Wilmington Harbor, North Carolina
Navigation Improvement Project

Integrated
Section 203 Study
&
Environmental Report

APPENDIX J

FISH HABITAT ASSESSMENT

February 2020

EXECUTIVE SUMMARY

The Wilmington Harbor Section 203 Feasibility Study investigated the potential impacts associated with improving the federal navigation channel at Wilmington Harbor. As a component of the study, Dial Cordy and Associates Inc. (DCA) conducted a fisheries habitat assessment using United States Fish and Wildlife Service (USFWS) Habitat Suitability Index (HSI) Models. Habitat Suitability Index models are approved by the United States Army Corps of Engineers (USACE) and offer a way to quantify habitat value by examining species habitat relationships. Habitat Suitability Index models produce an overall numerical index that scores areas on a 0.0 to 1.0 scale with 0.0 defining unsuitable habitat and 1.0 designating optimal habitat.

A Delft3D hydrodynamic and water quality model provided inputs for the HSI models, and MATLAB computing software was used to calculate HSI model variables. This coupled modeling approach afforded a method for predicting changes in habitat value per geographic grid cell from existing conditions to a future-without-project (FWOP) condition (year 2077 including 0.34 feet relative sea level rise) and the feasible alternative [future with project (FWP)], which includes deepening and widening sections of the federal navigation channel; as well as, extending the ocean entrance channel. Habitat Suitability Index model outputs were displayed in a geographical information system (ArcGIS) and are intended to inform decision making, while providing a visual way to interpret impacts and communicate results to natural resource agencies.

Studying all potentially affected species that occur within the project area was not practicable; therefore, DCA consulted with natural resource agencies to select species that would represent broader fish guilds and provide meaningful results. The following species were ultimately selected for HSI modeling:

- Atlantic sturgeon (*Acipenser oxyrinchus oxyrinchus*) - an anadromous, demersal, endangered species
- Striped bass (*Morone saxatilis*) - an anadromous, pelagic, recreationally fished species
- Atlantic menhaden (*Brevoortia tyrannus*) - a filter feeding, commercially fished species
- White shrimp (*Litopenaeus setiferus*) - an invertebrate, commercially fished species
- Southern flounder (*Paralichthys lethostigma*) - a benthic, recreationally fished species
- Red drum (*Sciaenops ocellatus*) - a demersal, estuarine-dependent, protected game fish

Although USFWS HSI models were easily acquired for red drum, striped bass, and southern flounder; only Gulf of Mexico models were available for white shrimp and Atlantic menhaden, and no HSI model was available for Atlantic sturgeon. Therefore, to model white shrimp and Atlantic menhaden, DCA modified existing Gulf of Mexico HSI models using local datasets specific to the Cape Fear River. Furthermore, a binary suitability model (pass/fail) was developed for Atlantic sturgeon based on a series of thresholds established by the Atlantic States Marine Fisheries Commission (ASMFC). All model details were reviewed by a Technical Working Group made up of representatives from state and federal natural resource agencies, and any recommendations were incorporated prior to initial model runs.

To standardize the fisheries assessment results across all modeled species, the project area was subdivided into six river reaches: lower estuary, middle estuary, upper estuary, Cape Fear River, Northeast Cape Fear River, and Black River. In addition, marine habitat seaward of the Cape Fear River mouth and floodplain cells were excluded from the assessment. Acreage per HSI class, Mean HSI, Maximum HSI, and Minimum HSI were determined for the FWOP condition and the FWP using the field calculator and statistics functions in ArcGIS. Habitat Suitability Index deltas and percent change in suitable habitat were also determined for each species. Negative deltas represent a reduction in habitat quality; whereas, positive deltas identify increases in habitat suitability per grid cell. The Deflt3D low flow year (2011) datasets were used for all HSI modeling, leading to more conservative results. The outputs for each HSI model were classified into equal interval classes whenever possible and color coded on a red to green scale, symbolizing poor to high quality habitat, respectively.

Fisheries assessment results indicate an upstream shift in salinity from existing conditions to the FWOP condition and the feasible alternative (FWP). Salinity increases; however, do not appear to have an adverse effect on euryhaline species like red drum or southern flounder. Furthermore, Atlantic menhaden habitat in the upper estuary, particularly the Brunswick River and the Cape Fear River from the Port of Wilmington to Smith Creek, is improved from an increase in salinity; which also serves as a proxy for food availability. Salinity reduces habitat quality for white shrimp in the lower estuary just inside the Cape Fear River mouth, but optimal conditions occur for white shrimp throughout the middle and upper estuary as well as the lower Cape Fear River and Northeast Cape Fear River. Lower salinity in the Black River and uppermost reaches of the Cape Fear River and Northeast Cape Fear River reduce habitat suitability because the model assumes salinity below 5 parts per thousand (ppt) reduces food availability.

Atlantic sturgeon habitat was unsuitable throughout much of the study area when all life history stages were integrated. This is due to the influence of the spawning and egg/larval components on the overall HSI and the pass/fail design of the model. However, further investigation revealed that the upper estuary reach was suitable when the spawning component was removed from the final HSI equation and analyzed separately. After removing the spawning component, the upper estuary was classified as suitable foraging habitat for juveniles and adults except for upper Sturgeon Creek and Smith Creek; whereas, the lower and middle estuary were unsuitable for these life stages due to average summer salinity above the acceptable thresholds. Large areas of the Cape Fear River above Wilmington and the Northeast Cape Fear River were classified as suitable foraging habitat for juveniles and adults. This is consistent with ongoing sampling and telemetry conducted by the North Carolina Division of Marine Fisheries and the North Carolina Wildlife Resources Commission. Only a small area of Atlantic sturgeon foraging habitat near Navassa, North Carolina, was affected by an increase in salinity from the FWOP and FWP conditions. Similarly, foraging habitat in the Northeast Cape Fear River is affected by increased salinity from the FWOP and the FWP conditions from the entrance of Smith Creek upstream approximately 0.25 and 1.5 river miles, respectively.

The striped bass HSI model, with all five life stage components combined, produces an HSI for the entire life cycle of the species. This version of the model; however, is highly constrained because it evaluates areas based on 11 habitat variables, and the larval component is the limiting life stage. Evaluating the model by examining each component/life stage index separately yields more meaningful results and provides a better understanding of how striped bass likely utilize the different areas of the system throughout their lives.

Results indicate that the lower estuary is unsuitable for spawning and egg development. Moreover, the lower estuary is unsuitable for larval development up to MOTSU. Habitat quality improves for larvae upstream of MOTSU, and the entire lower estuary is suitable for adults and juveniles.

The middle estuary is suitable for adult and juvenile striped bass except for upper Town Creek, which exhibits lower salinity. In addition, the middle estuary is unsuitable for egg development, but suitable for larvae apart from an area near Carolina Beach State Park. This location displays higher salinity likely from water entering through Snow's Cut from the Atlantic Intracoastal Waterway. The higher salinity conditions near Snow's Cut reduces habitat quality for larvae along the eastern bank of the Cape Fear River up to approximately Masonboro Country Club under the FWOP and FWP conditions.

Existing Conditions in the upper estuary are suitable for egg development in the lower Brunswick River and the Cape Fear River from the southern tip of Eagle Island to Smith Creek. Furthermore, the entire upper estuary is highly suitable for larval development aside from Smith Creek and upper Sturgeon Creek where salinity falls below the optimal threshold. Under the FWOP and FWP conditions, habitat quality for larval development is improved in the Brunswick River, and the upper estuary is highly suitable for adults and juveniles for all sets of conditions. Under the FWOP condition there is a reduction in foraging habitat suitability near the Kinder Morgan Liquid Bulk Pier due to increased salinity. Under the FWP condition, already poor foraging habitat (0.2-0.4) is reduced to unsuitable habitat due to an increase in salinity from the Port of Wilmington to the beginning of the Northeast Cape Fear River. Increased salinity also reduces foraging habitat quality in the upper Brunswick River under the FWOP and the FWP conditions.

The existing condition in the Cape Fear River below Lock and Dam #1 downstream to Wilmington is suitable for egg development other than areas with reduced current velocity and low summer dissolved oxygen. Larval development in this reach is only suitable below Sutton Lake where salinity is still above the 4 ppt threshold. Under all sets of conditions, highly suitable spawning habitat is found just below Lock and Dam #1, and areas further downstream to Wilmington are suitable foraging habitat for juveniles and adults.

The Northeast Cape Fear River is highly suitable for egg development in the channel upstream to Fishing Creek, but is unsuitable outside the channel due to lower current velocity. Habitat quality for egg development remains largely the same in this area under the FWOP and the FWP conditions. Habitat for larval development in the Northeast Cape Fear River is suitable until salinity drops below 4 ppt near Ness Creek. Under the FWOP and the FWP conditions, there is little change in habitat suitability for larval development from baseline conditions. Baseline modeling indicates the Northeast Cape Fear River is suitable foraging habitat for striped bass; however, increased salinity under the FWOP and the FWP conditions reduce habitat quality near the entrance to Smith Creek. Upstream of Smith Creek, salinity effects do not affect foraging habitat, but hypoxic conditions reduce habitat quality near Castle Hayne.

The lower Black River exhibits suitable conditions for egg and larval development as well as for adult and juvenile striped bass. Below Bear Branch conditions are suitable for foraging; however, above Bear Branch low summer dissolved oxygen and current velocity reduce habitat quality. Below Bear Branch, conditions are suitable for foraging; however, above Bear Branch, low summer dissolved oxygen and current velocity reduce habitat quality.

Table of Contents

List of Tables

List of Figures

List of Acronyms

ASMFC	Atlantic States Marine Fisheries Commission
ASSRT	Atlantic Sturgeon Status Review Team
C	Celsius
DCA	Dial Cordy and Associates Inc.
DO	Dissolved Oxygen
DPS	Distinct Population Segment
EFH	Essential Fish Habitat
ESA	Endangered Species Act
ETZ	Estuarine Transition Zone
F	Fahrenheit
FR	Federal Register
FT	Feet
FWOP	Future Without Project
FWP	Future With Project
HSI	Habitat Suitability Index
M	Meters
MG/L	Milligrams Per Liter
MOTSU	Military Ocean Terminal at Sunny Point
NC	North Carolina
NCDMF	North Carolina Division of Marine Fisheries
NCSPA	North Carolina State Ports Authority
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
POW	Port of Wilmington
PPT	Parts Per Thousand
SAV	Submerged Aquatic Vegetation
SRT	Status Review Team
USACE	United States Army Corps of Engineers
USFWS	United States Fish and Wildlife Service

1 INTRODUCTION

To determine the feasibility of improving the federal navigation channel at Wilmington Harbor, the North Carolina Ports Authority (NCSPA) is conducting a Section 203 Feasibility Study. Proposed harbor improvements include deepening and widening sections of the federal navigation channel, extending the ocean entrance channel, expanding the turning basin, and widening bends around channel turns. The purpose of these improvements is to prepare the Port of Wilmington to accommodate larger cargo vessels in the future. Primary objectives of the study include:

1. Accommodate future growth in cargo vessel traffic
2. Improve efficiency of cargo vessel operations
3. Make Wilmington Harbor accessible to larger more efficient cargo vessels
4. Allow the Port of Wilmington to remain competitive among major United States East Coast containership ports-of-call

As a component of the Wilmington Harbor Navigation Improvements Project Section 203 Feasibility Study, Dial Cordy and Associates Inc. (DCA) performed a fisheries habitat assessment. The objective of the fisheries assessment was to evaluate potential impacts to fisheries and fisheries habitat associated with the proposed improvements to the federal navigation channel. The fisheries assessment utilized a coupled modeling approach, combining a three-dimensional hydrodynamic and water quality model with United States Fish and Wildlife Service (USFWS) Habitat Suitability Index (HSI) models.

2 TECHNICAL APPROACH

2.1 Habitat Suitability Modeling

To evaluate impacts on fish and wildlife associated with deepening and widening sections of Wilmington Harbor, DCA applied USFWS HSI models. Habitat Suitability Index models are approved for use by the United States Army Corps of Engineers (USACE) and provide a way to quantify habitat value through species habitat relationships. These models use suitability graphs to represent the correlation between habitat variables and a suitability index (Figure 1). Habitat Suitability Index models produce an overall numerical index that scores areas on a 0.0 to 1.0 scale (1.0 = optimal habitat) (Schamberger et al. 1982).

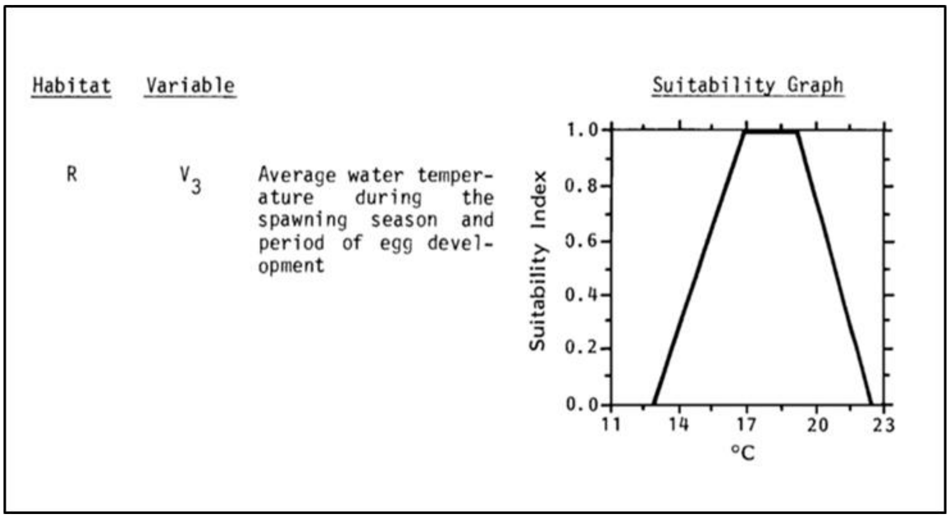


Figure 1
Typical HSI Suitability Graph

2.2 Delft3D and MATLAB

A Delft3D hydrodynamic model was used to predict changes in water quality per geographic grid cell within the project area (Figure 2). Delft3D model outputs provided source data for HSI modeling, and MATLAB computing software was used to perform calculations on HSI variables. Changes in habitat value were assessed per grid cell to analyze existing conditions, Future without Project (FWOP) conditions (year 2077 including sea level rise), and the feasible alternative [(Future with Project (FWP)]. Habitat Suitability Index model outputs were displayed in a geographical information system (ArcGIS) and are intended to inform decision making, while offering a visual way to interpret impacts and communicate results to natural resource managers. A similar approach has been implemented for the Savannah Harbor Expansion Project, Jacksonville Harbor Navigation Study, and Charleston Harbor Post-45 Study.

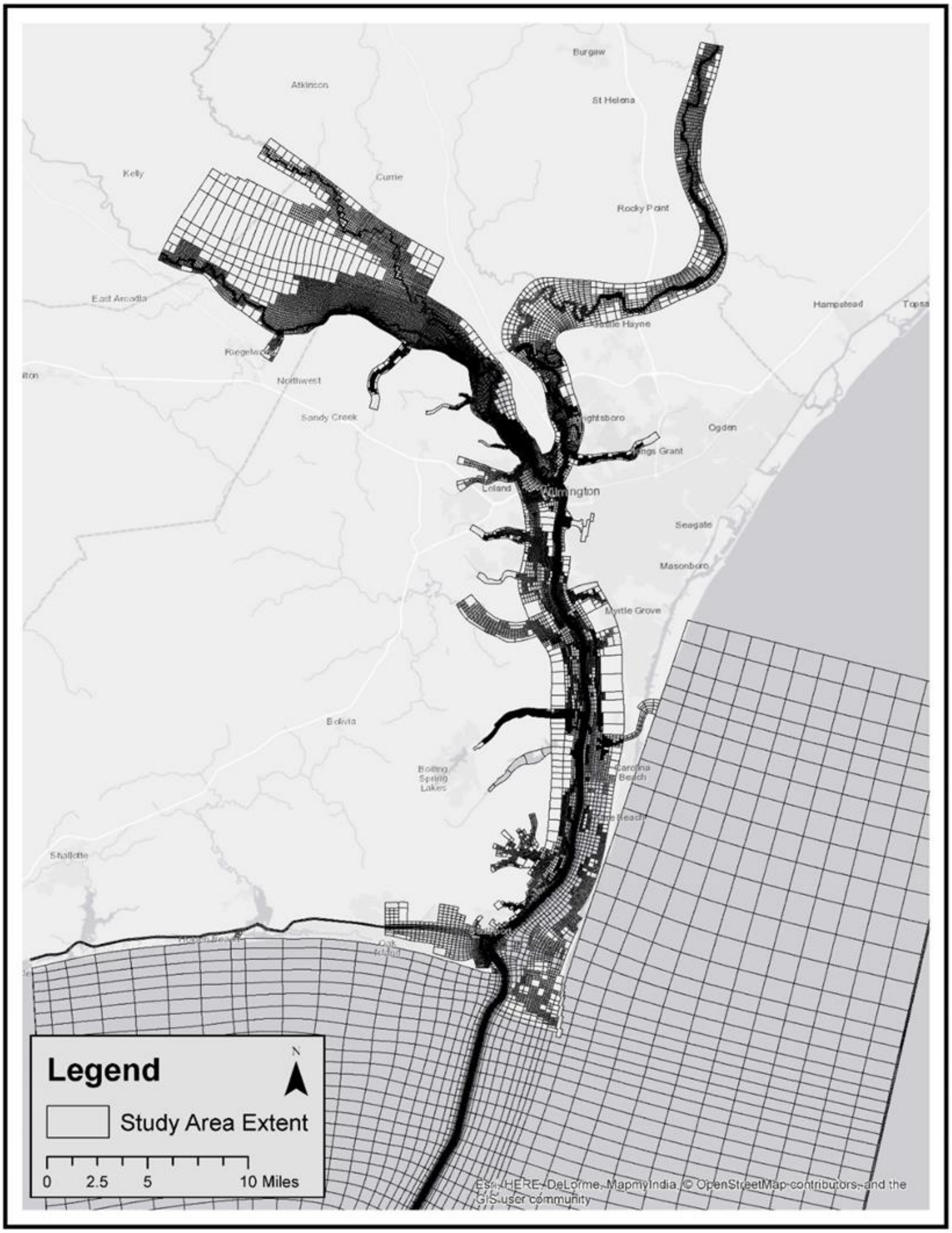


Figure 2
Study Area Extent Displayed Using the Delft3D Hydrodynamic and Water Quality Grid

2.3 Modeled Habitat Effects

To standardize the fisheries assessment results across all modeled species, the project area was subdivided into six river reaches; lower estuary, middle estuary, upper estuary, Cape Fear River, Northeast Cape Fear River, and Black River (Figure 3). In addition, marine habitat seaward of the Cape Fear River mouth and floodplain cells were excluded from the analysis.

Acreage per HSI class, mean HSI, maximum HSI, and minimum HSI were determined for all sets of conditions using the field calculator and statistics functions in ArcGIS. Additionally, HSI deltas and percent change in suitable habitat were calculated. Negative deltas representing a reduction in habitat quality; as well as, positive deltas that identify increases in habitat suitability were determined. The Deflt3D low flow year (2011) was used for all HSI modeling and serves to conserve the HSI model results. Habitat Suitability Index model outputs were classified into equal interval classes whenever possible and color coded on a red to green scale, symbolizing poor to high quality habitat, respectively.

2.4 Selection of Species

It was not practicable to study all potentially affected species that occur within the project area; therefore, DCA consulted with natural resource agencies to select species that represent broader fish guilds and provide the most meaningful results. The following species were selected for HSI modeling:

- Atlantic sturgeon (*Acipenser oxyrinchus oxyrinchus*) - an anadromous, demersal, endangered species
- Atlantic menhaden (*Brevoortia tyrannus*) - a filter feeding, commercially fished species
- White shrimp (*Litopenaeus setiferus*) - an invertebrate, commercially fished species
- Southern flounder (*Paralichthys lethostigma*) - a benthic, recreationally fished species
- Red drum (*Sciaenops ocellatus*) - a demersal, estuarine-dependent, protected game fish
- Striped bass (*Morone saxatilis*) - an anadromous, pelagic, recreationally fished species

Although USFWS HSI models were easily acquired for red drum, striped bass, and southern flounder; only Gulf of Mexico models were available for white shrimp and Atlantic menhaden, and no HSI model was available for Atlantic sturgeon. Therefore, to model white shrimp and Atlantic menhaden, DCA modified existing Gulf of Mexico HSI models using local datasets specific to the Cape Fear River. Furthermore, a binary suitability model (pass/fail) was developed for Atlantic sturgeon based on a series of thresholds established by the ASMFC. All model details were reviewed by a Technical Working Group made up of representatives from state and federal natural resource agencies, and all recommendations were incorporated prior to initial model runs.

Due to the importance placed on recovering Atlantic sturgeon and striped bass stock in the Cape Fear River, and to gain a better understanding of how anadromous species utilize different areas of the river throughout their lives, HIS models for the Atlantic sturgeon and striped bass were broken down into life stage components for analysis. The Cape Fear River was designated as critical habitat for Atlantic sturgeon in 2017, and in 2012, the Carolina Distinct Population Segment (DPS) was listed as endangered. Moreover, there is currently a harvest moratorium on

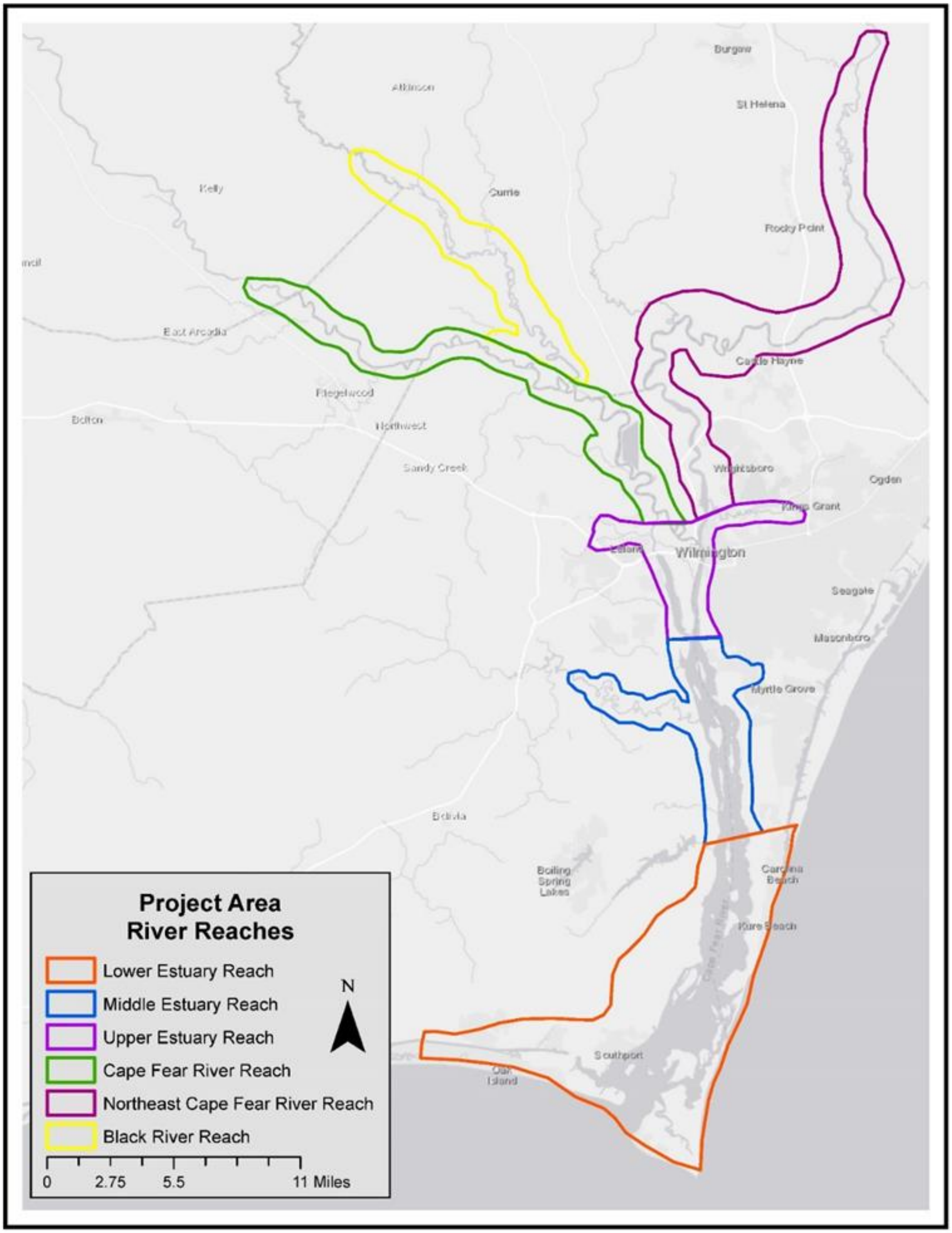


Figure 3
Designated River Reaches within the Study Area Used Across All HSI Models

striped bass in the Cape Fear River and an ongoing effort to improve fish passage for anadromous species by modifying the rock arch fishway at the USACE Lock and Dam #1 above Wilmington, North Carolina (NC).

The remaining selected species were evaluated using the overall HSI since the existing models did not support life stage analysis. Regardless, locations where changes from baseline conditions occurred were evaluated to determine which model variables were influencing habitat changes.

2.5 Substrate Composition

Substrate is an important habitat variable for nearly all selected species. For example, Atlantic sturgeon prefer to spawn over hard substrate to facilitate egg adhesion; whereas, southern flounder, red drum, Atlantic menhaden, and white shrimp prefer muddy bottoms over sand or shell bottom. Substrate is not as important for striped bass because they utilize a variety of habitat types and their eggs are semi-buoyant and non-adhesive. Unfortunately, substrate data for the Cape Fear River was unavailable, thus areas with unsuitable substrate were not excluded from the final analysis. To better understand model results, local knowledge and consultation with state and federal natural resource agencies was relied on to determine how substrate plays a role in the final habitat evaluation.

3 ANADROMOUS SPECIES

3.1 Atlantic Sturgeon

Atlantic sturgeon populations are considered either extirpated or at historically low abundances throughout their geographic range (ASMFC 1998). Like many systems that once contained healthy populations of anadromous sturgeon, the Cape Fear River has been reduced to a small population of breeding adults estimated at 300 individuals [Atlantic Sturgeon Status Review Team (ASSRT) 2007]. During 2007, the ASMFC Status Review Team (SRT) identified five Distinct Population Segments (DPS); and among others, the Carolina DPS was given a 50 percent (%) chance of becoming extinct within the next 20 years. On 6 February 2012, the National Oceanic and Atmospheric Administration's (NOAA's) National Marine Fisheries Service (NMFS) listed the Carolina DPS of Atlantic sturgeon as endangered under the Endangered Species Act (ESA); an action that triggers several additional conservation measures by federal and state agencies, private groups, and individuals [77 Federal Register (FR) 5914]. Habitat is given a critical designation when a species utilizing the area is listed as threatened or endangered. Under the ESA, critical habitat is described as specific geographic areas that contain features essential to the conservation of an endangered or threatened species (ASMFC 2017). The ASMFC designated critical habitat for the Carolina DPS of Atlantic sturgeon in 2017 (Figure 4).

Reported landings of Atlantic sturgeon peaked in 1890 at 7.5 million pounds and declined sharply thereafter. During the 1970s and 80s, most of the fishing effort and landings shifted from northern populations to the Carolinas and Georgia (ASMFC 1998). Historical overfishing, incidental bycatch, and the continued degradation or loss of essential fish habitats (EFH) are impediments to large scale recovery. Munro et al. (2007) states, the most important aspect in restoration of anadromous sturgeon is small scale habitat diversity and sufficient connectivity within a river system; specifically, overcoming obstacles such as passage over dams that prevent access to historical spawning grounds.

In the Cape Fear River, historical spawning grounds are located at Smiley Falls, approximately 180 miles from the river mouth, near Lillington, NC (Stevenson 1899). In 2011/2012 a rock arch ramp was constructed at the USACE Lock and Dam #1 to aid anadromous fish passage and reestablish connectivity with upstream habitat (Figure 5). However, passage rates of larger bodied anadromous fish are currently unsatisfactory and a modification to the rock arch ramp has been proposed for 2019/2020. A recent study (Raabe et. al. 2017) indicates that of those fish that approach Lock and Dam #1 in an apparent attempt to pass, 53% to 65% of American shad (*Alosa sapidissima*) and 19% to 25% of striped bass are successful. Atlantic sturgeon passage rates have been more difficult to assess, but the collective body of evidence suggests they are well below sustainable levels.

Atlantic sturgeons have a diverse life history and geographic range, occupying areas from the upper reaches of major rivers to marine feeding grounds. Moreover, depending on age class, salinity tolerance, and prey preference, they occur in different locations within a riverine/estuarine system. For instance, the Estuarine Transition Zone (ETZ) is used

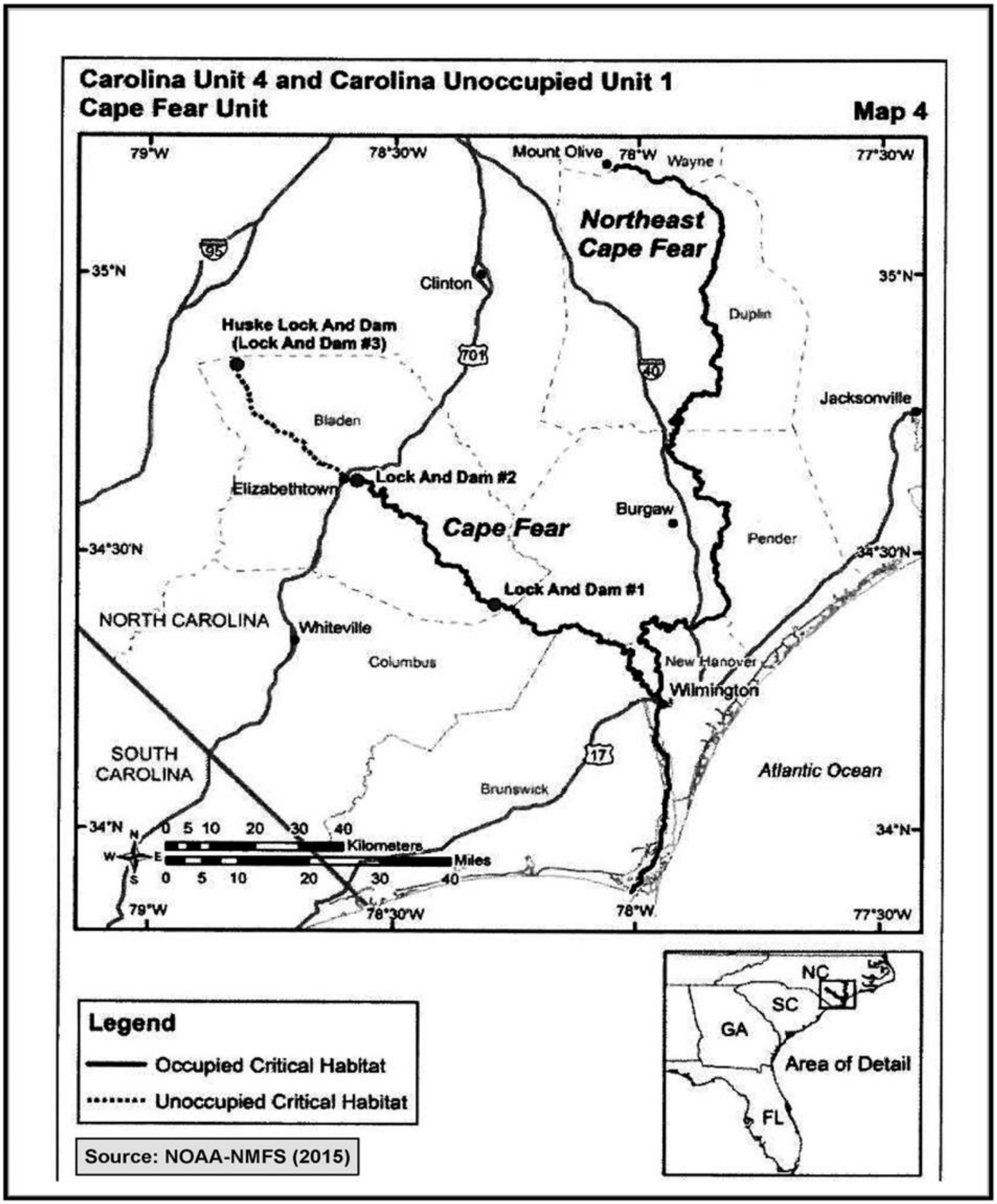
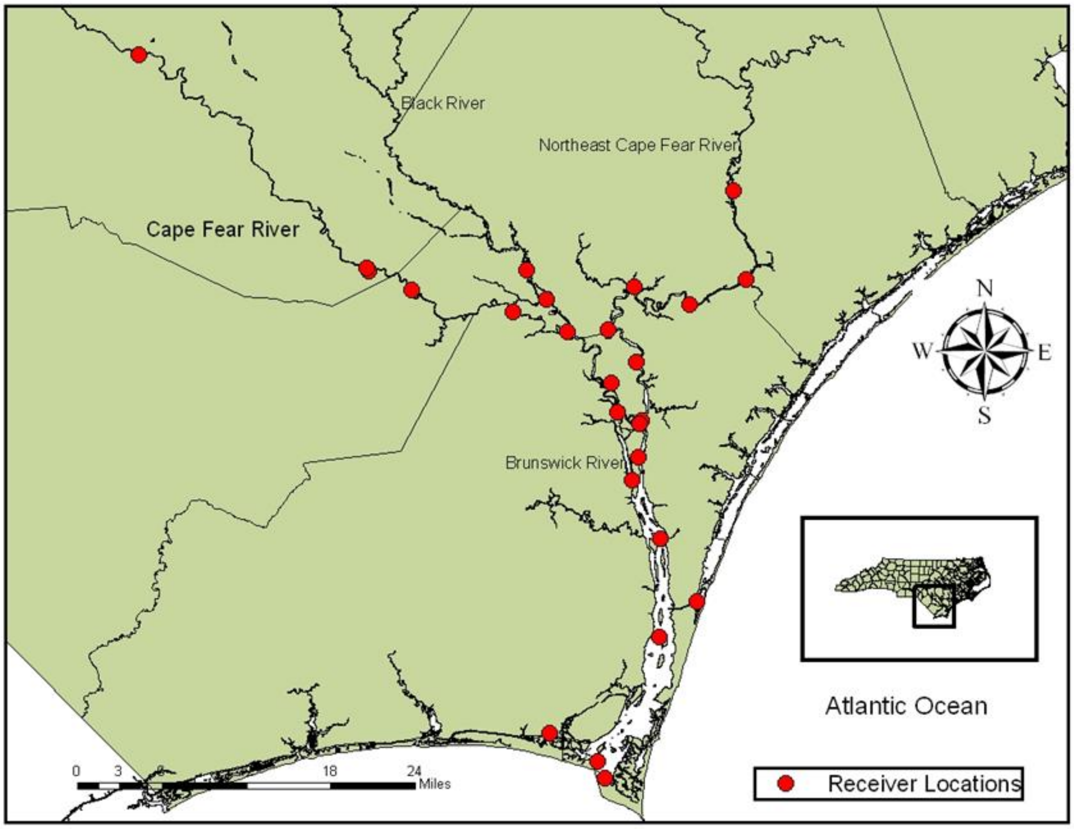


Figure 4
Atlantic Sturgeon Critical Habitat

Figure 5
Existing Rock Arch Rapids Fish Ramp at Lock and Dam #1

by age-0 to age-2 Atlantic sturgeons because it provides the preferred juvenile food resources. Nellis et al. (2007) and Simons (2004) showed that the ETZ is characterized by successional benthic fauna and oligochaete benthic assemblages associated with fine sediments that accumulate near the upper limit of the salt wedge. During stomach content analysis, Guilbard et al. (2007) showed oligochaete tubificids were the dominant taxon in stomachs of early juvenile Atlantic sturgeon. Similarly, age-0 class Atlantic sturgeons were found in the freshwater frontal zone where their main food source, *Gammarus tigrinus*, occurs in significant assemblages (Nellis et al. 2007, Guilbard et al. 2007). As this species matures past year two, its range expands to include more estuarine habitat; however, the ETZ is typically a small part of most estuaries and should be qualified as essential habitat necessary for age-0 to age-2 Atlantic sturgeons.

