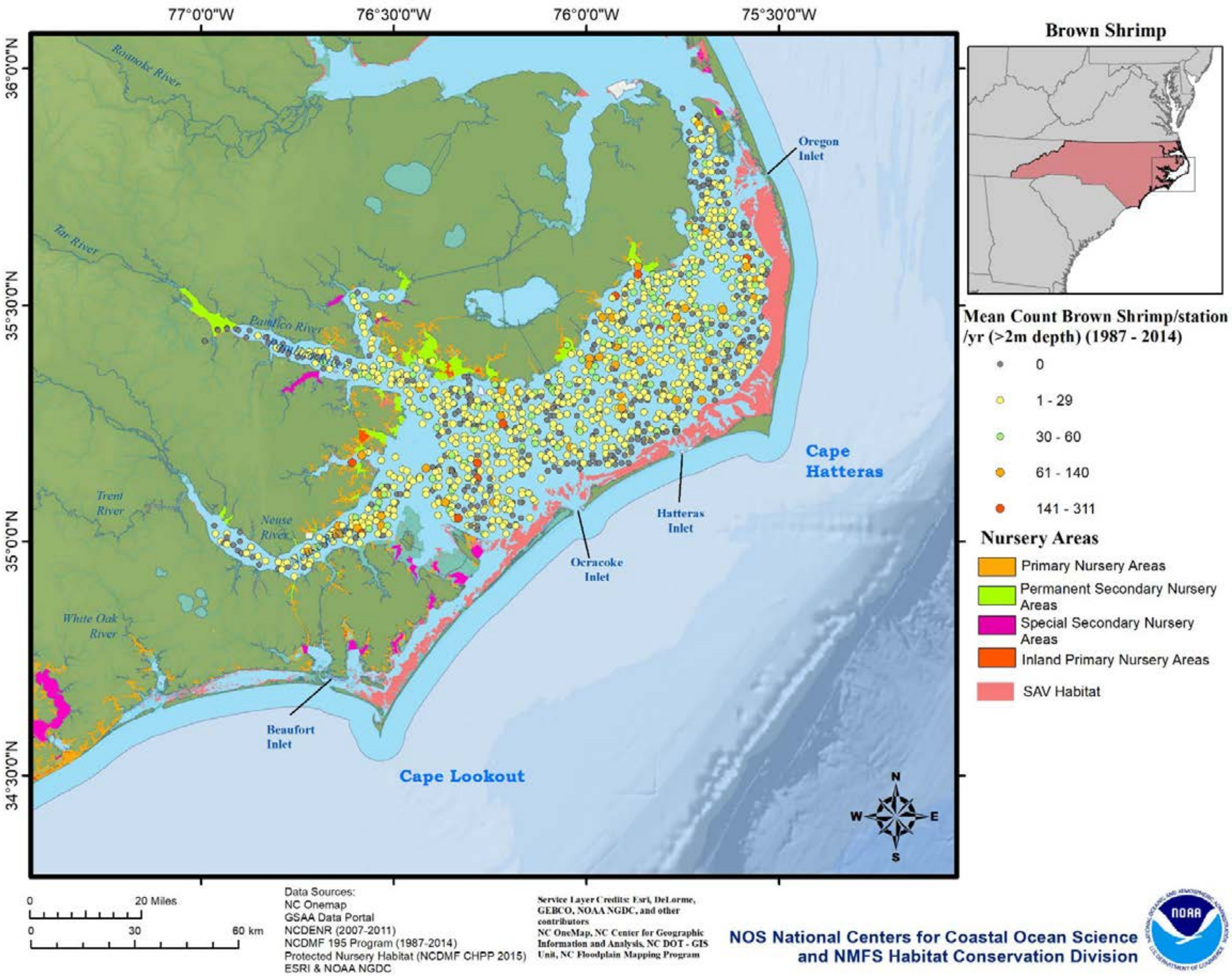

Figure 3.1.7: Abundance of Brown Shrimp from the NC Division of Marine Fisheries fishery independent Pamlico Sound survey (Roanoke River, Tar River, Neuse River and drainage basins and the Pamlico Sound proper) in deeper water habitats (>2 m depth) in North Carolina (1990-2014).

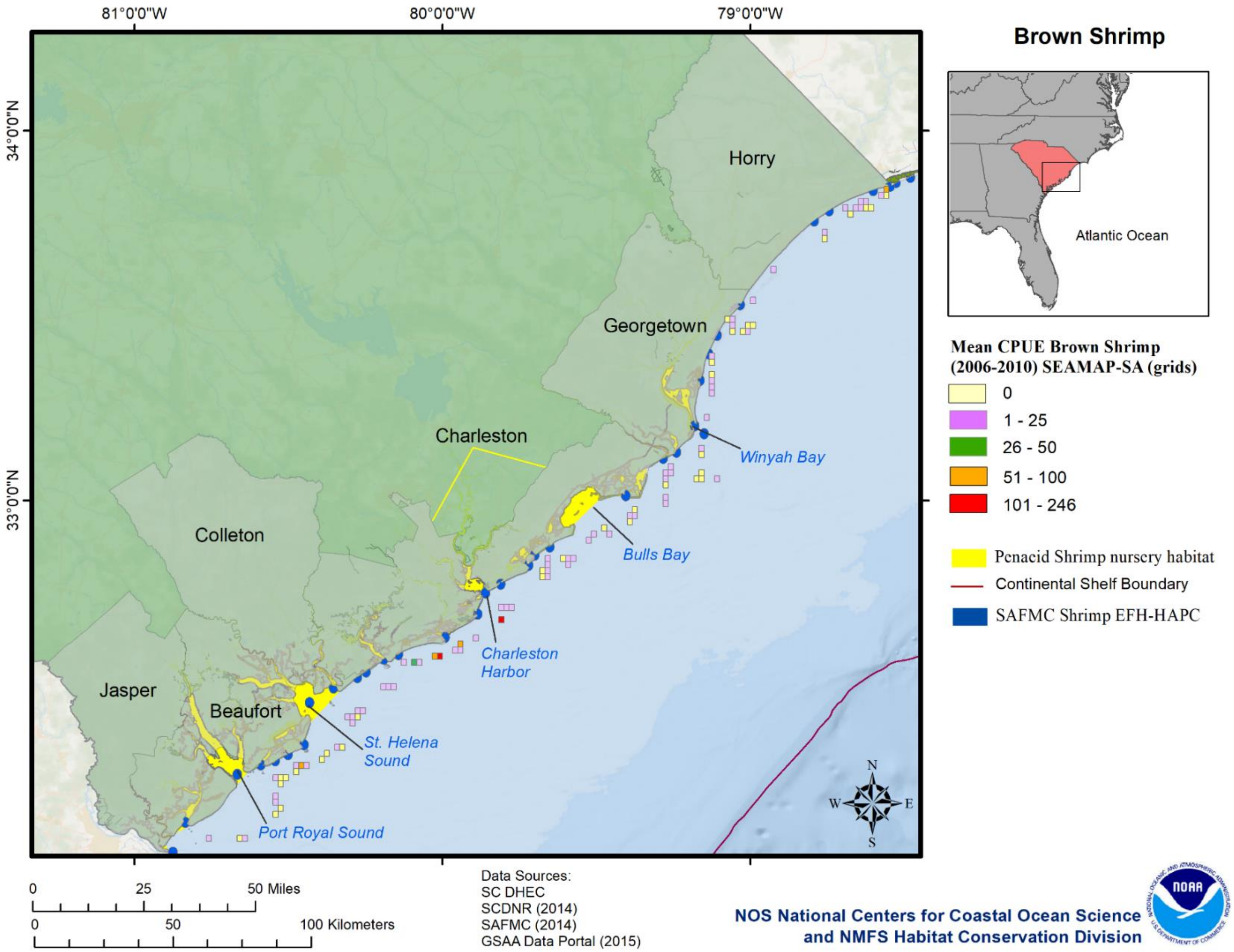

Figure 3.1.8: Abundance of Brown Shrimp from the SEAMAP survey program in South Carolina coastal water habitats (>2 m depth) (2006 to 2010).

Pink Shrimp: Spawning occurs in oceanic waters from April to July with postlarvae carried into estuaries from May through November (Table 3.1.3) (Williams 1965). Larval development takes approximately 15 - 25 days (SAFMC 2012) before postlarvae reach the estuaries. Year round spawning occurs in warmer regions (*e.g.*, Florida) of the Pink Shrimp range; it is unlikely to occur with seasonal variations in temperature in the northern range of the species (i.e., North Carolina). A significant number of Pink Shrimp overwinter in North Carolina's estuaries before moving to the ocean the following spring, although significant mortalities have been observed during severe winters (Figure 3.1.9) (NCDMF 2015). Female Pink Shrimp reach sexual maturity at about 85 mm (3.3 in) TL, while males are sexually mature at around 74 mm (2.9 in) TL (NCDMF 2015). Pink Shrimp have a maximum life span of 24 months.

Table 3.1.3: General temporal and spatial distribution of Pink Shrimp (*F. duorarum*) life stages in three habitats (estuary = 0 – 25 psu, inlets/coast = 25 – 35 psu, and ocean = >35 psu) in North Carolina waters. Peak events refer to time periods when the greatest densities of individuals during various life stages (spawning, egg, larvae and postlarvae, and juveniles) are present within the specified habitat.

Estuary / **Inlets/ coasts** / **Ocean**	**Life Stage**	**Q_1= Winter**			**Q_2=Spring**			**Q_3=Summer**			**Q_4=Fall**		
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Pink Shrimp (*Farfantepenaeus duorarum*)	Spawning Adults												
	Egg												
	Larvae/ postlarvae												
	Juveniles												

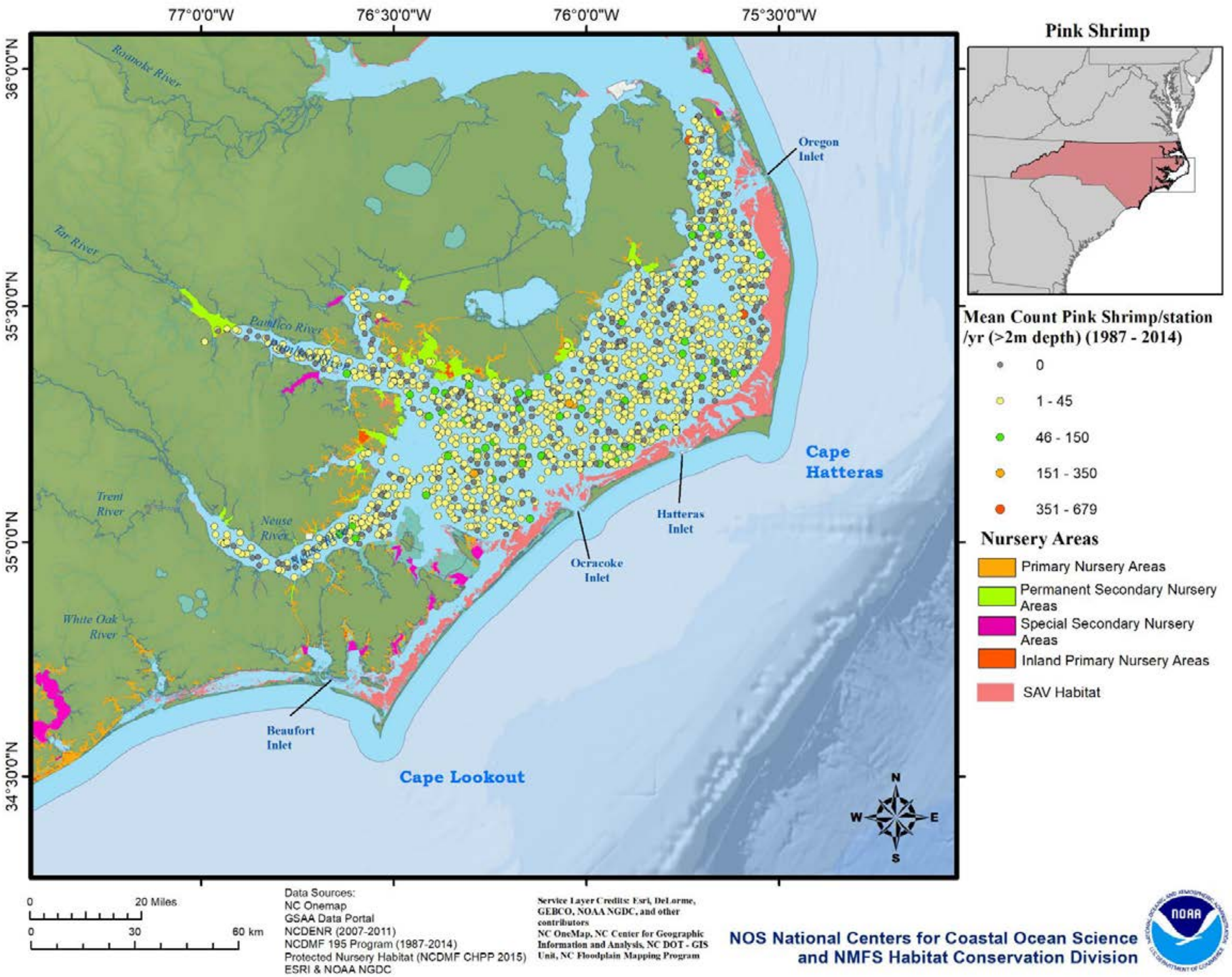

Figure 3.1.9: Abundance of Pink Shrimp in fishery habitats (>2 m depth) in Pamlico Sound, North Carolina (1990-2014) within the fishery independent Pamlico Sound survey (Program 195). Notable high catches are frequently observed in Pamlico Sound near Hatteras Inlet.

Physiology and Habitat

Increasing temperatures of bottom water in spring cue initiation of Penaeid Shrimp spawning and rapid decreases in fall water temperature coincide with the end of spawning (Lindner and Anderson 1956, Whitaker 1981, Muncy 1984). Correlations between heating-degree-days and catch/effort ratio were similar to those correlations for yield/hectare and latitude for Penaeid Shrimp (Turner 1977). As one would presume, growth is fastest in summer and slowest in the winter months (SAFMC 2012). Water temperatures below 20 °C (68 °F) inhibit juvenile shrimp growth (Etzold and Christmas 1977) and at 16 °C (61 °F) growth is virtually non-existent (St. Amant and Lindner 1966). In South Carolina, extremely cold water temperatures were found to delay sexual maturation while slightly warmer temperatures promoted maturation (DeLancey et al. 2005). For White Shrimp, water temperature directly or indirectly influences spawning, habitat selection, growth, osmoregulation, movement, migration, and mortality (Muncy 1984). In mild winters, White Shrimp catches landings often exceed 181 to 272 MT (400 to 600 thousand lbs) (head off) in South Carolina. White Shrimp have proliferated during recent mild winters, while Pink Shrimp abundance has steadily declined, potentially due to being out-competed for food resources or space by White Shrimp. White Shrimp can endure temperatures ranging from 7 to 37 °C (44 to 98 °F), Pink Shrimp can be found in 6 to 38 °C (42.8 to 100.4 °F) waters, and Brown Shrimp in 7 to 37 °C (45 to 98 °F) waters (NCDMF 2015). However, this range of tolerances varies based on which life stage is encountering the temperature.

Temperature is a dominant environmental factor driving estuarine post-larval shrimp growth. White Shrimp are more tolerant of high temperatures and less tolerant of low temperatures than Pink Shrimp or Brown Shrimp (Etzold and Christmas 1977). Temperature is also one mechanism to drive burrowing behavior of Penaeid Shrimp (Aldrich et al. 1968). Burrowing in response to low temperature has been shown to be an important survival mechanism for Brown Shrimp, known to reach bays and estuaries early in the year, when waters are still relatively cold (Aldrich et al.1968). Brown Shrimp exposed to controlled temperature regime, simulated to represent winter temperatures along the coasts of Louisiana and Texas, regularly burrowed when water temperatures dropped to 12 to 17 °C (54 to 63 °F), and emerged when temperatures rose from 18 to 21.5 °C (64 to 71 °F). White Shrimp have been shown to have diurnal burrowing patterns as a protective mechanism during daylight hours to survive colder temperatures (Aldrich et al. 1968). Pink Shrimp burrow in the substrate with the onset of cold weather, protecting them to some extent from winter mortalities (SAFMC 2012). Cold-induced mortality of over-wintering Pink Shrimp does occur during exceptionally cold winters in temperate waters. Brown Shrimp optimally grow in temperatures between 11 to 25 °C (52 to 77 °F) (Steele 2002). Temperature affects Brown Shrimp and Pink Shrimp growth rates, with the highest rates occurring (3.5 mm/day or 0.14 in/day) when temperatures exceed 25 °C (77 °F), but is reduced to less than 1 mm/day when temperatures drop below 20 °C (68 °F) (SAFMC 2012). Growth of Pink Shrimp increases with temperatures up to 35 °C (95 °F) (Browder et al. 2002). DeLancey et al. (2005) noted that relative abundance of White Shrimp in South Carolina was strongly affected by winter water temperature, with milder winter temperatures (i.e., warmer water temperatures in winter) producing higher relative abundances. There is also evidence that Brown Shrimp abundance is strongly affected by winter water temperatures, and may be to blame for recent declining recruitment and catches in South Carolina and southern North Carolina (Jason Rock, personal communication, February 15, 2019).

A relatively higher salinity (27 to 35 psu) is needed for the larval stages of Penaeid Shrimp. Salinity influences growth more in White Shrimp and Brown Shrimp as compared to Pink Shrimp (SAFMC 2012). Significant rainfall and river diversions that reduce estuarine salinities during peak recruitment periods may reduce overall growth rates and shrimp productivity (Rozas and Minello 2011). White Shrimp can travel over 200 km inland from the coast (Joyce 1965), whereas Brown Shrimp and Pink Shrimp typically do not penetrate as far into fresh water (Pérez Farfante 1969). Optimal salinities for juvenile Brown Shrimp are between 8 and 12 psu and for juvenile White Shrimp ideal salinity ranges from 12 to 18 psu (Dave Whitaker, personal communication, November 5, 2015). Pink Shrimp growth is optimal at 30 psu and is reduced with increases or decreases around this salinity mark (Browder et al. 2002). Extreme environmental conditions (*e.g.,* drought, unusually warm fall) potentially result in late movement of White Shrimp to the ocean (Whitaker and Kingsley-Smith 2014). Heavy rainfall, resulting in reduced salinities, may cause shrimp to move into the ocean prematurely (Whitaker and Kingsley-Smith 2014). In wet years, South Carolina White Shrimp may move to the ocean in August, about a month ahead of normal timing. This results in a poor October harvest (Whitaker and Kingsley-Smith 2014). In the absence of significant rainfall or river discharge during fall, White Shrimp appear to remain in estuaries until water temperatures drop to about 15 to 18 °C (60 to 65 °F) and then they will emigrate to the ocean primarily through Spring tides (i.e., tide just after a new or full moon, when there is the greatest difference between high and low water occur) (Whitaker and Kingsley-Smith 2014).

Shallow, muddy bottoms in low to moderate salinity waters serve as ideal nursery grounds for White Shrimp (NCDMF 2015). Highest abundances of White Shrimp occur in areas of extensive brackish marshes (NCDMF 2015). Brown Shrimp postlarvae prefer peat and muddy bottoms, but can also be found on silt, sand, clay mixed with shells, and rock fragments (Steele 2002). Pink Shrimp prefer sandy bottom areas that allow burrowing and have salinities around 30 psu. For White Shrimp and Brown Shrimp, dissolved oxygen (DO) levels <2 mg/l cause stressed conditions, while Pink Shrimp can withstand DO levels as low as 0.2 mg/l, but thrive in conditions where DO is 6.0 mg/l (NCDMF 2015).

Conclusions

Penaeid Shrimp population size is regulated by environmental conditions, with annual landings acting as a good indicator of relative abundance. The economics of the shrimp fishery are changing and in recent years, due to imported shrimp prices outcompeting those of wild caught shrimp. However, 2017 had the highest annual landings of wild caught shrimp in a 24-year time series in North Carolina. Notably, due to the high fecundity and migratory behavior of

Penaeid Shrimp, all three species may rebound from a low population size in one year to a large population size in the next, provided environmental conditions (i.e., salinity, temperature, adequate nursery habitat) are favorable (NCDMF 2015). One of the most serious pressures to regional shrimp stocks is loss of habitat due to pollution or physical alteration. Particularly vulnerable and critical to White Shrimp and Brown Shrimp production is the salt marsh and inshore seagrass habitat (especially for Pink Shrimp), which comprise the nursery areas for juvenile shrimp (NCDMF 2015).

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3.2 Gag Grouper

(*Mycteroperca microlepis*, Goode and Bean 1879)

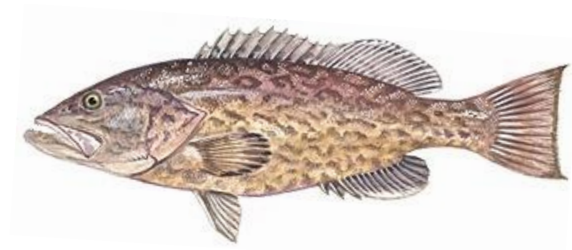

Photo credit: NOAA

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General Information

The Gag is a large (up to 1,200 mm [47.2 in] Total Length -TL), 39 kg [85.9 lbs] max weight) epinepheline serranid economically important in recreational (Huntsman 1976) and commerical (Rohde and Francesconi 1992) fisheries in the Carolinas (Ross and Moser 1995, Heemstra et al. 2002, Adamski et al. 2012, Murdy and Musick 2013). Gag have an estuarine dependent life cycle (Figure 3.2.1) and are one of the most abundant Groupers in the southeast, ranging from Massachusetts (mainly juveniles – but no overwintering) into the Gulf of Mexico, (Briggs 1958, Smith 1971, Hardy 1978, Ross and Moser 1995, NOAA 2014, Sedberry and Reichert 2015, NCDENR 2018). Along the Atlantic coast, the southern range extends southward to Key West, Florida, with the largest commercial harvest occuring off the west coast of Florida; relatively smaller numbers are caught off the Carolina coastlines (NOAA 2014). Gag are managed by the SAFMC Snapper Grouper FMP compliance requirements including Amendment 17B (2010) establishing the commercial annual catch limit for the south Atlantic (SAFMC 2015). The total current annual catch limit in the south Atlantic Gag fishery is allocated between the commercial (152 MT [335,188 lbs] gutted weight for 2018) and recreational (157.9 MT [348,194 lbs] gutted weight for 2018)

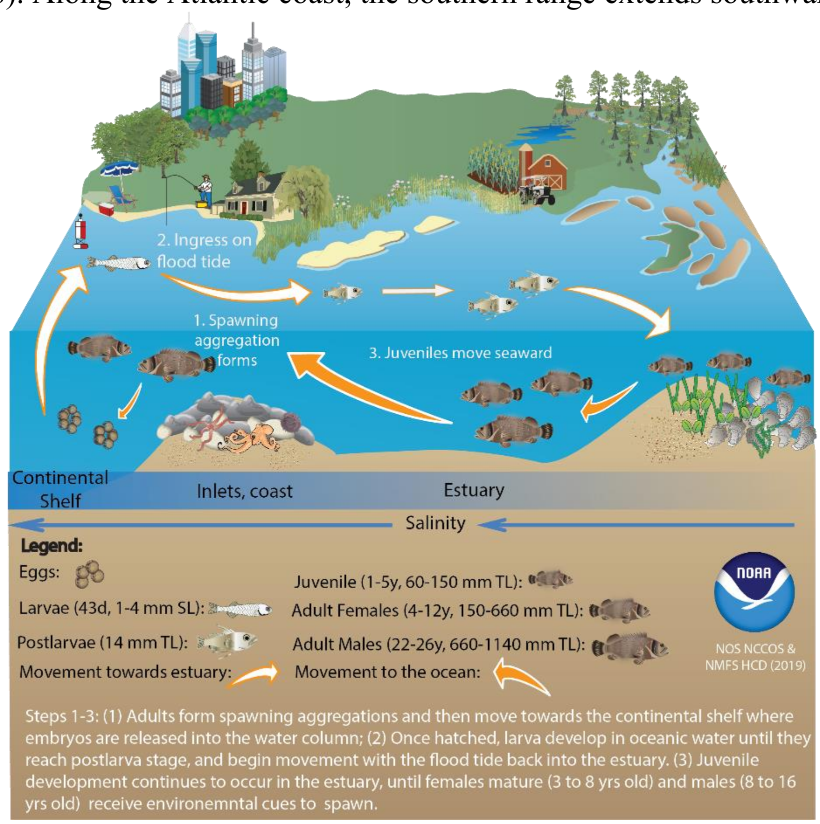

Figure 3.2.1: Life cycle of Gag (*Mycteroperca microlepis*) in North Carolina and South Carolina.

fishing sectors (NCDENR 2018) and predominantly is exploited through hook-and-line methods (Bacheler and Buckel 2004). For 2019, the commercial annual catch limit is 157.5 MT (347,301 lbs) and the recreational annual catch limit is 163.2 MT (359,832 lbs).

In 2001 Gag were considered overfished under the Magnuson-Stevens Fishery Conservation and Management Act. Changes in management of the fishery such as gear restrictions, spawning season closures, decreased bag limits, and increased size limits allowed for some recovery for the fishery (Adamski 2009, SAFMC 2009). In December 2014 NOAA NMFS removed Gag from the overfishing list, as the 2012 (the terminal year of the assessment) fishing mortality rate was below the threshold limit (i.e., no overfishing) (NCDENR 2018). Additionally, the projected fishing mortality rate in 2013 was below the overfishing threshold, with a steady and consistent decline in fishing mortality rate for the last five to six years of assessment (NCDENR 2018, NCDMF 2018). Therefore, as reported by NMFS in late 2017, Gag are not considered overfished and overfishing is not occurring (NMFS 2017). In 2017, the commercial landings were 42.05 MT (92,702 lbs) and the recreational landings were 3.6 MT (7,856 lbs) (NCDENR 2018). The ten year average (2008 – 2017) landings for Gag commerical landings in North Carolina was 76.5 MT (168,746 lbs) and for recreational landings was 26.3 MT (57,990 lbs) (NCDENR 2018). The North Carolina recreational annual catch limit has not been met since 2010 and rarely exceeded 50% of the quota (NCDENR 2018). In South Carolina, from 1980 to 2011 commerical landings averaged 119.1 MT (262,622 lbs) and from 1984 to 2011, the average recreational catch was 12.8 MT (28,195 lbs) (NOAA 2013, Sedberry and Reichert 2015). The current seasonal closure for the South Atlantic Gag fishery is from January 1st to April 30th for spawning season, with a minimum size limit of 610 mm (24 in) TL when the fishery is open (SAFMC 2009, SCDNR 2018).

Life History

Gag are slow-growing, large in size, reproduce later in life, and have a long life span (Parrish 1987, Reichert and Wyanski 2005). Gag are protogynous hermaphrodites, beginning life as females, maturing around three to four years of age at lengths averaging 610 to 660 mm (24 to 26 in) (Collins et al. 1987, McGovern et al. 1998, Harris and Collins 2000). One-hundred percent of females do not mature until age six (Harris and Collins 2000, Sedberry and Reichert 2015). Gag transform into males around 8 to 16 years of age at 890 to 1,140 mm (35 to 44.9 in) (McGovern et al. 1998, SCDNR-MARMAP unpublished data, Sedberry and Reichert 2015). Gag live to a maximum of 30 years (Sedberry and Reichert 2015). A number of factors likely contribute to the skewness of age composition and reproductive capability. These factors include formation of spawning aggregations in specific locations well known by fishermen, late maturation, and age-specific sex reversal (Sedberry and Reichert 2015). Overfishing is a primary management concern as it is likely to significantly affect age composition and reproductive ability of populations (Sedberry and Reichert 2015). Further, the largest fish (females undergoing sexual transition and males) are more vulnerable to the fishery and are usually first to be taken by fishing gear, leading to selective removal, skewed sex ratios, and reduced biomass of male Gag (McGovern et al. 1998, MARMAP 1998, Huntsman et al. 1999, Coleman et al. 2000).

Gag spawn during late winter to early spring (January to May), peaking in March and April in the Carolinas (Table 3.2.1) (McGovern et al. 1998, Sedberry et al. 2006, Sedberry and Reichert 2015). Gag may form pre-spawning aggregations in shallow water (20 m or 66 ft) before moving to the shelf-edge reefs to spawn (McGovern et al. 1998, Sedberry et al. 2006, Sedberry and Reichert 2015). Gag larvae develop for approximately 43 days (Keener et al. 1988, McGovern et al. 1998), after which they recruit to estuaries during flood tides (MARMAP 1998). Early juveniles (15 mm TL) ingress into South Carolina estuaries from April through June, peaking in April (Sedberry and Reichert 2015) and early May (Powles 1977, Collins et al. 1987, Keener et al. 1988, MARMAP 1998). The earliest collections of young juveniles in North Carolina were in May and June (Table 3.2.1) (Ross and Moser 1995). Keener et al. (1988) found the highest concentrations of planktonic Gag occurred at the surface during night time flood tide events near estuarine inlets in North Carolina and South Carolina. Additionally, larval and early juvenile Gag abundance was reported highest from June through September sampling period in North Carolina estuarine waters, with highest from late April to mid-May with peak ingress around new moons (Adamski et al. 2012, unpub. Bridgenet data). Juvenile Gag were caught from June through September sampling period in North Carolina estuarine waters, with highest catch per unit effort (CPUE) from July through August (Adamski et al. 2011). Adamski et al. (2011) also reported time of year, percent seagrass coverage, seagrass species, and sound (i.e., body of water) influenced juvenile Gag CPUE. Growth rate of juvenile Gag is rapid (~1.5 mm/day or 0.06 in/day) during summer months and is not different among years assessed (2007-2008) (Adamski et al. 2011).

Table 3.2.1: Temporal and spatial distribution of various Gag life stages in North Carolina and South Carolina waters. Shaded boxes correspond to various habitats going from inland freshwater inputs into estuaries to the ocean proper (estuaries = 0 – 25 psu, inlets/coast = 25 – 35 psu, and ocean/continental shelf = ≥35 psu). Here, it is noted that there is no juvenile Gag sampling program in place for estuarine waters. Primary literature was used to determine this use.

Estuary		**Q1=Winter**			**Q2=Spring**			**Q3=Summer**			**Q4=Fall**		
Inlets/ coasts / **Continental Shelf**	**Life Stage**	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Gag Grouper (*Mycteroperca microlepis*)	Spawning Adults												
	Larvae												
	Post-larvae												
	Juveniles												

Physiology and Habitat

Larval and juvenile transport from offshore spawning locations, away from adult populations, to estuarine nursery areas is a critical component of Gag life history. The interactions between spawning locations, physical processes, salinity, temperature, chemical cues, and habitat preferences are critical in determining larval settlement in estuaries (Peterson et al. 2000, Brown 2002). While significant data gaps exist, both natural and maintained inlets in North Carolina and South Carolina should be considered important habitat related to the migration dynamics of Gag and other estuarine dependent species of snapper and grouper (Peters et al. 1995, Peters and Settle 1994, Tzeng et al. 2003). Juvenile Gag live in estuarine waters during their first summer, typically residing in habitats high in salinity with natural and artificial structure. Juveniles prefer oyster reefs and shell rubble, seagrass beds, dredged canals, pilings, rock jetties, and artifical reefs (Keener et al. 1988, Ross and Moser 1995, Mullaney and Gale 1996, Koenig and Coleman 1998). In North Carolina, Gag have been observed to move from seagrass beds to these complex substrates within estuaries between late June and July (Ross and Moser 1995, Adamski 2009). Massive emigration from estuaries to nearshore ocean hard bottom habitats occurs in the fall (October) with the concurrent drop in water temperature (Ross and Moser 1995). Adult Gag can be found at depths of 15 to 107 m (49 to 351 ft) along the continental shelf once they leave the estuaries (Moser and Taylor 1995, Heemstra et al. 2002, SCDNR MARMAP unpublished data). In offshore waters, Gag occupy natural and artificial reefs, including wrecks, hard bottom, shelf-edge scarps, ledges, sponge/coral habitats, and various other habitats providing vertical relief from the bottom (Mullaney 1994, Koenig and Coleman 1998, Sadovy de Mitcheson and Colin 2011).

Gag are vulnerable to numerous anthropogenic influences that may alter or adversely impact estuarine habitat. Coastal development asserts constant pressure on estuarine ecosystems, altering potential habitat for larval and juvenile Gag (Sedberry and Reichert 2015). Inputs of sediment and loss of estuary from developments, polycyclic aromatic hydrocarbons from highways, pesticides, contaminants of emerging concern, and various other pollutants and destructive impacts consistently pose concerns to estuarine ecosystems (Coleman et al. 2000).

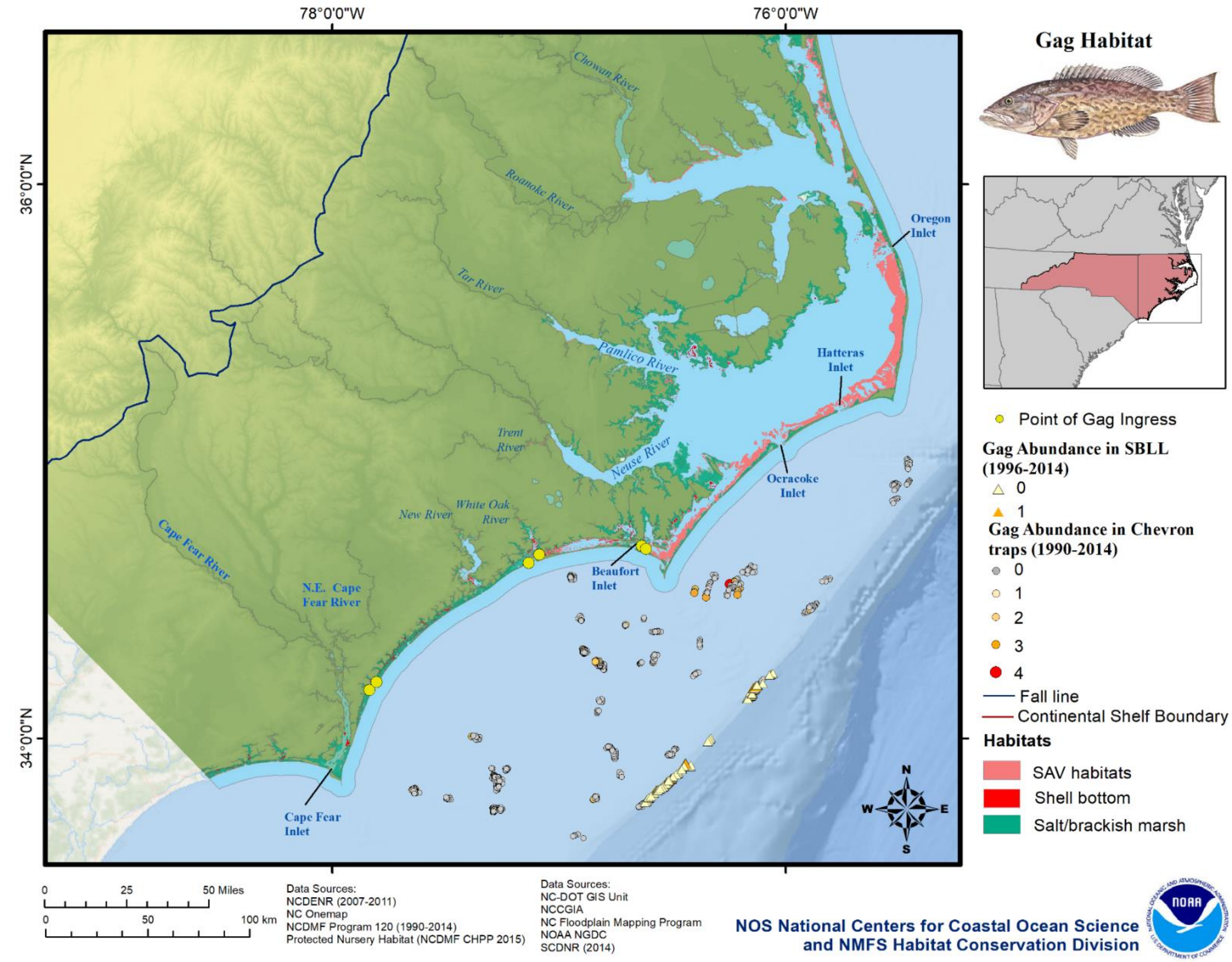

Figure 3.2.2: Gag presence in Chevron traps and short-bottom longlines (SBLL) in coastal North Carolina. Data are derived from MARMAP/SEAMAP-SA/SEFIS (SERFS) surveys. Point of ingress data for Gag postlarvae (yellow dots) were provided by Tracey Smart (SCDNR). Habitats for Gag life stages include hard bottom (blue lines), shell bottom habitat (juvenile recruitment), and submerged aquatic vegetation.

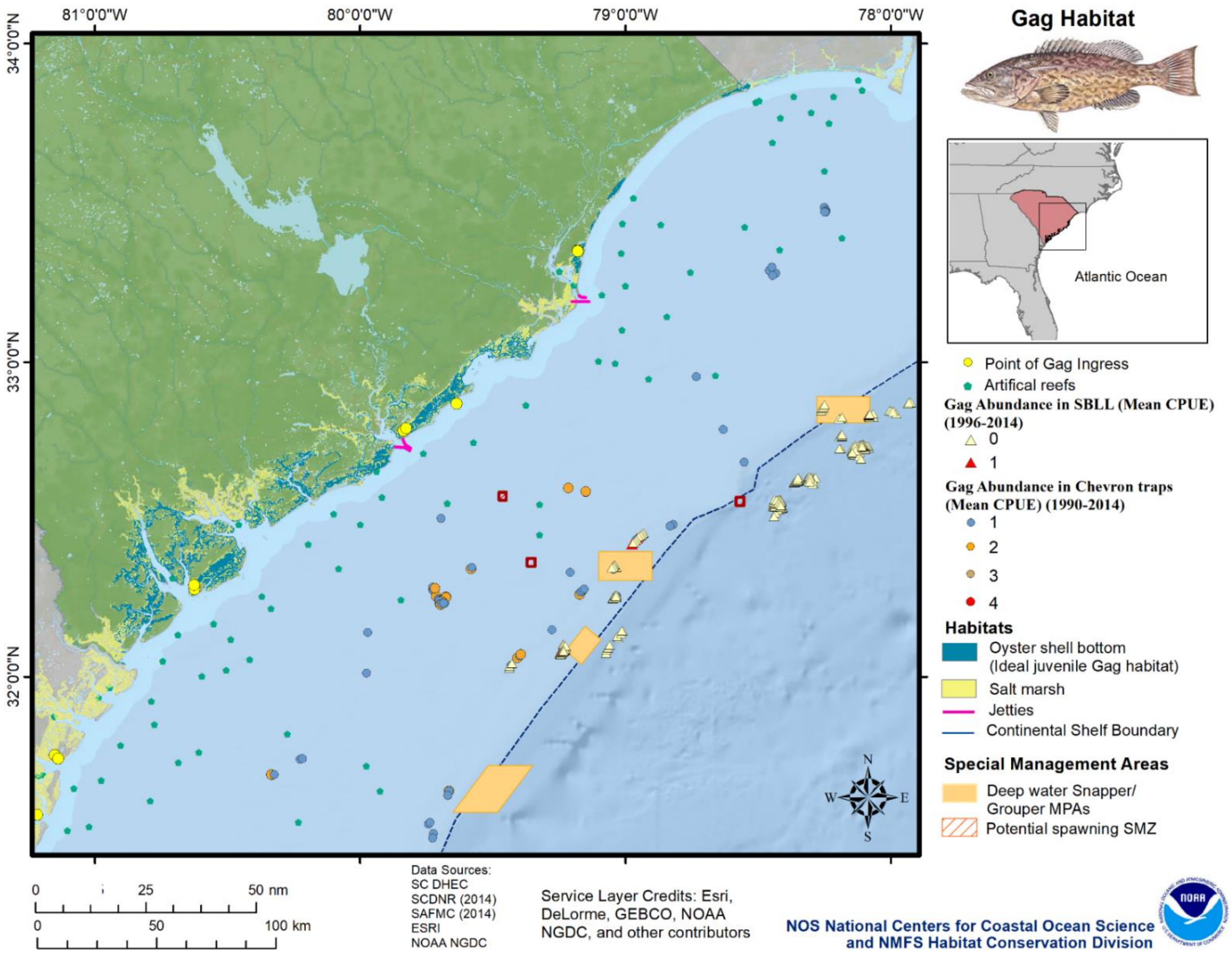

Figure 3.2.3: Gag presence in Chevron traps and short-bottom longlines (SBLL) in coastal South Carolina. Data are derived from MARMAP/SEAMAP-SA/SEFIS (now SERFS) surveys. Point of ingress data for Gag postlarvae (orange dots) were provided by Tracey Smart (SCDNR). Habitats for Gag life stages include hard bottom (deep water snapper/grouper MPAs), and shell bottom habitat.

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3.3 Summer Flounder

(*Paralichthys dentatus*, Linnaeus, 1766)

Photo credit: NOAA

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General Information

Summer Flounder (*Paralichthys dentatus*) are found in inshore and offshore waters ranging from Nova Scotia, Canada to the east coast of Florida (Ginsburg 1952, Bigelow and Schroeder 1953, Anderson and Gehringer 1965, Gutherz 1967, Wilk et al. 1980, Gilbert 1986, Scott and Scott 1988, Grimes et al. 1989, Klein-MacPhee 2002, Sackett et al. 2007, Able et al. 2010, Able and Fahay 2010). In the United States, Summer Flounder are most abundant along the continental shelf and adjoining estuaries from Cape Cod, Massachusetts to Cape Fear, North Carolina (Hildebrand and Schroeder 1928, Wilk et al. 1980, Grosslein and Azarovitz 1982, Able and Kaiser 1994, Able and Fahay 1998, ASMFC 2015). Juveniles and adults have seasonal inshore/offshore migrations, with movements into shallow estuaries or coastal areas in the spring, estuarine residence through the summer, and movement out of estuaries (emigration) and nearshore habitats in late summer and fall, overwintering on the edge of the continental shelf (Figure 3.3.1) (Westman and Neville 1946, Smith and Daiber 1977, Wilk et al. 1980, Able and Fahay 1998).

The Mid-Atlantic Fishery Management Council (MAFMC) and ASMFC FMP defines the management unit as all Summer Flounder from North Carolina northeast to the Canadian border as a single stock (Terceiro 2015). This management unit is consistent with a

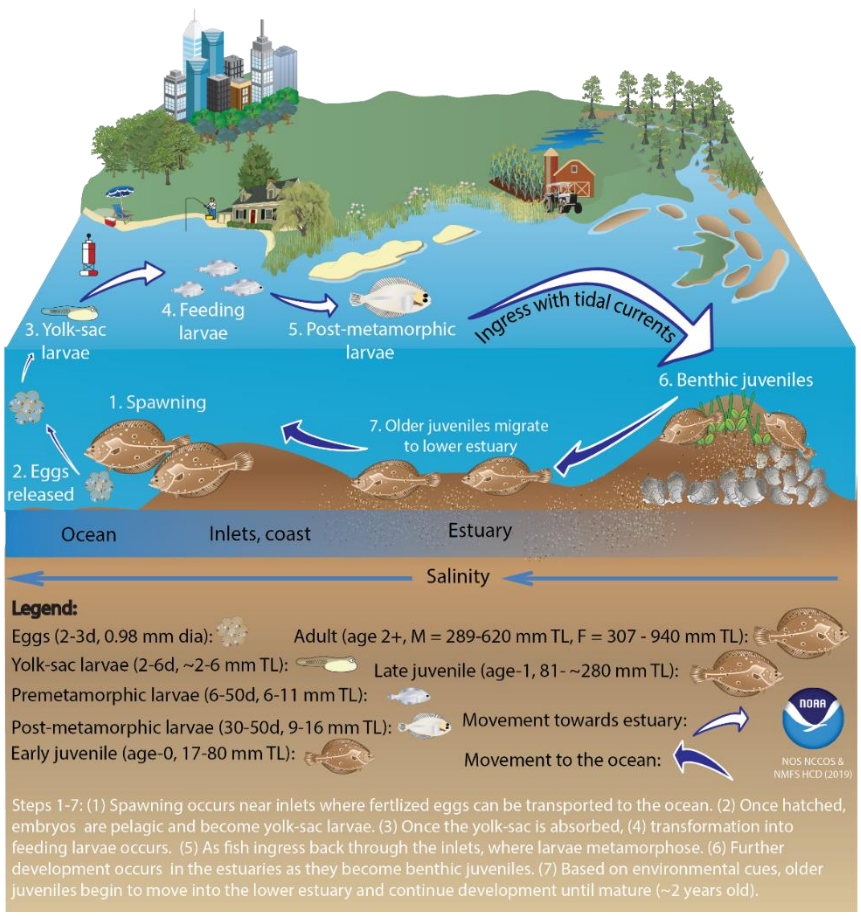


Figure 3.3.1: Life cycle of the Summer Flounder (*Paralichthys dentatus*).

Summer Flounder genetics study, revealing no population subdivision at Cape Hatteras and phenotypic divergences, may reflect differential environmental conditions (Jones and Quattro 1999). Initially the FMP was developed due to considerable concern in 1980s landings and stock biomass data, indicating a precipitous decline in landings and spawning stock biomass (Able et al. 2010). Significant revisions to the plan have occurred since inception, increasing the protection of juvenile fish and ensuring the maintenance of an adequate spawning population (ASMFC 2015). Conservation measures for protection of juveniles was achieved through the implementation of larger minimum size limits across all sectors, increased mesh sizes for nets, and decreased recreational possession limits. The most recent stock assessment indicates the Summer Flounder stock is not overfished, but overfishing is occurring (ASMFC 2017, MAFMC 2018). Average recruitment (the number of juvenile fish that will be able to reproduce in a given year) from 1982 to 2015 is estimated at 41 million fish (NMFS 2016). Importantly, the sex ratio of juveniles is skewed in favor of males, but as the cohort ages, the balance in sex ratio shifts toward females (Smith and Daiber 1977, Bonzek et al. 2009), indicating a higher natural mortality rate among males (Maunder and Wong 2011).

Summer Flounder are one of the most sought after commercial and recreational fishes along the Atlantic coast, with total landings of approximately 7,892.5 MT (17.4 million lbs) in 2014, making it an economically important fishery (Able et al. 2010, ASMFC 2015). Using baseline data from 1980 to 1989, current management allocates the Summer Flounder quota with 60% to commercial fisheries and 40% to recreational fisheries (ASMFC 2015). There are two major commercial trawl fisheries for Summer Flounder — a winter offshore and a summer inshore occurring predominately north of Cape Hatteras, North Carolina (ASMFC 2015). In 2014, commercial landings were estimated to be 4,944.2 MT (10.9 million lbs) (ASMFC 2015). The fishing mortality rate for 2014 was estimated to be 16% above the threshold reference point. These results appear to be largely driven by below average recruitment, which has been overestimated by 22% to 49% for five of the last seven year classes (ASMFC 2015). This ultimately led to an overestimation of stock size. The most recent stock assessment update estimates Summer Flounder biomass has been trending downward since 2010. Additionally, although reported landings have equaled or only slightly exceeded the quota, two separate investigations in 2013 and 2014 found evidence that substantial illegal harvest occurred in the form of unreported, underreported, or misreported landings (ASMFC 2015). With this new information, the ASMFC and MAFMC decreased the acceptable biological catch by 29% from the 2015 to 2016 fishing season. This quota was divided between commercial fishing (3,674.1 MT or 8.12 million lbs) and recreational fishing (2,458.5 MT or 5.42 million lbs) for 2016. Current commercial regulations require a 355.6 mm (14 in) total length (TL) minimum size limit in Atlantic Ocean waters and a 381 mm (15 in) TL minimum size limit in internal coastal waters as well as harvest seasons and minimum mesh size requirements for the flounder trawl fishery (NCDMF 2018). Trip limits are set for landings windows established by proclamation to constrain harvest to the quota allocation (NC FF-54-2018) on commercial summer flounder fishery). A bycatch trip limit of 45.4 kg (100 lbs) is in place during the closed trawl season. A license to land flounder from the Atlantic Ocean is required to land more than 45.4 kg per trip

(NCDMF 2018). As a prized recreational fish, anglers exploit Summer Flounder on hook and line from the shore, piers, and boats (ASMFC 2015). For the North Carolina inshore (i.e., those waters < 5.6 km (3 nm) from the North Carolina's shore) and offshore (i.e., > 5.6 to < 370.4 km, or > 3 and < 200 nautical miles from shore) fishery, the daily creel limit is 4 per person with a minimum size of 381 mm (15 in) TL (NCDMF 2018). For South Carolina recreational fishing of flounders (Summer Flounder, Southern Flounder, and Gulf Flounder) regulations require a limit of 10 per person per day not to exceed 20 per boat per day (rod and reel or gig) and a 381 mm (15 in) minimum TL (SCDNR 2018).

Life History

Summer Flounder are batch spawners, spawning more than once in a spawning season in response to environmental conditions. They spawn as they move from bays and estuarine grounds to the coasts and openocean along the continental shelf (Packer et al. 1999, Able et al. 2010). Powell (1974) estimated females ranging from 506-682 mm TL (19.9 – 26.9 in) have 1.67 to 1.70 million ova per fish. Spawning migrations are initiated at the peak of the gonadal development cycle (December and January south of Cape Hatteras) with the oldest and largest fish migrating first each year (Table 3.3.1) (Smith 1973). Female Summer Flounder grow three times faster (Poole 1961, Daniels 2000, King et al. 2001) and mature at a larger size than males (Wenner et al. 1990, Able and Kaiser 1994, Packer et al. 1999, Fischer and Thompson 2004). Summer Flounder spawn throughout the fall and winter as fish emigrate offshore or onto their wintering grounds (Packer et al. 1999); this movement coincides with the life stage (age-2) when capture in the commercial fishery occurs (Able et al. 2010). Offshore migration is correlated to cooling temperatures and decreasing photoperiod in the fall (Packer et al. 1999). Summer Flounder sampled from Pamlico Sound, NC were 350 mm (13.8 in) TL at maturity (Powell 1974) and fish from South Carolina were estimated to be 289 mm (11.4 in) TL for males and 307 mm (12 in) TL for females at maturity (Wenner et al. 1990) – all corresponding to fish approaching age-2 (Packer et al. 1999). Observations of fish maturity in the South Atlantic Bight indicate spawning begins as early as October and may continue through early March (Table 3.3.1) (Wenner et al. 1990).

Summer Flounder eggs (1 mm, or 0.04 in, in diameter) are transparent, pelagic, and buoyant and have been found at depths of 30 to70 m (98 to 230 ft) in the fall, as deep as 110 m (360 ft) in the winter, and between 10 and 30 m (33 to 98 ft) in the spring (Henderson-Arzapalo et al. 1988, Powell and Henley 1995, Packer et al. 1999). Rate of Summer Flounder egg development is positively correlated with temperature, with increasing developmental rate occurring with increasing temperatures (Packer et al. 1999). Peak abundances for eggs in the fall occur at temperatures around 14 to 17 °C (57 to 63 °F) (Reid et al. 1999). Watanabe et al. (1999) experimentally showed higher temperatures and salinity increased the rate of embryonic development through hatching, but at high temperature and low salinity, inhibition of hatching and growth of embryos occurred. Conversely, a low temperature of 16 °C (61 °F) at low salinities enhanced larval survival indicating a low temperature–low salinity synergistic effect. Watanabe et al. (1999) therefore posits moderate to high survival under all salinities at 16 °C reflects an adaptability of the yolk sac larvae to inshore movement during the pelagic larval phase. Eggs hatch between 72 and 75 hours post fertilization (Smith and Fahay 1970) with unpigmented eyes and no fin buds or mouth parts, surviving off the yolk-sac during initial development (Smith and Fahay 1970). After about two to three days, the yolk-sac is exhausted, and larvae have formed critical organs allowing them to begin consuming small planktonic food (Bisbal and Bengtson 1995).

Table 3.3.1: Temporal and spatial distribution of various Summer Flounder life stages in North Carolina and South Carolina waters. An asterisk indicates when main events (e.g., spawning) or abundance are expected during a particular month. Shaded boxes correspond to various habitats going from inland freshwater inputs into estuaries to the ocean proper (estuaries = 0 – 25 psu, inlets/coast = 25 – 35 psu, and ocean/continental shelf = ≥35 psu). Larvae exist in both the inlets and coasts as well as the ocean. Split colors show when both habitats utilized.

