## **Technical Summary**

Study Title	Ecological Function and Recovery of Biological Communities within Dredged Ridge-Swale Habitats in the South-Atlantic Bight
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**ABSTRACT:** Impact to biological assemblages from dredging a sand shoal off the east coast of Florida (Canaveral Shoal II Borrow Area, CSII-BA) was assessed using a Beyond-BACI (Before/After and Control/Impact) sampling design based on concurrent seasonal sampling of reference shoals (Chester and Bull Shoals, as well as a non-dredged portion of CSII) before and after two dredging events (winter 2013/14 to spring 2014 and another in spring 2018). Composition and abundance of plankton, invertebrates, and fish assemblages were used to determine potential impacts. In addition, the physical environments of the shoals (i.e., currents, flows, wave generation) were assessed through oceanographic processes, and habitat was classified through monitoring of the benthos using hydroacoustic surveys and benthic grabs.

Overall, season was the primary driver of changes in abundance and biomass over time in all assemblages, with habitat (swale versus ridge), shoal, and year less so. With few exceptions, the impacts from dredging CSII-BA relative to reference shoals (CSII, Chester, and Bull Shoals) were not significant on the abundance and biomass of the various plankton, benthic and demersal invertebrates, and demersal fish assemblages. The few changes in abundance or density of invertebrate groups detected in the dredged shoal relative to the reference shoals were short lived (i.e., returned to pre-dredged levels within a season). The dynamic nature of the sand shoals and surrounding area was further evidenced by telemetry of acoustically tagged fishes that showed ephemeral use and low residency within specific shoal areas. The importance of a seasonal driving factor was also observed in the isotopic niches of representative fish and invertebrate species over time among the shoals. At an ecosystem level, Ecopath models also showed the importance of a seasonal component in driving the trophic structure and productivity of the shoal ecosystems over time. This natural variability in the biological assemblages among the shoals was as great or greater than any detectable changes due to dredging.

**BACKGROUND:** Offshore sand shoals, which consist of submerged ridges covered by sand and surrounded by deeper relatively flat-bottomed areas, or swales (i.e., ridge-swale shoals) are coastal features that occur along the US Atlantic seaboard and are exemplified off Florida's east coast. These shoals are typically rich in sand particle sizes required for beach renourishment. However, these shoals also provide essential fish habitat (EFH) for commercial and recreational fisheries species (fishes and invertebrates), as well as threatened species or species of concern. Dredging these shoals for sand to renourish nearby beaches can have a negative impact to their biological communities.

CSII off the east coast of Florida is periodically dredged as a source of sand. Biological communities on this dredged shoal need to be monitored for any impacts that could be detrimental to the ecosystems of the shoals and essential fish habitat. Potential impacts to biological assemblages due to dredging activities are also associated with a recovery timeline, where any changes in the biotic assemblages after dredging return to pre-dredged conditions. This impact is important to assess so that the effects on fisheries resources and the ecosystems overall can be monitored to full recovery, and the timeline between dredging events can be better planned. Such assessments may require monitoring programs that are relatively long term.

**OBJECTIVES:** Our overall goal was to understand the potential impacts of dredging on the dynamics of species abundance, biomass, and assemblages on offshore sand shoals. To accomplish this goal, this study spanned both the physical environment as well as the biological communities of the sand shoals. Our specific objectives were the following:

- 1) Characterize the coastal oceanography and environments of the sand shoals to understand the physical forcing factors;
- 2) Compare the bathymetry and substrate features of the shoals before and after dredging events;
- 3) Characterize the benthic habitat available on the shoals and surrounding area;
- 4) Determine the temporal variability of species assemblages (phytoplankton, zooplankton, meroplankton, benthic and demersal invertebrates, and demersal fishes) on an annual, seasonal, and diurnal basis;
- 5) Examine the spatial variability of these species assemblages among the shoals and between ridge and swale habitats of the shoals;
- 6) On a spatiotemporal basis, compare species abundance, biomass, and assemblages of the dredged shoal (CSII-BA) relative to multiple "control/reference" (non-dredged) shoals (CSII, Chester, and Bull Shoals);
- 7) Determine the temporal sequence of recovery of biological assemblages in the dredged area relative to the biological assemblages of the reference shoals using pre-dredge versus post-dredge comparisons;