The North Carolina Division of Marine Fisheries (NCDMF) captured Atlantic and shortnose sturgeon during their upstream migration in late-winter and early-spring of 2013 (NCDMF 2013, Table 1). Using sinking monofilament gill and trammel nets, individuals were captured prior to spawning and telemetry tags were surgically implanted. To support tagging efforts, Vemco receivers were deployed in a passive array to relocate sturgeon within the Cape Fear River (Figure 6). Also, in the Brunswick River, sturgeon were targeted using gillnets on 30 different sampling events from January to June 2013. Gill netting and tagging of sturgeon has continued annually, but due to lack of funds, annual reports summarizing the data have not been prepared (Personal communication, Joe Facendola, North Carolina Division of Environmental Quality, January 2017).



Source: NCDMF 2013

Figure 6
Locations of Vemco Receivers Deployed in the Cape Fear River, North Carolina, June 2013

Table 1
Emigration and Return Dates for Atlantic Sturgeon Implanted with Sonic Tags in the Cape Fear River

Capture/Release Date	FL (mm)	Sonic ID	Date Emigrated	Date Returned	Days at Large Outside Cape Fear River
10/11/2012	958	29704	11/20/2012	3/26/2013	126
3/30/2012	1146	29705	11/5/2012	5/1/2013	177
10/11/2012	934	29706	11/14/2012	4/18/2013	155
9/20/2012	1015	29707	10/28/2012	5/4/2013	188
3/30/2012	1265	29716	10/30/2012	4/21/2013	173
6/11/2012	975	29717	11/2/2012		
5/24/2012	951	29718	10/24/2012		
10/24/2012	1021	29723	11/19/2012	4/27/2013	159
9/27/2011	793	45122	11/2/2012	4/28/2013	177
10/4/2011	909	45126	11/6/2012	4/26/2013	171
10/4/2011	962	45127	10/25/2012	3/29/2013	155
2/22/2012	1970	45129	4/13/2012	2/15/2013	308
2/21/2012	960	45131	3/27/2012		
3/28/2012	1102	45132	11/23/2012		
3/28/2012	981	45133	11/12/2012	4/20/2013	159
4/15/2011	931	45154	11/1/2012	4/28/2013	178
3/30/2011	668	45155	12/1/2012	2/21/2013	82
3/31/2011	683	45156	11/1/2012	4/30/2013	180
4/19/2011	1030	45157	11/4/2012	5/6/2013	183
4/27/2011	1025	45158	11/5/2012	5/6/2013	182
4/6/2011	825	45161	11/18/2012	4/22/2013	155
5/18/2011	780	45162	3/20/2012		
5/25/2011	891	45167	10/30/2012		
9/21/2011	1105	45173	10/19/2012	6/12/2013	236
9/21/2011	784	45174	10/31/2012		
9/22/2011	1110	45176	10/24/2012	4/18/2013	176

Source: NCDMF 2013

Habitat variables included in the HSI model for Atlantic sturgeon and associated thresholds are presented in Table 2. All life cycle components were evaluated separately to determine how Atlantic sturgeon use different locations within the project area throughout their lives. In addition, all life stage component indices were combined to provide an overall HSI for the entire life cycle.

Modifications to the ASMFC thresholds to adapt the model to the Cape Fear River include:

- Maximum temperature for adult spawning component increased to 24.6 degrees (°) Centigrade (C)
- Monthly range for adult spawning component; as well as, egg/larval component adjusted to include fall migration period (August through November)
- Minimum Dissolved Oxygen (DO) threshold for adult spawning component increased to 6.0 milligrams per liter (mg/L)
- Minimum DO threshold for adult estuarine component set at 4.3 mg/l

Table 2
Thresholds Used to Develop a Binary Suitability Model for Atlantic Sturgeon

Life Stage	Time of Year and Location	Depth (m)	Temperature (°C)	Salinity (ppt)	Substrate	Current Velocity (m/sec)	Dissolved Oxygen (mg/L)
Egg and Larval	Eggs are laid in flowing water in rivers along the Atlantic coast. Larval sturgeon are found in same habitat where spawned and are benthic.	**Tolerable:** NIF **Optimal:** 2.4 to 8+ m for egg incubation (HSI model for Southern Regions) **Reported:** Embryos remain in deep channels. Larvae collected 9.1 to 19.8 m	**Tolerable:** 15 to 24.5°C **Optimal:** 20 to 21°C in culture **Reported:** Eggs hatch in 94 to 140 hours ranging from 15.0 to 24.5°C	**Tolerable:** <5 ppt **Optimal:** 0 ppt **Reported:** Found upstream of salt front; have a low tolerance to salinity; mortality reported 5 to 10 ppt for some sturgeon species	**Tolerable: NIF Optimal:** Cobble/gravel >64mm to 250mm (HSI model for Southern Regions) **Reported:** After 20 minutes, eggs become adhesive and attach to hard substrate. Larvae also use hard substrate as refuge	**Tolerable:** NIF **Optimal:** NIF **Reported:** NIF	**Tolerable:** NIF **Optimal:** NIF **Reported:** NIF
Juvenile (Estuarine)	Remain in natal habitats within estuary for up to a year before migrating out to sea. Migrations to other estuaries are common. Use brackish water near month of estuary during winter and move up-estuary during warmer months	**Tolerable:** NIF **Optimal:** Deep water and holes serve as thermal refuge **Reported:** 2 to 37 m	**Tolerable:** 3 to 28°C **Optimal:** ~20°C **Unsuitable:** >28°C are sub-lethal **Reported:** Downstream migration begins when water reaches 20°C and peaks between 12 and 18°C. Documented range of 0.5 to 27°C	**Tolerable:** NIF **Optimal:** ~10 ppt **Reported:** Large juveniles found mostly where salinity is >3 ppt; found 0 to 27.5 ppt	**Tolerable:** NIF **Optimal:** NIF **Reported:** Found mostly over sand substrate and mud or transitional habitats. Also found over rocks and cobble	**Tolerable:** NIF **Optimal:** NIF **Reported:** NIF	**Tolerable:** NIF **Optimal:** >5 mg/L **Reported:** Summer mortality observed at <3.3mg/L and at 26°C
Juvenile and adult (At-sea)	Utilize marine waters during non-spawning seasons. Nearshore areas off the Atlantic coast from the Gulf of Maine to at least Cape Lookout, NC. Little is known about this part of their lives	**Tolerable: NIF Optimal: NIF Reported:** Most found in shallow waters; greatest depth recorded = 75 m; depth range 7 to 43m	**Tolerable:** NIF **Optimal:** NIF **Reported:** NIF	**Tolerable:** NIF **Optimal:** NIF **Reported:** Marine waters on the continental shelf	**Tolerable:** NIF **Optimal:** NIF **Reported:** Sand, gravel, silt and clay. Suggested that they will use any substrate that supports their food resource	**Tolerable:** NIF **Optimal:** NIF **Reported:** NIF	**Tolerable:** NIF **Optimal:** NIF **Reported:** NIF

Table 2 (concluded)

Life Stage	Time of Year and Location	Depth (m)	Temperature (oC)	Salinity (ppt)	Substrate	Current Velocity (m/sec)	Dissolved Oxygen (mg/L)
Adult (Spawning)	Freshwater rivers and possibly tidal freshwater regions of large estuaries (in the north) Feb – Southern states April and May – Mid-Atlantic May to July – Northern States and Canada Sept to Dec – Second spawning documented in Southern regions	**Tolerable:** NIF **Optimal:** 2.4 to 8+ m (HSI model for Southern Regions) **Reported:** 3 to 27 m	**Tolerable:** NIF **Optimal:** 16-21 (HSI model for Southern Regions); 20 to 21□C for cultured sturgeon **Reported:** Male migrations 5.6 to 6.1□C; Female migrations 12.2 to 13□C; Spawning 13 to 23.4□C	**Tolerable:** 0 ppt **Optimal:** 0 ppt **Reported:** Above the salt wedge in fresh water.	**Tolerable: NIF Optimal:** Cobble/gravel >64mm to 250mm (HSI model for Southern Regions) **Reported:** Hard substrate, including rubble, gravel, clay, rock, bedrock, slag from old steel mills and limestone	**Tolerable:** NIF **Optimal:** 0.2 to 0.76 m/sec **Reported:** 0.46 to 0.76 m/sec okay (based on modeling); unsuitable if ≤0.06 m/sec, or ≥ 1.07 m/sec	**Tolerable:** NIF **Optimal:** NIF **Reported:** NIF
Adult (Estuarine)	Sturgeon do not spawn every year, yet may participate in an upstream migration. After spawning, some sturgeon remain in the rivers through the summer, while others migrate to sea. Downstream migrations occur Sept to Nov in Canada. Present in South March to Oct. Overwinter in the ocean.	**Tolerable:** NIF **Optimal:** NIF **Reported:** 1.5 to 60 m	**Tolerable:** NIF **Optimal:** NIF **Reported:** Adult sturgeon documented in waters with temperatures as high as 33.1□C in SC	**Tolerable:** NIF **Optimal:** NIF **Reported:** Documented summer habitat in upper/fresh/ brackish interface, lower interface, and high salinity portions of estuaries in SC. Salinity ranged from 0 to 28.6 ppt.	**Tolerable:** NIF **Optimal:** NIF **Reported:** Found over fine mud, sand, pebbles, and shell substrate	**Tolerable:** NIF **Optimal:** NIF **Reported:** NIF	**Tolerable:** NIF **Optimal:** NIF **Reported:** NIF

3.2 Striped Bass

Striped bass is an anadromous species that migrates upriver to spawn in early spring. Migrations in NC have historically occurred in the Roanoke, Tar, Neuse, and Cape Fear rivers. The Cape Fear fishery, however, has declined and now only small populations within the upper estuary remain (Fisk and Dycus 2015). Due to dam construction along their migration route, the current Cape Fear populations of wild and stocked striped bass are unable to reach historic spawning grounds, and evidence indicates they may stay in the system for their entire lives (Fisk and Dycus 2015). Spawning takes place from March-June when females release as many as three million, semi-buoyant eggs into moving water to be fertilized by several males. For the first few days of life, striped bass larvae are sustained by a yolk; however, they begin to feed on zooplankton shortly thereafter and juveniles and adults prey mostly on other fish including shad and herring (Bain and Bain 1982, http://portal.ncdenr.org/web/mf/04-striped-bass-atlantic-ssr-2016).

The USFWS HSI model for striped bass is comprised of eleven habitat variables and five life stage components. Combined, these variables and components produce an HSI for the entire life cycle of the species. However, to better understand how striped bass are utilizing the project area, DCA assessed each life stage component separately before integrating component indices to compute an overall HSI.

<u>Habitat Variables used in the striped bass HSI model include:</u>

V1 = Percent Natural River Discharge during the spawning season.
V2 = Maximum Total Dissolved Solids during the spawning season (proxy Salinity)
V3 = Average Water Temperature during the spawning season
V4 = Minimum DO during egg and larval development
V5 = Average current velocity in water column during period of egg development
V6 = Percent original salt marsh in estuary
V7 = Percent original freshwater input to estuary during high flow period
V8 = Average water temperature during period of larval development
V9 = Average salinity during period of larval development
V10 = Average DO during the growing season
V11 = Average water temperature during growing season

<u>Life Stages for the Striped Bass HSI model (Figure 7)</u>
C1 = Adult
C2 = Spawning
C3 = Egg
C4 = Larval
C5 = Juvenile

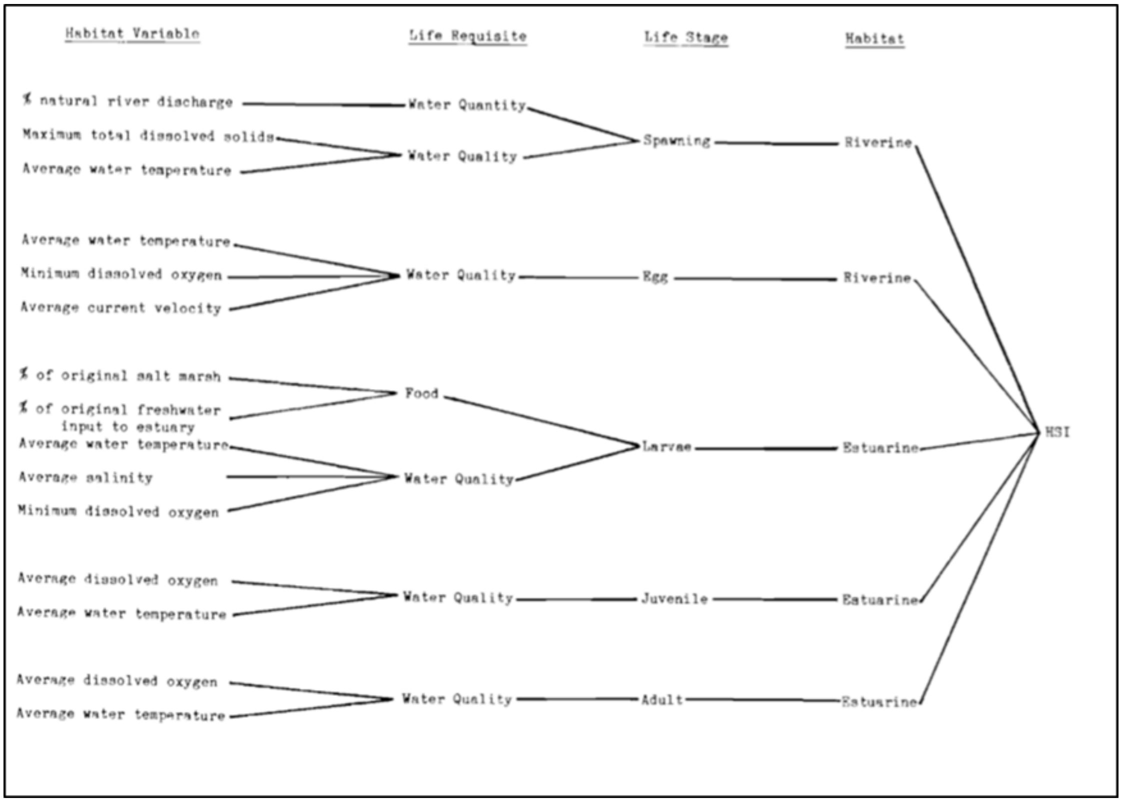


Figure 7
Flow Chart Illustrating the Relationship between Habitat Variables, Life Requisites, Life Stages, and the Habitat Suitability Index Value for Striped Bass

4 ADDITIONAL SELECTED SPECIES

4.1 Atlantic Menhaden

Atlantic menhaden are a vital seasonal component of estuarine and shelf fish assemblages; profoundly influencing the conversion and exchange of energy and organic matter within natural systems due to their abundance, vast migratory patterns, and importance as a prey species. Found in coastal waters and estuaries from Nova Scotia to Florida, Atlantic menhaden are believed to consist of a single population. In early fall, menhaden form schools and migrate south where they spawn off the coast of NC from November to March (Christmas et al. 1982). Typically, within three to five weeks of spawning, larvae are transported through inlets into estuarine nursery grounds and begin to metamorphose into filter-feeding fish. Recruitment depends on nearshore spawning activity and along-shore transport, but the magnitude of recruitment into specific estuaries depends on distribution and timing of spawning (Christmas, et al. 1982). In summer, menhaden are distributed according to size and age with larger fish occupying northern waters and smaller fish remaining further south.

A USFWS Atlantic menhaden HSI model was unavailable; therefore, natural resource agencies were consulted with and ultimately decided to use a modified gulf menhaden model. Salinity with respect to suitable water quality is included in the model parameters and determines the distribution of menhaden in estuarine and nearshore environments (Christmas et al. 1982). Furthermore, the model uses average annual salinity as a proxy for food availability and squares the food component in the final HSI equation, making salinity the most influential habitat variable.

The estuarine version of the model was used in this study and is based on six habitat variables (water temperature, salinity, dissolved oxygen, water color, substrate composition, and marsh area) aggregated into three life requisites (water quality, food, and cover). The food life requisite; however, is calculated without substrate composition data as it was unavailable. Furthermore, the model assumes that successful spawning was completed in the adjacent nearshore marine environment and larval transport into the estuary occurred normally. Aside from salinity, all other habitat variables used in the model are equally weighted. The component and overall HSI equations used for the Atlantic Menhaden model are shown in Figure 8.

Habitat Suitability Index variables for this species are the following:

- V3 = Average annual salinity
- V8 = Lowest monthly average winter water temperature (December – February)
- V9 = Lowest monthly average winter salinity (December – February)
- V10 = Lowest weekly average DO
- V11 = Marsh Acreage
- V12 = Water Color
- V13 = Highest monthly average summer water temperature (June – August)
- V14 = Average annual salinity

Estuarine.

Life requisite	Equation
Water quality	$\frac{(V_8 \times V_{13})^{1/2} + (V_9 \times V_{14})^{1/2} + V_{10}}{3}$
Food	$[(V_3)^2 \times (V_{12})^2 \times V_5]^{1/5}$
Cover	V_{11}

The following equation is used to determine an HSI for gulf menhaden in estuarine habitats:

$$HSI = [\text{Water quality} \times (\text{Food})^2 \times \text{Cover}]^{1/4}$$

Figure 8
Equations Used to Calculate Component and Overall HSI for Atlantic Menhaden

Life requisites and components are the following:

- C1 = Water quality
- C2 = Food
- C3 = Cover

4.2 White Shrimp

White shrimp thrive on muddy bottoms in estuaries from New York to Florida and in the Gulf of Mexico from the Ocklocknee River to Campeche. Wetlands within the estuary offer both a concentrated food source and refuge from predators (Kutkuhn 1966, Turner 1977). In NC, extensive estuarine marshes provide ideal habitat and support some of the most abundant populations on the Atlantic coast.

White shrimp are spawned in the ocean from March to November, and larvae are carried by tides and wind-driven currents into estuaries where they mature. Post-larval shrimp settle out in the shallow waters in the upper ends of salt marsh tidal creeks and stay in this "nursery habitat" for about two or three months, growing to about four inches long (Perez-Farfante 1969). During high tide, juveniles move into the marsh grass to feed and escape predators; and at low tide, when the water level is below salt marsh grass, shrimp gather in creek beds. The smallest shrimp stay close to the creek bank while larger juveniles prefer deeper water (Etzold and Christmas 1977).

As shrimp become larger, they leave the nursery area and move toward the ocean on the outgoing tide, particularly at night (Gaidry and White 1973, Blackmon 1974). They continue to grow as they move into the lower reaches of sounds, bays, and river mouths where they gather just before moving into the ocean.

During periods of heavy rain, shrimp leave shallow tidal creeks and move into deeper estuarine waters about a month earlier than in average years (Hunt et al. 1980, Jones and Sholar 1981, and Laney and Copeland 1981). If there is not significant rainfall and/or river discharge during fall, white shrimp remain in the estuary until water temperature falls to about 15-18°C. Migration into the ocean occurs during the large tides associated with new and full moons (Gaidry and White 1973, Blackmon 1974).

Although they have a maximum life span of 24 months and can grow as large as eight inches, white shrimp typically live for less than a year. Planktonic larvae live in the open ocean, and juveniles live in estuaries, before moving to the preferred adult habitat near the age of maturation. Unlike many aquatic invertebrates, white shrimp reproduce via internal fertilization, and a single female produces between 500,000 and 1,000,000 eggs (Anderson et al. 1949, 1965).

Adult white shrimp are omnivorous and eat a wide variety of food, including algal and plant material, other invertebrates, and dead/decaying organic matter (Etzold and Christmas 1977). Most soft bottom fishes and several invertebrates prey on juvenile and adult white shrimp. This species is also the target of a large commercial fishery throughout most of its range, and in NC, white shrimp account for approximately 28% of shrimp landings.

Given that no white shrimp HSI model was available for NC, a Gulf of Mexico model was applied and made geographically specific by using Cape Fear River source data and consulting with state and federal natural resource agencies. The amount of marsh and/or submerged grass beds in or near a bay or estuary is the most important habitat variable in the model with a 100% coverage of marsh and/or submerged grass considered optimal. To account for its importance, this variable is squared in the final HSI equation, and the heavier weighting is related to its effect on long-term carrying capacity. Substrate composition contributes to the food and cover component of the model and is important in determining shrimp distribution; however, lack of data required it to be omitted from this analysis. Salinity is important to white shrimp when post larvae and juveniles are in the estuary. Salinities of 1-15 ppt are considered optimal for white shrimp. Temperature is a localized habitat variable that experiences seasonal swings, variation by depth and other factors. Post-larvae and juveniles grow over a wide range of temperatures, but generally do best between 20° and 30°C [68° and 86°Fahrenheit (F)]. Temperature values below or above this range were considered less than optimal. The white shrimp model produces an overall HSI applicable to the post-larval, juvenile, and adult estuarine life stages. The model assumes spawning occurred successfully in nearshore marine waters and larvae were carried into the estuary under normal conditions.

<u>Habitat variables for the white shrimp HSI model are as follows (Figure 9):</u>

V1 = Percentage of estuary covered by vegetation
V2 = Substrate Composition (No data available)

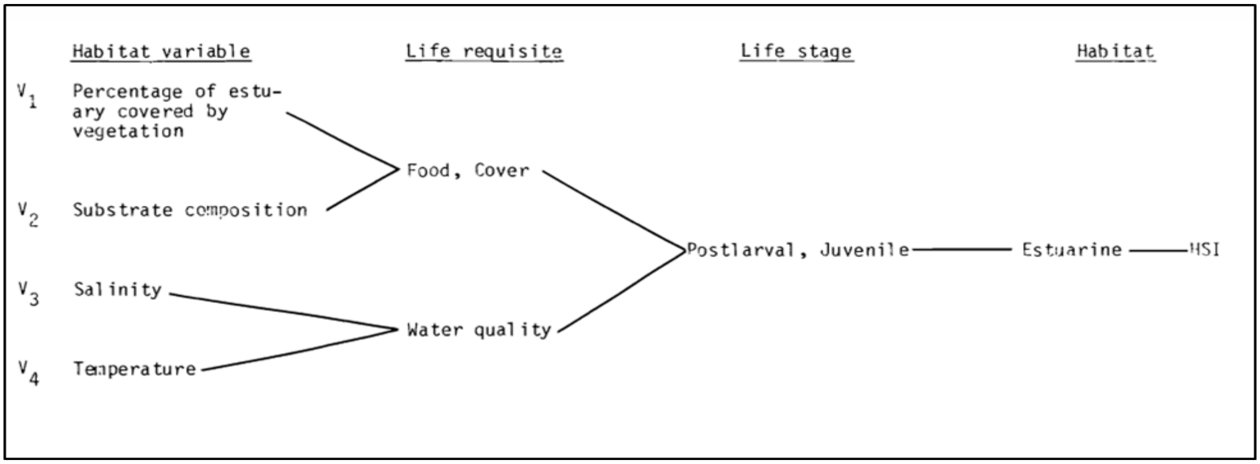


Figure 9
Relationship of Habitat Variables, Life Requisites, and Suitability Index for White Shrimp

V3 = Salinity
V4 = Temperature

Life Requisites for white shrimp HSI model include (Figure 9):
C1 = Food and Cover
C2 = Water Quality

4.3 Southern Flounder

The southern flounder ranges from northern Mexico to Nova Scotia and is considered an important recreational and commercial fishery in NC. This species is typically encountered in estuaries and bays from late spring until early fall before migration begins to the outer continental shelf wintering and spawning grounds (ASFMC 2012). Spawning typically occurs in late fall to early winter in these offshore habitats and the fertilized eggs are buoyant and hatch within 61-76 hours (Arnold et al. 1977). Eggs/larvae are passively transported by wind, waves, and currents from the offshore environment into sounds and bays and the upper oligohaline reaches of estuaries where metamorphosis into juveniles takes place. Active migration into marshes may occur when juveniles move to the surface at night and are carried laterally by the flood tide into tidal creeks (Weinstein et al. 1980). Juveniles spend up to 20 months in the estuarine environment before reaching maturity and migrating offshore to the continental shelf to begin the cycle again.

The southern flounder HSI model is applicable for juvenile and adult flounder occurring in the estuarine environment. The model is parsed into water quality and cover components; but given that the cover component requires substrate data, which was unavailable for the project area, it has been omitted from the analysis. Thus, the final HSI is computed using water quality parameters only.

Habitat Suitability Index variables for the southern flounder HSI model include:

V1 = Salinity
V2 = Temperature
V3 = DO Average Daily Minimum
V4 = Substrate Composition (No data available)

Life Requisties for southern flounder HSI include (Figure 10):

Water Quality = C1
Cover = C2 (omitted due to lack of substrate data)

Overall HSI equation for southern flounder is (V1)^2 x V2 x V3)^¼

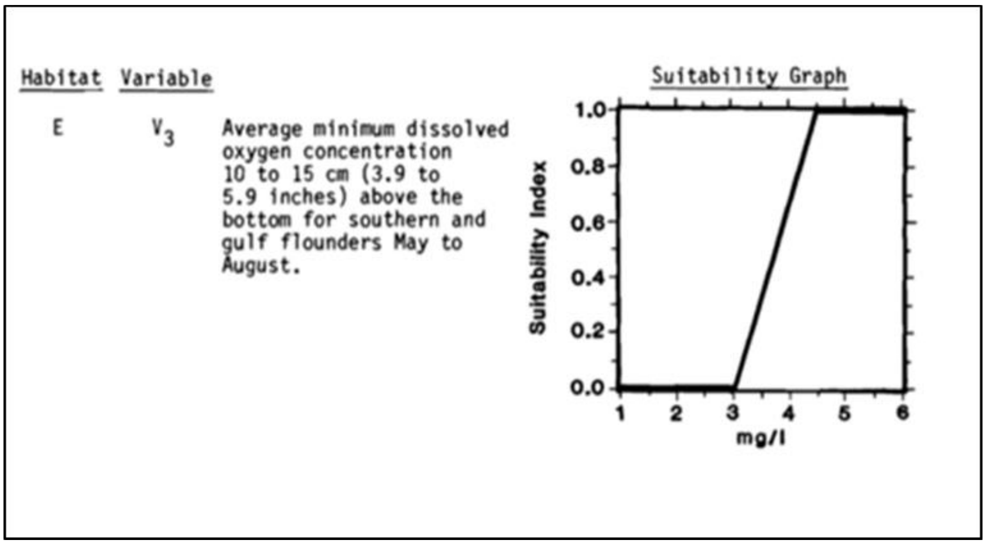


Figure 10
Suitability Graph Showing Correlation between Average Minimum Dissolved Oxygen Concentration and Southern Flounder Suitability Index

4.4 Red Drum

Red drum is an important recreationally fished species in the southeastern U.S. and Gulf of Mexico (Matlock 1980). These fish migrate inshore to spawning grounds in the spring and offshore to wintering grounds in the fall. Spawning typically occurs close to inlets, and eggs and larvae are carried by wind and currents from high saline waters into estuarine nursery areas where they grow into juvenile fish (Mansueti 1960). Juveniles remain in lower salinity estuarine habitat, preferring coastal marshes, shallow tidal creeks, and unconsolidated soft bottom.

Larger red drum migrate to offshore locations during the fall, occurring primarily on artificial reefs and hardbottom habitat (Appleman et al. 2015). Fish move back to inshore waters as temperatures warm in the spring, and spawning begins when water temperatures decrease in the fall. Fertilized eggs are buoyant and usually hatch between 28 and 29 hours, depending on water temperatures (South Carolina Department of Natural Resources 2019). Red drum are believed to remain in estuarine waters for three to four years before emigrating to oceanic waters (Stewart and Scharf 2008).

Adult red drums are euryhaline and eurythermal, having been observed predominately at salinities 30-55 ppt and at temperatures ranging from 2° to 33°C (Simmons and Breuer 1962). Therefore, this assessment only focuses on the larval and juvenile life stages that occur in the estuarine environment. Furthermore, the USFWS HSI model for red drum was available in two versions, Vegetated Substrate, and Non-vegetated substrate (Figure 11). Due to the absence of submerged aquatic vegetation (SAV) in most of the Cape Fear River Estuary, the latter model was selected for this assessment.

Red drum HSI variables include (Figure 12):

V1 = Mean Temperature
V2 = Mean Salinity
V3 = Percent of Open Water Fringed with persistent emergent vegetation
V5 = Dominant Substrate (No Data Available)
V6 = Mean Depth

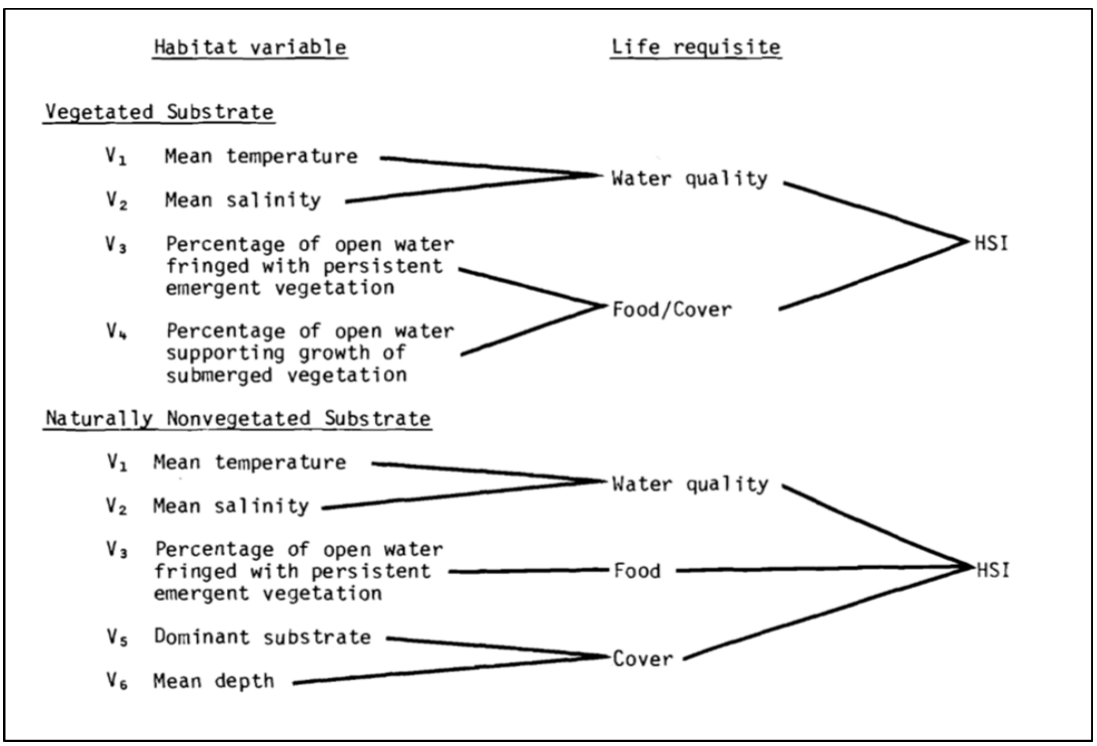


Figure 11
Two Versions of the USFWS HSI models Were Available for Red Drum, and the Naturally Non-vegetated Substrate Version Was Selected for This Project

Estuaries with little or no submerged vegetation.

