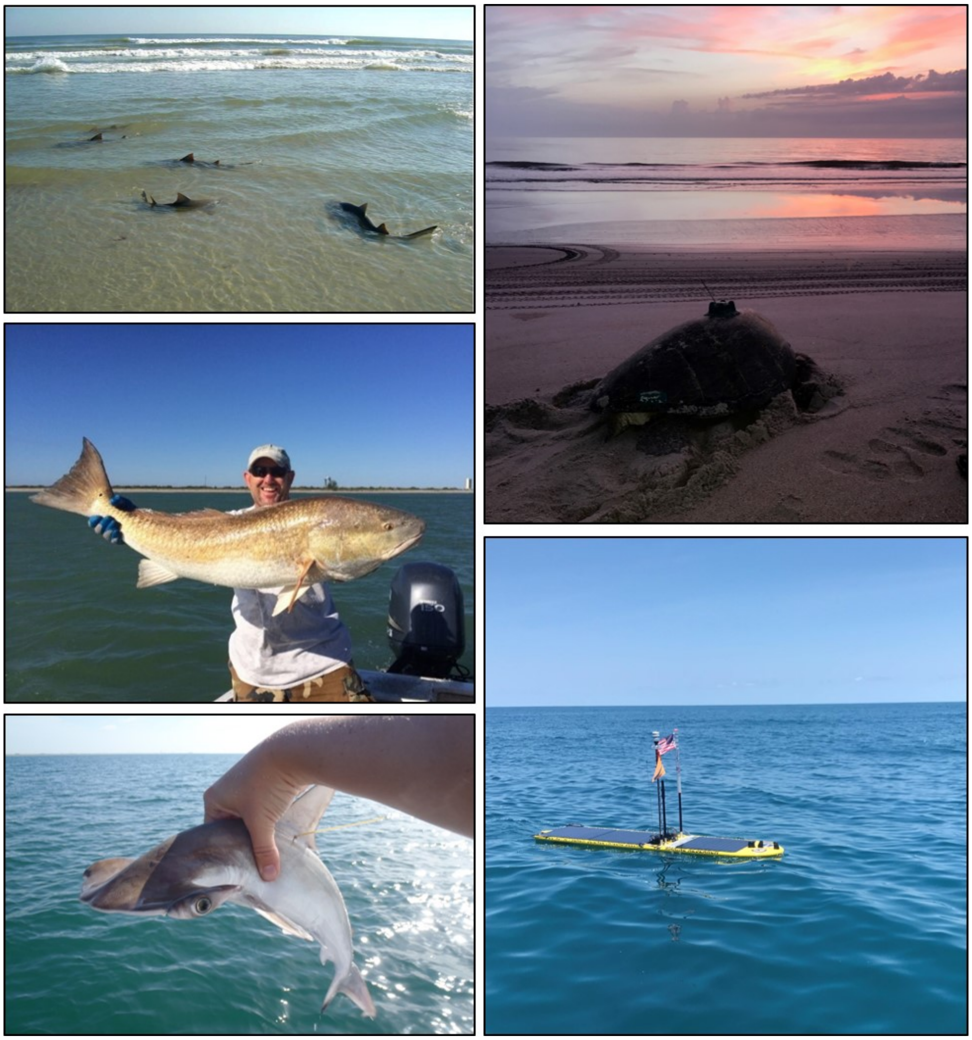
OCS Study
BOEM 2019-043

Behavior, Seasonality, and Habitat Preferences of Mobile Fishes and Sea Turtles Within a Large Sand Shoal Complex: Insights From Traditional Sampling and Emerging Technologies



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DISCLAIMER

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ABOUT THE COVER

Upper left: Juvenile lemon sharks aggregating in the surf zone at Cape Canaveral; *Center left:* Adult red drum caught on a longline set in the Canaveral Bight; *Lower left:* Cape Canaveral is a known nursery for scalloped hammerhead sharks; *Upper right:* An adult female green turtle released at Cape Canaveral after being tagged with satellite and acoustic transmitters; *Lower right:* A Wave Glider unmanned surface vehicle on transect offshore Cape Canaveral. Cover graphic by Eric Reyier.

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Executive Summary

Sand shoals of the Outer Continental Shelf (OCS) are an important source of beach-quality sand for coastal nourishment and restoration projects at many locations along the eastern United States (US) and Gulf of Mexico. Demand for this resource is predicted to grow in response to continued shoreline development, storm erosion, and rising sea levels, and ensuring continued access to sand is essential for safeguarding vulnerable coastal infrastructure. Sand shoals are also an important habitat for a myriad of marine species, many of which are of high economic value or conservation priority. Although benthic fish and invertebrate communities associated with sand shoals have been well documented at many sites, the importance of shoals to larger pelagic fish and sea turtles has been harder to define due to their generally high mobility in the open ocean.

The central goals of this study are to better quantify the habitat preferences and seasonality of federally managed fish and sea turtles associated with a large sand shoal complex at Cape Canaveral, in east-central Florida, and to compare animal use of an active sand borrow area relative to a nearby undisturbed control site with otherwise similar physical characteristics. Specifically, this study paired traditional fisheries-independent longline sampling and tag-recapture techniques with passive acoustic telemetry to characterize fish abundance and behavior over multiple annual cycles. Also presented are initial findings regarding local habitat use and coastal migrations of female green (*Chelonia mydas*) and loggerhead (*Caretta caretta*) turtles derived from satellite transmitter data, as well as early results from Wave Glider unmanned surface vehicle (USV) surveys, conducted to determine the locations and associated environmental conditions of acoustically tagged animals that dispersed outside the core study area.

Longline sampling was performed monthly on the Canaveral Shoals for five years (2012–2017), yielding 2,895 fish in 36 species. Coastal sharks were numerically dominant, comprising 90% of the total catch, with Atlantic sharpnose (*Rhizoprionodon terraenovae*), blacknose (*Carcharhinus acronotus*), blacktip (*C. limbatus*), and finetooth sharks (C. *isodon*) the most common species. Red drum (*Sciaenops ocellatus*) was the only common teleost fish (7% of catch), and species managed within the snapper-grouper management complex were virtually absent from samples, suggesting that hard bottom substrates are rare in the study area. Season was a paramount factor influencing both species catch rates and overall community composition, but water clarity also played an important role with several common species (e.g., blacknose, blacktip, and finetooth sharks, red drum) all preferring turbid conditions that commonly occur in the vicinity of shoals and near the beach. Nonetheless, catch rates were often low on the shallowest shoal ridges and there was no evidence that shallow water or seafloor slope themselves positively influenced catches of the most common species. Relationships between water depth and fish size were also generally modest.

Acoustic telemetry efforts involved tagging of 747 fishes from 14 target species including blacknose, finetooth, sharpnose, lemon (*Negaprion brevirostris*), and scalloped hammerhead (*Sphyrna* spp.) sharks, roughtail stingray (*Dasyatis centroura*), red drum, bluefish (*Pomatomus saltatrix*), Spanish mackerel (*Scomberomorus maculatus*), king mackerel (*S. cavalla*), cobia (*Rachycentron canadum*), red snapper (*Lutjanus campechanus*), spot (*Leiostomus xanthurus*), and Atlantic croaker (*Micropogonias undulatus*). Fish were followed though a local acoustic receiver array with tracking stations deployed on shoals and in adjacent deeper water, as well as along the shoreline and offshore reef tract. The array also included multiple stations positioned directly around an active dredge site and nearby control site, allowing comparisons of seasonality and site fidelity of tagged fish between disturbed and undisturbed shoal habitats. Additionally, any animals that migrated away from Cape Canaveral were subject to detection by the Florida Atlantic Coast Telemetry (FACT) Network, a multi-agency partnership, which collectively maintains several hundred additional acoustic receivers from southern Florida and the Bahamas to the Carolinas.

Over four years of tracking (2013–2018), 923 fish from 39 species (16 teleost fish, 15 sharks, and eight rays) were detected, including target species as well as 28 species released by 32 other research groups at various locations along the US East Coast. Most species were widely distributed in the study area but overall community structure and diversity was influenced by season, water depth, and distance from shore. Differences in use between the dredge and control sites were modest, with comparable numbers of individuals and species detected and with tagged fish spending similar amounts of time at each site. High mobility was consistently observed across species, with most remaining in the same location for less than one hour on average, and with regular exchange of sharks, drum, and cobia observed with the offshore reef tract. Coastal migrations of many species were revealed in fine detail with a general northward migration in spring and with many animals returning to east-central Florida in fall for several consecutive years. The study also documented the seasonal presence of Atlantic sturgeon (*Acipenser oxyrinchus*) and smalltooth sawfish (*Pristis pectinata*), Endangered Species Act (ESA)-listed species that have been considered rare in east-central Florida in recent decades, although none were detected near active dredging operations.

Fourteen loggerhead and 11 green sea turtles were tagged with satellite and acoustic transmitters while nesting on beaches adjacent to the Canaveral Shoals to assess inter-nesting habitat use and local reproductive behavior. Time spent in the Canaveral region averaged 13- and 39 days post-tagging, for loggerhead and green turtles, respectively, and several re-nesting events were observed for both species. Both loggerhead and green turtles strayed well beyond the shoals during inter-nesting periods but spent a disproportionate amount of time close to shore when within the study area. Loggerheads showed a somewhat greater affinity for shallow shoal margins although time spent associated with offshore shoals and within the dredge and control sites was very limited. After nesting concluded, loggerheads dispersed widely towards the US mid-Atlantic, Bahamas, Florida Keys, and eastern Gulf of Mexico, while greens moved almost exclusively towards south Florida and the Florida Keys.

Wave Glider surveys are ongoing but have surveyed an expanded operational zone of 812 km^2 on four separate deployments (November 2017, and March, May, and September 2018) including waters to the north, east, and south of the core Canaveral Shoals study area. On average, surveys lasted 24 days with the Wave Glider traveling 1,258 km at a mean speed of 2.2 km/hr. To date, the platform has recorded 80 unique acoustically tagged fish and sea turtles in 14 species as well as associated environmental conditions (e.g., temperature, dissolved oxygen, chlorophyll, turbidity). These early results validate the use of unmanned platforms to supplement and extend passive acoustic telemetry studies on the OCS.

As a whole, there was minimal evidence suggesting that sand shoals at Cape Canaveral served a proportionally more important role for large fish or sea turtles than other adjacent habitats within the study area, although shallow shoal ridges may alter conditions in surrounding waters (e.g., elevating turbidity, promoting accumulation of fine-grained sediment) in ways that are favorable for some species. Although all OCS dredging has potential to negatively impact benthic habitat quality and various metrics of ecosystem function, the relative impact to managed marine species in sand shoal systems is likely to be muted by the naturally low site fidelity, high mobility, and seasonal migrations that were common traits among large-bodied fish and sea turtles targeted in this study.

Contents

List of Figures

List of Tables

List of Abbreviations and Acronyms

°C	degrees Celsius
ACCSP	Atlantic Coastal Cooperative Statistics Program
ACT	Atlantic Cooperative Telemetry
AIC	Akaike Information Criterion
ANOSIM	analysis of similarities
BBFS	Bimini Biological Field Station
BOEM	Bureau of Ocean Energy Management
BTT	Bonefish & Tarpon Trust
CCAFS	Cape Canaveral Air Force Station
CCU	Coastal Carolina University
CDOM	colored dissolved organic matter
CEI	Cape Eleuthera Institute
cm	centimeter(s)
CPUE	catch per unit effort
CU	Clemson University
cy	cubic yard(s)
dB re 1 µPa	decibels referenced to 1 microPascal
DESU	Delaware State University
DO	dissolved oxygen
DOI	United States Department of the Interior
DPS	Distinct Population Segment
DW	disc width
EFH	Essential Fish Habitat
ESA	Endangered Species Act
ESP	Environmental Studies Program
ESPIS	Environmental Studies Program Information System
FACT	Florida Atlantic Coast Telemetry
FAU	Florida Atlantic University
FL	fork length
FMP	fishery management plan
FSU	Florida State University
ft.	foot/feet
FWC	Florida Fish & Wildlife Conservation Commission
GADNR	Georgia Department of Natural Resources
GAM	generalized additive models
GMFMC	Gulf of Mexico Fishery Management Council
GMRT	Global Multi-Resolution Topography
GPS	Global Positioning System
HAPC	Habitat Areas of Particular Concern
hr	hour(s)
IMU	inertial measurement unit
IRL	Indian River Lagoon
iTAG	Integrated Tracking of Aquatic Animals in the Gulf of Mexico

JU	Jacksonville University
KDE	kernel density estimation
km	kilometer(s)
km^2	square kilometer(s)
km/hr	kilometer(s) per hour
KSC	Kennedy Space Center
lb.	pound(s)
m	meter(s)
m/s	meter(s) per second
MADMF	Massachusetts Division of Marine Fisheries
MARMAP	Marine Resources Monitoring, Assessment and Prediction
MAFMC	Mid-Atlantic Fisheries Management Council
MCMC	Markov Chain Monte Carlo
MDS	multidimensional scaling
min	minute(s)
MMP	Marine Minerals Program
MMS	Marine Minerals Service
MSFCMA	Magnuson-Stevens Fishery Conservation and Management Act
MU	Monmouth University
NASA	National Aeronautics and Space Administration
NCDMF	North Carolina Division of Marine Fisheries
NDBC	National Data Buoy Center
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NTU	Nephelometric Turbidity Unit(s)
NUWC	Naval Undersea Warfare Center
OCS	Outer Continental Shelf
ODMDS	Offshore Dredge Material Disposal Site
PCL	precaudal length
PIT	Passive Integrated Transponder
ppt	parts per thousand
ROM	rate of movement
RSMAS	Rosenstiel School of Marine and Atmospheric Science
RFU	Relative Fluorescence Unit
s, sec	second(s)
SAB	South Atlantic Bight
SAFMC	South Atlantic Fishery Management Council
SBU	Stony Brook University
SCDNR	South Carolina Department of Natural Resources
SEAMAP	Southeast Area Monitoring and Assessment Program
SERC	Smithsonian Environmental Research Center
SIMPER	similarity of percent contribution
SL	standard length
SSM	state space model
TL	total length

UD	utilization distribution
UF	University of Florida
UNC	University of North Carolina Chapel Hill
US	United States
USFWS	U.S. Fish and Wildlife Service
USN	United States Navy
USV	unmanned surface vehicle
VIMS	Virginia Institute of Marine Science
VMT	VEMCO Mobile Transceiver
YOY	young-of-the-year
ziP	zero-inflated Poisson

1 Introduction

1.1 Background of the Study

In the aftermath of Hurricane Sandy (October 2012), post-storm damage assessments along the United States (US) East Coast identified several critically eroded shorelines in east Florida and other states that would require access to Outer Continental Shelf (OCS) sand resources for beach nourishment and other coastal restoration projects. The Marine Minerals Program (MMP) within the US Bureau of Ocean Energy Management (BOEM) is the federal agency tasked with negotiating rights to OCS sand for shore protection and is mandated to ensure these deposits are extracted with minimal impact to marine species and their habitat. In many instances, BOEM considers environmental monitoring as a necessary step to ensure that environmental risks from sand borrow activities are well understood and, when needed, mitigated through stewardship actions, without causing undue delay to dredging and construction projects.

Many previously mapped sand deposits along the US East Coast and Gulf of Mexico consist of discrete shoal features. To develop appropriate minimization and mitigation measures for sand borrow activities at these sites, more information is needed regarding the different ecosystem services that shoals provide over seasonal and annual timescales and how associated marine communities respond to natural and human-induced disturbances. Arguably one of the great data gaps relates to the value of shoals to large-bodied fishes and sea turtles that have historically been underrepresented in faunal surveys of borrow areas. To support management of future sand borrow activities, this study focused on better resolving: (1) the composition and spatio-temporal trends in shoal fish communities, (2) habitat preferences of federally managed and Endangered Species Act (ESA)-listed fish and sea turtles when associated with sand shoals, and (3) behavior of ecologically important fishes at locations directly impacted by dredging operations.

Obtaining this information allows BOEM to meet its environmental stewardship mandates and to streamline environmental reviews and consultations. Specifically, addressing these data gaps will allow BOEM to quickly identify (and avoid) the most valuable shoal habitats, simplify Essential Fish Habitat (EFH) and ESA consultations, and establish appropriate site monitoring protocols. This information may ultimately shorten the timeline of future shoreline restoration projects, which often require urgency to safeguard vulnerable public infrastructure and private property. Additionally, these data will also advance the basic life history understanding of many mobile coastal species of economic value or conservation priority to the region.

Cape Canaveral, east-central Florida, was selected by BOEM as a priority site for studies designed to better understand the habitat associations and behavior of shoal-associated fish and sea turtles. The Canaveral region possesses the largest sand shoal complex on the Florida east coast and includes one active sand borrow area on the OCS (> 3 nautical miles from shore) that has been repeatedly used for nearby shoreline nourishment projects. The region also possesses a robust complement of oceanographic and biological monitoring infrastructure, which provides context to study results. Most importantly, Cape Canaveral is recognized for its high biodiversity and possesses a large number of federally managed fish and turtles, many of which are widely distributed along the US East Coast and Gulf of Mexico, allowing findings to be more easily applied to analogous shoal sites in other regions.

1.2 Ecological Function of Sand Shoal Habitats

Shoals are underwater sand bars or ridges that are of shallower depths than adjacent areas, with shoal complexes (like those off Cape Canaveral) comprised of two or more interconnected shoals that often exhibit complex bathymetry (Rutecki et al. 2014). Although much is now known regarding the effects of dredging on benthic invertebrate and (to a lesser extent) benthic fish communities, important data gaps exist with respect to how larger mobile fish and sea turtles utilize shoals and how dredging may affect their abundance and behavior.

By definition, sand shoals differ from surrounding habitats in terms of depth but also typically offer greater variability in sediment types and turbidity and thus may provide unique foraging, predator avoidance, and reproductive opportunities for many marine organisms (Diaz et al. 2003, Vasslides and Able 2008). Shoals are also considered relatively dynamic environments, subjected to higher rates of natural change in their physical structure due to increased disturbance from wave action, currents, and storms. These conditions may collectively result in biological communities that qualitatively differ from those in adjacent waters (Rutecki et al. 2014), although direct evidence for increased diversity or richness for shoal communities is limited (Vasslides and Able 2008, Slacum et al. 2010, Michel et al. 2013). Moreover, like all shelf habitats, biological communities of shoals may also vary dramatically across seasons and be strongly influenced by their position relative to other habitat types (Zarillo et al. 2009). Close proximity to reefs, mangroves, or tidal inlets, for example, may act to elevate local richness, and in some cases, shoals may serve as transitional habitats for marine species with complex inshore-offshore migrations (Gilmore 2008).

In the US south Atlantic, sand shoals have been recognized as habitat for at least 215 species of fish (Rutecki et al. 2014). Smaller-bodied schooling planktivores such as sardines and herring may use shoals ephemerally for feeding, refuge, and spawning, whereas benthic flounder, skates, lizardfish, and drum may be true year-round residents (Brooks et al. 2004a, Michel et al. 2013). Although information detailing the behavior and side fidelity of fishes around shoals is rare, surveys to document the demersal fish community with trawls, camera sleds, and other gear have been conducted at several shoal sites in northeast and east-central Florida (Gilmore 2008, Hammer et al. 2004, Zarillo et al. 2009). At this site-specific scale, small-bodied demersal and pelagic species dominated catches, and fishes of direct economic value were relatively uncommon and primarily represented as juveniles, though the sampling gear selected is known to be ineffective at documenting the presence of larger mobile species. Despite some trends, patterns in biomass and diversity across depths and seasons were often obscured by high variability in catches or limited replication.

The use of shoals by sea turtles is even less understood. Four marine turtle species are widely distributed along the continental shelf off of the southeastern US, including loggerhead (*Caretta caretta)*, green (*Chelonia mydas*), Kemp’s ridley (*Lepidochelys kempii*), and leatherback (*Dermochelys coriacea*), with juvenile and adult life stages present at different times of the year (Carr et al. 1980, Butler et al. 1987, Henwood 1987, Dickerson et al. 1995). Loggerhead and green turtles are by far the two most abundant sea turtles in this region. Their range and habitat requirements broadly overlap, but their divergent diets suggest they may use sand shoals in different ways. Juvenile and adult loggerhead turtles feed primarily on benthic mollusks, crustaceans, and other invertebrates (Youngkin 2001) that are often abundant on sand shoals. In contrast, juvenile and adult green turtles predominantly forage on shallow seagrass and reef-attached macroalgae (Bjorndal 1980), which are rarely associated with offshore shoals. Green turtles use of shoals may therefore be ephemeral, with their presence primarily representing periods of transit between feeding grounds and nesting beaches. Leatherback turtles nest in small numbers on beaches in southeast Florida but otherwise prefer deep-water pelagic environs away from shoals where they feed predominately on gelatinous jellyfish and salps (Dodge et al. 2011). Like loggerheads, the Kemp’s ridley turtle feeds on invertebrate prey (Seney and Musick 2007) and may rely to some extent on shoals as foraging areas but is much rarer throughout the region.

1.3 Impacts of Dredging

Although sand borrowing for beach nourishment is conducted in a variety of ways, the most common approach requires the use of large ship-borne dredges. The dredge removes sand from offshore deposits and transfers the material shoreward where it is manipulated and graded to meet predefined engineered specifications. Common types of dredges include cutterhead suction, clamshell, and suction hopper dredges, with the latter generally being the most feasible for nourishment projects that exploit OCS sand deposits relatively far from shore (MMS 2004). Suction hopper dredges contain a draghead on the end of a suction pipe through which bottom sediment is removed from the seabed as a slurry and stored in the hopper on the vessel (**Figure 1**). These dredges then transport collected material to an approved dumping site, where it is offloaded through doors in the hull or via a pipeline on the seafloor connecting to the placement site (i.e., the beach). Hopper vessels travel at up to 5 km per hour while dredging and typically dredge depths of 3–37 m.

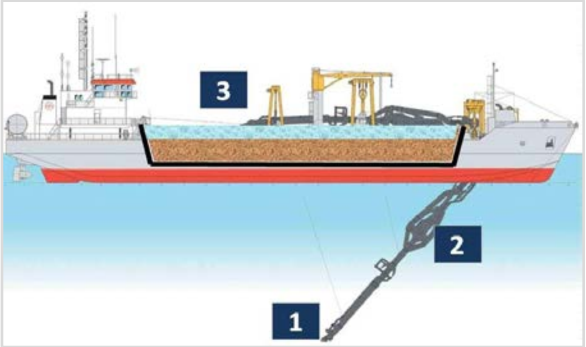

Figure 1. Diagram of a suction hopper dredge
Important components include the draghead (1), suction pipe (2), and hopper (3). Photo credit: BOEM.

Many environmental impacts from sand dredging have been well defined and include removal of sediment and its associated benthic invertebrate fauna, entrainment (physical uptake) of larger organisms, elevated turbidity, physical damage and siltation of nearby hardbottom habitats, and increased noise (Michel et al. 2013). The consequences of dredging to invertebrate communities is perhaps the best studied impact and can be severe, especially for immobile epifaunal (on surface) and infaunal (in substrate) groups unable to avoid the dredge itself or relocate to adjacent undisturbed substrates (see Brooks et al. [2004b] for an in-depth review). Suction hopper dredging can result in the near complete removal of resident benthic invertebrates, requiring that the communities reestablish over time with recruits drawn from surrounding areas (Michel et al. 2013). Recovery of invertebrate biomass often occurs rather quickly, while recovery of community composition and diversity can take several months or longer to return to pre-disturbance levels. Cumulative impacts from repeated dredging of the same sites generally slows this recovery and, in some instances, may result in permanent alterations in habitat quality and species assemblages. Dredging impacts are also recognized to be regionally variable with sites in warmer climates (including the southeastern US) expected to recover biomass and diversity more rapidly than in other areas (Michel et al. 2013).

There are also documented impacts to fish and sea turtles from dredging (Reine et al. 1998, Dickerson et al. 2004). Possibly of greatest concern is loss of the invertebrate food base, which reduces the ability of a borrow area to sustain its original carrying capacity of larger predators. Additionally, both fish and turtles are subject to entrainment in the dredge mechanism itself. Fish are generally entrained at relatively low levels with rates dependent on dredging method, habitat type, and location. Studies suggest that most entrained fish are primarily larvae and juveniles, though entrainment rates from OCS sand dredging activities are largely unstudied (Reine et al. 1998). Sea turtle entrainment has historically been a regular source of mortality in dredging projects throughout the southeastern US, although more often during navigation channel maintenance as compared to sand borrow activities. Loggerhead turtles are especially prone to entrainment due to their abundance near shore, benthic foraging habits, and use of dredged harbors and channels for thermal relief during cold-water periods (Henwood 1987, Dickerson et al. 1995). The Canaveral Harbor Navigation Channel is a known loggerhead turtle aggregation site and has experienced historically high mortality rates (Dickerson et al. 1995), although improved safety measures (including pre-dredge relocation trawling, observer programs, and turtle deflectors on dredge dragheads) have reduced entrainment mortality substantially.

For both large fish and sea turtles, it is reasonable to assume that foraging and reproduction could also be disrupted from sustained turbidity associated with sand removal, increased sedimentation on adjacent hard bottom, or noise from the dredge operation itself. Although these effects have historically been hard to investigate due to the highly mobile and migratory nature of larger species, others have stated that alteration of habitat likely has the greatest potential to impact foraging or reproduction. For example, removal of sand associated with dredging may alter the benthic forage base or spawning grounds, result in loss of fish eggs and/or larvae, and influence behavior of predators and prey. This has largely been reflected in the response of the National Marine Fisheries Service (NMFS) and other regulatory agencies to proposed dredging (Diaz et al. 2004, Johnson et al. 2008, Gilmore 2008, Michel et al. 2013).

1.4 Study Goals

Continued advances in technology are providing new ways to quantify the behavior and large fishes and sea turtles in the coastal ocean including details of how they utilize natural shoal features and disturbed sand borrow areas. For example, passive acoustic telemetry has been widely embraced as a low-cost and powerful tool for resolving the site fidelity, habitat needs, and migrations of highly mobile marine species without any reliance on visual observations or animal recaptures. This approach is aided by the recent formation of collaborative research networks that have dramatically expanded the geographic scale over which animals are being tracked. Innovations in satellite and inertial measurement unit (IMU) tags can now reveal the site-specific habitat needs and activity patterns of sea turtles. Finally, unmanned surface vehicles (USV) and subsea gliders have evolved to the point where they are often a more cost-effective means to survey physical and biological ocean conditions over large areas and can assist in linking animal distributions with environmental data.

The overarching goal of this study is to pair traditional sampling techniques with these emerging technologies to more fully appreciate the patterns of fish and sea turtle habitat use and residency when associated with a large sand shoal complex at Cape Canaveral, Florida, and to assess animal behavior when in the vicinity of an active sand borrow site. Specifically, year-round bottom longline and tag-recapture efforts (an extension of a survey initiated by National Aeronautics and Space Administration's [NASA's] Kennedy Space Center Ecological Program in 2012) was expanded to examine the abundance, seasonality, and size and sex distributions of federally managed fishes within and adjacent to the Canaveral Shoals. These efforts were complemented by 4 years of passive acoustic telemetry targeting multiple fish species, including blacknose (*Carcharhinus acronotus*), finetooth (*C. isodon*), Atlantic sharpnose (*Rhizoprionodon terraenovae*), lemon (*Negaprion brevirostris*), and scalloped hammerhead (*Sphyrna* spp.) sharks; roughtail stingray (*Dasyatis centroura*); red drum (*Sciaenops ocellatus*); bluefish (*Pomatomus saltatrix*); Spanish mackerel (*Scomberomorus maculatus*); king mackerel (*S. cavalla*); cobia (*Rachycentron canadum*); red snapper (*Lutjanus campechanus*); spot (*Leiostomus xanthurus*); and Atlantic croaker (*Micropogonias undulatus*). These taxa were selected for greater scrutiny due to their high economic value in the US south Atlantic and/or important ecological roles they fill in the nearshore benthic ecosystem.

This report also provides an initial summary of two ongoing study dimensions at Cape Canaveral. First, a total of 25 adult female loggerhead and green turtles have been tagged to date with both satellite and acoustic transmitters to assess sea turtle inter-nesting habitat use and behavior (e.g., resting, foraging) when associated with the Canaveral Shoals. Additionally, a Liquid Robotics, Inc., Wave Glider SV3 USV has been deployed on four quarterly surveys off Cape Canaveral. The vehicle was provisioned with sensors to relocate acoustically tagged animals in areas not monitored by fixed station acoustic receivers and to sample environmental conditions (e.g., temperature, dissolved oxygen, chlorophyll, turbidity) that may help explain animal habitat preferences. A final assessment of sea turtle tracking and Wave Glider operations is scheduled for completion in spring 2020. Also, BOEM is funding separate and concurrent studies by other research groups that provide detailed ocean current dynamics, sediment mapping, plankton surveys, trawl-based surveys of benthic fish and invertebrate communities, stable isotope analyses, and ecosystem modeling.

1.5 Habitat, Fisheries, and Sea Turtles Associated with the Canaveral Shoals

1.5.1 Study Area Description

The selection of Cape Canaveral as the study area is due largely to the presence of the most expansive sand shoals on the Florida east coast that serve as a primary source of beach-quality sand for shoreline nourishment projects throughout the region. The most prominent geomorphic features along the Canaveral coastline include the Southeast Shoal and Chester Shoal, two cape-associated shoals with minimum depths of 3 and 4 meters (m), respectively (**Figure 2)**. Additional smaller shoals, including the Bull and Ohio-Hetzel Shoals, are located farther offshore. The Canaveral Shoals complex has one active borrow area (CSII) that has been utilized as a sand source for eight shoreline nourishment projects since 2000, most recently in 2013 (2.4 million cubic yards [cy]) and 2017–2018 (1.7 million cy). CSII lies in federal waters of the OCS, 8 miles east of Port Canaveral at depths of 3 to 13 m, and currently contains approximately 20 million cy of beach compatible sand (BOEM 2017). A second site in Florida state waters (CSI) has been identified but not yet utilized. The Canaveral Offshore Dredge Material Disposal Site (ODMDS) lies due south of the Canaveral Shoals in 12–15 m of water. This site, jointly managed by the Environmental Protection Agency and US Army Corps of Engineers, serves as a repository for spoil generated during maintenance dredging of the Canaveral Harbor. The ODMDS was not a focal area of this study.

The greater Cape Canaveral region marks the southern extent of the South Atlantic Bight (SAB) and spans a climatic transition zone between warm-temperate and subtropical biogeographic realms (Briggs 1974, Gilmore 1995), a boundary largely defined by its transitional temperature regime. Winter water temperatures remain above 15 degrees Celsius (°C) most years, although periodic cold fronts can induce brief but rapid declines in ocean temperature. Water temperature and ocean currents along the inner continental shelf at Canaveral are not strongly coupled with the northward flowing Florida Current (the precursor to the Gulf Stream whose western edge lies 30–40 km offshore), although warm-water eddies and meanders do regularly encroach much closer. Upwelling of cold deep water from beneath the Florida Current can also dramatically lower water temperature during summer (Smith 1983) when temperatures would otherwise be near their seasonal highs. Severe upwellings occasionally result in mass temperature-induced mortality of tropical fishes (E. Reyier, pers. obs.). Currents alternate between a predominantly north or south flow. Mean velocity averaged through the water column is only 7 centimeters per second (cm/sec) and rarely exceeds 25 cm/sec (McArthur and Parsons 2005a). Mean tidal range is only 1.03 m, and no major rivers or tidal inlets are located in the region so salinity remains roughly 35–36 parts per thousand (ppt) year-round.

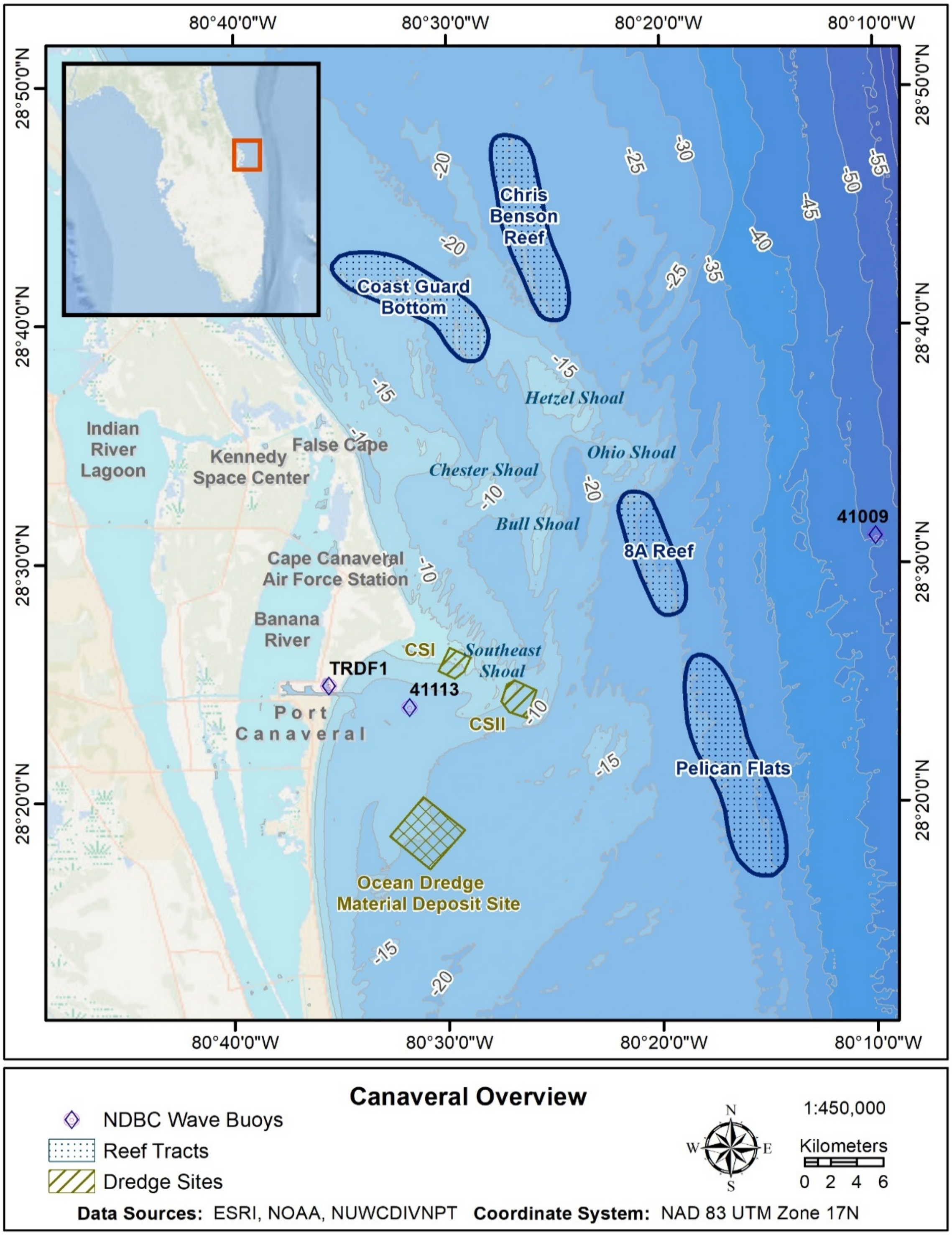

Figure 2. Overview Map of Cape Canaveral

Overview of the Canaveral Shoals region, including dredge and spoil deposit sites, 12-fathom reef tract, and National Data Buoy Center (NDBC) wave buoys.

Ocean waves at Cape Canaveral are primarily out of the east and northeast with a median significant height of 0.75 m and median period of 8.5 seconds (McArthur and Parsons 2005a). The largest waves are generated by tropical systems, and during the study, hurricanes directly impacted the region on two occasions. Hurricane Matthew passed 50 km east of the Canaveral Shoals on 6 October 2016 as a Category 3–4 storm, resulting in peak wave heights of 4.1 m and 9.1 m at the National Oceanic and Atmospheric Administration (NOAA) National Data Buoy Center (NDBC) 3-mile buoy (No. 41113) and 20-mile buoy (No. 41009), respectively (**Figure 2**). Hurricane Irma traveled up the Florida Peninsula on 10 Sept 2017 as a Category 1–2 storm, resulting in wave heights of 5.2 m and 8.1 m on the same inshore and offshore buoys. Even moderate sea states at any time of year can cause extensive and hazardous breaking waves along the crest of the Southeast Shoal (**Figure 3**), with higher sea states inducing similar wave conditions on the deeper shoals.

Bottom sediments along the east Florida shelf have been surveyed numerous times although spatial resolution within the study area is uneven except around the Canaveral Shoals borrow area and adjacent ODMDS. Sediments in this region are typified by medium to coarse quartzose-mollusk sand (Field and Duane 1974), with shallow areas along the beach and at the crest of shoals being generally coarser due to high amounts of shell fragments (Meisburger and Duane 1971). Sediments in deeper areas are typically smaller-grained and well sorted, with the finest sediments actively retained in Canaveral Bight in the shadow of the Southeast Shoal (Grosz et al. 1989, Hoenstine et al. 1995, McArthur and Parsons 2005b).

Figure 3. The Southeast Shoal intersecting Cape Canaveral
Breaking waves and turbid water are common conditions on the Southeast Shoal except under very calm seas. Photo credit: Eric Reyier.

Natural hard bottom reefs are widely distributed offshore Cape Canaveral and generally consist of low to moderate relief limestone outcroppings and pavements of relic Pleistocene dunes. They reef tracts are oriented north-south in lines commonly referred to as the 12-fathom, 21-fathom, and 27-fathom ridges. Reef substrates are colonized by a variety of corals and other sessile invertebrates, harbor very high fish diversity, and sustain populations of reef fish of great economic importance to east-central Florida (Sedberry and Van Dolah 1984, Coleman et al. 2000, Rowe and Sedberry 2006). Along the inshore ridge immediately east and north of the Canaveral Shoals, some of the most popular tracts for anglers and divers include Pelican Flats, 8A Reef, Chris Benson Reef, and Coast Guard Bottom (**Figure 2**). Dozens of shipwrecks and planned artificial reefs are also scattered throughout the area. While Rowe and Sedberry (2006) estimate that hard bottom composes 10–23% of the shelf throughout the SAB, reef habitat and its associated fauna remains poorly surveyed off Canaveral (Perkins et al. 1997), and there is little evidence of extensive reef substrates within the Canaveral Shoals study area. Sabellarid “worm rock,” a protected habitat due to its status as EFH, is not documented within the Canaveral Shoals, although small patches of consolidated humate sands (i.e., peat outcrops) are present in the intertidal and shallow subtidal zone near False Cape (Adams and Jaeger 2013).

The Canaveral shoreline itself is among the least altered of the Florida Atlantic Coast with no residential or commercial development. Human habitat disturbance is limited to NASA and US Air Force space launch infrastructure offset from the beach several hundred meters. The Indian River Lagoon (IRL) system lies directly inland of the study area although the nearest tidal inlets are Ponce de Leon Inlet (60 km north) and Sebastian Inlet (62 km south), as well as an intermittently open lock system in nearby Port Canaveral.

1.5.2 Fish Fauna at Cape Canaveral

The greater Cape Canaveral region has long been recognized as an area where tropical and warm-temperate fish faunas intermingle, resulting in a fish diversity among the highest in the western North Atlantic Ocean (Briggs 1974, Gilmore 1995). While many of the numerically dominant shelf species here are widely distributed throughout the SAB, fish communities as a whole vary markedly in response to latitudinal and longitudinal gradients in water temperature and other environmental factors (Sedberry and Van Dolah 1984, Wenner and Sedberry 1989, Rowe and Sedberry 2006). Much of this heterogeneity is due to Canaveral's position in relation to the Florida Current. Specifically, while this warm-water current moderates temperature in deep water off Canaveral and provides a steady source of tropical fish larvae from south Florida and the Caribbean, the shallow inner shelf is also influenced by ambient air temperature, allowing for the year-round or seasonal persistence of species with more temperate affinities. Several distinct habitat types also are interspersed locally throughout the continental shelf, each supporting a fish fauna adapted to specific conditions. In addition to sand shoals, these habitats include the high energy surf zone, unconsolidated sand-mud plains, nearshore reefs and wrecks, and deep-water corals (Durako et al. 1988, Gilmore 1995).

The most rigorous ichthyofaunal surveys from the Canaveral region have historically focused on estuarine waters of the IRL estuary (e.g., Mulligan and Snelson 1983, Tremain and Adams 1995, Paperno et al. 2001). Fortunately, a growing recognition of the economic value of OCS fisheries, and the more stringent management that ensued, has encouraged additional monitoring of shelf fishes in east and northeast Florida. Perhaps the most comprehensive is the Southeast Area Monitoring and Assessment Program (SEAMAP[1]), a standardized fishery-independent trawl survey designed to document the abundance and distribution of shelf fishes and macroinvertebrates over soft bottom habitats from Cape Hatteras to Cape Canaveral. Its most recent multi-year summary identified 195 finfish species, 30 elasmobranchs, and 90 decapod crustaceans, with catches numerically dominated by spot and Atlantic croaker, which together accounted for 36% of all fish and invertebrates collected (ASMFC 2000). Other numerically abundant fishes included Atlantic bumper (*Chloroscombrus chrysurus*), porgies (*Stenotomus* spp.), and striped anchovy (*Anchoa hepsetus*). BOEM itself has commissioned trawl surveys of sand shoals in east Florida, including exploratory inventories (with limited sampling effort) at potential future borrow sites from Canaveral to Jupiter (Hammer et al. 2004) and Daytona to Jacksonville (Zarillo et al. 2009). Both surveys documented a variety of fish groups with catches dominated by anchovies (family Engraulidae), lizardfish (Synodontidae), sea robins (Triglidae), small-bodied drums and croaker (Sciaenidae), jacks (Carangidae), seabass (Serranidae), and various flatfishes (Paralichthyidae), all of which are common over wide areas of the SAB but of little direct fisheries interest. A more thorough BOEM-funded trawl survey is now underway to document benthic fish communities within the Canaveral Shoals and compare densities and community characteristics between disturbed and undisturbed sites.

Surveys targeting reef-associated fishes, particularly those in the snapper-grouper complex, are also adding to knowledge of the regional fish fauna. Most notably, the Marine Resources Monitoring,

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[1] http://www.seamap.org/CoastalSurvey.html

Assessment and Prediction (MARMAP[2]) program has been assessing SAB reef habitats and associated communities since 1973 using traps, longlines, rod-reel, and video, demonstrating the high diversity and biomass of this habitat type (Sedberry and Van Dolah 1984, Coleman et al. 2000, Rowe and Sedberry 2006). Other surveys are underway by the Florida Fish & Wildlife Conservation Commission (FWC) to further refine life history characteristics of the intensively managed red snapper in east and northeast Florida.

Although potentially of great interest to managers, the habitat needs and behavior of many other fishes of regional economic value remain poorly resolved along the east Florida continental shelf. Among the most data-poor species include several small and large coastal sharks, mackerel, bluefish, red drum, and cobia (*Rachycentron canadum*). Their shared life history traits of high mobility, low site fidelity, and seasonal migrations leave them underrepresented in otherwise well-designed groundfish and reef fish surveys. The logistics and expense of open coastal research and limited governmental and university investment in this region are also factors. At Cape Canaveral, much of what we know regarding the distribution of migratory species is derived from fishery-dependent catch and observer data (Trent et al. 1997) or single species studies of coastal sharks (Adams and Paperno 2007, Aubrey and Snelson 2007, Reyier et al. 2008, 2014) that did not systematically address habitat preferences.

1.5.3 Fisheries Associated with the Canaveral Shoals

The Canaveral Shoals is located in a region of considerable economic importance to the recreational and commercial fishing industry. This stems in part from the region’s status as a climatic transition zone as well as its diversity of coastal habitat types, both factors that promote high numbers of fishery species (Gilmore 1995). The shoals are also proximate to Port Canaveral, Brevard County’s largest port and the only major embarkation point for fishermen to Atlantic fishing grounds between Daytona Beach and Sebastian Inlet (140 km). Port Canaveral offers marine services, fuel, fish houses, and other amenities that are utilized by resident and transient commercial fishing fleets, for-hire charter vessels, and recreational anglers. Local geography also helps promote fishing activity to some degree. During periods of prevailing north and northeast winds (common during winter), the Canaveral coastline and shoal complex combine to reduce sea state in the Canaveral Bight, allowing greater access by fishermen to nearshore waters than is possible in more exposed sections of the east Florida coastline. BOEM has previously recognized the potential impact of OCS sand borrow activities to regional fisheries, and Tomlinson et al. (2007) provides a summary of Port Canaveral fishing history and economics, plus fishermen opinions and earlier landing statistics. The most economically valuable fisheries in the Canaveral Shoals study area are described below.

1.5.3.1 Shrimp

Penaeid shrimp represents the largest commercial fishery by both pounds and dollar value in the Cape Canaveral region (Heather Konell, Atlantic Coastal Cooperative Statistics Program, pers. comm) with white shrimp (*Litopenaeus setiferus*) dominating landings most years (**Table 1**). Shrimp trawlers are active much of the year within the study area with heaviest effort occurring late fall through early spring. Trawling activity is highest in the Canaveral Bight and areas farther south, but some trawling occurs throughout the study area including within the CSII borrow area (**Figure 4)**. Due to net size regulations in Florida state waters, the largest trawlers generally operate more than one mile from shore but smaller “day” trawlers often operate very close to the beach.

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[2] http://www.seamap.org/Reef%20fish.html

1.5.3.2 Sharks

Coastal sharks have both commercial and recreational value to the Canaveral region (Trent et al. 1997). Commercial landings vary greatly by year and are not always reported to the species level but include both large coastal taxa (e.g., blacktip shark, sandbar shark [*Carcharhinus plumbeus*], bull shark [*Carcharhinus leucas*], lemon shark, hammerheads [*Sphyrna* spp.]) and small coastal species (e.g., Atlantic sharpnose shark, blacknose shark, finetooth shark, and bonnethead shark [*Sphyrna tiburo*]). Commercial gears include both gill nets and longlines, with some effort directed on the outer shoals more than 5.5 km (3 nautical miles) from shore. Port Canaveral is also the home port to a small number of for-hire charter vessels who specialize in nearshore shark fishing trips, often in the Canaveral Bight just south of the Southeast Shoal.

Table 1. Top 20 fishery species in commercial landings by dollar value and weight for Brevard County, Florida, 2013–2016

Values are summed over all four years and include landings from both state and federal waters. Data was obtained from the Atlantic Coastal Cooperative Statistics Program (ACCSP 2018).

Species	Dollars
Mackerel, King	$4,778,312
Shrimp, Northern White*	$2,927,452
Crab, Blue	$1,705,225
Mackerel, Spanish	$1,224,619
Tilefish	$1,219,015
Crab, Stone	$547,312
Mullet, Striped	$508,316
Grouper, Gag	$388,106
Swordfish	$341,560
Dolphin	$255,482
Cobia	$229,950
Amberjack, Greater	$200,711
Pompano, Florida	$185,649
Lionfishes	$167,950
Menhaden, Atlantic	$167,236
Tripletail	$166,365
Snapper, Red	$148,472
Shark, Blacktip	$133,559
Tuna, Yellowfin	$88,803
Drum, Black	$87,930
Total (All Species)	$16,127,191

Species	Weight (lbs.)
Mackerel, King	2,045,472
Mackerel, Spanish	1,242,674
Shrimp, Northern White*	933,650
Crab, Blue	844,371
Mullet, Striped	702,536
Menhaden, Atlantic	613,193
Tilefish	399,065
Bluefish	298,508
Shark, Blacktip	240,996
Amberjack, Greater	138,823
Tunny, Little	105,804
Dolphin	95,197
Jack, Crevalle	81,465
Swordfish	69,778
Sheepshead	65,022
Drum, Black	64,501
Grouper, Gag	63,233
Shark, Atlantic Sharpnose	56,313
Cobia	52,005
Whiting, King	47,745
Total (All Species)	8,486,799

*Due to ACCSP confidentiality guidelines, shrimp catch data is unavailable for 2013 and 2014 and is thus significantly underrepresented in landings (H. Konell, ACCSP, pers. comm).

1.5.3.3 Mackerel

Spanish mackerel are fished commercially directly on the Canaveral Shoals, primarily by small gill net boats during the species' spring and fall migratory periods. By law, all commercial gill netting occurs more than 5.5 km (3 nautical miles) from shore and is typically concentrated around the shallowest shoal ridges. Some commercial and recreational landings are also taken by hook-and-line angling throughout the area.

King mackerel are among the most valuable commercial and recreational species in the region (**Table 1**), and almost all landings are taken with hook-and-line angling, most commonly via trolling. Effort is concentrated on reef habitat east of the study area, but some fishing occurs within the shoals themselves, especially during summer when fish approach closer to shore.

1.5.3.4 Cobia

Cobia are present year-round off east Florida and are generally caught via hook-and-line angling by bottom fishing and sight fishing. Intensive but short-lived cobia fisheries often develop on the Canaveral Shoals in spring when cobia follow manta rays (*Manta birostris*) during their northward migration. Cobia are also heavily exploited during summer upwelling events when cold water compels mantas and roughtail stingrays (*Dasyatis centroura*) to aggregate on the outer shoals. Cobia associate with rays during this time as well, making them easier for anglers to exploit.

1.5.3.5 Red Drum

Red drum is among the region's most valuable sportfish and is common in the estuary and nearshore waters. Most fish residing on the Canaveral Shoals are adults larger than the legal harvestable size, and thus the fishery is primarily catch and release. Red drum can be found almost year-round but are often specifically targeted in fall and winter when they often form large schools on the shoals and in the Canaveral Bight.

Figure 4. Example fisheries associated with the Canaveral Shoals.
Left: Shrimp trawler working near Chester Shoal, December 2013. In recent years, most shrimpers working off Cape Canaveral are transient vessels that seasonally fish wide areas of the southeastern US coastline. *Right:* Intensive sight fishery for cobia near Hetzel Shoal during a summer cold-water upwelling event, July 2015. During upwellings, cobia often closely associate with the giant manta ray and roughtail stingray. Photo credits: Eric Reyier.

1.5.3.6 Other Economically Valuable Species

Small scale and ephemeral commercial fisheries exist in the Canaveral Shoals for striped mullet (*Mugil cephalus*), Florida pompano (*Trachinotus carolinus*), and kingcroaker (*Menticirrhus* spp.). Tarpon (*Megalops atlanticus*), bluefish, and tripletail (*Lobotes surinamensis*) are seasonally important targets of many recreational fishermen.

1.5.4 Protected Fish Species at Cape Canaveral

Cape Canaveral is included within the geographic range of at least three fish species that receive protection under the 1973 US Endangered Species Act and whose status must be taken into account during dredging and beach nourishment projects, and other federal activities. These species are described below.

1.5.4.1 Smalltooth Sawfish

The smalltooth sawfish (*Pristis pectinata*) was historically widespread from New York through Texas and was once common throughout estuarine (and presumably coastal) waters at Cape Canaveral (Snelson and Williams 1981). The species has suffered dramatic reductions in both its geographic range and population size due to habitat loss and bycatch mortality in fisheries gear (especially gill nets) and was listed as engendered under the ESA in 2003. The largest remaining sawfish populations are found in southwest Florida (Poulakis and Seitz 2004; Norton et al., 2012), although observations have been increasing along the Florida east coast, including incidental captures by biologists and fishermen at Cape Canaveral in 2004, 2013, and 2017 (E. Reyier, unpubl. data). Sawfish have a known affinity for sand shoals (NMFS 2009), so, in the future, the Canaveral Shoals complex may be considered important habitat for the species in the SAB as its population recovers.

1.5.4.2 Giant Manta Ray

Manta rays are widely distributed throughout the southeastern US (Miller and Klimovich 2016) and can be expected off east Florida at all times of the year (Harry Webb, Georgia Aquarium, pers. comm.). Aggregations at Cape Canaveral are common during the manta's northward spring migrations, and summer cold-water upwellings occasionally push manta rays onto the Canaveral Shoals in large numbers. Manta behavior and population size off east Florida is largely unknown and is an area of active research. The species was listed as threatened under the ESA in 2018 due to their small regional population sizes, unsustainable direct exploitation, and bycatch in commercial fisheries worldwide. The main threat to the manta off east Florida may be due to bycatch. The species was noted as a regular bycatch in the shark gillnet fishery off Cape Canaveral (Trent et al. 1997). Bycatch in research trawling have been exceptionally rare throughout the US south Atlantic and Gulf of Mexico (NMFS/Chris Slay, Coastwise Consulting, pers. comm.), and no manta bycatch has been recorded in BOEM-funded research trawling off east Florida (Hammer et al. 2004, Zarillo et al. 2009, D. Murie, Univ. Florida, unpubl. data). Trawling on the OCS generally targets bottom organisms so pelagic giant manta rays may not be particularly vulnerable to this gear type (Miller and Klimovich 2016).

1.5.4.3 Atlantic Sturgeon

Atlantic sturgeon (*Acipenser oxyrinchus oxyrinchus*) range from Canada to northeast Florida and historically sustained a massive fishery for both their roe and flesh along the East Coast of North America through the mid-1800s before populations were severely overfished (Gilbert 1989). The species spawns in rivers (the closest major spawning area being the Altamaha River in central Georgia) but also spends considerable time at sea. In east Florida, the species is considered very rare; Gilbert (1992) noted only 11 confirmed records south of the Georgia-Florida border since 1900, of which only four occurred south of the St. Johns River. True abundance is somewhat higher as indicated by local acoustic telemetry findings (see Section 3.3) and fishermen encounters in recent years. The south Atlantic Distinct Population Segment (DPS) of the species was listed as endangered under the ESA in 2012. The related and similar looking shortnose sturgeon (*Acipenser brevirostrum*) was declared federally endangered in 1967 but has not been recorded in east-central Florida in over 100 years (Evermann and Bean 1897). The shortnose sturgeon primarily occupies estuaries and rivers and would be rare on the inner shelf.

1.5.4.4 Other Protected & Prohibited Fish Species

The Nassau grouper (*Epinephelus striatus*) and oceanic whitetip shark (*Carcharhinus longimanus*) were listed as threatened under the ESA in 2017 and 2018, respectively, and have geographic ranges that potentially overlap Cape Canaveral. Nassau grouper prefer well developed coral reefs while oceanic whitetips are a pelagic species generally encountered far from shore. Both are expected to be rare in the Canaveral region and no recent local records are known. Other species, though not ESA-listed, are prohibited from harvest at the federal and/or state level due to their overfished status or low population resiliency. These include sand tiger shark (*Carcharias taurus*), white shark (*Carcharodon carcharias*), dusky shark (*Carcharhinus obscurus*), sandbar shark (*C. plumbeus*), lemon shark, tiger shark (*Galeocerdo cuvier*), scalloped hammerhead, great hammerhead (*Sphyrna mokarran*), spotted eagle ray (*Aetobatus narinari*), and goliath grouper (*Epinephelus itajara*).

1.5.5 Essential Fish Habitat Designations

The 1996 amendment to the 1976 Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA) established a mandate to identify and protect high value habitats for economically important marine and anadromous fishes and invertebrates in US waters. These areas are designated as EFH and are mapped for any species covered under a federal fishery management plan (FMP). EFH is defined as "those waters and substrate necessary to fish for spawning, breeding, feeding, or growth to maturity" (16 U.S.C. § 1801[10]). In addition, an important subset of EFH is further classified as Habitat Areas of Particular Concern (HAPC) in order to focus conservation efforts on smaller areas that play a particularly important role in the life history of managed species, are especially vulnerable to human-induced degradation, or are naturally rare. Federal agencies conducting work with the potential to damage EFH or HAPC must first consult with the NMFS to develop strategies to minimize negative effects. BOEM therefore has an obligation under the MSFCMA to minimize the damage to fish habitat as a result of sand borrow activities on the OCS. Baseline information detailing which federally managed fishes occur within the immediate vicinity of the Canaveral Shoals helps ensure that this mandate is met.

EFH has been defined for over 90 fishery species off Cape Canaveral, including those in the Spiny Lobster, Shrimp, Highly Migratory Species, Coastal Migratory Pelagics, Dolphin-Wahoo, Bluefish, Summer Flounder, Red Drum, and the Snapper-Grouper FMPs. Most species are managed by the South Atlantic Fishery Management Council (SAFMC), which has jurisdiction for federal waters from North Carolina to south Florida. A small number of species are jointly managed with the Gulf of Mexico Fishery Management Council (GMFMC) when stock boundaries so warrant. In addition, highly migratory fish species, such as tuna, billfish, swordfish, and sharks, are directly managed by the NMFS. Finally, the Atlantic States Marine Fisheries Commission and Mid-Atlantic Fisheries Management Council manage bluefish, summer flounder, and red drum because virtually all harvest now takes place in state (not federal) waters. Further, as of 2017, the entire east-central Florida Coast from Canaveral to Jupiter was classified as HAPC for lemon sharks, one of only three sharks on the east coast with an HAPC designation. Small amounts of HAPC have also been established locally (including near CSII) for spiny lobster and the grouper-snapper complex based on historic records of putative hard bottom. A complete list of species with local EFH is found in Appendix A.

1.5.6 Sea Turtles at Cape Canaveral

Three of four sea turtle life stages are found in the Canaveral region. Hatchlings enter the sea from the adjacent beaches; juveniles move to developmental habitats (lagoons and ports), where they stay for up to 10 years; and adult males and females transit through or to Canaveral for breeding and foraging. This study focuses on the breeding/nesting female life history stage. Four sea turtle species are known to nest at Cape Canaveral: loggerhead, green, leatherback, and the occasional Kemp’s ridley. The beaches adjacent to the Canaveral Shoals consistently support very high nest densities, on the order of 15,000 nests each year between Canaveral National Seashore to the north and the Cape Canaveral Air Force Station (CCAFS) to the south.

Peninsular Florida supports the largest loggerhead nesting population in the western hemisphere, accounting for 80% of all nests and 90% of all hatchlings produced in the Atlantic Ocean (TEWG 2009, Ehrhart et al. 2003). Although annual green turtle nesting in Florida and Canaveral occurred in relatively low numbers through the 1980s and 1990s, their numbers may soon surpass loggerheads based on trends observed over the last 20 years. In addition, green turtles display a biannual nesting cycle, which typically results in very high nesting numbers by a cohort one year, followed by an expected, significantly lower number the next year. This drop can be as much as 95% for this species as observed on Florida beaches. Leatherbacks nest annually but always in low numbers, and Kemp's ridley nesting is considered exceptionally rare. Hawksbill turtles (*Eretmochelys imbricata*) are also known locally from stranding records, but no nesting has been documented. The year 2017 was a high nesting year for green turtles. Nesting numbers, by species along the 67 km of Cape Canaveral federal beaches in 2017 were 8,255 for loggerheads, 9,438 for greens, and 34 for leatherbacks, while Kemp's and hawksbill were not observed.

Early marine turtle research in the Canaveral region primarily centered on the Port Canaveral Harbor and adjacent shipping channel with specific interest in understanding the interactions between turtles, shrimp trawls, dredging and construction activities, and vessel traffic (Dickerson et al. 1995, Dickerson et al. 2004, Henwood 1987). As early as the 1970s, large numbers of turtles, especially loggerheads, were noted using the Canaveral Harbor and navigation channel (Henwood 1987, Butler et al. 1987). Although more frequently observed in spring and summer, they were also present in winter when water temperatures dipped as low as 11°C (Schroeder and Thompson 1987) and were even found hibernating within the walls of the shipping channel itself (Carr et al. 1980). In the early 1980s, Canaveral Harbor was the only US channel that was regularly monitored for potential human-turtle interactions (Dickerson et al. 2004).

NMFS and the U.S. Fish and Wildlife Service (USFWS) jointly administer sea turtles in US waters, with NMFS responsible for animals in the marine environment, while USFWS manages turtles when nesting. For loggerheads, nine DPSs were designated worldwide for the loggerhead in 2011 (NMFS 2013). The Canaveral region is included within the Northwest Atlantic DPS where the loggerhead is listed as threatened under the ESA. In 2014, certain waters from North Carolina through the Gulf of Mexico was designated as Critical Habitat, the only such designation for a sea turtle in the continental US. This action was designed to protect breading and nearshore reproductive habitats, overwintering areas, Sargassum foraging grounds, and migratory corridors. Locally exempted from this designation are CCAFS and Patrick Air Force Base because mitigation measures at these military installations are deemed sufficient to provide protection and accountability sea turtles.

Eleven DPSs have been assigned for the green turtle globally with the Canaveral region considered part of the North Atlantic DPS (Seminoff et al. 2015) and no DPS assignments have yet been established for the leatherback or Kemp's ridley turtle. Critical Habitat for the green turtle is restricted to Culebra, Puerto Rico, and Critical Habitat for leatherbacks includes parts of the US Pacific Coast as well as St. Croix in the US Virgin Islands. No Critical Habitat has been designated Kemp's ridley, although protection for nesting females has been established at Rancho Nuevo, Tamaulipas, Mexico.

1.6 Local Habitat Characterization

Several key habitat characteristics expected to influence the distribution of managed fish and sea turtles on the Canaveral Shoals are either temporally variable or have only been coarsely measured along the east Florida continental shelf to date. Although the primary focus of this study was to document the abundance and habitat associations of mobile animals, efforts were also required to better quantify the bathymetry, water temperature regime, sediment characteristics, and various other oceanographic conditions of the study area in order to provide contextual value to animal capture and movement data.

1.6.1 Study Area Boundaries

Study area boundaries, bathymetry and overall area differed somewhat across the longline survey, acoustic telemetry research, sea turtle tracking, and Wave Glider USV deployments (**Table 2**). The bottom longline sampling was constrained within the Canaveral Shoals complex itself to a maximum depth of 20 m. Acoustic telemetry monitoring of fish and sea turtles shared this same general footprint, although some tagging and tracking of fish occurred on adjacent offshore reefs to a depth of 30 m in order to document any exchange of individuals between shoal and reef habitats. By design, the Wave Glider USV operations were intended to extend acoustic telemetry and oceanographic monitoring over a larger geographic area and thus included operations several miles to the north, south, and east of the Canaveral Shoals. Also, due to the capabilities of satellite transmitters, sea turtles were available to be tracked throughout the northwest Atlantic Ocean.