- 8) Examine spatial use of key fishes associated with the shoals, site fidelity, and movement between dredged and non-dredged shoals; and
- 9) Discern functional, ecosystem-level services that are potentially compromised by dredging and determine the degree of potential impact, relative to the ecosystem services of reference shoals.

**METHODS:** Our sampling framework was based on using a Beyond-BACI design, including multiple control (reference) shoals (Chester, Bull, and CSII), an impacted (dredged) shoal (CSII), and seasonal sampling before and after the dredging events. This study was initiated in fall 2013 and continued through summer 2019. Two dredging events occurred during this time period, one in winter 2013/14 to spring 2014, and a second one in spring 2018.

We examined the dynamic aspects of the physical environment of the shoals through oceanographic assessment of forcing factors such as currents, tides, and bathymetry using moored and towed current profilers (ADCPs). Direct dredging impacts to the bathymetry and substate of the shoals were estimated using hydroacoustic surveys, whereas direct sampling of the substrate with benthic grabs was used for classifying benthic habitat over the shoals and surrounding area. Impact of dredging on biological communities was assessed through stratified-random sampling of the shoals and examining any potential changes in species abundance, biomass, and assemblages for all major trophic levels, including phytoplankton, zooplankton, meroplankton, benthic invertebrates, demersal invertebrates, and demersal fishes. We sampled and collected the following: plankton using discrete water sampling; meroplankton using vertical plankton tows; benthic invertebrates using a benthic grab; and demersal invertebrates and fishes using a bottom trawl. Fish movement and residency was assessed using acoustic telemetry. Trophic-level changes were assessed using isotopic niches. The collective biomass at each trophic level was then integrated into ecosystem-level models using Ecopath to assess ecosystem function over time in relation to dredging events.

#### **RESULTS:**

Oceanography (Chapter 2): Sand shoals off the east coast of Cape Canaveral, Florida, are physically dominated by oceanographic processes and subject to frequent storm events. Ridges and swales produce spatial variability in tidal and non-tidal (subinertial) flows over the inner continental shelf. Shoals with gentle slopes between ridges and swales, such as at Chester Shoal, showed Bernoulli-type hydrodynamics, i.e., flow enhancement over ridges, whereas shoals with steep slopes between ridges and swales, such as between CSII-BA (the dredged shoal) and Shoal E adjacent to it, displayed frictional hydrodynamics, i.e., flow enhancement over swales. The critical bed slope to switch from frictional to Bernoulli-type (inertia-dominated) dynamics was equal to the non-dimensional bottom drag coefficient (typically 0.0025 for sandy bottom). It was evident that any alteration to a swale or ridge can modify the hydrodynamics by influencing friction and inertia. Because erosion will develop where strongest flows appear, any dredging alteration will also shift the erosional processes accordingly. Gulf Stream enhancements by southerly winds translate into strengthened northward inner shelf flows, and vice versa. The dynamics across the shelf are mostly geostrophic, with occasional influence from wave stresses. Tropical storm winds produce currents that distort tides and enhance shelf erosion. Comparisons of predredging to after-dredging conditions at a moored ADCP site suggested that changes can be grouped into three categories: 1) susceptibility for wave transformation caused by subinertial water-level variability; 2) infragravity (LGW) wave forcing by short waves (SGW); and 3) generation and dissipation of LGW over ridges. With respect to 1), susceptibility for wave transformations decreased after dredging. In reference to 2), there was decreased forcing of SGW after dredging and an increased proportion of free LGW. Related to 3), there was decreased generation and increased generation of LGW after dredging. Therefore, any alterations to the seabed through dredging, either to ridge or to swale, will necessarily produce alterations to wave-related energy fluxes and the amount of erosional LGW energy that reaches the shore.