Component	Equation
Water Quality (WQ)	$(SI_{V_1}{}^2 \times SI_{V_2})^{1/3}$
Food (F)	SI_{V_3}
Cover (C)	$(SI_{V_5} \times SI_{V_6})^{1/2}$

HSI = WQ, F, or C, whichever is lowest

Figure 12
Component and Overall HSI Equations Used to Quantify Red Drum Habitat Value in the Cape Fear River, Which Contains Little to No SAV

5 MODELING RESULTS

5.1 Anadromous Species

5.1.1 Atlantic Sturgeon

5.1.1.1 Lower Estuary

The average HSI value in the lower estuary for all model components (Adult, Spawning, Egg, Larvae, and Juvenile) is 0.0, resulting in 0 habitat units (HUs) under the existing conditions, FWOP, and FWP. Proximity to the Atlantic Ocean reduces habitat quality for Atlantic sturgeons in the lower estuary causing all cells to fail; however, adult Atlantic sturgeons still utilize the area as a migration corridor as indicated in NCDMF telemetric records. Future projections indicate a salinity increase in the lower estuary under the FWOP and FWP conditions; therefore, the lower estuary is expected to remain unsuitable.

5.1.1.2 Middle Estuary

Under all sets of conditions, the middle estuary is unsuitable for eggs and larval development due to the salinity being well above the established threshold. However, the middle estuary is suitable for foraging adults and juveniles, except for several cells where summer DO is below the 4.3 mg/L threshold. Furthermore, lower Town Creek is suitable for juveniles; whereas, upper Town Creek is unsuitable due to reduced food availability. These conditions do not change under the FWOP or the FWP conditions. The middle estuary is unsuitable spawning habitat under all conditions. The HSI for the entire life cycle of Atlantic sturgeons in the middle estuary is 0.0 and is limited by the spawning component.

5.1.1.3 Upper Estuary

Model results indicate unsuitable water quality conditions in the upper estuary for eggs and larvae due to salinity above 0.5 ppt. These conditions also make the area unsuitable spawning habitat and do not change under the FWOP or the FWP. The upper estuary is highly suitable for juveniles except upper Sturgeon Creek, which is only suitable under the FWP condition (Figure 13). Under the existing conditions, the upper estuary is suitable for foraging adults except for Smith Creek, upper Sturgeon Creek, and the upper Brunswick River where summer DO is below 4.3 mg/L (Figure 14). The FWP condition improves the adult foraging habitat in the upper Brunswick River; although, Smith Creek and upper Sturgeon Creek remain unsuitable (Figure 15). The combined HSI for the upper estuary is 0.0 due to the influence of the spawning and egg/larval components.

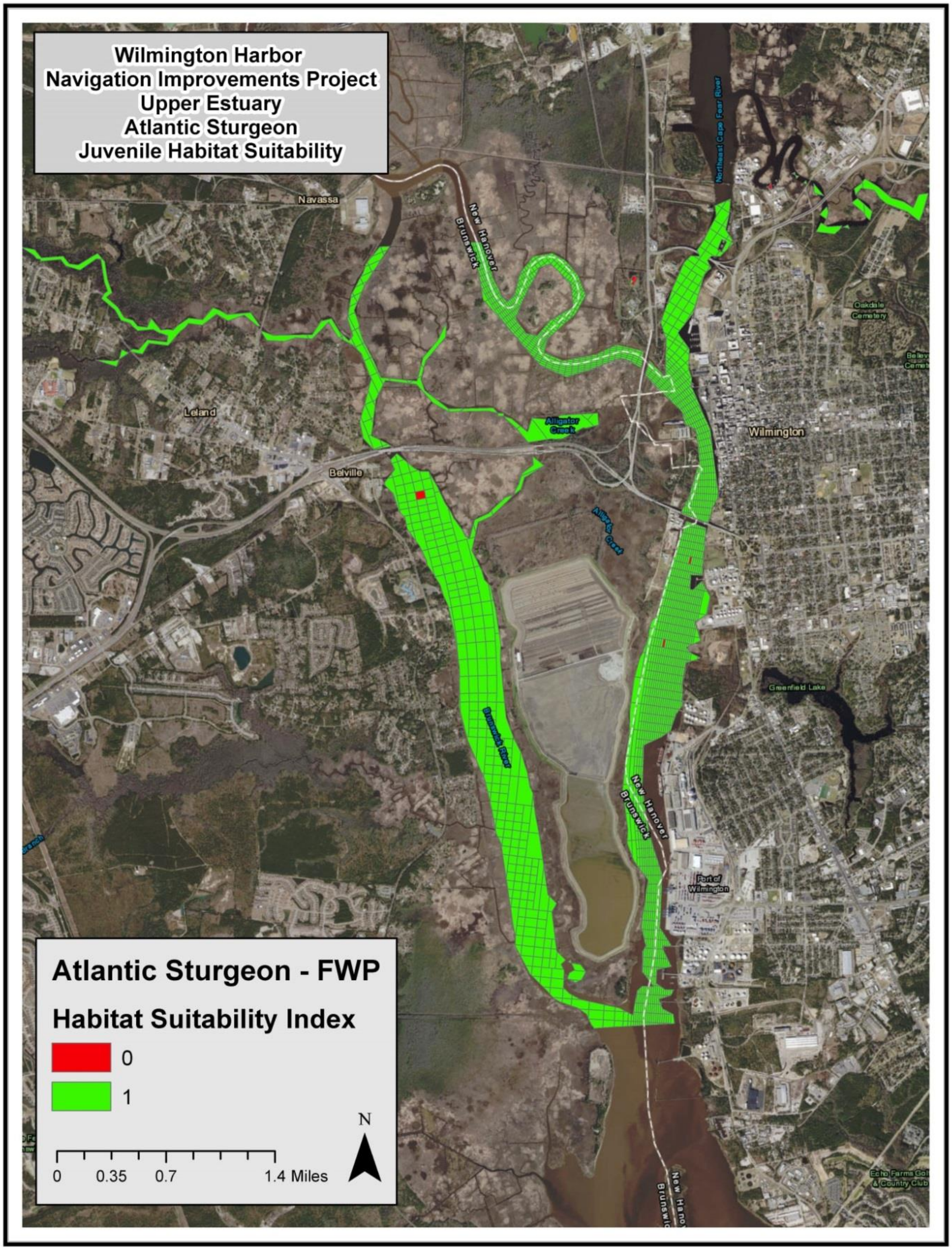


Figure 13
Future with Project Habitat Suitability for Juvenile Atlantic Sturgeon in the Upper Estuary

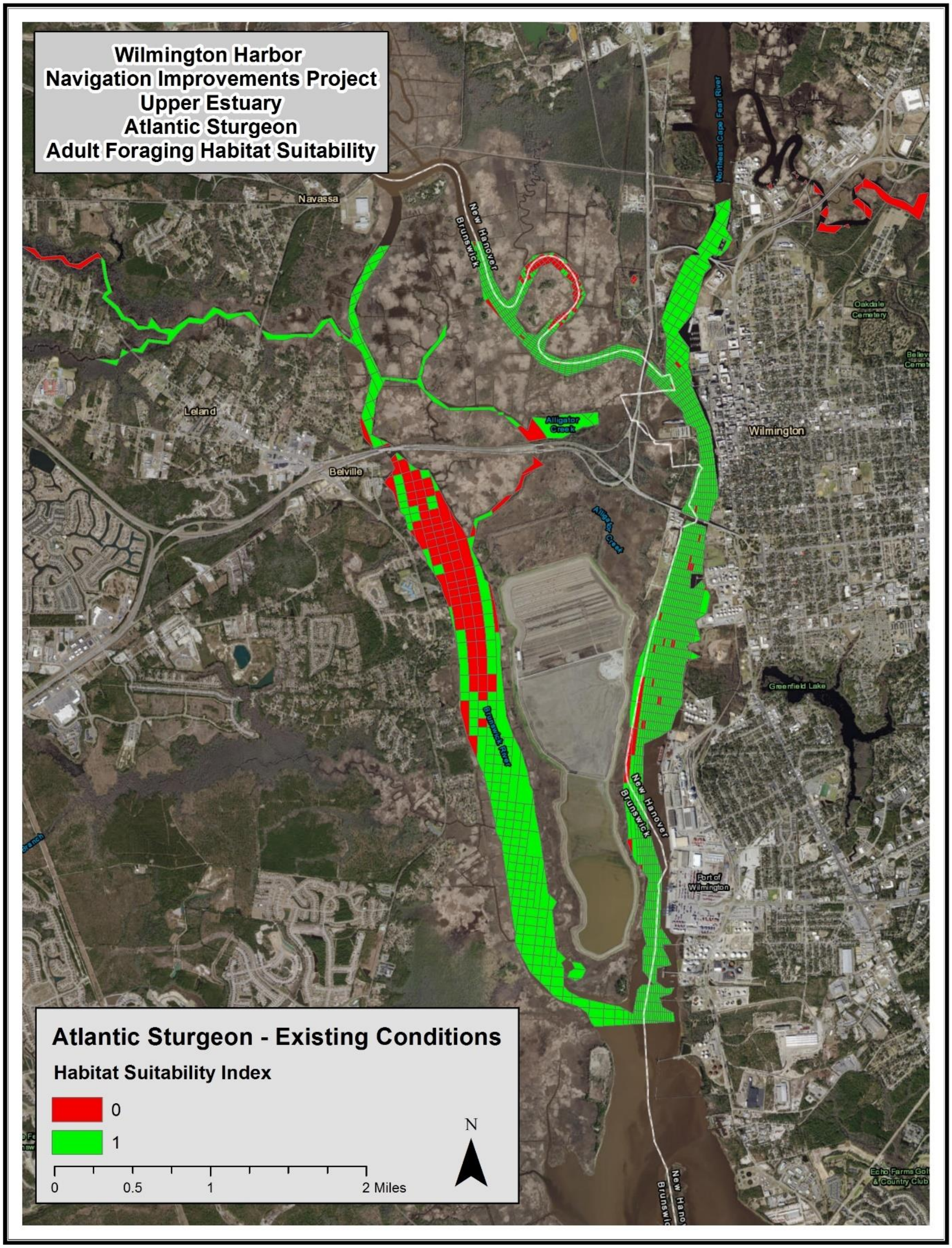


Figure 14
Existing Habitat Suitability for Adult Atlantic Sturgeon in the Upper Estuary

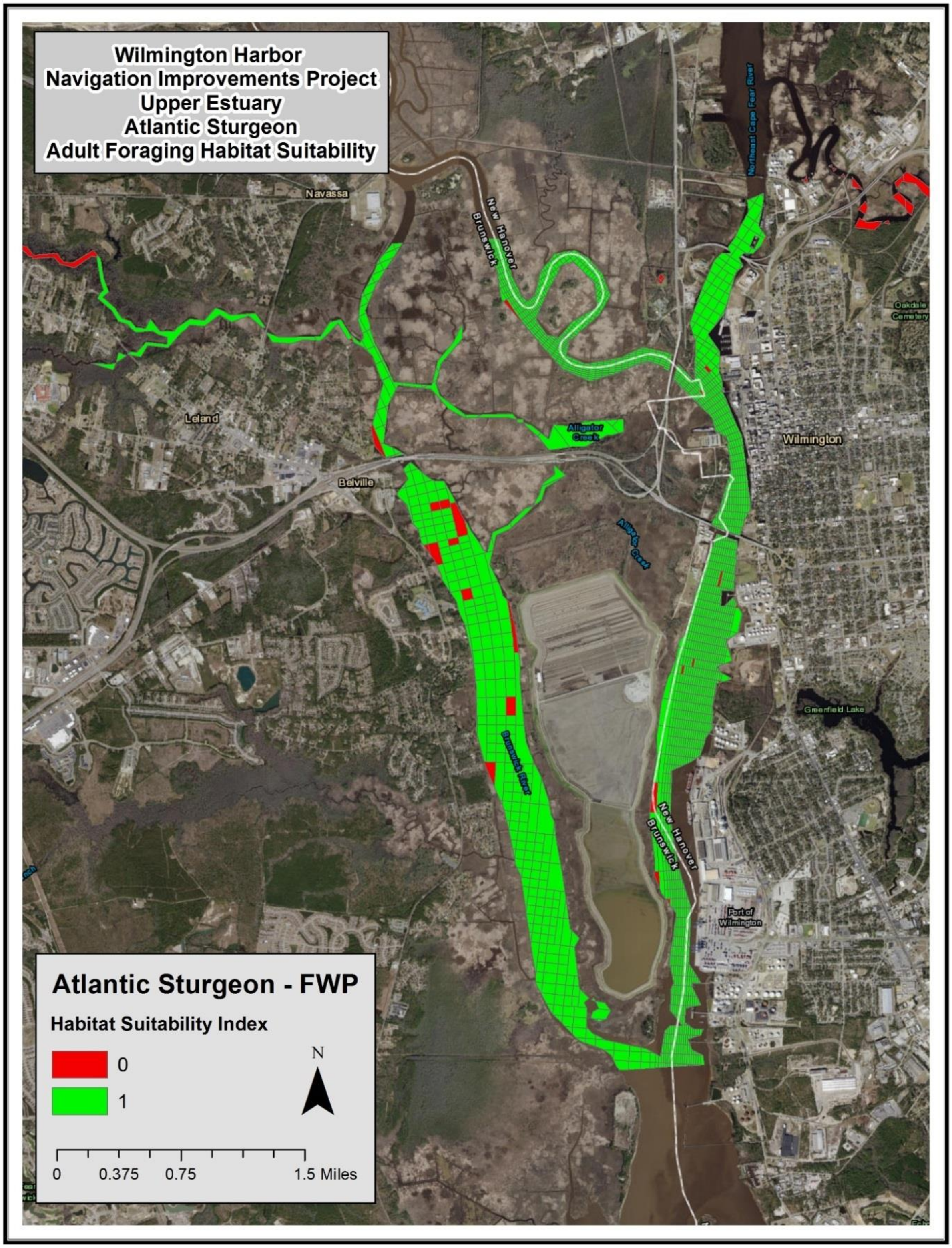


Figure 15
Future with Project Habitat Suitability for Adult Atlantic Sturgeon in the Upper Estuary

5.1.1.4 Cape Fear River

Habitat Suitability Index modeling classified the Cape Fear River from Lock and Dam #1 to Navassa as suitable for eggs and larvae of Atlantic sturgeons under all sets of conditions. Important to note, however, is that substrate composition was not accounted for. Also, several failing cells with DO below the 6 mg/L threshold were interspersed with suitable habitat and possibly correlated with depth or reduced current velocity. Many of these cells were located near Sutton Lake.

Habitat from Lock and Dam #1 to Navassa was also identified as suitable for juvenile Atlantic sturgeons, but several areas with average annual DO below 4.3 mg/L were detected. These failing cells are likely correlated with depth and/or reduced flow. The FWOP and FWP conditions do not alter the HSI outputs for juveniles in the Cape Fear River reach.

Most of the Cape Fear River reach is also suitable habitat for foraging adult Atlantic sturgeons; although, several clusters of cells fail due to average annual DO below 4.3 mg/L. Furthermore, under the existing conditions, unsuitable adult foraging habitat was identified from Navassa upstream to Cartwheel Branch (Figure 16). Under the FWOP, these unsuitable conditions extend approximately an additional .25 river mile; and under the FWP, they extend past Royster, NC (Figures 17 and 18). These changes in habitat suitability are attributed to an increase in salinity from sea level rise and indirectly from the navigation improvements project. Under all conditions, habitat is suitable for foraging adults above Royster, NC, upstream to Lock and Dam #1 except for the isolated areas with summer hypoxia and/or reduced current velocity.

The Cape Fear River is the primary corridor for Atlantic sturgeons in this system. Although the project area is bound to the upper reaches below Lock and Dam #1, historical spawning grounds for Atlantic sturgeons are located near Smiley Falls, approximately 180 river miles from the mouth of the Cape Fear River. When all component indices are combined; the HSI model outputs for the Cape Fear River reach indicate 1,171, 1,112, and 1,069 passing cells for the existing conditions, FWOP, and FWP conditions; respectively. Further analysis indicates an increase in average annual salinity near Navassa as well as pockets of low DO and reduced current velocities as the driving forces behind habitat changes among the sets of conditions. Average annual salinity during the spawning season of >0.5 ppt, DO <4.3 mg/l, and current velocity <0.06 meters per second result in failing grid cells. Changes in habitat suitability associated with sea level rise and the proposed project occur at the oligohaline-tidal freshwater interface. This interface is not a defined line and naturally fluctuates from year to year, depending on several environmental factors. This type of annual variability makes impacts to this location difficult to assess. Average HSI values for the Cape Fear River reach were 0.82, 0.75, and 0.71 with HUs of 781, 718, and 685 for baseline, FWOP, and FWP conditions, respectively.

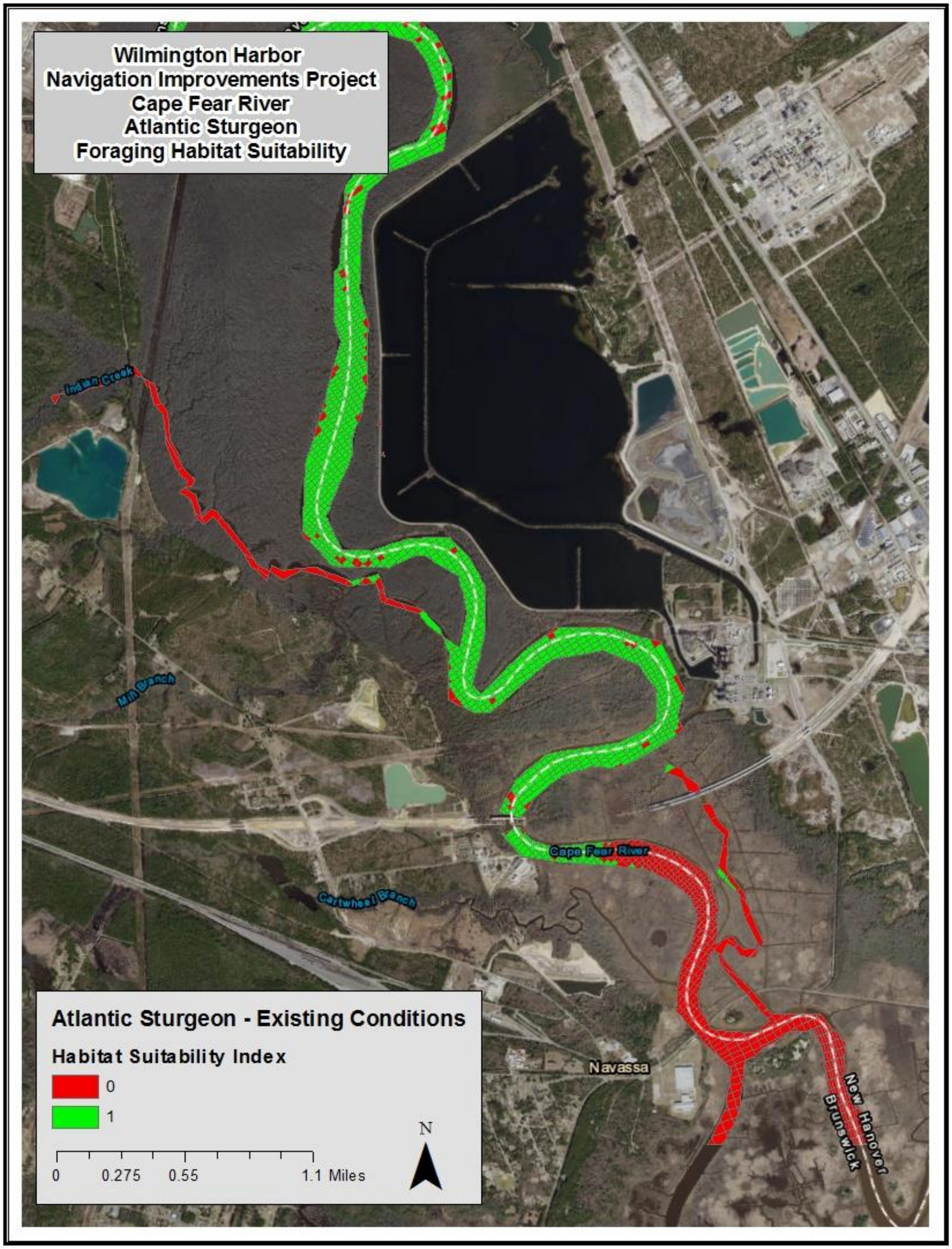


Figure 16
Unsuitable Atlantic Sturgeon Foraging Habitat Under the Existing Conditions Near Navassa, NC

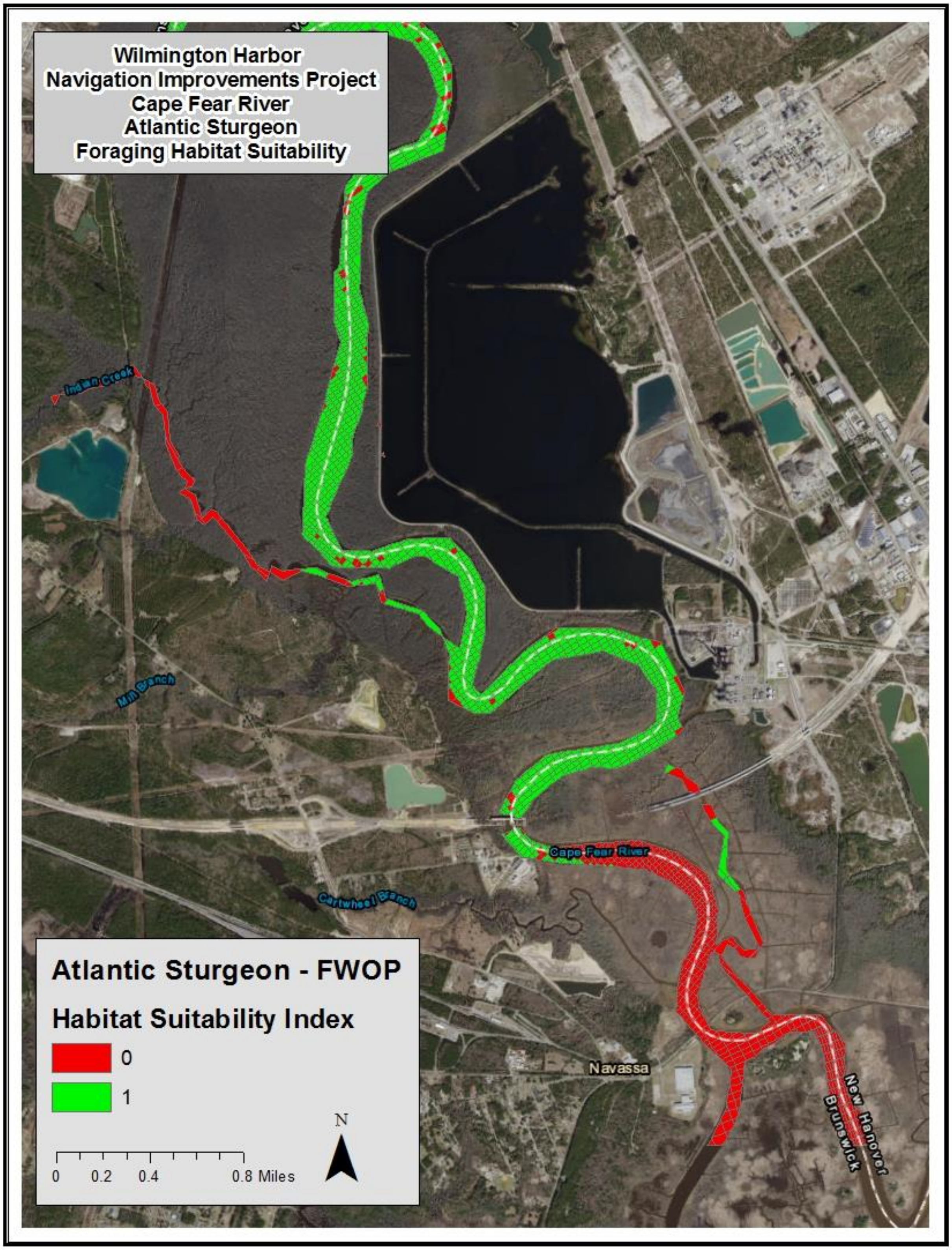


Figure 17
Future without Project Atlantic Sturgeon Foraging Habitat Near Navassa, NC

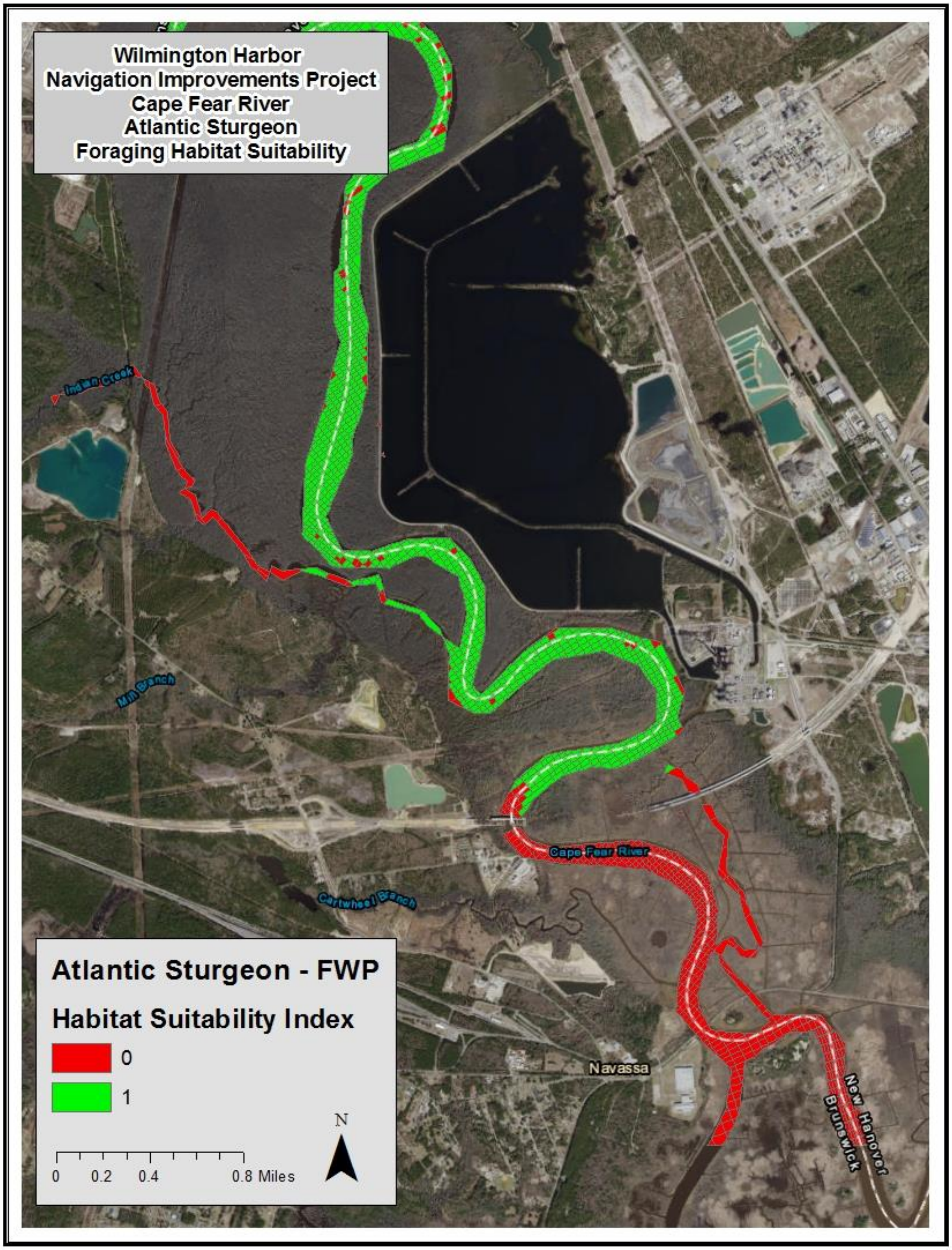


Figure 18
Future with Project Atlantic Sturgeon Foraging Habitat Near Navassa, NC

5.1.1.5 Black River

Model outputs classify the Black River as suitable for eggs and larvae during the spring spawning period (February-June), but summer hypoxia makes the area unsuitable for eggs and larvae during the potential fall migration (August-November). Moreover, substrate composition is not considered as part of this analysis and would further limit suitability. Regardless, water quality for egg and larval development meets the HSI requirements for all sets of conditions during the spring spawning period. Baseline conditions indicate high quality habitat for juvenile Atlantic sturgeons in the Black River up to approximately Bear Branch. Further upstream, habitat quality begins to decline due to areas of low summer DO possibly related to depth, current velocity, and/or increased biological oxygen demand. Under the FWOP and FWP conditions, habitat remains suitable for juveniles in the lower Black River with low summer DO and poorer quality habitat persisting above Bear Branch. Existing conditions in the Black River are suitable for foraging adult Atlantic sturgeons up to approximately Field Creek, but quickly deteriorate above this point from summertime hypoxia. This pattern is also apparent for the FWOP and FWP sets of conditions.

In summary, HSI modeling identified some suitable habitat for the Atlantic sturgeon in the Black River, particularly in the area below Bear Branch, and modeling results suggest an increase in passing cells from 216, 258, and 276 for existing conditions, FWOP, and FWP; respectively. However, above Roan Island, cells begin to fail for all scenarios due to low summertime DO levels. The average HSI values for the entire life cycle of Atlantic sturgeons in the Black River are 0.21, 0.23, and 0.24 for the existing conditions, FWOP, and FWP, respectively. Habitat units calculated for the Black River include 267, 299, and 309 for the existing conditions, FWOP, and FWP conditions, respectively.

5.1.1.6 Northeast Cape Fear River

Model results indicate the Northeast Cape Fear River is suitable habitat for Atlantic sturgeon eggs and larvae; however, substrate data was not considered and would further limit habitat suitability to areas with hardbottom (Figure 19). Furthermore, small isolated pockets of low summer DO reduce habitat suitability and cause some cells to fail. These areas could be correlated with depth and current velocity, but this cannot be determined without additional modeling. Under the FWOP and FWP conditions, the pattern is consistent.

Model outputs for juvenile Atlantic sturgeons in the Northeast Cape Fear River display a similar pattern to the egg/larval component for all sets of conditions. Failing cells are relatively sparse and are driven by low summer DO (< 4.3 mg/L).

Baseline modeling identified poor adult foraging habitat in the Northeast Cape Fear River from the entrance of Smith Creek upstream for approximately 3.5 river miles, (Figure 20). Results indicate an increase in salinity from the FWOP condition extends these failing cells upstream an additional .25 river mile (Figure 21), and the FWP condition extends the failing cells another river mile (Figure 22). Model results are based on water quality parameters only however, as substrate composition data was unavailable.

