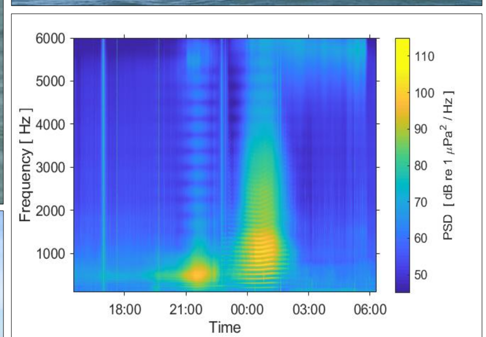
OCS Study
BOEM 2022-018

Behavior, Seasonality, and Habitat Preferences of Mobile Fishes and Sea Turtles Within a Large Sand Shoal Complex:

Habitat Connectivity, Ocean Glider Surveys, and Passive Acoustics



US Department of the Interior
Bureau of Ocean Energy Management
Sterling, VA

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Authors:
Joseph Iafrate[1]*, Eric Reyier[2]*, Bonnie Ahr[2]*
Stephanie Watwood[1], Douglas Scheidt[2], Jane Provancha[2], Karen Holloway-Adkins[3], Alexandra Carroll[1], Andrew DiMatteo[4], Jessica Greene[4], Jason Krumholz[4]
*Authors contributed equally to report preparation

Prepared under Interagency Agreement M13PG00031 by:
[1]Naval Undersea Warfare Center Division, Newport
1176 Howell Street, Newport, RI 02841

In collaboration with:

[2]Herndon Solutions Group &
NASA Environmental and Medical Contract #80KSC020D0023
Kennedy Space Center, FL 32899

[3]East Coast Biologists, Inc.
P.O. Box 33715
Indialantic, FL 32903

[4]McLaughlin Research Corporation
132 Johnny Cake Hill
Middletown, RI 02842

US Department of the Interior
Bureau of Ocean Energy Management
Sterling, VA

DISCLAIMER

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ABOUT THE COVER

Upper left: A jumping blacktip shark offshore Cape Canaveral; *Lower left:* A Wave Glider unmanned surface vehicle surveying offshore NASA Launch Complex 39; *Upper right:* A suction hopper dredge removing sand from the Canaveral Shoals II sand borrow site; *Middle right*: A spectrogram of a vocalizing Atlantic midshipman fish offshore Cape Canaveral; *Lower right:* An adult female green turtle released after being tagged with satellite and acoustic transmitters. Photo credits: Russell Lowers (*upper left*), Eric Reyier (*lower left, upper right*), Joe Iafrate (*center right*), Jane Provancha (*lower right*).

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Executive Summary

Offshore sand shoals are common geomorphic features of the US continental shelf and offer greater diversity in bathymetry, sediments, and ocean currents compared to the soft bottom habitats that surround them. Available evidence suggests that sand shoals support unique marine communities and are utilized by dozens of species of economic value or conservation concern. Given the strong spatial and seasonal heterogeneity that typifies shelf species assemblages, repeated sampling over multiple years is required to adequately characterize shoal communities. While challenging to obtain, the need for these long-term datasets is growing because offshore shoals are an increasingly coveted sand source for shoreline restoration projects.

The passage of Hurricane Sandy in October 2012 resulted in extensive shoreline erosion along much of the US Atlantic Coast. In response, Congress tasked the Bureau of Ocean Energy Management (BOEM) with improving coastal resiliency in the region, including, among other actions, research to better describe natural shoal ecosystems and to document dredging impacts on marine species. One area selected for in-depth study was the Canaveral Shoals, the largest sand shoal complex on the east Florida shelf and an important sand borrow site for multiple beach nourishment projects. The purpose of this effort was to better document local habitat and associated fauna, information important for refining dredging best management practices. Survey techniques have included traditional sampling such as sediment grabs, plankton tows, and benthic trawls, but an emphasis was also placed on the study of larger sharks, bony fishes, and sea turtles. These mobile and often migratory groups are rarely the focus of shoal surveys, but continued advances in automated monitoring technology now make it easier to document their distribution and behavior in open ocean habitats.

This report serves as a supplement to a 2019 BOEM report titled *Behavior, Seasonality, and Habitat Preferences of Mobile Fishes and Sea Turtles Within a Large Sand Shoal Complex: Insights from Traditional Sampling and Emerging Technologies* (Iafrate et al. 2019). This second account is intended to provide a final summary for several project aspects including (1) habitat use and behavior of coastal fishes determined using fixed-station acoustic telemetry, (2) Wave Glider unmanned surface vehicle (USV) surveys to relocate acoustically tagged animals over a wider area, (3) habitat use and migrations of nesting loggerhead (*Caretta caretta*) and green (*Chelonia mydas*) sea turtles using satellite telemetry and inertial measurement unit tags, and (4) passive acoustic monitoring to document the ambient, biological, and human components of the ocean soundscape of the Canaveral Shoals.

Acoustic tracking efforts included local tagging of 747 individuals from 14 target shark and bony fish species. Fish movements were followed through an acoustic receiver array of up to 62 stations deployed on the shoals and in adjacent deeper water, as well as along the Canaveral shoreline and offshore reef tract. Over a six-year period (2013–2020), 1,200 fish from 42 species (17 bony fishes, 16 sharks, and 9 rays) were detected, including species tagged locally plus those released by 32 other research groups at various locations along the US East Coast, Canada, Bahamas, and Mexico. Except for the reef-associated red snapper (*Lutjanus campechanus*), high mobility within the study area was consistently observed across species. In-depth analyses through 2018 demonstrated that community structure was influenced by season, water depth, and distance from shore. A general northward migration was also observed in many fish species each spring, with tagged individuals returning to east-central Florida in fall for several consecutive years. Additional evidence through 2020 further strengthened these conclusions. The Canaveral fixed-station array also regularly detected Atlantic sturgeon (*Acipenser oxyrinchus*) in winter and smalltooth sawfish (*Pristis pectinata*) in spring and summer, federally protected species whose habits off east Florida are poorly known.

Eight Wave Glider unmanned surface vehicle deployments were conducted quarterly from 2017–2019 and included a survey zone extending beyond the core Canaveral Shoals project area. On average,

deployments lasted 24 days and surveyed 1,200 km along a preplanned transect. A total of 331 separate encounters with 167 acoustically tagged animals in 20 species were recorded; blacktip shark (*Carcharhinus limbatus*), blacknose shark (*C. acronotus*), finetooth shark (*C. isodon*), and red drum (*Sciaenops ocellatus*) were the most commonly detected species. Higher encounter rates occurred in fall and winter, and generally in waters adjacent to the shoals. Range testing of the glider's integrated acoustic receiver at three separate depths yielded 50% and 20% positive detection ranges at 350 m and 500 m, respectively. Boosted regression tree models demonstrated that distance between the acoustic transmitter and the glider explained 65% of the variance in detection probability, while ocean currents explained a further 9%. When considering identical timeframes, the Wave Glider—functioning as a single mobile receiver— detected, on average, 64% of the species and 40% of the animals, but less than 2% of the detections logged by the local fixed-station receiver array. Further, the duration of animal encounters with the Wave Glider averaged only 14 min, shorter than encounters on fixed stations for almost all species. Nonetheless, the glider demonstrated its ability to navigate the complex bathymetry surrounding the shoals and to provide highly localized habitat information that is often unavailable for animals moving through fixed tracking arrays.

In summer 2018, 10 female loggerhead turtles were tagged with satellite and acoustic transmitters, and inertial measurement unit (IMU) tags as they nested on beaches adjacent to the shoals. This effort, which supplemented satellite and acoustic tagging of 14 loggerhead and 11 green turtles in summer 2017, was designed to reveal local habitat use, fine-scale diving behavior, energy consumption, and post-nesting migratory pathways. Turtles tagged in 2018 spent 2–25 days offshore east-central Florida but with visits to the core project area generally only lasting only 1–3 days. Shallow waters along the shoreline and flanks of the Southeast Shoal were areas of high use for loggerheads, and minimal use of the active dredge site or a nearby control site farther offshore was observed. A state-space model applied to satellite telemetry data determined that only 5 of 10 loggerheads exhibited local exploratory (as opposed to migratory) behavior, suggesting that some individuals may not forage locally during or after nesting periods. Dive behavior revealed by IMU tags was highly variable across individuals with dives averaging 2–10 m in depth and 2–18 min in duration, and with turtles spending 41–94% of their time submerged. After nesting, six loggerheads migrated north along the US East Coast as far as Virginia, with the rest moving to the Bahamas or Gulf of Mexico. In general, results from 2017 and 2018 were similar and confirmed that turtles range widely throughout east-central Florida during their summer nesting season, show a preference for shallow nearshore water and shoal margins when in the vicinity of the Canaveral Shoals, and disperse long distances throughout the northwest Atlantic once nesting is complete.

The ocean soundscape comprises sounds originating from physical processes, living organisms, and human activities. Analyzing soundscapes provides insight into species behavior, local biodiversity, and overall ecosystem health, but monitoring has historically been beset by technical and logistical challenges. Autonomous fixed-station and Wave Glider-mounted acoustic recorders were used to catalogue the sources of oceanographic, biological (e.g., invertebrate, fish, and marine mammals), and anthropogenic sounds in the Canaveral Shoals region. Seafloor-mounted recorders were deployed periodically from February 2018–August 2020 at three sites. Samples analyzed from June 2018 showed relatively high broadband sound levels (109–122 dB re 1 $\mu Pa^2/Hz$), and the relative contributions from vessel noise and fish was quantified. Glider-based recordings from July 2020 summarized the ambient spectrum across different depths, sea state, and wind speed. The highest variability in power spectrum density levels was noted in shallower transects, and an increase in biological noise after dusk was observed in all transects, largely linked to robust nocturnal fish spawning choruses. Fixed stations were also used to characterize sound produced by the suction hopper dredge *Liberty Island* during active sand borrow activities. Long term spectral average plots suggested high persistent noise levels—even when the vessel was not actively dredging—with results comparable to previous recordings from this same vessel off Virginia. Finally, both fixed and glider-mounted recorders documented multi-species fish spawning choruses, primarily comprising representatives from the families Sciaenidae, Triglidae, and Batrachoididae. Two distinct choruses were apparent in many summer recordings, including one with peak levels roughly one hour past sunset dominated by sciaenid fishes and a second peaking approximately 3 hours after sunset that was composed almost exclusively by loud and persistent hums of the Atlantic midshipman (*Porichthys plectrodon*). Greater intensity and diversity of species calls were noted near the control site relative to the dredge site, a finding that may be explained by natural variation in the benthic fish assemblage throughout the Canaveral Shoals or due to previous disturbances of the benthic community at the dredge site.

Taken together, and considered in context with earlier findings, the greater Cape Canaveral region clearly plays an important role for many federally managed marine species by consistently serving as an overwintering area for many coastal sharks, red drum, and even Atlantic sturgeon, and as regular summer destination for federally listed sea turtles and smalltooth sawfish. Nonetheless, no evidence was produced suggesting that shallow shoal ridges—features often targeted for sand extraction—were proportionally more valuable than surrounding habitat or that mobile fish or turtles used an active dredge site differently than a nearby control site. Moreover, high mobility, low site fidelity, and extensive seasonal migrations were behaviors observed across most managed fish and turtle species. While seasonal abundance patterns are always location-dependent, these behavioral traits are likely more consistent across shoal habitats throughout the US southeast and Gulf of Mexico and should moderate the impact of small-scale dredge disturbances, assuming that sites are not located near other sensitive habitats and appropriate operational and seasonal safeguards for dredging activities are implemented.

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List of Abbreviations and Acronyms

°C	degrees Celsius
ACNWR	Archie Carr National Wildlife Refuge
AIS	Automated Information System
ARS	area-restricted search
AUC	area under the curve
AUV	autonomous underwater vehicle
BACI	Before-After-Control-Impact
BBFS	Bimini Biological Field Station
BOEM	Bureau of Ocean Energy Management
BRT	boosted regression tree
BTT	Bonefish & Tarpon Trust
CCSFS	Cape Canaveral Space Force Station
CCU	Coastal Carolina University
CDOM	colored dissolved organic matter
CEI	Cape Eleuthera Institute
cm	centimeter(s)
cm/sec	centimeters per second
CMAST	Center for Marine Science and Technology
CSI	Canaveral Shoals I Dredge Site
CSII	Canaveral Shoals II Dredge Site
CU	Clemson University
CV	Cross-Validated
cy	cubic yard(s)
dB re 1 µPa	decibels referenced to 1 microPascal
DBA	Dynamic Body Acceleration
DESU	Delaware State University
DOI	United States Department of the Interior
DPS	Distinct Population Segment
EEZ	Exclusive Economic Zone
EFH	Essential Fish Habitat
ESA	Endangered Species Act
FA	Fins Attached
FACT	Florida Atlantic Coast Telemetry
FAU	Florida Atlantic University
FF	fundamental frequency
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
GMFMC	Gulf of Mexico Fishery Management Council
GPS	Global Positioning System

HAPC	Habitat Areas of Particular Concern
HBOI	Harbor Branch Oceanographic Institute
hr	hour(s)
IMU	inertial measurement unit
IRG	Inwater Research Group
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/hr	kilometer(s) per hour
km^2	square kilometer(s)
KS	Kolmogorov-Smirnov
KSC	Kennedy Space Center
lb	pound(s)
LTSA	Long Term Spectral Average
m	meter(s)
m/s	meter(s) per second
MADMF	Massachusetts Division of Marine Fisheries
MARMAP	Marine Resources Monitoring, Assessment and Prediction
MCMC	Markov Chain Monte Carlo
min	minute(s)
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
ODBA	Overall Dynamic Body Acceleration
PAM	passive acoustic monitoring
PAS	passive acoustic sensor
PF	peak frequency
ppt	parts per thousand
PSD	Power Spectral Density
PTT	platform terminal transmitter
REMUS	Remote Environmental Monitoring Unit System
RFU	Relative Fluorescence Unit
RMS	root mean square
ROM	rate of movement
RSMAS	Rosenstiel School of Marine and Atmospheric Science
s, sec	second(s)

SAFMC	South Atlantic Fishery Management Council
SBU	Stony Brook University
SCDNR	South Carolina Department of Natural Resources
SD	standard deviation
SEAMAP	Southeast Area Monitoring and Assessment Program
SEL	Sound Exposure Level
SERC	Smithsonian Environmental Research Center
SPD	Spectral Probability Density
SPL	sound pressure level
SSM	state-space model
TSHD	trailing suction hopper dredge
UD	utilization distribution
UF	University of Florida
UNC	University of North Carolina Chapel Hill
UNCW	University of North Carolina Wilmington
US	United States
USFWS	US Fish and Wildlife Service
USGS	United States Coast Guard
USN	United States Navy
USV	unmanned surface vehicle
VDBA	Vector Dynamic Body Acceleration
VHF	very high frequency
VIMS	Virginia Institute of Marine Science
VMT	Vemco Mobile Transceiver
W/m^2	watt(s) per square meter

1 Introduction

1.1 Background of the Study

Coastal erosion is a significant and growing issue along the US East Coast and Gulf of Mexico, as it is throughout much of the world. Erosion occurs naturally in response to waves and storms but is also increasingly and convincingly linked to human activity (Williams et al. 2018). Major sources of manmade erosion result from sea level rise and increased storm frequency and intensity spurred by rising greenhouse gas emissions, as well as purposeful alterations to coastlines during construction of jetties and seawalls, filling of wetlands, clearing of mangrove forests, and numerous other factors (Gracia et al. 2018). Given the high concentration of human population and infrastructure common along coastlines, efforts are often required to counteract erosion and to proactively fortify against future erosion risk.

One of the most common ways to restore shorelines is to supplement—or nourish—with sand from other sources. In many regions, sand from readily accessible terrestrial deposits is unavailable or depleted, and there is a growing demand for offshore sand to fill this deficit (de Jong et al. 2016; Knorr 2017). Significant deposits of beach quality sand can often be found in offshore shoals of the outer continental shelf (OCS). Shoals are submerged ridges, bars, or banks formed from sand or gravel that are shallower in depth than surrounding areas. Shoals can sometimes present undulating ridge and swale topography or connect to form shoal complexes (Hayes and Nairn 2004; Rutecki et al. 2014). Sand shoals are common geomorphic features found in many regions. In the US Atlantic, for example, shoals of various classifications cover roughly 5% of the continental shelf by area (Pickens et al. 2021). These deposits and are now increasingly tapped to rebuild beaches, dunes, and wetlands, with sand transfer to the shoreline generally facilitated with the use of large dredges.

The 1953 Outer Continental Shelf Lands Act charged the Bureau of Ocean Energy Management (BOEM) with the responsibility for managing mineral access on the US OCS, defined by law as water of the US Exclusive Economic Zone (EEZ) beyond 3 nautical miles from shore in most areas, and 9 miles from shore along Texas and the Florida gulf coast. BOEM’s Marine Minerals Program regulates access to offshore sand resources though a lease program and works with states and municipalities to identify suitable sand deposits and streamline project permitting and logistics. To date, OCS sand has been used in restoration projects from New Jersey through Louisiana, repairing over 700 km of shoreline (BOEM 2021). Like all Federal agencies, BOEM must take steps to minimize damage to habitat and wildlife resulting from actions they fund or sponsor under provisions set forth by the National Environmental Policy Act, Endangered Species Act (ESA), Marine Mammal Protection Act, and Magnuson-Stevens Fisheries Conservation and Management Act (Tomlinson et al. 2007). BOEM also funds research to describe the marine communities associated with shoals and to measure their response to and recovery from dredging operations. Results from these projects are used to responsibly select dredge sites and to customize best management practices that minimize impacts to marine life in or near offshore sand borrow project areas. Specific actions will often include mandating seasonal dredging restrictions, updating equipment requirements, monitoring threatened and endangered species, and establishing buffers around sensitive habitats like reefs.

1.2 Study Goals

In the aftermath of Hurricane Sandy in October 2012, post-storm damage assessments along the US East Coast identified several critically eroded shorelines that would likely require access to OCS sand for beach nourishment. Congress quickly funded BOEM to undertake several initiatives intended to accelerate coastal resiliency planning for the region. The initiatives included updating offshore sediment maps and databases, archiving sediment samples in a national repository, and forming cooperative agreements with Atlantic states to streamline nourishment projects. Funds were also allocated to support longer-term studies to better describe the habitat value of OCS sand shoals, recognizing that multi-year monitoring was needed to fully characterize the highly variable physical habitat and biological communities that typify these features.

Cape Canaveral, on the central east Florida coast, was selected by BOEM as a priority research area. The Canaveral region features the largest sand shoal complex on the Florida east coast and includes one active OCS sand borrow site that has been repeatedly used as a sand source for projects designed to renourish nearby eroding beaches (

Figure 1). The region also possesses a robust complement of oceanographic and biological monitoring infrastructure, adding valuable context to study results. Most importantly, Cape Canaveral is recognized for its high biodiversity and supports a large number of federally managed fish and sea turtles. Many of these species range widely throughout the US South Atlantic and Gulf of Mexico, so findings have relevance to analogous shoal sites in other areas. This BOEM-sponsored work was multi-disciplinary but included an emphasis on large predatory fishes and sea turtles, groups that are poorly represented in previous shoal assessments due to their high mobility and migratory life history strategies. This focus was facilitated by advances in electronic tagging and ocean glider technology that allows animal movement and environmental conditions to be more easily documented in open ocean environments.

The purpose of this report is to

(A) Provide a final six-year accounting of fish and sea turtle distribution on and adjacent to the Canaveral Shoals based on movement through a regional fixed-station acoustic telemetry array

(B) Summarize the results of eight Wave Glider unmanned surface vessel surveys of the Canaveral Shoals region designed for oceanographic mapping, mobile tracking of acoustically tagged animals, and acoustic range test trials

(C) Describe the distribution, behavior, and migrations of female loggerhead sea turtles on the Canaveral Shoals using satellite, inertial measurement unit (IMU), and acoustic tags

(D) Present findings of passive acoustic monitoring from fixed-station and Wave Glider sound recorders that quantified the ambient, biological, and anthropogenic components of the ocean soundscape of the Canaveral Shoals region

1.3 Relationship with Other Research

This report serves as an extension of work conducted from 2013 through 2018 by the same research team, whose initial results were released in a 2019 BOEM report titled *Behavior, Seasonality, and Habitat Preferences of Mobile Fishes and Sea Turtles Within a Large Sand Shoal Complex: Insights from Traditional Sampling and Emerging Technologies* (Iafrate et al. 2019). The synthesis, review, and dissemination of this long duration—and somewhat eclectic—research project was best served by offering results in two parts. Efforts were made here to not simply rehash previous analyses and conclusions. In the several instances where full details are already available in the 2019 report (or other resources), the reader is referred there. An emphasis of this second report is also to convey lessons learned with respect to animal tracking and Wave Glider deployments. This project had many successes but also unexpected challenges. Providing a forthright accounting of these shortcomings should aid future investigators with similar goals.

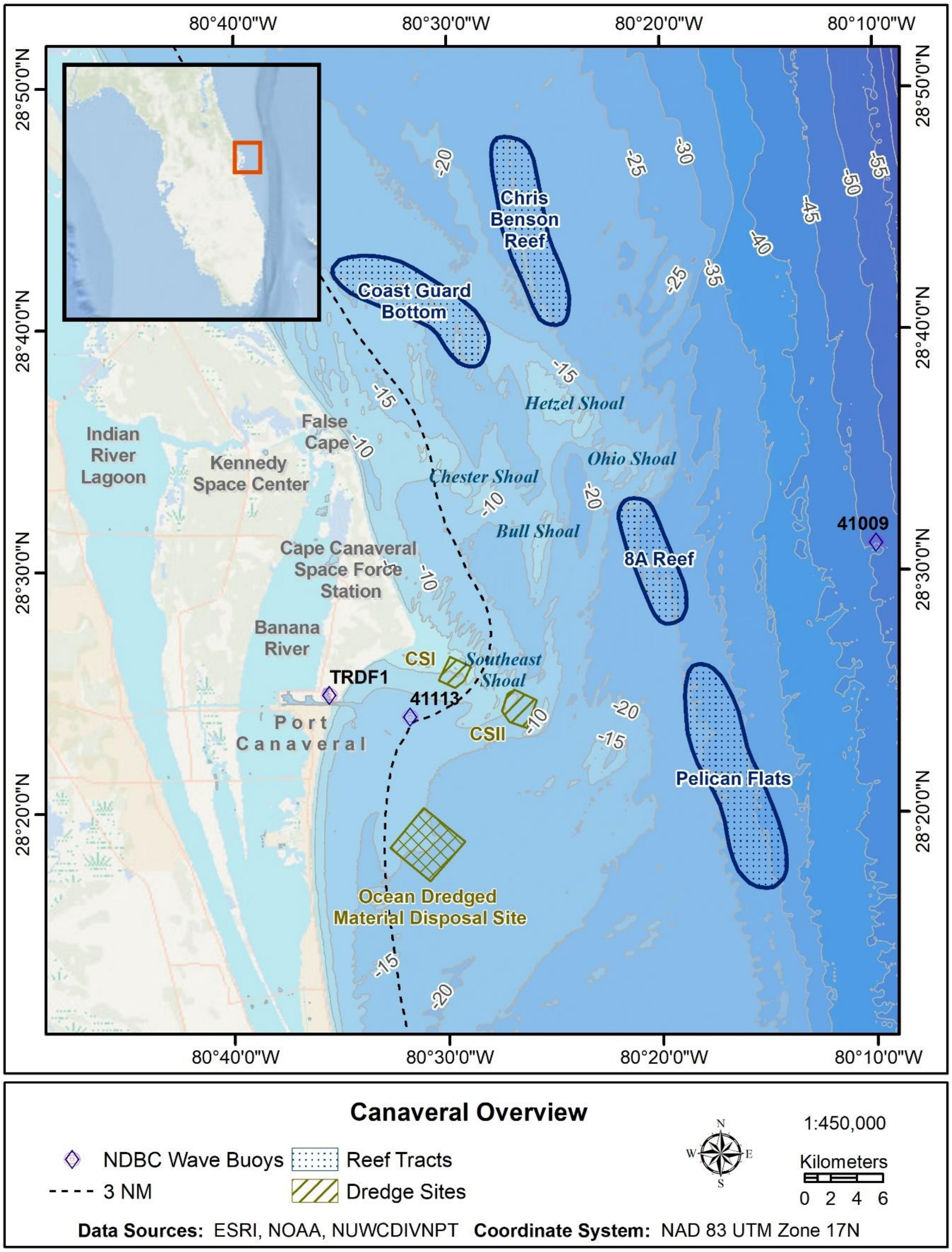


Figure 1. Overview map of Cape Canaveral

Important features of the Canaveral study area, including all named shoals, the active CSII dredge site, important nearby reef areas, and National Data Buoy Center (NDBC) wave buoys.

While the bulk of the research presented here focuses on mobile fishes and sea turtles, other BOEM-sponsored habitat mapping efforts and biological surveys were simultaneously conducted at Cape Canaveral. These efforts, led by the Program of Fisheries and Aquatic Sciences at the University of Florida, included bathymetric surveys, sediment mapping, plankton tows, invertebrate sampling, benthic trawls, dietary studies, trophic interaction models, and even additional acoustic tagging of fishes, primarily benthic rays, and flatfish. Details of these aspects, which are focused more narrowly on comparisons between the active dredge site and two nearby reference sites, can be found in a forthcoming report by Murie and Smith (2022). Finally, this research has both benefited from and subsequently supported many species-specific studies now published in the peer-reviewed literature including work on the lemon shark (Kessel et al. 2014; Reyier et al. 2014), sand tiger shark (Kneebone et al. 2014), scalloped hammerhead shark (Barker et al. 2019; Lyons et al. 2020; Barker et al. 2021), smalltooth sawfish (Graham et al. 2021; 2022), cownose ray (Ogburn et al. 2018; Bangley et al. 2021), and Atlantic tarpon (Griffin et al. 2018), with several others in development.

1.4 Value of Shoals to Fish and Sea Turtles

By definition, sand shoals on the continental shelf differ from adjacent habitats in terms of depth, but they also typically offer greater variability in sediment types, seafloor morphology, and turbidity, and thus provide unique foraging, predator avoidance, and reproductive opportunities for many marine organisms (Diaz et al. 2003). Shoals are also dynamic locations, subjected to higher rates of natural change in their physical structure due to increased disturbance from wave action, currents, and storms. These conditions often collectively result in biological communities that differ from adjacent habitat types (Rutecki et al. 2014).

The cumulative knowledge regarding the composition and diversity of sand shoal communities has expanded dramatically in recent decades, in large part due to monitoring that accompanies dredging operations, particularly in Europe and North America. These efforts have historically focused on benthic invertebrate groups because they are most directly disrupted by sand removal. The effects of dredging on invertebrate populations can be severe, albeit often temporary, especially for immobile epifaunal (on surface) and infaunal (in substrate) organisms unable to avoid the dredge itself or relocate to nearby undisturbed substrates. A full discussion on the consequences and recovery of dredging to benthic communities is beyond the scope of this report, but thorough reviews are available, including by Brooks et al. (2004, 2006) and Michel et al. (2013).

Shoal fish communities have received more limited attention to date, but there is evidence that they support unique, albeit sometimes depauperate, fish assemblages (Diaz et al. 2003; Kaiser et al. 2004; Vasslides and Able 2008; Slacum et al. 2010). In the US south Atlantic region, sand shoals have been recognized as habitat for at least 215 fish species (Rutecki et al. 2014). Small-bodied schooling planktivores such as sardines and herring likely use shoals intermittently for feeding, refuge, and spawning, whereas benthic flounder, skates, lizardfish, and drum may be true year-round residents (Brooks et al. 2005; Michel et al. 2013). As is the case in most shelf habitats, shoal-associated fish communities often vary dramatically across seasons and are also influenced by the habitats that surround them (Zarillo et al. 2009). Pickens and Taylor (2020), for example, determined that the abundance of many fish and shrimp species in the US Atlantic and Gulf of Mexico was positively related to (among other factors) distance from wetlands and estuaries. In many shoal surveys, however, patterns in biomass and diversity across depths and seasons are obscured by high catch variability or limited sampling effort. Fish of direct economic value are relatively rare and primarily represented as juveniles, in part because common sampling gears such as trawls, plankton nets, and benthic sleds are ill-suited for documenting the presence of larger mobile species. While managed fishes are common on shoals, data on shoal use by large species including sharks, red drum, reef fish, and coastal migratory pelagics (e.g., mackerel and cobia) remains a considerable knowledge gap (Pickens et al. 2020).

The use of shoals by sea turtles is even less understood. Four marine turtle species are widely distributed along the continental shelf 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). Loggerhead and green turtles are by far the two most abundant turtle species in this region. Their range and habitat requirements broadly overlap, but their divergent diets suggest they 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 prefer shallow seagrass and reef-attached macroalgae (Bjorndal 1980) that is rarely associated with offshore shoals. Green turtle use of shoals therefore may be sporadic, with their presence representing periods of transit between feeding grounds and nesting beaches. Leatherbacks nest in small numbers on southeast Florida beaches 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, Kemp's ridley turtles feed on invertebrate prey (Seney and Musick 2007) and may rely on shoals as foraging areas, but these turtles are much rarer throughout the region.

1.5 Dredging Impacts to Fish and Sea Turtles

OCS sand borrow activities generally require the use of large ship-borne dredges. The dredge removes sand from offshore deposits and transfers it to the shore where it is manipulated and graded to meet predefined engineered specifications. Common types of dredges include cutterhead suction and suction hopper dredges, with the latter generally the most feasible for projects exploiting sand deposits far from shore. Several good reviews summarize the effects of dredging on fishes and turtles, most recently by Michel et al. (2013), Wenger et al. (2017), and Pickens et al. (2020). Perhaps the most oft-cited impact to fish and turtles from dredging is the resulting damage to benthic invertebrates, which in turn reduces a borrow area's capacity to support consumers at higher trophic levels. Additionally, both fish and turtles are subject to entrainment in the dredge itself. Fish are generally entrained at relatively low levels with rates dependent on dredging method, habitat type, and location, although entrainment rates from OCS sand dredging activities are largely unstudied (Reine and Clarke 1998). Sea turtle entrainment has historically been a regular source of mortality in suction hopper dredging projects throughout the southeastern US, although it occurs 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). For both fish and sea turtles, foraging and reproduction could also be disrupted from turbidity associated with sand removal, increased sedimentation on adjacent hard bottom, and noise from the dredge operation.

1.6 Study Area Description

The greater Cape Canaveral region offers the most expansive sand shoals along the Florida east coast, including several individually named shoal features collectively referred to here as the Canaveral Shoals complex. The most significant are the Southeast Shoal and Chester Shoal, two cape-associated shoals with minimum depths of 3 and 4 meters (m), respectively, as well as the smaller Bull and Ohio-Hetzel Shoals located farther offshore (

Figure 1). The seafloor on and adjacent to these shoals consists of undulating and parallel ridges (bathymetric highs) and swales (lows) that are each generally several hundred meters across. One active sand borrow area—the Canaveral Shoals II (CSII) site—was established on the eastern edge of the Southeast Shoal. This site has been used as a sand source for several regional shoreline nourishment projects since 2000, including dredging events in 2013, 2017, and 2021, which coincided with this study.

CSII lies in Federal waters 8 miles east of Port Canaveral at depths of 3 to 13 m and currently contains approximately 20 million cubic yards of beach-compatible sand (BOEM 2017). A second sand borrow site in Florida state waters (CSI) has been identified but not yet utilized. The Canaveral shoreline is among the least altered of the Florida Atlantic Coast with no residential or commercial development. Human habitat disturbance is limited to National Aeronautics and Space Administration (NASA) and US Space Force space launch infrastructure offset from the beach several hundred meters. The shoreline itself is eroding in certain locations (Adams and Jaeger 2013), and dune nourishment from upland sand sources has been required to protect NASA launch pads from potential storm surge. A fuller description of the study area is available in Iafrate et al. (2019).

The Canaveral region is a widely recognized climatic transition zone, a boundary largely defined by its temperature regime (Gilmore 1995). While winter water temperature remains above 15 degrees Celsius (°C) most years, a strong north-south temperature gradient is often present with waters south of the Cape and is more directly influenced by the warm northward flowing Florida Current. Summer temperatures commonly reach 28–30°C, but deep-water upwellings occur every few years resulting in some of the coldest water temperatures of the year in July and August (Smith 1983). Nearshore currents alternate between a predominantly north or south flow with a mean velocity of only 7 centimeters per second (cm/sec) and a maximum rarely exceeding 25 cm/sec (McArthur and Parsons 2005a). Tidal range averages roughly 1 m and no major rivers or coastal inlets occur locally so salinity remains 35–36 parts per thousand (ppt) year-round. The Indian River Lagoon (IRL) estuary 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. Ocean waves are primarily out of the east and northeast with a median height of 0.75 m and median period of 8.5 s (McArthur and Parsons 2005a). During this study, three hurricanes directly impacted the Canaveral region, including Matthew (October 2016, Category 3–4), Irma (September 2017, Category 1–2), and Dorian (September 2019, Category 2), which resulted in maximum wave heights of 9.1, 8.1, and 7.3 m at the NDBC Buoy No. 41009 to the northeast of the shoals (

Figure 1).

Sediments in the project area are predominantly medium to coarse quartzose-mollusk sand (Field and Duane 1974). Sediments along the beach and at the crest of shoals are generally coarse 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 retained in Canaveral Bight in the lee of the Southeast Shoal (Grosz et al. 1989; Hoenstine et al. 1999; McArthur and Parsons 2005b). An updated BOEM-sponsored sediment map, whose underlying data from 2015 was used in certain analyses of fish and turtle core use areas in this study, can be found in Murie and Smith (2022).

Natural hard bottom reefs are widely distributed offshore Cape Canaveral and typically consist of low to moderate relief limestone outcroppings. Reefs to the east of the shoals orient in north-south lines commonly referred to as the 12-fathom, 21-fathom, and 27-fathom ridges. These reefs are colonized by a variety of sessile invertebrates, harbor high fish diversity, and sustain populations of reef fish of great economic value to east Florida (Sedberry and Dolah 1984; Coleman et al. 2000; Rowe and Sedberry 2006). Along the 12-fathom 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 1). Reef habitat is still poorly surveyed off Canaveral, but there is little evidence of extensive reef structures within the primary Canaveral Shoals study area (Perkins et al. 1997; Iafrate et al. 2019).

1.7 Fish and Fisheries Associated with the Canaveral Shoals

A full review of fish communities, historic and ongoing monitoring programs, and economically valuable fisheries in the greater Cape Canaveral region is found in Iafrate et al. (2019). To summarize, Cape Canaveral has long been recognized as an area where tropical and warm-temperate fish faunas intermix, resulting in among the highest fish diversity in the western North Atlantic Ocean (Briggs 1974; Gilmore 1995). This richness is due to several factors including Canaveral's position in relation to the Florida Current, which offers strong winter temperature gradients suitable for many species as well as a steady source of tropical fish larvae from south Florida and the Caribbean. There are also several available habitat types (in addition to sand shoals), including a high energy surf zone, unconsolidated sand-mud plains, nearshore reefs and wrecks, and deep-water corals, each supporting a somewhat unique fish fauna (Durako et al. 1988; Gilmore 1995).

A growing recognition of the economic value of shelf fisheries off the southeastern US has prompted more rigorous monitoring of shelf fish communities in east and northeast Florida. Perhaps the most comprehensive is the Southeast Area Monitoring and Assessment Program (SEAMAP), a standardized trawl survey designed to document the abundance of shelf fishes and macroinvertebrates over soft bottom habitats from Cape Hatteras to Cape Canaveral (ASMFC 2000). BOEM has commissioned trawl surveys in east Florida including exploratory inventories at potential future borrow sites from Canaveral to Jupiter (Hammer et al. 2005) and Daytona to Jacksonville (Zarillo et al. 2009), although sampling effort in both instances was limited. A recent and much more intensive BOEM-sponsored trawl survey at Cape Canaveral by Murie and Smith (2022) also has been completed recently. Reef fish communities of the South Atlantic Bight have been surveyed by the Marine Resources Monitoring, Assessment and Prediction (MARMAP) program using traps, longlines, rod-reel, and video. More recently, the Florida Fish & Wildlife Conservation Commission (FWC) has begun sampling to refine life history characteristics of the intensively managed red snapper in east Florida.

Waters on and around the Canaveral Shoals support robust recreational and commercial fisheries. Penaeid shrimp represents the largest commercial fishery by both pounds and dollar value in the region (Heather Konell, Atlantic Coastal Cooperative Statistics Program, pers. comm), with white shrimp (*Litopenaeus setiferus*) dominating landings most years. Shrimp are collected by bottom trawls, primarily in cooler months, and often on or very near the shoals. Coastal sharks are a regular target of both commercial and recreational fishermen. Commercial gears include longlines and gill nets, which by law are restricted to Federal waters more than 3 nautical miles from shore. Port Canaveral is also the home port to charter vessels who specialize in nearshore shark fishing trips, often in the Canaveral Bight just south of the Southeast Shoal. Spanish mackerel are fished commercially directly on the Canaveral Shoals, primarily by small gill net boats during the species' spring and fall migratory periods. There are also robust but seasonal recreational fisheries near the shoals for red drum, cobia, tripletail, tarpon, Florida pompano, and many other sportfish.

Cape Canaveral also lies within the geographic range of the protected smalltooth sawfish (*Pristis pectinata*), giant oceanic manta ray (*Mobula birostris*), and Atlantic sturgeon (*Acipenser oxyrinchus oxyrinchus*), all of which are listed under the 1973 ESA and whose status must be considered during dredging projects. The largest remaining sawfish populations are found in southwest Florida (Poulakis and Seitz 2004; Norton et al. 2012), but observations have been increasing along the Florida east coast (Graham et al. 2021), including several during this study that are summarized in Section 2. Sawfish have an affinity for sand shoals (NMFS 2009) so the Canaveral Shoals may be considered important habitat for the species as its population recovers. Manta rays are widely distributed throughout the southeastern US (Miller and Klimovich 2016), and some individuals can be expected off east Florida year-round. Based on genetic analyses, a second species of manta may also be present but has not yet been formally described (Hosegood et al. 2020). Manta aggregations at Cape Canaveral are common during the species' northward spring migration, and summer cold-water upwellings occasionally push manta rays onto the Canaveral Shoals in large numbers. Manta behavior and habitat needs off east Florida is poorly known but is a focus of future BOEM-sponsored research (Herman et al. 2021). Atlantic sturgeon range from Canada to northeast Florida. East-central Florida is considered the southern extent for the species, where it considered very rare; Gilbert (1992) noted only 11 confirmed records south of the Georgia-Florida border since 1900, of which only 4 occurred south of the St. Johns River. As with sawfish, however, observations are increasing and include multiple records from the current study, detailed in Section 2.