1.6.2 Water Temperature

Water temperature at Cape Canaveral is likely to help explain animal distribution patterns and was continuously monitored by placing programmable temperature loggers (Onset HOBO models U22-001 and TidbiT v2, Onset Computer Corporation, Massachusetts) at up to eight sites in the study area, including surf zone, shoal, and reef tract locations. Loggers were always anchored on the seafloor and co-located with acoustic receivers (see **Section 3.2.1** for details on acoustic array layout) and were set to record temperature hourly. Although site-specific temperature values were used when required, a continuous Canaveral-wide temperature profile was used for important analyses (e.g., site fidelity models) and migration plots, and was generated by averaging hourly detections from multiple sites.

Mean daily ocean temperatures off Cape Canaveral ranged from as low as 14°C in January to 29°C in July and August, but with considerable variability across years, especially during winter and summer months (**Figure 5**). Shallow inshore stations generally had lower and less stable winter temperatures (a minimum of 12.6°C was recorded January 2018 along the Canaveral shoreline), while deeper offshore sites were moderated by their proximity to the Florida Current. Perhaps the most notable characteristic of the local temperature regime was the repeated occurrence of brief but severe cold-water upwelling events in July and August each year, typically lasting 1–2 weeks. These upwellings, caused by intrusion of deep slope water onto the continental shelf (Smith 1983), resulted in ocean temperatures temporarily dipping below 20°C every summer except 2014, and with a minimum of 14.3°C recorded at one station in July 2016. Sites on the outer shoals were most influenced by these upwellings, with offshore and inshore temperature loggers registering differences of 10–13°C on occasion.

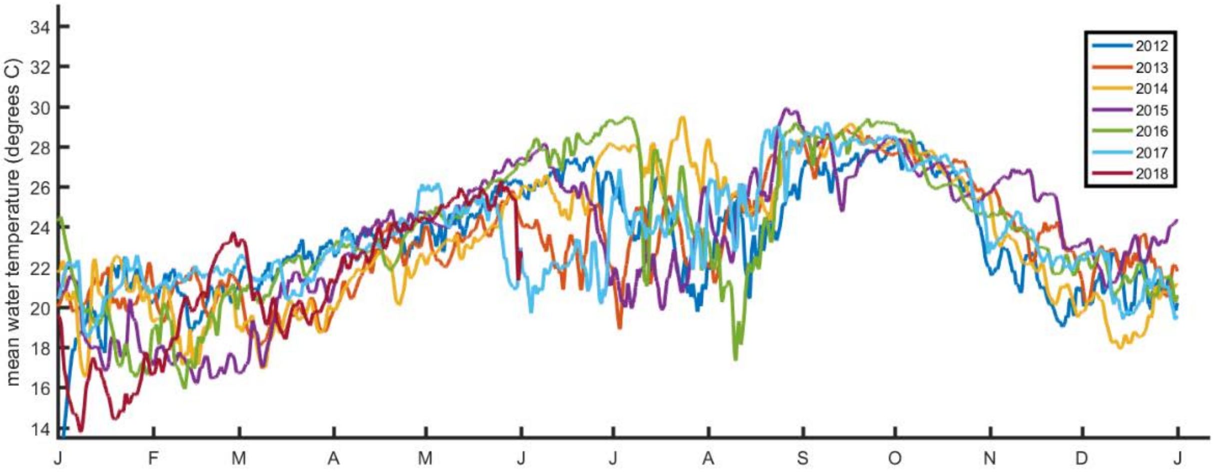

Figure 5. Mean daily water temperature at Cape Canaveral 2012-2018
Values are averaged from multiple temperature loggers deployed within and adjacent to the Canaveral Shoals.

1.6.3 Bathymetry and Sediments

An accurate assessment of bathymetry within the study area footprint was required for analyses of animal habitat use and was quantified by summing the area contained within each 5 m depth contour. These values (as a percentage of the overall study area footprint) were estimated from Global Multi-Resolution Topography (GMRT) southeast regional bathymetric contour data using ArcGIS 10.3 (Ryan et al. 2009).

Seafloor sediment quality at Cape Canaveral is also a factor that may influence the benthic marine fauna and local water quality (e.g., turbidity) and thus may help dictate the spatial distribution of pelagic fishes and sea turtles. At the outset of this project, detailed sediment maps of the Canaveral Shoals had not been produced except in the immediate vicinity of the CSII sand borrow area. As part of a concurrent BOEM-supported study, data on percent fine sediment (particles < 63 µm) and percent sediment organics was provided by the University of Florida Cooperative Ecological Studies Unit (Agreement M13AC00012) at each of 57 acoustic receiver tracking stations. These raw sediment data are found in **Appendix C**, and a full analysis of bathymetry and sediment data characteristics will be provided in a forthcoming report by the University of Florida in 2020.

Table 2. Project area size and water depths for each of the three project focus areas

Project	Area (km^2)	Depth Contour						Figure No.
		0–5 m	5–10 m	10–15 m	15–20 m	20–25 m	25–30 m	
Bottom Longline	426.5	5.3%	30.5%	43.6%	20.6%	0.0%	0.0%	Figure 6
Acoustic Telemetry	267.1	7.9%	39.9%	39.8%	12.3%	0.0%	0.0%	Figure 18
Wave Glider Survey	812.0	2.9%	18.0%	34.0%	33.3%	11.7%	< 0.1%	Figure 66

2 Quantifying Seasonal Abundance and Community Structure of Managed Fishes Using Bottom Longlines

2.1 Introduction

Despite the high economic value attributed to commercial and recreational fisheries in east-central Florida, the fish fauna associated with the Canaveral Shoals has not been regularly included in previous fisheries surveys of the region. One of the earliest local surveys was by Anderson and Gehringer (1965), who reported on shrimp trawl bycatch at Cape Canaveral from collections made in the mid-1930s, but did not provide sample locations. A more rigorous and ongoing effort is the SEAMAP shallow water trawl survey, which has been documenting the abundance and biomass of soft bottom finfish, shellfish, and small sharks during seasonal cruises from North Carolina to northeast Florida since 1990 (ASMFC 2000), but whose southern boundary lies north of the Canaveral Shoals. The MARMAP and SEAMAP programs, and more recently the FWC, also monitor reef fish populations off east Florida with hook-and-line angling, longlines, fish traps, and video (Mitchell et al. 2014), but these surveys are centered on well-developed reef tracts that lie offshore of the shoals. Further, although the NMFS Southeast Fisheries Science Center conducts an annual shark and reef fish longline survey along most of the southeastern US coastline, the samples are widely spaced off east Florida and include few nearshore sites in the Canaveral region most years (Ingram 2016).

In an effort to better define the seasonal abundance and habitat preferences of fishes directly associated with sand shoal features, a year-round stratified-random longline survey comparing shoal habitats with deeper waters was implemented in September 2012. This 5-year survey adopted longlines as the primary gear type (as opposed to gill nets or trawls) because longlines select for larger fish species (e.g., sharks, red drum, reef fish) that are more likely to be of direct management interest. Longlines are also easily quantifiable and allow for moderately high replication. Gill nets are also a widely used gear for quantifying fish abundance in coastal waters. In east-central Florida however, their use is prohibited outside of estuaries in winter due to the potential for entanglement with the endangered North Atlantic right whale (*Eubalaena glacialis*). Although no other year-round longline survey was simultaneously underway elsewhere in east Florida, local results could be compared to concurrent surveys taking place off Georgia, South Carolina, and North Carolina.

2.2 Methods

2.2.1 Field Sampling

The longline sampling footprint included nearshore waters off Cape Canaveral from 28° 22’ N to 28° 39’ N and from the shoreline out to 80° 25’ W (**Figure 6**). The footprint totaled 427 km^2 in area with boundaries chosen to encompass the Southeast Shoal and Chester Shoal, the two most prominent features of the Canaveral Shoals complex. Additional smaller shoals, including the Bull and Ohio-Hetzel Shoal, lie just inside the eastern boundary of the survey area. Sixteen longline sets were deployed each month from October 2012–September 2017 with locations divided equally among deep and shallow depth zones. The shallow zone included shoal ridge and beachfront habitats less than 6.1 m in depth, while deep sets sampled waters between shoals to a maximum available depth of 20 m. Within each zone, sampling points were selected using a random point generator in ArcGIS 10.3 (ESRI, Redlands, CA). Additional non-random longline sets were performed periodically (typically in winter within the Canaveral Bight) to obtain specimens for acoustic tagging. Results of these sets were excluded from statistical analyses.

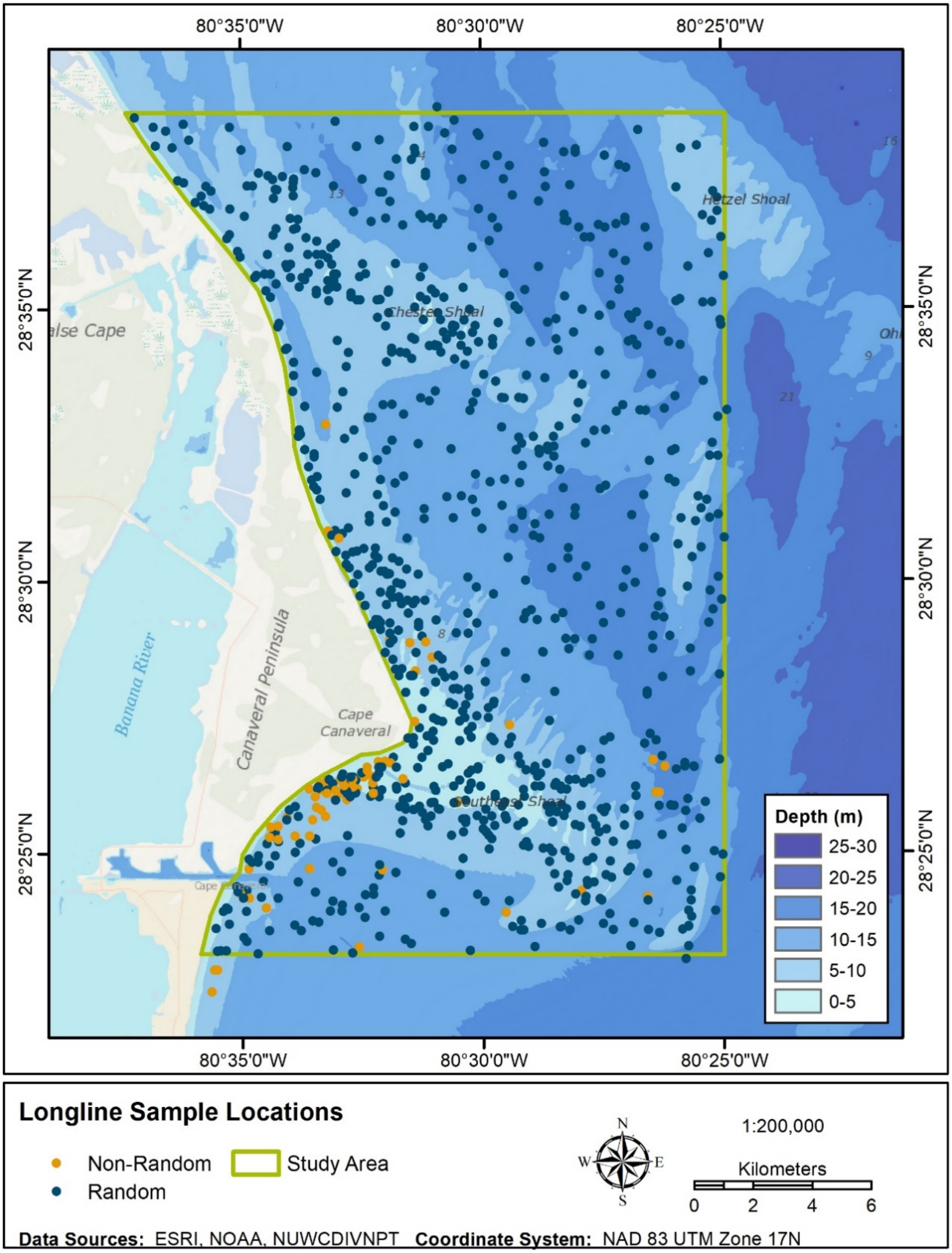

Figure 6. Bottom longline sample locations at Cape Canaveral (2012–2017)

Longline sets spanned 617 m (2,000 feet [ft].) with the mainline consisting of 700 lb. monofilament anchored to the bottom and marked at each end with large floats. Forty gangions were attached to each set, spaced at 15.2 m (50 ft.) intervals. Each gangion was comprised of a stainless-steel clip with 4/0 swivel, 0.7 m of 400 lb. test monofilament fishing line, and either a 12/0 or 15/0 Mustad circle hook with the barb depressed. Hook size was alternated along the mainline with 20 hooks of each size deployed on each set to target a broader size class of fishes. Bait consisted exclusively of fresh or fresh-frozen mullet (*Mugil cephalus* or *M. curema*), common forage fish locally obtainable throughout the year. Longline soak time was targeted for 30 min, calculated as the difference between the mid-point of each set and retrieval, with the mainline deployed and retrieved using a custom electric longline winch (**Figure 7**). Sets were generally made into or against the wave direction for safety. Sampling occurred during daylight hours from an 8.2 m pilothouse skiff embarking out of Port Canaveral. Environmental data collected with each set included water temperature, dissolved oxygen, salinity (all measured in the middle of the water column), Secchi depth (i.e., water clarity), wave height, time, mean water depth, seafloor slope (difference in depth between origin and end of each longline set), and GPS location at both the start and end of each deployment. GPS locations were also used to calculate the minimum distance from shore (km) for each sample.

There is no universally adopted longline survey protocol for nearshore waters along the US East Coast. Specifications were adopted here after consultation with other research groups and most closely mimic surveys conducted by the Georgia Department of Natural Resources (GADNR) and South Carolina Department of Natural Resources (SCDNR)[3]. All collection and handling was performed in accordance with a State of Florida Special Activity License (permit SAL-12-0512SR), NOAA Biological Opinion (F/SER/2011/05647), KSC Animal Care & Use protocol (GRD11-084), and all subsequent renewals.

All captured fish were identified and measured to the nearest 0.5 cm. Measurements were recorded as precaudal length (PCL), fork length (FL), and natural total length (TL) for sharks; disk width (DW) for benthic and pelagic rays; and standard length (SL) for teleosts. All elasmobranchs were sexed and the degree of umbilical scar healing (a sign of recent birth) was noted for the youngest sharks. Individuals were classified as either neonate/young-of-the-year (YOY), juvenile, or adults through the examination of elasmobranch claspers (males only), and using published lengths at 50% maturity for non-gravid female elasmobranchs and teleost fishes. Most sharks were externally tagged with roto tags or M-tags supplied by the NMFS Highly Migratory Species Program, and a subset of sharks and red drum were surgically implanted with acoustic transmitters to support the companion acoustic telemetry study (see **Section 3**).

2.2.2 Data Analysis

To account for variation in longline soak times across samples, catch was standardized to catch per unit effort (CPUE) in the form of fish captured per 100 hook-hours of gear soak time. For the most commonly captured species, bar charts were created to visualize CPUE averaged across season and depth zone. Season was defined as winter (December–February), spring (March–May), summer (June–August), and fall (September–November), with winter and summer representing the coolest and warmest three months, respectively, for the Canaveral region. The relationship of fish size and water depth was explored using Spearman's rank correlation, and the parity in the sex ratio of common elasmobranchs was examined using binomial tests.

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[3] http://www.seamap.org/red%20drum.html

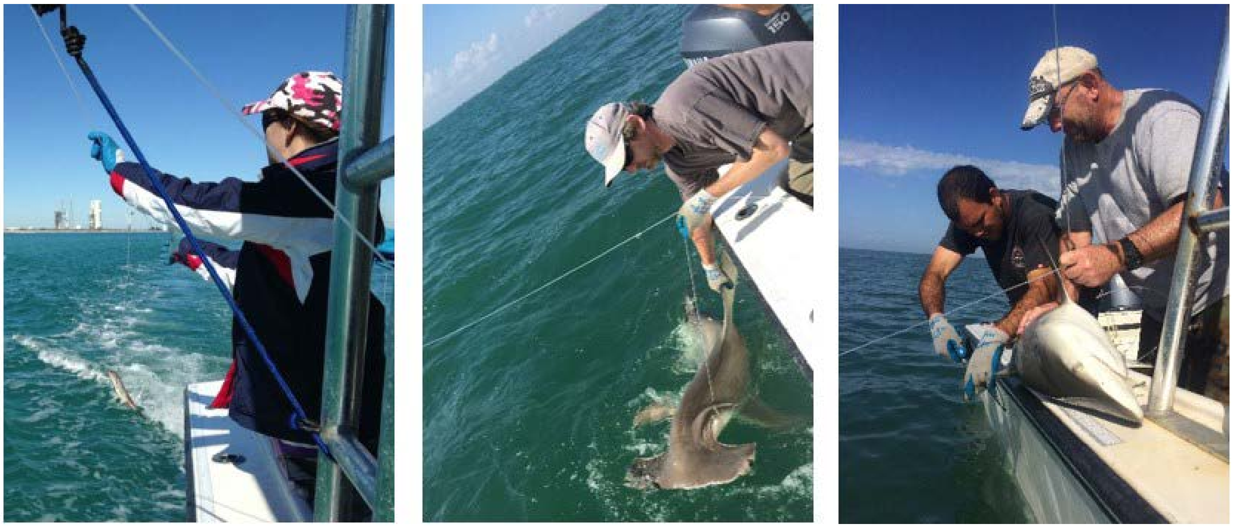


Figure 7. Longline deployment and recovery
Left: Baited hooks deployed out the stern of the research vessel, *Center*: a juvenile great hammerhead being measured alongside the boat, and *Right*: a blacktip shark being fitted with an external roto tag. Photo credits: Eric Reyier.

Potential differences in the observed fish community across depths and seasons were examined using a two-way crossed Analysis of Similarities (ANOSIM) test with replication. An ANOSIM is a non-parametric permutation procedure that produces an R-statistic whose value ranges from 0 (no shared species across groups) to 1 (all species shared and in equal densities), and generates a p-value to confer its significance level (Clarke and Ainsworth 1993). CPUE values for each species were first averaged by depth zone and season, and these resulting means were then root-transformed to reduce the dominance of common species, allowing less common yet equally important taxa species to also contribute to the separation of samples (Thorne et al. 1999). A sample similarity matrix (the basis of the ANOSIM) was then created using the Bray-Curtis correlation coefficient, and non-metric multidimensional scaling (MDS) ordination (map) on these values was used to visualize sample similarities across space and time. In addition, a similarity of percent contribution (SIMPER) routine was also run on the similarity matrix to determine which species were most responsible for difference in the community across depths and seasons. Finally, overall species diversity across depths and seasons was compared using the Shannon-Weiner (H’) statistic.

MDS was further used to discriminate between species (not samples) to determine if certain species were collected together as distinct groups or instead appeared randomly in longline sets. First, catch was standardized by total captures so species ratios within samples (not absolute abundance) were used to construct the species similarity matrix via the Bray-Curtis coefficient. Further, rare species often appear without pattern and disrupt ordination, so only the 12 most abundant species were considered to aid in visualization. Finally, the degree to which habitat conditions are correlated to or “explain” overall community structure was explored with a BEST procedure (Clarke and Ainsworth 1993) using all habitat variables measured at each site. These variables were log (1+x) transformed when necessary to reduce skewness and then normalized to remove the effect of differing measurement scales. A sample similarity matrix based on Euclidean distance (appropriate for continuous data containing relatively few zero values) using habitat variables was then constructed and compared to the Bray-Curtis sample similarity matrix using the Spearman rank correlation (ρ_s), allowing the variable(s) most strongly correlated to the biotic pattern to be identified. All multivariate procedures were performed with PRIMER 6.0 statistical software (Clarke and Warwick 2001).

Species-specific modeling was applied to understand the degree to which season and habitat conditions in the Canaveral Shoals complex influenced catch of the five most common species collected by longlines (i.e., sharpnose, blacknose, blacktip, and finetooth sharks, and red drum). Catch data for all five species were zero-inflated with a high percentage of longline sets with no captures and progressively fewer samples of increasing CPUE. This non-normal distribution is a common attribute of fisheries catch data (Su and He 2013, Weber and Wolter 2017) but complicates traditional linear modeling.

To address this issue, a two-part hurdle model (Zuur et al. 2009) was applied separately to catch data of each species. Each part of the model was fit separately to make interpretation more straightforward (Fletcher et al. 2005). For the first part, CPUE data were converted to a binary presence/absence dataset, and logistic regression mixed effects models were constructed to determine how different values of habitat covariates altered the probability of positive catches. Continuous variables included water temperature, dissolved oxygen, water depth, water clarity (Secchi depth), distance from shore, seafloor slope, and latitude. Salinity was not included because the minor observed fluctuations (mean 36.0±1.2 ppt) were considered to be of little biological significance. Season was included as a categorical fixed effect, and year was included as a random effect because, while potentially important, it provided no predictive value. All continuous habitat variables were first standardized (mean = 0, SD = 1) so their relative influence could be directly compared (Schielzeth 2010). The global model with no model simplification was used for all species so the effect (or lack thereof) of all variables could be presented identically across all species. Nagelkerke R^2 values (Nagelkerke 1991) were calculated to estimate variance explained by each model, and evidence ratios were calculated based on Akaike Information Criterion (AIC) scores of the global model vs. the null model (Anderson 2007). Diagnostic Tjur plots (Tjur 2009), simulated data probability plots (Hartig 2017), and random effect normality plots were used to assess model fit. All models were fit in R (R Core Team 2018) using the package *lme4* (Bates et al. 2015).

The second part of the hurdle model considered only longline sets where catch of the selected species was greater than zero with the goal of determining how environmental covariates affected the rate of catch in positive sets. CPUE values were first log transformed, and a log-normal mixed effects global model was run with the same standardized environmental variables used in the logistic regression part of the hurdle model and also using year as a random effect. Model assumptions were checked using residual plots, quantile-quantile plots, and random effect normality plots. After conducting log-normal modeling, it was determined that tested variables had only modest additional predictive value, explaining little additional variance in the data, and generally selecting similar continuous variables as logistic models (i.e., the conditions that improve probability of catch also increase the rate of catch). For the sake of brevity, these model results are not presented.

2.3 Results

2.3.1 Longline Sampling Overview

From October 2012 through September 2017, 978 longline sets (455 shallow, 445 deep, 78 non-random) were completed. Sampling occurred in all months except November 2013, October–November 2015, and October 2016 due to persistently high seas or permit delays. In total, 2,895 fishes from 36 species were recorded, 20 of which are managed under federal FMPs (**Table 3**). Coastal sharks dominated longline samples, comprising 90% of all fish caught. The Atlantic sharpnose shark alone accounted for 50% of captures. Teleost fish, primarily red drum, comprised 7% of catch, and benthic and pelagic rays represented the remaining 3%. Hard bottom substrates were only documented on a single longline set (due to line fouling on the reef), and reef-associated fish species managed within the snapper-grouper complex were virtually absent from collections, being represented by just a single black seabass (*Centropristis striata*), collected on the same set where hard bottom was encountered. Some of the less common species observed are abundant in the region but are generally too small to be effectively sampled by longlines (e.g., croaker, bumper, lizardfish) or became temporarily fouled in the gear (manta rays).

Table 3. Numbers and sizes of fish captured during longline survey

Lengths (cm) are reported as standard length for teleost fishes, natural total length for sharks, and disk width for rays. CPUE is expressed as fish per 100 hook-hours of soak time. Targeted (non-random) longline sets are not included in CPUE estimates. Species managed under federal FMPs are in bold.

Species	Total	Shallow < 6.1 m	Deep > 6.1 m	Non-Random	CPUE	Mean Length (Range, cm)	No. Measured
Sharpnose shark	1,436	364	1,072	0	5.37	85 (30–105)	1,429
Blacknose shark	488	209	184	95	1.23	113 (73–155)	485
Blacktip shark	277	145	74	58	0.65	132 (63–190)	275
Red drum	170	55	45	70	0.33	87 (73–100)	165
Finetooth shark	157	83	21	53	0.30	132 (70–156)	155
Nurse shark	52	25	26	1	0.18	213 (135–278)	51
Southern stingray	51	24	15	12	0.15	73 (54–104)	50
Bonnethead shark	40	14	13	13	0.09	105 (80–120)	39
Spinner shark	34	13	19	2	0.12	99 (64–210)	34
Scalloped hammerhead	29	5	24	1	0.10	135 (47–200)	29
Lemon shark	24	19	4	1	0.07	149 (115–189)	24
Sandbar shark	22	5	15	2	0.07	168 (78–220)	22
Roughtail stingray	21	3	2	16	0.02	136 (83–180)	21
Great hammerhead	13	7	5	1	0.04	265 (174–400)	13
Gafftopsail catfish	11	4	7	0	0.04	41 (22–51)	11
Bluefish	10	6	2	2	0.03	32 (23–40)	10
Bull shark	7	5	2	0	0.01	188 (171–210)	7
Cownose ray	7	2	1	4	0.01	82 (70–101)	7
Bullnose ray	6	3	1	2	0.01	109 (86–120)	6
Sand tiger shark	5	3	1	1	0.02	183 (138–268)	5
Tiger shark	5	1	4	0	0.02	191 (89–320)	5
Atlantic croaker	4	0	1	3	< 0.01	14 (12–16)	4
Unknown Carcharhinid	4	2	2	0	0.02	150 (100–200)	3
Bluntnose stingray	3	1	1	1	0.01	79 (69–95)	3
Cobia	3	3	0	0	0.01	96 (77–120)	3
Black drum	2	0	0	2	< 0.01	78 (70–86)	2
Southern kingcroaker	2	1	1	0	0.01	32 (30–33)	2
Atlantic bumper	2	0	1	1	< 0.01	18	1
Giant manta ray	2	2	0	0	0.01	180	1
Black seabass	1	0	1	0	< 0.01	19	1
Dusky shark	1	0	1	0	< 0.01	259	1
Hardhead catfish	1	1	0	0	< 0.01	29	1
Inshore lizardfish	1	1	0	0	< 0.01	26	1
Oyster toadfish	1	0	1	0	< 0.01	36	1
Lesser devil ray	1	1	0	0	< 0.01	85	1
Smooth hammerhead	1	1	0	0	< 0.01	152	1
Spanish mackerel	1	0	1	0	< 0.01	25	1
Total	**2,895**	**1,007**	**1,547**	**341**	**-**	**-**	**2,870**

Overall longline CPUE varied by species and season but on average was higher in the deep than shallow depth zone (11.2 vs 6.7 fish per 100 hook-hours, respectively). Sharpnose sharks were present year-round but were decidedly more common in warmer months and in deeper water away from shoal features (**Figure 8**). Other warm season species included nurse (*Ginglymostoma cirratum*) and spinner sharks (*Carcharhinus brevipinna*), both of which were distributed more evenly across depths. Cool-season species included red drum, finetooth, lemon, sandbar (*Carcharhinus plumbeus*), and to some extent blacktip sharks. With the exception of red drum and sandbar sharks, all were more frequently captured in longline sets near shore. Catch of bonnethead and scalloped hammerhead sharks suggested possible winter-spring peaks in abundance while blacknose sharks and southern stingray (*Dasyatis americana*) clearly showed true year-round occurrence in the study area.

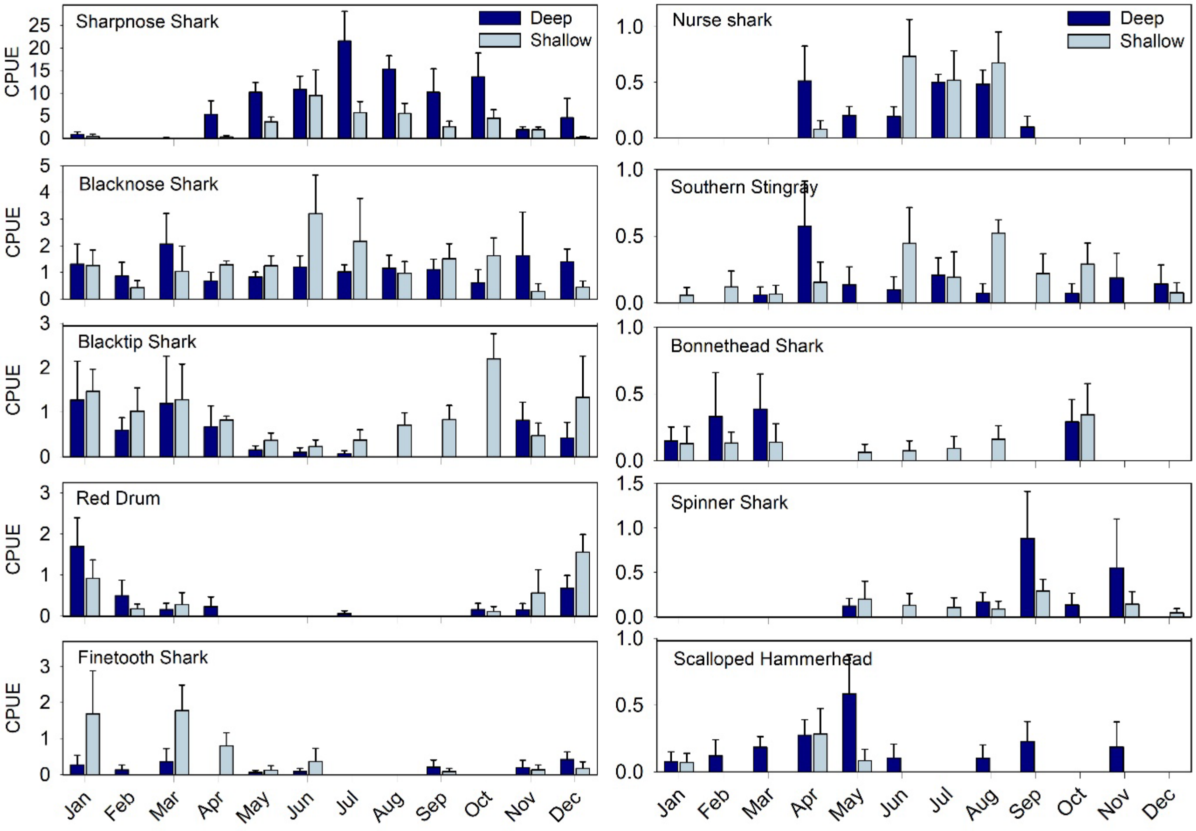


Figure 8. Monthly mean longline CPUE (±SE) by depth zone averaged across all years
Only the ten most common species are presented. Note the differing scale of the y-axis across species.

Table 4. Life stage classification and relationship between size and water depth
Only the ten most commonly captured species are listed. Young-of-the-year (YOY) includes neonate animals.

	Life Stage Classification				Size by Depth Relationship		Sex Ratios	
Species	**% Adult**	**% Juvenile**	**% YOY**	**No. Measured**	**Rho**	**P-Value**	**% Female**	**P-Value**
Sharpnose shark	84.0	12.6	3.4	1,429	0.231	**< 0.001**	24.5	**< 0.001**
Blacknose shark	72.7	27.1	0.2	485	-0.046	0.314	66.3	**< 0.001**
Blacktip shark	45.5	54.2	0.4	275	0.031	0.618	72.5	**< 0.001**
Red drum	100.0	0.0	0.0	165	-0.301	**< 0.001**	-	-
Finetooth shark	77.4	22.6	0.0	155	0.045	0.580	75.7	**< 0.001**
Nurse shark	55.8	44.2	0.0	51	-0.069	0.630	36.8	0.143
Southern stingray	56.9	43.1	0.0	50	0.194	0.177	72.0	**0.003**
Bonnethead shark	95.0	5.0	0.0	39	-0.016	0.924	92.3	**< 0.001**
Spinner shark	17.6	5.9	76.5	34	-0.381	**0.026**	47.1	0.864
Scalloped hammerhead	10.3	82.8	6.9	29	-0.153	0.420	25.0	**0.013**

All 165 measured red drum were classified as adults, and most sharks and rays were also considered either adults or large juveniles (**Table 4**). Some exceptions included the spinner shark, whose catch was dominated by YOY individuals. YOY and small juvenile sharpnose sharks were also sporadically encountered in shallower areas (particularly on Chester Shoal) during summer, and lemon sharks and scalloped hammerheads were almost exclusively juvenile size classes. Significant relationships between animal size and water depth were detected for only three of the 10 most commonly caught species, with larger sharpnose sharks collected in deeper water, while larger spinner sharks and red drum were observed in shallow waters (**Table 4**). A notable trend was apparent in elasmobranch sex ratios with the catch of cool-season sharks being dominated by females, and the catch of warm season sharks more being evenly distributed or male-dominated. Sex ratios were most extremely skewed towards females during winter, generally exceeding a ratio of 2:1 from January–March each year.

2.3.2 Patterns in Community Structure

The ANOSIM test confirmed that overall longline community composition differed across seasons (R=0.447, p=0.001) and to a lesser extent water depth (R=0.31, p=0.001; **Figure 9**). Pairwise comparisons suggested that the greatest seasonal differences in catches occurred between summer and winter longline samples (R=0.86, p=0.001), while spring and fall samples were most similar and only marginally significant (R=0.18, p=0.05). The species which contributed most to differences in sample composition across seasons were red drum, sharpnose shark, and nurse shark, while sharpnose, blacktip, and blacknose sharks contributed most to the observed community difference in catch across depths (**Table 5**).

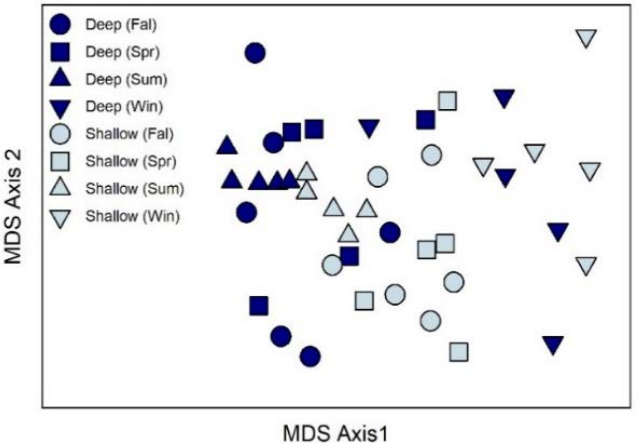


Figure 9. Non-metric multi-dimensional scaling plot of longline catch by season and depth
Distances between points are proportional to differences in community structure. 2D stress (0.18) is high, but the greater difference in community composition across seasons vs. depths remains apparent.

Table 5. Species contribution to community differences across seasons and depths
Only results from the most dissimilar seasonal combination (summer vs. winter) are presented.

By Season	Species % Contribution	Cumulative % Contribution
Sharpnose shark	32.5	32.5
Red drum	10.0	42.5
Nurse shark	8.6	51.1
Blacktip shark	6.7	57.8
Finetooth shark	6.0	63.8
Average total dissimilarity by season = 66.8		
By Depth	**Species % Contribution**	**Cumulative % Contribution**
Sharpnose shark	21.4	21.4
Blacktip shark	10.8	32.2
Blacknose shark	8.4	40.6
Finetooth shark	7.0	47.5
Southern stingray	5.7	53.3
Average total dissimilarity by depth = 46.8		

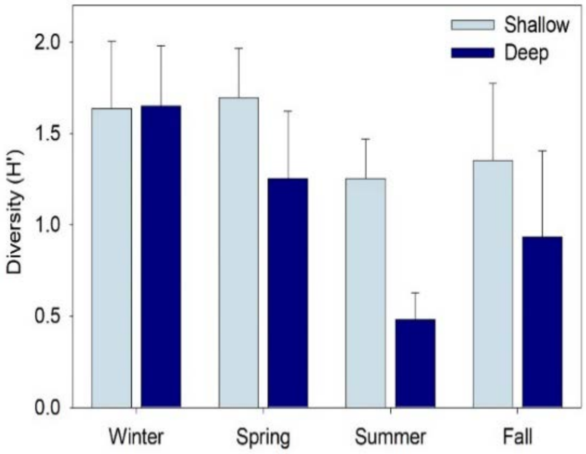


Figure 10. Shannon Diversity (H') by season and depth from longline samples
Values are mean (± SD).

Species diversity (H') ranged from 0.5–1.7 and was highest in winter and spring, and in shallow water (**Figure 10**), primarily due to the dominance of sharpnose shark during summer in deeper offshore habitats. Results of the BEST procedure (**Table 6**) concluded that water temperature was the environmental factor most strongly correlated with community structure but that distance from shore, latitude (which likely is accounting for other unmeasured habitat conditions) and water depth also influenced overall community structure. MDS plots also confirmed that the 12 most abundant species were collected more or less independently rather than in distinct species clusters **(Figure 11)**.

Table 6. Results of the BEST procedure for longline sampling
Habitat variables with higher correlations are more closely linked to differences in overall community structure. DO=Dissolved oxygen.

Single Habitat Variable	Spearman Rank Correlation (ρ_s)	Best Habitat Variable Combinations	Spearman Rank Correlation (ρ_s)
Temperature	0.234	Latitude, Shore Distance, Temperature	0.310
Latitude	0.154	Latitude, Depth, Temperature	0.306
Shore Distance	0.130	Latitude, Shore Distance, Depth, Temperature	0.301
Depth	0.121	Latitude, Temp	0.287
DO	0.106	Latitude, Shore Distance, Depth, Temperature, DO	0.285
Water Clarity	0.088	Latitude, Shore Distance, Temperature, DO	0.282
Seafloor Slope	0.003	Shore Distance, Temperature	0.279

2.3.3 Habitat Influence on Catch Rates

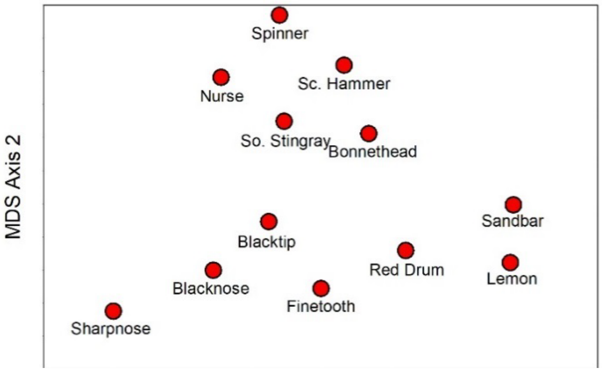


Figure 11. MDS plot of longline species associations
Species plotted closest together represent those most

Results of catch modeling for the top five species confirm that season was a significant factor affecting the catch probability for all species except blacktip shark, with sharpnose and blacknose sharks most commonly encountered on longline sets in summer, finetooth sharks in spring, and red drum in fall and winter (**Figure 12**). After accounting for season, water temperature remained important for two species, with sharpnose sharks more likely to be caught in warm water and red drum more likely caught in colder waters (**Figure 13**). Encounter rates of all five species were also significantly influenced by water clarity. Sharpnose sharks were more commonly observed in clear water (with positive catches over 80% in water with greater than 10 m Secchi depth) but all other species were more commonly collected in lower water clarity, a noteworthy trend that confirms that short longline soak times in low visibility conditions did not result in a strong negative bias in hook encounter rates. Distance from shore was an important factor for blacknose and blacktip sharks, with both being more common near the coast, and both blacknose and sharpnose sharks preferred deeper water once other habitat conditions were controlled for. Latitude was an important factor for sharpnose and blacktip sharks, although it is likely that both species were responding to unmeasured conditions that are collinear with latitude (possibly sediment type or proximity to reef habitat) because the gradient in latitude included in this study is a small fraction of the species overall geographic range. Seafloor slope and dissolved oxygen did not affect encounter rates in any species. Evidence ratios of the fitted model vs. the null model were at least 10^6 for all species, indicating strong support for the global model, although Nagelkerke R^2 values were low to moderate, ranging from 0.09 (blacknose shark) to 0.49 (sharpnose shark), confirming that catch probability was also strongly affected by other conditions that went unmeasured during sampling. Full model results tables are found in **Appendix B.**

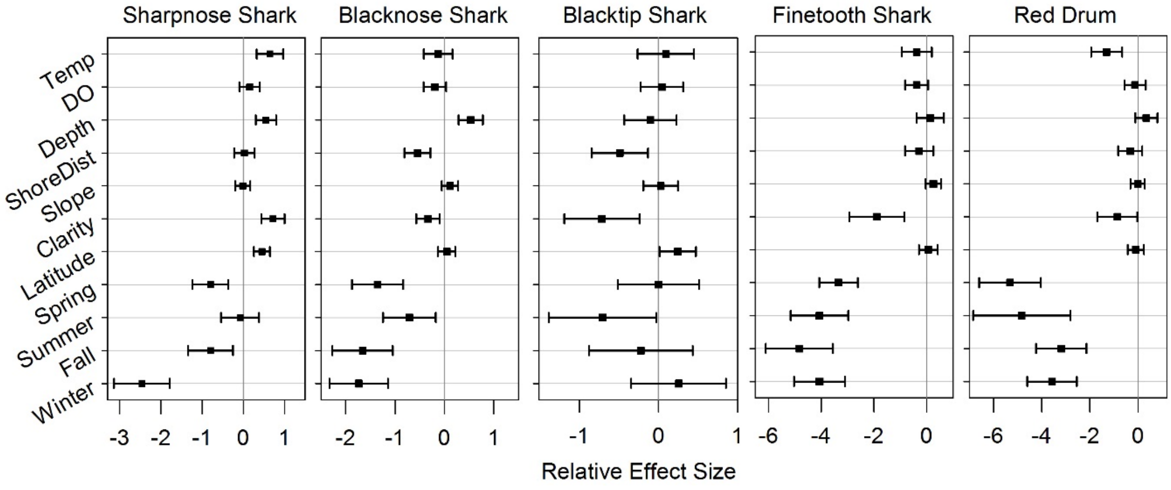


Figure 12. Parameter estimates for logistic regression models predicting the probability of positive catches of five common fish species caught on longlines
Error bars give the 95% confidence interval of the estimated parameters, which are significant if they do not overlap zero. Continuous habitat covariates were scaled prior to modeling so their relative effect sizes are directly comparable.

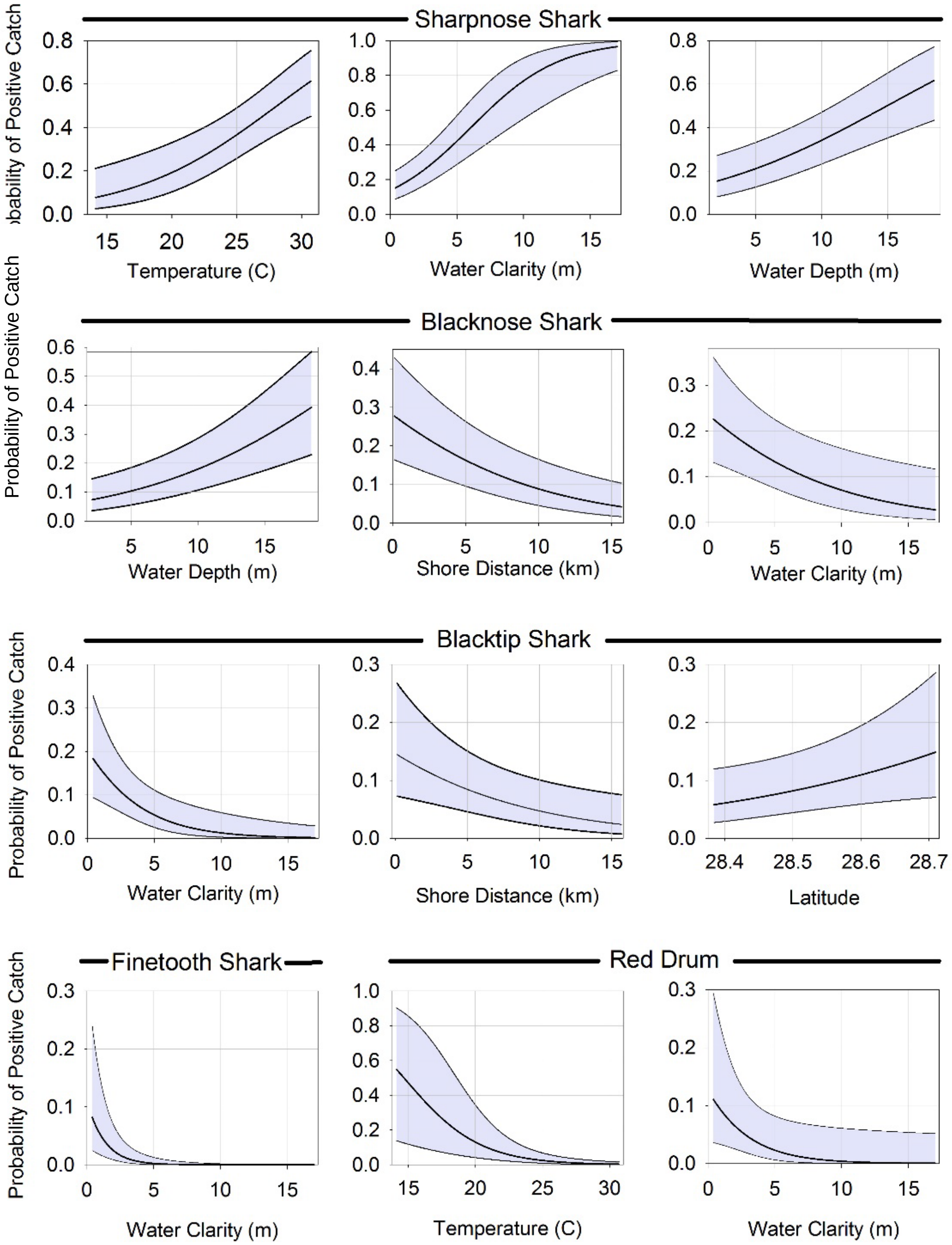


Figure 13. Marginal effect plots depicting the relationship between significant habitat covariates on the probability of positive catches for five common fish species collected on longlines
Plots are ordered by relative effect size of the top three habitat covariates for each species. Shaded regions represent the 95% confidence interval of predictions. Note the differing y-axis scale across species.

2.3.4 External Tag Recaptures

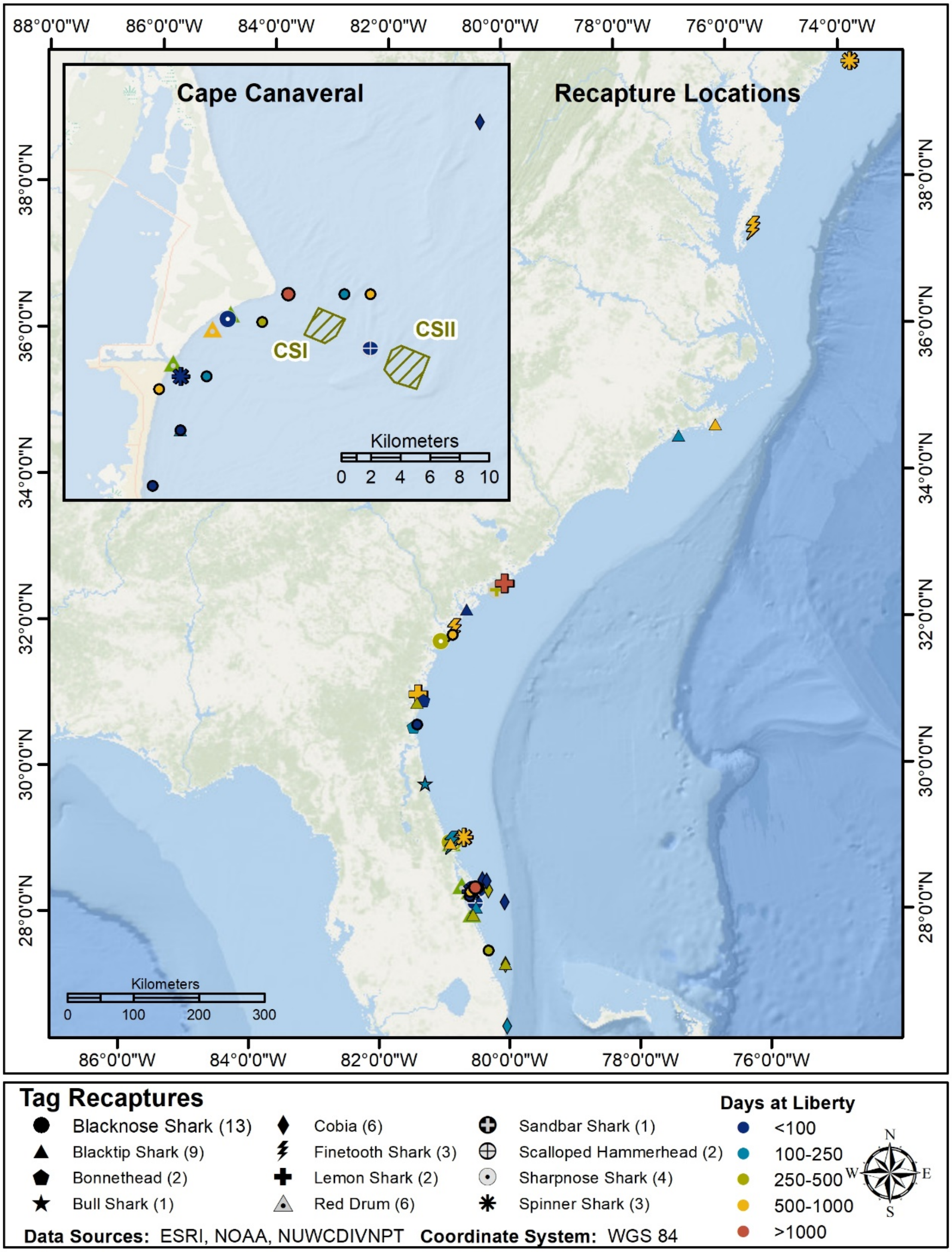
Traditional tag-recapture of fishes provides less behavioral detail than newer tagging technologies but still offers insight into general coastal movements. During the 2012–2017 study timeline, 1,576 sharks and red drum were fitted with external tags at Cape Canaveral, of which 43 (2.7%) were returned from various locations along the US East Coast (**Table 7**), confirming the highly migratory tendencies of many species. Six cobia, plus two lemon sharks and one blacknose shark tagged near the Canaveral Shoals locally for other studies, were also recaptured, and one sandbar shark originally tagged off Ocean City, Maryland, was recaptured on a longline locally. Most shark recaptures occurred to the north, generally between Cape Canaveral and South Carolina, but displacement varied dramatically across species (**Figure 14**). From these recaptures alone, blacknose sharks appeared the least mobile, with a mean displacement of only 75 km; one individual at liberty for 8.5 years was recaptured only 4 km from its tagging location. Conversely, finetooth and spinner sharks were recaptured as far away as Virginia (1,130 km) and New Jersey (1,405 km), respectfully. Red drum tags were generally returned from local waters, and cobia was the only species with multiple tag returns from south of Cape Canaveral. Most recaptures were returned by recreational anglers, although nine sharks (four blacknose, two blacktip, two sharpnose, one scalloped hammerhead) were reported as being taken in regional commercial longline and gill net fisheries.

Table 7. Recapture details for fish marked with traditional external tags

Lengths are reported as fork length for teleost fishes and natural total length for sharks, measured at time of tagging. Values are means with range in parentheses. Dispersal is calculated as minimum distance through water.

Species	No. Recaptured	Length (cm)	Days at Liberty	Dispersal (km)
Blacknose shark	14	119 (106–133)	376 (20–3,103)	75 (3–389)
Blacktip shark	9	141 (78–185)	341 (64–921)	282 (4–786)
Cobia	6	81 (72–85)	187 (3–487)	77 (8–234)
Red drum	6	81 (50–104)	371 (290–687)	51 (0–160)
Sharpnose shark	4	90 (86–97)	264 (11–378)	128 (5–363)
Finetooth shark	3	140 (125–156)	514 (152–880)	530 (81–1,130)
Spinner shark	3	85 (73–92)	532 (25–957)	498 (2–1,405)
Bonnethead shark	2	116 (111–120)	129 (99–158)	279 (272–285)
Lemon shark	2	120 (79–161)	1,457 (552–2,361)	324 (188–459)
Sandbar shark	2	150 (125–175)	858 (483–1,232)	828 (452–1,203)
Scalloped hammerhead	2	110 (88–132)	28 (10–45)	13 (5–20)
Bull shark	1	183	173	159

Figure 14. Recapture locations for fish externally tagged during longline sampling



2.4 Discussion

The 5-year study timeline and year-round sampling associated with this longline survey provides high confidence that coastal sharks and red drum, which collectively accounted for 97% of the total catch, are consistently among the most common piscine predators associated with the Canaveral Shoals. Although there were often significant seasonal fluctuations in catches of individual species, sharks as a whole were abundant in the study area year-round. All coastal sharks and red drum are managed under formal FMPs and should be of direct consideration when evaluating potential human impacts to local shoal habitat. That said, although some sharks (e.g., blacknose, sandbar, dusky, sand tiger) collected in this study have stocks that are classified as overfished by the NMFS, (resulting on stricter harvest regulations in commercial and recreational fisheries), all these species have broad geographic ranges (Castro 2011), and most have stable populations.

There was no evidence from longline sampling to indicate that adult reef fishes were present in substantial numbers on the Canaveral Shoals. Only a single individual (a black seabass) from the intensively managed grouper-snapper complex was collected in 978 longline sets, despite the fact that many species in this group are susceptible to longline gear. Further, although hard bottom is common to the east and north of the shoals and has also been previously reported near the shoals (Perkins et al. 1997), it was only conclusively encountered at one location in the study area (indicated by the mainline fouling on the seafloor and the presence of soft coral on the line at retrieval). Low coverage of hard bottom within the shoals may be advantageous from a regulatory perspective since reef communities are vulnerable to disruption by sand borrow and renourishment activities, including direct mechanical damage by the dredge itself, as well as associated turbidity, sedimentation, and noise (Lindeman and Snyder 1999, Michel et al. 2013). Mitigating potential damage to hardbottom during dredge and renourishment projects can be difficult and expensive and has even resulted in delays in local shoreline restoration efforts at the nearby Melbourne “Mid-Reach,” an eroding stretch of shoreline immediately south of Cape Canaveral.

The Canaveral Shoals region may still serve an important nursery function for small juvenile reef fish. Certain snapper and seabass, for example, initially settle on sand and shell substrates before transitioning to higher-relief reefs with age (Szedlmayer and Shipp 1994, Patterson et al. 2005, Mikulus and Rooker 2008). These smallest fish are not susceptible to longlines but are consistently noted in regional trawl surveys (ASMFC 2000, Pierce and Mahmoudi 2001). Dredging would reduce the function of these soft bottom nurseries, but given the massive areal coverage of sand-shell habitats in the Canaveral region, small scale sand borrowing should have negligible consequences to young reef fish populations. Ongoing BOEM-funded trawl surveys of the Canaveral Shoals are better suited to evaluate the distribution of juvenile reef fishes throughout the study area.

Not surprisingly, habitat preferences of sharks and red drum were species-specific, but little evidence was gathered to suggest that any species preferentially associated with shoal ridges. For the five most common species, water depth had either no significant effect on catch probability (blacktip and finetooth sharks, red drum) or was positively related to the catch of sharpnose and blacknose shark, which were more common in deeper water away from the shoals. Seafloor slope, another defining characteristic of shoals, was also uninformative in predicting catch probability of the five most common species. Although a maximum slope of 8 m was recorded over a 617 m longline set, the mean was a modest 1.3 m. Aside from water temperature and season, whose role structuring coastal fish communities is well documented, water clarity was the one measured habitat factor that most consistently affected catches. Sharpnose shark strongly preferred clear water, but the other common species were actually more abundant in low visibility conditions. A trend for higher catches in turbid water is noteworthy since water surrounding the shoals often exhibits elevated turbidity due to waves interacting with the shallow seabed (**Figure 3**;

Figure 15). As such, the presence of shoals may alter surrounding habitat in other ways that are advantageous to certain large fish predators.

Figure 15. LANDSAT 8 image, 17 February 2019
Note the turbid water surrounding the Southeast and Chester Shoals.

Although excessive turbidity can be detrimental to fishes by clogging gills and lowering dissolved oxygen, some prey fish favor moderately high turbidity because it reduces predation risk (Benfield and Minello 1996, Maes et al. 1998) which may in turn concentrate prey exploited by large piscivores. Broadly speaking, based on longline catches, the best habitat for sharks and red drum in the study area appeared to be the deeper turbid water on the flanks of the shoals. The Canaveral Bight, in particular, was identified early in the study as a particularly productive location for red drum; blacknose, blacktip, and finetooth shark; and roughtail stingray (among others) and not coincidentally where the otherwise numerically dominant sharpnose shark (which prefers clear water) was rare. High turbidity in the Canaveral Bight is likely due to persistent wave interaction with the adjacent Southeast Shoal, as well as easily suspended fine sediments that accumulate in the lee of this shoal (Hoenstine et al. 1995, McArthur and Parsons 2005b, D. Murie, unpubl. data).

Shoal flanks at Cape Canaveral also possess a complex undulating ridge-swale bathymetry that may also influence predator abundance. Although not measured directly in this project, trawl and camera sled studies in the US mid-Atlantic region have demonstrated that near-shoal sites with a similarly complex bathymetry tend to harbor greater benthic fish abundance and diversity than shoal ridges themselves due to the greater diversity of microhabitats (e.g., deep sand waves, invertebrate burrows, and casting mounds), which serve as a refuge from predators (Vasslides and Able 2008, Diaz et al. 2003). If the same principles structure fish communities off east Florida, high densities of benthic fish on shoal flanks may serve as productive foraging grounds for larger predators (**Figure 16**).

Although sharks dominated the longline catch year-round, there was a strong seasonal dimension to the presence of many species including sharpnose, finetooth, nurse, and spinner sharks, as well as red drum. The relative importance of season and water temperature on abundance can be hard to decouple. Temperature did not always affect catch probability after season was accounted for in modeling efforts, but both factors are likely important. As examples, lemon sharks are a predictable winter presence at Cape Canaveral but are also known to temporarily relocate south during strong cold fronts (Reyier et al. 2008, 2014). Sharpnose shark generally overwintered outside the Canaveral Shoals but would briefly move shoreward into the survey area during warm winter spells. The traditional external tagging that accompanied longline samples confirmed the migratory nature of many species and suggested regular seasonal exchange of animals between Cape Canaveral through South Carolina with more limited exchange farther north or to south Florida. The seasonal migratory habits of many coastal sharks have been coarsely resolved by previous tag-recapture studies (Kohler et al. 1998), although movement details are often lacking. Catch of individuals of highly migratory species at Canaveral in summer (e.g., blacktip and finetooth sharks) suggests that migrations are not obligate north-south movements of the entire population but more akin to a seasonal expansion and contraction of a species geographical range.

Compared to seasonal changes in the fish community, only subtle differences in the longline species assemblage was detected across deep and shallow depth zones. This spatial uniformity results from many factors. First, given the site-specific information needs of this project, the survey footprint was smaller than many longline surveys designed to examine regional-scale population trends, which often sample several hundred kilometers of coastline defined by state, provincial, or national boundaries. Second, other regional shark studies (e.g., Bethea et al. 2014, Bangley and Rulifson 2017, Bangley et al. 2018, Plumlee et al. 2018) have noted the importance of salinity, river mouths, and inlet distance in structuring shark catches. Canaveral is far removed from ocean inlets (> 30 km) and receives no freshwater inputs, and therefore offers a stable marine salinity regime. And as noted previously, scarcity of high-relief hard bottom may limit the presence of reef species to the benefit of non-reef associates whose distribution is more uniform across the continental shelf.

Figure 16. Sharks on the Southeast Shoal
Three nurse sharks (*left*) and a sub-adult lemon shark (*right*) on the ridge of the Southeast Shoal as observed from a helicopter June 2009. Photo credits: Russ Lowers.

It has been long recognized that many coastal sharks have discrete nursery habitats where females give birth and where young spend the first months or years of their life (Springer 1967, Castro 1993, Simpfendorfer and Milward 1993). Nurseries are selected based on factors including an optimal temperature and salinity regime, adequate food resources, and refuge from predators (Rountree and Able 1996, Branstetter 1990, Hopkins and Cech 2003). The exact definition of what defines a nursery (and which species have them) is a topic of continued debate (Heithaus 2007), but these areas generally sustain higher densities of young sharks than adjacent areas, sharks stay for extended periods, and the site is used repeatedly across years (Huepel et al. 2007). Based solely on the size distribution of sharks produced in the longline catch, support for nursery function of the Canaveral Shoals falls on a continuum with the best evidence for spinner, scalloped hammerhead, and sharpnose sharks, all of which appear to pup locally, along with lemon shark and blacktip shark, which are predictably present as larger juveniles but are known to give birth in coastal waters of Georgia and the Carolinas (Castro 2011).

When taking into account previous shark research at Cape Canaveral, this longline survey appears to considerably underestimate the local nursery value to lemon and scalloped hammerhead sharks in particular. For example, during the day, lemon sharks locally shelter in the surf zone (Reyier et al. 2008, 2014) where they are largely unavailable to longline gear (see **Section 3.3.10.4** for details on this behavior). But during a helicopter overflight in February 2017, an estimated 1,758 lemon sharks were counted over 29 km of the Canaveral shoreline, equating to one shark every 16 m (E. Reyier, unpubl.

data). Further, YOY scalloped hammerheads are known to be abundant in the Canaveral Bight (Adams and Paperno 2007) and can be collected with gill nets in large numbers. Gill net sampling to support various shark tagging and genetic studies resulted in the capture of 369 YOY hammerheads (mean 39 cm FL) in 66 hours from 2012–2016 (E. Reyier, unpubl. data). The species comprised 42% of the total shark catch from gill nets and many had open umbilical wounds in spring indicating a recent local birth (see **Section 3.3.10.5** for details).