Model results for the Northeast Cape Fear River show some variability in HSI values among datasets with 938, 947, and 818 acres of suitable habitat for the existing conditions, FWOP, and

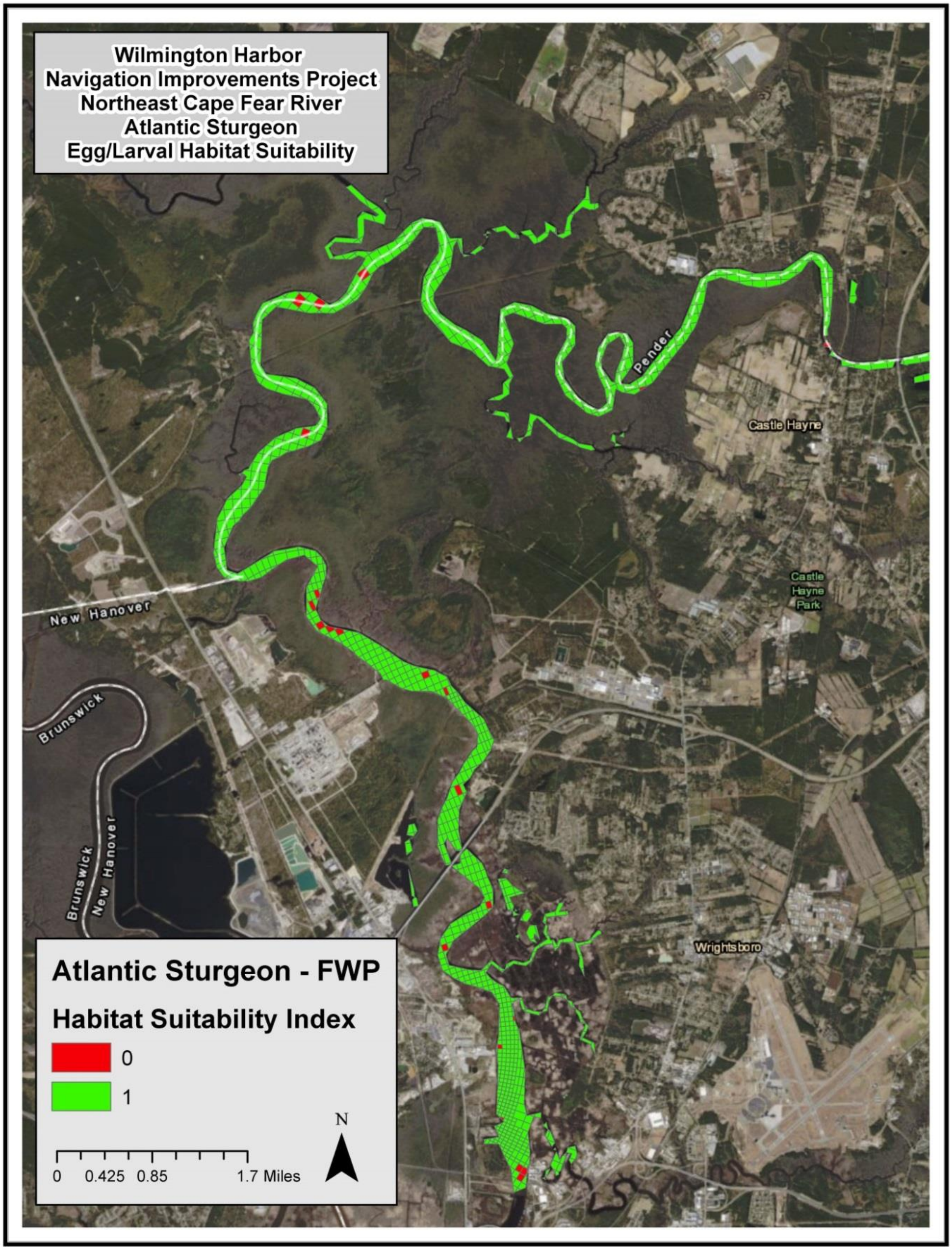


Figure 19
Suitable Habitat for Atlantic Sturgeon Larval and Egg Development in the Northeast Cape Fear River under the FWP Condition

FWP conditions; respectively. The driving factors depressing the overall HSI are increases in salinity and low summer DO. The average HSI values for the entire life cycle of Atlantic sturgeon in the Northeast Cape Fear River are 0.23, 0.23 and 0.20; while HUs are 687, 678, and 579 for the baseline, FWOP, and FWP conditions; respectively (Appendix A).

5.1.2 Striped Bass

5.1.2.1 Lower Estuary

Modeling indicates that the lower estuary is unsuitable for striped bass spawning and egg development under all conditions. However, the lower estuary is moderately suitable (0.4-0.6) under the existing conditions for larval development above MOTSU. Further upstream, water quality improves for larval development with HSI values ranging from 0.6-0.8 (Figure 23). Under the FWOP condition, suitability remains high on the east side of the river; however, unsuitable conditions persist to just above MOTSU on the west side (Figure 24). Under the FWP condition, unsuitable conditions for larval development extend further upstream past MOTSU on the west side, but conditions on the east side remain at least moderately suitable (Figure 25). Under all conditions, the lower estuary is highly suitable for striped bass juveniles. The overall HSI, representing the entire life cycle of the species, is 0.0 under all conditions and is limited by the spawning and egg components of the model.

5.1.2.2 Middle Estuary

The middle estuary is highly suitable foraging habitat for adults and juveniles under all sets of conditions; however, it’s unsuitable for egg development due to high salinity. The middle estuary is suitable for larvae apart from an area near Carolina Beach State Park. This location displays higher salinity; likely from water entering through Snow’s Cut from the Atlantic Intracoastal Waterway. Under the FWOP and FWP conditions the higher salinity near Snow’s Cut reduces habitat quality for larvae up to approximately Masonboro Country Club (Figures 26 and 27). The overall HSI in the middle estuary is 0.0 and is limited by the spawning and egg components of the model.

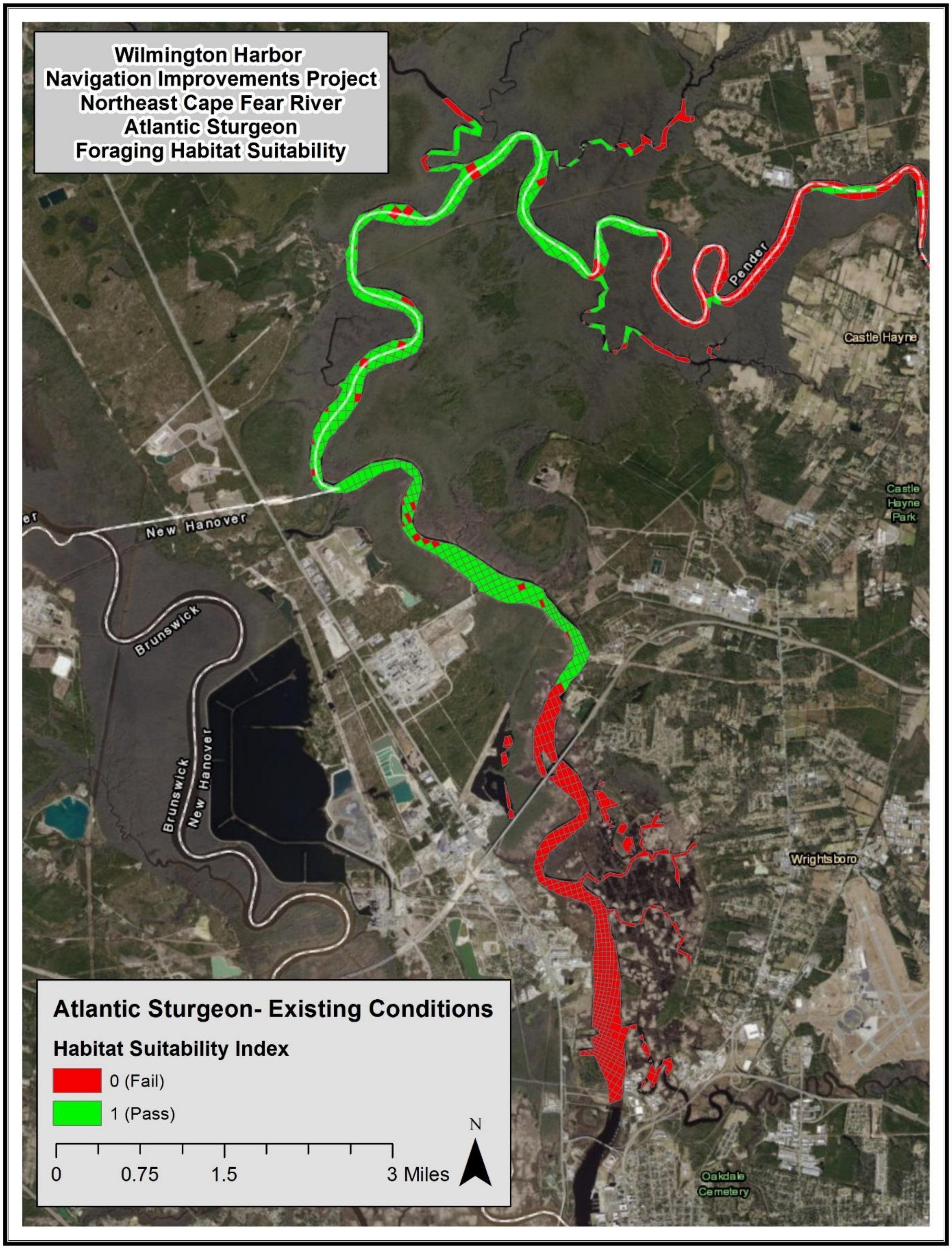


Figure 20
Adult Foraging Habitat for Atlantic Sturgeon in the Northeast Cape Fear River

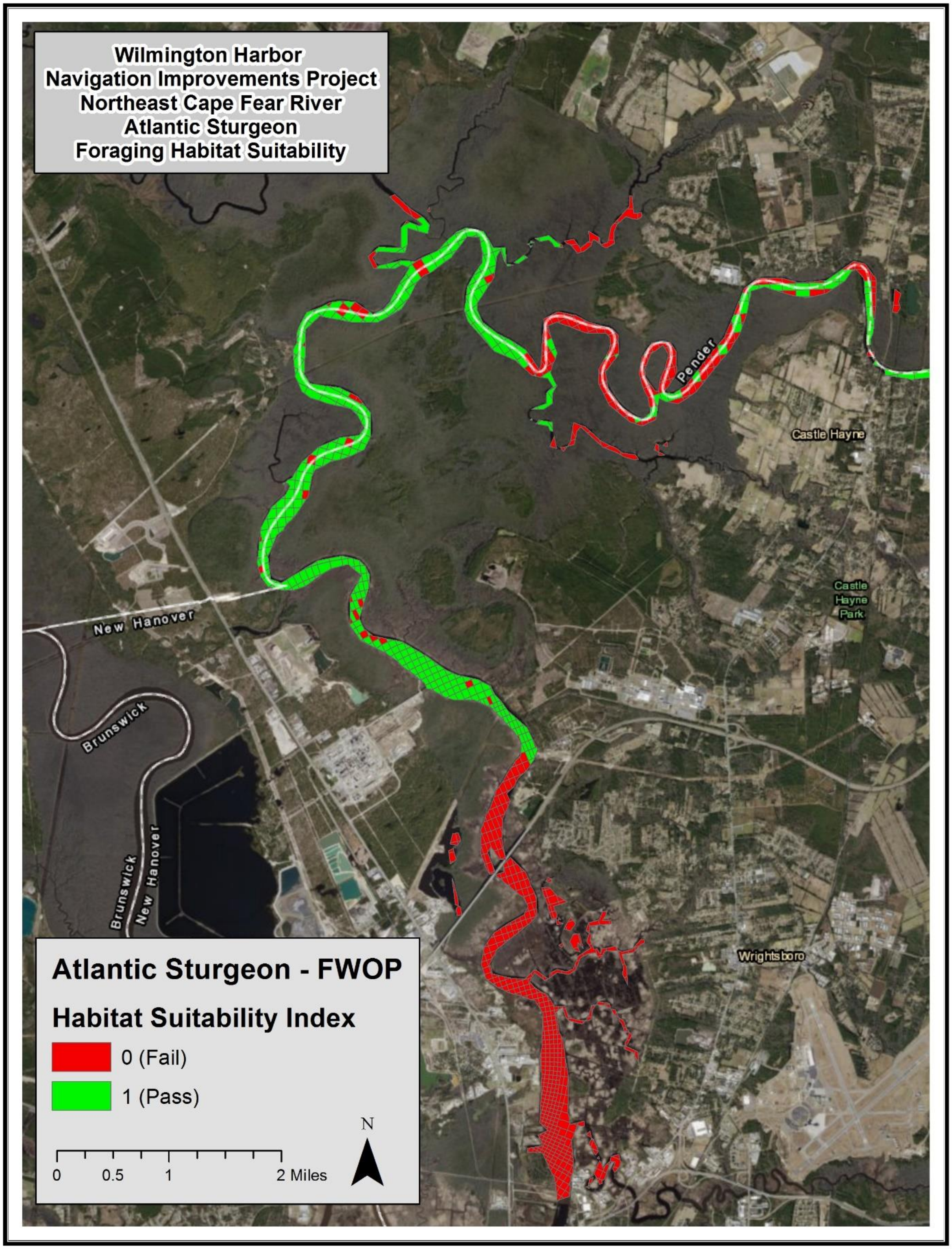


Figure 21
FWOP Foraging Habitat for Atlantic Sturgeon in the Northeast Cape Fear River

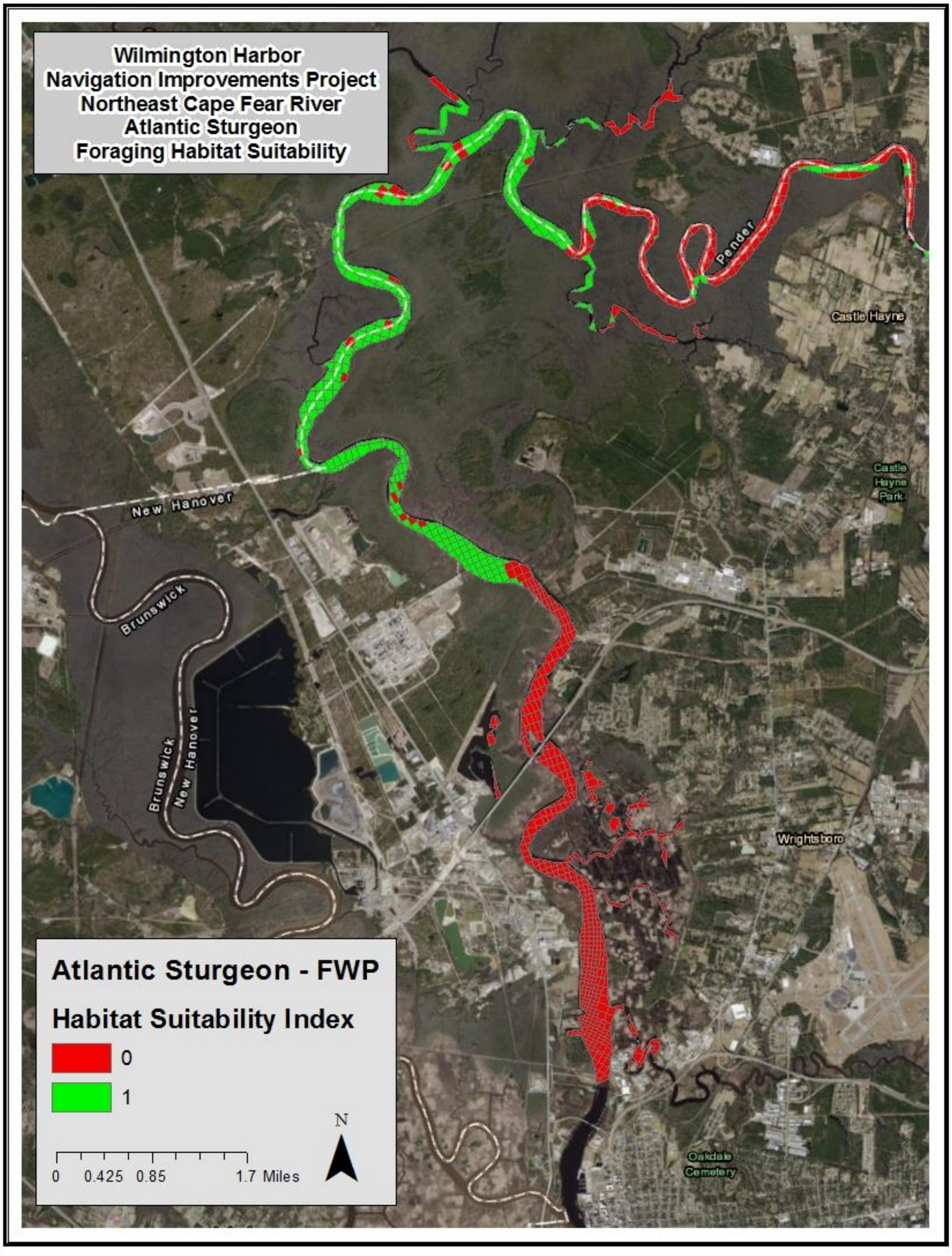


Figure 22
FWP Foraging Habitat for Atlantic Sturgeon in the Northeast Cape Fear River

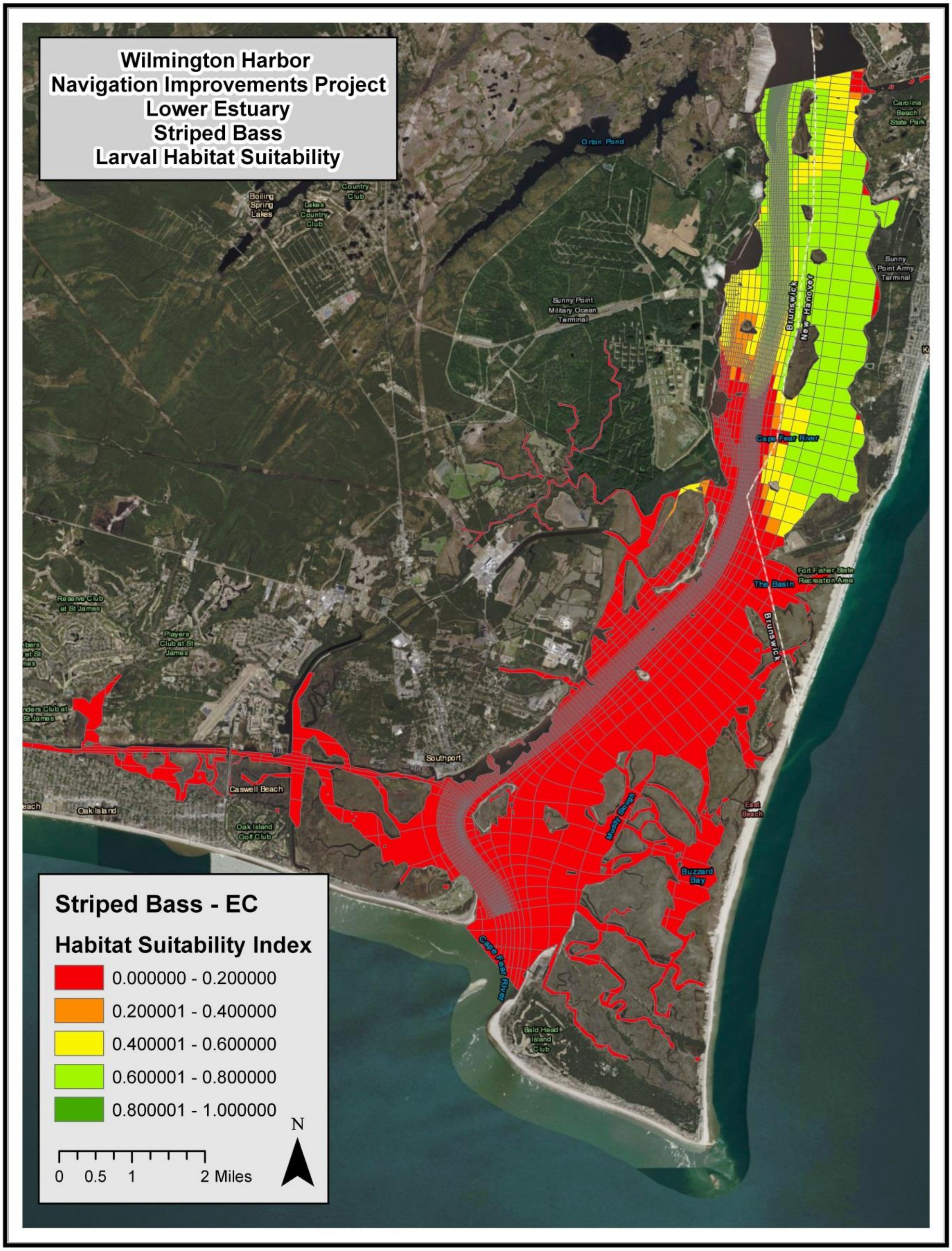


Figure 23
Existing Habitat Suitability for Striped Bass Larvae in the Lower Estuary

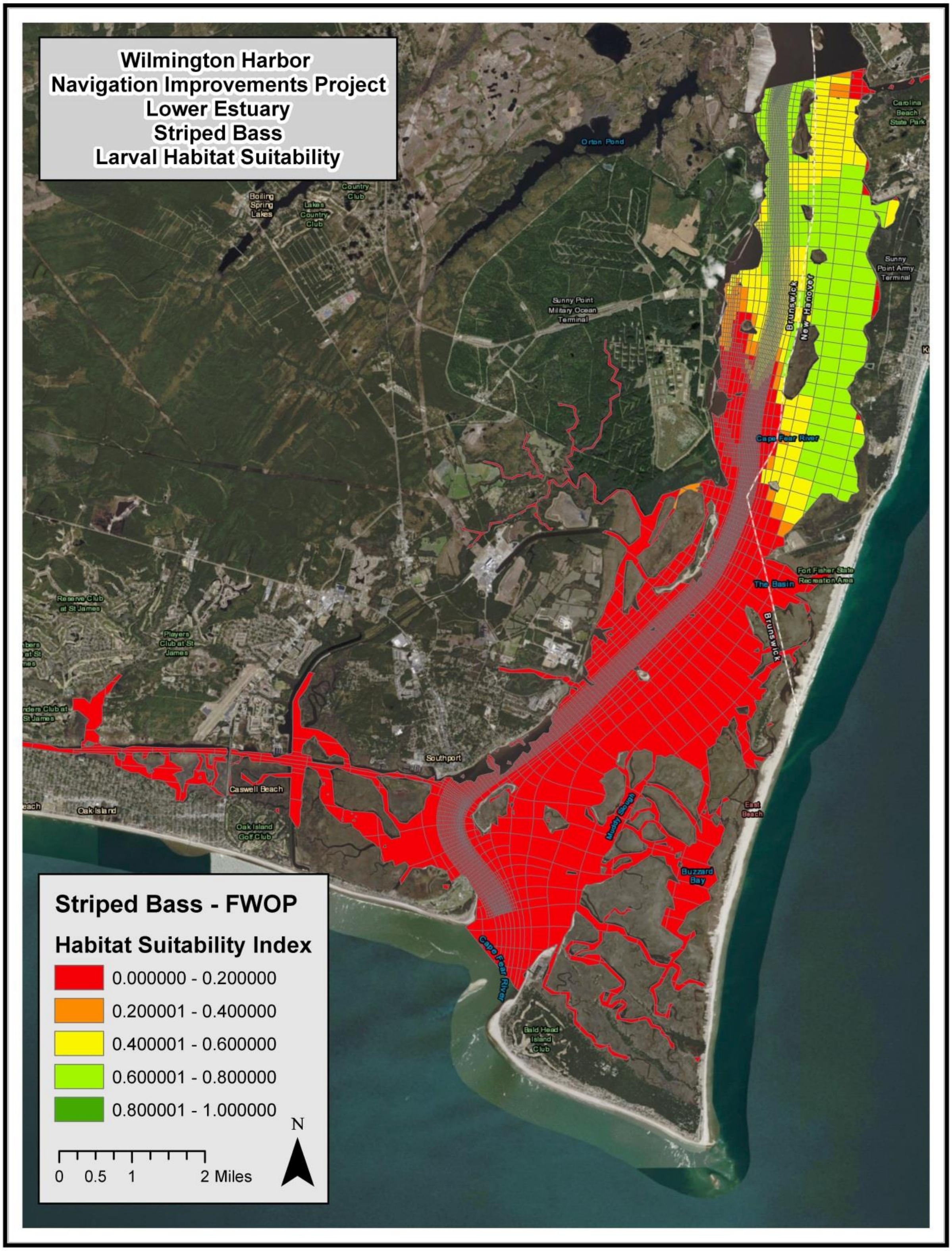


Figure 24
FWOP Habitat Suitability for Striped Bass Larvae in the Lower Estuary

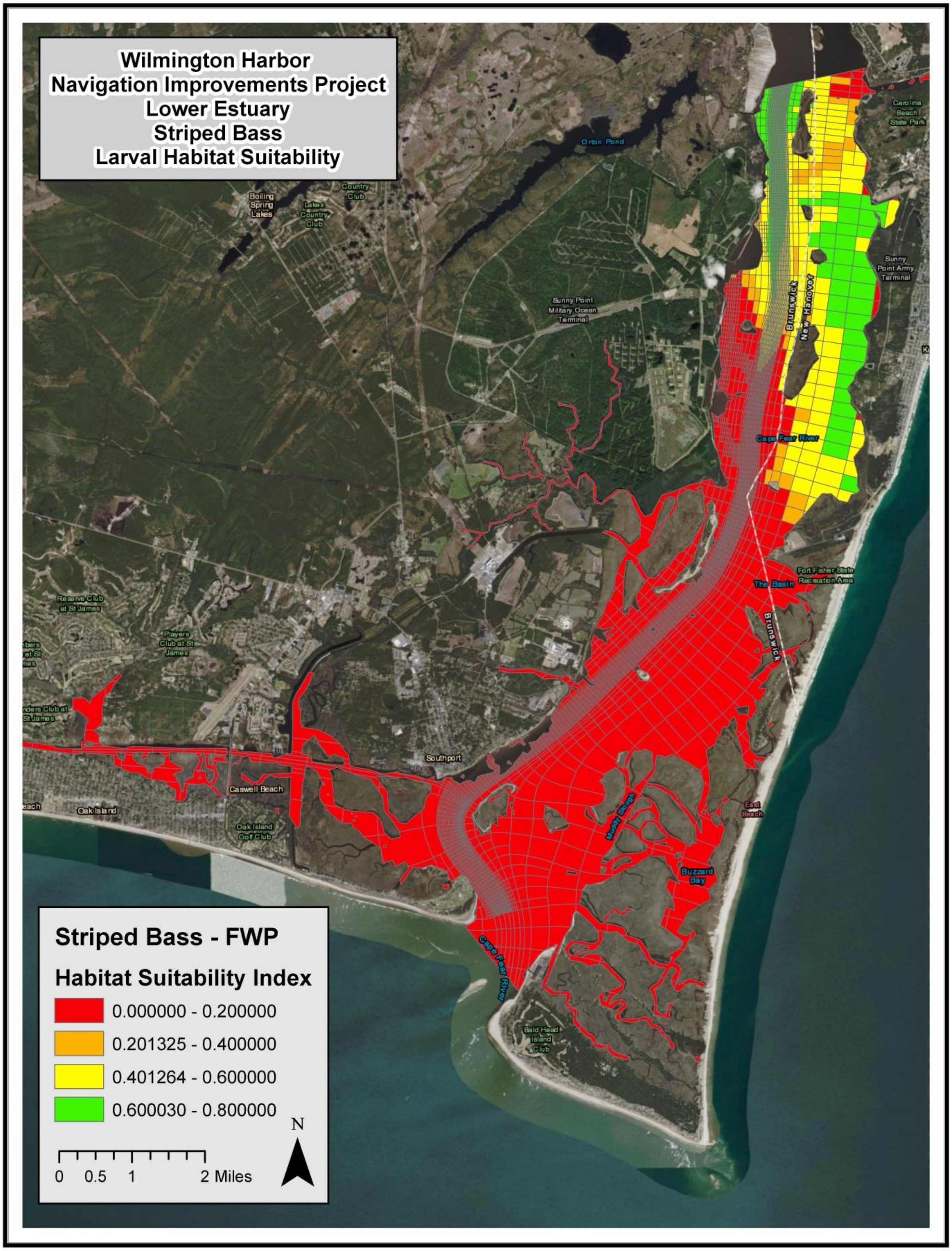


Figure 25
FWP Habitat Suitability for Striped Bass Larvae in the Lower Estuary

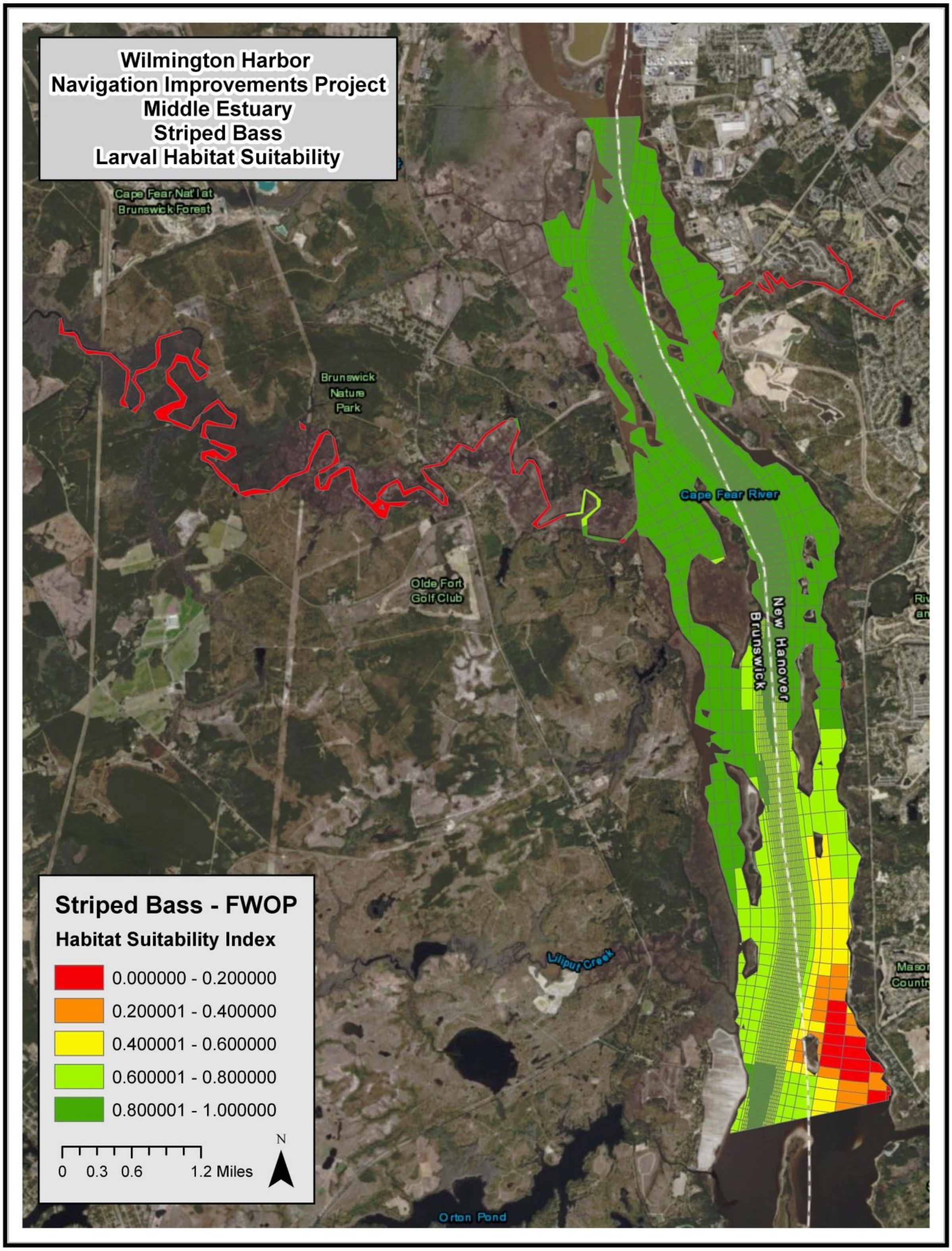


Figure 26
FWOP Habitat Suitability for Striped Bass Larvae in the Middle Estuary

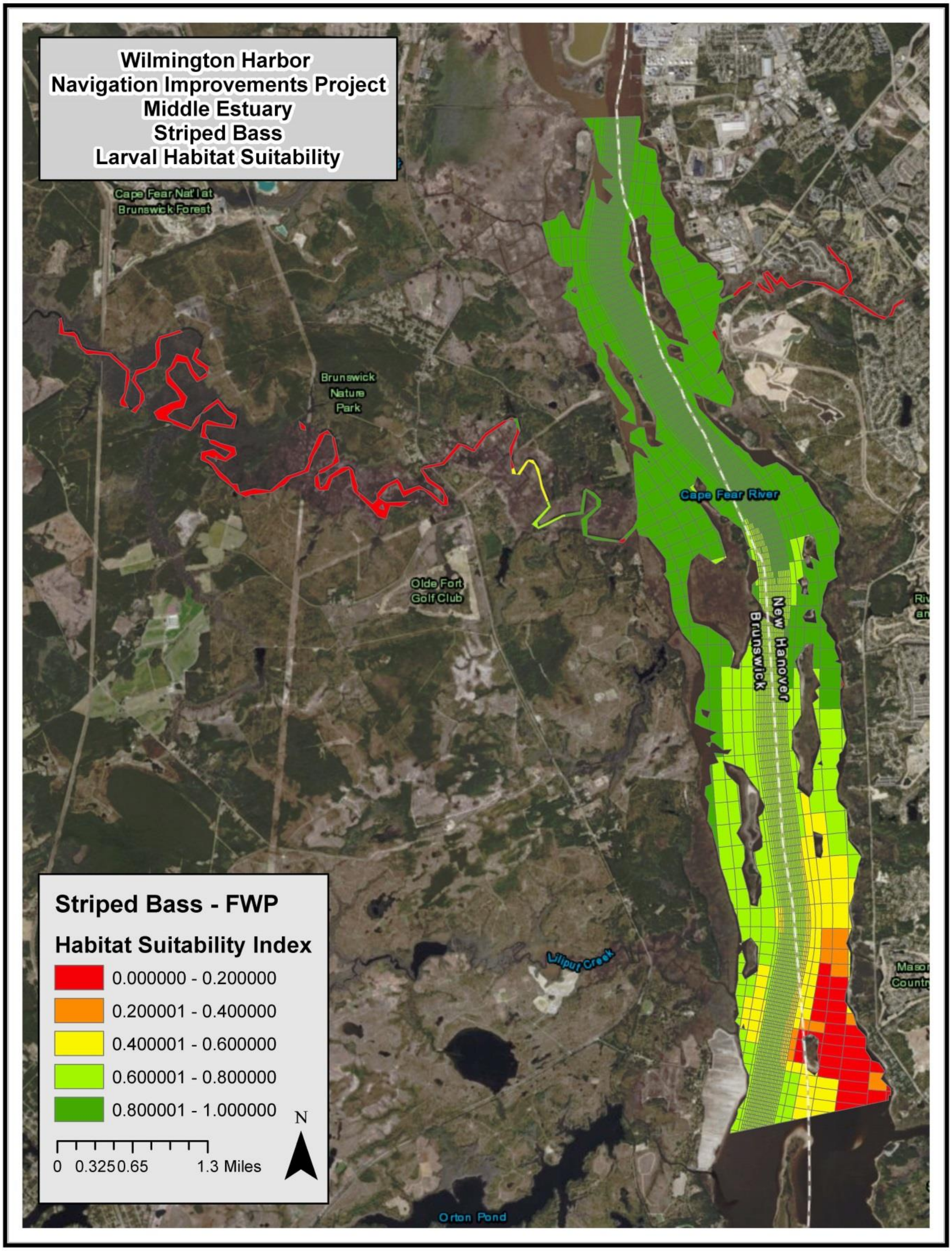


Figure 27
FWP Habitat Suitability for Striped Bass Larvae in the Middle Estuary

5.1.2.3 Upper Estuary

Existing Conditions in the upper estuary are suitable for egg development in the lower Brunswick River and the Cape Fear River from the southern tip of Eagle Island to Smith Creek. Furthermore, the entire upper estuary is highly suitable for larval development aside from Smith Creek and upper Sturgeon Creek where salinity falls below the optimal threshold. Under the FWOP and FWP conditions, habitat quality for larval development improves in the Brunswick River, and the upper estuary is highly suitable for foraging adults under all sets of conditions. Habitat suitability for juvenile Striped Bass in the upper estuary is variable due to natural fluctuations in salinity; however, model results indicate that under the FWOP there is a reduction in habitat suitability for juveniles near the Kinder Morgan Liquid Bulk Pier due to increased salinity (Figure 28). Under the FWP condition, already poor juvenile habitat (0.2-0.4) is reduced to unsuitable habitat (0.0-0.2) due to increased salinity from the Port of Wilmington upstream to the beginning of the Northeast Cape Fear River (Figure 29). Increased salinity also reduces juvenile habitat quality in the upper Brunswick River under the FWOP and the FWP conditions.

