DRAFT

-White Paper-

Assessment of Frying Pan Shoals as a Potential Sand Source in the Cape Fear Region

Prepared by Kearns & West, Inc.

September 2020

This White Paper is an effort to take stock of what is known and unknown, from a scientific perspective, about Frying Pan Shoals in the context of the potential for sand dredging in the Cape Fear, North Carolina region. The Bureau of Ocean Energy Management (BOEM) intends the document to be key reading material at an upcoming technical workshop where BOEM is seeking further input about information needs regarding Frying Pan Shoals. The White Paper and workshop are designed to seek information from technical experts to fill data gaps at Frying Pan Shoals in advance of possible future BOEM lease requests and help formulate a science/research strategy.

BOEM, through the Department of the Interior's Collaborative Action and Dispute Resolution office, contracted with Kearns & West to develop this white paper. Kearns & West is a collaboration, stakeholder engagement, and process design firm assisting with the planning, coordination, and facilitation of the Frying Pan Shoals technical workshop, scheduled to take place virtually on October 13 and 16, 2020.

Table of Contents

1.0 Introduction to Sand of the Cape Fear Region

1.1. Erosion and the Demand for Sand

The coastal communities of the Cape Fear region of North Carolina have experienced rapid population growth, increased economic growth via tourism, and increased land values. Investments in beach nourishment projects in the Cape Fear River region from 2000 to 2019 have exceeded $137 million dollars and brought > 20 million cubic yards of sand to beaches, including the beaches of Bald Head Island, Caswell Beach, Oak Island, Holden Beach, and Kure Beach (Table 1) (PSDS, 2020). Erosion continues to be problematic. A peer-reviewed study of Brunswick County beaches showed 52% of shorelines were eroding; erosion rates were up to 3.2 feet year^{-1} except for areas of higher erosion near inlets (Overton et al., 1999). The North Carolina Division of Coastal Management (2020) has compared ocean-side erosion rates from the 1940s to 2016 with the following results (Figure 1):

- Bald Head Island had lengthy shorelines that were eroding with an average of -5.1 feet year^{-1} where erosion occurred.
- Caswell Beach and Kure Beach have largely been eroding with rates averaging -1.9 feet year^{-1} where erosion occurred.
- Oak Island had erosion rates averaging -0.83 feet year^{-1} where erosion occurred.

Table 1. History of beach nourishment projects in the vicinity of Frying Pan Shoals since the year 2000. Data source: Western Carolina University (PSDS, 2020), http://beachnourishment.wcu.edu/

Beach	Number of Projects	Years of Re-nourishment (2000-2019)	Total Volume of Sand (yards^3)	Total Estimated Nominal Cost
Bald Head Island	9	2001, 2005, 2006, 2007, 2010, 2012, 2013, 2015, 2019	10.3 million	$68 million
Caswell Beach	2	2001, 2009	1.2 million	$13 million
Holden Beach	17	2002, 2003, 2004, 2006, 2008, 2009, 2010, 2011, 2012, 2014, 2017	3.3 million	$20.8
Oak Island	2	2001, 2015	2.6 million	$28 million
Kure Beach	6	2001, 2004, 2007, 2010, 2013, 2016	3.2 million	$28 million

Historically, limited sand resources have been available through various navigation-related dredging projects. Jay Bird shoals, located near the Cape Fear River, has a potential for approximately 19.6 million yd^{-3} of usable sand (Cleary et al., 2001). Although sand has been dredged from Jay Bird Shoals, the extent of sand on this ebb-tidal shoal is not large enough to be viewed as long-term solution for sand in the Cape Fear region. Based on recent sand search surveys conducted offshore of Brunswick County beaches, alternative long-term sand resource options are severely limited. Therefore, current coastal resilience strategies for southeast North Carolina communities include the use of Frying Pan Shoals (FPS) in federally-managed waters (Figure 2), as a long-term sand resource to support future beach nourishment projects.

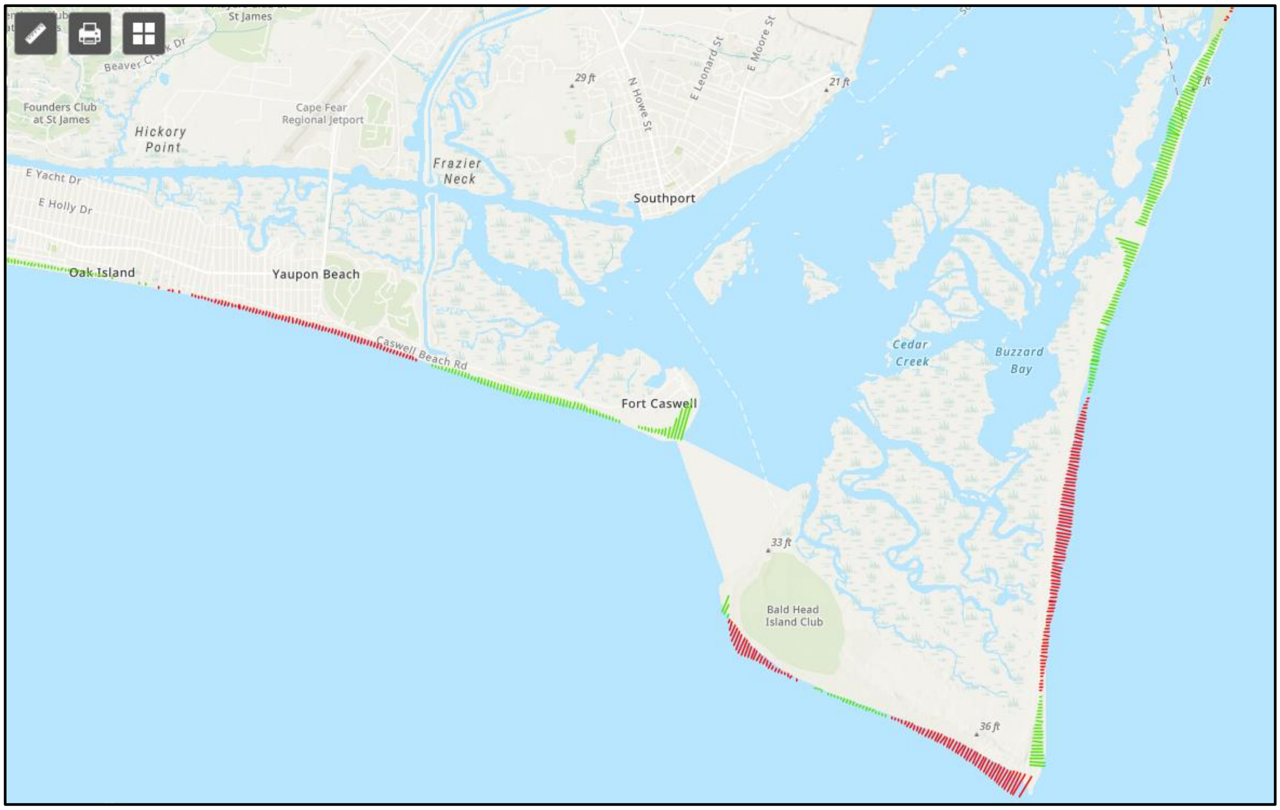

Figure 1. Long-term shoreline erosion rates estimates by the North Carolina Division of Coastal Management (2020). Red transects represent eroding shoreline and green transects represent accreting of shorelines from the 1940s to 2016.

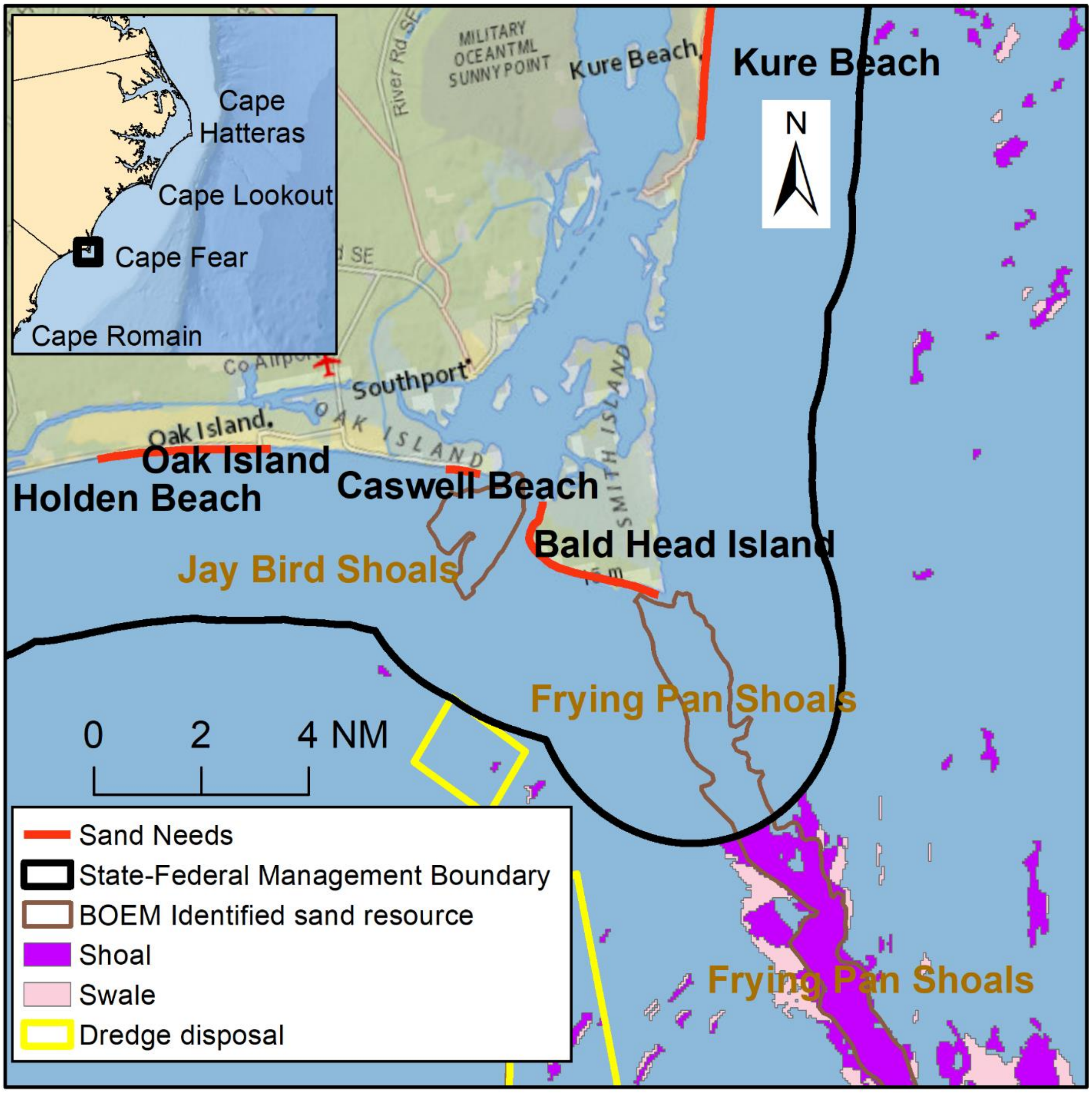

Figure 2. Overview of sand shoals and towns of interest near Frying Pan Shoals in North Carolina. The black line represents the border of state and federally managed waters. Shoal and swale modeling (pink colors) has been conducted for offshore federal waters. The BOEM identified sand resource map provides information for state-managed waters. The red line indicates sand needs identified by the US Army Corps of Engineers.

1.2. Introduction to Sand Shoals and Frying Pan Shoals

Sand shoals are composed of unconsolidated sediments formed into topographic highs, and they are often preferred for dredging because of their high volume of sand. Rutecki et al. (2014) defines sand shoals as:

> "A shoal is a natural, underwater ridge, bank, or bar consisting of, or covered by, sand or other unconsolidated material, resulting in shallower water depths than surrounding areas."