These alterations will have effects on morphodynamic equilibrium and on erosional and depositional horizons.

**Bathymetry (Chapter 3):** Multibeam acoustic surveys of CSII-BA (the borrow area of Canaveral Shoals II) immediately following the first dredging event in Winter 2013-14 to Spring 2014 showed that the dredging activity was contained solely within the swale area of CSII-BA. This post-dredge survey in May 2014 showed clearly distinguishable draghead lines (furrows) from the trailing suction hopper dredge; furrows were less pronounced 1 year following dredging in surveys repeated in June 2015. Of the surveyed area of CSII-BA, the overall average change in bathymetry was + 0.11 m in the year following the dredging event, showing some filling-in and smoothing of the dredged area of CSII-BA. Within the same time frame, Chester and Bull Shoals (the reference shoals) experienced an average change of - 0.09 m, indicating very little change over the intervening year. Both CSII-BA and Chester Shoals had a slight but noticeable migration of their ridge crest to the southeast from May 2014 to June 2015, which is a natural occurring phenomenon with these dynamic sand shoals that has been reported previously. These bed level changes indicate that these shallow shoal complexes are physically dominated.

Habitat Classification (Chapters 4 and 11): The physical substrate of the shoals is primarily sand, shell-sand, and sandy-mud with relatively low organic content, most likely a function of the high degree of water movement and resuspension of sand. Based on benthic grab cores, the majority of sediment grain size on CSII-BA (the dredged portion of Canaveral Shoals II), CSII (the non-dredged portion of Canaveral Shoals II as a reference/control shoal), and Chester and Bull Shoals (reference/control shoals) was 0.25-1.00 mm, and consisted of mostly fine, medium, and coarse sands, of both geologic and biogenic (i.e., crushed shell) origin. Canaveral Bight, which is shoreward of CSII and CSII-BA and southwest of Chester and Bull Shoals, had finer sediments mostly <0.0625 mm that was comprised of muddy sand with  $\sim 2\%$  organic content. Alternatively, based on classifying the substrate using surface views of the benthic grabs, the majority of the substrate on the shoals was medium and coarse shell sand and medium shell hash of biogenic origin. These surface-views of the substrate indicated a higher proportion of larger-sized biogenic shell hash, a product of extensive breaking and reshaping of mostly bivalve shells. Virtually none of the substrate types on CSII, CSII-BA, Chester, and Bull Shoals had vertical relief greater than a few centimeters. Overall, ridge sediments were significantly coarser and had lower organic content than swale sediments. Significant changes in sediment grain size and organic content at the dredged shoal (CSII-BA) were matched by similar changes at the reference shoals (CSII, Chester and Bull) at the same time, so could not be attributed to dredging.

Water Quality Characteristics and Chlorophyll-a as a Proxy for Primary Productivity (Chapters 5, 6, and 8): Water quality monitoring (Chapter 6) determined that mean surface water temperatures were greater than the bottom water temperatures within each of the four shoals (CSII-BA, CSII, Chester and Bull Shoals) but did not differ among the four shoals over the study period and followed the same general temporal pattern; mean bottom water temperature was higher at CSII compared to Bull Shoal, with CSII-BA and Chester Shoals overlapping with both of those shoals. Overall mean salinity, dissolved oxygen concentration, and pH for surface and bottom waters were not different within each shoal, nor were they different among the four shoals over the study period. Overall mean Secchi disk depths (i.e., light attenuation) did not differ among the four shoals over the study period. Mean turbidity levels over the study period were generally lower in surface than bottom water samples for all shoals. Post-dredge seasons showed no major differences among shoals, including the dredged shoal (CSII-BA) in the trends of mean surface and bottom turbidities, mean chlorophyll *a* in surface and bottom waters, and mean total phosphorus and total nitrogen in surface and bottom waters. Based on satellite imagery (Chapter 5), chlorophyll a concentration, as a proxy for surface phytoplankton productivity, varied widely on CSII-BA, CSII, Chester, and Bull Shoals, and in the surrounding area, during pre-dredge and post-dredge periods of the first dredging event in Winter 2013-14 to Spring 2014. This variability encompassed a range of higher chlorophyll a levels than those observed during active dredging. Dredging activities on