5.1.2.4 Cape Fear River

Baseline modeling for the mainstem Cape Fear River indicates highly suitable striped bass spawning habitat below Lock and Dam #1, but conditions become less suitable moving downstream toward Wilmington, NC, as salinity increases. Only minor changes in spawning habitat quality under the FWOP or the FWP conditions were detected for the Cape Fear River reach. Suitability for egg development is high in this reach of the river other than isolated areas with reduced current velocity and low summer DO. The FWOP and FWP conditions improve habitat quality for egg development below Sutton Lake due to increased salinity. Under all sets of conditions, water quality conditions above Sutton Lake are unsuitable for larval development; however, below Sutton Lake conditions improve. Under all conditions the Cape Fear River reach is highly suitable for adult and juvenile striped bass.

5.1.2.5 Northeast Cape Fear River

The Northeast Cape Fear River is highly suitable for egg development in the channel upstream to Fishing Creek, but is unsuitable outside the channel due to lower current velocity. Habitat quality for egg development remains largely the same in this area under the FWOP and the FWP conditions. Baseline modeling indicates habitat for larval development in the Northeast Cape Fear River is suitable until salinity drops below 4 ppt near Ness Creek. Under the FWOP and the FWP conditions, there is little change in habitat suitability for larval development. Modeling indicates the Northeast Cape Fear River is suitable spawning habitat for striped bass, and running ripe females have been captured during NCDMF sampling events. However, spawning likely occurs further upstream near Chinquapin, NC (Personal communication, Chris Stewart, NCDMF 28 August 2019), which is beyond the extent of the study area. Therefore, the lower Northeast Cape Fear River is likely used as a migration corridor and foraging habitat for juvenile and adult striped bass.

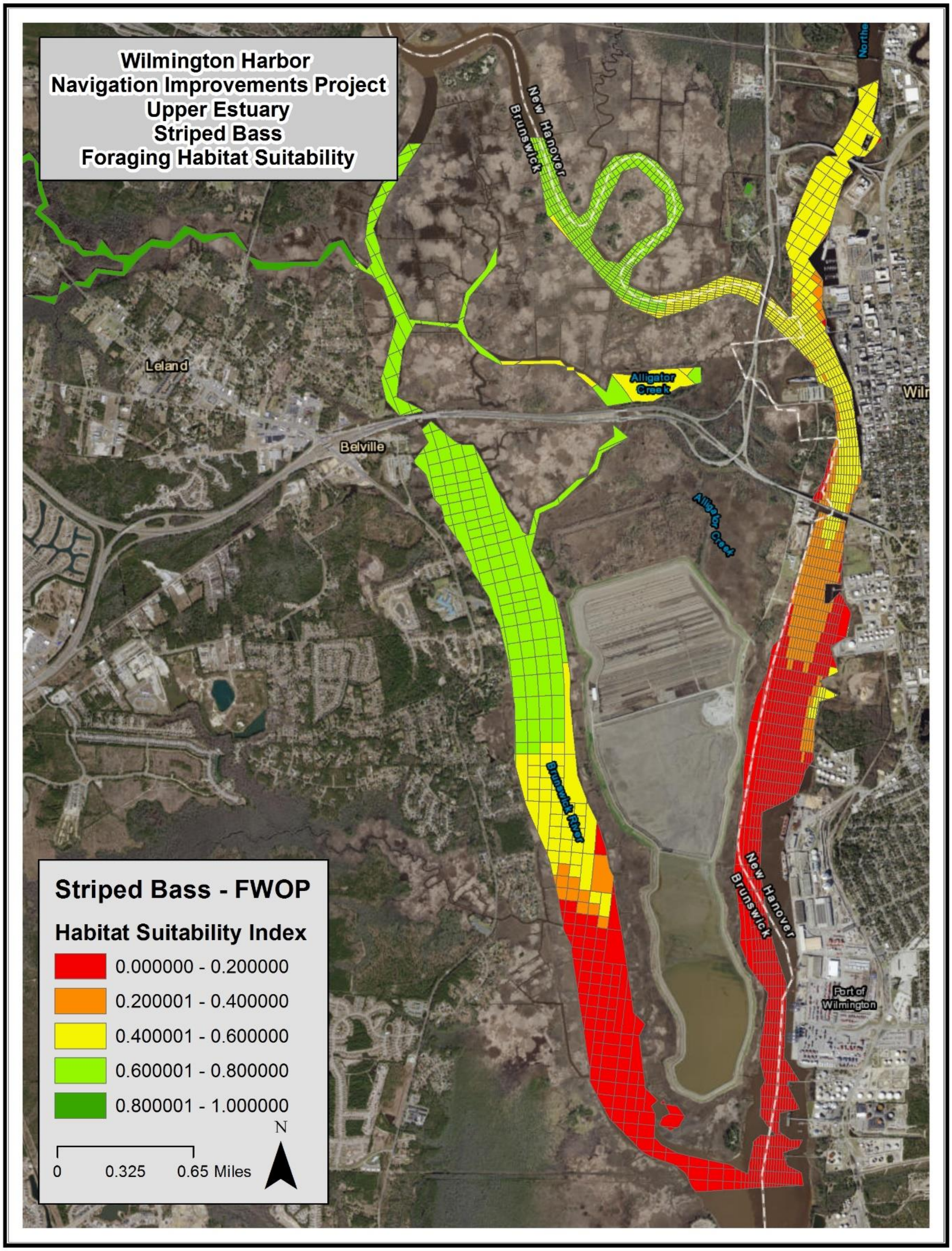


Figure 28
FWOP Striped Bass Foraging Habitat Suitability in the Upper Estuary

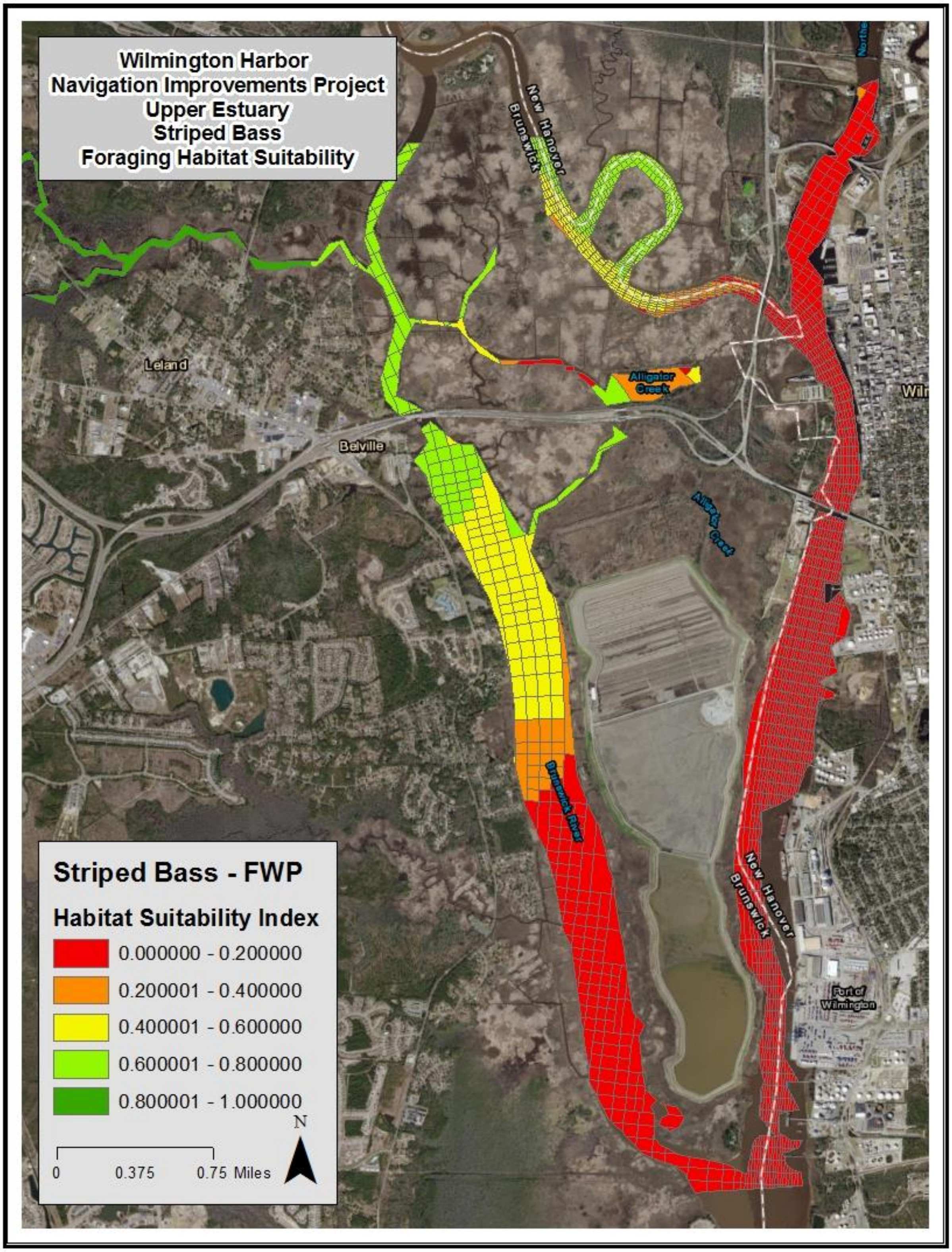


Figure 29
FWP Striped Bass Foraging Habitat Suitability in the Upper Estuary

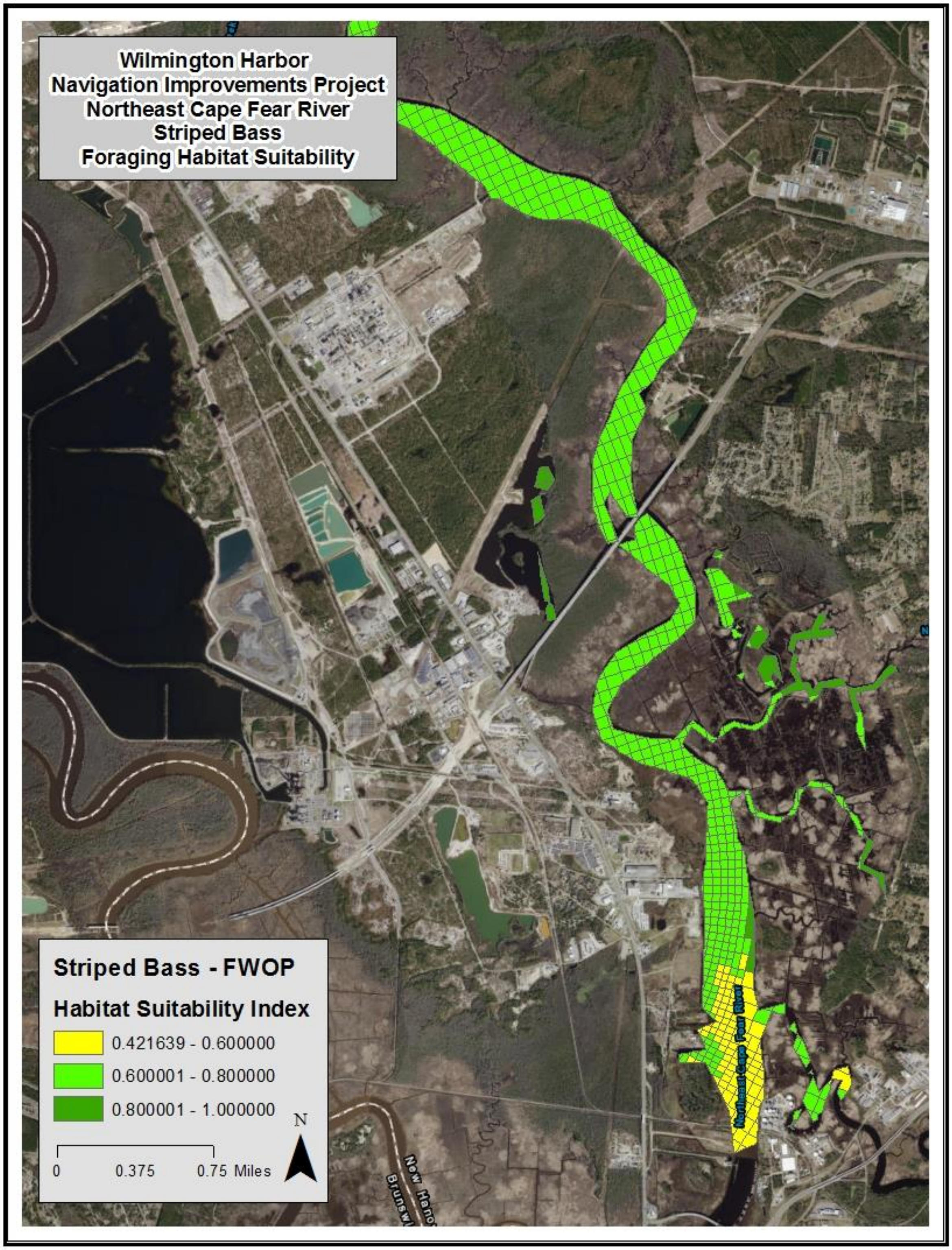


Figure 30
Striped Bass Foraging Habitat under the FWOP Condition in the Northeast Cape Fear River

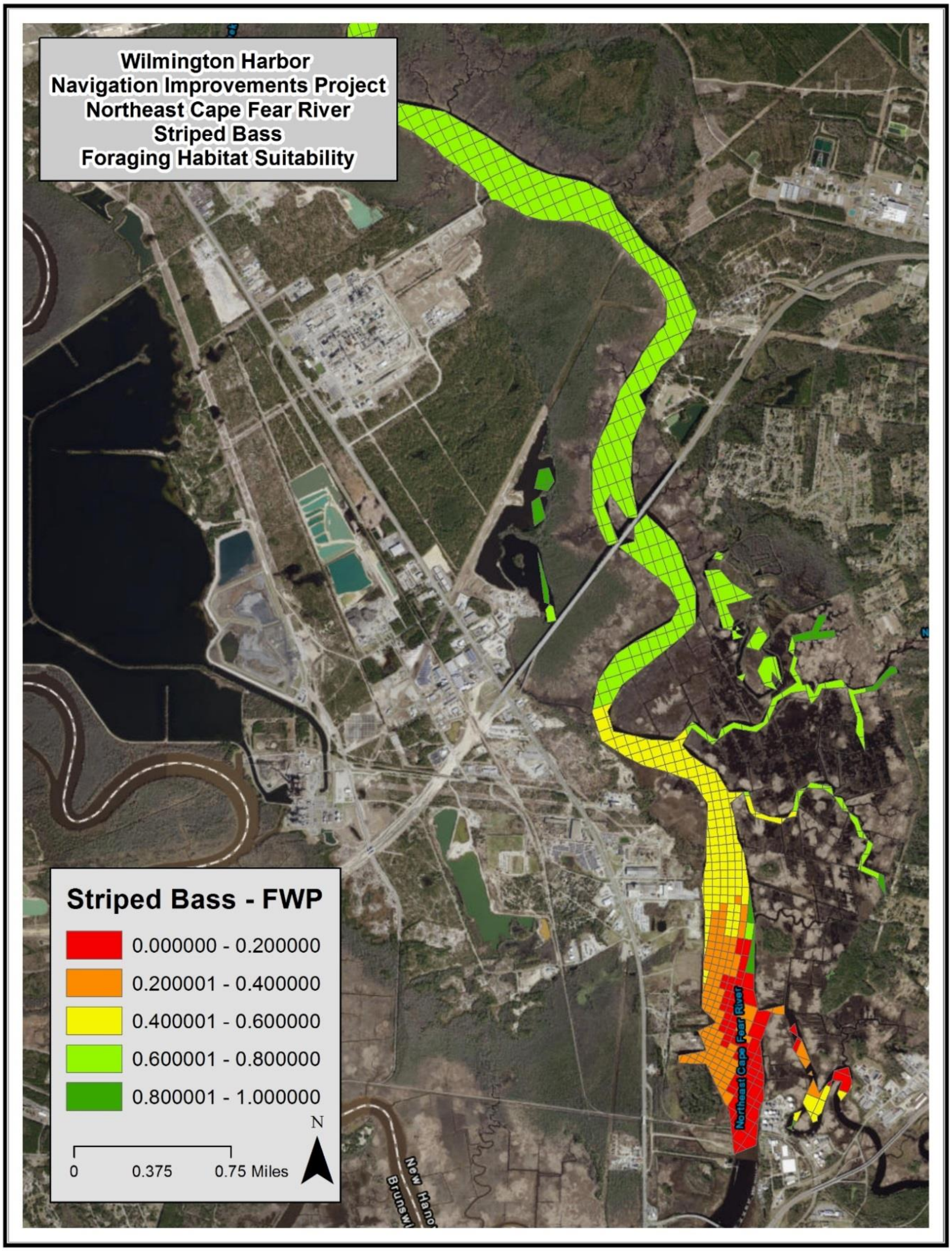


Figure 31
Striped Bass Foraging Habitat under the FWP Condition in the Northeast Cape Fear River

5.2 Additional Selected Species

5.2.1 Atlantic Menhaden

5.2.1.1 Lower Estuary and Middle Estuary

Under all conditions, the lower and middle estuary reaches were classified as highly suitable (0.8-1.0) for Atlantic menhaden except for uppermost Town Creek, which was given a slightly lower HSI of 0.6-0.8 (Figures 32-34). The average HSI for the lower estuary are 0.95, 0.94, and 0.94 for the baseline, FWOP, and FWP conditions, respectively. Habitat Units for the lower estuary are 16,659, 16,484, and 16484 for the baseline, FWOP, and FWP conditions, respectively. The middle estuary displayed even higher average HSI values of 0.98, 0.98, and 0.98 for the baseline, FWOP, and FWP conditions. Habitat Units computed for the middle estuary reach are 5,145 for all sets of conditions (Appendix A).

5.2.1.2 Upper Estuary

Habitat Suitability Index values in the upper estuary are more variable, ranging from 0.0-1.0. Still, most of the upper estuary remains highly suitable for Atlantic menhaden with the lowest suitability in the upper Brunswick River, Smith Creek, and Sturgeon Creek. The FWP condition improves habitat suitability in the upper Brunswick River and an area of the Cape Fear River mainstem just downstream of Navassa (Figures 35 and 36). Average HSI values for the upper estuary are 0.94, 0.75, and 0.82 for the existing, FWOP, and FWP conditions; respectively. Habitat Units for the upper estuary are 1,098, 876, and 958 for the existing, FWOP, and FWP conditions, respectively (Appendix A).

5.2.1.3 Remaining River Reaches

Habitat suitability for Atlantic menhaden deteriorates quickly above Wilmington due to low salinity, which is the most influential variable in the Atlantic menhaden model. Average HSI values and habitat units for these reaches are shown in Appendix A.

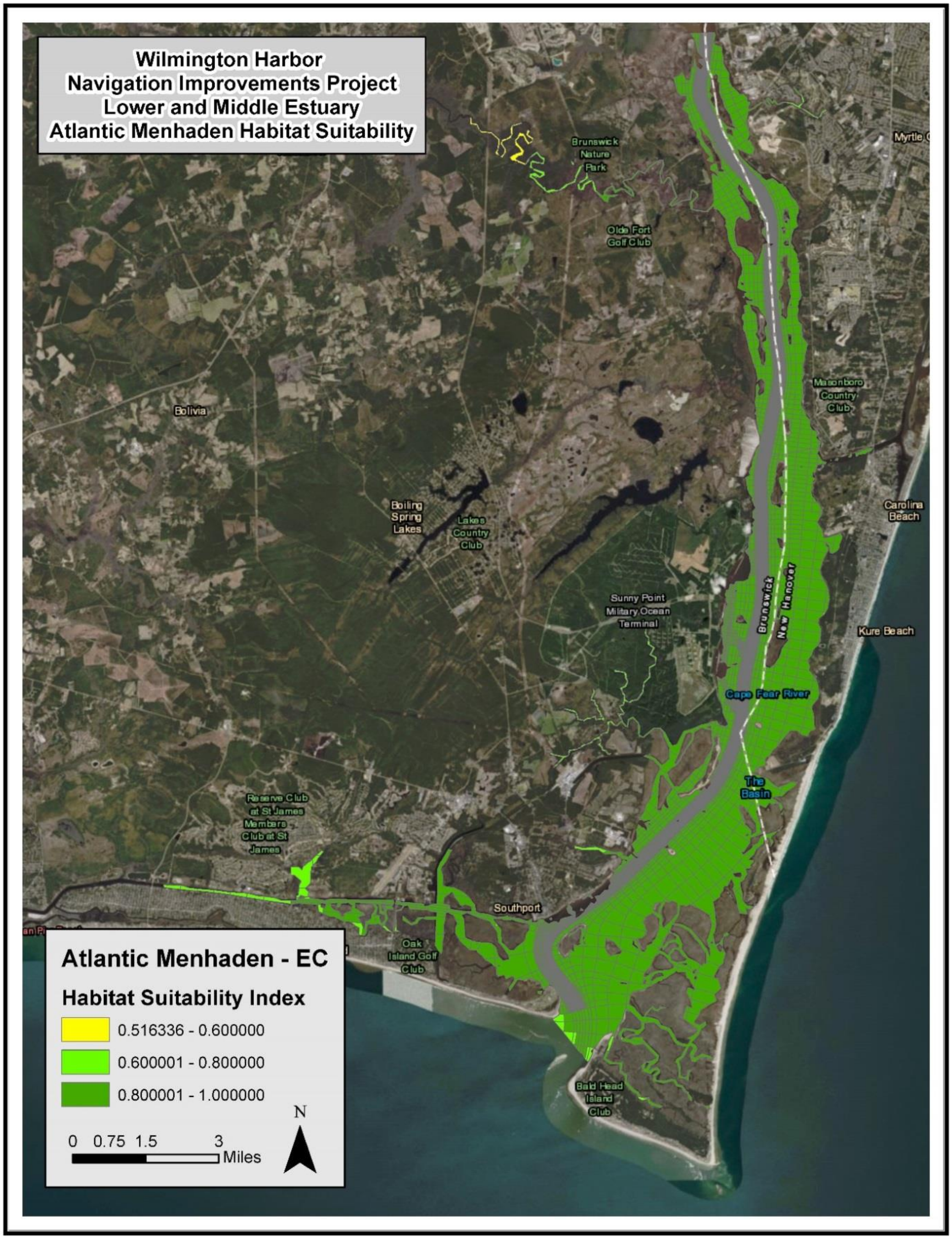


Figure 32
Atlantic Menhaden Habitat Suitability in the Lower and Middle Estuary under the Existing Conditions

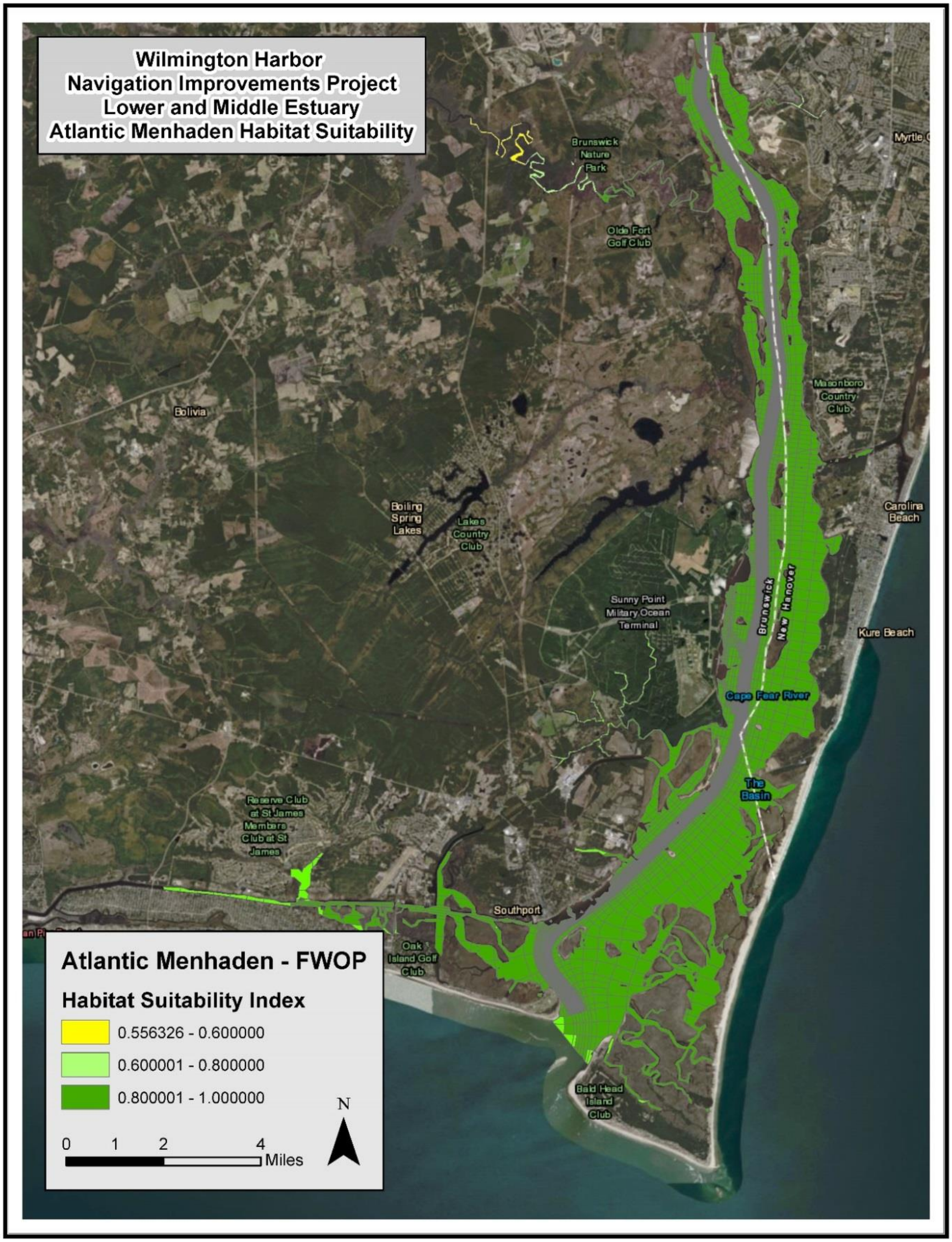


Figure 33
Atlantic Menhaden Habitat Suitability in the Lower and Middle Estuary under the FWOP Conditions

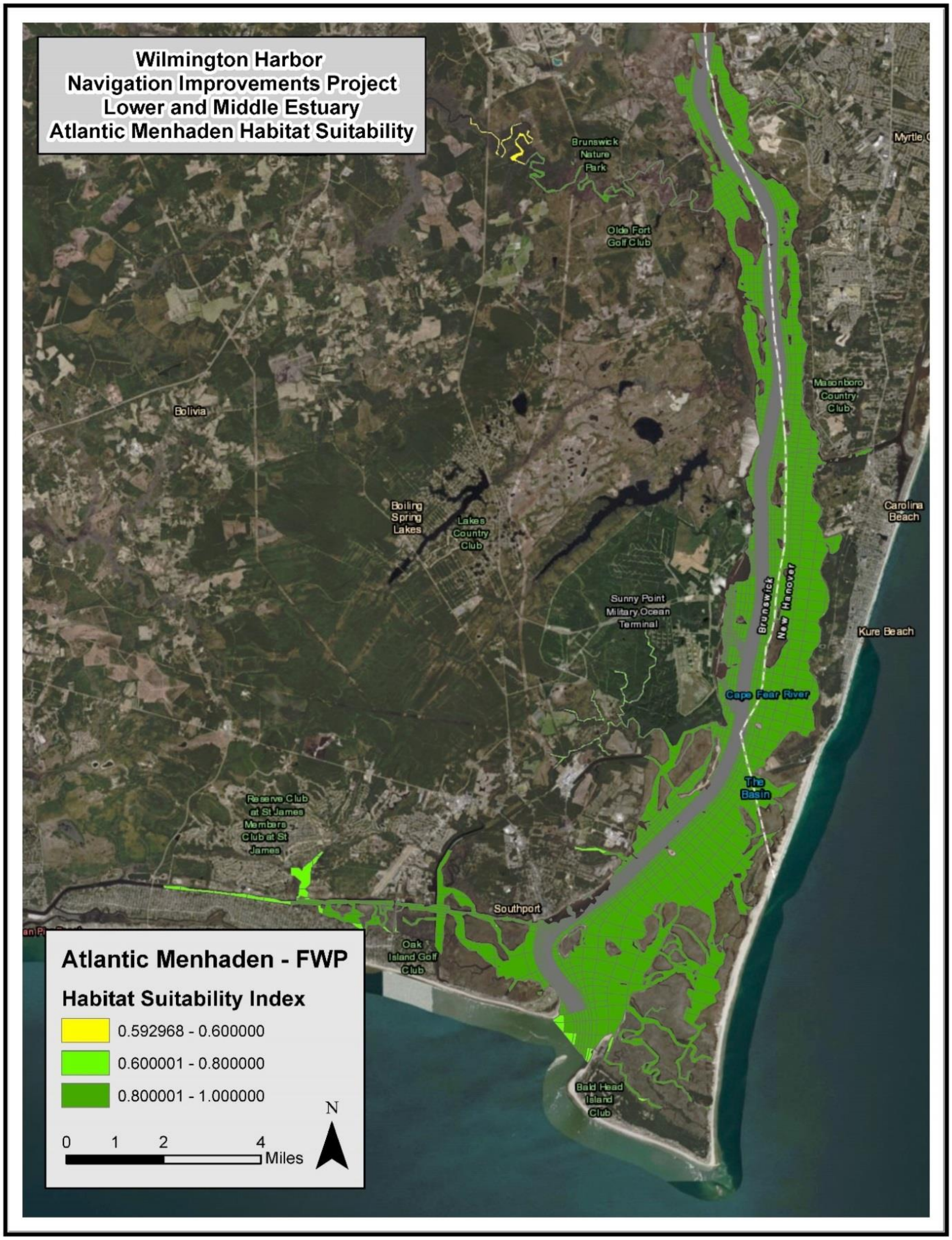


Figure 34
Atlantic Menhaden Habitat Suitability in the Lower and Middle Estuary under the FWP Conditions