As sand shoals are part of a broader system, the term shoal complex refers to: "...two or more shoals (and includes adjacent morphologies, such as troughs separating shoals) that are interconnected by past and or present sedimentary and hydrodynamic processes" (Rutecki et al., 2014). In particular, large cape-associated shoal complexes have the potential to affect the geology, oceanography, and ecology of the marine environment. Frying Pan Shoals (FPS) is a cape-associated shoal complex located southeast of Bald Head Island, North Carolina, and it extends seaward from the cape (Figure 2). FPS is currently designated by the National Marine Fisheries Service (NMFS) as an Essential Fish Habitat (EFH) Habitat Area of Particular Concern (HAPC), and dredging is considered a threat to EFH and EFH HAPCs. NMFS has expressed concern that long term and repeated dredging operations could impact the habitat value that supports several important commercial and recreational fisheries. The Bureau of Ocean Energy Management (BOEM) has prompted this white paper synthesis and is convening the FPS Workshop to bring together technical experts from academia as well as state/federal agencies to discuss this issue. This synthesis brings together the most relevant information, but does not yet highlight priority knowledge gaps and research recommendations. These sections, under oceanographic, geological, and biological conditions, have been intentionally left blank, and workshop participants will be asked to provide input for these recommendations. After the workshop, the white paper will be updated with this new information.

1.3. Technical and Proponent Interviews

Prior to the workshop and development of this white paper, interviews were conducted with technical experts and local stakeholders to identify major concerns and needs concerning the potential dredging of Frying Pan Shoals. The list of interviewees was developed in consultation with BOEM staff. A total of 22 confidential, informal, semi-structured interviews were conducted. Sixteen were focused on members of the scientific community and intended to represent a mix of specializations in the areas of fish and marine ecology, marine geomorphology, sediment transport, and oceanography. Six interviews were focused on local stakeholders that included project proponents, consultants, and representatives of local and state agencies. The interviews were conducted by Kearns & West, ranged from 45 to 60 minutes, and took place between April and early August 2020. For the purpose this white paper, the interviews acted as a guide to prioritize the major issues to be synthesized.

1.4. Structure of the Literature Synthesis

The literature synthesis is focused on specific topics that were deemed to be of high importance during the interviews. These were topics of concern or knowledge that was seen as being integral for decision-making given the potential for sand dredging of FPS. For each topic, we present a synthesis of information related to the topic with a focus on the Cape Fear region, North Carolina cape-associated shoals, or cape-associated shoals in general. Citations are available to assist with further exploration or in-depth investigations, as needed.

1.5. Objectives and Anticipated Long-term Outcomes

The objectives of the white paper are to:

A) Introduce sand dredging actions and summarize potential effects of dredging to the marine environment. This includes a particular emphasis on fish.

B) Highlight the collective knowledge of geology, oceanography, and biology of FPS. A focus was placed on topics that were noted as concerns by interviewees regarding the potential impact of sand dredging on species and their habitats in offshore, federally-managed waters.

C) Act as a foundation for identifying high priority knowledge gaps during the subsequent FPS Technical Workshop.

Potential long-term outcomes of this process recognized by interviewees included a need to better articulate the future demand for sand. Common considerations include:

- What time scale are we planning for (e.g., 15-20 years)?
- Where is erosion problematic?
- How much sand is needed and where will it be allocated?

The current short-term planning and project-by-project approach has been challenging for all stakeholders involved. Interviewees often suggested a long-term strategy would provide clarity and might better assess expected environmental impacts. For example, a broad strategy might answer some of the following questions:

- What is the appropriate dredging frequency in a borrow area that maximizes use of sand resources while also minimizing physical and biological impacts?
- Is it feasible to dredge regularly at a low volume rather than an erratic pattern in response to immediate need?
- How much area could be affected by individual and cumulative dredging events?

A broad strategy might have the advantage of considering multiple ocean uses, which is a major concern among interviewees. For instance, in addition to commercial and recreational fisheries, FPS and its vicinity have been considered as a site for offshore wind and aquaculture as well as a source for sand dredging (Figure 3). Several interviewees suggested that on-going demands for ocean space might make a cumulative impact assessment most beneficial to stakeholders in the Cape Fear region. Potential outcomes of this engagement process expressed by interviewees include a long-term plan of sand dredging in the Cape Fear region, improved management of fish of commercial and recreational importance, and a better understanding of the ecology of species of concern. Ultimately, this would lead to an improved assessment of potential short- and long-term impacts of dredging activities on FPS.

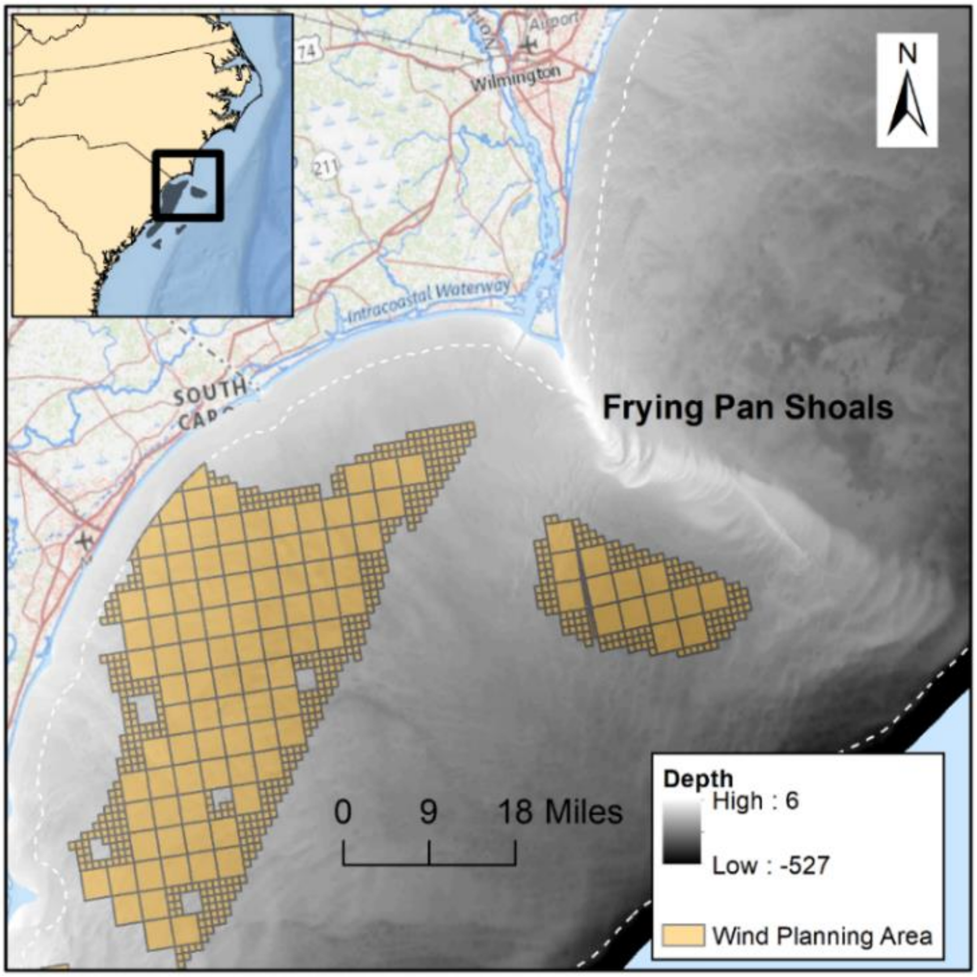

Figure 3. The Cape Fear Region with BOEM Wind Planning Areas delineated with the water depth of the region.

Interviewees expressed a need to clearly identify knowledge gaps and establish a plan to resolve them. Only a few research projects have been conducted on or near FPS and plans for future research at FPS are minimal at this time. Available data sources are not well known to interviewees, as much of it is raw oceanographic data collected continuously or are within grey literature sources, such as government reports or internal grant reports. The ecology of FPS is particularly poorly known. Notably, interviewees often discussed the surrounding environments of FPS, as the adjoining estuary brings additional concerns as do hardbottom habitats and distribution.

In summary, three main questions emerged from the interviews regarding long-term outcomes:

1) Where are the areas within FPS that are suitable for dredging?
2) What areas are critical to support fish communities and what times of year are critical to fish communities?
3) What can be done to alleviate concerns of fisheries impacts?

2.0. Sand Dredging Actions and Potential Impacts

2.1. Sand Dredging Actions

The most likely method of extracting marine sand at FPS is with a trailing suction hopper dredge (TSHD) (Figure 4), though a cutterhead dredge may also be considered. The TSHD vessel works by moving at 3–5 km hr^{-1} (1.5–3 knots) as an onboard dredge pump creates a suction that is transmitted through 1–3 pipes leading to each pipe's draghead, which are 1.5–4 m in width and lie on the seafloor (Michel et al., 2013). Sand is suctioned through the trailer arm pipe and into the hopper located in the hull of the ship. The dredge then moves to a stationary in-water pump-out station to pump sand to shore via pipelines.

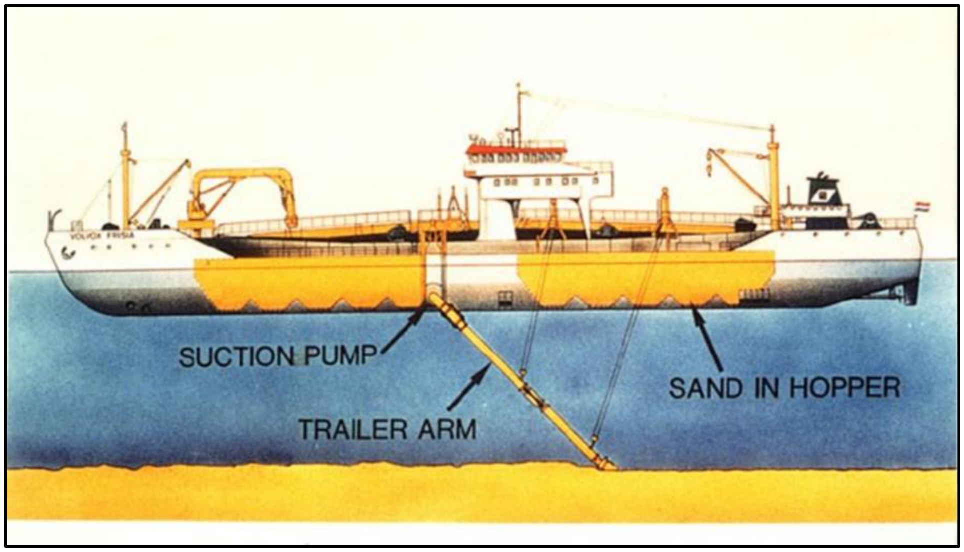

Figure 4. Main components of a TSHD. Additionally, the draghead is attached to the bottom of the trailer arm and is where the hydraulic suction is generated.
Source: Adapted from **https://oceanandairtechnology.wordpress.com/2013/06/11/trailing-suction-hopper-dredger/**

A visualization of the THSD demonstrates the equipment and a reasonable approximation of associated dredging actions; specific techniques differ in the US. A hydraulic cutterhead dredge agitates the sediments as the cutterhead rotates. To allow the cutterhead to swing back and forth, anchors, spuds, or a spud pole, are used to moor the vessel. A cutterhead may pump sand directly to shore from the dredge site via pipelines. A visualization of the cutterhead dredge demonstrates the equipment and a reasonable approximation of associated dredging actions; specific techniques differ in the US. For both dredges, additional boats are used to support operations, conduct monitoring, and to move anchors for cutterhead dredging. Further details of offshore dredging vessels and their operation are reviewed elsewhere (CSA International Inc et al., 2010; Michel et al., 2013).