The longline gear specifications and methods adopted for this study were chosen for their ability to quickly deploy and retrieve a large number of hooks, as well as for their selection for the large-bodied fish species likely to be of greatest management interest. Nonetheless, this gear still likely underrepresented the very largest sharks (e.g., bull, tiger, great hammerheads), which have the ability to sever gangions or the mainline (an occasional occurrence), as well as fishes who are not prone to taking baited hooks. Gill nets would provide a somewhat different species complement and, if paired with longlines, may produce a fuller picture of fish richness in the study area. For example, mobile pelagic teleosts, such as mackerel, bluefish (which are federally managed), and pelagic rays, may be better quantified. However, gill nets are more labor-intensive, resulting in a lower sample size and decreased power to discriminate across depth zones. Further, gill nets are not a permitted gear in east-central Florida from November to March in order to reduce entanglement risk of endangered North Atlantic right whales, which were observed directly on the Southeast Shoal during this study in January 2015 and January 2016. Finally, longline sampling was conducted only during the day since breaking waves on the shoal ridges are most hazardous at night. Studies have found that benthic fish communities associated with shoals may change between day and night (Diaz et al. 2003, Slacum et al. 2006), and this trend may also be true for sharks that depend on these fish as prey, an argument supported by the fact that day-night differences in foraging have been previously noted for several shark species (Driggers et al. 2012).

3 Fish Movement Patterns, Habitat Preferences, and Migration as Determined by Passive Acoustic Telemetry

3.1 Introduction

In recent years, acoustic telemetry has emerged as a powerful fishery-independent method for assessing the habitat requirements, migrations patterns, and survival of coastal fishes (Grothues 2009, Donaldson et al. 2014). The foundation of passive telemetry is arrays of submerged acoustic receivers (underwater tracking stations) that detect and record the presence of animals carrying acoustic transmitters. This approach has gained favor because it dramatically extends the duration and distance of animal tracking studies, revealing long-term behaviors generally unobtainable with traditional tag-recapture studies or active acoustic tracking (where individuals are followed with a mobile receiver). One limitation is that tagged animals are only detected when they pass within a few hundred meters of a receiver, a constraint that has hampered studies of highly mobile fish in the open ocean. This challenge is being overcome through the development of large multi-agency receiver networks where tag detection data are readily exchanged by researchers as animals pass by various locations along the coast. In the southeastern US, three major collaborative networks have taken shape, including the Florida Atlantic Coast Telemetry (FACT) Network[4] (which operates from the Carolinas though the Bahamas and Caribbean), the Atlantic Cooperative Telemetry (ACT) Network[5] (which covers the Carolinas though the Canadian Maritimes), and the Integrated Tracking of Aquatic Animals in the Gulf of Mexico (iTAG)[6] (which operates in the eastern and northern Gulf of Mexico) (**Figure 17)**. These collaborative projects have been rapidly expanding and now collectively maintain several thousand acoustic receivers deployed in a variety of coastal habitats from tidal freshwater rivers, open estuaries, nearshore surf zone and shoals, and offshore reefs and wrecks.

3.2 Methods

3.2.1 Acoustic Telemetry Array

Cape Canaveral has been incorporated within the FACT Network since its founding in 2008 and includes multiple tracking stations or "receivers" deployed in open coastal waters and throughout the adjacent IRL estuary. At the inception of this project in late 2013, the number of receivers deployed offshore Canaveral, hereafter referred to as the "Canaveral Array," was expanded from 28 to 57 receiver stations **(**VEMCO VR2W, Nova Scotia, Canada; **Figure 18**). These stations were deployed year-round and included nearshore sites to document animal movement along the shoreline (an important migratory corridor) as well as stations atop and between the major sand shoal features. This expansion also created a 12-station receiver ring immediately surrounding the CSII sand borrow area (dredge ring or "DRE" stations) on the Southeast Shoal and an identical ring at an undisturbed site on Chester Shoal (control ring or "CON" stations) chosen due to its similar habitat profile (**Figure 19)**. The purpose of these rings was to understand the seasonality and behavior of fish around the dredge site. **Section 3.2.3.3** provides a detailed rationale and description for this aspect of the study.

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[4] www.secoora.org/fact

[5] http://www.theactnetwork.com

[6] http://myfwc.com/research/saltwater/telemetry/itag/itag-network

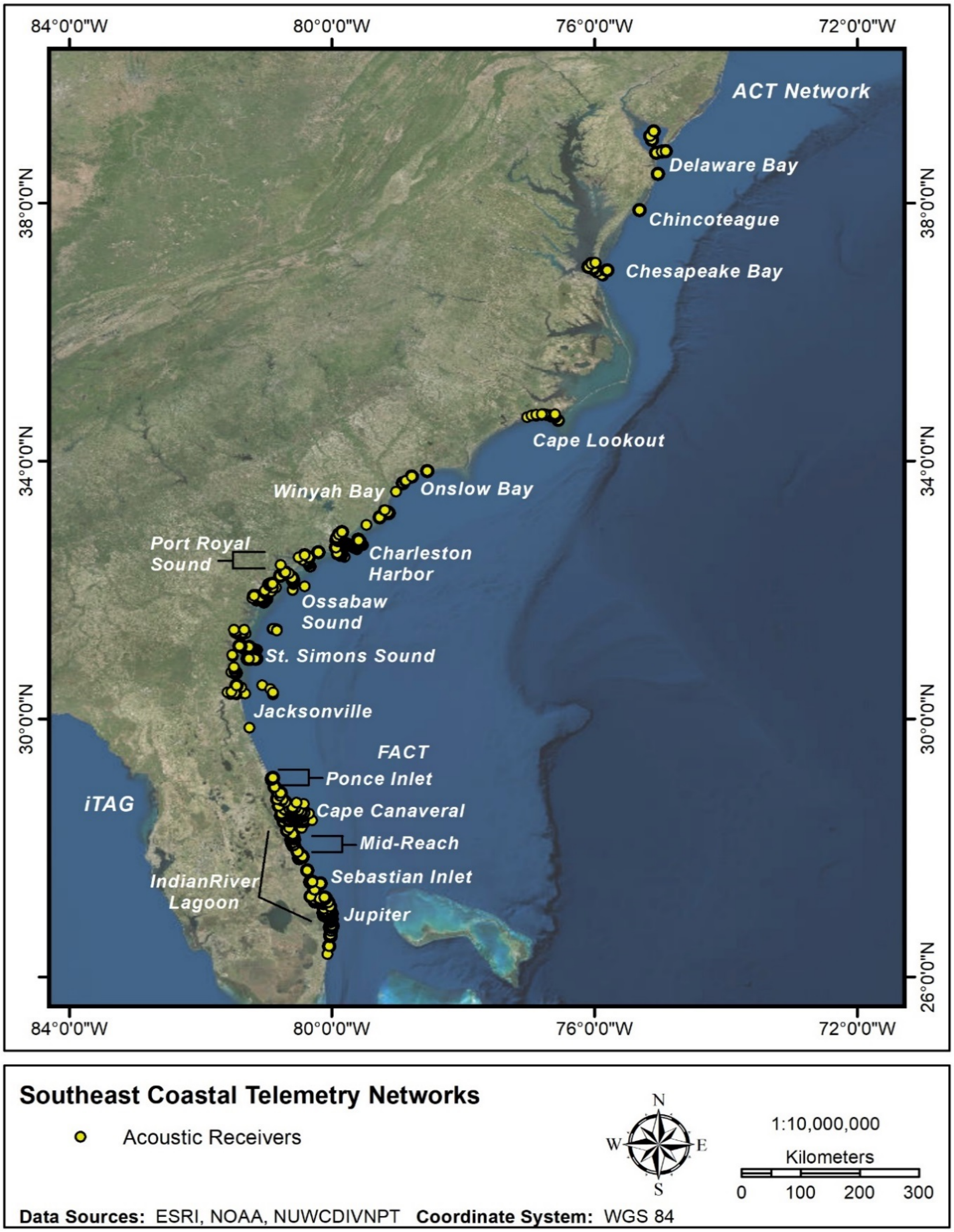


Figure 17. Acoustic telemetry network coverage in the US Southeast and Mid-Atlantic regions

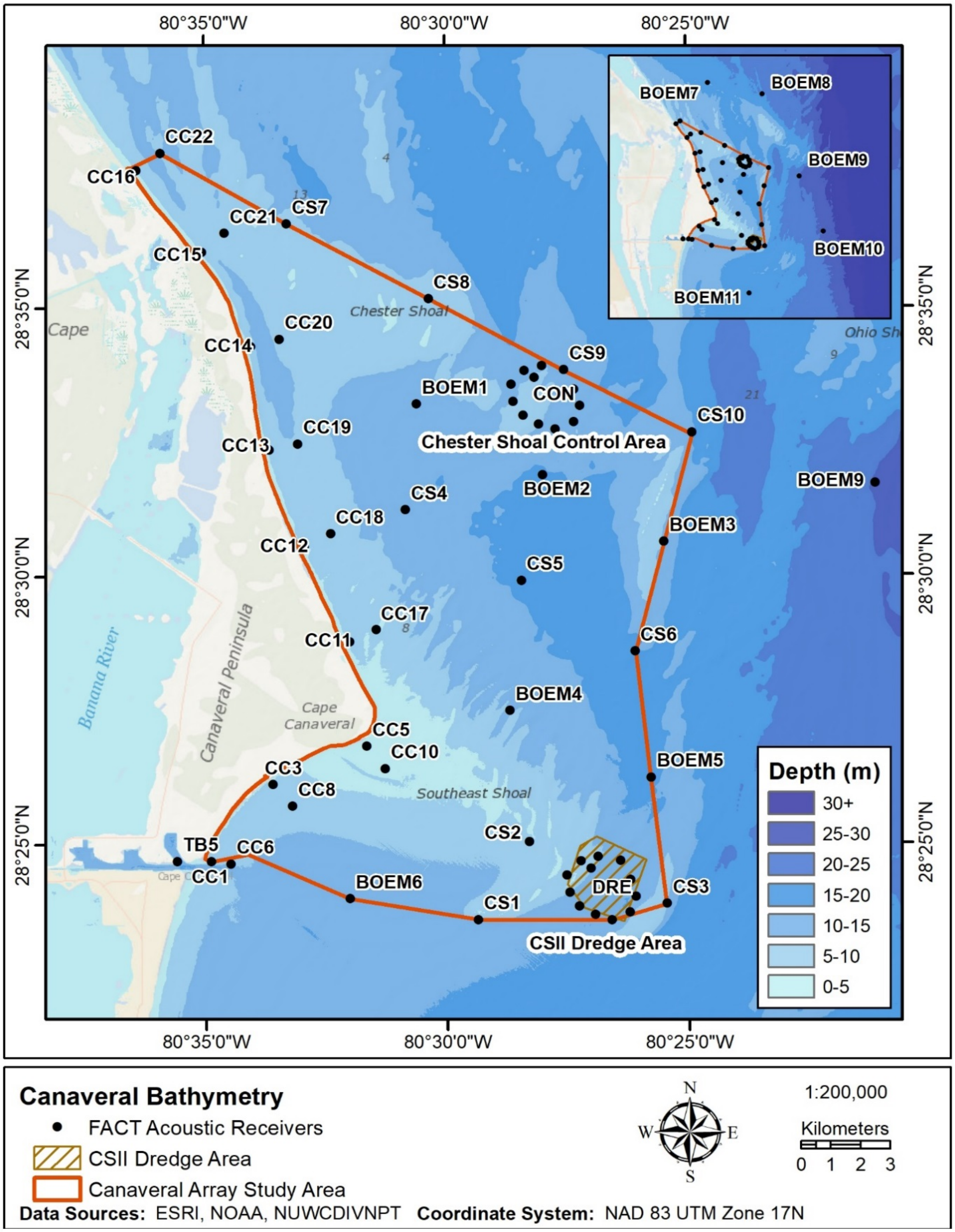


Figure 18. Map of the Canaveral Acoustic Telemetry Array, part of the larger FACT Network

A comparison of habitat conditions across different receiver station groups can be found in **Table 8** and **Figure 19** while values from individual stations are listed in Appendix C**.**

Table 8. Habitat characterization for acoustic receiver habitat types

Parameter	Dredge	Control	Shoal	Inter-Shoal	Shore
Depth (m)	9.5 (2.4)	10.2 (1.6)	10.0 (3.8)	13.4 (1.9)	5.6 (2.2)
Seafloor slope (m)	4.9 (1.2)	3.6 (1.1)	5.7 (3.6)	2.7 (2.1)	5.5 (3.6)
Distance from shore (km)	9.5 (0.9)	9.6 (0.8)	8.7 (3.3)	5.7 (1.9)	0.7 (0.5)
Sediment % fines	0.1 (0.1)	0.1 (0.1)	1.1 (2.4)	5.1 (5.7)	1.7 (3.3)
Sediment % organic	0.9 (0.1)	0.9 (0.1)	1.0 (0.4)	1.6 (0.5)	0.9 (0.5)

Note: Values are mean (SD).

In addition to receivers established in the immediate vicinity of the shoals, an additional five stations were established in September 2015 along the reef tract seaward of the shoals in order to document any exchange of animals between the two habitat types. Further, any animals migrating away from Cape Canaveral could be detected by other FACT, ACT, and iTAG stations at multiple points along the southeastern US coastline, including major receiver curtains off southeastern Florida and the Florida Keys; St. Simons Sound, Georgia; Port Royal Sound and Charleston Harbor, South Carolina; and Chesapeake Bay, Virginia.

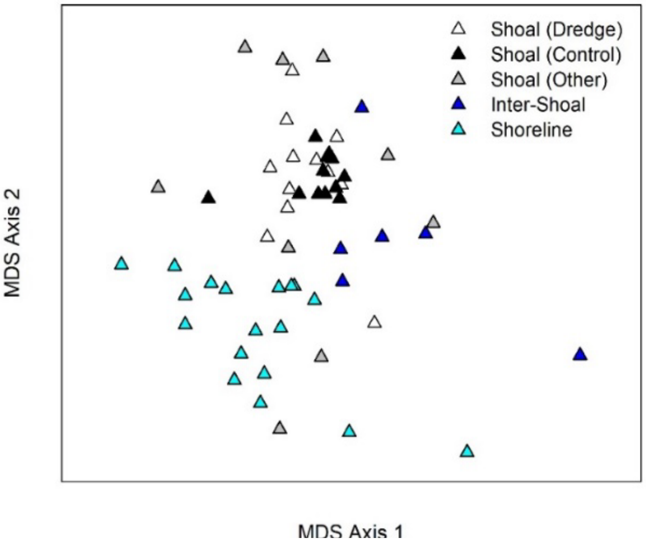


Figure 19. MDS plot of Canaveral Array receivers based on physical habitat characteristics
Each point represents a receiver station and the distance between stations is proportional to how similar they are in terms of water depth, distance from shore, seafloor slope, sediment % fines, and sediment organics.

Canaveral Array receivers were installed on the seafloor at depths from 1.4–25 m. Receivers near the surf zone were directly affixed to the top of 1.5 m sand screws with heavy duty plastic cable ties and stainless-steel safety cables, while those in deeper water were placed within 2 m tall "trawl-resistant" floats in order to minimize risk of loss to local shrimp trawlers and burial due to shifting sand on the shoals (**Figure 20)**. These floats were then attached to the seafloor using sand screws driven to grade or ~45 kg iron disk weights. Later models were protected with a hard plastic coating (Line-X brand) due to damage caused by burrowing animals and shark bites. All receivers were also coated with ablative anti-fouling paint and marked with "reward" stickers. In addition, water temperature loggers (Onset HOBO models U22-001 and TidbiT v2) were attached to a minimum of six receiver moorings including shoreline, shoal, and reef sites. Water temperature profiles are presented in **Section 1.6.2.**

Animal detection and water temperature data were retrieved during twice annual Canaveral Array servicing events using SCUBA. Each service event was a 6–8 day process but was often spread across 1–3 months, especially in winter, due to unsuitable weather for diving and low (less than 1 m) water visibility, which was common much of the year. Servicing of a typical site involved (1) marking the location with a dive flag to ± 3 m using GPS, (2) deploying divers to locate the existing mooring, often by conducting a circle search around the dive flag with a twine reel, (3) swapping the existing receiver with a new receiver and removing fouling from the mooring, and (4) returning to the boat to clean, download, and replace batteries in the recovered receiver to prepare for deployment at a future site.

Figure 20. Strategies for acoustic receiver deployment
Receivers were attached directly to sand screws at shallow, high energy sites (*left*) but were incorporated into trawl-resistant moorings in offshore areas where shrimp trawlers were more active (*center*). Shark bites (*right*), burrowing invertebrates, barnacles, and other fouling organisms added considerable time to array maintenance. Photo credits: Eric Reyier (right, left), Mike Arendt (center).

Range test trials with acoustic transmitters were performed in 2014 and 2015 to better understand detection distances that could be expected as animals moved through the Canaveral Array. Three separate multi-week trials were conducted, one each at the dredge ring and control ring, as well as one shallow shoreline site near station CC12 (**Table 9**). At all three sites, four high power (source level of 158 decibels referenced to 1 microPascal [dB re 1 µPa]) VEMCO V16 sentinel transmitters were deployed in a straight line 200, 400, 600, and 800 m away from a designated acoustic receiver. This tag model was the same used in the majority of large-bodied species under study including coastal sharks, red drum, red snapper, and cobia. Lower power (136 dB re 1 µPa B) V7 sentinel transmitters of the same style implanted into spot and Atlantic croaker were simultaneously deployed at 100, 200, and 300 m intervals for the dredge and control ring trials. Trials at these two sites were supplemented by other nearby receivers in each ring, providing the potential to record detections from up to 2,000 m away, albeit at less uniform distance intervals. In all cases, transmitters had a fixed 10-min ping rate and were positioned approximately 1 m off the seafloor using weights and small floats. Detection efficiency for each site and distance combination was estimated by dividing the detections received each day by the amount of detections possible in a day (144), and with detections at 0 m assumed to be 100%. These values were plotted and then fitted with a logistic regression curve to aid in visual interpretation. Wave height, an important factor in acoustic receiver performance, was averaged from a nearby wave buoy (NDBC Buoy 41009; **Figure 2**) for the duration of each trial to provide additional context for range test results.

Table 9. Details of acoustic range test trials in the Canaveral Array

Trial	Deployment Dates	Duration (Days)	Mean Depth (m)	Tag Type(s)	Mean Wave Height (m)
Dredge ring	Feb 19–Apr 1 2014	41	11.2	V16, V7	1.3
Control ring	Apr 25–Jul 24 2014	91	10.2	V16, V7	0.8
Shore	Aug 20 2014–Jun 7 2015	291	5.0	V16 only	1.2

3.2.2 Fish Collection and Tagging

A total of ten target fish species were selected as priorities for acoustic tagging: finetooth, blacknose, and sharpnose sharks, red drum, bluefish, Spanish and king mackerel, red snapper, spot, and Atlantic croaker (**Table 10**). These species were chosen for their local abundance, inclusion in FMPs, and/or their expected ecological importance to the benthic ecosystems potentially impacted by dredging activities. There were also practical considerations in that species were easily obtainable, large enough to carry acoustic transmitters, and not under intensive study by other regional researchers. Also classified here as target species for reporting purposes was a single roughtail stingray, which was opportunistically tagged on the Southeast Shoal and yielded unexpected results.

This project also took advantage of concurrent acoustic tagging underway locally, including a study by the authors evaluating the role of Cape Canaveral as a nursery for lemon and scalloped hammerhead sharks and a study examining cobia coastal migrations in an effort to refine cobia stock boundaries. The project also documented seasonal residence of many fish that were tagged by other researchers elsewhere along the US East Coast but subsequently passed through the Canaveral region. By convention, these data belong to the tagging agencies so only general trends in the abundance and seasonality of these species are presented.

Fish were collected for tagging using a variety of gears. Finetooth shark (n=61), blacknose shark (60), sharpnose shark (44), and red drum (83) were all primarily obtained via bottom longlines as they were encountered on the longline survey component of this study (see **Section 2.2.1** for capture methods). Animals were tagged throughout the Canaveral Shoals complex with VEMCO multi-year acoustic transmitters over 2–3 years as opportunity and resources allowed (**Table 10)**.

Bluefish (n=52), Spanish mackerel (49), king mackerel (41), and red snapper (14) were captured with hook-and-line angling. Bluefish were collected from shore while Spanish mackerel were generally obtained by visibly locating schools at the surface farther offshore. Both species were collected in the general vicinity of sand shoals and were tagged with transmitters with a battery life of 1.3 years. In contrast, all king mackerel and red snapper (whose tagging is ongoing) were collected along the reef tract east and northeast of the shoals. Although king mackerel are known to encroach onto the shoals on occasion, the timing of these inshore movements is difficult to predict. The degree to which red snapper use or transit the shoals was unclear but they were selected due to the intensive management interest the species now receives throughout the southeastern US.

Spot (n=107) and Atlantic croaker (n=132) were selected for their expected high abundance in the region, their role as an important forage species for many managed fish and marine mammals, and their benthic life history, which may leave them particularly susceptible to dredge-induced disturbance to the sea floor. The initial plan was to collect (via hook-and-line angling) and release 60 individuals of each species in separate winter (December 2013) and summer (June 2014) tagging events within both the dredge site and the control site (240 total fish). Lower than expected fish densities at these sites, especially for spot, made hook-and-line angling ineffective, however, so animals were instead obtained primarily with multiple short 5–10 min trawls using a for-hire shrimping vessel. Most individuals were collected from within the dredge and control site footprints, although very clear water in June 2014 required sampling up to 5 km inshore of the control site to acquire sufficient numbers of fish. Trawl-collected fish were placed in large holding tubs and only animals exhibiting minimal capture stress were retained. These individuals were transferred to onshore holding pens in Port Canaveral where they were tagged with VEMCO V7 acoustic transmitters, then released in the center of either the dredge or control site 24 hours later.

Table 10. Tagging details for target species released at Cape Canaveral

Size (cm) is listed as standard length for bony teleost fish, fork length for sharks, and disk width for rays. Details for other species tagged for concurrent telemetry studies at Cape Canaveral (e.g., cobia, lemon shark, and scalloped hammerhead) are also provided. All acoustic tags manufactured by VEMCO.

Target Species	No.	Mean Size (Range)	Sex Ratio (F:M)	Tagging Dates	Acoustic Tag Model	Tag Interval (sec), Batt (yrs), Pwr (dB)	Collection Gear
Atlantic croaker	132	19 (15–24)	-	Dec 2013–Jun 2014	V7-4L	60, 0.6, 136	trawl, hook-and-line
Blacknose shark	60	96 (89–115)	33:27	May 2014–Sep 2016	V16-4H or 6H	90, 5.2–9.7, 158	longline
Bluefish	52	30 (23–42)	-	Feb–Mar 2016	V9-2L	60, 1.3, 145	hook-and-line
Cobia	41	77 (59–98)	-	Dec 2014–Jul 2017	V16-4H	90, 5.2, 158	hook-and-line
Finetooth shark	61	104 (64–130)	39:22	Dec 2013–Sep 2016	V16-4H	90, 5.2–9.7, 158	longline
King mackerel	41	73 (60–98)	-	Jul 2015–Jul 2016	V13-1L	90, 2.7, 149	hook-and-line
Lemon shark	22	89 (55–143)	12:10	Dec 2009–Apr 2011	V16-4H or 6H	90, 5.2–9.7, 158	cast net, gill net
Red drum	83	79 (42–100)	-	Dec 2013–Dec 2016	V16-4H or 6H	90, 5.2–9.7, 158	longline
Red snapper	14	47 (37–72)	-	Nov 2017–Feb 2018	V16-4H	90, 5.2, 158	hook-and-line
Roughtail stingray	1	116	0:1	Jan 2015	V16-4H	90, 5.2, 158	longline
Scalloped hammerhead	40	45 (37–115)	17:23	May 2013–Sep 2014	V13-1L, V16-4H	90, 2.2, 149	gill net, longline
Sharpnose shark	44	74 (67–83)	24:19	Jul 2016–Aug 2017	V16-4H	90, 5.2, 158	longline, hook-and-line
Spanish mackerel	49	39 (31–49)	-	Apr 2015–Sep 2016	V9-2L	60, 1.3, 145	hook-and-line
Spot	107	17 (14–21)	-	Dec 2013–Jun 2014	V7-4L	60, 0.6, 136	trawl

Results for lemon sharks (n=22), scalloped hammerhead sharks (n=40), and cobia (n=41) are presented for individuals included in concurrent studies, but only if they were detected at Canaveral during the timeframe of the present study. Juvenile lemon sharks (54 originally tagged from 2009–2012) were collected with cast nets from winter surf zone aggregations along the Canaveral shoreline (Reyier et al. 2014). Scalloped hammerhead tagging (56 originally tagged) commenced in mid-2013. Juvenile hammerheads were taken on longlines, generally on the outer shoals while smaller YOY animals were collected with gill nets, primarily in the Canaveral Bight. A total of 140 cobia were collected via hook-and-line angling offshore Canaveral and other locations between South Carolina and Jupiter, Florida. Many of the 31 locally tagged fish were angled directly off manta rays as they moved into the shoal complex during summer cold-water upwelling events in July 2015 and August 2016.

Figure 21. Tagging an adult red drum with an internal transmitter

To anesthetize fish prior to tagging surgery, all teleost fish were quickly transferred to a water bath containing a solution of up to 0.75 mg/liter of MS-222; lower doses were used in mackerel. Sharks were inverted to induce tonic immobility (i.e., torpor) without this sedative, although intramuscular injections of lidocaine were made near the incision site. Once immobilized, fish were placed ventral side up in a v-board and a small bilge pump was placed in their mouth to circulate tank water across their gills. Any red drum or red snapper collected at greater than 15 m depth was first vented to reduce risk of barotrauma. A long-life acoustic transmitter was inserted into the body cavity and the 1–2 cm incision was closed with 2–3 absorbable sutures and Vetbond™ tissue adhesive **(Figure 21**).

Nine Spanish mackerel were fitted with externally attached transmitters for comparison purposes due to concern that the time and stress associated with internal tagging would result in high mortality. The sole roughtail stingray was also fitted with an external transmitter to avoid stress from landing. Transmitters are coded to allow identification of individual fish, pulsed at a 60–90 sec. intervals, and in all cases were less than 2% of fish body weight. Fish were measured, and most were marked with external dart tags, which offered a reward in case of later angler recapture and immediately released on site once they had recovered from sedation. Spot, croaker, bluefish, and Spanish mackerel did not receive external tags in an attempt to reduce stress on these smaller-bodied species. Total time from capture to release was generally less than 10 min with the exception of spot and croaker, which were held overnight prior to release. All surgical methods were conducted under the KSC Animal Care and Use Committee permit GRD-06-049 and renewals.

3.2.3 Data Analysis

Individual detection files from each receiver download event were collated into a central database (VEMCO VUE software), and the species identification of animals released by other researchers was resolved by consulting lists maintained by the FACT and ACT Networks or by contacting the tag manufacturer directly. Detection data were then exported for analysis by third party software. Due to the large volume of animal detections, a custom data script was developed in R statistical software to first screen, format, and calculate various indices of residency and movement for each individual and species. This data screening script first identified potential false detections that (infrequently) arise from tag code collisions or background noise. Specifically, it flagged data as “suspect” for any animal that entailed only a single detection within the Canaveral Array on a given day unless that animal was also detected the day prior or the day after in the study area. In total, false detections accounted for only 0.04% of all detections based on these criteria. The data screening script also flagged detections past the stated transmitter expiration date or known angler harvest events and highlighted individuals whose lack of movement may indicate mortality.

Behavior and habitat use analyses of acoustic telemetry data were not universally applied due to differences in total detections, track durations, and migratory patterns of target species. Further, in-depth analyses of non-target species tagged away from Cape Canaveral was not conducted to avoid revealing results of studies conducted by other researchers. An overview of which analyses were applied to each target species is found in **Table 11**.

Table 11. Telemetry analyses conducted for each target species

Species	Overview Behavior Metrics	Patterns in Community Structure	Space Use Maps (KUDs)	Visit Duration Models	Diel Shoal Use	Dredge & Control Site Use	Coastal Migration Plots
Finetooth Shark	✓	✓	✓	✓	✓	✓	✓
Blacknose Shark	✓	✓	✓	✓	✓	✓	✓
Sharpnose Shark	✓	✓	✓	✓	✓	✓	✓
Lemon Shark[1]	✓	✓	✓	✓	✓	✓	✓
Scalloped Hammerhead[1]	✓	✓	-	✓	✓	✓	✓
Roughtail Stingray	✓	✓	-	-	-	-	-
Red Drum	✓	✓	✓	✓	✓	✓	✓
Bluefish	✓	✓	✓	✓	✓	-	-
Spanish Mackerel	✓	✓	✓	-	-	-	-
King Mackerel	✓	✓	-	-	-	-	✓
Red Snapper	✓	✓	-	-	-	-	-
Cobia[1]	✓	✓	✓	✓	✓	✓	-
Spot	✓	✓	-	-	-	✓	-
Atlantic Croaker	✓	✓	-	-	-	✓	-
Non-Target Species	-	✓	-	-	-	-	-

[1] Indicates species included in acoustic telemetry studies simultaneously underway at Cape Canaveral

The following data were calculated from screened data:

Days at Liberty: the number of days between the release date and the date of last detection; useful for understanding the overall duration of an individual animal track.

Stations Visited: a tally of the total unique tracking stations visited anywhere within the FACT, ACT, and iTAG Networks; a simple proxy of space use for an individual.

Residency Index: a percentage calculated as the number of days detected within the Canaveral Array divided by the number of total days at liberty. This value provides a rough sense as to how much time an animal spent within the Cape Canaveral region.

Detection Index: a percentage calculated as the number of days detected anywhere divided by the total days at liberty; analogous to residency index but encompasses the entire geographic range of each animal, as detected on any receiver.

Consecutive Days Detected: the maximum number of consecutive days a fish was recorded in the Canaveral Array. This value was averaged for each individual and then for each species as an estimator of local site fidelity.

Distance Traveled (km): the minimum distance through water traveled by an animal as it transits between receiver stations. To return more accurate values, the script relied on the *marmap* package (Pante and Simon-Bouhet 2013) in R to account for complex shorelines (e.g., capes, inlets, rivers), so animal paths never crossed land. Distances between receiver stations less than 1 km apart were set to 0 since animals carrying powerful transmitters could conceivably be detected at two closely spaced stations simultaneously. These values were used to calculate observed rate of movement and overall dispersal.

Observed Rate of Movement (km/hr): distance traveled values coupled with detection timestamps were used to approximate the rate of movement (ROM) of tagged fish each time they traveled from one station to the next. These ROM events were then averaged across the study for each target species, and for eight species with the largest number of movement events, seasonal averages of observed ROM were calculated. This dataset was constrained only to movements occurring within the Canaveral Array, and only for events when animals traveled between 4–20 km between stations. ROM between stations spaced too closely together are overestimated during periods when tag signal propagation is high, while ROM over long distances will underestimate speed since the animal is more likely traveling in a non-linear fashion. This metric is not intended to measure true swimming speed but provides insights into life history strategy and is directly comparable across species carrying transmitters with identical power (see **Table 10** for transmitter details).

Overall Dispersal (km): the minimum straight-line distance between tagging location and last known detection for fish released at the dredge and control sites. This value was only calculated for spot and Atlantic croaker who were released at both sites in high numbers.

Visit Duration (min): as a separate metric of species mobility on the Canaveral Shoals, the time spent by each fish at each receiver station was calculated. A "visit" to a receiver station started at the first detection by an individual fish on at a station and ended when the fish was not detected again at the same station for > 60 min. If the fish, after being absent for > 60 min, was then detected again at that same station, it was considered a new visit. Since it is possible for an individual fish to be detected on two nearby stations within one hour, a flag was created to exclude visit duration events where a portion of the visit overlapped at another station.

Visit duration was assumed to provide valuable information regarding habitat suitability for a species within the Canaveral Array because animals presumably move more slowly through areas that offer optimal conditions for foraging, reproduction, and predator avoidance. To this end, visit duration values for several target species were used as a dependent variable in general linear models designed to explore which environmental conditions (e.g., season, temperature, water depth, seafloor slope) influence site fidelity within the Canaveral Shoals. Details of this modeling are found in **Section 3.2.3.4**.

3.2.3.1 Patterns in Community Structure

The multi-year study timeline and large numbers of acoustically tagged individuals and species active off east Florida allowed animal detections at a given station to be treated as a sample for that area, which in turn allowed for community comparisons across predefined habitat types. For each station of the Canaveral Array, a sample was constructed by tallying the total number of individuals detected for each species during the study. Since receiver performance is known to vary by depth, sea state, and other factors, these values were converted to percentages so the ratio of individuals across species (not raw animal counts) were used to explore community patterns. Each station was then classified *a priori* as one of three major habitat types including shoreline (those stations within 1.5 km of the coast), reef (stations on the offshore reef tract), and shoal complex (all stations in between). Two stations each in the dredge (DRE9 & 10) and control ring (CON 5 & 6) were excluded from this analysis because they went unmonitored for several months due to receiver loss after Hurricane Matthew (Oct 2016) and/or Hurricane Irma (Sep 2017).

Using procedures similar to that applied to longline catch samples (see **Section 2.2.2**), sample values were root-transformed to allow rarer species to contribute to site discrimination, and a similarity matrix was calculated for each pairwise sample combination using the Bray-Curtis coefficient. This matrix was used as a basis for a one-way ANOSIM (to formally test for significant differences in the species assemblage across habitat types) and for an MDS plot to visualize these differences. A BEST procedure was then used to determine which available habitat covariates most strongly correlate with and "explain" community composition. These covariates included water depth (m) at a station, seafloor slope (variation in depth within 500 m radius of a station), distance from shore, latitude, sediment percent fines (fraction of sediment passing through a 63 µm sieve), and sediment percent organics. Multivariate analyses were conducted with PRIMER 6.0 statistical software. Finally, Spearman's rank correlation was used to explore for simple trends in species counts and diversity (H') at each station in response to water depth and distance from shore.

3.2.3.2 Space Use Relative to Water Depth and Sediment Type

Detections from within the Canaveral Array were used to produce detailed habitat association maps for eight target fish species including finetooth, blacknose, sharpnose, and lemon shark, red drum, bluefish, Spanish mackerel, and cobia. Kernel Density Estimation (KDE) techniques were first applied to identify areas of concentrated use by each species and to quantify how these areas overlapped local bathymetry and sediment types. KDE methods are used to quantify space use for an individual by creation of utilization distribution (UD) map contours that help visualize an area where an animal has a certain probability of being located. KDE was preferred here to calculate point density without a temporal component and is suitable for datasets with irregular detection times. Other estimation methods (e.g., Brownian Bridge estimation) assume that consecutive locations are independent in order to interpolate positions between detections, whereas KDE provides a tool to handle this non-independence and examine relative use of areas for large datasets.

KDEs were then used to generate UD maps for individual fish using a customized model based on the "kernels with barriers tool" in ArcGIS™ 10.2 (ESRI, Redlands, CA). The bandwidth or search radius controls the probability spread around a particular point and the smoothness of the density estimate. The default search radius in ArcGIS™ 10.2 was used due to the high variability in detection data with sparse data for some seasons. The search radius or bandwidth selection in the tool is optimized for each individual based on the input data, and this method also corrects for spatial outliers in the data. The bandwidth controls the smoothing for the kernel density distribution and smaller values are more indicative of a larger sample set available. A summary of bandwidth parameters is provided in Appendix D.

KDEs were first calculated from the average acoustic telemetry position of each fish (i.e., mean of receiver locations weighted by the number of detections in a given time window; Heupel et al. 2004, Simpfendorfer et al. 2002, Simpfendorfer et al. 2012). For this dataset, average 12-hr position estimates were used. Because closely spaced receivers may overestimate an animal's use of a given area, stations with overlapping detection ranges (i.e., dredge ring, control ring, and paired stations along the beach) were grouped and averaged prior to KDE calculations. This created a roughly uniform spacing in receiver locations across the Canaveral Array.

Average position estimates for each individual fish were pooled by season across years prior to output of KDEs and generation of 50% UDs (i.e., core use area) and 95% UDs (i.e., activity space). The absolute size (km^2) of the 50% and 95% UDs within the Canaveral study area were then averaged for each species. Individual UDs were used to calculate average overlap of 50% UDs with local bathymetry contours (0–5 m, 5–10 m, 10–15 m, 15–20 m) and sediment percent fines. For sediments, 390 core sampling locations collected by the University of Florida within the study area (**see Section 1.6.3**) were used to create a set of Thiessen polygons, which were converted to a raster based on sediment percentage values with a cell size matching the KDE analysis. The raster was reclassified into bins (0–5%, 5–10%, 10–15%, 15–20%, 20–25% fine sediments) and the overlap of 50% UDs with each of these bins was calculated for each fish (normalized by sediment % fines available) and summarized by species and season. Within the project boundaries, areas with greater than 10–25% sediment fines are mostly associated with the Canaveral Bight. Habitats with 5–10% sediment fines are typically associated with inshore areas between Chester and Southeast Shoals, while the 0–5% fine sediments class is indicative of high energy areas along the beach or the shoal complexes themselves. Finally, distribution contours for individual fish were stacked in composite maps to determine which areas of the Canaveral Shoals were utilized by the most individuals in a given season.

3.2.3.3 Fish Use of the Dredge and Control Site

Twelve receivers were deployed at both the dredge site and nearby control site for the duration of the study (4.25 years) to determine if the dredge site exhibited reduced use by fish at an individual or species level, or if overall community composition of detected fish was dissimilar to undisturbed shoals. Stations at the dredge site were spaced roughly 600 m apart in a rough circle and were either moored just outside the dredge footprint or at archeological sites within the footprint that were off limits to dredging due to unknown objects (possibly historic rocket debris) noted during earlier magnetometer surveys. Although placing receivers on the edge of the dredge footprint meant that animals outside of the footprint would also be detected on dredge ring receivers, it was necessary because receivers moored inside the footprint would otherwise be dislodged or destroyed by (and possibly damage) the dredge. Acoustic receivers at the control site had no such logistical constraints, but an identical receiver layout was adopted to keep dredge vs. control comparisons as similar as possible.

Comparisons in fish use between the dredge and control sites were explored in several ways. First, individual and species counts were tabulated separately for each site to provide a simple tally of all species detected as well as their seasonal abundance trends. To explore for overall community differences, a one-way ANOSIM and related MDS plot were applied to test if the species assemblage of tagged animals differed across the two sites, which was followed with a SIMPER procedure to identify the species most responsible for those observed differences. Finally, differences in species behavior was explored by calculating the average visit duration of all species detected at either the dredge or control sites and by calculating the overall dispersal of spot and Atlantic croaker, the two target species released inside the dredge and control site footprints in large numbers.

Two dredging events occurred at the CSII site during the study (November 2013–April 2014 and again in January–April 2018), providing an opportunity to observe fish behavior in concert with sand borrowing activity. Detections from all species on the dredge ring were first pooled on a daily basis for analysis. The time periods before, during, and after dredging were then examined in 2014 and 2018 by fitting generalized additive models (GAMs) using the *mgcv* package in R (Wood 2011). The goal of the model was to explore for trends in the number of animal detections before, during, and after active dredging. Although dredging started end-November 2013, benthic forage fish (spot or Atlantic croaker) were tagged subsequent to this in early December. Additionally, there was a work stoppage from 1/28/14–2/25/14 due to equipment issues. As a result, this stoppage window with no dredging was used as the "before" period for analysis of the 2014 event.

The time windows before, during, and after active dredging were quantized into 14 8-day (2014) or 9-day (2018) time blocks, creating three "before," seven "during," and three "after" time blocks. The total number of detections in each block was then summarized as inputs to the models and the model was fit with time block as the explanatory variable. GAMs were considered for Poisson, negative binomial, and zero-inflated Poisson (ziP) models as all may be appropriate for count data with zeros (Zuur et al. 2009). Model selection was performed by examining a combination of deviance explained, residual diagnostics, and relative AIC values. ZiP GAMs with a smoothing function for time blocks were selected and fitted to data for both years. Final models were examined for changes in detections as a function of time blocks through the time series.

3.2.3.4 Visit Duration Modeling

Tagged fish moved through the Canaveral Array at varying speeds, and the time an individual spends at a given site is likely to be influenced by local habitat quality and life history traits. Linear mixed effects models were developed for eight target species to examine the relationship between visit duration (in min) at receiver stations and various habitat conditions. The eight target species (finetooth, blacknose, sharpnose, lemon, and scalloped hammerhead sharks; red drum; bluefish; and cobia) chosen for this modeling were selected due to their large datasets and because they represent a mixture of life history strategies.

Several habitat covariates were included in the global model, all of which have the potential to influence fish site fidelity, and model selection was used to identify the best model for each species. Habitat covariates included season, water temperature, depth, distance from shore, seafloor slope, solar irradiance, sediment percent fines, and sediment percent organics. Latitude was also included in the model as a proxy for unmeasured conditions (e.g., turbidity, distance from hard bottom), which may be collinear with latitude. Solar irradiance data were acquired from the National Renewable Energy Laboratory (NREL 2017). Season was included as a fixed categorical variable in order to relate season to life history characteristics, and individual fish was included as a random effect. Models were fit in R using the *lme4* package (Bates et al. 2015) with model selection performed using the *lmerTest* package (Kuznetsova et al. 2017. The dependent variable (visit duration) was first log transformed, and all continuous habitat variables were standardized so their relative influence could be directly compared (Schielzeth 2010). Model assumptions were checked using residual plots and quantile-quantile plots (Zuur et al. 2009). Evidence ratios were calculated based on AIC scores of the global model vs. the null model (Anderson and Burnham 2002). Estimated marginal means were calculated for season for comparison in caterpillar plots using the *emmeans* package (Lenth 2018).

3.2.3.5 Daily Patterns in Shoal Use

Previous studies of shoal fish communities have suggested possible day-night differences in abundance, with use of shoals being elevated at night. Daily patterns of shoal use by fishes was explored locally by examining raw detections from a subset of shoal receiver stations (CC10, CC17, CC20, CC21, CON5, CON6, CS2, CS7, CS8, DRE9, DRE10; **Figure 18**) that did not have detection ranges overlapping other habitat types. Detections were considered to be directly proportional to time a species spent on the shoals, and the maximum contribution of any individual to the species total ranged from 5% (red drum) to 36% (scalloped hammerhead). Each detection was first categorized as either day, night, dawn, or dusk based on published sunrise and sunset times for its date of occurrence. Detections were classified as dawn if occurring within an hour of sunrise, and dusk if occurring within an hour of sunset. A Pearson's chi-squared test was then performed to assess if observed detection counts differed from what would be expected by chance. The expected probability for both dawn and dusk detections on a given date was always 0.083 (2 hours/24 hours). The expected probability for day and night detections on a given date was calculated from the time difference between sunrise/sunset values (which vary throughout the year) but always accounted for two hours each at dawn and dusk. Tests were run separately for the eight target species who had the most detections on the Canaveral Shoals including finetooth, blacknose, sharpnose, lemon, and scalloped hammerhead sharks, red drum, bluefish, and cobia.

3.2.3.6 Target Species Summaries

Summary accounts were developed for each target species to provide the reader a concise species-level synopsis of local behavior and, in particular, to describe the timing and geographic extent of coastal migrations. Migrations away from Canaveral were common for many species and were summarized from detection data provided by FACT and ACT Network partners working at other locations along the US East Coast. To aid in interpretation, counts of individuals within a species were grouped by month (irrespective of year) and by state for each state from Florida through Virginia. Water temperatures associated with migrations were obtained from the NOAA NDBC (NDBC 2018), which maintains oceanographic buoys at in representative areas for each state, and were overlaid on detection plots.

3.3 Results

3.3.1 Range Testing Summary

Range testing with acoustic receivers confirms that acoustically tagged animals can typically be detected over a distance of several hundred meters when passing through the Canaveral Array. When considering all three range test trials, the percentage of high power (model V16) tag transmissions that were successfully logged on acoustic receivers averaged 81% at a distance of 200 m, 50% at 400 m, 23% at 600 m, and 10% at 800 m. There was considerable site variability, however, with the shore range test location having the lowest detection rate at all distance intervals (**Figure 22**), likely due to the shallow depth (5 m) and proximity to the surf zone, both factors expected to degrade acoustic signal propagation. There was also variability between offshore sites with detection rates near the control ring generally higher than the dredge ring, despite similar depths. This discrepancy may include a temporal component because the dredge ring trial was conducted in winter and spring during higher seas (mean wave height 1.3 m), while the control ring trial extended into summer with calmer conditions (mean wave height 0.8 m). Range test tags at both sites were also logged by other nearby receivers out to maximum distance of 1,700 m but were infrequent. As expected, detection distances of low power transmitters (model V7) were less, averaging 46% at 100 m, 20% at 200 m, and 12% at 300 m. Performance between the dredge and control rings was more similar, and a small number of detections (< 1%) were logged out to nearly 800 m.

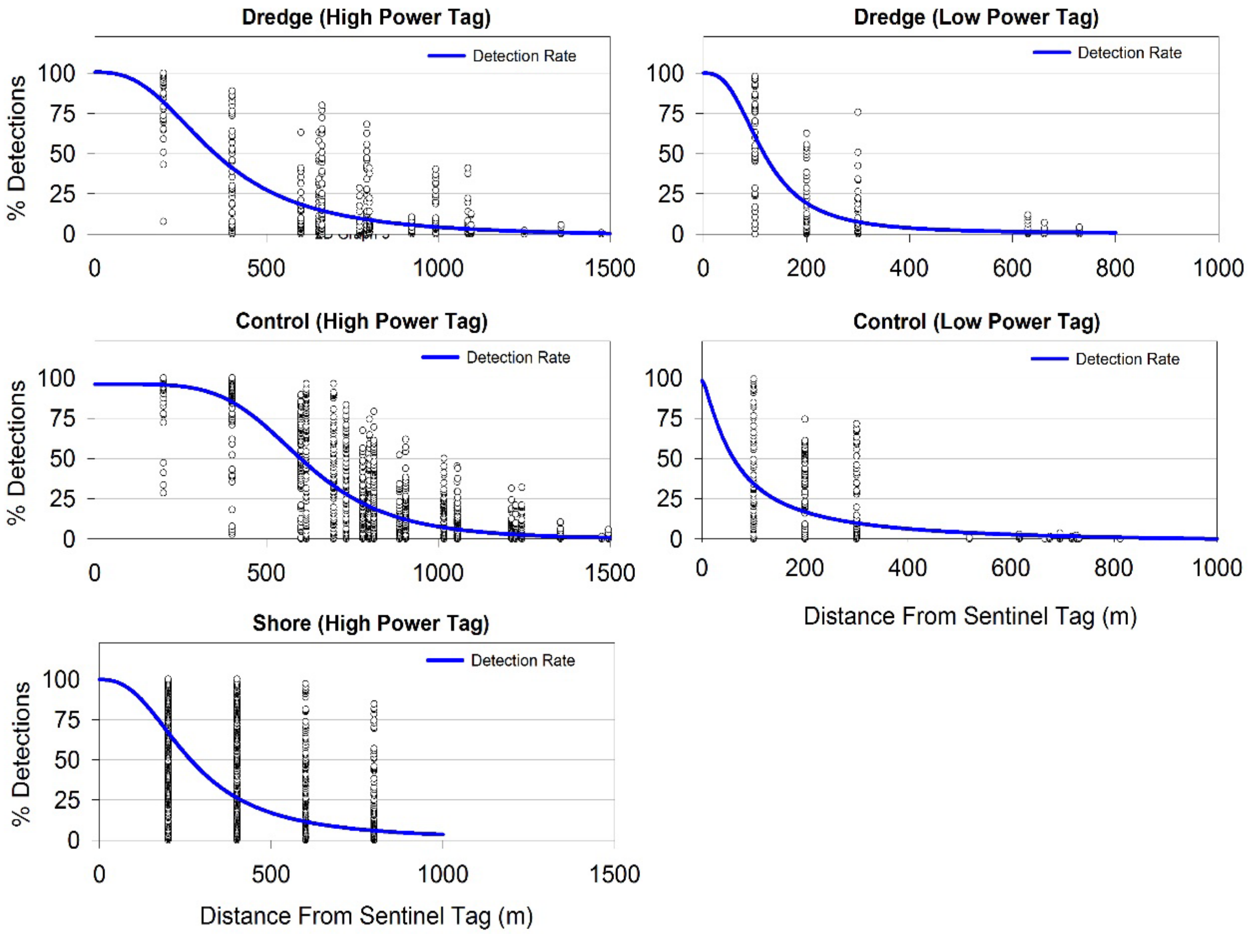


Figure 22. Results of acoustic transmitter range test trials in the Canaveral Array
Each open circle represents the daily detection rate at a given distance, and the blue line represents the best fit through these values. Battery expiration precluded range testing of V7 transmitters at the shoreline site.

3.3.2 Overview of Fish Detections

Over the 4-year study, 926 acoustically tagged fish from 39 species were detected within the Canaveral Array, including 16 species of teleost fish, 15 species of shark, and 8 species of benthic and pelagic rays. This number includes 581 individuals in 14 species targeted for this and concurrent acoustic telemetry studies by the authors at Cape Canaveral (**Table 12**), as well as an additional 345 individuals and 28 species released by 31 other research organizations at various locations along the coast (**Table 13**). These non-target species were originally tagged over a wide breadth of coastline from New England (e.g., sand tiger shark, white shark), the mid-Atlantic (e.g., Atlantic sturgeon, cownose ray), the Carolinas and Georgia (tripletail, sandbar shark), southern Florida (tiger shark, smalltooth sawfish), west Florida (cobia, tarpon), and the Bahamas (nurse, tiger and bull sharks). Twenty-one of the species detected are covered under federal FMPs, with many others actively managed at the state level. Also detected locally were 12 ESA-listed Atlantic sturgeon and three smalltooth sawfish, all originally released several hundred kilometers outside the Canaveral Array. The most widely ranging species within the Canaveral Array were red drum, plus finetooth, blacknose, lemon, blacktip, bull, and scalloped hammerhead sharks, all of which were detected at 60 or more stations.

Table 12. Target fish species detected by the Canaveral Array

Species in bold have local EFH designations. Species in underscore are listed under the US Endangered Species Act. Detection Data from receiver stations to the north and south of Canaveral are not included. All detections from Dec 2013 through February 2018.

Target Species	Tagging Location	Tagging Agencies[1]	Animals Detected				Total Detections
			All Canaveral	Dredge Site	Control Site	Offshore Reefs	
Red drum	Canaveral	NUWC, KSC	81	71	35	35	1,054,221
Blacknose shark	Canaveral	NUWC, KSC	55	44	43	44	534,681
Red snapper	Canaveral	NUWC, KSC	12	0	2	12	201,537
Finetooth shark	Canaveral	NUWC, KSC	55	46	36	43	183,126
Lemon shark (juvenile)	Canaveral, GA	BBFS, JU, KSC	22	16	13	8	76,290
Sharpnose shark	Canaveral	NUWC, KSC	36	10	24	22	39,712
Scalloped hammerhead	Canaveral	KSC	39	10	8	3	16,683
Cobia	Canaveral, SC, S FL	FWC, KSC, SCDNR	42	13	22	35	13,070
Bluefish	Canaveral	NUWC, KSC	48	3	1	1	5,968
Spot	Canaveral	NUWC, KSC	62	31	32	NA[2]	5,136
Atlantic croaker	Canaveral	NUWC, KSC	91	35	50	NA[2]	3,904
King mackerel	Canaveral	NUWC, KSC	5	1	2	4	2,100
Spanish mackerel	Canaveral	NUWC, KSC	30	10	7	1	1,058
Roughtail stingray	Canaveral	NUWC, KSC	1	1	1	0	406
Total	-	-	581	291	276	208	2,137,892

[1] BBFS = Bimini Biological Field Station, FWC = Florida Fish & Wildlife Conservation Commission, JU = Jacksonville University, KSC = Kennedy Space Center, NUWC = Naval Undersea Warfare Center, SCDNR = South Carolina Department of Natural Resources

[2] No fish of this species with active transmitters were available for detection, as these stations were established subsequent to expiration of tags.

Table 13. Non-target fish species detected by the Canaveral Array

Non-target species are those tagged for other research projects but detected locally. Species in bold have local EFH designations. Species in underscore are listed under the US Endangered Species Act. All detections from Dec 2013 through February 2018.

Non-Target Species	Tagging Location	Tagging Agencies[1]	Animals Detected				Total Detections
			All Canaveral	Dredge Ring	Control Ring	Offshore Reefs	
Blacktip shark ***(Carcharhinus limbatus)***	Bahamas, South FL, SC, VA	BBFS, CCU, FAU, SERC, SCDNR,	72	49	44	58	45,486
Tripletail *(Lobotes surinamensis)*	GA	GADNR	5	3	0	0	42,272
Goliath grouper ***(Epinephelus itajara)***	South FL	FSU, Mote	10	6	5	7	28,102
Tarpon *(Megalops atlanticus)*	South FL, SC	BTT	14	7	4	4	25,964
Smooth butterfly ray *(Gymnura micrura)*	Canaveral	UF	14	7	1	0	20,130
Lemon shark (adult) *(Negaprion brevirostris)*	Bahamas, south FL	BBFS	40	17	11	11	18,391
Cownose ray *(Rhinoptera bonasus)*	GA, VA	FSU, HBOI, SERC, UF	51	23	18	24	13,297
Bull shark ***(Carcharhinus leucas)***	Bahamas, Indian River, south FL	BBFS, CEI, RSMAS, SBU, SERC	20	13	14	13	5,102
Sand tiger shark ***(Carcharias taurus)***	DE, MA	DESU, MU, MADMF	8	1	2	1	2,422
Red drum (juvenile) ***(Sciaenops ocellatus)***	Canaveral	KSC	3	1	3	2	2,401
Tiger shark ***(Galeocerdo cuvier)***	Bahamas, SC	RSMAS, SCDNR	11	6	5	10	2,362
White Shark ***(Carcharodon carcharias)***	MA	MADMF	21	10	8	9	2,207
Bonnethead shark ***(Sphyrna tiburo)***	GA, NC, SC	FSU, UNC, SCDNR,	24	2	9	17	1,669
Smalltooth sawfish *(Pristis pectinata)*	South FL	NOAA	3	2	1	2	1,656
Nurse shark ***(Ginglymostoma cirratum)***	Bahamas	BBFS, HBOI	5	3	2	4	1,409
Atlantic sturgeon *(Acipencer oxyrinchus)*	DE, NC, NJ, SC, VA	DESU, MU, SCDNR, USN, VIMS	12	1	5	4	1,201
Bluntnose stingray *(Dasyatis say)*	Canaveral	UF	1	1	0	1	1,042
Southern stingray *(Dasyatis americana)*	Canaveral	UF	1	1	0	1	856
Spotted eagle ray *(Aetobatis narinari)*	Indian River	HBOI	3	1	1	1	721

[1] BBFS = Bimini Biological Field Station, BTT= Bonefish & Tarpon Trust, CCU = Coastal Carolina University, CEI = Cape Eleuthera Institute, CU = Clemson University, DESU = Delaware State University, FAU = Florida Atlantic Univ., FSU = Florida State University, FWC = Florida Fish & Wildlife Conservation Commission, GADNR = Georgia Department of Natural Resources, JU = Jacksonville University, KSC = Kennedy Space Center, MADMF = Massachusetts Division of Marine Fisheries, MU = Monmouth University, NCDMF = North Carolina Division of Marine Fisheries, NOAA = National Oceanographic and Atmospheric Administration, NUWC = Naval Undersea Warfare Center, RSMAS = Rosenstiel School of Marine and Atmospheric Science, SBU = Stony Brook University, SCDNR = South Carolina Department of Natural Resources, SERC = Smithsonian Environmental Research Center, UF = University of Florida, UNC = University of North Carolina Chapel Hill, USN = US Navy (VA), VIMS = Virginia Institute of Marine Science.

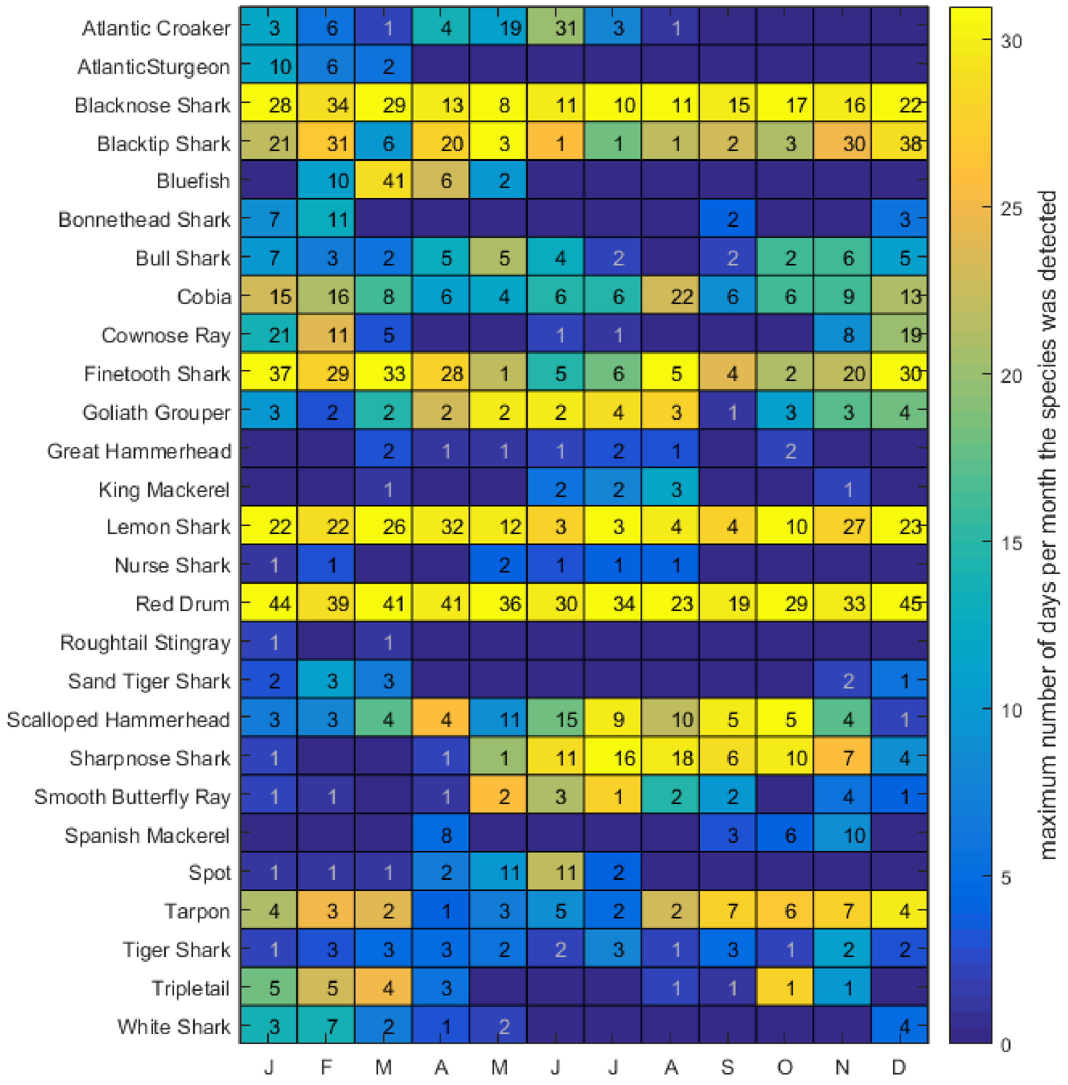
Table 13 (cont'd). Non-target fish species detected by the Canaveral Array

Non-Target Species	Tagging Location	Tagging Agencies[1]	Animals Detected				Total Detections
			All Canaveral	Dredge Ring	Control Ring	Offshore Reefs	
Spinner shark ***(Carcharhinus brevipinna)***	Canaveral	KSC	4	3	1	0	546
Black drum *(Pogonias cromis)*	Indian River	KSC	2	0	0	0	234
Great hammerhead ***(Sphyrna mokarran)***	Bahamas, South FL	BBFS, RSMAS	11	3	1	4	228
Blacknose shark ***(Carcharhinus acronotus)***	Canaveral	KSC	1	1	0	0	182
Sandbar shark ***(Carcharhinus plumbeus)***	GA	CCU	3	0	1	3	181
Stoplight parrotfish *(Sparisoma viride)*	South FL	CU	1	0	1	1	165
Bullnose ray *(Myliobatis freminvillei)*	Canaveral	UF	2	1	0	0	136
Gulf flounder *(Paralichthys albigutta)*	Canaveral	UF	2	0	1	0	83
Summer flounder *(Paralichthys dentatus)*	Canaveral	UF	1	1	0	0	7
Total	-	-	345	163	138	177	218,452

3.3.3 Seasonal Occurrence of Fish at Cape Canaveral

A summary of species detections across months illustrates the high variability in seasonal abundance and residency of tagged fish within the Canaveral Array. Among elasmobranchs, finetooth, blacknose, and juvenile lemon sharks were most abundant in winter and early spring (**Figure 23**). Scalloped hammerhead were best represented spring through fall, and detections of sharpnose shark were highest in summer and fall. Other elasmobranchs detected included primarily cool-season species (blacktip, sand tiger, white, bonnethead, and adult lemon sharks, cownose rays), warm season species (nurse and great hammerhead sharks, smooth butterfly rays), or year-round (bull and tiger shark). For many shark species, however, detections commonly occurred well outside their seasons of peak abundance revealing some complexity in their migration patterns along the coast.

Red drum, tarpon, goliath grouper, and cobia all had individuals present in the Canaveral Array throughout the year, while Atlantic sturgeon and tripletail were mostly present in the colder months. Detections of king mackerel, Spanish mackerel, and bluefish were sporadic with individuals generally remaining in the array for a few days post-tagging. Spot and Atlantic croaker are presumed to have a year-round presence but were mostly detected in the few months following when they were tagged (December and May), which limited ability to document seasonal trends.