BOEM has an obligation under the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA) to minimize disruptions to fish habitat resulting from sand borrow activities on the OCS. Essential Fish Habitat (EFH) under the MSFCMA 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 justify it. 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 most harvest now takes place in state (not Federal) waters. Furthermore, as of 2017, the entire east-central Florida Coast from Canaveral to Jupiter was classified as Habitat Area of Particular Concern (HAPC) for lemon sharks, one of only three sharks in the US Atlantic 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 Iafrate et al. (2019).

1.8 Sea Turtles Associated with the Canaveral Shoals

Four species of marine turtles regularly occur in the vicinity of Canaveral Shoals: loggerhead (*Caretta caretta*), green (*Chelonia mydas*), Kemp's ridley (*Lepidochelys kempii*), and leatherback (*Dermochelys coriacea*). Loggerheads and greens are by far the most common, and both nest in large and increasing numbers along Cape beaches. A small number of leatherbacks nest each year, and there are recent confirmations of Kemp's ridley nesting, a behavior that had not been previously documented. 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 (Ehrhart et al. 2003; TEWG 2009). Although annual green turtle nesting in Florida and Cape 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.

Early marine turtle research in the Canaveral region centered on the Port Canaveral Harbor and associated shipping channel, with specific interest in understanding the interactions between turtles, shrimp trawling, dredging and construction activities, and vessel traffic (Henwood 1987; Dickerson et al. 1995; Dickerson et al. 2004). As early as the 1970s, large numbers of turtles, especially loggerheads, were noted using the Canaveral Harbor and navigation channel (Butler et al. 1987; Henwood 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 navigation channel regularly monitored for potential human-turtle interactions (Dickerson et al. 2004).

NMFS and the US Fish and Wildlife Service (USFWS) jointly manage sea turtles in US waters, with NMFS responsible for animals in the marine environment, while the USFWS manages turtles when nesting. For loggerheads, nine distinct population segments (DPS) were designated worldwide 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 were designated as Critical Habitat, the only such designation for a sea turtle in the continental US. This action was designed to protect breeding and nearshore foraging habitats, overwintering areas, important Sargassum habitat, and migratory corridors. 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 for Kemp's ridley, although protection for nesting females has been established at Rancho Nuevo, Tamaulipas, Mexico.

2 Fish Movement Patterns as Determined by Acoustic Telemetry

2.1 Introduction

Passive acoustic telemetry is now an established technique for documenting the movements and habitat needs of coastal fishes in the US southeast and many other regions around the world (Donaldson et al. 2014). The foundation of passive telemetry studies are arrays of submerged acoustic receivers that function as underwater tracking stations and autonomously detect the presence of animals carrying acoustic transmitters. By strategically mooring receivers throughout an area of interest, these systems can reveal details on animal daily activity, seasonal migrations, habitat associations, and survival. While the technology has existed for decades, transmitter and receiver hardware continue to evolve, resulting in smaller tag sizes, increased battery life, integration with environmental sensors, and remote data retrieval, among other improvements (Hussey et al. 2015). As importantly, marine researchers have begun coalescing into regional-scale tracking partnerships, recognizing that by adopting compatible equipment and sharing detection data, tagged animals can be followed much farther and for much longer than if researchers work independently (Bangley et al. 2020). The datasets that result from these collaborations often contain millions of animal relocations that span years and reveal the estuarine-ocean shifts and coastal migrations that have genuine value to resource managers (Crossin et al. 2017).

In 2008, the FACT Network[1] (originally the Florida Atlantic Coast Telemetry Network) was founded to track fish and sea turtle movement along the east-central Florida coast (Young et al. 2020). This partnership has expanded rapidly in both membership and scale. As of 2022, FACT consists of over 90 research groups collectively maintaining approximately 1,500 tracking stations and tagging over 100 species in estuarine and open Atlantic waters from the Carolinas to south Florida, the Bahamas, and the northern Caribbean. Animal movement data produced by FACT equipment are aggregated, parsed, and dispersed to researchers through a central data sharing node, streamlining a once cumbersome process. Analogous networks are in place in the northern Gulf of Mexico (iTAG[2], Lowerre-Barbieri et al. 2021), US Mid-Atlantic (ACT_MATOS[3]), Europe, and Australia.

The expansion of acoustic telemetry networks, and in particular the extension of tracking infrastructure onto the US continental shelf, has relevance to BOEM operations. Like all Federal agencies, BOEM must consult with the National Marine Fisheries Service (NMFS) to ensure that activities under their purview do not unduly impact federally managed species or their habitat. Acoustic telemetry studies can be designed to support this consultation process. Tracking receivers can be placed near dredge sites, offshore wind farms, and oil and gas facilities, collecting localized information on marine species covered under the ESA and MSFCMA. Movements can then be applied to infer avoidance behaviors of animals near active dredge sites, assess the value of disturbed areas relative to nearby unimpacted habitats, estimate a species' risk from boat strikes, and help establish seasonal exclusion windows that minimize disruption to animal reproduction and migration.

Since 2008, biologists with NASA's Kennedy Space Center, the US Navy, and other regional partners have maintained acoustic tracking infrastructure at Cape Canaveral in association with the FACT Network. BOEM funded an expansion of this work beginning in 2013 to improve monitoring of the Canaveral Shoals complex including sites adjacent to the active CSII sand borrow site, resulting in the largest concentration of tracking receivers deployed on the east Florida shelf. Fourteen select fish species and over 700 individuals were tagged between 2013 and 2018 with priority given to mobile and

[1] https://secoora.org/fact/
[2] https://myfwc.com/research/saltwater/telemetry/itag/network/
[3] https://www.theactnetwork.com/

economically valuable species that are covered under Federal fisheries management plans but that lacked local life history data (detailed in Section 2.2.2). The first summary of this tracking work is provided in Iafrate et al. (2019) including various behavioral metrics, space use maps, habitat models, and migration plots. Local information was also collected for an additional 28 fish species tagged by researchers at multiple other locations along the US East Coast, Canada, and Bahamas.

The Canaveral tracking array remained in place after 2018, generating additional insights on previously tagged animals, detections of new individuals, and even additional species, and has now generated one of the richest acoustic telemetry datasets ever compiled on fish movement on the continental shelf of the southeastern US. The primary goal of this section is simply to provide the full and final accounting of fish use of the Canaveral Shoals over the entire six-year study timeline including species detections, seasonal abundance trends, and updates to various behavioral metrics including residency indices and rate of movement. A secondary aspect is to assess shoal-reef animal exchanges, a topic not given much consideration in the original 2019 report. Results are intended to help BOEM understand which managed fishes commonly associate with sand shoal habitat in east Florida and which protected species could be potentially impacted by dredging at the CSII sand borrow site.

2.2 Methods

2.2.1 Acoustic Telemetry Array

A full description of the FACT Network offshore Cape Canaveral, hereafter the "Canaveral Array", can be found in Iafrate et al. (2019). Briefly, in 2013, the Canaveral Array was expanded from 28 to 57 stations, each monitored by a Vemco VR2W acoustic receiver (Innovasea, Nova Scotia, Canada). All stations were deployed year-round and were established directly on shoal ridges and adjacent deeper water, as well as at nearshore sites to capture animal movements along the shoreline (**Figure 2**). This expansion also included a 12-station receiver ring on the perimeter of the CSII dredge site ("DRE" stations) on the Southeast Shoal. The purpose of this ring was to better understand fish activity in and near the dredge site although receivers could generally not be placed inside the dredge site boundary due to risk of damage by the dredge itself. A second identical ring of receivers was replicated at an undisturbed control site on nearby Chester Shoal ("CON" stations) that was similar with respect to depth, sediment, and distance from shore. Both dredge and control rings were reduced in size by 50% in February 2018 after dedicated monitoring at these two sites was completed. Finally, in September 2015, five Vemco VR2AR acoustic release receivers were deployed along the reef tract seaward of the Canaveral Shoals specifically to document exchange of animals between these two habitat types, resulting in a final array size totaling 62 receiver stations for much of the study timeline.

All receivers were moored to the seafloor at depths of 1.4–25 m. Those near the surf zone were directly attached to the top of 1.5 m sand augers while receivers in deeper water were placed inside 2 m tall "trawl-resistant" floats on thick rope mooring lines to minimize losses from shrimp trawlers and burial due to shifting sand on the shoals (see photos in Iafrate et al. 2019). In addition, small water temperature loggers (Onset HOBO models U22-001 and TidbiT v2, logging hourly) were always attached to a minimum of six receiver moorings. Local animal detections were downloaded from the receivers during twice annual Canaveral Array servicing events using SCUBA. Tagged animals migrating away from Cape Canaveral were commonly detected by other FACT, ACT, and iTAG stations at multiple points along the southeastern US seaboard including major coastal receiver lines off southeastern Florida and the Florida Keys; St. Simons Sound, Georgia; Port Royal Sound and Charleston Harbor, South Carolina; and Chesapeake Bay, Virginia (**Figure 3**).

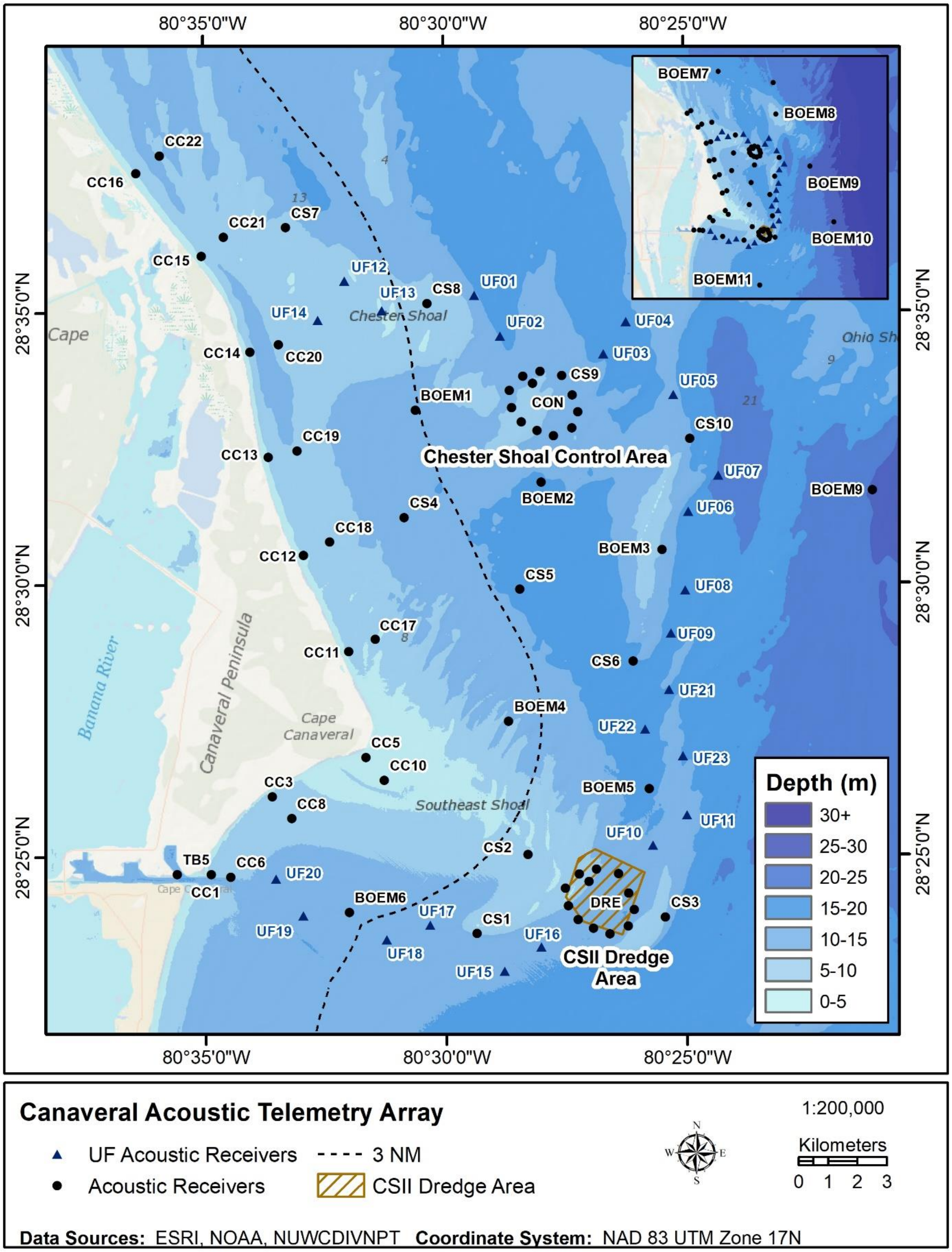


Figure 2. Map of the Canaveral Acoustic Telemetry Array, part of the larger FACT Network

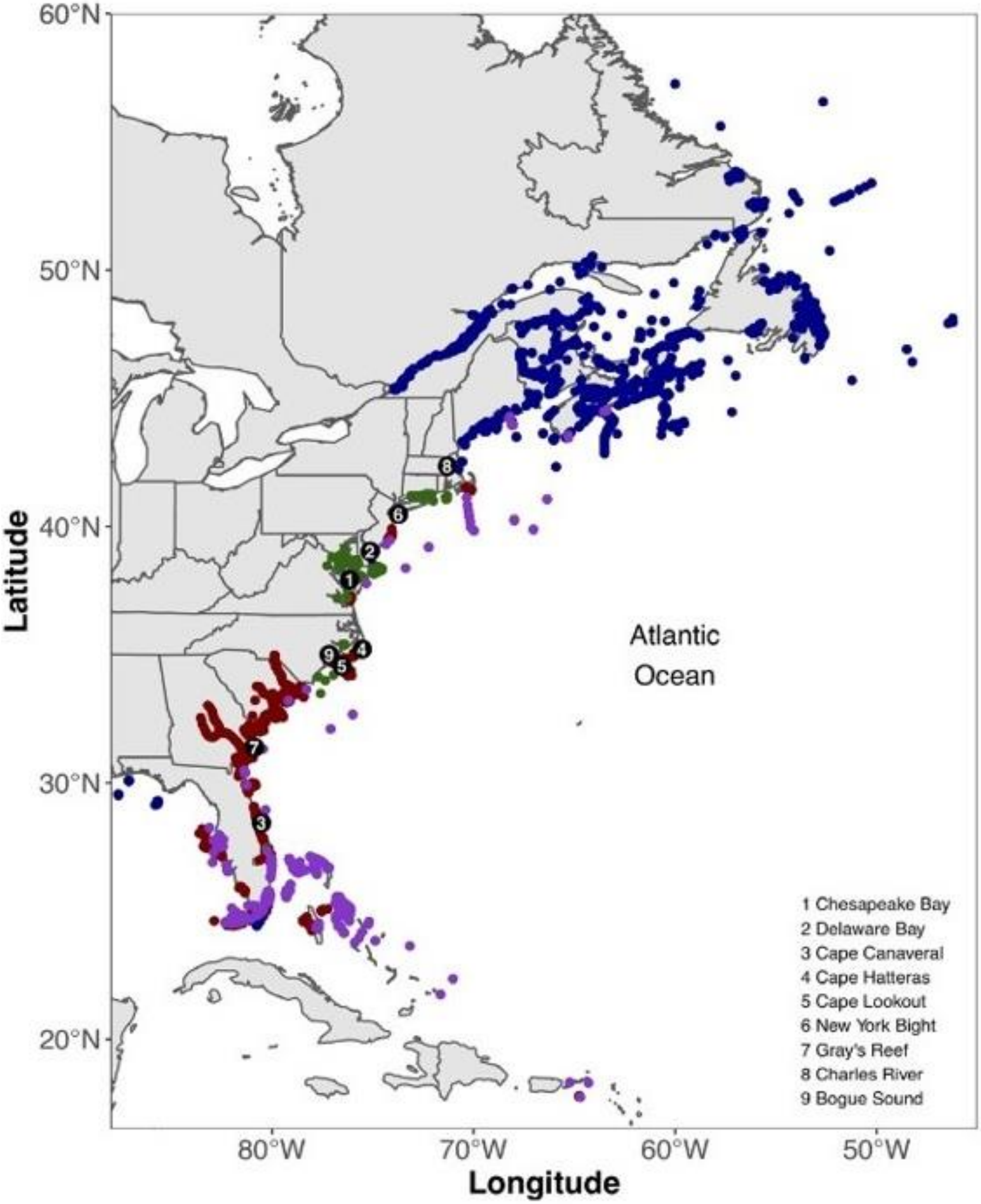


Figure 3. Acoustic telemetry network coverage in the US Southeast and Mid-Atlantic regions.
Reprinted from Bangley et al. (2020) with permission

2.2.2 Fish Collection and Tagging

Ten target fish species were selected for acoustic tagging starting in 2013 including finetooth shark (*Carcharhinus isodon,* n = 61), blacknose shark (*C. acronotus,* n = 60), Atlantic sharpnose shark (*Rhizoprionodon terraenovae* n = 44), red drum (*Sciaenops ocellatus,* n = 83), bluefish (*Pomatomus saltatrix,* n = 52), Spanish mackerel (*Scomberomorus maculatus,* n = 49), king mackerel (*S. cavalla,* n = 41), red snapper (*Lutjanus campechanus,* n = 15), spot (*Leiostomus xanthurus,* n = 107), and Atlantic croaker (*Micropogonias undulatus,* n = 132; **Table 1**). These species were chosen due to their local abundance, inclusion in Federal fishery management plans, and/or their expected ecological importance in the vicinity of the shoals. There were also practical considerations in that these species were easily obtainable, large enough to carry acoustic transmitters, and not under intensive study by other regional researchers. Also classified as target species was a single roughtail stingray (*Bathytoshia centroura*) opportunistically tagged on the Southeast Shoal that produced interesting movements. This project also incorporated data from other local tagging projects supported by the authors including a shark nursery study of lemon (*Negaprion brevirostris;* Reyier et al. 2014) and scalloped hammerhead sharks (*Sphyrna lewini*), and a coastal migration study of cobia (*Rachycentron canadum*).

Fish were collected with several gears including longlines (finetooth, blacknose, and sharpnose sharks, red drum), hook-line angling (bluefish, Spanish and king mackerel, cobia, red snapper), gill net (hammerheads), cast net (lemon shark), and trawl (spot and croaker). Most species were tagged across more than one year and at multiple locations in the Canaveral Array. Fish were fitted internally implanted coded transmitters (Vemco V7, V9, V13, or V16 styles) with batteries lasting 0.6–9.6 years, and most were also marked with external dart tags prior to release in case of later angler recapture. An in-depth description of Canaveral fish collection and tagging methods is provided in Iafrate et al. (2019). Although fish tagging was limited after 2018, several dozen transmittered fish were still active in the Canaveral Array through 2020. The project also continued to document large numbers of fish (and some sea turtles; see **Section 4**) that were tagged elsewhere along the US East Coast but periodically passed through the Canaveral region. By convention, data produced by these animals belong to the tagging organization so only the coarsest trends in abundance and seasonality for these species are presented here although in-depth analyses have been, or will be, provided by the tagging agency in separate publications.

2.2.3 Data Analysis

Detection files from all receiver downloads were collated into a central database (Vemco User Environment software), and tag ID codes from animals released by other researchers were matched to species and owner by consulting lists maintained by FACT and other regional networks, or by contacting the tag manufacturer directly. Detections were also uploaded to the FACT data node, and data on fish tagged outside Canaveral region were distributed to tag owners. A custom R Script was then used to proof and format local detection data and to calculate various indices of residency and movement for each individual and species. Data were first screened to remove potential false detections, detections past estimated tag expiration dates or angler harvest events, and mortalities suggested by lack of movement. More stringent data cleaning was performed than in Iafrate et al. (2019) due to the development of more capable and nuanced screening tools as well as additional detection data that confirmed the status (live or dead) for several animals. Updated and expanded summary tables of fish detections were produced to include new data through February 2020 resulting in a final report timeline spanning 6.25 years. Species with substantial new data in this update include finetooth, blacknose, sharpnose, and lemon sharks, red drum, cobia, and red snapper, plus several dozen non-target species tagged by other researchers. The metrics calculated from the full 2013–2020 Canaveral Array dataset include:

Number of Animals Detected: the number of unique individuals detected on Canaveral stations. For target species, this count can be lower than the number of individuals tagged due to mortality, predation, tag malfunction, or animals simply leaving the study area without detection.

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.

Canaveral 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 characterizes how much time an animal spent within the Cape Canaveral region.

Overall 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.

Visit Duration (min): a metric of species mobility in the Canaveral Array calculated as time spent by each fish at each station before leaving. Each "visit" to a station started at the first detection and ended when that fish was not detected again at that same station for > 60 min. If after being absent for > 60 min, the fish was detected again at that same station, it was considered a new visit. Since it is possible for an individual to be detected on two adjacent stations within 1 hour, a flag was created to exclude visit duration events where a portion of the visit overlapped 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.

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. This dataset was constrained only to movements occurring within the Canaveral Array, and only for events when animals traveled 4–20 km between stations. ROM between stations spaced too closely together is 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 1** for transmitter details).

Shoal-Reef Exchange: To assess the frequency and seasons in which the 14 target fish species (and 2 turtle species, see Section 4) transited between shoal and offshore reef habitat, custom R functions were created. Receiver stations were classified as either "Shoal," "Reef," or "Other" designations. "Reef" stations consisted of stations BOEM7–BOEM11. "Shoal" stations included all stations within the core

Canaveral Array study area (

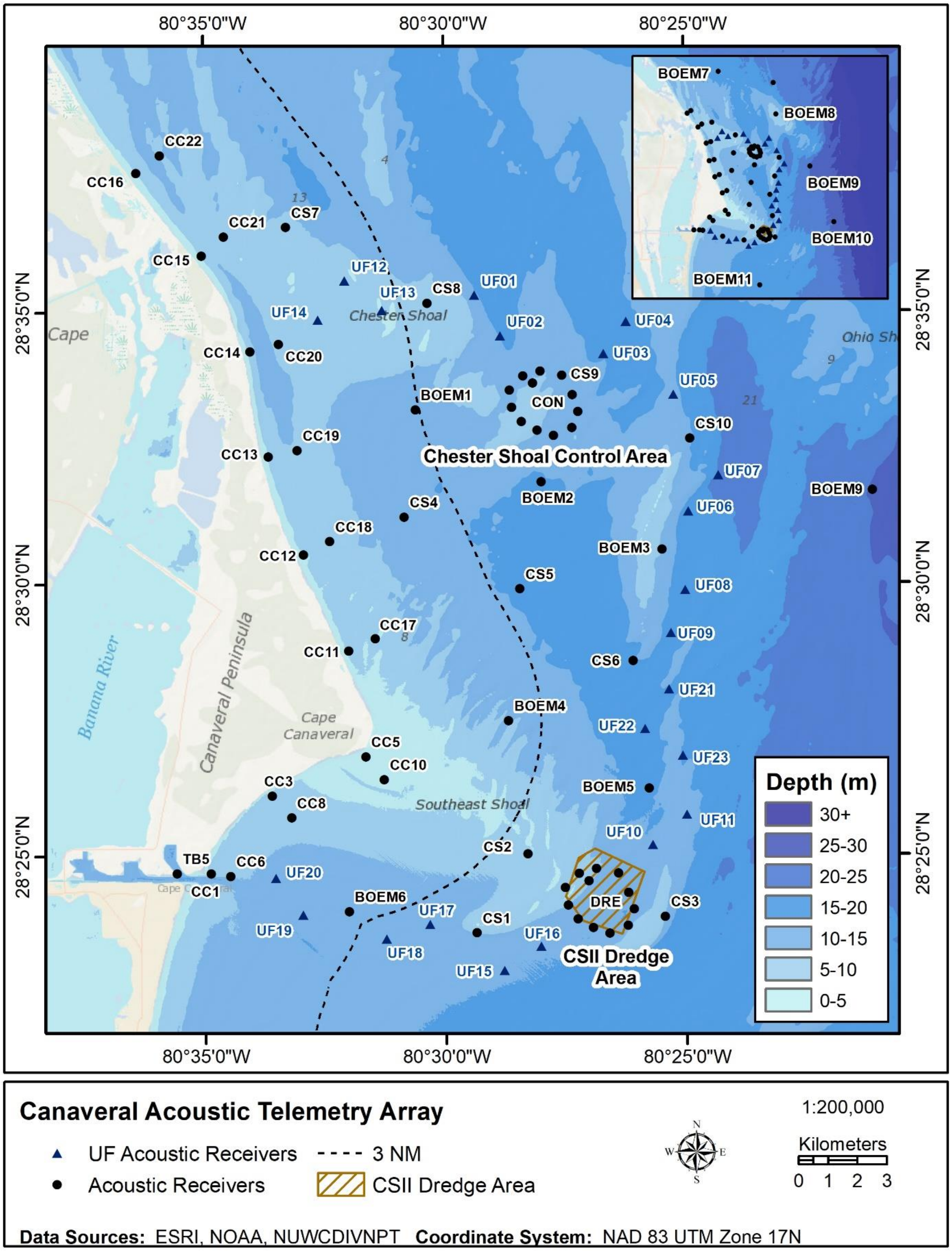


Figure 2). “Other” stations included any site outside the Canaveral region. Detection data was summarized for each animal to show arrival and departure dates/times in each habitat designation (e.g., Shoal, Reef, Other). Any exchanges where the animal visited an “Other” habitat designation between the Shoal or Reef locations were excluded. The percentage of tagged animals making the shoal-reef exchange were calculated by the number of individuals that made the exchange divided by the number of tagged individuals that were detected in the cleaned dataset. Seasonal differences were explored with seasons defined as winter (December–February), spring (March–May), summer (June–August), and fall (September–November) as in Iafrate et al. (2019).

Table 1. Tagging details for BOEM target species released at Cape Canaveral

Size is listed as standard length in centimeters (cm) for bony fish, fork length for sharks, and disk width for rays. Details for other species tagged at Cape Canaveral (e.g., cobia, lemon shark, scalloped hammerhead shark) are also provided.

BOEM Target Species	No. Tagged	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-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-Line
Cobia	67	77 (59–98)	-	Dec 2014–Jul 2019	V16-4H or 6H	90, 5.2, 158	Hook-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-Line
Lemon Shark	54	77 (56–135)	27:27	Dec 2008–Apr 2011	V9-2H, 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	21	48 (37–72)	-	Nov 2017–May 2019	V16-4H	90, 5.2, 158	Hook-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-Line
Spanish Mackerel	49	39 (31–49)	-	Apr 2015–Sep 2016	V9-2L	60, 1.3, 145	Hook-Line
Spot	107	17 (14–21)	-	Dec 2013–Jun 2014	V7-4L	60, 0.6, 136	Trawl

2.3 Results

2.3.1 Overview of Fish Detections

Over the full six-year study, 1,189 acoustically tagged fish from 43 species were detected within the Canaveral Array, including 16 shark species, 9 ray species, and 18 species of bony fish. This number includes 606 individuals from the 14 target fish species tagged locally at Cape Canaveral (**Table 2**) as well as an additional 583 individuals from 30 non-target species tagged by 31 other research organizations (**Table 3**). These non-target fishes were originally released over a wide expanse of coastline from New England and Canada (e.g., white shark, sand tiger shark), the Mid-Atlantic (cownose ray, Atlantic sturgeon), the Carolinas and Georgia (sandbar shark, tripletail), south Florida (tiger shark, smalltooth sawfish, tarpon), west Florida (tarpon, cobia), the Bahamas (nurse, tiger, and bull sharks), and Mexico (bull shark). Twenty-two of the 43 species are covered under Federal fishery management plans while many others are intensively managed at the state level. Moreover, the 15 Atlantic sturgeon and 7 smalltooth sawfish detected, all originally released several hundred kilometers outside the Canaveral Array, are protected under the ESA. For target species, the percentage of fish successfully detected was highest for red drum (82 of 83 or 99%) and above 80% for most sharks, bluefish, and cobia. Detections were lowest for Atlantic croaker (69%), spot (58%), Spanish mackerel (61%), and king mackerel (12%), likely due to a combination of lower power tags, high natural mortality (spot and croaker), and high mobility (mackerel).

2.3.2 Seasonal Occurrence of Fish at Cape Canaveral

A summary of species detections by month (**Figure 4**) illustrates the high variability in seasonal abundance for most tagged fish in the Canaveral region. Among sharks, winter and early spring was the period of highest abundance and species richness, and included peaks in detections for finetooth, blacknose, blacktip, lemon, bonnethead, white, and sand tiger sharks. This pattern was consistent across years and reflects the tendency of many coastal sharks to overwinter in the relatively warm waters off east-central Florida. The contingent of warm season sharks was less diverse but included Atlantic sharpnose, nurse, and great hammerhead sharks. Tiger and bull sharks had a more uniform presence throughout the year, and a subset of many cool season species, most notably blacknose and lemon sharks, either did not migrate or migrated but quickly returned to Cape Canaveral in summer or early fall. Detailed accounts of habitat use and seasonal migrations of target fish species are found in Iafrate et al. (2019).

Benthic and pelagic rays were also well represented in the dataset (131 individuals) although often with fewer individuals and detections than other species. This may be a result of reduced tagging effort in rays due to lower management interest (with the notable exception of smalltooth sawfish) and generally smaller sizes which often necessitate the use of less powerful transmitters. As with sharks, some rays demonstrated a strongly seasonal presence off east Florida. Cownose rays, for example, were primarily tagged in the US Mid-Atlantic but were regular winter visitors to the Canaveral Array while smalltooth sawfish tagged in south Florida were primarily detected in late spring and summer.

Bony fish such as tarpon, red drum, goliath grouper, and cobia were active in the Canaveral Array throughout the year while Atlantic sturgeon and tripletail were primarily winter visitors. Detections of Spanish mackerel and bluefish were episodic with individuals generally remaining in the array for only a short period post-tagging. Spot and Atlantic croaker are known to be year-round residents, but detections were mostly limited to the few months following major tagging events in December 2013 and May 2014 which limited ability to conclusively document seasonal movements.

Table 2. Target fish species detected in the Canaveral Array (2013–2020)

Species in bold and with an asterisk (*) have local EFH designations. Shoal sites are all 57 receiver stations on or directly adjacent to the Canaveral Shoals. Dredge and Control Sites are the subsets of stations surrounding the CSII dredge site and Chester Shoal control sites (12 stations each), and Reef Sites are the 5 stations deployed along the offshore reef tract. Detections from north and south of Canaveral are excluded.

Target Species	Tagging Location	Tagging Agencies[1]	Animals Detected					Total Detects
			All Sites	Shoal Sites	Dredge Sites	Control Sites	Reef Sites	
Red snapper*	Canaveral	NUWC, KSC	15	2	0	2	15	1,561,932
Red drum*	Canaveral	NUWC, KSC	82	82	77	63	42	1,135,320
Blacknose shark*	Canaveral	NUWC, KSC	56	56	47	48	47	742,541
Finetooth shark*	Canaveral	NUWC, KSC	51	51	48	38	44	220,027
Sharpnose shark*	Canaveral	NUWC, KSC	37	37	14	27	26	97,445
Lemon shark (juvenile)*	Canaveral, GA	BBFS, JU, KSC	33	33	17	14	10	78,737
Cobia*	Canaveral, FL, GA, SC	FWC, KSC, SCDNR	56	53	17	29	43	20,859
Scalloped hammerhead*	Canaveral	KSC	39	39	10	8	3	16,683
Bluefish	Canaveral	NUWC, KSC	48	48	3	1	1	5,968
Spot	Canaveral	NUWC, KSC	62	62	31	32	NA[2]	5,136
Atlantic croaker	Canaveral	NUWC, KSC	91	91	35	50	NA[2]	3,904
King mackerel*	Canaveral	NUWC, KSC	5	4	1	2	4	2,100
Spanish mackerel*	Canaveral	NUWC, KSC	30	30	10	7	1	1,058
Roughtail stingray	Canaveral	NUWC, KSC	1	1	1	1	0	406
Total	-	-	**606**	**589**	**311**	**322**	**236**	**3,892,116**

[1]BBFS = Bimini Biological Field Station, FWC = Florida Fish & Wildlife Conserv. Comm., JU = Jacksonville Univ., KSC = Kennedy Space Center, NUWC = Naval Undersea Warfare Center, SCDNR = South Carolina Dept. Natural Resources

[2]Tags for this species had expired before reef stations were established

Table 3. Non-target fish species detected in the Canaveral Array (2013–2020)

Non-target species are those tagged by other research organizations but detected locally. Species in bold have local EFH designations. Species in underscore are listed under the ESA. Shoal sites are all 57 receiver stations on or directly adjacent to the Canaveral Shoals. Dredge and Control Sites are the subsets of stations surrounding the CSII dredge site and Chester Shoal control sites (12 stations each), and Reef Sites are the 5 stations deployed along the offshore reef tract.

Non-Target Species	Tagging Location	Tagging Agencies [1]	Animals Detected					Total Detects
			All Sites	Shoal Sites	Dredge Sites	Control Sites	Reef Sites	
Blacktip shark *Carcharhinus limbatus*	FL, SC, VA, Bahamas	BBFS, CCU, FAU, SERC, SCDNR	114	113	93	83	103	341,821
Tarpon *Megalops atlanticus*	FL, SC	BTT	35	35	9	13	11	87,460
Tripletail *Lobotes surinamensis*	FL, GA	GADNR, HBOI	6	6	3	1	1	42,333
Goliath grouper *Epinephelus itajara*	FL	FSU, Mote	16	13	9	8	12	32,565
Smooth butterfly ray *Gymnura micrura*	Canaveral	UF	26	26	9	1	0	25,146
Cownose ray *Rhinoptera bonasus*	FL, GA, VA	FSU, HBOI, SERC, UF	74	71	35	33	41	24,754
Lemon shark *Negaprion brevirostris*	FL, SC, Bahamas	BBFS, CCU	40	40	18	13	16	21,758
Bonnethead shark *Sphyrna tiburo*	GA, SC, NC	FSU, SCDNR, UNC	39	37	11	18	30	16,991
Bull shark *Carcharhinus leucas*	FL, SC, Mexico, Bahamas	BBFS, CCU, CEI, HBOI, RSMAS, SBU, SERC, FA	39	36	20	22	26	8,322
Whitespotted eagle ray *Aetobatis narinari*	FL	HBOI	13	13	6	6	4	8,203
Smalltooth sawfish *Pristis pectinata*	FL	HBOI, NOAA	7	7	5	3	5	6,747
Bluntnose stingray *Hypanus say*	Canaveral	UF	6	6	3	0	1	4,331
Tiger shark *Galeocerdo cuvier*	FL, SC, Bahamas	BBFS, OCEARCH, RSMAS, SCDNR	20	14	9	8	17	3,762
White shark *Carcharodon carcharias*	MA, SC, Canada	MADMF, OCEARCH	53	34	12	13	31	3,380
Sand tiger shark *Carcharias taurus*	NC, DE, NJ, MA	DESU, MADMF, MU, UNCW	9	4	2	2	3	2,874
Cobia *Rachycentron canadum*	FL, NC, VA	CMAST, NOAA, VIMS	14	11	4	6	13	2,707

Table 3 continued

Non-Target Species	Tagging Location	Tagging Agencies[1]	Animals Detected					Total Detects
			All Sites	Shoal Sites	Dredge Sites	Control Sites	Reef Sites	
Nurse shark *Ginglymostoma cirratum*	FL, Bahamas	BBFS, HBOI, RSMAS	11	6	3	5	8	1,895
Sandbar shark *Carcharhinus plumbeus*	GA, NY	CCU, MU	7	4	2	4	4	1,686
Atlantic sturgeon *Acipencer oxyrinchus*	DE, NC, NJ, SC, VA	DESU, MU, NCDMF, SCDNR, USN, VIMS	15	12	1	6	4	1,227
Summer flounder *Paralichthys dentatus*	Canaveral	UF	2	2	2	0	0	913
Southern stingray *Hypanus americana*	Canaveral	UF	1	1	1	0	1	856
Great hammerhead *Sphyrna mokarran*	FL, Bahamas	BBFS, RSMAS	14	11	4	4	6	812
Southern flounder *Paralichthys lethostigma*	Canaveral, SC	SCDNR, UF	7	7	1	0	0	587
Spinner shark *Carcharhinus brevipinna*	Canaveral	KSC	5	5	3	1	0	547
Black drum *Pogonias cromis*	FL	HBOI, KSC	3	3	0	0	0	264
Stoplight parrotfish *Sparisoma viride*	FL	CU	1	1	0	1	1	165
Bullnose ray *Myliobatis freminvillei*	Canaveral	UF	2	2	1	0	0	136
Gulf flounder *Paralichthys albigutta*	Canaveral	UF	2	2	0	1	0	86
Clearnose skate *Raja eglanteria*	Canaveral	UF	1	1	1	0	0	63
Thresher shark *Alopias vulpinus*	NA[2]	SBU	1	1	0	1	1	37
Total	-	-	**583**	**524**	**267**	**253**	**339**	**642,428**

[1]BBFS = Bimini Biological Field Station, BTT= Bonefish & Tarpon Trust, CCU = Coastal Carolina Univ., CEI = Cape Eleuthera Inst., CMAST = Center for Marine Sciences and Technology, CU = Clemson Univ., DESU = Delaware State Univ., FA = Fins Attached, FAU = Florida Atlantic Univ., FSU = Florida State Univ., FWC = Florida Fish & Wildlife Conserv. Comm., GADNR = Georgia Div. of Natural Resources, HBOI = Harbor Branch Oceanographic Inst., IRG = Inwater Research Group, JU = Jacksonville Univ., KSC = Kennedy Space Center, MADMF = Massachusetts Div. of Marine Fisheries, Mote = Mote Marine Laboratory, MU = Monmouth Univ., NCDMF = North Carolina Div. Marine Fisheries, NOAA = National Oceanographic and Atmospheric Admin., NUWC = Naval Undersea Warfare Ctr., RSMAS = Rosenstiel School of Marine and Atmospheric Science, SBU = Stony Brook Univ., SCDNR = South Carolina Dept. Natural Resources, SERC = Smithsonian Environmental Research Center, UF = Univ. Florida, UNC = Univ. North Carolina Chapel Hill, UNCW = Univ. North Carolina Wilmington, USN = US Navy, VIMS = Virginia Institute of Marine Science.