2.2. Potential Impacts of Sand Dredging

The short-term effects of dredging include entrainment, human-made sounds, loss of prey or alteration of food webs, suspended and resuspended sediments, sedimentation of the seafloor, and, in some circumstances, the release of contaminants is a concern (Kim et al., 2008; Suedel et al., 2008; Wenger et al., 2017). Given the uncertainty surrounding the effects of dredging, seasonal restrictions on dredging operations are sometimes implemented. Of the dredging operations conducted by the U.S. Army Corps of Engineers from 1987 to 1996, time window restrictions for dredging to address biological concerns were implemented in 85% of Atlantic operations (Dickerson et al., 1998). Seasonal restrictions on dredging are most likely to be implemented for protected species; however, diverse species have been a basis for restrictions. Fish species used as a basis for seasonal dredging restrictions include American shad, Atlantic tomcod, blue crab, Gulf sturgeon, shortnose sturgeon, striped bass, winter flounder, and shrimp species (Reine and Clarke, 1998). Unfortunately, the lack of available data may result in inefficient restrictions on dredging activity, which can drive up costs, increase transportation distances, and delay projects (Dickerson et al., 1998).

From a review of the effects of sand dredging on fish, Pickens et al. (2020) highlight the following:

a. Fish are most vulnerable to dredging effects during egg or larvae stages, spawning periods, or during migration, when compared to other life stages. Demersal species have been suggested to be more vulnerable than pelagic, though evidence is lacking.

b. Entrainment of benthic fish and invertebrates occurs locally during dredging. A few studies have examined entrainments rates of fish in estuaries, but rates in marine ecosystems are lacking.

c. Turbidity occurs during and shortly after dredging activity, but resuspension of sediments at the borrow area has reoccurred 1.5 years post-dredging. Studies have regularly found turbidity to influence a 3-km radius around dredging, though concentrations are not high enough to cause direct fish mortality.

d. Sedimentation may threaten hard bottom and reef fish habitats because of burial and mortality of live bottom species.

e. Underwater sounds during dredging are not severe enough to cause fish mortality, but sounds may persist above ambient conditions for 400 m to 2.7 km.

f. Avoidance responses (including response distance) of fish to underwater sounds and turbidity are unknown. Fish behavioral responses will determine habitat loss, disruptions to migration, and other impacts.

g. Substrate removal by dredging may result in bathymetric depressions or more homogeneous, flattened topography within the footprint of dredging.

2.3. Interview Responses Concerning Sand Dredging Effects

During the course of interviews, most concerns regarding sand dredging effects were about the disruption of migratory routes of fish. These concerns ranged from seasonal fish movements along latitudinal gradients, inshore-offshore fish movements, movements from the ocean to estuarine waters for spawning, larvae transport to the estuary, and movements of juveniles from estuarine waters to the ocean. Disruptions could be caused by turbidity plumes, underwater sounds, and to a lesser extent, disruptions to food resources.

3.0 Oceanographic Conditions

3.1. Interview Responses on Oceanography

Sand shoals are recognized as unique, shallow water features in the marine environment. Interviewees frequently recognized that upwelling and eddies are a major source of energy and productivity in cape-associated shoal systems, including FPS. Waves and currents near shoals result in well-mixed, high dissolved oxygen waters. The high topographic complexity and shallow water nature of shoals facilitates this water movement, and there is concern that sand dredging over extended periods could change this oceanographic system and reduce productivity. Respondents often identified the link between currents and sediment transport as being important.

Interviewees recognized cross-shelf water movements lead to temperature change, cold water incursions, and cross-shelf temperature gradients. Fish are likely to respond to seasonal changes. For example, small overwintering fish in nearshore habitats may be forced offshore when cold water incursion occurs. Temperature will also affect latitudinal migration of fish.
Salinity is likely an important factor to consider because of the proximity of the Cape Fear River and nearby estuarine waters.

3.2. Coarse Measures of Currents, Waves, and Productivity

Coarse measures of wind, currents, and waves for the FPS region are as follows (Figure 5):

- NOAA predictions of tidal currents at Wrightsville Beach in 2020 range -1.2 to 5.9 feet MLLW (Mean Lower Low Water) with tidal heights typically being 3 to 4 feet (NOAA, 2020).

- Weber and Blanton (1980) show the seasonality of winds as originating from the northwest in the winter (November–February) and the southwest in summer (June–July). The mean annual wind speed and direction also show this pattern (Figure 5) (NOAA Office for Coastal Management, 2020).

- Significant wave height, period, and duration show waves primarily originate from the northeast, east, and north-northeast.
- Predominate ocean currents originate from the west.

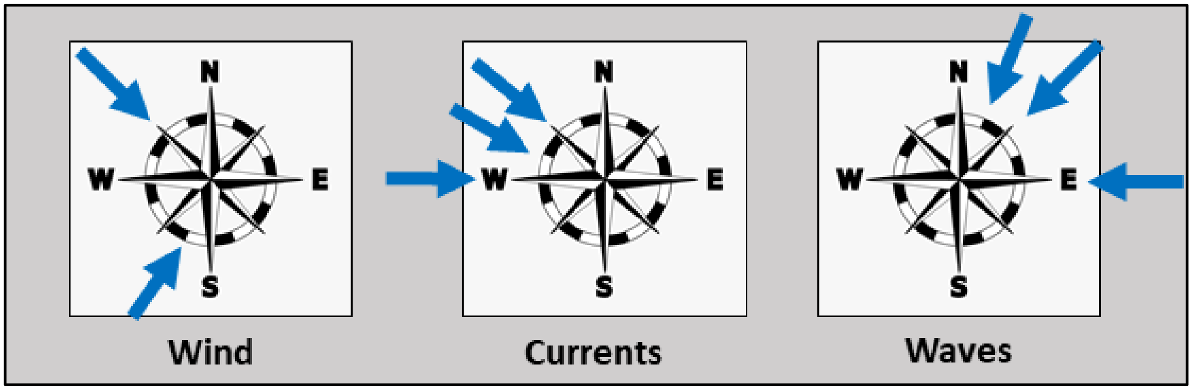

Figure 5. The dominant direction and velocity of wind, ocean currents, and waves based on frequency and duration of these forces on annual basis in the vicinity of FPS. Data source: Ocean Reports (NOAA Office for Coastal Management, 2020) at https://coast.noaa.gov/digitalcoast/tools/ort.html.

A concern with sand dredging is whether there is a threshold where sand removal from a shoal might result in deflation or the disappearance of a feature because the wave pattern is reduced in magnitude or if depth is increased to a point where sand deposition is minimal (Hayes and Nairn, 2004). Simulations have been conducted elsewhere to determine potential effects of sand extraction on wave heights and bottom currents (Byrnes et al., 2004a; Byrnes et al., 2004b; Maa et al., 2004; Stone et al., 2009). For example, Byrnes et al. (2004b) simulated various dredging sand volumes and showed dredging in the mid-Atlantic is expected to increase wave heights by 0.20–0.50 m in the lee of the shoal and decrease wave heights (maximum -0.4 m) adjacent to the shoal. Changes became minimal when waves approached the shoreline (Byrnes et al., 2004b). In contrast, Maa et al. (2004) simulated removal of 31.4 million yd^3 of sand shoals and found wave height increased by a factor of two and may contribute to increased shoreline erosion.

Interviewees frequently recognized that upwelling and eddies are a major source of energy and productivity in Cuspate-Foreland systems, including FPS. However, the biological productivity that might result from such oceanographic characteristics has not been explicitly studied at cape-associated shoals. The combination of tidal currents, wind and waves, and bottom currents interact with sand shoals at Cape Lookout Shoals to form two rotating eddies that help determine sediment transport (McNinch and Luettich, 2000). The details of these currents and the resulting sediment transport are covered in Section 3.5 below.

3.3. Temperature and Salinity Regime

Atkinson et al. (1983) describes the breadth of oceanographic climatology of the South Atlantic Bight, and their synthesis is summarized as follows:

- Shallow shelf waters of the South Atlantic Bight respond quickly to atmospheric conditions and river discharge
- Deeper waters are moderated by the deep ocean and respond to the Gulf Stream.
- At moderate depths (20–40 m), wind forcing plays a role in temperature fluctuations.
- Generally, shelf temperatures reach a maximum in August and September when temperatures are high at all depths.
- The strongest cross-shelf temperature gradients occur in winter (November–January).

As an example of cross-shelf temperature gradients, Freshwater et al. (2016) monitored winter bottom temperatures at varying depths in Onslow Bay. They found winter temperatures were progressively higher at greater depths, and this also resulted in lower temperature ranges. For example, depths of 18–20 m had a mean temperature of approximately 14℃ and range of 13.5℃, whereas depths of 38.5–42 m had a mean temperature of >18℃ with range of 8.5℃ (Freshwater et al., 2016).

The Gulf Stream can intrude upon shelf waters by surface water intrusion, interlayering, or via a bottom water intrusion (Atkinson, 1977). Surface and bottom water intrusions are most frequent in the summer months, are influenced by wind stress, interact with salinity, and are more frequent at the extreme northern and southern waters of the South Atlantic Bight (Castelao, 2011).

Salinity in the South Atlantic Bight is typically lowest in April and May when runoff is at its annual peak (Atkinson et al., 1983). Xia et al. (2007) modeled the Cape Fear River plume using simulations. They investigated the distribution of salinities based on the effect of river discharge, wind, and tidal effects were included. Predicted salinities ranged 20 to 36 ppt, and the following patterns emerged:

- Normal river discharge without wind effects shows a low salinity plume moving west of the river near the shoreline.
- Common southwest winds simulated at 5 m s^{-1} drives the salinity to levels ranging approximately 24 to 36 ppt in the vicinity of FPS.
- The effect of a moderate southwest wind (5 m s^{-1}) was highly sensitive to river discharge, as the response to flood conditions showed a great expansion of low salinity waters. In fact, the simulation to river flood conditions coincided well with the pattern of finer grained sediments (Figure 6).
- Common southwest winds simulated at a high 20 m s^{-1} restricts the low salinity plume to the mouth of the Cape Fear River.

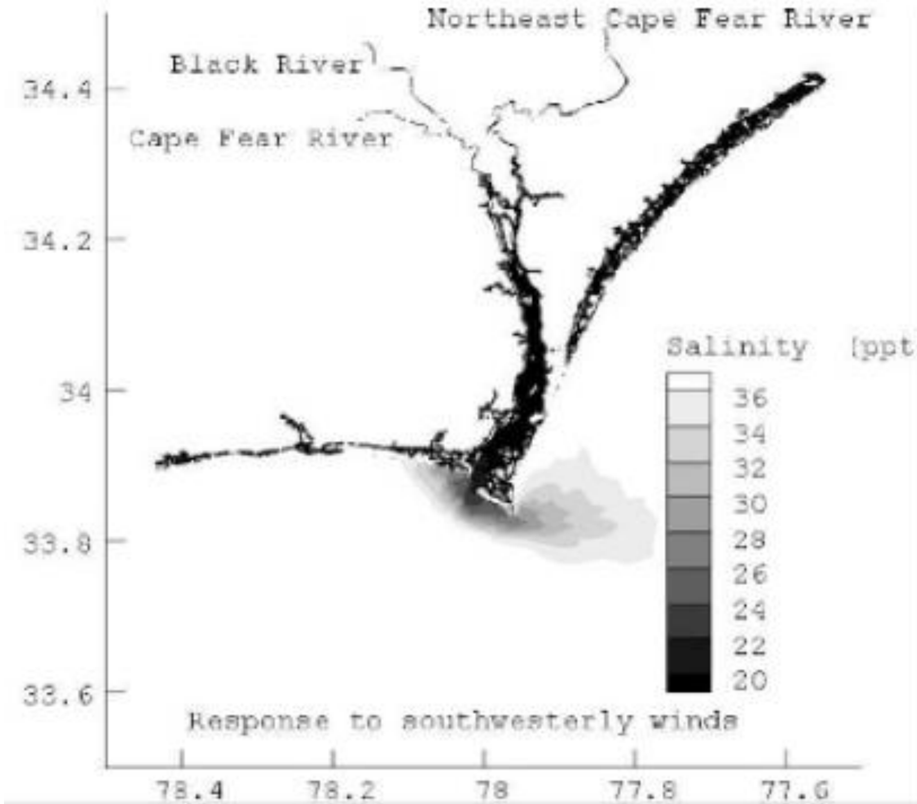

Figure 6. Surface salinity with a forcing of southwesterly winds of 5 m s^{-1}. Figure from Xia et al. (2007).