Estuary	* = spawning	Q_1=Winter			Q_2=Spring			Q_3=Summer			Q_4=Fall		
Inlets/ coasts Ocean	Life Stage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Summer Flounder (*Paralichthys dentatus)*	Adults	*	*	*							*	*	*
	Egg												
	Larvae												
	Juveniles												

Based on morphometric and meristic data, Smith and Fahay (1970) describe 11 larval size classes during development ranging from 2 to 13 mm (0.08 to 0.5 in) TL (Packer et al. 1999). Larvae begin swimming upright and stay in this orientation until ingress into estuarine nursery grounds occurs during nighttime flood tides (late-stage larvae, Burke et al. 1998). Metamorphosis – generally taking between 30 to 70 days post hatch – from larvae to juvenile involves the migration of the right eye across the top of the head, and occurs at 8-11 mm (0.3 to 0.4 in) Standard Length (SL) (Arnold et al. 1977, Miller et al. 1991, Keefe and Able 1993, Able and Kaiser 1994, NCDMF 2012). Metamorphosis in Summer Flounder is regulated by thyroid hormones and takes place as the larvae move from a salinity of about 35 psu in the ocean to salinity ranging from 0 to 35 psu in estuaries (Able and Kaiser 1994, Schreiber and Specker 1999). Once metamorphosis occurs, individuals leave the water column, settle to the bottom and generally bury themselves in sediment to complete development to the juvenile stage (Keefe and Able 1993, 1994). In North Carolina, the highest densities of larvae are documented at Oregon Inlet in April, in Ocracoke Inlet in February (Hettler and Barker 1993), at Beaufort Inlet in February and March (Packer et al. 1999, Able et al. 2010), in the Newport River estuary in early March (Warlen and Burke 1990), and in the Cape Fear River between March and April (9-16 mm, or 0.35 to 0.63, SL) (Weinstein 1979, Weinstein et al. 1980). After immigration, flounders were locally very abundant in the Newport River estuary as compared to offshore waters of Onslow Bay and initial settlement was in the intertidal zone (Figure 3.3.2) (Packer et al. 1999). Ingress patterns in Beaufort Inlet, North Carolina indicate larvae occurred from December through the end of the sampling period in May, but larvae were most abundant from February through April (Able et al. 2010). In February, most were transforming larvae, but by March a portion were completely settled juveniles (11 to 21 mm [0.3 to 0.8 in] SL) (Packer et al. 1999). In South Carolina, peak larval densities occurred in North Inlet estuary in February and March (Burns 1974), in the Port Royal Sound from January through March (Bearden and Farmer 1972), in the Charleston Harbor from January to April (Wenner et al. 1990), and in the Chainey Creek area around the same time period (Figure 3.3.3a, Figure 3.3.3b, Figure 3.3.4a, Figure 3.3.4b) (Wenner et al. 1986). Notably, some Summer Flounder emigrate early in the summer or temporarily emigrate out of estuaries (Sackett et al. 2007, Capossela 2010). These early migrations are likely not related to offshore spawning, but rather these individuals may occupy habitats on the inner continental shelf or move among coastal estuarine systems (Figure 3.3.5) (Capossela 2010).

Juveniles are distributed in bays, sounds, and many estuaries throughout the species range during spring, summer, and fall (Figure 3.3.5, Figure 3.3.6) (Dubler 1958, Pearcy and Richards 1962, Poole 1966, Miller and Jorgenson 1969, Powell and Schwartz 1977, Fogarty 1981, Able and Kaiser 1994, Rountree and Able 1997, Walsh et al. 1999). Patterns of juvenile estuarine use vary by latitude (Packer et al. 1999). Juveniles in southern waters generally overwinter in bays and sounds (Able and Kaiser 1994). In North Carolina sounds, juveniles often remain for 18 to 20 months (Figure 3.3.2) (Powell and Schwartz 1977). Juveniles located offshore return to coasts and bays in the spring and generally stay the entire summer (Packer et al. 1999). Once estuarine residency is established, individuals will only make minor movements as they become sedentary until fall migration (Desfosse 1995, Capossela 2010). First year Summer Flounder grow rapidly; in North Carolina's Pamlico Sound, age-0 individuals obtained mean lengths 167 mm (6.6 in) TL for males and 171 mm (6.7 in) TL for females (Powell 1982). In Charleston Harbor, Wenner et al. (1990) found juveniles recruited to estuarine creeks when they reached 100 to 200 mm (3.9 to 7.9 in) TL. Growth of these juveniles accelerated in May and June when individuals reached modal sizes of 140 mm (5.5 in) TL (Wenner et al. 1990). By September, modal size was 160 mm (6.3 in) TL, and reached 230 to 250 mm (9 to 9.8 in) TL through October and November. January through June the same general size classes were sampled, with juveniles generally reaching 280 mm (11 in) TL by October (Packer et al. 1999). Estuarine waters west and northwest of Cape Hatteras, North Carolina (Monaghan 1996) and in high salinity bays and tidal creeks of Core Sound (Noble and Monroe 1991), serve as significant nursery areas for juvenile Summer Flounder. Powell and Schwartz (1977) found that juveniles were most abundant in the relatively high salinities of the eastern and central parts of Pamlico Sound, all of Croatan Sound, and around inlets (Packer et al. 1999). Age-0 juveniles in the Pamlico Sound and Croatan Sound areas disappeared from the catch in late summer, suggesting that these fish are leaving estuarine habitats at that time (Powell and Schwartz 1977). Juveniles located from Cape Hatteras northward enter the north-south, inshore-offshore movement of the Bight once exiting the estuaries (Monaghan 1996). In contrast, those juveniles south of Cape Hatteras in the South Atlantic Bight, do not exhibit the same inshore-offshore, north-south migratory movement; juveniles > 300 mm (11.8 in) TL are rarely found in North Carolina estuaries, but larger fish are found around the inlets and along coastal beaches (Packer et al. 1999).

Physiology and Habitat

Sackett et al. (2007) used ultrasonic telemetry to track seasonal migrations of Summer Flounder to and from estuaries in Great Bay Estuary, New Jersey and found emigration may be associated with storm events on an episodic scale and dissolved oxygen (DO) and temperature on a seasonal scale. As DO decreases in estuaries, increased numbers of tagged individuals emigrated from estuarine areas (Sackett et al. 2007). Movement into estuaries may result from a large proportion of Summer Flounder homing to natal estuaries (Sackett et al. 2007, Capossela 2010). Environmental conditions (i.e., hypoxia and temperature) influencing fish activity are primarily mediated through aerobic metabolism (Capossela 2010). Unless acutely thermally stressed, Summer Flounder have the ability to maintain aerobic metabolism in low oxygen conditions and are not likely to avoid hypoxic conditions in the wild (Capossela 2010). Hypoxia can decrease aerobic scope and consequently negatively impact somatic and gonadal growth rates (Capossela 2010).

Larvae and early juvenile Summer Flounder use several different types of estuarine habitats (Packer et al. 1999). Estuarine marsh creeks and SAV are important juvenile habitat in North Carolina (Burke et al. 1991) and South Carolina (Bozeman and Dean 1980, McGovern and Wenner 1990, Wenner et al. 1990). Early juveniles may use open bay areas during winter months, and make use of seagrass beds when present (Lascara 1981, Wyanski 1990, Szedlmayer et al. 1992, Walsh et al. 1999). Early juveniles were most abundant in areas with a predominantly sandy or sand/shell substrate, or where there was a transition zone from fine sand to silt or clay. Recently settled Summer Flounder in Charleston Harbor were abundant over a wide variety of substrates including mud, sand, shell hash, and oyster bars (Hoffman 1991). Adult Summer Flounder prefer coarse, sandy substrate, where burying behavior can easily be initiated (Powell and Schwartz 1977).

These estuarine habitats are directly impacted by numerous coastal development activities, such as estuarine shoreline stabilization, dredging for navigational purposes, fishery harvest (including trawling activities), and inlet stabilization (NCDMF 2012). Protection of each habitat type is critical to the sustainability of the Summer Flounder stock.

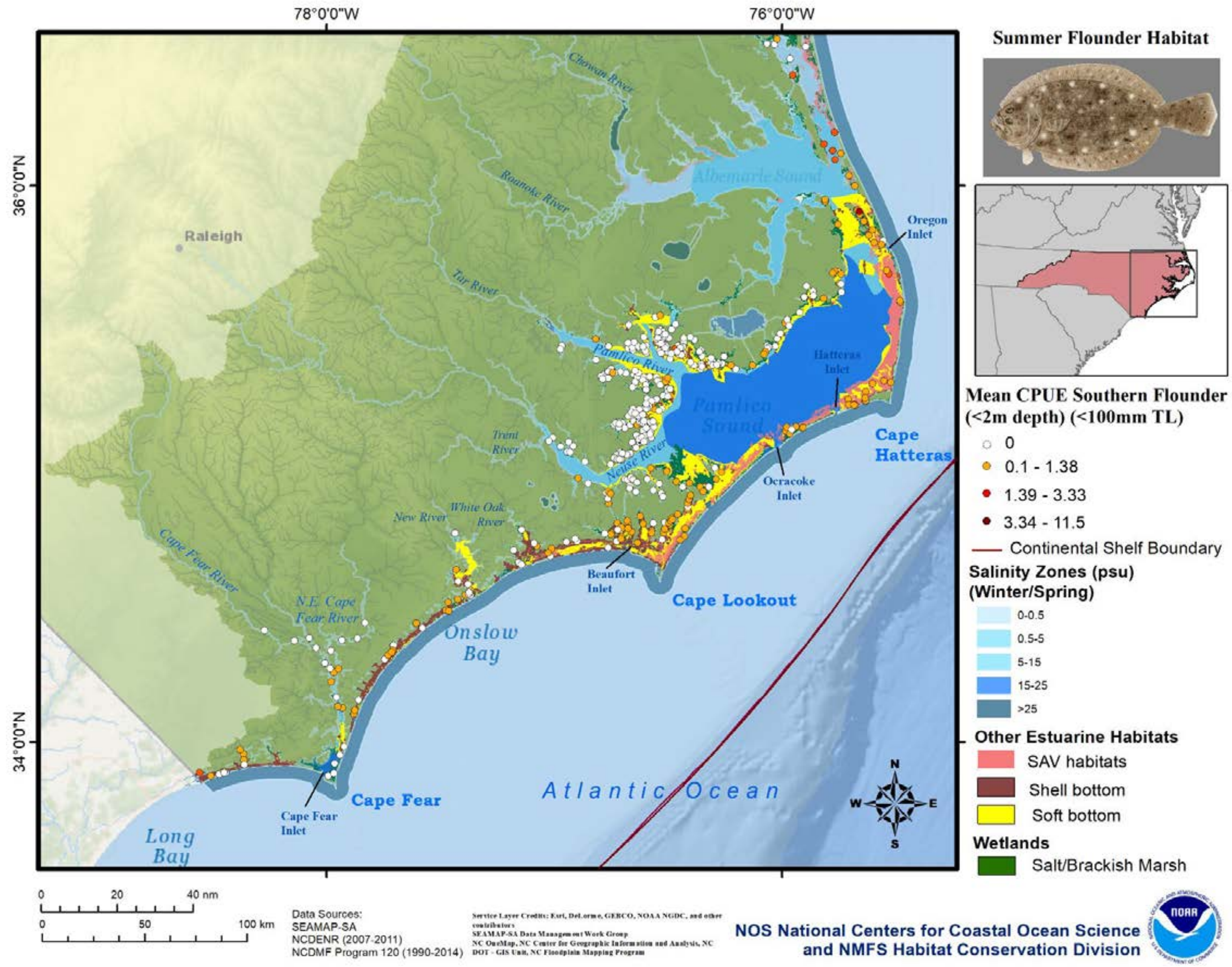


Figure 3.3.2: Fishery independent survey data (NCDMF Program 120) for Summer Flounder less than 100 mm TL in North Carolina estuarine waters from 1990 to 2014. Sampling occurred in May and June of each year and a mean abundance was calculated for each sampling station/year. Various habitats are also depicted indicating where certain life stages will likely be based on preferred habitat distribution.

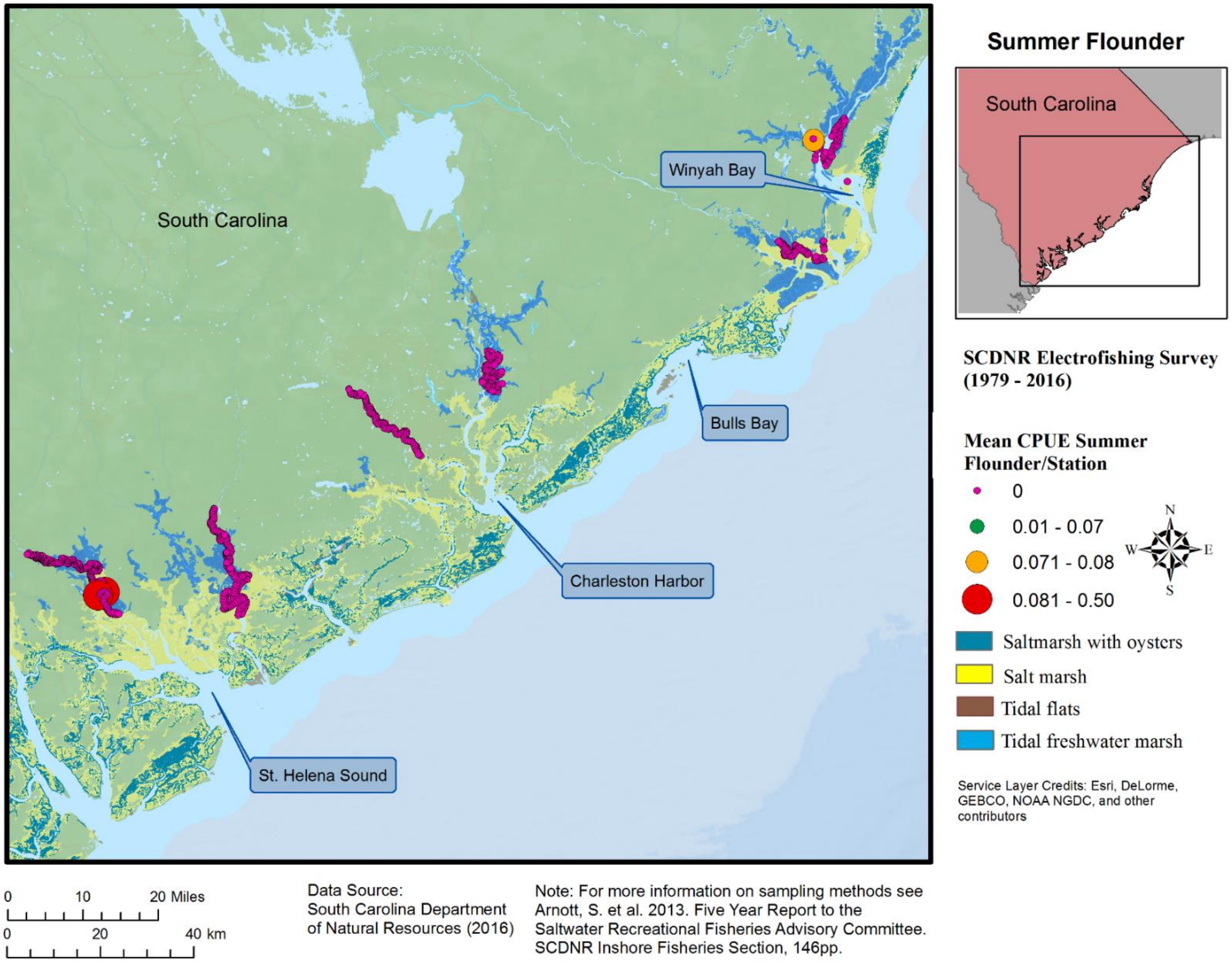


Figure 3.3.3a: Fishery independent electrofishing survey data (SCDNR 2016) for Summer Flounder in South Carolina from 1979 to 2016. Various habitats are also depicted indicating where certain life stages will likely be based on preferred habitat distribution. Graduated proportional symbols were used to visualize stations with higher mean CPUE.

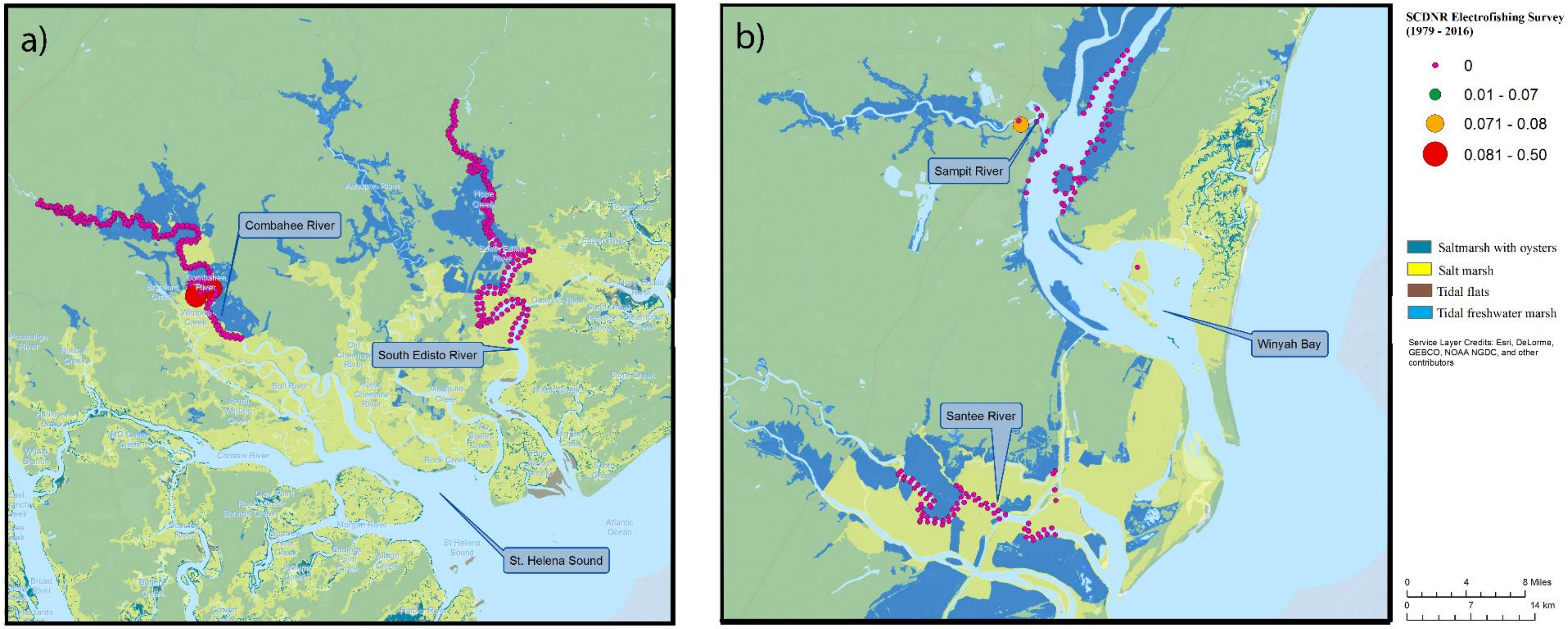


Figure 3.3.3b: Fishery independent electrofishing survey data (SCDNR 2016) for Summer Flounder in South Carolina from 1979 to 2016. Tile a) is a view of sampling from the St. Helena Sound area. High catches can be observed in the Combahee River. Tile b) is of a more northern South Carolina Bay, Winyah Bay, where relatively higher catches can be observed on the Sampit River. Various habitats are depicted indicating where certain life stages will likely be based on preferred habitat distribution.

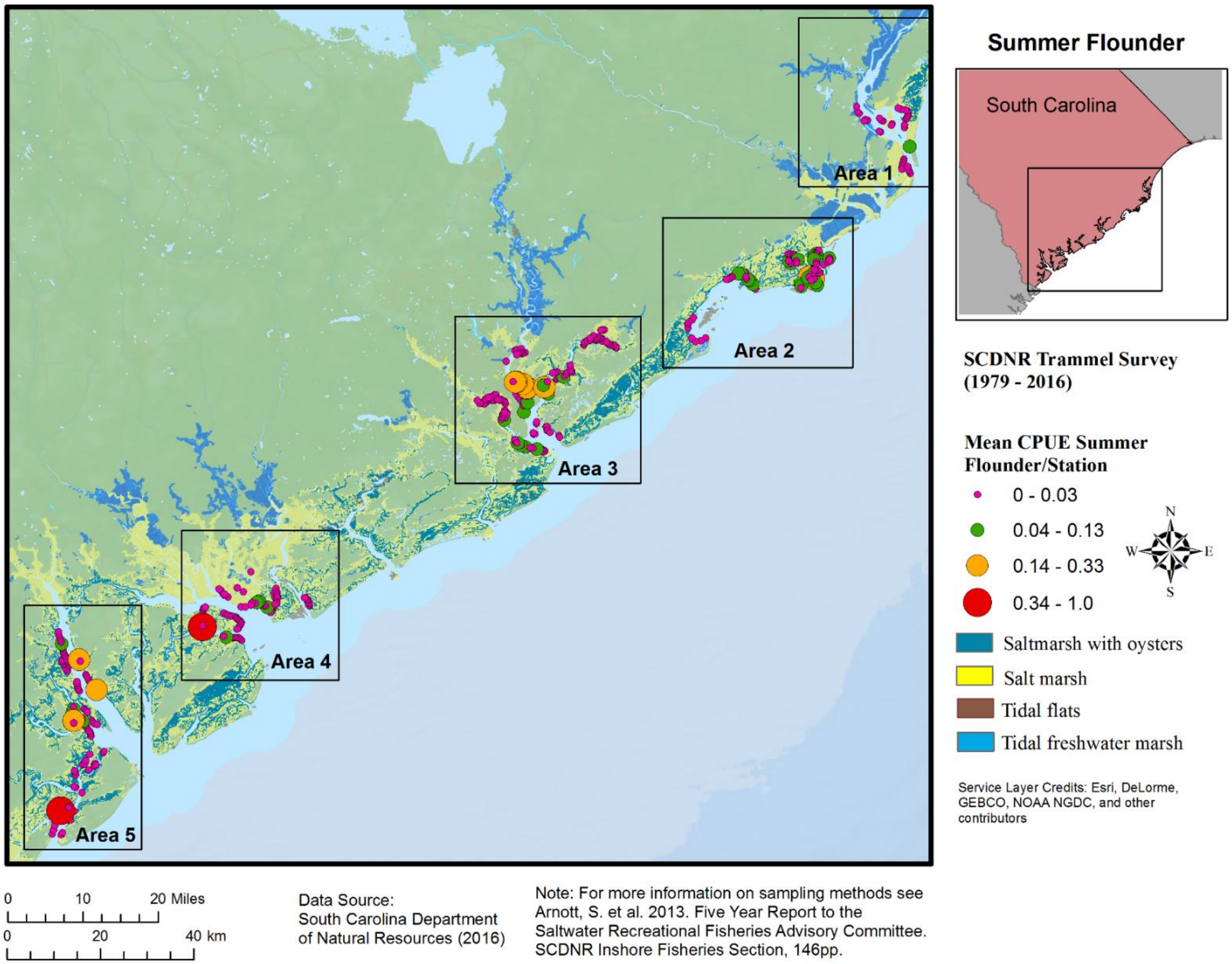
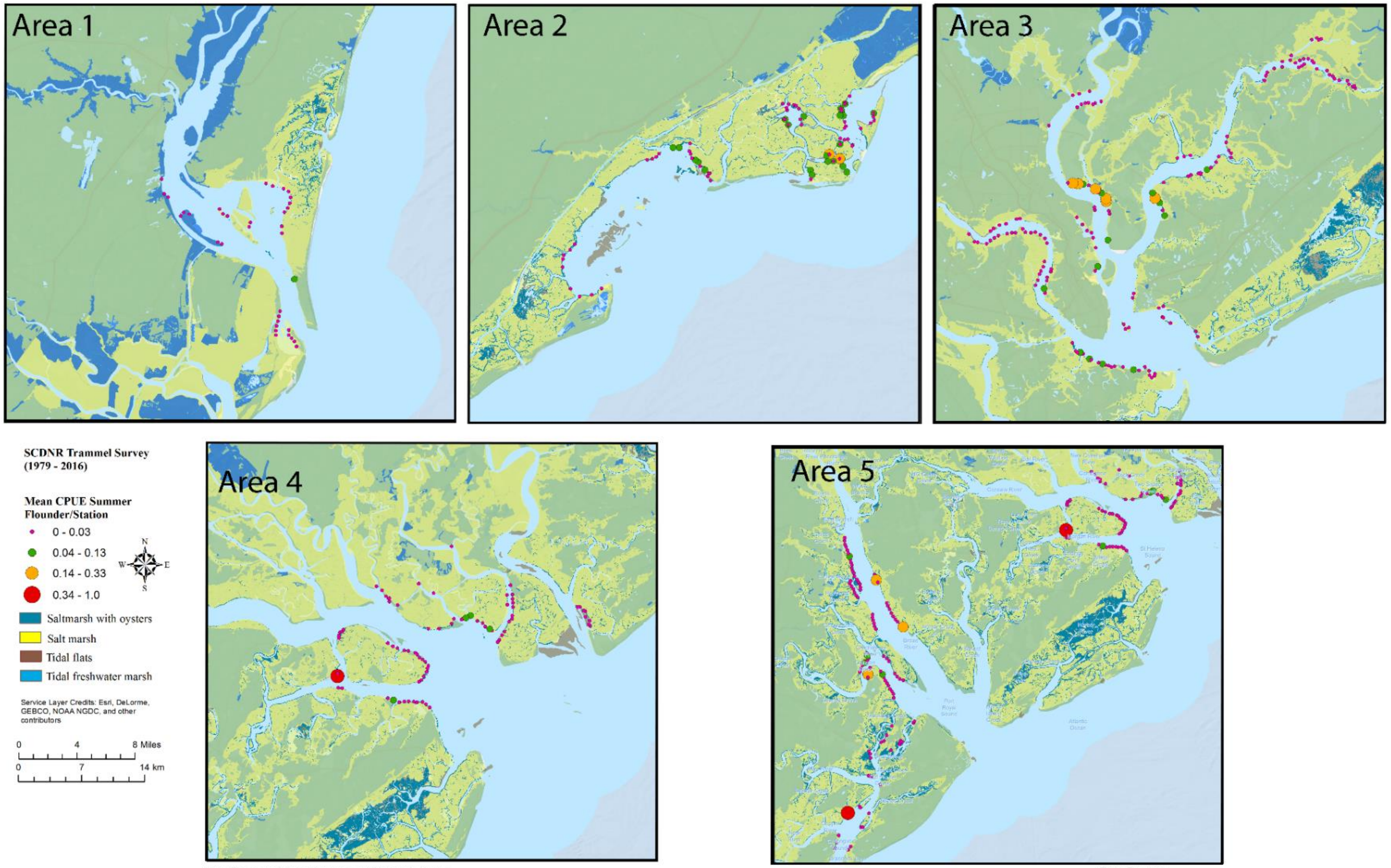


Figure 3.3.4a: Fishery independent trammel net survey data (SCDNR 2016) for Summer Flounder in South Carolina from 1979 to 2016. Various habitats are also depicted indicating where certain life stages will likely be based on preferred habitat distribution. Distinct geographical areas were grouped into Areas 1-5 for reference in Figure 5b.



Note: For more information on sampling methods see Arnott, S. et al. 2013. Five Year Report to the Saltwater Recreational Fisheries Advisory Committee. SCDNR Inshore Fisheries Section, 146pp.

Data Source:
South Carolina Department of Natural Resources (2016)

Figure 3.3.4b: Fishery independent trammel net survey data (SCDNR 2016) for Summer Flounder in South Carolina from 1979 to 2016. Various habitats are depicted indicating where certain life stages will likely be based on preferred habitat distribution. Area 1 = Winyah Bay, Area 2 = Bulls Bay, Area 3 = Charleston Harbor, Area 4 = St. Helena Sound, and Area 5 = Port Royal Sound, South Carolina.

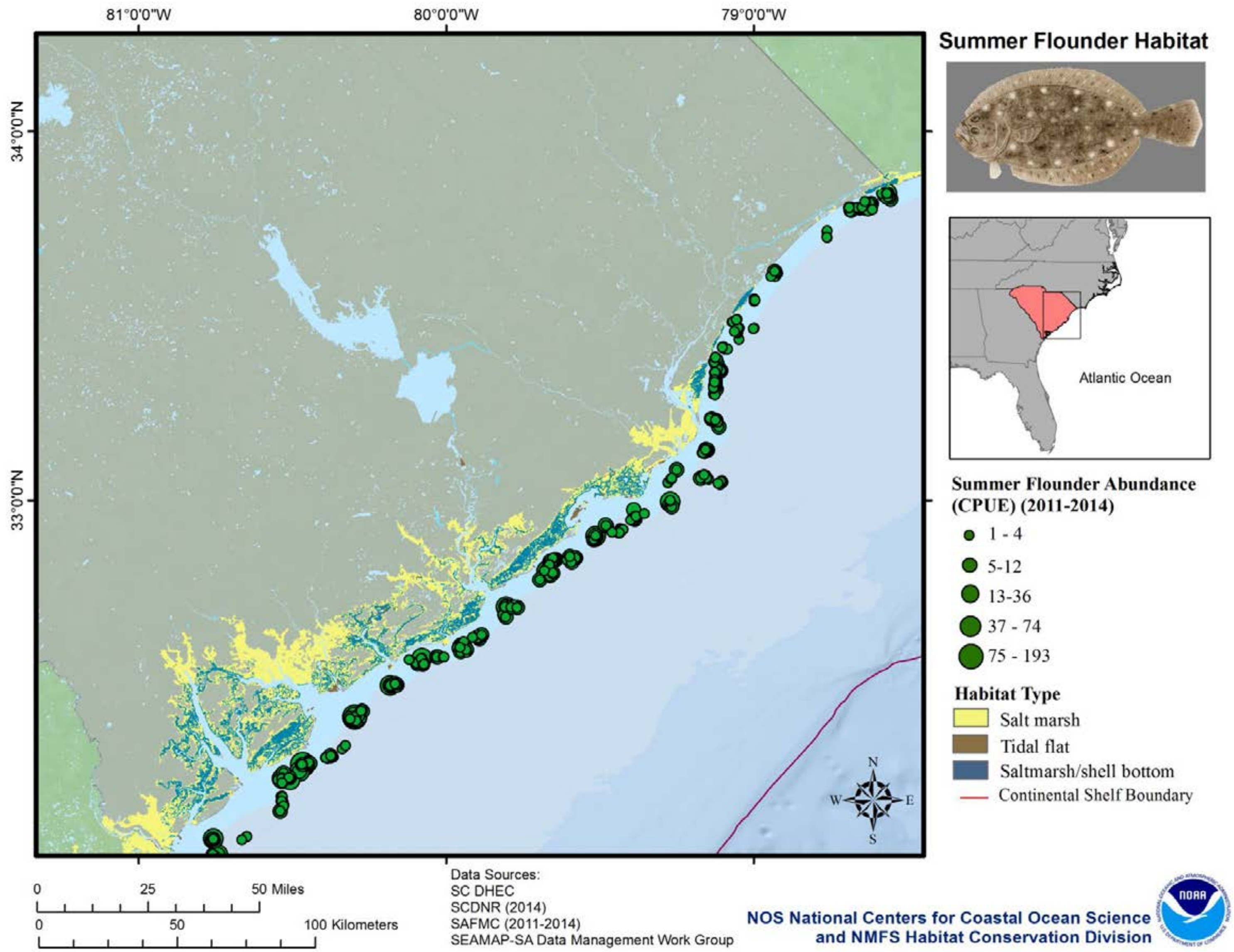


Figure 3.3.5: Distribution of Summer Flounder (2011 – 2014) off South Carolina based on fishery independent survey data from the Southeast Area Monitoring and Assessment Program – South Atlantic (SEAMAP-SA) Data Management Work Group.

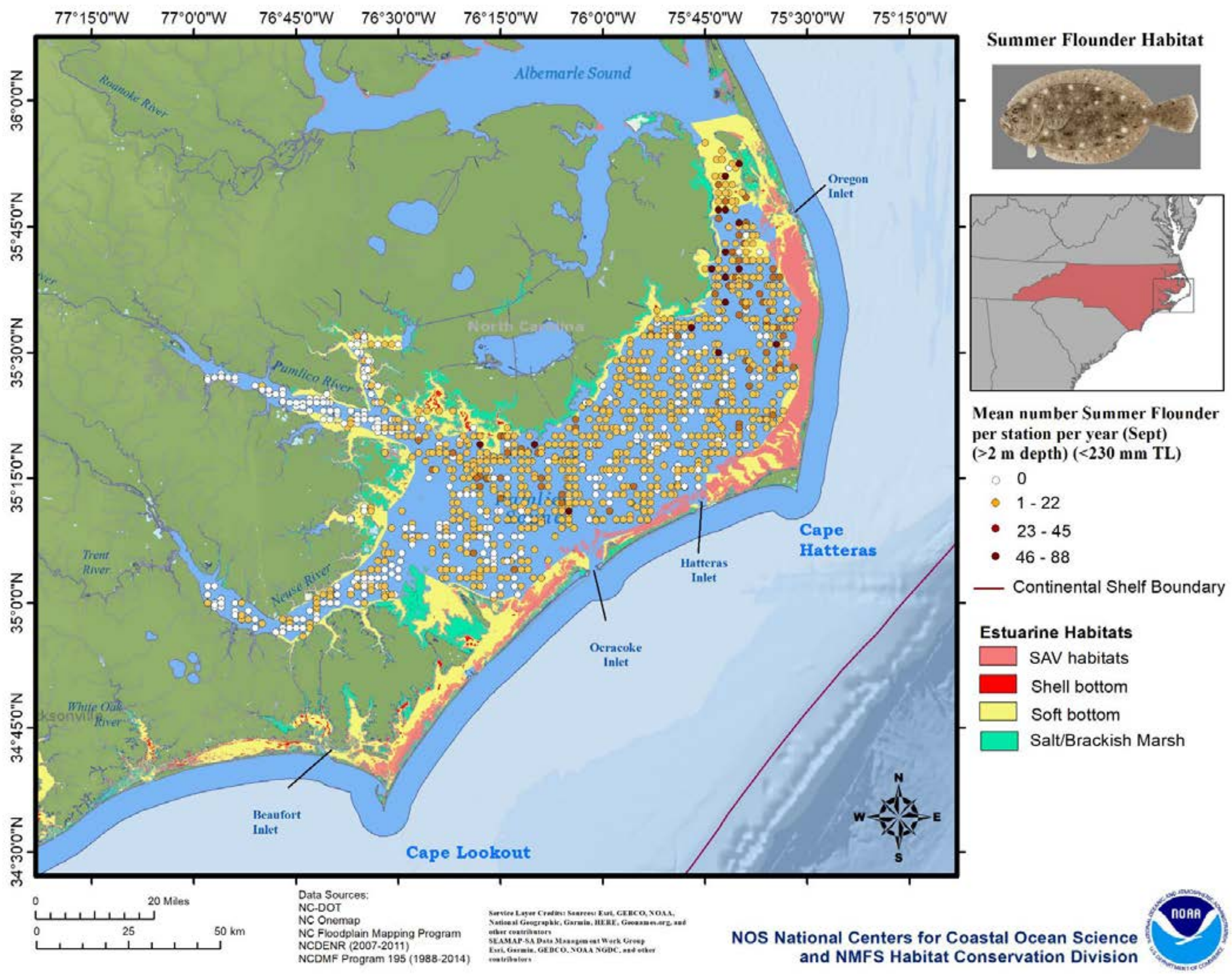


Figure 3.3.6: Fishery independent survey data (NCDMF Program 195) for Summer Flounder <230 mm TL in North Carolina estuarine waters from 1990 to 2014. Sampling occurred in May and June of each year and a mean abundance was calculated for each sampling station/year. Various habitats are also depicted indicating where certain life stages will likely be based on preferred habitat distribution. The dark blue outline indicates all state waters.

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3.4 Atlantic Sturgeon

(*Acipenser oxyrinchus*, Mitchill, 1815)

Photo credit: University of Maryland Center for Environmental Science

Authors: Lisa C. Wickliffe[1], Keith Hanson[2], and W.C. (Bill) Post[3]

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General Information

Atlantic Sturgeon are an anadromous (Figure 3.4.1), late-maturing, long-lived species that once supported an important commercial fishery along the Atlantic coast (Goode 1887). Exploitation for food along with construction of mainstream dams during the 19th and 20th centuries led to the drastic decline of Atlantic Sturgeon throughout their range, with extirpation occurring in some river systems (ASMFC 1998, USFWS-NMFS 1998, ASSRT 2007, Greene et al. 2009). About 65% of the historical landings were based on the Delaware stock and were landed in New Jersey and Delaware; only about 20% of landings were from southeastern states (ASMFC 1998). Since 1950, the majority of the catch is from southern states with North Carolina and South Carolina accounting for about 50% (Burke and Rohde 2015).

Historically, Atlantic Sturgeon inhabited coastal rivers from Labrador (the most eastern province in Canada) to as far south as the St. Johns River in Florida (Grunchy and Parker 1980, Greene et al. 2009). In the U.S., Atlantic Sturgeon

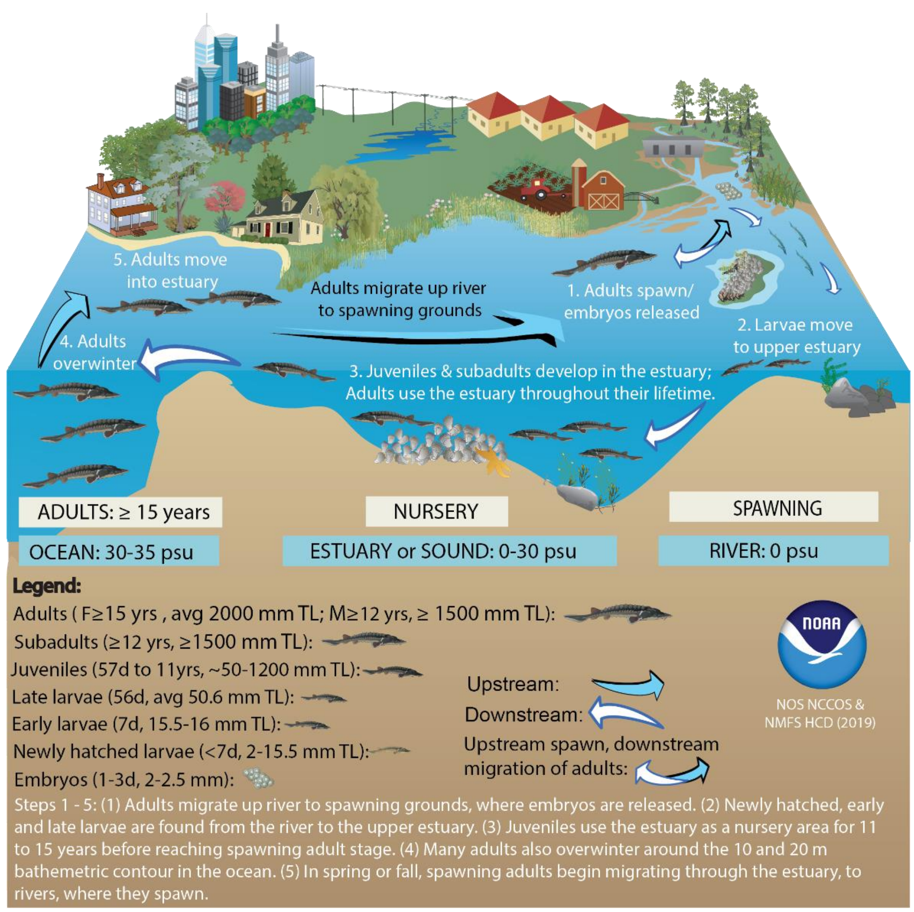

Figure 3.4.1: Life cycle of the Atlantic Sturgeon (*Acipenser oxyrinchus*).

inhabited approximately 38 rivers spanning from Maine to Florida, 35 of which were spawning rivers (ASSRT 2007). In recent years, the species has been documented in 32 of these river systems, and spawn in at least 20 of them (ASSRT 2007, NOAA 2014).

In 1990, the ASMFC produced a FMP for Atlantic Sturgeon and amended it in 1998, closing all Atlantic Sturgeon fisheries in the United States, recommending a 20 to 40 year moratorium to allow spawning stocks to be restored to a level where 20 year classes of adult females are present (ASMFC 1998). In 2009, the Natural Resources Defense Council petitioned the NMFS to list the Atlantic Sturgeon under the Endangered Species Act (ESA). Listing was proposed for five distinct population segments (DPS) in 2010 (75 FR 61872 and 75 FR 61904). In 2012 the NMFS listed four DPSs of Atlantic Sturgeon as endangered and one DPS as threatened (77 FR 5880 and 77 FR 5914). Endangered DPSs include New York Bight DPS, Chesapeake Bay DPS, Carolina DPS, South Atlantic DPS, and threatened status for the Gulf of Maine DPS (NMFS 2017a). Each DPS is markedly genetically distinct and has unique physical and physiological characteristics (ASSRT 2007). Each DPS is located in unique ecological settings and if a certain DPS were to become extinct, a significant gap in the range of the taxon would exist (ASSRT 2007). Of particular interest to this review are those individuals comprising the Carolina DPS and the northern portion of the South Atlantic DPS. The Carolina DPS includes all Atlantic Sturgeon found in the watersheds (including all rivers and tributaries) from the Albemarle Sound, North Carolina southward to the Cooper River, South Carolina (NOAA 2012, Smith et al. 2015,). Title 15A NCAC 03M.0508 prohibits possession of any sturgeon in North Carolina's coastal waters. The northern portion of the South Atlantic DPS includes all Atlantic Sturgeon spawning in Ashepoo, Combahee, and Edisto (ACE) Basin watershed, South Carolina to the St. Johns River, Florida (NMFS 2017a).

A total of 4,852 km (3,015 mi) of critical habitat in coastal rivers of North Carolina and South Carolina were identified based on physical and biological features, such as substrate type in the river bed, water temperature and salinity, and submerged aquatic vegetation, which are considered essential to the conservation of Atlantic Sturgeon (NMFS 2017a). Specific occupied areas designated as critical habitat for the Carolina DPS of Atlantic Sturgeon contain 1,939 km (1,205 miles) of aquatic habitat in the following river systems: Roanoke, Tar - Pamlico, Neuse, Cape Fear, Northeast Cape Fear, Waccamaw, Pee Dee, Bull Creek, Black, Santee, North Santee, South Santee, and Cooper (NMFS 2017a). Specific occupied areas for the South Atlantic DPS contain 1,075 km (668 miles) of aquatic habitat in the following South Carolina Rivers: Edisto, Combahee, Salkehatchie, and Savannah (NMFS 2017a).

Life History

When Atlantic Sturgeon are not ascending rivers to spawn, they mix extensively during non-spawning stages (ASSRT 2007). When spawning occurs, spawning female adults are considered to be at a minimum of 15 years of age and about 2,000 mm (78.7 in) total length (TL), while males can begin spawning as early as 12 years old at 1,500 to 2,100 mm (59 to 82.7 in) TL (Bain 1997, Greene et al. 2009). Atlantic Sturgeon historically ascend hundreds of miles upstream, migrating to natal, non-tidal flowing fresh waters to spawn. Atlantic Sturgeon range from Florida, Georgia, and South Carolina, and where some rivers remain unblocked by obstructions at the Fall line, this migratory spawning behavior still occurs (Greene et al. 2009). Within portions of historical ranges where fish passage is blocked, spawning often transpires in tidal freshwater regions of estuaries (Figure 3.4.2, Figure 3.4.3) (Colette and Klein-MacPhee 2002). Spawning intervals for females range from two to five years and for males between one to five years (Greene et al. 2009). Fecundity has been correlated with age and body size, with egg production ranging from 400,000 to 8 million eggs per spawning female (Smith et al. 1982). As the spawning migration upstream begins, spatial and temporal separation occurs as individuals navigate to their natal streams (King et al. 2001, Waldman et al. 2002, Wirgin et al. 2005, ASSRT 2007). Initiation of upstream spawning migrations is cued by water temperature. Atlantic Sturgeon originating in southern systems have faster growth rates and mature sooner relative to northern systems; males grow faster than females, and fully mature females attain a larger size (i.e., length) than fully mature males (Smith 1985a, Smith 1985b, Collins et al. 1996, Stevenson and Secor 1999, NMFS 2013).

While adult Atlantic Sturgeon from all DPS mix extensively in marine waters, the majority of fish return to their natal rivers to spawn. There are two distinct spawning periods for Atlantic Sturgeon, spring and fall (Van Den Avyle 1984, Smith 1985a, Bain 1997, Smith and Clugston 1997, NMFS and USFWS 1998, Smith et al. 2014) (Table 3.4.1). Rivers known to support spawning within the Carolina DPS include the Roanoke, Cape Fear, Neuse, Pee Dee, Cooper, Edisto, Combahee, and Savannah (Figure 3.4.2, Figure 3.4.3) (NMFS 2013, Post et al. 2014, Federal Register 2017). The Carolina DPS used the Santee River for spawning; however, spawning has not occurred since the completion of the Santee Cooper Project (Federal Register 2017). Critical Habitat for Atlantic Sturgeon includes the mainstem of the Santee River from the Santee Dam to RM 0, including the Rediversion Canal and the Cooper River from Pinopolis Dam to RM 0 (Federal Register 2017). During the spring, southern populations begin using estuarine corridors as upstream migrations begin in February and March (Collins et al. 2000). The spring spawning period is from March 1 to May 30 in the Edisto, Great Pee Dee, and Combahee Rivers (Fritz Rohde, personal communication, October 12, 2016). Collins et al. (2000) found that in the Edisto River, ripe males were captured as early as March 2, and a single ripe female was captured on March 7. Moreover, the researchers captured spent males in late March and spent females (i.e., eggs released) as late as mid-May (Collins et al. 2000). Spawning could occur as early as February and as late as June depending on seasonal differences in water temperature. In South Carolina waters, fall spawning is most common for Atlantic Sturgeon. Evidence obtained from the James River (Virginia), Roanoke River (North Carolina), three South Carolina rivers, and two Georgia rivers indicates the importance of the fall spawning period (Smith et al. 1984, Collins et al. 2000, Balazik et al. 2012, Smith et al. 2014, Smith et al. 2015; Bill Post, personal communication, November 2, 2015; Peterson unpublished data). Fall spawning occurs from September 1 to November 30, but since it is cued by increasing water temperature, it could occur as early as August or as late as December.

Table 3.4.1: Temporal and spatial distribution of various Atlantic Sturgeon (*Acipenser oxyrinchus*) life stages in the Carolinas and the northern portion of the South Atlantic distinct population segment.

		Q1=Winter			Q2=Spring			Q3=Summer			Q4=Fall		
River / **Estuary** / **Ocean**	**Life Stage**	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Atlantic Sturgeon (*Acipenser oxyrinchus)*	Pre-spawn & Spawning Adults*					*	*	*	*				
	Egg												
	Larvae												
	YOY Growth												
	Subadults year-round												
	Subadult overwinter												

* Pre-spawn adults are present in estuaries May through August as they stage to get ready to run up the river. In North Carolina subadults are in the estuaries year round. A certain proportion of these individuals overwinter in the ocean.

Once spawning does occur, eggs are initially non-adhesive, but special protuberances on the egg membrane form adhesive strings shortly after fertilization (approximately 20 minutes post-fertilization) and are on the bottom for a small period of incubation (Murawski and Pacheco 1977, Dadswell et al. 1984, Van den Avyle 1984, Colette and MacPhee 2002, Mohler 2003, Greene et al. 2009, Able and Fahay 2010). The young sturgeon hatch a few days after spawning, and are initially photonegative, finding refuge from predators on the hard bottom substrate (Smith et al. 1980, Kieffer and Kynard 1996, Collins et al. 2000b, Fox et al. 2000, ASMFC 2009, Able and Fahay 2010). Positive correlations have been observed between egg characteristics (e.g., egg density, egg diameter) and watershed type (e.g., low, medium, or high energy) (Bergey et al. 2003). It is likely differences in eggs are a result of subpopulation adaptations to the watershed they inhabit (Greene et al. 2009). Although the manner in which these adaptations were produced was not determined, the unique behaviors and physiology probably exist for each extant subpopulation, with the exception being those individuals that share drainage basins (ASSRT 2007).

Larvae will first absorb their yolk sac, and then feed on small bottom-dwelling organisms (e.g., copepods) during development (Gilbert 1989). Once they are more highly developed, larvae will travel downstream day and night to rearing grounds in the brackish waters of estuaries, where they will develop into juveniles. Once the juvenile stage is reached, individuals

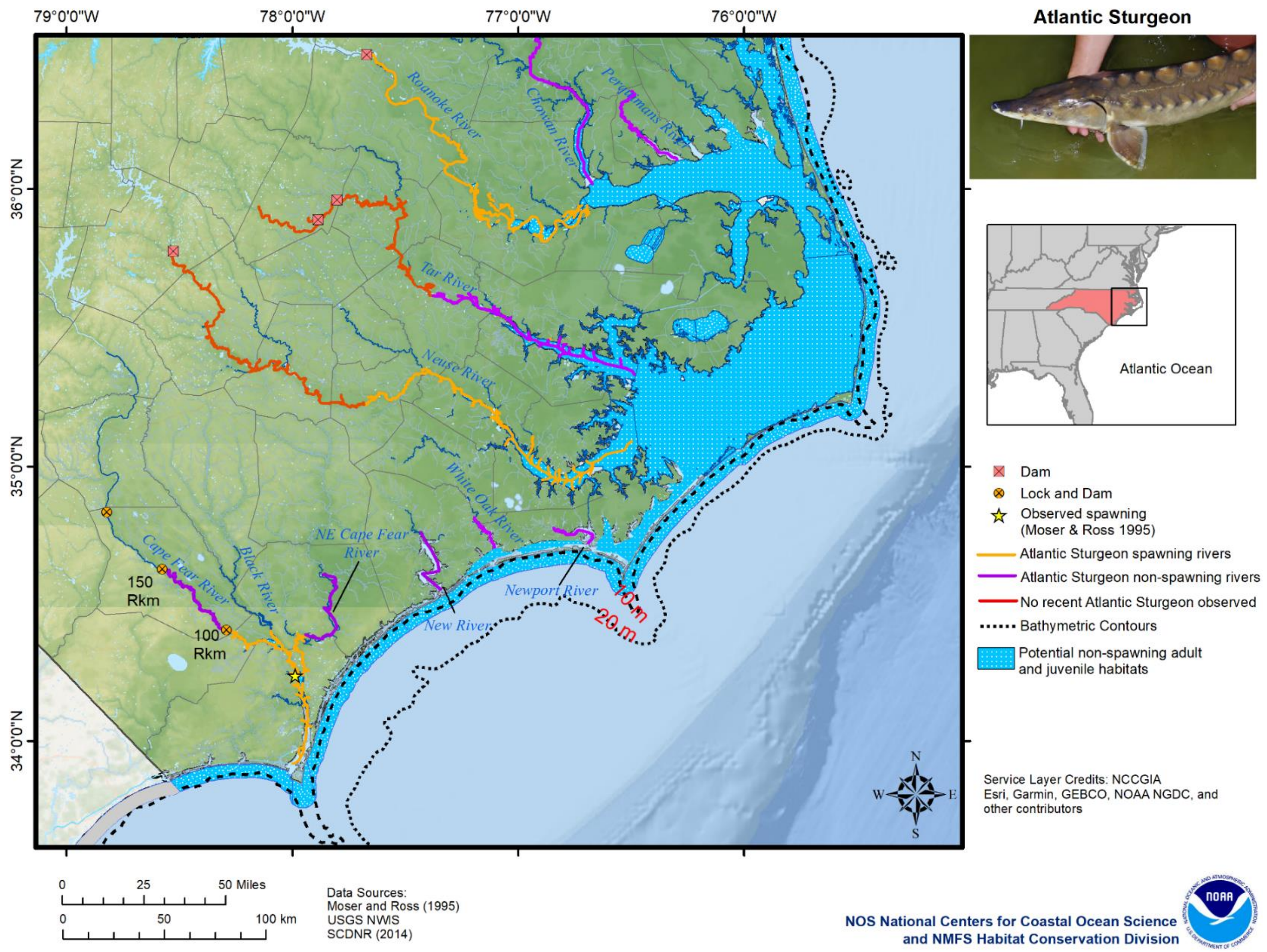

Figure 3.4.2: Main spawning rivers, potential obstructions to passage (dams) on the rivers, significant river kilometers, and non-spawning juvenile and adult habitat for Atlantic Sturgeon in North Carolina. Non-spawning rivers refer to rivers where Atlantic Sturgeon are present, but no spawning has been observed.