[2]Tagging locations unknown

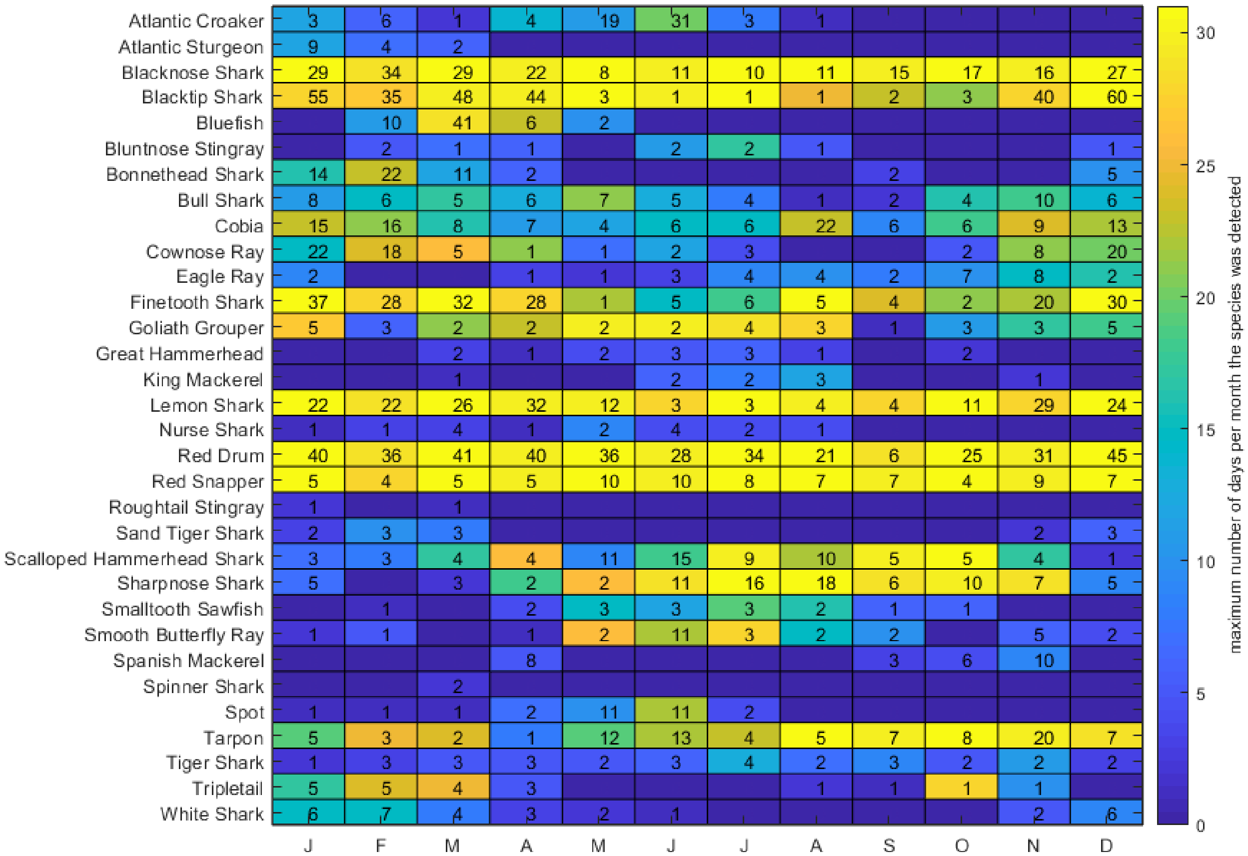


Figure 4. Seasonal presence of tagged fish in the Canaveral Array

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 are included.

2.3.3 Fish Movement Metrics

While at Cape Canaveral, most tagged fish demonstrated high mobility and low site fidelity. Across all target species, apart from red snapper (see below), the time in which a tagged fish remained within range of an acoustic receiver before leaving averaged only 42 minutes. Mackerel, bluefish, and cobia had the shortest visits to any single location (21–31 minutes) and blacknose shark, spot, and red drum had the longest visits (~ 60 minutes; **Table 4**). While this comparison is imperfect due to variations in tagging habitat, transmitter power, and the local acoustic environment, it likely also reflects differing life history strategies with pelagic species less inclined to associate with a single location.

Red snapper results were particularly difficult to interpret. Fifteen snapper were tagged, all on the reef tract within range of an acoustic receiver. Movement away from release sites was limited and red snapper thus produced more detections and longer visit durations (mean 35 hours) than any other species. Only two animals were recorded at more than one location, both just a few days after tagging. Many others were detected continuously or intermittently at their release location for days to over a year, one of which was recaptured by an angler 52 days after release. These results are thought to indicate a combination of high site fidelity and mortality (including possible shark predation events) so the limited observed movement, while consistent with findings from other regions, should be interpreted cautiously.

Table 4. Movement metrics for target species released at Cape Canaveral

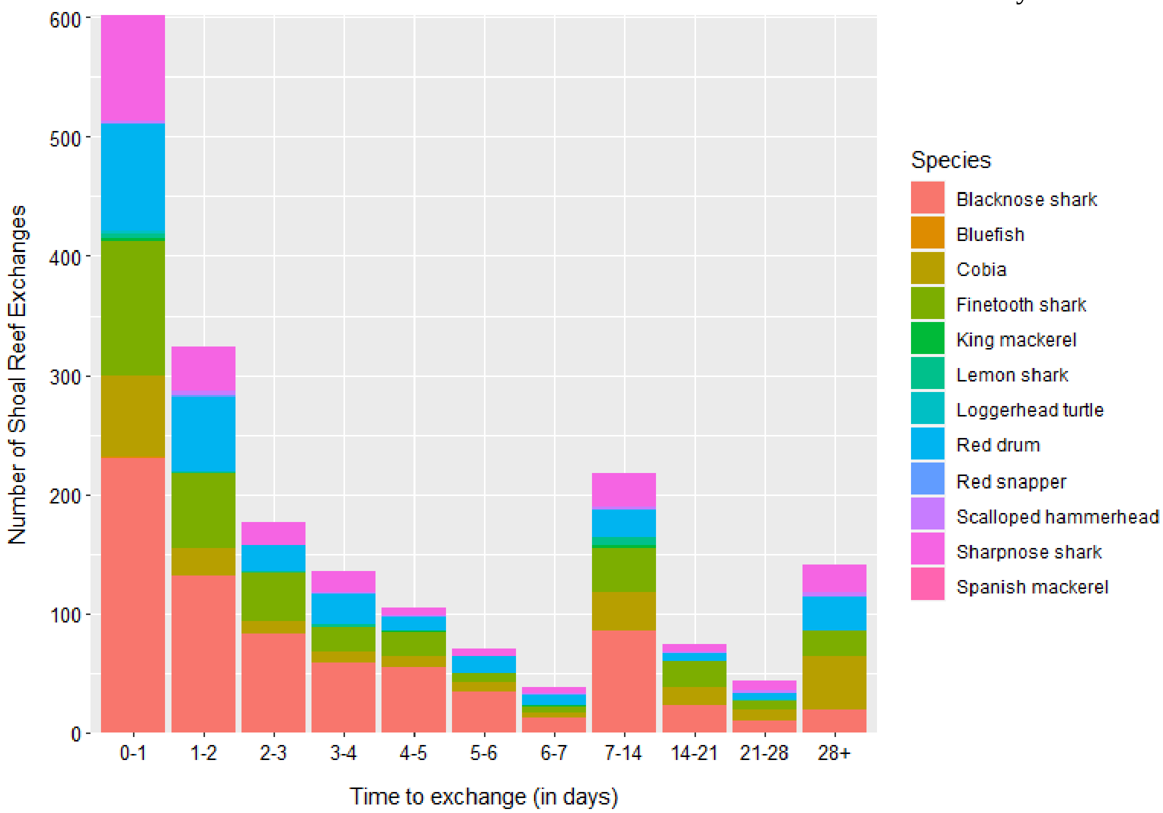
Values are means for each species with range in parentheses. Definitions of metrics can be found in **Section 2.2.3**

Target Species	No. Detected	Days at Liberty	Stations Visited	Residency Index	Detection Index	Visit Duration (Minutes)
Atlantic croaker	91	16 (1–215)	3 (1–14)	85 (1–100)	83 (1–100)	48 (0–1,491)
Blacknose shark	56	1,242 (8–1,885)	61 (8–106)	21 (1–75)	22 (2–75)	62 (0–3,224)
Bluefish	48	17 (1–208)	6 (1–22)	54 (4–100)	58 (8–100)	29 (0–678)
Cobia	56	353 (2–1,775)	14 (1–73)	11 (1–100)	10 (1–100)	31 (0–758)
Finetooth shark	51	1,154 (29–1,901)	79 (8–125)	13 (4–96)	18 (7–66)	43 (0–1,911)
King mackerel	5	63 (1–129)	11 (1–26)	43 (3–100)	44 (7–100)	28 (0–620)
Lemon shark	33	2,111 (1,155–2,362)	32 (8–45)	8 (3–22)	8 (3–22)	29 (0–1,365)
Red drum	82	687 (1–1,892)	52 (1–93)	40 (5–100)	42 (13–100)	63 (0–17,703)
Red snapper	15	288 (3–768)	2 (1–10)	73 (3–100)	73 (3–100)	2,142 (0–273,565)
Roughtail stingray	1	160	24	2	5	41 (0–325)
Scalloped hammerhead	39	128 (2–1,215)	8 (1–48)	65 (0–100)	56 (0–100)	36 (0–796)
Sharpnose shark	37	465 (1–1,244)	29 (1–88)	38 (1–100)	35 (1–100)	47 (0–1,499)
Spanish mackerel	30	3 (1–22)	4 (1–8)	89 (14–100)	91 (14–100)	21 (0–324)
Spot	62	19 (1–216)	3 (1–13)	87 (2–100)	87 (2–100)	61 (0–2,076)

The number of locations visited by tagged fish independently supports the idea of high mobility. Target fish tagged at Cape Canaveral were detected at an average of 3 (Atlantic croaker) to 79 receiver stations (finetooth shark) during their movements along the US East Coast. Considering just the Canaveral Array, the most widely ranging species were finetooth, blacknose, lemon, blacktip, bull, and scalloped hammerhead sharks, plus tarpon and red drum, all of which were detected at 60 or more stations (of a possible 62) from the shoreline to the offshore reefs.

2.3.4 **Shoal-Reef Fish Exchanges**

Blacknose and finetooth sharks showed the greatest number of observed movements between the Canaveral Shoals and offshore reef tract. Both species moved between shoal and reef habitat year-round but with greatest frequency in winter and with fewer exchanges in warmer months (**Table 5**). These species also had the highest shoal-reef exchange rates with over 80% of tagged individuals detected making these onshore-offshore movements on at least one occasion. Sharpnose shark, red drum, and cobia also commonly moved between the shoals and reef although participation rates appeared lower. Sharpnose movements peaked in summer and fall, red drum in spring, while cobia were more active year-round. Also of note, juvenile lemon sharks, a species commonly observed in large aggregations in the shallow Canaveral surf zone, were detected on the offshore reefs periodically, always in winter. There were also two observed movements of red snapper onto the shoals although these events occurred right after tagging on the reef and may reflect instances where released snapper were predated on by sharks. The time it took for animals to transit from one habitat to the other varied from less than a day to over 28



days (

Figure 5). Many shoal-reef movements occurred in less than one day confirming rather direct movements. The greatest distance between two shoal and reef receiver sites was ~ 38 km so exchanges taking longer than a few days were instances when animals were not moving in a linear fashion or were visiting reef sites not monitored by acoustic receivers.

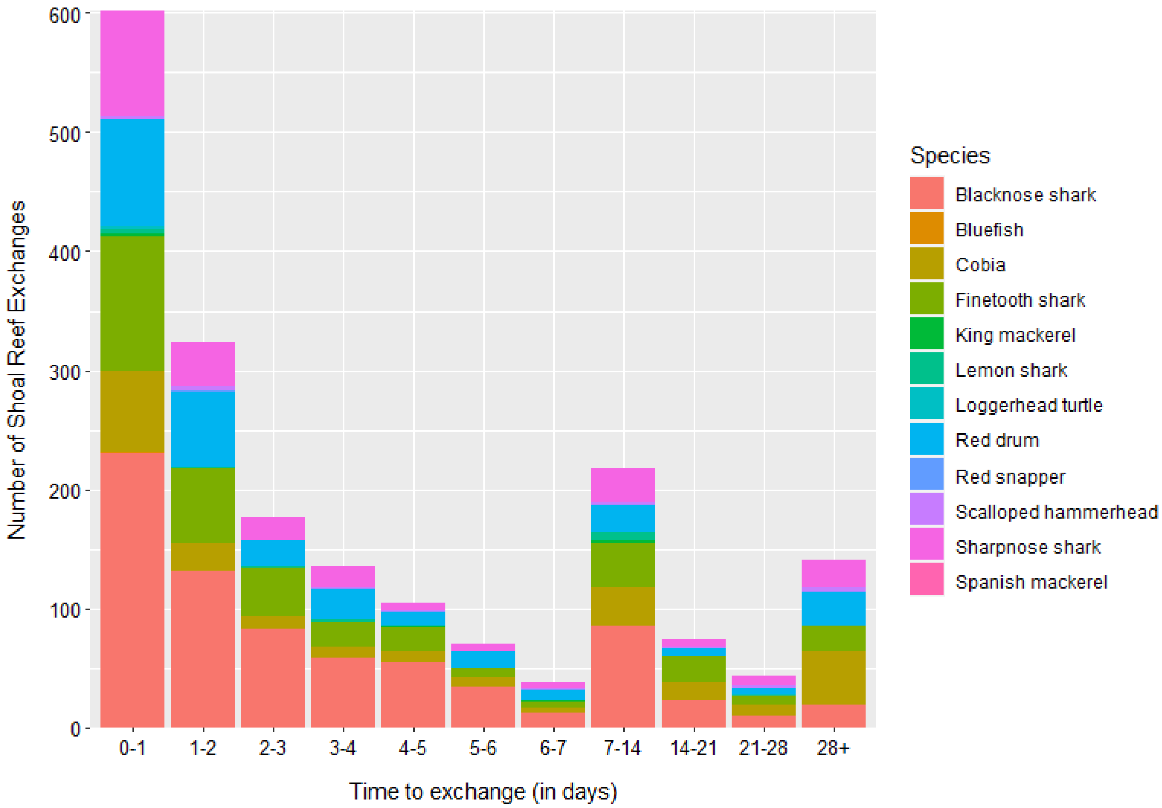


Figure 5. Time (days) for tagged animals to transit between sand shoals and offshore reefs

Table 5. Observed shoal-reef movements by acoustically tagged fish and sea turtles

Each exchange is a one-way movement from one habitat to the other. Values in parentheses are the mean number of exchanges per individual. Percent Animals is the percentage of tagged animals that made this movement at least one time.

Species	Fall		Winter		Spring		Summer		
	Total Exchanges	No. Animals	Total Exchanges	No. Animals	Total Exchanges	No. Animals	Total Exchanges	No. Animals	Percent Animals
Blacknose shark	104	18 (5.8)	475	41 (11.6)	126	36 (3.5)	37	11 (3.4)	85
Finetooth shark	7	5 (1.4)	282	42 (6.7)	68	23 (2.9)	0	0	86
Red drum	15	11 (1.4)	81	20 (4.1)	132	26 (5.1)	68	24 (2.8)	50
Sharpnose shark	107	14 (7.6)	23	7 (3.3)	10	3 (3.3)	107	23 (4.7)	67
Cobia	53	14 (3.8)	88	31 (2.8)	38	14 (2.7)	53	18 (2.9)	71
Scalloped hammerhead	7	3 (2.3)	5	2 (2.5)	9	3 (3)	0	0	7.5
Lemon shark	0	0	17	8 (2.1)	0	0	0	0	40
King mackerel	0	0	0	0	0	0	8	3 (2.7)	60
Loggerhead turtle	1	1 (1)	0	0	0	0	2	2 (1)	13
Red snapper	2	2 (1)	0	0	0	0	0	0	13
Spanish mackerel	1	1 (1)	0	0	0	0	0	0	3
Bluefish	0	0	1	1 (1)	0	0	0	0	2
Atlantic croaker	0	0	0	0	0	0	0	0	0
Spot	0	0	0	0	0	0	0	0	0
Roughtail stingray	0	0	0	0	0	0	0	0	0
Green turtle	0	0	0	0	0	0	0	0	0

2.3.5 ESA-Listed Fish Summaries

Fifteen Atlantic sturgeon, all listed as threatened or endangered under the ESA (depending on their population of origin) were confirmed within the Canaveral Array from 2015–2019. Sturgeon were detected at 32 widely spaced locations from 250 m to 22 km from the shore and in water 3–25 m deep. These fish were tagged by six organizations working from South Carolina through New Jersey. All detections occurred winter from early January though early March (**Figure 4**). Winter 2018 was a particularly active year with 10 tagged sturgeon inhabiting the Canaveral Array at roughly the same time. Atlantic sturgeon was one of the few species noticeably less common near the CSII dredge site (n = 1) compared to the control site (n = 6) although this sample is too small to draw meaningful conclusions. Details of sturgeon size, migrations, and behavior are the purview of the tagging organizations although it was noted that most fish were present for only one winter except for a single fish that returned three winters in a row. Further, like many other mobile species tracked at Canaveral, sturgeon were rarely within range of a given receiver for more than a few minutes at a time.

Seven ESA-endangered smalltooth sawfish were also detected at Canaveral from 2016–2020, all of which were tagged in south or southeast Florida. Multiple local angler encounters were also reported during this same time (E. Reyier, unpubl. data). As with sturgeon, sawfish were widely dispersed in the tracking array, being collectively detected at 54 stations from the beach out to 22 km and in water up to 25 m deep. Five animals were confirmed in the vicinity of the CSII dredge site and three near the control site. Sawfish were present February through October but with a clear peak in activity May to August. Unlike sturgeon, sawfish often remained in the general area for several weeks and moved into or through the Canaveral Array multiple times with one fish making visits for four consecutive years.

2.4 Discussion

2.4.1 Overview of Findings

Across the six-year study time frame, the fixed-station acoustic telemetry array deployed on and adjacent to the Canaveral Shoals proved to be an exceptionally productive tool for documenting the movements and seasonal abundance trends of coastal fishes. Nearly 1,200 animals from 43 fish species (producing over 4.5 million unique detections) were tracked through the Canaveral Array, the majority of which are covered under Federal or state fishery management plans. While it was expected that the fishes tagged locally would provide valuable insights, the quantity and diversity of fishes tagged by other researchers that passed through the Canaveral Array was unexpectedly high. Thirty fish species and almost half of the individual fish detected off the Canaveral coastline were released by other research organizations working as far away as Nova Scotia, the Bahamas, and Mexico. Collectively the information provided by these animals, made possible by a strong culture of data sharing across the research community, expanded our understanding of shoals as fish habitat beyond what was originally anticipated.

Detailed analyses of tagged fish distribution and movement offshore Cape Canaveral through 2018 can be found in Iafrate et al. (2019). Specific products presented there include species-level space use estimates, habitat association summaries, and in-depth migration accounts for all target fish species. Also presented are comparisons of fish use between the CSII dredge and nearby control site, assessments of community structure across habitats, analyses of habitat factors that influence fish site fidelity, and fixed-station acoustic range test results. Results from the most recent time period (2018–2020) were equally substantial but generally reinforced these initial conclusions so the analyses were not repeated here.

When considering the entirety of the acoustic telemetry dataset from 2013–2020, several high-level trends in fish distribution and space use become apparent, all of which have relevance to offshore dredging projects or fisheries management in the region. For example, while results demonstrated that most species with locally designated EFH occur year-round, there were consistent seasonal fluctuations in the presence of most species. Winter was an especially dynamic time in east-central Florida, and the Canaveral region clearly serves as an important overwintering area for many sharks, pelagic rays, and bony fish like red drum, mackerel, and tripletail, among others. Secondly, most target species apart from red snapper, as well as the majority of species tagged by other organizations, demonstrated high mobility and low site fidelity. On average, most species only remained in the same location for 30–60 minutes before moving away, and individual animals ranged widely through the Canaveral Array in relatively short periods of time. Finally, this study, in collaboration with other regional researchers, detailed the coastal migrations of many sharks and bony fishes for the first time, documenting the consistent seasonal exchange of tagged fish along the southeastern US East Coast, and very limited exchange of animals with the Gulf of Mexico.

The additional findings presented in this second report only strengthen earlier conclusions of fish movement and behavior. Estimates of local residency, duration of visits to single locations, and rate of movement along the coast now span multiple years and migratory cycles with several individual fish tracked for the full 6 years. These new results also suggest a high rate of animal exchange between the Canaveral Shoals and offshore reefs, especially in winter, and demonstrate more broadly that the activity space of many species regularly extends beyond the bounds of the Canaveral Shoals. One particular surprise was the regular use of offshore reefs by red drum, a species whose adult distribution offshore east-central Florida has never been studied in depth. Finally, results through 2020 generated new insights into the movements of ESA-listed Atlantic sturgeon and particularly smalltooth sawfish (with even more animals and detections collected after the 2020 data cutoff), information which may help with future endangered species consultations at other sand borrow sites in east Florida.

2.4.2 Lessons Learned and Best Practices

2.4.2.1 Acoustic Array Deployment and Maintenance

Acoustic arrays deployed on the open continental shelf are often exposed to extreme forces. The Canaveral Array itself was hit by three hurricanes in 6 years including Matthew (October 2016), Irma (September 2017) and Dorian (September 2019), each resulting in wave heights of 7–9 m for several hours, as well as several tropical storms and severe winter storms. Wave energy from these events caused significant accumulation or erosion of sand at certain locations and fatigued receiver moorings over time. Sand movement was greatest near the crests of shoals and receivers deployed there were exposed to sand accumulation and scouring of up to 1 m over time, resulting in occasional receiver burial and loss. Strong coastal currents during Hurricane Dorian also temporarily displaced 45-kg reef receiver moorings up to 5 km (see details in **Section 3.4.2**) although receivers in deeper water between shoals and along the offshore reef tract were generally less prone to burial or scouring. Shrimp trawlers are also seasonally active off Cape Canaveral, as they are along much of the US southeast coastline and have the capacity to easily displace and destroy acoustic tracking stations.

The deployment and maintenance strategy of the Canaveral Array evolved through time. and the refinements adopted during this study may help improve the design of future arrays established in similar habitat. Perhaps of greatest importance, water visibility at Cape Canaveral was often poor but marking moorings with surface floats was not possible due to entanglement risk to the northern right whale; surface floats would have also been quite challenging to maintain. All servicing was therefore conducted by SCUBA and recording the latitude and longitude of receivers at first deployment with a boat Global Positioning System (GPS) chartplotter (ideally to within < 2 meters) was critical for ensuring quick and reliable receiver recovery by divers on subsequent visits.

Deploying receivers on subsurface moorings with ropes and floats, as was done in the present study, has advantages (e.g., inexpensive, easy to assemble, easier to relocate with a boat echosounder) but wave action and sand burial caused continuous rope abrasion. One recommendation would be to integrate a length of 316 grade stainless steel chain into the base of mooring lines since rope abrasion and failure was generally greatest at the attachment point with the sand auger or at the sediment surface in instances when sand accumulation overtopped the auger head. Long augers are also advantageous since scouring will cause short augers to topple and roll away.

Finally, the adoption of a "trawl-resistant" float design locally (see photos in Iafrate et al. 2019) reduced but did not wholly eliminate gear damage or loss by shrimp trawler strikes. Co-locating moorings with (or on) navigation buoys and charted wrecks and reefs whenever possible may result in a less uniform array spacing but will significantly reduce risk of strikes and data loss. Regardless, there is still a real need in the acoustic telemetry community for an inexpensive acoustic receiver mooring design for open shelf waters that can reliably withstand major storm events, sediment accumulation, and trawler strikes with high confidence.

2.4.2.2 Fish Tagging

The quality of movement data ultimately produced by the Canaveral Array varied dramatically across species. Coastal sharks and adult red drum tagged at Cape Canaveral regularly produced multi-year tracks, and similar results are being produced by researchers tracking other large-bodied fishes (e.g., tarpon, goliath grouper, cobia) in the FACT Network. In contrast, many of the smaller species produced sparser datasets that only allowed for general descriptions of their movement. These discrepancies in data quality are partially driven by a species' life history. Bluefish and Spanish mackerel, for example, are highly migratory and were tagged as they rapidly passed through the Canaveral region. Small-bodied fish also often have higher natural—and likely tagging-related—mortality rates. High mortality was likely a factor explaining the limited detections of spot and Atlantic croaker, species not known for extensive migrations. Smaller fish also generally require smaller (i.e., lower power) tags that are detectable over shorter distances. Body size and migration strategies are critical considerations when working on the open shelf where the space available to a tagged fish is massive and few natural barriers exist to funnel fish past specific locations. While the species of interest should dictate the tag specifications and not the other way around, results from this study suggest that studies of small and highly mobile species may require a larger sample size or a more closely spaced receiver array to achieve quality results, and that tag power and fish size within the species of interest should be maximized to improve results.

Tagging benthic fish within the boundaries of a dredge site to estimate residency or home range (and perhaps compare with nearby reference sites) is also a challenging prospect, especially if a dredge site is small. Comparing residency of spot and Atlantic croaker, both of which can be exceptionally abundant on the Canaveral Shoals, was an early study objective. During dedicated sampling in June 2014, however, both species were scarce, likely due to unseasonably clear water, requiring extensive trawling needed to collect a suitable sample size. Other species, especially those of management value, may also be challenging to collect inside a dredge site footprint in sufficient numbers. Moreover, the naturally high mobility of even strongly benthic species may make comparisons difficult. The roughtail stingray tagged within the CSII dredge site left after only 8 hours before traveling to Virginia, and a southern flounder detected just outside CSII was originally released in South Carolina. The most valuable data at CSII came from fish originally tagged elsewhere that eventually passed though CSII. If dredge site assessments are not species-specific, tagging larger and hardier fish in the vicinity of a dredge site—not just small benthic fish exclusively inside the dredge site—may ultimately produce superior results.

2.4.2.3 Study Design

With respect to fishes, the dual goals of acoustic telemetry studies at Cape Canaveral were to (1) document natural habitat associations of mobile species on sand shoals in east Florida, and (2) understand the dynamics of fish around an active sand borrow site relative to an adjacent control site. Many of the important findings on both fronts are found in Iafrate et al. (2019). Achieving the first goal, while labor-intensive, was conceptually straightforward; deploy receivers, catch and tag fish, characterize the habitat, and observe and summarize their movements. Meeting the latter objective of contrasting fish behavior and community structure between a dredge site and nearby reference site is also simple in principle but attributing any observed differences to degradation from dredging or other human disturbance is more challenging, especially when dealing with mobile species in open ocean soft bottom habitats.

In the case of the Canaveral Shoals, the dredge and control sites appeared to receive similar use. Most fish species were detected in relatively equal numbers and exhibited similar (and generally low) site fidelity at both sites. This was likely due to the lack of complex habitat, apparently rapid recolonization of the benthic invertebrate community at CSII (see Murie and Smith 2022 for details), and a focus on large and migratory fish species, some of which do not preferentially feed in the benthos. Had major differences in fish use been apparent, conclusively explaining these differences would have been difficult. The gold standard of such comparisons are Before-After-Control-Impact (BACI) studies, a design that was never an option locally since the CSII site was dredged eight times from 2000–2013 prior to the start of the study (Murie and Smith 2022). Further, many explanatory covariates were initially unavailable. Sediments at Cape Canaveral were poorly mapped initially, and data on fish prey, competitors, and predators was unavailable. Future efforts to compare—and then explain—the impacts of dredging on large mobile fishes should strive to collect considerable data prior to any dredge disturbance. Notably, the data collected on fish movement at Cape Canaveral, coupled with new data on benthic invertebrates and fishes and updated sediment maps produced by Murie and Smith (2022) provides excellent baseline data for which to rigorously assess impacts at any new dredge sites that may be permitted on the Canaveral Shoals in the coming years.

3 Wave Glider Surveys

3.1 Introduction

Oceanographic and biological surveys of the OCS are logistically complex and expensive activities, realities that constrain the exploration of these expansive ecosystems. Unmanned ocean gliders, often more specifically classified as autonomous underwater vehicles (AUVs) and unmanned surface vehicles (USVs), are becoming important tools for expanding the duration and geographic scope of oceanographic data collection (Verfuss et al. 2019). Long-duration ocean gliders all share several characteristics in that they are powered by internal or external energy sources that allow deployments spanning weeks to months, are designed to carry customizable sensor payloads, and maintain a communication link to shore that allows for remote piloting and data transmission. Their unmanned nature, persistence, and ability to operate in a wide range of sea states gives ocean gliders operational and economic advantages over crewed vessels for certain applications, particularly for mundane or repetitive tasks (Nicholson and Healey 2008). Gliders can also be deployed in fleets if necessary to scale up monitoring over a wider geographic area.

While the variety of ocean gliders continues to expand, three main classes of gliders are currently conducting the bulk of long-duration survey work in shelf and open ocean habitats. Buoyancy gliders (e.g., Slocum Glider, Spray Glider) are subsurface platforms that convert subtle changes in buoyancy into horizontal movement. Wave Gliders are USVs that convert wave action and solar energy into forward thrust. Most recently, sail drones harness ocean wind for propulsion. A detailed list of available glider systems is found in Verfuss et al. (2019). Ocean gliders are most commonly used for physical oceanographic surveys, including mapping of ocean currents and bathymetry, and measuring biogeochemical properties of the water column such as temperature, conductivity, dissolved oxygen, and chlorophyll (Rudnick 2016). Advances in sensor technology are also increasingly allowing gliders to effectively monitor living resources such as plankton and forage fish biomass (e.g., Greene et al. 2014; Guihen et al. 2014), sound production by marine mammals and fishes (e.g., Wall et al. 2017; Aniceto et al. 2020), detections of acoustically tagged animals (e.g., Cote et al. 2019), and even remote retrieval of animal movement data from deep-water acoustic tracking stations.

Unmanned ocean gliders have the potential to complement, and in some instances even replace, crewed surveys of sand shoals and other sites of interest to BOEM on the continental shelf. High heterogeneity in bathymetry and sediments around shoals and the strongly seasonal nature of their biological communities generally require repeated and fine-scale sampling to document habitat quality and animal distribution. This is a daunting prospect in many locations where weather and site remoteness often limit access. Gliders can potentially overcome these constraints but have been a minor component of shoal monitoring programs to date. The Canaveral Shoals monitoring program provided a valuable opportunity to evaluate the advantages, limitations, and logistical considerations of unmanned gliders for surveying sand shoals, with results having application to similar sites along the US southeast coastline. The specific objectives of this evaluation were to (1) assess the ability of an ocean glider to systematically relocate acoustically tagged animals and compare its performance with the fixed-station Canaveral Array, and (2) pair the glider with a passive acoustic monitoring (PAM) sensor to document ocean soundscapes near the shoals with an emphasis on ambient sounds, dredging noise, and the vocalizations of fish and marine mammals (activities detailed in **Section 5**). A suite of environmental sensors integrated with the glider provided important habitat context supporting both objectives.

3.2 Methods

The platform utilized for this study was a Liquid Robotics Wave Glider SV3 unmanned surface vehicle. The SV3 consists 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 6**) resulting in 5 m of total draft. As the float and sub rise on a wave, the sub wings tilt down, providing forward propulsion. As the float moves down the wave, the wings tilt up and the sub sinks while also pulling the float forward. During the day, solar panels on the float charge lithium-ion batteries that in turn provide power as needed to onboard sensors, communications equipment, and to drive a small propeller if extra thrust is required. Watertight payload boxes beneath the solar panels accommodate sensors in user-customized configurations, and standalone sensors can also be mounted in various locations on both the float and sub. A GPS receiver allows the glider to track its location and autonomously navigate courses through preprogrammed waypoints while an Automated Information System (AIS) receiver and collision avoidance system allows it to identify and avoid the path of vessels carrying AIS beacons. Vehicle telemetry and science data are relayed to shore via an Iridium satellite modem or through a faster cellular modem when close to shore, and pilots can send navigation and sensor commands to the vehicle. Average speed is greater than 2 km/hr, maximum speed is 6 km/hr, and the vehicle is theoretically capable of deployments up to one year in duration. The Wave Glider was considered the most appropriate platform for the present study area because it can navigate a preprogrammed course with high fidelity (< 20-m course deviation in most conditions) in shallow water, allowing safer navigation through the complex bathymetry surrounding the shoals and avoidance of physical hazards such as navigation buoys and anchored ships. Unlike buoyancy gliders, the Wave Glider does not allow easy vertical profiling of the water column, but this was a minor concern given the relative shallowness (less than 30 m) of the project area.

Eight quarterly deployments were undertaken from November 2017 through August 2019, all of which followed the same path and included a minimum transect distance of 930 km defined by 179 preprogrammed waypoints (**Figure 7**). The transect was divided into four operational areas including (in order of completion) a Shoal Zone (315 linear km), North Zone (376 km), Reef Zone (92 km), and South Zone (146 km). During some deployments when the glider was moving quickly or seas were unfavorable for recovery, the Shoal Zone was surveyed a second time. To avoid the shallowest shoal ridges and the busy shipping lanes due east of Port Canaveral, the vehicle was constrained to operate in water depths of 10 m or greater. Before the start of the study, water depth in particularly shallow areas was surveyed in a small boat with an echosounder and the final path was subtly adjusted to avoid areas shallower than depicted on nautical charts. The final 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 multiple known reefs and wrecks along the 12-fathom ridge east of the shoals. The glider was launched and recovered east of Port Canaveral from an 8-m pilothouse skiff and its status was monitored from shore by pilots typically operating on 12-hour shifts.

The Wave Glider sensor payload included two acoustic receivers for detecting acoustically tagged animals plus sensors measuring water temperature, dissolved oxygen, chlorophyll, turbidity, colored dissolved organic matter (CDOM), and various meteorological conditions. A Remora passive acoustic recorder (Loggerhead Instruments, Sarasota, Florida) for recording ambient ocean sounds was also present on each deployment (described in detail in **Section 5**) and a wave height sensor was added in Deployment 7. All sensors were programmed to operate continuously, although when extended periods of overcast skies reduced solar energy generation, sensors were powered off starting with those of least value to vehicle safety and scientific objectives.

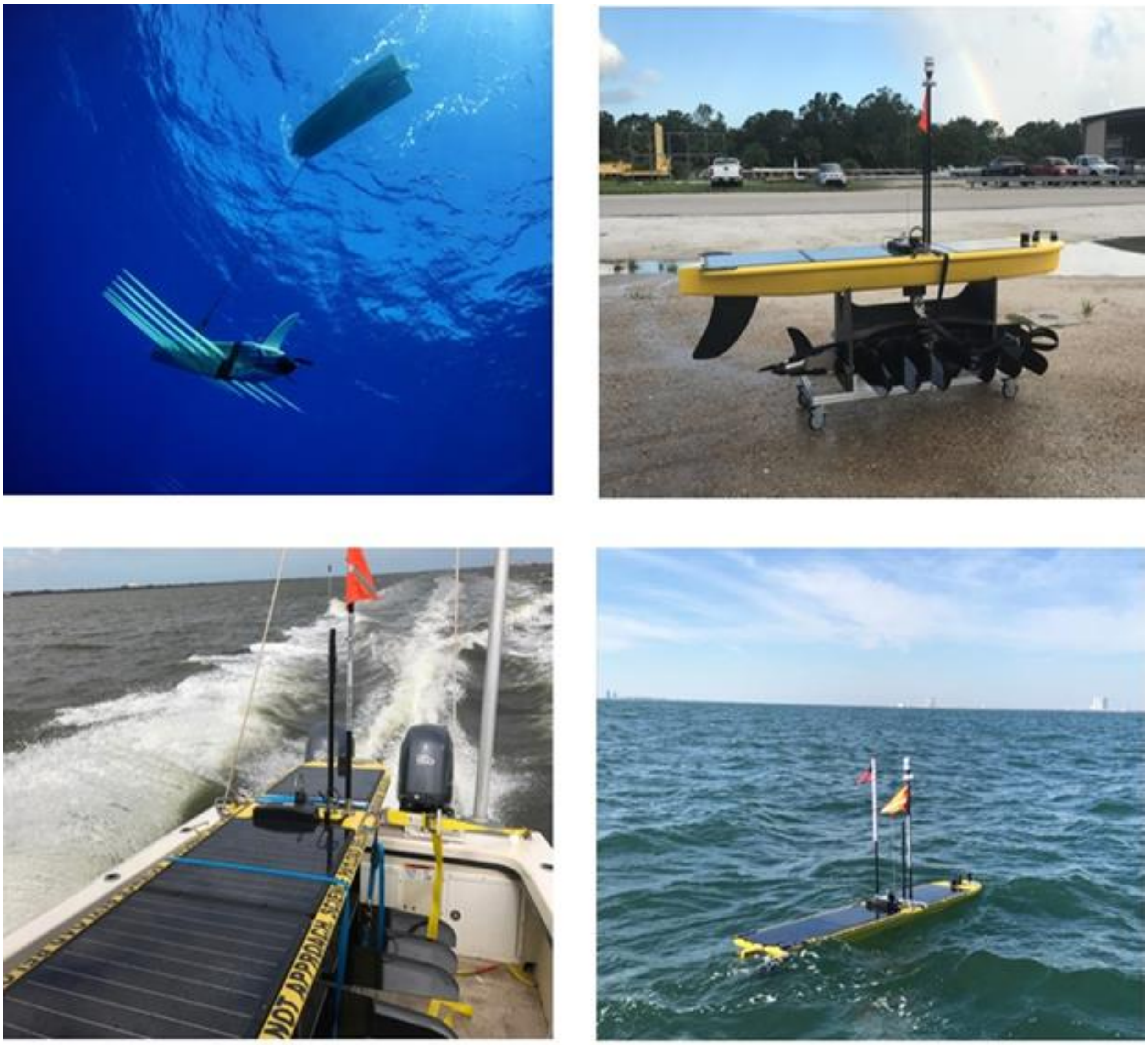


Figure 6. Wave Glider acoustic tracking and oceanographic surveys

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.