CSII-BA did not result in an increase in primary productivity in the surface waters of CSII-BA or any of the study shoals overall. For microphytobenthos (Chapter 8), the range of chlorophyll *a* levels observed were in line with the range of values observed in other shallow ecosystems on the east and west coasts of Florida. The highest mean chlorophyll *a* concentrations were observed at CSII Shoal, followed by Bull Shoal, and the lowest concentrations were at Chester and CSII-BA Shoals. Seasonally, chlorophyll *a* concentrations generally peaked in the summer. A comparison of microphytobenthos chlorophyll *a* concentrations in the pre- to post-dredge sediment samples showed no major differences in concentrations, and patterns observed for the post-dredge period were generally similar at all the shoals.

Species Abundance, Biomass, and Assemblages (Chapters 7-13): For phytoplankton (Chapter 7), there were no consistent significant differences in total mean phytoplankton biomass among shoals for either surface or bottom water. Diatoms, dinoflagellates, and cyanobacteria were regular major contributors to total phytoplankton biomass throughout the study. Dinoflagellates generally had higher mean biomass in surface-water than bottom-water samples, in part reflecting their ability to move up in the water column via flagellar motility. By contrast, diatoms generally had higher mean biomass in bottom-water than surface-water samples, in part reflecting a combination of sinking of cells in the water column and resuspension of sedimented cells from the benthos into the lower layers of the water column. Small-sized phytoplankton was found to be important in terms of both abundance and biomass as picoplanktonic cyanobacteria combined with nanoplanktonic eukaryotes often represented over 50% of total phytoplankton biomass. This observation highlights the importance of the microbial loop in the Cape Canaveral shelf. Seasonally, the highest mean total phytoplankton biomass levels over the study period were observed in the fall, followed by winter, and lowest levels were observed in the spring and summer. Seasonal differences were in part attributable to shifts in predominant seasonal wind directions, which drive water along the coast from the north in the fall and winter, but from the south in the spring and summer, including eddies and upwelling from the Gulf Stream. In terms of the comparison of phytoplankton in post-dredge periods, and similar seasons in other years, no reproducible differences were observed at any of the shoals. These observations suggest that any impacts of dredging on phytoplankton composition and biomass were comparatively short-lived (i.e., not extending beyond one season).

For zooplankton (Chapter 9), the two most important groups in terms of biomass (mg carbon L<sup>-1</sup>) throughout the study period and shoals were arthropods and protozoans. Similar to phytoplankton, the high biomass levels of small-sized ciliates highlight the important role the microbial loop plays in food webs of the Cape Canaveral shelf. In terms of the influence of dredging activity on the zooplankton community, no major differences were observed in post-dredge seasons (i.e., spring and summer of 2014 and 2018) compared to similar seasons in other years, or in trends in biomass or composition among the four shoals, suggesting that any impacts of dredging were relatively short-lived.

Meroplankton (Chapter 10) over the sand shoals off the east coast of Florida was dominated by bivalve and polychaete larvae. Season had the strongest impact, affecting all functional groups of meroplankton except molluscan larvae, with the greatest abundance in summer and the lowest in fall. In contrast, abundance was not different for most meroplankton groups between ridge and swale habitat, with the exception of molluscan larvae (mostly Bivalvia) that was significantly greater over ridges than swales. Total meroplankton abundance, however, did not differ among any of the shoals, dredged or not. Echinoderm and polychaete larvae showed limited shoal effects but were not different between the dredged shoal (CSII-BA) and the non-dredged shoal (CSII).