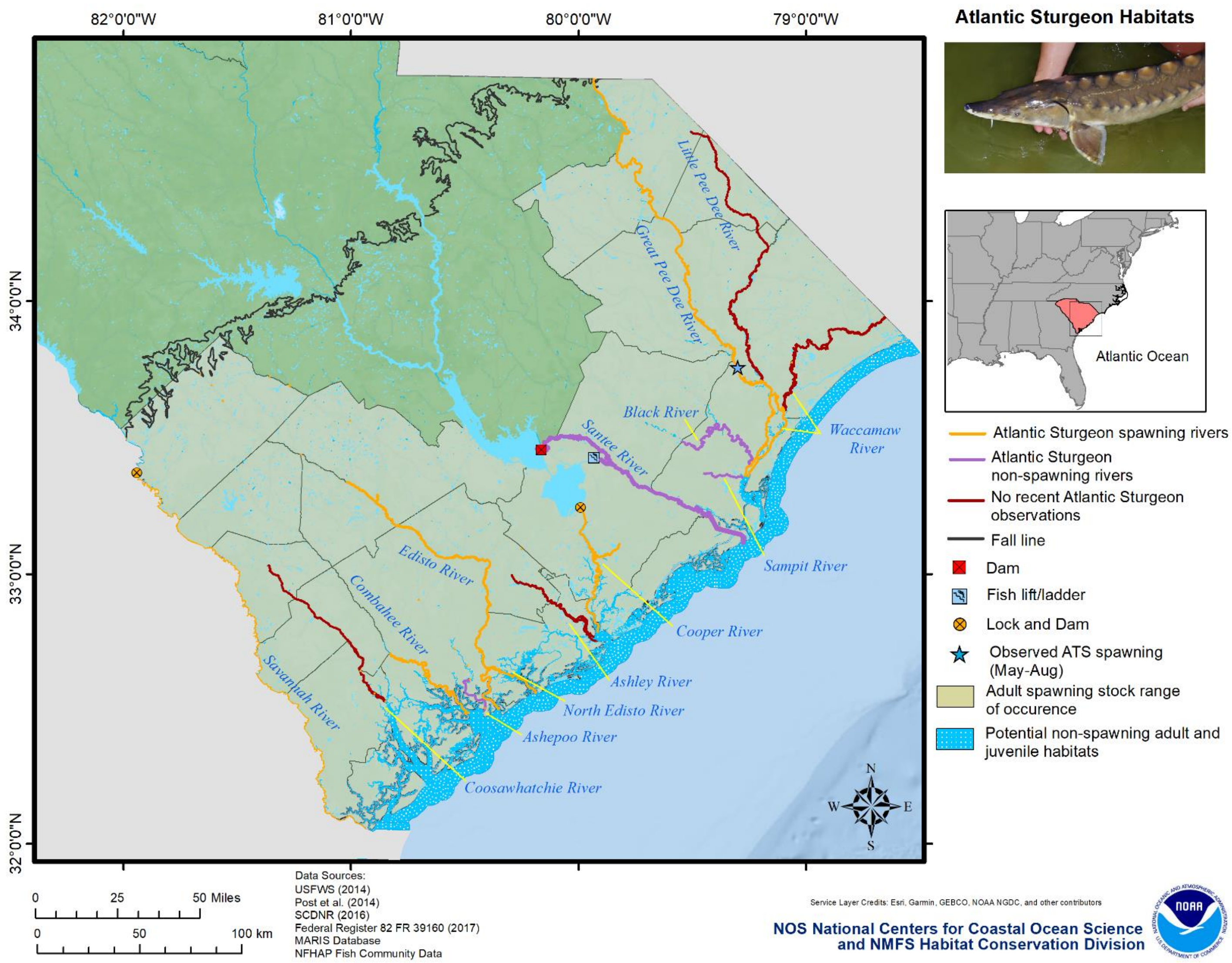

Figure 3.4.3: Main spawning rivers, potential obstructions to passage (dams) on the rivers, historical spawning range, observed Atlantic Sturgeon spawning, adult spawning stock range of occurrence, and non-spawning juvenile and adult habitats for Atlantic Sturgeon in South Carolina.

may remain in their natal estuary for months to years before becoming subadults and emigrating to oceanic habitat (Figure 3.4.3); telemetry suggest this is not always the case as individuals as small as 550 mm (21.7 in) in length have been tracked leaving river systems (Holland and Yelverton 1973, Dovel and Berggen 1983, Waldman et al. 1996, Dadswell 2006, ASSRT 2007, Bill Post personal communication, November 2, 2015).

Physiology and Habitat

Completion of the sturgeon's life cycle is dependent on a wide range of estuarine and freshwater habitats for spawning, early life stage survival, and juvenile survival and growth (Beamesderfer and Farr 1997). Migratory Atlantic Sturgeon commonly aggregate around coastal features and shorelines that offer optimal foraging opportunities (Kynard et al. 2000, Eyler et al. 2004, Stein et al. 2004, Dadswell 2006). Smith (1985b) found individuals tagged in South Carolina migrated as far north as the Pamlico Sound and the Chesapeake Bay. Through telemetry data, Atlantic Sturgeon have been tracked showing distinct north-south migration patterns. Within the Albemarle Sound subpopulation, the Roanoke River, and to a lesser degree the Chowan River, have potential as suitable spawning habitat (NCDMF 2009). It is probable that other habitats in North Carolina and South Carolina are equally as important for foraging. After emigration from the natal estuary subadults and adults travel within the marine environment, typically in waters less than 50 m (164 ft) in depth, using coastal bays, sounds, and ocean waters (Vladykov and Greeley 1963, Murawski and Pacheco 1977, Dovel and Berggren 1983, Smith 1985a, Collins and Smith 1997, Welsh et al. 2002, Savoy and Pacileo 2003, Stein et al. 2004, Laney et al. 2007, Dunton et al. 2010, Erickson et al. 2011, Wirgin and King 2011). Juvenile fish in later stages often reside in non-natal rivers, which lack spawning activity, as well as non-natal estuarine habitats (Bain 1997). These juvenile habitats act as nursery grounds with thermal and salinity refuges that provide abundant foraging opportunities and reduced predation (Figure 3.4.4). Therefore, habitats not used for spawning are equally as vital to the Atlantic Sturgeon's survival (Moser and Ross 1995).

General Habitat Characteristics for Various Atlantic Sturgeon Life Stages

Atlantic Sturgeon eggs must be spawned upstream of a salt wedge, with mortality documented at 5 to 10 psu (McEnroe and Chech 1985, Jenkins et al. 1993, Van Eenennaam et al. 1996). Spawning typically occurs where rivers have flow rates between 46 to 76 cm per second (18 to 30 inches per second) and depths are 10.9 to 27.1 m (36 to 89 ft), though spawning in water depths outside of this range has been documented (Borodin 1925, Leland 1968, Scott and Crossman 1973, Crance 1987, Bain et al. 2000). Incubation time for Atlantic Sturgeon eggs increases as water temperature decreases (Mohler 2003). For instance, once eggs are deposited hatching occurs at 94 hours at temperatures of 20 °C (68 °F) and 140 hours at 18 °C (64.4 °F) (ASSRT 2007). Atlantic Sturgeon larvae settle and attach to bedrock, cobble, coarse sand, shells, weeds, or logs (Greene et al. 2009, Able and Fahay 2010). From this point forward, Atlantic Sturgeon become demersal with these substrates as the principal habitat type for the remainder of the sturgeon's life (USFWS-NMFS 1998), with the exception of hatched individuals under heavy predation, which tend to migrate from the area immediately after hatching (Kynard and Horgan 2002). Studies suggest young-of-year, age-1, and age-2 juveniles occur in low salinity waters in natal estuaries (Haley 1999, Hatin et al. 2007, McCord et al. 2007, Munro 2007), while older fish (i.e., adults) have a higher salinity buffering capacity, and therefore occur in both high and low salinity waters (Collins et al. 2000). Researchers have also found that later stage juveniles congregate in deep-water pools (e.g., North Carolina populations), particularly in summertime where these habitats act as thermal refuges. Of particular concern during the first two years of life, is the inability of young sturgeon to move to thermal refuges that deep water pools provide, as they are confined to lower salinity waters. High temperatures in these areas during summer months can lead to low DO and high salinity, causing loss of nursery habitat for juveniles.

Critical Habitat Features as described by the NMFS 2017 Critical Habitat Proclamation

The NMFS (2017b) determined key conservation objectives for Carolina and South Atlantic Atlantic Sturgeon DPSs are to increase the DPS abundance by facilitating increased survival of all life stages, juvenile and subadult recruitment into the adult population, and successful adult reproduction. Many of the physical features included in the critical habitat description are also described above in the general habitat overview. However, as a designation, habitat that contain the physical features essential to the conservation of the species, may require special management. These characteristics include:

1. Hard bottom substrate (e.g., rock, cobble, gravel, etc.) in low salinity waters (i.e., 0.0 to 0.5 psu range) is needed for settlement of fertilized eggs, refuge, and growth and development of early life stages;
2. Transitional salinity zones, including waters with a gradual downstream gradient of 0.5 to 30 psu, and soft substrate (e.g., sand, mud) between the river mouths and spawning sites for juvenile foraging and physiological development;
3. Water of appropriate spawning depth and absent of physical barriers to upstream river passage (e.g., locks, dams, thermal plumes, turbidity, sound, reservoirs, gear, etc.) to support:
    a. Unimpeded migration of adults to and from spawning sites,
    b. Seasonal and physiologically-dependent movement of juvenile Atlantic Sturgeon to needed salinity zones within the upper estuary and river system, and
    c. Staging, resting, or holding of subadults or spawning condition adults. Water depths in main river channels must also be deep enough (≥ 1.2 m or 3.9 ft) to ensure continuous flow in the main channel at all times when any sturgeon life stage would be in the river.
4. Water quality conditions, particularly in the bottom meter of the water column, between the river mouths and spawning sites with temperature and oxygen values that support:
    a. Spawning,
    b. Annual and inter-annual adult, subadult, larval, and juvenile survival, and
    c. Larval, juvenile, and subadult growth, development, and recruitment.

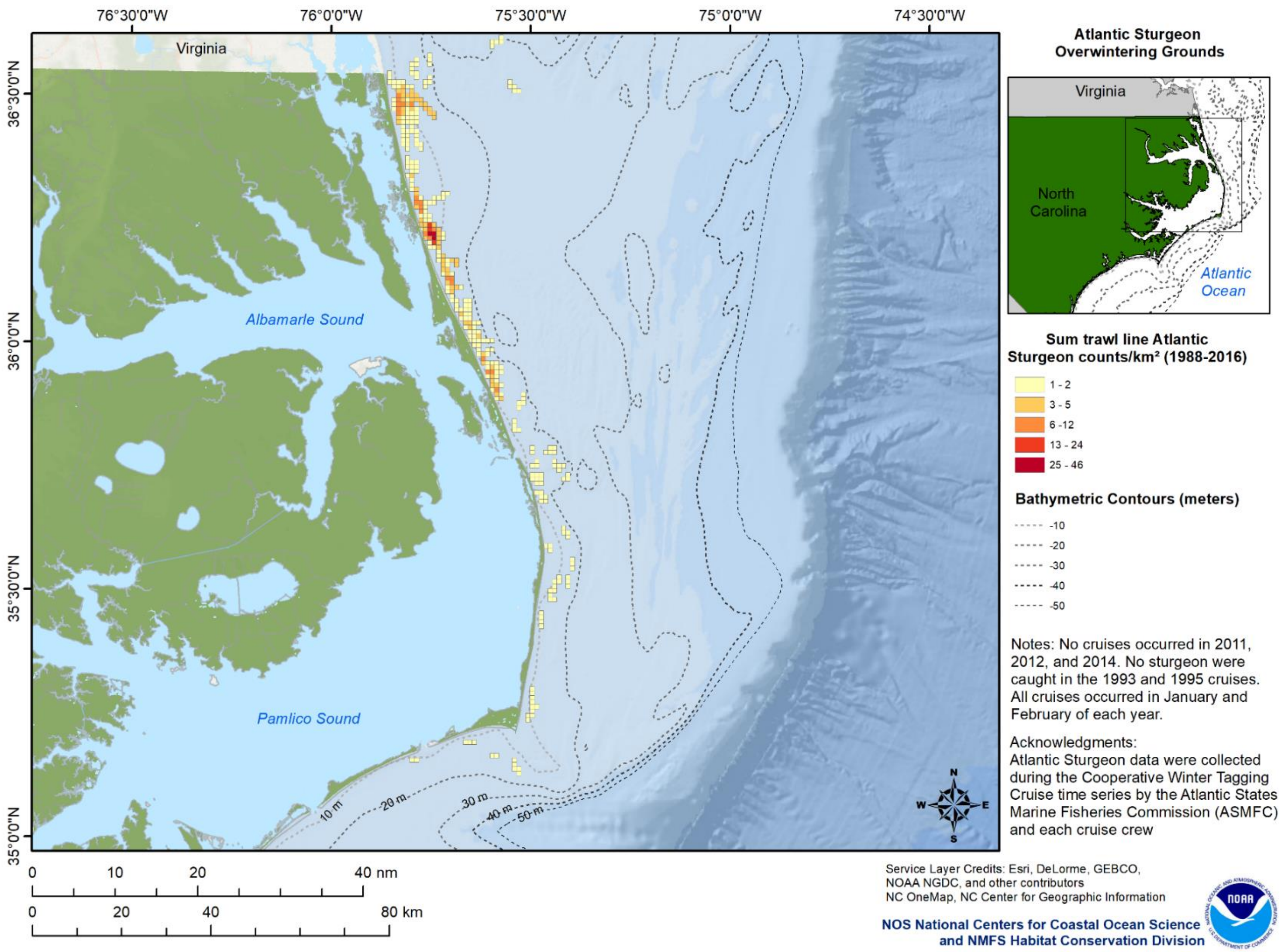

Figure 3.4.4: Atlantic Sturgeon density of trawl count (positive catch) per 1 km² from ASMFC Cooperative Winter Tagging Cruise (January and February) from 1988 to 2016. Highest densities of adult overwintering Atlantic Sturgeon can be observed along the 10-m contour line off the coast outside the Currituck Sound area.

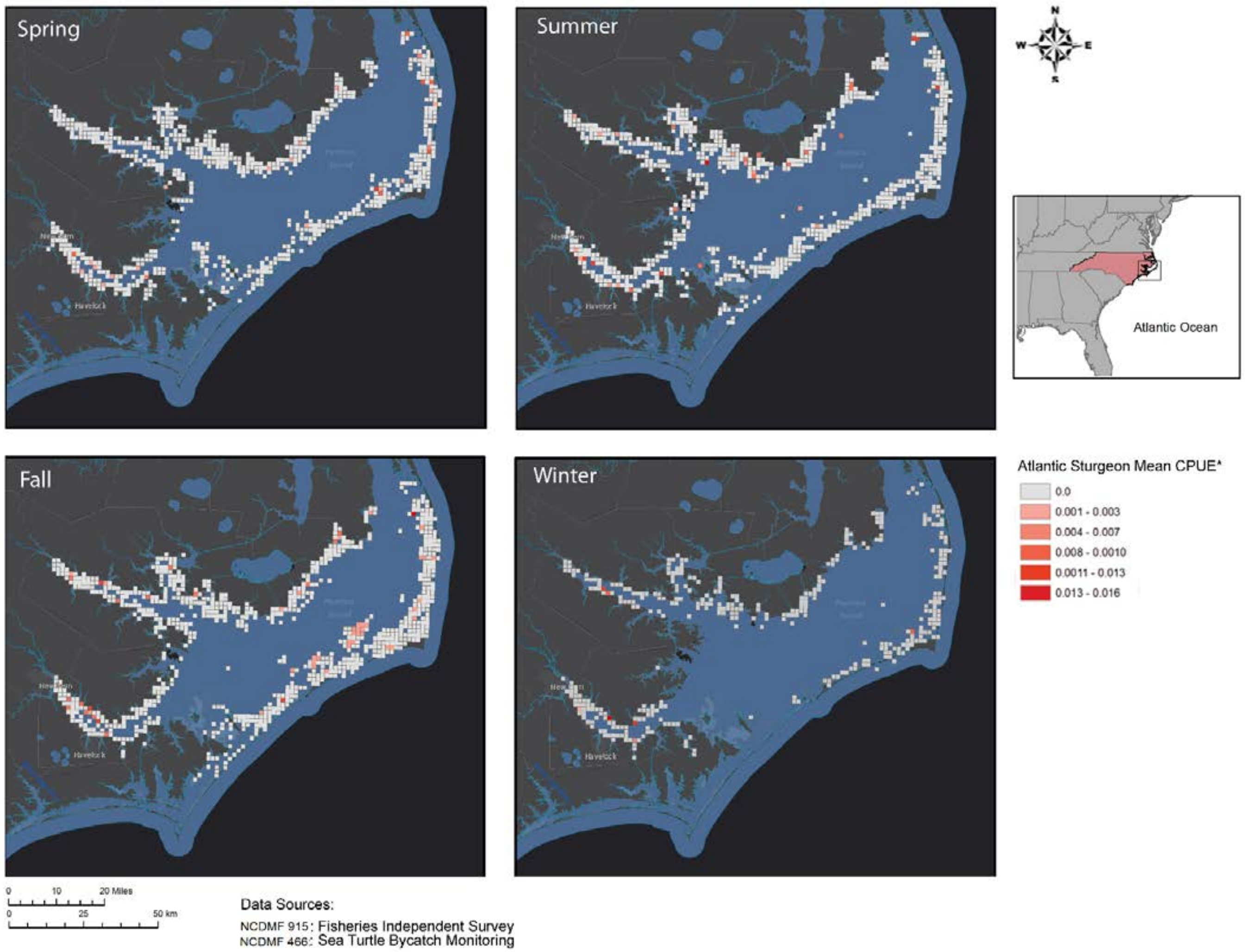

Figure 3.4.5: Merged data from NCDMF Programs 466 (Sea Turtle Bycatch Monitoring) and 915 (Fishery Independent Survey) from 2003-2014 for Atlantic Sturgeon CPUE. For the seasons: spring = March, April, May; summer = June, July, August; fall = September, October, November; and winter = December, January, February. Each grid cell is 1 mi².

Vulnerability of Atlantic Sturgeon populations

Atlantic Sturgeon are presently vulnerable to a suite of habitat impacts due to their movement and use of rivers, estuaries, bays, and the ocean at different life stages (ASSRT 2007). The direct take of Atlantic Sturgeon is a threat to the species, including mortality due to fisheries by-catch, impingement and entrainment by hydrologic and mechanic operations, and other causes. Habitat degradation and interruption of life processes remain some of the most common threats. Coastal alterations such as dredging and disposal, dam construction and operation, and installation of culverts and impoundments consequently have led to habitat and water quality issues (e.g., low DO, high turbidity, decreased flow rate, loss of spawning habitat, changes in water temperature, increase in contaminant load) potentially adversely impacting Atlantic Sturgeon populations (ASSRT 2007). Importantly, effects of coastal alterations and anthropogenic disturbance vary from river to river and over time. Atlantic Sturgeon habitat has been degraded or decreased due to numerous anthropogenic influences including the aforementioned river obstructions, clear-cutting, agricultural practices and inputs, reduced water quality, overfishing, and many other watershed-level modifications (Bushnoe et al. 2005, Greene et al. 2009). Consequently, Atlantic Sturgeon still occur throughout their historical range, but at historically low numbers (ASSRT 2007).

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3.5 Shortnose Sturgeon

(*Acipenser brevirostrum*, Lesueur, 1818)

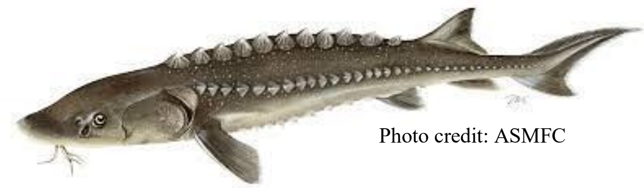

Photo credit: ASMFC

Authors: Lisa C. Wickliffe[1], Keith Hanson[2], and W.C. (Bill) Post[3]

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General Information

Of the 27 species among 4 genera in the family Acipenseridae – the most primitive of the bony fishes – the Shortnose Sturgeon is the smallest and most endangered of the species occurring in eastern North America (Birstein 1993, NMFS 2014). Shortnose Sturgeon grow up to 1.3 m (4.2 ft) and can weigh up to 23 kg (50 lbs) (NMFS 2014). Sturgeon life history is characterized by a relatively long life span, delayed maturity, and infrequent spawning periodicity (Artyukhin 1995, Bemis and Kynard 1997, Billard and Lecointre 2001). The life cycle of the anadromous Shortnose Sturgeon involves use of the rivers, the upper estuary, the lower estuary, and bays, sounds, and inlet areas (Figure 3.5.1). The range of the Shortnose Sturgeon historically extended from New Brunswick (Canada) to the St. Johns River in northern Florida (NMFS 1998, USACE 2010). However, Kynard (1997) suggests the historical range is greatly diminished and as few as 16 rivers currently support Shortnose Sturgeon populations. The

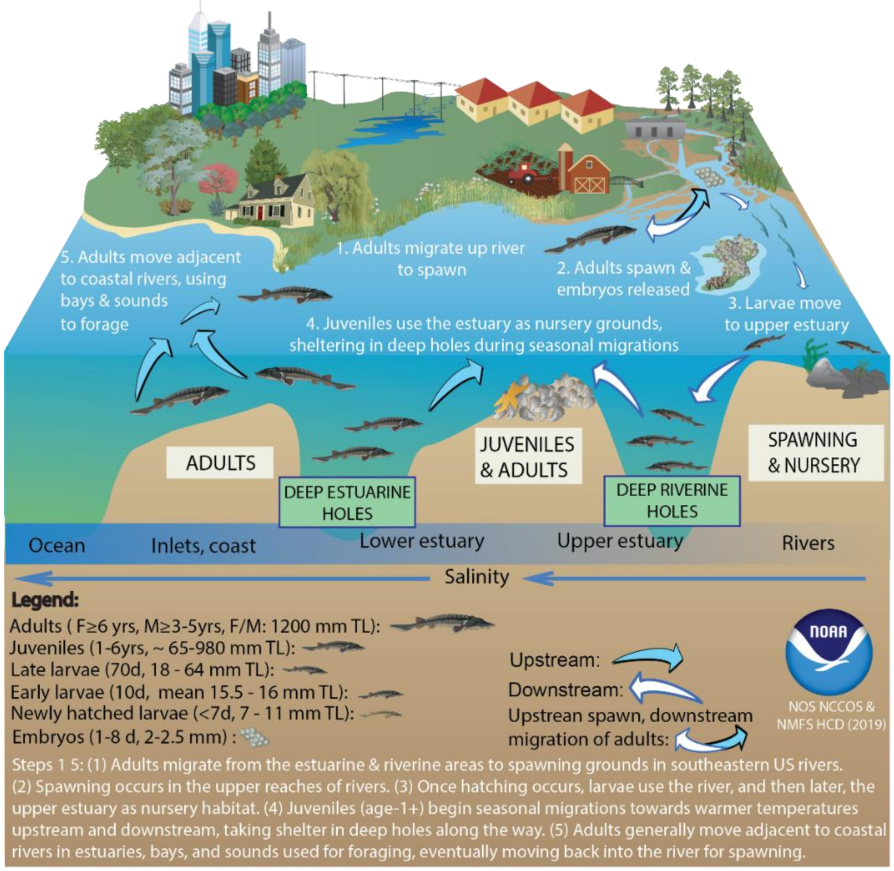

Figure 3.5.1: Life cycle of the Shortnose Sturgeon (*Acipenser brevirostrum*).

current distribution is also disjunct with northern populations separated from southern populations by about 400 km (248.5 mi) near their geographic center in Virginia (Kynard 1997, SSSRT 2010).

Although no historically large populations of Shortnose Sturgeon have been described in the literature, exploitation occurred along with Atlantic Sturgeon (Smith et al. 1984). The majority of the precipitous population declines due to commercial harvest occurred at the turn of the 20th century (Murawski and Pacheco 1977). Due to the exceedingly low population sizes of Shortnose Sturgeon, it was listed as endangered throughout its range on March 11, 1967 under the Endangered Species Preservation Act of 1966, a predecessor to the ESA of 1973. NMFS later assumed jurisdiction for Shortnose Sturgeon under a 1974 government reorganization plan (38 FR 41370). Critical habitat has not been designated or proposed for Shortnose Sturgeon, and populations are managed as a single population unit comprised of population segments that occur in coastal rivers throughout the Atlantic coast from Saint John River, Canada, to St. Johns River, Florida, and still remains listed as an endangered species (USACE 2010, NMFS 2010, NMFS 2019). In all rivers utilized as Shortnose Sturgeon spawning and nursery grounds, impacts to habitat are the greatest threat to the population status, whether the adverse impacts are from dams and obstructions, dredging, poor water quality, or bycatch (SSSRT 2010). For instance, in the Savannah River population segment, USACE suggested recruitment (i.e., the number of viable young produced following spawning) was low from habitat loss and degradation, leading to a skewed ratio of adults to juveniles (USACE 2010). However, recent data suggests adult/juvenile skewedness may not be as serious as once thought and recruitment may be higher than initially suggested (D. Peterson, personal communication, November 5, 2015).

Shortnose Sturgeon are classified as estuarine anadromous or freshwater amphidromous and were once thought to inhabit and spawn in their natal rivers throughout their life (Kieffer and Kynard 1993). Telemetry data indicate Shortnose Sturgeon make long coastal migrations to other river systems (Bill Post, personal communication, November 2, 2015). Shortnose Sturgeon are sympatric with Atlantic Sturgeon in many rivers throughout their range, but Shortnose Sturgeon do not spend as much of their lives in the open ocean, are smaller in size, and generally spawn farther upriver (Kynard 1997, Bain 1997, SSSRT 2010). There is little evidence for occurrence of Shortnose Sturgeon at sea, but rather substantial supporting evidence for Shortnose Sturgeon making coastal movements to adjacent rivers (Wilk and Silverman 1976, Smith et al. 2002a, SSSRT 2010). Sexually dimorphic growth patterns occur in Shortnose Sturgeon, as females can live up to 67 years, but males seldom exceed 30 years (NMFS 2014). Thus, the ratio of females to males among young Shortnose Sturgeon adults is 1:1, but goes to 4:1 for individuals larger than 0.9 m (3 ft) in length (NMFS 2014). Wirgin et al. (2005) found southern populations displayed pronounced differences in the genetic stock structures among rivers indicating minimal gene flow among the southern populations and genetic similarities may be indicative of environmental similarities (Quattro et al. 2002, Waldman et al. 2002, DeVries 2006). Research suggests gene flow may not be as isolated as once thought, and population sizes in southern rivers are larger than previous estimates (Bill Post, personal communication, November 2, 2015).

Life History

Due to conservation efforts, many northern Shortnose Sturgeon populations originate from several established spawning stocks (Sector and Woodland 2005). In contrast, southern stocks are relatively smaller and have a slightly different life history in terms of spawning periodicity and migratory patterns (Heidt and Gilbert 1978, Marchette and Smiley 1982, Hall et al. 1991, Collins and Smith 1993). Males mature at 2 to 3 years in Georgia and 3 to 5 years from South Carolina to New York, while females mature at about age-6 in Georgia, and around age-7 from South Carolina to New York (SSSRT 2010, NMFS 2014). Shortnose Sturgeon in southern waters grow rapidly and mature at younger ages, but attain smaller sizes than those populations in the north (Dadswell et al. 1984).

Shortnose Sturgeon in South Carolina are estimated to spawn from mid-January through the end of April (Table 3.5.1). Spawning appears correlated with temperature, so spawning could occur as early as December or as late as May. Shortnose Sturgeon are long-duration spawners where a female spawns eggs in discrete batches during multiple spawning sessions over many hours (24 to 36 h for Shortnose Sturgeon) (Kynard et al. 2012). Reported Shortnose Sturgeon fecundity estimates vary, but range from 30,000 to 200,000, with an average of 11,600 eggs/kg body weight (Heidt and Gilbert 1978, Dadswell 1979, Gilbert 1989, COSEWIC 2005). Ripe eggs (i.e., fully matured) are dark brown to olive-gray in color and are generally between 3.0 to 3.2 mm (0.10 to 0.13 in) in diameter (Dadswell 1979). Special protuberances on the chorion develop within a few minutes after water exposure and maximize surface area available for adhesion to substrate (Meehan 1910, Dadswell et al. 1984). Fertilized eggs hatch more quickly in warmer waters 17 ºC (63 °F) relative to cooler waters (8 to 12 °C or 46 to 54 °F) (Meehan 1910, Wang et al. 1985, Hardy and Litvak 2004). At 17 °C, Shortnose Sturgeon hatched after just 8 days, whereas at the aforementioned cooler temperatures, incubation was approximately 13 days (Buckley and Kynard 1981).

Yolk-sac larvae that have recently hatched have poorly developed eyes, mouth, and fins (Richmond and Kynard 1995). These larvae measure 7.0 to 11.0 mm (0.3 to 0.4 in) TL, and are only capable of swim-up and drift behavior, limiting them to survive as free-swimming individuals in an open river environment (Buckley and Kynard 1981, Richmond and Kynard 1995, NMFS 2010). To increase chances of survival, yolk-sac larvae form aggregations with other larvae for concealment purposes (Buckley 1982). A few days after hatching occurs, larvae begin to exhibit shoaling behavior when in flowing water, forming tight well-spaced schools that swim against the current (COSEWIC 2005). Sheltering in dark substrate (e.g., crevasses of rocks or cobble) provides some protection from predators (Richmond and Kynard 1995). From egg through yolk-sac absorption, Shortnose Sturgeon larvae may remain concentrated in the spawning area for up to a month (SSSRT 2010); however, residence near the spawning location is often shorter than four weeks in southern populations.

Larvae absorb their yolk-sac reserves at approximately 15.5 to 16.0 mm (0.6 to 0.6 in) TL. Larvae have well-developed eyes and fins; experience a rapid change in sensory, feeding, and locomotor systems; have well-developed teeth that aid in specialized larval feeding behavior, which are later absorbed; and coloration begins to resemble that of an adult (Taubert and Dadswell 1980, Buckley and Kynard 1981, Bemis and Grande 1992, Richmond and Kynard 1995, Kynard and Horgan 2002). At 18 to 19 mm (0.70 to 0.72 in) TL, larvae become photopositive and are ready for exogenous feeding (SSSRT 2010). Downstream migration of these individuals occurs around 20 mm (0.8 in) TL, lasts about 48 hours, and usually occurs nocturnally (Buckley and Kynard 1981, Richmond and Kynard 1995). Notably, Dovel et al. (1989) states downstream migrations continue throughout the first year of life. Field studies suggest that the young-of-year are usually found in the deepest freshwater within a channel upstream of the salt wedge for the first year of life (Taubert and Dadswell 1980, Bath et al. 1981, Kieffer and Kynard 1993, Kynard 1997). Based on morphological studies, Shortnose Sturgeon are considered to be juveniles once they are greater than 65 mm (2.6 in) TL (Snyder 1988, Parker 2007, Bill Post, personal communication, November 2, 2015). From the Savannah River stocks, juvenile status was reached within 41 to 42 days after spawning (Parker 2007). Growth of juveniles is rapid in the first year, with individuals in southern waters reaching an average of 300 mm (12 in) TL (Dadswell 1984). These young-of-year have lower salinity tolerances than that of older juveniles and thus use markedly different habitats (SSSRT 2010). Shortnose Sturgeon are considered juveniles until the fish matures at 3 to 10 years of age (Gilbert 1989, Richmond and Kynard 1995).

In southeastern populations, juveniles age-1 and older make seasonal migrations similar to adults, moving upriver during warmer months where they shelter in deep holes before returning to the interface of freshwater and saltwater when temperatures decrease (Flournoy et al. 1992, Collins et al. 2002). Dadswell (1979) observed that juveniles and subadults preferentially use freshwater habitats until growth to 450 mm (17.7 in) TL (i.e., age 8). Prey items of this size class include aquatic insects, isopods, and amphipods (Dadswell 1979, Carlson and Simpson 1987, Bain 1997). Kynard (1997) noted young sturgeon have a size dependent dominance hierarchy that determines use of foraging habitat. In the southern extent of their range, Shortnose Sturgeon are known to forage widely throughout estuaries during the winter, fall, and spring (Collins and Smith 1993, Weber et al. 1998). Approximate age at first spawning for males occurs one to two years after maturity, but for females, spawning is delayed up to five years after maturation (Dadswell 1979, NMFS 2014). Female Shortnose Sturgeon generally grow larger and live longer than males (Dadswell et al. 1984, Gilbert 1989, COSEWIC 2005, SSSRT 2010). Adult Shortnose Sturgeon in southern waters on average are 1200 mm (47 in) TL at maturity, with slightly larger sizes occurring in the northeast (Dadswell 1979, Gilbert 1989).

Physiology and Habitat

Shortnose Sturgeon move through all areas of a river system, but riverine areas remain important for resting and feeding aggregations for extended periods of time (Hastings et al. 1987, Kieffer and Kynard 1993). Southeastern piedmont river basins contain main stem and tributary reaches with rocky shoal habitat, often extending hundreds of miles from the coast (NMFS 2007). These rocky shoals and outcrop habitat consist of cobble-gravel mixtures, large and small boulders, bedrock ledges mixed with sand and gravel runs, and riffle-pool complexes (NMFS

2007). These spawning areas provide abundant food sources and well-oxygenated waters for Shortnose Sturgeon eggs and larvae to develop (NMFS 2007). To qualitatively evaluate Shortnose Sturgeon spawning habitat, USFWS and NMFS developed a Habitat Suitability Index in 1986, which was revised in 2003, to be used as a starting point for habitat evaluation. Water temperature, water depth and velocity, and substrate type were the habitat characteristics found to be important for Shortnose Sturgeon spawning locations (NMFS 2007). Optimal spawning temperatures extend from 9 to 12 ºC (48.2 to 53.6 °F) with depths ranging from 2 to 4 m (6.5 to 13.1 ft) and water velocities ranging from 0.4 to 1.0 m/s (0.9 to 2.2 mph) (NMFS 2007).

When Shortnose Sturgeon have unobstructed access to the full length of a river, spawning areas may be located at the farthest accessible upstream reach of the river (Figure 3.5.2) (Kynard 1997). In South Carolina along the Savannah River, spawning occurs near the U.S. Highway 301 bridge (located at river kilometer [RKM] 191), which is well downstream of the first barrier to upstream migration – the New Savannah Bluff Lock and Dam, located at RKM 301 (Figure 3.5.3). Another very important spawning area in the Great Pee Dee River near the SC-34/Cashua Ferry Road Bridge is well downstream of the first barrier to migration – Blewett Falls Dam (RKM 314). For some dammed rivers such as the Cooper River, spawning occurs near the base of the dam or in the tailrace (Kynard 1997, Cooke et al. 2004). Importantly, distance up river for spawning is variable and may need to be tracked on each river known to support spawning runs.

Table 3.5.1: Temporal and spatial distribution of various Shortnose Sturgeon (*Acipenser brevirostrum*) life stages in North Carolina and South Carolina waters.

River / **Estuary** / **Ocean**		**Q^1=Winter**			**Q^2=Spring**			**Q^3=Summer**			**Q^4=Fall**		
	Life Stage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Shortnose Sturgeon (*Acipenser brevirostrum)*	Spawning Adults												
	Egg												
	Larvae												
	YOY Growth												
	sub-adult overwinter												

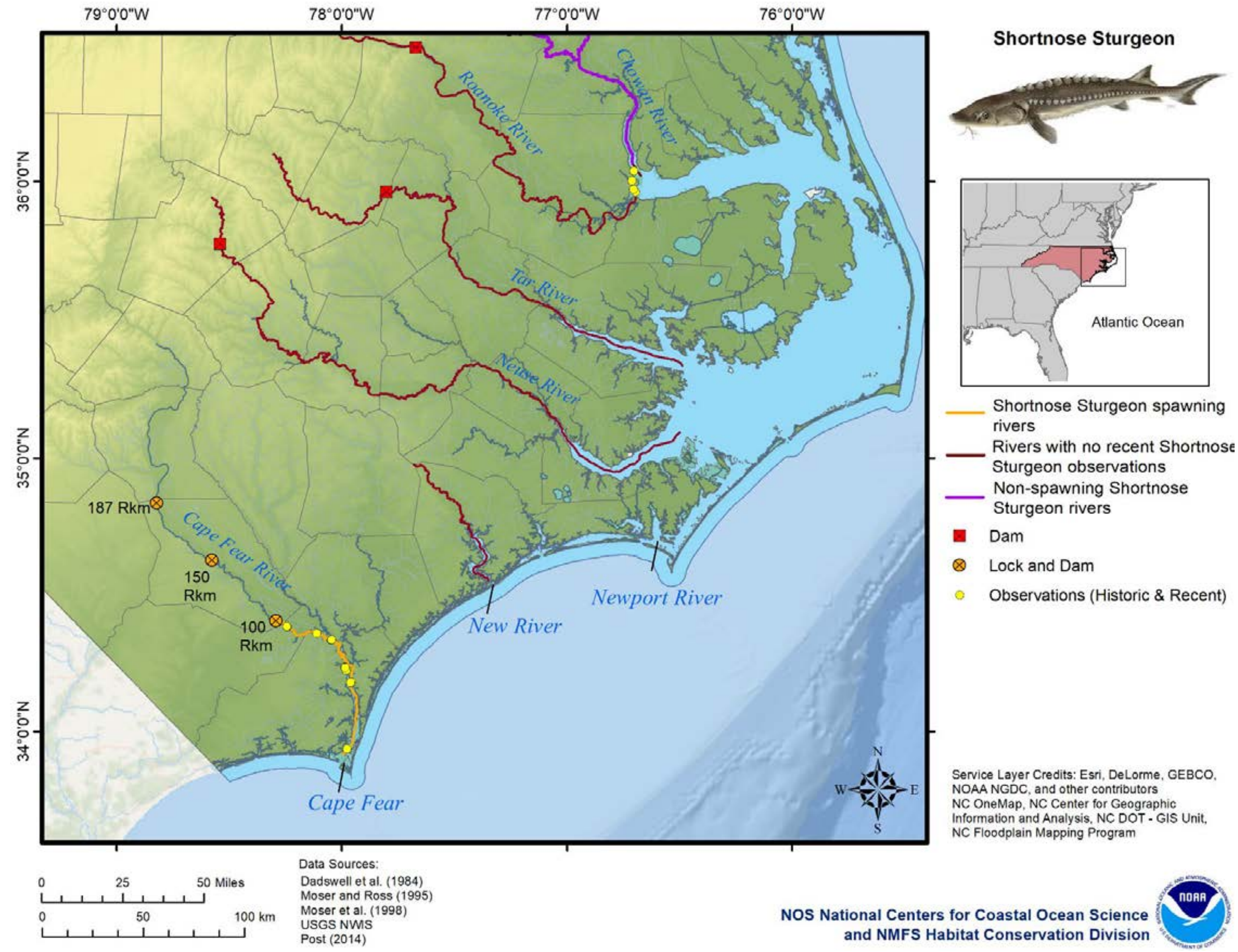

Figure 3.5.2: Main spawning rivers, obstructions to passage, and non-spawning adult habitat for Shortnose Sturgeon in North Carolina. There was one observation of a Shortnose Sturgeon in the Albemarle Sound in 2016 near other historical observations in the Chowan River. Observations have occurred in the Cape Fear River by Post et al. (2014).

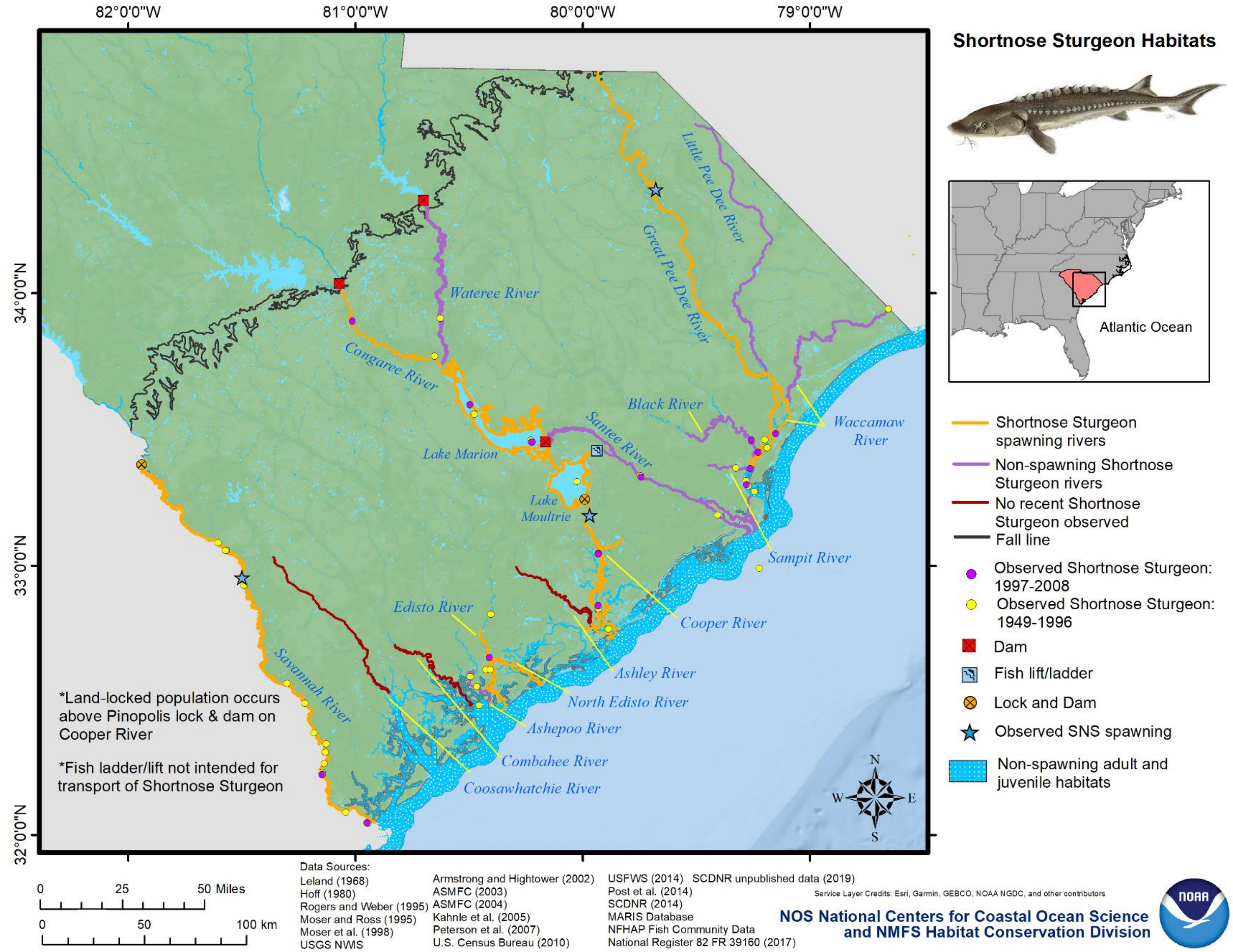

Figure 3.5.3: Main spawning rivers, obstructions to passage, observed spawning, observed Shortnose Sturgeon, and non-spawning juvenile and adult habitats for Shortnose Sturgeon in South Carolina.

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3.6 American Shad

(*Alosa sapidissima* Wilson, 1811)

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General Information

American Shad (*Alosa sapidissima*) are an anadromous, highly migratory, schooling species of fish (Colette and Klein-MacPhee 2002, Greene et al. 2009, ASMFC 2014). American Shad are the largest of the alosines, with adults reaching 1.4 to 3.6 kg (3.1 to 7.9 lbs) and up to 10 years of age (NCDEQ 2018). Most individuals spend the majority of their lives in marine systems, with adults migrating into natal coastal rivers and tributaries to spawn (Figure 3.6.1) (Greene et al. 2009, ASMFC 2014). Young adults may spend up to five years in the ocean before returning to spawning grounds. During the winter and summer, time at sea is spent at feeding grounds along the continental shelf (Neves and Depres 1979, Burke and Rohde 2015). The southernmost populations have been observed traveling over 20,000 km (12,427 mi) in the coastal ocean as they migrate to feeding grounds (Dadswell et al. 1987). Historically, the spawning range of American Shad included all accessible Atlantic coast rivers and tributaries, with associated rivers, bays, and estuaries used as nursery areas (MacKinzie et al. 1987, ASMFC 1999, ASMFC 2007). Within this historical range, it is estimated that spawning American Shad once ascended some 130 rivers along the Atlantic coast, but now ascend fewer than 70 systems (Limburg et al. 2003). The current geographic spawning range extends from the St.

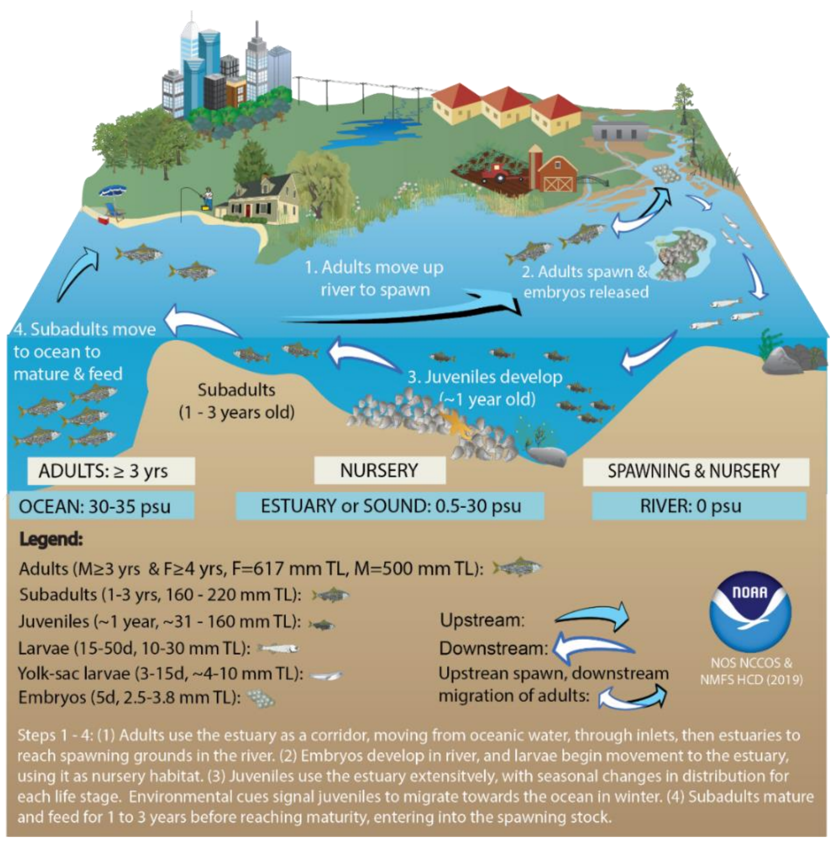

Figure 3.6.1: Life cycle of the American Shad (*Alosa sapidissima*).

Johns River in Florida to the St. Lawrence River in Canada (Walburg and Nichols 1967, Greene et al. 2009). The center of American Shad abundance lies between Connecticut and South Carolina, with early life stages found in estuaries with available freshwater input in the South and Middle Atlantic Bights (Able and Fahay 2010).

American Shad once supported the most culturally and economically important fishery along the east coast of the U.S. (Stevenson 1899, Burke and Rohde 2015). However, over a 170-year period, American Shad stocks have declined as a result of overfishing, pollution, and habitat loss from dams, upland development, and numerous other anthropogenic factors (e.g., climate change) (Limburg et al. 2003, ASMFC 2014). Habitat loss continues to play a critical role in population declines of American Shad in many coastal rivers. In North Carolina, a habitat plan was released in 2014, addressing threats to spawning, nursery, and juvenile habitats, as American Shad stocks are listed as depleted due to habitat threats (ASMFC 2014, NCDEQ 2018). In recent years, South Carolina (i.e., Santee River) and Florida stocks have shown signs of population stabilization (Cooke and Leach 2003, Burke and Rohde 2015). Stocking efforts potentially play an important role in population stabilization in the southeastern populations (Burke and Rohde 2015). In North Carolina, there are no size or possession limits for American Shad taken commercially, but are regulated by season for four regions including the Albemarle Sound/Roanoke River, Tar/Pamlico River, Neuse River, and Cape Fear River (Figure 3.6.2) (NCDEQ 2018). In 2017, Albemarle Sound/Roanoke River commercial season was open from March 3 through the 24; Tar/Pamlico River and Neuse River systems were open from February 15 to April 14; and Cape Fear River system was open from February 20 to April 11 (NCDEQ 2018). The commercial season for all other coastal and joint fishing waters was open from February 15 to April 11. There is no recreational size limit for American Shad, with open season declared by an annual proclamation (NCDMQ 2018). The bag limit in Albemarle Sound, Roanoke River, Neuse and Bay Rivers is a 10-fish aggregate (Hickory Shad and American Shad combined) per person, per day, of which one American Shad can be taken. The Cape Fear River and tributaries recreational limit is a 10 fish aggregate of which no more than five American Shad can be possessed. In Tar/Pamlico River and Pungo River, Pamlico Sound, and other coastal and joint waters, the limit is no more than 10 shad fish in the aggregate per person, per day recreationally (NCDEQ 2018). The majority of catch occurs in the Cape Fear River, as this is where effort is the highest (NCDEQ 2018). In South Carolina, American Shad occur and spawn in the Waccamaw River, Greater Pee Dee River, Lyches River, Black River, Sampit River, Santee River, Edisto River, Broad River, and Savannah River (Figure 3.6.3). The South Carolina commercial season harvest must use a skimbow net and lasts from February through April (SCDNR 2018). The recreational limit is set at 10 shad (American Shad and Hickory Shad) per person per day, with the exception being the Santee River and Rediversion Canal, where the limit is 20 fish per person per day (SCDNR 2018).

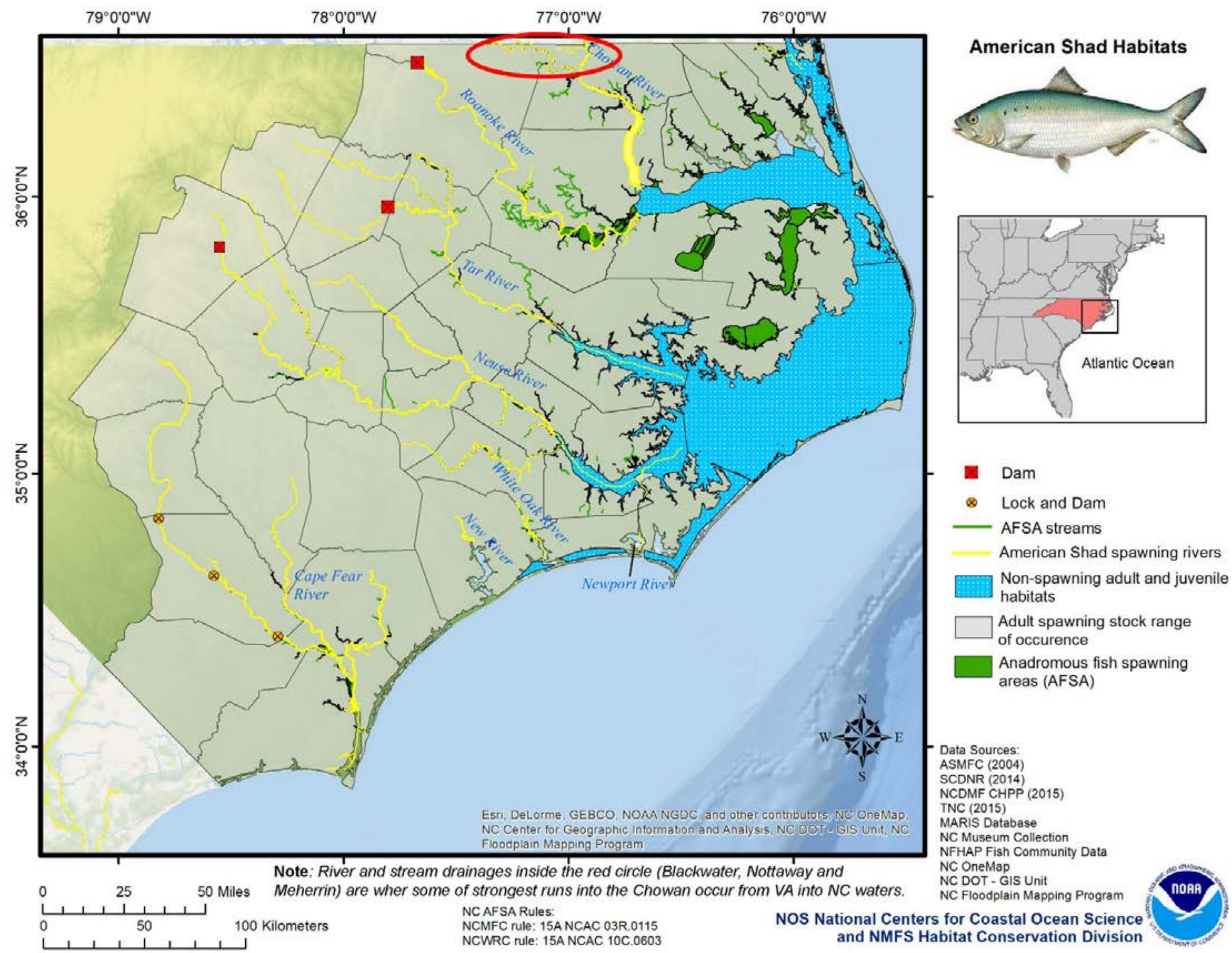

Figure 3.6.2: Main spawning rivers and streams for American Shad. NCDMF designated anadromous fish spawning areas (AFSA). Along the Chowan River, American Shad cross over from Virginia into North Carolina as indicated by the red circle. This includes the drainages of the Chowan (Blackwater, Nottaway and Meherrin) where some of the strongest runs of the fishery historically occurred.