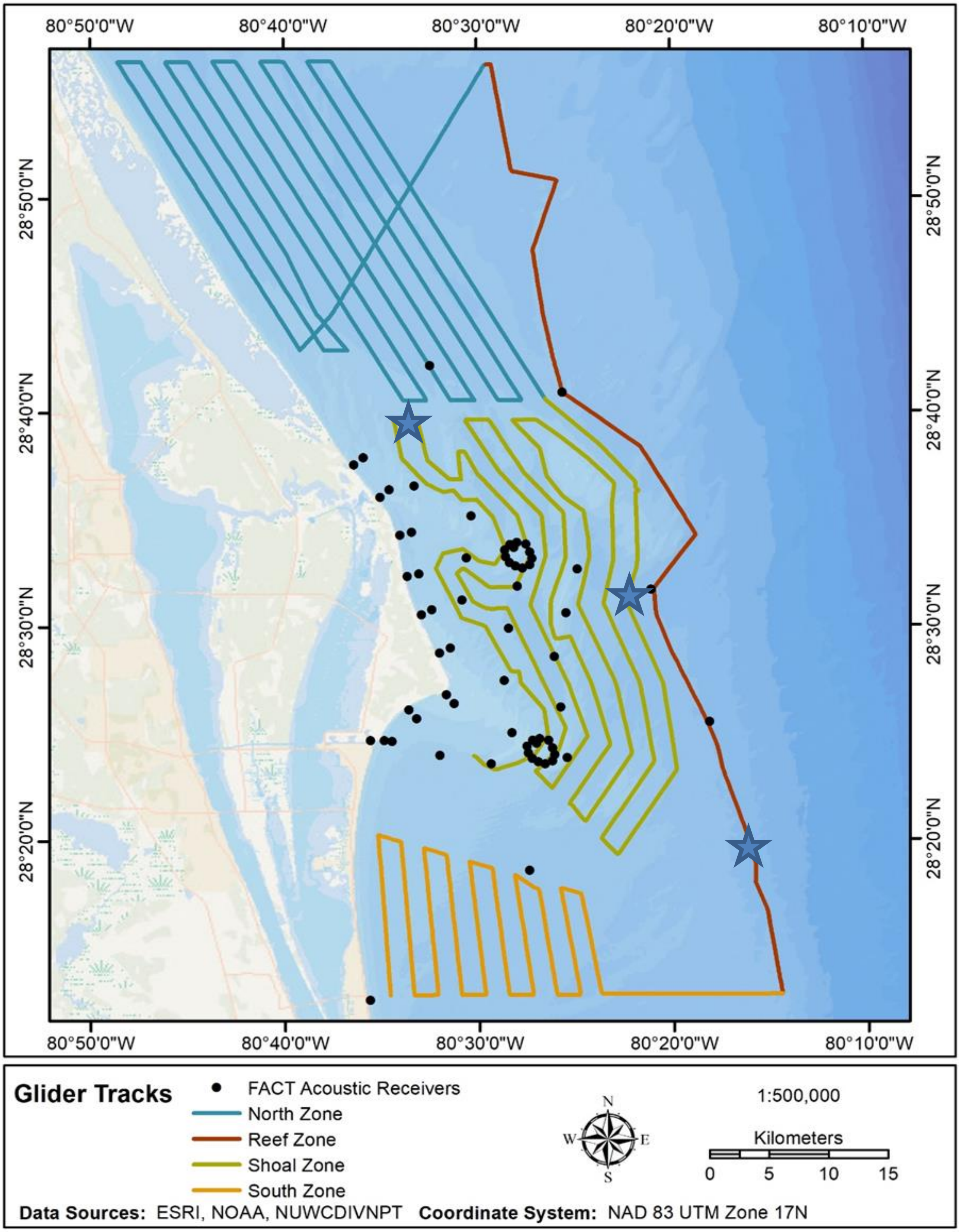


Figure 7. Wave Glider transect survey zones offshore Cape Canaveral

Blue stars indicate acoustic telemetry range testing locations. Non-uniform transect spacing in the Shoal Zone is to avoid water less than 10 m deep.

Two types of acoustic receivers were attached to the Wave Glider on each deployment for animal detection. The first was a Vemco mini-VR2C cabled acoustic receiver, which has a direct connection to the onboard computer, allowing it to draw power from glider batteries and relay animal detections to shore in near real time. The second was a standalone Vemco Mobile Transceiver (VMT), a miniaturized battery-powered unit commonly attached to subsurface gliders (e.g., Slocum and REMUS systems). The VMT was primarily deployed for redundancy but also allowed for a performance assessment between the two receiver types. Both receivers were mounted on the sub with the VR2C facing down, while the VMT was mounted horizontally on the first deployment but facing down for all subsequent missions (**Figure 8**). Both receivers are omni-directional, allowing the detection of animals within a few hundred meters of the glider but not providing exact locations via estimates of tag range or bearing.

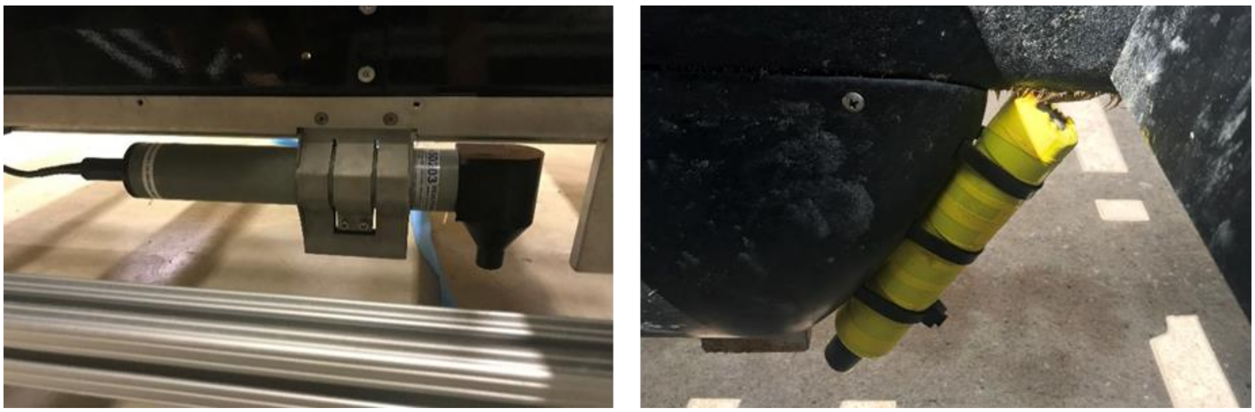


Figure 8. Acoustic receivers mounted to the Wave Glider

Left: VR2C, *Right*: VMT. Photo credits: Eric Reyier.

To evaluate the detection efficiencies of these acoustic receivers, on the first four deployments the glider sequentially orbited three range test transmitters (Vemco V16-4H tags, 69 kHz, 158 dB, 3 min fixed ping interval) pre-deployed along the transect, one each in 10, 20, and 30 m of water, in flat areas thought to be devoid of reef structure. Transmitters were moored with a horizontal orientation roughly 2 m off the bottom, a depth thought to approximate the distribution of many benthic fishes targeted in the study. Upon reaching each range test site, the glider then circled the transmitter twice at a 250 m horizontal radius, and once each at 500 m, 750 m, and 1,000 m (**Figure 9**), although the glider operated at a variety of distances from range tags as it entered and departed the area and moved between orbits. Similar spiraling orbits were also conducted at three reef locations where red snapper were acoustically tagged and released (see **Section 2**). The species is known to have high site fidelity to tagging locations in other regions and demonstrated little movement through the Canaveral fixed array. These glider searches were therefore conducted with the intent of detecting smaller-scale movements of snapper away from tagging locations.

Surface water chlorophyll, turbidity, and CDOM were measured every 10 minutes by a Turner Designs C3 flow-through fluorometer housed in the Wave Glider 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 Van Lancker and Baeye (2015). Fluorometer readings were validated by collecting and lab-analyzing water samples from glider launch and recovery points. Dissolved oxygen and surface water temperature were also logged at 10-minute intervals using an Onset dissolved oxygen logger. The details of all onboard sensors are found in **Table 6**.

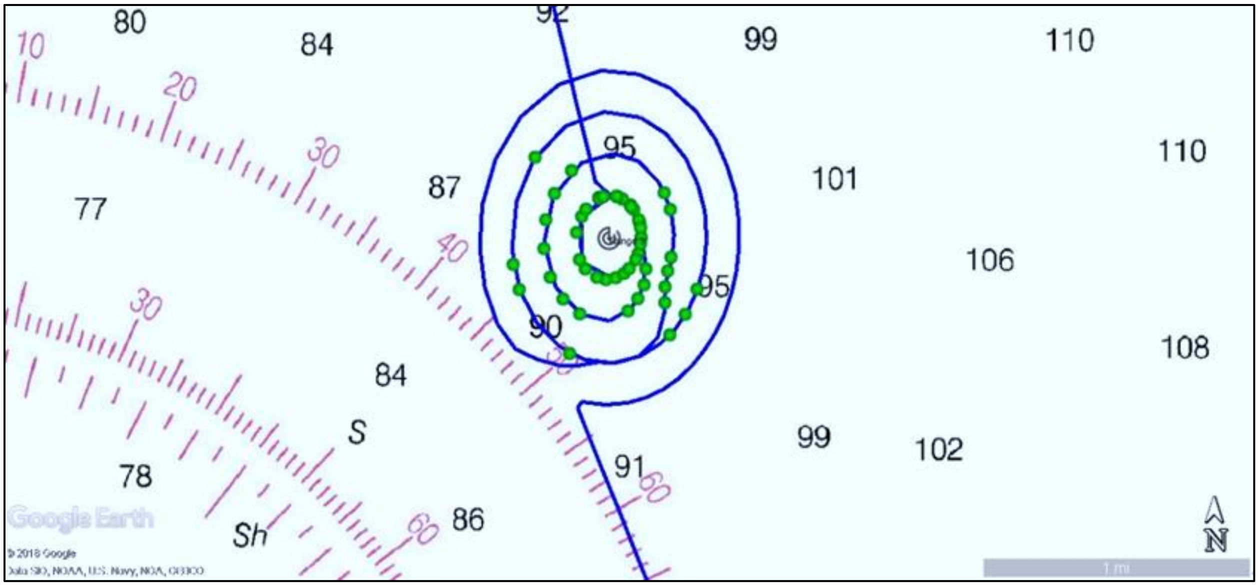


Figure 9. Wave Glider acoustic receiver range testing path

A typical range test pattern including orbits at 250, 500, 750, and 1,000 m from a pre-deployed range test transmitter (center of orbit). Green dots represent the Wave Glider location when it detected the test transmitter.

Table 6. Purpose and description of the Wave Glider science payload

Sensor	Measurement	Real-Time Data	Sampling Interval	Location on Glider
Vemco mini-VR2C Acoustic Receiver	Detection of acoustically tagged animals	Yes	Continuous	Sub
Vemco Mobile Transceiver	Detection of acoustically tagged animals	No	Continuous	Sub
Turner Designs C3 Fluorometer	Turbidity, chlorophyll, CDOM, water temp	Yes	Every 10 min	Float
Onset U26-001 HOBO Dissolved Oxygen Logger	Dissolved oxygen and water temp	No	Every 10 min	Sub
Loggerhead Instruments Remora Acoustic Recorder	Ambient biological (e.g., fish, marine mammal) and anthropogenic noise	No	10 min every 20 min	Sub
Airmar PB200 Weather Station	Air temp, wind speed, direction, and gusts, and atmospheric pressure	Yes	Every 10 min	Float
Airmar CS4500 Water Speed Sensor	Surface water current speed and direction	Yes	Every 5 min	Float
GPSWaves Wave Height Sensor*	Wave height, direction, and frequency	Yes	30 min	Float

*Deployments 7–8 only

3.2.1 Data Analysis

3.2.1.1 Range Testing

Binary boosted regression tree (BRT) models were developed to evaluate the detection efficiency of the Wave Glider's acoustic receivers as a function of distance and several other potentially explanatory covariates. BRTs are a machine learning approach that has some advantages over generalized linear and additive models in that it is suitable for datasets containing a large fraction of zeros, can account for multiple predictor variables without penalty, fit complex non-linear interactions, and is relatively insensitive to outliers, missing predictor variables, and multi-collinearity (Dedman et al. 2017; Elith et al. 2008).

Because all deployed range test tags had a three-minute fixed transmission interval, the exact time of each tag transmission was known. The BRT model binary response variable was whether (or not) each tag transmission was detected by the glider's acoustic receivers. All possible transmissions when the Wave Glider was within 1,000 m of a tag were included, either during dedicated range test trials or when on its regularly planned path, and separate models were constructed for the mini-VR2C and VMT, plus a combined model including both receiver types. Exploratory models were also run using transmissions out to 1,300 m from the range tag, a distance used by both Oliver et al. (2017) and Cimino et al. (2018). The 1,000-m and 1,300-m runs performed very similarly so only the 1,000 m model is presented. Distance (m) between the range test tag and glider (considered the predictor variable of greatest interest) was calculated using the geosphere package in R. To assess the relative importance of environmental covariates, the models also included depth (the 10-, 20-, and 30-m sites), wind speed (kts), water temperature (°C), ocean current (kts), wave height (m), vehicle speed (km/hr), solar irradiance (W/m^2), deployment number (as a factor), and ambient sound (sound pressure level [SPL]). Wind speed, temperature, and ocean current were obtained directly from the glider's onboard sensors with current data averaged across a moving 30-min time window to minimize high variability in this sensor. Wave data were obtained from the NDBC Buoy 41009 located 18–41 km east of range test sites. Ambient noise was accounted for by including broadband sound pressure levels (SPL-RMS in decibels) recorded by the glider's onboard Remora acoustic recorder. Glider orientation (i.e., heading) was not considered since receivers were mounted vertically, suggesting similar detection ranges regardless of the direction of glider travel. The VMT was mounted horizontally during Deployment 1 but vertically in all other deployments. Exploratory runs with and without Deployment 1 performed similarly so all data from all four deployments were retained in the final VMT model.

BRT models were run in the gbm.auto package in R (v.1.5.3, Dedman et al. 2017). This package can evaluate multiple mixtures of learning rate (lr), tree complexity (tc), and bag fraction (bf) to determine the best BRT model. Briefly, learning rate is the rate at which the model learns and increases complexity. A slower learning rate is generally better as long as the model is not being overfit and are within computing capabilities. Tree complexity is the number of tree splits or interactions the model allows for (Leathwick et al. 2006). Bag fraction refers to the proportion of data that is randomly chosen without replacement to train the model with cross validation. Model performance was evaluated by assessing model CV deviance, area under the [receiver operating] curve (AUC), CV correlation (CV Score), and percent deviance explained relative to the null model. Briefly, in assessing model performance, the lower deviance the better, AUC scores closer to 1 the better (anything over 0.8 is considered 'good', while values over 0.9 are considered 'great'), CV Correlation over 0.6 is good, and higher deviance explained is better (Dedman et al. 2017). Models were also checked for overfitting (determined by comparing the Training AUC score to the CV AUC score, the smaller difference the better) and if at least 1,000 trees were achieved (Elith et al. 2008). Learning rates of 0.01, 0.001, and 0.005 and bag fractions of 0.5, 0.6, and 0.7 were tested. Tree complexities of 2 and 3 were tested (Elith et al. 2008; Cimino et al. 2018; Bangley et al. 2021). Tree simplification was evaluated within the gbm.auto function call to determine if the dropping of any predictors increased model performance. Marginal effects plots and relative influence graphs were also created using gbm.auto.

3.2.1.2 Oceanographic Monitoring

A detailed assessment of water quality conditions measured by the Wave Glider was not a primary study objective. Nonetheless, general trends in water temperature, dissolved oxygen, chlorophyll, turbidity and CDOM were often apparent across survey zones and seasons. Each deployment was classified as the season in which it began although three deployments spanned more than one season. Tabular summaries of oceanographic measurements along the Wave Glider transect were generated for each deployment, and detailed maps are provided in Error! Reference source not found..

3.2.1.3 Glider-Based Animal Tracking

Animal encounters typically consisted of multiple acoustic detections of an individual in a short period of time. The duration of each encounter was calculated (in minutes) as the time between the first and last detection by the glider. When an animal went undetected for a period longer than one hour, future detections were considered the start of a new encounter. Each encounter was classified as *valid*, *likely valid*, or *suspect* based on the movement history of that animal. An encounter was considered *valid* if that animal could be confirmed as alive and moving based on subsequent Wave Glider or fixed-station FACT Network detections. Encounters were classified as *likely valid* if no evidence was produced through the Wave Glider or FACT Network that confirmed subsequent movement. Encounters were considered *suspect* when detections from the Wave Glider on subsequent deployments confirmed that the tag was not moving, suggesting either a mortality or a shed tag. Suspect encounters were removed from subsequent statistical analyses.

Two-sample Kolmogorov-Smirnov (KS) tests were used to assess whether the three most commonly detected fish species (blacktip shark, blacknose shark, and red drum) were encountered randomly in the project area (the null hypothesis) or instead appeared to be selecting for certain habitat conditions as measured by the Wave Glider. Alternatively stated, KS tests can be used to test whether values from two datasets—in this case the habitat available to a species vs. the habitat at a species' encounter locations—are drawn from the same distribution. Available habitat were simply all readings logged by Wave Glider environmental sensors (water temperature, dissolved oxygen, chlorophyll, turbidity, CDOM) or derived from the vehicle location (water depth and distance from shore), while encounter data were these same variables drawn only from animal encounter locations. KS tests are nonparametric and do not require that data be normally distributed or have equal sample sizes. The test does assume that all habitat was equally available to animals and that the Wave Glider, with its systematic path, surveyed the full range of available habitat, both of which seemed reasonable. Separate tests were run for each combination of habitat variable and species, plus an omnibus test for all fish. Available habitat data generally included data from all eight deployments, even those where a species was not encountered, because all three species are present at Canaveral in at least low numbers year-round. Red drum was an exception; many red drum transmitters expired in the second year of the study so only data from Deployments 1–4 was considered.

3.3 Results

The Wave Glider successfully completed all eight missions with deployments lasting on average 24 days, covering 1,202 km, with mean speed of 2.1 km/hr and a maximum recorded speed of 6.0 km/hr (**Table 7).** A total of 9,600 km was traveled across the entire two-year study. Deployment 8 was suspended for 10 days, with the glider temporarily retrieved and redeployed to minimize risk during the passage of Hurricane Dorian in September 2019.

Table 7. Summary statistics for all eight 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
5	11/27/18	12/18/18	21.0	990	2.0	5.4
6	02/22/19	03/15/19	21.0	1,073	2.1	6.0
7	05/22/19	06/19/19	27.9	1,176	1.8	5.2
8	08/23/19	09/26/19	24.1*	1,345	2.3	5.6
Mean	**-**	**-**	**23.8**	**1,202**	**2.1**	**5.3**

* Glider temporarily retrieved during Hurricane Dorian

3.3.1 Oceanographic Monitoring

Water temperature recorded by the glider ranged from 18°C (February 2019) to over 29°C (September 2018) with a maximum 2.6°C difference observed between survey zones on any single deployment. No consistent temperature gradients were detected across zones (**Table 8**), although water temperature was somewhat warmer in the South Zone each winter, apparently reflecting the strong north-south temperature gradient that is typical for east Florida shelf this time of year. Mean dissolved oxygen ranged from 5.5–8.0 mg/l with the highest values coinciding with periods of low water temperature. No instances of hypoxia were observed. Chlorophyll was extremely patchy across and even within survey zones but was generally lowest in the spring and highest in the fall. An obvious diel cycle was also detected (not presented) with peak values from sunset through early morning and a distinct mid-day minimum. The fluorometer sensors fouled towards the end of Deployment 1 due to growth of filamentous algae, an issue corrected by the addition of a motorized wiper on subsequent deployments. Mean turbidity ranged from 0.3–14.7 NTU but was also highly variable over small spatial scales. Areas with consistently elevated turbidity were the South Zone in the Canaveral Bight, and, to a lesser extent the Shoal Zone, both areas where deposits of fine sediment have been identified and may be resuspended by physical and biological processes. CDOM was relatively uniform across zones but was lower in spring and summer sampling. Maps of temperature, dissolved oxygen, chlorophyll, and turbidity measurements for each deployment are found in Error! Reference source not found.**.**

Table 8. Oceanographic conditions measured by the Wave Glider by survey zone

Values are means with standard deviation (SD) in parentheses. The season listed is based on the date the survey began. N/A values are for periods when the sensor readings were inaccurate due to biofouling.

Deployment	Parameter	Shoal	North	Reef	South
1 (Fall)	Water Temperature (°C)	22.3 (0.3)	21.5 (0.6)	21.4 (0.7)	20.6 (0.6)
	Dissolved Oxygen (mg/l)	7.0 (0.2)	7.2 (0.3)	6.9 (0.1)	6.9 (0.5)
	Chlorophyll (RFU)	498 (134)	633 (175)	824 (509)	N/A
	Turbidity (NTU)	4.5 (2.2)	1.6 (1.2)	N/A	N/A
	CDOM (RFU)	443 (80)	465 (60)	308 (80)	N/A
2 (Winter)	Water Temperature (°C)	19.4 (1.4)	19.4 (0.8)	21.0 (1.1)	22.0 (0.7)
	Dissolved Oxygen (mg/l)	7.3 (0.3)	7.3 (0.1)	7.1 (0.2)	7.0 (0.2)
	Chlorophyll (RFU)	339 (133)	260 (110)	227 (85)	288 (138)
	Turbidity (NTU)	2.6 (1.4)	1.6 (1.2)	3.2 (2.1)	4.1 (1.7)
	CDOM (RFU)	177 (67)	156 (40)	97 (50)	96 (30)
3 (Spring)	Water Temperature (°C)	25.4 (0.7)	26.2 (0.7)	26.4 (0.2)	27.0 (0.8)
	Dissolved Oxygen (mg/l)	6.6 (0.2)	6.6 (0.2)	6.6 (0.1)	6.4 (0.2)
	Chlorophyll (RFU)	239 (176)	89 (44)	128 (35)	132 (51)
	Turbidity (NTU)	2.5 (3.0)	0.4 (0.4)	0.3 (0.4)	3.0 (4.6)
	CDOM (RFU)	40 (6)	52 (33)	30 (6)	35 (6)
4 (Summer)	Water Temperature (°C)	28.9 (0.4)	29.2 (0.3)	28.7 (0.1)	28.8 (0.2)
	Dissolved Oxygen (mg/l)	6.1 (0.3)	6.1 (0.3)	6.2 (0.2)	6.2 (0.2)
	Chlorophyll (RFU)	280.4 (113.1)	275.5 (165.3)	351.2 (81.3)	529.6 (99.5)
	Turbidity (NTU)	2.5 (5.0)	1.4 (1.7)	2.3 (1.1)	7.0 (2.3)
	CDOM (RFU)	60.5 (11.2)	90.9 (14.3)	65.4 (13.7)	85.4 (12.4)
5 (Fall)	Water Temperature (°C)	21.7 (1.2)	20.3 (0.8)	19.8 (0.9)	19.5 (0.3)
	Dissolved Oxygen (mg/l)	7.1 (0.2)	7.1 (0.2)	7.3 (0.1)	7.4 (0.2)
	Chlorophyll (RFU)	608 (277)	442 (110)	290 (79)	554 (183)
	Turbidity (NTU)	2.6 (2.5)	2.2 (1.4)	1.1 (0.5)	3.8 (2)
	CDOM (RFU)	278 (143)	268 (43)	165 (57)	281 (10)

Table 8 continued

Deployment	Parameter	Shoal	North	Reef	South
6 (Winter)	Water Temperature (°C)	17.9 (0.6)	17.9 (0.7)	17.9 (0.4)	19.7 (0.4)
	Dissolved Oxygen (mg/l)	7.9 (0.2)	8.0 (0.2)	7.7 (0.2)	7.7 (0.2)
	Chlorophyll (RFU)	332 (133)	267 (78)	202 (76)	255 (90)
	Turbidity (NTU)	0.8 (0.5)	0.7 (1.2)	0.3 (0.2)	0.4 (0.2)
	CDOM (RFU)	398 (45)	407 (40)	287 (49)	331 (15)
7 (Spring)	Water Temperature (°C)	25.9 (0.9)	24.8 (0.8)	25.4 (1.2)	25.1 (0.4)
	Dissolved Oxygen (mg/l)	7.1 (0.3)	7.7 (0.2)	7.7 (0.1)	7.9 (0.1)
	Chlorophyll (RFU)	94 (69)	107 (82)	235 (59)	189 (53)
	Turbidity (NTU)	0.4 (0.7)	0.2 (0.3)	0.1 (0.1)	0.3 (0.1)
	CDOM (RFU)	36.0 (7.0)	34.4 (6.4)	31.2 (8.2)	35.5 (5.5)
8 (Summer)	Water Temperature (°C)	27.6 (1.4)	28.4 (0.2)	28.0 (0.1)	27.5 (0.2)
	Dissolved Oxygen (mg/l)	6.5 (0.2)	6.1 (0.2)	5.8 (0.1)	6.0 (0.2)
	Chlorophyll (RFU)	160 (100)	405 (145)	372 (81)	508 (61)
	Turbidity (NTU)	1.0 (0.9)	7.2 (5.0)	8.8 (2.8)	14.7 (3.2)
	CDOM (RFU)	43.2 (12.8)	73.7 (32.3)	45.4 (11.3)	67.7 (9.5)

3.3.2 **Acoustic Range Testing**

Range testing of Wave Glider acoustic receivers was conducted on each of the first four deployments to determine the performance of each receiver type as a function of distance, water depth, and other environmental factors. There were a combined 33 instances when the glider passed within 1 km of a deployed range tag. This included 17 dedicated trials when the glider orbited a range tag at predefined distances and 16 instances when it passed near a range tag while on its normal survey transect. Meteorological conditions at range test sites included wave heights of 0.3–2.0 m, wind speeds of 2–28 kts, and water temperatures of 17–30°C. A total of 3,386 test tag transmissions were generated when the vehicle was within 1,000 m of the moored test tags. Both the mini-VR2C and smaller VMT performed similarly well within the first 100 m of a test tag after which the mini-VR2C outperformed the VMT (**Figure 10**). The 50% and 20% detection range (i.e., the distance at which 50% and 20% of all test tag transmissions were successfully detected) was achieved at roughly 350 m and 500 m for VR2C, and 300 m and 400 m for VMT. The furthest successful detection from the glider was 889 m for the mini-VR2C and 602 m for the VMT. There were no clear improvements in detection efficiency at progressively deeper range test sites although the sample size for distances less than 250 m away from test tags was relatively small. For comparison, range testing around fixed VR2W receivers in the Canaveral Array with a similarly powered tag (detailed in Iafrate et al. 2019) had 50% detection ranges of 250–400 m and 20% detection ranges of 500–800 m depending on location, suggesting that both glider-based receiver types modestly underperform bottom-mounted receivers in this environment.

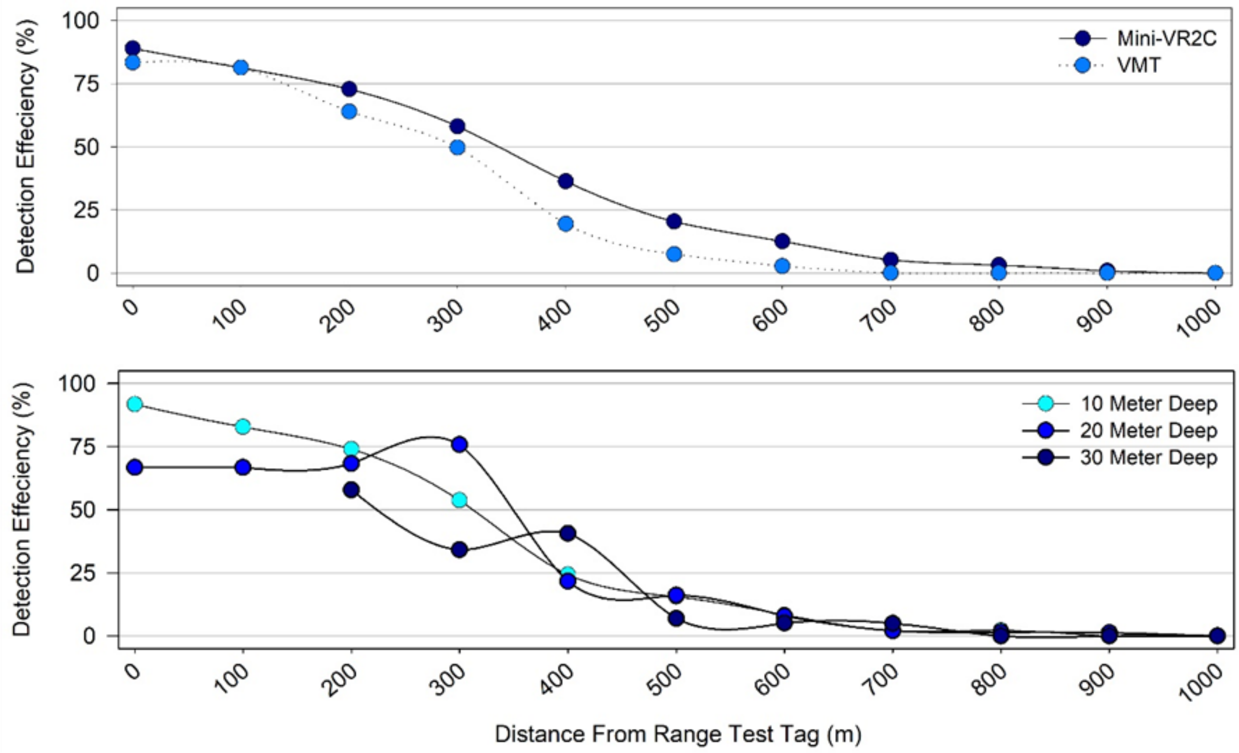


Figure 10. Wave Glider acoustic receiver detection efficiency

Detection efficiency by (A) receiver type (all depths combined), and (B) by water depth (both receivers combined). Distance values are binned to the nearest 100 m.

BRT models were run to assess the factors related to Wave Glider acoustic receiver performance. Range test tag detection opportunities out to 1,000 m (100 m past the farthest actual detection) were included, and with separate runs for the VR2C, VMT, and both receivers combined. The only model that benefited from simplification was the VR2C model run which dropped the depth/site covariate; all predictors were retained in the VMT and Combined model (**Table 9**). The best learning rate was 0.01 for all models and a tree complexity of 3 outperformed models where *tc* = 2. Bag fraction was 0.7 for the VR2C and VMT models and 0.5 for the combined model. All final models reached over the minimum of 1,000 trees. Model performance was high with AUC scores considered excellent for all models at 0.95–0.96 and CV scores were over 0.6. Additionally, no models showed overfitting as the difference between the training AUC score and CV AUV Score were minimal (0.02–0.04). Deviance explained ranged from 56.6–60.7%. The biggest two-way interaction was Current Speed and Distance for the VR2C and Combined model, while the interaction between Solar Irradiance and Distance was the largest for the VMT model.

Distance between the glider and range test tag was the most important factor in all models (64.9, 75.3, and 58.3% respectively, **Table 10**) with the likelihood of a tag detection decreasing with distance (**Figure 11**). Ocean current speed was the second most influential covariate in the VR2C and Combined model (8.6 and 8.8%) while solar irradiance was the second most influential predictor in the VMT model (5.8%). Likelihood of a positive detection increased with increasing Solar Irradiance, which corresponds to a greater likelihood of detection during the daylight hours. All other covariates contributed 6% or less in each one of the models. Additionally, in the Combined model, receiver type (VR2C or VMT), only made up 2.8% of the relative influence, suggesting receiver type was not a large contributing factor to detection range of the glider despite the receivers being in slightly different orientations.

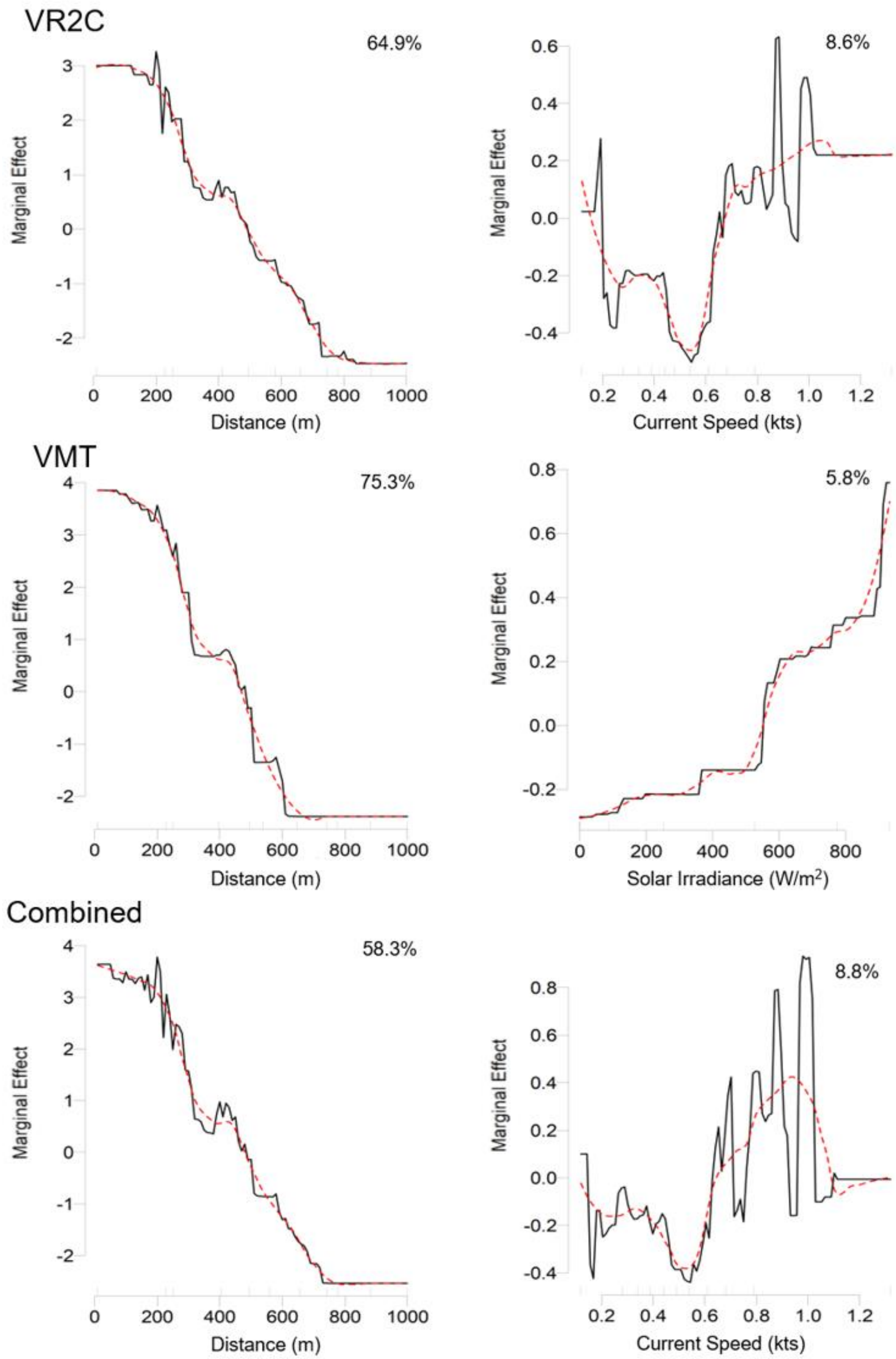


Figure 11. Wave Glider BRT model marginal effects plots
Plots depict the influence of environmental variables on the detection efficiency of Wave Glider acoustic receivers. The red dashed smoothing line (Tukey's running median smoothing) is provided on each plot. Relative influence for each covariate shown are provided in parentheses. Only the top two most influential covariates are shown.

Table 9. BRT model parameters and performance scores

Model	*n* trees	*bf*	Training AUC Score	CV AUC Score (SE)	TAUC - CVAUC	CV Correlation (SE)	Deviance Explained (%)	Model Simplified?
VR2C	1,900	0.7	0.95	0.91 (0.007)	0.04	0.67 (0.01)	56.6	Y
VMT	1,050	0.7	0.96	0.94 (0.004)	0.02	0.70 (0.01)	58.8	N
Combined	4,250	0.5	0.96	0.93 (0.004)	0.03	0.71 (0.01)	60.7	N

Number of trees = n trees, bag fraction = bf, Training Data Area Under Curve (AUC), Cross-Validated (CV) AUC). TAUC - CVAUC is used to assess model overfitting. CV Correlation = CV Score.

Table 10. Wave Glider range test BRT model relative influence

VR2C		VMT		Combined (VR2C and VMT)	
Variable	**% Relative Influence**	**Variable**	**% Relative Influence**	**Variable**	**% Relative Influence**
Distance	64.9	Distance	75.3	Distance	58.3
Current Speed	8.6	Solar Irradiance	5.8	Current Speed	8.8
Vehicle Speed	6.3	Wave Height	4.0	Wind Speed	6.4
Temperature	5.9	Current Speed	3.4	Temperature	5.8
Wind Speed	5.0	Wind Speed	3.2	Vehicle Speed	5.6
Wave Height	4.6	Temperature	2.9	Wave Height	5.2
SPL (noise)	2.2	Vehicle Speed	2.3	Solar Irradiance	3.6
Solar Irradiance	1.8	Deployment	1.6	Receiver Type	2.8
Deployment	0.9	SPL (noise)	1.6	SPL (noise)	2.3
-	-	Depth	0.1	Deployment	0.7
-	-	-	-	Depth	0.4

3.3.3 Animal Encounters

A total of 167 acoustically tagged animals from 20 species (9 sharks, 6 bony fish, 4 rays, 1 sea turtle) were relocated across the 8 Wave Glider deployments (**Table 11**). Blacktip shark (47 individuals), blacknose shark (22), red drum (18), finetooth shark (15) and cobia (14) were the most commonly encountered species. Seventy-nine (47%) of these animals were tagged locally at Cape Canaveral while the remaining 88 were tagged independently by 14 other research groups at various locations along the US East Coast, Gulf of Mexico, and Bahamas. Many animals were relocated multiple times within the same deployment or even across deployments resulting in 331 unique animal encounters (**Figure 12**). The larger VR2C acoustic receiver produced 62% of all animal detections (each animal encounter is generally composed of multiple tag detections), and of the 3,735 total animal detections logged by both receivers combined, only one could not be matched to known tagged animals in the region and was considered a false detection. The overall encounter rate along the survey path was 0.02 animals per kilometer traveled and was highest in the Shoal Zone (0.030 animals/km) and lowest in the North and Reef Zone (0.017 animals/km, **Table 12**). Some encounters also occurred off-transect while bringing the glider in closer to port for recovery. Encounters were also consistently elevated in late fall and winter surveys, and lowest in summer. Similarly, cumulative species counts were also higher in the Shoal Zone and in fall and winter. This seasonal disparity is likely because many fish species are overwintering in east Florida, a phenomenon also thoroughly documented within the fixed-station Canaveral Array.