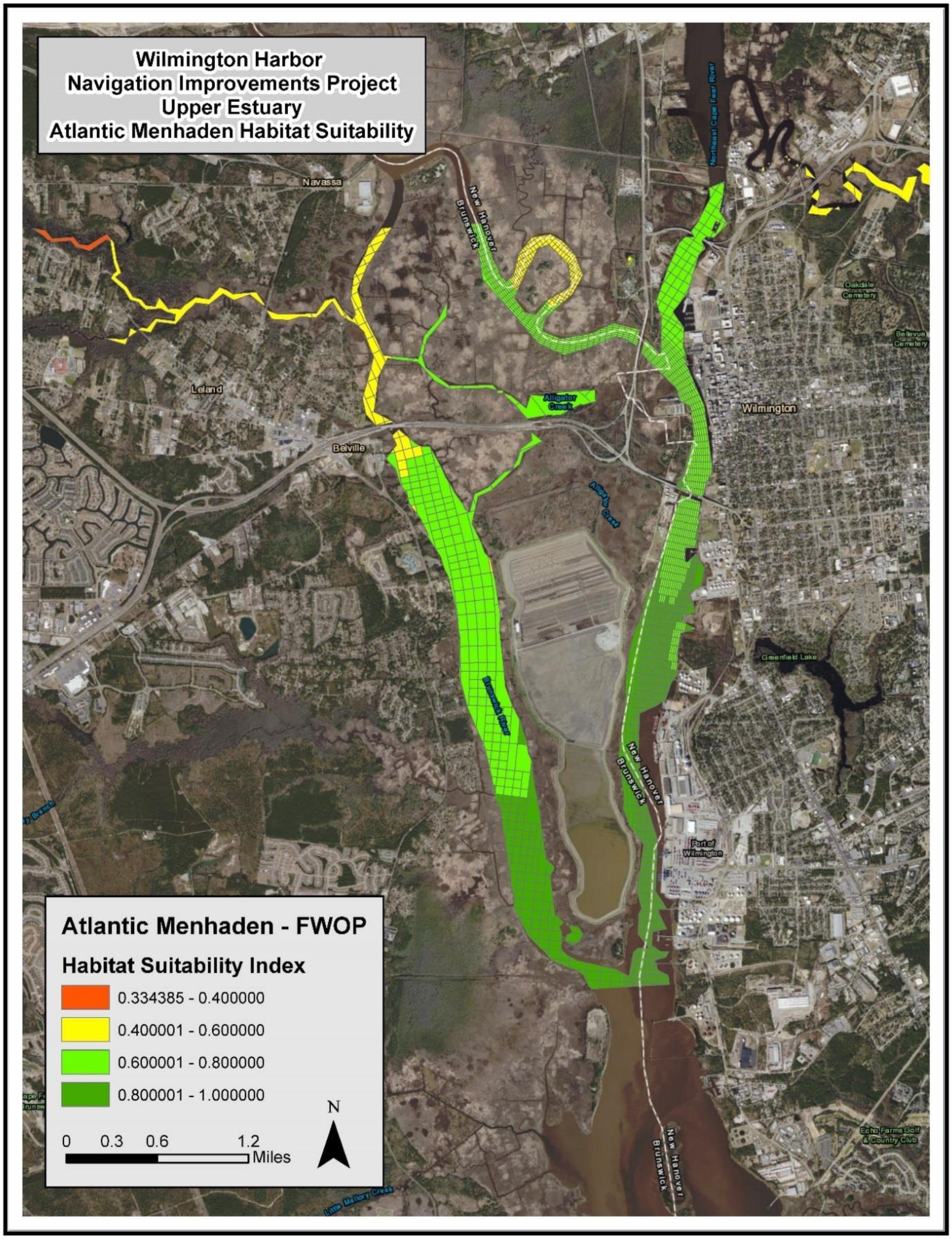


Figure 35
Atlantic Menhaden Habitat Suitability in the Upper Estuary under the FWOP Conditions

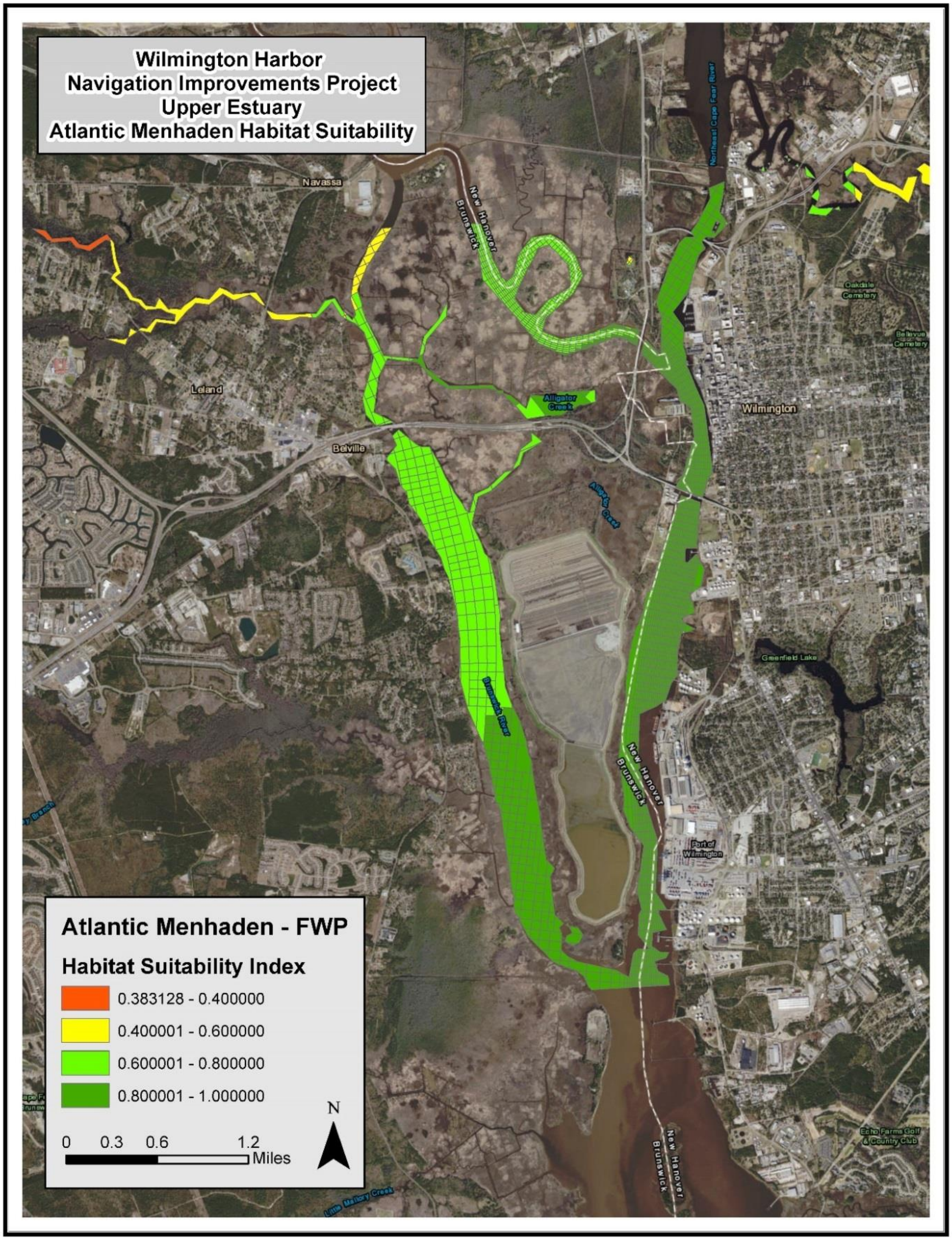


Figure 36
Atlantic Menhaden Habitat Suitability in the Upper Estuary under the FWP Conditions

5.2.2 White Shrimp

5.2.2.1 Lower Estuary and Middle Estuary

Baseline modeling indicates habitat suitability for white shrimp in the lower estuary is suitable with the lowest suitability isolated just inside the Cape Fear River mouth (Figure 37). This area is highly influenced by the Atlantic Ocean and salinity is above the established threshold for white shrimp development. Under the FWOP condition, the extent of unsuitable habitat extends to MOTSU; whereas, under the FWP condition it extends to Southport (Figures 38 and 39). Under all conditions, habitat suitability improves upstream as the Atlantic Ocean has less influence on water quality. Average HSI values for the lower estuary are 0.67, 0.52, and 0.63 under the existing, FWOP, and FWP conditions; respectively. Habitat units computed for white shrimp in the lower estuary are 11,749, 9,119, and 11,048 under the existing, FWOP, and FWP conditions; respectively (Appendix A). The middle estuary is highly suitable for white shrimp under all sets of conditions with an average HSI of 0.81. Habitat units calculated for the middle estuary are 4,253 for all conditions (Appendix A). Located further from the Atlantic Ocean, the middle estuary exhibits improved overall conditions for white shrimp primarily from lower salinity.

5.2.2.2 Remaining River Reaches

Throughout the remaining river reaches, habitat suitability is constant (HSI = 0.81) among all sets of conditions. However, substrate data, which was unavailable for the project area, would have introduced more variability in habitat quality in the upper river reaches.

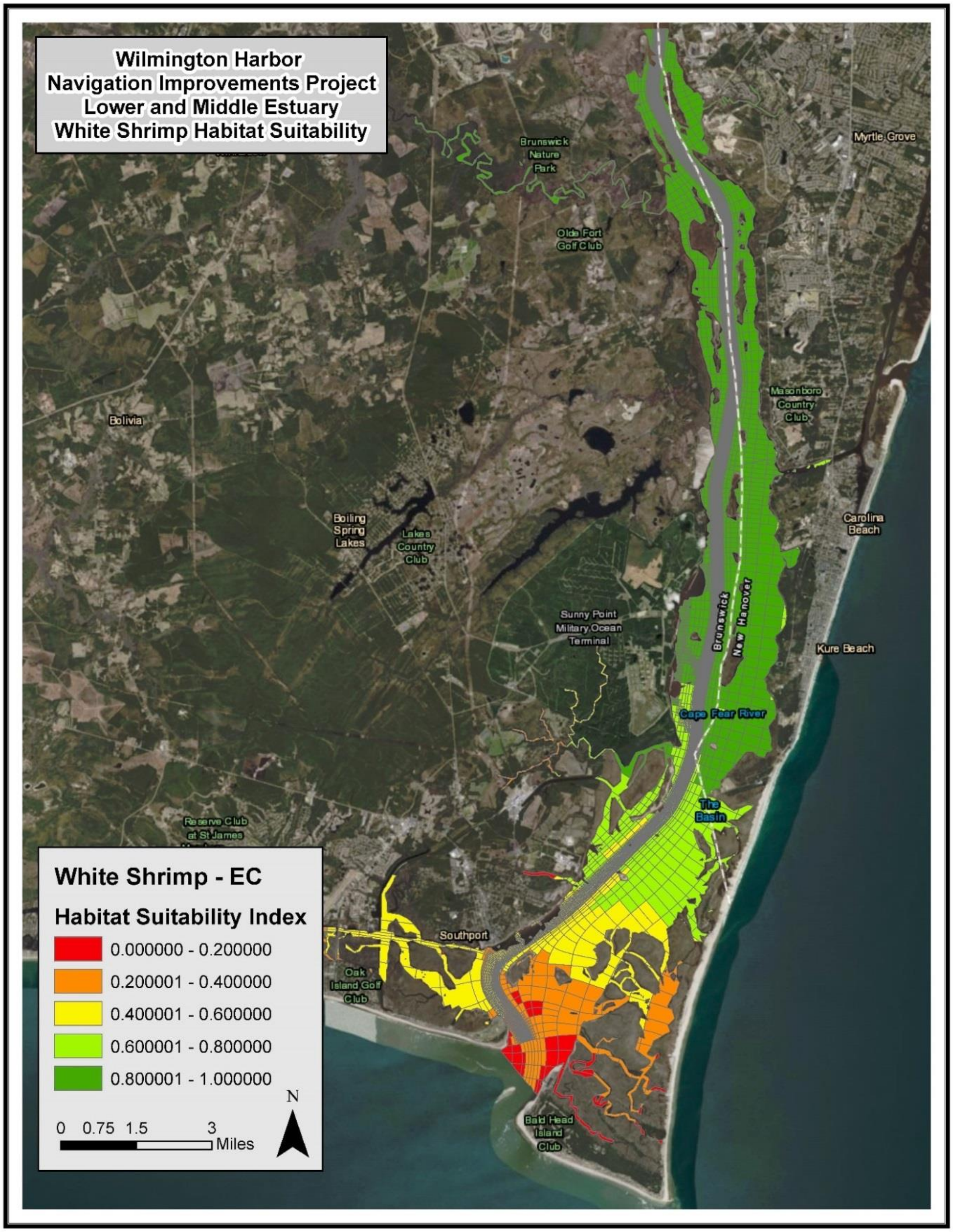


Figure 37
White Shrimp Habitat Suitability in the Lower and Middle Estuary under the Existing Conditions

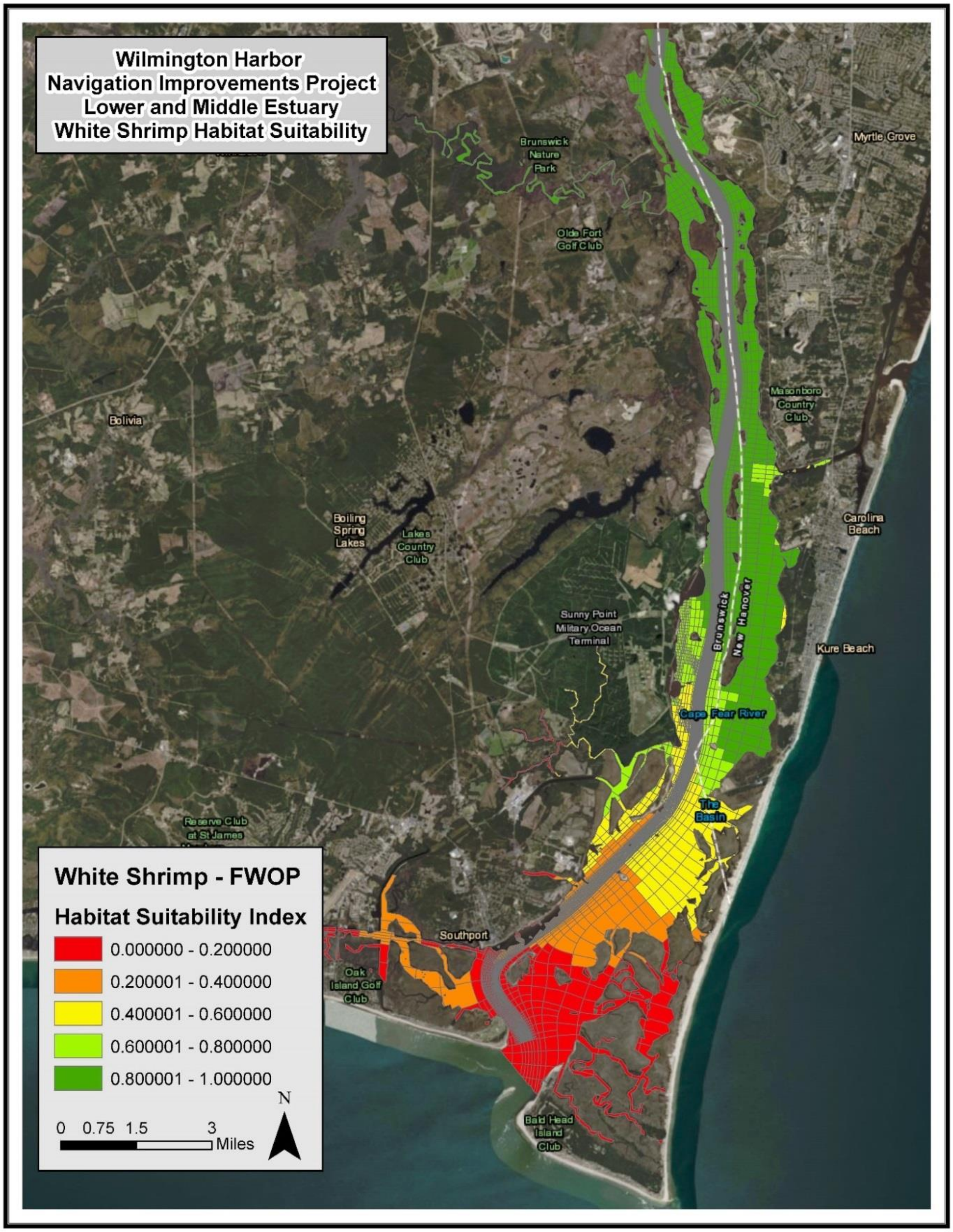


Figure 38
White Shrimp Habitat Suitability in the Lower and Middle Estuary under the FWOP Conditions

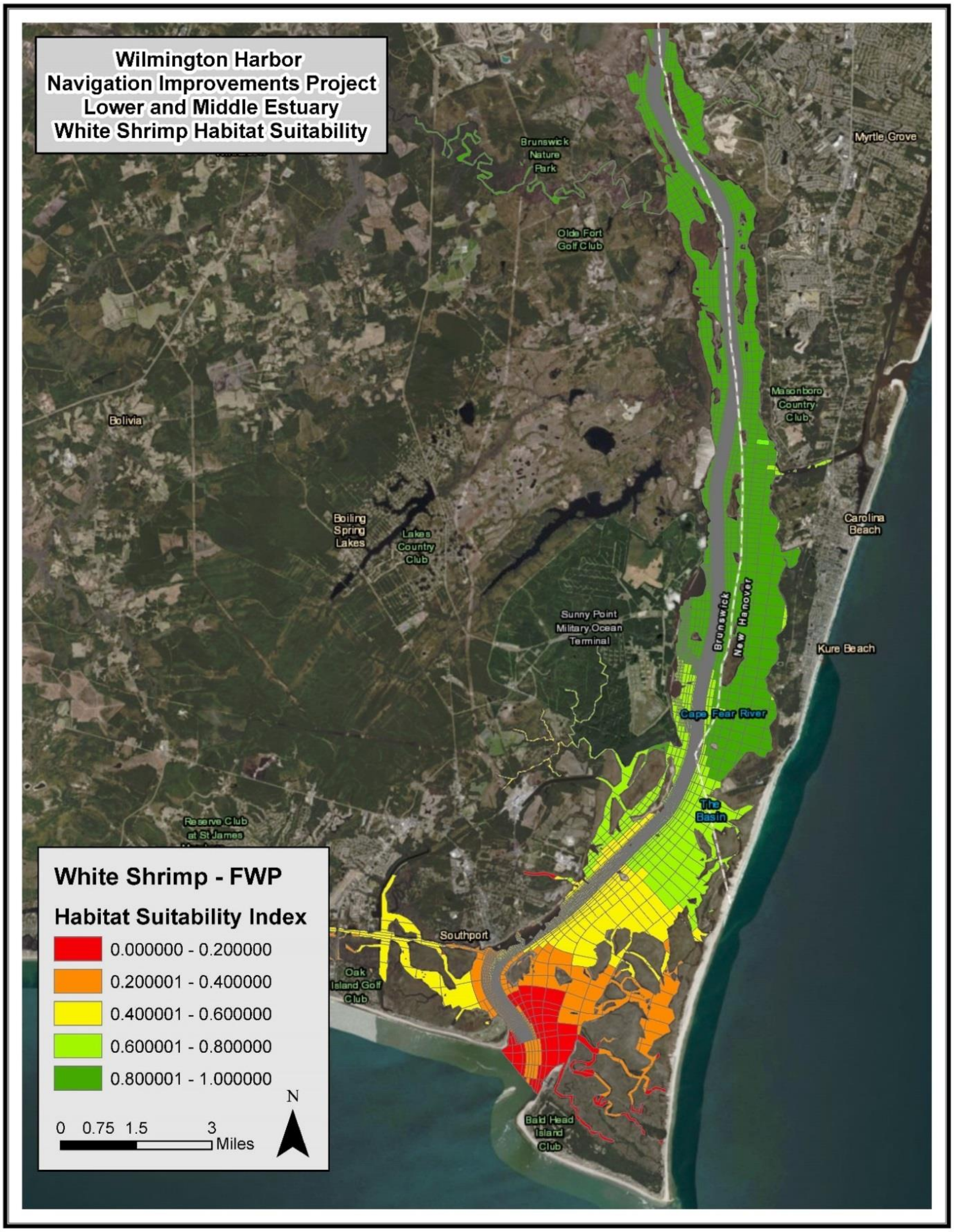


Figure 39
White Shrimp Habitat Suitability in the Lower and Middle Estuary under the FWP Conditions

5.2.3 Southern Flounder

5.2.3.1 Lower Estuary and Middle Estuary

The lower estuary is highly suitable for southern flounder, with only Town Creek and several isolated pixels classified as unsuitable due to summer DO falling below the established threshold (Figures 40-42). Given that flounders are highly euryhaline and eurythermal, these results were anticipated. However, substrate data, which was not available for use in the model, would likely have introduced more variability. Southern flounder prefer mud bottoms over sand and shell bottom; therefore, some of the lower estuary would have received lower HSI values, particularly higher energy areas. Regardless, the average HSI values for the lower estuary are 0.89, 0.88, and 0.81 under the existing, FWOP, and FWP conditions, respectively. Habitat units computed for this reach are 15,607, 15,432, and 14,204 for the existing, FWOP, and FWP conditions; respectively. Average HSI values for the middle estuary are 0.98, 0.99, and 0.98 under the existing, FWOP, and FWP conditions; respectively (Appendix A).

5.2.3.2 Upper Estuary

Baseline conditions in the upper estuary indicate highly suitable habitat for southern flounder apart from the upper Brunswick River and Smith Creek (Figure 43). Conditions improve in the Brunswick River under the FWOP due to increased salinity, resulting in the conversion of grid cells to the next higher HSI class (Figure 44). This pattern is more pronounced under the FWP condition with most of the Brunswick River converting to the highest HSI class (Figure 45). The average HSI values for the upper estuary reach are 0.79, 0.87, and 0.88 for the baseline, FWOP, and FWP conditions, respectively. Habitat Units computed for this reach are 923, 1016, and 1,028 under the baseline, FWOP, and FWP conditions; respectively (Appendix A).

5.2.3.3 Remaining River Reaches

The lower Northeast Cape Fear River exhibits suitable conditions for southern flounder; although, habitat suitability deteriorates rapidly near Castle Hayne, NC, from low summer DO. Little change was detected among sets of conditions; as is evident from the average HSI values of 0.55, 0.56, and 0.57 for the existing, FWOP, and FWP; respectively. Habitat Units for the Northeast Cape Fear River reach are shown in Appendix A. The Cape Fear River reach just above Wilmington, NC, was suitable under all conditions; although above Sutton Lake, several areas were plagued by low summer DO and habitat quality was highly variable. The Black River was least suitable due to summer hypoxia likely caused by the high amount of organic matter in the system (biological oxygen demand) and perhaps low flows. For more information regarding the average HSI values and HUs computed for the Cape Fear River and Black River reaches, see Appendix A.

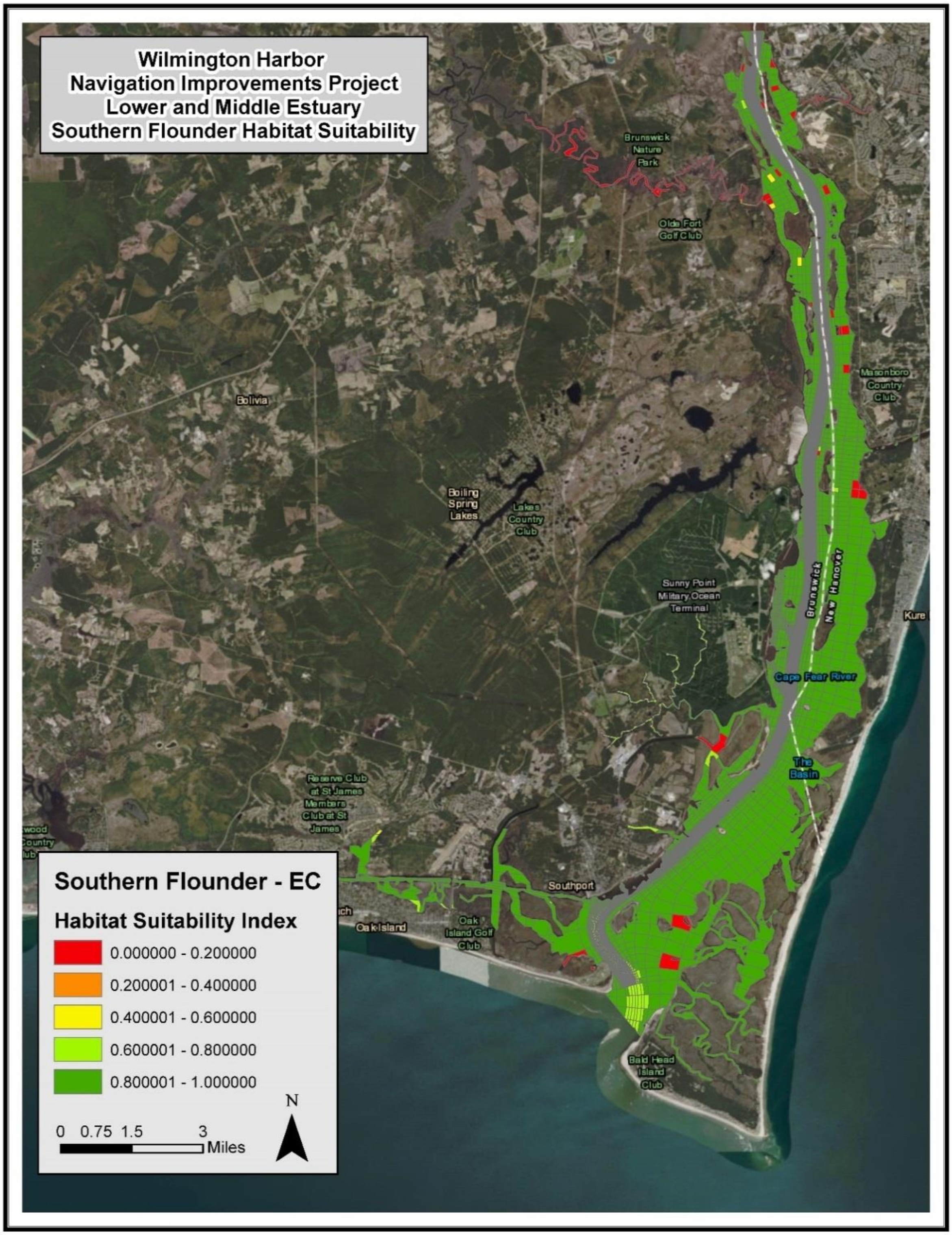


Figure 40
Southern Flounder Habitat Suitability in the Lower and Middle Estuary under the Existing Conditions

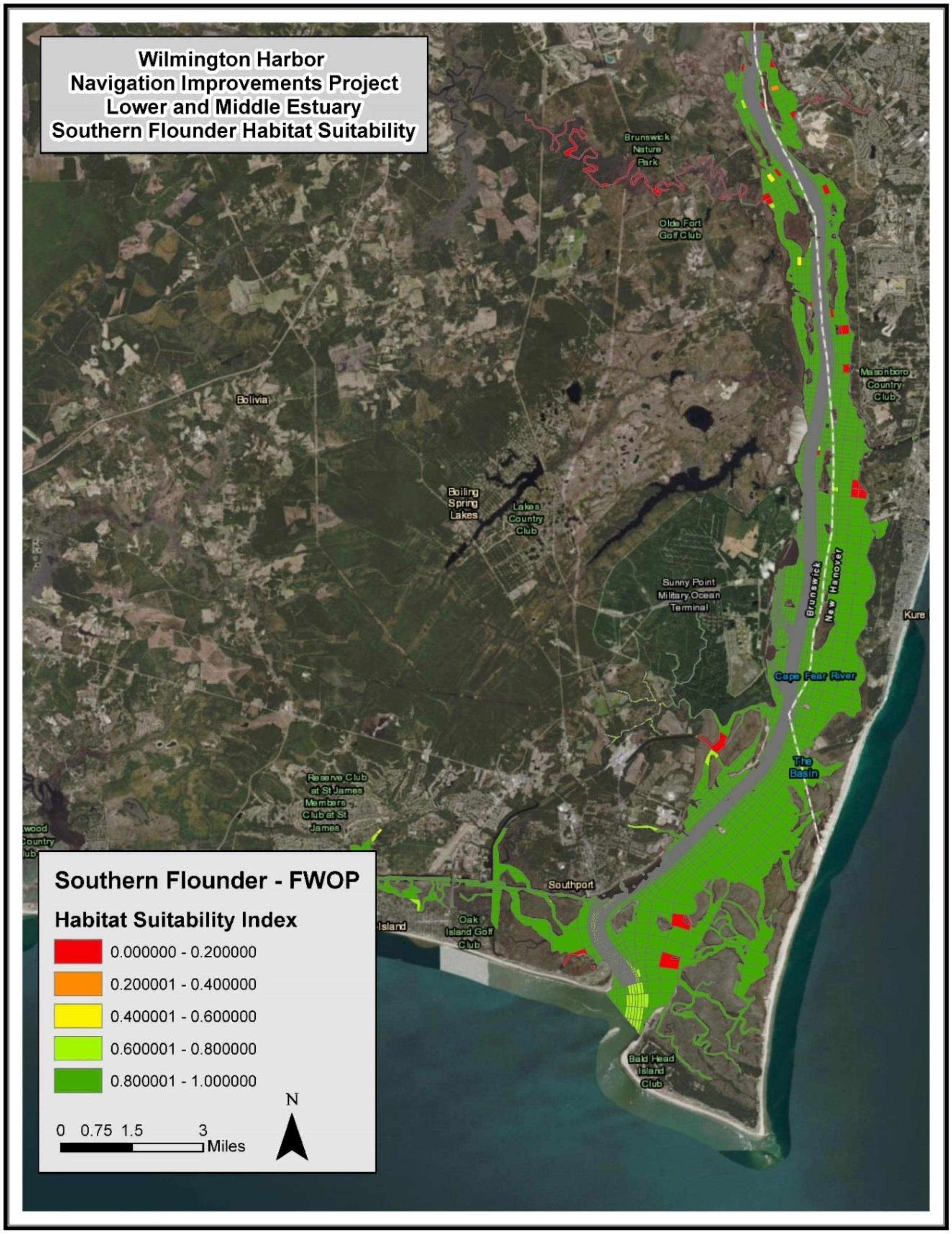


Figure 41
Southern Flounder Habitat Suitability in the Lower and Middle Estuary under the FWOP Conditions

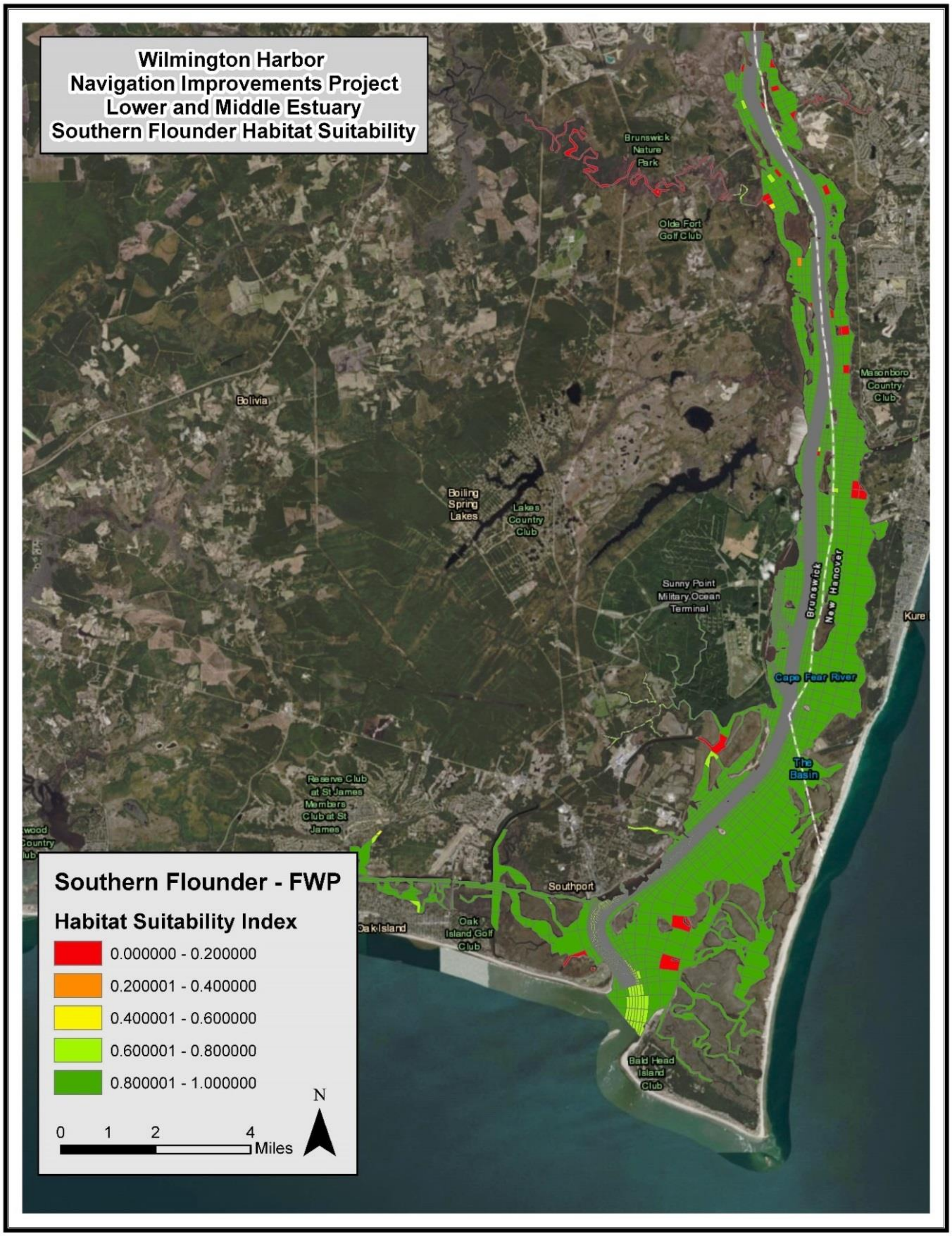


Figure 42
Southern Flounder Habitat Suitability in the Lower and Middle Estuary under the FWP Conditions