Shoals, habitat (ridge versus swale), and seasons all significantly affected abundance of benthic invertebrates (Chapter 11), including at dredged (CSII-BA) and non-dredged (CSII) portions of Canaveral Shoal II, Chester Shoal, and Bull Shoal. However, most of these differences were unrelated to dredging events. No general biological factors, including invertebrate abundance, biomass, species richness, or Simpson's Index of Diversity changed following either of the two dredging events at CSII-BA or at any

of the reference shoals. The only taxon for which abundance clearly changed at CSII-BA following dredging were amphipods (small crustaceans) in the Family Haustoriidae, which increased in abundance following the second dredging event This specific change was not observed at CSII, Chester, or Bull Shoals, nor were any changes observed during the first dredging event at any of the shoals. The most abundant taxa, such as amphipods, sand dollars, lancelets, and even colonial bryozoans, were motile, and thus able to quickly recolonize any disturbed area. Benthic invertebrates were expected to be the most directly impacted biota by the dredging events but, with limited exceptions, they were either not impacted or recovered from dredging within one season.

For demersal invertebrates (Chapter 12), there were no clear effects of dredging on the diversity or mean biomass metrics used to assess demersal invertebrate communities on CSII-BA, CSII, Chester, and Bull Shoals. Bull Shoal had higher community diversity and mean biomass than Chester and CSII-All (the entirety of Canaveral Shoal II) but this pattern was not pronounced with respect to the dredged portion (CSII-BA). Diversity and biomass of demersal invertebrates varied from year to year for all shoals. The most consistent pattern was higher diversity on the ridges and higher biomass in the swales, but this was also seasonal. Summer generally had the highest diversity of all seasons. The assessment of dredging on demersal invertebrates was consistent with similar studies on the effects of dredging on soft-bottom communities in high energy, subtropical environments that favor diverse communities of small, mobile, opportunistic species. These characteristics may ameliorate any effect of dredging through a continuous and diverse supply of recruits available to colonize the recently disturbed habitat.

Sand shoals off the east coast of Florida have diverse fish assemblages (Chapter 13) that are dynamic in all aspects of space and time. Fish species richness varied among shoals: it was highest on Bull Shoal (150 species), followed by Chester Shoal (134 species), and lastly CSII-BA and CSII (118 and 117 species, respectively). Both the Shannon Diversity Index and Simpson's Index of Diversity were moderate for all seasons except most winters, which was associated with low diversity but high abundance of juvenile sciaenids (drums and croakers). Swale habitat on the shoals had significantly greater diversity, abundance, and biomass compared to ridge habitat. Temporally, fish abundance, biomass, and assemblages varied significantly on an annual (year to year), seasonal, and diel basis, with seasonal and diel factors contributing more to the temporal differences than year. Seasonal changes in abundance and biomass were highly significant, with Fall having the greatest abundance and biomass, followed by Winter, Summer, and Spring. Based on abundance, smaller fish species, such as juvenile sciaenids, anchovy species, juvenile cusk eels, and Leopard Searobin were common among shoals. Larger fishes were more common on a biomass basis, including Atlantic Croaker, Banded Drum, Silver Seatrout and Leopard Searobin. Diel patterns were also observed, with abundance and biomass of fishes 2.5X and 2.8X higher, respectively, at night compared to day, and fish assemblages were also significantly different between day and night. Spatially, all the shoals had fish assemblages that were relatively different in multidimensional space based on both abundance and biomass (standardized on a per area basis). This indicated that the shoals all had some individualistic features and natural variation that could make it difficult to generalize to other shoals in the area that were not sampled. For two dredging events (Winter 2013-14 to Spring 2014 and then again in Spring 2018), there was no significant impact on the fish assemblages of CSII-BA (the dredged shoal), relative to the natural variability observed in the fish assemblages of the reference shoals (CSII, Chester and Bull Shoals).