	J	F	M	A	M	J	J	A	S	O	N	D
Atlantic Croaker	3	6	1	4	19	31	3	1				
AtlanticSturgeon	10	6	2									
Blacknose Shark	28	34	29	13	8	11	10	11	15	17	16	22
Blacktip Shark	21	31	6	20	3	1	1	1	2	3	30	38
Bluefish		10	41	6	2							
Bonnethead Shark	7	11							2			3
Bull Shark	7	3	2	5	5	4	2		2	2	6	5
Cobia	15	16	8	6	4	6	6	22	6	6	9	13
Cownose Ray	21	11	5			1	1				8	19
Finetooth Shark	37	29	33	28	1	5	6	5	4	2	20	30
Goliath Grouper	3	2	2	2	2	2	4	3	1	3	3	4
Great Hammerhead			2	1	1	1	2	1		2		
King Mackerel			1			2	2	3			1	
Lemon Shark	22	22	26	32	12	3	3	4	4	10	27	23
Nurse Shark	1	1			2	1	1	1				
Red Drum	44	39	41	41	36	30	34	23	19	29	33	45
Roughtail Stingray	1		1									
Sand Tiger Shark	2	3	3								2	1
Scalloped Hammerhead	3	3	4	4	11	15	9	10	5	5	4	1
Sharpnose Shark	1			1	1	11	16	18	6	10	7	4
Smooth Butterfly Ray	1	1		1	2	3	1	2	2		4	1
Spanish Mackerel				8					3	6	10	
Spot	1	1	1	2	11	11	2					
Tarpon	4	3	2	1	3	5	2	2	7	6	7	4
Tiger Shark	1	3	3	3	2	2	3	1	3	1	2	2
Tripletail	5	5	4	3				1	1	1	1	
White Shark	3	7	2	1	2							4

Figure 23. Seasonal presence of tagged fish within the Canaveral array
The color of each square represents the maximum number of days the species was detected in a given month, while the number in each square represents the maximum number of individuals of a species that were detected in a given month for any year in the study. Only species where more than five individuals were detected were included.

Days at liberty for target species ranged 1 day to 6.5 years (**Table 14**). Individual red drum, finetooth sharks, and blacknose sharks were detected on the most receivers, confirming widespread movement within the Canaveral Array. Those three species, along with lemon sharks, also had the highest average days at liberty. Red snapper had by far the highest mean number of consecutive days detected, over 18 days (although their days at liberty were fairly low) followed by red drum, at just over 4 days. The highest number of consecutive days detected for any individual included a single red snapper detected for 94 days in a row, a blacknose shark for 85 days, a red drum for 68 days, a lemon shark for 52 days, and a scalloped hammerhead for 45 days.

Table 14. Movement metrics for target species released at Cape Canaveral

Details for other species tagged in related local telemetry studies are also listed. Values are means averaged across individuals within a species with range in parentheses. Details of these metrics are found in **Section 3.2.3**.

Target Species	Number Detected	Days at Liberty	Stations Visited	Residency Index (Canaveral)	Detection Index (All)	Consecutive Days Present
Atlantic croaker	91	16 (1–215)	3 (1–14)	85 (1–100)	85 (1–100)	1.0 (1)
Blacknose shark	56	798 (5–1,184)	45 (1–77)	20 (1–100)	23 (2–80)	3.0 (1–82)
Bluefish	48	17 (1–208)	6 (1–22)	54 (4–100)	58 (8–100)	1.9 (1–7)
Cobia	41	316 (4–927)	14 (1–56)	9 (1–75)	9 (1–75)	1.5 (1–9)
Finetooth shark	55	841 (1–1,535)	62 (1–110)	16 (1–100)	23 (4–100)	3.0 (1–27)
King mackerel	5	63 (1–129)	11 (1–26)	43 (3–100)	44 (7–100)	1.6 (1–11)
Lemon shark	22	1,939 (211–2,362)	30 (7–45)	18 (2–61)	20 (3–61)	2.1 (1–52)
Red drum	81	607 (1–1,249)	47 (2–87)	41 (5–100)	44 (12–100)	4.2 (1–68)
Red snapper	12	43 (1–94)	2 (1–10)	83 (16–100)	83 (16–100)	18.6 (1–94)
Roughtail stingray	1	160	24	2	5	1.5 (1–2)
Scalloped hammerhead	40	128 (2–1,215)	8 (1–48)	49 (0–100)	50 (0–100)	2.4 (1–45)
Sharpnose shark	39	159 (1–524)	19 (1–64)	41 (0–100)	42 (1–100)	2.7 (1–29)
Spanish mackerel	30	3 (1–22)	4 (1–8)	89 (14–100)	91 (14–100)	1.4 (1–3)
Spot	62	19 (1–216)	3 (1–13)	87 (2–100)	87 (2–100)	1.0 (1)

3.3.4 Patterns in Community Structure

The number of species and individuals detected within the Canaveral Array was highly variable. A maximum of 35 tagged species were detected at a single station (BOEM5) just north of the CSII dredge site. Other stations within the dredge site itself (DRE5-8) and shoreline stations near Chester Shoal (CC14, CC15) also detected 30 or more species. There was a modest and positive correlation between total species detected and water depth (r_s=0.404, p=0.003) but not between total species and distance from shore (r_s=0.215, p=0.122). Shoreline stations CC14 and CC15 also detected the greatest number of individuals, 406 and 386, respectively, but sites much farther offshore and in deeper water also had high counts. Overall, no significant trends in animal counts vs. depth (r_s=0.169, p=0.228) or vs. distance from shore (rs=-0.217, p=0.118) were observed.

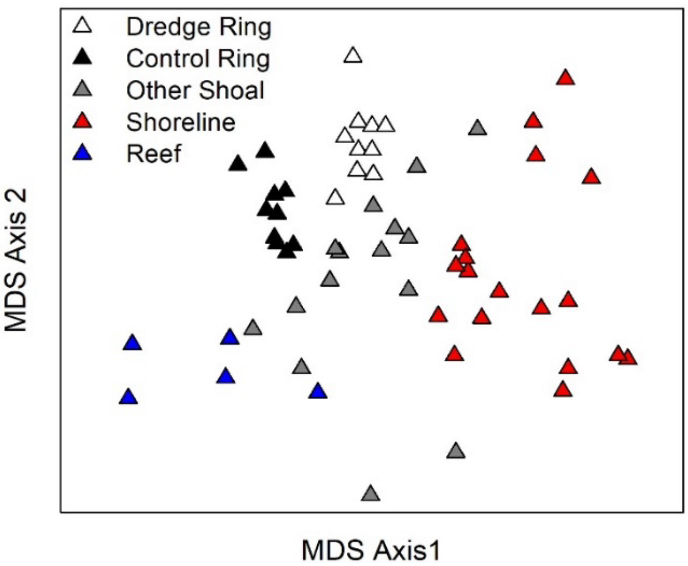


Figure 24. MDS plot of fish community structure as detected by Canaveral Array receivers
Each point represents a station and the distance between stations is proportional to difference in the community of detected fish. 2D stress = 0.13.

Trends in diversity through the Canaveral Array were more obvious with Shannon-Weiner Diversity increasing with both water depth (r_s=0.601, p<0.001) and distance from shore (r_s=0.537, p<0.001). An ANOSIM test (Global R=0.713, p=0.001) and associated MDS plot (**Figure 24**) also clear spatial differences in the community tagged of fishes using the Canaveral Shoals. Pairwise ANOSIMs concluded that shoreline, shoal, and reef sites all differ from each other (R=0.638–0.979, p=0.001), with the greatest differences observed between shoreline and reef sites. A BEST procedure suggested that distance from shore, depth, and, to some extent, latitude help explain these differences, while depth variation and sediment characteristics (% fines, % organics) are of little explanatory value (**Table 15**).

Table 15. Results of a BEST procedure for acoustic detections
A BEST procedure determines which habitat factors, alone or in combination, correlate most strongly with the species assemblage “samples” constructed from receiver station detections

Single Habitat Variable	Spearman Rank Correlation (ρ_s)
Distance from shore	0.668
Depth	0.509
Latitude	0.251
% Fine sediments	0.103
% Organics	0.087
Slope	0.065

Best Habitat Variable Combinations	Spearman Rank Correlation (ρ_s)
Distance from shore, depth, latitude	0.684
Distance from shore	0.668
Distance from shore, depth	0.664
Distance from shore, latitude	0.648
Distance from shore, depth, organics, latitude	0.619
Distance from shore, depth, % fine sediments, latitude	0.601

3.3.5 Space Use Patterns of Fishes in Relation to Water Depth and Sediment Type

Utilization distributions of eight target fish species were overlaid on bathymetry and sediment grain size maps to determine the degree of association with various water depths and sediment types, providing insights into each species’ habitat preferences (**Figure 25; Figure 26).**

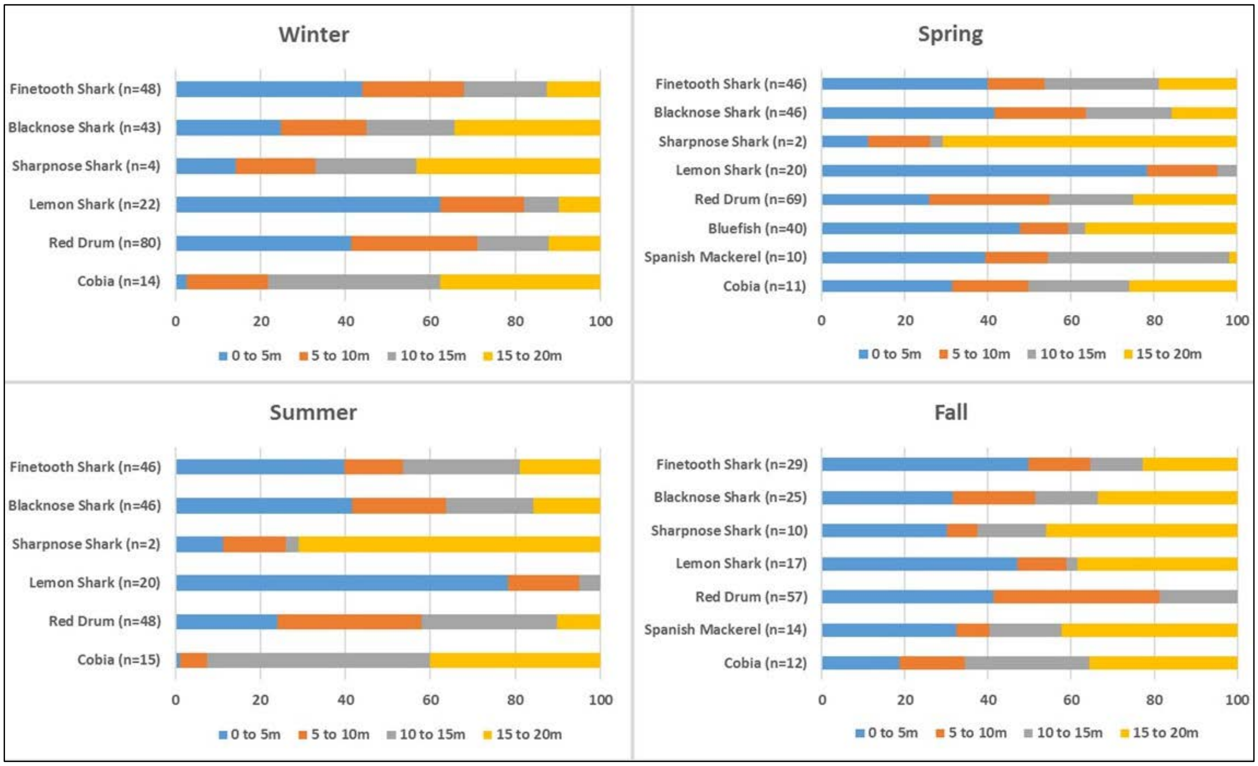


Figure 25. Seasonal overlap of fish core use areas (50% UD) with water depth

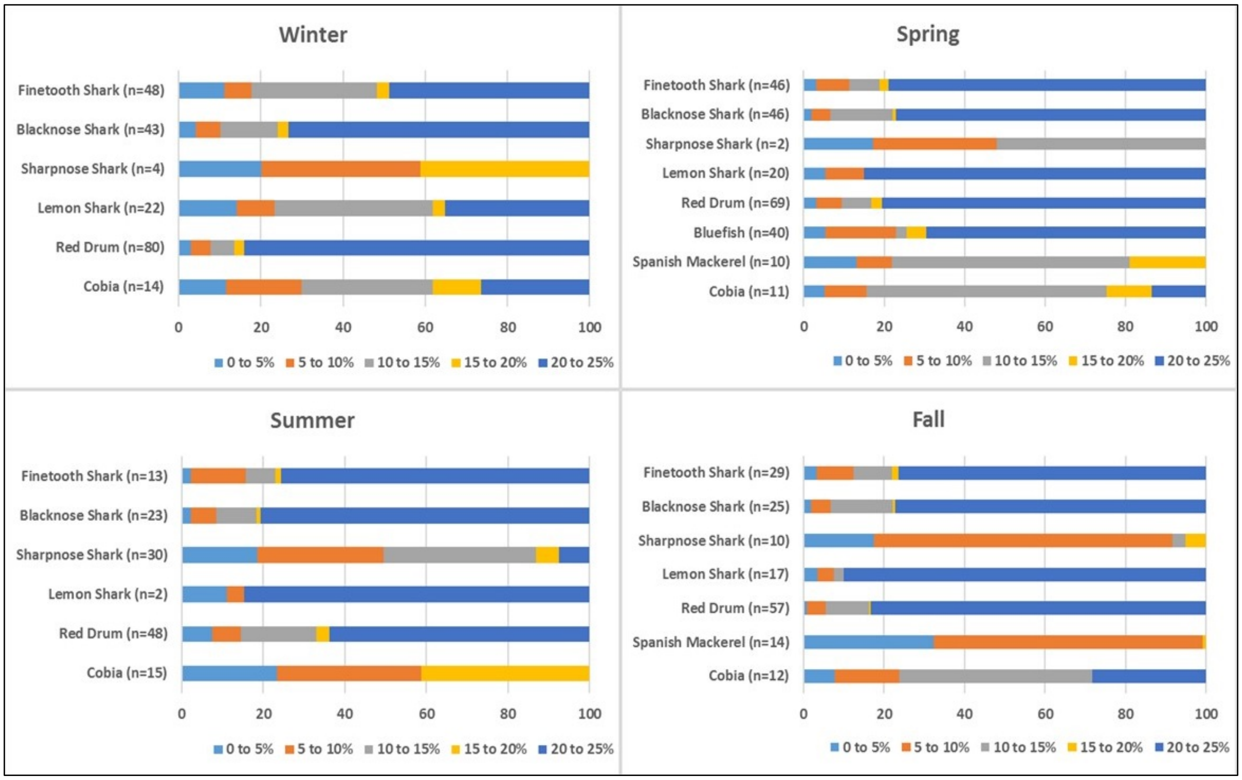


Figure 26. Seasonal overlap of fish core use areas (50% UD) with sediment percent fines

3.3.5.1 Finetooth Shark

Finetooth sharks were strongly shore-associated with 40–54% of their core use area (50% UDs) in water less than 5 m deep, depending on season (**Figure 25**). The species also spent roughly 50% of its time over areas with 20–25% fine sediments, an intermediate value relative to other tagged sharks such as blacknose and sharpnose shark (**Figure 26**). High use areas in winter, when the species was most abundant, included the beach north of the Cape, portions of the Canaveral Bight, and deeper waters on the southern and eastern flanks of the Southeast Shoal and Chester Shoal (**Figure 27**). Nonetheless, the species occupied all available depths, especially in winter, with an apparent shoreward shift in spring and summer. The average size of core use areas in winter was 175 km^2 (**Table 16**), the largest of any shark, and their 95% activity space was the largest of any target species.

3.3.5.2 Blacknose Shark

Core use areas for blacknose sharks suggested high affinity for water only 0–5 m deep in spring and summer (42–43% UD overlap), and expanding use of deeper water (15–20 m) in fall and winter; **Figure 25**). The species also preferred areas typified by very fine sediments (73–81% UD overlap), a trend that held year-round; **Figure 26**). High value locations for blacknose shark included the Canaveral Bight and waters south of Southeast Shoal throughout most of the year (**Figure 28**). In winter and spring, core use areas expanded to include swale habitat on Canaveral Shoals within the dredge site, the beach north of the Cape, and deeper waters (10–20 m) adjacent to Chester and Southeast Shoals. The average size of blacknose shark core use areas ranged from 61–89 km^2 from spring through fall, before more than doubling in winter (**Table 16**), and with over 20% of fish having core use areas greater than 250 km^2 (**Figure 35**).

3.3.5.3 Sharpnose Shark

Sharpnose sharks were most abundant summer through fall and spent more time in deep water than any other target species (63–74% UD overlap in water 15–20 m deep; **Figure 25**). They also exhibited the greatest association (~20% in summer and fall) with coarser sediments (< 15% fines, indicative of shoals) than any other shark species (**Figure 26)**. There was especially high use in deeper waters adjacent to Chester and Southeast Shoals, both inshore and offshore (**Figure 29**). The average size of core use areas (149 km^2) was very large in summer in comparison to other sharks, and second only to red drum for all target species (**Table 16**; **Figure 35**).

3.3.5.4 Lemon Shark

As with finetooth sharks, juvenile lemon sharks were strongly shore-associated with a preference for waters less than 5 m deep for all seasons (**Figure 25**) and only ephemeral use of the deepest (> 15 m) portions of the study area. When most abundant in winter, lemon sharks generally preferred moderately fine (10–15% fines) sediments (38% UD overlap), distinct from other shark species (**Figure 26**). Favored areas included the beach north of the Cape and in the Canaveral Bight (**Figure 30**). Their space use was lower than other sharks across all seasons (**Table 16**) with all individuals having core use areas less than 100 km^2 (**Figure 35**).

3.3.5.5 Red Drum

Red drum generally preferred waters less than 10 m deep when they were most common in the project area in late fall and winter (70–81% overlap; **Figure 25**) and were associated with relatively fine sediments (20–25% sediment fines; **Figure 26**). The Canaveral Bight in particular appeared to be high use area year-round (**Figure 31**), and the Canaveral shoreline and the flanks of both the Southeast and Chester Shoals were also regularly used in all seasons except fall. Red drum had the largest average core use area and activity space of all target species for all seasons except winter (**Table 16**), although there was considerable seasonal variability observed across individuals (**Figure 35**).

3.3.5.6 Bluefish

Tagged bluefish displayed limited site fidelity to the study area and detections were only sufficient for spatial analysis during spring 2016. Bluefish core use areas was somewhat bi-modal with respect to water depth with the highest use (84%) observed in the 0–5 m and 15–20 m contours (**Figure 25**). They were also strongly associated with the finest sediments in the area (69% overlap; **Figure 26)**. High value areas included the Canaveral Bight, along the beach north of the Cape, and in deeper waters along the outer flanks of the Southeast and Chester Shoals (**Figure 32**). The estimated core use area (28 km^2) was the smallest of all tagged fish (**Table 16**).

3.3.5.7 Spanish Mackerel

Most Spanish mackerel were tagged during their spring and fall migrations, and their low site fidelity to Canaveral did not allow for year-round movement analyses. Core use areas most broadly overlapped the 0–5 m and 10–15 m depth contours (83% overlap) in spring, and the 0–5 m and 15–20 m contours in fall (75%; **Figure 25**). They also used areas of coarse to moderately fine sediments (**Figure 26**). Spanish mackerel were most commonly detected on the outer margins of Southeast Shoal in spring, with increased detections along the beach north of the Cape and on Chester Shoal in fall (**Figure 33**). Core use areas were comparatively small (27 km^2; **Table 16**; **Figure 35**), although these values are likely skewed by rapid movement away of the project area as opposed to truly small home ranges.

3.3.5.8 Cobia

Cobia preferred waters 10–20 m deep in the study area during winter and summer (78–92% UD overlap), but with a slightly shallower distribution in fall and especially spring (**Figure 25**). Cobia also spent less time in areas with fine sediment (e.g., Canaveral Bight) relative to other species (**Figure 26**). Important locations for cobia included beaches north of Cape Canaveral in spring and fall, and the outer portions of Chester Shoals and Southeast Shoals (**Figure 34**). These areas appear mostly aligned with the 10–15 m contour on these shoal complexes and are associated with ridge-swale features. The size of cobia core use and activity space areas was elevated in spring and fall (45 and 43 km^2), reduced in summer and winter (24 and 25 km^2), and comparatively smaller than for other species (**Table 16)**. Half of fish had small core use areas (0–5 km^2) in summer and winter **(Figure 35**), which could be explained by repeated rapid movements into and out of the interior of the Canaveral study area.

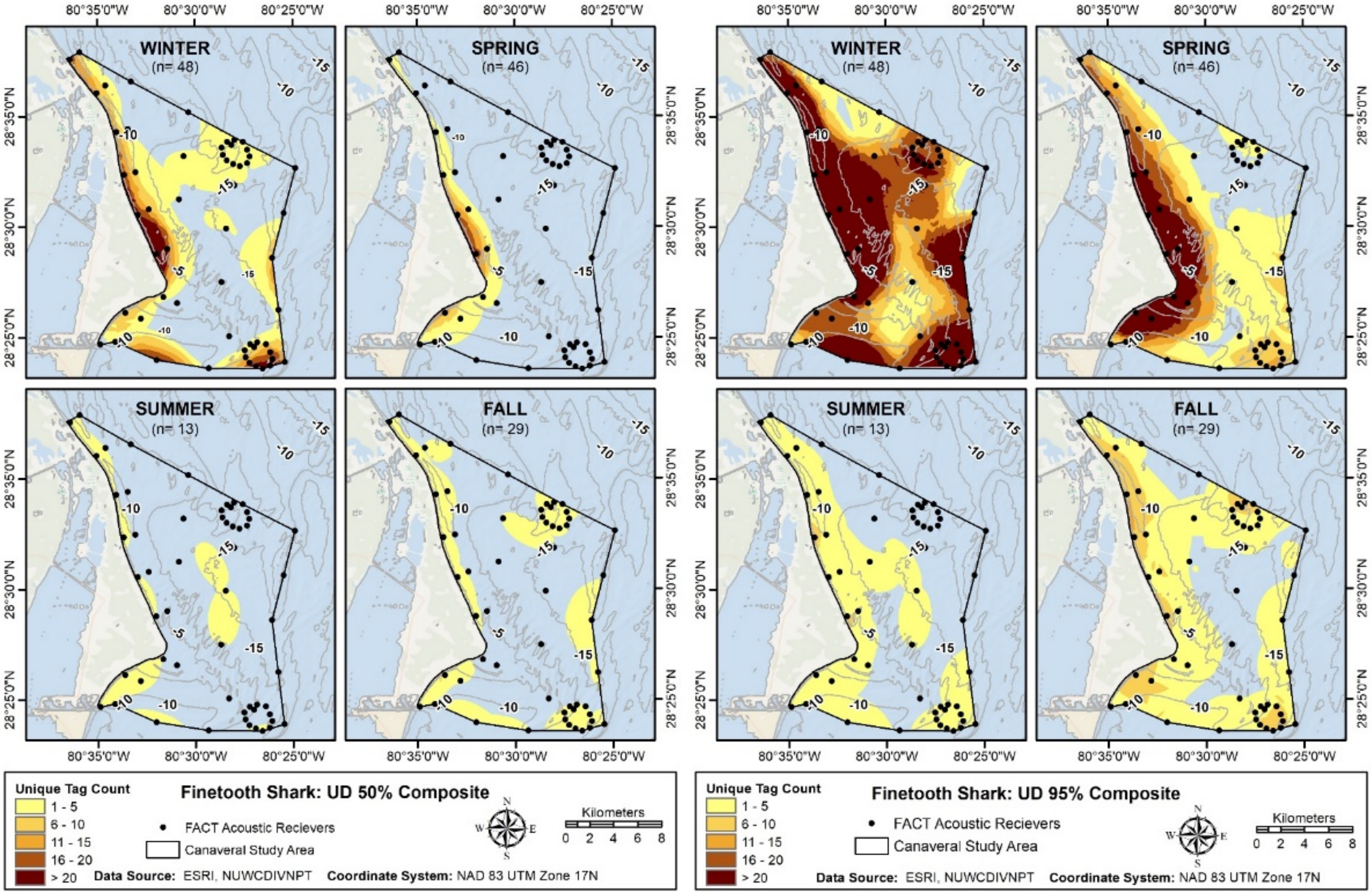


Figure 27. Local habitat use by finetooth sharks
Maps include 50% UD (core use area) and 95% UD (overall activity space).

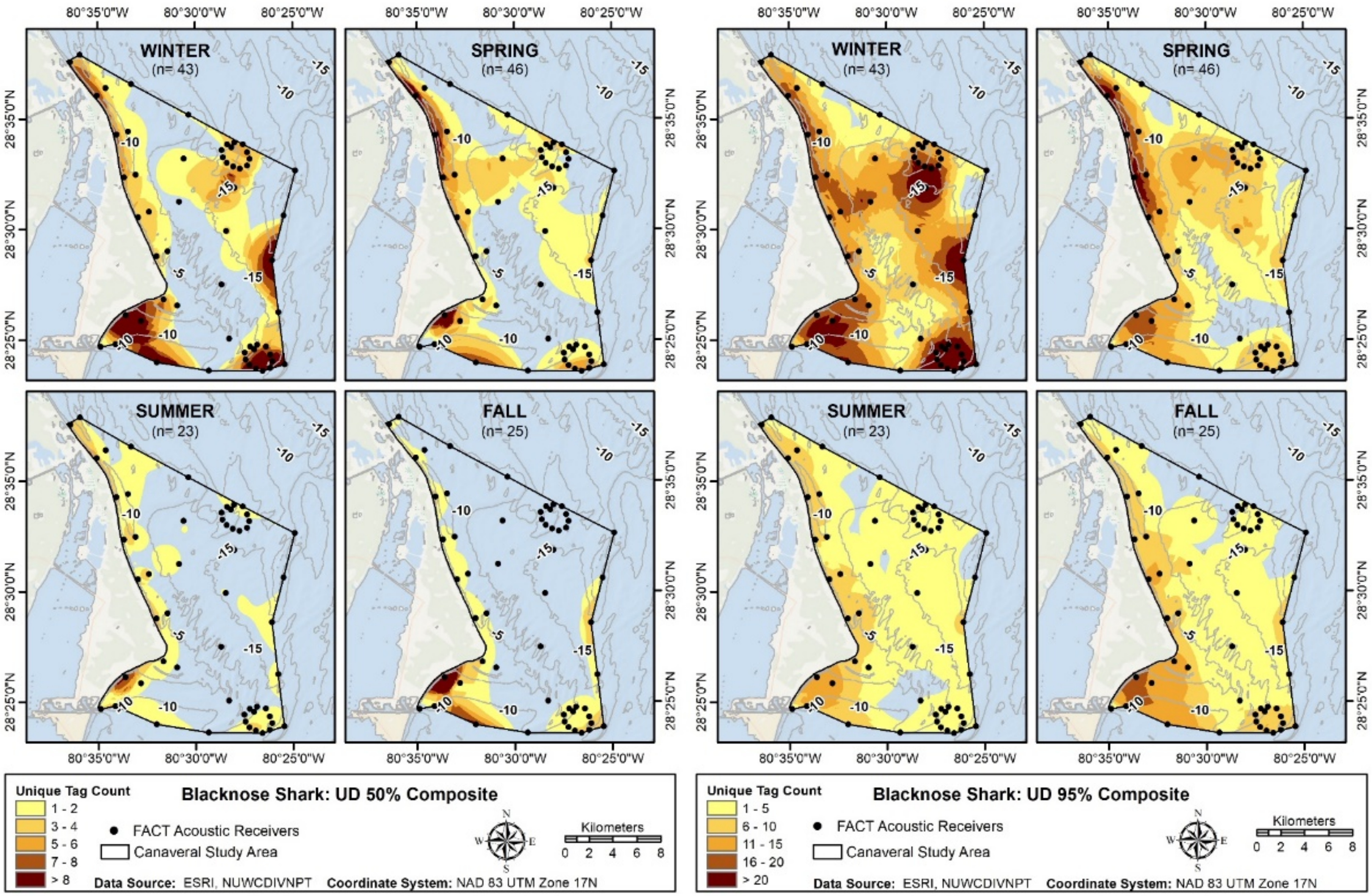


Figure 28. Local habitat use by blacknose sharks

Maps include 50% UD (core use area) and 95% UD (overall activity space).

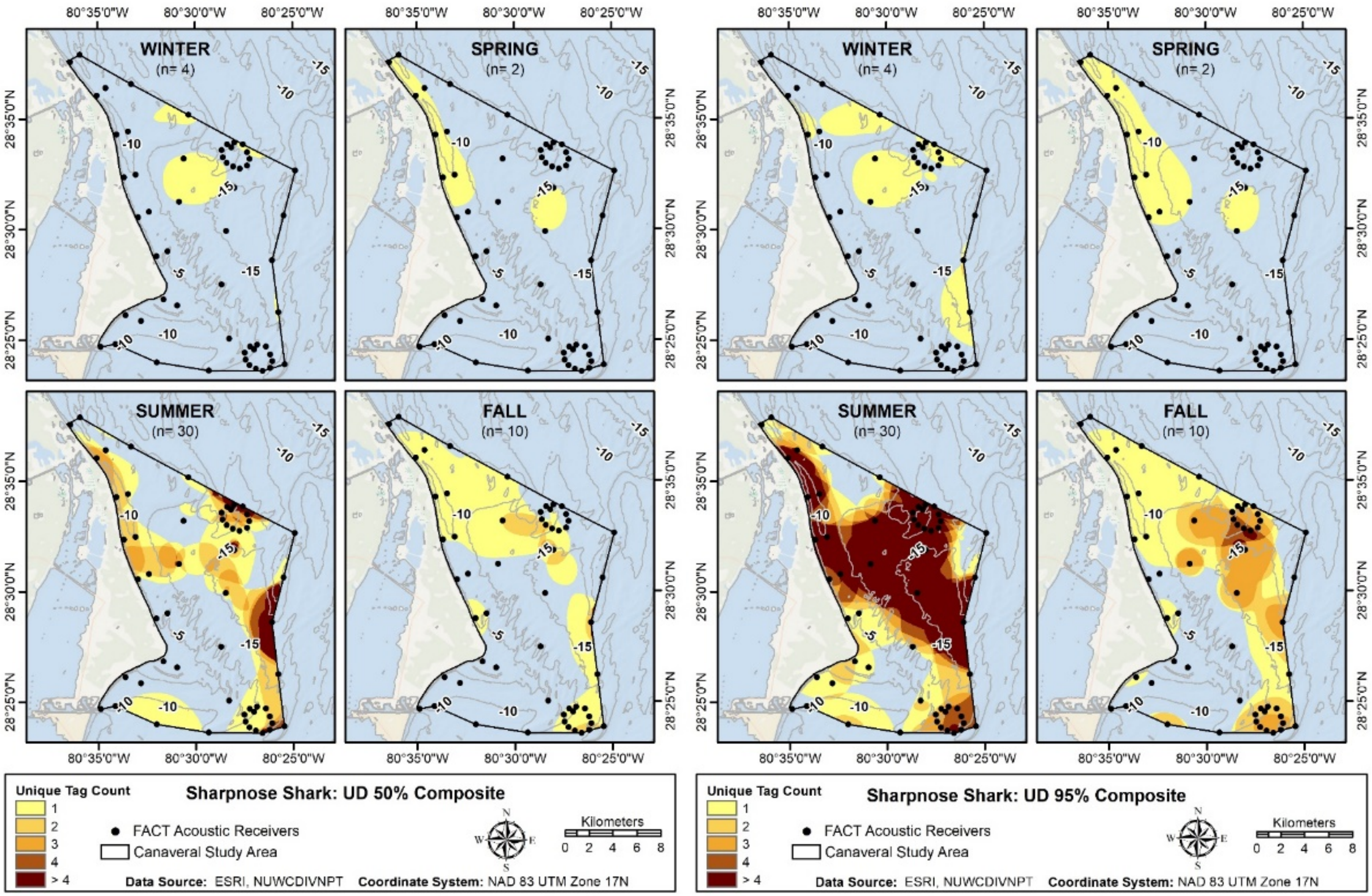


Figure 29. Local habitat use by sharpnose sharks
Maps include 50% UD (core use area) and 95% UD (overall activity space).

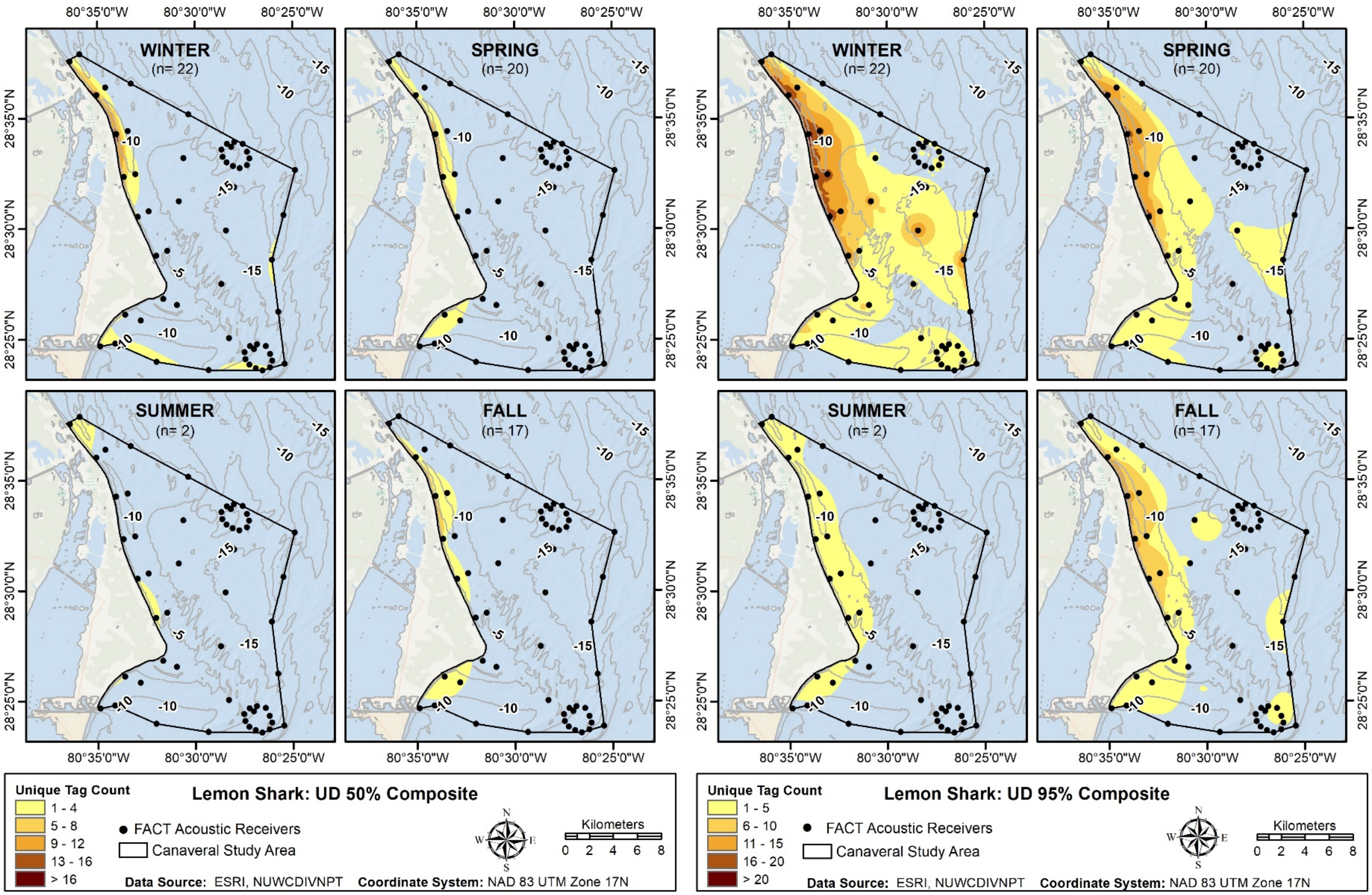


Figure 30. Local habitat use by lemon sharks
Maps include 50% UD (core use area) and 95% UD (overall activity space).

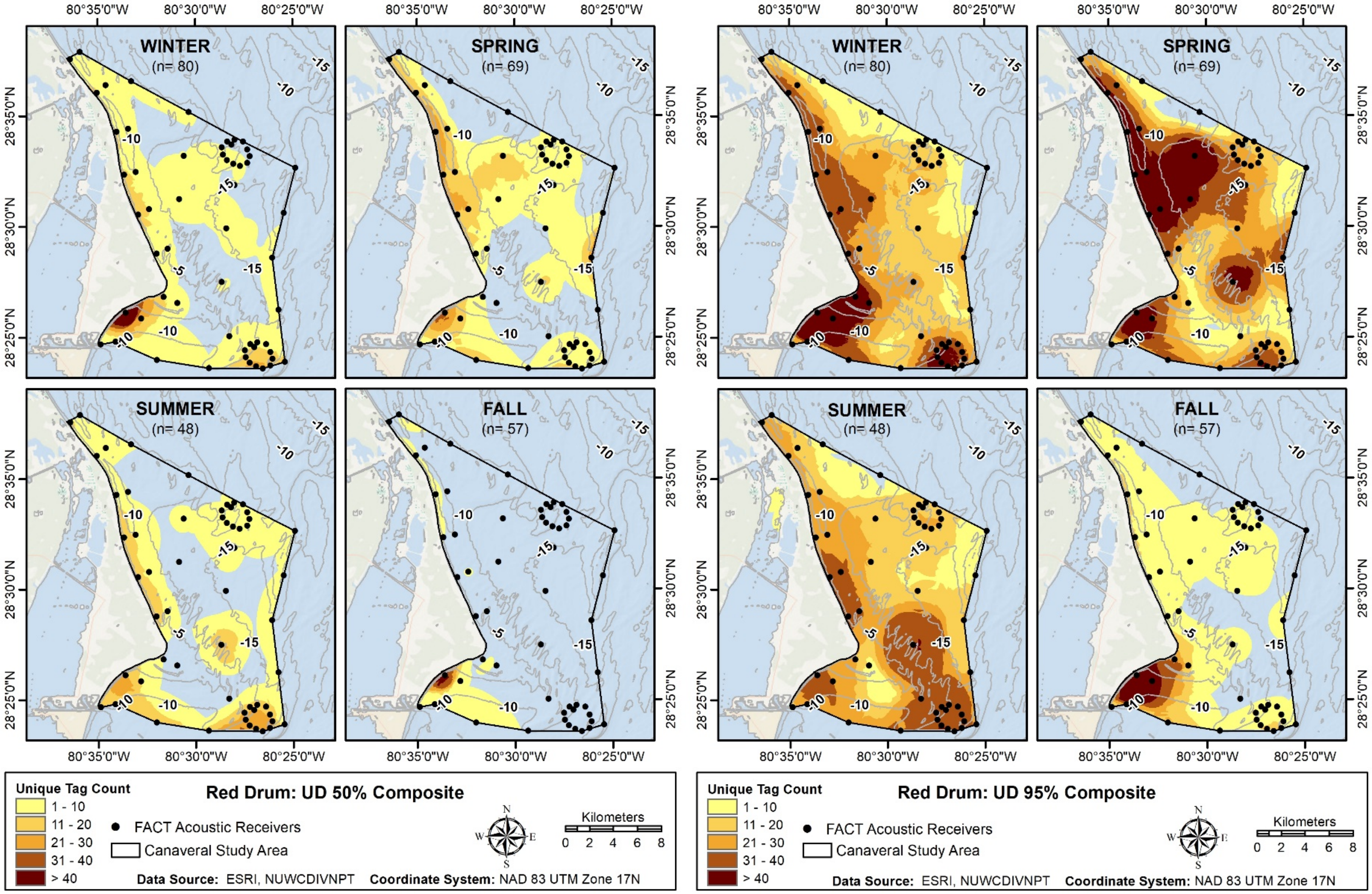


Figure 31. Local habitat use by red drum
Maps include 50% UD (core use area) and 95% UD (overall activity space)

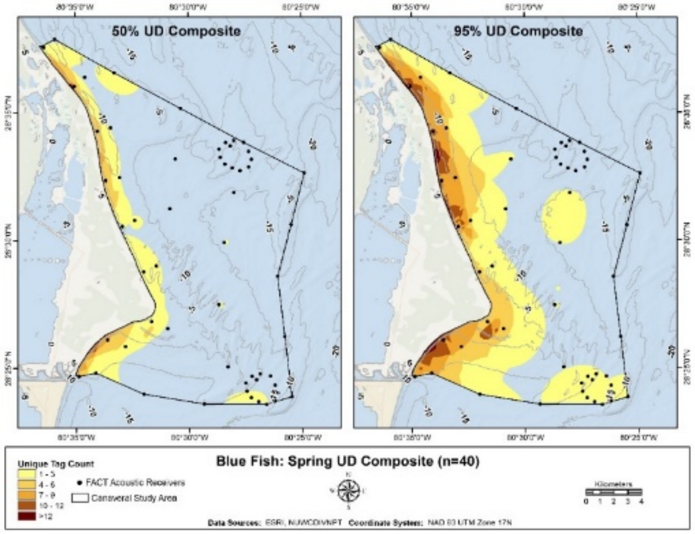


Figure 33. Local habitat use by bluefish
Maps include 50% UD (core use area) and 95% UD (overall activity space).

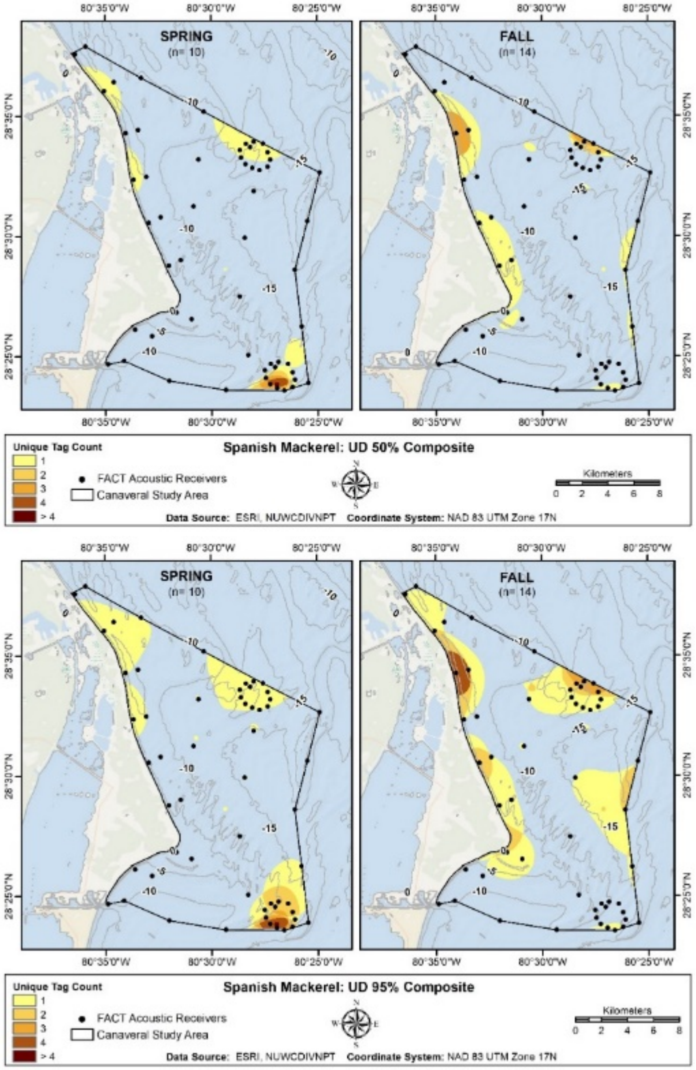


Figure 32. Local habitat use by Spanish mackerel
Maps include 50% UD (core use area) and 95% UD (overall activity space).

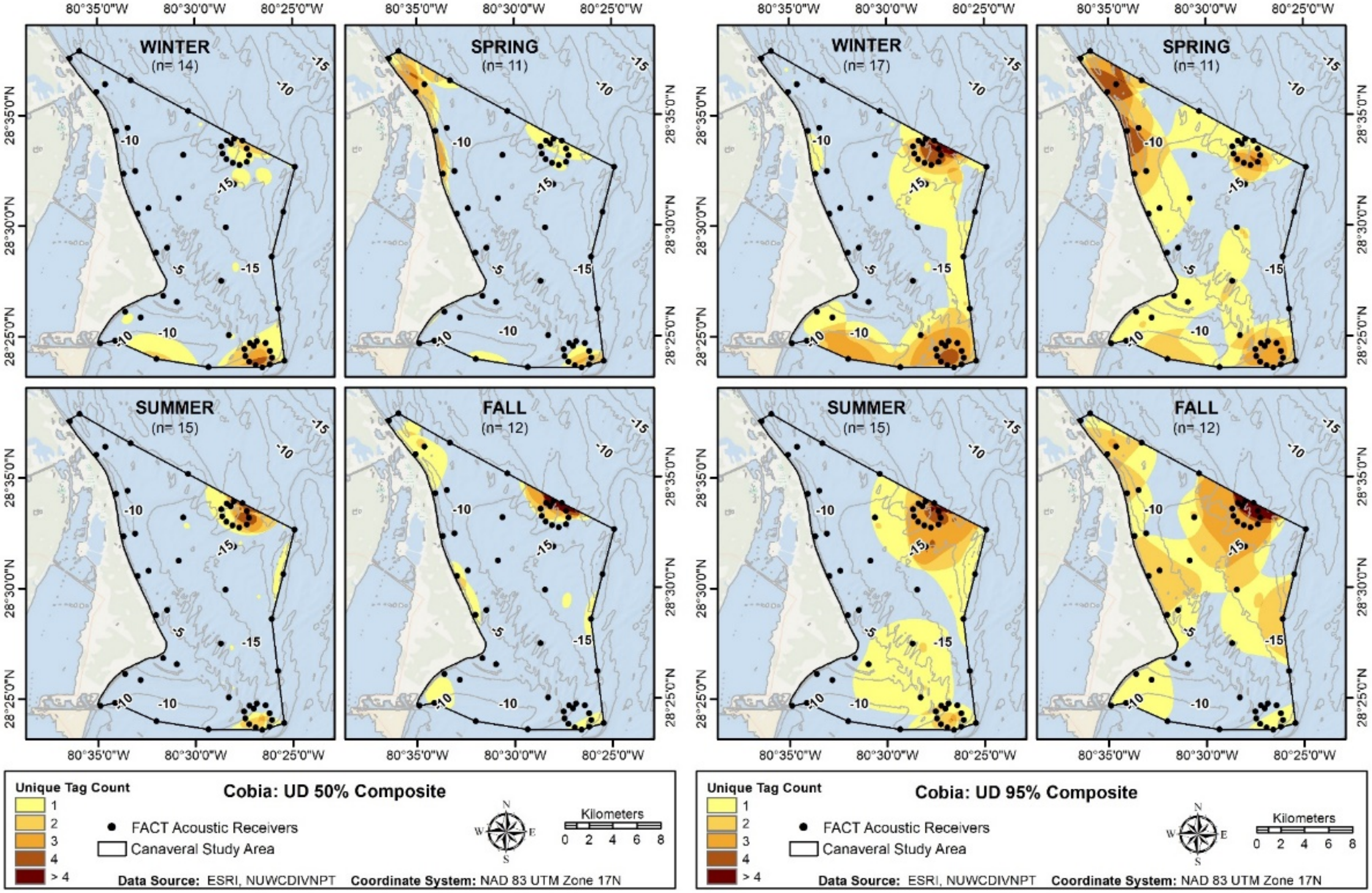


Figure 34. Local habitat use by cobia

Maps include 50% UD (core use area) and 95% UD (overall activity space)

Table 16. Mean core use (50% UD) and activity space (95% UD) area sizes for target fish species

UD size is rounded to nearest km^2 and numbers in parentheses are SD. N/A values represent seasons where too few detections were available for generation of UDs.

Target Species	50% Utilization Distribution (km^2) (SD)				95% Utilization Distribution (km^2) (SD)			
	Spring	**Summer**	**Fall**	**Winter**	**Spring**	**Summer**	**Fall**	**Winter**
Finetooth shark	44 (51)	40 (49)	43 (55)	175 (117)	468 (424)	196 (191)	219 (222)	1,025 (573)
Blacknose shark	89 (98)	61 (87)	65 (66)	147 (127)	396 (309)	409 (472)	483 (460)	730 (527)
Sharpnose shark	48 (77)	149 (90)	84 (100)	118 (299)	109 (83)	274 (248)	346 (395)	285 (450)
Lemon shark	40 (31)	24 (23)	37 (5.0)	29 (25)	486 (440)	239 (262)	387 (83)	198 (205)
Red drum	112 (118)	190 (159)	207 (104)	31 (35)	72 (564)	989 (558)	1,191 (589)	243 (212)
Bluefish	28 (39)	N/A	N/A	N/A	119 (154)	N/A	N/A	N/A
Spanish mackerel	N/A	27 (29)	N/A	27 (38)	N/A	62 (83)	N/A	70 (79)
Cobia	45 (42)	24 (42)	43 (64)	25 (55)	236 (296)	118 (277)	240 (388)	109 (244)

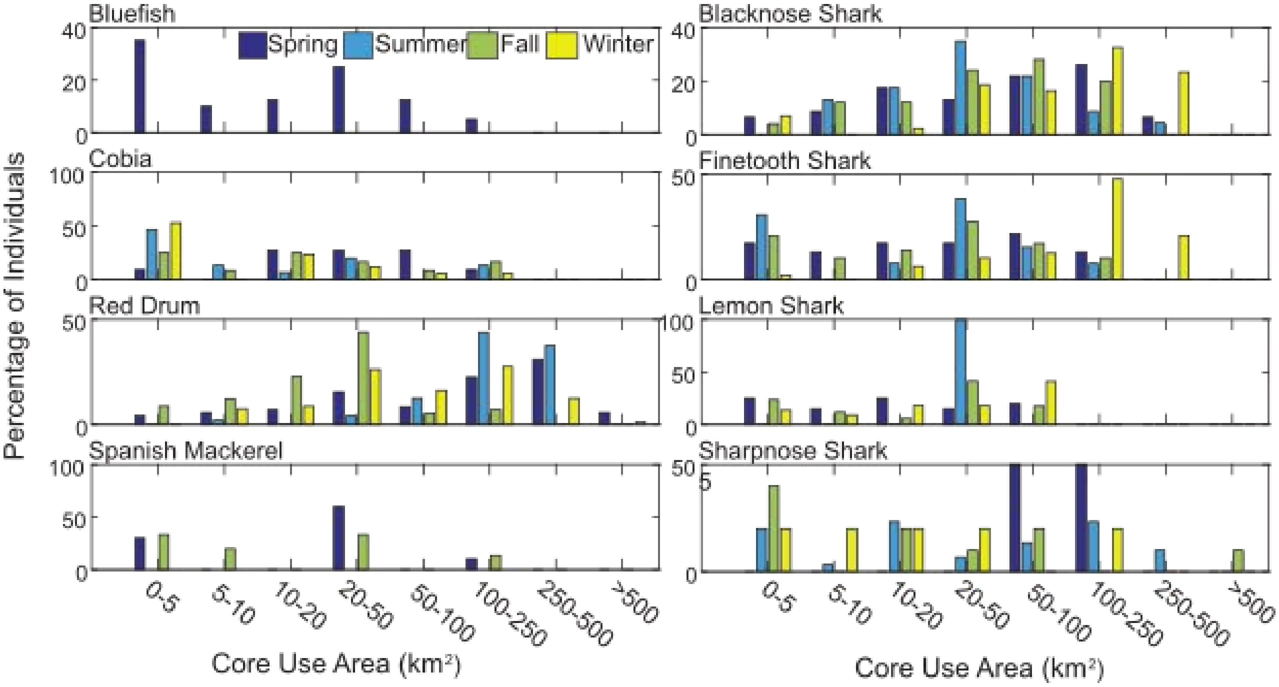
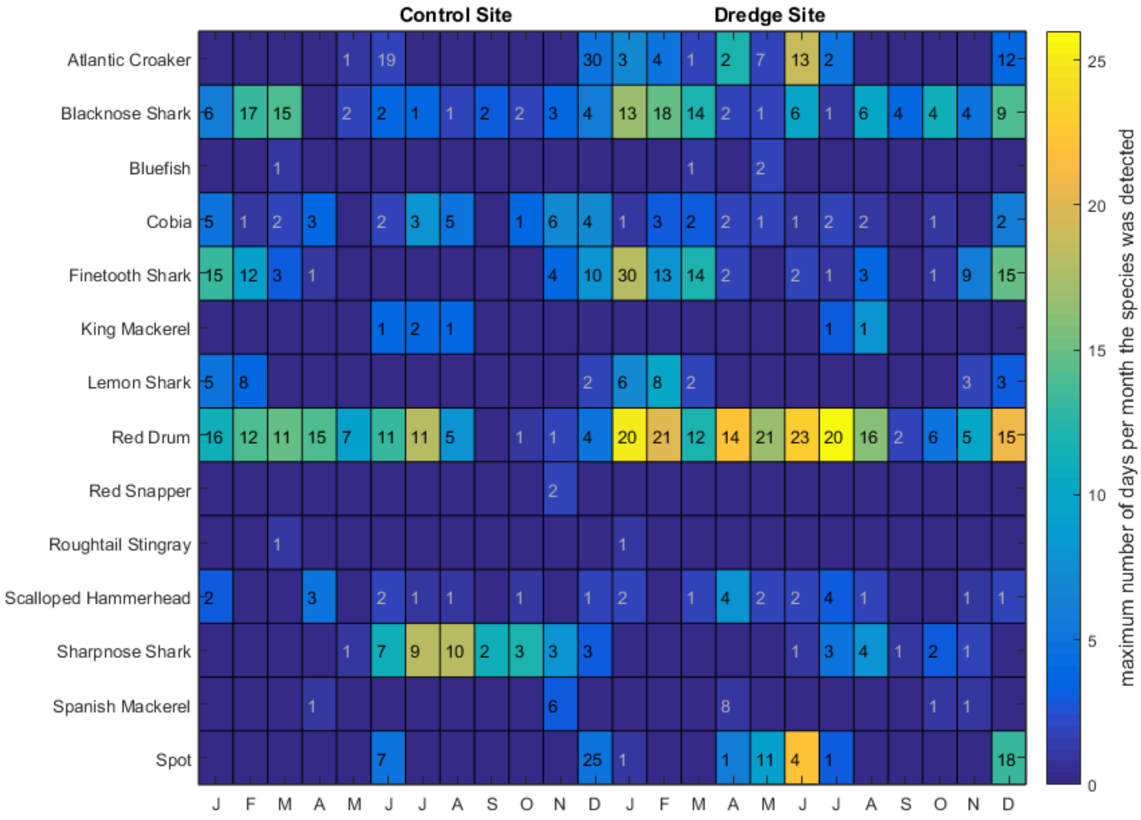


Figure 35. 50% Distribution of core use area (50% UD) by season for target fish species

3.3.6 Fish Use of the CSII Dredge Site vs. Chester Shoal Control Site

The dredge and control sites were very similar in both the number of tagged species (34 vs. 33) and individuals (454 vs. 414) detected (**Table 12**, **Table 13**) and also shared 30 species in common. Further, although the community detected at each site was clearly different as confirmed by a one-way ANOSIM test comparing only dredge and control site stations (R=0.922, p=0.001), the overall community was compositionally similar when viewed in context with other stations of the Canaveral Array (**Figure 24; Figure 36**). A SIMPER analysis suggested that sharpnose shark, Atlantic croaker, bonnethead shark, Atlantic sturgeon (all more common at the control site) and tripletail (more common at the dredge site) were the species most important in explaining the divergence of communities in these two areas.



	Control Site												Dredge Site											
	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
Atlantic Croaker					1	19						30	3	4	1	2	7	13	2					12
Blacknose Shark	6	17	15		2	2	1	1	2	2	3	4	13	18	14	2	1	6	1	6	4	4	4	9
Bluefish			1												1		2							
Cobia	5	1	2	3		2	3	5		1	6	4	1	3	2	2	1	1	2	2		1		2
Finetooth Shark	15	12	3	1							4	10	30	13	14	2		2	1	3		1	9	15
King Mackerel						1	2	1											1	1				
Lemon Shark	5	8										2	6	8	2								3	3
Red Drum	16	12	11	15	7	11	11	5		1	1	4	20	21	12	14	21	23	20	16	2	6	5	15
Red Snapper											2													
Roughtail Stingray			1										1											
Scalloped Hammerhead	2			3		2	1	1		1		1	2		1	4	2	2	4	1			1	1
Sharpnose Shark					1	7	9	10	2	3	3	3						1	3	4	1	2	1	
Spanish Mackerel				1							6					8						1	1	
Spot						7						25	1			1	11	4	1					18

Figure 36. Seasonal presence of tagged fish at the dredge and control site
The color of each square represents the maximum number of days a species was detected in a given month, while the number in each square represents the maximum number of individuals of a species that were detected in a given month for any year in the study. Only species with more than five individuals detected were included.

On average, about one quarter of tagged individuals from each target species were detected on the dredge and control sites **(Table 17**). As a whole, visit duration of fishes was similar across sites, with a mean of 0.6 and 0.7 hours, respectively, and on average involved only 2–3 receivers, although some red drum were detected on all 12 receivers during a single visit. Red drum also had the highest number of individuals detected at both the dredge and control sites, as well as the highest mean number of visits per individual. Over 70% of red drum visited the control site, while over 90% visited the dredge site; more than half of tagged finetooth and blacknose sharks also visited both sites. Overall, individuals were detected at the dredge site more often than the control site (7.3 vs 4.5 visits, respectively) although the difference was not statistically significant (paired t-test, p=0.06). Sharpnose sharks were the only species to have fewer average visits at the dredge site than the control site.

Table 17. Detections of species at the dredge and control sites

Values are mean (SD).

Species	Site	% of Tagged Individuals	Visits Per Individual	Visit Duration (hrs)	Receivers Per Visit
Atlantic croaker	Control	41.7	2.1	0.5 (3.3)	1.6 (4)
	Dredge	29.5	5.8	0.3 (14.7)	1.1(4)
Blacknose shark	Control	70.5	6.6	0.8 (7.9)	2.5 (10)
	Dredge	73.8	10.6	0.7 (10.8)	2.1 (10)
Cobia	Control	53.7	3.6	0.8 (9.8)	3 (9)
	Dredge	31.7	4.5	0.9 (7.7)	2.7 (8)
Finetooth shark	Control	59.0	5.3	0.6 (7.4)	2.2 (10)
	Dredge	75.4	11.2	0.7 (6.3)	2.3 (9)
Lemon shark	Control	38.7	3.1	0.7 (9.2)	2.3 (7)
	Dredge	53.2	3.6	0.3 (2.3)	2 (5)
Red drum	Control	71.1	14.8	0.9 (20.2)	2.3 (12)
	Dredge	92.8	36.9	1 (18.0)	2.4 (12)
Scalloped hammerhead	Control	20.0	3.5	0.6 (2.1)	2.8 (7)
	Dredge	25.0	5.5	0.5 (5.5)	2.8 (7)
Sharpnose shark	Control	54.5	10.1	1.2 (7.3)	3.3 (8)
	Dredge	22.7	3.4	1.4 (6.7)	2.9 (7)
Spot	Control	29.9	2.4	0.7 (10)	1.7 (4)
	Dredge	29.0	7.2	0.3 (32.3)	1.1 (4)

Overall dispersal away from the dredge and control site was calculated for both spot and Atlantic croaker, the two species tagged in large numbers at each location. Subsequent detection rates of both species were low relative to other target species. Only 62 of 107 spot (58%) and 91 of 132 croaker (69%) were detected on the Canaveral Array post-release, and mean time at liberty was only 19 and 16 days, respectively. Dispersal averaged only 7 km for each species, with no clear directional patterns (**Table 18**). Spot were observed to disperse farther from the control site while croaker dispersed farther from the dredge site, but site differences for each species were small and insignificant (Wilcoxon rank sum test, p=0.13–0.27), with perceived dispersal likely influenced to some degree by the locations of acoustic receivers as well as actual fish behavior.

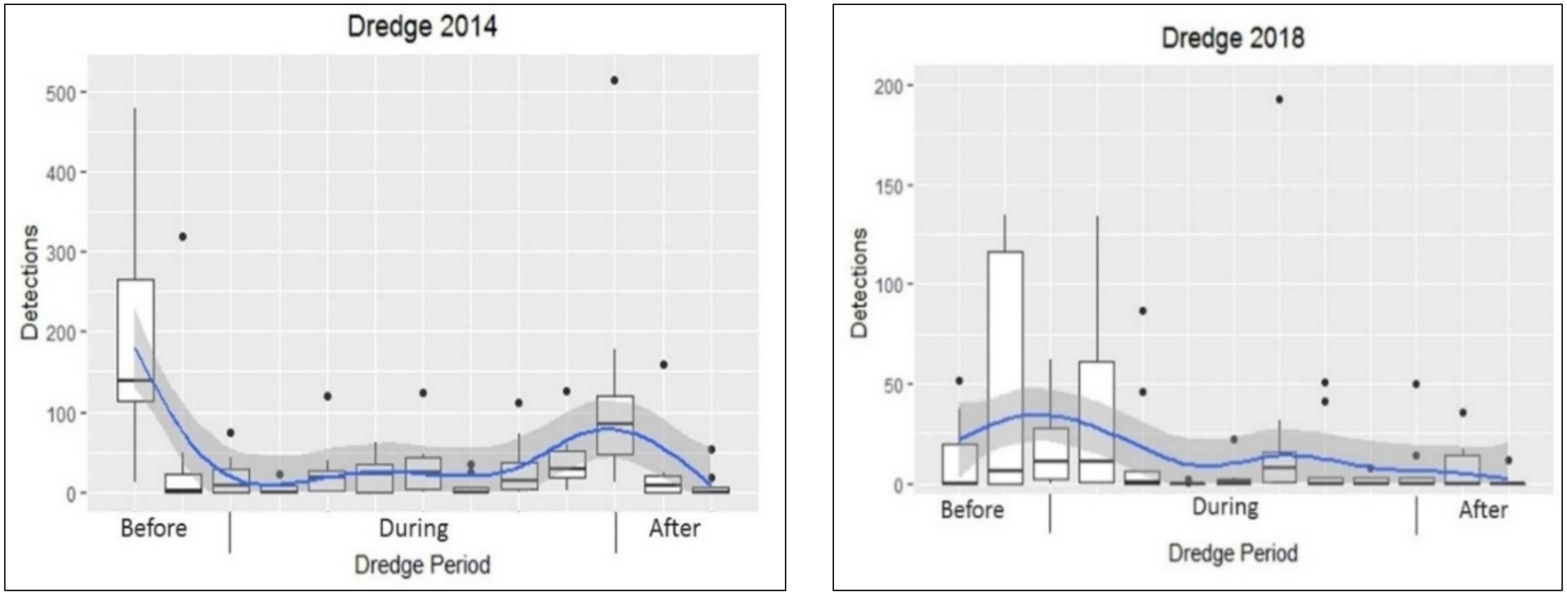
Table 18. Overall dispersal (km) of spot and Atlantic croaker from dredge and control sites
Values are mean ± SD with maximum in parentheses.