Table 11. Acoustically tagged animals detected by the Wave Glider

The mean duration (minutes) of encounters recorded by the Wave Glider and the FACT Network at Cape Canaveral is also provided. Suspect encounters are excluded from means.

Species	No. Animals	Valid Encounters	Likely Valid Encounters	Suspect Encounters	Total Detections	Tagging Org.[1]	Mean Encounter Duration (Glider / FACT)
Blacktip shark	47	69	1	1	1,561	5, 12, 13	20.5 / 42.8
Blacknose shark	22	34	1	-	262	1	12.4 / 61.7
Red drum	18	30	1	21	211	1	5.6 / 62.8
Finetooth shark	15	20	-	2	179	1	14.8 / 42.9
Cobia	14	14	2	6	131	4, 12, 15	10.9 / 31.0
Red snapper	13	-	-	64	900	1	* / *
Sharpnose shark	8	13	-	7	185	1	15.6 / 46.6
Tarpon	6	7	-	-	20	3	4.1 / 61.9
Bonnethead shark	5	6	-	-	94	6, 12	15.5 / 45.4
Goliath grouper	4	7	1	2	46	6, 9	6.6 / 75.3
Cownose ray	3	5	-	-	22	7, 13	5.2 / 50.1
Loggerhead turtle	2	1	1	-	7	1	5.3 / 55.9
Smooth butterfly ray	2	-	1	2	14	14	5.4 / 171.6
Tiger shark	2	4	1	-	59	2, 11	34.4 / 18.2
Bull shark	1	1	-	-	8	13	18 / 15.2
Gulf flounder	1	-	1	-	1	14	1.0 / 14.6
Lemon shark	1	1	-	-	1	1	1.0 / 28.6
Smalltooth sawfish	1	1	-	-	3	10	4.2 / 31.2
White shark	1	1	-	-	24	8	24.0 / 13.9
Whitespotted eagle ray	1	2	-	-	6	7	13.5 / 38.3
Total	**167**	**216**	**10**	**105**	**3,734**	**-**	**-**

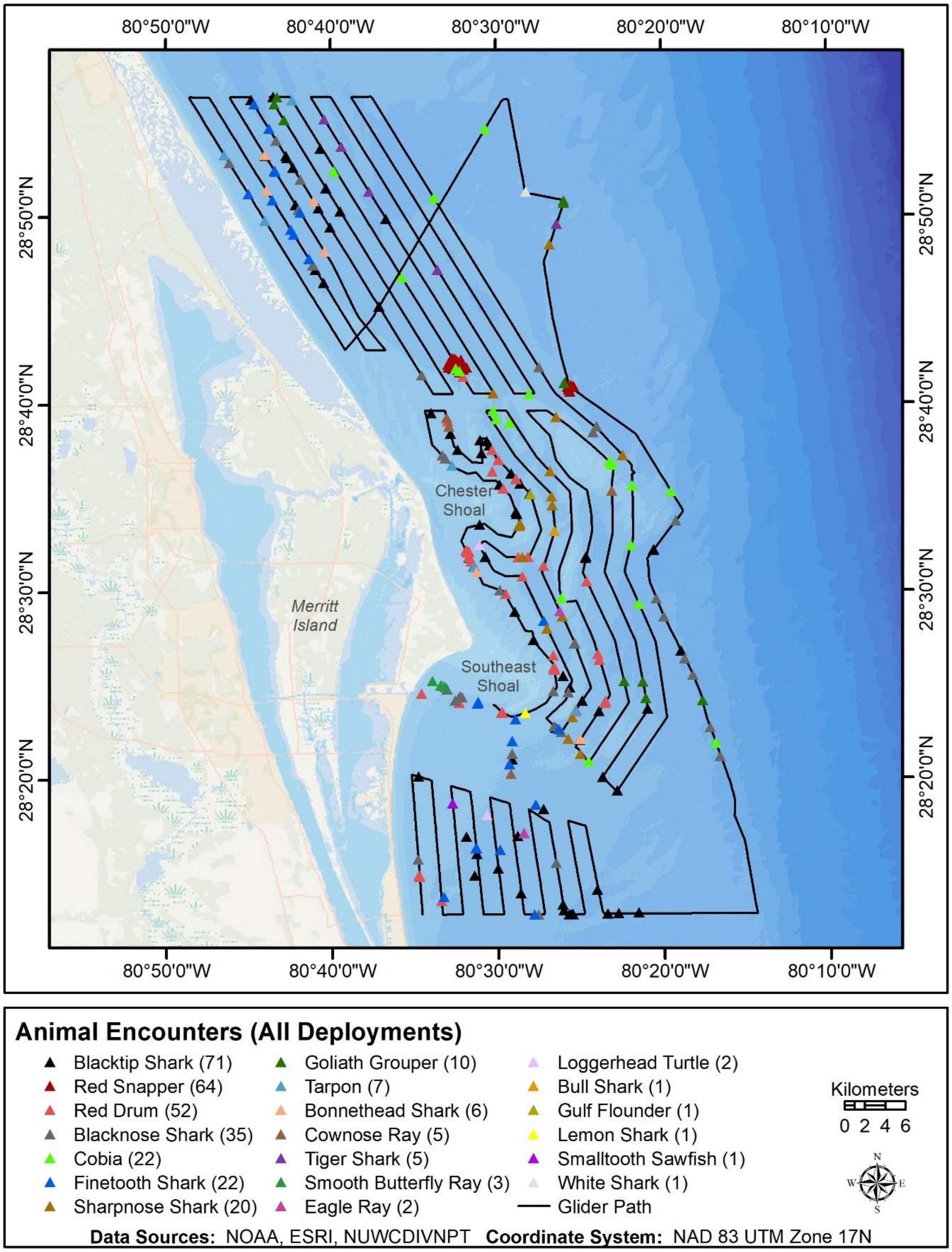


Figure 12. Locations of all tagged animal encounters recorded by the Wave Glider

Values in parentheses are number of unique encounters for each species

Table 12. Wave Glider tag encounter rate and species counts by survey zone and season
Suspect encounters are excluded.

Survey Zone	Distance Traveled (km)	Animal Encounters	Encounter Rate	No. Species
Shoal	3,624	108	0.030	15
North	3,243	56	0.017	10
Reef	1,047	18	0.017	7
South	1,363	32	0.023	7
Off-Transect*	362	12	0.033	6
Total	9,639	226	0.023	19

*When transiting to launch and recovery points

Season	Distance Traveled (km)	Animal Encounters	Encounter Rate	No. Species
Spring	2,452	19	0.008	7
Summer	2,531	27	0.011	6
Fall	2,128	116	0.055	13
Winter	2,528	64	0.025	11
Total	9,639	226	0.023	19

Of the 226 valid or likely valid detections across all species, exactly half (113) were confirmed as live animals solely using Wave Glider detections while the other half could only be verified with subsequent movements through the fixed-station Canaveral Array. Not all relocated animals could be confirmed as alive. Over 100 encounters were classified as suspect because the animal was relocated by the Wave Glider at the same location across multiple deployments, suggesting a mortality or expelled tag, especially for mobile species such as sharpnose and finetooth shark, red drum, and cobia. Red snapper, which alone accounted for more than half of all suspect encounters, were the notable exception. Despite 900 detections, no snapper valid movements were ever confirmed by the glider but their naturally high site fidelity makes it feasible that some detections were of living animals that simply did not disperse from their tagging locations.

Blacktip shark, blacknose shark, and red drum, the three most common species detected by the Wave Glider, were not evenly distributed with respect to the habitat available to them in the study area, suggesting they were selecting for specific conditions to meet their individual life history needs (**Table 13**). Red drum, for example, were encountered in shallower depths and closer to shore on average than areas surveyed by the Wave Glider while a contingent of blacknose sharks were encountered in deeper water along the reef tract (**Figure 13**). Blacktip shark (and many other species not explicitly tested) preferred cooler temperatures during winter and spring and were largely absent during Wave Glider surveys in late spring and fall. Most common fish species were associated with above average chlorophyll levels while the relationship with turbidity and CDOM was much more species-specific. It is recognized, however, that many environmental variables measured by the Wave Glider are correlated. Preference or avoidance of certain conditions may be decisions made in response to other related factors, as well as to many other unmeasured conditions such as the habitat preferences of predators and prey. A summary of the full habitat conditions recorded for each species is found in **Appendix B**.

Table 13. Wave Glider relocations vs. available habitat

KS tests were used to assess whether animal encounters by the Wave Glider occurred randomly with respect to measured habitat conditions. Significant p-values (<0.05, in bold) suggest that animals were associating with a subset of available habitat.

Encounters (All Species)	D	p	Blacktip Shark	D	p
Water Depth	0.126	**0.002**	Water Depth	0.133	0.172
Distance From Shore	0.149	**<0.001**	Distance From Shore	0.151	0.081
Temperature	0.329	**<0.001**	Temperature	0.536	**<0.001**
Dissolved Oxygen	0.208	**<0.001**	Dissolved Oxygen	0.37	**<0.001**
Chlorophyll	0.273	**<0.001**	Chlorophyll	0.422	**<0.001**
Turbidity	0.225	**<0.001**	Turbidity	0.241	**0.003**
CDOM	0.36	**<0.001**	CDOM	0.636	**<0.001**
Blacknose Shark	**D**	**p**	**Red Drum**	**D**	**p**
Water Depth	0.204	**0.019**	Water Depth	0.458	**<0.001**
Distance From Shore	0.198	0.128	Distance From Shore	0.424	**<0.001**
Temperature	0.277	**0.009**	Temperature	0.294	**0.009**
Dissolved Oxygen	0.139	0.508	Dissolved Oxygen	0.274	**0.019**
Chlorophyll	0.211	0.137	Chlorophyll	0.275	**0.018**
Turbidity	0.268	0.085	Turbidity	0.374	**0.001**
CDOM	0.313	**0.012**	CDOM	0.294	**0.019**

3.3.4 Wave Glider vs. Canaveral Array Performance

Of the 331 unique encounters with acoustically tagged animals by the glider, only 60 (18%) were at locations within 500 m of a fixed-station receiver of the Canaveral Array (mostly red snapper on the reef tract), demonstrating the ability of this mobile platform to supplement fixed-station acoustic telemetry by expanding searches into previously unmonitored areas. Nonetheless, when considering the 190 days in which the Wave Glider was at sea, the vehicle detected, on average, 64% of the species, 40% of the tags, but less than 2% of the detections of the fixed Canaveral Array in the same time period (**Table 14**). All but four live fish encountered by the Wave Glider were also detected in the Canaveral Array, and 55% of all encounters were with animals detected in the Canaveral Array within 24 hours of a Wave Glider detection.

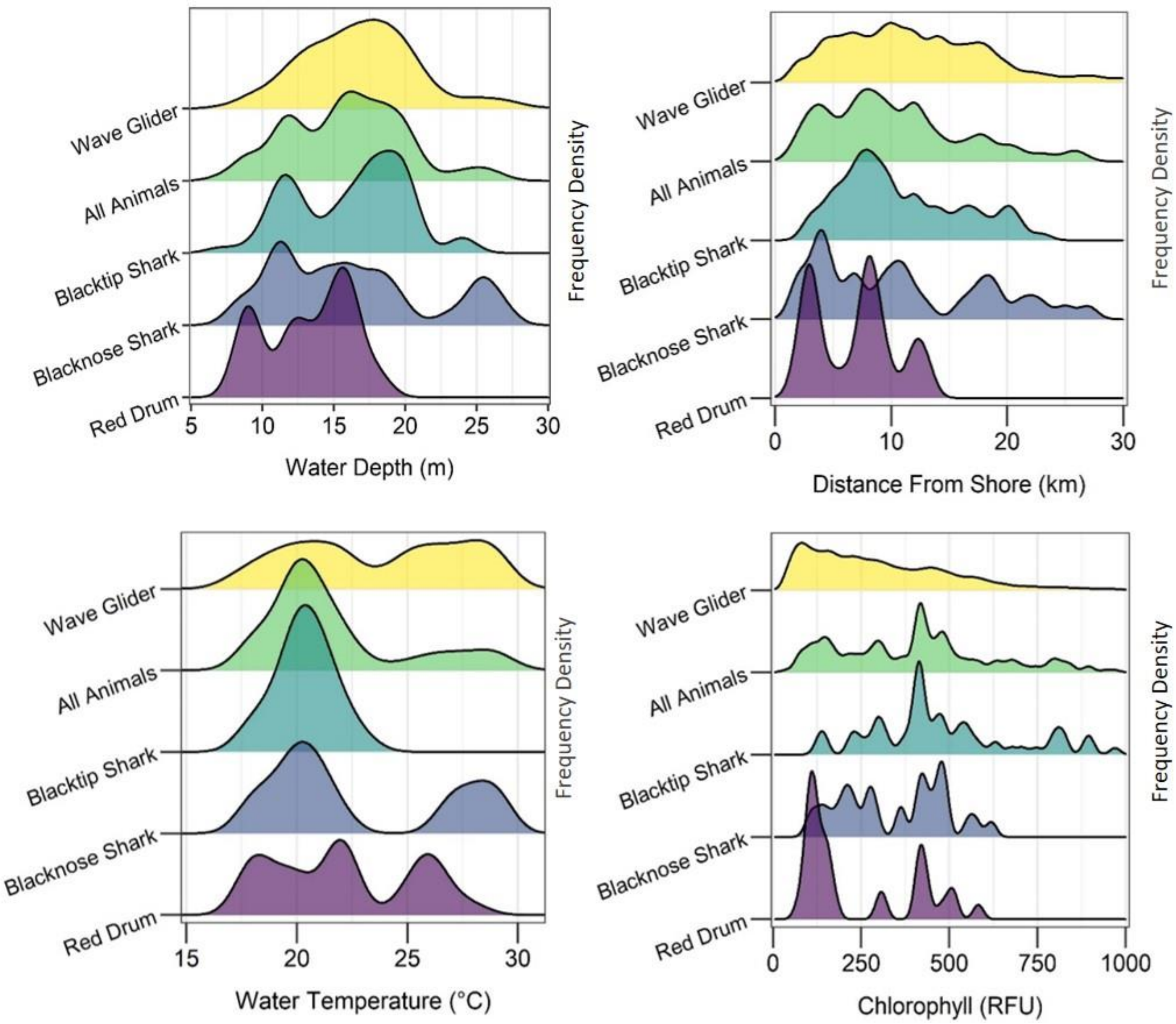


Figure 13. Frequency distribution of available vs. selected habitat recorded by the Wave Glider
The category 'All Animals' includes all individuals of all nineteen detected species

Animal encounters with the Wave Glider averaged only 14.1 (± 24.2) minutes. The longest encounter was with a blacktip shark in March 2018 whose course of travel paralleled that of the Wave Glider for over 4 hours. In contrast, encounters of animals with fixed stations in the Canaveral Array lasted over twice as long on average (**Table 14)** although direct comparison between the two approaches were often confounded by a small sample size and the variety of tag styles used across species and researchers. Tiger, bull, and white sharks were the only species whose interactions with the Wave Glider lasted longer than the mean encounter with Canaveral fixed-station receivers.

Table 14. Production of the Wave Glider receivers vs. the Canaveral Fixed Array

Comparison only includes acoustic data collected on days when the Wave Glider was deployed

-	Wave Glider			Canaveral Array			Glider / Canaveral Array Ratios		
Deployment	No. Species	No. Tags	No. Detects*	No. Species	No. Tags	No. Detects*	% Species	% Tags	% Detects*
1	10	44	366	11	112	56,872	90.9	39.3	0.6
2	7	28	937	16	108	27,574	43.8	25.9	3.4
3	7	20	82	13	49	13,433	53.8	40.8	0.6
4	8	19	95	7	30	10,217	114.3	63.3	0.9
5	12	62	753	17	124	14,813	70.6	50.0	5.1
6	10	33	379	16	138	28,630	62.5	23.9	1.3
7	6	16	87	18	73	48,499	33.3	21.9	0.2
8	5	21	136	11	39	7,783	45.5	53.8	1.7
Mean	**8.1**	**30.4**	**354.4**	**13.6**	**84.1**	**25,977.6**	**64.3**	**39.9**	**1.7**

*Red snapper detections excluded due to the high likelihood detections are from shed tags

3.4 Discussion

Over this two-year evaluation, the Wave Glider proved itself as a platform capable of supporting tracking studies of acoustically tagged animals on the continental shelf. The vehicle cumulatively traveled nearly 10,000 km, repeatedly navigated a preprogrammed course without serious issue, and collected high resolution water quality data along a gradient from shallow inshore shoal margins to deeper offshore reefs. Moreover, it detected more tagged fish and species than has generally been reported elsewhere and paired these detections with localized oceanographic and meteorological readings, providing habitat context that is hard to collect in fixed tracking arrays.

3.4.1 Operational Considerations

Ocean gliders are likely to have increased relevance to BOEM field operations in the coming years. Besides the animal tracking and ocean soundscape survey capabilities utilized here, gliders of various configurations may become suitable platforms for monitoring ocean currents and turbidity plumes near active dredge sites, detecting leaks of petroleum products from oil platforms and pipelines, and conducting bathymetric surveys of new project areas, among other goals. While these routine tasks are still generally performed from crewed vessels, gliders may soon provide greater frequency and duration of sampling at a reduced cost.

The results and lessons learned from the present study should help improve project planning and reduce the operational risks associated with future glider projects undertaken by BOEM or other organizations conducting biological surveys over the continental shelf. Perhaps the primary advantage of the Wave Glider when operating near the Canaveral Shoals was that its continuous satellite link allowed it to follow a predefined and systematic survey path with high fidelity and thus avoid known hazards such as the shoreline, shallow shoal ridges, and navigation buoys. Significant deviations from the planned course only occurred for one day at the end of Deployment 1 due to a combination of calm seas and a longshore current of roughly 2.5 km/hr, although an unrelated soundscape mission in July 2021 was ended early due to similarly unsuitable conditions. At the end of Deployment 4, the survey path was even modified to bring the glider inside Port Canaveral for retrieval due to hazardous seas offshore. Moreover, restricting operations to water depths greater than 10 m provided a sufficient safety margin, and the vehicle (which drafts 5 m) never grounded. This safety buffer precluded sampling the shallowest areas of the Canaveral Shoals but did allow operations over the CSII dredge site; many other sites identified for sand extraction by BOEM are also over 10 m deep. Published navigational charts were somewhat inaccurate near the shoals, likely due to sand migrating after the map was produced, and the project benefited from first verifying water depths along the shoal margins and adjusting the final transect prior to the first deployment. Wave Gliders can also be fitted with echosounders to improve navigational awareness in areas where depth is unknown.

Despite certain operational advantages when operating in shallow coastal waters, surface gliders have drawbacks relative to subsurface gliders that will be relevant for certain survey tasks. Notably, surface gliders cannot easily measure vertical gradients in temperature, salinity, and other chemical or biological properties of the water column. This constraint is important for projects requiring access to deeper habitats, although Wave Gliders are available with much longer tethers to access greater depths, and glider fleets could easily include both surface and subsurface vehicles. In addition, surface gliders are more susceptible to interactions with boats and fishermen. While no boat strikes occurred in the present study, it was common for the Wave Glider to undertake temporary automated course deviations to reduce the risk of collision with AIS-enabled vessels. Fisherman interactions were confirmed in the form of fishing line left on the glider on at least two deployments, one of which tangled the thruster and degraded the vehicle rate of movement. The northern Gulf of Mexico, a region with considerable maritime traffic associated with offshore energy production and commercial shipping, is an area where vessel strike risk could be particularly high.

3.4.2 Gliders for Animal Tracking

Ocean gliders are already in use by several groups for acoustic tracking purposes (see Oliver et al. 2013; Haulsee et al. 2018; Cote et al. 2019, though many studies remain unpublished)**,** are used to demonstrate proof-of-concept, or are byproducts of other oceanographic research. As capabilities improve and costs decrease, ocean gliders will increasingly be viewed as core assets for collection of animal tracking data from which to base management decisions. One likely point of deliberation is how much to invest in mobile tracking platforms vs. fixed-station tracking arrays. In the present study, the concurrent operation of a glider and a large fixed-station acoustic tracking array at Cape Canaveral provided a rare opportunity to compare the strengths and limitations of each approach.

Of greatest significance, the Wave Glider demonstrated itself as a technically capable tracking platform, detecting a relatively large number of species (20) and individuals (167). This number of animal relocations is higher than reported elsewhere but is due in part to operating in east Florida, a region with multiple ongoing fish tracking studies and a strong culture of researcher collaboration which helped for identifying animals tagged by others. The platform did not produce many false detections (a common artifact in acoustic tracking), relocated at least five tags shed by animals, and data were retrieved without the need of SCUBA diving. The Wave Glider (as with other glider platforms) also allowed for the simultaneous collection of multiple environmental covariates as animals were detected, providing important localized habitat context. These included sea surface temperature, dissolved oxygen, chlorophyll, and turbidity but if properly provisioned, the glider could also measure other water quality characteristics, baitfish biomass, or seafloor rugosity. Finally, the Wave Glider unexpectedly assisted in the management of the Canaveral Array itself. Specifically, four VR2AR tracking receivers deployed on the reef tract and weighted with 45-kg cement moorings were displaced during Hurricane Dorian (September 2019) despite being originally placed in water 15–25 m deep. Because each receiver had an internal transmitter detectable by the Wave Glider, these displacements were recognized during the next glider deployment. Subsequently, systematic orbital glider searches were conducted, and all four units were relocated and recovered 0.5, 0.8, 4.4, and 5.3 km southeast of their original sites.

The central limitation of glider-mounted acoustic tracking is that monitoring occurs around a single, albeit ever-changing, location at any given time, resulting in a sparser dataset with which to infer animal movement. In this study, when considering only the days when the glider was on mission, the glider logged only 64% of the species, 40% of the tags, and less than 2% of the detections of that produced by the 62 station Canaveral Array. Moreover, the status of an animal (i.e., living vs. dead) generally required at least two encounters at different locations, and in many cases, tag status was only confirmed with subsequent animal movements through the Canaveral Array. One possible way to reduce this issue would be to incorporate available depth or swim speed sensors into acoustic transmitters to confirm animal motion more quickly or to loiter at detection locations to detect movement away from the site.

3.4.3 System Performance

Range testing is key to the appropriate design of acoustic telemetry studies and should be a component of any major tracking effort (Kessel et al. 2014). This is perhaps even more true for glider-based surveys, an emerging approach that clearly holds promise, but for which real world tracking applications remain rare. Results from glider-based range tests will help set realistic expectations regarding study area boundaries, transect spacing, and overall mission duration, among other factors.

Range testing with the Wave Glider suggested that animals can regularly be detected from several hundred meters away, but performance was somewhat reduced compared to nearby bottom-mounted receivers in the Canaveral Array. Further, at least two previous glider-based range test studies have been conducted with which to draw comparisons. Oliver et al. (2017) evaluated the performance of VR2C and VMT receivers integrated into a Slocum buoyancy glider during a 20-day deployment off New Jersey and Delaware while Cimino et al. (2018) assessed Vemco VR2W and VR2Tx receivers mounted on a Wave Glider SV3 during a one-week trial off Southern California. The present study complemented these earlier efforts by evaluating the VR2C and VMT receiver types—models designed explicitly for glider operations—on the Wave Glider platform and by testing across multiple deployments and a wider range of environmental conditions. While the previous studies each had different designs, both reported the distance at which 20% of range tag transmissions were successfully received. Using a 156 dB tag, Oliver et al. (2017) found that 20% of transmissions were detected at 600 m for a VR2C and 400 m for a VMT. Cimino et al. (2018) reported 20% of detections on the best performing receiver occurred at 500 m for a 153 dB tag and 800 m for a more powerful 160 dB tag. This was comparable to the 20% detection distance of 500 m and 400 m observed in the present study (158 dB tag) for the VR2C and VMT respectively. Combined, the studies suggest that Wave Gliders have superior performance at closer distances than the Slocum glider but also confirmed that detection rates remain below 100% even when within 100 m of a tag.

There were limitations in the Canaveral range test trials that may be worth addressing in future tests. For example, the study used only a single style of high-power tag, albeit one commonly adopted in open ocean tracking studies. Species requiring smaller (and therefore generally lower power) tags will have reduced detection ranges and these tags should be directly evaluated. Second, range test orbits occurred at 250 m increments which in hindsight was a relatively large interval given the maximum detection range of 900 m. Time permitting, range test orbits of 100 m would provide finer resolution, especially when low power tags are under consideration. Finally, the study did not account for water quality stratification (e.g., thermoclines), features which are seasonally common off the east Florida shelf and have been shown to affect acoustic tag propagation in other studies (Oliver et al. 2017).

Scenarios where ocean gliders, and a Wave Glider in particular, might be preferred over a fixed tracking array could include mitigation monitoring of dredge and construction sites for protected fish species (Verfuss et al. 2019), which in the southeastern US might include smalltooth sawfish, giant oceanic mantas, or Atlantic sturgeon. The real-time data stream would allow operations to be modified or halted when animals are detected inside a predefined perimeter (with the caveat that lack of detections does not assure that a species is absent). Wave Gliders would also be useful in studies where tagged animals are likely to disperse across patchy habitat such as isolated reefs, offshore wind turbines and oil platforms, or along linear habitat features such as barrier reefs and steep rocky coastlines. In such instances, animals are likely concentrated in a small subset of an overall project area and well-designed and repeatable transects should generate robust movement data over time. With some prior knowledge of a species' life history, sample size, tag specifications, and system detection range, various search strategies could even be simulated and optimized prior to the first glider deployment. The glider could also conceivably follow along with the migrations of certain coastal species including sharks and manta rays to help understand distribution of fish across environmental gradients in temperature, chlorophyll, or other parameters. Finally, further investment into capabilities for active tracking that generate animal range and bearing would allow fine-scale positions of tagged animals to be produced. The omni-directional receivers commonly mounted on ocean gliders can only confirm when an animal is within its overall detection range, typically a radius of hundreds of meters. Progress has been made on active tracking (see Clark et al. 2013; Skomal et al. 2015; White et al. 2016; Lin et al. 2017; Dodson et al. 2018), but these efforts are still generally limited to short deployment durations in a small area. Developing the means to track fine-scale movements of 'fish of opportunity' when encountered on long deployments would dramatically improve home range estimates of mobile species on the open shelf, document microhabitat associations, and allow responses to anthropogenic disturbances such as pile driving and dredging to be quantified.

4 Sea Turtle Habitat Associations

4.1 Introduction

Global impact of climate change and sea level rise obligate balancing protection of infrastructure as well as minimizing habitat loss, especially for threatened and endangered species. There are seven sea turtle species in the world, six of them have been found in the southeastern US, and all of these are federally protected. Most abundant are loggerhead (*Caretta caretta)* and green (*Chelonia mydas*) sea turtles that utilize nearshore waters and adult females that nest on sandy beaches. In comparatively fewer number are leatherback (*Dermochelys coriacea*) and Kemp's ridley (*Lepidochelys kempii*) turtles that also nest on these beaches. Offshore or migrating in comparatively lower numbers are hawksbill (*Eretmochelys imbricata*) and Olive ridley (*Lepidochelys olivacea*) turtles. The presence or abundance of different life stages and size classes of all these turtle species vary.

In and around the sand shoals off Cape Canaveral, loggerhead, green, and Kemp's ridley are the most frequently sighted sea turtles with juvenile and adult life stages present at different times of the year (Carr et al. 1980; Butler et al. 1987; Dickerson et al. 1995; Schmid 1995). Present but in lower abundance is the adult leatherback turtle (Schroeder and Thompson 1987). Just south of this area, but less frequently observed, are hawksbill turtles (Eaton et al. 2008). Uniquely, there have been a handful of local encounters of the Olive ridley turtle.

Shoals off Cape Canaveral provide sand resources that can be useful in restoring nearby shorelines that protect infrastructure and are important for nesting sea turtles. Little is known, however, about impacts to sea turtles during and after construction and dredging activities necessary to restore sand depleted areas. In the past three decades, advances in technology and management of dredging activities have worked to minimize direct impacts to sea turtles (i.e., the injury or mortality from a dredge strike or entrainment in equipment) (Reine and Clarke 1998; Dickerson et al. 2004). However, little is known about indirect impacts from habitat loss for sea turtles. Potential indirect threats include loss of refuge (resting areas) and/or changes in foraging resources (e.g., invertebrate diversity and abundance) or trophic level feeding (Nairn et al. 2004). Habitat alterations can negatively influence sea turtle energetics (i.e., wider home ranges) caused by food scarcity or introduce competition. Sandy shoals can be virtual 'hotspots' of high invertebrate density and diversity (Dubois et al. 2009). After disturbance from dredging activities the recovery of invertebrate communities may be dependent upon numerous factors. High current regimes have been associated with rapid and short recovery times (1-3 years), similar to areas with high productivity (van der Veer et al. 1985; van Dalfsen et al. 2000). Areas with low currents may take much as much as 5 years or longer to recover (van der Veer et al. 1985). The duration of disturbance is also important, with less disturbed sites showing recovery in 2 years (Boyd et al. 2005). Recovery of benthic and infaunal invertebrates at Canaveral shoals from dredging is expected to be rapid, given the high energy, shallow, dynamic environment, with effects mostly considered transient (Murie and Smith 2022). Data concerning the potential role of sand shoal habitat in the life history of sea turtles are important for making informative decisions concerning the management of these areas.

Sea turtles, as are many marine fauna, are notoriously difficult to study as they spend nearly all their lives at sea (~ 95% for females, 100% for males). Well-designed telemetry studies allow researchers to gain insight into sea turtle movement and behavior. Multiple products are available, each with its own advantages for the animal studied and/or environment constraints, and the hypothesis being tested. For sea turtles, satellite telemetry has been used for more than 40 years to track their movements (Stoneburner 1982; Hart and Hyrenbach 2010). The Argos satellite system and improvements in tag technology and instrument attachment has provided opportunities for higher resolution tracking for much longer periods of time (Hays et al. 2016). Additionally, the utility of Fastloc GPS technology has improved location accuracy within tens of meters (Hazel 2009). Improved resolution allows more reliable application of environmental data as well as improves directionality detail (Dujon et al. 2014; Christiansen et al. 2017). Data filtering, refinements and additions to state-space models (SSMs) and other programs (e.g., Markov Chain Monte Carlo [MCMC]), have improved autocorrelation detection and convergence diagnostics, resulting in improved data analysis of Utilization Distributions (UDs) and activity space.

Coupled with satellite tracking, acoustic tracking data can reduce gaps in movement and location data. Acoustic transmitter tags are generally smaller and lighter weight than satellite tags and can provide continuous transmission signals underwater. They have been successfully applied to track sea turtle movement over the past three decades. (Hart et al. 2012) tracked hawksbill turtles using satellite and acoustic telemetry and was able to improve overall movement data resolution in the Dry Tortugas, US. In areas that are semi-enclosed (e.g., bays, estuaries), acoustic telemetry can provide optimal movement resolution (Lamont et al. 2015) or arrays can be concentrated in an area of interest to allow no signal leakage of tagged animals.

IMU (inertial measurement unit) devices are a newer available instrument with technology to detect linear acceleration (via accelerometer), rotation (via gyroscopes), and heading or orientation (via magnetometers). Data collected provide a fine-scale 'picture' of how an animal moves through its environment, discerning behavior—such as resting, diving, foraging (Tyson et al. 2017)—that are translatable into metabolic and energetic status.

In 2017, (Iafrate et al. 2019) employed the use of satellite and acoustic telemetry to investigate the movement and habitat use of nesting female green and loggerhead sea turtles in the vicinity of Canaveral Shoals during their inter- and post-nesting activities. The study explored differences in habitat use between species, the potential relationship of habitat use and environmental variables (site depth and sediment fines), and examined individual migratory paths to foraging ground destinations. The goals of this study are to build on the previous findings and utilize IMU instruments to quantify metabolic and energetic status of sea turtles within Canaveral sand shoals. Specific questions addressed for loggerhead sea turtles during this study period include:

1. Do the UD and core areas of adult female loggerhead turtles include shoal areas in Canaveral?
2. Is there a relationship between habitat use and water depth or sediment grain size?
3. What is the behavior (resting, sleeping, foraging) of turtles within shoal areas?
4. How do sea turtle tracking results in 2017 study compare with the current study?

Combined, these results will help determine whether sand shoals of the east Florida shelf serve a unique role in the life history of managed sea turtles and help better define the risk of sand borrow activity on protected sea turtle species. Ultimately, this information is important to mitigate potential impacts through closer examination of the temporal and spatial relationship of sea turtle behavior within the water column near shoal habitat.

4.2 Methods

4.2.1 Sea Turtle Collection and Satellite, Acoustic, and IMU Tagging

The Canaveral study area boundaries adjacent to the turtle nesting beaches are shown in **Figure 4**. Ten female loggerhead turtles were tagged from mid-June to early July 2018, within what is considered peak loggerhead nesting season. Females were contained on the beach after they completed nesting or false crawled. Only loggerheads were tagged in 2018 to maximize the more labor-intensive deployment and retrieval involved with the IMU dataloggers. Capture and handling of each animal followed the same methods and permitted protocols described in Iafrate et al. (2019). All turtles were fitted with a satellite transmitter (tag number pre-fix PTT), acoustic transmitter, and IMU tag (labeled A-J) (**Table 15**). Wildlife Computers SPLASH10-BF-334D satellite transmitters (8.4 x 8.4 x 3.8 cm; estimated battery life 470 days) were ideal for documenting turtle movements throughout the Canaveral region and as they commenced long-distance, post-nesting migrations. These platform terminal transmitters (PTT) provide animal location data through Fastloc GPS with precision of up to 20 m. The tags also produce less accurate positions from Argos satellites when GPS locations cannot be obtained. These Argos locations are assigned a location class based on the relative accuracy of the location, which could range from 100s of meters to several kilometers. Each satellite transmitter also contained a wet/dry sensor that flagged extended periods at the surface (i.e., "haulouts") that suggested possible nesting events.

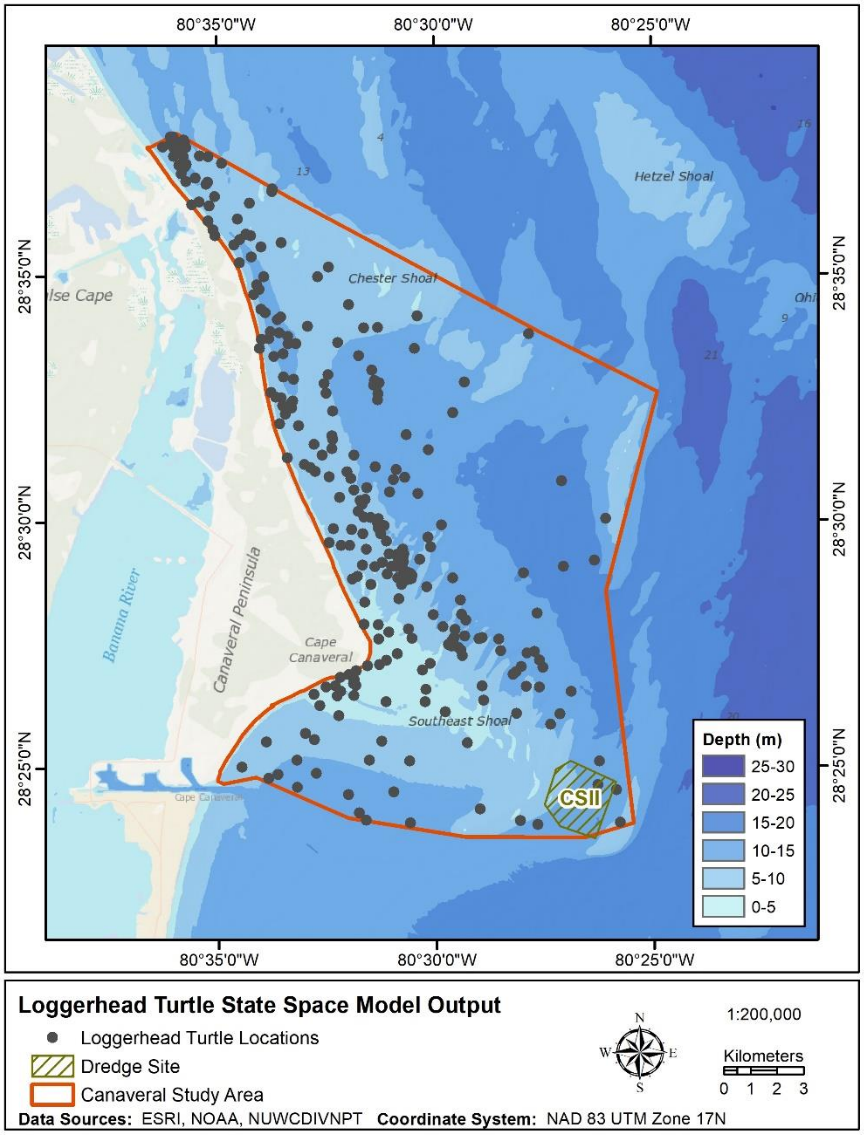


Figure 14. Loggerhead turtle satellite relocations within the core Canaveral study area (2018)

Table 15. Tagging details for female loggerhead turtles tagged at Cape Canaveral

SCLn-t refers to straight carapace length notch to tip and SCLmin refers to minimum straight carapace.

Release Date	SCLn-t	SCLmin	PTT ID	IMU Tag ID	Acoustic Tag ID
6/14/2018	NR	84.0	171973	A	15993
6/14/2018	86.7	84.7	171974	D	15995
6/14/2018	98.2	96.7	171976	B	20079
6/14/2018	82.8	80.5	171977	C	15983
6/30/2018	96.1	94.0	171979	E	15986
6/30/2018	82.7	82.7	176062	F	15990
6/30/2018	92.9	90.2	176064	G	15987
6/30/2018	81.0	78.3	176065	H	15977
7/02/2018	98.7	NR	176063	I	15989
7/02/2018	100.5	98.3	176066	J	15992

An acoustic transmitter (Innovasea V16-4H coded transmitter, 50–130 sec. ping interval) was attached to the lower left or right posterior costal scute (#5) near the marginal scutes (Figure 77 in Iafrate et al. 2019) using two-part marine grade epoxy. These transmitters, while less capable than satellite tags in that they only allow positions to be detected within a few hundred meters of a deployed receiver, are inexpensive, often have long retention rates, and are useful in data validation of satellite tracking data (Hart et al. 2012). The acoustic tags were compatible with receivers in the Canaveral Array and the wider FACT Network.