Movements and residency of demersal fishes (Chapter 14) showed low residency over the sand shoals; on average, fish were detected over the sand shoals <3% of the time that they were at large. Detections for a Summer Flounder, a Smooth Butterfly Ray, a Bluntnose Stingray, and a Clearnose Skate all indicated that these fish were within the area of the dredged shoal (CSII-BA) either before or during dredging, and then again after dredging activities, indicating that they were not directly affected by dredging (specifically the second dredging event in Spring 2018).

Stable isotopes of  $\delta^{13}$ C and  $\delta^{15}$ N used to trace potential trophic changes in basal carbon resources and trophic level, respectively, for focal invertebrate and fish species were compared between the dredged shoal (CSII-BA) and the non-dredged reference/control shoals (CSII, Bull, and Chester Shoals) (Chapter 15). Overall, seasonal isotopic composition and isotope niche sizes of amphipods, Roughneck Shrimp, Aviu Shrimp, Leopard Searobin, Spotted Whiff, and Atlantic Croaker varied among the reference shoals as much or more than between the reference shoals and the dredged shoal. For all focal species except Aviu Shrimp, there were no differences in their trophic position based on their  $\delta^{13}$ C or  $\delta^{15}$ N isotope values in Fall 2013 (i.e., immediately prior to the first dredging event in Winter 2013-14/Spring 2014) compared to post-dredge fall seasons (Fall 2014 and Fall 2015) for CSII-BA, CSII, or Bull Shoals. Trophic positions of Aviu Shrimp changed between pre- and post-dredge fall periods associated with the first dredging event, but they did so simultaneously on all three shoals and therefore could not be ascribed to the dredging event itself. Isotope values of  $\delta^{13}$ C and  $\delta^{15}$ N for all focal species for all shoals were not different between the pre- and post-dredge seasons for the second dredging event in Spring 2018, with few exceptions. Overall, the stability in the trophic positions of the focal invertebrate and fish species during pre-versus post-dredge seasons, and within the dredged shoal relative to the reference shoals, indicated that dredging did not fundamentally change the trophic state and linkages of the food web of the shoals, as observed through focal species that spanned different trophic levels and feeding lifestyles.

At the ecosystem level (Chapter 16), ecological indicators compared across shoals and seasons to determined that there were no clear effects of dredging on the CSII-BA ecosystem based on seasonal sampling over a study period of 6 years. Most ecological indicators showed greater similarities between CSII-BA (dredged shoal) and Chester (reference shoal) over time than between CSII-BA and CSII, which indicated no impact on CSII-BA due to dredging events. Regarding ecosystem flows, in spring 2014 when CSII-BA was dredged it had a production (P) flow rate in proportion to Total System Throughput (TST) (P/TST) and a consumption (Q) flow rate in proportion to TST (Q/TST) that was similar to CSII, which indicated that the rates were similar between dredged and non-dredged shoals. Relative to CSII. both CSII-BA and Chester Shoals had increases in P/TST and decreases in Q/TST during spring 2018 when CSII-BA was dredged. This suggested a potential change in the community structure and composition, but changes occurred on both shoals and therefore were unrelated to any direct dredging impact. Similarly, total biomass (excluding detritus) among the shoals in spring 2014 also indicated a lack of dredging impact on CSII-BA, and CSII-BA and Chester Shoals remained similar but relatively low compared to CSII. Although CSII-BA total biomass was lower in spring 2018 (second dredging event on CSII-BA) compared to both Chester and CSII, it was not significantly lower and had fully recovered by summer 2018, indicating that any impact from dredging was very short lived. Overall, the ecosystem model analysis suggested that the ecological indicators of the dredged shoal (CSII-BA) were mostly similar to the reference shoal (Chester), and whenever any differences were noted they were recovered with one season following the dredging event. After two dredging events at CSII-BA, the scale and nature of any differences in the dredged ecosystem was comparable to the control shoal, suggesting that this difference or change may also be explained by the dynamic variability in the system.