3.4. Priority Oceanography Knowledge Gaps and Research Recommendations

TBD at workshop.

4.0. Geological Conditions

Cuspate forelands are large shoreline promontories created by the convergence of barrier islands or mainland beach ridges at an approximately right angle (McNinch and Wells, 1999). These features often have an underwater sand shoal that projects from the convergence point outward into the sea (Shepard and Wanless, 1971). These cape-associated shoals are found worldwide, and these shoals occupy as much as 30% of the shoreface of North Carolina (defined as the area between the -10 m isobath and shoreline) (McNinch and Wells, 1999). In particular, FPS has been less studied than Cape Lookout or Cape Hatteras, and we draw inferences from these North Carolina sand shoals.

4.1. Interview Responses on Geological Conditions

The topic of sediment grain size was initiated by most interviewees. As a first step, the distribution of beach-suitable sediment grain sizes will determine the potential areas for sand dredging. There is considerable uncertainty among interviewees about our collective knowledge on sediment grain sizes, and it's likely that the information is fragmented among various entities. The US Army Corps of Engineers has conducted surveys in limited parts of FPS, though the information has not been formally shared with the public. This information will answer the question of, "How and where on FPS do you get sand?" The answer to this question will help determine biological impacts. Sediment grain size and presence of shell may affect fish habitat use too. The thickness and volume of sand were secondary topics.

Sediment transport was commonly mentioned as a concern, as the rates of shoal accretion and erosion were identified as important measures to consider. Important questions are, "Are the shoals growing? How stable is the shoal [regarding movement]? and "What sediment grain sizes will infill?" The process of sediment transport seaward from the eroding beaches, and therefore, shoreline erosion was a concern. Recovery of shoals was mentioned, but interviewees often had to be asked specifically about recovery to obtain feedback on the topic. Several respondents noted that the dynamic sand habitats are associated with early successional benthos, which are likely to recover quickly if sediment grain size remained the same. Monitoring of bathymetry, post-mining depths, and sediment grain size was suggested.

4.2. Sediment Grain Size

At a coarse level, Conley et al. (2017) used an interpolation of us SEABED data, along with supplemental data points, to map sediment grain sizes of the South Atlantic continental shelf. They used a simplified version of Wentworth (1922) to classify sediment grain size. These data show FPS, and the area directly east of FPS, primarily consists of medium sand (0.25–0.5 mm) as well as coarse and very coarse sand (0.5–2 mm). Immediately to the west of FPS, there are primarily fine and very fine sands (0.063–0.25 mm) (Figure 7). In this dataset, a pattern can be observed that very fine and fine sands are generally distributed southwest of cape-associated shoals. Medium and coarser sediment grain sizes are often found east/northeast of cape-associated shoals. This pattern may have implications for infilling sediments if sand dredging were to occur.

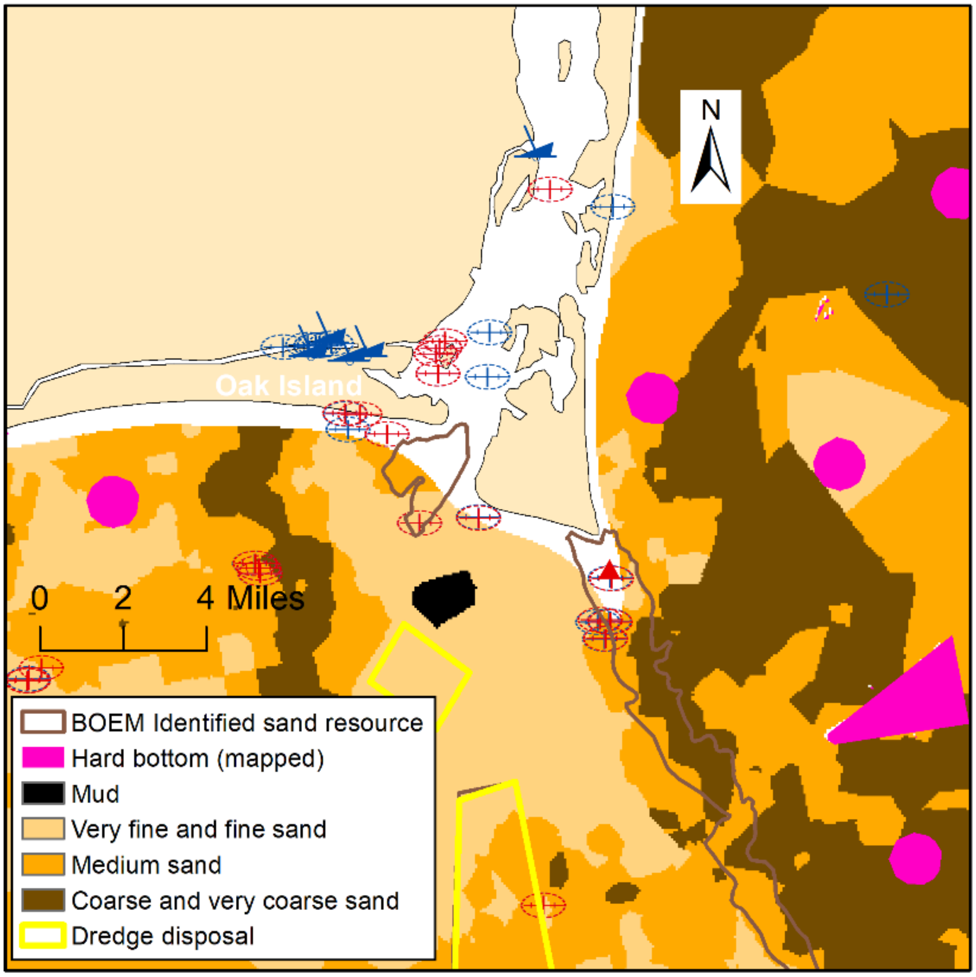

Figure 7. Mapped hard bottom (with a buffer of 1 km), sediment grain sizes derived from The Nature Conservancy's South Atlantic Marine Bight Assessment, and shipwrecks. Shipwrecks are represented by red and blue open circles with crosses. Shipwreck data are from NOAA Office of Coast Survey's Public Wrecks and Obstructions database.

The Corps Wilmington District and Land Management Group, Inc. (2014) "Corps Wilmington District") reported that geotechnical evaluations of sediments at FPS were conducted by Catlin (2010). In Catlin's study of FPS, Vibracore samples showed sediment grain size ranged from 1.47 (phi) to 2.83 (phi) with a weighted mean average of 2.53 (phi). There was a mean silt content of 3.2% and a mean percentage by weight shell content of 1.5%. Based on these measures, FPS sands in the southwest flank are generally compatible with native beach material (Catlin 2010). Although the stratigraphy of FPS has not been scientifically studied, Cape Lookout Shoals are composed of unconsolidated sediments with a maximum thickness of 20 m (McNinch and Wells, 1999).

4.3. Physical Processes of Sediment Transport and Accretion

The physical processes of sediment transport, and the subsequent accretion of sediments, are critical to the sustainability of FPS. Research on these mechanisms have not been conducted at FPS. Instead, we focus on the geologic processes described for Cape Lookout Shoals, which has a similar geomorphology and has been the subject of extensive study. A thorough review of these studies is presented by McNinch (2009), and a synopsis is presented here.

McNinch and Luettich (2000) used near-bottom current meters located at the east and west margin of Cape Lookout Shoals, at the shoal crest, and near its seaward terminal location. They identified the residual flow, which is defined as the tidally-averaged flow that can be influenced by topography, density gradients, wind, and the discharge of freshwater (Duran-Matute and Gerkema, 2015). The residual flow had two major components (Figure 8): 1) water movement towards the cape-associated shoal at a speed of 2.1–3.7 cm s^{-1} and 2) water movement along the axis of the shoal crest outward to the outer continental shelf at 3.7–5.9 cm s^{-1} (McNinch and Luettich, 2000). The first component is apparently influenced by two counter-rotating eddies at the margins of Cape Lookout Shoals that unite near the shoal crest (Figure 8). Such eddies are a product of tidal vorticity created by spatial changes in water depth (i.e., topography) and tidal amplitude as water flow bends around the headland (Pattiaratchi and Collins, 1987). The tidal component explained 75% of the total semi-diurnal energy (McNinch and Luettich, 2000). The second component of water flow was from the headland to the sea along the shoal crest, which has previously been documented where two eddies are united (Figure 8) (Dyer, 1991). At Cape Lookout Shoals, particle tracking confirmed the major seaward movement of water along the shoal crest to the outer continental shelf (McNinch and Luettich, 2000).

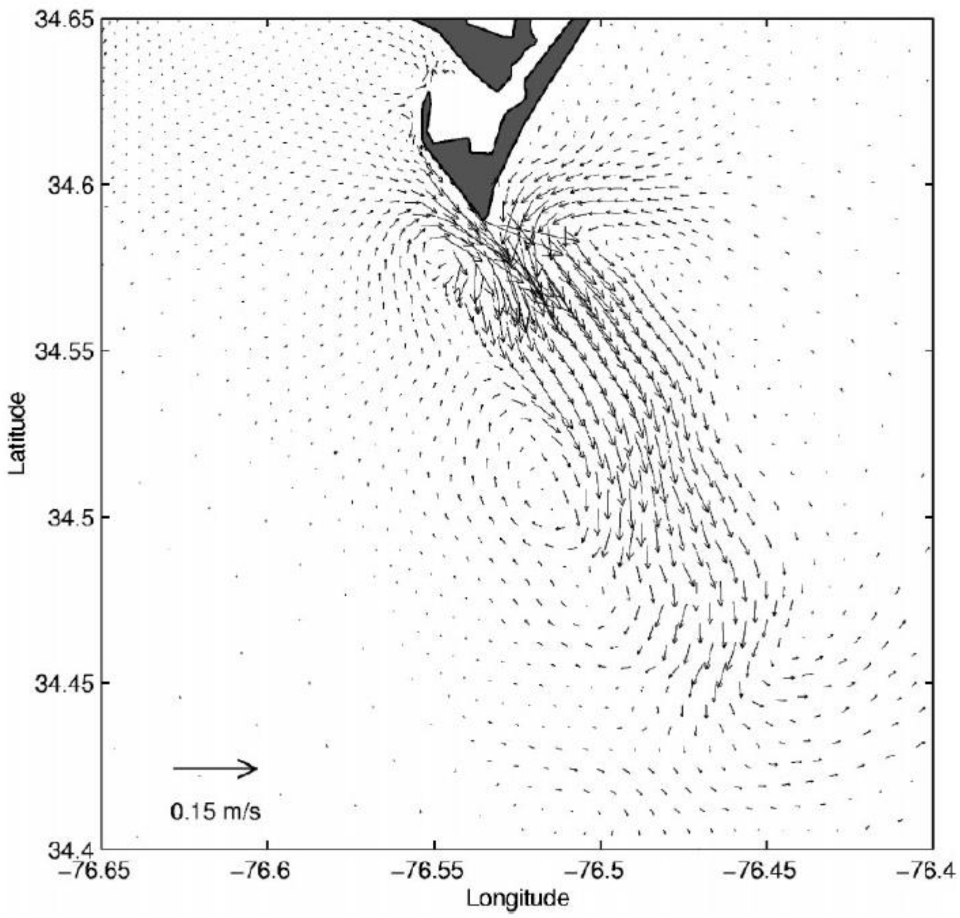

Figure 8. Direction of ocean currents near Frying Pan Shoals. Figure from McNinch and Luettich (2000).