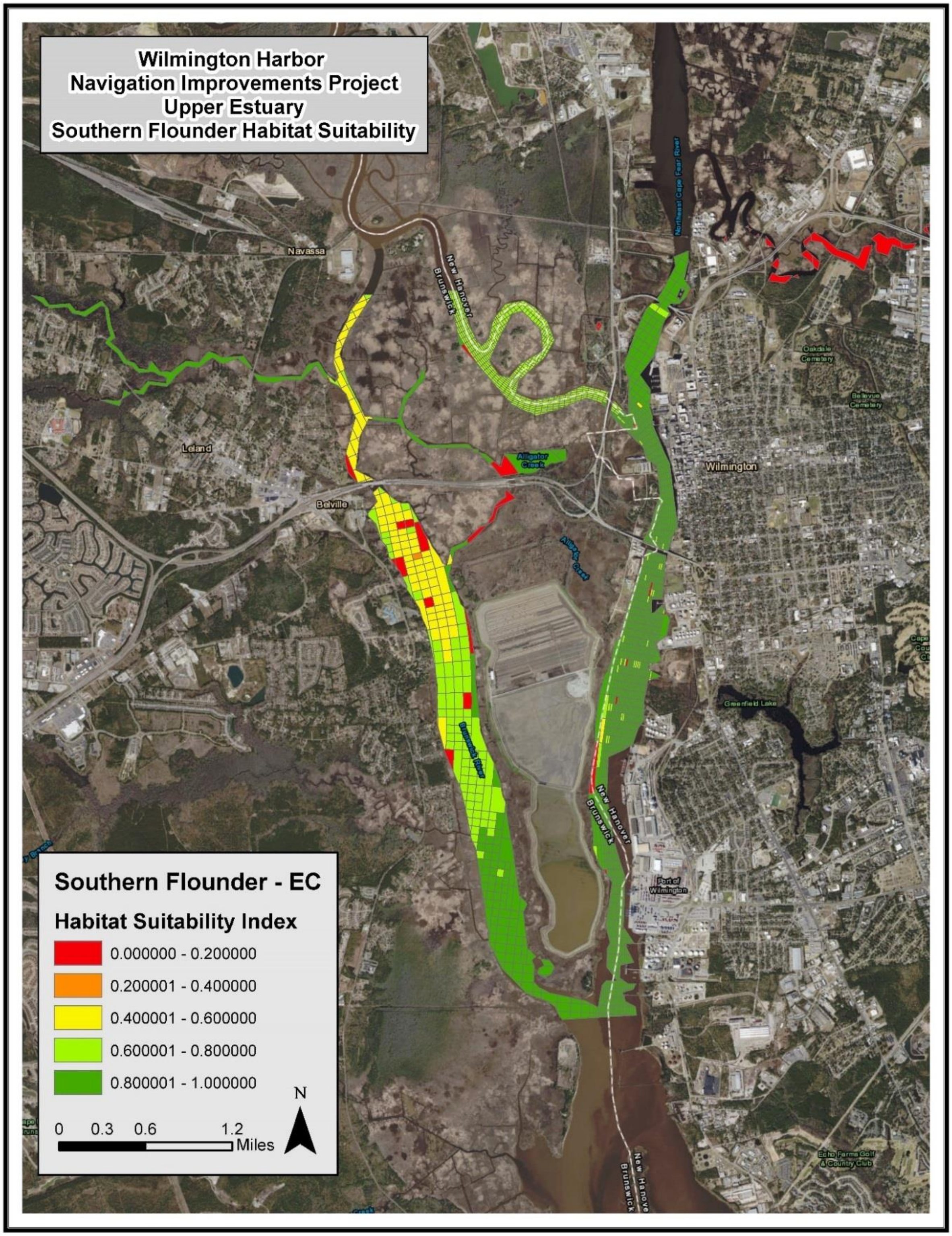


Figure 43
Southern Flounder Habitat Suitability in the Upper Estuary under the Existing Conditions

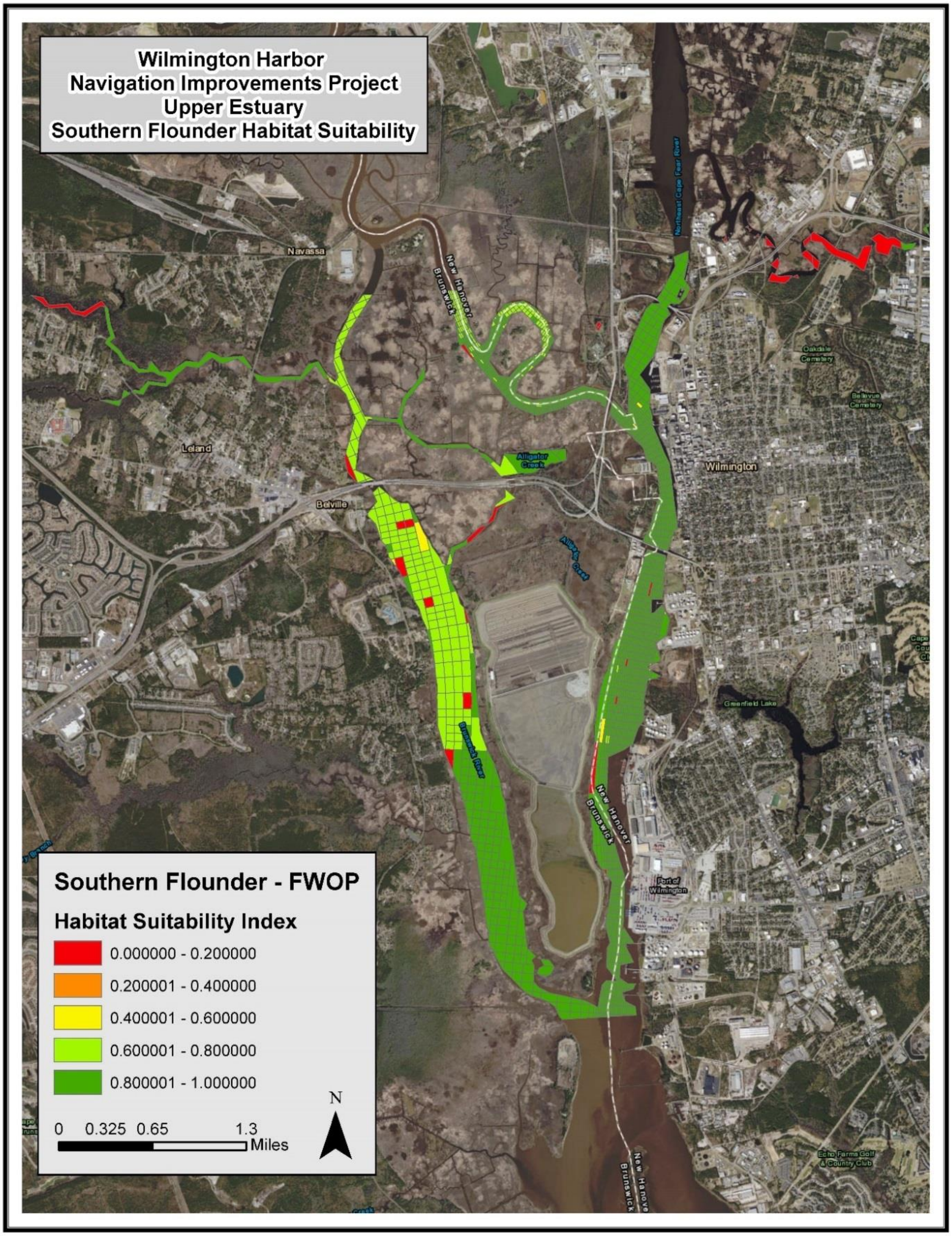


Figure 44
Southern Flounder Habitat Suitability in the Upper Estuary under the FWOP Conditions

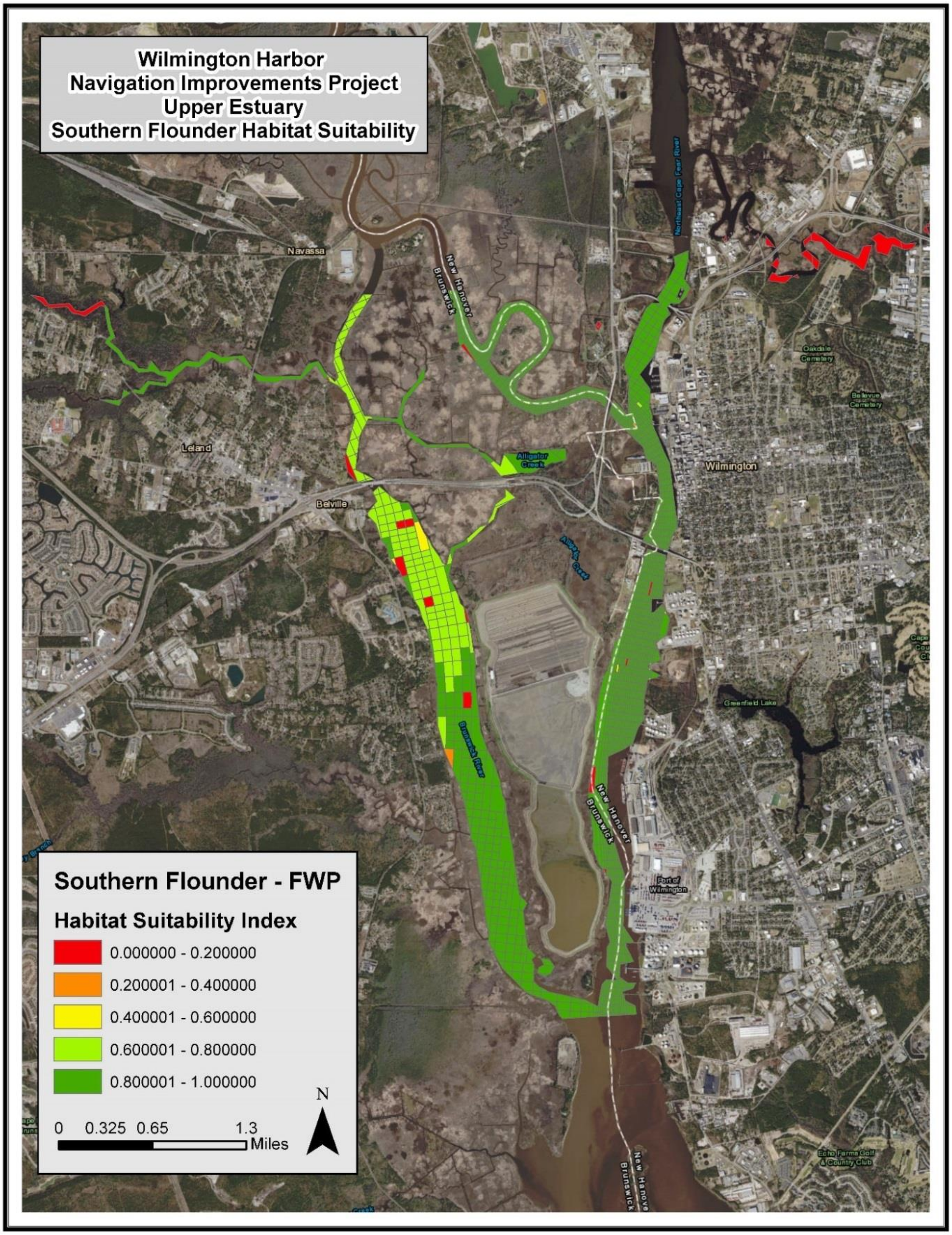


Figure 45
Southern Flounder Habitat Suitability in the Upper Estuary under the FWP Conditions

5.2.4 Red Drum

5.2.4.1 Lower Estuary and Middle Estuary

The red drum HSI model has the most variability among all the habitat models, specifically because it has a depth variable that highly influences the model outputs. Areas ≤ 0.5 meters (m) and areas ≥ 4.0 m are considered unsuitable. Remaining locations are scored according to water quality conditions, mean depth, and percentage of open water fringed with emergent wetlands. Substrate composition was not included as it was unavailable. The lower and middle estuary reaches have large areas of open water fringed with emergent vegetation and salinity that falls well within the suitable range for red drum, which is a highly euryhaline species. Therefore, model outputs are primarily driven by changes in mean depth at low tide and mean temperature. Under all conditions, the most suitable habitat in the lower estuary is a cluster of cells north of Shellbed Island extending upstream to The Basin (Figures 46 – 48). The average HSI value under all conditions for red drum in the lower estuary is 0.53. Computed HUs for this reach were 9,294 for all sets of conditions (Appendix A). Conditions in the middle estuary for red drum remain variable under all conditions, mostly due to the mean depth at low tide variable. Areas of high suitability for red drum in the middle estuary are located near Campbell Island and near the Masonboro Country Club north of Snow's Cut. The average HSI value under all conditions in the middle estuary is 0.56. Habitat Units calculated for this reach under all sets of conditions total 2,940 (Appendix A).

5.2.4.2 Upper Estuary

Habitat suitability in the upper estuary under all conditions is highly variable and influenced primarily by mean depth. Highly suitable habitat is located on the banks of the Brunswick River near the entrance to Jackey's Creek and Redmond Creek (Figure 49). Most remaining areas in the upper estuary reach are unsuitable except for some isolated areas where depth falls within the optimal range. Conditions do not change under the FWOP or FWP conditions in the upper estuary, as these sets of conditions do not alter depth apart from the immediate dredging footprint related to the project (Figures 50 and 51). The average HSI value in the upper estuary for all sets of conditions is 0.56 and HUs computed are 654 (Appendix A).

5.2.4.3 Remaining River Reaches

Habitat suitability in the remaining river reaches is mostly unsuitable due to low salinity; however, below Sutton Lake, there are some areas with higher suitability closest to the riverbanks where depth is optimal. The Black River; however, was not modeled for red drum because no mean depth data was available. Average HSI values for these reaches; as well as, computed HUs are shown in Appendix A.

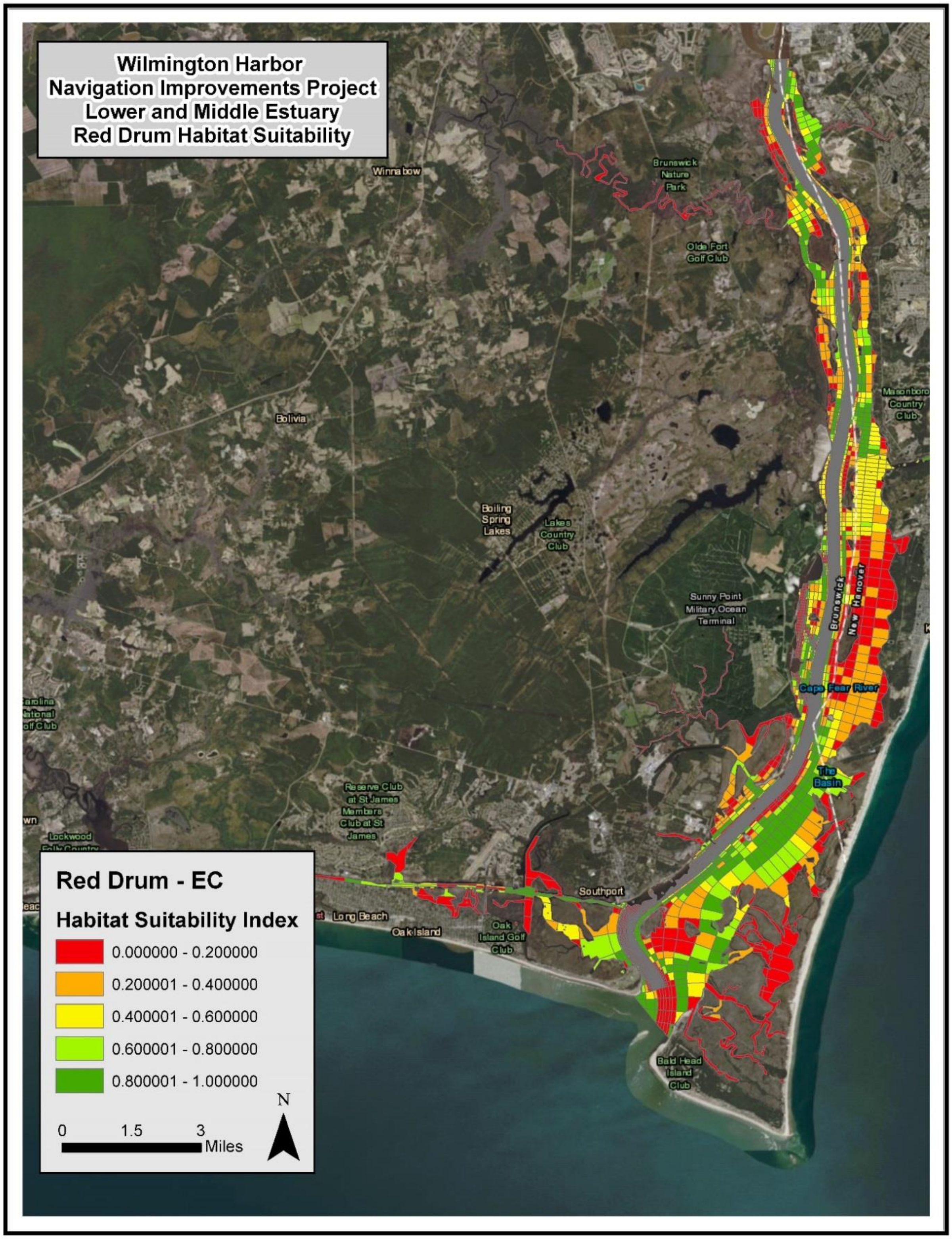


Figure 46
Red Drum Habitat Suitability in the Lower and Middle Estuary under the Existing Conditions

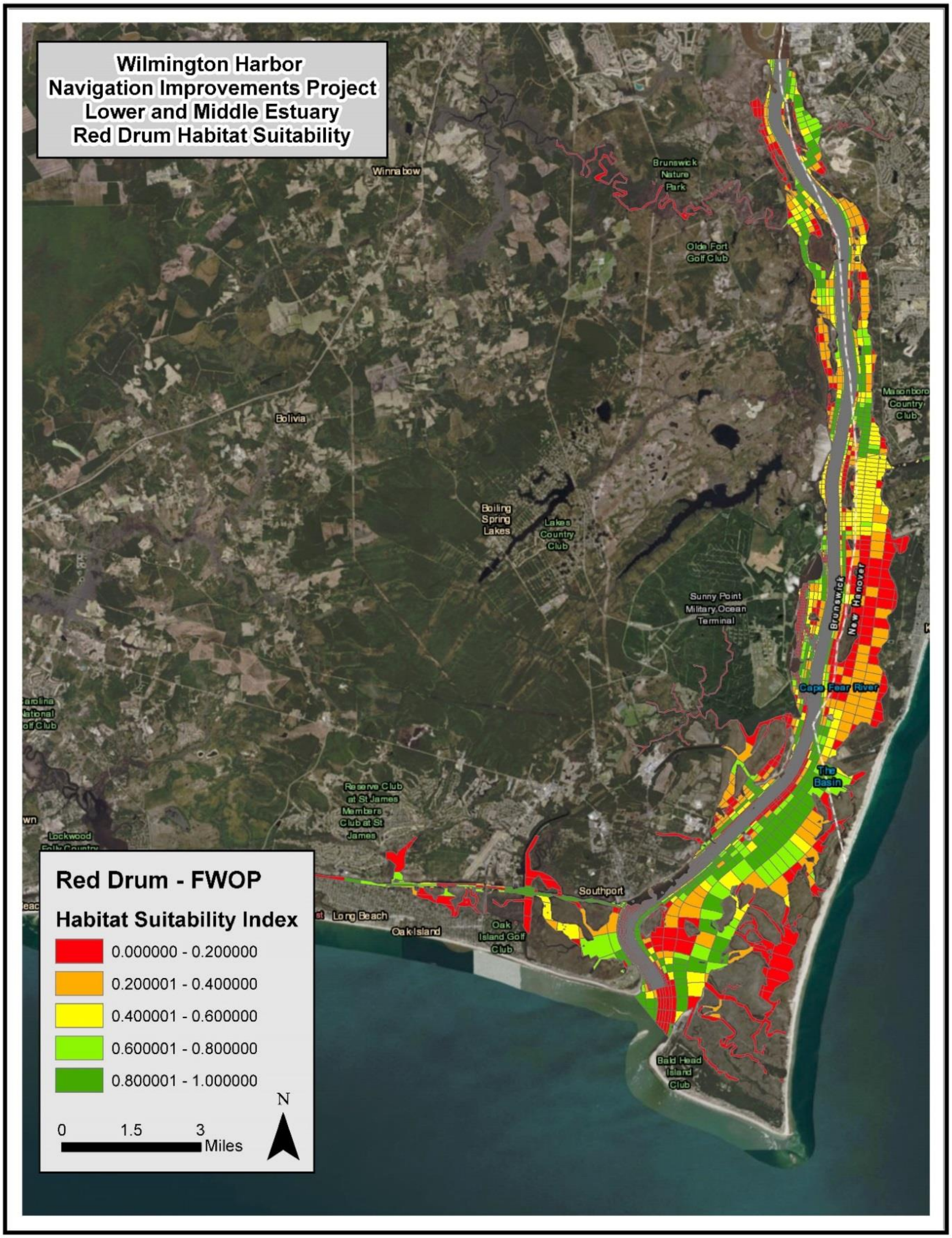


Figure 47
Red Drum Habitat Suitability in the Lower and Middle Estuary under the FWOP Conditions

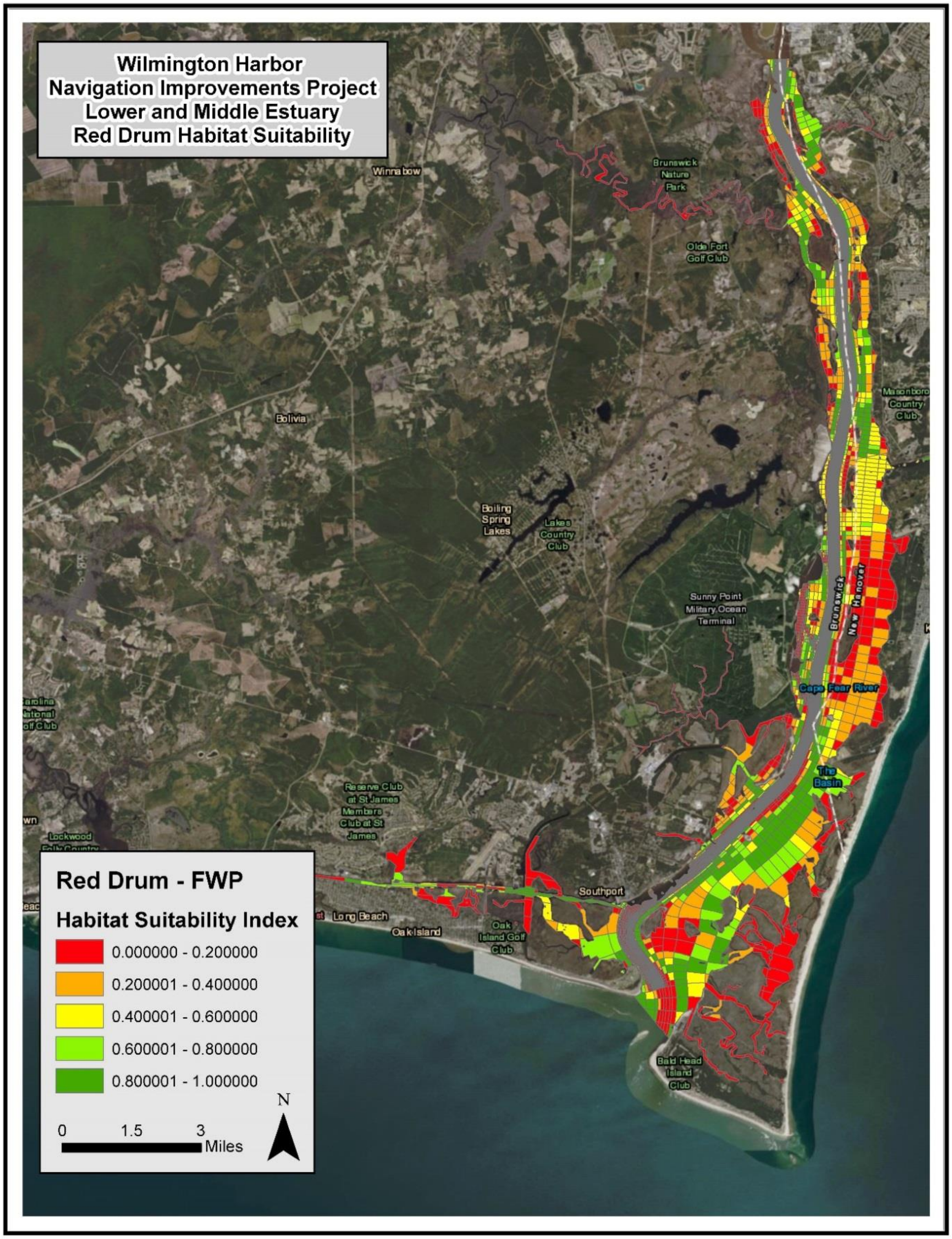


Figure 48
Red Drum Habitat Suitability in the Lower and Middle Estuary under the FWP Conditions

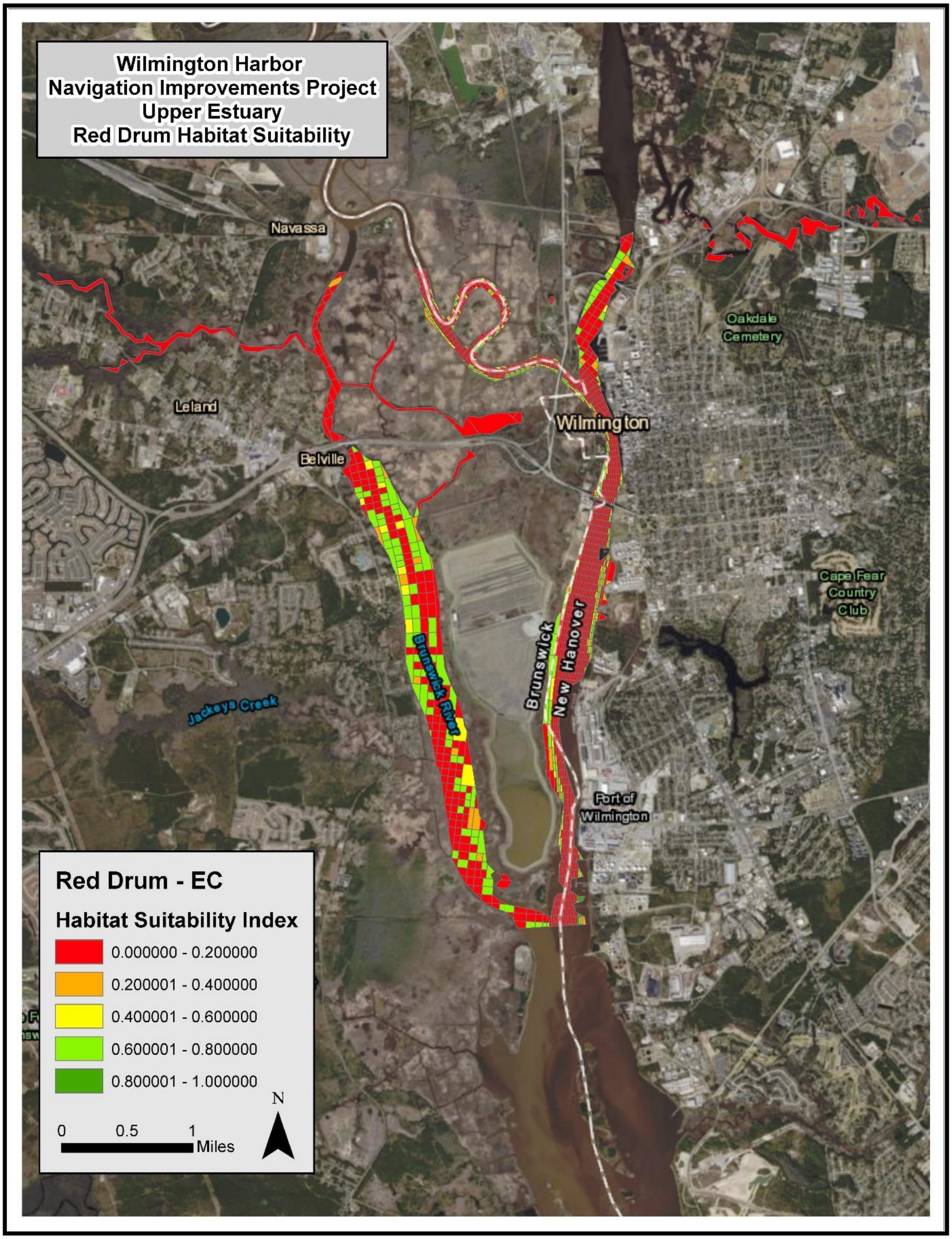


Figure 49
Red Drum Habitat Suitability in the Upper Estuary under the Existing Conditions

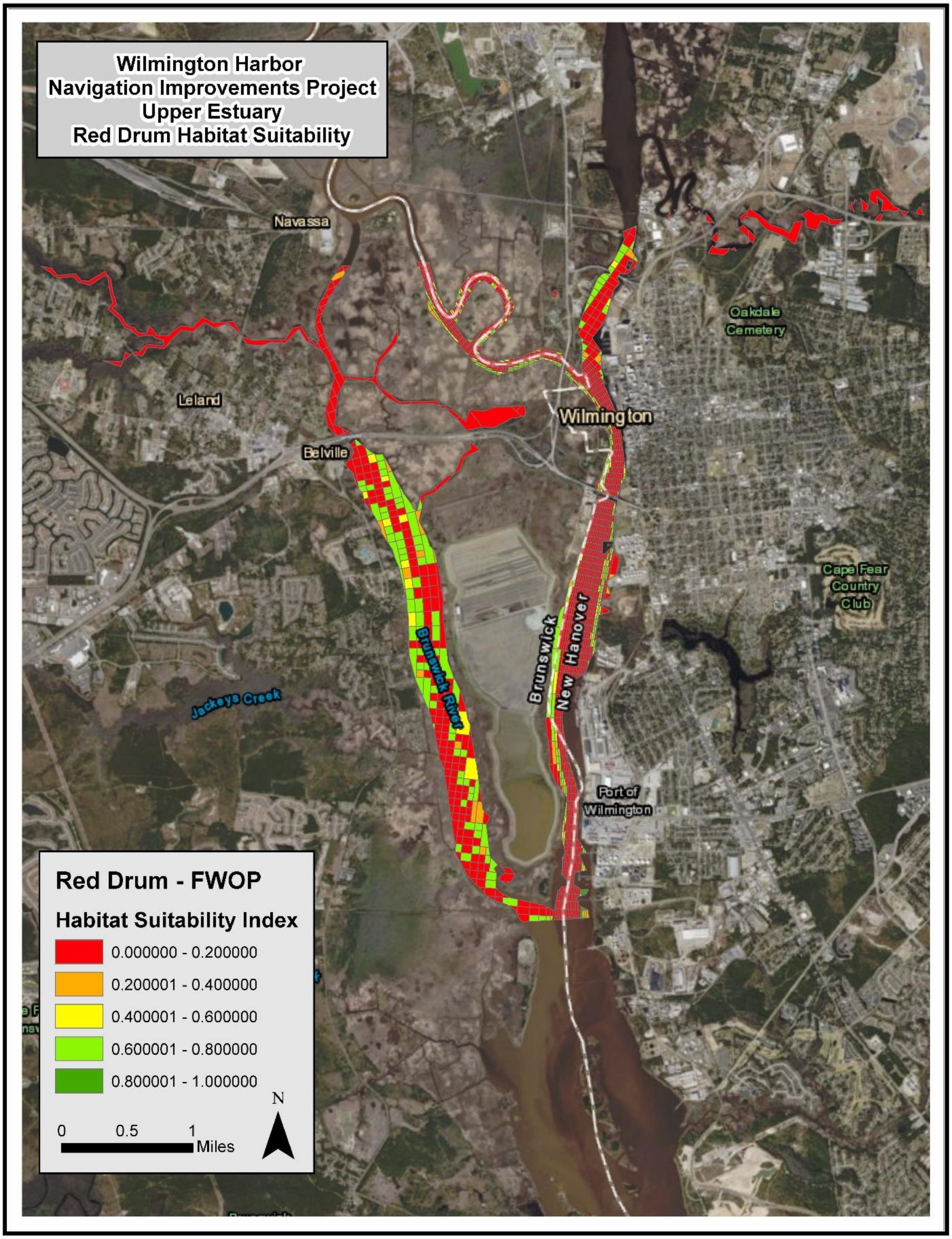


Figure 50
Red Drum Habitat Suitability in the Upper Estuary under the FWOP Conditions