IMU tags (OpenTag, Loggerhead Instruments, Sarasota, FL, USA, 10.5 x 4.7 x 2.2 cm, 110 g) integrate a 3D accelerometer, magnetometer, and gyroscope with pressure, temperature, and light sensors. The tag produces accelerometer, gyroscope, and magnetometer data at 50 Hz and temperature and pressure at 1 Hz. As only accelerometer and pressure data were used for the analysis in this study, no specific calibration was required with exception of verifying a magnitude of 1.0 g for the accelerometer at rest. Each IMU tag was powered by 2 lithium-polymer batteries with an estimated life of 14 days and was encased in sufficient syntactic foam to make it positively buoyant. Tags were equipped with a very high frequency (VHF) transmitter to assist in recovery once it detached from the turtle since these tags had to be retrieved to download recorded data. The IMU tags were programmed to release in the early morning to allow maximum time for tag recovery by boat during daylight. IMU recording began at the time of programming, typically at 2200 hrs (local) on the night of deployment. This allowed collection of pre-deployment baseline data and a unified tag detachment time to facilitate recovery. Due to the instrument's sensitive connections, the IMU tag was affixed after the satellite and acoustic tags. Marine epoxy was used to secure the IMU attachment plate to the carapace just behind the satellite transmitter tag (**Figure 15**). A smaller piece of putty was affixed 10 to 15 cm posterior to the first on the carapace to create a level resting spot for the posterior end of the IMU tag. The tag was then secured to the attachment plate with 0.3-mm diameter stainless steel wire. When an electric current is signaled from the tag, the wire rapidly corrodes through the connection and the tag is released from the plate and floats to the surface of the water. A double-wire arrangement was implemented when it was discovered that initial deployments using only a single-wire link broke and prematurely released the IMU.

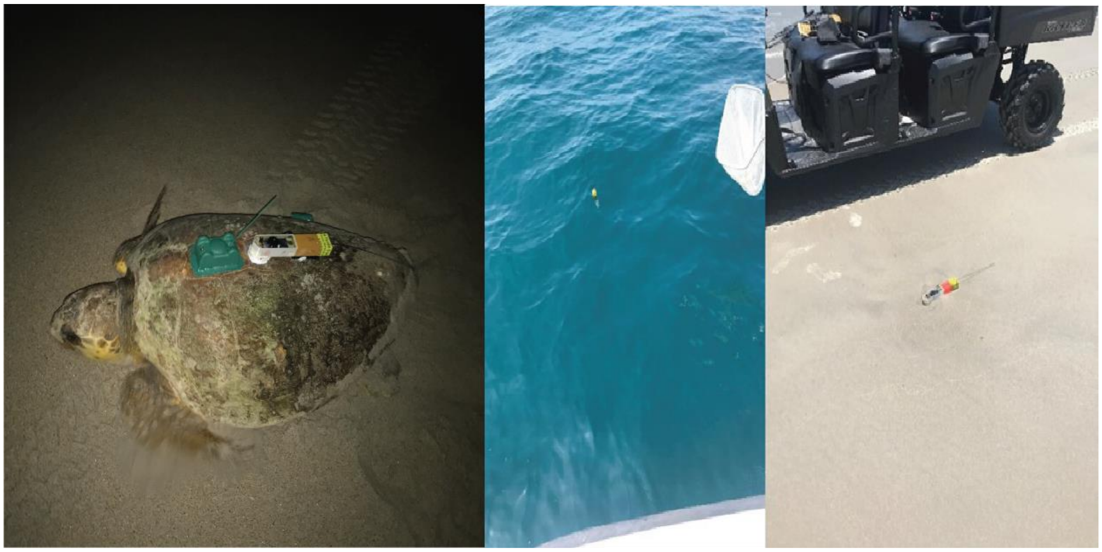


Figure 15. IMU and satellite tag attachment (left), recovery from boat (center), and beach (right)

IMU tag separation was necessarily shortened for turtles captured late June and early July for recovery purposes. The decrease in deployment period was implemented to reduce data loss risks for turtles nesting in late June and July that could be depositing their last nests and departing the Canaveral region, making instrument retrieval more difficult or unlikely. Therefore, the IMU tags deployed on turtles captured June 14 were set to disconnect 14.5 days post-deployment while tags on turtles captured June 30 and July 2 were set to disconnect 6.5 days after deployment.

A VHF receiver with a directional antenna was used on each scheduled release date to search for floating IMU tags with the latest signal from the satellite transmitter used as the starting point for recovery efforts. Sweeps were made with the directional radio antenna from land first, up the beach, across the water, and back onto the beach listening for the signal. Sweeps continued further along the beach until a signal was acquired and then signal strength triangulation was confirmed from several locations. This method proved successful in locating IMU tags that had washed up on local beaches as well as for tags still drifting farther offshore.

4.2.2 **Data Analysis**

4.2.2.1 Satellite Telemetry and State-Space Modeling

Data from loggerhead turtle satellite tags were retrieved via the Argos satellite system and positions were reviewed for the overall status, extent, and quality of tag transmissions. To refine tracks and classify behavior of tagged turtles within the Canaveral region and to improve the quality of locations, a Bayesian switching SSM was applied to satellite telemetry data, which takes into account Argos and Fastloc GPS location error when estimating animals' locations. SSM turtle locations were subsequently used to quantify water depth and sediment associations. Loggerhead turtle locations were analyzed with a first-difference correlated random walk model (Jonsen et al. 2005). Each reported location was 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. For more detail on the process of filtering and the methods for the SSM, see (Iafrate et al. 2019).

All satellite tag 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 used as input for each individual in the SSM. The SSM was run using R using the *bsam* package (Jonsen et al. 2005) and JAGS (Plummer 2017) for MCMC sampling. After evaluation of variability and average time interval between detections for all individuals, a time step of 5.5 hours was used to improve time to model converge and eliminate unrealistic fine time intervals. Convergence diagnostics of each model included visual examination tests for autocorrelation and evaluation to determine if the MCMC chains had converged as expected for each parameter (Brooks and Gelman 1998).

Positional data output from the SSM were reimported into the ArcGIS 10.3 environment for visual examination of tracks. All positions were classified by depth contour bins (0–5 m, 5–10 m, 10–15 m, or 15–20 m) and % of sediment fines (0–5, 5–10, 10–15, 15–20) for each individual track within the Canaveral study area. UDs of 50% (core use areas) and 95% (activity space) were also calculated locally from kernel density estimates, including overlap with bathymetry and % of fine sediments for the study area, similar to Iafrate et al. (2019). Overlap of core use areas was calculated in ArcGIS. The metrics are defined as follows:

Core Use Areas: areas of concentrated space use within the range of the animal, estimated using the 50% volume contour of the kernel density estimation.

Activity Space: Larger areas of overall occurrence for the animal, estimated using the 95% volume contour of the kernel density estimation.

Finally, Manly selectivity analysis (Manly et al. 2002)was conducted on both the pooled and individual animal results using points from SSM output, using the R package *adehabitatHS* (Calenge 2006). The Manly selectivity measure corresponds to the selection ratio (used/available), and as part of this test the preference and/or avoidance is tested for each habitat variable, and differences between ratios. This statistical test was used to investigate whether a habitat preference or association for specific depth bands (0–5, 5–10, 10–15, 15–20 m) or % sediment fines (0–5, 5–10, 10–15, 15–20%) exists.

4.2.2.2 IMU Tags and Analysis of Dive Behavior

R Software, specifically the *diveMove* package (Luque 2007) and base R functions were used for organizing, plotting, and analyzing IMU dive data. Pressure (depth) data were corrected using the Zero Offset Correction method in the *diveMove* package. Calculations included average depth, max depth, dive mean duration, dive max duration, mean surface interval, and percent (%) time submerged. Diel patterns in dive parameters were tested using Wilcoxon signed-rank matched-pairs test. Additionally, plots of dive depth versus time were produced and Vector Dynamic Body Acceleration (VDBA) and Overall Dynamic Body Acceleration (ODBA) were calculated based on the description provided in (Halsey et al. 2009)and (Wilson et al. 2017). ODBA is considered a proxy for activity level. VDBA can be used as a proxy for energy consumption or metabolic rate. Satellite GPS locations were linked to dives occurring within 100 s of the recorded location to allow analysis of dive habitat (i.e., GPS-linked dives). Only GPS locations with dives occurring within 100 s were considered for this analysis given the assumptions of the average swimming speed of sea turtles and the locational accuracy of GPS locations. VDBA and ODBA were also characterized for time periods within 3 hours of a 2-D SSM position estimate to assess changes in activity by behavioral state.

4.3 Results

4.3.1 Movement Summary

Satellite transmission data from tagged loggerhead females averaged 179.3 days (± 162.2 SD), ranging from 29–495 days; **Table 16**). The last transmission received from a satellite tag was 18 October 2020. Location data points from the 10 tags totaled 7,865 (5,591 Fastloc GPS and 2,274 Argos-only). Based on "haulout" data, only two turtles appeared to have nested one or more times (i.e., re-nest) after they were initially tagged on the nesting beach. The haulout data from one turtle (tag id. PTT 171973) indicated it potentially nested on Melbourne Beach (approximately 25 miles south). The other turtle (PTT 176064) appeared to have nested on Cape Canaveral Space Force Station (CCSFS), north of the cape tip and re-nested on at least two occasions July 14 and August 9. Before departing the vicinity of Canaveral altogether, turtles spent 2–41 days in the region (**Table 16)**. The actual percentage of time tracked (based on days) that turtles were in the Canaveral region ranged between 3.1–51.7% (average 19.1 ± 16.9 SD). All but one turtle (PTT 176064) completely left the area by the end of July. Therefore, it appears from tracking data the majority of turtles were at or near the end of their nesting period. For the most part, turtles were not fixed in the Canaveral region but instead passed through the study area several times over the course of tracking with individual visits lasting only 1–3 days. Overall, loggerheads utilized slightly deeper waters in 2018 vs 2017. In 2018, 66% of the raw, non-normalized SSM locations were between 10–15 m deep, while in the 2017, 65% of non-normalized SSM locations occurred in water only 5–10 m deep (**Figure 14**, Iafrate et al. 2019).

Table 16. Movement summary for loggerhead turtles tagged in June and July 2018

The term "Inter" use refers to satellite relocations on shoal habitat between nesting events, while "Post" use refers to satellite tag relocations on shoal habitat after nesting was completed.

PTT Identity	Release Date	Date Left Canaveral	Days in Canaveral Region	Shoal Detections	Days Tracked	Date of Last Position	Last Known Location
171973	6/14/2018	7/2/2018	18	Inter	108	09/29/2018	82 km S of Little St. George Island, FL
171974	6/14/2018	7/2/2018	18	Post	425	08/11/2019	85 km SW of Great Exuma Island, Bahamas
171976	6/14/2018	6/27/2018	13	None	117	10/08/2018	33 km E of Jacksonville Beach, FL
171977	6/14/2018	7/12/2018	28	Post	60	08/12/2018	80 km SE of St. Augustine Beach, FL
171979	6/30/2018	7/1/2018	2	None	65	09/02/2018	60 Km SE of Mayport, Jacksonville, FL
176062	6/30/2018	7/14/2018	15	Post	29	07/28/2018	25 km E of Cape Fear, NC
176064	6/30/2018	8/9/2018	41	Inter	495	11/06/2019	25 km S of Great Exuma Island, Bahamas
176065	6/30/2018	7/29/2018	30	Post	149	11/25/2018	110 km E of Fernandina Beach, FL
176063	7/2/2018	7/31/2018	29	Post	264	03/22/2019	57 km SW of Cape Romano, FL
176066	7/2/2018	7/17/2018	15	Post	81	09/20/2018	10 km SW of Cape Charles, VA

4.3.2 **Local Habitat Use (Including CSII Dredge Site)**

4.3.2.1 Utilization Distribution Maps, Core Use Areas, and Individual Variation

The most heavily used areas were the shallow areas along the coast to the north of and immediately adjacent to Cape Canaveral (**Figure 16**). Loggerhead turtles regularly used nearshore waters north of Cape Canaveral as well as the ridge and swale habitat on the northern flank of the Southeast Shoal. Core use area (50% UD) overlapped with the CSII dredge site for only one turtle while activity space use (95% UD) overlapped the dredge site for two turtles. Core and activity use areas had minimal overlap with the Chester Shoal control site. Core use areas for most of the individual turtles were small, less than 5 km^2, in more than half of the individuals monitored. Only one turtle's core area exceeded 10 km^2 (**Table 17**). Turtles' core and activity use areas tended to be closer to shore in shallow water (≤ 5-m depth), where percent sediment fines were low (0–5%; **Table 17**; **Figure 16**).

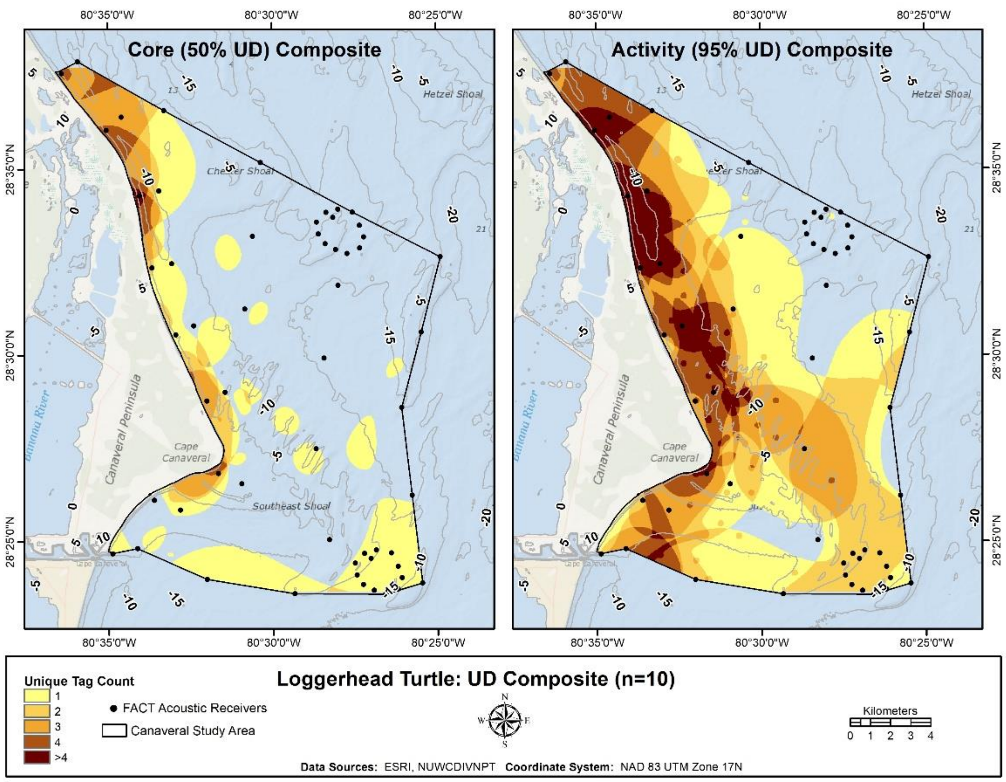


Figure 16. Local habitat use by loggerhead turtles tagged in 2018

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

Table 17. Overlap of loggerhead turtle core use areas with bathymetry and sediment % fines

Values shown for bathymetry and sediment % fines are mean, displayed as a percentage, normalized based on habitat available in each bin.

Core Use Area Size	**0–5 km²**	**5-10 km²**	**10-15 km²**	**15-20 km²**	**20-25 km²**
% of turtles	60	30	10	NA	NA
Water Depth	**0–5 m**	**5–10 m**	**10–15 m**	**15–20 m**	**20-25 m**
% of core use area	44	25	13	18	NA
Sediment % Fines	**0–5%**	**5–10%**	**10–15%**	**15–20%**	**20-25%**
% of core use area	26	16	20	11	27*

*This percentage comes from overlap of the 50% UD with 20-25% sediment fines polygons. However, no SSM estimated locations directly occurred in these areas, resulting in no data for the Manly analysis described below. Both analyses show preference for low sediment fines.

4.3.2.2 Manly Selectivity Analysis from SSM Output

Manly selectivity analyses were used to examine resource selection (habitat used/habitat available) for turtles by comparing selection ratios for bathymetry and sediment % fines, and specifically testing for preference/avoidance of different binned habitat types. While non-significant ($p > 0.05$), pooled results of individual turtles indicate there was a positive association of turtles for low sediment % fines, and negative relationship for other sediment classes (

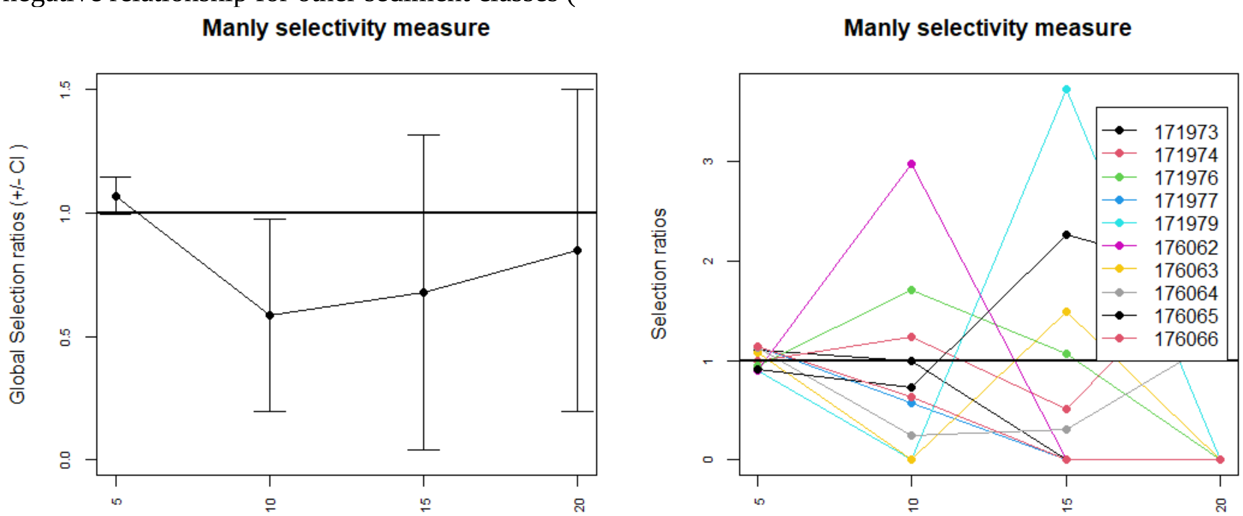


Figure 17). When analyzed for depth preference, the association was positive for water 5–10 m deep, negative for depths 15–20 m, and roughly neutral for the other depths. Turtle utilization of 5–10-m and 10–15-m depths was significantly greater ($p < 0.05$) when compared with use of 15–20-m depths (**Figure 18**).

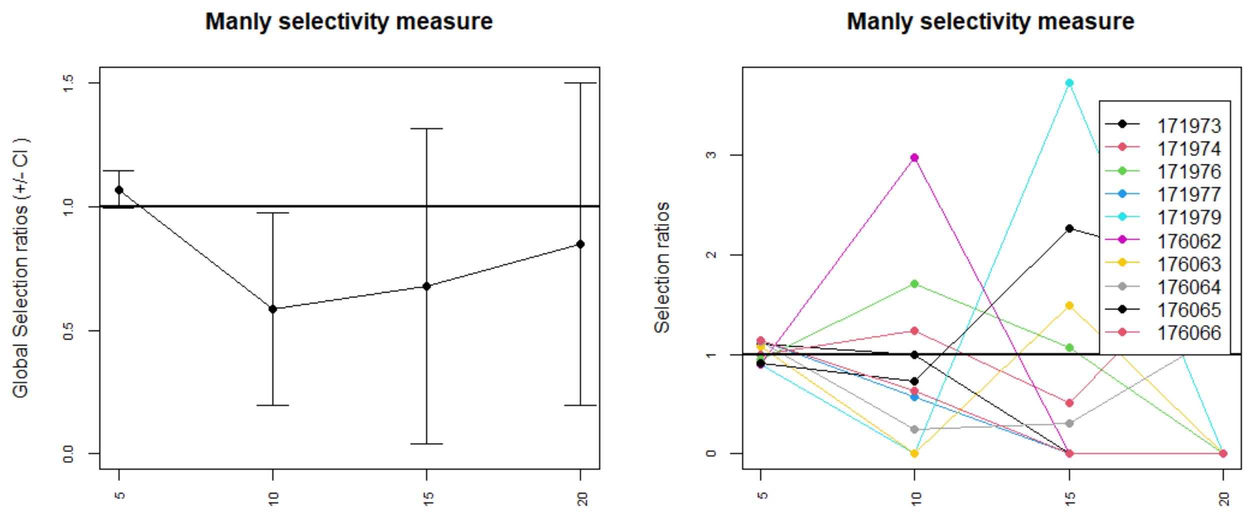


Figure 17: Manly selectivity for sediment type by % fines, pooled for all turtles (left) and individual turtles (right)

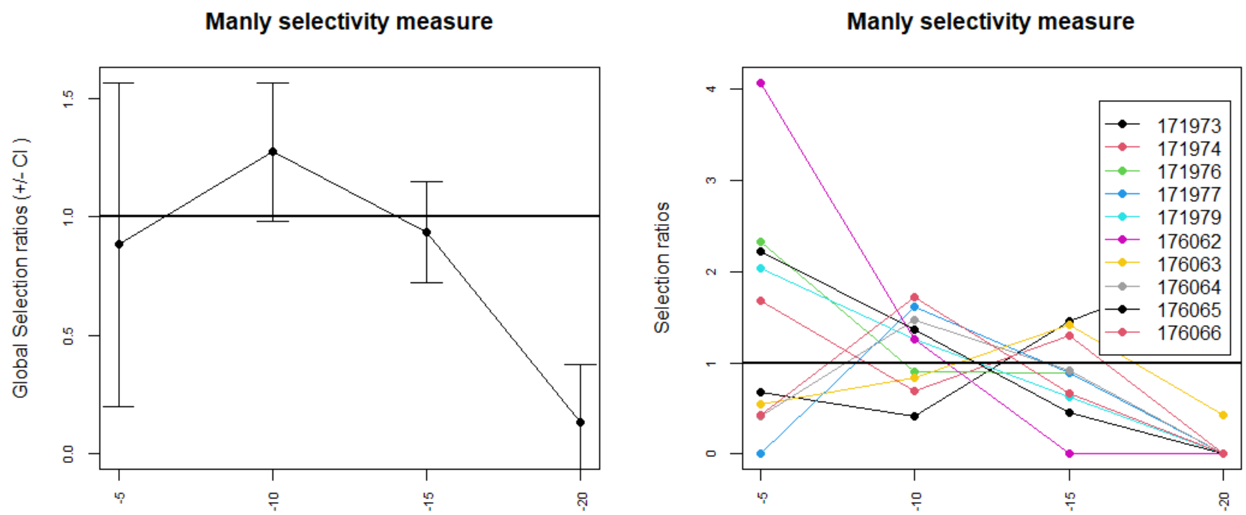


Figure 18: Manly selectivity for water depth, pooled for all turtles (left) and individual turtles (right)

4.3.3 Loggerhead Post-Nesting Migrations in 2018

4.3.3.1 Rate of Movement Averages by Behavioral State

Based on the evaluation of the 7,776 satellite locations, 77% of behavior of tracked loggerheads was classified as exploratory (foraging), 22.5% as transiting (or migratory), and remaining 0.5% could not be classified (based on move persistence). There were clear differences in loggerhead turtle swimming speeds and depth preferences when animals were engaged in exploratory vs. migratory behaviors. Turtle frequently exhibited exploratory behavior in shallow water (average depth 17 m), and this was characterized by slow swimming speeds and comparatively increased turning. Migratory behavior typically involved higher speeds and more linear movement and was evident more often when turtles were in deeper water (**Table 18**). Only 5 out of the 10 turtles exhibited exploratory behavior inside the Canaveral study area, indicating foraging for only a subset of tagged turtles. In general, swimming speed for the same behavior category was similar when turtles were inside and outside the study area.

Table 18. Comparison of swim speeds inside and outside the study area

Behavior	Location	Mean Speed (km/hr)	Mean Depth (m[SD])
Exploratory	Inside Study Area (n=5)	0.23	12(22)
Exploratory	Outside Study Area (n=10)	0.28	12(22)
Migratory	Inside Study Area (n=9)	0.93	224(824)
Migratory	Outside Study Area (n=10)	1.38	224(824)

The overall behavior of loggerhead turtles was highly variable, as only 4 of the 10 satellite tracked turtles remained in or near the Canaveral study area for an extended period (≥ 10 days) after they were tagged on the nesting beach. In addition, turtles widely dispersed to different foraging grounds. Two turtles migrated south into the Gulf of Mexico, two migrated southeast into the Bahamas, and others migrated north along the US East Coast as far as Virginia before their satellite tags ceased transmitting (**Figure 19, Figure 20**). Once turtles began migrating, very little exploratory behavior was detected until the animals reached what was likely their primary foraging grounds.

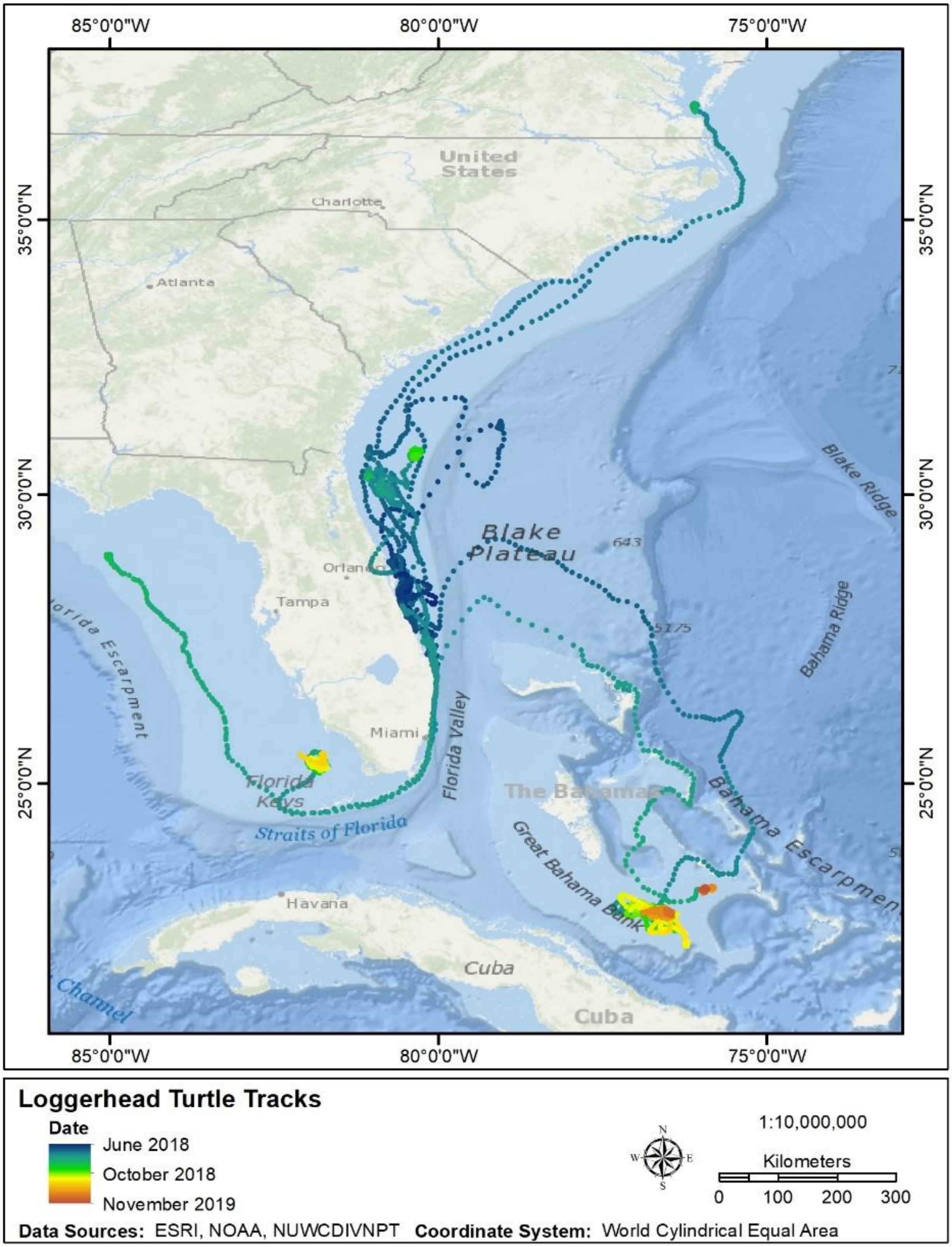


Figure 19. Post-nesting migrations of loggerhead turtles tagged in 2018

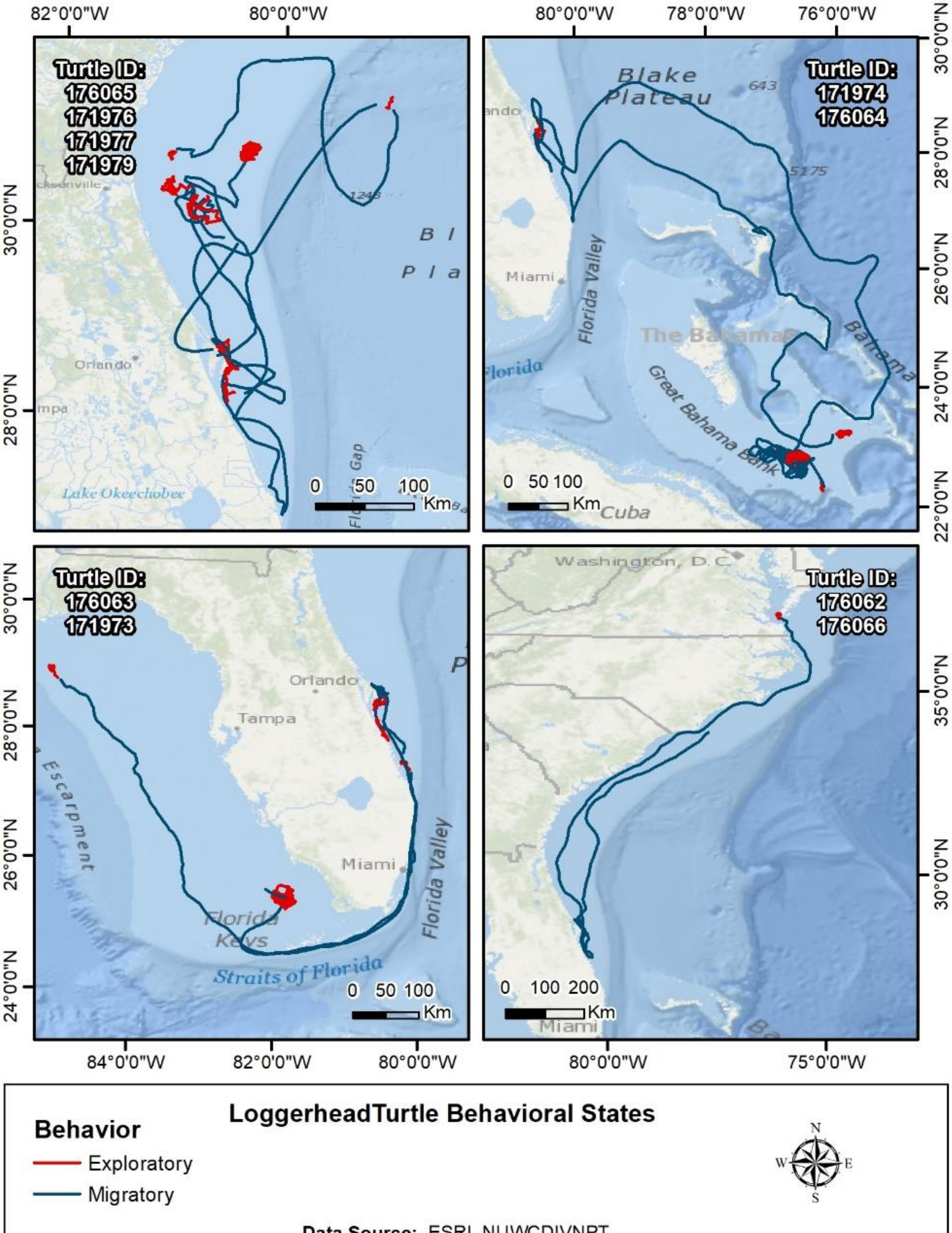


Figure 20. Behavioral states of loggerhead turtles tagged at Cape Canaveral in 2018

4.3.4 Inertial Measurement Unit Findings

Nine of the 10 deployed IMU tags were successfully recovered. Three of the four single burn wire IMU tags released early and were recovered on the Canaveral beach while a fourth was never relocated. All six IMUs attached with a double burn (corrosion) wire were recovered although three still released earlier than the programmed 6.5 day planned deployment and one flooded with seawater.

4.3.4.1 Summary of Dive Statistics

Data from eight recovered IMU tags were available for analysis, although duration of available data were highly variable (**Table 19**). Three tags provided less than 10 hours of data, while 3 others collected for over 100 hours. As a result, not all tags provided equal behavioral insight into turtles' activities within the study area. There were notable differences in dive behavior between individuals with some tags reporting an average dive depth of nearly 10 m while other tags logged average dive depths < 3 m. Mean dive duration ranged from 101–1,207 s, surface intervals from 28–651 s, total time submerged from 41–94%, and dynamic body acceleration from 0.01–0.06 g. For turtles with IMU data in both a transiting and migratory state, a shorter mean surface interval was observed when foraging, along with a greater proportion of time submerged (**Table 19)**.

Basic dive parameters were not always indicative of energy use or VDBA values (**Table 19, Table 24**). For example, the IMU data for PTT 171979 corresponded to active migration from the study area, as this turtle left the Canaveral study area within one day after tagging. Lower dive mean duration, low % time submerged, and high VDBA were noted for this animal. Low % time submerged and high VDBA was also noted for PTT 176065, but this turtle had relative high values for dive mean duration and dive max duration. Another turtle (PTT 171976) exhibited high dive mean duration, high % time submerged, but low VDBA, while PTT 171973 exhibited low dive mean duration, high % time submerged, and high VDBA. Individual turtles exhibited widely divergent dive patterns (**Figure 21**), including some with observed day (n = 1,282 dives)/night (n = 2,115) differences, but did not show statistically significant patterns using a Wilcoxon signed-rank matched-pairs test (**Table 20**). This may be due to individual circumstances encountered by each turtle and may also be related to the small sample size.

Table 19. IMU summary results for eight loggerhead turtles

IMU Tag	PTT Identity	Behavior	No. Depth Records	Tag Duration (hrs)	Mean Depth (m)	Max Depth (m)	No. Dives	Dive Mean Duration (s)	Dive Max Duration (s)	Mean Surface Interval (s)	Prop. Time Submerged (>2)
A*	171973	transiting	24,894	6.9	10.7	15.2	50	469	2,137	28	0.94
B	171976	transiting	35,698	9.9	4.5	10.7	63	162	680	141	0.65
B	171976	foraging	456,186	126.7	8.9	11.1	325	1,207	7,724	94	0.95
C*	171977	foraging	29,592	8.2	7.8	10.5	24	1,100	2,072	62	0.95
E	171979	transiting	266,111	73.9	2.4	12.1	970	101	2,550	180	0.41
G*	176063	transiting	16,701	4.6	3.6	9.4	14	541	2,950	651	0.48
H	176064	transiting	140,727	39.1	4.8	11.7	291	324	5,993	149	0.65
H	176064	foraging	303,874	84.4	7.5	14.6	472	401	6,227	111	0.83
I	176065	transiting	382,602	106.3	5.1	43.3	434	432	4,510	481	0.48
I	176065	foraging	38,915	10.8	5.3	20.5	44	295	2,195	178	0.60
J	176066	transiting	248,990	83.0	2.9	18.1	710	147	5,209	206	0.42

*single-wire configuration released prematurely
VDBA = Vector of Dynamic Body Acceleration

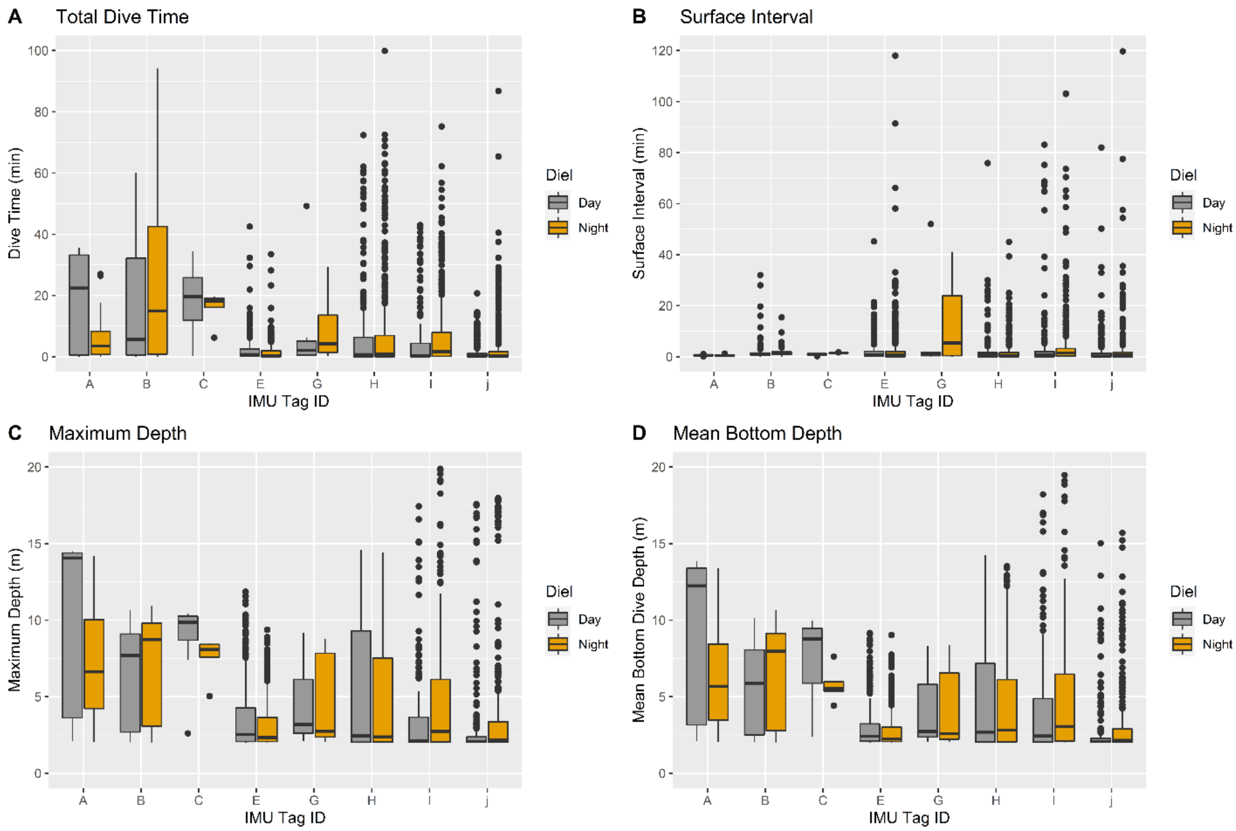


Figure 21. Diel dive behavior in loggerhead turtles

Boxplots represents (A) total dive time, (B) surface interval length, (C) maximum depth reached, and (D) mean bottom depth for IMU tags A, B, C, E, G, H, I & J. Outliers were removed from each plot to allow better visualization (A: No. outliers = 3 > 100 minutes; B: No. outliers = 9 > 120 minutes; C: No. outliers = 26 > 20 m (IMU Tag I only); D: No. outliers = 3 > 20 m (IMU Tag I only)).