The primary sediment source for Cape Lookout Shoals is derived from longshore transport of materials from the north (McNinch and Wells, 1999). Longshore current velocity, and thus the delivery of sediments to the Cuspate-foreland headland, is chiefly driven by wave direction and intensity, particularly during nor'easters (Park and Wells, 2005). The shoal causes the refraction of waves and blocks wave action on the leeward side of the shoals (McNinch, 2009). A model of sediment transport at Cape Lookout Shoals provides evidence that the energy needed to move 80–90% of sand-sized sediments is provided by wave action (McNinch and Luettich, 2000). Given the sediment movement, accretion on the shoal is distributed by the residual currents at the shoal (Figure 9). By these mechanisms, an estimated 400–700 million m^3 of sediments can delivered from the headland to the shoal each year (McNinch and Luettich, 2000). McNinch and Wells (1999) also provide evidence that the shoal is a sediment sink and remains active throughout its length.

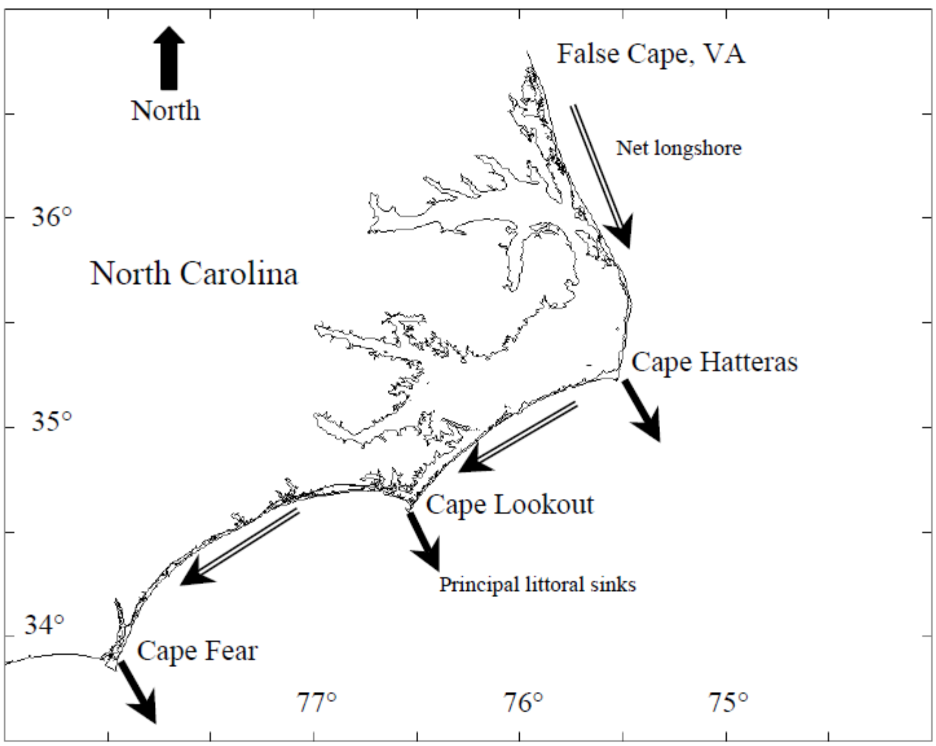

Figure 9. Map of the northern South Atlantic Bight showing principal littoral cells (after Inman and Dolan, 1989) and long-term sediment sinks. Figure from McNinch et al. (1999).

Based on work with Cape Lookout Shoals, McNinch (2009) made following inferences about FPS:

- The primary sediment source of FPS is likely sand within the littoral cells of the updrift beaches, Wrightsville-Carolina-Kure Beach.

- The volume of sediment delivered to FPS is likely comparable to the magnitude of the southern longshore drift.

- The most active region of sediment recharge within FPS is likely near the cape point, particularly along the crest of the shoal where it extends seaward from the subaerial cape point and the shore-parallel sandbar that merges into FPS from the updrift beach.

- Sediment along the flanks of FPS likely migrates crestward during swell conditions and seaward when it reaches the crest.

- The crest of the shoal is likely planed-off during storms, when waves are steep and breaking across the shoal, and sediment is transported to the flanks.

- Sediment dredged from the northwest flank of FPS will likely recharge episodically from sediment transported from the crest during storms, particularly extratropical nor'easters

4.4. Geological Knowledge Gaps and Research Recommendations

TBD at workshop.

5.0. Biological Conditions

5.1. Interview Responses on Biology

There was widespread belief among interviewees that sand shoal habitats are extremely productive habitats. In particular, forage fish (i.e., bait fish, pelagic prey) were frequently mentioned in a variety of contexts. High productivity and biomass were also commonly mentioned in relation to phytoplankton, [demersal] zooplankton, shrimp, blue crab, coastal migratory pelagic fish, and sharks. Concurrently, the reason for high productivity on shoal habitats is poorly known. Seasonality was also consistently mentioned in regard to productivity, as winter and spring were suggested to be less productive. Benthic invertebrate fauna were an uncommon topic of concern, as sand habitats are thought to support early successional species that recover from disturbance quickly.

Common themes arose concerning the habitat use of fish at FPS, and the following sections represent those themes. At the beginning of each section, we briefly summarize specific interviewee concerns.

5.2. Forage Fish and Fish/Invertebrate Pathways Linking the Estuary and Ocean

Interviewees had concerns about spawning, larvae transport, and fish movements linking estuarine and ocean habitats near FPS. There was emphasis on the importance of the shrimp and blue crab fishery. Other species, or groups of species, with concerns included juvenile reef fish [that use estuaries] (e.g., black sea bass), red drum, striped bass, spotted seatrout, flounder species, and coastal migratory pelagics. Forage fish such as croaker, menhaden, spot, pinfish, juvenile herring, and sea mullet were mentioned in this context as well as being perceived as the main reason that FPS is very biologically productive. Juvenile flatfish (e.g., southern flounder) migratory movements in the fall and flatfish spawning in the winter were recognized as important considerations.

Wickliffe et al. (2019) summarized the life history, habitat use, and seasonality of select fish and invertebrate species that use coastal inlets in North Carolina. Their summaries include Penaeid shrimp, gag grouper, summer flounder, American shad, river herring, blue crab, summer flounder, and red drum (Figure 10, 11). Reiterating the emphasis on blue crab, new Blue Crab Spawning Sanctuaries have now been designated by NCDMF at the Cape Fear River, Masonboro, and Carolina Beach inlets.

Pickens and Taylor (2020) found the distribution of Penaeid shrimp in the Gulf of Mexico marine environment were associated with oceanographic conditions, nearby estuarine wetlands,

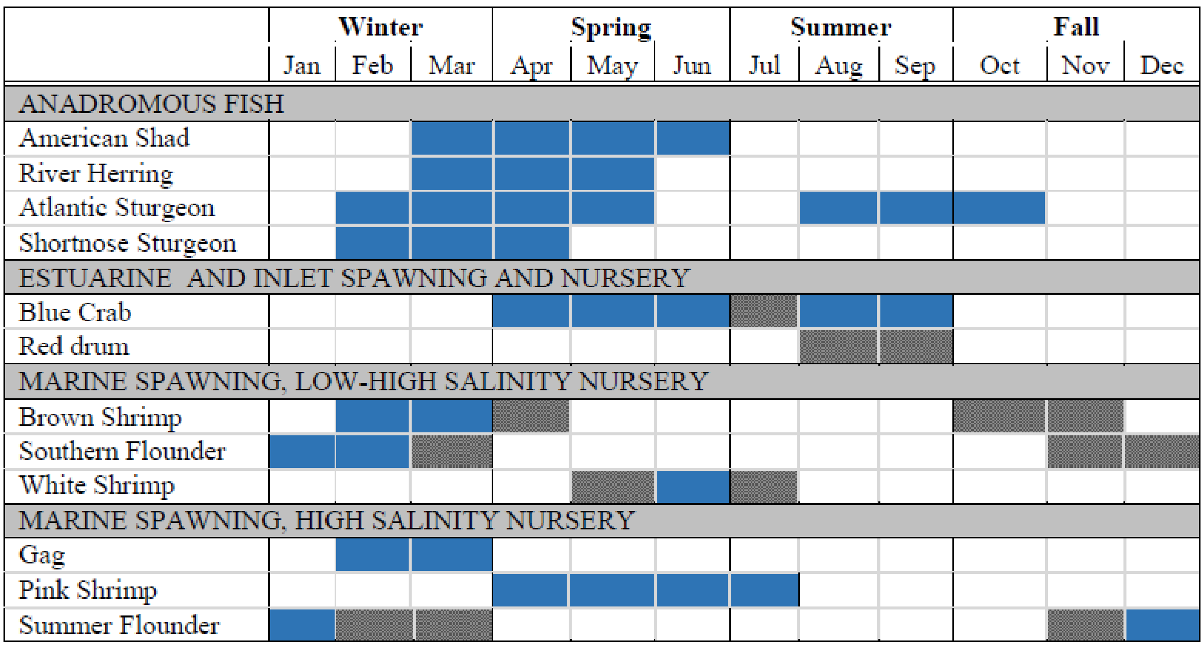

Figure 10. Spawning seasons for coastal fish and invertebrate species occurring in North Carolina that broadcast planktonic or semi-demersal eggs. Blue indicates peak spawning season, and the gray areas indicate spawning occurrence. Figure from Wickliffe et al. (2019) and adapted from NCDEQ (2016).

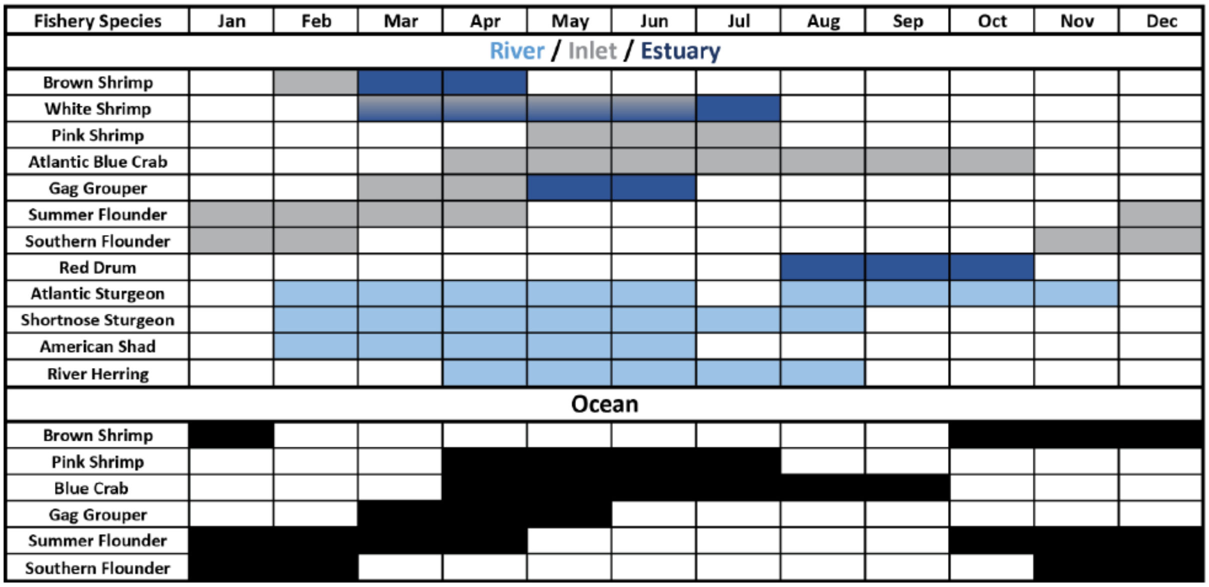

Figure 11. Summary of the most sensitive life stages (eggs, larvae, and early juveniles) for select fisher species and their distribution throughout the year. Boxes represent abundant eggs and/or larvae present in a given area. Light blue = River habitat; Gray = Inlet habitat; Dark blue = Estuarine habitat; Black= ocean. Figure from Wickliffe et al. (2019) and adapted from NCDEQ (2016).

and water temperature. Although geomorphology was a minor influence, some shoals were clearly important than others based on the other characteristics. In this study, sharks that specialized on foraging on menhaden and croaker may have applications to forage fish ecology (see Shark section above).