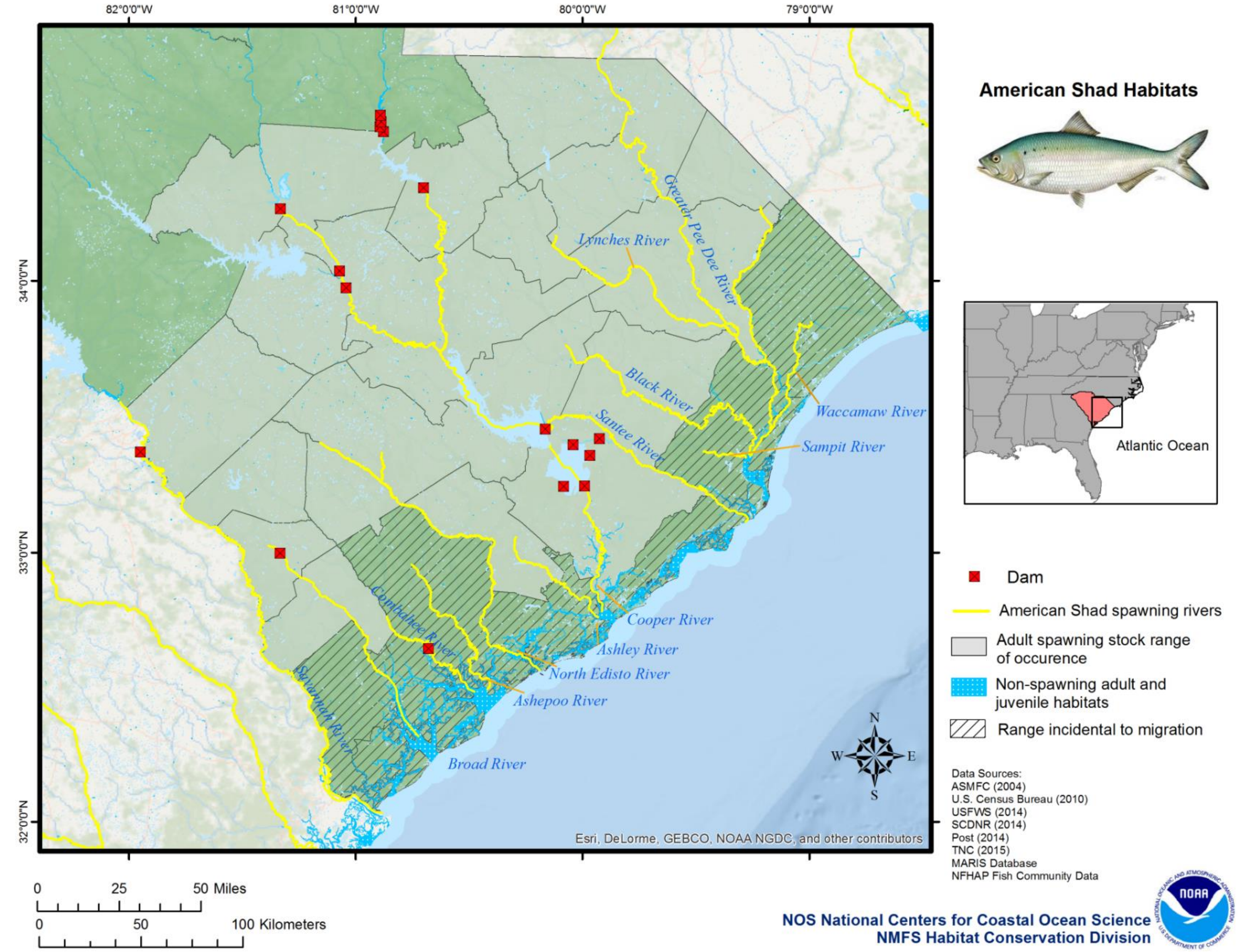

Figure 3.6.3: Main spawning rivers, potential obstructions to passage (dams) on the rivers, range incidental to migration, adult spawning stock range of occurrence, and non-spawning juvenile and adult habitat for American Shad in South Carolina.

Life History

American Shad spend several years in oceanic waters (35 psu) as non-breeding adults before reaching maturity and navigating upstream to natal grounds to spawn during the spring (Figure 3.6.1, Figure 3.6.4) (Able and Fahay 2010). Males mature between three to five years of age whereas females mature between four and six years of age (Leim 1924, Leggett 1976). As coastal ocean seawater temperatures approach 12 ˚C (53.6 °F), mature individuals begin the inshore and upstream migration (ocean → inlet → estuary → river) towards natal grounds to begin spawning (Able and Fahay 2010). Southern populations are first to arrive at natal grounds since the waters are first to warm (SAMFC 2008). Peak inshore movement for spawning occurs when bottom water temperatures range from 8.6 to 19.9 °C (47.5 to 67.8 °F) and spawning occurs at river temperatures ranging from 16.5 to 21.5 °C (61.7 to 70.7 °F) (SAMFC 2008). Adult males generally arrive at riverine spawning grounds before mature females (Leim 1924). Spawning has been observed with a variety of river conditions. Eggs are released and fertilized in open water at dusk in clear water (Leim 1924, Whitney 1961), or eggs may be released during the daytime in turbid rivers (Chittenden 1976) or on overcast days (Miller et al. 1982). Spawning activity extends through the evening and usually peaks around midnight in shallow waters with moderate currents (Massmann 1952, Miller et al. 1971, Miller et al. 1975). Spawning season usually last between two to three months, but varies depending on weather conditions (Limburg et al. 2003).

Maturation and reproductive characteristics vary with changing latitude (Leggett and Carscadden 1978) and among tributaries (Carscadden and Leggett 1975). Regional differences exist in spawning periodicity (Greene et al. 2009). American Shad north of Cape Hatteras, North Carolina are iteroparous (repeat spawners), while the majority of American Shad below Cape Hatteras are semelparous (die after one spawning season) (Greene et al. 2009). Leggett (1969) posits that populations south of Cape Hatteras are constrained physiologically due to long oceanic migrations and higher water temperatures. The ability for spent adults to survive post-spawning has been correlated with the degree of energy lost during migration (Bernatchez and Dodson 1987). The semelparous spawning behavior of southern populations is likely driven by relatively higher temperatures in the southern range of American Shad, the lack of available food during migration, and long migrations leading to relatively higher energy expenditures.

Fertilized eggs (i.e., embryos) incubate between 2 and 17 days, with warmer waters correlating with shorter incubation times. After hatching, larvae are pelagic for two to three weeks before transforming into juveniles (Jones et al. 1978). In southern rivers, fish can be found in areas of lower flows near the backside of sandbars or in naturally occurring eddies. Size variation is frequently observed with downstream migration; small YOY tend to remain upstream (Chittenden 1969). YOY reside in coastal rivers and estuaries through spring, Typically, YOY move out towards the continental shelf in late June, July, and August (Table 3.6.1). These fish will congregate on the continental shelf through the arrival of winter, and are found at depths ranging from 12 to 81 meters (39 to 266 ft) (Able and Fahay 2010). Individuals will grow from 100 to 150 mm (3.9 to 5.9 in) TL through the winter (Able and Fahay 2010).

Table 3.6.1: Temporal and spatial distribution of various American Shad life stages in North Carolina and South Carolina waters. Peak spawning for American Shad occurs in March and April in North Carolina and South Carolina (Bill Post, personal communication, November 2, 2015).

River / Estuary / Ocean		Q1= Winter			Q2= Spring			Q3= Summer			Q4= Fall		
	Life Stage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
American Shad *(Alosa sapidissima)*	Spawning Adults												
	Egg												
	Larvae												
	YOY Growth												
	Sub-adults												

Juveniles and adults ≥1 year in age have a different distribution than YOY that also varies with season (Able and Fahay 2010). In the fall, most occur along the continental shelf but with the arrival of winter fish move in a southerly direction between the southern portions of Georges Bank to the mouth of the Chesapeake Bay. By spring, American Shad have the widest distribution of any season with adults extending the entire length of the continental shelf throughout the Middle Atlantic Bight (Able and Fahay 2010). Findings from tagging studies conducted in North Carolina suggest a high percentage (27%) of American Shad captured in the ocean gill net fishery near the Cape Fear River were homing to South Carolina and Georgia (Parker 1990, Burke and Rohde 2015).

Physiology and Habitat

American Shad are found in habitats such as water column, wetlands, SAV, soft bottom, hard bottom, and shell bottom, but usage varies by the life stage using the habitat type (ASMFC 2014). American shad spend the majority of their life in the ocean along the Atlantic coast and in spring enter freshwater areas as adults to spawn (ASMFC 2014). Environmental conditions vary according to waterbody and season, leading to variations in length of time American Shad reside in riverine, estuarine, or marine waters. Spawning events for American Shad are primarily driven by temperature, but photoperiod, water flow, velocity, and turbidity also play a role in determining spawning periods (Leggett and Whitney 1972). Spring spawning migrations begin in the south and gradually move north as water temperatures increase (Walburg 1960). Additionally, water temperature may influence the rate of gonadal and egg development (Greene et al. 2009). Colder waters (12.8 °C or 55 °F) cause slower gonadal development as compared to warmer temperatures (20 to 25 °C or 68 to 77 °F) (Mansueti and Kolb 1953).

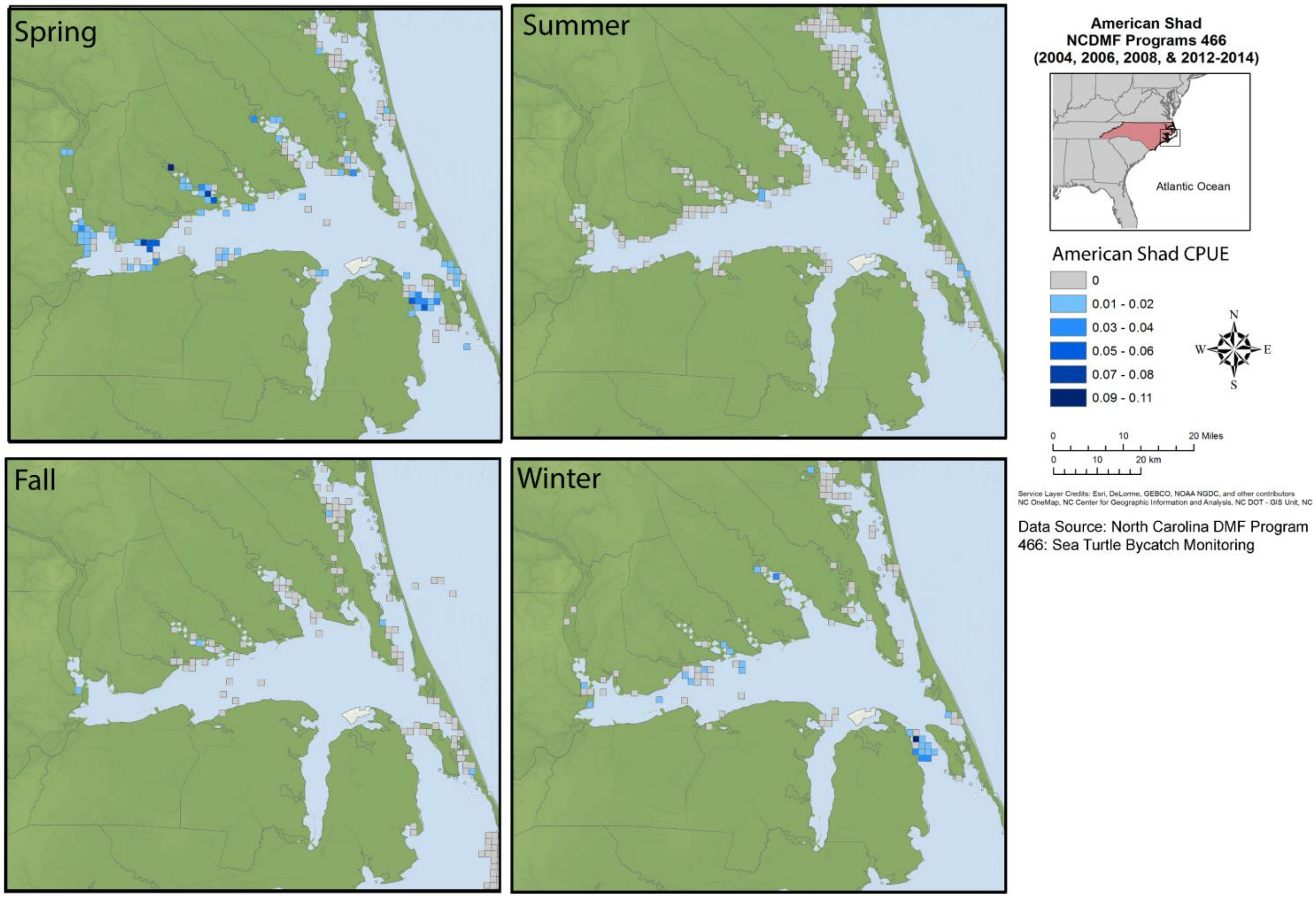

Figure 3.6.4: Seasonal distribution of American Shad as shown as captures in the NC Sea Turtle Bycatch Monitoring Survey (fishery-dependent), in Albemarle Sound. Higher catch per unit effort (CPUE) occurred in winter and fall seasons. For the seasons: spring = March, April, May; summer = June, July, August; fall = September, October, November; and winter = December, January, February. Each grid cell is 1 mi².

Instances have been reported where American Shad YOY have enhanced growth under favorable environmental conditions (Limburg 1995). Notably, these individuals may migrate into marine waters in late June at ages of six to nine weeks old. In contrast, late oceanic migrations can produce physiological disadvantages for YOY (Zydlewski et al. 2003). Once temperatures are consistently ≤ 6 °C (42.8 °F), sub-lethal or lethal effects may occur to YOY, particularly in fall and winter as YOY are not yet acclimated (Chittenden 1972a). YOY tolerate increases in salinity (5 to 30 psu) much better than decreases (30 to 0 psu), with mortality occurring with rapid salinity decreases (Chittenden 1973b). Eggs are always released in freshwater, but most American Shad life stages have a high tolerance to a wide range of salinities (SAMFC 2008).

American Shad require well-oxygenated waters in all habitats for each life stage (MacKenzie et al. 1985). Jessop (1975) found migrating adults require a minimum of 4 to 5 mg/l of dissolved oxygen (DO) once reaching riverine habitats. Minimum levels of 2.5 mg/l will support migration through polluted waters, but suitable spawning habitats are described as having DO levels of ≥ 4.0 mg/l (Chittenden 1973a). DO levels below 2.0 mg/l can produce high incidences of mortality, with 100% mortality occurring at DO below 0.6 mg/l (Tagatz 1961, Chittenden 1969). Juveniles show marked sub-lethal effects at DO concentrations less than 5.0 mg/l (Miller et al. 1982).

Research has shown that total suspended solid concentrations (TSS) of 1000 mg/l did not prevent movement of migrating adults (Leim 1924). American Shad eggs also can tolerate high levels of TSS (1000 mg/l) without significant decreases in hatching success (Auld and Schubel 1978). In contrast, larvae exposed to 100 mg/l TSS had significantly reduced survival rates as compared to controls (Auld and Schubel 1978). Turbid waters may also affect the visual acuity of shad larvae causing fish to lose sight of their prey (Theilacker and Dorsey 1980). This can in turn affect larvae survival rates. Therefore, larvae are the most sensitive life stage to high levels of suspended solids.

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3.7 River Herring

Blueback Herring (*Alosa aestivalis*, Mitchill, 1814) / Alewife (*Alosa pseudoharengus*, Wilson, 1811)

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Photo Credit: NOAA

General Information

Blueback Herring (*Alosa aestivalis*) and Alewife (*Alosa pseudoharengus*) are often referred to as *River Herring*, which serves as a collective term for the two inter-schooling species (Murdy et al. 1997, Greene et al. 2009). Blueback Herring and Alewife are highly migratory, anadromous species using multiple habitat types throughout its life cycle (Figure 3.7.1) (Greene et al. 2009, ASMFC 2017). River Herring was the classification referenced in most historic commercial harvests, with no distinction between the two species (ASMFC 1985). Until 1998, NMFS landings data reported both species as Alewife because of similarities in appearances, time of spawning, methods of capture, and marketing (Loesch 1987, Burke and Rohde 2015). Most FMPs combine Blueback Herring and Alewife for stock assessment purposes where significant overlap in spatiotemporal (ASMFC 2017). For this publication, the two species are reported together as River Herring. Notable differences between the two species, including biogeographical distinctions, are discussed throughout.

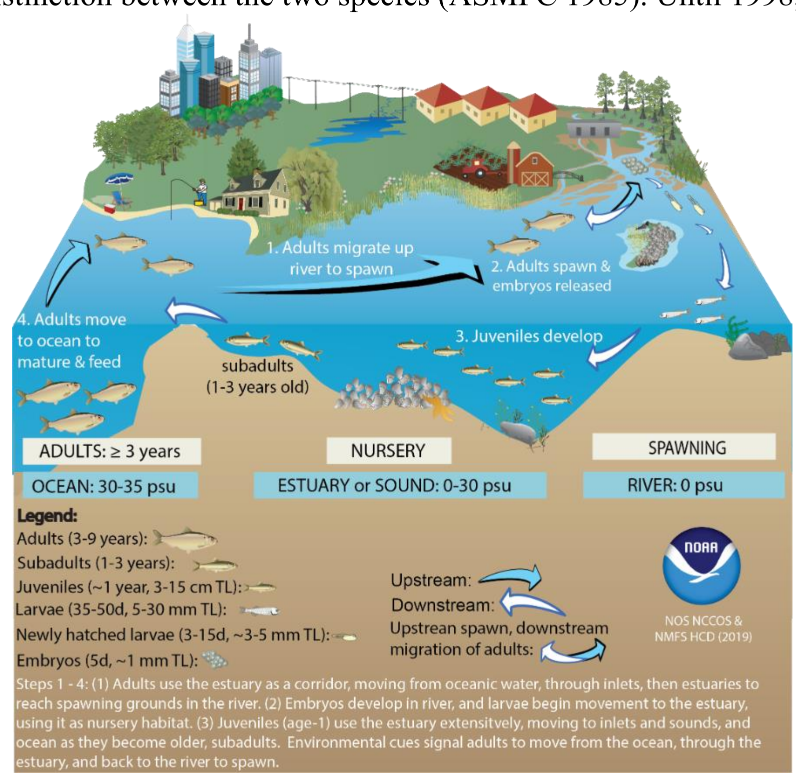

Figure 3.7.1: Life cycle of the River Herring (Blueback Herring *Alosa aestivalis* and Alewife *A. pseudoharengus*).

The range of Blueback Herring spans from

Cape Breton, Nova Scotia (Scott and Crossman 1973) to as far south as a tributary of the St. Johns River in Florida (Williams et al. 1975). Alewife range from the Gulf of St. Lawrence to South Carolina, but are most abundant between the Gulf of Maine and the Chesapeake Bay (Berry 1964, Winters et al. 1973). Even though Blueback Herring and Alewife co-occur throughout most of their range, Blueback Herring are higher in abundance by one to two orders of magnitude along the middle and southern parts of their ranges (Schmidt et al. 2003). Blueback Herring from southern regions are capable of migrating distances greater than 2000 km along the Atlantic seaboard, much like the lengthy migrations of American Shad (Neves 1981). Survey data suggest that Blueback Herring, Alewife, and American Shad segregate by depth distribution offshore offering some differentiation among species (Burke and Rohde 2015). While in oceanic waters, alosines act as prey for a multitude of species including sharks, tuna, mackerel, and marine mammals (Weiss-Glanz et al. 1986, ASMFC 1999, SCDNR 2015).

The River Herring fishery in coastal rivers of North Carolina were once among the largest freshwater fisheries globally (White et al. 2017). The historic abundance of River Herring biomass has substantially decreased over time throughout its range (Burke and Rohde 2015). For instance, in North Carolina, during the mid-1970s stocks plummeted, likely a result of an ocean-intercept fishery by foreign vessels (e.g., refrigerated trawlers, factory ships) (Holland and Yelverton 1973). Establishment of the Exclusive Economic Zone (EEZ) appeared to halt the decline, until 1989 when stocks precipitously dropped again (Burke and Rohde 2015). The second decline and overall lack of recovery may partially be due to modifications of normal flow conditions in natal rivers from dams and other obstructions. Modifying normal flow may negatively affect River Herring migrations, spawning success, and larval survival. For example, Riley (2012) examined the relationship between flow conditions on the Roanoke River, North Carolina, and larval alosine abundance from 1984-2009. Findings indicate larval fish abundance was negatively affected by low spring river flow, and improved flow conditions (i.e., increase in water velocity) could support the recovery of River Herring in the Roanoke River (Riley 2012).

Regulations in North Carolina (NC 15A NCAC 03R .0202) define two River Herring Management Areas (see Figure 3.7.2) – one in the Albemarle Sound (defined as the Coastal and Joint Fishing Waters of Albemarle, Currituck, Roanoke, Croatan, and Pamlico Sounds and all their joint water tributaries spanning from Roanoke Marshes Point southeasterly to the east shore on the north point of Eagles Nest Bay) and a second one in the Chowan River (defined as northwest of a point on Black Walnut Point running northeasterly to the east shore on Reedy Point, to the North Carolina/Virginia state line; including the Meherrin River) (NCDEQ 2016). These River Herring Management Areas align with regions delineated for surveys and stock assessment. The North Carolina River Herring stock assessment lists River Herring as depleted for both management areas and the stock status is listed as unknown for other waters across the state (NCDEQ 2016).

North Carolina adopted a River Herring FMP in 2000, which focused on issues pertaining to an overfished stock (a stock exploited to a level of abundance considered too low to ensure safe reproduction), recruitment overfishing (the number of fish removed is greater than the number gained from fish remain and reproducing in the population), and habitat degradation. The FMP was updated with Amendment 1 in 2007, which implemented a no-harvest provision for commercial and recreational fisheries of River Herring in coastal waters of the state with the exception of 3.4 MT (7,500 lbs) limited harvest for stock analysis and to provide local product for herring festivals (ASMFC 2017). The fishery closures were implemented as a management measure resulting from a River Herring stock assessment in 2005 that determined the stock was overfished and overfishing was occurring while the stock was also experiencing recruitment failure. The FMP was also updated with Amendment 2 in 2015, which eliminated the discretionary harvest season, codified the Albemarle Sound/Chowan River Herring Management Areas in rule, and expanded research to provide stock assessment data and socioeconomic data (ASMFC 2017). Despite restoration efforts, including habitat and water quality improvements, fish passage projects, and harvest restrictions, there are few signs of recovery for River Herring, especially populations within the Chowan River and Albemarle Sound, where some of the strongest runs of the fishery were historically recorded (White et al. 2017).

Historically, Blueback Herring occupied most of the major rivers in South Carolina (Post and Holbrook 2017). The SCDNR Marine Resources and Freshwater Divisions share management responsibility for River Herring through a combination of seasons, daily catch reports, gear restrictions, and catch limits, and an approved FMP for the commercial and recreational harvest of blueback herring (ASMFC 2017, Post and Holbrook 2017). Commercial Blueback Herring fisheries in South Carolina are limited in open rivers, such as Winyah Bay tributaries (e.g., Lowther's Lake area in the Pee Dee River), with the majority of river fishing activity occurring in hydro-electric tailraces of the Santee-Cooper River system (Figure 3.7.3) (Post and Holbrook 2017). SCDNR defines management units by stock and river complex utilized. Management units include rivers and tributaries within each area complex, including Winyah Bay (Sampit, Lynches, Pee Dee, Bull Creek, Black, and Waccamaw Rivers) and the Santee-Cooper River complex (Post and Holbrook 2017). South Carolina regulatory restrictions include a 227 kg (500 lbs) limit per boat per day in the Cooper and Santee Rivers and the Santee-Cooper Rediversion Canal; the Santee-Cooper Lakes have a 113 kg (250 lbs) per boat limit (ASMFC 2017). Recreational fisheries for Blueback Herring exist in South Carolina, but only as bycatch to the American Shad fishery (Post and Holbrook 2017). The recreational fishery has a daily limit of 1-bushel limit (23 kg or 50 lbs). Fishing is prohibited within one hundred feet of the fish lift exit channel at St. Stephens Powerhouse (SCDNR 2018).

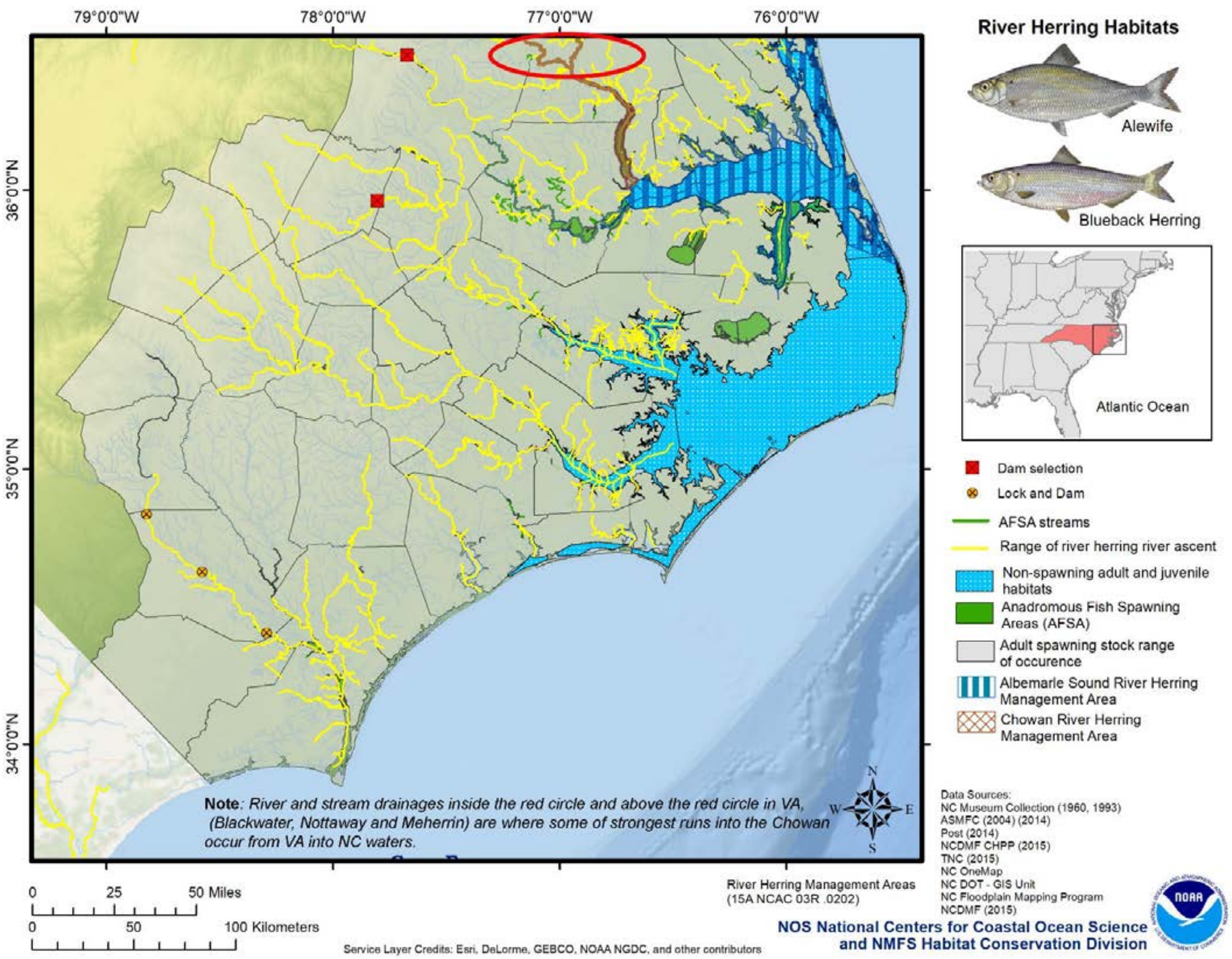

Figure 3.7.2: Main spawning rivers and streams for River Herring and NCDMF designated anadromous fish spawning areas (AFSA). Along the Chowan River, River Herring cross over from Virginia into North Carolina as indicated by the red circle. This includes the drainages of the Chowan (Blackwater, Nottaway and Meherrin) where some of the strongest runs of the fishery were historically recorded.

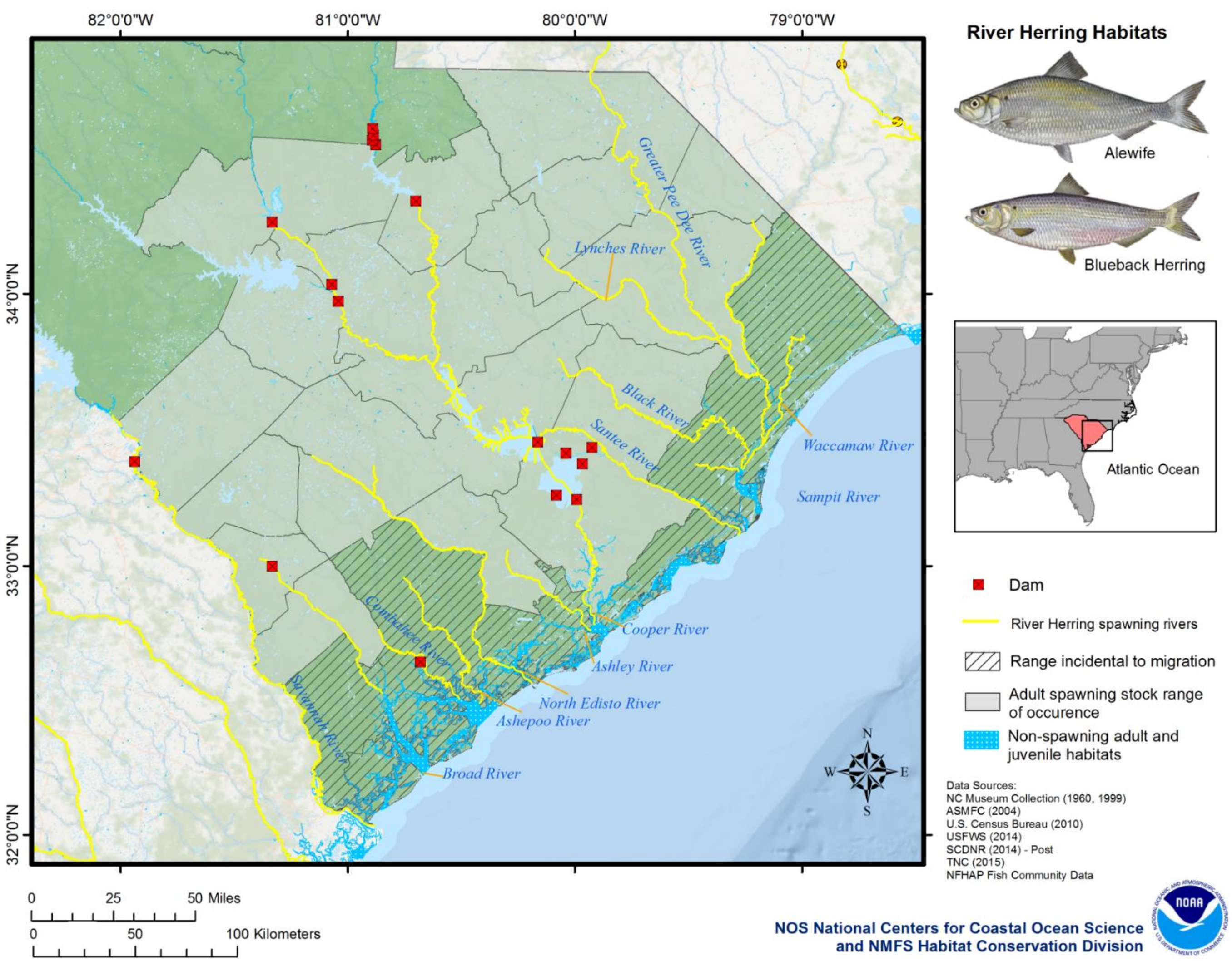

Figure 3.7.3: Main spawning rivers, obstructions to passage (dams) on the rivers, range incidental to migration, adult spawning stock range of occurrence, and non-spawning juvenile, and adult habitat by River Herring in South Carolina.

Life History

Spawning adult Blueback Herring populations north of Cape Hatteras migrate inland from offshore ocean waters; during this migratory movement, individuals encounter a thermal barrier, forcing them to turn either south towards natal south Atlantic rivers or north along the coast (Neves 1981, Greene et al. 2009). In contrast to American Shad, Blueback Herring swim at mid-water depths during their freshwater migration (Witherell 1987). Spawning begins as early as March in warmer, southern waters and continues through July or August (Table 3.7.1) (Greene et al. 2009). During migration to natal streams, spawning adults consume large, diverse quantities of zooplankton, benthic and terrestrial insects, mollusks, fish eggs, hydrozoans, and stratoblasts (Creed 1985). Spawning adults must avoid predation from other fish (e.g., Striped Bass), reptiles, and piscivorous birds (Loesch 1987, Scott and Scott 1988). Alewife begin spawning about three to four weeks before Blueback Herring; however, there may be considerable overlap with peak spawning only differing by two to three weeks (Hildebrand and Schroeder 1928, Loesch 1987). Spawning events occur over an extended period, with groups of migrants staying 4 to 5 days before rapidly returning to sea (Klauda et al. 1991).

Blueback Herring egg incubation time varies from about two days in warm waters (29 ˚C or 84 °F) to 15 days in colder waters (7 °C or 45 °F) (Jones et al. 1978). Once larvae hatch, they are between 3.1 to 5.0 mm (0.12 to 0.20 in) TL, with transformation of morphology into the juvenile stage occurring at 25 mm (1 in) (Hildebrand 1963). Growth is arrested in winter months and resumes the spring. Due to the lack of growth during winter, young-of-the-year (YOY) and age-1 are similar in size, only separated by 5 to 10 mm (0.2 to 0.4 in) (Able and Fahay 2010). YOY appear in April and continue through June in estuaries (Able et al. 2007). In the middle Atlantic Bight, YOY are about 50 mm (2 in) during July and 100 mm (4 in) by the end of summer (Able and Fahay 1998). Through spring and summer, juveniles are found most frequently in 0 to 2 psu waters (spring and summer) before fall migration to sea. Blueback Herring may stay in freshwater up to one month longer than juvenile Alewife (Loesch 1968). Males mature at an earlier age (3 to 4 years) than females (4 to 5 years), but are not as long-lived as females (Joseph and Davis 1965). The majority of the mature adult life stage (3 to 9 years) is spent in coastal waters, with the remainder of life spent in migration routes through estuaries and further into natal freshwater rivers and streams.

Physiology and Habitat

Blueback Herring are more numerous in populations south of North Carolina, as Alewife are largely absent (Greene et al. 2009). Southern populations of spawning Blueback Herring have been documented in small tributaries upstream from the tidal zone (ASMFC 1999), seasonally flooded rice fields, small densely vegetated streams, cypress swamps, and oxbows where soft substrate and detritus are present (Adams and Street 1969, Godwin and Adams 1969, Adams 1970, Curtis et al. 1982, Meador et al. 1984, Greene et al. 2009). Spawning occurs in waters with a minimum DO level of 5 mg/l and temperatures ranging from 13 to 27 °C (55.4 to 80.6 °F) (Hawkins 1979, Rulifson et al. 1982, Loesch 1968).

Table 3.7.1: Temporal and spatial distribution of various River Herring life stages in North Carolina and South Carolina waters.

River / Estuary / Ocean		Q_1= Winter			Q_2= Spring			Q_3= Summer			Q_4= Fall		
	Life Stage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Blueback Herring (*Alosa aestivalis*)/ Alewife (*Alosa pseudoharengus*)	Spawning Adults												
	Egg												
	Larvae												
	Juveniles												
	Sub-adult												

Adult Blueback Herring navigate to their natal rivers; however, a small number of individuals may stray to adjacent streams or colonize new streams (Messieh 1977). Loesch (1987) reports Blueback Herring having adaptive spawning behaviors when environmental conditions are more favorable than conditions within the natal stream, as demonstrated by populations in the Santee-Cooper River system in South Carolina. Distribution is ultimately a function of habitat suitability and hydrological conditions (e.g., swift flowing water) (Loesch and Lund 1977). Generally, Blueback Herring and Alewife attempt to occupy different freshwater spawning areas, unless forced into the same area due to an impediment or blocked passage (e.g., dam, culvert, impoundment) (Greene et al. 2009). When co-occurrence does occur, Blueback Herring will spawn in the main stream flow preferably with gravel or clean sand substrates, while Alewife will spawn along shore bank eddies and deep pools (Loesch and Lund 1977, Johnson and Cheverie 1988, Greene et al. 2009).

After spawning occurs, eggs and larvae move downstream and can survive in salinities as high as 18 to 22 psu in estuarine waters, but optimally develop in freshwater (Johnston and Cheverie 1988, Klauda et al. 1991). Egg and larval habitats are described by Pardue (1983) as substrates with 75% silt or other soft bottom materials containing detritus, while Johnston and Cheverie (1988) posit eggs adhere to sticks, stones, gravel, and aquatic vegetation along the bottom of swift-flowing streams. Larvae require a minimum of 5 mg/l DO for survival (Jones et al. 1978). An upper lethal temperature for eggs of 29.7 ºC (85.5 °F) was documented in Hudson River, New York (Kellogg 1982). Turbidity reduces larval growth and survival (Dixon 1996). Alewife and Blueback Herring eggs are tolerant of suspended solids up to concentrations of 1,000 mg/l (Auld and Schubel 1972). High levels of suspended solids during and after spawning of Alewife and Blueback Herring significantly increases egg and larval mortality because of fungal infections (Schubel and Wang 1973, Klauda et al. 1991). It has been noted that yolk-sac larvae are likely more sensitive to suspended solids than eggs and that a suitable maximum of suspended solids is 500 mg/l for larval alosines (Klauda et al. 1991).

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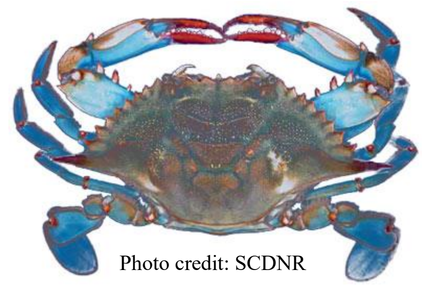
3.8 Blue Crab

(*Callinectes sapidus,* Rathbun 1896)



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General Information

The Blue Crab, a swimming crab (family Portunidae), acts as a fundamental component of estuarine systems, playing critical ecological, economic, and cultural roles (DeLancey 2015, Read 2015). Functioning as predator and prey within estuarine food webs, Blue Crabs occupy habitat susceptible to human-induced ecosystem change (Huang 2015). As a predator, Blue Crabs are perhaps one of the most important determinants of community structure within estuarine ecosystems (Mansour 1992, Guillory 2001, Gandy et al. 2011). For example, Blue Crab predation is an important factor in controlling marsh snails (*Littoraria littorea*) that if over populated can lead to a loss of salt marsh (Angelini and Silliman 2012). Habitat selection of the Blue Crab depends on the physiological requirements for each stage of its intricate life cycle that includes time spent as plankton, nekton, and in the benthos (Figure 3.8.1) (Gandy et al. 2011). Blue Crab fisheries are divided between commercial and recreational sectors, with a suite of different fishing gear and effort levels, and several different markets (i.e., peeler, soft, hard) (Read 2015). Worldwide the *Callinectes* fishery is the largest of all crabs (Lipcius and Eggleston

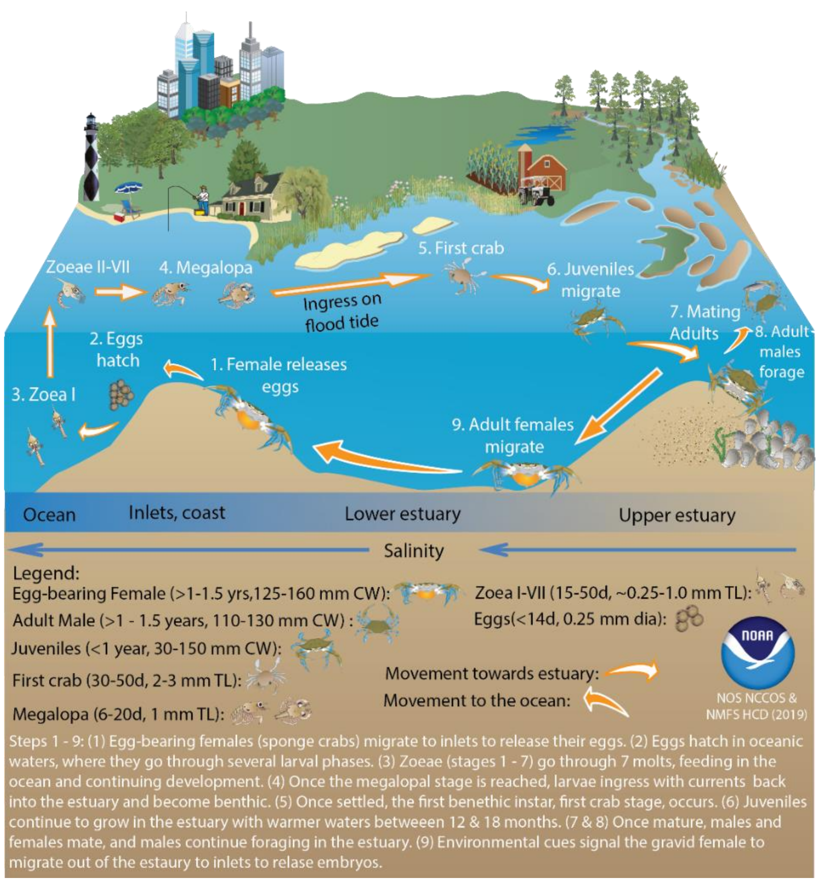

Figure 3.8.1: Life cycle of the Blue Crab (*Callinectes sapidus*).

2001). In the United States, Blue Crab range from Maine southward to the Gulf of Mexico, but are most common from Cape Cod, Massachusetts to the southernmost extent of Texas (Hay 1905, Guillory et al. 2001). This distribution occurs where water temperatures reach ≥ 20 ºC (≥ 68 °F) (Norse 1977). In the south Atlantic region (North Carolina, South Carolina, Georgia, Florida), Blue Crab commercial fisheries contributed almost 13,426.3 MT (29.6 million lbs) in 2017 (NMFS 2018).

The Blue Crab fishery represents one of North Carolina's most valuable commercial fisheries (NCDMF 2004). Hard crabs account for over 95% of the annual Blue Crab harvest (NCDEQ 2018). From 1994 to 2009, North Carolina ranked second among Blue Crab producing states in the country accounting for 22% of the national total commercial harvest (NCDMF 2013). In North Carolina, the Blue Crab is common in all coastal waters, but the largest aggregations tend to live in Albemarle Sound, Pamlico Sound, and associated tributaries (Figure 3.8.2, Figure 3.8.3) (NCDMF 2013). Albemarle Sound is one of the most productive areas in North Carolina, accounting for, on average, over 50% of the state's overall Blue Crab landings (NCDEQ 2018). Using a sex-specific two-stage model approach (for sexually dimorphic species' stock assessments), North Carolina's Blue Crab stock is currently listed as overfished and overfishing is occurring (NCDMF 2018). Reductions in landings from 2000 to 2002 and 2005 to 2007 followed record-high commercial landings observed during 1996 through 1999 (NCDMF 2011). Landings in 2017 were the lowest since the 1970s. Harvest from Pamlico and Core Sounds and their tributaries continue to remain significantly less than historical levels. Albemarle Sound and its tributaries continue to be the dominant contributors, landing 5,897 MT (13.0 million lbs) of the state's total Blue Crab commercial harvest (11204 MT or 24.7 million lbs) of hard crabs in 2016, and accounted for 62% of landings from 2011 to 2017 (NCDMF 2017). From a regulatory perspective, male Blue Crabs must have a minimum 5-inch (127 mm) carapace width to harvest. The recreational harvest bag limit is 50 crabs per day not to exceed 100 crabs/day/vessel. There is no commercial trip limit. Harvest of immature females and mature females are not subject to the minimum size limit; however, dark sponge crabs (e.g., gravid females) cannot be harvested during the month of April (NCDMF 2013, NCDMF 2016).

Similar to the North Carolina Blue Crab population, the South Carolina population has declined over the past 30 years (Parmenter 2012). Annual South Carolina commercial landings range from 1,814.4 to 2,721.6 MT (4.0 to 6.0 million lbs), with an estimated total population in the tens of millions (Harris 2001, DeLancey 2015). Retention of any Blue Crab caught in the freshwaters of South Carolina is prohibited (SCDNR 2015). Historically, the Blue Crab fishery was the most stable of South Carolina's commercial fisheries, but during the period of 2002 to 2012, landings and relative abundance as observed in fishery independent sampling indicated a significant decline in the Blue Crab resource. Landings in 2010 reached a 50 year low of 1,451.5 MT (3.2 million lbs) before rebounding to near average levels in the following three years (SCDNR 2015). This long-term decline (2002 to 2012) in landings appeared to be related to a sustained period of drought in the Southeast with river runoff being well below averages for multiple (Whitaker et al. 1998, SCDNR 2007, (Knapp et al. 2008, SCDNR 2015). Increases

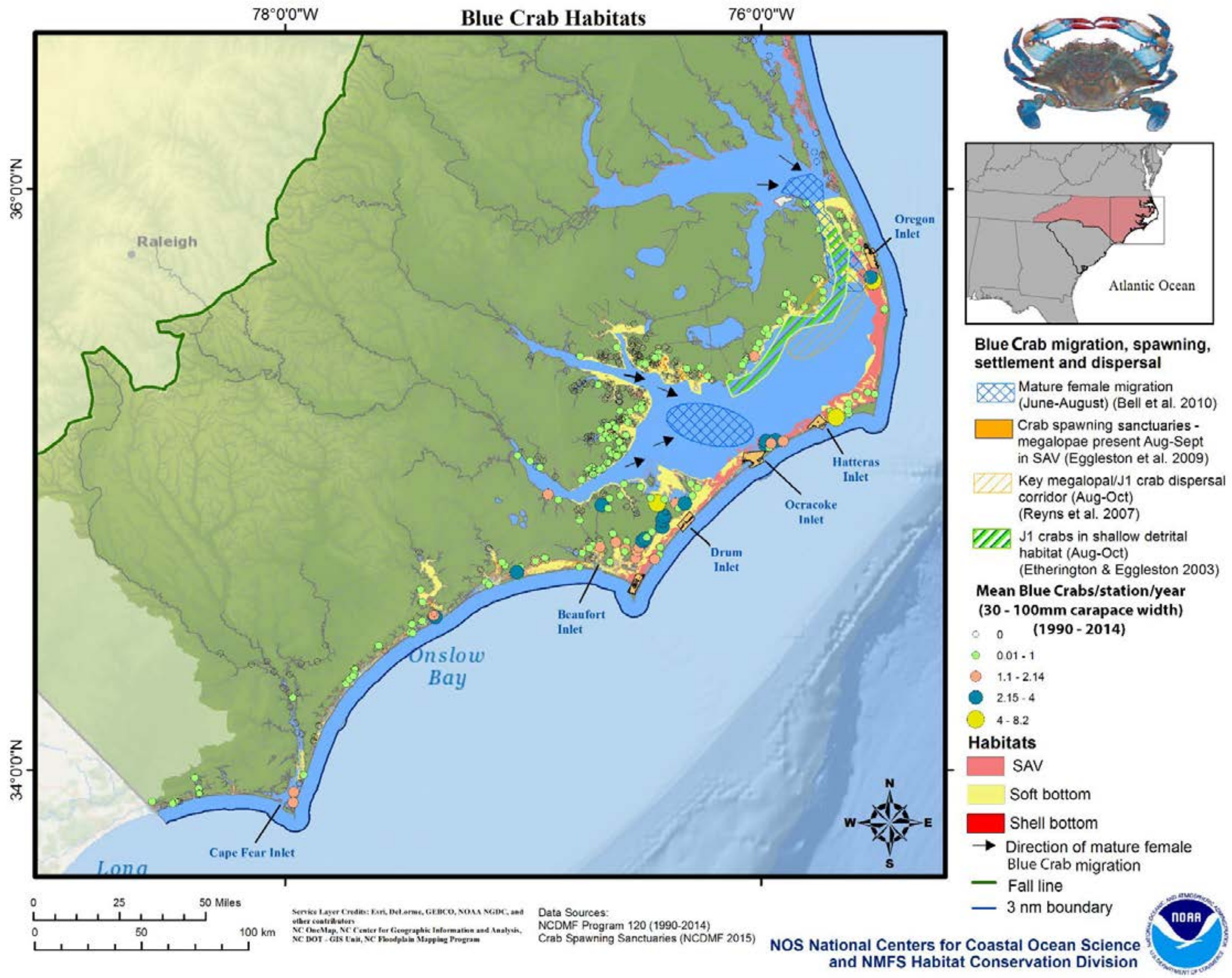

Figure 3.8.2: Critical Blue Crab timing and migration pathways, direction of movement and settlement, and dispersal corridors in North Carolina as defined by published literature. Habitats associated with various Blue Crab life stages are also shown, as well as mean Blue Crab abundance/station/year for May and June in the 24-year sampling period from NCDMF Program 120.