Table 20. Comparison of paired dive parameters for IMU Tags A, B, C, E, G, H, I, & J (n = 8 pairs) between day and night dives

Dive Parameter	Day	Night	V	p-value	Effect Size	n	Significant
Mean Dive Time (minute)	5.62	6.49	13	0.93	0.07	8	No
Mean Surface Interval (minute)	3.36	3.41	7.5	0.16	0.52	8	No
Mean Maximum Depth (m)	4.47	4.59	23	0.55	0.25	8	No
Mean Bottom Depth (m)	3.94	4.00	22	0.64	0.20	8	No

By spatial review in ArcGIS, a portion of GPS-linked dives (10 out of 15) in the study area were qualitatively categorized as “shoal” dives (≤ 10 m on Southeast or Chester shoal) or “beach” dives. Though we precluded statistical analysis due to small sample size, there were notable differences in activity occurring over shoals vs. near beaches based on IMU dive data linked within 100 s of a Fastloc GPS position (IMU/GPS referenced data; **Table 21**). Dives over shoals were on average much deeper and longer than dives near beaches. Furthermore, the maximum depth of “beach” dives was often short of the total water depth, while dives in shoal areas appeared to almost always extend at or just above the seafloor. Although spatial data (e.g., the core use data in **Figure**) suggest that the Canaveral shoals do not constitute core habitat for these turtles, based on IMU data, turtles diving on the shoals were executing longer dives indicative of feeding or bottom resting. Results need to be interpreted with caution, however, due to small sample sizes (n = 6 for beach and n = 4 for shoal).

Table 21. Shoal vs. beach dive behaviors for IMU GPS-linked data

Location	Depth (m)	Mean Dive Duration (s)	Mean Maximum Dive Depth (m)	Mean Post-Dive Duration (s)	No. Dives
Beach	10–15	277	6.5	165	3
Beach	5–10	134	6.4	25	3
Shoal	10–15	1,399	10.8	93	4

4.3.4.2 Dive Behavior by Sediment and Bathymetry

IMU tag data were examined for differences in dive behavior across varying sediment fine percentages and water depth ranges. Analysis was limited to the IMU GPS referenced data, ensuring that dive locations was known with high confidence. Of the 57 confirmed IMU GPS-linked data dives, 15 dives were inside the core study area and 17 dives had available percent sediment fines data (**Table 22**). Low sample sizes preclude statistical analysis; however, some patterns were evident. Over shallower water, mean maximum dive depth fell within the bathymetry contour, for 0–5 m and 5–10 m depth. However, dive data for depths exceeding 10 m suggest that turtles did not routinely feed on or near the bottom. This depth range above 10 m includes most of the CSII dredge site. Mean post-dive duration was also substantially longer in the shallowest water (0–5 m) than all other groups. Within the range of dive duration for which a reasonable sample size exists, dive duration appears to increase with increasing depth (**Table 23**).

Table 22. Dive parameter data by available sediment (% fines) data

% Fine Sediment	Mean Dive Duration (s)	Mean Maximum Dive Depth (m)	Mean Post-Dive Duration (s)	No. Dives
0–5	667	8.3	96	14
5–10	1,124	6.1	65	2
10–15	359	10.6	84	1

Table 23 Dive parameter data by bathymetry contour depth (m)

Depth (m)	Mean Dive Duration (s)	Mean Maximum Dive Depth (m)	Mean Post-Dive Duration (s)	No. Dives
40–50	253	2.9	0	1
30–40	2,419	12.4	103	1
30–35	763	10.4	105	1
25–30	1,014	8.4	142	3
15–25	3,345	14.2	253	2
10–15	1,388	9.5	109	28
5–10	402	5.7	140	11
0–5	2	2.1	363	10

4.3.4.3 Dynamic Body Acceleration (DBA) and Comparative Energy Use by Behavioral State (e.g., Foraging and Migratory)

No conspicuous relationship was discernable between overall turtle activity (as measured by ODBA and VDBA) and timing of departure from the study area (i.e., immediately migrating from vs. remaining in the study area; **Table 19)**. However, SSM could be used to infer some relationship with regards to specific activities. For example, the 94 SSM locations that were within 3 hours of the same period as the IMU dataset of seven animals showed significant differences between traveling versus foraging behavior activity for both ODBA and VDBA (p = 0.01 for both comparisons, weighed t-test by PTT id.), with turtles less active while exhibiting a foraging behavior. This was noted for each turtle for which both exploratory/foraging and transiting behavior could be identified (**Table 24**). Spatially, ODBA and VDBA appear to be higher inside the Canaveral study area than outside (**Figure 22**), but this is likely because no behaviors categorized as "foraging" (or area-restricted search (ARS) behavior) were identified within the Canaveral study area (of the 94 SSM locations). Foraging behavior corresponded to lower ODBA and VDBA measurements overall.

Table 24. Activity level comparison between foraging (exploratory) and transiting (migratory) loggerhead sea turtles tagged in 2018 based on IMU data

Behavior	IMU ID	PTT Tag	Mean ODBA (g)	Mean VDBA (g)
transiting	A	171973	0.08	0.06
transiting	B	171976	0.10	0.07
foraging	B	171976	0.02	0.01
foraging	C	171977	0.06	0.04
transiting	E	171979	0.10	0.07
transiting	G	176063	0.05	0.04
transiting	H	176064	0.05	0.04
foraging	H	176064	0.04	0.03
transiting	I	176065	0.08	0.06
foraging	I	176065	0.11	0.07
transiting	J	176066	0.06	0.05
transiting	Pooled	Pooled	0.08	0.06
foraging	Pooled	Pooled	0.03	0.02

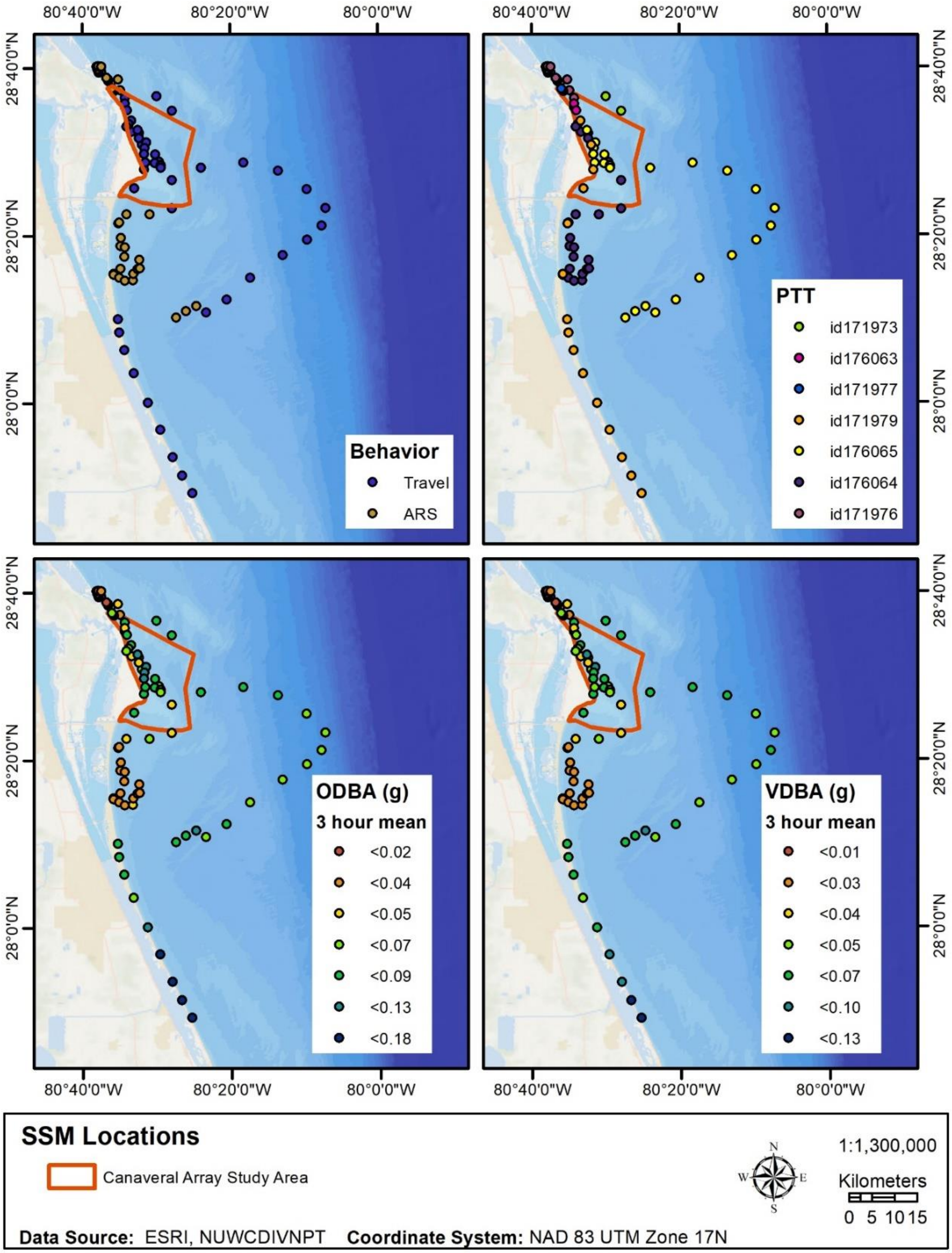


Figure 22. Spatial comparison of loggerhead turtle activity levels

ARS = area-restricted search or exploratory behavior. Travel = transiting or migratory behavior.

4.3.5 Acoustic Tracking of Loggerhead, Kemp's Ridley, and Olive Ridley Turtles

Over the duration of the study, all 10 loggerhead turtles acoustically tagged in 2018 were detected within the Canaveral Array. This brings the 2-year total to 24 of 25 loggerhead turtles and all 11 green turtles with acoustic detections in the study area. Most activity was noted from receivers close to the shoreline and some inter-shoal acoustic receivers. Seven loggerheads were last acoustically detected in the Canaveral Array between June 27–July 29, 2018, while three others were last detected at stations in south Florida (Sebastian Inlet and St. Lucie) July 5–11 2018. Duration tracked or days at liberty ranged from 2–30 days, and residency index (No. days detected / No. days at liberty) for Canaveral ranged from 0.37 to 0.88 with one loggerhead that registered 1,670 detections. Several marine turtles with acoustic transmitters placed by other agencies have been detected within the Canaveral array since 2013, including Kemp's ridley turtles originally released from Virginia and a rare Olive ridley turtle initially tagged in Jensen Beach, Florida (**Table 25**).

Table 25. Target and non-target sea turtles detected by the Canaveral Array (2013–2020)
Non-target species are animals tagged for other research projects but detected locally.

Type	Species	Tagging Location	Tagging Agencies[1]	Animals Detected					Total Detections
				All Sites	Shoal Sites	Dredge Sites	Control Sites	Offshore Reef Sites	
Target	Loggerhead turtle	Canaveral	NUWC, KSC	24	24	3	2	3	7,791
Target	Green turtle	Canaveral	NUWC, KSC	10	10	1	1	0	5,753
Non-Target	Loggerhead turtle	SC, VA	SCDNR, Vaq	4	4	1	1	1	891
Non-Target	Kemp's ridley turtle	VA	USN, Vaq	2	2	2	1	0	1,746
Non-Target	Olive ridley turtle	FL	IRG	1	1	0	0	0	64
Total	**-**	**-**	**-**	**41**	**41**	**7**	**5**	**4**	**16,245**

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

4.4 Discussion

The loggerhead nesting season along the east-central coast of Florida had a relatively later start in 2017 (Iafrate et al. 2019). While tags were not attached to nesting females until late-July, turtles re-nested anywhere from 0 to 2 times afterward which allowed a longer period to investigate their spatial use of the Canaveral study area. In 2018, tags were deployed much earlier (June) to align with the early phases of the nesting season. Overall, 2017 and 2018 were similar for loggerhead turtle nesting based on first nests recorded and overall numbers reported from Merritt Island National Wildlife Refuge. However, very few turtles re-nested after they were tagged in 2018 (2 out of 10 in 2018 vs. 9 out of 14 in 2017 or 20.0% vs. 64.3%). Early nesting of turtles has been attributed to apparent warming sea surface temperatures at foraging grounds which may influence timing of migration to nesting beaches (Weishampel et al. 2004; Weishampel et al. 2010), but this trend was not observed locally.

4.4.1 Core Use Areas and Occurrence on Shoals

As documented with other turtle studies, movement behavior can be highly variable among populations, aggregations, as well as between cohorts (Eckert et al. 2008; Barceló et al. 2013; Dodge et al. 2014; Chimienti et al. 2020). While some spatial and temporal patterns were apparent among animals tagged in 2017 and 2018, variation was nevertheless evident, but likely biased due to low sample size. For example, in both years loggerheads preferentially explored nearshore shallow (5–10 m depth) areas within the Canaveral area. In 2018 they spent 10 days on average within the area before moving to other areas north and south of Canaveral. In several individuals, shoals were simply areas traversed during inter-nesting periods, while other individuals explored shoal or shallow areas near the shoreline in behavior indicative of foraging, food searching, or resting along the bottom. Some turtles stayed within the Canaveral area one or more days beyond the time that they laid their last nest of the season. Other turtles moved out of the area within hours of their last nest.

Size of core use areas was also similar between the two study years, with a slightly higher average in 2018 than 2017. In 2017, neither the CSII dredge site or Chester Shoal control site was within any tagged loggerhead core use area, and in 2018 the core use area of only one loggerhead turtle overlapped with CSII dredge site. Activity use areas were substantially larger than the core use estimates but showed a similar pattern of association with coastal areas north of Canaveral and limited use of the CSII dredge site. However, an affinity for coarser grained sediments and Southeast Shoal was noted in both years. Tag data supports the previous finding in Iafrate et al. (2019) that the shoal margins or flanks are potentially important habitat for this species. The large shoal flanks in the 5–10 m depth range seen at Southeast Shoal may be a determining factor for the increased occurrence in that habitat.

Some turtles remained in the area and did not exhibit definitive exploratory or foraging behavior. Using depth and movement data from tracking and loggers, a turtle's "exploratory" behavior was assumed to be indicative of foraging, searching for food, or resting. One questions this raises is "could a turtle delay migration, waiting for an olfactory (hormone-driven) physiological signal that they are finished with nesting and ready to migrate?" To date, this hypothesis has not been tested. Lingering in or near the nesting beach may indicate hesitancy to depart. More recently, others have suggested that local foraging may be occurring offshore from the nesting beach or relatively close by and may be a selection based on opportunity and not the best available foraging grounds (Eder et al. 2012). This raises an important point for further exploration here and in other studies that use the data from IMU or other data logger instruments to identify behavior.

4.4.2 Post-Nesting and Foraging Grounds

Post-nesting loggerhead migration pathways were similar between years with some turtles remaining along the Atlantic coast of Florida, while others migrated into the Gulf of Mexico, the Bahamas, and north along the US East Coast (e.g., Georgia, Carolinas, and beyond).

The foraging grounds reached by loggerhead turtles tracked during this study, while diverse, are the same areas previously identified by others (Ceriani et al. 2012; Zanden et al. 2015; Evans et al. 2019). On one hand, a geographically widely dispersed population is important for the health and diversity of the species but on the other hand it creates complex challenges in sea turtle recovery and conservation efforts (Wallace et al. 2010). Similar to other recent studies (Ceriani et al. 2012; Zanden et al. 2015; Evans et al. 2019), loggerhead turtles tracked in Florida dispersed into one of four main regions after nesting: Mid-Atlantic Bight, South Atlantic Bight, West Florida Shelf, or Great Bahama Bank foraging grounds. (Evans et al. 2019) also described secondary foraging grounds or distinct "foraging loops" for some adult female loggerheads tracked from the Archie Carr National Wildlife Refuge (ACNWR) in Melbourne Beach, Florida. Turtles from this study that moved into the eastern Gulf of Mexico also appeared to share some of the same (or similar) secondary foraging areas.

A relationship between the size of adult female loggerhead turtles has been suggested as a possible determinant of foraging ground destination. A stable isotope study of approximately 300 loggerhead turtles that nested at ACNWR indicate that larger turtles migrate to more distant foraging ground destinations while smaller individuals chose closer regions to forage (Ceriani et al. 2015). The implication and importance of dichotomous foraging destinations has also been discovered through tracking and stable isotope analysis studies of loggerhead turtles in the Eastern and Northern Gulf of Mexico (Girard et al. 2009; Hart et al. 2014), Mediterranean (Zbinden et al. 2011), Africa (Eder et al. 2012), and Japan (Hatase et al. 2002; Hatase et al. 2006). A recent review of datasets from multiple loggerhead turtle satellite tagging projects (Patel et al. 2021) suggests that thermal states wrought by climate change will force a northern shift in major foraging grounds, placing pressure on habitats already compromised by anthropogenic influences. Suggestions for effective management of sensitive areas include mapping and examination of benthic foraging grounds in planning for marine protected areas (Hart et al. 2013). In many cases, there is substantial evidence that these are key to marine turtle conservation (Hart et al. 2013; Schofield et al. 2013; Stokes et al. 2015) and, in most cases, support more than just sea turtles (Hays et al. 2020).

It is important to note that these full migratory paths with classification of behavioral state 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 (Iafrate et al. 2019). This is particularly true for loggerhead turtles that had wide-ranging post-nesting migrations, with other areas of exploratory behaviors on the Atlantic coast. Data are useful in facilitating management in beach restoration planning that potentially involves the disturbance of and threat to sea turtles and their habitat, especially as it concerns dredging of nearshore shoals.

4.4.3 Dive Behavior and IMU

The 2018 study was enhanced with dive data from IMU tags which were not used in 2017. A very limited qualitative analysis of diving patterns by habitat type showed that over shoal habitats, turtle dives were deeper and longer, and their maximum dive depths were indicative of the bathymetry contour bottom depth. However, along the beach dives were shorter and shallower, and not necessarily indicative of bathymetry. This finding indicates that although the shoal habitats may not be preferred or highly associated with loggerheads, they may be foraging opportunistically over these habitats to some extent.

IMU data showed statistically significant differences between the activity levels (in terms of both ODBA and VDBA), swim speeds, and average depths between turtles engaged in foraging type behaviors, relative to those migrating. Data for turtles exhibiting migratory behavior showed faster swim speeds, shallower dives, and much higher ODBA and VDBA values. These patterns held both within individual turtles, and when pooled, and matched the output of the SSM analysis. The high variability in basic dive parameters (e.g., length of dive vs. average depth of dive, length of dive vs. surface interval, average depth of dive vs. maximum dive depth) was also not explained by whether turtles remained in the Canaveral area or migrated quickly out of the study area. Turtles that are transiting to foraging grounds may be swimming with or against predominant currents. In many cases these animals may have shorter dives coupled with longer surface intervals due to the amount of energy they are expending to reach their foraging grounds. Overall, migrating turtles may travel shallower or deeper depending on environmental conditions (storm activity, cold-water upwelling, overall water depth).

IMU tag data were successfully collected for 8 out of 10 turtles, with a range of retention time from several hours to several days. One of the single release wire tags detached early and was not recovered while another was recovered but was damaged by flooding. This study determined that the double-wire release system enhanced proper timing of tag releases. Future IMU tag studies could include targeted release times earlier in the nesting season to capture inter-nesting habitat use and behavior. Additionally, geospatial cross referencing of sediment type and bathymetry maps may prove useful to examine correlations between environmental parameters, and the relative influence on behavioral classification. IMU tags should continue to be paired with satellite-linked GPS tags to allow dives and locations to be linked to the environment with increased spatial fidelity.

4.4.4 Other Species of Marine Turtles

Unlike adult loggerhead and green turtles, tracking data from several nesting populations of leatherbacks indicate that adult female leatherbacks utilize similar migration patterns (Shillinger et al. 2008), which can be helpful when planning conservation efforts. Like loggerheads, the Kemp's ridley turtle also feeds on benthic invertebrate prey (Seney and Musick 2007) and may rely to some extent on shoals as foraging areas. Although considered rare in the region, subadult and adults of this species has been observed on multiple occasions on the Canaveral Shoals, as supported by tagging and recapture data (Schmid 1995) acoustic telemetry data from animals tagged by others (Gitschlag 1996).Together with more recent documented nesting activity of Kemp's ridleys on Florida beaches, this species foraging, and migration pathways may be impacted by alterations to nearshore habitat features.

5 Passive Acoustic Monitoring and Soundscape of the Canaveral Shoals

5.1 Introduction

5.1.1 Defining Ocean Soundscapes

The ocean soundscape is comprised of a diversity of sounds originating from natural physical processes, living organisms, and human activities, all of which span a wide range of frequencies and amplitudes (Putland et al. 2017; Haver et al. 2018). Most marine species that use sound do so as a means of interacting with and interpreting their environment, including hetero- and conspecifics. Acoustic cues are used to facilitate biological and ecological processes such as breeding, maintaining group cohesion, foraging, predator-prey interactions, navigation, and habitat selection (Bass and Ladich 2008; Parks et al. 2014; van Oosterom et al. 2016; Mullet et al. 2017; Cusano et al. 2020; Zapetis et al. 2020). Fish in particular are known to have a strong temporal aspect to reproductive and social acoustic behaviors, with increased calling rates at different times of year, moon phases, and times of the day (Putland et al. 2017). Combined, these activities contribute to the acoustic diversity of a given marine environment with animals creating and relying upon unique acoustic signatures that can be compared within and between habitats. These biotic sources combine with natural sound sources such as wind-driven noise and waves, as well as anthropogenic sources such as vessel noise, sonar, and dredging to create a generally complex and dynamic marine soundscape. The study of marine soundscapes is invaluable for understanding the diversity of acoustic environments, and ultimately supporting important long-term assessment and management of ecosystem health.

5.1.2 Importance of Recording Ambient and Biological Sounds

The study of soundscapes can yield valuable insights about the dynamics of a variety of coastal habitat types along with the quality and function of habitats. The audibility and behavioral responses of marine fauna to acoustic inputs is reliant on many factors in addition to the acoustic characteristics of a received signal, such as the physical environment (e.g., water depth, substrate type), existing ambient sound levels, hearing ability of the animal, and behavioral context of the animal upon receiving the signal (e.g., feeding, migrating, resting) (Michel et al. 2013). Better characterization of the soundscape through acoustic monitoring can provide valuable information on where and when animals spawn, interspecies acoustic partitioning in space and time, and the value of different types of "acoustic habitat" that are important to invertebrates, fish, and mammals.

Establishing baselines that document ambient sound spectra over time and among different areas improves our understanding of the marine environment by revealing the presence of vocalizing animals, anthropogenic activities, and illuminating the presence and ramifications of environmental changes (Knowlton et al. 2016; Haver et al. 2018). For example, acoustic monitoring of Australia's Great Barrier Reef has shown shifts in the soundscape following habitat degradation events with significantly reduced acoustic complexity, richness, and rates of invertebrate snaps (Hughes et al. 2017; Gordon et al. 2018) leading to the reduction in auditory settlement behavior of coral reef fishes, a severe threat to reef recovery. Additionally, an improved understanding of soundscape ecology can subsequently enhance our understanding of how humans affect ecosystems (Pijanowski et al. 2011). Years of acoustic monitoring have shown the rise of oceanic ambient levels since the industrial revolution (Hildebrand 2009; Andrew et al. 2011; Širović et al. 2013), with further studies showcasing resulting habitat degradation and fragmentation (McQuinn et al. 2011; Merchant et al. 2014; Rice et al. 2014).

The southeastern US continental shelf is home to a multitude of soniferous species including marine mammals (e.g., North Atlantic right whale, bottlenose dolphins), invertebrates (e.g., snapping shrimp) and a variety of fishes including the economically valuable grouper and jack families, all reliant on the acoustic environment. However, relatively few acoustic studies have been conducted along the SE US continental shelf, most covering short durations due to the logistical difficulties of deploying, retrieving, and maintaining acoustic equipment in often tempestuous open ocean environments, and technological limitations in the scientific sector. Additional study is needed to better understand the acoustic ecology of native species and their potential responses to oceanographic and anthropogenic inputs over time.

Recent technological advances in passive acoustic recorders and unmanned vehicles have provided new opportunities for studying this diverse ecosystem. Using fixed-station passive acoustic recorders and Wave Glider unmanned surface vessel deployments, this study provides the first opportunity to catalogue different sources of oceanographic, biological, and anthropogenic sound inputs within the Canaveral region. Fixed stations are ideal for providing long-term ambient averages; the deployment periods creating structured duty-cycled datasets that allow for long-term trends (season, day vs. night) at single points of interest or comparisons across discrete habitat types. These stations supported various analyses including the comparison of ambient sound levels during and after dredging, and trends in fish chorusing by habitat, month, moon phase, and time of day.

In contrast, glider-based surveys provide continuous datasets on a greater spatial scale than fixed stations by providing the means to design mission paths within and across varying depth contours while collecting environmental data concurrent with sound recordings. These deployments allow for closer examination of different "acoustic habitats" in proximity to sand shoals, advantageously capturing unique sources of biological sounds not necessarily recorded on fixed inshore stations. These surveys supported multiple analyses informing biological soundscape trends and our understanding of relative ambient sound levels for a variety of depths and sea states.

5.1.3 Anthropogenic Sound Sources: Dredge Noise

In the Canaveral region, sources of anthropogenic sound include boat traffic, seismic surveys, coastal construction, military activities, and dredging. Trailing suction hopper dredges (TSHDs) are a common hydraulic dredge platform supporting coastal restoration projects that require sand from the OCS. TSHDs are often preferred because of the long distances between the borrow area and placement site. They can travel at speeds of up to 14 knots when unloaded and 1–2 knots slower when loaded. Underwater noise from hydraulic hopper dredging comes from two main sources including from the vessel itself, as well as the dredging equipment including the draghead moving over the seafloor and the noise from the submerged pipework and pumps during loading operations. Although there is significant variation in measured sound levels from dredges, the maximum sound levels reported for large hopper dredges are consistently greater than mechanical dredges, although both are lower than commercial shipping noise (Reine et al. 2014). Dredging noise is also partly dependent on substrate with sand having relatively lower source levels than dredging of gravel substrate (Michel et al. 2013). Underwater sound from vessels and dredging equipment has the highest energy at relatively low frequencies, usually between 5 and 500 Hz and up to approximately 150 dB re: 1 µPa at close range (Wenz 1962; NRC 2003; Hildebrand 2009; Southall et al. 2017). Underwater sound from vessels is generally low frequency (tens to hundreds of Hz) although at closer range it can extend above 100 kHz at received levels above 100 dB re: 1 µPa (Hermannsen et al. 2014).

5.1.4 Implications for Marine Species

While noise from vessels or dredging generally lacks the source level and duration to cause hearing loss or mortality in marine organisms, loud or persistent noise may invoke a behavioral response including disruption of normal activities or potentially avoidance of an area. Most fish and sea turtles have greatest hearing sensitivities at lower frequencies (e.g., less than 2 kHz). Therefore, they are likely to detect vessel or dredge noise if in the vicinity of the source. This noise can also mask vocalizations and other biologically important sounds (e.g., sounds of prey or predators) that marine organisms rely on. Masking can vary depending on the ambient sound level within the environment, the received level and frequency of the vessel noise, the received level and frequency of the sound of biological interest, and behavior of the animal including avoidance. In the open ocean, ambient sound levels are typically between about 60 and 80 dB re 1 μPa in the frequency band between 10 Hz and 10 kHz due to a combination of natural (e.g., wind) and anthropogenic sources (Urick 1983), while coastal ambient levels, especially around busy ports, are louder and can exceed 120 dB re 1 μPa (Rice et al. 2014).

Prior to this study, no longer-term or focused soundscape monitoring had been conducted off Canaveral. Fixed-station passive acoustic recorders and Wave Glider unmanned surface vessel deployments provided the first opportunity to catalogue different oceanographic, biological, and anthropogenic sound sources contributing to the local soundscape. Fixed stations provide long-term ambient averages, comparison of noise levels during and after dredging, and trends in fish chorusing by habitat, month, moon phase, and time of day. The deployment periods of these stations create structured datasets that allow for analysis of trends within the soundscape. In contrast, Wave Glider surveys provide an opportunity to design mission paths within and across depth contours, and the opportunity to collect environmental data concurrent with sound recordings. These deployments allow for closer examination of different "acoustic habitats" in proximity to sand shoals. Additionally, glider surveys provide continuous datasets with the flexibility to cover a variety of spatial scales, the opportunity to examine unique sources of biological sounds not necessarily recorded on inshore stations, and the relative ambient sound levels for a variety of depths and sea states.

5.1.5 Objectives

The specific goals of this work were the following: 1) measure average ambient sound levels from fixed passive acoustic recorder stations, and catalogue acoustic spectra for oceanographic, biological, and anthropogenic sounds; 2) summarize dredge noise from recorders in close proximity to the CSII sand borrow area and compare these results with previous work; 3) analyze fish chorusing from fixed stations and correlate with environmental variables such as month, time of day, and moon phase; 4) catalogue vocalizations for common fish species and identify to the family level; and 5) examine acoustic data from mobile Wave Glider recordings and provide data for ambient spectra for different environmental conditions and biological soundscape.

5.2 Methods

5.2.1 Fixed-Station Acoustic Monitoring

Three fixed passive acoustic recording stations were established from February of 2018 through February 2020 to document ocean soundscapes at specific locations within the Canaveral Shoals, with various deployment and recovery dates. This time period overlapped with dredge activity at CSII that occurred from February 9, 2018, through April 11, 2018, with an inactive period from February 22, 2018, through February 28, 2018. These fixed stations included a site directly adjacent to the CSII dredge footprint (station DRE1,11 m deep), a site 4 km west of CSII (station DRE2; 7 m deep that provides a comparison directly adjacent but outside of shoal habitat), and a site adjacent to the Chester Shoals control site (station CON, 12 m deep; **Figure 23**). LS1 recorders (Loggerhead Instruments, Inc) were tethered 1m off the bottom with concrete moorings and floats for a period of 70–396 days in mostly sand and shell habitat, with limited documented hardbottom. Periods of actual recording were discontinuous with recorder service intervals dictated by weather and competing project tasks. Actual battery life was over 100 days in several instances. Nonetheless, there were several periods in which two or all three stations were simultaneously recording, and these times are the focus of the dredge noise and fish chorusing analysis presented below. The sensitivity of these LS-1 recorders (inclusive of gain) is -168 dB re

1Volt/µPa, with a sampling rate of 44.1 kHz. The sensitivity for the LS1 recorder is uncertain below approximately 50 Hz so the lower limit was considered 50 Hz for the low frequency band for the purposes of comparative Power Spectral Density (PSD) levels. The recording duty cycle was programmed at either 15% or 30% (e.g., 3 minutes ON, 7 minutes OFF) to extend the duration of recordings. Recordings are saved as .wav files for analysis.

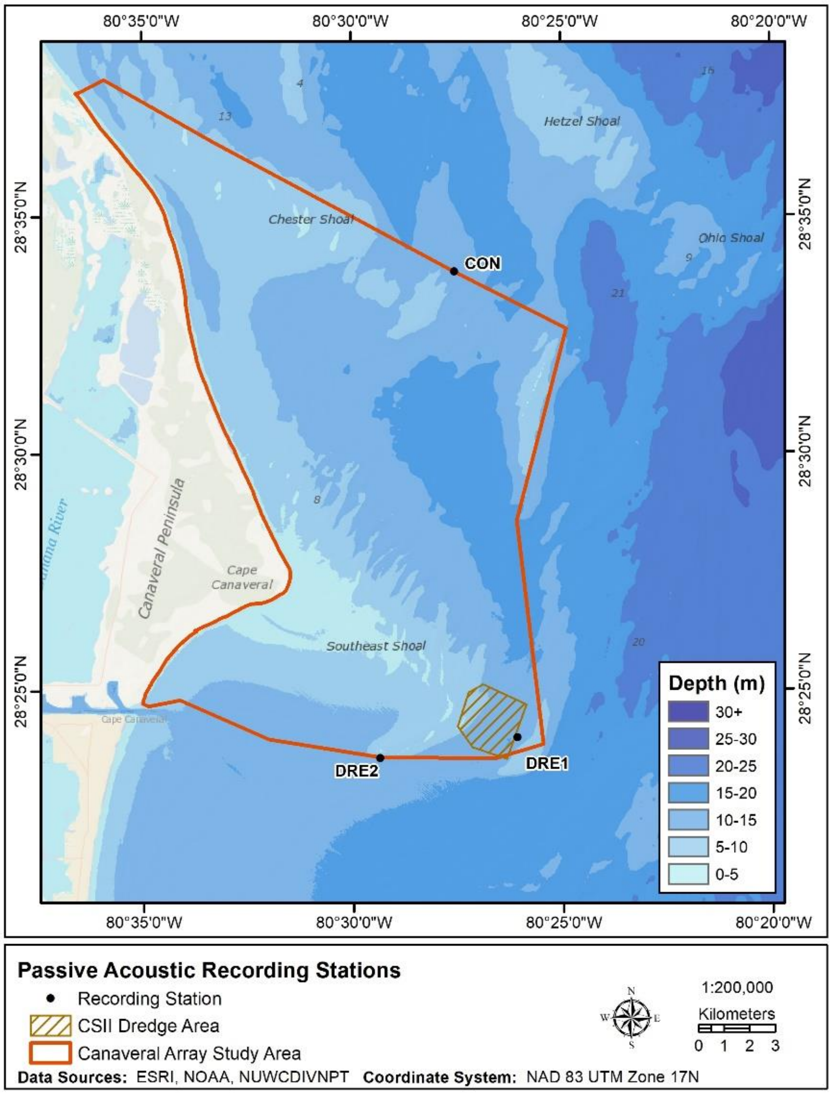


Figure 23. Locations of fixed-station passive acoustic recorders

5.2.2 Wave Glider Acoustic Monitoring

In July 2020 and July–August 2021, the Wave Glider was deployed for two dedicated mobile acoustic soundscape surveys that were separate in purpose and scope from animal tracking deployments described in Section 3. For each survey, a 7.6-m tow cable and towbody (Liquid Robotics, Inc) was added to the glider, a system designed to vastly reduce the "self-noise" that originates from the glider (flow noise, thruster noise, mechanical noise, wave action on the float) and complicates ambient sound recordings (**Figure 24**). The towbody was integrated with a passive acoustic sensor (PAS) compact five-channel multiple hydrophone array (Ultra Electronics UnderSea Sensor Systems, Inc.). The PAS has a sampling rate of 12 kHz and an end-to-end sensitivity of -150 dB re 1/µPa. A separate single-channel Remora acoustic recorder (Loggerhead Instruments), with a sensitivity (inclusive of gain) of -165 dB re 1Volt/μPa and sampling rate of 144 kHz was added to the towbody for redundancy, but its data was not utilized in this soundscape analysis. The glider was also upgraded with a GPSWaves wave height sensor (see Section 3) for recording wave spectral data and sea state (located on a mast on the glider float) to accompany atmospheric data produced by the weather station. The weather station and wave height sensor produce physical and oceanographic variables that are important for characterizing the ambient acoustic environment in coastal waters. A full description of the Wave Glider design and capabilities is found in Section 3.

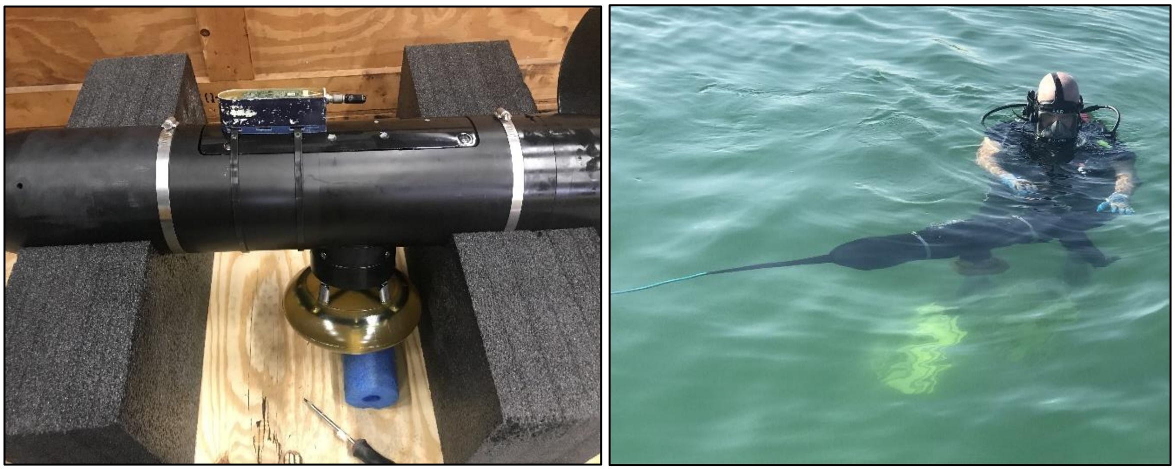


Figure 24. Wave Glider passive acoustic recorders

The primary PAS sensor was installed beneath the towbody with a smaller stand-alone Remora recorder located forward and above the PAS.