Ecological indicators did not suggest that there were any notable impacts from dredging at an ecosystem level, and the estimated oscillation of ecological indicators may be due to the inner variability in the system at a seasonal level. This was similar to a seasonal effect that was observed in plankton, invertebrate, and fish assemblages. Since high variability of ecological indicators were also exhibited at the reference shoal (Chester), indicators may suggest that dredging impact is not outside the bounds of natural variation in these systems.

**CONCLUSIONS:** A Beyond-BACI sampling design provided a robust framework for assessing the impact of dredging on composition and abundance of plankton, invertebrates, and fish assemblages of the sand shoals, relative to their natural variability. Overall, sand shoals off the east coast of Cape Canaveral, Florida, are shallow, dynamic ridge-swale ecosystems. These environments are physically dominated by

oceanographic processes and subject to frequent storm events. Season was the primary driver of changes in abundance and biomass over time in all assemblages, with habitat (swale versus ridge), shoal, and year less so. With few exceptions, the impacts from dredging CSII-BA relative to reference shoals (CSII, Chester, and Bull Shoals) was not significant on the abundance and biomass of the various plankton, benthic and demersal invertebrates, and demersal fish assemblages. The few changes in abundance or density of invertebrate groups detected in the dredged shoal relative to the reference shoals were shortlived (i.e., returned to pre-dredged levels within a season). The dynamic nature of the sand shoals and surrounding area was further evidenced by telemetry of acoustically tagged fishes that showed ephemeral use and low residency within specific shoal areas. The importance of a seasonal driving factor was also observed in the isotopic niches of representative fish and invertebrate species over time among the shoals, as indicated by the combined basal carbon resources assimilated and the trophic levels. At an ecosystem level, Ecopath models also showed the importance of a seasonal component in driving the trophic structure and productivity of the shoal ecosystems over time. In summary, sand shoals off the east coast of Cape Canaveral, Florida, are dynamic ridge-swale ecosystems dominated by seasonal variation. Their position in relatively shallow, exposed waters is a contributing factor to their natural variability in both their physical and biological attributes. This natural variability in the biological assemblages among the shoals was as great or greater than any detectable changes due to dredging.

### **STUDY PRODUCT(S):**

### 1. BOEM study reports (3 volumes):

Murie D, Bucatari J, Hansen D. (Editors). 2023. Ecological Function and Recovery of Biological Communities within Dredged Ridge-Swale Habitats in the South-Atlantic Bight: Volume 1. Final Report on the Physical Environments of the Sand Shoals. Sterling (VA): U.S. Department of the Interior, Bureau of Ocean Energy Management. 166 p. Report No.: OCS Study BOEM 2024-016. Contract No.: M13AC00012.

Murie D, Bucatari J, Hansen D. (Editors). 2023. Ecological Function and Recovery of Biological Communities within Dredged Ridge-Swale Habitats in the South-Atlantic Bight: Volume 2. Final Report on the Primary Producers and Invertebrates of the Sand Shoals. Sterling (VA): U.S. Department of the Interior, Bureau of Ocean Energy Management. 276 p. Report No.: OCS Study BOEM 2024-016. Contract No.: M13AC00012.

Murie D, Bucatari J, Hansen D. (Editors). 2023. Ecological Function and Recovery of Biological Communities within Dredged Ridge-Swale Habitats in the South-Atlantic Bight: Volume 3. Final Report on the Fishes and Ecosystems of the Sand Shoals. Sterling (VA): U.S. Department of the Interior, Bureau of Ocean Energy Management. 201 p. Report No.: OCS Study BOEM 2024-016. Contract No.: M13AC00012.

# 2. See complete study products list in Volume 3, Chapter 17 (Appendix G) of the study reports.

MAP OF STUDY AREA: Figure 1-1 of report OCS Study BOEM 2024-016 (volume 1).