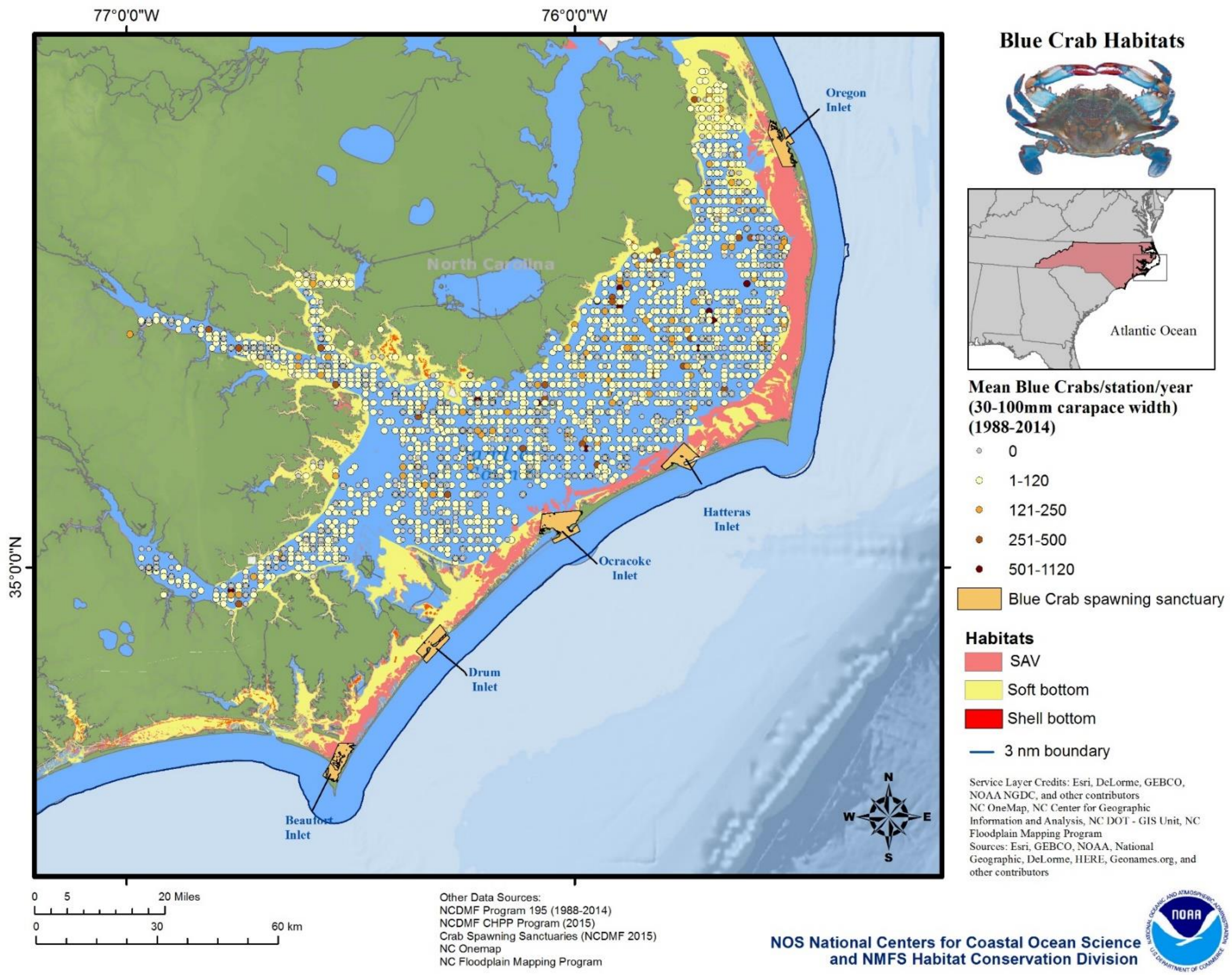

Figure 3.8.3: Habitats associated with various Blue Crab life stages as well as mean blue crab abundance/station/year from NCDMF Pamlico Sound Survey Program 195 (1988 – 2014).

in salinity were also observed during this decline, most likely from decreased freshwater discharge into estuaries (Hart et al. 2003, Posey et al. 2005, White and Alber 2009, Parmenter 2012). Conditions such as drought helps proliferate the parasitic dinoflagellate, *Hematodinium perez*, which may result in crabs being farther inland out of historic fishing grounds, possible interference with the natural reproduction process, and reduced cover within salt marsh habitat (ASMFC 2004). Preliminary observations from 2015 indicated the Blue Crab population was at or near normal levels. This apparent recovery is coincident with a return to normal to above normal rainfall and runoff beginning in 2013. There has been a significant positive correlation between river discharge and annual landings of Blue Crabs in South Carolina since 1979 (Parmenter 2012). Despite the potential physiological constraints and perhaps constriction of optimal juvenile habitat related to the long-duration drought, SCDNR currently lists Blue Crab population as being in good to fair condition, as the populations seems to be responding to recent increases in regional rainfall (Bill Post, personal communication, November 2, 2015).

Life History

Mating typically occurs in the mesohaline and oligohaline zones of estuaries in North Carolina from May to October (Dudley and Judy 1971, Eggleston et al. 2009) and in South Carolina from March until early fall (Table 3.8.1) (Eldridge and Waltz 1977). Females collect sperm from the single mating event, which occurs when the female is in a soft condition, and store it in seminal receptacles used each time she spawns (ASMFC 2004). All young produced from mature females must be fertilized by stored sperm (Darnell et al. 2009). Males may mate after their third or fourth intermolt and may mate multiple times during their lives (NCDMF 2013). The timing between mating and spawning varies with location and when mating occurs. It can be anywhere from 2 to 9 months post mating (Van Den Avyle 1984). When mating occurs in the spring and summer, a 2 month interval is common (Grandy et al. 2011), but a longer interval occurs when mated females overwinter and spawn in March or April. Spawning involves the formation of a "sponge" of 700,000 to 8,000,000 fertilized eggs held to the female abdomen by hair-like branches called setae (Van Heukelem 1991). In North Carolina and South Carolina, spawning occurs from April to November, and peaks from June until August (Dudley and Judy 1971, Archambault et al. 1990, Epifanio 1995, Eggleston et al. 2009).

Mature female Blue Crabs typically mate in mesohaline or oligohaline estuarine waters before moving to higher salinity waters in the lower estuary or just offshore to release their eggs (Figure 3.8.3, Figure 3.8.4,) (Hines et al. 1987, Steele and Bert 1994, Grandy et al. 2011). The gradual migration of females to the sea was documented via collections throughout spring and early summer months where 96% of tagged females were found downstream of the release point (Tagatz 1968). The fertilized eggs (i.e., embryos) (0.25 mm or 0.1 in diameter) are attached to the pleopods on the female abdomen and are bright orange when first extruded into the ocean, becoming yellow, brown, and then dark brown before hatching (Van Engel 1958). Dickinson et al. (2006) conducted a fecundity study in one spawning season in North Carolina and found female Blue Crabs could produce at least three and up to seven clutches (i.e., sponges) in one season. Darnell et al. (2009) studied the lifetime reproductive potential of female Blue Crabs in

North Carolina, finding that most of the crab's reproductive output was in the first few clutches (clutches 1 through 3).

Table 3.8.1: Temporal and spatial distribution of various Blue Crab life stages in North Carolina and South Carolina waters. An asterisk indicates when peak events (e.g., spawning) are occurring during a particular month. S = individuals <50 mm TL (September – March), and L is individuals between 50-100 mm TL (March – August).

Upper Estuary / **Lower Estuary** / **Inlets/ coasts** / **Ocean**	**Peak Events***	**Q$_1$=Winter**			**Q$_2$=Spring**			**Q$_3$=Summer**			**Q$_4$=Fall**		
	Life Stage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Blue Crab (*Callinectes sapidus*)	Spawning Adults						*	*	*				
	Egg								*	*			
	Larvae												
	Juveniles	S	S	S/L	L	L	L	L	L	L	S	S	S
	Non-spawning adults									*	*	*	

*peak events (e.g., highest abundance, spawning)
S = individuals <50 mm TL (September – March)
S/L =individuals <50 to 100 mm TL (March)
L = individuals 50-100 mm TL (March – August)

Once embryos hatch and leave the female after about 15 days, the first larval stage (zoea) develops while floating in the water column where they undergo seven to eight additional developmental stages over a 30 to 50 day time period (Costlow et al. 1959, Costlow and Bookhout 1959, Epifanio 1995). Zoea larvae are confined to high-salinity areas because of their intolerance of low-salinity water (Costlow and Bookhout 1959). This stage and all following life stages only increase in body size through molting (Hay 1905, Hill et al. 1989). Following the final zoeal stage, metamorphosis occurs into the post-larval megalopal stage lasting about 6 to 20 days (Figure 3.8.1) (Van Engel 1958, Costlow and Bookhout 1959). Along the western North Atlantic (Delaware to South Carolina) megalopae settlement is generally characterized by constant low levels with episodic peaks that vary in duration and intensity based on tidal and lunar events (Van Montfrans et al. 1995). However, Boylan and Wenner (1993) found Blue Crab

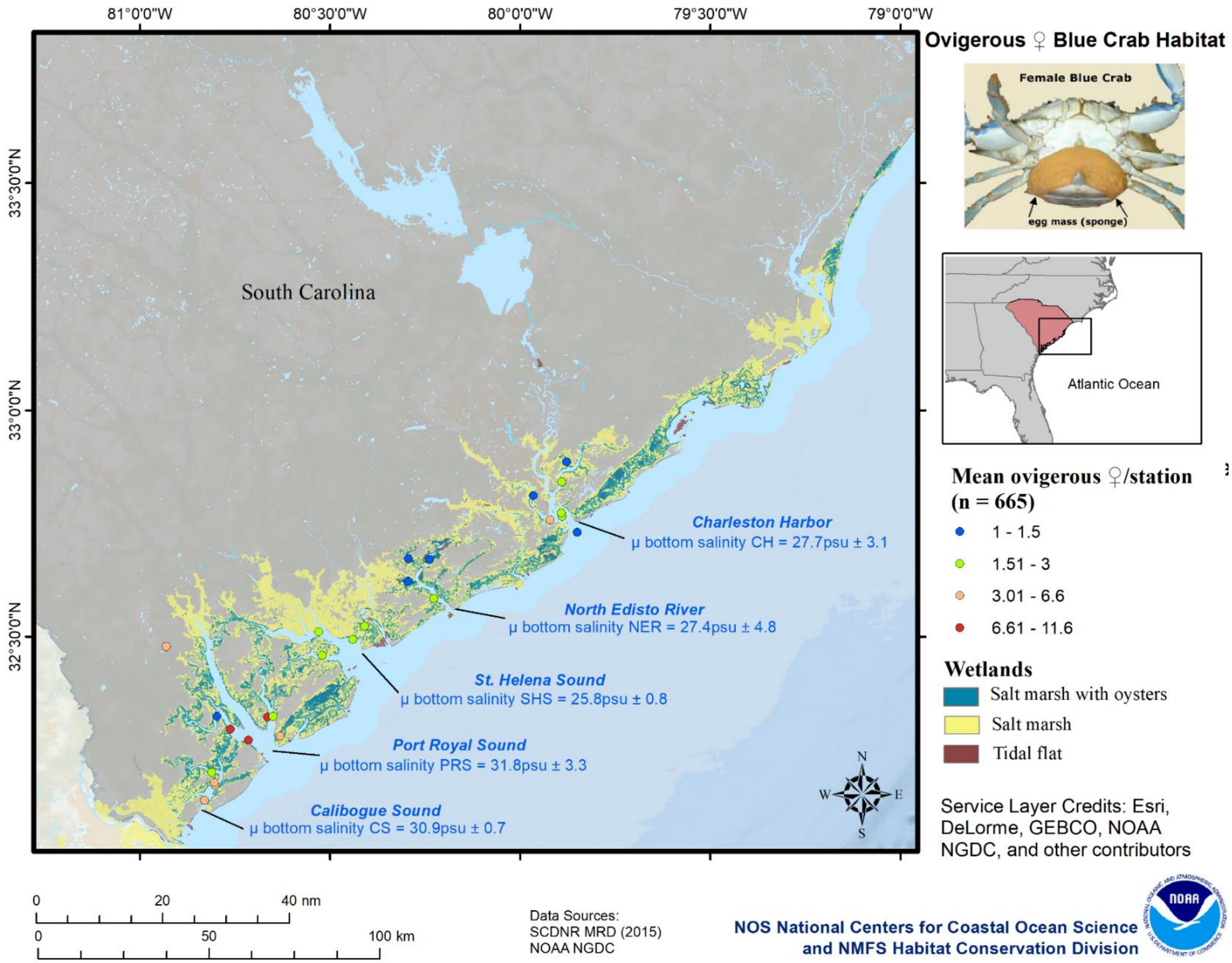

Figure 3.8.4: Mean ovigerous female Blue Crabs per sampling station (n = 665) in the tidal creeks and estuary proper in the South Carolina coastal zone. Various habitats used by Blue Crabs at different life stages are also depicted showing distribution of oyster bottom habitat, salt marsh habitat, and tidal flats.

postlarvae settlement on substrates in Charleston Harbor in all months but March, but the period of major settlement was August through October. Blue Crab megalopae in Albemarle Sound and Pamlico Sound are transported through wind-driven Ekman circulation and into inshore estuaries for settlement by means of barotropic flow moving in from the shelf (Figure 3.8.2) (Epifanio 2007, Eggelston et al. 2010). Megalopal settlement in the southern region of North Carolina and into South Carolina and Georgia is tidally influenced with highest settlement at neap tides during quarter phases of the moon and increasing with hours of dark flood tides (Forward et al. 2004, NCDMF 2013). Peak settlement in most of North Carolina is based on direction and magnitude of wind events associated with tropical storms and other significant, seasonal wind producing weather events (Epifanio 2007, Eggleston et al. 2010). Colton et al. (2014) provided evidence that Blue Crab populations in the Carolinas may be related to nearshore circulation patterns as related to the position of the Gulf Stream.

Once megalopal (1-mm width) settlement occurs within estuaries, metamorphosis occurs into the first benthic instar (J1), crab stage (2 to 3 mm or 0.04 to 0.01 inches) (Tagatz 1968). Juvenile Blue Crabs grow through the fall until water temperatures begin falling in December (Table 3.8.1, Figure 3.8.2, Figure 3.8.5). Growth resumes in March or April as water temperature exceeds 17 to 18 °C (62.6 to 64.2 °F). Blue Crabs reach maturity between 12 and 18 months of age (NCDMF 2013), usually in August or September (Figure 3.8.3, Figure 3.8.6). Optimal growth of Blue Crabs occurs at temperatures between 15 to 30 ºC (59 to 86 °F), with growth halting when temperatures drop below 10 ºC (50 °F) (Cadman and Weinstein 1988). The average life span of Blue Crabs is about 3 years and spans up to 8 years maximum (ASMFC 2004), although much of the adult population is harvested soon after reaching 127 mm (5 in) in carapace width.

During the fall, high intensity storms (i.e., hurricanes) and above normal runoff can cause massive relocation of crabs from up-estuary tributaries to central estuarine areas in North Carolina (ASMFC 2004). For instance, three sequential hurricanes that hit North Carolina's Pamlico Sound in fall 1999 were correlated with crowding crabs into the central region of the Sound where they were exposed to intense localized fishing pressure (Dave Eggleston, personal communication, December 5, 2016). That event ran concurrent with the precipitous decline in North Carolina's Blue Crab population beginning in 1999-2000. Record-setting rains and associated runoff in South Carolina in October 2015 resulted in significant drops in estuarine salinity for much of the state and concurrently, fishers reported improvements in their catch rates in the ensuing weeks.

Physiology and Habitat

Hatching of Blue Crab eggs generally occurs at salinities of 23 to 33 psu and temperatures of 19 to 29 °C (66 to 84 °F) (Sandoz and Rogers 1944). Working in North Carolina, Judy and Dudley (1971) observed that tagged, mature females crabs moved to high-salinity water to spawn and hatch eggs. Archambault et al. (1990) found the average salinity where sponge crabs were found was 25.4 psu with 96% of ovigerous females collected near the mouth of Charleston Harbor. More recently, an examination of salinities observed when sponge crabs were harvested in South Carolina found the average salinity to be 28.9 psu (Bill Post, personal communication, November 2, 2015; Jeff Brunson, personal communication, February 5, 2016). Mortality of eggs has been attributed to a multitude of environmental factors including fungal infection, nemertean worms, predation, suffocation in stagnant water, and exposure to extreme temperatures (Couch 1942, Humes 1942). On average, one out of every million eggs survives to become a mature adult (Van Engel 1958). Once hatched, currents transport zoea along the continental shelf where they develop and feed on zooplankton and plant material in the water column (Sulkin and Van Heukelem 1986).

Once megalopae settle into a benthic lifestyle, it is in shallow nearshore areas critical for foraging and refuge from predators (Figure 3.8.2, Figure 3.8.5) (More 1969, King 1971, Perry 1975, Perry and Stuck 1982, Olmi 1994, 1995, Rabalais et al. 1995, Johnson and Perry 1999, Heck et al. 2001, Tankersley et al. 2002). These inshore areas in North Carolina are characterized by beds of SAV and other complex habitats in South Carolina (e.g., salt marsh, detritus, and oyster shell) where they undergo further metamorphosis to become juveniles (Heck and Thoman 1981, Orth and van Montfrans 1987, Hill et al. 1989, Ruiz et al. 1993, Pardieck et al. 1999, Posey et al. 1999, Etherington and Eggleston 2000). Juveniles continue to utilize SAV habitats, as well as intertidal saltmarsh, soft detritus, and mud or mud-shell bottoms, to develop during the earliest juvenile instars (Hill et al. 1989). Older juveniles in less-saline waters in the upper estuaries and rivers most likely grow faster than crabs in higher salinity areas (Figure 3.8.6) (Mense and Wenner 1989, NCDMF 2013).

Hypoxic events (DO < 2.0 mg/l) lead to complex ecological consequences for mobile organisms such as the Blue Crab, due to an array of behavioral and physiological responses that may occur (Taylor 1982, Bell et al. 2009). South Carolina estuarine tidal creeks have naturally reduced DO at low tide during warm weather, and many juvenile organisms have a high tolerance to low DO allowing them to withstand these conditions and inhabit areas beyond the physiological tolerance of many predators (Holland et al. 2004). Low DO conditions could potentially affect adult Blue Crab distribution and mortality. Shallow estuaries and nearshore areas of deeper estuaries experience episodic hypoxic conditions due to diel cycles of DO production and respiration by algae (D'Avanzo and Kremer 1994, Bell et al. 2009). On an acute basis, Blue Crabs will move away from low DO conditions, and those with hemocyanins with low affinity for oxygen more actively move away from hypoxic conditions (Bell et al. 2009). When chronic hypoxic conditions occur in the deepest portions of estuaries, mobile organisms move from the deep water into nearshore environments that are normoxic (Bell and Eggleston 2005). This causes habitat compression potentially leading to decreased growth rates as inter- and intra-specific competition for prey increases. It can also lead to increased incidence of cannibalism as juvenile and adult conspecifics, normally spatially segregated, overlap (Eggleston et al. 2005). During some hypoxic upwelling events, thousands of mobile animals will form dense aggregations at the land-water interface as an avoidance strategy (Loesch 1960). Low DO events in North Carolina estuaries are most likely more of a stressor than in South Carolina where larger tidal amplitude allows for substantial water circulation in its open inlets. Low oxygen conditions are also common in estuaries receiving excess nutrient loads. In such cases, crabs and fishers tend to get crowded, resulting in the possibility for excessive resource drain in either case. The Neuse River estuary in North Carolina has been the site of such hypoxic events, as holding basins for hog sludge overflowed into the river. Concerning turbidity and total suspended solids, high levels of suspended silt could potentially clog crab gills (Van Heukelem 1987).

The Blue Crab exhibits highly variable population dynamics driven by a combination of endogenous and exogenous variables, as is the case with many crustacean populations (Higgins et al. 1997). Exogenous variables might include wind-driven forcing that influences spatiotemporal variation in megalopal influx to local and regional populations (Van Montfrans et al. 2005, Eggleston et al. 2010), to endogenous factors that include variable spawning stock biomass and density-dependent mortality (Lipcius and Stockhausen 2002, Eggleston et al. 2004). Blue Crab populations in North Carolina's Pamlico Sound and the Virginia portion of Chesapeake Bay exhibit a significant spawning stock recruit relationship (Lipcius and Stockhausen 2002, Eggleston et al. 2004). Blue Crab spawning stock in Chesapeake Bay remained at historic low levels from 2002 to 2012 until stringent harvest restrictions were put into place in 2012, with subsequent recovery of the blue crab spawning stock. Conversely, the Blue Crab spawning stock in North Carolina remains at historic low levels. Thus, fishery managers faced with a declining or low level of spawning stock can consider the life history and spatial habitat information presented in this publication as a means to help inform management strategies to conserve or rebuild Blue Crab populations in the southeastern United States.

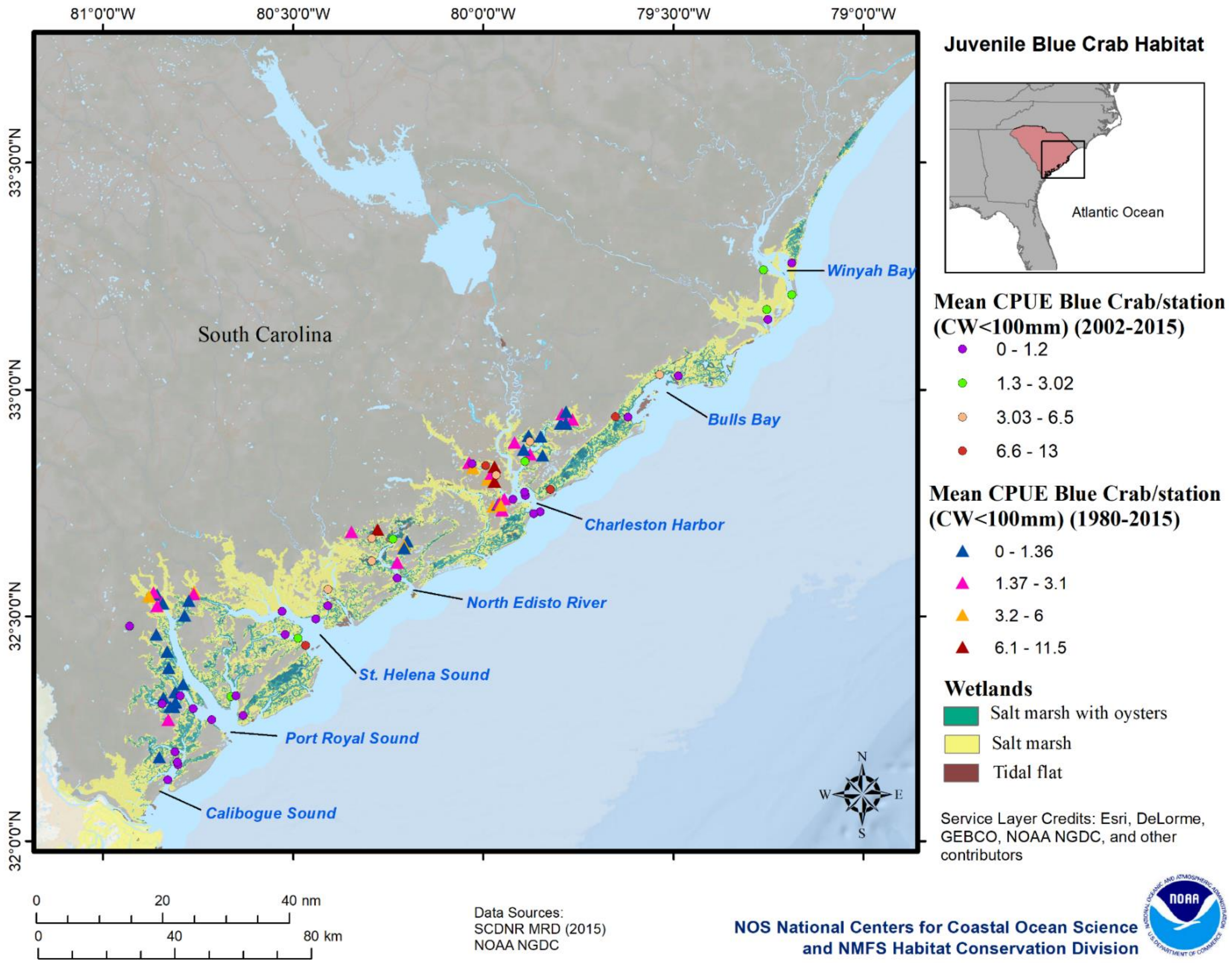

Figure 3.8.5: The mean catch per unit effort (CPUE) of juvenile Blue Crabs from two different sampling programs in coastal South Carolina. The highest average CPUE of Blue Crabs from both sampling programs was observed in tidal creeks of Bull's Bay, Charleston Harbor, and the mouth of the St. Helena Sound.

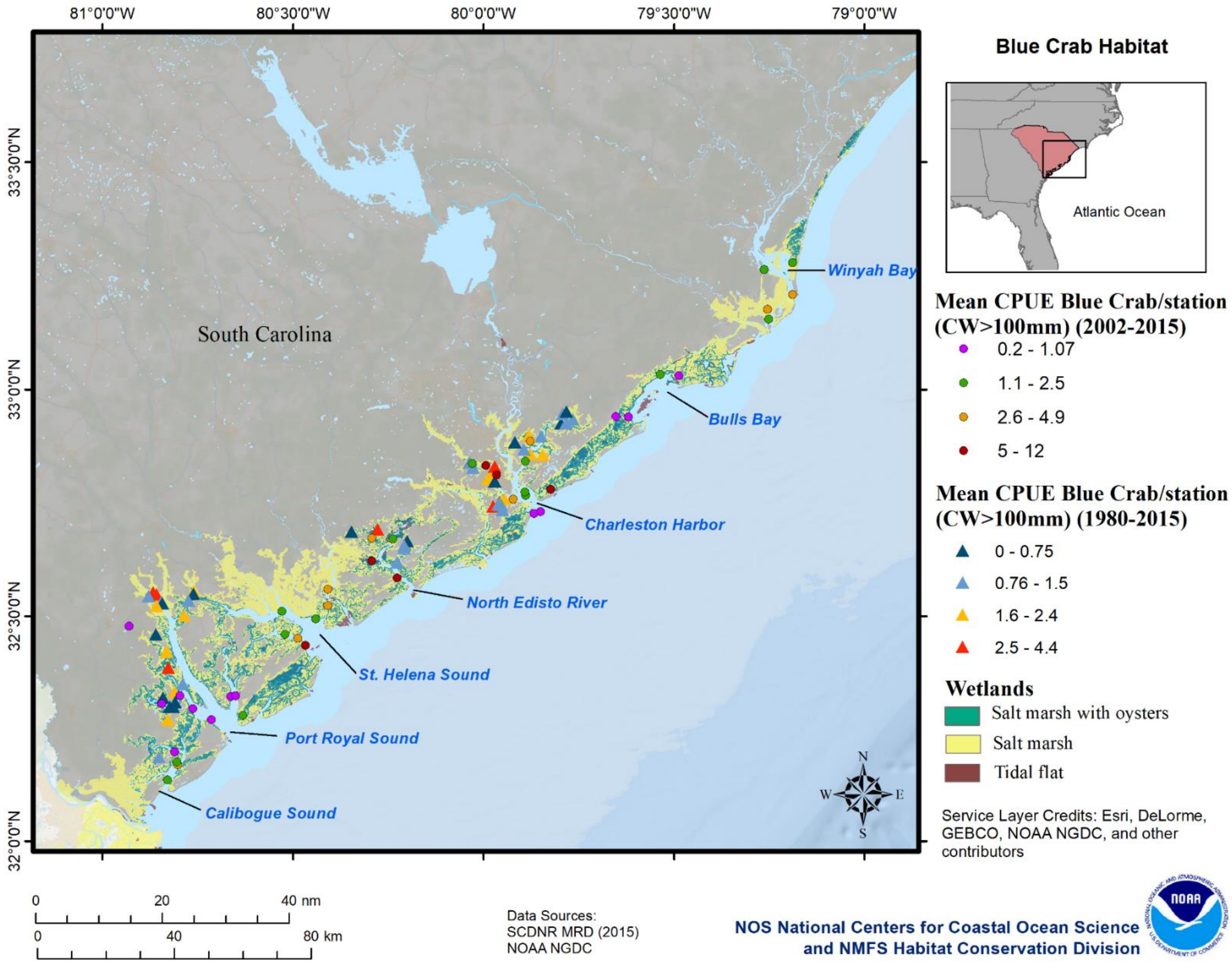

Figure 3.8.6: The mean catch per unit effort (CPUE) of adult Blue Crabs from two different sampling programs in coastal South Carolina. The highest average CPUE of Blue Crabs from both sampling programs was observed in Charleston Harbor, North Edisto, the mouth of the St. Helena Sound, and the upper reaches of Port Royal Sound.

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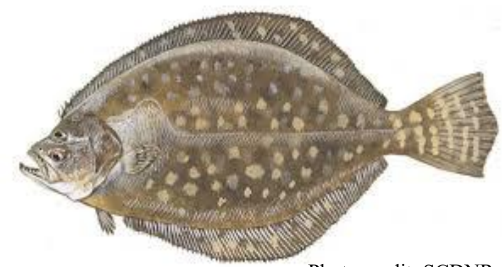
3.9 Southern Flounder

(*Paralichthys lethostigma*, Jordon and Gilbert, 1884)



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[2]NOAA, NOS, NCCOS, Beaufort, NC

General Information

Southern Flounder, *Paralichthys lethostigma*, is an estuarine dependent left-eyed flounder species (family Bothidae) with a complex life history involving utilization of a wide range of habitats from the larval stage through maturation (Figure 3.9.1) (Safrit and Schwartz 1998, Taylor et al. 2008, Taylor et al. 2010). Southern Flounder have a United States south Atlantic coastal distribution from southern Virginia to central Florida and throughout the northern Gulf of Mexico, with the exception of a gap occurring in south Florida (Gilbert 1986, Munroe 2002, NCDMF 2005, Smith and Scharf 2010, Craig et al. 2015). They are fast growing, have early maturation, and a moderately short life span (Smith and Scharf 2010).

Southern Flounder support valuable commercial and recreational fisheries throughout its geographic range (Wenner and Archambault 2005, Craig et al. 2015, NCDMF 2016). Southern Flounder represents approximately 20 to 26% of the value of finfish landed overall in North Carolina, making it an exceptionally valuable fishery in the state (2005 to 2016 average of 861.8 MT/yr or 1.9 million lbs/yr) (NCDEQ 2018). Southern Flounder are managed independently by

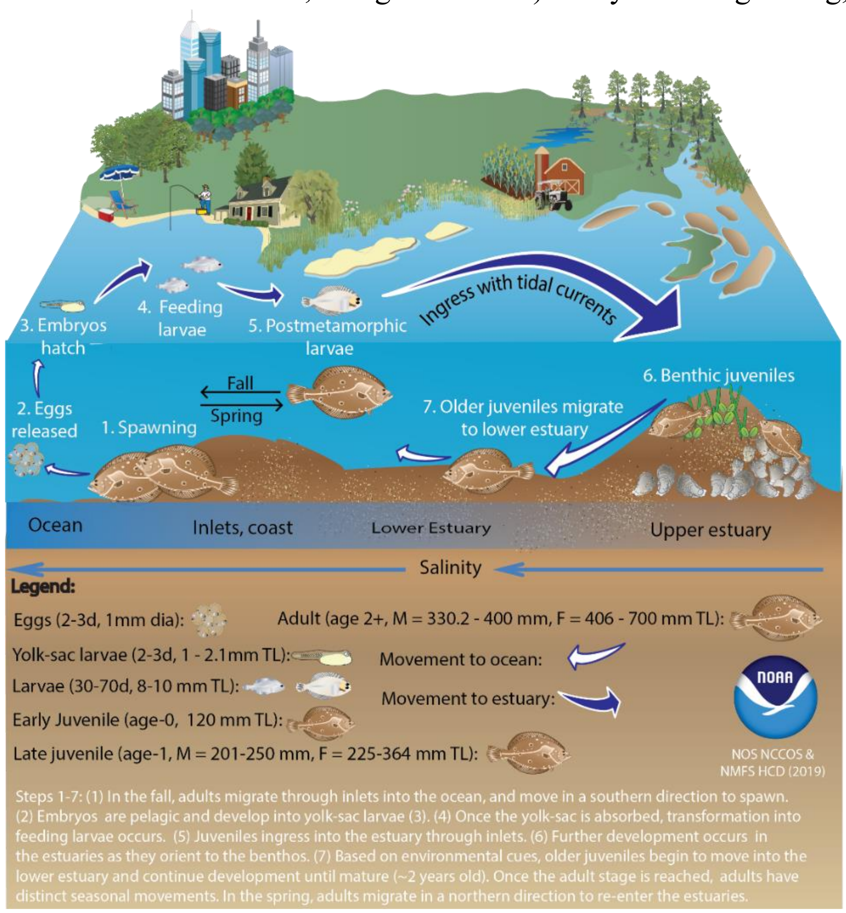


Figure 3.9.1: Life cycle of the Southern Flounder (*Paralichthys lethostigma*).

individual states, and North Carolina is presently the only state in the southeast region with a comprehensive management plan (Craig et al. 2015). The NCDMF reports the sex ratio of Southern Flounder harvested in North Carolina consists of 75% females for age 0 to 2 years old, 97% for individuals 3 to 4 years old, and 100% for fish over 5 years in age (Monaghan and Armstrong 2000). Due to this age ratio, stock assessments have focused on the female portion of the population (Takade-Heumaker and Batsavage 2009). Abundance indices derived from fishery-independent data in North Carolina and South Carolina state waters indicate a generally consistent pattern of coast-wide, multi-decadal decline in recruitment and general abundance of older juveniles and adult Summer Flounder (NCDMF 2013, SCDNR 2014). The selective removal of immature or fast-growing individuals (i.e., recruitment overfishing) is a potential driver of lower long-term yield from the fish stock (Heino 1998, Conover and Munch 2002, Jorgenson et al. 2007, Smith and Scharf 2010). The NCDMF 2005 FMP set forth new harvest restrictions in an attempt to lessen the impact on the stock by reducing fishing mortality rates (Midway 2013).

Genetic data, otolith morphometric data, and tagging data indicate Southern Flounder appear to form a single stock from North Carolina to Florida (Anderson and Karel 2012, Anderson et al. 2012, Midway et al. 2014). It has been reported in literature that failure to match the spatial scale of a fisheries stock assessment to ecologically relevant factors influencing population dynamics may hinder fishery harvest and conservation objectives, particularly with state-by-state management (Fay et al. 2011, Taylor et al. 2011, Ying et al. 2011, Craig et al. 2015). In 2018, NCDMF performed a stock assessment for the state, and importantly, included the entire Southern Flounder south Atlantic stock.

In the latest stock assessment, it was determined the stock remains both overfished and is undergoing overfishing (Lee et al. 2018, NCDMF 2018). Previously, regulatory Amendment 1 to the FMP addressed fisheries issues with the overall stock through size restrictions, gear restrictions, and harvest limits (NCDMF 2013, NCDMF 2015). Observations by Smith and Scharf (2010) indicate commercial estuarine gill-net fishery, mainly operating in low salinity nursery habitats, predominantly harvests individuals 0 to 1 year old (many of which are likely immature), potentially only allowing a small portion of the harvestable stock the opportunity to reproduce. Since 2014, gillnet harvest has decreased in all areas of the state, particularly in the Albemarle Sound as a result of widespread closures to avoid catches of Red Drum and closures due to protected species interactions. In North Carolina, pound net harvest surpassed gillnet harvest from 2014 through 2017 (NCDMF 2018). The state of South Carolina does not allow gillnets or pound nets, and therefore is not a factor in state management of Southern Flounder.

In North Carolina, the seasonal offshore spawning migration (September through November) is when the majority of Southern Flounder are landed in the pound net, gillnet, and gig fisheries. The gig fishery is most extensive in the Core and Bogue Sounds, with some estimates of total catch putting the fishery ahead of the hook and line fishery (Wenner and Archambault 2005). South Carolina also has an extensive gig fishery, but total landings data are unavailable (Wenner and Archambault 2005). For South Carolina recreational fishing of flounders (Summer Flounder, Southern Flounder, and Gulf Flounder), are regulated through creel limits of 15 per person per day, not to exceed 30 per boat per day (rod and reel or gig), and a 355-mm (14-in) minimum TL (SCDNR 2015).

Life History

Southern Flounder are sexually dimorphic (Stokes 1977, Music and Pafford 1984, Wenner et al. 1990), with females reaching the largest sizes (700 mm [27.6 in] TL at 8 years old) and most males rarely achieving sizes > 400 mm (> 15.7 in) TL (4 to 5 years old) (Fisher and Thompson 2004, NCDMF 2005, Taylor et al. 2008). Southern Flounder are batch spawners, potentially releasing several batches in a spawning season (Wenner and Archambault 2005). In a laboratory environment, mature males began following gravid females 3 weeks before spawning (Enge and Mulholland 1985). In the fall as water temperatures drop, adults (females are generally larger and older than males) migrate out through the inlets into the ocean waters to spawn (Shepard 1986, Pattillo et al. 1997, Wenner and Archambault 2005) (Table 3.9.1) (Figure 3.9.2). In general, Southern Flounder spawn in nearshore oceanic waters from November to March in the U.S. South Atlantic (Safrit and Schwartz 1998, NCDMF 2008). Average gonadosomatic index values from North Carolina were highly significant between months, with small values from August through October and much larger values November through January indicating most adults were mature and/or spawning from November to January (Safrit and Schwartz 1998). In South Carolina, peak spawning occurs in the ocean in December, January, and February in waters estimated to be around 20 °C (68 °F) (Figure 3.9.2) (Wenner and Archambault 2005). In North Carolina, Southern Flounder migrate offshore and south during late fall and winter and return to inshore habitats moving during late spring and summer (NCDMF 2008). Although tagging studies suggest that spawning-related offshore migrations of most Southern Flounder are directed south (Monaghan 1992, Craig and Rice 2008), the extent of mixing among stocks in North Carolina and other states is unknown. In North Carolina, the oldest female Southern Flounder collected was 9 years old and the oldest male was 6 years old (Takade-Heumacher and Batsavage 2009). Wenner and Archambault (2005) reported maximum ages for female and male Southern Flounder from South Carolina at ages 7 and 5 years old, respectively. In general, the larger the female the more eggs per batch, more batches per season, and they maintain longer spawning periods (Wenner and Archambault 2005).

Adults spawn offshore along the continental shelf in the winter (Table 3.9.1). Embryos drift in surface currents for 3 to 4 days until hatching. Planktonic larvae drift with ichthyoplankton moving nearshore with surface currents. These individuals then ingress through coastal inlets and undergo metamorphosis, settling in shallow, oligo- and mesohaline (5 to 15 psu, Walsh et al. 1999) estuarine nursery habitats during late winter and early spring (Wenner et al. 1990, Taylor et al. 2008, Lowe et al. 2011, Midway 2013) (Figure 3.9.3, Figure 3.9.4). Juvenile Southern Flounder thrive in shallow estuarine creeks from January to March (Wenner and Archambault 2005). They exhibit rapid growth (0.35 to 1.5 mm/day or 0.01 to 0.06 in/day) during this life stage and in early summer begin movement from shallow nursery habitats to deep waters of the river and sounds in estuary (Figure 3.9.5, Figure 3.9.6) (Fitzhugh et al. 1996, Taylor et al. 2008). Juveniles remain in estuarine habitats for about two years (330-mm or 13-in TL) or until they mature, and then emigrate from estuarine nursery grounds to offshore spawning grounds (Taylor et al. 2008, Monaghan and Armstrong 2000).

Table 3.9.1: Temporal and spatial distribution of various Southern Flounder life stages in North Carolina and South Carolina waters.

Estuary		**Q_1=Winter**			**Q_2=Spring**			**Q_3=Summer**			**Q_4=Fall**		
Inlets/ coasts	**Life Stage**	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Ocean													
Southern Flounder (*Paralichthys lethostigma)*	Spawning Adults[1]												
	Egg[2]												
	Larvae[3]*												
	Juveniles[4]												

[1] Safrit and Schwartz 1998, Wenner and Archambault 2005
[2] Burke et al. 1991, Walsh et al. 1999, Smith and Scharf 2010, SCDNR 2014
[3] Balon 1975, SCDNR 2014
[4] Fitzhugh et al. 1996
*Lavae are pelagic and lasts 30–60 days before metamorphosis occurs and individuals enter estuaries and move towards low salinity head waters to settle (Burke et al. 1991, Walsh et al. 1999, Smith and Scharf 2010, SCDNR 2014). To represent larval presence in both the ocean and estuary during these months, we have colored the corresponding cells gray (estuary) and black (ocean).

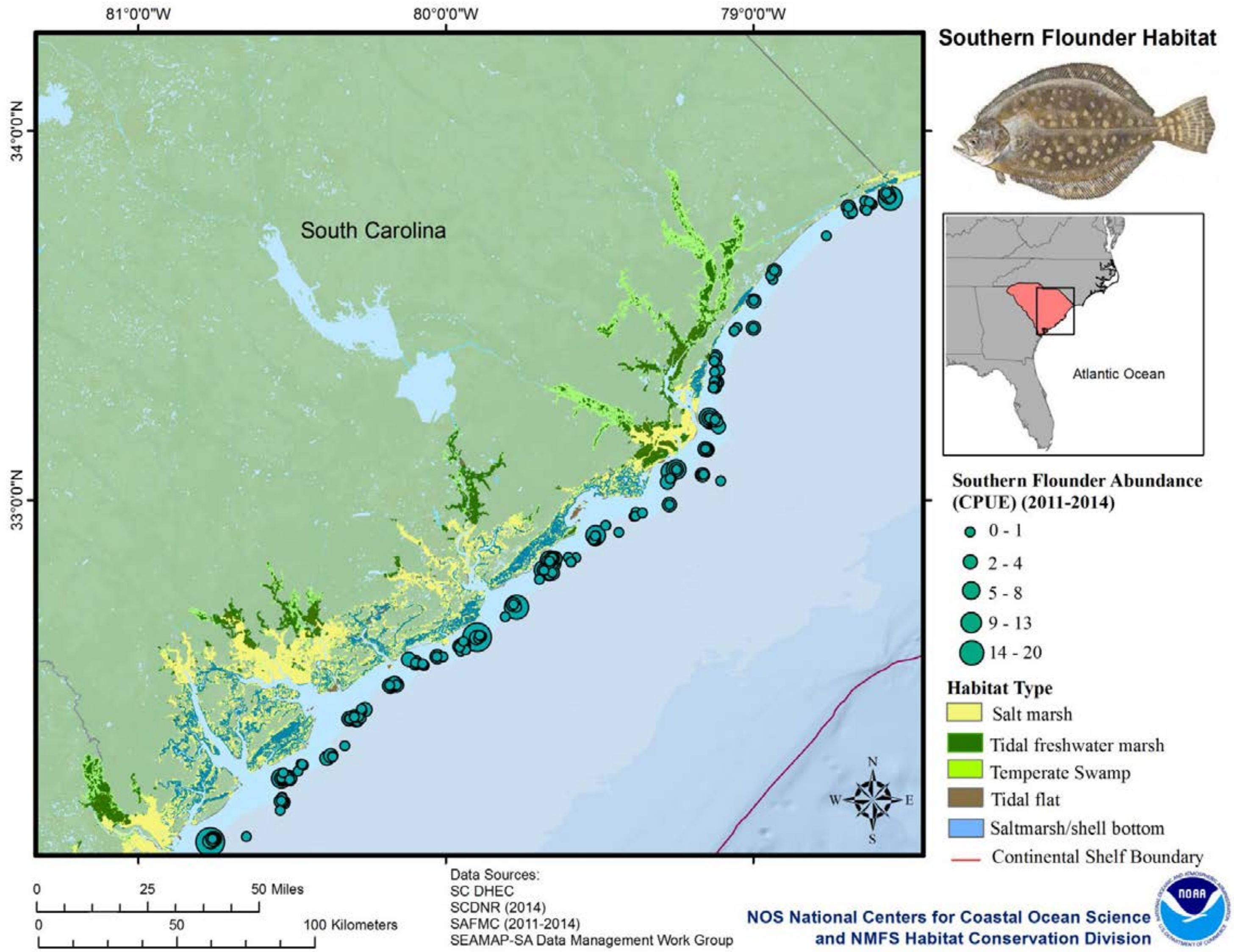


Figure 3.9.2: Distribution of Southern Flounder (2011 – 2014) off South Carolina based on fishery independent survey data from the SEAMAP-SA Data Management Work Group.

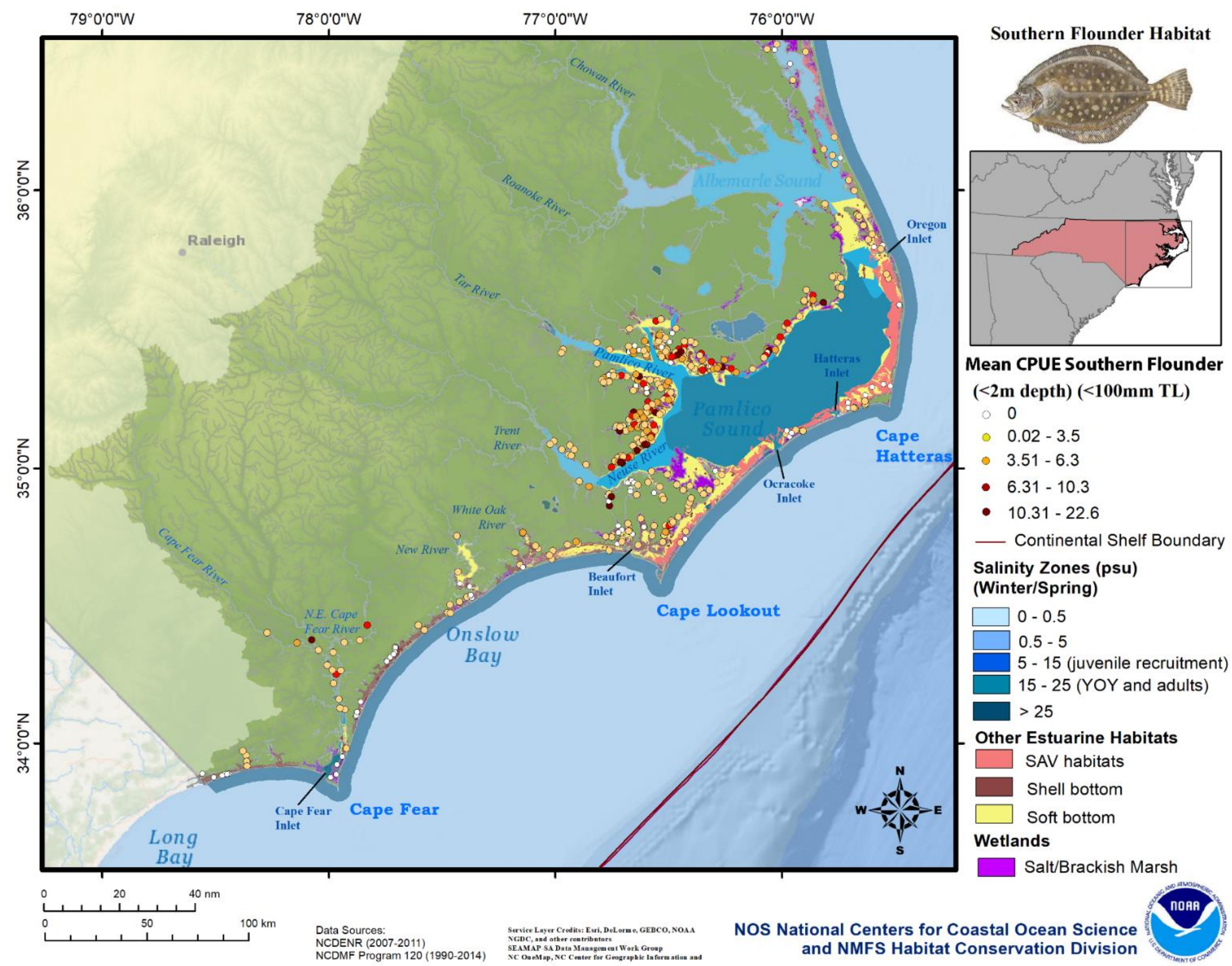


Figure 3.9.3: Fishery independent survey data (NCDMF Program 120) for Southern Flounder less than 100-mm TL in North Carolina from 1990 to 2014. Sampling occurred in May and June of each year and a mean abundance was calculated for each sampling station/year. Various habitats are also depicted indicating where certain life stages will likely be based on preferred habitat type and salinity distribution.

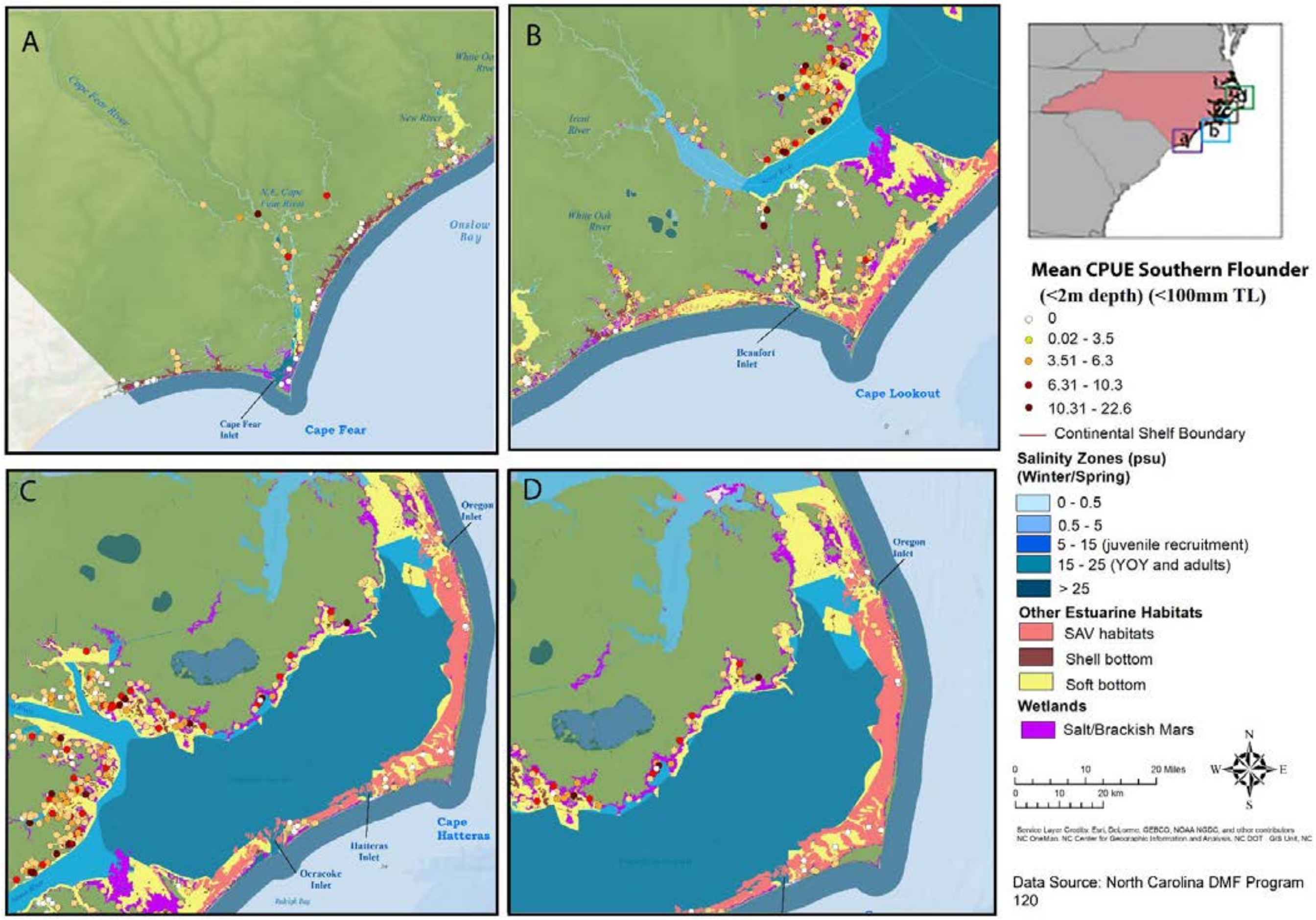


Figure 3.9.4: Fishery independent survey data (NCDMF Program 120) for Southern Flounder less than 100-mm (3.9 in) TL in North Carolina from 1990 to 2014. Sampling occurred in May and June of each year and a mean abundance was calculated for each sampling station/year. Panel A depicts habitats and Program 120 data from Cape Fear River to New River. Panel B is from the White Oak River to the Core Sound area. Panel C shows the Neuse and Pamlico Rivers flowing into the Pamlico Sound. Panel D shows eastern Pamlico Sound, North Carolina.