Species	CSII Dredge Site	Control Site	All Fish
Spot	5.5 ± 7.0 (25.7)	8.0 ± 14.8 (72.7)	6.8 ± 14.0 (72.7)
Atlantic Croaker	9.9 ± 15.2 (88.0)	4.7 ± 6.0 (18.7)	7.0 ± 11.3 (88.0)

For fish that dispersed away from their original release sites, detections were recorded throughout the Canaveral Array, including the outer shoals, along the shoreline, and in the Canaveral Bight. Results for those fish tracked the longest suggest a capacity for substantial movements along the coast (**Figure 38**, **Figure 39**). Most notably, three spot and one Atlantic croaker, all released December 2013, were subsequently detected at the mouth of Ponce Inlet (60 km north) the following May or June, and one individual returned to Cape Canaveral by July. A fifth fish, an Atlantic croaker, also tagged in December 2013, was detected the following July over 30 km south at Melbourne Beach. The multi-month duration of these tracks provides confidence that these movements were from the tagged fish themselves, and not the result of predation events.

Active dredging at CSII with a suction hopper dredge occurred from November 2013–April 2014 (hereafter the 2014 event) and January–April 2018 (2018 event), providing opportunities to examine fish residency in response to dredge disturbance. Trends in detections were fit and evaluated across predefined time blocks to provide higher temporal resolution than simple before, during, and after periods. Detections during 2014 (which commenced at the very beginning of this study) were fairly sparse, with only recently tagged spot, Atlantic croaker, and red drum present locally, and with 35% of days containing zero detections. There was a sharp decrease in the number of detections before dredging commenced as fish naturally dispersed after tagging (**Figure 37**). There was then a gradual increase in the number of detections during the dredge period, culminating in a peak in detections during time block 11, immediately after dredging ceased. Examination of transition periods between dredge activity (before-during, during-after) via the smoother plots with confidence intervals showed an increase in the relationship for number of detections from time blocks 9–11, followed by an equivalent decrease in blocks 12–13.

During the 2018 event, detections at CSII were also fairly sparse in early spring, with no detections on almost half of the days, and fewer average and maximum number of detections than observed in 2014. The target species present during this 2018 event included red drum, finetooth shark, and blacknose shark. The number of detections dropped sharply after block 1, likely due to dispersal of recently tagged fish. There was a decrease in fish occurring during time blocks 2 through 6 (9 days each) followed by an increase for blocks 7 and 8, although this was mostly influenced by one particular day of high detections. There was a gradual decrease in the number of detections for the rest of the time periods.



Dredge 2014

Dredge 2018

Figure 37. GAM comparison of fish detections during the 2014 and 2018 dredge events

Box plots for individual time blocks are shown grouped by before, during, and after the dredge event. Shaded areas represent 95% confidence interval. Dots represent outliers in the data.

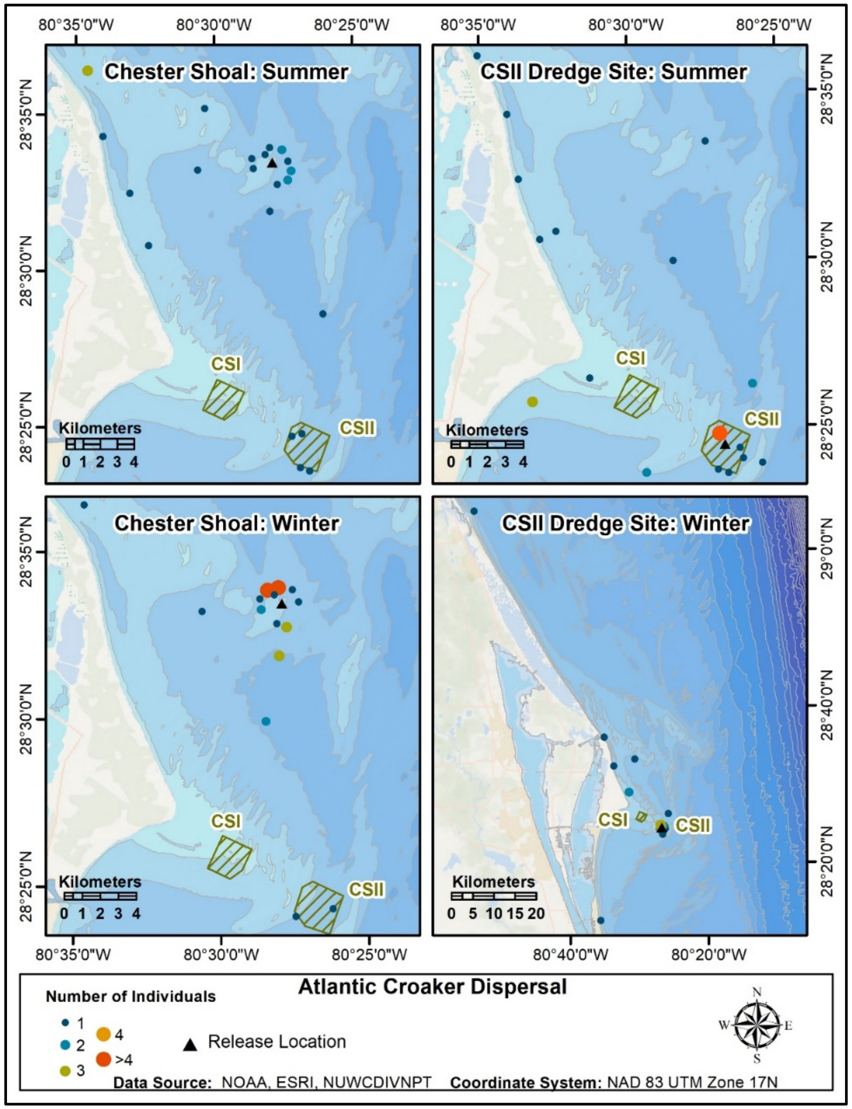


Figure 38. Dispersal of Atlantic croaker after release at the dredge and control sites

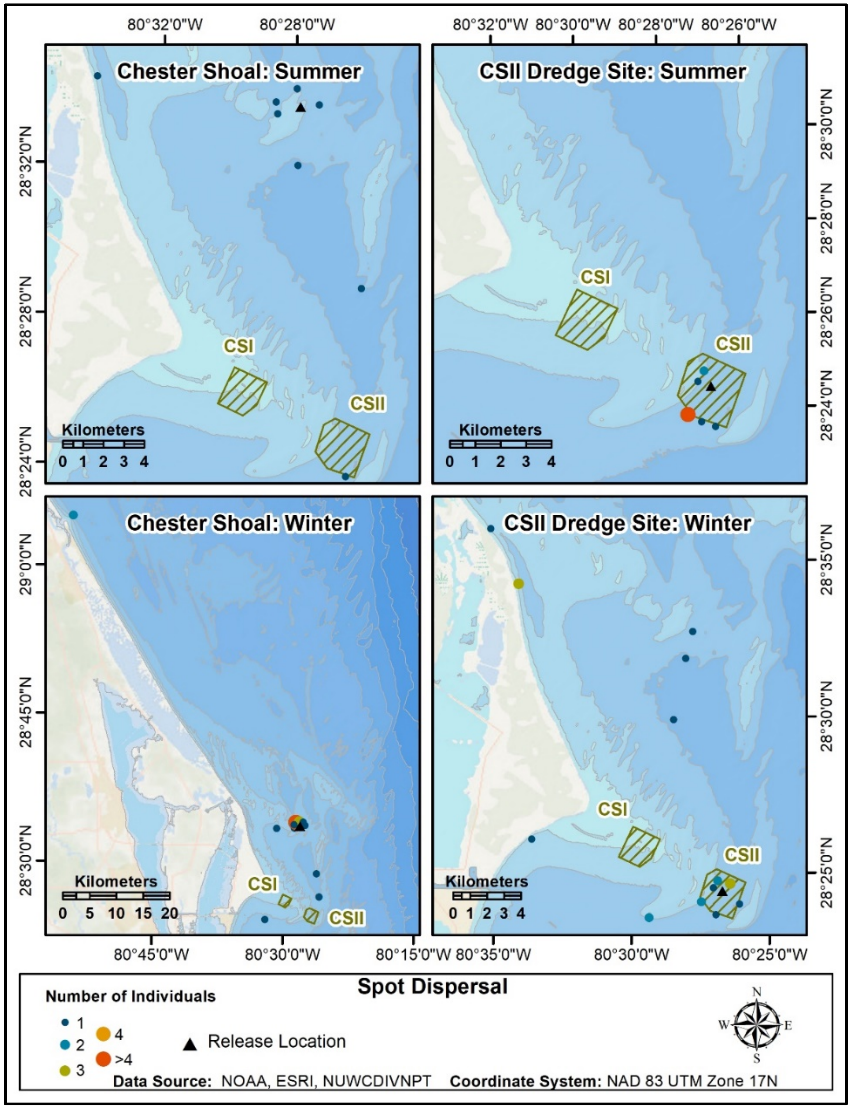


Figure 39. Dispersal of spot after release at the dredge and control sites

3.3.7 Factors Influencing Fish Site Fidelity

Observed rate of movement (ROM) for target fish species on the Canaveral Shoals ranged from 0.7–1.7 km/hr (**Figure 40**). With the exception of a single tagged roughtail stingray that moved rapidly through the Canaveral Array, Spanish mackerel exhibited the fastest movements between receivers at 1.5 km/hr. Small-bodied spot and Atlantic croaker had the slowest ROM at 0.7 km/hr, and no red snappers made movements of sufficient distance between acoustic receivers for their ROM to be accurately estimated.

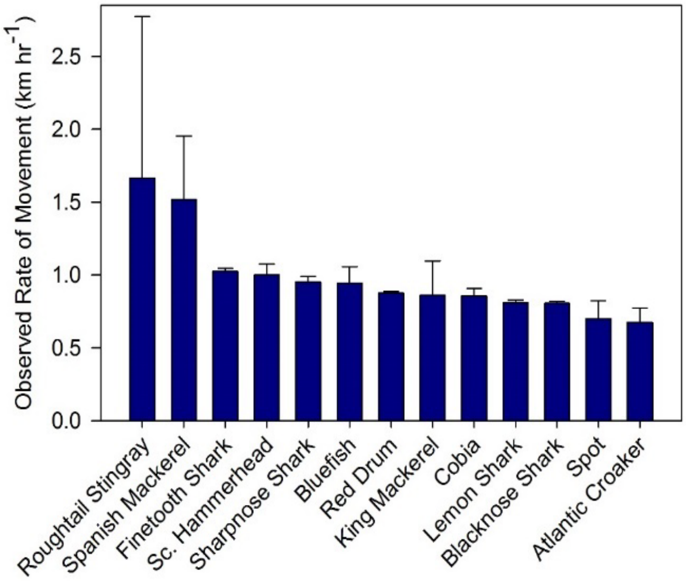


Figure 40. Observed rate of movement (mean ± SE) for target species

Many species provided sufficient detections to examine seasonal changes in ROM. In general, winter, a non-migratory period for many fishes in east Florida, was the season in which most species exhibited their slowest ROM through the Canaveral Array (**Figure 41**). Conversely most species exhibited their fastest observed ROMs in summer with the clear exception of sharpnose shark.

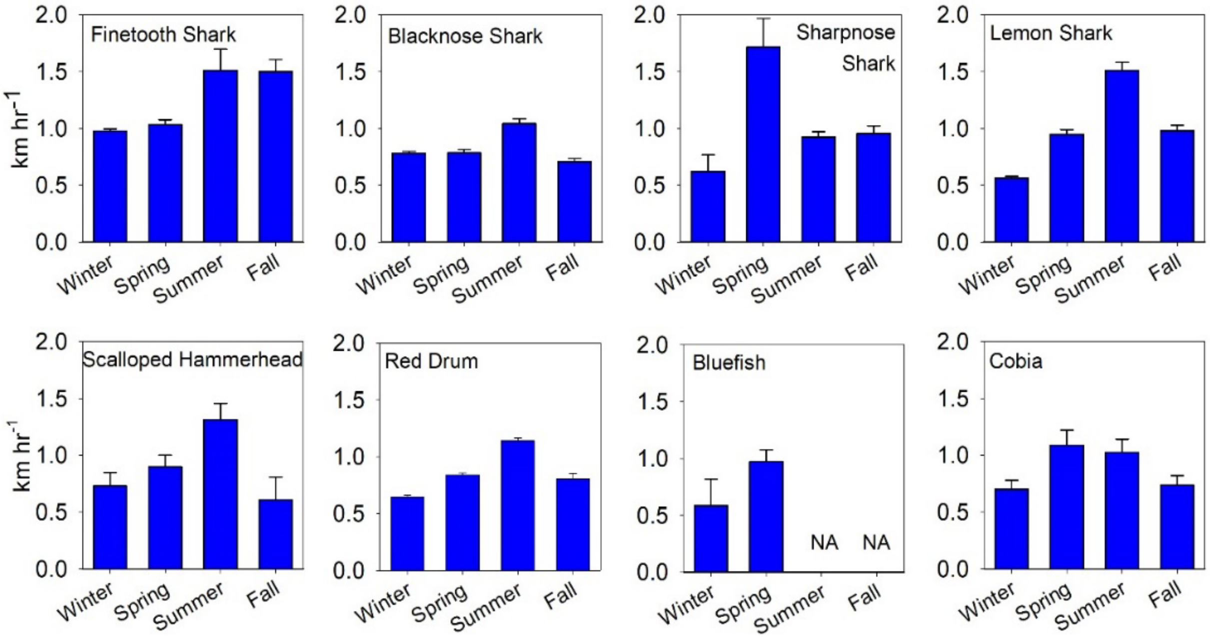


Figure 41. Observed rate of movement (mean ± SE) by season for eight of the most common fish species detected in the study

Nearly 123,000 unique receiver visits to the Canaveral Array were recorded across all target species during the study. Mean visit duration to any given receiver ranged from 21 to 65 min, depending on species, and was shortest for Spanish mackerel, king mackerel, bluefish, and cobia, all of which are highly mobile, pelagic taxa **(Figure 42).** Sharks largely fell in the middle with the exception of blacknose sharks, which had the longest average visit duration at 65 min. Spot and red drum had the longest visit durations of teleost fishes. The longest recorded visit by any tagged fish to a receiver was a red drum, which was consistently detected at station BOEM 6 in the Canaveral Bight for 17,702 min (= 12.3 days) before moving to an adjacent receiver. Notably, visit durations were actually shorter at offshore reef receivers than shoal receivers for all species except lemon sharks and cobia (**Table 19**), suggesting that low site fidelity is not solely related to lack of hard bottom substrate for which to associate.

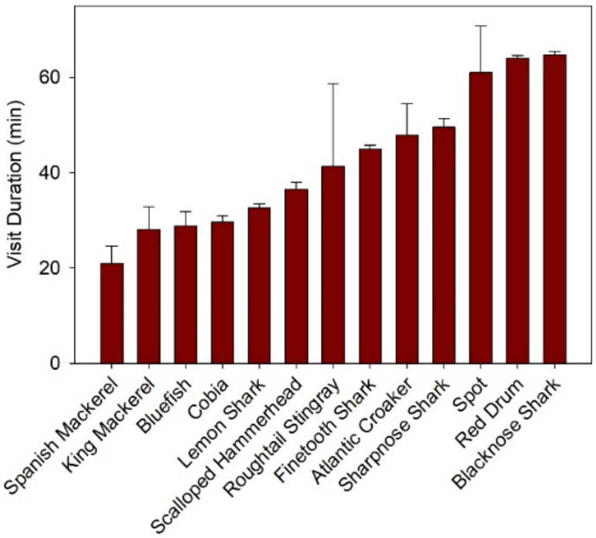


Figure 42. Visit duration (mean ± SE) to acoustic receiver sites for all target species

Distance from shore, water depth, and sediment % fines were identified as important habitat conditions influencing visit duration of fish to acoustic receivers at Cape Canaveral based on general linear modeling results (**Figure 43**). Distance from shore was among the top three most important habitat covariates (i.e., highest effect size) for all species modeled except cobia, and, in every instance, visit duration was higher when fish were closer to shore (**Figure 44**), suggesting that nearshore water may be of proportionally high value for many species or that the physical barrier provided by the shoreline slows dispersal away from a site. The effect of water depth was also uni-directional, with visit duration always increasing with increasing water depth after other factors were accounted for; however, it should be noted that generally improved acoustic propagation (i.e., detection distance) in deep water may be a confounding factor. Finally, fish generally moved more slowly at receivers in areas of finer sediment, although the magnitude of this effect was muted in some species. Bluefish was the only species where both water depth and percent fine sediments appeared unimportant, although this may due in part to a low sample size compared to other species.

Table 19. Mean visit duration (min) to reef and shoal receivers within the Canaveral Array

VD given as mean ± SD. Note bluefish only had one visit duration at a reef receiver

Species	Reef Receivers	Shoal Receivers
Finetooth shark	32.5 ± 3.0	42.6 ± 0.8
Blacknose shark	37.3 ± 2.0	54.4 ± 0.6
Sharpnose shark	38.5 ± 4.5	52.4 ± 2.4
Lemon shark	82 ± 48.8	35.6 ± 0.9
Scalloped Hammerhead	40.6 ± 8.8	48.4 ± 2.0
Red drum	36.0 ± 3.7	60.5 ± 0.8
Bluefish	1.4	34.7 ± 3.7
Cobia	34.3 ± 3.5	30.9 ± 1.7

The importance of other habitat factors varied by species. After accounting for seasonal effects, water temperature was still positively related to visit duration in blacknose and sharpnose sharks and had the opposite effect for lemon sharks and red drum, although it was often less influential than other habitat conditions. When retained, sediment organics were negatively related to visit duration in blacknose and finetooth sharks, and red drum. Seafloor slope was positively related to visit duration for all species except blacknose shark. Latitude and solar irradiance generally had low effect sizes compared to other habitat covariates, although solar irradiance had a moderate positive effect on sharpnose and scalloped hammerhead shark visit duration.

Season affected visit duration for all species except cobia. Visits were longer in winter for finetooth shark and bluefish, spring and summer for sharpnose shark, summer for lemon and blacknose sharks, and fall for scalloped hammerheads and red drum. All models except bluefish indicated strong support for final models based on evidence ratios of the fitted model vs. the null model. Evidence ratios were at least 10^4 for all species except bluefish. Final visit duration model results are available in **Appendix C.**

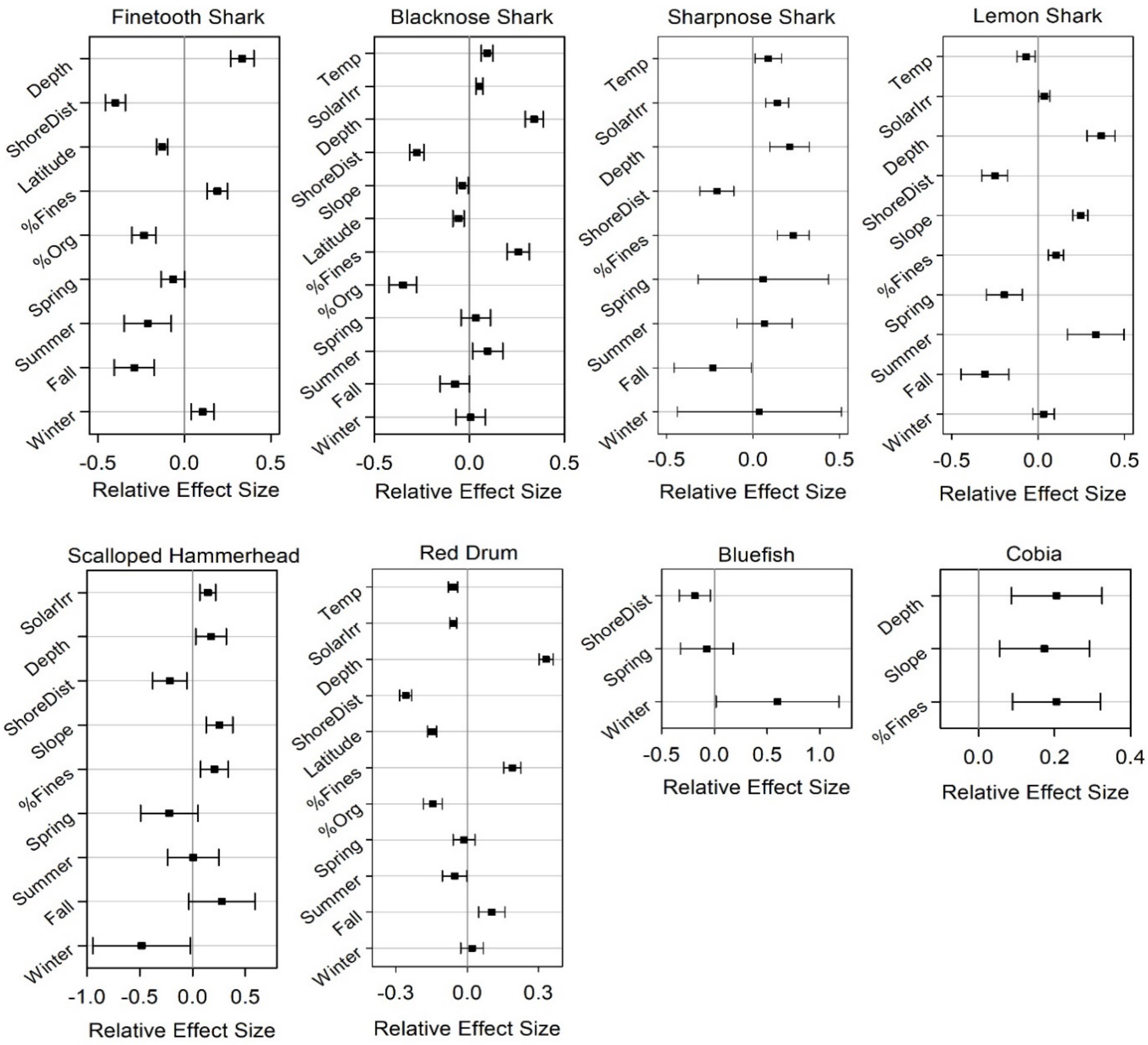


Figure 43. Parameter estimates for mixed effects models showing factors influencing visit duration

Note the intercept (calculated from the global model without season) was subtracted from season for ease in visually displaying all habitat covariates and season in one plot; readers should remember this when comparing season with other habitat covariates on caterpillar plots.

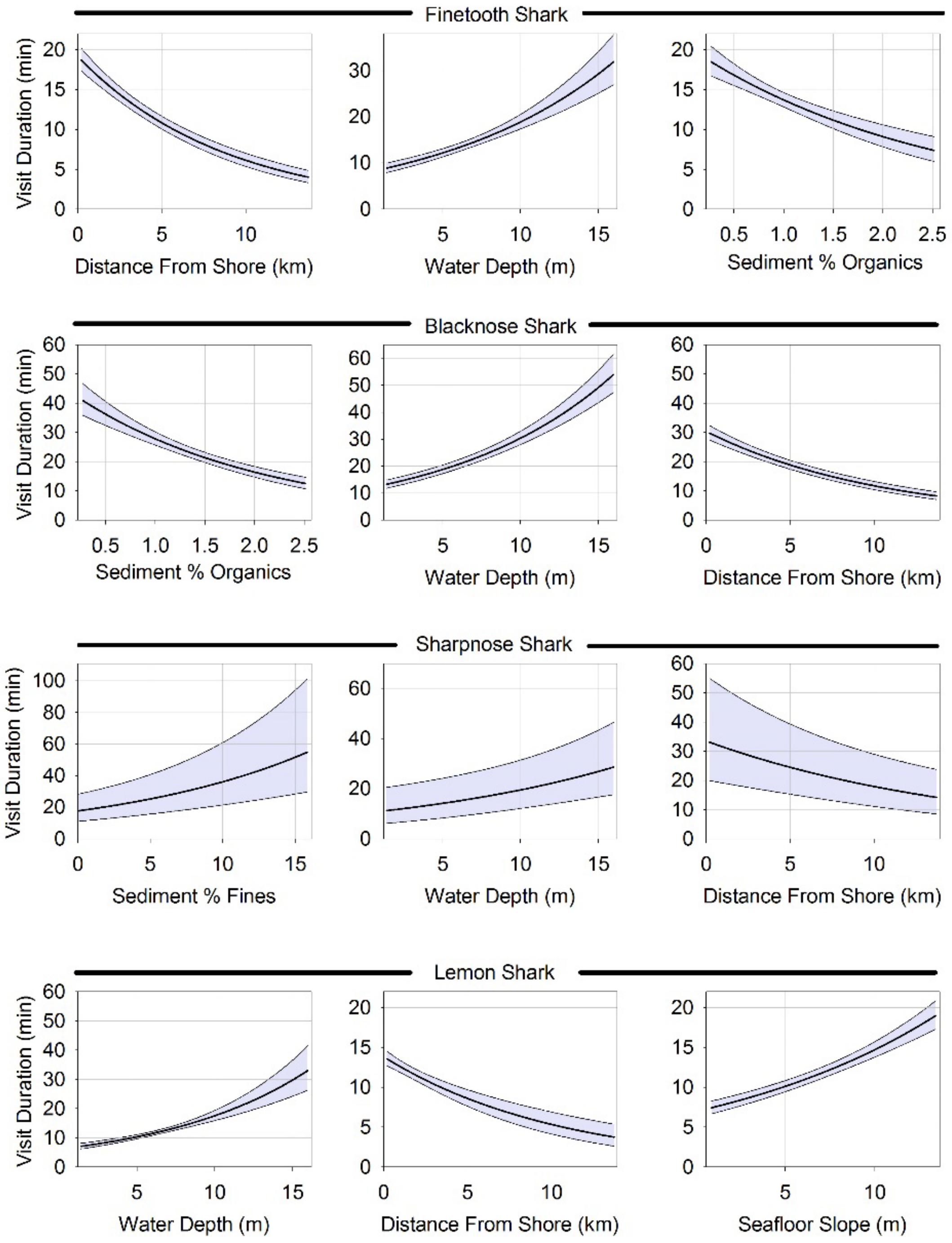


Figure 44. Marginal effect plots depicting relationships between important habitat covariates and visit duration

Plots are ordered from left to right for each species in decreasing order of effect size (top three covariates only). Shaded regions represent the 95% confidence interval.

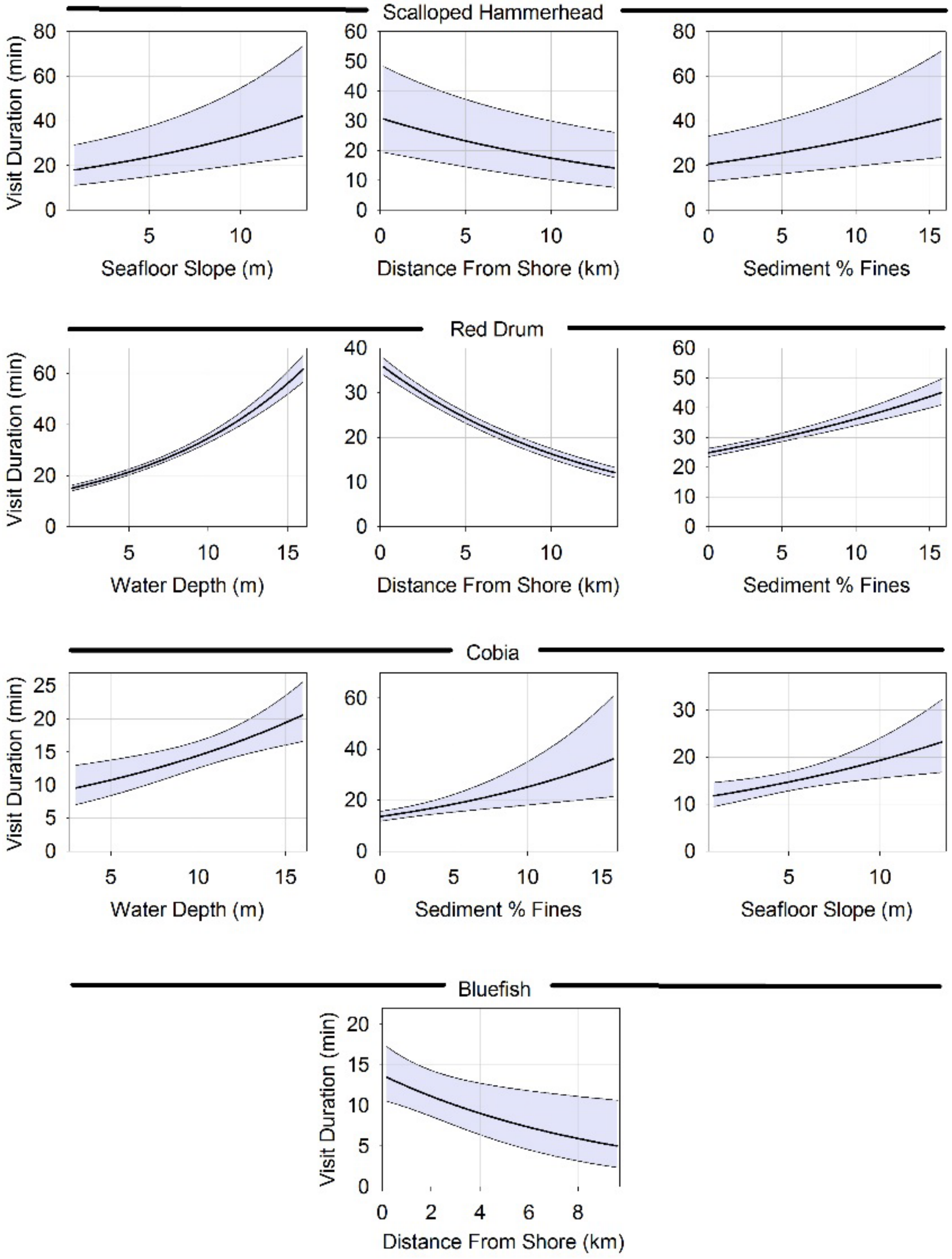


Figure 44 (cont'd). Marginal effect plots depicting relationships between important habitat covariates and visit duration

Plots are ordered from left to right for each species in decreasing order of effect size (top three covariates only). Shaded regions represent the 95% confidence interval.

3.3.8 Daily Patterns in Shoal Use

The distribution of fish detections at shoal receivers through time suggests that true differences in shoal use by fish across day, night, and crepuscular periods may be commonplace, with all eight species tested displaying significantly non-uniform detection patterns (**Table 20**). No universal day-night trend in shoal use was apparent across species or even across higher level groups (e.g., sharks vs. teleost fish). However, broadly speaking, shoal associations may have been somewhat elevated during the day (five of eight species were detected more often than expected by chance) and lower at night (six of eight species detected less than expected). The most extreme daily variability was observed in species with lower sample sizes, including scalloped hammerheads, bluefish, and cobia, and should therefore be interpreted with caution. These species-specific differences likely reflect divergent life history strategies and local niche partitioning in shoal-associated fishes.

Table 20. Daily patterns in fish detections on the Canaveral Shoals

Arrows indicate whether the observed number of fish detections were higher or lower than would be expected from a uniform daily distribution based on results of a Pearson's Chi-Squared test. Cells are color-coded for easier interpretation. Analyses include only shoal receivers that do not simultaneously monitor adjacent non-shoal habitat types.

Species	Shoal Detects	All Local Detects	No. Fish	Dawn	Day	Dusk	Night	χ^2	df	P-value
Finetooth shark	6,015	183,048	45	↓	↑	↓	↓	40.7	3	< 0.001
Blacknose shark	28,041	534,681	48	↓	↑	↑	↓	85.8	3	< 0.001
Sharpnose shark	2,112	39,769	20	↑	↓	↓	↑	188.5	3	< 0.001
Lemon shark	6,291	76,001	19	↑	↑	↓	↓	12.7	3	0.005
Scalloped hammerhead	100	16,683	9	↑	↓	↑	↑	20.5	3	< 0.001
Red drum	35,415	1,050,025	76	↓	↑	↑	↓	358.9	3	< 0.001
Bluefish	561	5,968	20	↑	↓	↑	↓	300.9	3	< 0.001
Cobia	316	12,960	17	↑	↑	↓	↓	52.9	3	< 0.001

3.3.9 Migration Overview

Collaboration with the FACT and ACT Networks enabled continued tracking of tagged fish as they left the Canaveral region during their seasonal migrations. Individual finetooth shark, blacknose shark, lemon shark, sharpnose shark, scalloped hammerhead, red drum, bluefish, king mackerel, and roughtail stingray were all documented well outside of the Canaveral study area. Considering only animals that were documented away from Cape Canaveral, Georgia represented the northernmost region reached and accounted for 3% of red drum, 2% of finetooth sharks, 47% of blacknose sharks, 57% of lemons sharks, 10% of sharpnose sharks, and 2% of bluefish. South Carolina was reached at least once by 89% of finetooth sharks, 33% of blacknose sharks, 24% of lemon sharks, 15% of sharpnose sharks, and 40% of king mackerel (out of those with data). Six percent of finetooth sharks and 2% of blacknose sharks were detected in North Carolina, while one finetooth shark was detected at the entrance to the Chesapeake Bay. For most individuals, migrations to and from Cape Canaveral occurred on an annual cycle, with individuals making repeated return trips to the Canaveral region (**Figure 45**).

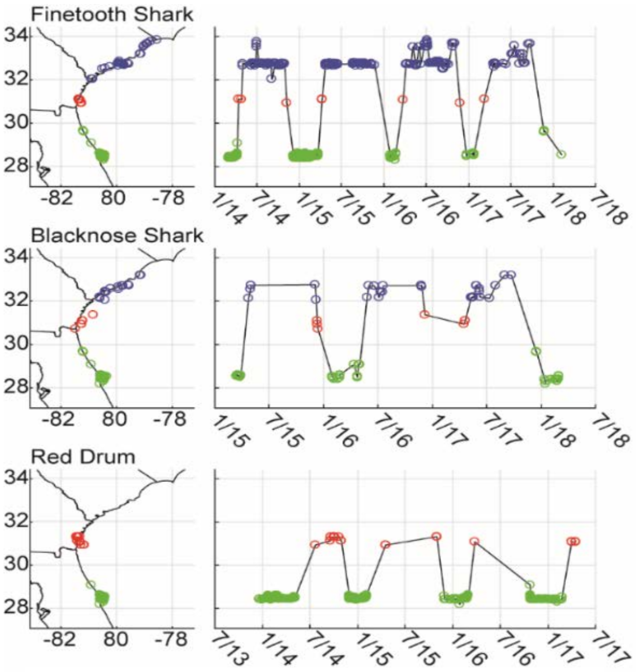


Figure 45. Examples of individual movement behavior

3.3.10 Target Species Accounts

Species-level summaries are provided below to offer a concise overview of local behavior for all target species, to detail the timing and geographic extent of coastal migrations, and to convey local life history insights that, while potentially valuable, were difficult to capture in previous formal analyses.

3.3.10.1 Blacknose Shark

Sixty-one adult and large juvenile blacknose sharks were tagged from May 2014–March 2016 and ranged in size from 75–115 cm FL (mean 98 cm; **Table 10; Figure 46**). Sharks were collected exclusively with longlines and were released at multiple locations throughout the Canaveral Shoals. With the exception of red drum, blacknose sharks provided the richest dataset of all target species. Fifty-five individuals were detected and tracked for an average of 798 days (2.2 years) and a maximum of 1,184 days (3.2 years; **Table 14**). One additional animal released in 2011 for an earlier pilot study was also active in the Canaveral Array through mid-2015.

Blacknose sharks were recorded on all 62 Canaveral Array receivers with nearly equal numbers visiting the CSII dredge site (44) and control site (43). Habitat use at Canaveral varied seasonally. The species was most widely dispersed in winter, commonly ranging from the shoreline to the outer shoals (**Figure 28**). Moreover, of the 470 blacknose shark visits recorded on reef tract receivers offshore of the core Canaveral Array, 359 (76%) occurred during winter. From spring through fall, however, there was a clear inshore movement with sharks using the outer shoals and reef tract much less frequently, a trend that was similarly observed in longline catches. The Canaveral Bight south of the Southeast Shoal was the only area where observed blacknose shark use was high year-round.

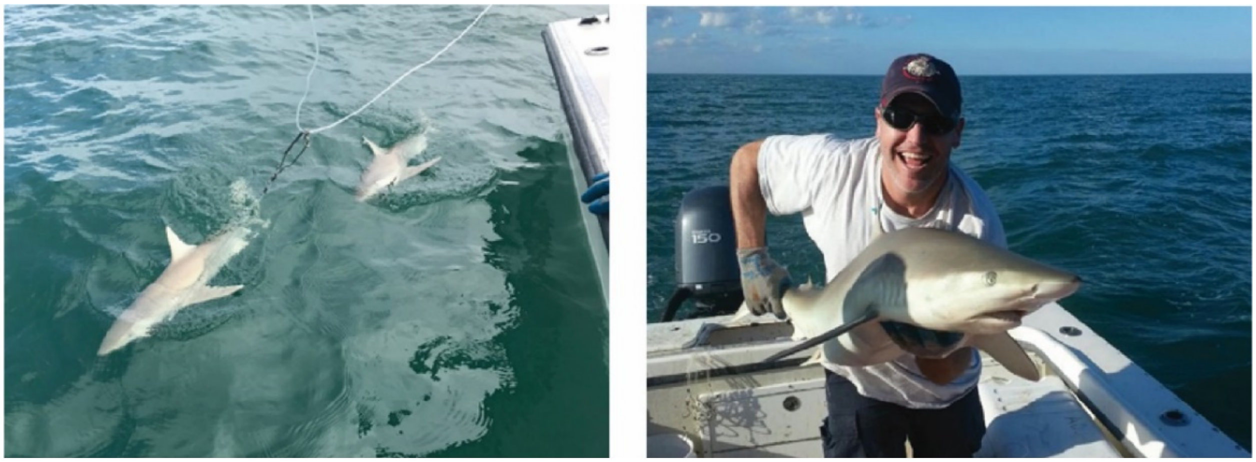


Figure 46. Blacknose shark captures
(*left*) Two blacknose sharks collected together on a longline. (*right*) Note the characteristic black smudge on nose. Photo credits: Eric Reyier.

Although blacknose sharks were detected locally in every month of the study since their initial tagging, a sizeable subset of the population would migrate each year, with individuals detected on a combined 195 FACT and ACT Network receiver stations from Cape Lookout, North Carolina, to West Palm Beach, Florida (**Figure 47**). Sharks began expanding north in spring, arriving in Georgia (n=38) by March, South Carolina (n=17) by April, and North Carolina (n=2) by August. Some of these sharks, particularly females, would return to Canaveral as early as June–August, long before temperature declines in fall would require a southward migration. These short-term, north-south movements suggest that northward migrations may in part be for reproductive purposes, as females are known to pup in spring. By November, most tagged sharks had again returned to or passed through Canaveral, although a small number of individuals appeared to overwinter in northeastern Florida. No blacknose sharks penetrated far into the IRL estuary although individuals regularly used the lower reaches of river mouths (up to 20 km up estuary) to the north from St. Mary’s River, Georgia, to the Edisto River, South Carolina. Movement south of Canaveral was rare. Only four sharks (three females, one male) were detected south of Sebastian Inlet; all detections occurred during summer or fall.

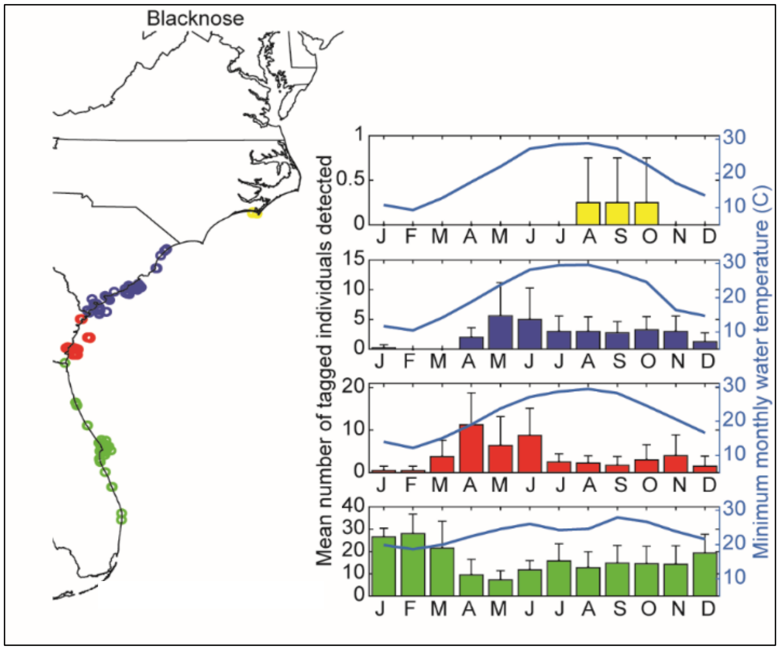


Figure 47. Average annual regional movements by blacknose sharks

3.3.10.2 Finetooth Shark

A total of 61 finetooth sharks from 64–130 cm FL (mean 104 cm FL) were tagged between December 2013 and September 2016 (**Table 10; Figure 48**). Initial releases were primarily adults (including six females who were noted to be gravid), but several individuals released later in the study were clearly juveniles. Finetooth shark were among the most active of all target species. They were detected on all 62 Canaveral Array receivers and were tracked for an average of 841 days (2.3 years) and up to 1,535 days (4.2 years; **Table 14**).

Figure 48. Adult and juvenile finetooth sharks at Cape Canaveral
The species is characterized by its slate gray coloration and lack of distinctive fin markings. Photo credits: Eric Reyier.

Finetooth sharks were most abundant and widespread at Canaveral in winter and early spring and were strongly associated with the shoreline (**Figure 27**), a trend similarly observed in longline sampling. Nearshore waters directly north of the Southeast Shoal appeared especially important. That said, the species was exceptionally mobile and periodically moved away from the coast with 43 of the 55 animals also detected using the offshore reef tract in water up to 25 m deep and greater than 20 km from shore. Over 93% of the 251 observed visits to the reef tract were in winter. Finetooth sharks were also slightly more abundant within the dredge site (46 animals) vs. the control site (36 animals).

Finetooth sharks appeared to be obligate migrators, overwintering off east-central Florida but undertaking rapid and extensive northward migrations each spring (**Figure 49**). Tagged sharks were observed exiting the Canaveral region in March each year, and virtually all had left by April. Only a single finetooth was ever detected in the Canaveral Array in the month of May. For reasons not yet understood, females began their northward migrations 1–2 weeks earlier than males each year.

Finetooth sharks appeared to spend the majority of the summer and fall offshore GA and SC, arriving by May most years. A small number of animals strayed as far north as NC and one was detected near the mouth of Chesapeake Bay, Virginia. This section of the US coastline was not well instrumented with acoustic receivers early in the study so use of coastal waters north of South Carolina may be higher than was observed. As with blacknose sharks, some female finetooth sharks would briefly return to the Canaveral region in late summer, illustrating that seasonal migrations are a complex behavior more akin to an expansion and contraction of their geographic range as opposed to a synchronized shift of the entire population along the coast. From November through January, most surviving sharks were detected returning to the Canaveral Array. Sharks also spent time south of Canaveral in winter, as far south as

Jupiter Inlet (170 km away). Their movement always occurred when water temperature within the Canaveral Array was less than 18°C, and the most extensive southern movements were made by males.

Six finetooth sharks entered nearby Port Canaveral Harbor, but the species rarely utilized the adjacent Indian River estuary in winter and spring. Only a single female was detected utilizing the central IRL from Sebastian Inlet to Palm Bay from March–May 2015. Inshore use in summer and fall was much more common with sharks detected up to 20 km inside estuaries such as the Savannah River, St. Helena Sound, and Ossabaw Sound, Georgia; Charleston Harbor and Winyah Bay, South Carolina; and Back Sound, North Carolina. All told, finetooth sharks visited a collective 296 receiver stations along the southeast US coastline (mean 62 stations per individual), by far the most of any target species.

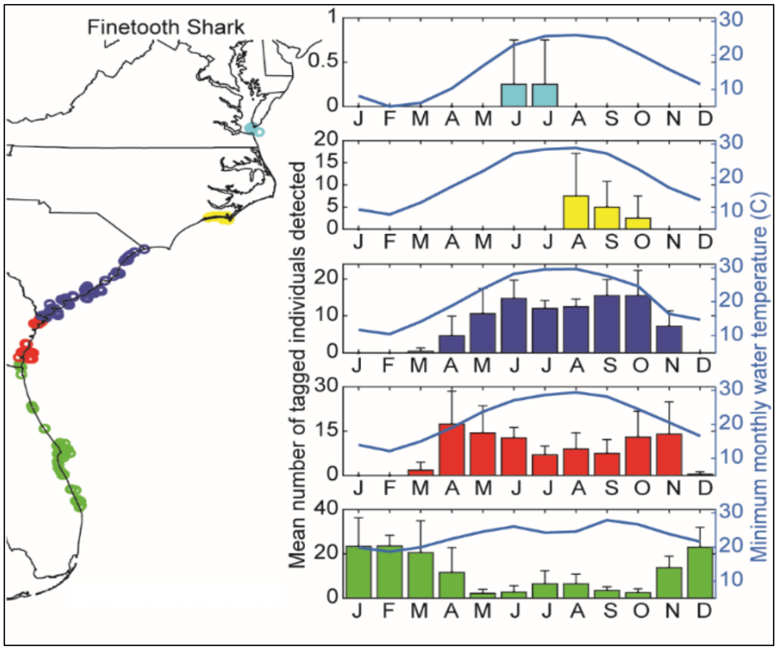


Figure 49. Average annual regional movements by finetooth sharks

3.3.10.3 Atlantic Sharpnose Shark

Sharpnose shark were released in summer 2016 (n=17) and spring–summer 2017 (n=27) after collection on longlines or using hook-and-line angling, and were tracked for an average of 159 days and up to 524 days **(Table 14)**. Size at tagging ranged from 63–83 cm FL (mean 74 cm; **Table 10**) suggesting that all animals were sexually mature **(Figure 50)**. Recent genetic studies confirm that the congeneric and similar looking Caribbean sharpnose shark (*Rhizoprionodon porosus*), once thought to range no farther north than the Bahamas, also is present from at least northeast Florida to Virginia (Davis et al. 2018). Although 31 genetic samples provided from Cape Canaveral for that study were identified exclusively as Atlantic sharpnose shark, the inclusion of a small number of Caribbean sharpnose shark in tagging efforts cannot be ruled out.

Sharpnose shark used the Canaveral Shoals differently than other target shark species both seasonally and spatially. Not only did the species have a greater affinity for deeper offshore waters and largely avoided the shallowest ridges of the Southeast and Chester Shoals, they were also more prevalent in the Canaveral Array in summer and early fall, when other target species had migrated away from east-central Florida (**Figure 29**). Sharpnose sharks were especially common in the northern half of the study area and were one of the few species more commonly detected at the control site (n=24) than the dredge site (n=10). They were also regular visitors to the adjacent reef tract (n=22), primarily during summer and fall.

Figure 50. Sharpnose sharks at Cape Canaveral
This species often schooled locally, with up to 22 individuals collected on a single longline set. As is the case with many shark species, immature individuals (*right*) were more common close to shore. Photo credits: Eric Reyier.

Seasonal movements of sharpnose sharks were less predictable than other sharks studied. Individuals stayed within the Canaveral Shoals for two weeks to several months post-tagging, but their intermittent detections and the movement of a few individuals to Georgia and South Carolina in fall (as far north as Myrtle Beach, South Carolina; **Figure 51**) indicates that they range widely over the continental shelf at this time. By December of each year, all remaining sharks had exited the Canaveral Array, with some evidence of a southern migration; one sharpnose was subsequently detected in the middle Florida Keys in October 2016 and January–February 2017, the farthest movement south observed in any shark species. Eleven sharpnose were detected in Georgia and South Carolina without passing though the Canaveral Shoals in April–June the following year (**Table 14**), and the arrivals in Georgia and South Carolina were typically different animals, not the same individuals traveling north along the coast. This pattern suggests that the core sharpnose shark migration occurs in deeper offshore water where acoustic receiver coverage is sparse. Seven sharks returned to Canaveral (at least temporarily) for a second summer, four of which migrated directly from Georgia or South Carolina, providing another example of sharks migrating south through the SAB in spring and summer. Sharpnose sharks were rarely detected within estuaries in Florida or elsewhere, with one individual each (both males) briefly visiting the lower reaches of Ossabaw Sound, Georgia, and Edisto River, South Carolina.

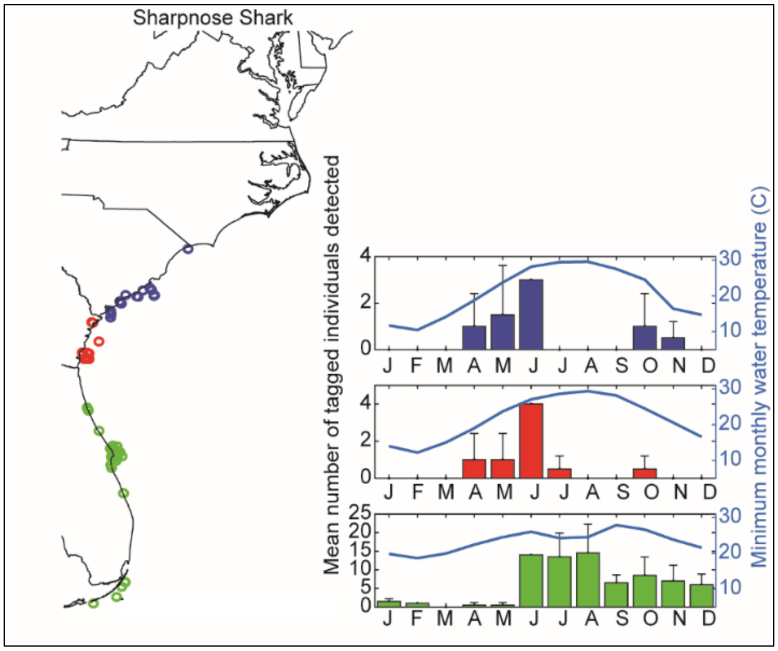


Figure 51. Average annual regional movements by sharpnose sharks

3.3.10.4 Lemon Shark

Juvenile lemon sharks form predictable aggregations along the Cape Canaveral shoreline each winter (**Figure 52**) and have been tracked via acoustic telemetry since 2008, resulting in a detailed description of their coastal migrations (see Reyier et al. 2014). A total of 54 individuals were tagged from 2008–2011, averaging 89 cm FL (range 55–143 cm) at release (**Table 10**). Twenty-two sharks remained active in the region during the present study, presumably now as much larger animals, and the expansion of the Canaveral Array allowed sharks to be tracked over a longer time period, providing greater insight regarding use of the Canaveral Shoal complex than was originally possible.

Figure 52. Lemon sharks at Cape Canaveral
(Left) Juvenile lemon shark aggregation along the Canaveral shoreline as observed from a helicopter, 1 February 2017. Each dark object represents an individual shark. An estimated 1,758 lemon sharks were counted over 29 km of shoreline, equating to one shark every 16 m. *(Right)* Lemon sharks observed in the shallow surf, December 2007. Photo credits: Eric Reyier.

As of February 2018, the 22 remaining lemon sharks had been tracked an average of 1,939 days (5.3 years) (max 2,362 days, 6.5 years) since their initial release (**Table 14).** From 2013–2018, these sharks were detected at Canaveral 18% of the days they were at large, with 79% of all detections occurring in winter months. As was observed in earlier years, lemon sharks were strongly shoreline associated, especially to a region near Chester Shoal. These sharks nonetheless made periodic and brief excursions offshore; 16 animals were detected at the dredge site, 13 at the control site, and 8 at the reef tract, with over 97% of the 197 visits to these receivers occurring in winter. The seasonal fidelity of lemon sharks to Cape Canaveral in winter was very strong. Nineteen of the 22 sharks available for detection overwintered in the Canaveral Array every year, which was 3–5 years in all cases before tag

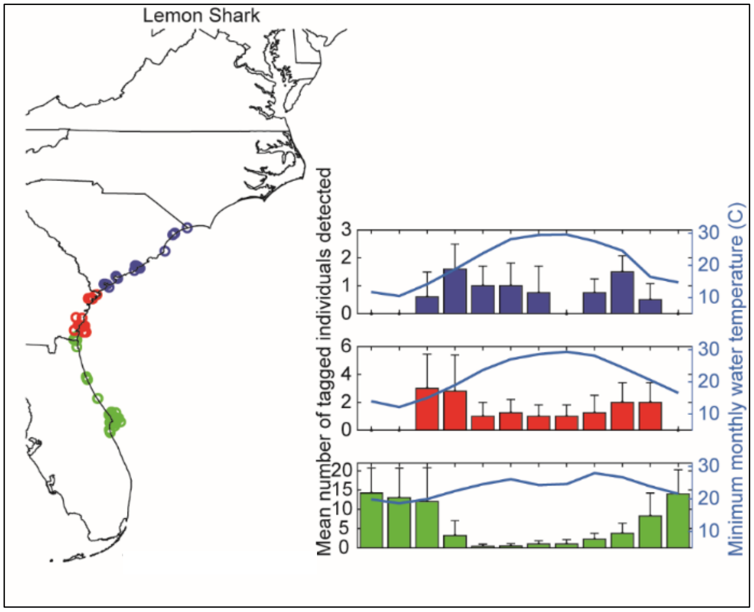


Figure 53. Average annual regional movements by lemon sharks

batteries began to expire, and a twentieth individual remained at Canaveral basically year-round. Only two animals failed to return in consecutive winters, possibly due to mortalities or tag failures. Moreover, the presence of these sharks was consistent through winter with only two individuals ever detected south of the Canaveral Array near Melbourne. Two additional lemon sharks, including one YOY (originally tagged near the Altamaha River, Georgia, in July 2017) also recruited to these winter aggregations, demonstrating that Canaveral seasonally supports animals drawn from a wide area of the SAB coastline.

Lemon sharks generally began their northward migration along the coast in early March, arriving in Georgia by late March and South Carolina by April (**Figure 53**). The species remained strongly shore-associated and was detected within every estuary and river mouth known to have acoustic receiver coverage from Nassau Sound, Florida, to Charleston Harbor, South Carolina. No animals were detected north of South Carolina although movements of Canaveral-tagged lemon sharks to North Carolina have been documented in the earlier years. The southern migration occurred in fall with sharks returning October through December.

3.3.10.5 Scalloped Hammerhead

Like lemon sharks, scalloped hammerheads use nearshore waters at Cape Canaveral as a nursery (**Figure 54)** and a parallel acoustic tracking effort was already underway at the onset of this study, a summary of which is provided here. Species identity of tagged sharks were somewhat uncertain because scalloped hammerheads in the US south Atlantic were recently confirmed via genetics to consist of two distinct species. They include the previously described *Sphyrna lewini* as well as the newly discovered *S. gilberti*, which differs in the number of vertebrae but otherwise appears visually identical (Quattro et al. 2013) and are known to locally hybridize (Barker et al. 2019). No means of distinguishing between the two species in the field is available although tissue samples (small fin clips) were collected from each shark for future genetic analyses.

Figure 54. Scalloped hammerheads at Cape Canaveral
Young-of-the-year hammerheads (*left*) were under-represented in longline catches but are easily collected with gill nets in the Canaveral Bight. Larger juveniles (right) were typically encountered farther offshore, most commonly in spring. The local population likely consists of two nearly identical species. Photo credits: Eric Reyier.

A total of 56 immature scalloped hammerheads were tagged from July 2012 to September 2014. These included nine larger juveniles 57–115 cm FL, collected early in this period, primarily from longline sets on the outer shoals (**Table 10**). An additional 47 neonates (confirmed via open umbilical wounds) and YOY sharks (37–48 cm FL) were taken using targeted gill net sets in the Canaveral Bight, mostly in spring and summer 2014. Results are presented here only for the 40 sharks active in the Canaveral Array during the December 2013 through February 2018 study timeline.

As a group, scalloped hammerheads were followed for an average of 128 days post-release (with a range of 2–1,215 days) and were widely distributed within the Canaveral Array, visiting 60 of 62 available receivers (**Table 14**). There was a great disparity in the quality of tracks however. The five larger juveniles active in the Canaveral Array were at liberty an average of 629 days (range of 181–1,215 days), while tracks of the 35 YOY sharks averaged only 10 days (range of 1–110 days), suggesting some combination of high emigration or elevated post-tagging or natural mortality. Total residency in the Canaveral Array averaged 49%, a value inflated by short tracks of these smallest fish. When considering only sharks tracked greater than one month, mean residency index was reduced to 16%.

Although the smallest scalloped hammerheads were all tagged in the Canaveral Bight where they are seasonally very common (E. Reyier, unpubl. data), they made brief excursions to the north and south along the shoreline and occasionally to the outer shoals, and seven sharks also entered Port Canaveral Harbor. Individual hammerheads were detected locally year-round, indicating that a portion of the population is non-migratory. Nonetheless, sharks of various sizes moved away from Canaveral periodically and were detected on acoustic receivers from West Palm Beach, Florida, to Charleston Harbor, South Carolina (**Figure 55**). All detections in southeast Florida (three sharks) occurred during January 2015. Detections off Georgia and South Carolina occurred in the months of May, July, and October, one of which was recorded in approximately 180 m of water offshore Charleston by a Slocum glider equipped with a mobile acoustic receiver (Chad Lembke, Univ. South Florida, pers. comm.).

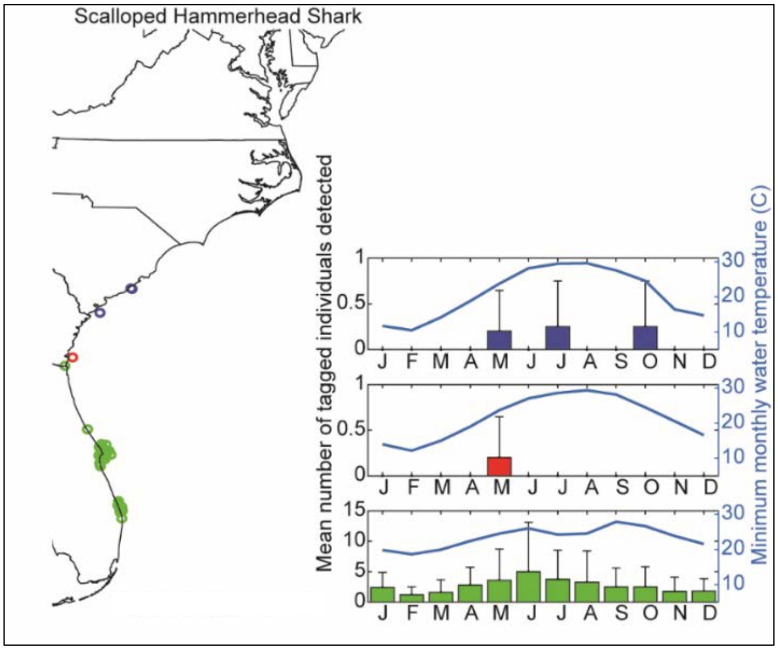


Figure 55. Average annual regional movements by scalloped hammerheads

3.3.10.6 Red Drum

Figure 56. Adult red drum captured on a longline
Photo credit: Eric Reyier.

Red drum produced by far the most complete acoustic telemetry dataset of any target or non-target species, generating over one million position detections through February 2018. A total of 83 adult red drum were tagged (size range 79–100 cm SL), of which 81 were subsequently detected (**Table 10; Figure 56**). Three smaller red drum (49–59 cm SL when tagged), originally tagged in the surf zone at Cape Canaveral in early 2012 for a separate study, were also active at times in the Canaveral Array.

Red drum were highly mobile, but unlike many other target species who demonstrated strong seasonal migrations, at least some fish were present in the Canaveral Array year-round. Individuals were detected on average 41% of their days at liberty, despite tracks that lasted 607 days (1.7 years) on average (**Table 14**). The species collectively visited all 62 Canaveral Array receivers and, when present on the shoals, showed a strong affinity to the Canaveral Bight and to the shoreline north of the Southeast Shoal (**Figure 31**). It was also the only species that was clearly more common on the dredge site (71 individuals) than the control site (35 individuals). Red drum were also regular visitors to the 12-fathom reef tract (particularly 8A Reef) nearly 20 km offshore, a broad offshore distribution not previously known from east-central Florida. This repeated use of offshore reefs, primarily in January through July, requires that red drum regularly range well beyond the Canaveral Shoals area monitored by the fixed station receivers.