In regard to larvae transport, Delft3D hydrodynamic simulations were conducted to better understand the effect of tidal currents on the transport of larvae into the estuary (Corps Wilmington District). Drogues were then placed in the waters near Bald Head Island to track potential pathways (Figure 12). The findings were interpreted in the context of examining the potential impact of hard structures, but the drogue pathways show that larvae are expected to flow from the western part of Bald Head Island into the estuary. Markovsky (2004) examined the distribution and abundance of larval fishes and decapods in the Cape Fear River plume (described in the Oceanography section above) and at ocean sites west of FPS. The majority of fish caught were estuarine-dependent species that spawn on the continental shelf. Croaker, spot, and pinfish were abundant as well as families Blenniidae (blennies), Gobiidae (gobies), anchovy, and flounder.

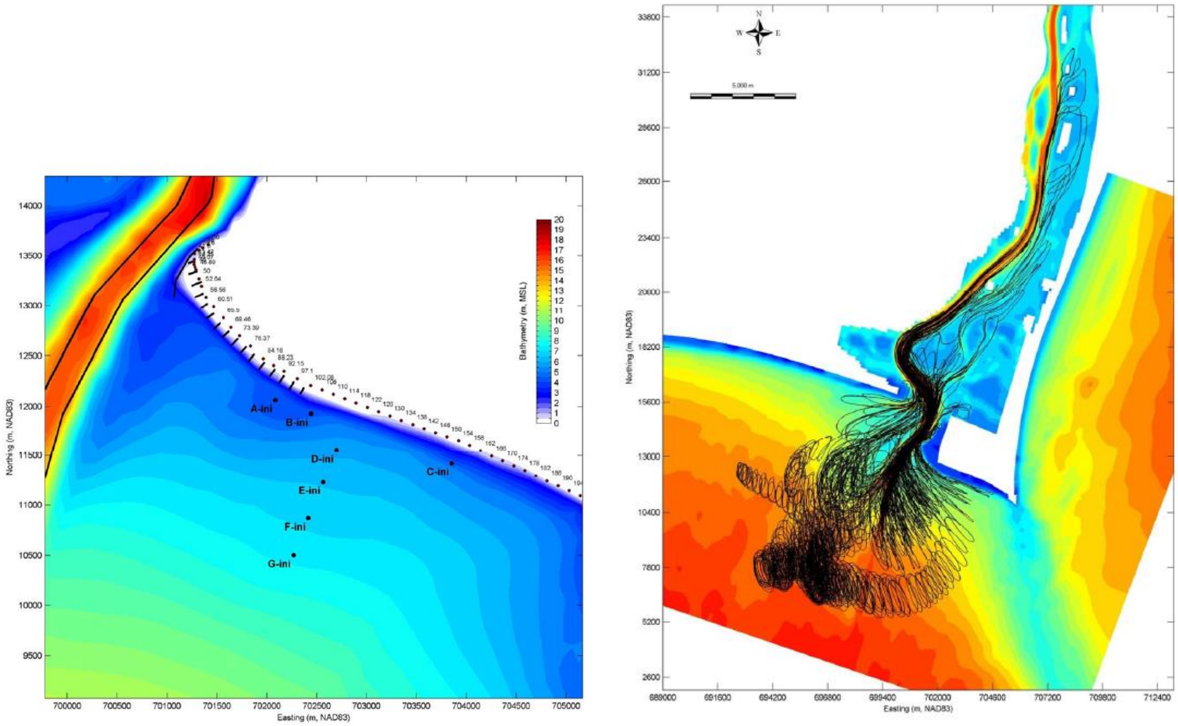

Figure 12. (left) Initial sites for deployment of drogues for tracking and (right) all drogue tracks simulated larvae transport into the estuary. Figures from USACE Wilmington District and Land Management Group Inc. (2014).

Knowledge gaps related to the concerns of interviewees include:

- Species composition, abundance, habitat use, and seasonality of forage fish that contribute to biological productivity at shoal habitats. Some forage fish studies have been conducted within the lower reaches of the Cape Fear River estuary (Friedland et al., 1996; Ross, 2003), but not beyond the mouth of the river

- Distribution, habitat use, and importance of shoals to Penaeid shrimp and shrimpers. At Cape Canavaral Shoals (FL), shrimpers are well-known to harvest from sand shoal habitats, especially in the early spring and late fall (Iafrate JD et al., 2019). Documentation at FPS is nonexistent.

- Blue crab habitat use, or lack thereof, directly at FPS and its close vicinity. Blue crab in the Gulf of Mexico spawn in high numbers at sand shoals that are miles from the shoreline (Condrey and Gelpi, 2010).

5.3. Atlantic Sturgeon and Diadromous Fish

Atlantic sturgeon was listed as an endangered species in 2012 with the recognition of five distinct population segments, including the Carolinas population. In North Carolina, Atlantic sturgeon critical habitat is found in the following rivers: Cape Fear, Northeast Cape Fear, Roanoke, Tar-Pamlico, Waccamaw, and Neuse (Federal Register, 2017). Wickliffe et al. (2019) provides an in-depth examination of the natural history of the species (Figure 13). Atlantic sturgeon primarily forage on benthic species (Johnson et al., 1997), which makes them potentially vulnerable to the loss of substrate and its associated invertebrates. In the context of sand dredging, we summarize Atlantic sturgeon ecology in relation to spawning, movement pathways, aggregations, and marine habitat use.

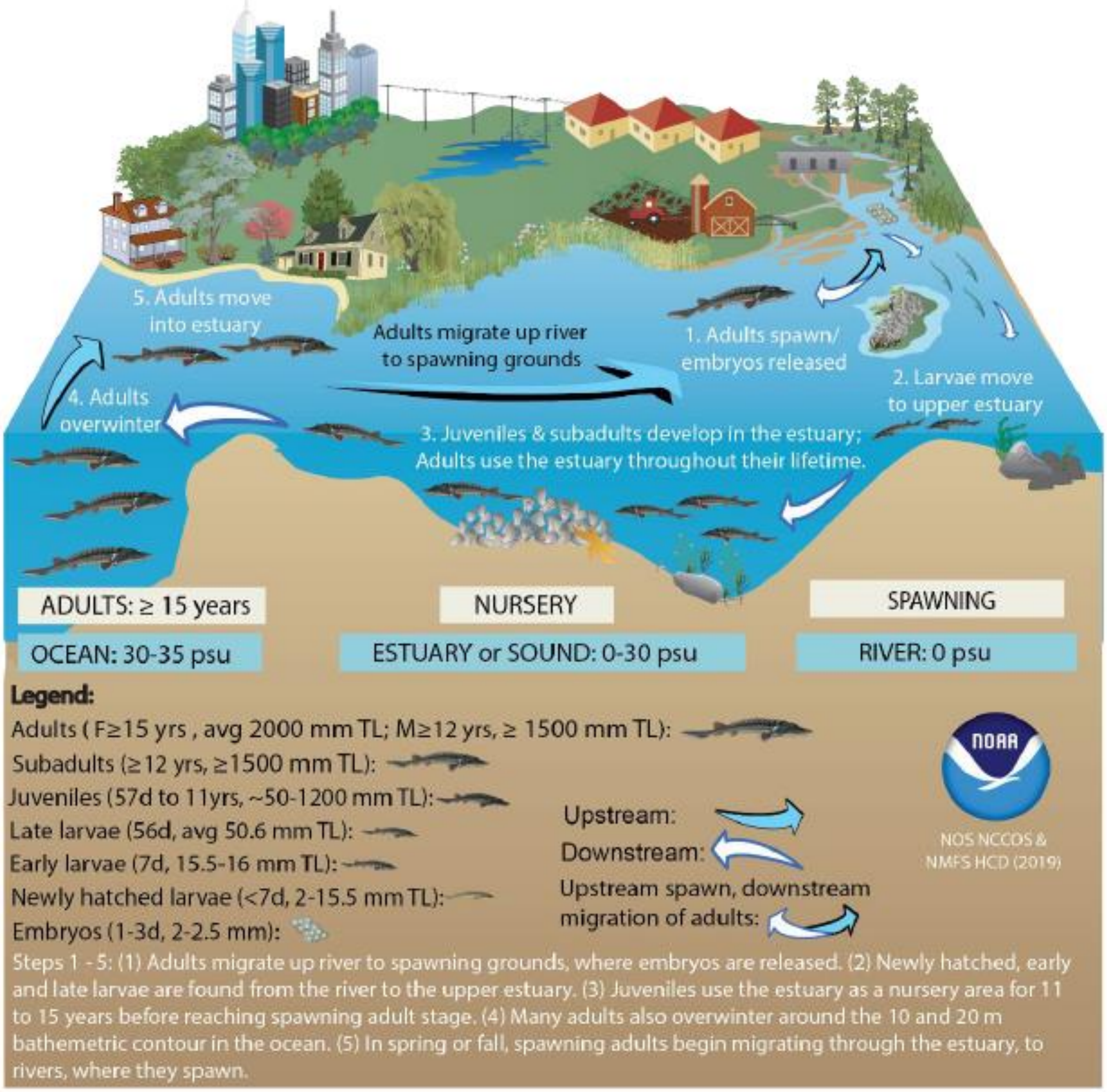

Figure 13. Life cycle of Atlantic sturgeon. Graphic from Wickliffe et al. (2019).

Spawning, Movement Pathways, and Aggregations

Movement pathways to and from spawning sites in the Cape Fear River are largely unknown and were a concern of interviewees. Spawning-related movements to estuarine corridors and farther upstream begin in February and March in South Carolina (Collins et al., 2000). Although Atlantic sturgeon are historically well-known to spawn in the spring along the Atlantic Coast, recent evidence shows fall spawning occurs in northeast North Carolina (Smith et al., 2015) and in South Carolina (Collins et al., 2000). Fall spawning occurs September 1 to November 30th (Wickliffe et al., 2019). Atlantic sturgeon have been documented aggregating in marine waters in the vicinity of the mouth of large rivers during the spring and fall spawning seasons (Breece et al., 2016; Dunton et al., 2015; Dunton et al., 2010). In the mid-Atlantic, Atlantic sturgeon spent long periods of time at the mouth of Delaware Bay spanning May to October, presumably because of cooler water temperatures and possibly upwelling conditions (Breece et al., 2018). The location and timing of potential aggregations of Atlantic sturgeon offshore of the Cape Fear River is not known.

In North Carolina, Moser and Ross (1995) tagged 100 juvenile Atlantic sturgeon in the Cape Fear River and Brunswick River. They reported that four Atlantic sturgeon were recaptured by commercial fishers located at Carolina Beach, Kure Beach, and Ft. Fisher. One of these fish came within 100 m of a hydraulic pipeline dredge. For a previous Bald Head Island assessment (Corps Wilmington District), the NC Division of Marine Fisheries (NCDMF) summarized information on Atlantic sturgeon in the Cape Fear River. Movements of acoustically tagged fish were tracked by acoustic stations, including 80 Atlantic sturgeon and 2 shortnose sturgeon that were implanted with acoustic transmitters. The findings indicate that mature and sub-adult Atlantic sturgeon start entering the Cape Fear River in February with a peak in March and April (Figure 14), and they exit the river by the end of May. Sub-adult Atlantic sturgeon spend the summer above the saltwater interface north of Wilmington and start to emigrate to the ocean beginning in September with a peak in November. Little is known about their habitat use after this time.