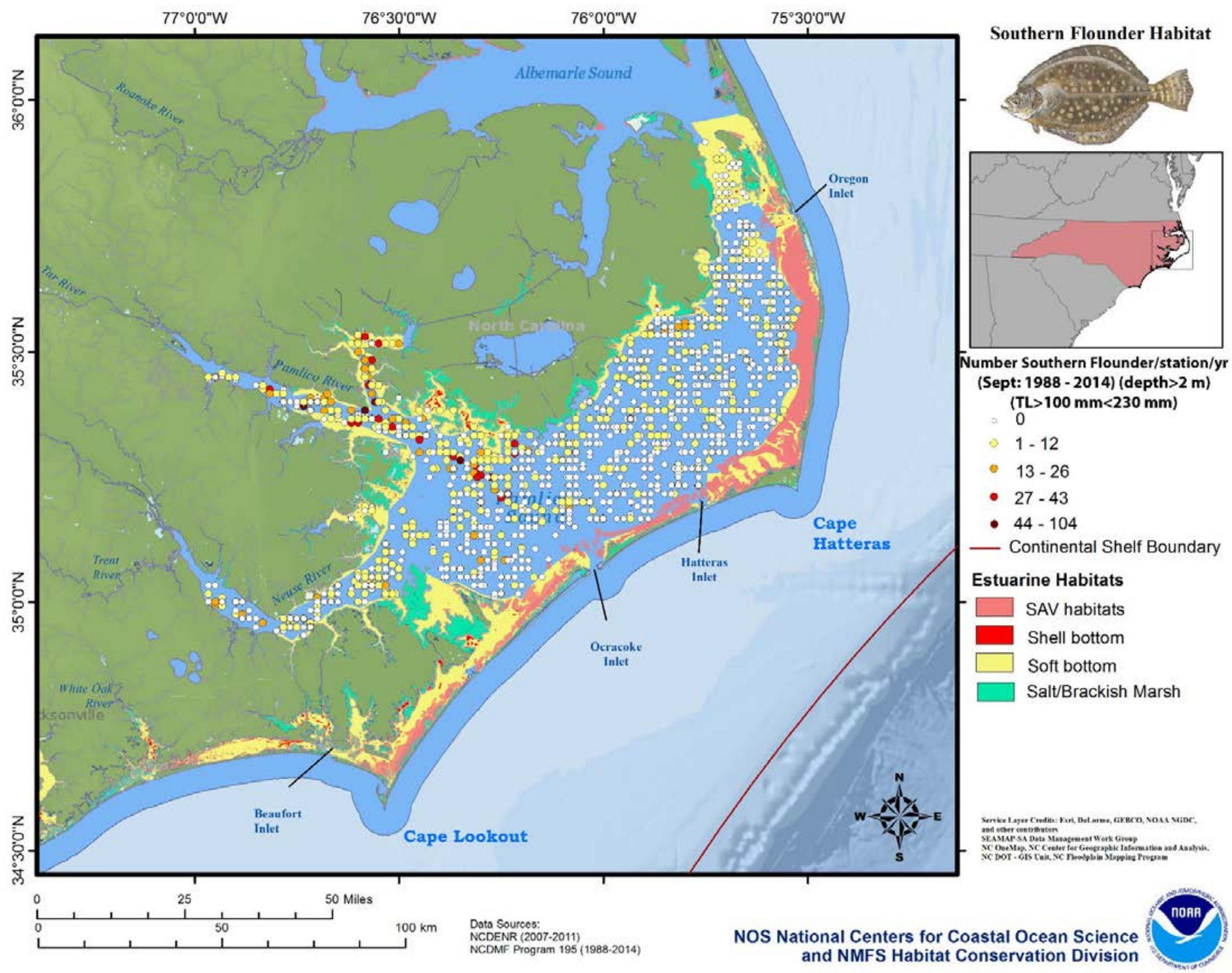


Figure 3.9.5: Fishery independent survey data (NCDMF Program 195) for Southern Flounder < 230 mm (9 in) TL in North Carolina from 1990 to 2014. Sampling occurred in May and June of each year and a mean abundance was calculated for each sampling station/year. Various habitats are also depicted indicating where certain life stages will likely be based on preferred habitat type.

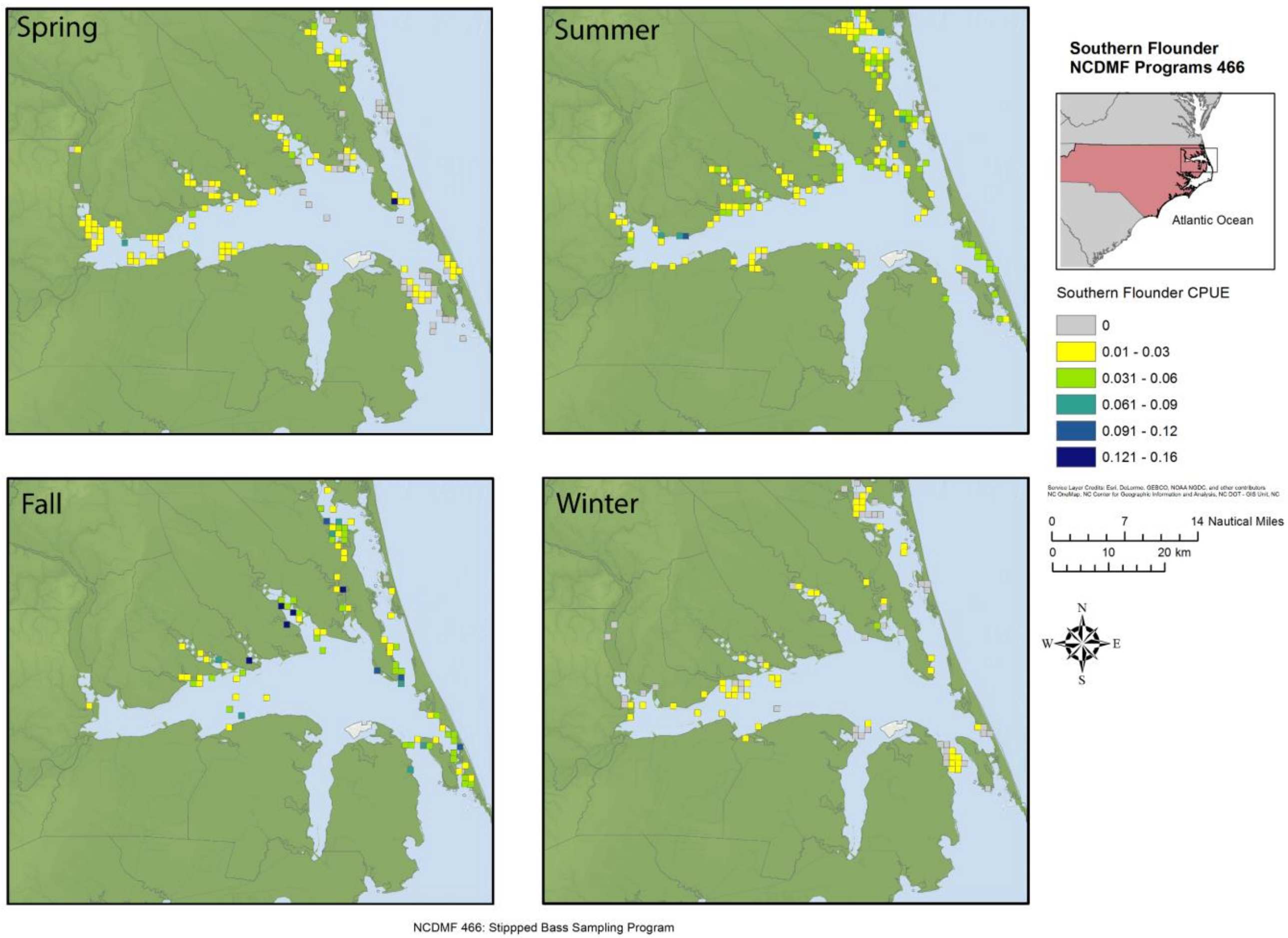


Figure 3.9.6: NCDMF Program 466 (Sea Turtle Bycatch Monitoring) data from 2003-2014 for Southern Flounder shown as catch per unit effort (CPUE). Merged data was for only common date/yr ranges. For the seasons: spring = March, April, May; summer = June, July, August; fall = September, October, November; and winter = December, January, February. Each grid cell is 1 mi². Highest CPUE were observed in the northeastern arms of the Albemarle Sound during the fall season.

Physiology and Habitat

Critical habitats for young Southern Flounder are soft bottom areas, including SAV, in coastal rivers and estuaries (Burke et al. 1991, Spidel 2009). These habitats are essential fish habitat for the Southern Flounder potentially increasing growth, survival, and reproduction. Juvenile Southern Flounder were most abundant in relatively high salinity waters of the eastern and central portions of the Pamlico Sound, all of Croatan Sound, and around inlet areas (Figure 3.9.2, Figure 3.9.6) (Powell and Schwartz 1977). Following metamorphosis, many juvenile flounder settle on tidal flats towards the head of the estuaries and move upstream to lower salinity riverine habitats (Figure 3.9.7a, Figure 3.9.7b, Figure 3.9.8) (Burke et al. 1991, NCDMF 2012). In North Carolina, adult Southern Flounder inhabit estuarine waters during the spring and summer (Figure 3.9.5).

The predominant view posits that after spawning, flounder return to estuarine habitats, but the fraction of fish returning and the extent of coastal ocean habitat use is still under debate (Wenner et al. 1990, Watterson and Alexander 2004, Taylor et al. 2008). After collecting Southern Flounder from offshore and inshore habitats in North Carolina, otolith microstructure and elemental concentrations revealed, many of the fish sampled offshore emigrated from estuarine habitats during the second or third year of life and several did not show signs of returning to estuarine habitats after spawning (Taylor et al. 2008). More recently, Craig et al. (2015) improved our understanding of Southern Flounder estuarine residency and migratory patterns by analyzing conventional tagging data at multiple spatial scales. This study reports restricted movements of flounder within estuarine rivers during summer months, but as fish migrated out of estuarine systems, all recovered tags were found south of the system in which fish were tagged (Craig et al. 2015). This observation suggests spawning occurs off South Carolina and points south in the South Atlantic Bight. Using otolith microchemistry, Spidel (2009) sampled 811 older juvenile and young adult Southern Flounder from the Tar River, Pamlico River, and Pamlico Sound. This study noted individual flounder exhibit habitat and site fidelity once they have completed their larval migration into estuary waters. Using strontium concentrations in otoliths as an indicator of salinity, and therefore habitat use, overtime it was determined that 74% of fish captured in freshwater (i.e., Tar River) were residents until migration offshore (Spidel 2009). This suggests that a relatively small proportion of Southern Flounder utilize North Carolina coastal rivers, but they are nonetheless important, secondary juvenile habitats for Southern Flounder (Spidel 2009). Further, Southern Flounder collected in the study maintained consistent strontium concentrations after the first year of life, indicating movements are localized (Spidel 2009).

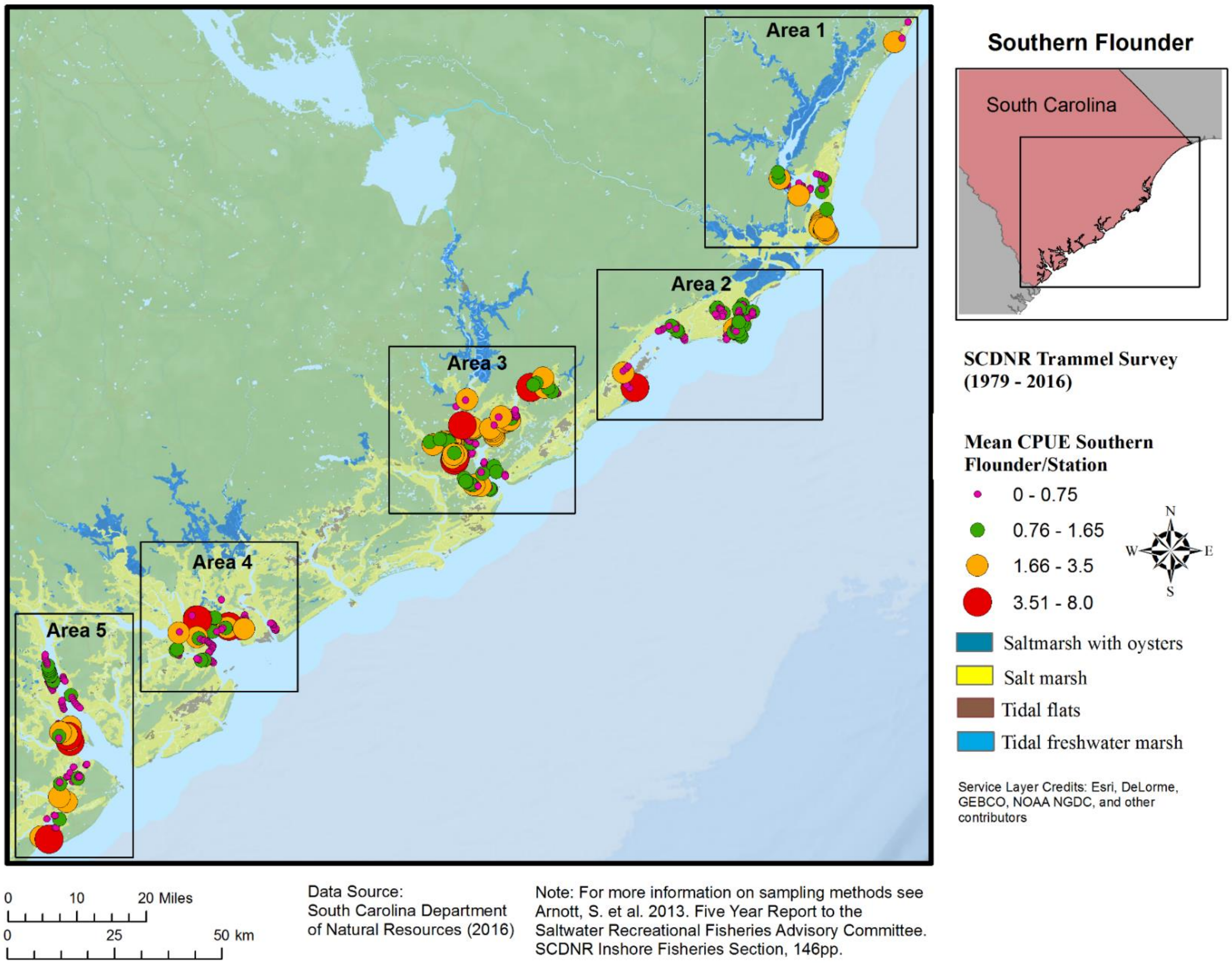
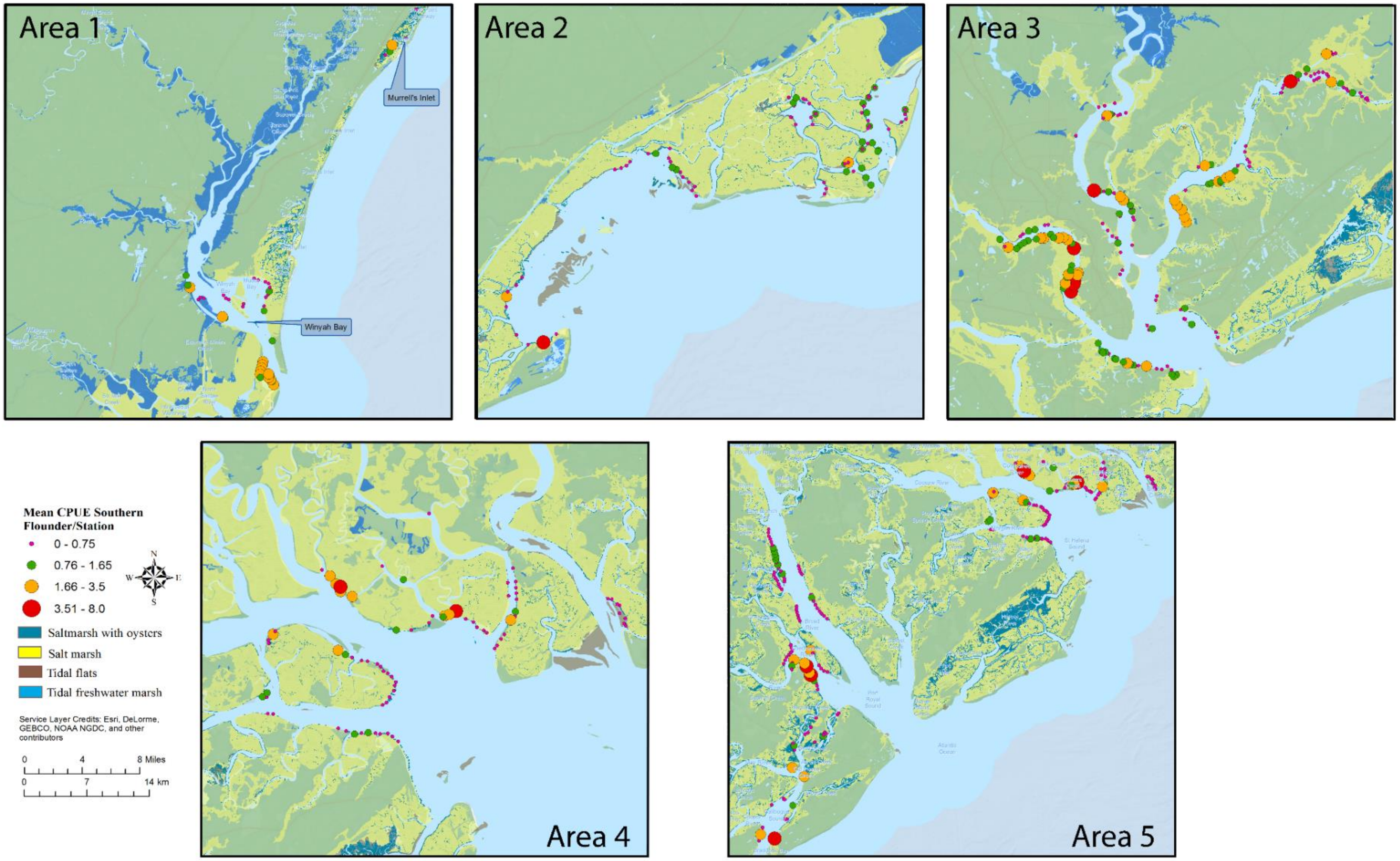


Figure 3.9.7a: Distribution of Southern Flounder (1979 – 2016) in South Carolina waters based on fishery independent survey data from the South Carolina Department of Natural Resources, Saltwater Recreational Fisheries Advisory Committee trammel net survey.



Note: For more information on sampling methods see Arnott, S. et al. 2013. Five Year Report to the Saltwater Recreational Fisheries Advisory Committee. SCDNR Inshore Fisheries Section, 146pp.

Data Source: South Carolina Department of Natural Resources (2016)

Figure 3.9.7b: Distribution of Southern Flounder (1979 – 2016) in South Carolina waters based on fishery independent survey data from the South Carolina Department of Natural Resources, Saltwater Recreational Fisheries Advisory Committee trammel net survey.

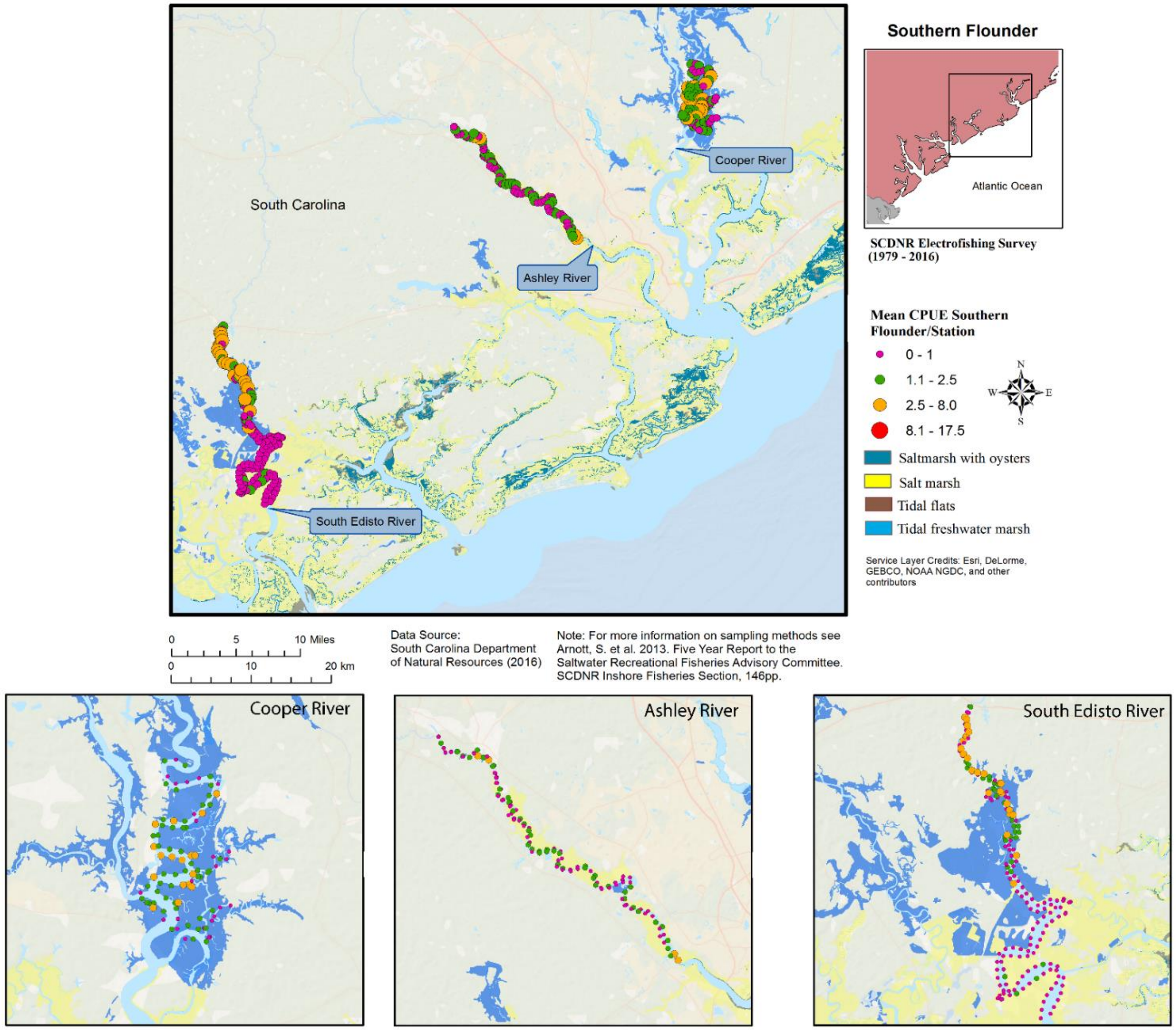


Figure 3.9.8: Distribution of Southern Flounder (1979 – 2016) in South Carolina waters based on fishery independent survey data from the South Carolina Department of Natural Resources, Saltwater Recreational Fisheries Advisory Committee.

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3.10 Red Drum

(*Sciaenops ocellatus*, Linnaeus, 1766)

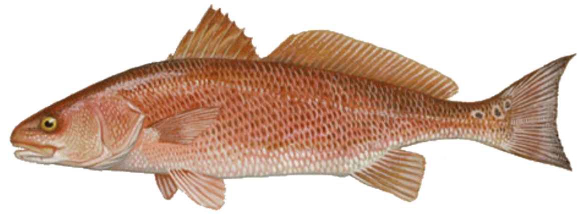

Photo credit: USFWS

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[3]NOAA Fisheries, Southeast Fisheries Science Center, Beaufort, NC

General Information

Red Drum (*Sciaenops ocellatus*) (i.e., spot-tail bass, redfish, channel bass) is an estuarine-dependent (Figure 3.10.1) euryhaline species historically ranging from Massachusetts to Key West, Florida along the Atlantic coast of the United States, with few fish reported north of the Chesapeake (Lux and Mahoney 1969, Fischer 1978, Yokel 1980, Mercer 1984, NCDENR 1992, GDNR 2012, ASMFC 2015). Red Drum also are distributed across the Gulf of Mexico, but are not the target stock or population for this review. Red Drum are managed by the ASMFC Interstate FMP initially established in 1984 and revised in 1988 to recommend management measures to all states from Maine to Florida (ASMFC 2015). The primary goal of the initial management plan was to aid states in reducing overfishing in estuaries, preventing recruitment overfishing, and promoting coordinated interstate research and monitoring to effectively manage Red Drum fisheries (ASMFC 1984). Early assessments of the stock indicated fishing mortality was high for juvenile fish (Vaughan and Helser 1990, Vaughan 1992, 1993). An initial Red Drum FMP was passed in 1990 and harvest of Red Drum was prohibited in the EEZ, a moratorium that remains in effect today. In 1991, Amendment 1 to the ASMFC FMP was enacted after the stock assessment indicated poor stock condition due to high juvenile mortality leading

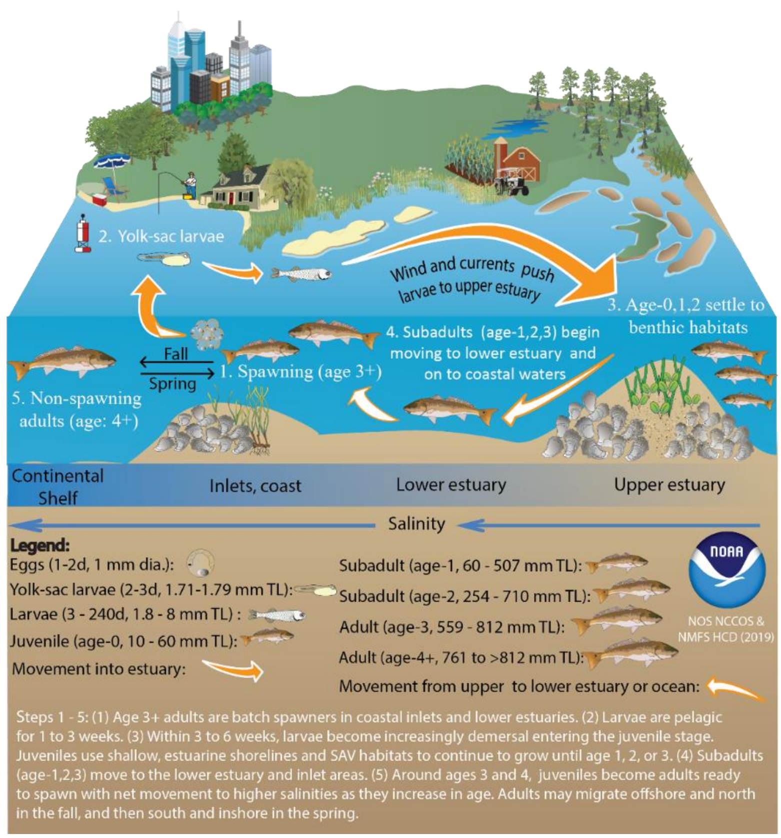

Figure 3.10.1: Life cycle of Red Drum (*Sciaenops ocellatus*).

to significant decreases in the spawning stock (Murphy and Taylor 1990, ASMFC 1991, ASMFC 2015). Management measures ensued targeting growth and recruitment overfishing. The 2000 stock assessment indicated conditions had improved, but there were still not enough juveniles surviving to produce eggs to sustain the stock (Vaughan and Carmichael 2000). Individual states set unique management measures for protection of Red Drum within the three-mile state territorial boundary. North Carolina maintained more stringent regulations that had been implemented a few years prior through the implementation of the North Carolina Red Drum FMP. These restrictions satisfied the compliance requirements of the ASMFC plan and included: a reduction in the recreational bag limit from five fish per day to one fish per day; a recreational and commercial size limit of 457.2 to 685.8 mm (18 to 27 in) total length (TL); a seasonal gillnet attendance requirement; an annual commercial cap of 113.4 MT (250,000 lbs) (representing maximum historical commercial Red Drum landings); a sliding trip limit that can be increased or decreased at the discretion of the NCDMF director; and a shift in the fishing year to run September 1 to August 31 (NCDMF 2008). South Carolina also implemented harvest and size limit changes to comply with the ASMFC plan. In South Carolina state waters, Red Drum can only be harvested by rod and reel and gigging (slot size: 381 to 584.2 mm [5 to 23 in] TL) and cannot be harvested by gig from December through February (SCDNR 2015). Management measures at the state and federal levels have been successful, as the stock assessment now lists Red Drum as recovering.

The Atlantic commercial Red Drum fishery was prevalent in the 1980's, but has declined with an average annual landing of 81.6 MT (180,000 lbs) since 1990 (ASMFC 2015). In 2013, coast-wide commercial landings were at the highest level since 1984, with 182.3 MT (402,000 lbs) landed – 92% of which were landed in North Carolina waters (ASMFC 2015). In North Carolina, commercially harvested Red Drum are bycatch from other fisheries and not its own commercial fishery. In South Carolina, Red Drum are listed as gamefish with the last reported Red Drum commercial harvest in 1989 (Ross and Stevens 1992, NMFS 2013).

Red Drum is one of the most recreationally sought after fish throughout the South Atlantic Fishery (ASMFC 2015). It is a nearshore fishery that targets smaller drum in shallow estuarine waters and large trophy fish along the Mid-Atlantic and South Atlantic barrier islands. Recreational harvest peaked in 1984 at 1,179.3 MT (2.6 million lbs), with harvests fluctuating between 362.9 to 952.5 MT (800,000 to 2.1 million lbs) with no particular trend since 1988 (ASMFC 2015). The 2013 recreational landings of 1,224.7 MT (2.7 million lbs) in the South Atlantic fishery represent a 58% increase from the previous 11-year average (2003-2013), and a new high for the time series (ASMFC 2015). Red Drum landings typically peak in the fall, but are harvested commercially and recreationally on a year-round basis throughout North Carolina estuarine and nearshore coastal waters (NCDMF 2008). The all-tackle International Game Fish Association world record Red Drum was captured at Avon, North Carolina in 1984 and weighed 41.8 kg (94 lbs, 2 oz) (Wenner 1992).

Life History

Red Drum are considered group synchronous, batch spawners with a spawning periodicity for adult females of every two to four days (Wallace and Selman 1981, Wilson and Nieland 1994). Diel broadcast spawning is an advantageous strategy for batch spawners like Red Drum, as it ensures large numbers will be in spawning condition at the same time in future generations (Holt et al. 1985). Red Drum spawn exclusively in the evening (Holt et al. 1985) and peak spawning coincides with new and full moons (Peters and McMichael 1987, Comyns et al. 1995, Lyczkowski-Shultz et al. 1998). Mean batch fecundity for Red Drum is 1.7 million eggs (Fitzhugh et al. 1988, Barrios 2004). Throughout the Red Drum range, spawning season and habitat show considerable variation (Figure 3.10.1) (Barrios 2004). Based on the examination of gonadosomatic indices and maturity stages, Ross et al. (1995) determined peak spawning occurred in August and September in North Carolina (Table 3.10.1). Spawning activity has also been documented through use of passive acoustic monitoring technology. Male scianeids produce sounds during spawning (Fish and Mowbray 1970, Guest 1978, Saucier and Baltz 1992, Connaughton and Taylor 1995, 1996, Luczkovich et al. 1999, Sprague et al. 2000). Barrios (2004) used passive acoustic monitoring to determine spatial and temporal patterns of Red Drum spawning in the Neuse River, North Carolina. Using the acoustic measurements taken by sonobuoys, Barrios (2004) found that 85% of vocalizations were at water depths below 5 m (16.4 ft) and 97% occurred in August and September when spawning occurs in North Carolina. Red drum exhibit a similar spawning season (August to September) in South Carolina (Table 3.10.1) (Wenner et al. 1990). As coastal waters cool in mid to late August, adult Red Drum move to spawning grounds to initiate reproductive activity in South Carolina estuaries (Wenner et al. 1990). One-month old Red Drum are abundant in estuarine nursery areas during October confirming peak spawning in South Carolina occurs in September (Wenner 1992).

Fertilization occurs when females release ripe eggs (i.e., mature eggs) and males release sperm into the water (Figure 3.10.1) (Wenner 1992). At a temperature of 22.2 °C (72 °F) and salinities of > 25 psu, eggs (~ 1 mm or 0.04 in diameter) remain in the water column for 28 to 29 hours before hatching. Embyo development and time to hatch is dependent upon water temperature, but is usually complete within 2 days (Wenner 1992). At hatching, small larvae (~1.8 mm or 0.07 in TL) have no mouth and rely upon the yolk-sac as their initial food source for 2 to 3 days (Holt et al. 1981, Wenner 1992). Thereafter, larvae have formed critical organs and begin actively feeding on small planktonic organisms (Holt et al. 1981). Following a brief pelagic state at 6 to 8 mm (0.24 to 0.31 in) TL (Rooker et al. 1997), larvae become increasingly demersal and reach the juvenile stage in three to six weeks depending on temperature (Davis 1990). During this time – a particularly critical point in the Red Drum life cycle – movement occurs passively with currents and tidal exchange in estuaries and the coastal ocean (Mansueti 1960, Holt et al. 1989, Arnold 1991). Juveniles utilize shallow, estuarine shorelines, oyster reefs, and SAV habitat as nursery grounds as they continue to grow (Figure 3.10.2, Figure 3.10.3, 3.10.4, Figure 3.10.5, Figure 3.10.6) (Davis 1990, Rooker et al. 1998). Around 3 years old and by 4 years of age, individuals will leave nursery grounds (Ross and Stevens 1992, Adams and

Tremain 2000) and migrate to offshore waters joining the adult stock (Figure 3.10.7) (Pearson 1929, Overstreet 1983, Matlock 1987, Arnold 1991, Bacheler et al. 2009a).

Table 3.10.1: Temporal and spatial distribution of various Red Drum life stages in North Carolina and South Carolina waters. Split colors for a month indicates individual life stages are present in two habitats at once.

Estuary		**Q_1= Winter**			**Q_2=Spring**			**Q_3=Summer**			**Q_4=Fall**		
Inlets/ coasts **Ocean**	**Life Stage**	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Red Drum (*Sciaenops ocellatus*)	Spawning Adults												
	Egg												
	Larvae												
	Juveniles												
	Adults												

Growth of Red Drum, as a function of length, is rapid in the first 5 years of life, and then slows throughout the remainder of life (Ross et al. 1995). In North Carolina, over 50% of Red Drum mature by 2 (males) and 3 (females) years old and all become mature within the next year (Ross et al. 1995). Lanier and Scharf (2007) studied spatial and temporal variation in growth of Red Drum in North Carolina estuaries. Substantial variability in growth was reported implying the timing of estuarine arrival and settlement can potentially have a strong influence on size at age patterns of first year Red Drum and may impact early juvenile survival and eventual year-class success (Figure 3.10.2). Consistent spatial variation was noted in Lanier and Scharf (2007), with fast growing Red Drum in areas with consistent, moderate salinities (15 to 25 psu), perhaps due to osmoregulatory efficiency, allowing for a greater scope of growth (Figure 3.10.5, Figure 3.10.6, Figure 3.10.8). Bacheler et al. (2012) found density-dependent effects have potential negative feedbacks on juvenile Red Drum population growth in North Carolina estuaries (i.e., larger year-classes tend to exhibit slower individual growth). Maximum observed age and size of Red Drum reported by Ross et al. (1995) was 56 years and 1,250 mm (49.2 in) fork length (FL) for males, and 52 years and 1,346 mm (53 in) FL for females.

Physiology and Habitat

Red Drum spawn in a range of habitats including estuaries, inlets, passes, and bay mouths (Pearson 1929, Miles 1950, Yokel 1966, Jannke 1971, Setzler 1977, Music and Pafford 1984, Holt et al. 1985, Peters and McMichael 1987). More recent literature illustrates in addition to nearshore habitats, Red Drum also spawn in high-salinity estuarine areas along the coast (Murphy and Taylor 1990, Johnson and Funicelli 1991, Nicholson and Jordon 1994, Woodward 1994, Luczkovich et al. 1999, Beckwith et al. 2006), and far upstream from inlets near the mouth of bays, rivers, and lagoons in some areas (Johnson and Funicelli 1991, Ross et al. 1995, Luczkovich et al. 1999, Barrios 2004, Bacheler et al. 2008). Predictable changes in environmental conditions (*e.g.,* water temperature, photoperiod) trigger spawning for Red Drum (Wenner 1992). Ross and Stevens (1992) noted coastal areas with high salinity provide ideal conditions for egg and larvae development and circulation patterns conducive to transporting larvae to suitable nursery grounds. Optimal spawning temperature ranges from 25 to 30 °C (77 to 86 °F) (Renkas 2010). Renkas (2010) verified this through mariculture in Charleston Harbor, South Carolina, showing egg release occurred in August as water temperature dropped from 30 ºC, continued through 25 ºC (86 °F), and stopped at lower temperatures. Luczkovich et al. (1999) also noted spawning production at 25 to 30 °C (77 to 86 °F) in Pamlico Sound.

Salinities of 20 to 25 psu may suffice for Red Drum egg development in Pamlico Sound, North Carolina and are consistent with typical spawning areas (Barrios 2004). Lower salinities may cause eggs to sink possibly leading to viability issues (Holt et al. 1981). In laboratory experiments, optimal temperature for Red Drum embyo and larval development was 25 °C (77 °F) and salinity was 30 psu (Neill 1987, Holt et al. 1981). As with spawning adults, eggs and early larvae are found in high salinity waters of inlets, passes, and estuaries (ASMFC 2013). Upon hatching, Red Drum larvae are pelagic (Johnson 1978) and development is temperature-dependent (Holt et al. 1981). At metamorphosis, Red Drum settle to demersal habitats in nursery areas (Pearson 1929, Peters and McMichael 1987, Comyns et al. 1991, Rooker and Holt 1997). Tidal currents (Setzler 1977, Holt et al. 1989) or density-driven currents (Mansueti 1960) may drive juvenile YOY to a lower salinity (i.e., 10 to 20 psu) nursery in upper areas of estuaries (Mansueti 1960, Bass and Avault 1975, Setzler 1977, Weinstein 1979, Holt et al. 1983, Holt et al. 1989, Peters and McMichael 1987, McGovern 1986, Daniel 1988). Ross and Stevens (1992) documented YOY Red Drum in a wide range of salinities from 0 to 33 psu.

Juvenile Red Drum may use a variety of inshore habitats within estuaries, including SAV, tidal freshwater estuaries, low-salinity reaches of estuaries, estuarine emergent wetlands, estuarine scrub/shrub, oyster reefs, shell banks, and unconsolidated bottom (Figure 3.10.6) (SAFMC 1998, ASMFC 2002, ASMFC 2013). In the winter, juveniles seeking more thermally stable environments, may transition to deeper portions of bays and river channels in depths ranging from 3 to 15 m (10 to 50 ft) (Pearson 1929, ASMFC 2013). Juveniles move in August to mid-October into shallow creeks and shorelines that cut into emergent marsh systems (ASMFC 2013). The following spring, juveniles become more common in the shallow water habitats (Figure 3.10.9) (ASMFC 2013). At the mouth of the Neuse River and in smaller bays and rivers between Pamilico Sound and the Neuse River, NCDMF surveys indicate juvenile Red Drum were consistently abundant in shallow waters (i.e.,< 1.5 m (5.0 ft) in depth) (ASMFC 2013). In general, Red Drum juvenile habitats in North Carolina are characterized as detritus-laden or mud-bottom tidal creeks (i.e., Pamlico Sound) and mud or sand bottom habitat in other areas

(Ross and Stevens 1992). In South Carolina waters, small Red Drum occupy tidal creeks with mud/shell hash and live oyster as common substrates given the absence of SAV is South Carolina estuaries (Figure 3.10.4, Figure 3.10.5, Figure 3.10.6) (Wenner 1992).

The subadult phase for Red Drum begins when late-stage juveniles begin leaving shallow nursery habitats at approximately 10 months old (200 mm [7.9 in] TL) and ends with the maturation of gonads (ASMFC 2013). Subadults are most vulnerable to exploitation within the fishery as they fall within the slot size, and use a variety of habitats within estuaries, including tidal creeks, rivers, inlets, and waters around barrier islands, jetties, and sandbars (Pafford et al. 1990, Wenner 1992). While subadults are found in habitats similar to that of smaller juvenile Red Drum, they are also found in large aggregations on SAV beds, oyster bars, mud flats, and sand bottoms (Figure 3.10. 2, Figure 3.10.5) (FWCC 2008). In a study conducted by Bacheler et al. (2009a), Red Drum subadults (0 to 3 years) were commonly found in upper estuarine environments (Figure 3.10.6). The study noted that each fall a portion of 1 and 2 year old cohorts move to high-salinity coastal waters as temperature and feeding activity decreases (Figure 3.10.9). While some Red Drum remain in upper estuarine habitat until 3 years of age, net movement is to higher salinities with increasing age (ASMFC 2013). Once mature, adult Red Drum typically travel inshore and offshore as opposed to north and south directions (along shore) (ASMFC 2013). Bacheler et al. (2009b) concluded Red Drum 4 years or older generally moved furthest north and south, but traveled distances shorter than other life stages when moving east or west, from coastal waters to inshore waters (Figure 3.10.8). The exception are Red Drum with seasonal migrations from overwintering grounds in North Carolina northward to Virgina in the spring and the subsequent return (from Virgina to North Carolina) in the fall (Bacheler et al. 2009b). Seasonal migrations onshore occur in the spring and offshore in the fall (Figure 3.10.1) (ASMFC 2013). Typical substrates include hard/live bottom, high salinity surf zones, and artificial reefs (ASMFC 2013).

Coastal spawning habitat can be compromised by the effects of industrial, residential, and recreational coastal development (Vernberg et al. 1999). Between 1986 and 1997, estuarine and marine wetlands nationwide experienced an approximate net loss of 10,400 acres predominantly due to urban and rural activities and conversion of wetlands areas (Dahl 2000, ASMFC 2013). Navigation and boating access development and maintenance activities, such as dredging, are a threat to Red Drum spawning habitats. According to the SAFMC (1998) and ASMFC (2002), "navigation related activities can result in removal or burial of organisms from dredging or disposal of dredged material, effects due to turbidity and siltation, release of contaminants and uptake in nutrients, metals and organics, release of oxygen-consuming substances, noise disturbance, and alteration of hydrodynamic regime and habitat characteristics." Beach nourishment projects and development of wind and tidal energy can also alter spawning dynamics. Beach nourishment can remove offshore sediments resulting in depressions, altering sediment characteristics along the shoreline (Wanless 2009). Sediments eroded from beaches after nourishment projects can also be transported offshore and bury hard bottoms, which can diminish spawning aggregation habitat, alter forage species abundance, and change distribution and species composition in the high-energy surf zone; this varies based on timing of nourishment activities (Irlandi and Arnold 2008). Wind and tidal energy projects can create artificial structure in migration corridors and submarine cables produce electrical fields that can affect movement patterns and habitat use (DONG 2006, OEER 2008, ASMFC-Habitat Committee 2012).

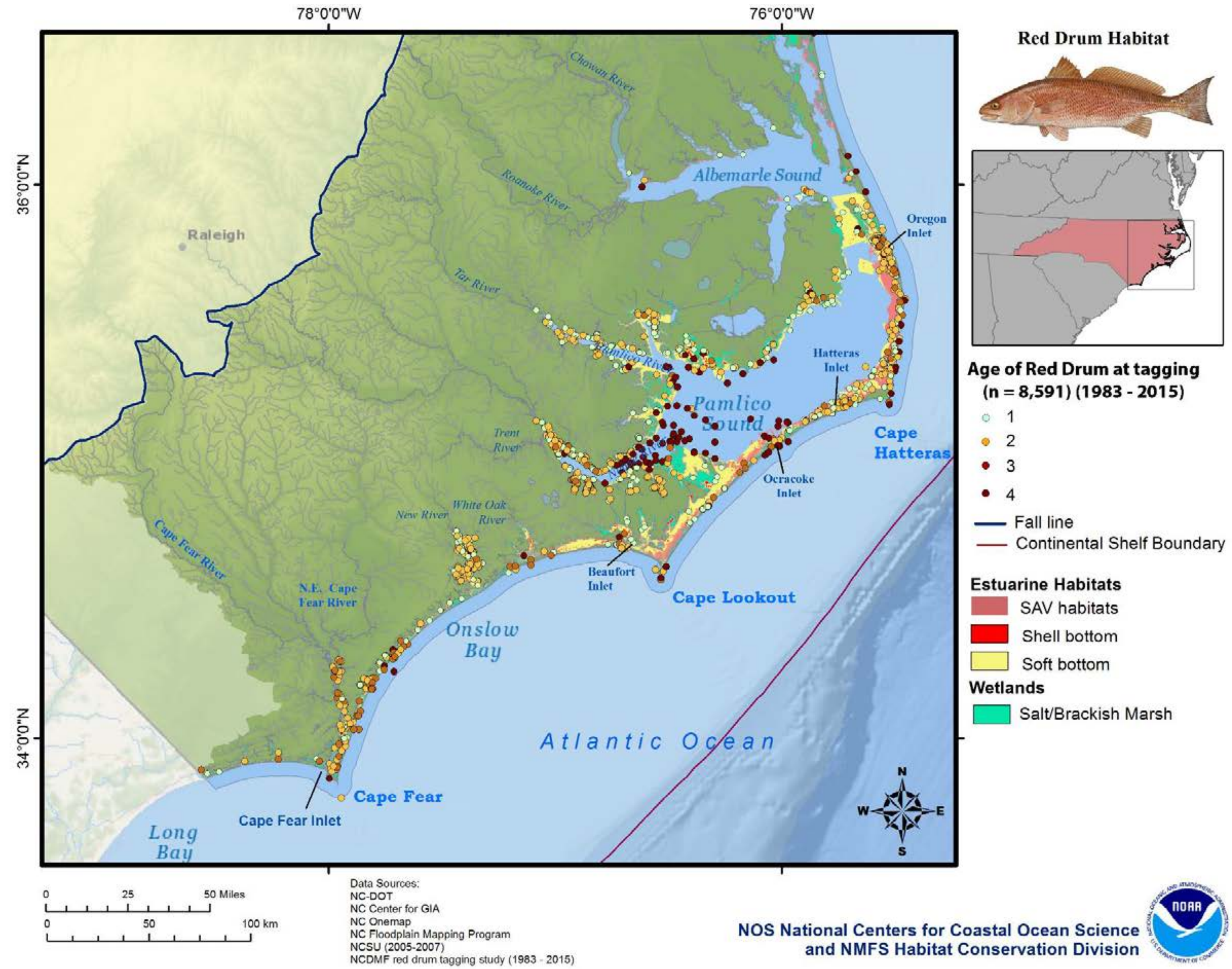

Figure 3.10.2: Locations and age of tagged individuals in the Red Drum tag and recapture study from 1983-2015.

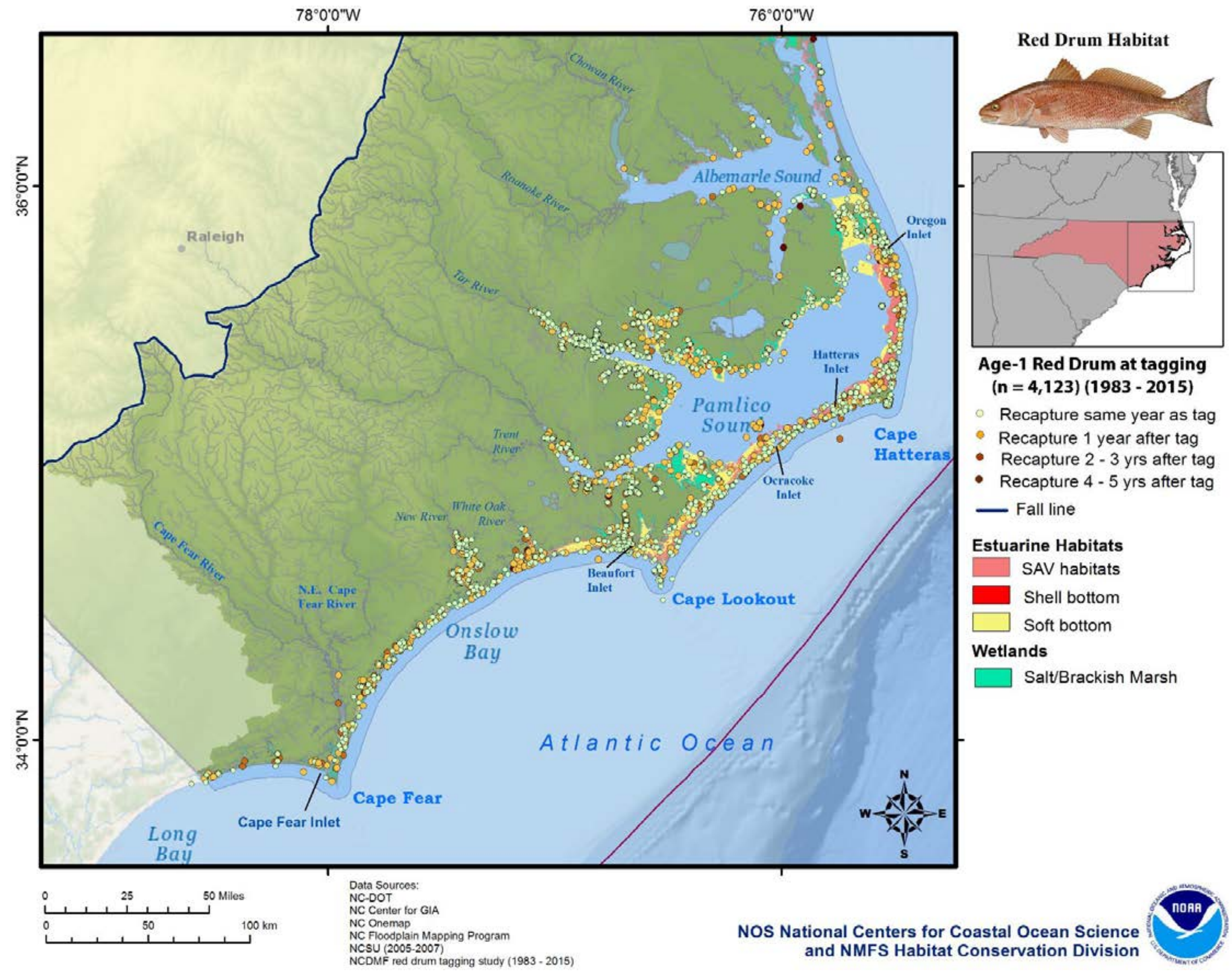

Figure 3.10.3: Locations of recaptured individuals tagged at age-1 in the Red Drum tag and recapture study from 1983-2015. 48% of the initial tagged individuals were age-1, and had high rates of recapture the same year as tagging occurred (green dots).

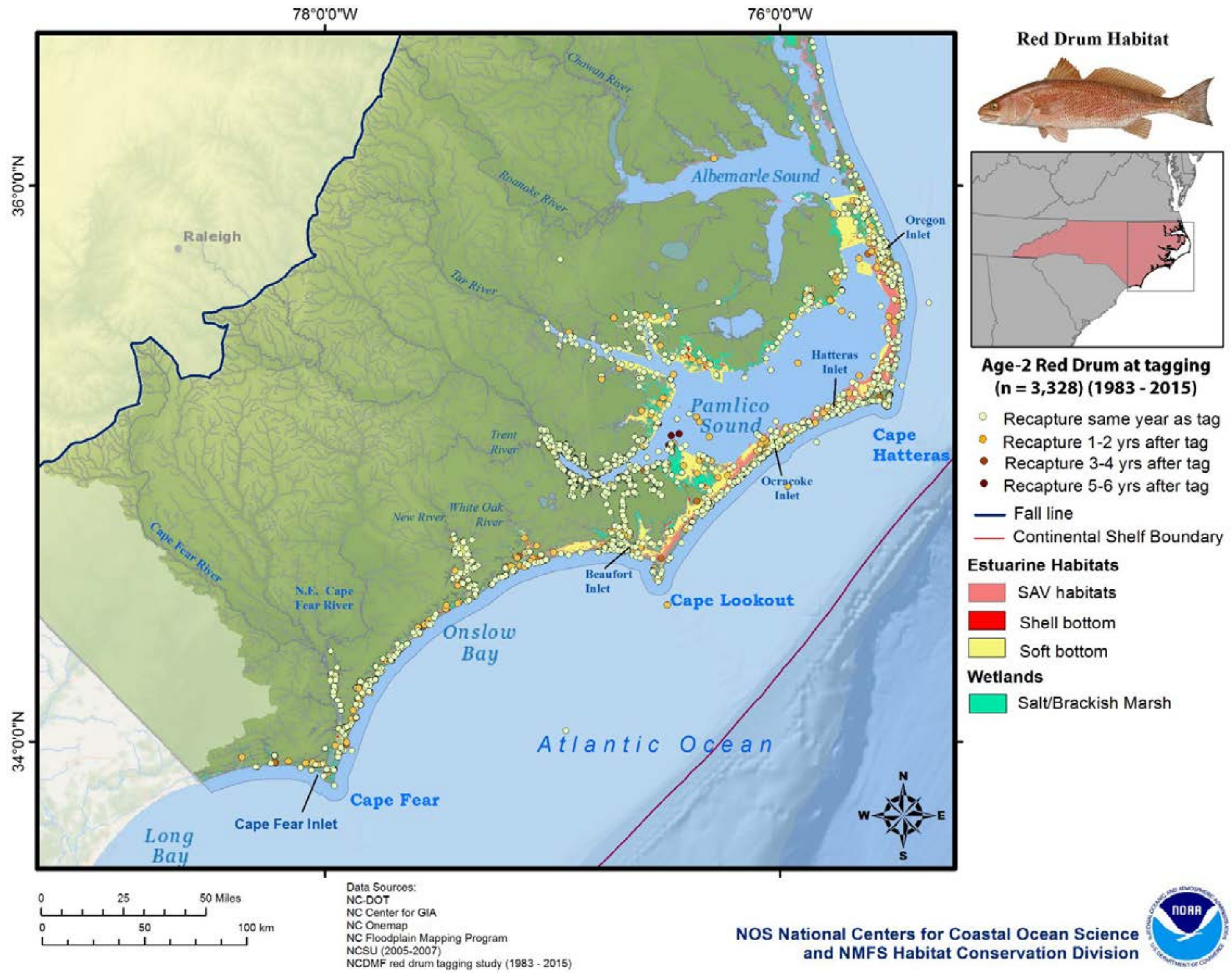

Figure 3.10.4: Locations of recaptured individuals tagged at age-2 in the Red Drum tag and recapture study from 1983-2015. 39% of individuals were age-2 at tagging, with many recaptured during the same year as tagging. These juveniles and subadults use the estuary and inlet areas as thermal refuges, foraging grounds, corridors, with lower predation pressure relative to oceanic areas.