Peak abundance in the Canaveral Array was from late fall through early spring **(Figure 23;** Figure 57), a pattern similar to that observed in longline catches (**Figure 8)**, although continued presence of red drum through summer demonstrated that the species was underestimated by longlines at these times. There was a notable drop in red drum abundance each fall, which corresponds with their known spawning period. At this time, a general expansion of their range was observed with many fish moving north, and often observed entering estuaries. Nineteen fish utilized the IRL system, almost always from July through October. Eight of these fish used the system for 2 or 3 consecutive years, most commonly entering via Ponce Inlet to the north (24 visit events), vs. Sebastian Inlet (5) or the Canaveral

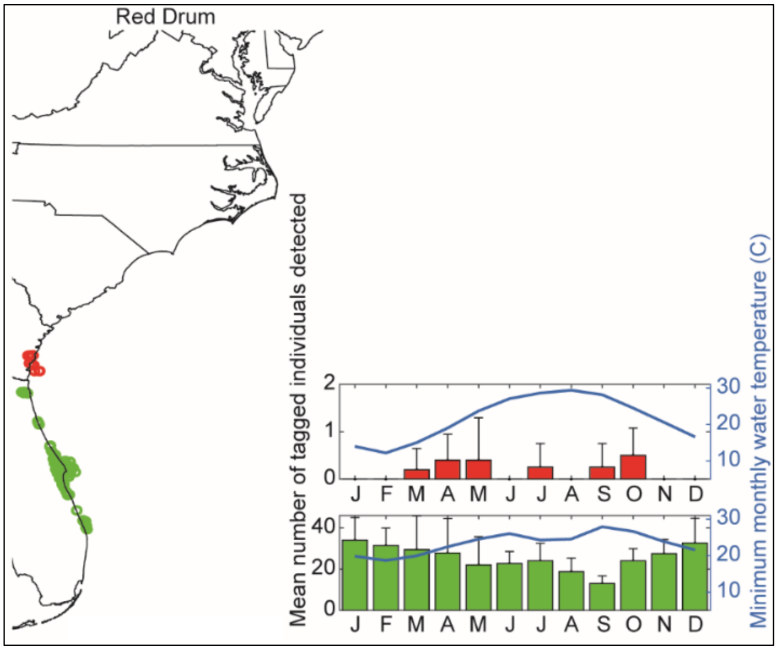


Figure 57. Annual average regional movements by red drum

Lock (1), although fish also occasionally left through a different inlet than they entered. The IRL was also a location of high apparent mortality, with several fish disappearing permanently while within the estuary.

A total of 36 fish were detected offshore Ponce Inlet and St. Augustine, Florida. Two of these fish traveled as far as the St. Johns River, Florida, and another two to the Altamaha River, Georgia, including one individual who made four separate trips to central Georgia, returning to Cape Canaveral each winter (**Figure 45**). The farthest south a red drum was detected was offshore Jupiter Inlet, and only four fish were ever detected south of Sebastian Inlet, none of which were detected in an estuary.

3.3.10.7 Bluefish

Fifty-two bluefish averaging 30 cm SL (range 23–42 cm SL) were tagged in February and March 2016 exclusively via hook-and-line angling from the Canaveral shoreline (**Table 10; Figure 58**). Individual fish tracks were generally short, averaging only 17 days (maximum 208 days; **Table 14**), with 99% of detections recorded in late winter or spring immediately after tagging. Bluefish remained strongly shore-associated when within the Canaveral Array with only limited evidence of offshore excursions (**Figure 32**). Of the 48 bluefish detected, only three were observed passing through the CSII dredge site, plus one each on the control site and along the adjacent reef tract. The observed travel speed of bluefish through the Canaveral Array was just under 1 km/hr (**Figure 40**), and their visit duration averaged only 28 min at any given receiver.

Figure 58. Bluefish being tagged at Cape Canaveral
The species was strongly shore-associated and most easily collected from the beach. Photo credits: Eric Reyier.

Movements away from Cape Canaveral appeared common with fish dispersing both to the north and south in spring, but were documented with poor resolution. Eight individuals were detected 20 km south off Melbourne Beach from February–May, and three of these fish were subsequently detected offshore Sebastian Inlet (n=2) and St. Lucie Inlet (n=1) up to 180 km south of their release points. Five other animals were detected to the north offshore Ponce Inlet and sixth at the mouth of the St. Johns River 230 km north, all from March to May. One of these fish reappeared off Deerfield Beach, in southeast Florida the following October and thus utilized at least 320 km of shoreline during its track. Only two fish entered the adjacent IRL estuary, one each through Sebastian and Ponce Inlets.

3.3.10.8 Spanish Mackerel

Spanish mackerel (**Figure 59**) proved to be one of the most mobile species tracked during this study. A total of 49 fish were tagged (mean length 39 cm FL; **Table 10**) with collections occurring in April 2015 (n=11), October 2015 (21), April 2016 (11), and September 2016 (6), periods when the species is known to pass through Cape Canaveral waters in large numbers during its seasonal migration.

Of the 30 mackerel subsequently detected, average duration of stay at Cape Canaveral was a mere 3 days with individual fish demonstrating very rapid movements. The observed rate of travel through the Canaveral Array averaged 1.5 km/hr (**Figure 40**), the highest of any target species other than the lone roughtail stingray, and the mean visit duration to any receiver site was only 21 min, lower than any other species. Its calculated residency was high (91%; **Table 14**) but is an artifact of the short tracks; individual fish clearly spent limited time within the Canaveral Array. The nine tagged mackerel fitted with externally attached transmitters did not yield improved results; only five were detected with a maximum track of 3 days and maximum observed movement locally totaling only 88 km.

When present, behavior within the Canaveral Array suggested a bi-modal distribution with Spanish mackerel preferentially utilizing shallow water near the beach as well as shallow ridges of the Southeast, Chester, and Bull Shoals (**Figure 33**). Ten individuals were detected at the dredge site, seven on the control site, and one on the adjacent reef tract, 18 km offshore **(Table 12**). Only two fish were detected away from Canaveral, both 20 km south at Melbourne Beach in fall 2015, just 1–10 days post-release, confirming that coastal migrations were not adequately captured by the FACT Network.

Figure 59. Spanish and king mackerel at Cape Canaveral
Spanish mackerel (*left*) were highly seasonal but conspicuous, with schools often associated with shoal ridges. King mackerel (*right*) were most abundant on reefs east and north of the core Canaveral Array. Photo credits: Eric Reyier (*left*), Doug Scheidt (right).

3.3.10.9 King Mackerel

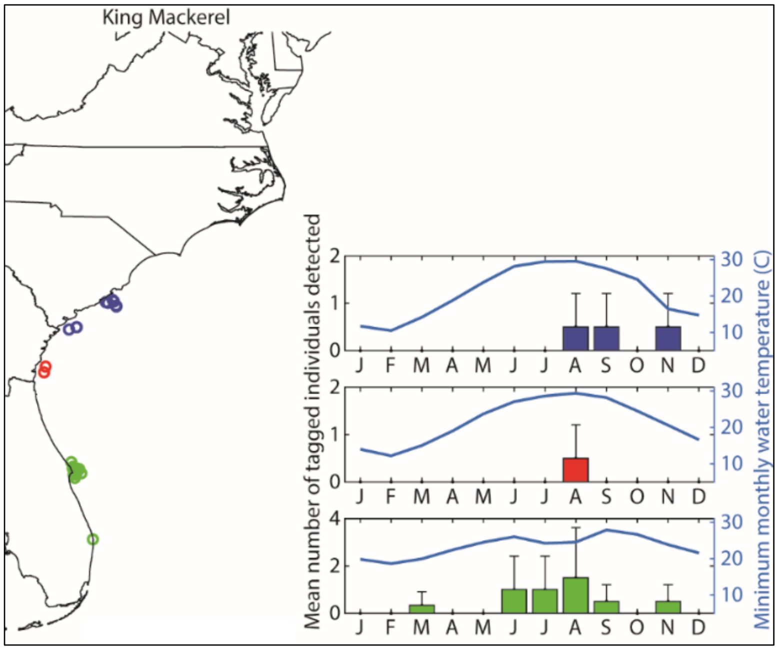


Figure 60. Annual average regional movements by king mackerel

Adult and large juvenile king mackerel (mean 73 cm FL; **Table 10; Figure 59**) were collected from July 2015–July 2016 by trolling live baitfish. King mackerel presence near the coast is locally unpredictable, so all tagging occurred over the offshore reef tract, with the expectation that the Canaveral Array would capture any shoreward movements over the shoals. Results from this species were very limited. Of the 41 fish tagged, only 5 were ever detected with tracks averaging only 63 days in duration, and a maximum of 129 days (**Table 14**). Occurrence in the Canaveral Array was restricted to outer shoal stations, with four fish visiting reef tract stations, plus one fish detected on the dredge site and two at the control site; these observations consisted of several distinct visits over several weeks from June–August 2016. No fish approached closer than 5 km to shore. Extensive coastal migrations were observed in two individuals (**Figure 60**). One fish departed Canaveral in early August 2016 and was detected offshore Georgia by mid-August and off central South Carolina mid-September before it returned to Canaveral early November. A second fish migrated from Canaveral to northern Georgia from August to November 2016 but did not return. Data collection may have been limited due to the necessity to tag king mackerel outside the core Canaveral Array (which reduced opportunities for later detection) and elevated post-release mortality, including predation by large sandbar sharks who were present at most king mackerel tagging sites.

3.3.10.10 Cobia

Over 140 juvenile and adult cobia (mean 77 cm SL; **Table 10; Figure 61**) were tagged off South Carolina, Georgia, and east Florida from December 2014–August 2016, including 31 tagged near Cape Canaveral, for a concurrent stock migration study led by the South Carolina Department of Natural Resources. Forty-one of these fish (mean 77 cm FL) passed through Canaveral Array during their seasonal migrations, allowing their behavior on the shoals to be examined. Because regional-scale migrations were a central goal of the concurrent study, those results are not presented here.

Tagged cobia were widespread at Cape Canaveral, collectively visiting 58 of 62 receiver stations including nearshore and shoal sites, but more commonly were detected away from the coast (**Figure 34**). Cobia were especially abundant on the adjacent reef tract, where 35 fish were detected despite only five receivers deployed in this habitat (**Table 12**). Although fish were present every month of the year, their fidelity to the region was low, being detected within the Canaveral Array only 9% of their days at liberty (**Table 14**). Although rate of travel through the study area was moderate compared to other target species (**Figure 40**), visit duration to any single receiver location averaged less than 30 min (n=1,201 events) and never exceeded 7 hours, further confirming the high mobility and low site fidelity of this species locally. Seasonally, more animals were present in the Array from November–February (15–18 individuals) and during an August 2016 cold upwelling (n=22) than during the months of March–May (5–8 individuals), which generally correspond to the species northward coastal migration.

Figure 61. Cobia tagged as part of a multi-state stock migration study
Left: First cobia tagged at Cape Canaveral was tracked over two years. Note the stingray tail protruding from its mouth. Photo credits: Tim Kozusko (*left*), Eric Reyier (*right*).

3.3.10.11 Red Snapper

The purpose of tagging red snapper differed from that of other target species. Although there is interest in better defining their habitat needs (including any use of the Canaveral Shoals) in east-central Florida, the species' known affinity for reef substrates also makes it useful for evaluating the performance of the onboard acoustic telemetry detection system of the Wave Glider USV. For this study, the Wave Glider was programmed to survey a 92-km section of the 12-fathom reef tract and circled red snapper release sites, allowing any dispersal from tagging areas and along the reef tract to be explored.

Tagging of red snapper is ongoing (**Figure 62**). Fourteen of a planned 40 red snapper (37–72 cm SL; **Table 10**) were released November 2017–December 2018 at three reef locations, with the remainder to be tagged prior to future Wave Glider deployments. All releases were associated with the predefined Wave Glider transect, and 12 were also within 1 km of fixed station acoustic receivers positioned along the reef tract. To date, all 12 snapper tagged near fixed station receivers were detected at their release sites, and seven were also detected by the Wave Glider over its first three missions, also near their point of release. Most detected fish consistently remained within the range of receivers for days or weeks (residency index 83%; **Table 14**), although two snapper were detected moving over Chester Shoal within 2 days post-release. Whether these movements represent natural movements or predation events has not yet been fully evaluated.

Figure 62. Red snapper tagged on reef tract adjacent to Canaveral Shoals
Fish from 2-5 kg (*left*) are very common although the largest tagged to date was 11 kg (*right*). Tagging is ongoing. and the species is being used to assess the degree to which the Wave Glider can relocate acoustically tagged fish. Photo credits: Eric Reyier (*left*), Doug Scheidt (*right*).

3.3.10.12 Roughtail Stingray

This species was captured periodically during longline sampling (**Figure 63**). A single 116 cm juvenile male roughtail stingray was opportunistically tagged January 2015 on a longline set within the CSII dredge site (**Table 10**) and subsequently demonstrated unexpectedly wide-ranging movements throughout the SAB. The ray remained at the dredge site for only 8 hours, left the Canaveral Shoals within a day, and then was detected 30 km south at Satellite Beach, Florida (March 10); Canaveral again (March 12); Cumberland Island, Georgia (May 7); Charleston Harbor South Carolina (May 13); and finally at the mouth of Chesapeake Bay, Virginia (June 14). In total, its Florida to Virginia migration totaled approximately 1,400 km along the coast with a rate of 12 km/day. The life history and behavior of the roughtail stingray has received limited scrutiny. These results, albeit from a single animal, provide some evidence that this benthic species may nonetheless be highly migratory.

Figure 63. Roughtail stingrays at Cape Canaveral
Left: Twenty-one individuals were captured via longline, primarily in the Canaveral Bight. More were likely encountered, but the species buries in the mud once hooked making them difficult to dislodge from the seafloor. Note the one individual with a probable shark bite wound (*right*). Photo credits: Eric Reyier.

3.4 Discussion

3.4.1 Patterns in Fish Movement

High mobility and low site fidelity were common traits for most acoustically tagged fish inhabiting the Canaveral Shoals. For target species, observed ROM across the shoals averaged 0.7–1.7 km/hr depending on species; this range includes spot, Atlantic croaker, and a roughtail stingray, benthic fishes that are not typically recognized for high mobility. Estimates of visit duration (our metric of site fidelity) showed similar trends, with species spending a mere 21–65 min on average within range of a given station before relocating. As might be expected, pelagic species such as mackerel, bluefish, and cobia had the lowest observed visit duration at a given site (20–30 min), while visits by blacknose shark and red drum were the only two species whose mean visit duration exceeded one hour. There was a regular exchange of tagged animals between the shoals and the offshore reef tract (observed in 11target species and 200 individuals), confirming that many fishes have home ranges that extend well beyond the area monitored by the core Canaveral Array. Equally high mobility was also observed in most fish species tagged by other researchers as they passed through the Canaveral region, although these data were not examined in detail. Considering just target species, only red snapper appeared to maintain high site fidelity as shown through visit duration; most of the 14 snappers released to date have only been detected at their release site. Red snapper tagging is an ongoing avenue of research, and full results for this species will be presented at a later time.

3.4.2 Habitat Factors Influencing Movement

As expected, fish behavior varied both temporarily and spatially across the Canaveral Shoals. Season was an important factor across species, with rates of movement through the Canaveral Array generally lower in winter than in other seasons. This may be due to the fact that winter is a non-migratory period for many of the species tagged but may also have a physiological basis since most fish are poikilothermic and typically have reduced maximum swimming speeds at cooler temperatures (Wardle 1980, Koumoundouros et al. 2002). Location-based differences in visit duration off Canaveral were also apparent. Over 123,000 receiver visits were recorded for target species on the Canaveral Shoals, and the slowest movements were generally observed at receiver stations on the southern flanks of the Southeast Shoal (the Canaveral Bight) and Chester Shoal. Surprisingly, more rapid movement was observed at offshore reef sites relative to shoal sites for all target species except lemon shark and cobia, an unexpected trend since reef-associated fishes are often considered to have relatively high site fidelity.

Detailed movement modeling for selected species (finetooth, blacknose, sharpnose, lemon, and scalloped hammerhead sharks; red drum; bluefish; and cobia) suggested that most typically moved more slowly when close to shore and through areas with finer sediments (e.g., regions in the Canaveral Bight and south side of Chester Shoal) after controlling for other habitat factors. These same locations often coincided with the core use areas identified in UD maps. Several factors may help account for elevated site fidelity under these habitat conditions. First, areas adjacent to the Canaveral shoreline and those with fine sediment accumulation are also typically the most turbid, a condition thoroughly documented during concurrent longline sampling. Small benthic fishes and invertebrates often prefer high turbidity since it affords a refuge from predation (Abrahams and Kattenfeld 1997, De Robertis et al. 2003). In this study, spot and Atlantic croaker were easier to collect for tagging in turbid water, and tagged individuals that survived made shoreward shifts in summer as offshore water became clearer. Larger predatory fish likely move in concert with these forage fish and similarly spend more time in turbid conditions. For example, tagged blacknose and sharpnose shark made noticeable shoreward movements in summer. Also, areas of fine sediment may contain higher invertebrate biomass and be productive foraging ground for bottom-feeding species like red drum. Finally, the physical barrier of the shoreline may increase site fidelity simply by constraining fish movement more than in open offshore waters. These findings are consistent with a recent review by Sequeira et al. (2018), who demonstrated that movement patterns of marine vertebrates become more complex and less directed near the coast, regardless of taxonomy or body size, a convergence they link to increased microhabitat complexity in nearshore waters. After other conditions were accounted for, visit duration was also notably higher in deeper vs. shallow water for all species except bluefish (where no effect was detected). This finding may indicate high ROM through shallowest shoal ridges and surf zone sites, though the results may have been influenced by improved detection performance of acoustic receivers in deeper water.

3.4.3 Fish Use of Dredge and Control Sites

Based solely on acoustic telemetry results, there was no evidence to indicate that fish use of the CSII borrow area, which has experienced multiple dredge operations since 2000, differed in a meaningful way from that at the nearby Chester Shoal control site. Raw counts of unique species and individual fish recorded at each site were nearly identical (34 species and 454 animals at the dredge site vs. 33 species and 414 animals at control site), and the overall “community” of detected animals was also quite similar. Even animal behavior seemed comparable, with fish spending an average of 0.6 hours at dredge site receivers vs. 0.7 hours at control site receivers when averaged across all fish. The only species that appeared to favor one location over the other was red drum, which was clearly more abundant at the dredge site, possibly due to the proximity of the dredge site to the Canaveral Bight, a preferred habitat for red drum throughout the study.

Results from multiple site assessments in a variety of coastal settings worldwide confirm that benthic marine invertebrate can be severely disrupted by dredging operations, and there is concern and growing evidence that this applies to benthic fish communities as well (Michel et al. 2013). Similar impacts undoubtedly occur on the Canaveral Shoals as well, although no evidence of fish displacement associated with the onset of dredging was observed based on detection data from stations on the perimeter of the CSII dredge site in 2014 and 2018. However, as previously noted, fish detections during this time period were limited to red drum, spot, and croaker in 2014 and red drum plus several highly mobile shark species in 2018. Given these results, it is likely that determining the behavior of fish with acoustic telemetry in the immediate vicinity of dredging operations on the OCS is hampered by the logistical difficulties of safely deploying acoustic tracking equipment inside a dredge footprint, by the high mobility of large-bodied fishes (which often naturally disperse before disturbance effects can be measured), and by the limited detection range of small acoustic tags that are required to track smaller-bodied forage species.

Several factors may explain the overall muted differences in large fish use and behavior observed between the dredge and undisturbed control sites. First, some species detected at these sites do not preferentially feed on the bottom. For example, the favored prey for finetooth sharks (and many other predatory fishes) is menhaden (Castro 2011), which typically form mid-water schools. Spanish mackerel also feed on small mid-water schooling fishes, and associate with shoal ridges (perhaps more closely than any other managed fish in the study area), where they are a target of intense, albeit seasonal, exploitation by commercial fishermen. Species (such as white and sand tiger sharks, tarpon, and tripletail) tagged by other groups may also preferentially feed in the water column.

Dredging impacts in the CSII project footprint might also be spatially uneven. For example, several avoidance areas on CSII have been designated around archeological sites, where unknown metal objects (presumed rocket debris from historic Air Force and NASA operations) were detected during earlier magnetometer surveys. Dredgers may also concentrate activity on a small portion of an established dredge site during any given project. Remaining undredged areas would likely retain a largely intact benthic community, which can promote faster recovery and also help retain the natural overall carrying capacity of forage fish species. It is possible that the time between dredging (historically 2–4 years locally) is sufficient for benthic communities to recover adequately to again become productive foraging grounds for larger predators. Finally, tagged fish may be using the CSII site for other purposes (e.g., reproduction), or are simply transiting across the shoals.

3.4.4 Seasonal Migrations of Managed Fishes

The majority of fish tagged locally were highly migratory and only seasonally abundant on the Canaveral Shoals. The coastal migrations of finetooth, blacknose, sharpnose, and lemon shark; red drum; and cobia were captured with excellent resolution, and many fish still carry active transmitters. Movements of locally tagged bluefish, Spanish mackerel, and king mackerel also suggested a largely seasonal presence on the shoals, although detections away from Cape Canaveral were sparse. Even roughtail stingray, a benthic species whose habits are largely unknown, appears highly migratory with the lone tagged individual moving rapidly along the coast as far as Virginia.

Seasonal migrations for sharks and red drum revealed consistent patterns across years. Results of this tracking study confirmed that most sharks overwintering at Cape Canaveral move predominantly north to Georgia and South Carolina, although some finetooth and blacknose sharks were occasional visitors to North Carolina. These results match the general trends coarsely observed through traditional tag-recapture studies in the southeastern US (Kohler et al. 2012). Red drum also undertook seasonal migrations of shorter distances, and usually later in the summer than many other species. Migratory movements for both sharks and red drum are likely a means to take advantage of productive estuarine systems to the north that offer optimal conditions for growth and reproduction (and serve as important shark nurseries [Castro 1993, Abel et al. 2007, Gurshin 2007]) but are seasonally unsuitable due to cold winter temperatures. Tracks of individual sharks and red drum typically lasted longer than one annual cycle, and in most instances these fish would return to the Canaveral region by fall or early winter each year after tagging. For most fish tagged locally, east-central Florida appears to be the southern extent of their coastal migrations, and movements into southeastern Florida were uncommon. Of all the sharks and red drum tagged locally, only a single sharpnose shark was detected as far south as the Florida Keys. Cobia, tagged locally as a joint stock assessment study with other FACT Network partners, was the one species where movements to south Florida and the Florida Keys (and into the Gulf of Mexico) was a common occurrence.

3.4.5 Value of Canaveral Shoals for ESA-Listed Species

The Canaveral Shoals may be more important habitat for ESA-listed fish species than previously recognized. Federally endangered Atlantic sturgeon and smalltooth sawfish, as well as threatened giant manta rays, were all detected or observed on the Canaveral Shoals on multiple occasions. Prior to the current study, Gilbert (1992) found only four confirmed accounts of Atlantic sturgeon south of the St. Johns River (often cited as the southern range of the species) since 1900, although a small number of recent fisherman reports appear credible. While not tagged locally, 12 sturgeon were detected within the Canaveral Array in this 4-year study, all originally released at various sites from Georgia through New York. Several other sturgeon were detected by the FACT Network at Ponce Inlet, 60 km north of Canaveral. These local detections occurred from January to March, coinciding with previous studies which show that sturgeon overwinter on the continental shelf, where they range widely after spending the rest of the year in rivers and estuaries (Smith 1985, Collins and Smith 1997, Fernandes et al. 2010). By convention, movement of fish tagged by other research groups was not analyzed in detail, but these sturgeon, like most species observed in the study, exhibited limited site fidelity and often passed through the Canaveral Array within a few hours.

Three smalltooth sawfish originally tagged in south Florida were also detected on the Canaveral Array summer–fall 2016 and spring–summer 2017, including two at the CSII dredge site. Another animal was physically captured and released in the Canaveral Bight for an unrelated fisheries study in 2017. Though once very abundant in the nearby IRL (Snelson and Williams 1981), sawfish populations declined dramatically by the mid-1900s and now remain abundant only in southwest Florida (Poulakis and Seitz 2004, Wiley and Simpfendorfer 2010). It is unclear if local detections represent a gradual return of species to the Florida east coast (a trend supported by increasing reports to the International Sawfish Encounter Database; ISED 2018) or is simply due to expanding coverage of acoustic telemetry networks.

Although not targeted for tagging locally, giant manta rays were regularly observed near the shoals (**Figure 64**) and were sporadically abundant during summer cold-water upwelling events. The habits of mantas are largely unknown on the US East Coast, although studies in Indonesia and the Caribbean show that certain manta populations undertake seasonal movements, likely driven by temperature and productivity shifts (Dewar et al. 2008) and often associated with upwelling events (Graham et al. 2012). In August 2012, KSC biologists opportunistically tagged a 2-m manta in the Canaveral Bight with an external transmitter. Over a 3-month period, this animal made repeated movements between the Canaveral Shoals and Sebastian Inlet (30 km south) with occasional excursions as far as St. Lucie Inlet 140 km to the south. Given its recent listing under the US Endangered Species Act, manta rays are excellent candidates for acoustic and satellite tracking off east Florida.

Figure 64. Manta feeding in the Canaveral Bight, April 2015
Photo credit: Eric Reyier.

3.4.6 Advantages and Limitations of Acoustic Telemetry

The recent but rapid adoption of acoustic telemetry for animal tracking in open coastal settings is driven by the superior movement details that well-designed arrays provide when compared to traditional tag-recapture approaches. In the present study, the technology allowed for uninterrupted monitoring of fish and turtle behaviors across multiple years, two dredging events, cold-water upwellings, and several storms, including Hurricanes Matthew (October 2016) and Irma (September 2017). This study also benefited greatly from inclusion in the FACT Network, which provided the means to follow tagged animals much farther and for much longer than if working independently. Thirteen target species (all except red snapper) were detected away from the Canaveral Shoals. Some dispersed 20–50 km along the coast to adjacent ocean inlets, although movements of several dozen animals (primarily sharks) was captured in great detail as they performed repeated round-trip migrations to Georgia and South Carolina and even as far as the Chesapeake Bay and Florida Keys. For many of these fish, movements data produced at these distant locations were as detailed as those collected locally. Nearly 200 tagged animals were tracked a year or more; over a dozen lemon sharks (released prior to the start of this study) have been tracked for over 6 years.

Of equal value, the Canaveral Array noted the local presence of 28 fish species tagged by other researchers at numerous other locations along the US East Coast. By convention, full analyses of these movements are not permissible without approval of the tagging agency, but even documenting the coarse seasonal and spatial patterns of these animals provides management value, especially for the ESA-listed species that generally occur at low densities and would be hard to collect locally. Neither sawfish nor sturgeon, for example, were captured once during the companion 5-year longline survey.

Acoustic telemetry can be even more compelling when paired with traditional survey techniques, in this case longline surveys. Often times, both approaches will yield identical results, in which case the observed patterns are unambiguous. In this study for example, both acoustic tagging and longline captures suggested that Atlantic sharpnose shark preferred deeper offshore water, that blacknose sharks move shoreward in summer, and that red drum are most common in the Canaveral Bight. Alternatively, sometimes one technique may reveal the limitations of the other. Acoustic telemetry demonstrated the presence of goliath grouper transiting the shoals, whereas the species was entirely absent from longline samples. Telemetry also confirmed that red drum remained in the study area through summer even as they had disappeared from longline catches by spring, possibly indicating a behavior change as opposed to a migration. In contrast, longline sampling confirmed that some blacknose sharks were abundant year-round residents to Canaveral, even though many acoustically tagged animals migrated to the Carolinas in spring.

Although the Canaveral Array provided many new insights into the local behavior of marine fishes, limitations were apparent with both the technology and to some extent the study design. Advances in transmitter miniaturization now allow fish as small as a few centimeters to be tagged and tracked, but reductions in tag size also result in reductions in power and battery life. Fish carrying small transmitters must pass closer to a receiver to be detected. This was illustrated in principle by our range testing trials in which the small (VEMCO V7) transmitters implanted in spot and croaker had detection ranges several hundred meters less than transmitters (VEMCO V16) destined for sharks and drum. At Cape Canaveral and many other acoustic arrays in open coastal settings, receivers were spaced several kilometers apart, and species (including spot, croaker, bluefish, and mackerel) that required small transmitters simply produced less data as they moved across the shoals. Higher mortality of small-bodied fishes, the exceptional mobility of bluefish and Spanish mackerel, and the need to tag king mackerel outside the footprint of the core array may have also been contributing factors, and the end result was less detail upon which to draw inferences on behavior and habitat needs of these species. Researchers considering future studies on fishes over the open shelf should be wary of using small tags in mobile species unless this limitation is accounted for in the array design.

A second challenge of the study design was the requirement to moor receivers on the perimeter of the CSII dredge footprint in most instances, a layout replicated at the control site to aid in comparison. This step was necessary to avoid equipment loss to the dredge (which was active in 2013 when the array was being established) but also meant that a portion of animal detections from the CSII site were from animals outside the disturbance footprint. This layout likely had the effect of softening any dredge-induced differences across sites in species use and community composition. Repeated dredging at CSII since 2000 (BOEM 2017) also eliminated the option to conduct a true before-after-control-impact (BACI) study, an optimal design for disturbance studies, but one which would have required that monitoring be in place for months or years before the initial dredge disturbance in 2000. Any modest differences in fish use across sites therefore cannot be conclusively attributed solely to dredging activity.

4 Wave Glider Surveys

4.1 Introduction

Ocean gliders are emerging as platforms capable of dramatically expanding the duration and geographic scope of oceanographic data collection and have the potential to lower the costs associated with environmental monitoring in the coastal ocean (Daniel et al. 2011). BOEM acquired a Liquid Robotics Wave Glider SV3 unmanned surface vessel (USV) to support environmental monitoring off east-central Florida. The vehicle's primary purpose was to survey shelf waters at Cape Canaveral to detect acoustically tagged fish and sea turtles in areas not monitored by the existing fixed station acoustic array (the details of which are found in **Section 3).** The Wave Glider is highly customizable, however, and also carries a suite of environmental sensors that allowed it to characterize various physical and biological oceanographic conditions along its survey transect, information that provides valuable habitat context when tagged animals are relocated. A total of eight quarterly Wave Glider deployments were scheduled from fall 2017 through fall 2019, four of which have been successfully completed as of submission of this present report. The purpose of this appendix is to provide an interim summary of Wave Glider survey results. A final report, to include in-depth analyses of Wave Glider performance, and a comparison of fixed station vs. mobile acoustic telemetry survey results, is scheduled for spring 2020.

4.2 Methods

The Wave Glider SV3 is composed of a 3.1 m by 0.8 m surface float that is attached to a submersible (sub) via a 4-m long tether umbilical (**Figure 65**). As the float and sub rise on a wave, the fins on the sub tilt down, providing forward propulsion. As the float moves down the wave, the wings tilt up and the sub sinks, also pulling the float forward. During the day, three solar panels on the float charge ten lithium-ion batteries that in turn provide power on demand to onboard sensors and communications equipment. Watertight payload boxes beneath the solar panels accommodate sensors in user-customized configurations, and stand-alone sensors can also be mounted in various locations on both the float and sub. A Global Positioning System (GPS) receiver allows the glider to track its location and autonomously navigate courses through preprogrammed waypoints. Regardless of location, vehicle telemetry and science data are relayed via an Iridium Communications satellite modem, or through a faster cellular modem when close to shore. Average speed is slightly greater than 2 km/hr, maximum speed is 6 km/hr, and the vehicle is capable of deployments up to one year in duration.

All deployments at Cape Canaveral followed the same general path and included a minimum transect distance of 930 km composed of 179 preprogrammed waypoints **(Figure 66).** The transect was divided into four operational areas, including (in order of completion) a Shoal Zone (315 km), North Zone (376 km), Reef Zone (92 km), and South Zone (146 km). For vehicle safety purposes and to avoid the busy shipping lanes due east of Port Canaveral, the vehicle was constrained to operate in water depths greater than 10 m. The transect was repeated with as much fidelity as possible on each deployment and generally adopted a "mow the lawn" approach to maximize the area surveyed. The one exception was the offshore Reef Zone which instead sought to traverse known reefs and wrecks along the 12-fathom ridge east of the shoals. During all deployments, the glider's status was monitored from shore by NUWC and KSC pilots, typically operating on 12-hour shifts.

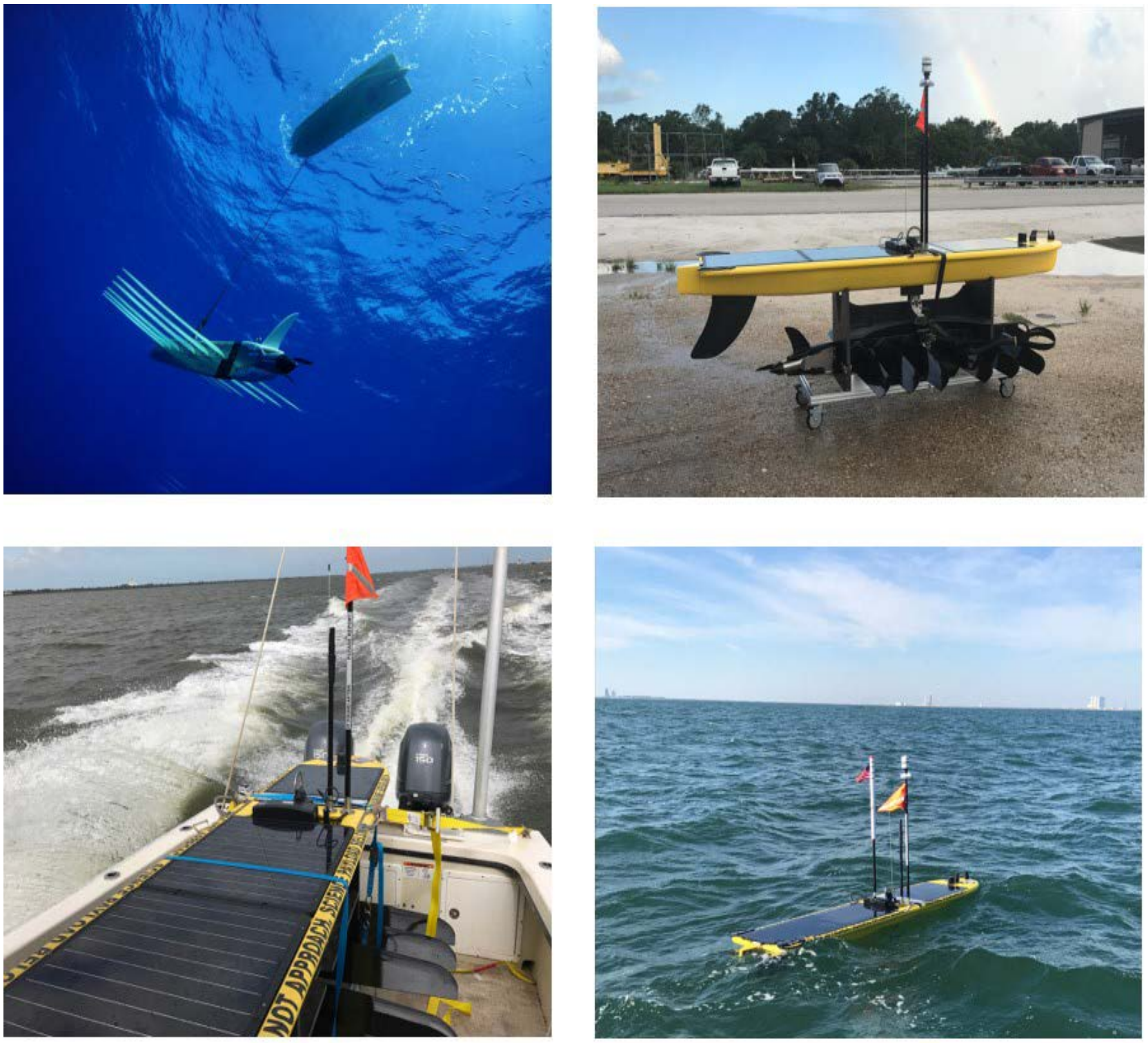


Figure 65. Wave Glider acoustic tracking and oceanographic surveys
Top left: A deployed Wave Glider USV as viewed from beneath, *Top right*: BOEM Wave Glider during pre-launch checkout, *Bottom left:* Glider in transit to launch site, and *Bottom right:* On transect offshore Cape Canaveral. Photo credits: Liquid Robotics, Inc. (top left), Eric Reyier.

The Wave Glider science payload included two acoustic receivers for detecting acoustically tagged animals, and sensors for measuring water temperature, dissolved oxygen, chlorophyll, turbidity, colored dissolved organic matter (CDOM), ambient biological and manmade sounds, and various meteorological conditions. All sensors were programmed to operate 24 hours a day, although extended periods of overcast skies occasionally limited solar energy generation. In these instances, sensors were powered off starting with those of least value to vehicle safety and scientific objectives.

Two types of acoustic receivers were attached on each deployment. The first was a VEMCO mini-VR2C cabled acoustic receiver. This unit has a wired connection to the onboard computer, allowing it to draw power from the glider batteries and relay animal detections to shore in real time. The second was a stand-alone VEMCO Mobile Transceiver (VMT), a miniaturized battery-powered unit commonly attached to sub-surface gliders (e.g., Slocum and REMUS systems). The VMT was primarily deployed for redundancy but also allowed for a performance assessment of the two receiver types. Both receivers were

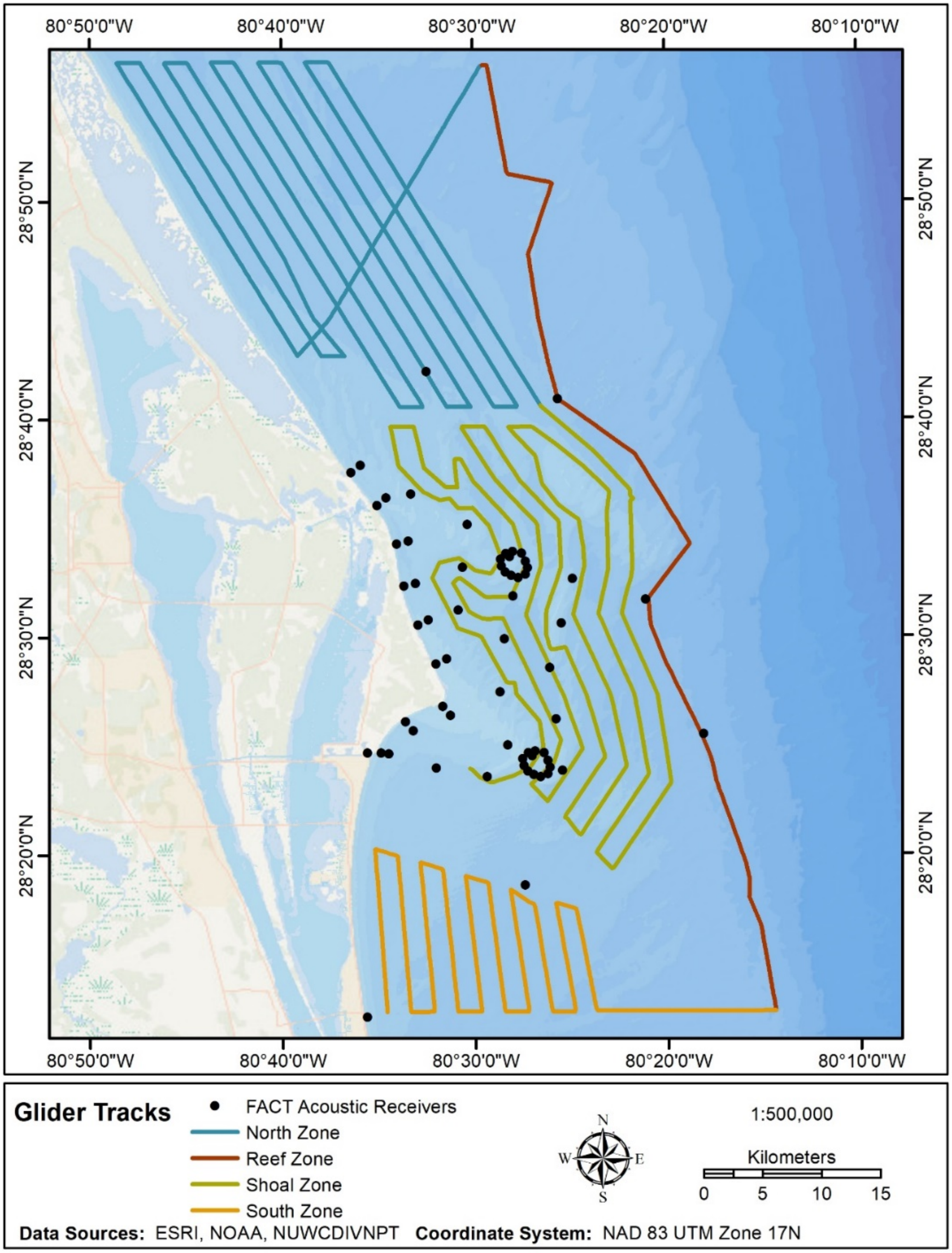


Figure 66. Wave Glider transect survey zones offshore Cape Canaveral
Non-uniform transect line spacing in the Shoal Zone is to avoid water less than 10 m deep.

mounted on the sub with the VR2C facing down, while the VMT was mounted horizontally on Deployment 1 but facing down for subsequent missions (**Figure 67**). To test the detection range of these acoustic receivers, the glider orbited range test transmitters (VEMCO V16-4H tags, 158 dB) that were pre-deployed along the transect at 10, 20, and 30 m depths. Upon reaching each range test site, the glider then circled the transmitter twice at a 250 m radius, and once each at 500 m, 750 m, and 1,000 m. Range testing results will be presented in the spring 2020 final report. Similar circular transmitter searches occurred at three locations where red snapper were tagged and released (see **Section 3**), in an attempt to confirm continued residency of these fish, which often have high site fidelity in hard bottom habitats.

Figure 67. Acoustic receivers mounted to the Wave Glider
Left: VR2C, Right: VMT (left-hand side of image).

Surface water chlorophyll, turbidity, and CDOM were measured at 10-min intervals by a Turner Designs C3 flow-through fluorometer housed in the Wave Glider's float. The native units from this fluorometer are Relative Fluorescence Units (RFU), although turbidity was converted to the more familiar Nephelometric Turbidity Units (NTU) using the equation NTU = (RFU-6.9)/16.6) as suggested by VanLacker and Baeye (2015). Chlorophyll, turbidity, and CDOM readings were validated by collecting and lab-analyzing water samples collected at glider launch and/or recovery points. Surface dissolved oxygen and surface temperature were also logged at 10-min intervals using an Onset dissolved oxygen logger. Ambient noise in the vicinity of the glider was recorded by a Loggerhead Instruments Remora passive acoustic monitor operating on a 50% duty cycle although sound files from this sensor have not been fully analyzed. The details of all sensors are found in **Table 21**.

Table 21. Purpose and description of Wave Glider science payload for the first four deployments

Sensor	Measurement	Real-Time Data	Duty Cycle	Location on Wave Glider
VEMCO mini-VR2C Acoustic Receiver	Detection of acoustically tagged fishes and sea turtles	Yes	Continuous	Sub
VEMCO Mobile Transceiver	Detection of acoustically tagged fishes and sea turtles. Carried for redundancy	No	Continuous	Sub
Turner C3 Fluorometer	Surface turbidity, chlorophyll, CDOM, and water temperature	Yes	Sampled once every 10 min	Float
Onset U26-001 HOBO Dissolved Oxygen Logger	Dissolved oxygen and water temperature	No	Sampled once every 10 min	Sub
Loggerhead Instruments Remora-ST Passive Acoustic Recorder	Ambient biological (e.g., fish, marine mammals) and anthropogenic noise	No	10 min every 20 min	Sub
Airmar Weather Station	Air temp; wind speed, direction, and gusts; and atmospheric pressure	Yes	Sampled once every 10 min	Float

4.3 Results

4.3.1 Oceanographic Monitoring

The Wave Glider has successfully completed its first four missions with the average deployment lasting 24 days, covering 1,258 km, and having a mean speed of 2.2 km/hr (**Table 22**). Mean surface water temperature differed across missions (ranging from 19°C in spring to 29°C in summer) but only had a maximum of 2.6°C difference observed between survey zones on any given deployment and showed no consistent north-south gradients (**Table 23; Figure 68**). Dissolved oxygen ranged from 6.1–7.2 mg/l, with the highest values occurring in the first two deployments when water temperature was relatively low (**Table 23; Figure 69**). Chlorophyll was highest in winter and lowest in summer (**Table 23; Figure 70**) and also displayed an obvious diel cycle (data not presented), with peak values from sunset through early morning and distinct mid-day minima. Mean turbidity ranged from 0.3–7.0 NTUs but was highly variable over even small distances (**Table 23; Figure 71**). The one area with consistently elevated turbidity was the South Zone in the Canaveral Bight and, to a lesser extent, the Shoal Zone. CDOM levels showed no consistent trends across missions, and the importance of this condition to the distribution of fishes is not well understood. On all deployments, water temperature, dissolved oxygen, turbidity, and chlorophyll at the CSII dredge site and adjacent control site were similar to surrounding waters.

Table 22. Mission summary statistics for the first four Wave Glider deployments

Deployment	Glider Launched	Glider Recovered	Duration (days)	Distance Traveled (km)	Mean Speed (km/hr)	Max Speed (km/hr)
1	11/26/17	12/20/17	24.1	1,137	2.0	4.6
2	03/15/18	04/10/18	26.0	1,459	2.3	5.6
3	05/24/18	06/19/18	26.1	1,310	2.1	5.9
4	09/19/18	10/09/18	20.1	1,126	2.3	4.3

Table 23. Oceanographic conditions measured by the Wave Glider for each survey zone
Values are means with standard deviation in parenthesis. N/A values are for periods when the sensor readings were inaccurate due to biofouling.

Deployment	Condition	Shoal	North	Reef	South
1	Water Temperature (°C)	22.3 (0.3)	21.5 (0.6)	21.4 (0.7)	20.6 (0.6)
1	Dissolved Oxygen (mg/l)	7.0 (0.2)	7.2 (0.3)	6.9 (0.1)	6.9 (0.5)
1	Chlorophyll (RFU)	498 (134)	633 (175)	824 (509)	N/A
1	Turbidity (NTU)	4.5 (2.2)	1.6 (1.2)	N/A	N/A
1	CDOM (RFU)	443 (80)	465 (60)	308 (80)	N/A
2	Water Temperature (°C)	19.4 (1.4)	19.4 (0.8)	21.0 (1.1)	22.0 (0.7)
2	Dissolved Oxygen (mg/l)	7.3 (0.3)	7.3 (0.1)	7.1 (0.2)	7.0 (0.2)
2	Chlorophyll (RFU)	339 (133)	260 (110)	227 (85)	288 (138)
2	Turbidity (NTU)	2.6 (1.4)	1.6 (1.2)	3.2 (2.1)	4.1 (1.7)
2	CDOM (RFU)	177 (67)	156 (40)	97 (50)	96 (30)
3	Water Temperature (°C)	25.4 (0.7)	26.2 (0.7)	26.4 (0.2)	27.0 (0.8)
3	Dissolved Oxygen (mg/l)	6.6 (0.2)	6.6 (0.2)	6.6 (0.1)	6.4 (0.2)
3	Chlorophyll (RFU)	239 (176)	89 (44)	128 (35)	132 (51)
3	Turbidity (NTU)	2.5 (3.0)	0.4 (0.4)	0.3 (0.4)	3.0 (4.6)
3	CDOM (RFU)	40 (6)	52 (33)	30 (6)	35 (6)
4	Water Temperature (°C)	28.9 (0.4)	29.2 (0.3)	28.7 (0.1)	28.8 (0.2)
4	Dissolved Oxygen (mg/l)	6.1 (0.3)	6.1 (0.3)	6.2 (0.2)	6.2 (0.2)
4	Chlorophyll (RFU)	280.4 (113.1)	275.5 (165.3)	351.2 (81.3)	529.6 (99.5)
4	Turbidity (NTU)	2.5 (5.0)	1.4 (1.7)	2.3 (1.1)	7.0 (2.3)
4	CDOM (RFU)	60.5 (11.2)	90.9 (14.3)	65.4 (13.7)	85.4 (12.4)

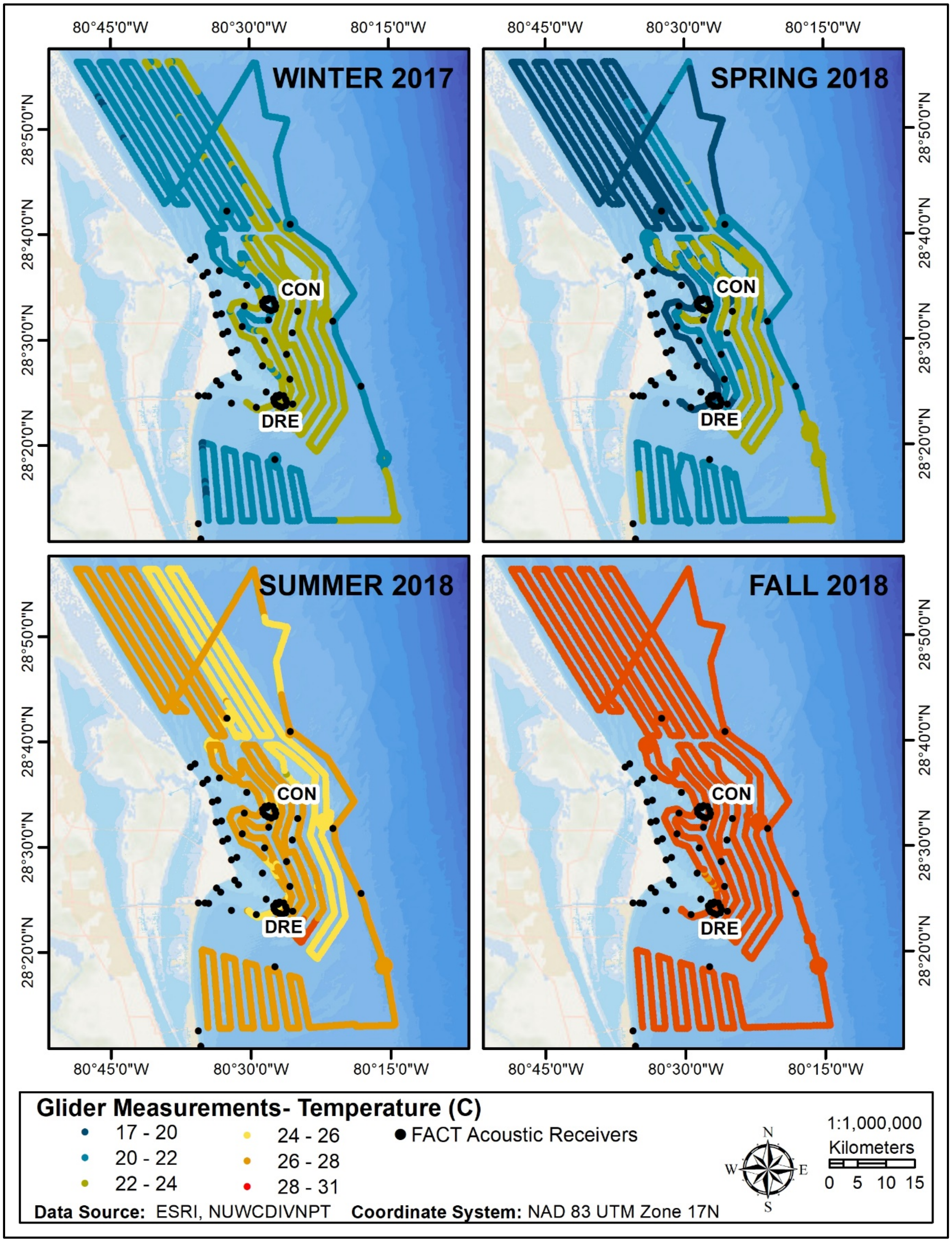


Figure 68. Surface water temperature observed during the first four Wave Glider deployments
DRE denotes location of CSII dredge site while CON denotes adjacent control site.

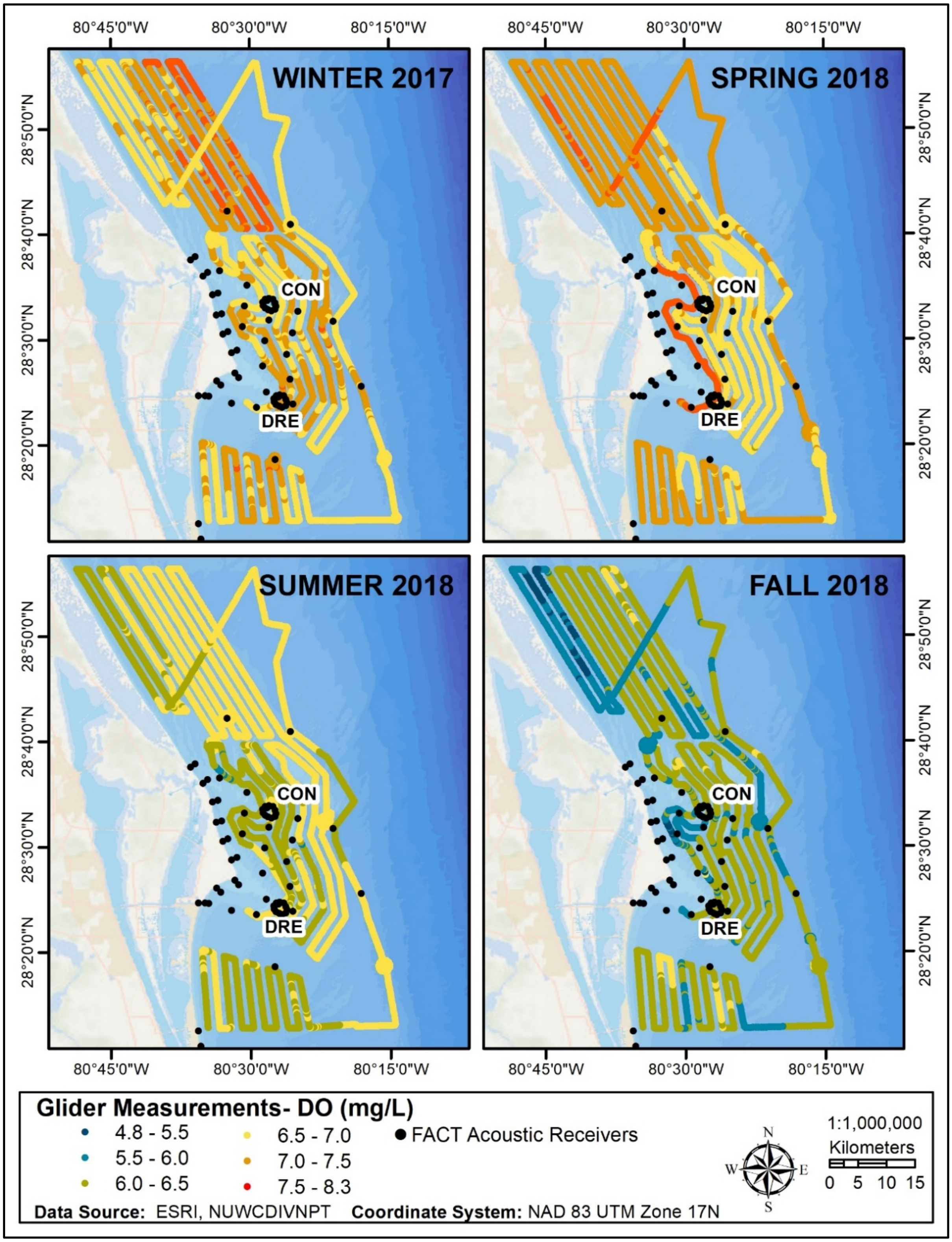


Figure 69. Dissolved oxygen observed during the first four Wave Glider deployments
DRE denotes location of CSII dredge site while CON denotes adjacent control site.

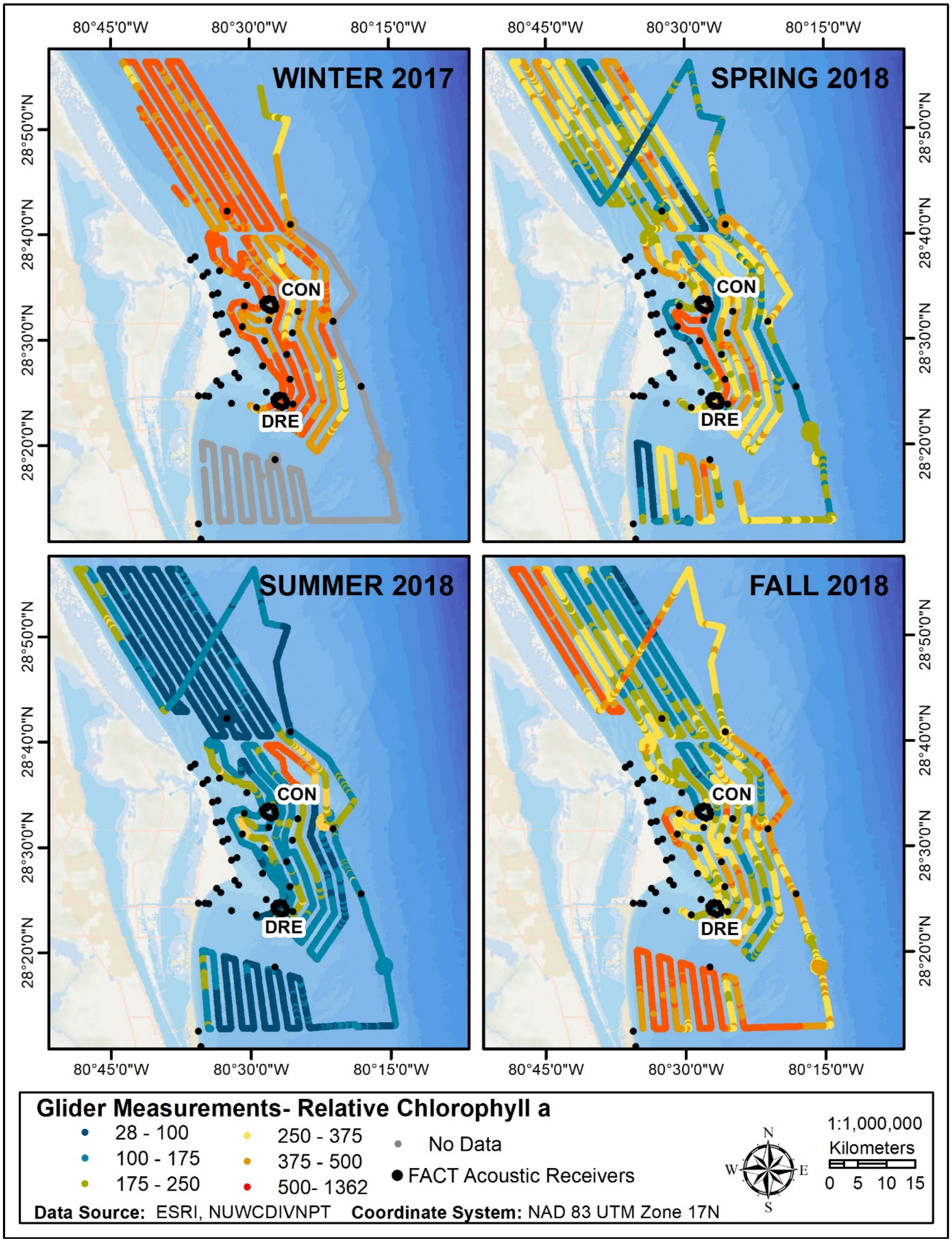


Figure 70. Surface chlorophyll observed during the first four Wave Glider deployments
DRE denotes location of CSII dredge site while CON denotes adjacent control site.

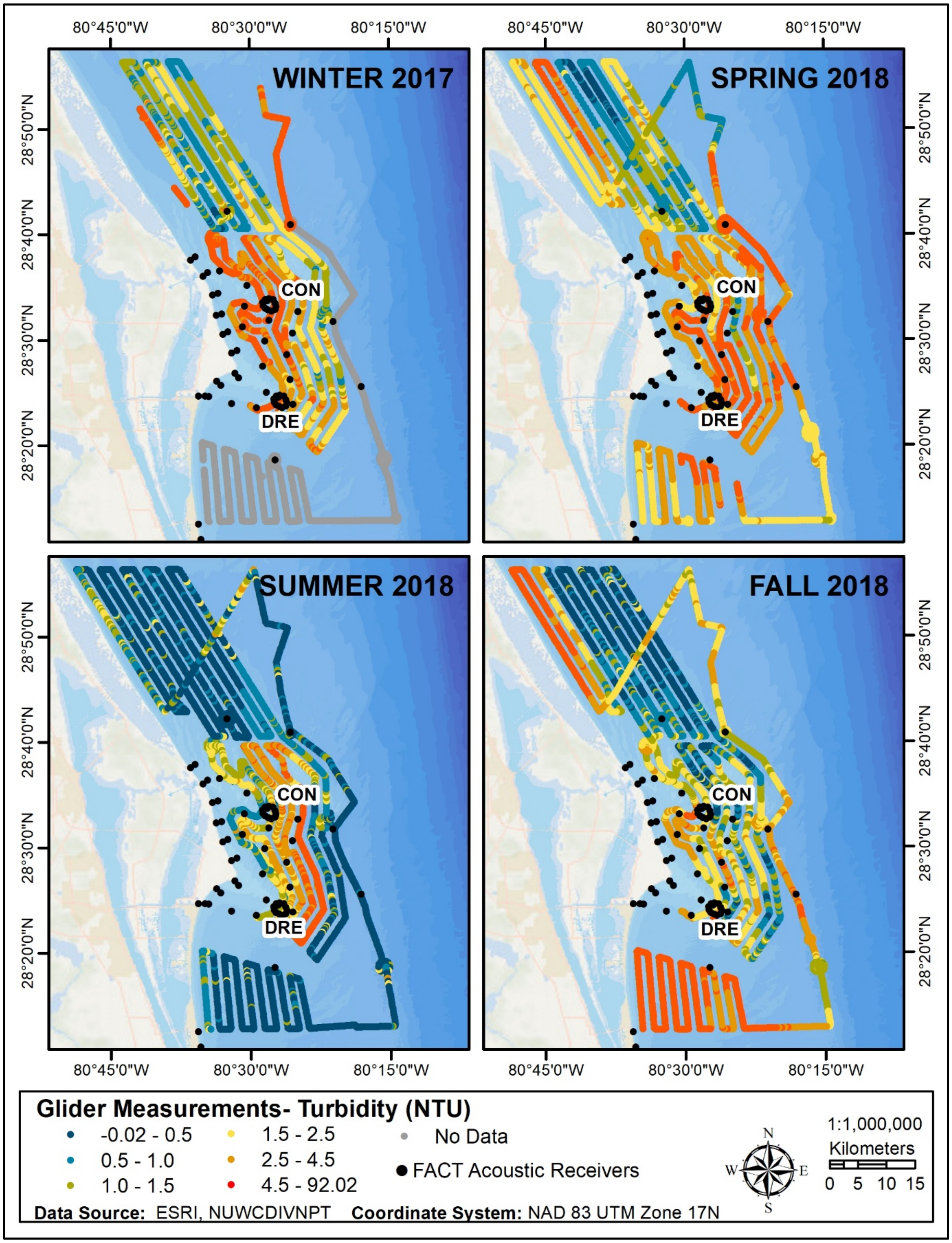


Figure 71. Surface turbidity observed during the first four Wave Glider deployments
DRE denotes location of CSII dredge site while CON denotes adjacent control site.