Marine Habitat Use

Interviewees suggested Atlantic sturgeon marine habitat use in the late fall and winter were a concern. During winter, Atlantic sturgeon from various geographies share marine habitats (Erickson et al., 2011). Knowledge of Atlantic sturgeon distributions in marine habitats is limited (Ingram et al., 2019), particularly in the Carolinas. Information from other geographies suggest that Atlantic sturgeon primarily use waters of < 50 m in depth during this time (Dunton et al., 2010; Ingram et al., 2019; Stein et al., 2004). Similarly, Atlantic sturgeon were often observed at depths of < 20 m during migration periods (Dunton et al., 2015). In the mid-Atlantic, Rothermel et al. (2020) found Atlantic sturgeon were closer to shore in spring and summer when temperatures there were relatively warmer there, but were detected farther offshore in winter when those waters were comparatively warmer (Rothermel et al., 2020).

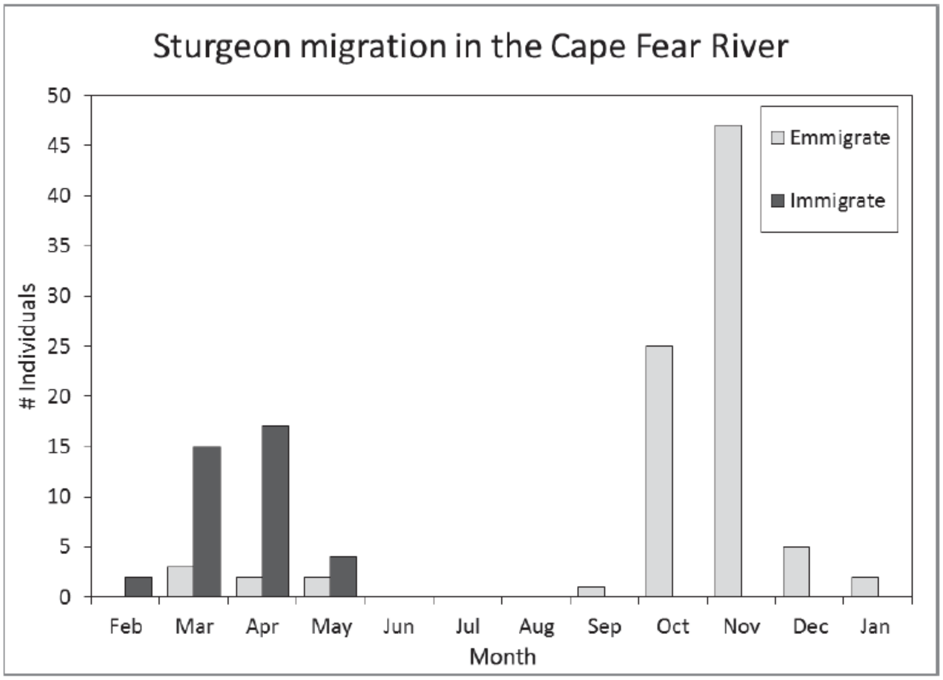

Figure 14. Number of individual, acoustically-tagged sturgeon entering or leaving the Cape Fear River April 2011 to January 2014.

Other diadromous fish of commercial or recreational fisheries importance in North Carolina, and the Cape Fear River, include alewife, blueback herring, American shad, hickory shad, and striped bass. Greene et al. (2009) provides an in-depth analysis of habitat associations of each of these diadromous species for the Atlantic Coast. The seasonality of spawning seasons and related movements is detailed by Wickliffe et al. (2019) (Figure 10,11). Anadromous species such as shad, river herring, and striped bass utilize the cape shoals as staging areas for migration along the coast. (NCDEQ, 2016). Shortnose sturgeon is an endangered species, but is rare in the Cape Fear River (Moser and Ross, 1995); the species also uses inshore waters rather than the federally-managed waters of interest here.

5.4. Coastal Migratory Pelagics

Coastal migratory pelagic fish in the Cape Fear region include Spanish mackerel, king mackerel, cobia, and bluefish. These fish are among the most data-poor species, as their traits of being highly mobile and seasonal lead to poor representation in reef fish or groundfish studies (Iafrate JD et al., 2019; Pickens and Taylor, 2020). Interviewees suggested aggregations of these fish occur in winter (late November to April), and biomass of juvenile coastal pelagic fish are high during this time. One concern is the disruption of spring and fall migration. King and Spanish mackerels feed on baitfish (i.e., forage fish), seasonally congregating on shoals and reefs (NCDEQ, 2016). NMFS has designated the cape shoals of North Carolina as Habitat Areas of Particular Concern (HAPCs) for both mackerels (NCDEQ, 2016).

In a comparative study at Cape Canaveral, Iafrate et al. (Iafrate JD et al., 2019) used acoustic transmitter to detect fish. They found the following:

- Detections of individual cobia were 13 at a dredge site, 22 at a control site, and 35 at offshore reefs. Cobia were widespread on the cape-associated shoal, including 56 of 62 acoustic receivers.
- Detections of individual Spanish mackerel were 10 at a dredge site, 7 at a control site, and 1 at offshore reefs. Spanish and king mackerel were extremely ephemeral during the study
- Only 5 king mackerel were detected with 4 being detected at offshore reefs

Spanish mackerel is a piscivore that commonly use depths of 10–35 m (Froese and Pauly, 2018). Schmidt et al. (1993) showed the Spanish mackerel spawning season ranges primarily May–August 31 in the South Atlantic. Ichthyoplankton samples also show larvae in depths spanning 11–29 m (Collins and Stender, 1987). Larvae and juvenile Spanish mackerel have been captured in the nearshore of North Carolina from May–October (Peters and Schmidt, 1997), and the species likely winters in south Florida.

King mackerel is a piscivore that uses depths of 5–140 m (Froese and Pauly, 2018), and winters near south Florida (Sutter et al., 1991). In the South Atlantic, serial spawning occurs from April through early October, with a peak in September (Collins and Stender, 1987; Finucane et al., 1986). King mackerel larvae were found to be more abundant at depth ranges of 21–200 m compared to more shallow waters (only 2 of 175 surveys in depths $\leq$ 20 m had larvae). The abundance of king mackerel is greatest in the spring (April peak) and fall (November peak) as the species migrates through North Carolina waters (Trent et al., 1987).

As of 2019, Atlantic cobia are managed by the Atlantic States Marine Fisheries Commission. Beginning in April, cobia move to inshore waters to spawn in bay and estuaries of North Carolina (Shaffer and Nakamura, 1989). Spawning spans May–August in North Carolina (NCDEQ, 2016). From data on tagged individuals, Crear et al. (2020) found the following:

- Cobia use temperatures of 22.5–29.5°C during warm months
- Cobia used depths of 0–20 m during the summer and depths of 0–40 m during the spring and fall.
- Habitat suitability models showed high suitability near FPS in the fall, but not the spring.
- With climate change scenarios, North Carolina is expected to have large decreases in suitable habitat over time.

Bluefish offshore of North Carolina primarily spawn in the spring, but may have limited spawning in the fall as fish migrate southward (Wuenschel et al., 2012). Sampling in Onslow Bay, North Carolina shows that spring-spawned young-of-year bluefish begin appearing in April, remain along the coast in summer, and are followed by a pulse of more young-of-year that have likely migrated south from the mid-Atlantic (Wuenschel et al., 2012). These fish primarily used waters < 20 m in depth and occur September–December. Morley et al. (2007) found 95.5% of young-of-year bluefish were caught within 1.6 km of shore (sampled to 8 km). These bluefish were common September–December and April–July. Variability appeared to be driven by water temperature; bluefish appeared during times of warmer temperatures (Morley et al., 2007).

5.5. Reef Fish and Hardbottom Habitat

Interviewees recognized the high value of hardbottom outcroppings as habitat for reef fish, and they recognized the value of shipwrecks from a biological and cultural perspective. Among interviewees and other experts, there was substantial uncertainty about the relevance of hardbottom habitats to potential FPS dredging because: 1) Is hardbottom close enough to FPS to be a concern? 2) No surveys of juvenile reef fish have been conducted on cape-associated shoals in North Carolina. The distribution of known hardbottom and shipwrecks near FPS has been mapped (Figure 7), although hardbottom locations only represent approximate centroids of hardbottom. Hardbottom was also identified near the seaward limit of the former federal navigation channel approximately five miles offshore (Corps Wilmington District). NCDEQ (2016) provides more detailed locations of these habitats.

Natural hardbottom, or "live bottom", provides substrate for the colonization of sessile invertebrates such as sponges, hard corals, soft corals, and algae (SAFMC, 1998, 2008). As a result of this structural complexity, a tremendous diversity of adult and juvenile reef fish use these habitats for shelter, foraging, and spawning. Man-made structures, such as shipwrecks also serve as similar habitat for reef fish (NCDEQ, 2016). The North Carolina Coastal Habitat Protection Plan (NCDEQ, 2016) provides a comprehensive list of fish that use hardbottom and highlights the high economic value of these fish. The South Atlantic Fishery Management Council manages reef fish as part of the Snapper-Grouper Complex, which includes 59 species. Hardbottom in nearshore waters are thought to be valuable for snapper-grouper because it acts as stopping points for fish emigrating offshore (Lindeman and Snyder, 1999; NCDEQ, 2016). If hardbottom were to be found in close vicinity to FPS, then burial from sedimentation (Lindeman and Snyder, 1999) and loss of nearby soft-bottom foraging areas would be concerns. For adult reef fish, Bacheler et al. (2016) found the distribution of hardbottom fish were primarily structured by depth, latitude, and the percent of hardbottom substrate. Pickens and Taylor (2020) tested habitat associations of adult red snapper and black sea bass on hardbottom habitats in the South Atlantic. Black sea bass had a broad distribution, whereas red snapper were more limited. Red snapper were associated with westward currents, distance to the Gulf Stream, nearby wetlands, and were frequently in depths of 25–35 m. Studies of reef fish at large cape-associated shoals are rare. In a study encompassing adult reef fish at Cape Canaveral Shoals in Florida, only one individual of the snapper-grouper complex was caught in 978 longline surveys (Iafrate JD et al., 2019).

Notably, no surveys of juvenile reef fish have occurred at FPS or other North Carolina cape-associated shoals. Numerous reef fish species, such as red snapper, use sand substrates as juveniles and then undergo an ontogenetic shift to waters with natural or artificial reefs. For example, Pickens and Taylor (2020) found juvenile red snapper were positively influenced by sand shoals and topography, although the effect was minor compared to oceanographic influences. In Florida, as much as 80% of hardbottom fish visually sampled represented early life stages (Lindeman and Snyder, 1999). Walsh et al. (2006) studied reef fish habitat use of unconsolidated sediment substrates by conducting trawl surveys offshore of Georgia. They classified 121 of 181 fish species as being a juvenile life stage, and they suggest that unconsolidated sediments of the continental shelf are important for early life stages of reef-associated species.

5.6. Sharks

Interviewees suggested coastal sharks are a dominant component of the predator community on sand shoal complexes. This has been confirmed at Cape Canaveral Shoals (FL), as 90% of predators surveyed by longline were sharks (Iafrate JD et al., 2019). Anecdotes of interviewees suggested the productivity of forage fish are likely to be the reason for this phenomenon. Concerns with coastal sharks were mixed with some interviewees suggesting seasonal migratory movements to be most important in the Cape Fear region, while others expressed concern about movements to and from pupping areas in the estuary. For both movement types, seasonality is expected to play a large role in habitat use and abundance of sharks on FPS. As a migration route, interviewees suggested FPS is likely to be a stopover habitat that has predictable resources for sharks and has the structural complexity that some species prefer (e.g., sand tiger shark, spiny dogfish).