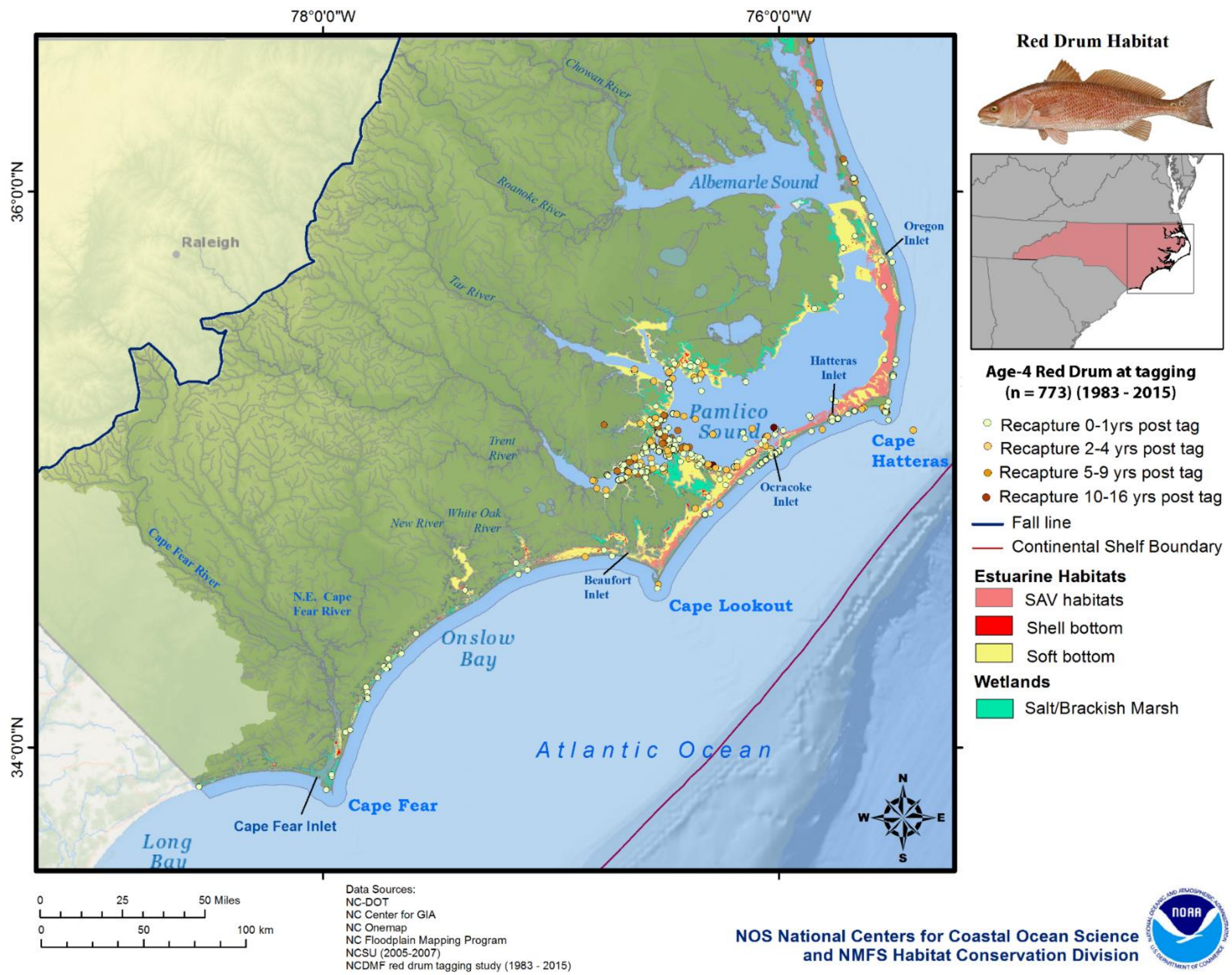

Figure 3.10.5: Locations of recaptured individuals tagged at age-4 in the Red Drum tag and recapture study from 1983-2015. These were the oldest individuals at tagging and all adults. The data indicate clear aggregation around the mouth of the Nuese River, highlighting the importance this area and habitat to the species.

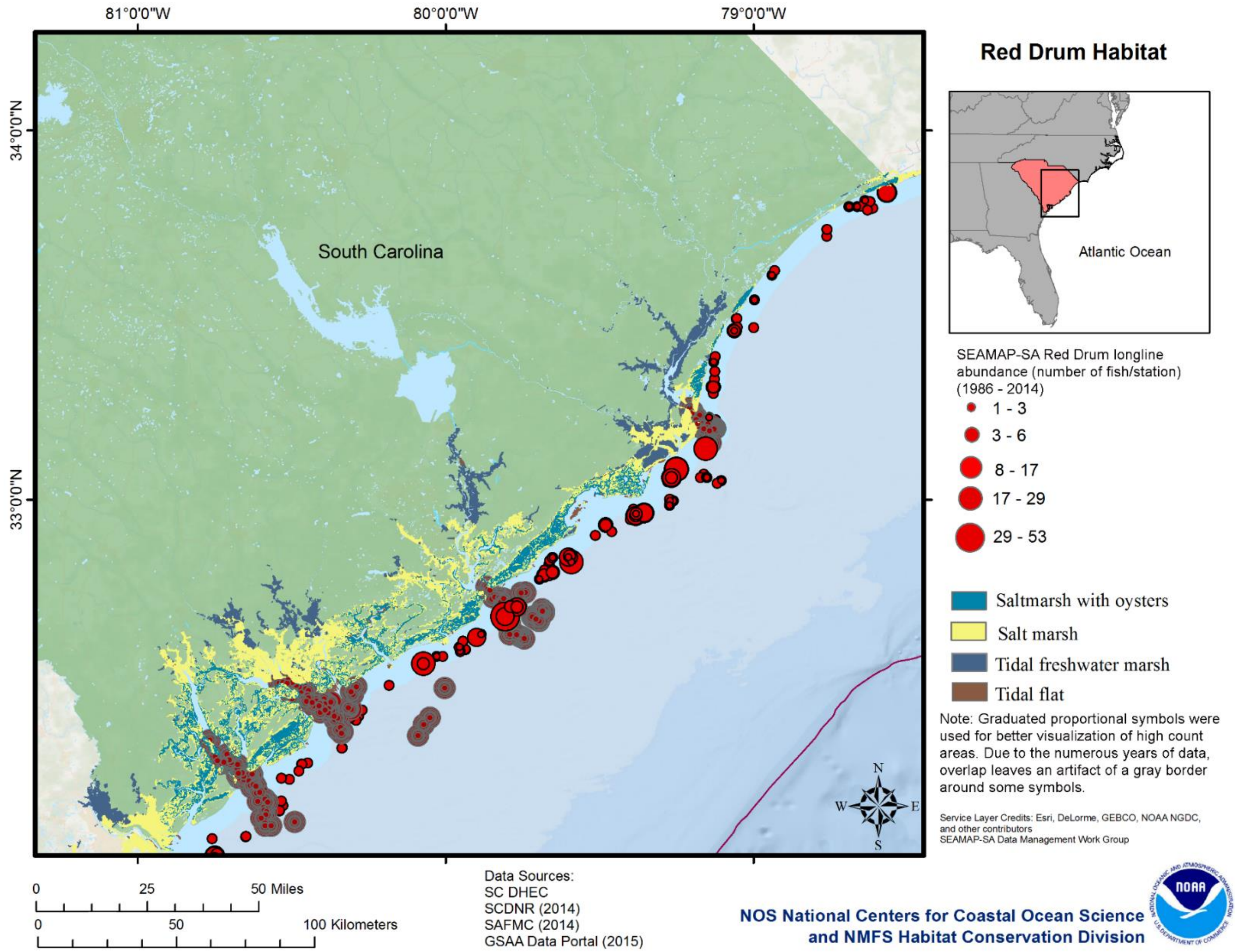

Figure 3.10.6: Abundance of Red Drum from longline fishing from 1986-2014 off the coast of South Carolina. The data present a long-term climatology; however, because of the multi-year data, a gray outer ring is present around some of the graduated proportional symbols rather than black. This is a mapping artifact.

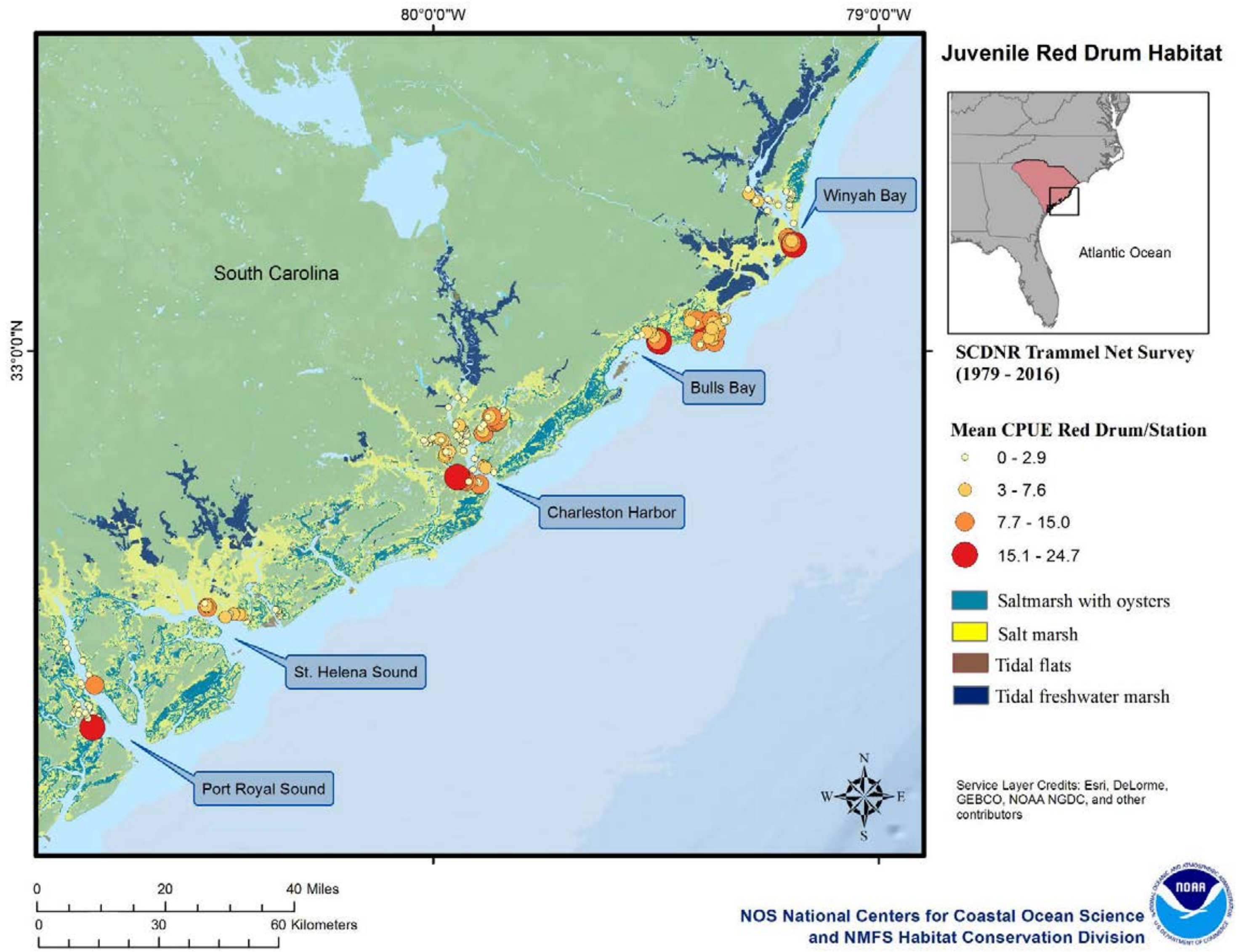

Figure 3.10.7: Abundance of juvenile Red Drum from longline fishing from 1979-2016 off the coast of South Carolina. Data from SEAMAP sampling program.

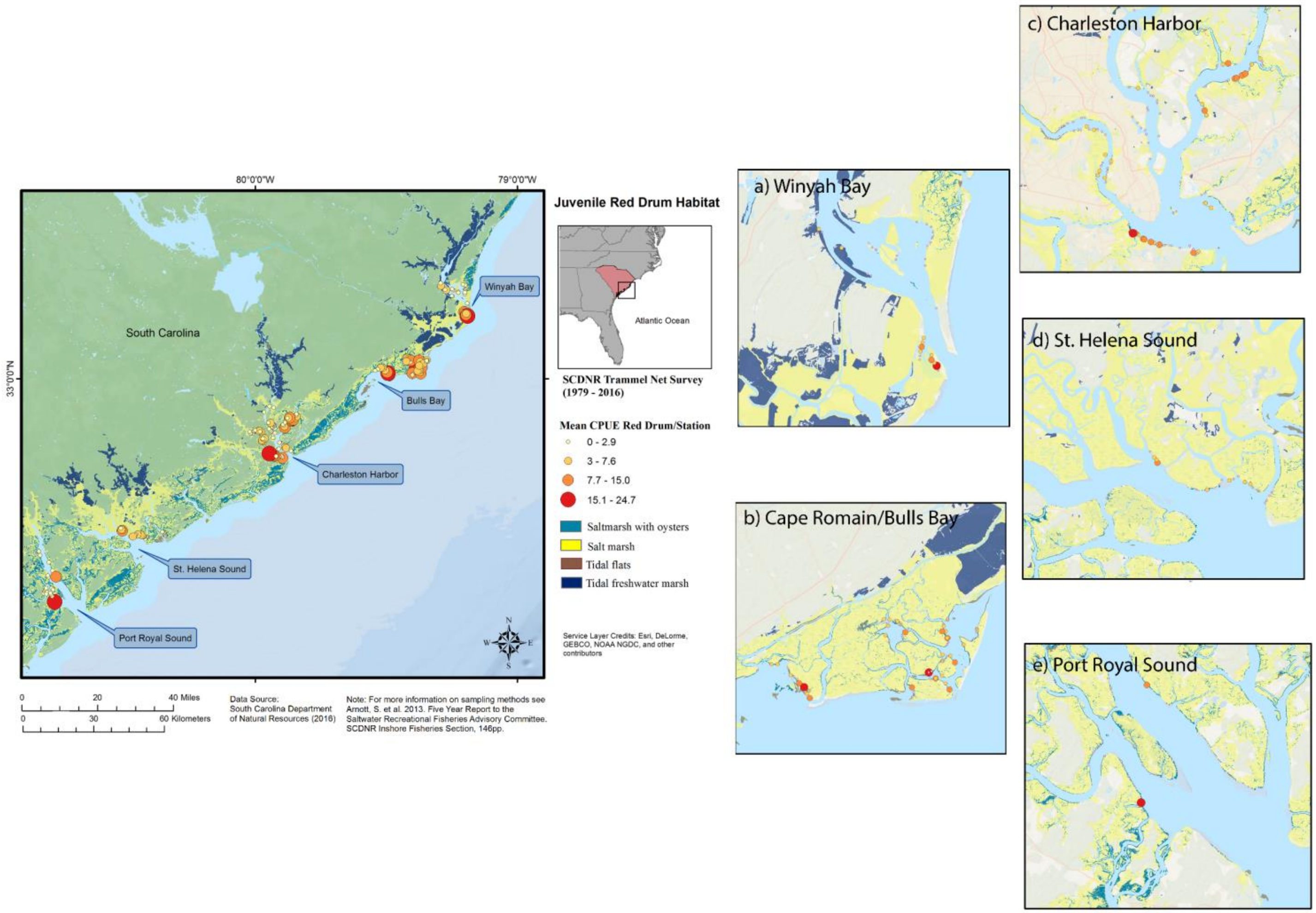

Figure 3.10.8: Abundance of juvenile Red Drum from trammel net surveys 1979-2016 off the coast of South Carolina. Data from SEAMAP sampling program. Map insets improve visualization of the data.

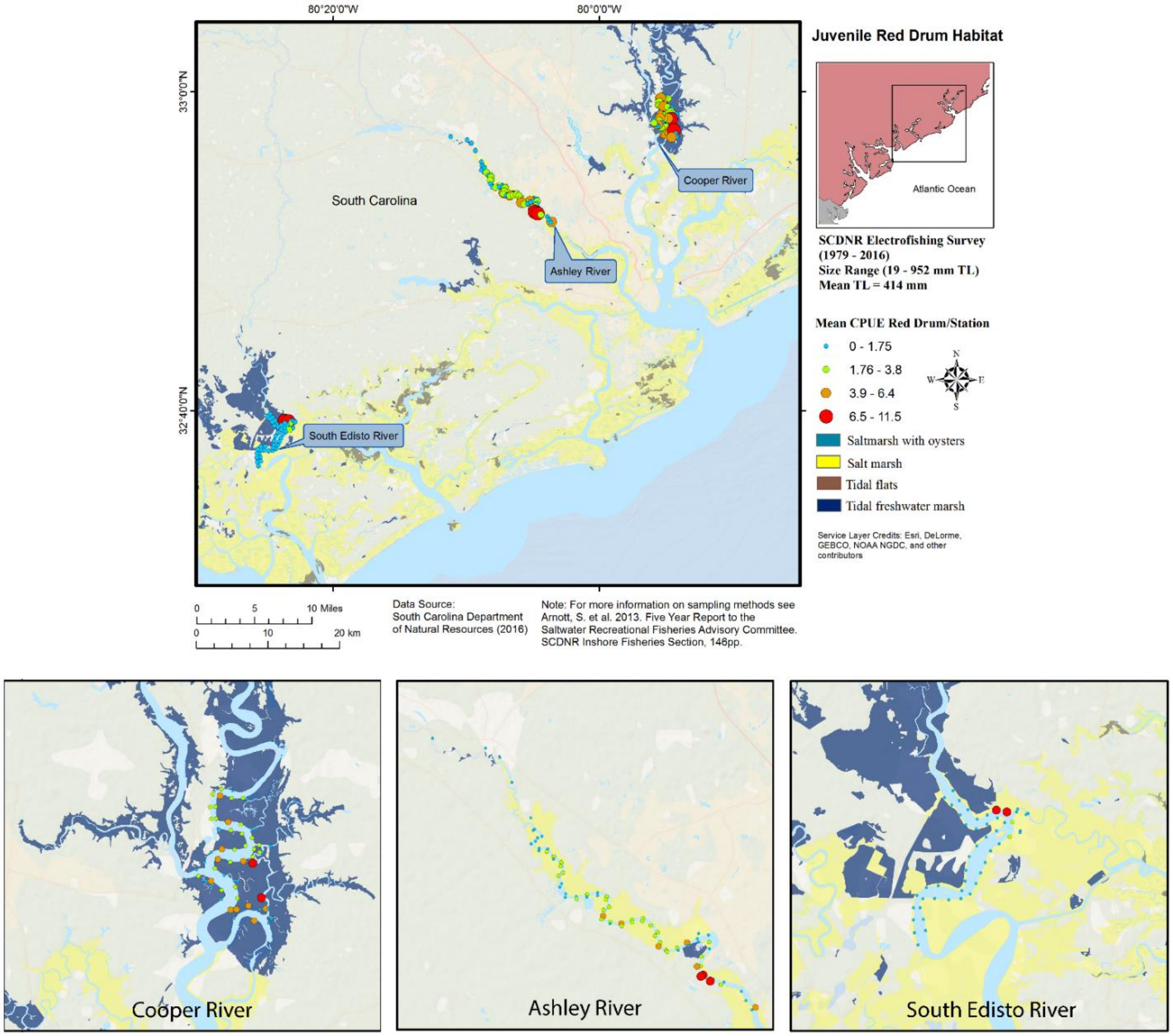

Figure 3.10.9: Abundance of juvenile and subadult Red Drum from electrofishing from 1979-2016 off the coast of South Carolina. Data from SEAMAP sampling program.

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Section 4: Final Synthesis

4.1 Integrating Science into the Decision-Support Framework for Moratoria

Expert knowledge and monitoring data are critical for developing a decision-support framework for natural resource conservation. This report collates expert knowledge and the most credible data to form the underlying scientific basis for establishing moratoria in North Carolina and South Carolina. Data are included from long-term state monitoring programs (e.g., NCDMF fisheries-independent sampling program) and federal research programs (e.g., ASMFC Cooperative Striped Bass Tagging Program). A significant product of this work is the maps and underlying geographic database used for the spatiotemporal assessment of fishes and habitat. These data capitalize on decades of data collection and mapping from numerous sources. Some data sources herein have never been synthesized or reported prior to this assessment (e.g., Figure 3.4.3).

Many NMFS stewardship mandates result in regulation of marine areas, including designation of EFH and HAPCs for fishery species and Critical Habitat for ESA-listed species. The MSA requires federal agencies to consult with the NMFS on actions that may adversely affect EFH and that NMFS provide conservation recommendations to those agencies. The ability of NMFS to convince other agencies to implement conservation recommendations often depends on availability of authoritative habitat assessments and direct, quantifiable evidence of impacts based on habitat recovery rates. Such information is sometimes not available, even for impacts that have been occurring for years (e.g., dredge and fill activities, dock and pier construction, beach renourishment, mining, and oil and gas development (NMFS 2010).

This assessement advances knowledge on the life history and EFH of federally managed species in North Carolina and South Carolina. Some of the information in this document may be used by the NMFS when developing conservation recommendations for specific actions to protect EFH (e.g., EFH consultation). The data and interpretation are intended to support meaningful conservation measures to avoid, minimize, or mitigate impacts from coastal development activities. Life history and distribution information contained within this report, when cited properly, may be used in the preparation of Environmental Assessments and other documentation for environmental review including NEPA.

There is broad recognition that adaptive management is required in the face of variable environmental conditions and uncertainties as outcomes from management actions are realized (NRC 2004). Processes for setting and managing moratoria vary widely among regions, likely a reflection of differences among natural environments, geography, sociopolitical influences, and stakeholder perspectives. In some cases, moratoria are set without rigorous data and are solely based on professional judgement (NRC 2001). Some species in this report may exhibit life history strategies or behavior that share similar characteristics of other estuarine-dependent species. Coastal managers may find this information useful for setting moratoria when biological information is scarce for some species.

An Interagency Working Group (IWG), or similar state-federal partnership organization, can provide a forum to bring together all interested and affected government parties to facilitate information sharing and foster informed and efficient decision-making. An IWG is typically composed of representatives from the USACE, USEPA, USFWS, NOAA NMFS, other federal agencies, and tribal, state, and local regulatory and resource agencies. IWGs allow for the setting and managing of moratoria for a region or state. They also provide transparency, inclusion, and cooperation among agencies. Implementation of consensus recommendations will occur through applicable regulatory and interagency review processes. Cooperating agencies in North Carolina and South Carolina routinely organize multi-agency coordination meetings to address coastal management issues (e.g., moratoria), transportation projects (Merger Team), renewable energy development (Interagency Taskforce), and mitigation banking (Interagency Review Team). These partnerships facilitate priority development and compromise among regulators and help document how competing agency mandates are balanced during a shared decision-making process.

In this final chapter, the tables and figure were prepared to guide development of recommendations for moratoria in North Carolina and South Carolina. For general trends in seasonal movements of species, spatiotemporal tables for each species provide adequate information various habitats utilized during certain time periods and seasons. Table 4.1.1 summarizes the spawning strategy and distribution patterns for adult fishes and invertebrates. Table 4.1.2 summarizes peak spawning and seasonal variation observed for each species. Table 4.1.3 evaluates the relationship among managed species and the functional use of each habitat during various life stages and movements. These tables can be used to identify important periods with significant spatiotemporal overlap (i.e., number of species life stages overlapping at the same time in the same habitat). Most agencies agree that peak spawning and recruitment periods are particularly sensitive to disturbance and should be considered for moratorium during in-water construction and maintenance activities. Further, Figure 4.1.1 defines those times of year most critical to protection, and where (river, estuary, inlet, ocean) they occur. These tables and figures also provide justification for relief of a construction moratorium when impacts to spawning or recruitment are considered low risk. Using best management practices, knowledge of potentially impacted species and habitats, coastal managers may denote the distinct differences and considerations for setting moratoria for anadromous fishes and other estuarine-dependent species.

The geospatial data provided with this report may be especially useful when evaluating and setting moratoria. All maps within this document are intended to be viewed within a high-resolution Portable Document Format (PDF), so the intricacies of the maps can be observed. All spatial data used in this publication have been delivered to NMFS so maps may be further refined, and the map extent changed to visualize the data for decision-making purposes.

Table 4.1.1: Spawning location/strategy and vertical orientation of fishery species (adapted from NCDEQ 2016).

Species	Vertical Orientation[1]	
	Demersal[2]	Pelagic[2]
<u>Anadromous fish</u>		
River Herring (Alewife and Blueback Herring)	E	A, J, L
American Shad	E	A, J, L
Sturgeon (Atlantic Sturgeon and Shortnose Sturgeon)	A, J, E	L
<u>Estuarine and inlet spawning and nursery</u>		
Blue Crab	A, J, E	L
Red Drum	A, J	E, L
<u>Marine spawning, low-high salinity nursery</u>		
Shrimp	A, J, E	L
Southern Flounder	A, J	E, L
<u>Marine spawning, high salinity nursery</u>		
Gag	A, J	E, L
Summer Flounder	A, J	E, L

[1] Epperly and Ross (1986), Funderburk et al. (1991), Pattilo et al. (1997), SAFMC (1998), NOAA (2001), NCDMF (2015).
[2] Demersal species live primarily in, on, or near bottom; pelagic species live primarily in the water column. A=adult, J=juvenile, L=larvae, and E=egg.

Table 4.1.2: Spawning seasons for coastal fish and invertebrate species occurring in North Carolina and South Carolina that broadcast planktonic or semidemersal eggs. Blue indicates peak spawning season, while the hatched areas indicates times when spawning is still occurring, but is non-peak spawning periods (adapted from NCDEQ 2016).

	Winter			Spring			Summer			Fall		
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ANADROMOUS FISH												
American Shad												
River Herring												
Atlantic Sturgeon												
Shortnose Sturgeon												
ESTUARINE AND INLET SPAWNING AND NURSERY												
Blue Crab												
Red drum												
MARINE SPAWNING, LOW-HIGH SALINITY NURSERY												
Brown Shrimp												
Southern Flounder												
White Shrimp												
MARINE SPAWNING, HIGH SALINITY NURSERY												
Gag												
Pink Shrimp												
Summer Flounder												

Table 4.1.3: Relationship among managed species and the functional use of habitat during various life stages and movements.

		Function				
Species	**Habitat**	**Nursery**	**Foraging**	**Refuge**	**Spawning**	**Corridor**
White Shrimp	Water Column				■ *	
	Shell Bottom					
	SAV	■	■	■		■
	Wetlands	■	■	■		■
	Soft Bottom	■	■	■		■
	Hard Bottom					
Brown Shrimp	Water Column				■ *	
	Shell Bottom	■	■	■		■
	SAV	■	■	■		■
	Wetlands	■	■	■		■
	Soft Bottom	■	■	■		■
	Hard Bottom					
Pink Shrimp	Water Column				■ *	
	Shell Bottom	■	■	■		■
	SAV	■	■	■		■
	Wetlands	■	■	■		■
	Soft Bottom	■	■	■		■
	Hard Bottom					
Gag	Water Column					
	Shell Bottom	■	■	■		■
	SAV	■	■	■		■
	Wetlands					
	Soft Bottom					
	Hard Bottom	■	■	■	■ **	■
Summer Flounder	Water Column					
	Shell Bottom		■	■		■
	SAV	■	■			
	Wetlands	■	■	■		■
	Soft Bottom	■	■	■	■	■
	Hard Bottom					

Table 4.1.3 continued: Relationship among managed species and the functional use of habitat during various life stages and movements.

		Function				
Species	**Habitat**	**Nursery**	**Foraging**	**Refuge**	**Spawning**	**Corridor**
Atlantic Sturgeon	Water Column					
	Shell Bottom					
	SAV					
	Wetlands	■	■	■		■
	Soft Bottom	■	■		■	■
	Hard Bottom				■	
Shortnose Sturgeon	Water Column					
	Shell Bottom					
	SAV					
	Wetlands	■	■	■		■
	Soft Bottom	■	■		■	■
	Hard Bottom					
American Shad	Water Column					
	Shell Bottom					
	SAV	■	■	■		■
	Wetlands	■	■	■	■	■
	Soft Bottom					
	Hard Bottom					
River Herring	Water Column					
	Shell Bottom					
	SAV	■	■	■		■
	Wetlands	■	■	■	■	■
	Soft Bottom					
	Hard Bottom					
Blue Crab	Water Column					
	Shell Bottom	■	■	■	■	■
	SAV	■	■	■		■
	Wetlands	■	■	■		■
	Soft Bottom	■	■	■	■	■
	Hard Bottom					

Table 4.1.3 continued: Relationship among managed species and the functional use of habitat during various life stages and movements.

		Function				
Species	**Habitat**	**Nursery**	**Foraging**	**Refuge**	**Spawning**	**Corridor**
Southern Flounder	Water Column					
	Shell Bottom					
	SAV					
	Wetlands					
	Soft Bottom					
	Hard Bottom					
Red Drum	Water Column					
	Shell Bottom					
	SAV					
	Wetlands					
	Soft Bottom					
	Hard Bottom					

*White Shrimp, Brown Shrimp, and Pink Shrimp spawn in offshore waters with pelagic eggs that develop in the water column.

** Gag spawn at shelf-edge reefs (hard bottom habitat) in the offshore environment (McGovern et al. 1998, Sedberry et al. 2006, Sedberry and Reichert 2015). Hard bottom structures may occur in state waters (e.g., artificial reefs) or federal waters (e.g., shelf edge).

Critical Early Life Stages for Important Fishery Species in the Carolinas

National Centers for Coastal Ocean Science

Brown Shrimp
(*Farfantepenaeus aztecus*)[1]

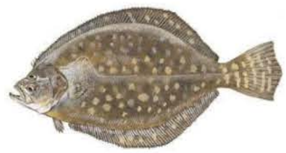
White Shrimp
(*Litopenaeus setiferus*)[1]

Pink Shrimp
(*Farfantepenaeus duorarum*)[1]

Blue Crab
(*Callinectes sapidus*)[2]

Gag Grouper
(*Mycteroperca microlepis*)[1]

Summer Flounder
(*Paralichthys dentatus*)[1]



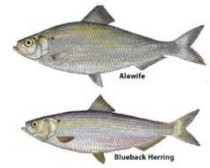
Southern Flounder
(*Paralichthys lethostigma*)[2]

Red Drum
(*Sciaenops ocellatus*)[4]

Atlantic Sturgeon
(*Acipenser oxyrinchus*)[3]

Shortnose Sturgeon
(*Acipenser brevirostrum*)[3]

American Shad
(*Alosa sapidissima*)[3]



River Herring
(*Alosa aestivalis* / *Alosa pseudoharengus*)[1]

Table. Summary of the most sensitive life stages (eggs, larvae, and early juveniles) for each fisheries species assessed, and their distribution throughout the year. Boxes represent abundant eggs and/or larvae present in a given area. Light blue = River habitat; Gray = Inlet habitat; Dark blue = Estuarine habitat; Black = Ocean

Fishery Species	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
River / Inlet / Estuary												
Brown Shrimp		Inlet	Estuary	Estuary								
White Shrimp			Estuary	Estuary	Estuary	Estuary	Estuary					
Pink Shrimp					Inlet	Inlet	Inlet					
Atlantic Blue Crab				Inlet	Inlet	Inlet	Inlet	Inlet	Inlet	Inlet		
Gag Grouper			Inlet	Inlet	Estuary	Estuary						
Summer Flounder	Inlet	Inlet	Inlet	Inlet								Inlet
Southern Flounder	Inlet	Inlet									Inlet	Inlet
Red Drum								Estuary	Estuary	Estuary		
Atlantic Sturgeon		River	River	River	River	River		River	River	River	River	
Shortnose Sturgeon		River	River	River	River	River	River	River				
American Shad		River	River	River	River	River						
River Herring				River	River	River	River	River				
Ocean												
Brown Shrimp	Ocean									Ocean	Ocean	Ocean
Pink Shrimp				Ocean	Ocean	Ocean	Ocean					
Blue Crab				Ocean	Ocean	Ocean	Ocean	Ocean	Ocean			
Gag Grouper			Ocean	Ocean	Ocean							
Summer Flounder	Ocean	Ocean	Ocean	Ocean						Ocean	Ocean	Ocean
Southern Flounder	Ocean	Ocean									Ocean	Ocean

**Species photos courtesy of NOAA[1], SC Dep. of Natural Resources (DNR)[2], Atlantic States Marine Fisheries Commission[3] and MD DNR.[4]*

Figure 4.1.1: Summary of the sensitive life stages (i.e., eggs, larvae, early juveniles) for each of the fisheries species assessed in this study. Light blue boxes indicate presence in river, dark blue indicates estuary, dark blue and gray boxes (faded gray into blue) indicate presence in both habitats, and black indicates presence in the ocean.

4.2 Conclusions

This assessment of estuarine-dependent species emphasizes the importance of coastal waters for economically important fisheries species. Many of the reviewed fisheries species have overlapping occupation of geographical areas during the same temporal range in rivers, estuaries, inlet areas, or the ocean. Although each species may use the area of interest for a different habitat function, the presence and overlap create complex ecological webs within the coastal ecosystems of North Carolina and South Carolina. For instance, Table 4.1.2 reveals the overlap in temporal movements of anadromous fish during spawning with high temporal and spatial overlap as spawning is occurring in riverine systems for all anadromous species covered occurring from February to June in coastal rivers. Figure 4.1.1 summarizes the high-level of overlap of critical life stages (i.e., eggs, larvae, early juveniles). The highest level of overlap of critical life stages of species in inlet habitats occurs from April to June. Inlet areas are particularly vital to Blue Crab given the time spent by critical life stages in this habitat annually. Coastal ocean habitats are important to Blue Crab, Pink Shrimp, and Gag from March until July. These aforementioned overlaps demonstrate the importance of visualizing the distribution of each species and groups of species and ultimately determining the relative vulnerability and economic impact to coastal development. This synthesis of information and associated maps offers coastal managers the opportunity to visualize spatially explicit fisheries and habitat conservation considerations and potentially develop more impactful conservation recommendations going forward.

Without careful consideration of ecological factors before in-water development activities occur, short-term and long-term economic and ecological impact may occur. Moratoria, if properly implemented, can protect valuable fisheries species (and protected species), which if lost, would translate into a substantial impact on local and regional economies, ecosystems, and livelihoods. These protections aim to allow for development activities to occur during times when activities are least impactful to fisheries and protected species. This assessment adds updated, temporal and spatial data and information for 13 estuarine-dependent fisheries species in North Carolina and South Carolina waters. As many in-water coastal development activities are within riverine and estuarine areas, updating information and data for these species are needed for setting moratoria as effective conservation measures. This document, along with state and federal regulatory authorities, fisheries management plans, stock assessments, habitat plans, and other federally protected species protection considerations can serve as primary aids in considerations for evaluating proposed development activities and provide comprehensive conservation considerations to inform sustainable coastal development.

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Appendix A: Additional Information on Pile Driving and Sound Production

Sound is defined as small disturbances in a fluid from ambient conditions through which energy is transferred away from a source by progressive fluctuations of pressure (Oestman et al. 2009). Sound is always produced by vibrating objects (e.g., a pile), which has been struck by another object (e.g., pile driver hammer). Acoustic sound waves form as a disturbance occurs in a field of physical particles, causing particles to oscillate (Burgess et al. 2005). As the surface vibrates and particles oscillate against undisturbed particles, it compresses molecules in the adjacent medium, creating a high-pressure region (Burgess et al. 2005). As the object vibrates back to its original position, the molecules in contact with the vibrating surface produce a low-pressure region. These areas are known as compressions and rarefactions, respectively (Oestman et al. 2009). Alternating fluctuations of pressure and particle motion comprise the acoustic wave (Burgess et al. 2005). In fluids (e.g., gases and liquids) sound waves can only be longitudinal, but in solids, sound can exist as either a longitudinal or a transverse wave, making the characterization of sound derived from the fluid/solid matrix derived from pile driving intricate in nature (Oestman et al. 2009).

Table A.1: Typical sound levels in underwater environments where pile driving normally occurs. Adapted from Oestman et al. (2009).

Sound Source	Sound Pressure Level (dB RMS)	Sound Pressure (Pascals)
High explosive at 100 meters	220	100,000
Airgun array at 100 meters	200	10,000
Unattenuated pile strike at 200-300 meters	180	1,000
Large ship at 100 meters	160	100
Fish trawler passby (low speed) at 20 meters	140	10
Background with boat traffic (ranging from water body with boat traffic to quiet estuary)	120 100 80 60	1 0.1 0.01 0.001

Underwater sound propagation is complex, but is similar in some respects to sound propagation through the air. Specifically, sound propagation in water is subject to the same governing propagation equations (i.e., physics) that apply in air. Notable differences include the speed of sound in sea water at a standard temperature of 21°C is equal to three times the speed of sound in air at the same standard temperature and pressure ($Sound_{seawater}$ ~1,500 m/s vs. $Sound_{air}$ ~500 m/s). The difference in the characteristic impedance values (the product of the density and speed of sound of a material) in air vs. water causes loss of sound transmission between air and water of about 30 dB. Another significant difference between the propagation of sound underwater versus sound in air is that the underwater medium has distinct boundaries (the water surface and the bottom) substantially affecting propagation characteristics (Oestman et al. 2009). Temporal characteristics of sound may play an important role in its effect on listeners as its amplitude and spectrum. For instance, a strong sound that occurs occasionally may affect listeners less than a weaker sound that is continually present. This challenges attempts to label a sound with a single measure of its potential for disturbance (Burgess et al. 2005).

In underwater acoustics, the word *level* denotes a sound measurement in *decibels*. A decibel (dB) expresses the logarithmic strength of a sound signal relative to a reference. The decibel is defined as:

$$\text{decibels (dB)} = 10\log_{10}\frac{(\text{signal amplitude}^2)}{(\text{reference amplitude}^2)}$$

The level of a propagating sound is dependent upon where the measurement is recorded (Burgess et al. 2005). Adjacent to the source, sound levels vary in complex ways with the spatial distribution of the source, its proximity to the surface or bottom, and the presence of interfering objects such as a vessel hull. The source level of a sound may be defined as the sound level existing at a 1-meter distance from an idealized point source emitting the same sound as the actual source in question (e.g., pile driver/pile) (Burgess et al. 2005). However, most actual sources are not point sources; in order to address this, a hydrophone is placed 1 m from the source to gather data, and then usually placed in a model to determine sound at greater distances from the source (Burgess et al. 2005). In calculating an average sound level over a specified length of time, common practice is to square the sound pressures measured over a given time and average them, obtaining a mean-square pressure, and then compute log (mean square) to obtain the sound pressure level (SPL). Transient sounds are often described in terms of their instantaneous peak amplitude and an integrated measure of energy contained in each sound pulse known as sound exposure level (SEL). SEL is the constant sound level in one second, which has the same amount of acoustic energy as the original time-varying sound (i.e., the total energy of an event) (Oestman et al. 2009) Both peak SPL and SEL – as well as Root Mean Square (RMS) – are useful metrics in evaluating hydroacoustic impacts on fish (Oestman et al. 2009). These metrics do not work well for continuous sounds, but do work well for impact hammer measurements (Burgess et al. 2005). For vibratory hammers (i.e., continuous sound) used on shallow substrate (1 to 5.4 m depth), the substrate itself conducts acoustic energy from the vibratory driver. The shallow substrate supports propagation of the infrasonic tone within the water column, consisting only of a boundary wave associated with the substrate that diminishes rapidly with height above the bottom (Burgess et al. 2005). This effect occurs even at close range to the driver.

It is also important to consider the effects of cumulative exposures on mortality, physiology, and behavior, including the effects of exposure to multiple impacts from pile driving and their intermittency (e.g., one strike every few seconds to several strikes per second) (Oestman et al. 2009). One issue in this regard is whether there are any physiological differences when an animal is exposed to a very frequent sequence of high-level sound exposures vs. there being some "recovery" time between exposures. Another aspect of cumulative exposure that needs consideration is the potential effect on a fish that is in an area of impact exposed to pile driving and then exposed again to pile driving noise several hours, days, or weeks later. In an evaluation of pile driving impacts on fish, it may be necessary to estimate the cumulative SEL associated with a series of pile strike events. $SEL_{cumulative}$ can be estimated from a representative single-strike SEL value and the number of strikes that likely would be required to place the pile at its final depth by using the following equation:

$$SEL_{cumulative} = SEL_{single\ strike} + 10\log(\#\ of\ pile\ strikes)$$

Pile Boring

Bored piles are another type of reinforced concrete pile used to support heavy vertical loads (Oestman et al. 2009). A bored pile is a cast-in-place concrete pile that is assembled on the construction site. The construction procedure of boring pile is as follows:

> (1) Construction of drilling platform → (2) drill hole → (3) clean hole → (4) installation of steel reinforcement cage → (5) repeat hole cleaning → (6) pour live concrete → (7) test integrity of pile.

The main advantage of a bored pile system relative to a traditional pile system is that noise level and high levels of vibration are significantly reduced during installation. The method of drilling a bored pile is different from reinforced concrete square pile or spun pile. Bored piling work requires a specialist and skilled bored piling contractor instead of using a general piling contractor. The main advantages of bored piles or drilled shafts over conventional footings or other types of piles are: a) piles of variable lengths can be extended through soft compressible or swelling soils, into suitable bearing material; b) large excavations and subsequent backfill are minimized; c) less disruption to adjacent soil than traditional driving methods; d) there is minimal vibration and the technique will not disturb adjacent piles or structures; e) extremely high capacity caissons can be obtained by expanding the base of the shaft up to three times the shaft diameter, thus eliminating construction of caps over multiple pile groups; and f) for many design situations bored piles offer higher capacities with potentially better economics than driven piles (Oestman et al. 2009).

Table A.2: Various hammer types of pile driving hammers used for in-water construction projects. Adapted from CADOT (2015).

Hammer Type	Description
Drop hammer/Gravity hammer	Oldest impact hammer design; consists of steel ram guided with leads; raised by crane load lines and dropped on top of pile producing the drive action; used when only a small number of piles are driven.
Single acting air/steam driven hammer (power gravity hammer)	Consists of a ram encased in a steel frame raised by compressed air or steam; increased frequency of strikes to pile relative to drop with less vertical travel; more efficient than drop because less time between strikes for soil to set around pile; good for driving heavy piles in compact or hard soils; hammer has low driving speed and large headroom requirement.
Double acting air/steam driven hammer	Consists of similar mechanisms as single acting air/steam hammer, but when the ram approaches top of stroke a valve is opened into chamber at top of cylinder forcing the ram downward; lighter ram hammer can be used leaving less time between strikes reducing soil settlement, and increasing drive efficiency; good for light to moderate weight soils; hammer drive at fast speeds, requires less headroom, and can extract piles by turning them.
Diesel power driven hammer (single or double-action)	A one cylinder diesel engine with a steel cylinder containing a ram and anvil; Ram is raised by crane, as it drops a fuel pump is activated injecting fuel into a cup on top of the anvil; as ram continues down it blocks the exhaust ports compressing the air in combustion chamber; a ball forces the fuel into the hot compressed air between the ram and anvil causing the fuel to explode, forcing the ram up and the anvil, and in turn, the pile down; driving may become difficult in extremely soft ground.
Hydraulic or diesel hammer with built-in energy measurement	Similar to diesel power hammer, but with a built in energy measurement unit.
Vibratory and sonic power driven hammer	Newest hammer design; vibratory hammer vibrates the pile at frequencies and amplitudes that will break the bonds between adjacent soils, delivering more of the developed energy to the tip of the pile; these hammers have reduced driving vibrations, reduced noise, and great speed of penetration; fairly good to use in silty or clay deposits, but are mostly used with heavy clays or soils with boulders.

Table A.3: Representative data are limited from past projects on the actual number of pile strikes per pile and per day. This table summarizes typical strike data for a range of pile types.

Pile Type, Size, and Shape	Typical Use	Typical Installation Duration	Typical Strikes per Pile (per day)
Concrete, 24-inch hexagon	Wharf construction projects	1 to 5 piles per day	580
Thin steel H, small	Temporary construction projects	6 piles per day	550
Steel pipe, 40-inch diameter	Permanent construction projects	1 to 5 piles per day	600
Cast-in-steel shell (CISS) pipe, 30-inch diameter	Permanent construction projects	2 to 4 piles per day	1,600 to 2,400
CISS pipe, 96-inch diameter	Permanent construction projects	1 to 3 pile sections per day	7,000

Table A.4: Summary of near source (10 m away from pile) unattenuated sound pressure levels for in-water pile driving using a drop or impact hammer. These data show that different types of piles result in different sound pressures. The data also illustrate the relationship between the peak pressure, the RMS sound pressure, and the SEL. Adapted from Oestman et al. (2009).

Approximate Pile Size and Pile Type	Relative Water Depth	Average Sound Pressure Level Measured in dB		
		Peak	**RMS**	**SEL**
Timber (12-inch) drop	--	177	165	157
Cast-in-shell steel (CISS) (12-inch) drop	--	177	165	152
0.30-meter (12-inch) steel H-type – thin	<5m	190	175	160
0.30-meter (12-inch) steel H-type – thick	5m	200	183	170
0.36-meter (14-inch) steel H-type – thick	±6m	208	--	177
0.6-meter (24-inch) AZ steel sheet	15m	205	190	180
0.33-meter (13-inch) plastic pile	10m	177	153	--
0.46-meter (18-inch) concrete pile	<3m	185	166	155
0.61-meter (24-inch) concrete pile	5m	185	170	160
0.61-meter (24-inch) concrete pile	15m	188	176	166
0.30-meter (12-inch) steel pipe pile	<5 m	192	177	--
0.36-meter (14-inch) steel pipe pile	15m	200	184	174
0.41-meters (16-inch) steel pipe pile	3m	182	--	158
0.51-meter (20-inch) steel pipe pile	±3m	204	161	--
0.61-meter (24-inch)steel pipe pile	15m	207	194	178
0.61-meter (24-inch) steel pipe pile	5m	203	190	177
0.76-meter (30-inch) steel pipe pile	±3m	210	190	177
1-meter (36-inch) steel pipe pile	<5m	208	190	180
1-meter (36-inch) steel pipe pile	10m	210	193	183
1.5-meter (60-inch) steel CISS pile	<5m	210	195	185
1.8-meter (72-inch) steel pipe pile	Land-based	204	--	175
2.4-meter (96-inch) steel CISS pile	10m	220	205	195

dB = Decibels
CISS = Cast-in-steel shell
RMS = Root mean square
SEL = Sound exposure level

Table A.5: Summary of near-source (10-meter) unattenuated sound pressure levels for in-water pile installation using a vibratory driver/extractor.

Pile Type and Approximate Size	Relative Water Depth	Average Sound Pressure Measured in dB		
		Peak	RMS*	SEL**
0.30-meter (12-inch) steel H-type	<5m	165	150	150
0.30-meter (12-inch) steel pipe pile	<5m	171	155	155
1-meter (36-inch) steel pipe – typical	5m	180	170	170
0.6-meter (24-inch) AZ steel sheet –typical	15m	175	160	160
0.6-meters (24-inch) AZ steel sheet – loudest	15m	182	165	165
1-meter (36-inch) steel pipe pile – loudest	5m	185	175	175
1.8-meter (72-inch steel pipe pile – typical	5m	183	170	170
1.8-meter (72-inch steel pipe pile – loudest	5m	195	180	180

*Impulse level (35 millisecond average)
** Sound exposure level (SEL) for 1 sec of continuous driving
dB = Decibels
RMS = Root mean square
SEL = Sound exposure level

Literature Cited

Burgess, W.C., S.B. Blackwell, and R. Abbott. 2005. Underwater Acoustic Measurements of Vibratory Pile Driving at the Pipeline 5 Crossing in the Snohomish River, Everett, Washington. URS Project number 33756899, Seattle, WA. 40 p.

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Oestman, R., D. Buehler, J. Reyff, and R. Rodkin. 2009. Technical Guidance for Assessment and Mitigation of the Hydroacoustic Effects of Pile Driving on Fish. Report by ICF International and Illingworth and Rodkin Inc. 298 p.

Wilbur L. Ross, *Secretary*
United States Department of Commerce

Neil Jacobs, Acting Under Secretary
National Oceanic and Atmospheric Administration

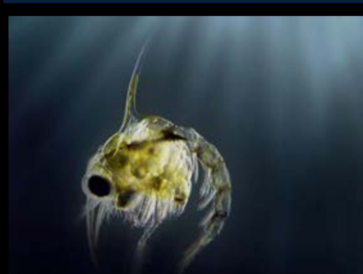
Nicole LeBoeuf, *Acting Assistant Administrator*
National Ocean Service



An Assessment of Fisheries Species to Inform Time-of-Year Restrictions for North Carolina and South Carolina

Lisa C. Wickliffe[1], Fritz Rohde[2], Ken L. Riley[3], and , James A. Morris, Jr.[3]

[1] CSS under contract to NOS NCCOS
[2]NOAA National Marine Fisheries Service
[3]NOAA National Ocean Service NCCOS



Project Goal

Identify the times of year when vulnerable life stages of fisheries species are present within habitats that have the potential to be affected by nearby coastal development.