4.3.2 Animal Tracking

Over the course of the first four Wave Glider deployments, a total of 2,096 detections belonging to 80 tagged animals and 14 different species were recorded. Forty-six of these animals were target species tagged locally at Cape Canaveral, while the remaining 34 were tagged independently by 11 other research groups at various locations along the US East Coast and Bahamas. Target species detected include blacknose, finetooth, and sharpnose shark; red drum; red snapper; and loggerhead sea turtles. Species tagged by outside researchers include smalltooth sawfish, cownose ray, blacktip shark, tiger shark, tarpon, cobia, goliath grouper, and gulf flounder (**Table 24**). One tag has not yet been identified to species. Tagged individuals were occasionally detected more than once on a single deployment, and 15 animals were detected on two or more separate deployments, factors which improve the ability to resolve habitat preferences in some species.

Table 24. Tagged animals detected on initial Wave Glider surveys by deployment and receiver style

Species	Deployment 1		Deployment 2		Deployment 3*		Deployment 4		All
	VR2C	VMT	VR2C	VMT	VR2C	VMT	VR2C	VMT	Unique Animals
Red drum	4	2	10	9	9	8	4	2	20
Blacktip shark	14	6	3	3	0	0	1	1	17
Blacknose shark	4	3	3	3	0	1	3	2	10
Red snapper	7	7	3	3	3	4	2	2	9
Sharpnose shark	2	0	2	1	1	0	4	4	7
Cobia	4	2	3	2	1	1	0	0	6
Finetooth shark	4	2	1	1	0	0	1	0	6
Cownose ray	2	2	0	0	0	0	0	0	2
Goliath grouper	1	1	1	1	1	1	0	0	2
Tarpon	1	1	0	0	0	0	1	0	2
Loggerhead sea turtle	0	0	0	0	1	1	0	1	2
Gulf flounder	1	0	0	0	0	0	0	0	1
Smalltooth sawfish	0	0	0	0	1	1	0	0	1
Tiger shark	0	0	0	0	0	0	1	1	1
Unknown	0	0	0	0	0	0	1	0	1
Total Animals	**44**	**26**	**26**	**23**	**17**	**17**	**18**	**13**	**80**

*In Deployment 3, the VR2C was malfunctioning and powered OFF for one week.

Detection rates of animals ranged from 0.0–0.07 animals/km and was highest in Deployment 1 (winter 2017) and lowest in Deployment 4 (fall 2018). Further, with the exception of Deployment 1, the encounter rate of tagged animals was higher in the Shoal Zone than the adjacent North, South, or Reef Zones (**Table 25**). Of the 111 unique encounters of tagged animals by the Wave Glider across the first four missions (**Figure 72-Figure 75**), only 27 (24%) were simultaneously within range (≤ 500 m) of a fixed station receiver in the Canaveral Array, demonstrating the ability of this mobile platform to supplement fixed station acoustic telemetry and to expand monitoring over a wider geographic area.

Table 25. Animal detection rate (tags/km) by zone during Wave Glider deployments

Deployment	Shoal Zone	North Zone	Reef Zone	South Zone
1	0.04	0.03	0.05	0.07
2	0.03	0.02	0.01	0.00
3	0.03	0.01	0.01	0.01
4	0.03	0.01	0.02	0.01

Performance of the integrated mini-VR2C acoustic receiver (1,263 total animal detections) was consistently better than the smaller stand-alone VMT (829 total animal detections) on all four missions, but the difference in performance depended in part on VMT orientation when mounted to the Wave Glider. During Deployment 1, the VMT was oriented horizontally on the sub with its hydrophone pointing forward and detected only 59% of the animals also detected by downward facing mini-VR2C. The VMT was reoriented to face down on all subsequent deployments, and detection rates improved to 88%, 100%, and 72% of the mini-VR2C, and in all cases even relocated a small number of animals that the mini-VR2C did not detect.

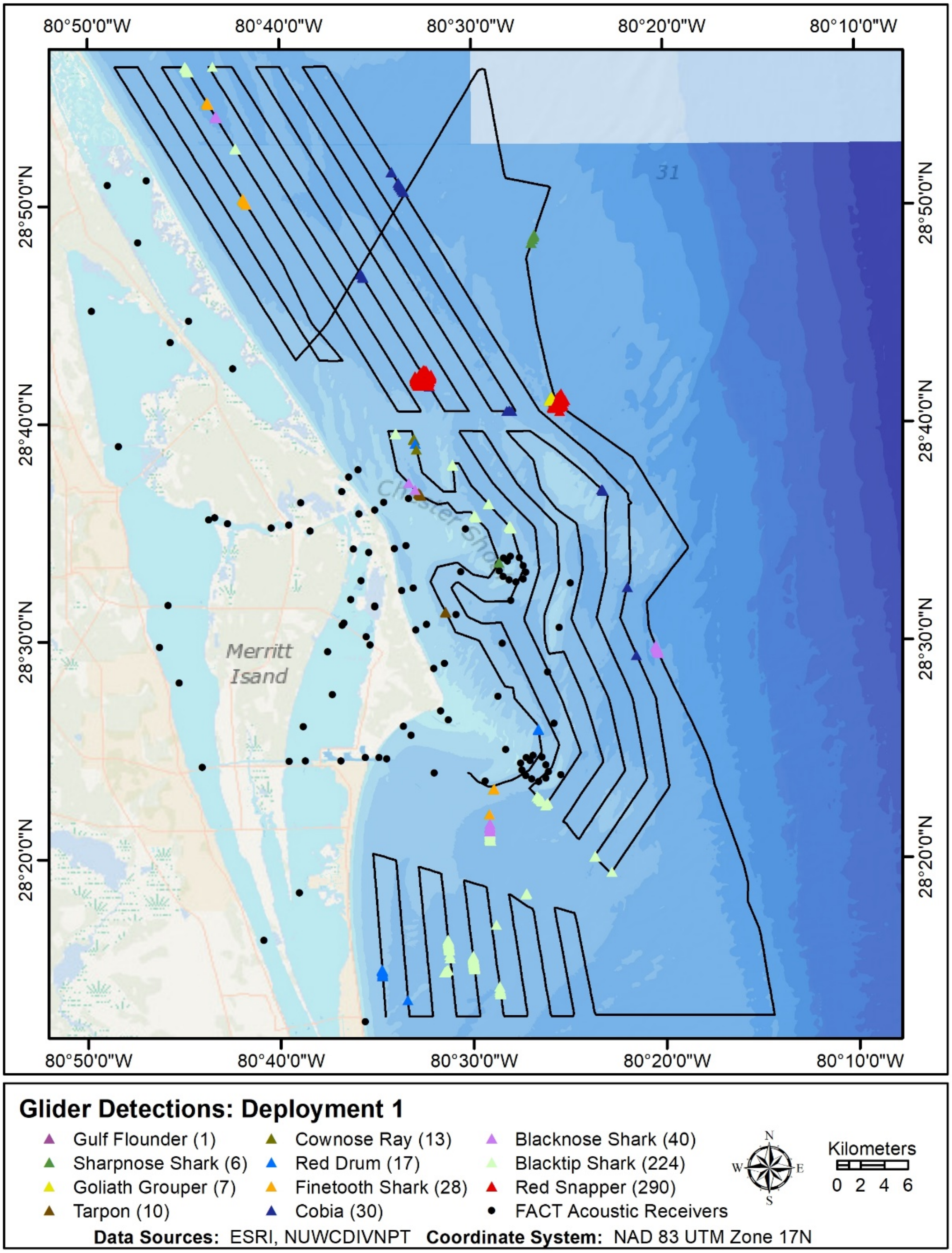


Figure 72. Tagged animals relocated by the Wave Glider during Deployment 1
Values in parentheses are number of detections for each species.

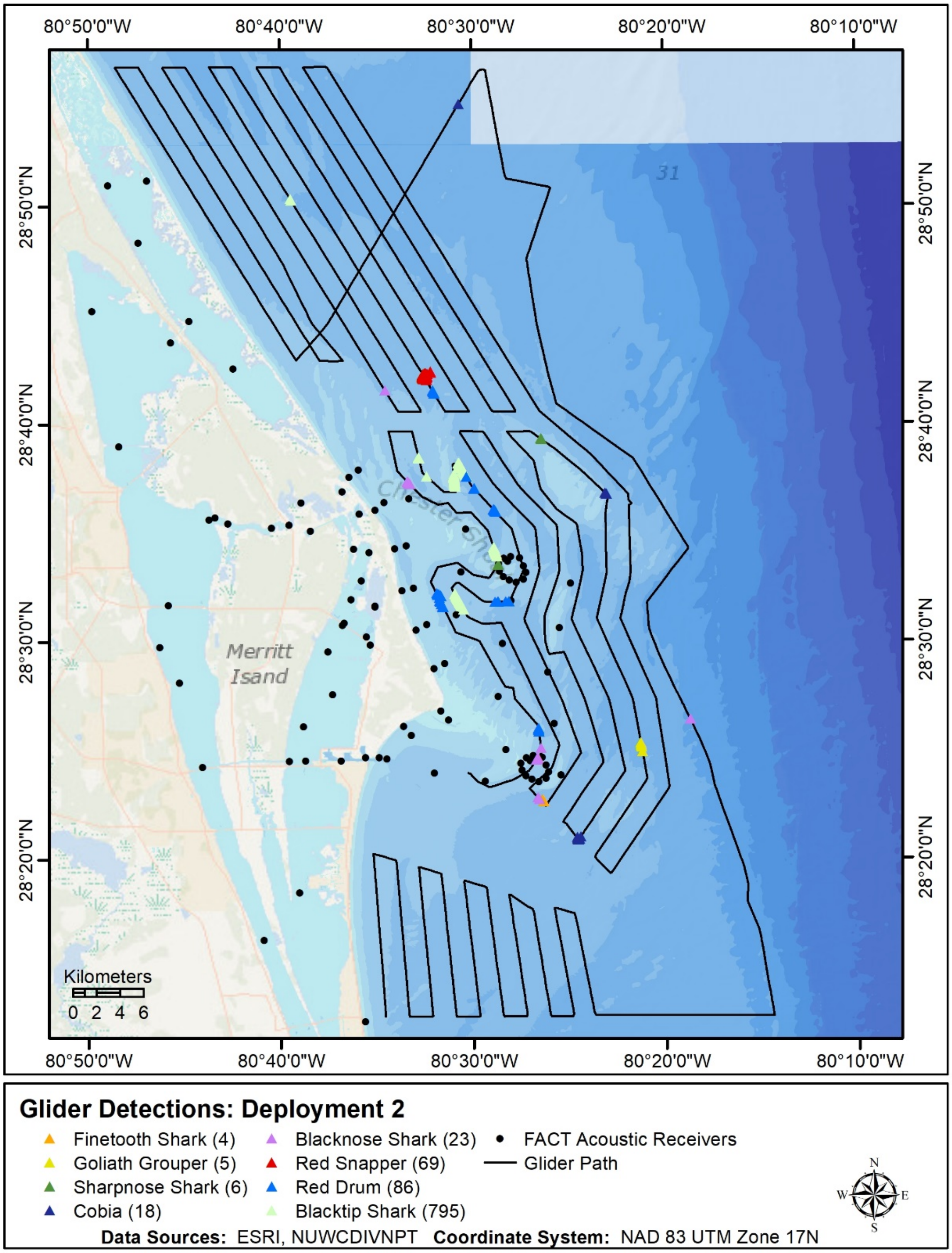


Figure 73. Tagged animals relocated by the Wave Glider during Deployment 2
Values in parentheses are number of detections for each species.

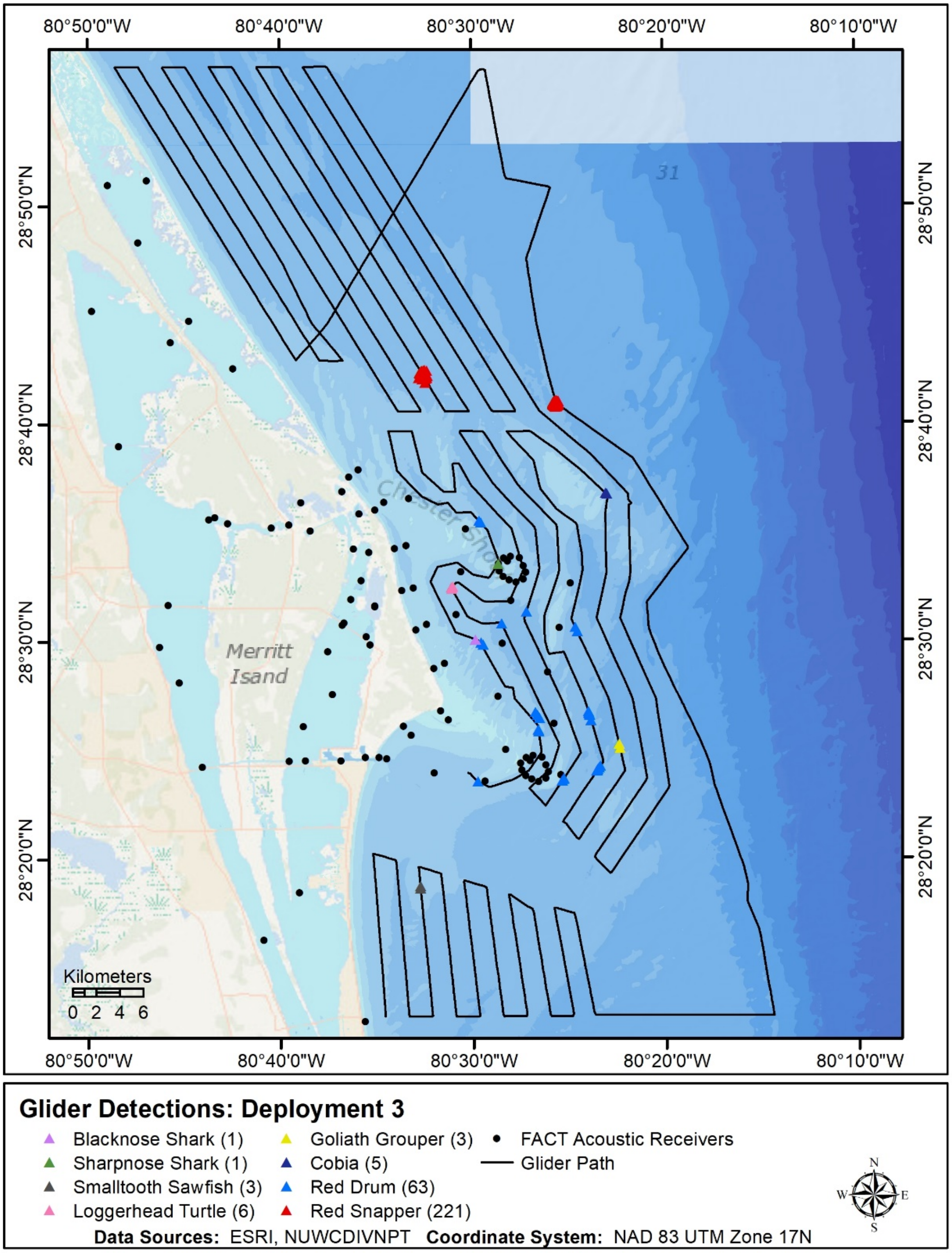


Figure 74. Tagged animals relocated by the Wave Glider during Deployment 3
Values in parentheses are number of detections for each species

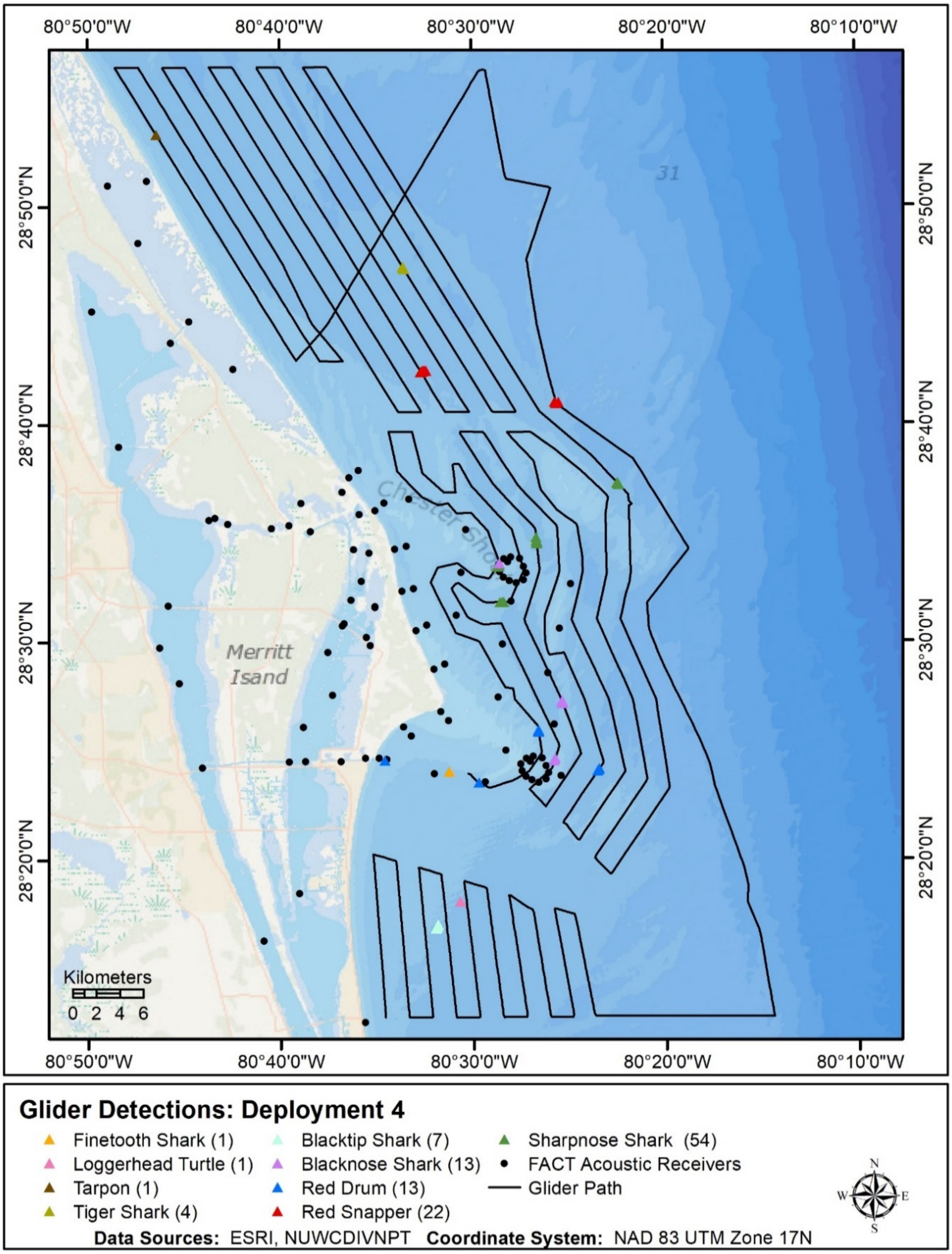


Figure 75. Tagged animals relocated by the Wave Glider during Deployment 4
Values in parentheses are number of detections for each species.

4.4 Discussion

The integration of acoustic telemetry capabilities into USVs is a promising advancement for broadening our understanding of animal movements in the open ocean. The Wave Glider USV now in use at Cape Canaveral is a highly customizable scientific platform where new sensors can be interchanged to meet mission-specific requirements. Autonomous surface platforms may have certain advantages over sub-surface gliders (e.g., Slocum, REMUS systems) for animal tracking purposes in that they can communicate shoreside in near real time, can generally operate in shallower waters, and can closely adhere to preprogrammed transects, thus allowing for accurate surveys of shallow shoals (as in the present study), complex shorelines, and patchy habitats like reefs and wrecks. They also have the potential to continuously monitor the locations of certain highly mobile species (e.g., coastal sharks and sportfish) as they undertake seasonal migrations. Although few studies using Wave Gliders to detect acoustically tagged animals have been published thus far (Carlon 2015, LRI 2017), several are now underway.

Wave Gliders are also regularly used to address a variety of other coastal research data needs, including oceanographic and geological surveys (Anderson et al. 2018), algal biomass monitoring (Frolov et al. 2011), dredge sediment plume mapping (Vanlacker and Baeye 2015), passive acoustic surveys of marine mammals and fish spawning aggregations (Bittencourt et al. 2018, Wall et al. 2012), and fish biomass estimates (Warner et al. 2012). For certain applications, Wave Gliders may be the most cost-effective option for data collection, allowing surveys of large areas that would otherwise require logistically complex and expensive crewed expeditions or the deployment of fixed station instruments that are challenging and costly to maintain (LRI 2017, Frolov et al. 2011, Swart et al. 2016). The present study at Cape Canaveral is one of the few fisheries applications to date that goes beyond proof-of-concept deployments by undertaking repeated, long distance transects to relocate tagged fish and simultaneously quantify environmental conditions at these detection sites. Although a full evaluation will come after the study is complete, early results are promising with the vehicle successfully detecting 19–44 animals (primarily coastal sharks and teleost sportfish) in each of the first four deployments, with the majority of individuals being relocated beyond the boundary of the fixed receiver array. Many of these animals were detected multiple times per deployment and even across deployments. The first mission (November–December 2017) remains the most productive (44 animals detected), but seasonal variation in detection rates was expected because, as demonstrated via the fixed array tracking (Section 3), many fish species migrate to east-central Florida in winter but disperse widely throughout the SAB from late spring through fall.

Wave Glider operations face different challenges depending on the region and mission objectives. For fish tracking, operations in the southeastern US may be more feasible than in other areas. One of the most significant factors for early successes at Cape Canaveral is the presence of large numbers of acoustically tagged fish now at liberty. Over 40% of animals detected to date were originally tagged by other research organizations working at various locations from Chesapeake Bay to south Florida and the Bahamas. As such, insights about fish use of shoals extended beyond those species that were targeted locally, and membership in the FACT Network allows these data to be quickly shared with partner agencies. Additionally, operations on the east Florida shelf (which has a relatively low latitude) generally provide sufficient sunlight for powering payloads, and the coastal ocean environment harbors fewer navigational hazards (e.g., complex rocky shorelines, swift currents, oil rigs, kelp forests) common to many other regions.

5 Sea Turtle Habitat Associations and Migrations

5.1 Introduction

Four of the world's seven marine turtle species (loggerhead, green, leatherback, and Kemp's ridley) are regularly observed in waters adjacent to Cape Canaveral. Coarse-scale movements of sea turtles, in particular loggerhead and green turtles, in the Canaveral region have been documented since the 1950s by tag returns of nesting females (Caldwell et al. 1959, Ehrhart 1979). As described in **Section 1**, focal studies locally were initially driven by concerns over high mortality associated with commercial fisheries and dredging of navigation channels; more recently, the studies have emphasized behavior, diet, and population connectivity. Considerable progress has been made in recent years to better understand the ecological role, habitat associations, and migration routes of loggerhead turtles in the SAB (Ceriani et al. 2012, Arendt et al. 2012). These and other studies (Henwood 1987, Schroeder et al. 2003) have clarified the seasonal patterns within the Canaveral region as well. In addition, the locations of multiple important foraging grounds in the NW Atlantic have been confirmed through satellite tracking and stable isotope analysis for the species (Pajuelo et al. 2012, Ceriani et al. 2014, Vander-Zanden et al. 2015).

Few published data exist on the migration of adult green turtles from warm-temperate/subtropical nesting beaches of the SAB. In 2017, Bagley (unpubl. data) tagged reproductively active male green turtles with Fastloc GPS satellite transmitters on Melbourne Beach (Archie Carr National Wildlife Refuge) south of Canaveral. After leaving the nesting beach, two of the tagged turtles traveled north as far as the waters adjacent to Daytona Beach before migrating south to the Florida Keys foraging grounds. Most of the tagged turtles abruptly left the waters off Melbourne Beach in mid-July, with direct movements to the south Florida foraging grounds.

The present study builds upon these previous efforts but with a specific focus on resolving the finer-scale movements and habitat use of nesting female sea turtles when associated with shoal features at Cape Canaveral. This study addressed several specific questions:

1. What is the affinity of female turtles for shoal habitats during their inter- and post-nesting periods?
2. How does behavior differ locally between female loggerhead and green turtles?
3. What are the primary migratory pathways for each species as they transition from their nesting beaches to distant foraging grounds?

5.2 Methods

5.2.1 Sea Turtle Collection and Tagging

Turtle tagging occurred in July and August 2017 in the latter half of the loggerhead nesting season and mid-season for green turtles. A total of 14 loggerhead and 11 green turtles were tagged as they nested on beaches of Kennedy Space Center and Cape Canaveral Air Force Station, both directly adjacent to the Canaveral Shoals. Each turtle received both a satellite and acoustic transmitter (**Table 26)**.

The satellite transmitters (Wildlife Computers SPLASH10-BF-334D/Fastloc GPS) have dimensions of 8.4 x 8.4 x 3.8 cm (length, width, and height). Each transmitter contains a wet/dry sensor that determines when data transmissions to the satellite will occur and also flags extended transmitter exposure periods at the surface as "haulout" (i.e., possible nesting) events. The transmitters provide animal location data through Fastloc GPS positional data obtained through multiple satellites with precision up to 20 m. Additionally, the tags also use Argos satellites based on their relative position and the Doppler shift for position estimates of varying precision depending on the assigned location class.

Table 26. Release dates and measurements of sea turtles tagged at Cape Canaveral
GCL refers to greatest carapace length and SCL refers to minimum straight carapace length. NR refers to not recorded.

Species	Release Date	GCL	SCL
Loggerhead Turtle	7/24/2017	94.5	NR
	7/25/2017	88.0	86.3
	7/25/2017	92.4	89.9
	7/25/2017	92.0	89.8
	7/26/2017	97.8	96.0
	7/26/2017	NR	85.0
	7/26/2017	93.1	88.5
	7/28/2017	92.7	89.5
	7/28/2017	86.5	82.2
	7/29/2017	NR	86.2
	7/29/2017	85.5	82.5
	7/31/2017	NR	84.5
	8/1/2017	92.0	89.3
	8/1/2017	91.9	88.0

Species	Release Date	GCL	SCL
Green Turtle	7/24/2017	107.6	106.0
	7/26/2017	100.9	99.6
	7/26/2017	101.7	100.6
	7/28/2017	101.1	100.6
	7/28/2017	96.1	94.0
	7/29/2017	102.5	101.1
	7/29/2017	102.5	102.0
	7/29/2017	100.0	100.0
	8/1/2017	100.7	100.3
	8/1/2017	103.6	102.5
	8/2/2017	102.4	101.9

A minimum of four months of frequent and high quality, satellite-derived location data during the nesting season was required for this study. To achieve this, tags were set to be continuously active, which reduced battery life to approximately one year, thus leaving time to capture movements well after local nesting had ceased. Per manufacturer instructions, satellite transmitters were initially sanded and wiped clean with 70% isopropyl alcohol. The tags were then painted with primer (Interlux Interprotect® 2000E) and anti-fouling paint (Interlux Micron® 66), taking care to avoid the sensors. In addition to satellite transmitters, sea turtles were also fitted with acoustic transmitters (VEMCO V16-4H). These transmitters are fully compatible with the FACT Network (see **Section 3.2.1** for details), and their 5.2 year battery life potentially provides the means to monitor turtle nearshore movements over a much longer time period.

On tagging nights, the beach was surveyed after sunset using all-terrain vehicles. Care was taken to avoid disturbing any turtles emerging from the surf or actively nesting, and less disruptive red lights were used for all tagging operations except during initial safety checks of the worksite. After locating a turtle and observing that she had completed nesting or had false crawled and was returning to the ocean, the animal was restrained by a portable, 5x5 ft box (2 ft in height) composed of plywood panels with joining dovetail notches (**Figure 76)**. Once restrained, each turtle was examined to determine the best location for satellite and acoustic tag placement, and all tags were positioned to reduce entanglement risk and hydrodynamic effects. Attachment points, typically near the first and second vertebral scutes for the satellite tag, and 1–2 posterior costal and marginal scutes for the acoustic tag, were then cleaned, lightly sanded, and dried. The satellite tag was affixed to the carapace using a two-part, cool-setting epoxy (Super Bond™), and the acoustic tag was affixed using a marine-grade, two-part epoxy (West Marine™). After attachment, both tags were further protected with anti-fouling paint (**Figure 77**). The total cumulative weight of all transmitters and attachment material did not exceed 5% of turtle weight as required by FWC permit guidelines. Inconel sea turtle tags were then attached to both front flippers and a Passive Integrated Transponder (PIT) was implanted into the right front flipper of each turtle. Measurements of greatest carapace (GCL), straight carapace length (SCL), and many other metrics were made using large calipers. Any anomalies were noted, as well as capture time and location, time of release, and whether the turtle

Figure 76. A green turtle being released just at sunrise (rare) after tagging

nested or false crawled (a non-nesting emergence). All methods followed NMFS (14655-01) and FWC/USFWS (MTP-18-114) permit protocols outlined in NMFS Sea Turtle Research Techniques (NMFS 2008).

5.2.2 Data Analysis

Data from satellite tags were retrieved via Argos Service and available daily through the Wildlife Computers web portal. Positions were reviewed for the overall status, extent, and quality of tag transmissions, and the duration of inter-nesting movements across the Canaveral Shoals were calculated from Fastloc GPS and Argos location reports. The duration and timing of suspected "haulout" activity (i.e., when tag sensor and position suggest the turtle was on the beach) were examined to distinguish between nesting and false crawl emergences vs. shallow nearshore basking and/or mating. Haulout event durations ranged from 10 to 385 min. Because the entire nesting process (i.e., emergence, body pitting, digging the egg chamber, egg laying, covering, and returning to sea) generally takes greater than 45 min, haulouts less than 45 min were classified as false crawls, as were the first of multiple haulouts on the same night or subsequent nights. The interval between turtle nesting and re-nesting varies across species and individuals but generally ranges from 9 to 14 days. This knowledge was also used to identify nesting events vs. surf dwelling occurrences (potential mating or basking). In cases where it was uncertain whether a turtle had returned to nest, subsequent haulout data provided better informed assumptions on the nest status for the night of capture.

To further classify movements of tagged turtles within the Canaveral region and to quantify water depth associations in the study area, a Bayesian switching state space model (SSM) was applied to satellite telemetry data. Loggerhead and green turtle locations were analyzed with a first-difference correlated random walk model (Jonsen et al. 2005). In this SSM, the observed track for each turtle is smoothed based on a predetermined time step, creating an even time series for each animal. Additionally, the move persistence between time steps is estimated, and each location is assigned a behavioral state value that may correlate with migratory movements or exploratory behaviors (i.e., area-restricted search, defined by slower speeds and increased turning angles) that are commonly observed during foraging, mating, or resting activities. In some locations, the behavior was unclassified without a clear indication of migratory versus exploratory movements.

The 25 tagged turtles reported a total of 57,620 locations, including 22,426 Fastloc GPS values and 32,330 Argos-only values. All location points were first spatially filtered in ArcGIS 10.3, and positions on land unlikely to be associated with a nesting event were removed. Data were then filtered by positions accuracy with only Argos location class 2 (accuracy < 500m), class 3 (accuracy < 250m), and GPS data retained. These high quality locations were then processed through a speed filter using the R Package *argosfilter* (McConnell et al. 1992), which removes locations based on unrealistic swimming speeds, with the exception of locations less than 5 km apart. A speed threshold of 1.25 m/s (4.5 km/hr) was utilized based on recommendations of the Turtle Expert Working Group (TEWG 2009). After filtering, the final dataset input for the SSM consisted of 16,969 locations for loggerhead turtles and 7,892 locations for green turtles, roughly 46% of the original dataset.

Figure 77. Tag placement on a loggerhead turtle
A Wildlife Computers SPLASH10 satellite tag is attached to the 2nd vertebral scute, while a VEMCO V16 acoustic transmitter is attached along the rear costal scute. Both tags are coated with anti-fouling paint to increase retention.

These data were then used as input for each species in the SSM. The SSM was run using R using the *bsam* package (Jonsen et al. 2005) and JAGS (Plummer 2017) for Markov Chain Monte Carlo (MCMC) sampling. After evaluation of variability and average time interval between detections for each species, a time step of 210 min (3.5 hrs) was selected for loggerheads and 150 min (2.5 hrs) for green turtles. Separate hierarchical models were run for each species, which allowed for movement parameters to be estimated jointly for all individuals in the dataset, while keeping distinct positional data and behavioral state for each input. Convergence diagnostics of each model included visual examination tests for autocorrelation and evaluation if the MCMC chains had converged as expected for each parameter (Brooks and Gelman 1998).

Positional data output from the SSM for each species were then re-imported into the ArcGIS 10.3 environment for visual examination of tracks. All positions were then classified by depth contour bins (0–5 m, 5–10 m, 10–15 m, or 15–20 m) for each individual track within the Canaveral study area. Positions on land within the expected range of class 3 Argos error (250 m) were associated with the 0–5 m bathymetry contour for this analysis. UDs of 50% (core use areas) and 95% (activity space) were also calculated locally from kernel density estimates and compared for loggerhead and green turtles, including overlap with bathymetry and sediment % fines. Overlap of core use areas was calculated after normalizing for the amount of habitat available in different depth and sediment bins.

5.3 Results

By far, the most robust dataset was generated via satellite tracking. As of August 2018, satellite tags on loggerhead females transmitted on average 184 days (range 7–375 days), with three turtles still carrying active transmitters (**Table 27).** Satellite telemetry confirmed local shoal use in 50% (7 of 14) of tagged loggerheads, although the time spent in this habitat type (mean 12.7 days) was limited since many individuals ceased nesting relatively soon after tagging. Haulout data suggest that loggerhead re-nesting events were few with an average of only 0.7 per female (range 0–2). For those individuals that did re-nest, the interval averaged 14.1 days. Many individuals temporarily ranged beyond the study area for periods of 0.5 to 25 days, and one animal (PTT171359) left the study area for the season within 24 hours of release.

When within the Canaveral study area, the spatial distribution of modeling output for loggerhead turtles confirmed regular use of nearshore waters to the north of Cape Canaveral and also ridge and swale habitat on the northern flank of the Southeast Shoal (**Figure 78)**, but with activity space showing no overlap with the CSII dredge site or Chester Shoal control site (**Figure 79**). Loggerhead core use areas averaged 42 ± 48 km^2, considerably smaller than that of green turtles (**Figure 80**). Overall, loggerheads preferentially

Table 27. Movement summary for loggerhead turtles

The term “Inter” use refers to shoal use between nesting events, while “Post” use refers to shoal use after nesting was completed.

PTT Identity	Release Date	Date Left Canaveral	Days in Study Area	Shoal Use	Date of Last Detection	Last Known Location
171354	07/25/19	08/19/19	25	Inter	12/19/17	18 km NW of Matecumbe Keys, FL
171355	07/25/19	08/11/19	17	Inter	10/19/17	81 km W of Naples, FL
171356	07/25/19	07/27/19	2	Inter	08/01/17	14 km E of Hutchinson Island, FL
171357	07/24/19	08/10/19	17	Post	08/03/18	24 km S of Tongue of Ocean, Bahamas
171358	07/26/19	08/10/19	15	Post	08/28/17	6 km E of N Bimini, Bahamas
171359	07/26/19	07/26/19	0	None	11/13/17	18 km NE of Cape Lookout, NC
171362	07/28/19	08/13/19	16	None	05/09/18	16 km NW of Key Largo, FL
171367	07/26/19	07/29/19	3	None	01/04/18	81 km E of Cape Island, SC
171368	07/28/19	08/11/19	14	Post	12/27/17	24 km E of Ft. Pierce, FL
171369	07/29/19	08/15/19	17	None	08/03/18	21 km SW of Cedar Key, FL
171370	07/29/19	08/12/19	14	None	04/04/18	662 km E of Pamlico Sound, NC
171372	07/31/19	08/08/19	7	Post	11/06/17	81 km E of Wilmington, NC
171374	08/01/19	08/15/19	14	None	08/03/18	89 km E of DE
171376	08/01/19	08/18/19	17	None	12/14/17	105 km S of Apalachicola, FL

utilized shallow water with 65% of non-normalized position relocations occurring in water only 5–10 m deep (**Figure 81)**. Seasonal core use areas of sea turtles were also evaluated for associations with sediment type (**Table 28**) and loggerhead turtles most closely associated with areas of 0–5% and 15–20% fine sediments, after normalizing for habitat available. Satellite tags on green turtles transmitted for an average of 77 days (range 35–120 days), with the last tag transmitting until November 26, 2017 (**Table 29**). Green turtles spent 25–63 days in the vicinity of Cape Canaveral (including periodic excursions away from the coast) with a mean of 39.1 ± 13.6 days. Haulout data indicated that the species re-nested an average of 2.9 times (range 1–5 times) with a re-nesting interval of 11.5 ± 1.3 days. Core use areas averaged 48 km^2, but with high variability (SD = 62 km^2; **Figure 80**), and were mostly limited to locations along the beach north of Cape Canaveral, with only one turtle commonly using water south of the Southeast Shoal (**Figure 78**; **Figure 82**). Similar to that of loggerhead turtles, green turtles demonstrated limited overall use of shoal habitat itself with no occurrence at the CSII dredge site and only a single reported location within Chester Shoal control site. Green turtles occupied slightly shallower water than loggerheads, preferentially associating with the 5–10 m depth range (54% of non-normalized position relocations), and two turtles most strongly associated with water less than 5 m deep near the beach (**Figure 78; Figure 81)**. Core use areas were most highly associated with locations with 0–5% (43% overlap) and 10–15% (47% overlap) fine sediments, after normalizing for habitat available (**Table 28**).

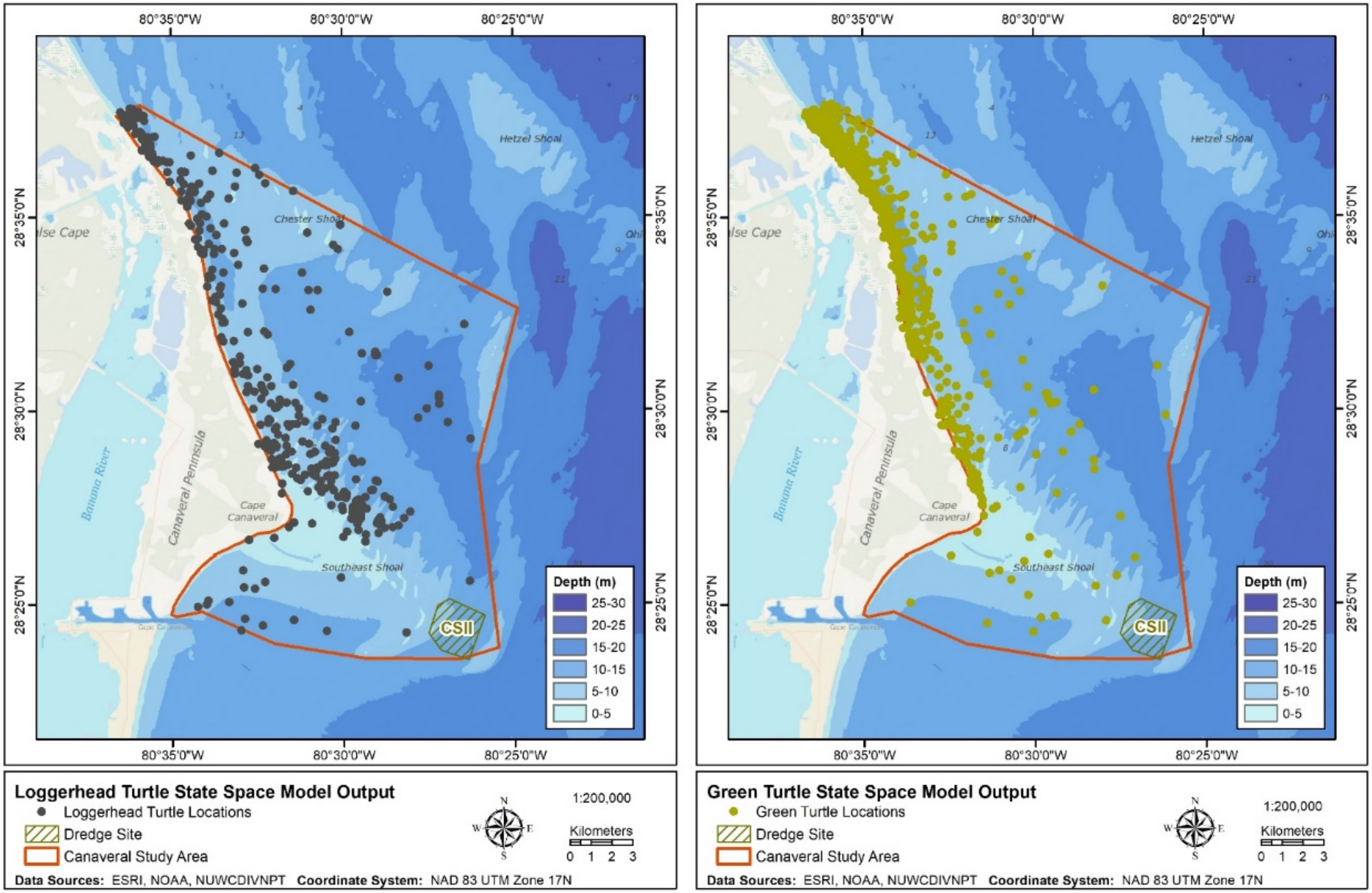


Figure 78. Loggerhead and green turtle satellite relocations within the core Canaveral study area

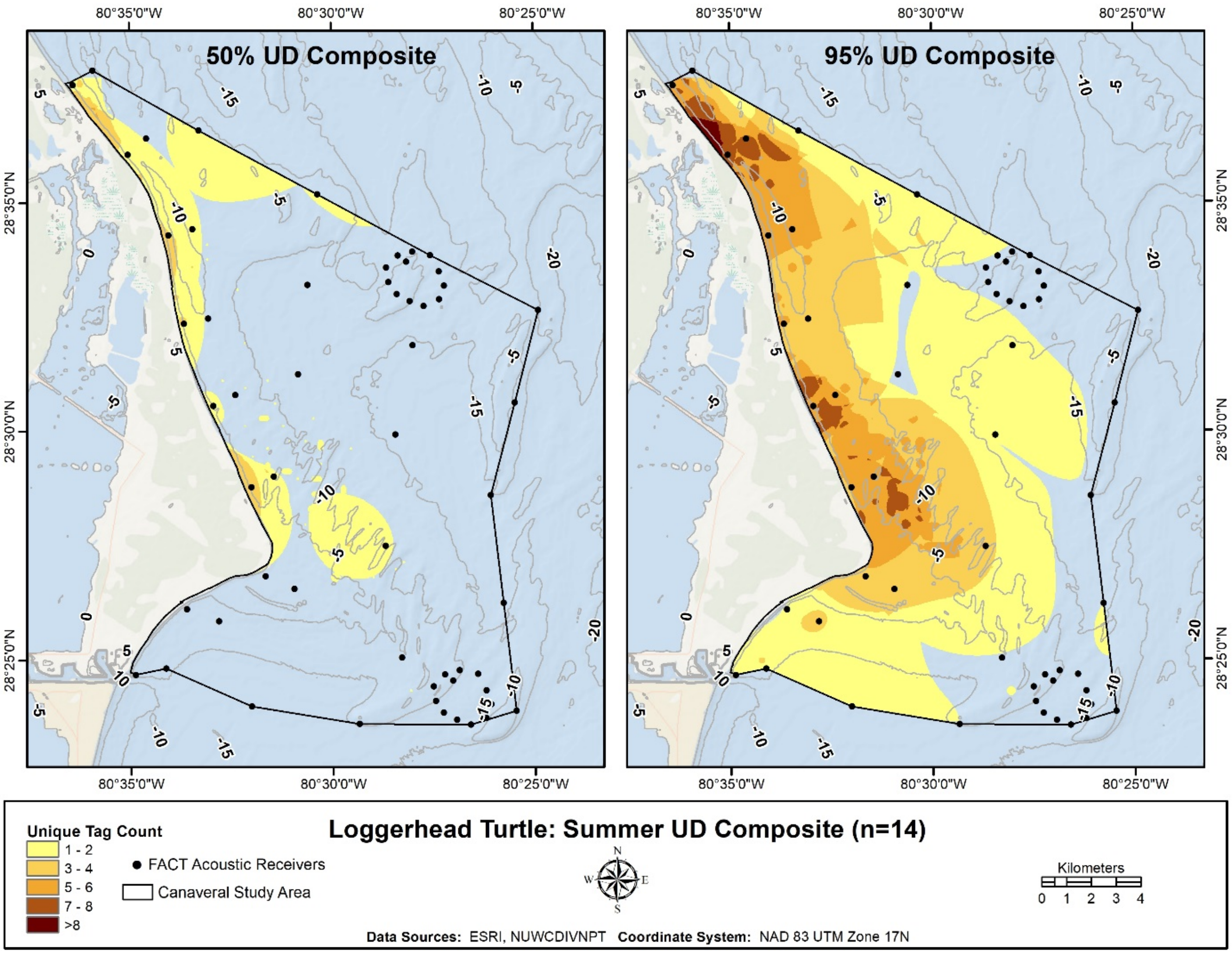


Figure 79. Local habitat use by loggerhead turtles
Maps include 50% UD (core use area) and 95% UD (overall activity space).

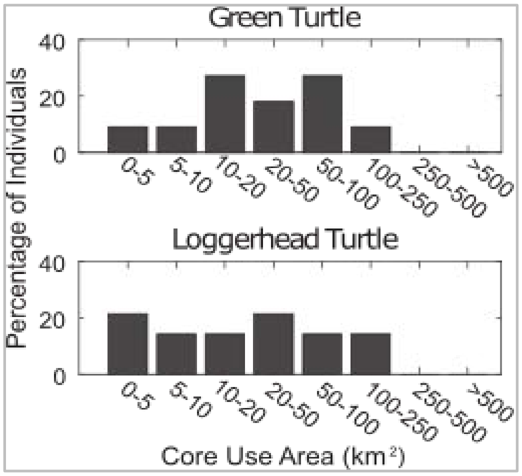


Figure 80. 50% core use area size for turtles when within the Canaveral study area

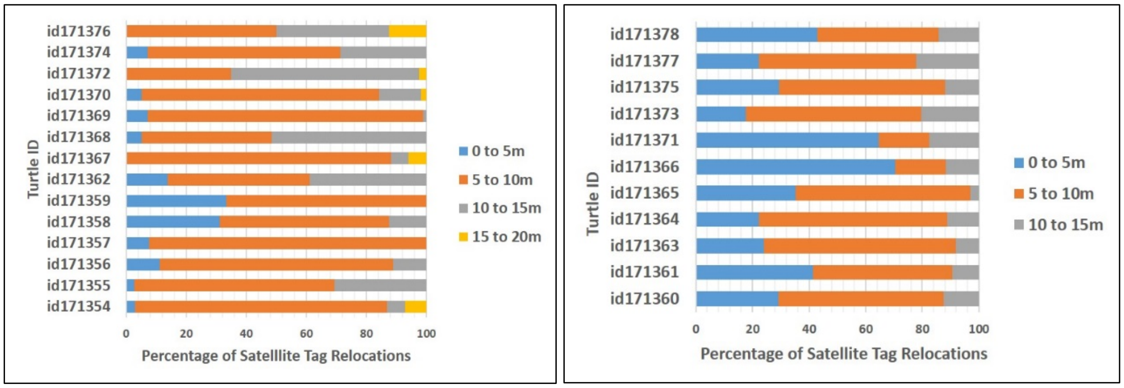


Figure 81. Loggerhead (left) and green (right) sea turtle occurrence by depth bin

Table 28. Overlap of loggerhead and green turtle core use areas with bathymetry contours and sediment % fines

Values shown are mean for each species, displayed as a percentage, calculated based on habitat available in each bin. No data is represented by “ND.”

Bathymetry Contour	0–5 m	5–10 m	10–15 m	15–20 m
Loggerhead (n=14)	60	29	11	ND
Green (n=11)	73	21	6	ND
Sediment % Fines	**0–5%**	**5–10%**	**10–15%**	**15–20%**
Loggerhead (n=14)	27	6	22	46
Green (n=11)	43	10	47	0

Table 29. Movement summary for green turtles

The term “Inter” use refers to shoal use between nesting events.

PTT Identity	Release Date	Date Left Canaveral	Days in Study Area	Shoal Use	Date of Last Detection	Last Known Location
171360	07/26/19	08/29/19	34	Inter	11/13/17	Marquesas Keys, FL
171361	07/24/19	08/28/19	35	Inter	09/25/17	5 km ESE of Key Largo, FL
171363	07/28/19	09/28/19	62	Inter	10/21/17	Boca Grande Key, FL
171364	07/26/19	08/23/19	28	None	10/21/17	Boca Grande Key, FL
171365	07/28/19	08/22/19	25	None	09/15/17	5 km E of Key Largo, FL
171366	07/29/19	09/02/19	63	None	11/26/17	3 km W of Boca Grande Key, FL
171371	07/29/19	08/26/19	28	None	09/29/17	5 miles NE of Boca Chica Key, FL
171363	08/01/19	09/16/19	46	Inter	10/18/17	Boca Grande Key, FL
171365	08/01/19	09/18/19	47	Inter	10/17/17	Long Key, FL
171377	07/29/19	08/28/19	28	None	09/02/17	2 km E Patrick Air Force Base, FL
171378	08/02/19	09/09/19	34	Inter	10/23/17	Bahia Honda Key, FL

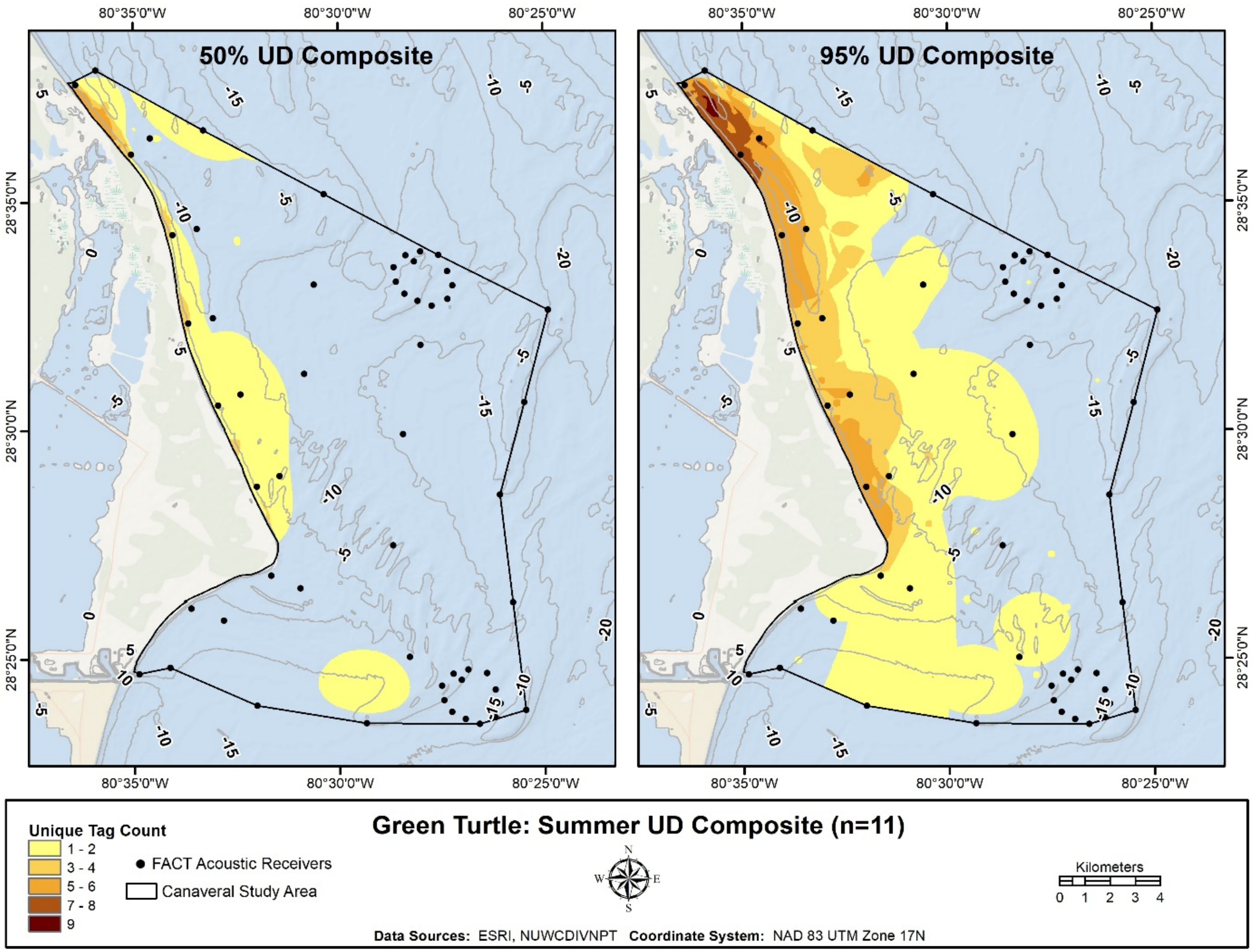


Figure 82. Local habitat use by green turtles
Maps include 50% UD (core use area) and 95% UD (overall activity space).

5.3.1 Post-Nesting Migrations

After nesting at Cape Canaveral ceased, long distance migrations were captured in detail for most turtles but differed greatly between species (**Figure 83**). Long distance migrations were resolved in detail for most individuals but with clear differences in the distance and direction of travel observed between the two species. The average distance of loggerhead turtle tracks from the SSM model output was 2,281 ± 1,429 km (range 167–6,022 km), and the average duration was 180.8 days. At the end of their nesting season, loggerhead turtles migrated to widely spaced foraging grounds along the eastern seaboard that have been previously identified by earlier researchers. The average green turtle track distance from the model output was 1,245 ± 368 km (range 548–1,764 km), with a mean duration of 76.2 days. Green sea turtles exhibited much more uniformity in their migrations to foraging grounds after nesting was completed, with nine animals making rather direct movements south along the coast to various locations in the Florida Keys. The transmitter of the tenth animal stopped reporting in early September before leaving the Canaveral region, so the timing and path of its migration was not recorded.

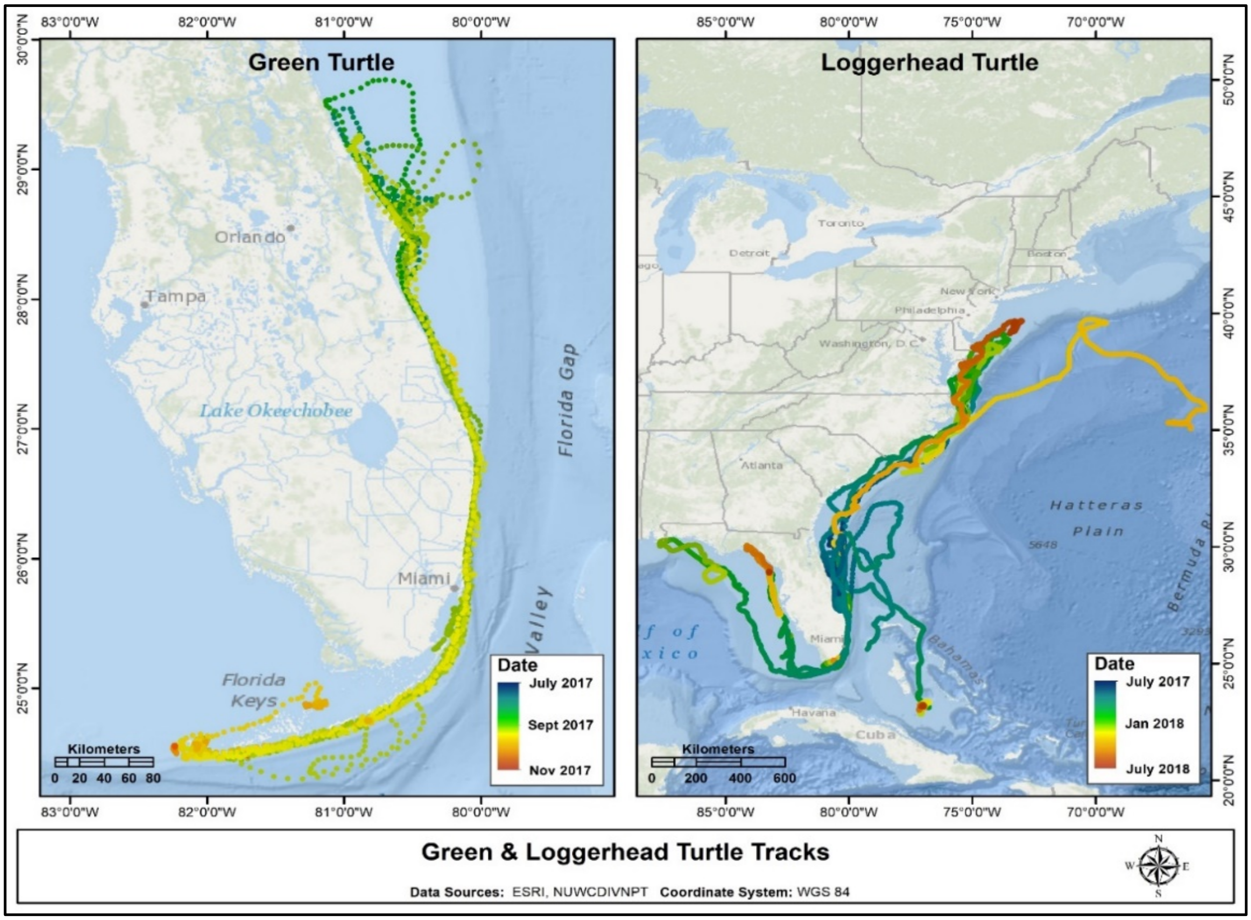


Figure 83. Post-nesting migrations for green and loggerhead turtles tagged in 2017

Review of the entire tracks for all individual turtles showed unique areas of exploratory behavior for each species. Sixty-four percent of loggerhead relocations were classified by the SSM model as being in an exploratory behavioral state. Local tracks for loggerhead turtles off Canaveral were shorter than for green turtles and showed evidence of brief foraging behavior prior to long migrations (**Figure 84**). Individual plots for this species display the diversity of behavior seen for tagged animals, with some turtles remaining closer to shore after nesting, while others showing limited movement in slightly deeper waters.

Of the total SSM output (8,392 locations), 73% of green turtle locations were classified as being in an exploratory behavioral state. Behavior for tagged green turtles when off Canaveral aligned with inter-nesting periods and was mostly estimated as exploratory (marked by limited speed and frequent turns associated with mating or resting behavior) (**Figure 85**). After leaving for previously identified foraging grounds, green turtles continued to re-nest within the Cape Canaveral region from 1 to 5 times.

After leaving the Canaveral study area, the post-nesting migratory tracks of loggerhead turtles were comparatively farther offshore and had a wider-range than the post-nesting migratory tracks of green turtles. Loggerheads were tracked north far off the continental shelf, southeast to the Bahamas, south to the Florida Keys, and north along the coast up to New Jersey (**Figure 86**). Areas of exploratory behavior were much more numerous than green turtles, including off Cape Canaveral, Florida Keys, Andros Island in the Bahamas; in the Gulf of Mexico; off Chesapeake Bay, Virginia; and off the coast of New Jersey. Green turtle tracks were limited to the region from east-central to south Florida including the Florida Keys, with most turtles migrating south within just a month or two after tagging **(Figure 87)**. Pathways were generally limited to the continental shelf. Areas of exploratory behavior for green turtles occurred off Canaveral, off south Florida, and in the Florida Keys.

5.3.2 Acoustic Telemetry Data

Over the duration of the study, 24 of 25 turtles with acoustic tags were detected in the Canaveral Array. Additionally, four loggerhead turtles and one Kemp's ridley turtle originally tagged in South Carolina and Virginia were also detected locally (**Table 30).** Most activity was noted close to the shoreline, with very little use of the CSII dredge site, adjacent control site, or offshore reefs. Acoustic transmitters are anticipated to last longer than satellite transmitters and have the possibility to reveal additional habitat use patterns as turtles return to the Canaveral region in future nesting seasons, depending on tag retention.