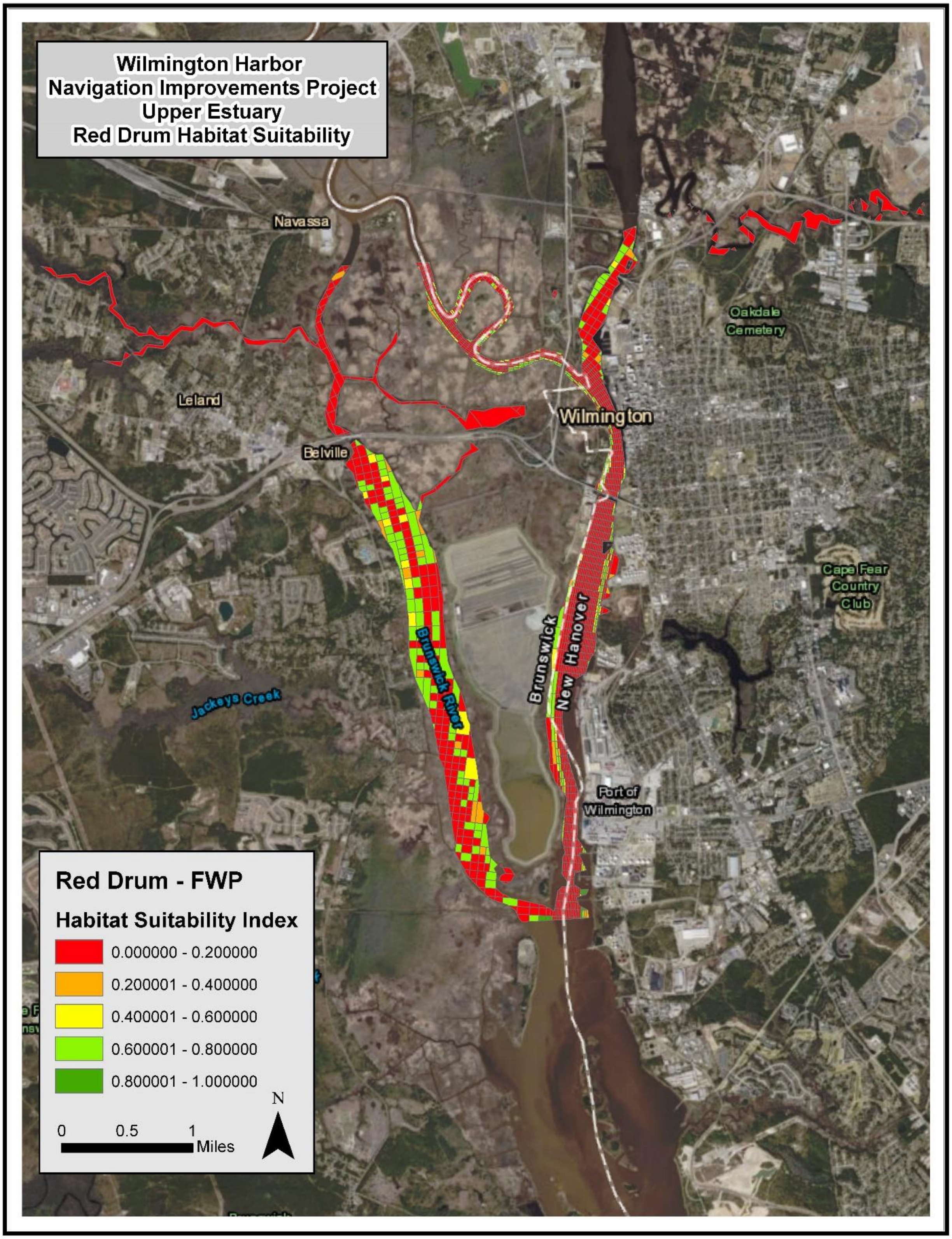


Figure 51
Red Drum Habitat Suitability in the Upper Estuary under the FWP Conditions

6 CONCLUSIONS

The Cape Fear River is a dynamic system that has been highly modified over the last 200 years. Before anthropogenic modification began in the 1790s, the Cape Fear River was a shallow [6-12 feet (ft) deep] freshwater river surrounded by bottomland hardwood forest and hardwood swamp (USACE 2011). By the 1890s, a channel had been dredged to 20-ft deep and 270-ft wide with continued alteration to the system by dredging deeper and wider to accommodate more and larger ships calling on the Port of Wilmington. The most recent harbor improvement was termed The Wilmington Harbor, NC – 96 Act Project. This project authorized channel dredging to a depth of -40 to -44-ft with a 600-ft width in certain reaches. Currently the habitat in the lower Cape Fear River is dominated by smooth cordgrass (*Spartina alterniflora*) and tidal brackish marsh up to the I-40 Bridge. Current conditions represent the habitat change from an unmodified freshwater system to a highly modified estuarine system. This report considered three modeled conditions; Existing, FWOP, and FWP. All modeled conditions were displayed graphically for interpretation of changes expected for FWOP and FWP to the year 2077, a 50-year projection from the expected project completion date. The FWOP estimates sea level rise; whereas, the FWP estimates sea level rise along with effects from deepening and widening of the river to -47-ft (plus 2-ft over dredge) and 500 to 1,300-ft, respectively (1,300-ft is the maximum width that only occurs in the Battery Island turn, the majority of the channel width is much smaller).

All models are dependent on quality data to derive quantitative relationships between key environmental variables and species-specific habitat suitability. Some models used for the representative species required data that is not readily available, thus reducing their effectiveness in accurately predicting habitat suitability within the Cape Fear River system. However, even with accurate data sets, natural variability should be considered and knowledge of the system by natural resource managers should play an important role in drawing conclusions. Aside from the modeling limitations stated above, these HSI model outputs provide a reasonable representation of expected future conditions. Modeling efforts utilized datasets from low-flow conditions, providing conservative outputs so resource managers can make informed decisions on the expected conditions analyzed in the above document. Additionally, models provide resource managers with graphical representations identifying the most limiting factor for a specific population. Often, larval/egg development or spawning habitat criteria may limit a model, driving the HSI value to zero. This underestimates other life stage suitability within the system; however, it points towards specific reaches of the system as extremely important. Specifically, Atlantic sturgeon modeling provides a clear graphic that more effort is needed to restore access to the historical spawning grounds at Smiley Falls.

Fisheries assessment results indicate an upstream shift in salinity from existing conditions to the FWOP condition and the feasible alternative (FWP). Salinity increases; however, do not appear to have an adverse effect on euryhaline species like red drum or southern flounder. Furthermore, Atlantic menhaden habitat in the upper estuary, particularly the Brunswick River and the Cape Fear River from the Port of Wilmington to Smith Creek, is improved from an increase in salinity, which also serves as a proxy for food availability.

Existing habitat for Atlantic sturgeon was unsuitable throughout much of the study area due to the influence of the spawning component on the final HSI and the pass/fail design of the model. However, further investigation revealed that the upper estuary reach was more suitable when the spawning component was removed from the final HSI equation and analyzed separately. After removing the spawning component, under the existing condition, the upper estuary was classified as suitable foraging habitat for juveniles and adults, except for upper Sturgeon Creek and Smith Creek. The lower and middle estuary were unsuitable for these life stages due to average summer salinity above the acceptable thresholds. The Cape Fear River from Wilmington to Lock and Dam #1 as well as the Northeast Cape Fear River near Wilmington were suitable foraging habitat for juveniles and adults. Only a small area of Atlantic sturgeon foraging habitat near Navassa, NC, was affected by an increase in salinity from the FWOP and FWP conditions. Similarly, foraging habitat in the Northeast Cape Fear River is affected by increased salinity from the FWOP and the FWP conditions from the entrance of Smith Creek upstream approximately 0.25 and 1.5 river miles, respectively

The striped bass HSI model, with all five life stage components combined, produces an HSI for the entire life cycle of the species. This version of the model; however, is highly constrained because it evaluates areas based on 11 habitat variables, and the larval component is the limiting life stage. Evaluating the model by examining each component/life stage index separately yields more meaningful results and provides a better understanding of how striped bass likely utilize the different areas of the system throughout their lives.

Results indicate that the lower estuary is unsuitable for spawning and egg development. Moreover, the lower estuary is unsuitable for larval development up to MOTSU. Habitat quality improves for larvae upstream of MOTSU, and the entire lower estuary is suitable foraging habitat for adults and juveniles.

The middle estuary is suitable for adult and juvenile striped bass except for upper Town Creek, which exhibits low salinity. In addition, the middle estuary is unsuitable for egg development but suitable for larvae apart from an area near Carolina Beach State Park. This location displays higher salinity likely from water entering through Snow’s Cut from the Atlantic Intracoastal Waterway. The higher salinity conditions near Snow’s Cut reduce habitat quality for larvae along the eastern bank of the Cape Fear River up to approximately Masonboro Country Club under the FWOP and FWP conditions.

Existing Conditions in the upper estuary are suitable for egg development in the lower Brunswick River and the Cape Fear River from the southern tip of Eagle Island to Smith Creek. Furthermore, the entire upper estuary is highly suitable for larval development aside from Smith Creek and upper Sturgeon Creek where salinity falls below the optimal threshold. Under the FWOP and FWP conditions, habitat quality for larval development is improved in the Brunswick River, and the upper estuary is highly suitable for adults and juveniles for all sets of conditions. Habitat suitability for spawning in the upper estuary is unsuitable, and model results indicate that under the FWOP there is a reduction in foraging habitat suitability near the Kinder Morgan Liquid Bulk Pier due to increased salinity. Under the FWP condition, already poor foraging habitat (0.2-0.4) is reduced to unsuitable habitat due to an increase in salinity from the Port of Wilmington to the beginning of the Northeast Cape Fear River. Increased salinity also reduces foraging habitat quality in the upper Brunswick River under the FWOP and the FWP conditions.

The existing condition in the Cape Fear River below Lock and Dam #1 downstream to Wilmington is suitable for egg development other than areas with reduced current velocity and low summer DO. Larval development in this reach is only suitable below Sutton Lake where salinity is still above the 4 ppt threshold. All sets of conditions show highly suitable foraging habitat from Sutton Lake to Lock and Dam #1.

The Northeast Cape Fear River is highly suitable for egg development in the channel upstream to Fishing Creek but is unsuitable outside the channel due to lower current velocity. Habitat quality for egg development remains largely the same in this area under the FWOP and the FWP conditions. Habitat for larval development in the Northeast Cape Fear River is suitable until salinity drops below 4 ppt near Ness Creek. Under the FWOP and the FWP conditions, there is little change in habitat suitability for larval development from baseline conditions. Baseline modeling indicates the Northeast Cape Fear River is suitable foraging habitat for striped bass; however, increased salinity under the FWOP and the FWP conditions reduces habitat quality near the entrance to Smith Creek.

The Black River exhibits suitable conditions for adult and juvenile striped bass; and is suitable for foraging. Low DO and current velocity; however, reduce habitat quality for egg and larval development.

This document and the modeling conducted should help resource managers better identify areas that should receive enhanced protections to further the species identified by the interagency team and the other 172+ species (Schwartz 1997) that utilize the Cape Fear River Estuary. Understanding that this system has seen anthropogenic modification to industrial levels, completely changing the dynamics from fresh to brackish 30+ miles upriver, helps to frame the FWP conditions. Although salinity is expected to encroach farther upriver, the difference between the projected FWOP and FWP in the year 2077 is minimal and certain species identified in this document will benefit from these relatively small changes in salinity. Another aspect that is worth noting is the environmental swings from drought to wet years. The most recent dredging (The NC-96 Act) and the subsequent 10-year monitoring that occurred was unable to determine any patterns caused by that dredging due to the extremes in the system observed during this study (USACE 2011). The modeling efforts did show clearly that the endangered Atlantic sturgeon recovery is limited by available spawning habitat and reduced access to historical spawning grounds and therefore, should receive the most attention for this species recovery efforts.

7 REFERENCES

Anderson, W.W., J.E. King, and M.J. Lindner. 1965. Early stages in the history of the common marine shrimp, Penaeus setiferus (Linnaeus). Bio1. Bull. (Woods Ho1 e) 96: 168-172.

Anderson, W.W., M.J. Lindner, and J.E. King. 1949. The shrimp fishery of the Southern United States. Commer. Fish. Rev. 11(2):1-17.

Appleman, M., D. Fox, and K. Mckown (n.d.). 2017. REVIEW OF THE ATLANTIC STATES MARINE FISHERIES COMMISSION FISHERY MANAGEMENT PLAN FOR ATLANTIC STURGEON (Acipenser oxyrinchus oxyrinchus) 2015 FISHING YEAR [Review of report *Atlantic States Marine fisheries commission*].

Arnold, C.R., W.H. Bailey, T.D. Williams, A. Johnson, and J.L. Lasswell. 1977. Laboratory spawning and larval rearing of red drum and southern flounder. Proc. Southeast. Assoc. Fish Wildlife. Agencies 31:437-440.

Atlantic Sturgeon Status Review Team. 2007. Status Review of Atlantic sturgeon (*Acipenser oxyrinchus oxyrinchus*). Report to National Marine Fisheries Service, Northeast Regional Office. February 23, 2007.

ASMFC. 2012. Managed Species Summer Flounder, Habitat Fact Sheet. Washington, D.C. Accessed March 2012. Available online at www.asmfc.org.

ASMFC. 1998. Atlantic Sturgeon Stock Assessment Peer Review. Terms of reference and advisory report. Washington D.C. p.33. National Oceanic Atmospheric Administration. 1998.

Bain, K.B., and J.L. Bain. 1982. Habitat suitability index models: Coastal stocks of striped bass. US Fish and Wildlife Service, Office of Biological Services, Washington, D.C. FWS/OBS-82/10.1. 29 pp.

Blackmon, J.H., Jr. 1974. Observation on the immigration of the brown shrimp, Penaeus aztecus, through a tidal pass in the Caminada Bay, Louisiana area. ~1.S. Thesis. Louisiana State University, Baton Rouge. 58 pp.

Christmas, J.Y., J.T. McBee, R.S. Waller, and F.C. Sutter III. 1982. Habitat suitability index models: Gulf menhaden. U.S. Dept. Int. Fish Wildl. Servo FWS/OBS-82/10.23. 23 pp.

Etzold, D.J., and J.Y. Christmas. 1977. A comprehensive summary of the shrimp fishery of the Gulf of Mexico United States: a regional manaqement plan. Gulf Coast Res. Lab. Tech. Ser. No. 2, Part 2. 20 pp.

Fisk II, J.M. and J.C. Dycus. 2015. Cape Fear River Striped Bass Survey 2014. North Carolina Wildlife Resources Commission Inland Fisheries Division. Federal Aid in Sport Fish Restoration, Project F-108, Final Report, Raleigh.

Gaidry, W.J., III, and C.J. White. 1973. Investigations of commercially important penaeid shrimp in Louisiana estuaries. La. Wildl. Fish. Comm. Tech. Bull. 8. 154 pp.

Guilbard, F., J. Munro, P. Dumont, D. Hatin, and R. Fortin. 2007. Feeding ecology of Atlantic sturgeon and lake sturgeon co-occurring in the St. Lawrence estuarine transition zone. Pages 85-104 in J. Munro, D. Hatin, J.e. Hightower, K. A. McKown, K. J. Sulak, A. W. Kahnle, and F. Caron, editors. Anadromous sturgeons: Habitats, threats, and management. American Fisheries Society, Symposium 56, Bethesda, Maryland.

Hunt, J.H., R.J. Carroll, V. Chinchilli, and D. Frankenburg. 1980. Relationship between environmenal factors and brown shrimp production in Pamlico Sound, North Carolina. N.C. Dep. Nat. Resour. Comm. Devel., Div. Mar. Fish., Spec. Sci. Rep. 33:1-29.

Jones, R.A., and T.M. Sholare. 1981. The effects of freshwater discharge on estuarine nursery areas of Pamlico Sound, North Carolina. N.C. Dep. Nat. Resour. Comm. Devel., Div. Mar. Fish., Completion Rep., Proj. CEIP 79-11. 60 pp.

Kutkuhn, J. H. 1966. The role of estuaries in the development and perpetuation of commercial shrimp resources. Pages 16-36 in R.F. Smith, A.H. Swartz, and W.H. Massmann, eds. A symposium on estuarine fisheries. An. Fish. Soc. Spec. Publ. 3.

Laney, R.W., and B.J. Copeland. 1981. Population dynamics of penaeid shrimp in two North Carolina tidal creeks. Rep. 81-1 to Carolina Power and Light Company, Raleigh, N.C. 161 pp.

Mansueti, R.J. 1960. Restriction of very young red drums Sciaenops ocelleta to shallow estuarine waters of Chesapeake Bay during late autumn. Chesapeake Sci. 1:207-210.

Matlock, G.C. 1980. History and management of the red drum fishery. Pages 37-54 in Proceedings of the colloquium on the biology and management of red drum and seatrout. Gulf States Marine Fisheries Commissions Ocean Springs Miss.

Munro, J., R. Edwards, and A. Kahnle. 2007. Anadromous Sturgeons: Habitat, Threats, and Management Synthesis and Summary. American Fisheries Society Symposium 56:1-15, 2007

Nellis, P., J. Munro, D. Hatin, G. Desrosiers, R.D. Simons, and F. Guilbard. 2007. Macro benthos assemblages in the St. Lawrence estuarine transition zone and their potential as food for Atlantic sturgeon and lake sturgeon. Pages 105-128 in J. Munro, D. Hatin, J.E. Hightower, K.A. McKown, K.J. Sulak, A.W. Kahnle, and F. Caron, editors. Anadromous sturgeons: Habitats, threats, and management. American Fisheries Society, Symposium 56, Bethesda, Maryland.

North Carolina Division of Marine Fisheries. 2013. Research and Management of Endangered and Threatened Species in the South East: Riverine Movements of Shortnose and

Atlantic Sturgeon. Semi-annual progress report under Account #P24019087211 (NOAA Award #NA10NMF4720036).

Perez-Farfante, I. 1969. Western Atlantic shrimp of the genus Penaeus. U.S. Fish Wildl. Serv Fish. Bull. 67:461-591.

Raabe, J.K., T. Ellis, J. Hightower, and J. Facendola. 2017. 147th meeting AM Fish Society.

Schamberger, M., A.H. Farmer, and J.W. Terrell. 1982. Habitat suitability index models: introduction. USDOI Fish and Wildlife Service. FWS/OBS-82/10. 2pp.

Schwartz, F.J. 1997. Distance movements of fishes, white shrimp, and blue crabs tagged in or near the estuarine Cape Fear River and adjacent Atlantic Ocean, North Carolina, 1973 through 1978. The journal of the Elisha Mitchell Scientific Society, 113(3), 1997, pp. 123-132.

Simmons, E.G. and J.P. Breuer. 1962. A study of redfish, *Sciaenops ocellata* (Linnaeus), and black drum, *Pegonias cromis* (Linnaeus). Publ. Inst. Mar. Sci. Univ. Tex. 8:184-211.

Simons, R.D. 2004. Circulation and zooplankton transport in the estuarine transition zone of the St. Lawrence estuary: a modeling and field study. Doctoral dissertation. Stanford University, Palo Alto, California.

South Carolina Department of Natural Resources. 2013. Red drum- Life history. Website accessed 30 April 2019. http://www.dnr.sc.gov/marine/mrri/insh_fish/reddrum/reddrum.html.

Stewart, C.B., & Scharf, F.S. 2008. Estuarine recruitment, growth, and first-year survival of juvenile red drum in North Carolina. Transactions of the American Fisheries Society, 137(4), 1089-1103.

Stevenson, C.H. 1899. The shad fisheries of the Atlantic Coast of the United States. Rep. U.S. Comm. Fish., Pt.24, 1898: 101-269.

Turner, R.E. 1977. Intertidal vegetation and commercial yields of penaeid shrimp. Tran S. Pm • Fish • Soc. 106: 411- 416•

United States Army Corps of Engineers. 2011. U.S. Army Corps of Engineers, Wilmington District. Monitoring Effects of a Potential Increased Tidal Range in the Cape Fear River Ecosystem Due to Deepening Wilmington Harbor, North Carolina Final Report: October 1, 2000 – May 31, 2010. Contract No. W912HN-05-D-0014.

Weinstein, M.P., S.L. Weiss, R.G. Hodson, and L.R. Gerry. 1980. Retention of three taxa of postlarval fishes in an intensively flushed tidal estuary, Cape Fear River, North Carolina. U.S. Natl. Mar. Fish. Servo Fish. Bull. 78:419-436.

APPENDIX A

HABITAT SUITABILITY INDEX MODEL DATASHEETS FOR SELECTED SPECIES

Table A-1
HSI Model for Atlantic Menhaden

	Total Acreage	Average HSI	Min HSI	Max HSI	Habitat Units
EC Lower Estuary (Acreage)	17,536	0.95	0.69	1.00	16659.2
EC Middle Estuary (Acreage)	5,250	0.98	0.52	1.00	5145
EC Upper Estuary Acreage (Acreage)	1,168	0.94	0.34	0.94	1097.92
EC Cape Fear River (Acreage)	958	0.09	0.00	0.57	86.22
EC Black River (Acreage)	1,277	0.00	0.00	0.00	0
EC NE Cape Fear River (Acreage)	2,937	0.21	0.00	0.77	616.77
FWOP Lower Estuary (Acreage)	17,536	0.94	0.69	1.00	16,484
FWOP Middle Estuary (Acreage)	5,250	0.98	0.56	1.00	5,145
FWOP Upper Estuary Acreage (Acreage)	1,168	0.75	0.33	0.95	876
FWOP Cape Fear River (Acreage)	958	0.10	0.00	0.70	96
FWOP Black River (Acreage)	1,277	0.00	0.00	0.00	0
FWOP NE Cape Fear River (Acreage)	2,937	0.22	0.00	0.78	646
FWP Lower Estuary (Acreage)	17,536	0.94	0.69	1.00	16,484
FWP Middle Estuary (Acreage)	5,250	0.98	0.59	1.00	5,145
FWP Upper Estuary Acreage (Acreage)	1,168	0.82	0.38	0.96	958
FWP Cape Fear River (Acreage)	958	0.11	0.78	0.00	105
FWP Black River (Acreage)	1,277	0.00	0.00	0.004	0
FWP NE Cape Fear River (Acreage)	2,937	0.25	0.00	0.87	734

Notes: EC = Existing Conditions, FWOP = Future Without Project Conditions, FWP = Future With Project Conditions

Table A-2
HSI Model for Red Drum

	Total Acreage	Average HSI	Min HSI	Max HSI	Habitat Units
EC Lower Estuary (Acreage)	17,536	0.53	0.00	0.90	9294.08
EC Middle Estuary (Acreage)	5,250	0.56	0.00	0.85	2940
EC Upper Estuary Acreage (Acreage)	1,168	0.56	0.00	0.80	654.08
EC Cape Fear River (Acreage)	958	0.53	0.00	0.72	507.74
EC Black River (Acreage)	1,277	NODATA	NODATA	NODATA	NO DATA
EC NE Cape Fear River (Acreage)	2,937	0.56	0.00	0.75	1644.72
FWOP Lower Estuary (Acreage)	17,536	0.53	0.00	0.90	9294.08
FWOP Middle Estuary (Acreage)	5,250	0.56	0.00	0.86	2940
FWOP Upper Estuary Acreage (Acreage)	1,168	0.56	0.00	0.80	654.08
FWOP Cape Fear River (Acreage)	958	0.53	0.00	0.72	507.74
FWOP Black River (Acreage)	1,277	NODATA	NODATA	NODATA	NO DATA
FWOP NE Cape Fear River (Acreage)	2,937	0.56	0.00	0.75	1644.72
FWP Lower Estuary (Acreage)	17,536	0.53	0.00	0.90	9294.08
FWP Middle Estuary (Acreage)	5,250	0.56	0.00	0.86	2940
FWP Upper Estuary Acreage (Acreage)	1,168	0.56	0.00	0.80	654.08
FWP Cape Fear River (Acreage)	958	0.53	0.00	0.72	507.74
FWP Black River (Acreage)	1,277	NODATA	NODATA	NODATA	NO DATA
FWP NE Cape Fear River (Acreage)	2,937	0.56	0.00	0.75	1644.72

Notes: EC = Existing Conditions, FWOP = Future Without Project Conditions, FWP = Future With Project Conditions

Table A-3
HSI Model for White Shrimp

	Total Acreage	Average HSI	Min HSI	Max HSI	Habitat Units
EC Lower Estuary (Acreage)	17,536	0.67	0.00	0.81	11749.12
EC Middle Estuary (Acreage)	5,250	0.81	0.81	0.81	4252.5
EC Upper Estuary Acreage (Acreage)	1,168	0.81	0.81	0.81	946.08
EC Cape Fear River (Acreage)	958	0.81	0.81	0.81	775.98
EC Black River (Acreage)	1,277	0.81	0.81	0.81	1034.37
EC NE Cape Fear River (Acreage)	2,937	0.81	0.81	0.81	2378.97
FWOP Lower Estuary (Acreage)	17,536	0.52	0.00	0.81	9118.72
FWOP Middle Estuary (Acreage)	5,250	0.81	0.76	0.81	4252.5
FWOP Upper Estuary Acreage (Acreage)	1,168	0.81	0.81	0.81	946.08
FWOP Cape Fear River (Acreage)	958	0.81	0.00	0.81	775.98
FWOP Black River (Acreage)	1,277	0.81	0.81	0.81	1034.37
FWOP NE Cape Fear River (Acreage)	2,937	0.81	0.81	0.81	2378.97
FWP Lower Estuary (Acreage)	17,536	0.63	0.00	0.81	11047.68
FWP Middle Estuary (Acreage)	5,250	0.81	0.77	0.81	4252.5
FWP Upper Estuary Acreage (Acreage)	1,168	0.81	0.81	0.81	946.08
FWP Cape Fear River (Acreage)	958	0.81	0.81	0.81	775.98
FWP Black River (Acreage)	1,277	0.81	0.81	0.81	1034.37
FWP NE Cape Fear River (Acreage)	2,937	0.81	0.81	0.81	2378.97

Notes: EC = Existing Conditions, FWOP = Future Without Project Conditions, FWP = Future With Project Conditions

Table A-4
HSI Model for Atlantic Sturgeon

	Total Acreage	HSI (0.00000, FAIL)	HSI (1.00000, PASS)	Average HSI	Min HSI	Max HSI	Habitat Units
EC Lower Estuary (Acreage)	**17536**	17034	0	0.00	0.00	0.00	0
EC Middle Estuary (Acreage)	**5250**	5551	0	0.00	0.00	0.00	0
EC Upper Estuary Acreage (Acreage)	**1168**	1656	0	0.00	0.00	0.00	0
EC Upper Cape Fear River (Acreage)	**958**	351	1171	0.82	0.00	1.00	781.15
EC Black River (Acreage)	**1277**	1099	216	0.21	0.00	1.00	267.28
EC NE Cape Fear River (Acreage)	**2937**	2051	938	0.23	0.00	1.00	686.67
FWOP Lower Estuary (Acreage)	**17536**	17034	0	0.00	0.00	0.00	0
FWOP Middle Estuary (Acreage)	**5250**	5551	0	0.00	0.00	0.00	0
FWOP Upper Estuary Acreage (Acreage)	**1168**	1656	0	0.00	0.00	0.00	0
FWOP Upper Cape Fear River (Acreage)	**958**	410	1112	0.75	0.00	1.00	718.12
FWOP Black River (Acreage)	**1277**	1057	258	0.23	0.00	1.00	298.69
FWOP NE Cape Fear River (Acreage)	**2937**	2042	947	0.23	0.00	1.00	677.57
FWP Lower Estuary (Acreage)	**17536**	17034	0	0.00	0.00	0.00	0
FWP Middle Estuary (Acreage)	**5250**	5551	0	0.00	0.00	0.00	0
FWP Upper Estuary Acreage (Acreage)	**1168**	1656	0	0.00	0.00	0.00	0
FWP Upper Cape Fear River (Acreage)	**958**	453	1069	0.71	0.00	1.00	684.68
FWP Black River (Acreage)	**1277**	1039	276	0.24	0.00	1.00	308.91
FWP NE Cape Fear River (Acreage)	**2937**	2171	818	0.20	0.00	1.00	577.71

Notes: EC = Existing Conditions, FWOP = Future Without Project Conditions, FWP = Future With Project Conditions

Table A-5
HSI Model for Striped Bass

	Total Acreage	Average HSI	Min HSI	Max HSI	Habitat Units
EC Lower Estuary (Acreage)	17,536	0.00	0.00	0.00	0
EC Middle Estuary (Acreage)	5,250	0.00	0.00	0.00	0
EC Upper Estuary Acreage (Acreage)	1,168	0.35	0.00	0.82	408.8
EC Cape Fear River (Acreage)	958	0.06	0.00	0.70	57.48
EC Black River (Acreage)	1,277	0.00	0.00	0.00	0
EC NE Cape Fear River (Acreage)	2,937	0.12	0.00	0.83	352.44
FWOP Lower Estuary (Acreage)	17,536	0.00	0.00	0.00	0
FWOP Middle Estuary (Acreage)	5,250	0.00	0.00	0.00	0
FWOP Upper Estuary Acreage (Acreage)	1,168	0.32	0.00	0.84	373.76
FWOP Cape Fear River (Acreage)	958	0.07	0.00	0.69	67.06
FWOP Black River (Acreage)	1,277	0.00	0.00	0.00	0
FWOP NE Cape Fear River (Acreage)	2,937	0.13	0.00	0.82	381.81
FWP Lower Estuary (Acreage)	17,536	0.00	0.00	0.00	0
FWP Middle Estuary (Acreage)	5,250	0.00	0.00	0.00	0
FWP Upper Estuary Acreage (Acreage)	1,168	0.11	0.00	0.84	128.48
FWP Cape Fear River (Acreage)	958	0.09	0.00	0.84	86.22
FWP Black River (Acreage)	1,277	0.00	0.00	0.000	0
FWP NE Cape Fear River (Acreage)	2,937	0.13	0.00	0.83	381.81

Notes: EC = Existing Conditions, FWOP = Future Without Project Conditions, FWP = Future With Project Conditions

Table A-6
HSI Model for Southern Flounder

	Total Acreage	Average HSI	Min HSI	Max HSI	Habitat Units
EC Lower Estuary (Acreage)	17,536	0.89	0.00	1.00	15607
EC Middle Estuary (Acreage)	5,250	0.98	0.00	1.00	5145
EC Upper Estuary Acreage (Acreage)	1,168	0.79	0.00	0.99	923
EC Cape Fear River (Acreage)	958	0.63	0.00	0.88	604
EC Black River (Acreage)	1,277	0.45	0.00	0.86	575
EC NE Cape Fear River (Acreage)	2,937	0.55	0.00	0.93	1615
FWOP Lower Estuary (Acreage)	17,536	0.88	0.00	1.00	15432
FWOP Middle Estuary (Acreage)	5,250	0.99	0.00	1.00	5198
FWOP Upper Estuary Acreage (Acreage)	1,168	0.87	0.00	1.00	1016
FWOP Cape Fear River (Acreage)	958	0.68	0.00	0.89	651
FWOP Black River (Acreage)	1,277	0.51	0.00	0.86	651
FWOP NE Cape Fear River (Acreage)	2,937	0.56	0.00	0.94	1645
FWP Lower Estuary (Acreage)	17,536	0.81	0.00	1.00	14204
FWP Middle Estuary (Acreage)	5,250	0.98	0.00	1.00	5145
FWP Upper Estuary Acreage (Acreage)	1,168	0.88	0.00	1.00	1028
FWP Cape Fear River (Acreage)	958	0.69	0.00	0.90	661
FWP Black River (Acreage)	1,277	0.50	0.00	0.86	639
FWP NE Cape Fear River (Acreage)	2,937	0.57	0.00	0.98	1674

Notes: EC = Existing Conditions, FWOP = Future Without Project Conditions, FWP = Future With Project Conditions