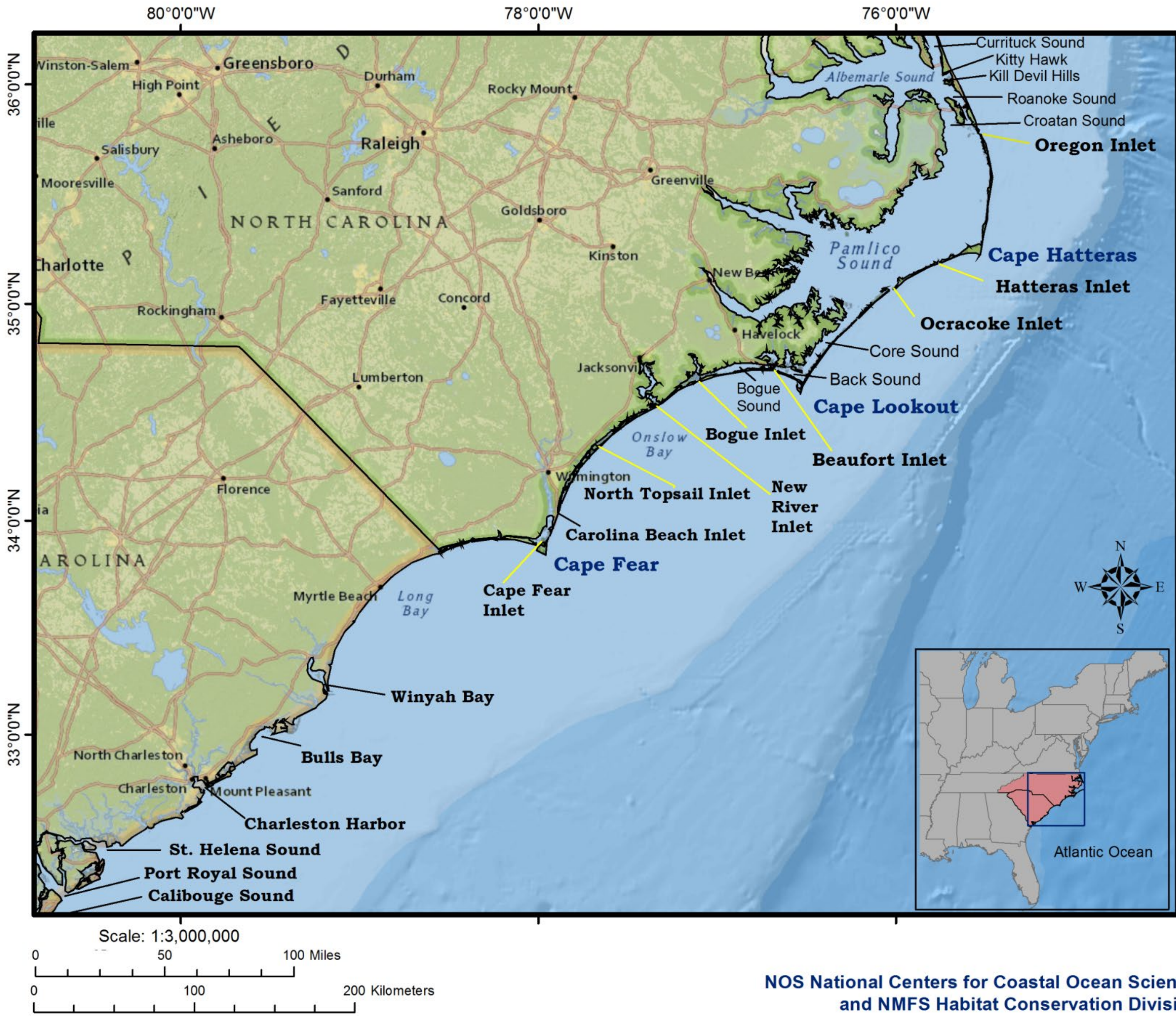
Objectives

1) Provide an overview of coastal development and potential impacts to fisheries

2) Complete life history reviews for priority estuarine-dependent species

3) Determine life history temporal and spatial patterns for 13 species

Study Area



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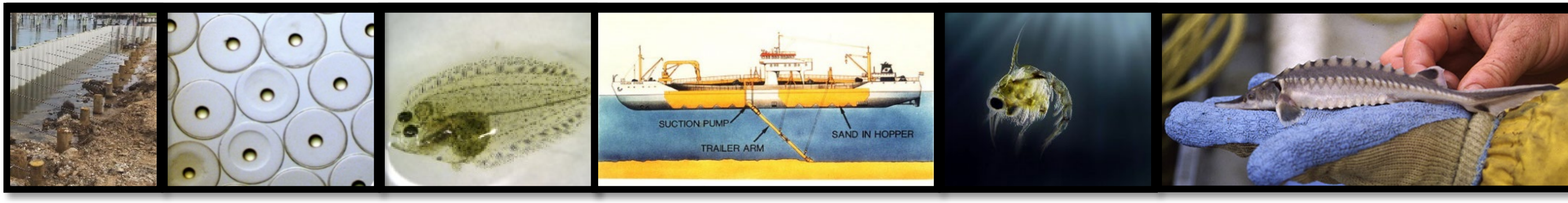
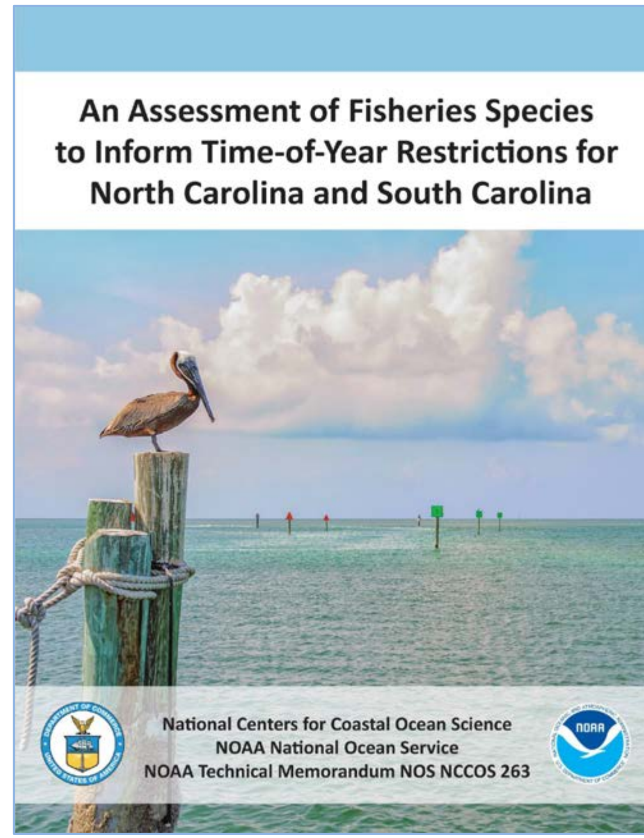
Moratoria



- Rules for coastal projects when development should be limited at certain times of year (**moratoria**)
- Moratoria can reduce impact to essential fish habitat and vulnerable life stages of federally managed species
- Seasonal restrictions on construction is a practicable way to minimize impacts to larvae and juvenile fish

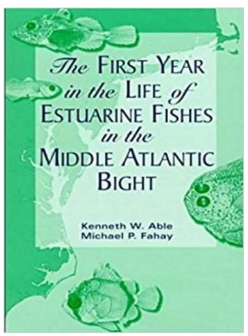
https://coastalscience.noaa.gov/data_reports/an-assessment-of-fisheries-species-to-inform-time-of-year-restrictions-for-north-carolina-and-south-carolina/

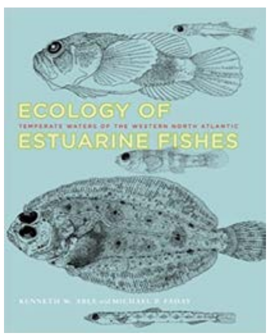

An Assessment of Fisheries Species to Inform Time-of-Year Restrictions for North Carolina and South Carolina

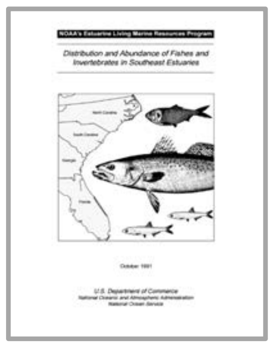
National Centers for Coastal Ocean Science
NOAA National Ocean Service
NOAA Technical Memorandum NOS NCCOS 263

Moratoria

- Current moratoria are based on generalized knowledge of life history
  - Historical moratoria for the southeast U.S/ were set according to Nelson et al. (1991) and Able and Fahay (1998, 2010)
- Windows often require tailoring to individual states based on biogeographic considerations, including the range of a particular stock







South Carolina does not have formalized agreements for moratoria. SC agencies and the NMFS recommend conservation measures to protect recruitment periods for larval fish, shrimp, and crabs. General recommendations include construction moratoria periods extending from February 1 to September 30. Spring and summer are considered peak recruitment periods and are highly regarded as the most important seasons for conservation.

Region	Area	Standard fish moratorium period	Anadromous fish moratorium period
Southern	South Carolina border north through Onslow County	1 April – 30 September	1 February – 30 June
Central and Pamlico	Carteret County north through Long Shoal River, including the Neuse River basin above New Bern and all of Tar-Pamlico basin	1 April – 30 September	1 February – 30 September
Northern - Albemarle (sounds/tributaries)	North of Long Shoal River and including the Roanoke River basin	1 April – 30 September	15 February – 30 September (extended to 31 October east of Alligator River)
Northern - Outer Banks (sounds/tributaries)	North from Ocracoke Inlet in high energy, sandy estuaries	1 April – 30 September	N/A
Inlets	Shoals/channels dynamic	April 1 – 31 July	N/A
WRC		15 February – 30 September (Inland Primary Nursery Habitats)	15 February – 30 June*

*Depending on the river system and inland extent of the tributary, the anadromous fish moratoria may be adjusted to February 1.

Objective 1

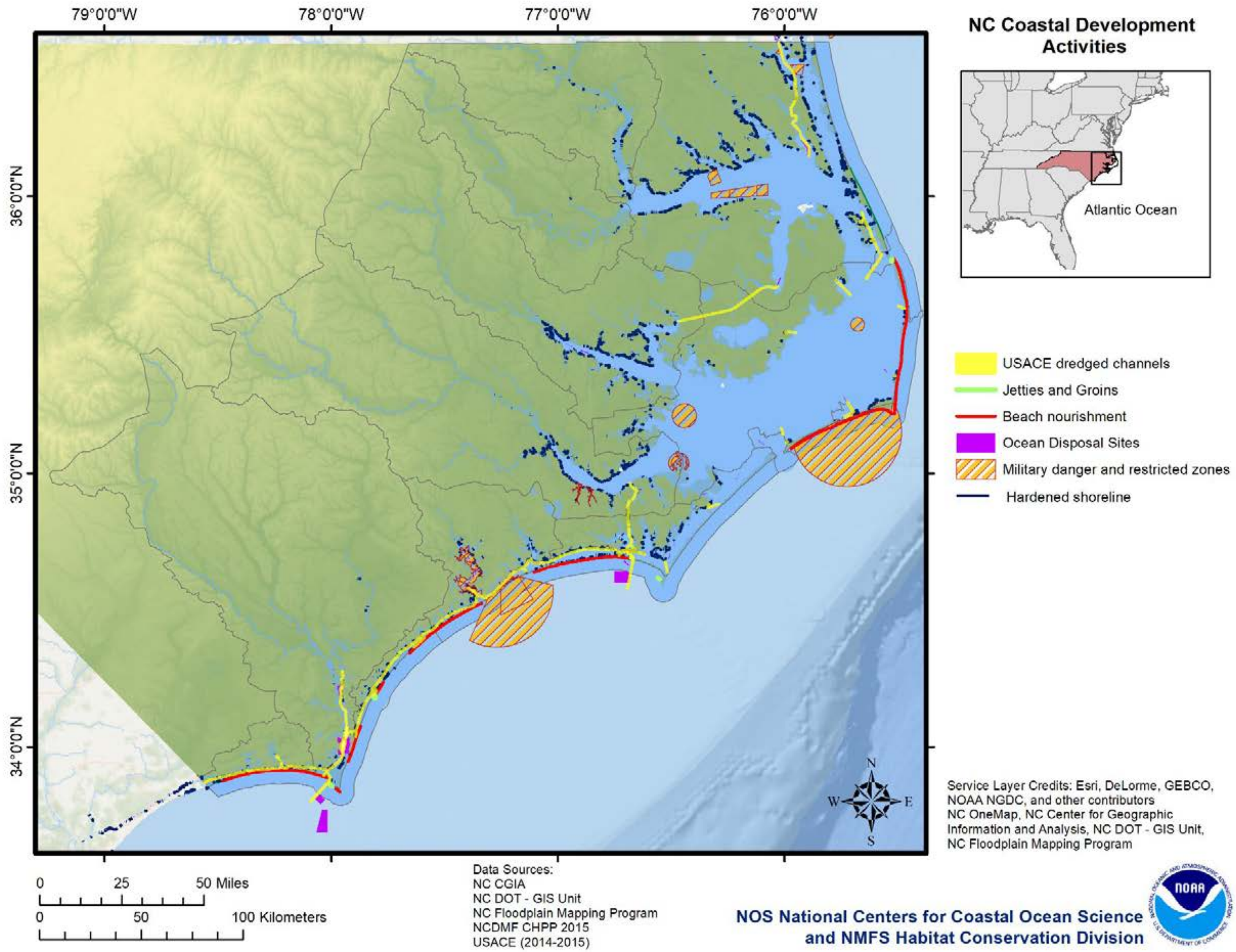
Provide an overview of coastal development activities and potential impacts to fisheries

USACE Wilmington District

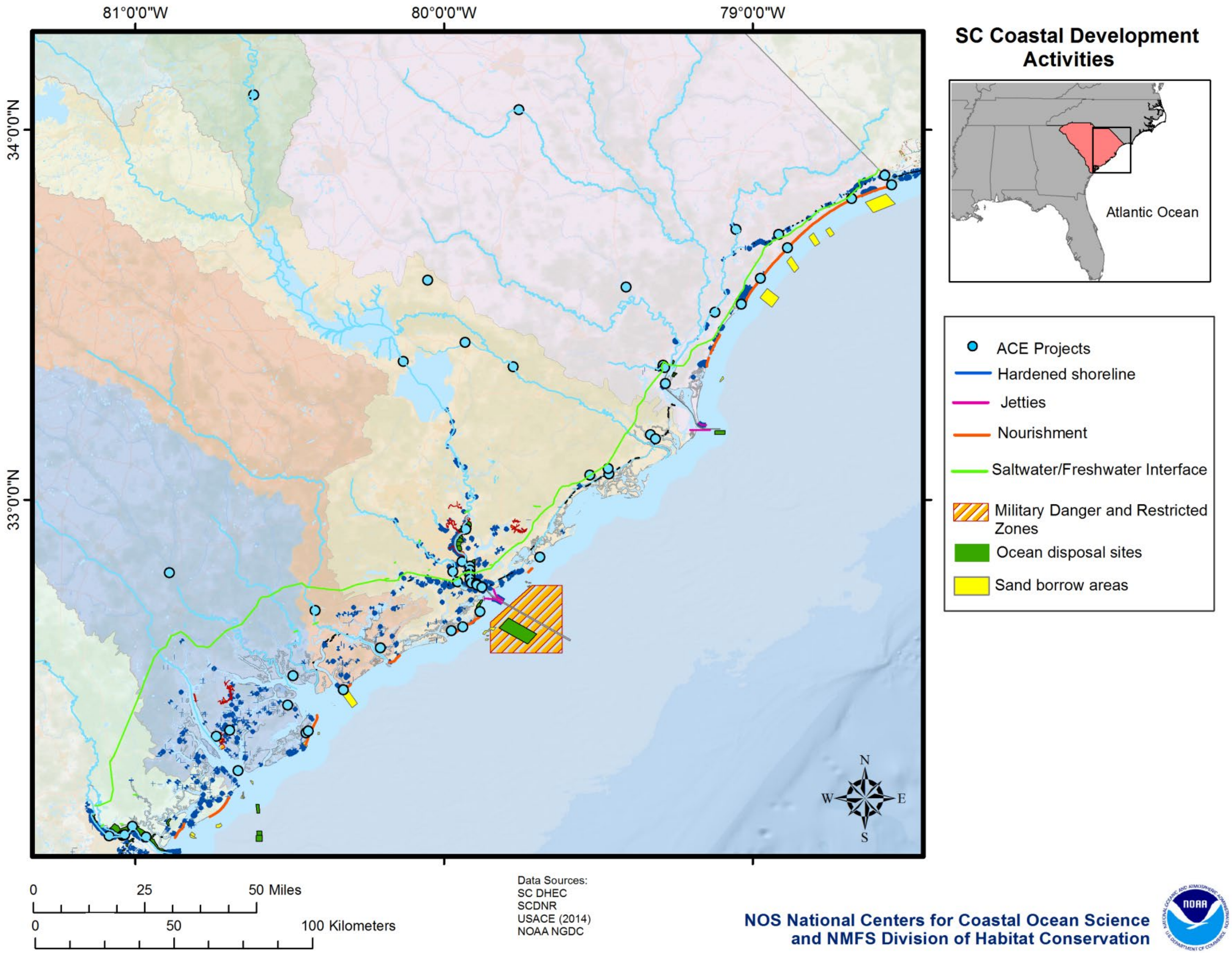
Coastal Development Activity	Potential Impact to Fisheries
Beach nourishment and shoreline protection (soft stabilization) 	• Change in flow characteristics (longshore drift) • Increased sedimentation and turbidity • Smothering of eggs • Smothering of habitat (e.g., mud-flats, subtidal habitats, and intertidal zones) and habitat conversion or loss • Direct mortality
Dredging 	• Change in flow characteristics • Loss of spawning habitat • Egg smothering • Impaired respiration and feeding • Direct mortality of vulnerable life stages • Benthic habitat alteration or loss • Impediments for anadromous fish migrations • Increased turbidity • Increased vulnerability of eggs to predation • Substrate and water quality degradation due to increased levels of pollutants • Entrainment

Coastal Development Activity	Potential Impact to Fisheries
Pile Driving 	• Sound production and noise impact • Increased turbidity • Substrate and water quality degradation • Alteration in flow characteristics • Direct mortality • Impediments for anadromous fish migrations
Obstructions (Dams, Culverts, and Impoundments) 	• Blockage of upstream migration for anadromous fishes • Decreases water flow rate, with potential adverse impacts on larval dispersion, recruitment, and survival

Coastal Happenings



Coastal Happenings



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Objective 2

Complete life history reviews for priority estuarine-dependent species with the most up-to-date data available

Red Drum Migration

River Herring Migration

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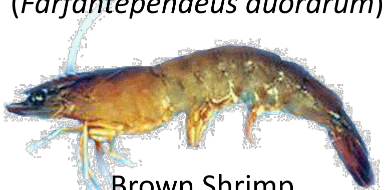
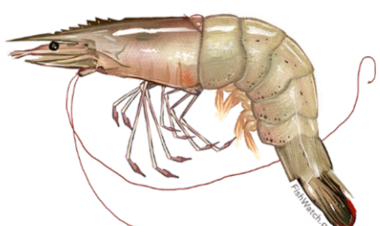
Fishery Species Covered


Blue Crab (*Callinectes sapidus*)


Pink Shrimp
(*Farfantepenaeus duorarum*)


Brown Shrimp
(*Farfantepenaeus aztecus*)


White Shrimp
(*Litopenaeus setiferus*)


Southern Flounder
(*Paralichthys lethostigma*)


Gag (*Mycteroperca microlepis*)

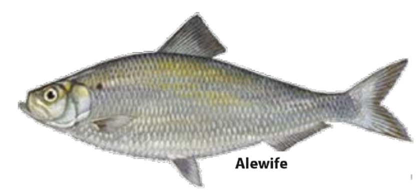

Summer Flounder (*Paralichthys dentatus*)


Red Drum (*Sciaenops ocellatus*)


American Shad (*Alosa sapidissima*)


✓ Atlantic Sturgeon (*Acipenser oxyrinchus*)

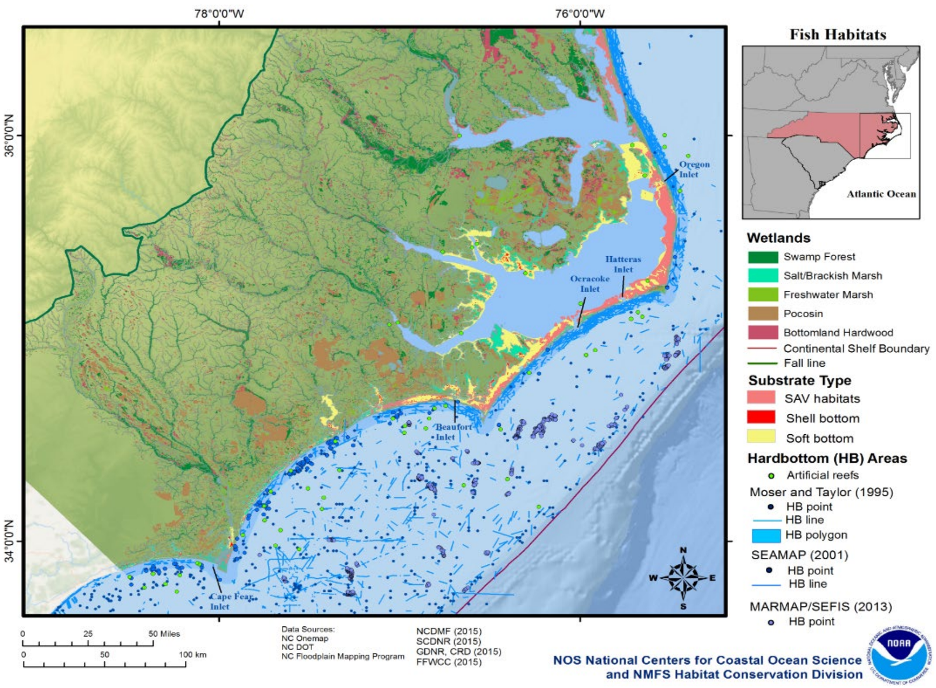

Shortnose Sturgeon (*Acipenser brevirostrum*)

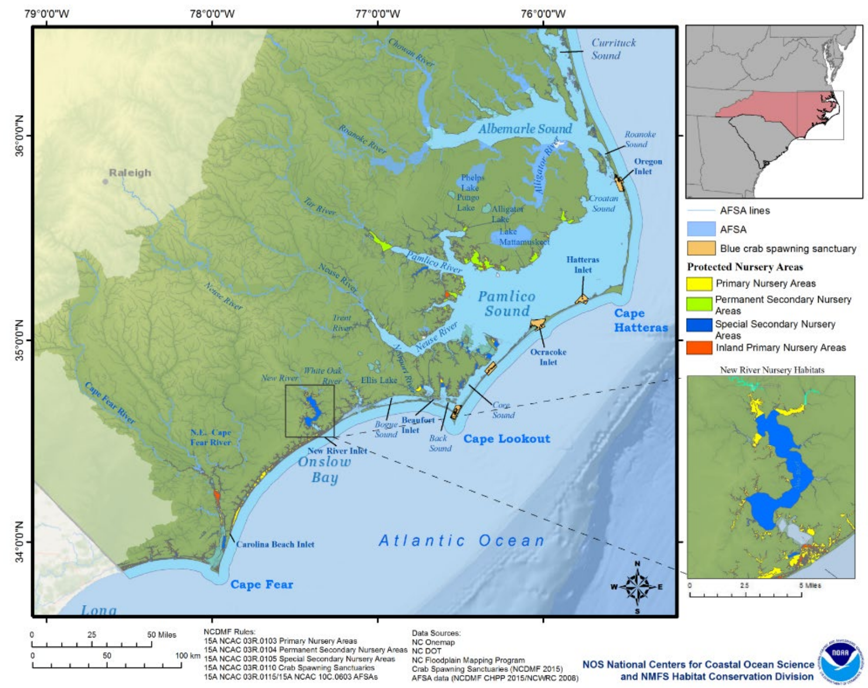


River Herring
(*Alosa aestivalis*)/(*Alosa pseudoharengus*)

**Species photos courtesy of NOAA[1], SC Dep. of Natural Resources (DNR)[2], Atlantic States Marine Fisheries Commission[3] and MD DNR.[4]*

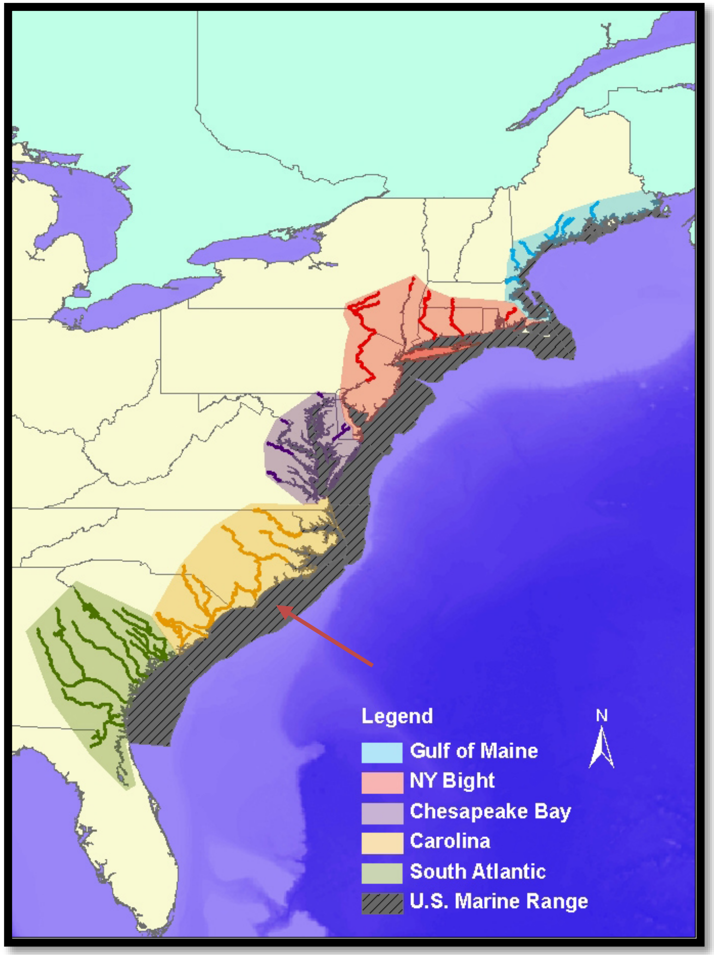
Fishery Habitats





Atlantic Sturgeon

(*Acipenser oxyrinchus*)



General Facts

- Carolina and South Atlantic DPSs
- Anadromous, estuarine-dependent, late-maturing, long-lived species
- Fall and Spring spawning periods

Atlantic Sturgeon
Life Cycle

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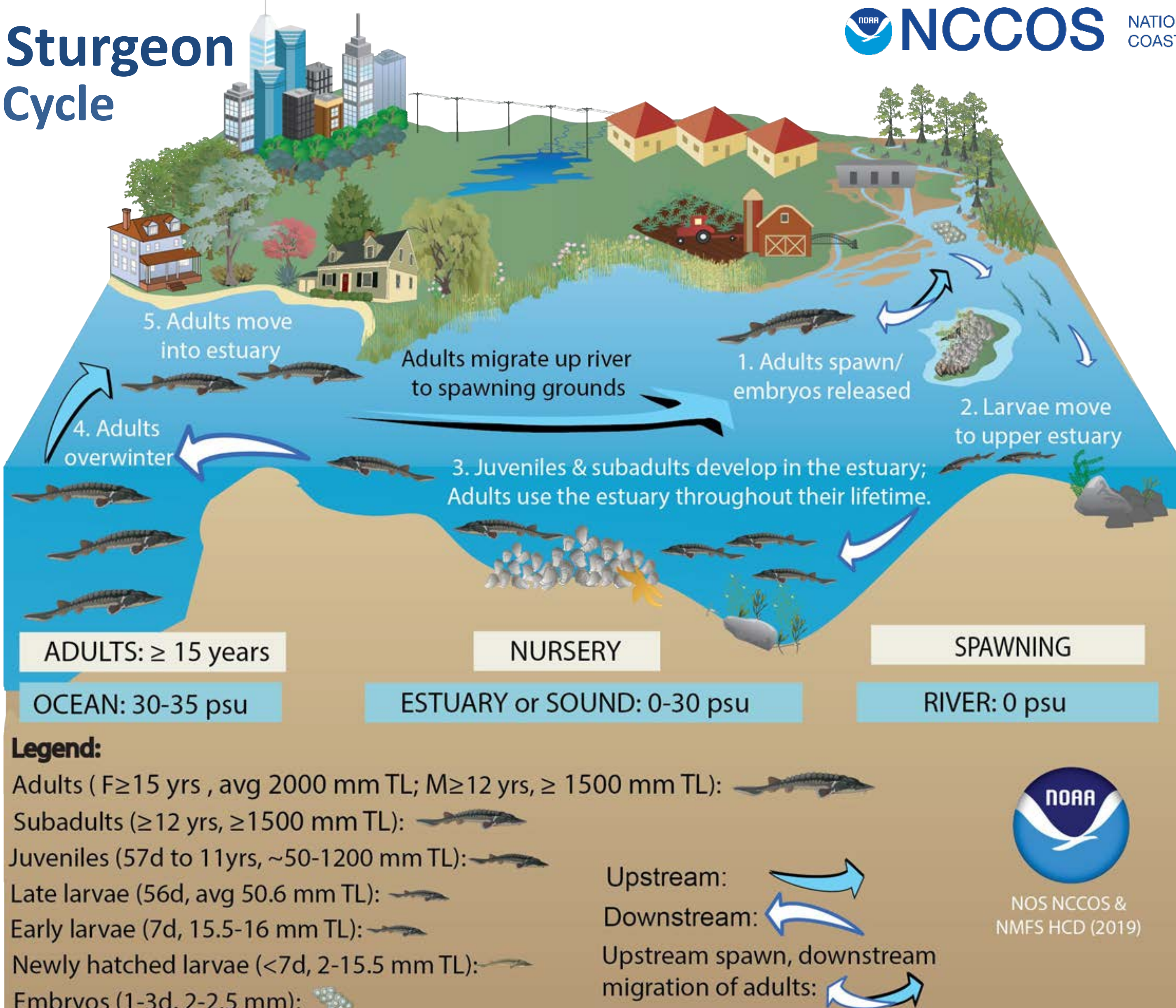
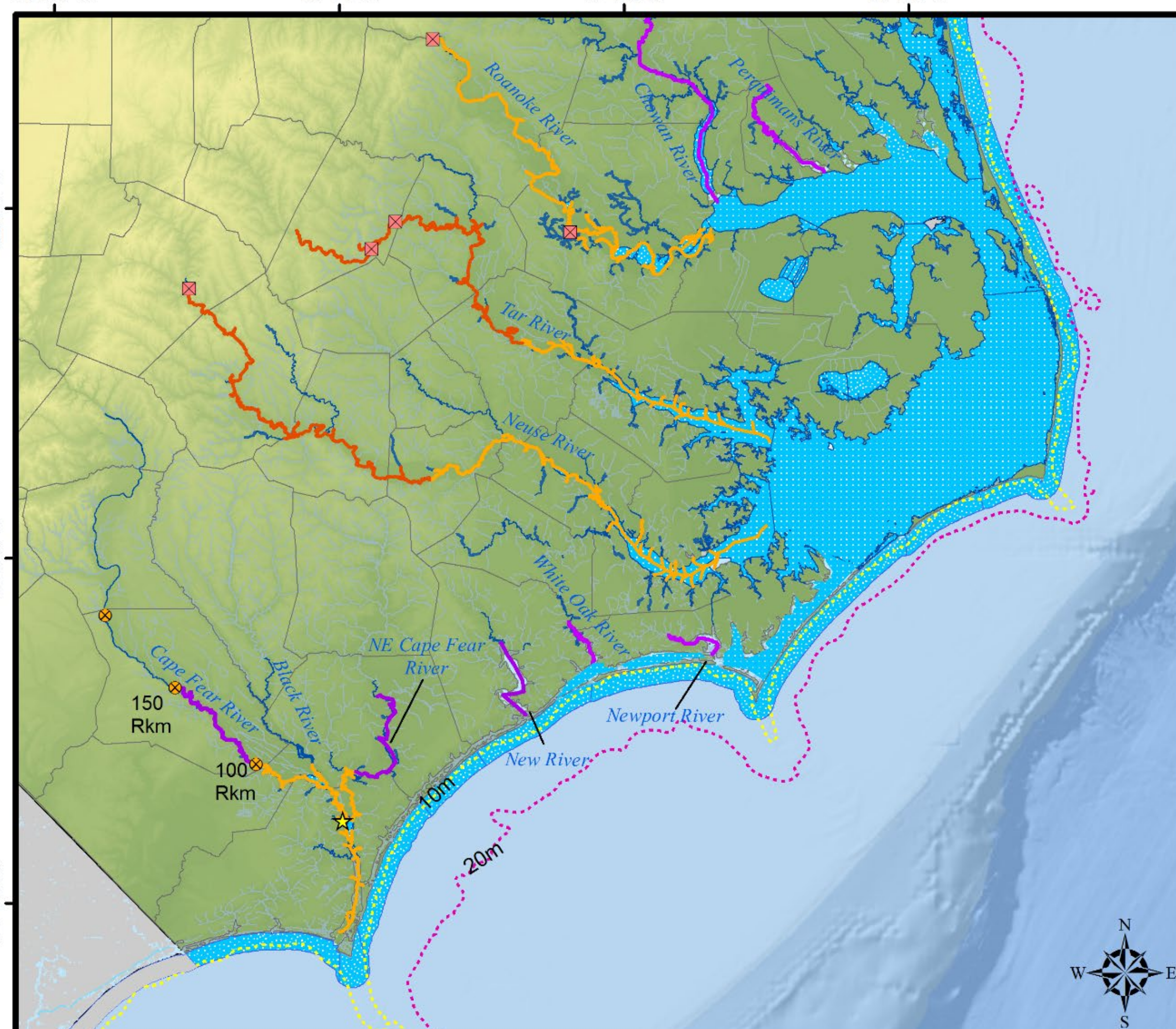
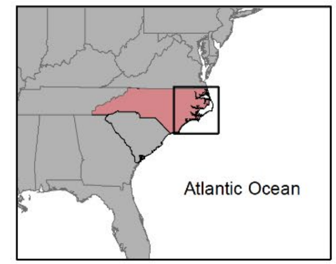


Steps 1 - 5: (1) Adults migrate up river to spawning grounds, where embryos are released. (2) Newly hatched, early and late larvae are found from the river to the upper estuary. (3) Juveniles use the estuary as a nursery area for 11 to 15 years before reaching spawning adult stage. (4) Many adults also overwinter around the 10 and 20 m bathemetric contour in the ocean. (5) In spring or fall, spawning adults begin migrating through the estuary, to rivers, where they spawn.

Atlantic Sturgeon



Atlantic Sturgeon Habitats



Dam
Lock and Dam
Observed spawning (Moser & Ross 1995)
ATS spawning rivers
ATS non-spawning rivers
No recent ATS onserved

Bathymetric Contours

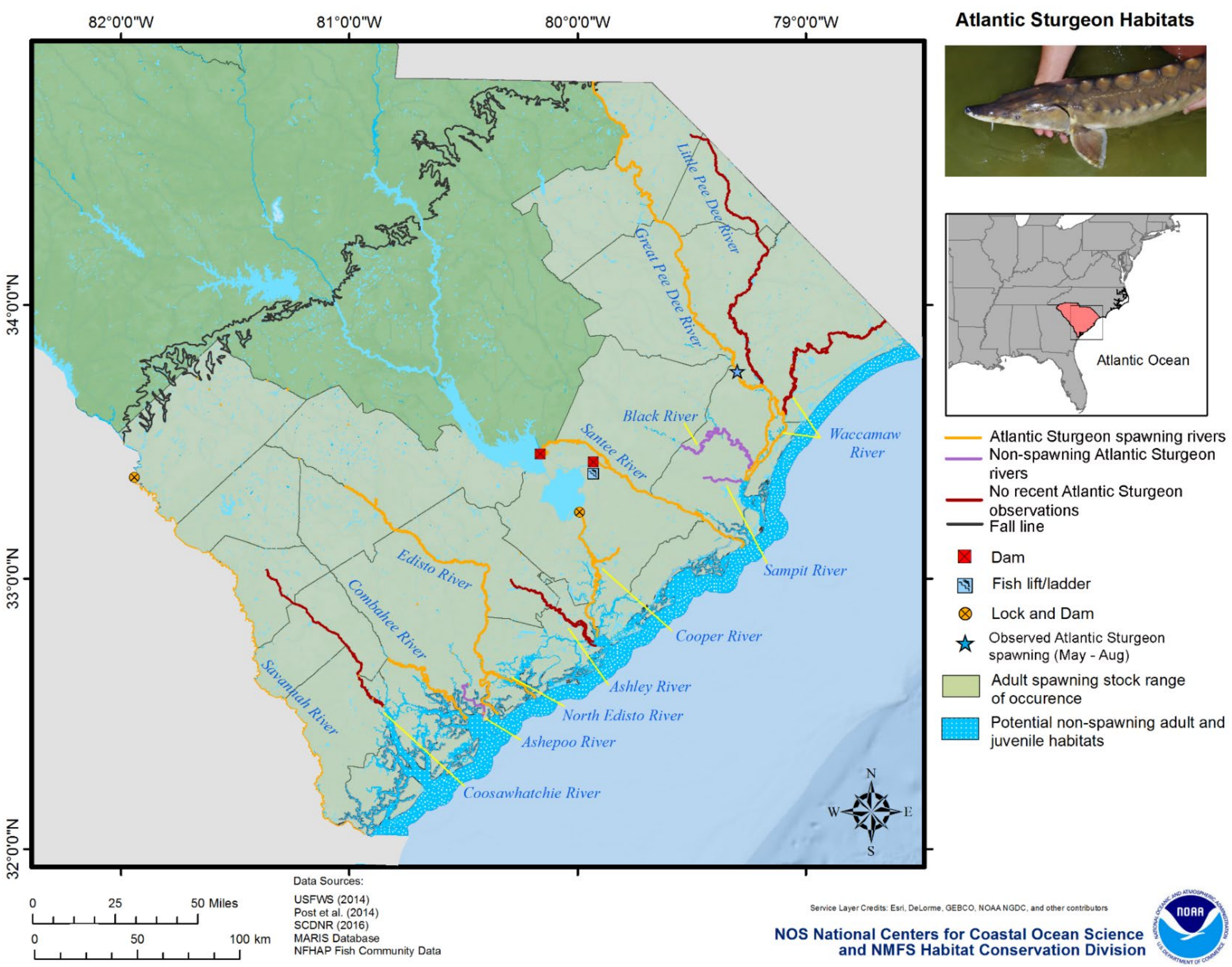
10 meter
20 meter
Potential non-spawning adult and juvenile habitats

Service Layer Credits: Esri, DeLorme, GEBCO, NOAA NGDC, and other contributors
NC OneMap, NC Center for Geographic Information and Analysis, NC DOT - GIS Unit, NC Floodplain Mapping Program

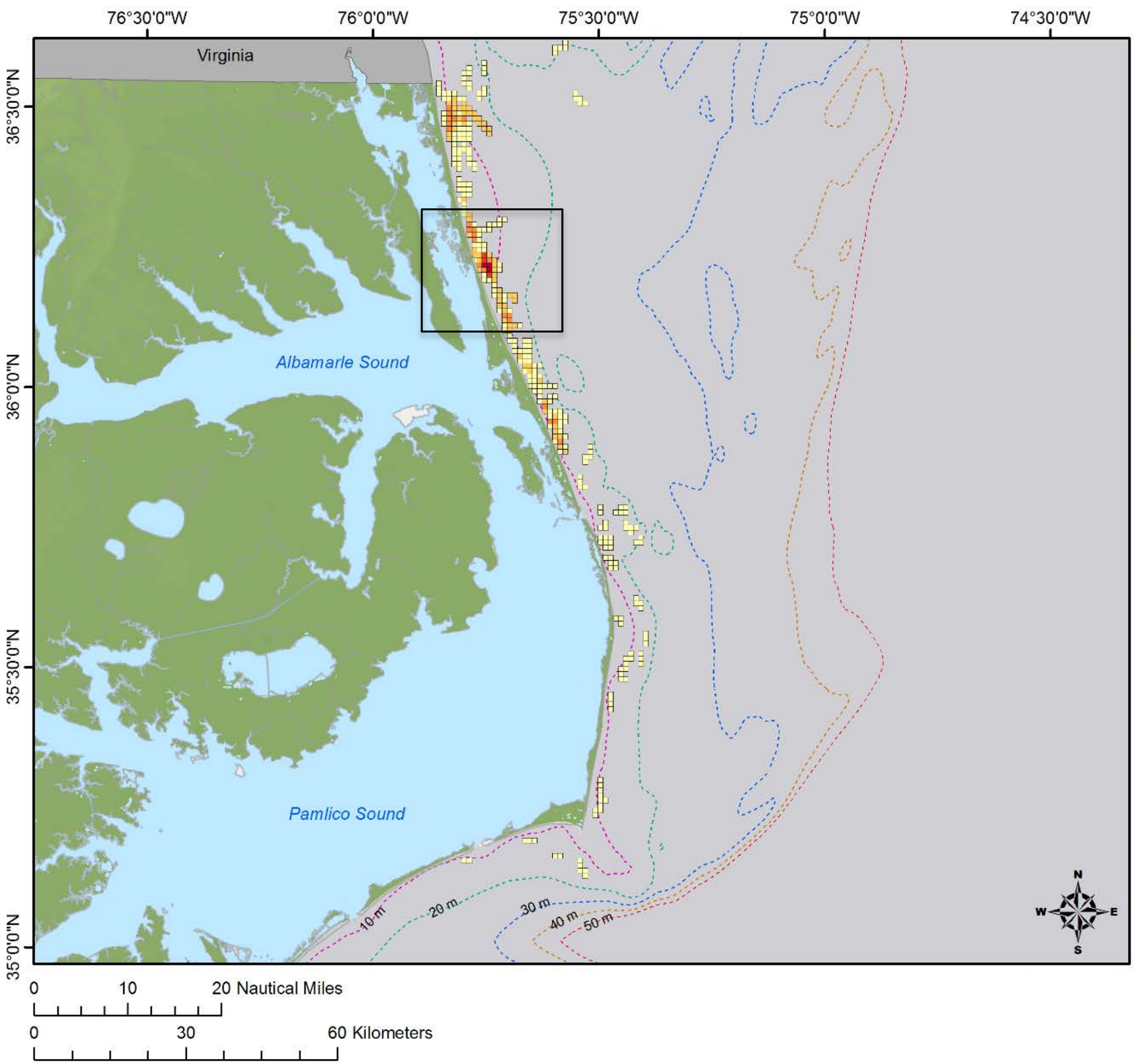
0 25 50 Miles
0 50 100 km

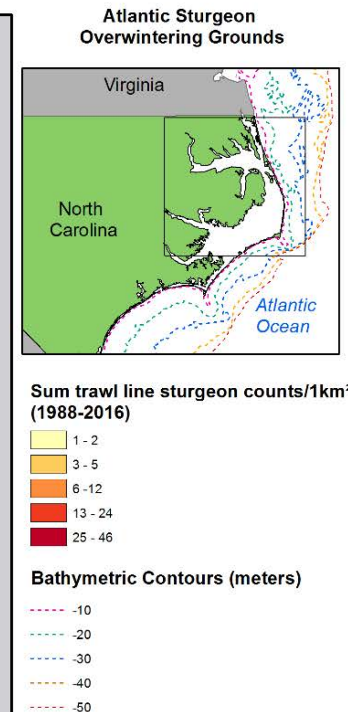
Data Sources:
Moser and Ross (1995)
USGS NWIS
SCDNR (2014)

Atlantic Sturgeon



Atlantic Sturgeon





Notes: No cruises occurred in 2011, 2012, and 2014. No sturgeon were caught in the 1993 and 1995 cruises. All cruises occurred in January and February of each year.

Acknowledgments:
Atlantic Sturgeon data were collected during the Cooperative Winter Tagging Cruise time series by the Atlantic States Marine Fisheries Commission (ASMFC) and each cruise crew

Atlantic Sturgeon

Spatiotemporal Table

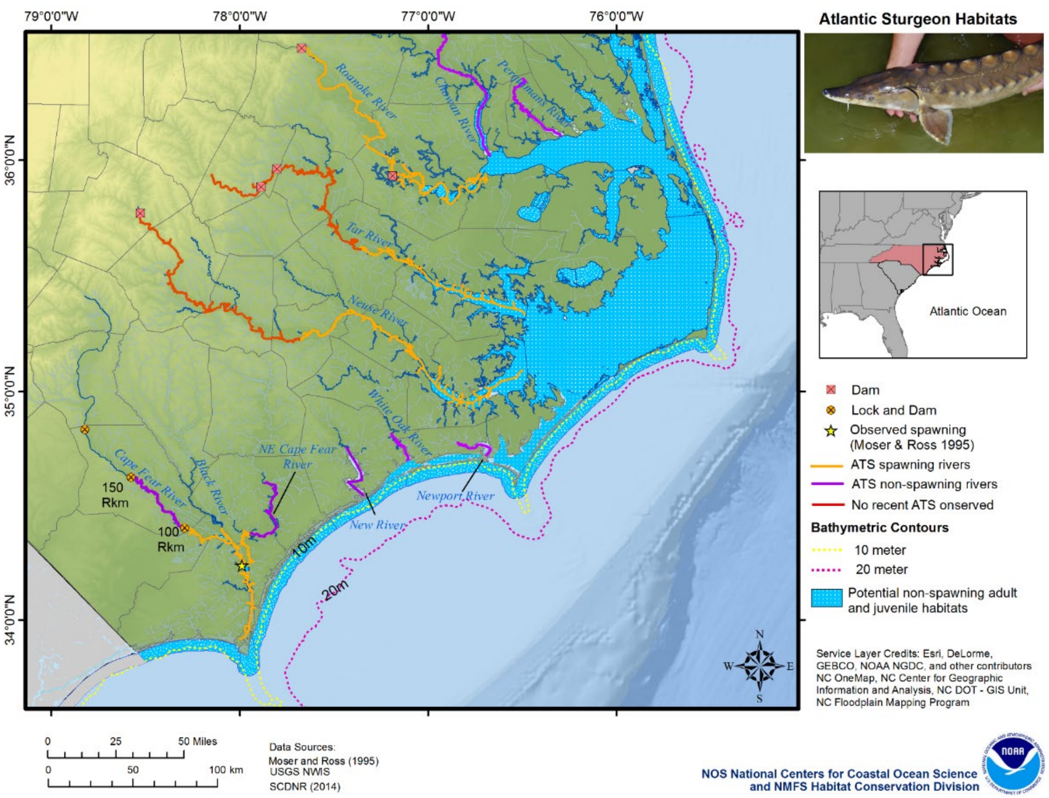
River / Estuary / Ocean	Life Stage	Q1=Winter			Q2=Spring			Q3=Summer			Q4=Fall		
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Atlantic Sturgeon (*Acipenser oxyrinchus*)	Pre-spawn & Spawning Adults*					*	*	*	*				
	Egg												
	Larvae												
	YOY Growth												
	Subadults year-round												
	Subadult overwinter												

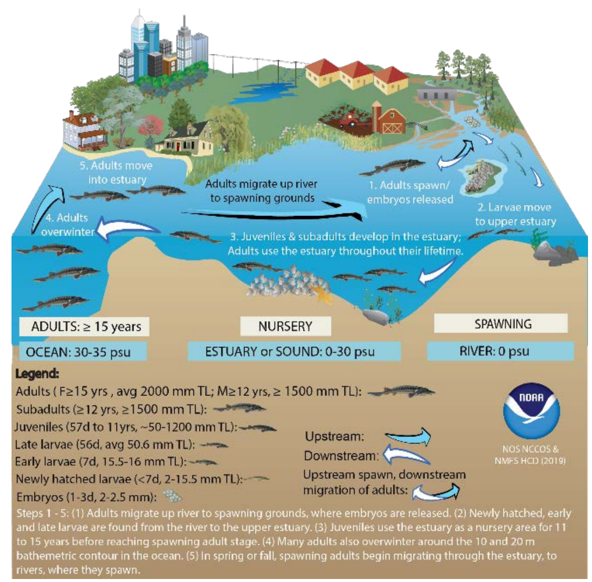
* Pre-spawn adults are present in estuaries May through August as they stage to get ready to run up the river. In North Carolina subadults are in the estuaries year round. A certain proportion of these individuals overwinter in the ocean.

- Spawning and Eggs: river bedrock, cobble, coarse sand, shells, weeds, or logs on the bottom
- Subadults and adults travel within the marine environment, typically in waters less than 50 meters in depth, using coastal bays, sounds, and ocean waters

Objective 3

Determine temporal and spatial patterns at various life stages providing a synthesis of 13 species, establishing a decision-making basis for coastal development moratoria





River / Estuary / Ocean	Life Stage	Q₁=Winter Jan	Feb	Mar	Q₂=Spring Apr	May	Jun	Q₃=Summer Jul	Aug	Sep	Q₄=Fall Oct	Nov	Dec
Atlantic Sturgeon (*Acipenser oxyrinchus*)	Pre-spawn & Spawning Adults*					*	*	*	*				
	Egg												
	Larvae												
	YOY Growth												
	Subadults year-round												
	Subadult overwinter												

* Pre-spawn adults are present in estuaries May through August as they stage to get ready to run up the river. In North Carolina subadults are in the estuaries year round. A certain proportion of these individuals overwinter in the ocean.

Habitat Use

		Function				
Species	**Habitat**	**Nursery**	**Foraging**	**Refuge**	**Spawning**	**Corridor**
Atlantic Sturgeon	Water Column					
	Shell Bottom					
	SAV					
	Wetlands					
	Soft Bottom					
	Hard Bottom					
Shortnose Sturgeon	Water Column					
	Shell Bottom					
	SAV					
	Wetlands					
	Soft Bottom					
	Hard Bottom					
American Shad	Water Column					
	Shell Bottom					
	SAV					
	Wetlands					
	Soft Bottom					
	Hard Bottom					
River Herring	Water Column					
	Shell Bottom					
	SAV					
	Wetlands					
	Soft Bottom					
	Hard Bottom					
Blue Crab	Water Column					
	Shell Bottom					
	SAV					
	Wetlands					
	Soft Bottom					
	Hard Bottom					

Optimizing Moratoria – Spawning

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	Winter			Spring			Summer			Fall		
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ANADROMOUS FISH												
American Shad												
River Herring												
Atlantic Sturgeon												
Shortnose Sturgeon												
ESTUARINE AND INLET SPAWNING AND NURSERY												
Blue Crab												
Red drum												
MARINE SPAWNING, LOW-HIGH SALINITY NURSERY												
Brown Shrimp												
Southern Flounder												
White Shrimp												
MARINE SPAWNING, HIGH SALINITY NURSERY												
Gag												
Pink Shrimp												
Summer Flounder												

Spawning seasons for coastal fish and invertebrate species occurring in North Carolina and South Carolina that broadcast planktonic or semidemersal eggs. Blue indicates peak spawning season, while the hatched areas indicates times when spawning is still occurring, but is non-peak spawning periods (adapted from NCDEQ 2016).

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Optimizing Moratoria – Eggs, larvae, juveniles

Table. Summary of the most sensitive life stages (eggs, larvae, and early juveniles) for each fisheries species assessed, and their distribution throughout the year. Boxes represent abundant eggs and/or larvae present in a given area. Light blue = River habitat; Gray = Inlet habitat; Dark blue = Estuarine habitat; Black = Ocean

Fishery Species	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
River / Inlet / Estuary												
Brown Shrimp												
White Shrimp												
Pink Shrimp												
Atlantic Blue Crab												
Gag Grouper												
Summer Flounder												
Southern Flounder												
Red Drum												
Atlantic Sturgeon												
Shortnose Sturgeon												
American Shad												
River Herring												
Ocean												
Brown Shrimp												
Pink Shrimp												
Blue Crab												
Gag Grouper												
Summer Flounder												
Southern Flounder												

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Upcoming Work from Our Lab

NOAA/NOS/NCCOS/Marine Spatial Ecology Division

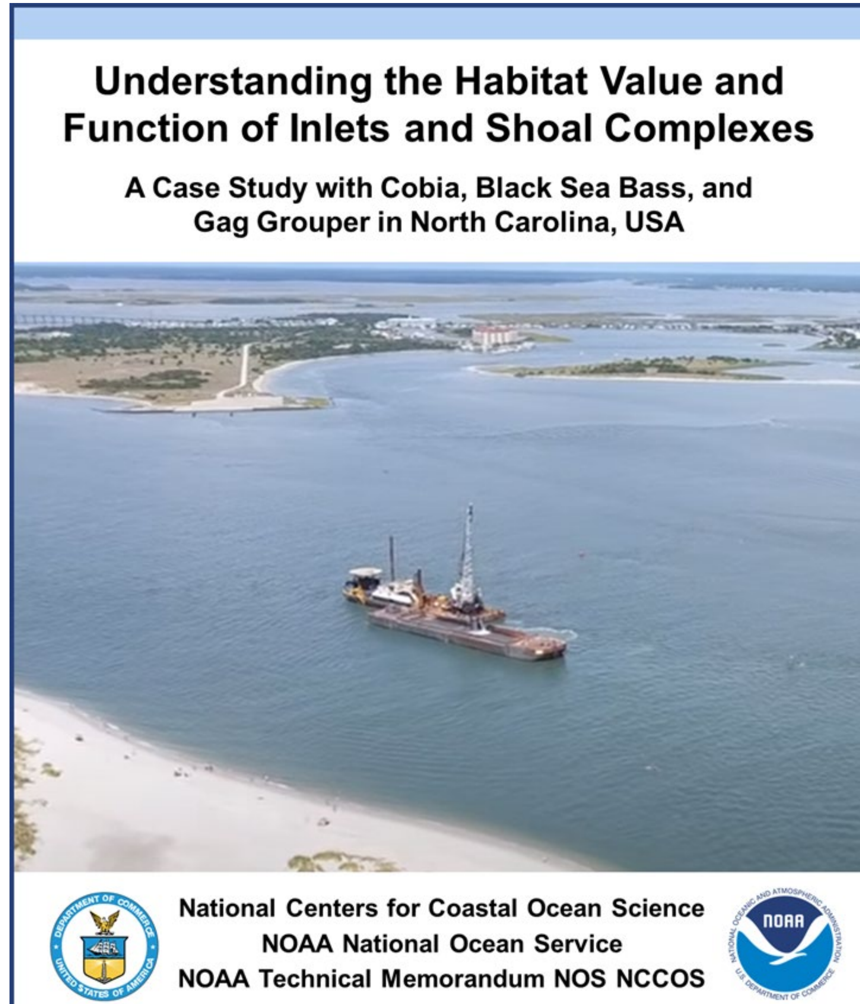
Jensen, B. Bogdanoff, A., Morris, Jr., J., and K. Riley (2020). Understanding the Habitat Value and Function of Inlets and Shoal Complexes

This study aims to understand how Cobia, Black Sea Bass, and Gag utilize inlets and shoal habitat in NC.

Preliminary findings:

- Dredging ranks as one of the most concerning threats to EFH
- Substantial knowledge gaps exist understanding full life history habitat requirements for these species
- Immediate need for studying the direct interactions of dredging at coastal inlets on larval fish and EFH

Coming Soon!



Understanding the Habitat Value and Function of Inlets and Shoal Complexes

A Case Study with Cobia, Black Sea Bass, and Gag Grouper in North Carolina, USA

National Centers for Coastal Ocean Science
NOAA National Ocean Service
NOAA Technical Memorandum NOS NCCOS

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Questions?