Table 30. Target and non-target sea turtles detected by the FACT Network at Cape Canaveral

Species	Tagging Location	Tagging Agencies[1]	Animals Detected				Total Detections
			All Canaveral	Dredge Ring	Control Ring	Offshore Reefs	
Target animals							
Green turtle	Canaveral	NUWC, KSC	10	1	1	0	5,753
Loggerhead turtle	Canaveral	NUWC, KSC	14	0	1	1	3,612
Non-target animals							
Loggerhead turtle	SC, VA	SCDNR, Vaq	4	1	1	1	891
Kemp's ridley turtle	VA	USN/Vaq	1	1	0	0	19

[1] SCDNR = South Carolina Dept. Natural Resources, USN = US Navy (VA), VAq = Virginia Aquarium

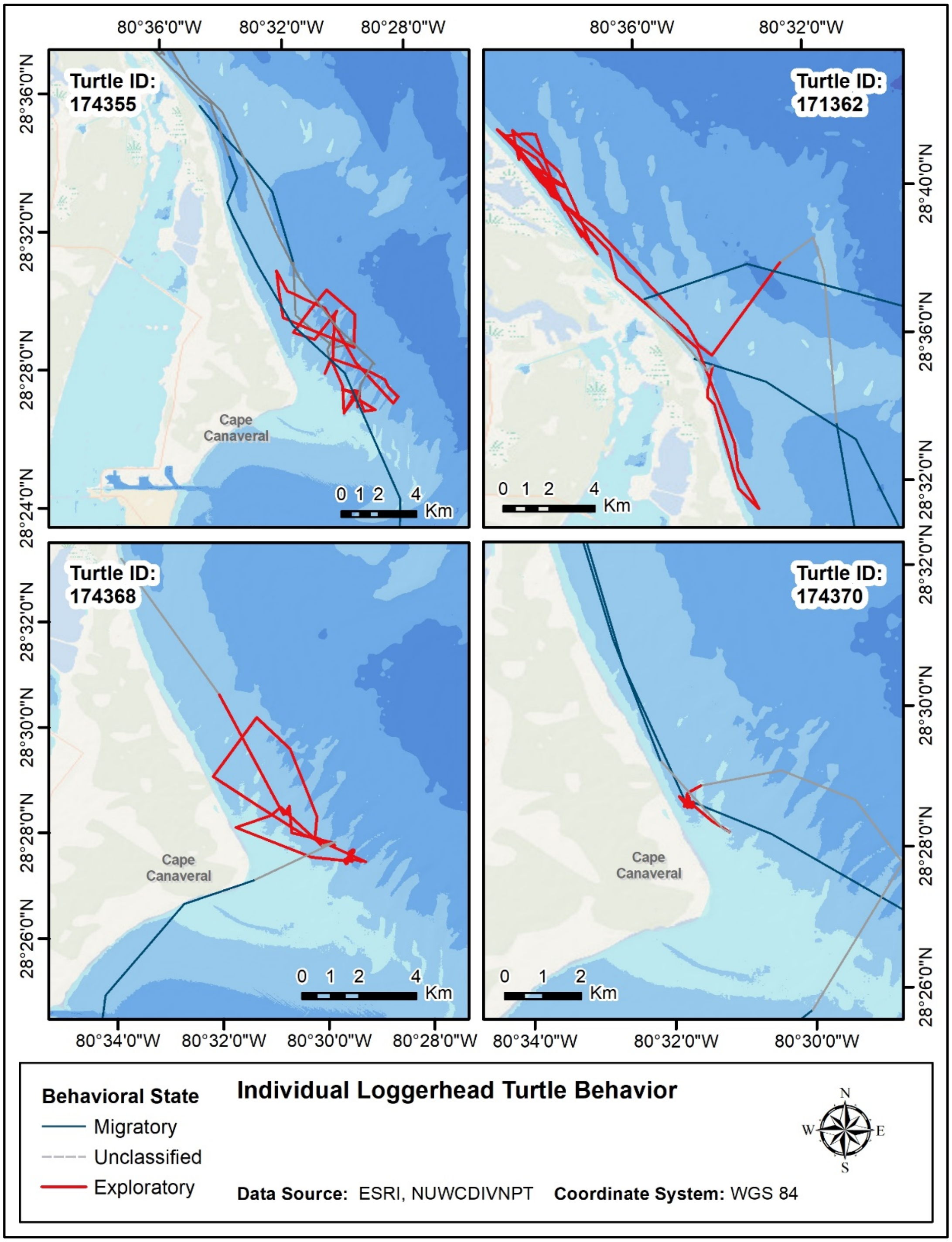


Figure 84. Movements of four individual loggerhead turtles in the Canaveral study area

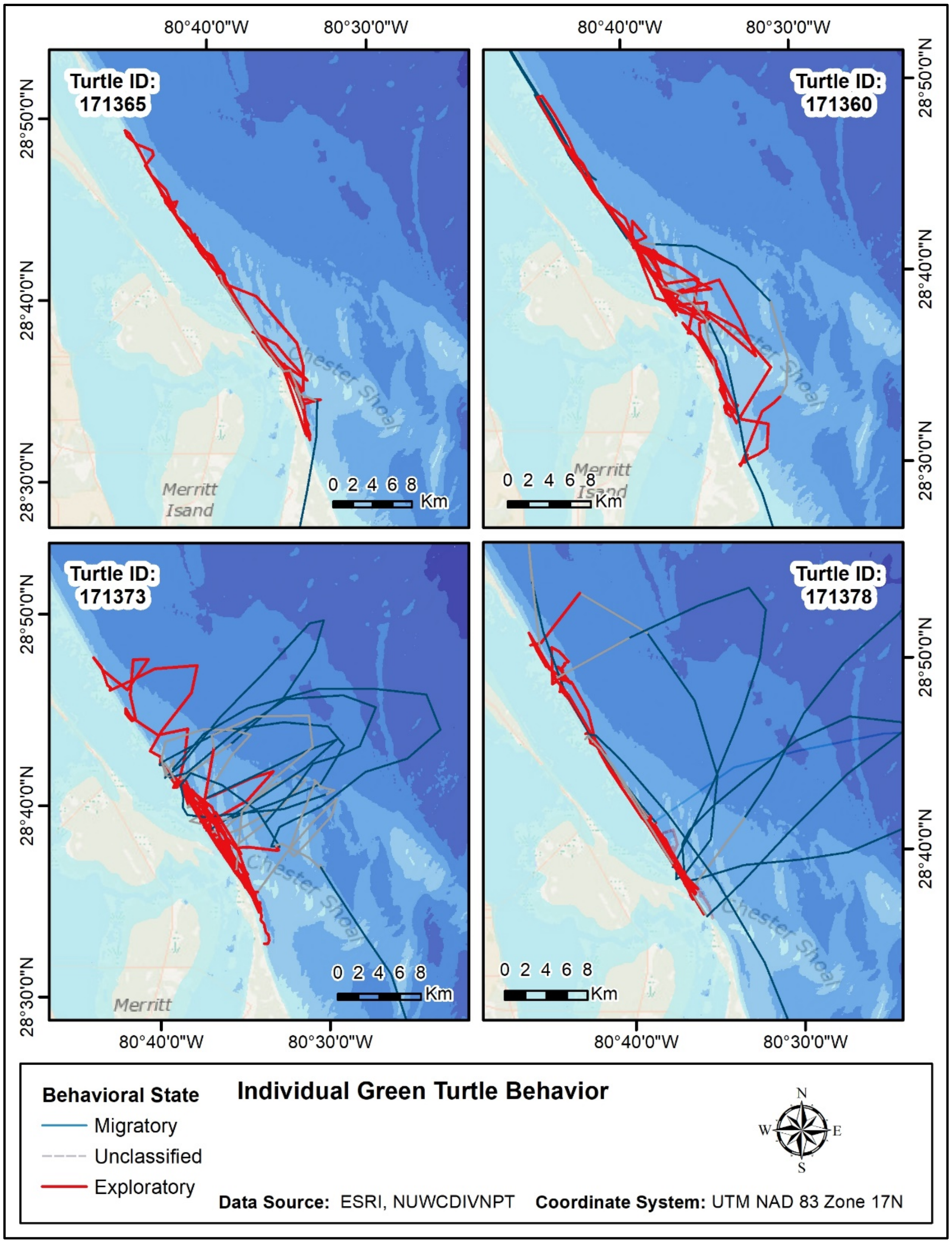


Figure 85. Movements of four individual green turtles in the Canaveral study area

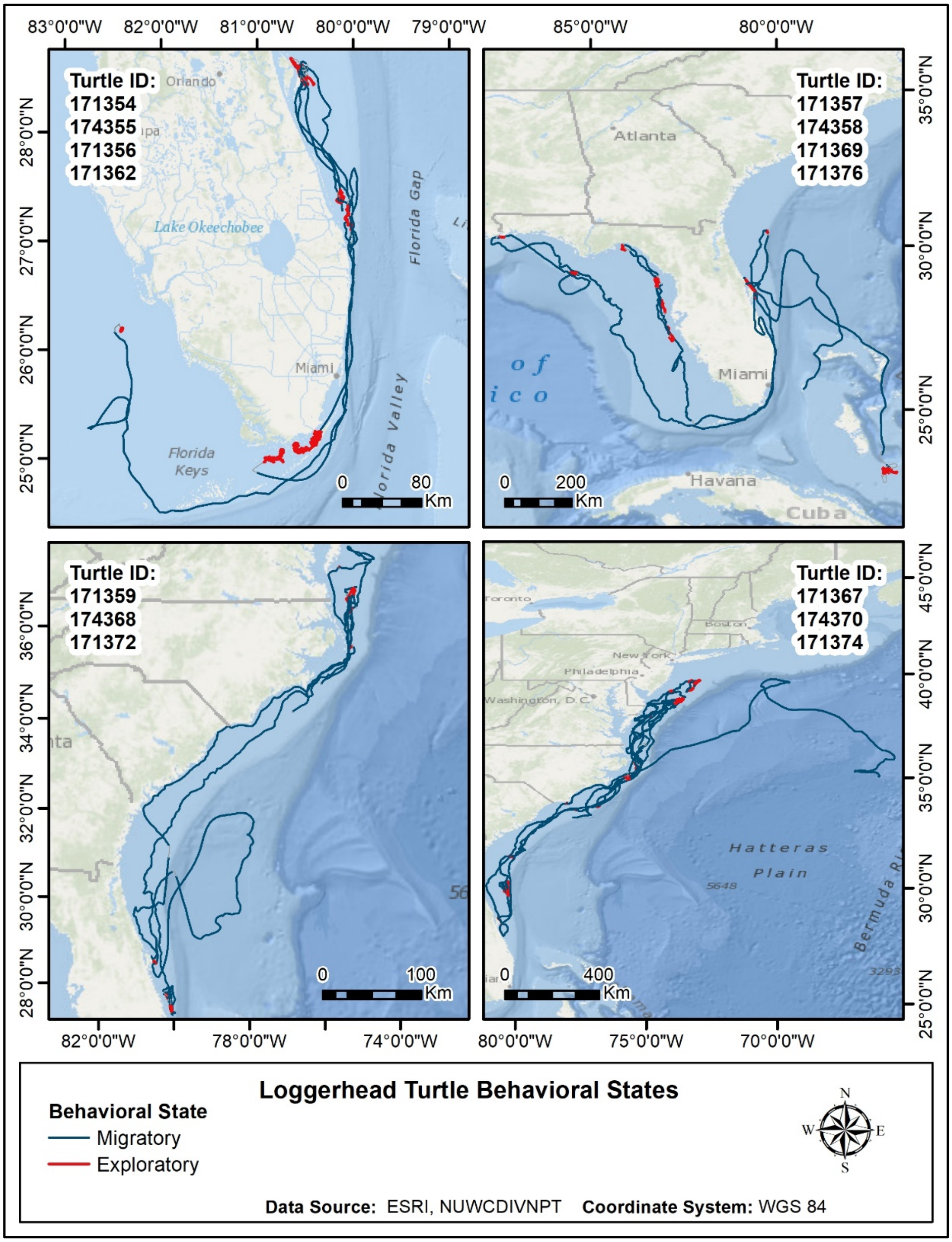


Figure 86. Behavioral states of loggerhead turtles derived from satellite tracks

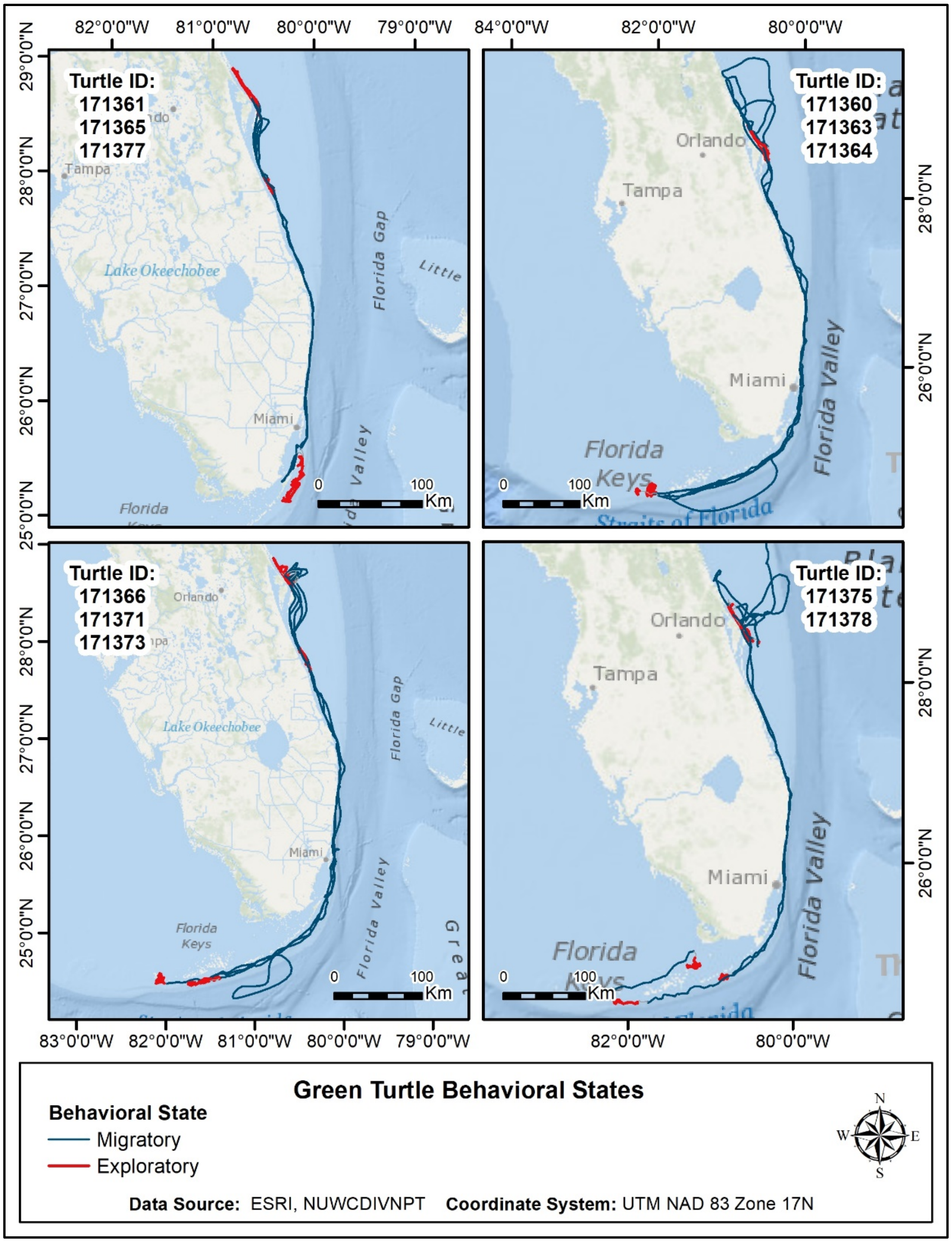


Figure 87. Behavioral states of green turtles derived from satellite tracks

5.4 Discussion

Data from this study contribute important insights regarding local movement patterns and habitat use by nesting sea turtles in the Cape Canaveral region and subsequent migratory pathways to distant foraging habitat. This tracking study was the first to focus on local nesting females and to examine in detail behavior during inter-nesting periods. Prior studies were limited to post-nesting behavior of turtles that nested on other beaches and were only transiting through the area.

Tagging of female sea turtles in this study occurred during what was considered an average nesting year for loggerheads (over 6,000 nests between beaches on the Canaveral National Seashore and the Cape Canaveral Air Force Station; Merritt Island National Wildlife Refuge and CCAFS unpubl. data), although the season started slightly later than usual. For green turtles, 2017 was a high nesting year, with over 8,000 nests counted during the official sea turtle nesting season. Satellite tag transmissions from green turtles were considerably fewer than that of loggerheads, a result that was not unexpected. Greens are known to shed their tags more quickly than loggerheads due to scute characteristics and behavioral differences (e.g., carapace rubbing [K Holloway-Adkins, unpubl. data]). Regardless, the study met the intended goal of tracking nesting females and examination of their potential use of offshore sand shoals during inter-nesting and/or post-nesting movements.

Core use areas for loggerhead and green turtles suggested preferred inter-nesting habitats and depth associations. The mean size of loggerhead inter-nesting habitat core use areas was 31% smaller than nesting loggerheads tracked by Hart et al. (2013) in the Dry Tortugas. When on the Canaveral Shoals, loggerheads remained primarily within waters 5–15 m deep and on substrates with greater habitat complexity, such as shoal margins or flanks. Hart et al. (2013) described a similar pattern in the Dry Tortugas with loggerheads showing affinity for 7.6–11.5 m water depths. They attributed selection of relatively shallow nearshore waters to be driven by the turtles' preference for close proximity to the nesting beach (Hart et al. 2013). By contrast, green turtles primarily utilized nearshore habitats along the beach with limited occurrence in inter-shoal regions or on shoal flanks. Green turtle core use areas (mean 48 km^2) were only slightly larger than loggerheads (mean 42 km^2) and had higher variability. This differs from the results of similar studies comparing core use areas of these two species in the Gulf of California, Mexico (Seminoff et al. 2002), and Australia (Whiting and Miller 1998) and in Cyprus, where Broderick et al. (2007) reported 77 km^2 for greens and 331 km^2 for loggerheads.

The relatively late start of the Canaveral study (late July 2017) resulted in only 9 of 14 loggerheads nesting a subsequent time after being tagged. Two of nine loggerhead turtles that re-nested and laid nests on beaches south of Canaveral. On average, turtles that re-nested in the Canaveral region returned to within 5 km of their previous nest site locations. Mark-recapture data from adult female loggerheads on multiple Florida nesting beaches indicated that loggerheads nesting in Florida exhibit relatively high nest site fidelity (Schroeder et al. 2003) similar to the observations in this study.

Although there was high variability for individual turtle movements across the Canaveral Shoals, there were still notable differences in use by the two species. Loggerheads were more common on the deeper margins of the shoals of greater habitat complexity or shoal flanks and also further offshore. Other studies have shown aggregations of female loggerheads off nesting beaches during inter-nesting periods and evidence of movements over sand shoals in coastal areas (et al., McClellan and Read 2007). Loggerheads appeared to have a higher affinity for Southeast Shoal than for Chester Shoal to the north. Seven of 14 tracked loggerhead turtles transited through and/or rested within Southeast Shoal. Three of the seven did so during inter-nesting, and the other four utilized shoals during post-nest period. It was assumed that by August–September 2017 loggerheads were closer to the end of the nesting season than green turtles and perhaps began foraging in benthic shoal habitats prior to migrations. Green turtles remained closer to shore, primarily at depths of less than 5 m during inter-nesting periods, with very limited occurrence on shoals. Six of 11 tracked green turtles transited through and/or rested within a Canaveral shoal area but only during the inter-nesting period.

Tracking results in other studies suggest that green and loggerhead turtles do not forage during the inter-nesting period (Hays et al. 1999). However, post-nesting turtles are assumed to begin foraging as adequate habitats are encountered, and Canaveral Shoals habitats support the benthic invertebrates (e.g., gastropods, echinoderms, bivalves) that are frequently consumed by loggerheads (Seney and Musick 2007, Youngkin 2001). Results of the sediment analysis conducted for this study reveal that the percentage of sediment fines in loggerhead high core use areas were comparatively higher than other areas. This is in contrast to Foley et al. (2014), who found that foraging loggerheads preferentially utilized areas with larger-grained, gravel/rock sediments vs. smaller-grained, mud-like sediment. This may be due to unique characteristics typical of shoal sediments and habitat complexity that supports greater diversity of benthic communities (Diaz et al. 2003). For green turtles, the Canaveral study area is devoid of seagrass and macroalgae, and therefore shoals and surrounding soft bottom substrates likely do not support the herbivorous foraging needs of this species.

Loggerhead and green turtles showed very different post-nesting migrations in both direction and distance but largely mirrored behaviors documented in previous studies. Nesting loggerheads spent limited time off Canaveral after nesting, similar to results found locally by Henwood (1987). Upon examination of post-nesting migratory paths, this study supports earlier inferences that Florida loggerheads migrate to feeding grounds via multiple pathways (Ceriani et al. 2012, Foley et al. 2013, Dodd and Byles 2003). In some instances, loggerheads traveled to the northern regions of the US Atlantic coastline, similar to Dodd and Byles (2003). This post-nesting study group included animals residing for very long periods off the coasts of Virginia, Maryland, Delaware, and North Carolina, as did several of the loggerheads tagged in this study. Foley et al. (2013) also reported nesting loggerheads tagged from three different Florida rookeries traveling a mean of 191 km (and some up to 2,000 km) from the nesting beach where they were tagged. Satellite tracks from post-nesting loggerheads originally tagged in the Archie Carr National Wildlife Refuge, approximately 20 miles south of Canaveral Shoals, included migrations to northern foraging grounds off the Atlantic coastline and others south to the Bahamas, the Florida Keys, and/or the Gulf of Mexico (Ceriani et al. 2012), all similar results as seen with this study.

Green turtle post-nesting migrations were more linear and exclusively in the direction SE Florida, Florida Keys, and Marquesas. Hays et al. (2014) indicated that the distance to and the amount of time adult green turtles spent in transit to foraging grounds in the Indian Ocean were highly variable (4 to 68 days and 160 to > 3,800 km). In contrast, green turtles in this study appeared to reach their foraging grounds in south Florida rather quickly, typically in only 30–60 days. Blanco et al. (2012) tracked post-nesting green turtles from Costa Rica and noted that all post-nesting movements were along coastal routes ranging up to 1,086 km from the nesting beach. They found that home ranges during foraging varied widely among individuals, with calculated sizes of feeding grounds ranging from 315 to 18,335 km^2. Cheng (2000) tracked post-nesting green turtles from 1994–1997 off the coast of Wan An Island, Taiwan using Argos-linked satellite tags to describe movements of eight turtles. Turtles migrated widely along the Chinese continental shelf with distances of 193–1,909 km and speeds of 1.2–2.8 km h^{-1}. Those turtles utilized several coastal foraging sites but migrations included trans-oceanic as well as coastal regions.

It is unclear whether the Canaveral Shoals provide specific feeding opportunities for these inter-nesting females, but a further evaluation of this point will be made for loggerheads with the larger 2018 dataset, which includes data on dive behavior, depth, and orientation with movement for nesting female loggerheads. This work will help to examine resting and foraging behavior off

Canaveral in finer detail. Future data analyses will also summarize individual turtle behavior patterns to identify key habitats that are re-visited and also examine mean depth occurrence locally for each turtle species. The full migratory paths with classification of behavioral state also offer mapping of other important foraging or resident areas along the Atlantic Coast that may be associated with sand resources and shoal complexes of interest to BOEM.

6 Study Conclusions

The OCS of the southeastern US sustains a large number of marine fish and sea turtle species that are of direct management concern due to their economic value or reduced population size. By law, BOEM must consider how dredging operations under their purview will affect these species and their habitat and attempt to avoid, minimize, or mitigate negative effects where possible. This mandate has historically been complicated by the high mobility and low site fidelity of many large fishes and sea turtles in the open ocean, although new technology is beginning to provide detailed and actionable insights on animal distribution and behavior, which can reduce the environmental risks of OCS resource development.

This study merged traditional longline and tag-recapture efforts with acoustic and satellite tagging, as well as USV deployments, to better characterize the habitat needs of managed fishes and sea turtles associated with a large sand shoal complex at Cape Canaveral, Florida. The study design also allowed for comparisons of residency and behavior at an active borrow area relative to a nearby undisturbed control site. This information will be valuable to BOEM and partner agencies as it develops new lease agreements and National Environmental Policy Act (NEPA) documentation for east-central Florida and similar borrow areas throughout the US south Atlantic and Gulf of Mexico.

Shoals as Fish and Sea Turtle Habitat

The combined results from longline sampling and acoustic telemetry illustrate the importance of the Canaveral Shoals region to coastal sharks and red drum, the two most common managed fish groups observed in the study area. Sharks dominated catches across all 5 years of sampling, and acoustically tagged individuals that undertook northward spring migrations commonly returned to the study area each fall (or sooner). For certain shark species, including lemon, scalloped hammerhead, and spinner sharks, the region also clearly serves an important nursery function. Red drum were the only common teleost fish caught on longlines, were present locally much of the year, and commonly returned to Canaveral after leaving temporarily in fall, presumably to spawn. In contrast, adult reef fish (and the hard bottom substrates they require) appeared to be relatively rare in this shoal system, although acoustic tagging by collaborating agencies confirm that certain reef-associated fishes (e.g., nurse sharks, goliath grouper, cobia) do commonly traverse the shoals during their respective coastal migrations. The ESA-listed Atlantic sturgeon and smalltooth sawfish, both of which have been considered quite rare in east-central Florida, were also detected in the study area, albeit ephemerally, after being tagged by other researchers at various locations along the US East Coast.

High mobility and large activity areas were characteristics of most tagged fish and inter-nesting sea turtles when on the shoals. On average, tagged fish remained at the same location for only 20–65 min, and core use areas within the Canaveral tracking array ranged from 25–200 km^2, depending on species and season. Further, acoustic telemetry documented regular exchanges of various sharks, red drum, and cobia with the offshore reef tract, as well as repeated, and typically round trip, seasonal migrations of fishes, most commonly to Georgia and the Carolinas. Even benthic fishes with supposedly limited mobility (such as Atlantic croaker, spot, and one roughtail stingray) were observed undertaking long distance coastal movements. Nesting green and loggerhead sea turtles similarly utilized large areas offshore of Cape Canaveral during the summer, often straying far from the Canaveral Shoals during their inter-nesting periods before returning and then dispersing widely along the US East Coast, Bahamas, and Gulf of Mexico during their post-nesting migrations to foraging grounds.

Although sand shoals are the most prominent bathymetric features of the Cape Canaveral coastline, longline catches and tagging results provided little evidence that managed fish or sea turtles preferentially associated with the shallowest shoal ridges. Instead, data suggest that the deeper shoal margins or flanks may be proportionally more valuable habitat, a notion previously suggested for other shoal sites. Although not conclusive, the complex bathymetry, reduced water clarity, diverse microhabitats, and fine sand-mud sediments that typify shoal edges may provide productive foraging grounds and refuge from predation.

Low site fidelity and large activity spaces required by many large-bodied fishes and sea turtles on the OCS suggests that small scale sand borrow operations conducted with the current best management practices may have only modest impacts on these managed species, a prediction supported here by telemetry data. Specifically, the number of species and individuals detected at the disturbed CSII dredge site, as well as the overall “community” of detected fish, was similar to that observed at a nearby control site. Tagged fish spent similar amounts of time at each site, while female sea turtles spent little time at either site. The effects of dredging on small-bodied benthic fish communities was not addressed in the present study but remains a topic of active research at Cape Canaveral.

Wave Glider USV deployments were undertaken to relocate acoustically tagged animals that have moved beyond the Canaveral Shoals and to quantify habitat conditions (e.g., water temperature, dissolved oxygen, chlorophyll, turbidity) associated with these detection events. Deployments are ongoing but early results show that this autonomous platform, though not likely to wholly replace fixed station acoustic telemetry, is capable of relocating widely dispersed animals, at least in regions like east Florida where large numbers of acoustically tagged animals are available for detection.

Recommendations for Future Studies

Although several aspects of this research program have concluded, including the longline survey and most acoustic tagging efforts, other portions are ongoing. The Canaveral Array will remain in place though 2019 with the continued goal of detecting acoustically tagged animals released at Cape Canaveral and by other researchers along the coast. This project also supports additional analyses of sea turtle movement, including ten additional nesting loggerhead turtles tagged in summer 2018. These turtles are carrying satellite and acoustic transmitters, as well as inertial measurement units (IMUs), designed to precisely record swimming, diving, and foraging behavior within shoal habitats during the inter-nesting periods. An additional year of Wave Glider deployments is also underway (quarterly through fall 2019) to further document the benefits and limitations of USVs for oceanographic and biological observations on the OCS.

The present study was multi-disciplinary in nature, but supplementary research could provide additional management insights concerning managed fish and sea turtle use on the Canaveral Shoals, as well as analogous sites elsewhere in the US southeast:

Continued Acoustic Telemetry Monitoring: Passive acoustic telemetry has proven to be well suited for observing the movements of coastal animals and is rapidly revealing the habitat needs of many fish and turtle species, including those that frequent OCS sand shoals. Improvements in the technology are partly responsible, but the greatest advancement may be the continued expansion and collaboration of regional-scale acoustic telemetry arrays, including the FACT (Caribbean though the Carolinas), ACT (Carolinas to Canadian Maritimes), and iTag Networks (Gulf of Mexico). Although the behavior of certain managed fishes is coming into sharp focus (most notably sharks), other important groups have received little direct study. Many groupers and snappers have received little attention outside of south Florida due to the historically limited coverage of acoustic telemetry infrastructure on offshore reef structures. The habits of the manta ray in the region remain relatively unknown despite recent listing under the US ESA. Future advances in tag power and miniaturization will improve data collection for smaller benthic fishes and coastal migratory pelagics. Additional integration of acoustic telemetry on USVs and sub-surface gliders and the development of technologies that will allow dedicated tracking of individual animals will also fill critical information gaps that are challenging to collect with fixed station monitoring.

Passive Acoustic Monitoring: Many marine species produce sound for the purpose of communication, predator defense, foraging, and reproduction; these species include several fish families (e.g., groupers, snappers, jacks, drum) and marine mammals, whose presence at OCS dredge sites is of direct management interest. Passive acoustic monitoring, in which fixed station or mobile (e.g., glider-mounted) sound recorders are deployed, provide the ability to remotely detect the local presence of these species and to understand how anthropogenic disturbance from shipping and dredging may alter behavior. The Wave Glider in particular provides an autonomous, quiet platform that contains high potential for efficient mapping of both biological sounds and the prevailing soundscape of a region. Many of the passive acoustic recorders now have improved longevity, which allows for multi-month deployments, although automated data processing and species identification of certain groups remain areas of further research.

Environmental DNA (eDNA): Through recent advances in next-generation sequencing technologies and molecular techniques, free-floating DNA that is passively shed into the water column by all animals can be filtered, amplified, sequenced, and identified directly from water samples, allowing the presence of species, including rare and cryptic taxa, to be confirmed without the need of traditional fisheries sampling. In the context of dredging and renourishment activities, eDNA could be useful for confirming the presence (or absence) of protected species, including sturgeon and sawfish, which are a high priority but can be challenging or cost-prohibitive to detect with traditional sampling. eDNA also has application for broad faunal surveys that compare species assemblages across habitats and seasons, although sampling on the open shelf would have to account for oceanographic conditions that may introduce uncertainty into the origin of genetic material.

The Canaveral Shoals complex presents higher variability in depth, water clarity, and sediment composition relative to many other locations along the east Florida continental shelf. This elevated habitat complexity, as well as the region’s status as a climactic transition zone, allows Cape Canaveral to sustain high marine species diversity and serve as an important foraging, overwintering, spawning, and nursery habitat for many managed fish and turtles. In the coming years, there likely will be a continued, if not growing, demand to exploit offshore sand deposits in support of coastal restoration projects. Although the effects of dredging to marine organisms, especially benthic communities, is now well documented, the consequence to larger-bodied species has been difficult to gauge. At Cape Canaveral at least, the high mobility, low site fidelity, and migratory tendencies of the fish and turtles targeted in this study suggest that dredging disturbances are unlikely to pose serious risk to important spawning or foraging habitats, and thus the risk may be modest relative to other anthropogenic threats faced by these animals.

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Appendix A: Canaveral Essential Fish Habitat Designations

Table A-1. Essential Fish Habitat (EFH) designations

Common Name	Scientific Name	EFH	HAPC	Agency
Spiny Lobster FMP	*Panulirus argus*	All Stages	All Stages	SAFMC,GMFMC
Shrimp FMP				
Pink shrimp	*Farfantepenaeus duorarum*	All Stages		SAFMC
White shrimp	*Litopenaeus setiferus*	All Stages		SAFMC
Brown shrimp	*Farfantepenaeus aztecus*	All Stages		SAFMC
Rock shrimp	*Sicyonia brevirostris*			SAFMC
Royal red shrimp	*Pleoticus robustus*			SAFMC
Highly Migratory Species FMP				
Sharpnose Shark	*Rhizoprionodon terraenovae*	All Stages		NMFS
Bigeye Tuna	*Thunnus obesus*	Juvenile		NMFS
Blacknose Shark	*Carcharhinus acronotus*	Juvenile, Adult		NMFS
Blacktip Shark	*Carcharhinus limbatus*	Juvenile, Adult		NMFS
Bonnethead Shark	*Sphyrna tiburo*	All Stages		NMFS
Bull Shark	*Carcharhinus leucas*	All Stages		NMFS
Dusky Shark	*Carcharhinus obscurus*	Juvenile, Adult		NMFS
Finetooth Shark	*Carcharhinus isodon*	Juvenile, Adult		NMFS
Great Hammerhead	*Sphyrna mokorran*	All Stages		NMFS
Lemon Shark	*Negaprion brevirostris*	Juvenile	Juvenile	NMFS
Nurse Shark	*Ginglymostoma cirratum*	Juvenile, Adult		NMFS
Sailfish	*Istiophorus platypterus*	Juvenile, Adult		NMFS
Sand Tiger Shark	*Carcharius taurus*	All Stages		NMFS
Sandbar Shark	*Charhinus plumbeus*	Juvenile, Adult		NMFS
Scalloped Hammerhead	*Sphyrna lewini*	All Stages		NMFS
Silky Shark	*Carcharhinus falciformis*	All Stages		NMFS
Spinner Shark	*Carcharhinus brevipinna*	All Stages		NMFS

Source: NOAA (2018)

Common Name	Scientific Name	EFH	HAPC	Council
Tiger shark	*Galeocerdo cuvier*	All Stages	-	AHMS
White shark	*Carcharodon carcharias*	Juvenile, Adult	-	AHMS
Yellowfin tuna	*Thunnus albacares*	Juvenile	-	AHMS
Coastal Migratory Pelagics FMP				
Cero	*Scomberomorus regalis*	All Stages	-	SAFMC,GMFMC
Cobia	*Rachycentron canadum*	All Stages	-	SAFMC,GMFMC
King mackerel	*Scomberomorus cavalla*	All Stages	-	SAFMC,GMFMC
Little tunny	*Euthynnus alletteratus*	All Stages	-	SAFMC,GMFMC
Spanish mackerel	*Scomberomorus maculatus*	All Stages	-	SAFMC,GMFMC
Dolphin-Wahoo FMP				
Dolphinfish	*Coryphaena hippurus*	All Stages	-	SAFMC
Wahoo	*Acanthocybium solandri*	All Stages	-	SAFMC
Bluefish FMP	*Pomatomus saltatrix*	All Stages	-	MAFMC
Summer Flounder FMP	*Paralichthys dentatus*	Larvae	-	MAFMC
Red Drum FMP	*Sciaenops ocellatus*	All Stages	-	ASMFC
Snapper-Grouper FMP				
Almaco jack	*Seriola rivoliana*	All Stages	All Stages	SAFMC
Banded rudderfish	*Seriola zonata*	All Stages	All Stages	SAFMC
Bank sea bass	*Centropristis ocyurus*	All Stages	All Stages	SAFMC
Bar jack	*Caranx ruber*	All Stages	All Stages	SAFMC
Black grouper	*Mycteroperca bonaci*	All Stages	All Stages	SAFMC
Black sea bass	*Centropristis striata*	All Stages	All Stages	SAFMC
Blackfin snapper	*Lutjanus buccanella*	All Stages	All Stages	SAFMC
Blueline tilefish	*Caulolatilus microps*	All Stages	All Stages	SAFMC
Coney	*Cephalopholis fulva*	All Stages	All Stages	SAFMC
Cottonwick	*Haemulon melanurum*	All Stages	All Stages	SAFMC
Cubera snapper	*Lutjanus cyanopterus*	All Stages	All Stages	SAFMC
Gag	*Mycteroperca microlepis*	All Stages	All Stages	SAFMC
Golden tilefish	*L. chamaeleonticeps*	All Stages	All Stages	SAFMC

Source: NOAA (2018)

Common Name	**Scientific Name**	**EFH**	**HAPC**	**Council**
Goliath grouper	*Epinephelus itajara*	All Stages	All Stages	SAFMC
Gray snapper	*Lutjanus griseus*	All Stages	All Stages	SAFMC
Gray triggerfish	*Balistes capriscus*	All Stages	All Stages	SAFMC
Graysby	*Cephalopholis cruentata*	All Stages	All Stages	SAFMC
Greater amberjack	*Seriola dumerili*	All Stages	All Stages	SAFMC
Hogfish	*Lachnolaimus maximus*	All Stages	All Stages	SAFMC
Jolthead porgy	*Calamus bajonado*	All Stages	All Stages	SAFMC
Knobbed porgy	*Calamus nodosus*	All Stages	All Stages	SAFMC
Lane snapper	*Lutjanus synagris*	All Stages	All Stages	SAFMC
Lesser amberjack	*Seriola fasciata*	All Stages	All Stages	SAFMC
Longspine porgy	*Stenotomus caprinus*	All Stages	All Stages	SAFMC
Margate	*Haemulon album*	All Stages	All Stages	SAFMC
Misty grouper	*Hyporthodus mystacinus*	All Stages	All Stages	SAFMC
Mutton snapper	*Lutjanus analis*	All Stages	All Stages	SAFMC
Nassau grouper[a]	*Epinephelus striatus*	All Stages	All Stages	SAFMC
Ocean triggerfish	*Canthidermis sufflamen*	All Stages	All Stages	SAFMC
Queen snapper	*Etelis oculatus*	All Stages	All Stages	SAFMC
Red grouper	*Epinephelus morio*	All Stages	All Stages	SAFMC
Red hind	*Epinephelus guttatus*	All Stages	All Stages	SAFMC
Red porgy	*Pagrus pagrus*	All Stages	All Stages	SAFMC
Red snapper	*Lutjanus campechanus*	All Stages	All Stages	SAFMC
Rock hind	*Epinephelus adscensionis*	All Stages	All Stages	SAFMC
Rock sea bass	*Centropristis philadelphica*	All Stages	All Stages	SAFMC
Sailors choice	*Haemulon parra*	All Stages	All Stages	SAFMC
Sand tilefish	*Malacanthus plumieri*	All Stages	All Stages	SAFMC
Saucereye porgy	*Calamus calamus*	All Stages	All Stages	SAFMC
Scamp	*Mycteroperca phenax*	All Stages	All Stages	SAFMC
Scup	*Stenotomus chrysops*	All Stages	All Stages	SAFMC

Source: NOAA (2018)

Common Name	**Scientific Name**	**EFH**	**HAPC**	**Council**
Silk snapper	*Lutjanus vivanus*	All Stages	All Stages	SAFMC
Snowy grouper	*Hyporthodus niveatus*	All Stages	All Stages	SAFMC
Atlantic spadefish	*Chaetodipterus faber*	All Stages	All Stages	SAFMC
Speckled hind	*Epinephelus drummondhayi*	All Stages	All Stages	SAFMC
Tomtate	*Haemulon aurolineatum*	All Stages	All Stages	SAFMC
Vermilion snapper	*Rhomboplites aurorubens*	All Stages	All Stages	SAFMC
Warsaw grouper	*Hyporthodus nigritus*	All Stages	All Stages	SAFMC
White grunt	*Haemulon plumierii*	All Stages	All Stages	SAFMC
Whitebone porgy	*Calamus leucosteus*	All Stages	All Stages	SAFMC
Wreckfish	*Polyprion americanus*	All Stages	All Stages	SAFMC
Yellowedge grouper	*Hyporthodus flavolimbatus*	All Stages	All Stages	SAFMC
Yellowfin grouper	*Mycteroperca venenosa*	All Stages	All Stages	SAFMC
Yellowmouth grouper	*Mycteroperca interstitialis*	All Stages	All Stages	SAFMC
Yellowtail snapper	*Ocyurus chrysurus*	All Stages	All Stages	SAFMC

Source: NOAA (2018)

Appendix B: Longline Catch Model Summary Tables

Table B-1. Full results of logistic regression models for identifying habitat conditions that influenced longline catch probability

Sharpnose Shark Final Model

Fixed Effect	**Estimate**	**Std. Error**	**Z Value**	**P-Value**
(Intercept)	-0.80	0.22	-3.61	< 0.001
Temp	0.65	0.16	3.93	< 0.001
DO	0.15	0.13	1.23	0.22
Depth	0.55	0.13	4.34	< 0.001
ShoreDist	0.03	0.13	0.22	0.83
Slope	-0.01	0.09	-0.11	0.91
Clarity	0.72	0.14	5.00	< 0.001
Latitude	0.45	0.10	4.60	< 0.001
Summer	0.72	0.26	2.80	0.005
Fall	0.00	0.30	0.01	0.99
Winter	-1.66	0.34	-4.85	< 0.001

Random Effect	**Name**	**Variance**	**Std.Dev**
Year	(Intercept)	0.10	0.33

Notes:

- Model: Present ~ Temp + DO + Depth + ShoreDist + Slope + Clarity + Latitude + Season + (1 | Year)
- NagelKerke: $R^2 = 0.49$
- Evidence Based Ratio = 1.08×10^{80}

Blacknose Shark Final Model

Fixed Effect	Estimate	Std. Error	Z Value	P-Value
(Intercept)	-1.35	0.27	-5.10	< 0.001
Temp	-0.13	0.15	-0.86	0.392
DO	-0.19	0.12	-1.64	0.101
Depth	0.53	0.12	4.29	< 0.001
ShoreDist	-0.55	0.13	-4.11	< 0.001
Slope	0.11	0.08	1.33	0.184
Clarity	-0.33	0.12	-2.73	0.006
Latitude	0.05	0.09	0.51	0.612
Summer	0.64	0.26	2.48	0.013
Fall	-0.30	0.30	-1.02	0.307
Winter	-0.38	0.25	-1.50	0.133

Random Effect	Name	Variance	Std.Dev
Year	(Intercept)	0.21	0.46

Notes:

- Model: Present ~ Temp + DO + Depth + ShoreDist + Slope + Clarity + Latitude + Season + (1 | Year)
- NagelKerke: $R^2 = 0.09$
- Evidence Based Ratio = 7.78×10^6

Blacktip Shark Final Model

Fixed Effect	**Estimate**	**Std. Error**	**Z Value**	**P-Value**
(Intercept)	-2.18	0.26	-8.29	< 0.001
Temp	0.09	0.18	0.51	0.608
DO	0.05	0.14	0.33	0.739
Depth	-0.10	0.17	-0.61	0.545
ShoreDist	-0.49	0.18	-2.68	0.007
Slope	0.03	0.11	0.26	0.797
Clarity	-0.71	0.24	-2.94	0.003
Latitude	0.24	0.12	2.09	0.037
Summer	-0.70	0.38	-1.87	0.062
Fall	-0.22	0.36	-0.61	0.539
Winter	0.26	0.29	0.87	0.382

Random Effect	**Name**	**Variance**	**Std.Dev**
Year	(Intercept)	0.11	0.33

Notes:

- Model: Present ~ Temp + DO + Depth + ShoreDist + Slope + Clarity + Latitude + Season + (1 | Year)
- NagelKerke: $R^2 = 0.15$
- Evidence Based Ratio = 5.68×10^{10}

Finetooth Shark Final Model

Fixed Effect	Estimate	Std. Error	Z Value	P-Value
(Intercept)	-3.34	0.37	-8.93	< 0.001
Temp	-0.37	0.29	-1.30	0.193
DO	-0.38	0.22	-1.72	0.086
Depth	0.14	0.26	0.52	0.600
ShoreDist	-0.28	0.27	-1.03	0.302
Slope	0.25	0.15	1.69	0.091
Clarity	-1.89	0.53	-3.57	< 0.001
Latitude	0.06	0.18	0.35	0.727
Summer	-0.72	0.61	-1.19	0.236
Fall	-1.48	0.65	-2.29	0.022
Winter	-0.72	0.41	-1.76	0.078

Random Effect	Name	Variance	Std.Dev
Year	(Intercept)	0.00	0

Notes:

- Model: Present ~ Temp + DO + Depth + ShoreDist + Slope + Clarity + Latitude + Season + (1 | Year)
- NagelKerke: $R^2 = 0.17$
- Evidence Based Ratio = 1.56×10^6

Red Drum Final Model

Fixed Effect	**Estimate**	**Std. Error**	**Z Value**	**P-Value**
(Intercept)	-5.31	0.65	-8.13	< 0.001
Temp	-1.31	0.33	-3.96	< 0.001
DO	-0.13	0.22	-0.58	0.563
Depth	0.34	0.23	1.47	0.143
ShoreDist	-0.32	0.25	-1.27	0.203
Slope	-0.02	0.15	-0.15	0.881
Clarity	-0.86	0.42	-2.03	0.042
Latitude	-0.10	0.17	-0.56	0.576
Summer	0.49	1.19	0.41	0.683
Fall	2.13	0.75	2.83	< 0.005
Winter	1.75	0.56	3.13	0.002

Random Effect	**Name**	**Variance**	**Std.Dev**
Year	(Intercept)	0.23	0.48

Notes:

- Model: Present ~ Temp + DO + Depth + ShoreDist + Slope + Clarity + Latitude + Season + (1 | Year)
- NagelKerke: $R^2 = 0.31$
- Evidence Based Ratio = 2.74×10^{19}

Appendix C: Canaveral Array Receiver Site Characteristics

Table C-1. Habitat conditions associated with each acoustic receiver site

Station	Latitude	Longitude	Depth (m)	Seafloor Slope (m)	Dist From Shore (km)	Sediment % Fines	Sediment % Organics	Habitat Group
BOEM1	28.553	-80.510	12.3	1.8	5.4	4.53	1.24	Inter-Shoal
BOEM2	28.531	-80.467	14.6	1.5	8.5	7.14	1.72	Shoal
BOEM3	28.510	-80.425	9.7	7.9	11.3	0.05	0.66	Shoal
BOEM4	28.458	-80.478	12.0	2.7	4.6	1.42	1.30	Inter-Shoal
BOEM5	28.437	-80.430	16.0	4.0	9.6	2.10	1.50	Shoal
BOEM6	28.400	-80.534	13.1	0.9	4.9	15.82	2.52	Inter-Shoal
BOEM7	28.703	-80.541	15.2	3.0	10.2	NA	NA	Reef
BOEM8	28.682	-80.427	18.9	1.8	17.9	NA	NA	Reef
BOEM9	28.528	-80.352	24.1	1.8	18.6	NA	NA	Reef
BOEM10	28.425	-80.302	25.3	1.2	22.1	NA	NA	Reef
BOEM11	28.310	-80.457	16.8	0.6	14.7	NA	NA	Reef
DRE1	28.411	-80.440	10.8	2.1	9.6	0.00	0.88	Dredge
DRE2	28.405	-80.437	9.9	4.0	10.2	0.05	0.81	Dredge
DRE3	28.400	-80.435	11.0	6.1	10.7	0.11	0.86	Dredge
DRE4	28.395	-80.437	10.0	7.0	10.8	0.02	1.11	Dredge
DRE5	28.393	-80.443	12.9	4.9	10.5	0.10	1.09	Dredge
DRE6	28.394	-80.449	12.3	4.3	9.9	0.16	0.69	Dredge
DRE7	28.397	-80.454	11.7	4.3	9.3	0.24	0.91	Dredge
DRE8	28.401	-80.458	7.9	5.5	8.8	0.07	0.83	Dredge
DRE9	28.407	-80.459	6.1	5.2	8.3	0.02	0.95	Dredge
DRE10	28.411	-80.454	5.2	4.3	8.4	0.04	0.90	Dredge
DRE11	28.409	-80.450	7.3	4.9	8.8	0.06	0.70	Dredge
DRE12	28.413	-80.448	8.9	5.8	8.9	0.04	0.89	Dredge
CON1	28.558	-80.456	10.8	3.0	10.7	0.05	0.95	Control
CON2	28.553	-80.454	11.0	3.4	10.7	0.11	0.72	Control
CON3	28.548	-80.456	11.2	3.0	10.3	0.14	0.96	Control
CON4	28.545	-80.462	11.0	3.4	9.7	0.11	0.70	Control
CON5	28.547	-80.468	6.5	6.7	9.2	0.00	0.78	Control
CON6	28.550	-80.473	8.1	4.3	8.8	0.02	0.76	Control
CON7	28.554	-80.477	9.6	3.0	8.6	0.17	0.94	Control

Station	Latitude	Longitude	Depth (m)	Seafloor Slope (m)	Dist From Shore (km)	Sediment % Fines	Sediment % Organics	Habitat Group
CON8	28.559	-80.477	10.8	2.7	8.7	0.14	0.95	Control
CON9	28.564	-80.473	11.3	4.3	9.2	0.16	0.90	Control
CON10	28.561	-80.469	9.5	3.4	9.5	0.04	0.91	Control
CON11	28.565	-80.467	9.8	2.7	9.8	0.07	0.90	Control
CS1	28.393	-80.489	6.9	10.7	7.4	0.00	1.01	Shoal
CS2	28.417	-80.472	4.6	2.7	6.6	0.00	0.57	Shoal
CS3	28.398	-80.424	8.8	10.7	11.7	0.02	0.93	Shoal
CS4	28.520	-80.514	11.4	2.1	3.9	2.09	1.46	Inter-Shoal
CS5	28.498	-80.474	15.6	1.8	6.4	6.21	1.92	Inter-Shoal
CS6	28.476	-80.435	15.7	6.7	9.1	0.48	1.10	Inter-Shoal
CS7	28.609	-80.555	8.1	4.0	3.1	0.15	1.52	Shoal
CS8	28.586	-80.506	8.1	2.1	6.5	0.00	0.87	Shoal
CS9	28.564	-80.459	12.1	3.0	10.5	0.07	0.81	Control
CS10	28.544	-80.415	12.9	7.6	13.7	0.02	0.64	Shoal
CC1	28.412	-80.580	4.7	13.4	0.2	0.64	0.36	Shore
CC3	28.435	-80.560	4.7	7.0	0.3	0.80	0.62	Shore
CC5	28.447	-80.528	1.4	2.7	0.3	0.14	1.06	Shore
CC6	28.412	-80.570	8.9	7.6	0.9	8.38	1.48	Shore
CC8	28.428	-80.554	7.5	1.5	1.2	12.63	1.91	Shore
CC10	28.440	-80.521	3.0	1.2	1.3	0.20	0.63	Shore
CC11	28.480	-80.533	4.4	4.0	0.3	0.70	0.43	Shore
CC12	28.509	-80.549	3.7	4.6	0.3	0.71	0.54	Shore
CC13	28.539	-80.561	4.2	9.1	0.2	0.55	0.27	Shore
CC14	28.571	-80.567	5.6	11.0	0.2	0.46	0.52	Shore
CC15	28.601	-80.584	5.3	8.5	0.2	1.46	0.61	Shore
CC16	28.626	-80.607	3.7	9.4	0.2	0.16	0.29	Shore
CC17	28.483	-80.524	4.2	2.7	1.3	0.06	0.81	Shore
CC18	28.513	-80.540	6.4	3.4	1.3	1.73	0.70	Shore
CC19	28.541	-80.551	8.5	3.4	1.2	0.29	0.98	Shore
CC20	28.574	-80.557	7.5	4.6	1.2	1.30	1.73	Shore
CC21	28.607	-80.576	7.9	3.0	1.2	0.17	1.11	Shore
CC22	28.631	-80.598	9.1	1.5	1.2	0.29	1.48	Shore

Appendix D: Summary of Kernel Density Estimated Bandwidth

Table D-1. Bandwidth for kernel density estimates used in generation of UDs
Values shown are mean for each species for each season. N/A values are not enough data for calculation of standard deviation.

Species	Season	Count	Mean (m)	SD (m)
Finetooth shark	Fall	29	4,651	1,694
Finetooth shark	Spring	46	4,314	1,991
Finetooth shark	Summer	13	3,481	2,244
Finetooth shark	Winter	50	5,029	1,292
Blacknose shark	Fall	25	4,786	1,244
Blacknose shark	Spring	47	4,490	1,580
Blacknose shark	Summer	23	4,079	1,856
Blacknose shark	Winter	43	4,616	1,356
Sharpnose shark	Fall	12	4,679	1,432
Sharpnose shark	Spring	2	5,456	n/a
Sharpnose shark	Summer	31	4,372	1,894
Sharpnose shark	Winter	7	4,560	1,879
Lemon shark	Fall	17	5,070	1,151
Lemon shark	Spring	20	3,419	2,149
Lemon shark	Summer	2	5,456	n/a
Lemon shark	Winter	22	3,585	2,324
Red drum	Fall	57	4,253	1,593
Red drum	Spring	72	4,560	1,372
Red drum	Summer	50	4,936	1,060
Red drum	Winter	80	4,421	1,503
Bluefish	Spring	40	4,095	2,173
Spanish mackerel	Fall	15	4,983	1,330
Spanish mackerel	Spring	10	3,873	2,344
Cobia	Fall	12	4,943	1,432
Cobia	Spring	13	5,288	420
Cobia	Summer	18	3,805	2,233
Cobia	Winter	18	4,176	2,089
Loggerhead sea turtle	Summer	14	3,654	2,166
Green sea turtle	Summer	11	2,679	1,830

Appendix E: Visit Duration Model Summary Tables

Table E-1. Full results of *glmm* models for identifying habitat conditions that influenced visit duration of tagged fish to acoustic receivers

Finetooth Shark Visit Duration Model

Fixed Effect	Estimate	Std. Error	DF	T Value	P-Value
(Intercept)	3.07	0.03	59	93.0	< 0.001
Depth	0.34	0.03	8008	9.9	< 0.001
ShoreDist	-0.40	0.03	7889	-13.6	< 0.001
Sediment Fines	0.19	0.03	8082	6.3	< 0.001
Sediment Organics	-0.23	0.04	8081	-6.5	< 0.001
Latitude	-0.13	0.02	6499	-7.4	< 0.001
Spring	-0.17	0.03	6574	-5.2	< 0.001
Summer	-0.32	0.07	6045	-4.6	< 0.001
Fall	-0.40	0.06	6081	-6.9	< 0.001

Random Effects	Name	Variance	Std.Dev
Individual Fish	(Intercept)	0.03	0.17
Residual		1.47	1.21

Notes:

- Model: log(Visit Duration) ~ ShoreDist + Depth + Latitude + Season + Sediment Fines + Sediment Organics + (1|Individual Fish)

Blacknose Shark Visit Duration Model

Fixed Effect	Estimate	Std. Error	DF	T Value	P-Value
(Intercept)	3.28	0.04	37	84.4	< 0.001
Depth	0.34	0.02	16110	14.3	< 0.001
ShoreDist	-0.28	0.02	13450	-14.5	< 0.001
Slope	-0.04	0.02	15380	-2.4	0.017
Sediment Fines	0.26	0.03	16180	8.5	< 0.001
Sediment Organics	-0.35	0.04	16180	-9.4	< 0.001
Solar Irradiance	0.05	0.01	16180	5.4	< 0.001
Temperature	0.09	0.02	14500	6.1	< 0.001
Latitude	-0.06	0.01	5834	-3.9	< 0.001
Spring	0.03	0.03	11270	0.9	0.383
Summer	0.09	0.04	13960	2.4	0.017
Fall	-0.08	0.04	15790	-2.3	0.023

Random Effects	Name	Variance	Std.Dev
Individual Fish	(Intercept)	0.03	0.18
Residual		1.49	1.22

Notes:

- Model: log(Visit Duration) ~ Temperature + Solar Irradiance + ShoreDist + Depth + Slope + Latitude + Season + Sediment Fines + Sediment Organics + (1|Individual Fish)

Sharpnose Shark Visit Duration Model

Fixed Effect	**Estimate**	**Std. Error**	**DF**	**T Value**	**P-Value**
(Intercept)	3.37	0.24	471.9	14.0	< 0.001
Depth	0.21	0.06	1031.2	3.7	< 0.001
ShoreDist	-0.21	0.05	952.3	-4.1	< 0.001
Sediment Fines	0.23	0.05	1072.9	5.0	< 0.001
Solar Irradiance	0.14	0.03	1112.8	4.2	< 0.001
Temperature	0.09	0.04	833	2.3	0.02
Spring	0.02	0.29	1013.7	0.1	0.94
Summer	0.03	0.24	966	0.1	0.90
Fall	-0.27	0.24	1114.4	-1.1	0.26

Random Effects	**Name**	**Variance**	**Std.Dev**
Individual Fish	(Intercept)	0.08	0.27
Residual		1.18	1.09

Notes:

- Model: log(Visit Duration) ~ Temperature + Solar Irradiance + ShoreDist + Depth + Season + Sediment Fines + (1|Individual Fish)

Lemon Shark Visit Duration Model

Fixed Effect	Estimate	Std. Error	DF	T Value	P-Value
(Intercept)	2.83	0.03	24	93.59	< 0.001
Depth	0.37	0.04	5450	8.81	< 0.001
ShoreDist	-0.25	0.04	5336	-6.50	< 0.001
Slope	0.25	0.02	5475	11.36	< 0.001
Sediment Fines	0.10	0.02	5520	4.69	< 0.001
Solar Irradiance	0.04	0.02	5523	2.15	0.03
Temperature	-0.07	0.03	1364	-2.58	0.009
Spring	-0.23	0.05	3846	-4.41	< 0.001
Summer	0.30	0.09	1093	3.52	< 0.001
Fall	-0.34	0.07	5263	-4.63	< 0.001

Random Effects	Name	Variance	Std.Dev
Individual Fish	(Intercept)	0.01	0.09
Residual		1.46	1.21

Notes:

- Model: log(Visit Duration) ~ Temperature + Solar Irradiance + ShoreDist + Depth + Slope + Season + Sediment Fines + (1|Individual Fish)

Red Drum Visit Duration Model

Fixed Effect	Estimate	Std. Error	DF	T Value	P-Value
(Intercept)	3.28	0.02	153	136.1	< 0.001
Depth	0.33	0.02	32860	22.1	< 0.001
ShoreDist	-0.26	0.01	31040	-20.5	< 0.001
Sediment Fines	0.19	0.02	33140	10.2	< 0.001
Sediment Organics	-0.14	0.02	33080	-7.2	< 0.001
Solar Irradiance	-0.06	0.01	33160	-8.0	< 0.001
Latitude	-0.15	0.01	21820	-15.4	< 0.001
Temperature	-0.06	0.01	31870	-5.8	< 0.001
Spring	-0.03	0.02	30770	-1.6	0.11
Summer	-0.07	0.03	27640	-2.6	0.01
Fall	0.08	0.03	31720	3.0	0.003

Random Effects	Name	Variance	Std.Dev
Individual Fish	(Intercept)	0.02	0.15
Residual		1.71	1.31

Notes:

- Model: log(Visit Duration) ~ Temperature + Solar Irradiance + ShoreDist + Depth + Latitude + Season + Sediment Fines + Sediment Organics + (1|Individial Fish)

Scalloped Hammerhead Shark Visit Duration Model

Fixed Effect	Estimate	Std. Error	DF	T Value	P-Value
(Intercept)	2.50	0.23	407.3	10.7	< 0.001
Depth	0.17	0.07	922.9	2.4	0.018
ShoreDist	-0.22	0.08	819.6	-2.6	0.009
Slope	0.25	0.06	804	3.9	< 0.001
Sediment Fines	0.21	0.07	711.1	3.1	0.002
Solar Irradiance	0.14	0.04	1046.4	3.8	< 0.001
Spring	0.26	0.22	1039.2	1.2	0.230
Summer	0.49	0.23	1021.2	2.1	0.033
Fall	0.76	0.24	1011.8	3.1	0.002

Random Effects	Name	Variance	Std.Dev
Individual Fish	(Intercept)	0.10	0.33
Residual		1.43	1.19

Notes:

- Model: log(visit duration) ~ Solar Irradiance + ShoreDist + Depth + Slope + Season + Sediment Fines + (1 \| Individual Fish)

Cobia Visit Duration Model

Fixed Effect	Estimate	Std. Error	DF	T Value	P-Value
(Intercept)	2.71	0.07	22.5	38.9	< 0.001
Depth	0.21	0.06	266.8	3.4	< 0.001
Slope	0.17	0.06	455	2.9	0.004
Sediment Fines	0.21	0.06	453.4	3.5	< 0.001

Random Effects	Name	Variance	Std.Dev
Individual Fish	(Intercept)	0.03	0.1813
Residual		1.18	1.0874

Notes:

- Model: log(visit duration) ~ Depth + Slope + Sediment Fines + (1 | Individual Fish)

Bluefish Visit Duration Model

Fixed Effect	Estimate	Std. Error	DF	T Value	P-Value
(Intercept)	2.52	0.12	33.92	20.7	< 0.001
ShoreDist	-0.19	0.08	311.37	-2.5	0.010
Winter	0.67	0.30	183.5	2.2	0.029

Random Effects	Name	Variance	Std.Dev
Individual Fish	(Intercept)	0.27	0.5229
Residual		1.59	1.2604

Notes:

- Model: log(visit duration) ~ ShoreDist + Season + (1 | Individual Fish)

Department of the Interior (DOI)

The Department of the Interior protects and manages the Nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors the Nation’s trust responsibilities or special commitments to American Indians, Alaska Natives, and affiliated island communities.

Bureau of Ocean Energy Management (BOEM)

The mission of the Bureau of Ocean Energy Management is to manage development of U.S. Outer Continental Shelf energy and mineral resources in an environmentally and economically responsible way.

BOEM Environmental Studies Program

The mission of the Environmental Studies Program is to provide the information needed to predict, assess, and manage impacts from offshore energy and marine mineral exploration, development, and production activities on human, marine, and coastal environments. The proposal, selection, research, review, collaboration, production, and dissemination of each of BOEM’s Environmental Studies follows the DOI Code of Scientific and Scholarly Conduct, in support of a culture of scientific and professional integrity, as set out in the DOI Departmental Manual (305 DM 3).