Studies conducted in the shallow waters offshore of North Carolina (Thorpe et al., 2004) and South Carolina (Ulrich et al., 2007) investigated waters of 3–15 m depths and Atlantic sharpnose, blacknose, blacktip, bonnethead, finetooth, sandbar, and spinner shark were common. Pickens and Taylor (2020) developed predictive models for blacknose, sandbar, and tiger shark in the South Atlantic. They found the following (Figure 15).

- Blacknose shark had positive relationships with chlorophyll, nearby estuaries, and east-west current velocities. Spatial modeling showed these associated translated to an affinity towards coastal inlets.

- Sandbar shark had their highest probability of occurrence in water depths of 42–50 m, and they were more common in areas with higher bottom temperatures in the autumn, particularly with waters > 24.5°C.

- Tiger shark were associated with a greater amount of nearby wetlands and with greater water depths; peak occurrence correlated with depths of 25–50 m.

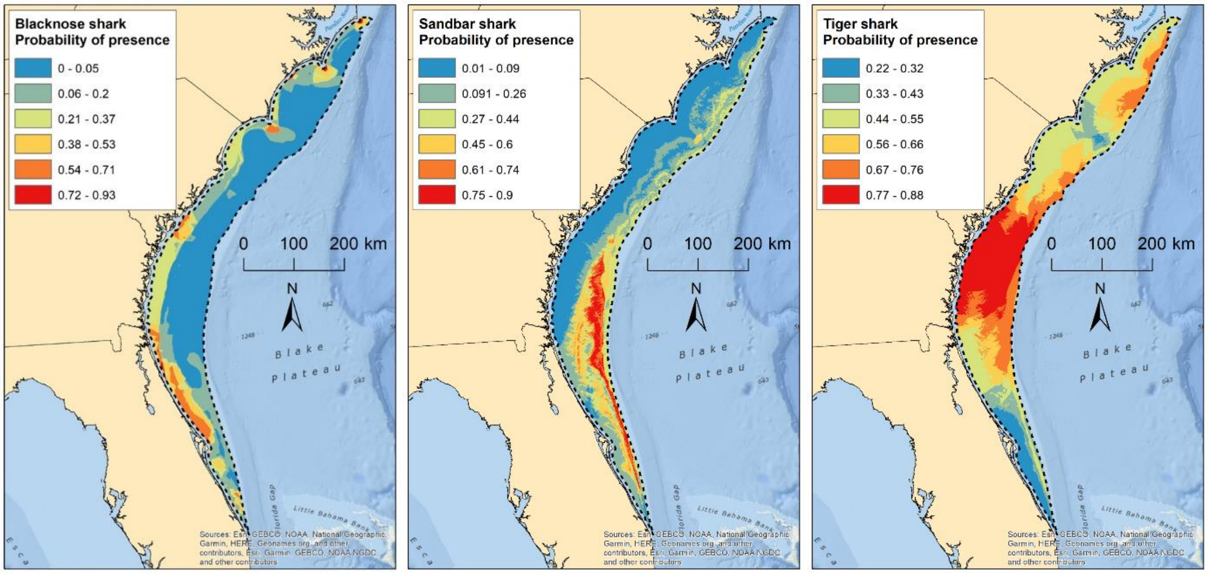

Figure 15. Predictive models of probability of occurrence for blacknose shark (left), sandbar shark (middle), and tiger shark (right). Figures from Pickens and Taylor (2020).

No research in the South Atlantic has linked the distribution of sharks to their prey. In the Gulf of Mexico, Pickens and Taylor (2020) studied spinner and blacktip shark, which are menhaden and forage fish specialist. These sharks were associated with the amount of nearby wetlands and estuaries, chlorophyll, and a lower salinity of waters, which are all indicative of their prey's habitat. Blacktip shark and Atlantic sharpnose were associated with croaker abundance and sharpnose shark was associated with nearby wetlands and shrimp distribution.

At Cape Canaveral Shoals, Iafrate et al. (2019) found the following:

- With longline surveys, the most common sharks captured were Atlantic sharpnose (1,436 captures), blacknose (488), blacktip (277), and finetooth (157), nurse (52), bonnethead (40), spinner (34, mostly young-of-year), and sandbar shark (22).
- In a comparison of a dredge site and control site, Atlantic sharpnose sharks were more common at a control site, finetooth shark were more common at the dredge site, blacknose and blacktip shark detections were similar at both sites
- Finetooth and blacknose shark spent much of their time in depths of < 5 m with deeper locations used in the winter. All available depths were used.
- Atlantic sharpnose used comparatively deeper waters on the shoals (15–20 m)

Specifics of latitudinal migrations and inshore-offshore shark migrations are species-specific, unknown for many species, and are difficult to generalize. There is a reasonable consensus that migration timing and movements are directly linked to water temperature (Haulsee et al., 2018; Kessel et al., 2014), and several species are restricted during winter to waters south of Cape Hatteras, North Carolina (Pickens et al., 2020). Interviewees stated that the spring migration in

North Carolina spans April to mid-June as sharks move northward and fall migration peaks October–November when sharks migrate southward. Wintering species, such as spiny dogfish, reside offshore of North Carolina from December–March (Bangley, 2012). Below we provide case studies of pelagic, wintering, and migratory shark studies. Specific details of habitat associations of species are provided by Pickens et al. (2020). Data gaps include habitat use of species at, or near FPS, and the importance of cape-associated shoals compared to other available habitats.

Pelagic Sharks

Research on pelagic sharks is largely lacking. In a study of pelagic sharks including tiger, blue, shortfin mako, and great hammerhead shark, Queiroz et al. (2016) found they were distributed along the Atlantic Coast during March–August, but during September–February they were more limited to waters near Florida and deep offshore waters. Hotspots of use were predictable based on temperature and fronts of temperature or productivity gradients (Queiroz et al., 2016).

Wintering Locations and Migration

North Carolina is a wintering area for sharks and a common migratory stopover, although data specific to FPS are lacking. Evidence is provided by:

- Conrath and Musick (2008) tracked sandbar sharks offshore of Virginia during the summer, and all seven individuals wintered offshore of North Carolina. The authors suggest that central North Carolina could be an important wintering area for sharks because of its proximity to the warm Gulf Stream.

- Kneebone et al. (2014) tracked sand tiger sharks in the northeastern US and found 27 sand tiger sharks (43% of individuals studied) were detected transiting near Cape Hatteras, North Carolina during migration and 20% had residency there. This is likely due to Cape Hatteras being a temperature break point with warmer waters, and possibly, because a steep depth gradient exists there and may funnel shallow water species along the cape-associated shoals. The value of habitat farther south, such as FPS, remains unknown.

- A sand tiger shark study in Delaware Bay showed all seven tagged males migrated south to the vicinity of Cape Hatteras, North Carolina, whereas females moved outward to the edge of the continental shelf (Teter et al., 2015). Again, waters near North Carolina were thought to be important to wintering sharks because of relatively high temperatures of the Gulf Stream.

- In the mid-Atlantic, sand tiger shark were found to migrate northward along a narrow, nearshore band of shallow water in the spring (Haulsee et al., 2015). Haulsee et al. (2018) further suggest that sand tigers may use the shoreline and sand shoals as landmarks for their migration in the fall.

Pupping and Nursery Waters

Published studies on shark species using the Cape Fear River estuary as a nursery are lacking. Castro (1993) investigated estuaries of South Carolina during the spring and summer (March to late September) for evidence of gravid females, females carrying embryos, neonate, and young-of-year sharks. Most species were observed in very shallow waters (< 10 m in depth). Common species using the estuaries as nurseries include:

- Blacknose shark
- Blacktip
- Spinner shark
- Sandbar shark
- Finetooth shark
- Dusky shark
- Atlantic sharpnose shark
- Scalloped hammerhead
- Smooth dogfish

5.7. Sea Turtles, Marine Mammals, and Seabirds

Sea turtles, marine mammals, and seabirds were not a major focus of this review, but several of these species will need to be addressed in any potential FPS sand dredging project. Therefore, we provide a brief overview here with a basis on a previous environmental impact statement (Corps Wilmington District).

- Marine mammals that might potentially use these waters are right whale and humpback whale. Humpback whale migrate through the area December–April. Right whale occasionally winter offshore of North Carolina, and breeding of right whale has been observed offshore of Wrightsville Beach, North Carolina.

- State-listed birds that forage in the ocean near FPS include least tern, common tern, and brown pelican. These bird species prey on forage fish, but little is known about foraging-related movements of these birds or their habitat use in the region. Addressing impacts to forage fish would indirectly affect these birds.

- Sea turtle species in the vicinity of FPS are loggerhead, Kemp's Ridley, leatherback, green, and Hawksbill (less common) sea turtles. Hopper dredges are known to lethally entrain sea turtles, and further details regarding this issue are provided by Dickerson et al. (2004). Certain dredging conditions and borrow area designs may increase the risk of sea turtle entrainment and may be mitigated.

5.8. Priority Biological Knowledge Gaps and Research Recommendations

TBD at workshop.

6.0 Potential Mitigation Measures for Dredging of FPS

Mitigation methods have not been developed specifically for FPS; however, we summarize measures that have been previously proposed in the literature to promote biological recovery and reduce impacts to shoal integrity. This suite of mitigation measures should be considered "tools in the toolbox" to reduce risk from specific dredging related impacts. Other mitigation measures not included in detail here are ship strike avoidance and mitigation for entrainment. For marine mammals, the greatest risk from dredging activities are related to ship strike, which can be mitigated with observers and slow down procedures.

Mitigation methods related to dredging action and fisheries identified by Tomlinson et al. (2007), Diaz et al. (2004), and Slacum Jr et al. (2010) include:

a) Spatial zoning to protect areas important to fish or areas that are sensitive to disturbance

b) Agree upon navigation routes that minimize conflict with fishing

c) Select a dredging technique and timing of dredging to minimize potential negative effects. These may be seasonal exclusions or using knowledge of tidal stages or ocean currents. Dredging sand during the winter could minimize adverse ecological effects by avoiding periods of peak recruitment of species.

d) To reduce direct injury to fish, sand could be dredged at night, when some species migrate vertically into the water column.

e) Shoals could be mined in a rotation, or be partially dredged, to allow shoal-associated fauna assemblages to recover between dredging events; this should be done with consideration of recovery rates of shoals. Limit the distance between shoal features to facilitate recolonization of biota.

f) Shoals with less relief should be targeted for mining instead of steeper shoals when the option is available

g) Dredging should be avoided when demersal finfish are using the inner continental shelf as a nursery ground

h) Prevent on-board screening or minimize material passing through spillways when outside the dredging area to reduce the area of sediment plumes

i) Modification of dredging depth and design to reduce changes to hydrodynamics and sediment transport

Mitigation measures identified or implied by Dibajnia and Nairn (2011), CSA International Inc. (CSA International Inc et al., 2010) to protect the geomorphic integrity of shoals include:

a) Avoid dredging shoals in waters > 30 m in depth because it has been shown that a decrease in shoal height occurs beyond this depth, and shoal may not recover to its pre-dredging height.

b) Prioritize locations for shoal dredging to minimize physical impacts. Dredging of the leading edge of a shoal often leads to a net long-term deposition and faster infilling rates, followed by the crest and the trailing edge.

c) Use innovative dredging methodologies such as a “striped” dredging pattern that appears to support a more timely and uniform recovery

d) Extract sand from a deposition center, leading edge, or down drift margin of a shoal, to avoid interrupting natural shoal migration and potentially reduce the time required for site refilling. Avoid dredging in erosional areas that source down drift depocenters, which also may be slow to refill after dredging

e) Utilize shallow dredging over large areas rather than excavating small, but deep pits

f) Dredging should occur on shoal crests and higher areas of the leading edge rather than lower areas of the shoals because of greater exposure to wave-generated turbulence and greater sediment mobility, which potentially results in more rapid sediment reworking and site infilling, and likely would induce the benthic community to recover more rapidly.

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