In Acoustic Survey 1, the Wave Glider was deployed off Cape Canaveral on 20 July 2020 and retrieved on 28 July 2020 after traveling 348 km (

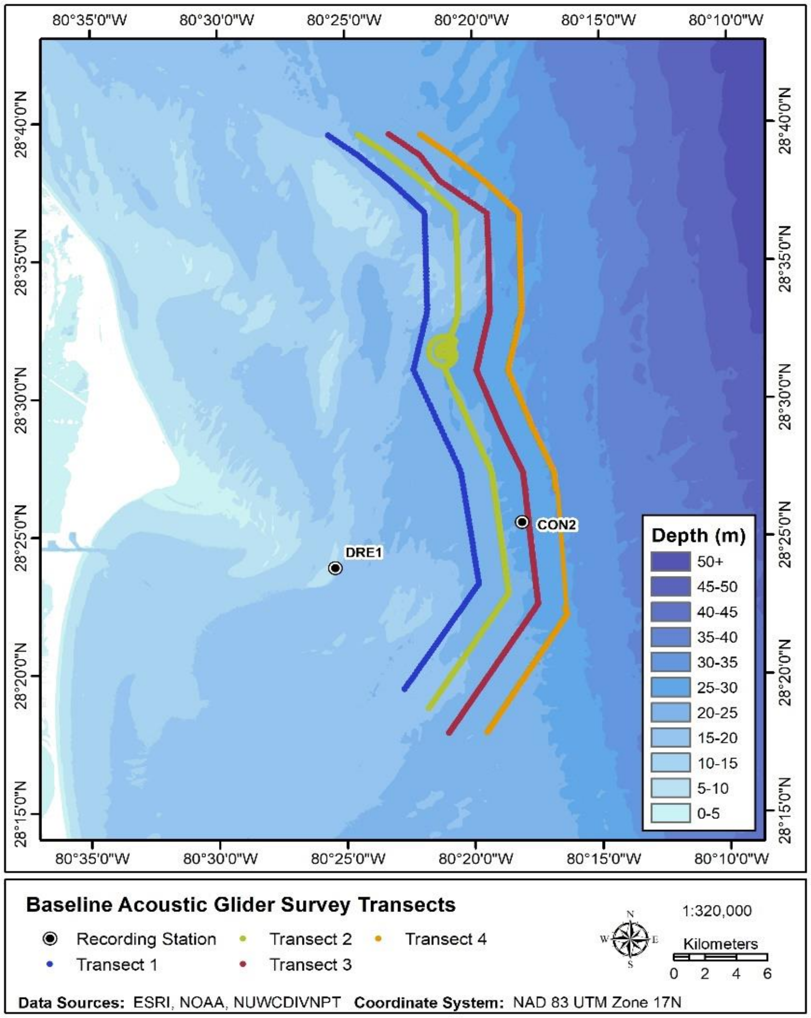


Figure 25). Water temperature and salinity at launch was uniform across depths (0, 3, and 6 m) at 28.8°C and 36.2–36.3 ppt. There were intermittent ethernet connectivity issues with the glider towbody that could not be resolved prior to deployment. The dates of 23–28 July were selected for detailed analysis, a period that represents quality data from parallel transects 1-4. Acoustic data from this date range were of very high quality with limited glider self-noise, and likely representative of the ambient noise spectrum and biological sounds for these offshore habitats at this time of year. For this survey, two fixed recording stations (DRE1 and CON2 as shown in **Figure 25**) were also deployed, and data archived**.**

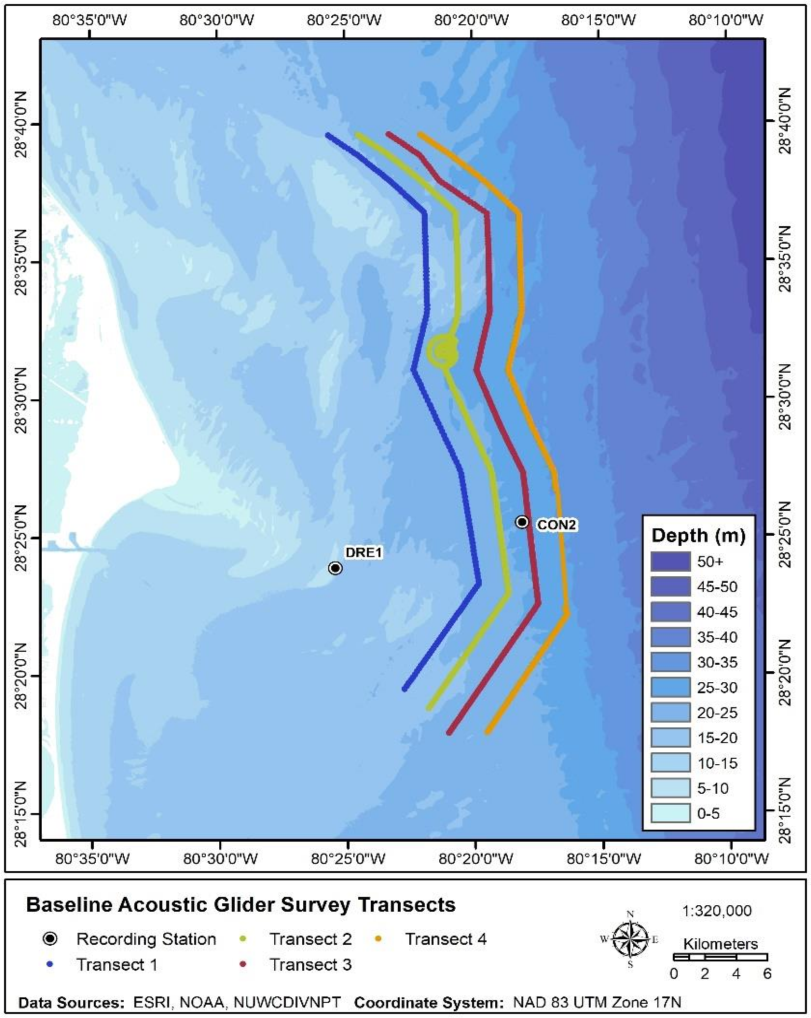


Figure 25. Planned transects for dedicated Wave Glider acoustic surveys

Wave Glider Acoustic Survey 2 was completed in November 2021. This survey provided a unique comparison for the fall season with Acoustic Survey 1 that was completed in the summer.

5.2.3 Data Analysis

Several acoustic metrics were utilized for analysis of fixed-station and Wave Glider acoustic data that are considered standard in the literature (Merchant et al. 2015; URI Graduate School of Oceanography 2021). These include the following:

Spectrogram: a graphic representation of sound, plotted as frequency versus time showing the intensity of different frequencies.

Power Spectral Density (PSD): spectrum of sound levels across frequency bands.

Sound Pressure Level–Root Mean Square (SPL-RMS): sound level over a specified frequency range presented as a single number – root mean square is directly related to the intensity of the sound.

One-Third Octave: sound level spectrum scaled by logarithmic frequency, presented as SPL-RMS. The frequency of the upper end is double that of the lower end.

Long Term Spectral Average (LTSA): time series plot that displays how sound levels vary over time at each frequency.

Spectral Probability Density (SPD): shows the distribution of sound levels by display of probability density for each frequency.

Sound Exposure Level (SEL): summation over pressure over the duration, cumulative measure of energy.

5.2.3.1 Fixed-Station Sound Assessments: Ambient Ocean Sound

Ambient noise spectrum analyses (baseline spectrum that includes biological and anthropogenic noise) were focused on four days in June 2018 (June 14–15 and June 22–23; **Table 26**) when all three fixed-station acoustic monitors were actively recording. This allowed for simultaneous evaluation of average ambient noise levels for sea states 0.75–1.16 m at the CSII dredge site, just outside CSII, and the control site on Chester Shoal. During this deployment period, DRE2 station was programmed at a lower duty cycle (15%) to extend deployment life, but for unknown reasons stopped recording 13 days after deployment on June 11, 2018. Plots of PSD were generated in MATLAB for these time periods and are presented as SPL-RMS. Data were time-averaged in 60-s windows at a frequency resolution of 1 Hz with a Hanning window and 50% overlap. These were also the averaging, frequency resolution, and window selection parameters used for all subsequent acoustic analyses unless otherwise noted. For analysis of relative SPL for different frequency bands from ambient recordings, low frequency was considered < 250 Hz, mid frequency was 250–2,500 Hz, and > 2,500 Hz was the highest frequency band, with the upper limit dependent upon recorder sampling rate. These frequency bands represent a minor variation of those presented in (Putland et al. 2017) for soundscape analysis.

Table 26. Date, sea state, and schedules for acoustic data used for concurrent analysis

Date	Sea State (m)
6/14/2018	0.80
6/15/2018	1.16
6/22/2018	0.84
6/23/2018	0.75
Station	**Recording Duty Cycle**
DRE1	3 min ON; 7 min OFF
DRE2	1.5 min ON; 8.5 min OFF
CON	3 min ON; 7 min OFF

5.2.3.2 Fixed-Station Sound Assessments: Dredge Noise

In February and May 2018, concurrent acoustic data from recorders at DRE1 and DRE2 were also used to examine the change in ambient sound averages (that include dredge noise) during dredging, post-dredging, and 3 months post-dredging. The dredge vessel was the *Liberty Island*, a 99-m long by 18-m wide suction hopper dredge built in 2001 with a gross tonnage of 5,201 tons. During this deployment period, these passive acoustic stations were on a 30% duty cycle, recording three-minute audio files every 10 minutes. For all time periods, 1/3-octave plots were generated for each station. RMS level for 1/3-octave bands represents the mean of the squared sound pressure, averaged over 60-s intervals. Additionally, during the dredge period at DRE1, LTSA, and SPD plots were generated over 3-day intervals. SPD plots show the distribution of noise levels during dredging at a finer resolution. Finally, PSD figures were also generated for the DRE1 site for a representative day post-dredge period and for 3 months post (RMS, 50th, 5th, 95th Percentile). Broadband measurement data are also presented during dredging for RMS level, median SPL, Mode SPL, and SEL.

5.2.3.3 Fixed-Station Sound Assessments: Biological Soundscapes

To quantify fish chorusing dynamics on and near the Canaveral Shoals, four days of audio files were reviewed each month from all three fixed-station recorders from February–August 2018. Emphasis was on recordings taken 2 hours before to 8 hours after sunset, to capture time periods likely to coincide with peak chorusing activity in the southeast US (Monczak et al. 2017). To further analyze biological trends in the soundscape across months and stations, days were selected to represent distinct moon phases (i.e., new moon, 1st quarter, full moon, third quarter) because fish spawning, and thus chorusing, has been shown to be linked to lunar cycles/tides in many regions. Audio files from these days were 3 minutes (out of every 10), and for any given day approximately 60 3-minute files were manually reviewed and scored in Adobe Audition.

Each wav file was analyzed and marked with a value for chorusing intensity based on the following scale (a modification of a scoring system presented in (Monczak et al. 2017)): 0 = no calls, 1 = individual calls, 2 = overlapping calls, 3 = chorusing of 1 or 2 species, 4 = chorusing 3 or more species. Fish choruses detected at great distances (i.e., at obvious lower sound levels and were not clearly identifiable in the recording) were not scored. Data are presented for all stations by month, time of day, moon phase, and for different combinations of these variables.

In addition to scoring fish chorusing intensity, PSD plots were generated for one representative dataset (i.e., one day) for a Score 3 and Score 4 from CON in June and July, respectively, and for a Score 3 from DRE1 in July. These figures provide the SPL-RMS at different frequencies for the period 2 hours before up until 8 hours after sunset.

Finally, a subsample of audio files (n = 19) was manually reviewed for mammal vocalizations using Raven Lite Sound Analysis Software (version 2.0.1). Groups or bouts of vocalizations were selected in Raven to determine generalized frequency ranges, and these manually generated selection boxes represented the sample size for the following results. The selection boxes varied in duration but encompassed the overall minimum and maximum frequencies heard during the bout. Sample spectrograms for the most common fish calls and distinguishable marine mammal vocalizations are presented in **Appendix C**.

5.2.3.4 Wave Glider Sound Assessments: Ambient Noise and Biological Soundscapes

Data summaries for Wave Glider Acoustic Survey 1 (July 2020) include average ambient ocean sound levels by survey transect, water depth, sea state, and wind speed. Additionally, LTSAs were plotted to reveal trends in fish chorusing on the east Florida shelf. The data show the temporal nature and timing of distinct fish choruses in proximity to Canaveral Shoals and the CSII dredge site.

5.3 Results

5.3.1 Fixed-Station Ambient Sound Assessment

Representative examples of PSD for the three fixed passive acoustic recording stations from June 2018 are shown in **Figure 26**. These consist of separate 2-day comparisons representing different sea states when all three stations were recording simultaneously during this month. The sensitivity for the LS1 recorder is uncertain below approximately 50 Hz so the lower limit was considered 50 Hz for the low frequency band for the purposes of comparative PSD levels.

Sea states were on average 1 m during June 14 and 15 (period 1). PSD levels were similar for the three sites during this period, averaging between 80–90 dB re 1 μPa^2/Hz. A spike in PSD levels to almost 95 dB re 1 μPa^2/Hz for the 250–800 Hz band was observed and associated with increased fish chorusing. Harmonics associated with higher band fish chorusing (> 800 Hz) were observed in the rest of the mid-frequency band up to 2,500 Hz. PSD levels were lower in upper frequency band, averaging between 60–70 dB re 1 μPa^2/Hz. RMS levels of broadband sound (50–22,050 Hz) ranged from 121–122 dB re 1 μPa/Hz.

Sea states during the second period June 22 and 23, 2018, (period 2) averaged 0.8 m. Averages for the low frequency band were similar to the first period in June, with vessel noise a major contributor of noise at these frequencies. PSD levels for mid frequencies 250–1,000 Hz were observed to be much lower than the first period, with averages 70–85 dB re 1 μPa^2/Hz. PSD levels were also lower for almost all frequencies at the CON station during these dates, particularly with a separation of 10 dB re 1 μPa^2/Hz at frequencies greater than 1,500 Hz. RMS levels of broadband sound (50–22,050 Hz) ranged from 109–115 dB re 1 μPa^2/Hz. In both periods, ship noise in the low and mid bands documented include those from larger vessels such as cruise ships, and those more transitory sounds from recreational and fishing boats. The CON station is located further north from the Port then DRE1 or DRE2, and subject to less regular recreational boat traffic.

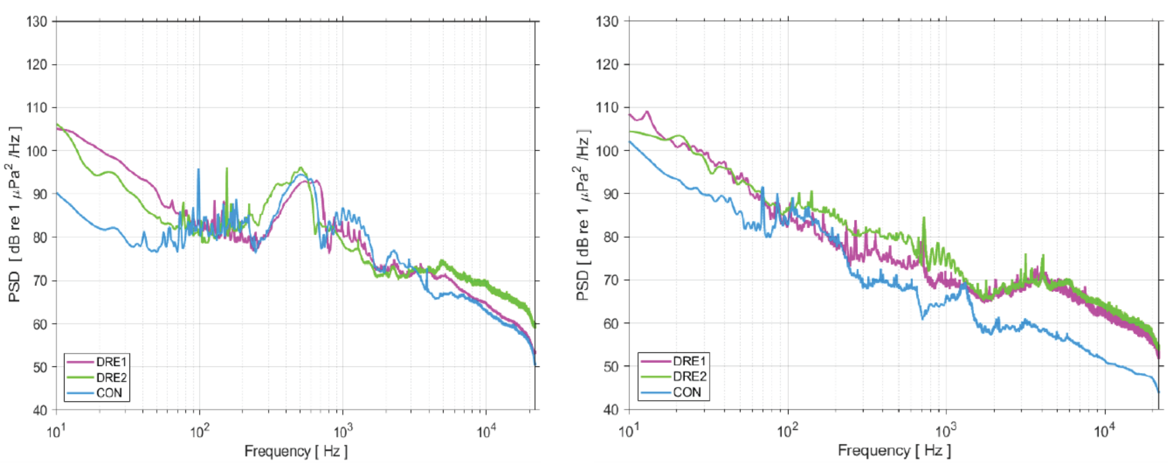
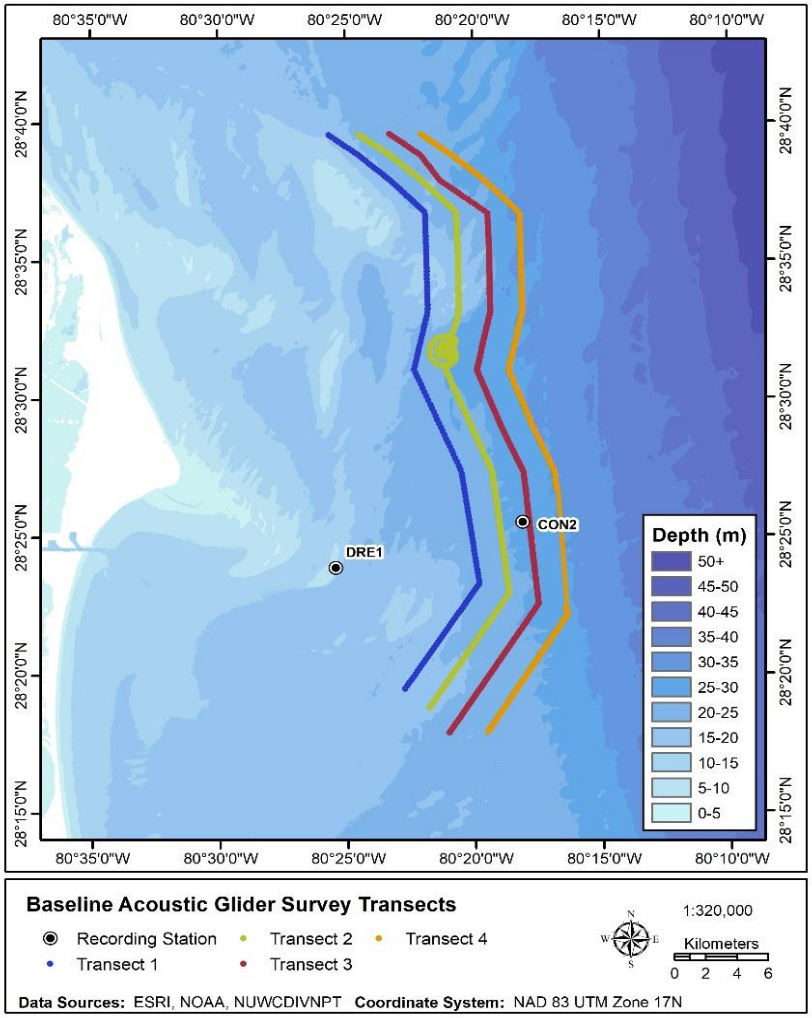


Figure 26. Comparative PSD for separate 2-day ambient periods at fixed stations on June 14–15 (left) and June 22–23, 2018 (right)

5.3.2 Wave Glider Ambient Sound Assessment

Significant wave height during the entire July 2020 survey averaged 1.4 ± 0.26 m (SD), while average wind speed was 9.6 ± 2.5 knots (**Figure 27, Table 27**). Comparatively, significant wave height for the survey December 31, 2021, to January 5, 2022, was more variable by transect, ranging from 0.7 ± 0.3 m to 2.0 ± 0.2 m as the survey progressed. Wind speed in January 2022 also reached a maximum of 16.7 ±

2.1 knots for the final transect 4. Analysis of ambient sound levels by transect provides for a comparison for different depths, distance from shore, and for different habitats under similar oceanographic conditions. Transects 1 and 2 cover the outer edges of Canaveral and Chester Shoal and run parallel to



both Hetzel and Ohio Shoal (see

Figure 25). The average depth for these transects is shallow at 20–22.9 m, and contain shallower areas less than 12–13 m. These transects provide a baseline recording of ambient levels at approximate 20–22 m average depth in fairly high sea states averaging 1.6 m and average wind speeds of 9.2–9.4 knots.

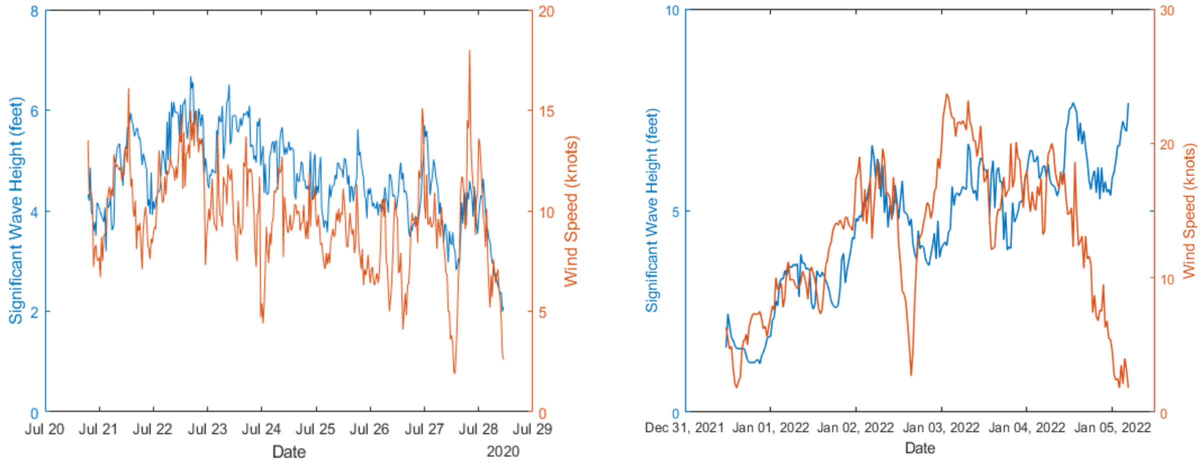


Figure 27. Significant wave height (blue) and wind speed (red) during Wave Glider Acoustic Survey no. 1 (left) and no. 2 (right)

Table 27. Wave Glider survey conditions July 20–27, 2020, December 31, 2021–January 5, 2022
Values for wave height and wind speed represent mean (SD). Depth values approximated from bathymetry data.

Date	Transect No.	Direction of Travel	Duration (hrs)	Min Depth (m)	Max Depth (m)	Mean Depth (m)	Wave Height (m)	Wind Speed (kts)
Jul 2020	1	N	14.8	12	24	20	1.6 (0.2)	9.4 (2.5)
Jul 2020	2	S	36.7	13	26	23	1.4 (0.2)	9.2 (1.3)
Jul 2020	3	N	26.2	20	29	25	1.3 (0.2)	8.4 (2.4)
Jul 2020	4	S	24.8	21	32	27	1.2 (0.2)	9.0 (3.3)
Dec 31 / Jan 2022	1	N	21.0	12	24	20	0.7 (0.3)	7.0 (2.4)
Dec 31 / Jan 2022	2	S	48.4	13	26	23	1.4 (0.3)	15.0 (4.8)
Dec 31 / Jan 2022	3	N	24.5	20	29	25	1.7 (0.2)	16.7 (2.1)
Dec 31 / Jan 2022	4	S	16.2	21	32	27	2.0 (0.2)	8.4 (4.5)

<u>Glider Survey July 2020</u>

For July 2020, soundscape and average sound levels by parallel transect 1–4 are presented through LTSA plots (**Figure 28)** and comparative SPD (**Figure 29**) for frequencies 100–250 Hz (low), 250–2,500 Hz (mid), and 2,500–6,000 Hz (high). These results were for continuous (non-duty-cycled) recordings from the PAS. For transect 1, noise in low frequency bands that included ship noise had a median PSD 68–70 dB re 1 μPa^2/Hz, with a spike at approximately 110 Hz. Quieter median PSD levels for middle frequencies at 60–70 dB re 1 μPa^2/Hz were observed, although with a large range in the SPD up to 50 dB. Harmonics from fish chorusing are clearly visible for this mid-frequency band (RMS average 85 dB re 1 μPa^2/Hz). There were also harmonics from boat/vessel noise visible for both mid-frequency and upper-frequency bands. For transect 2, a large range in SPD up to 50 dB was observed for low frequency band

< 250 Hz. Also, higher peak PSD values are apparent in the mid-frequency band 250–800 Hz. Aside from these differences, median PSD levels were similar to transect 1 across the acoustic spectrum, although increased vessel noise could be seen in the LTSA comparative plots. Distribution of the SPD showed highest density of data points representative of the median (50%) PSD.

Transects 3 and 4 covered greater average depths (25.3–26.9 m), wave heights (1.2–1.3 m), and wind speeds (8.4–9.0 kts). Under these conditions, quieter levels for median PSD were observed at approximately 65 dB re 1 µPa^2/Hz for lower frequencies, 55–65 dB re 1 µPa^2/Hz for mid frequencies, and 55 dB re 1 µPa^2/Hz for higher frequencies with a spike in PSD levels at 5 kHz. Overall, the range in SPD was smaller than transects 5 and 6 ranging from 30–40 dB, showing less variability. Harmonics from fish chorusing are also clearly visible for this mid-frequency band, and harmonics from boat/vessel noise are also noted in both mid-frequency and upper-frequency bands. Distribution of the SPD showed highest density of data points representative of the median (50%) PSD.

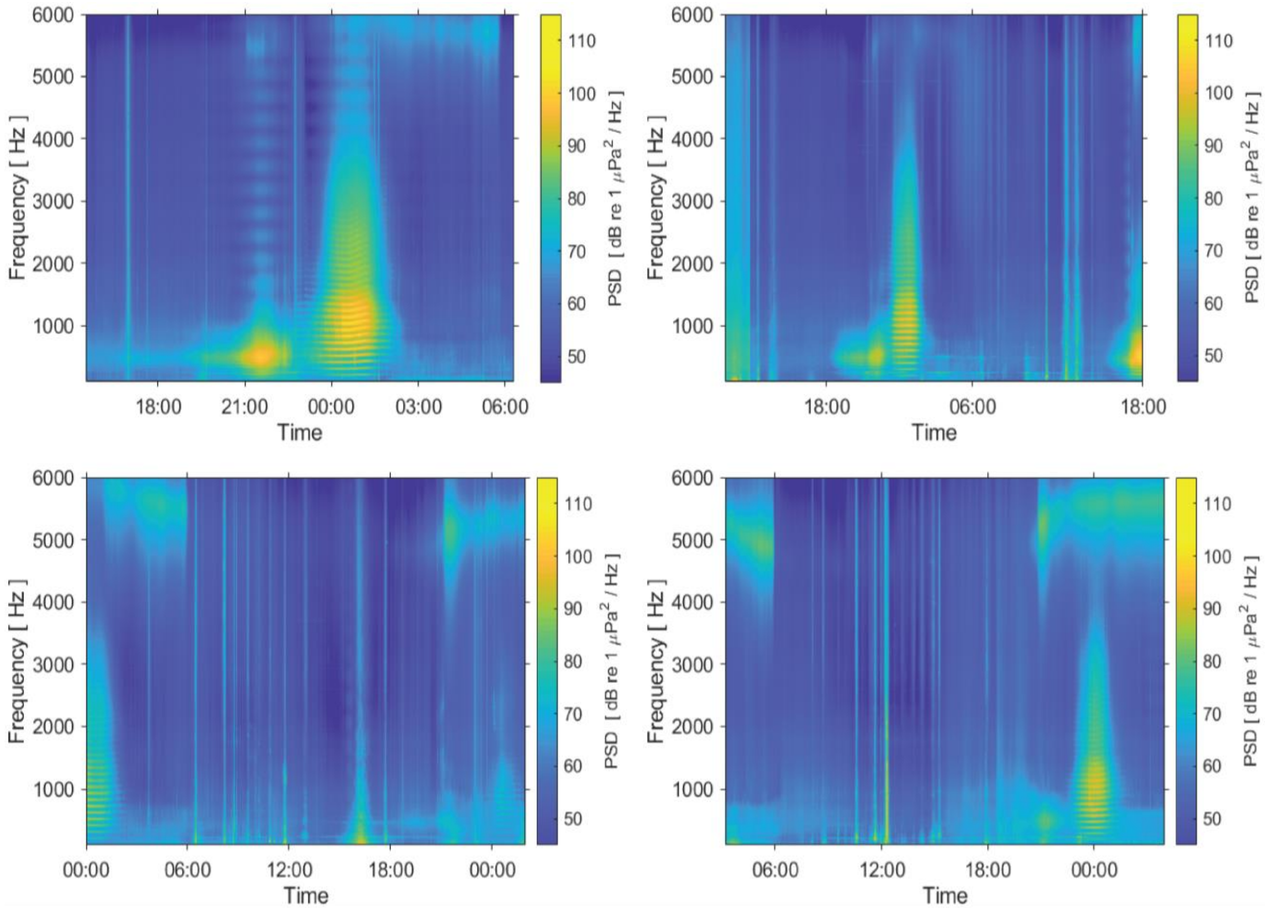


Figure 28. LTSA plots for Wave Glider transects in July 2020
Transect 1 (upper left), Transect 2 (upper right), Transect 3 (lower left), Transect 4 (lower right)

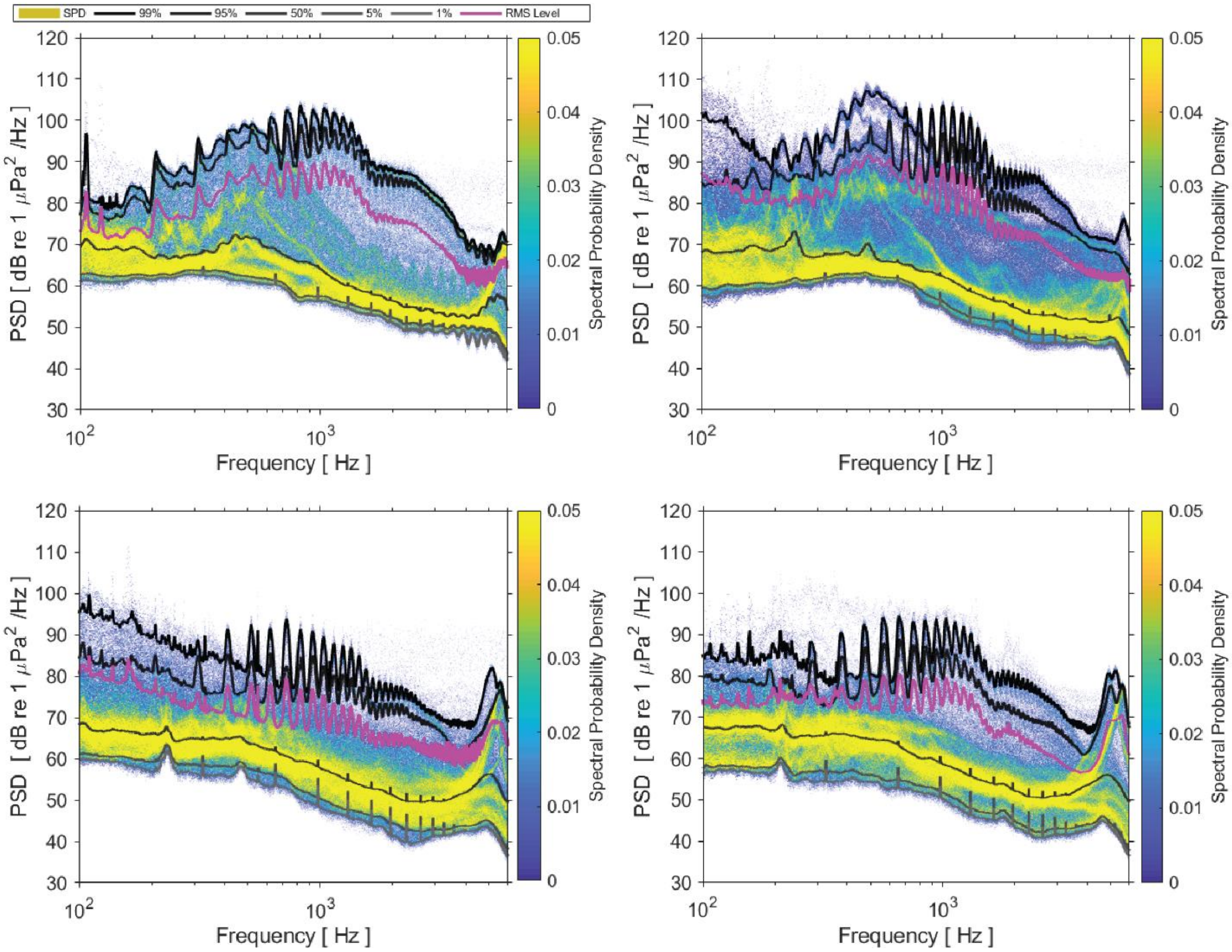


Figure 29. RMS averages and percentiles of the PSD and SPD for Wave Glider transects July 2020

Transect no. 1 (upper left), 2 (upper right), 3 (lower left), and 4 (lower right). Averaging windows are 60 s with exceptions of transect 1 at 45 s.

To evaluate ambient noise levels during day hours versus night hours in the summer, data collected on the Wave Glider for two specific 4-hr periods during transect 6 were compared (0600–1000 and 2200–0200; **Figure 30** and **Figure 31**, respectively). There was a median broadband SPL of 104 dB re 1 µPa (100–6,000 Hz) during daytime hours. The highest sound levels in the daytime recording were observed on the 100–300 Hz frequency band. There was a median broadband SPL of 129 dB re 1 µPa during night hours (2200–0200). For these recordings, the high intensity chorusing of the Atlantic midshipman (*Porichthys plectrodon*) was persistent and loud after midnight. As a result, distinct differences could be seen in the 1/3-octave band levels and amplitude over time as compared with daytime, with highest sound levels closer to the 750–1,200 Hz frequency band. Peak levels in amplitude over time for night hours were observed around midnight.

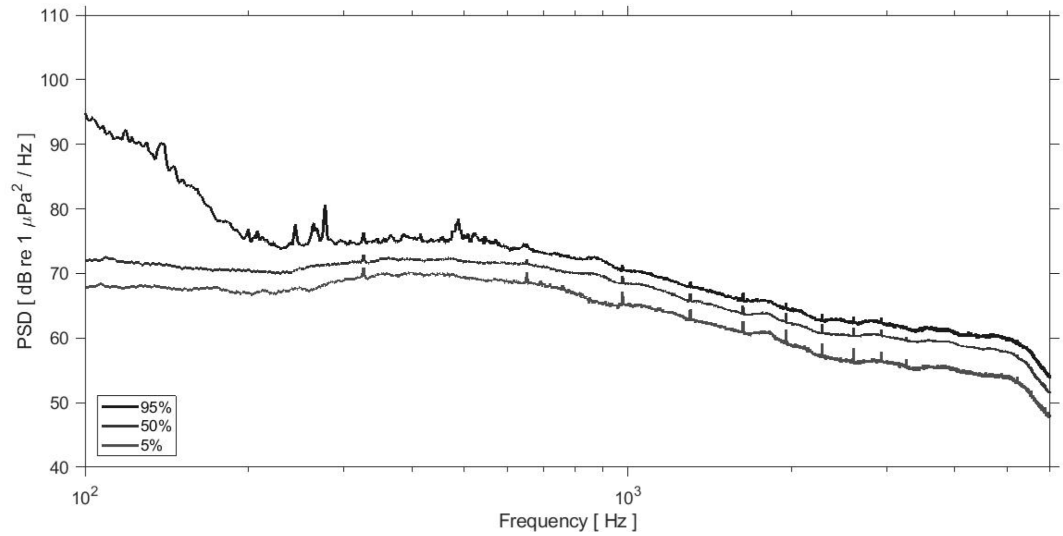


Figure 30. Comparative PSD (SPL-RMS) for a 4-hour Wave Glider daytime recording
Data collected 24 July 2020, 0600–1000. Lines represents the 5th, 50th, and 95th percentiles

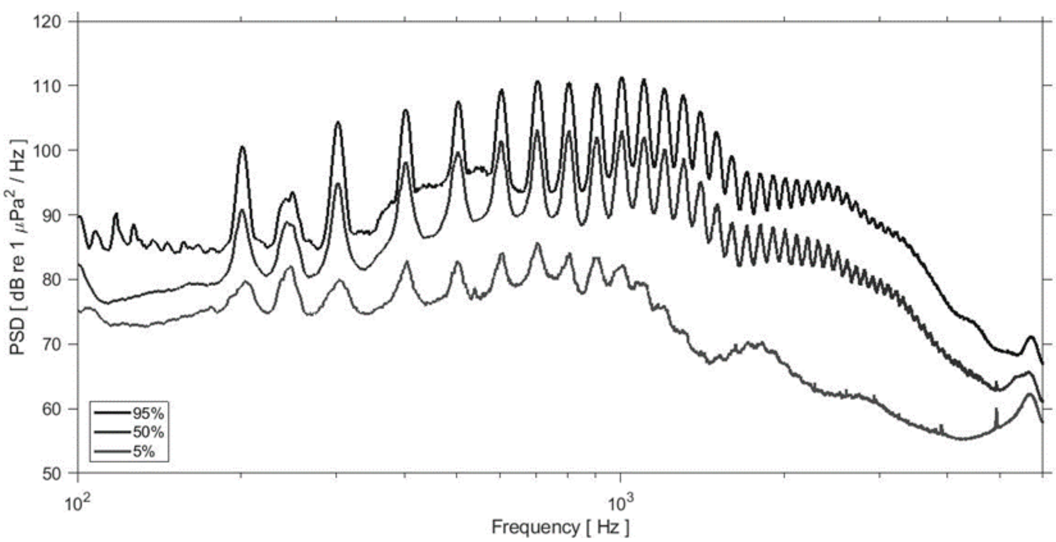


Figure 31. Comparative PSD for a 4-hour Wave Glider nighttime recording (2200 24 July–0200 25 July 2020)
Data represent the 5th, 50th, and 95th percentiles

Glider Survey December 2021 – January 2022

For December 2021 / January 2022, soundscape and average sound levels by parallel transect 1–4 are presented through LTSA plots (**Figure 32)** and comparative SPD (**Figure 33**) for frequencies 100–250 Hz (low), 250–2,500 Hz (mid), and 2,500–6,000 Hz (high). As with July 2020, these results were for continuous (non-duty-cycled) recordings from the PAS.

For transect 1, noise in low frequency bands that included ship noise had a median PSD 70 dB re 1 μPa^2/Hz, with quieter median PSD levels for middle frequencies above 800 Hz, with a minimum of 60 dB re 1 μPa^2/Hz. There was also a smaller range in SPD in this band as compared with July 2020, differing by up to 25 dB. This is largely the result of lower levels of fish chorusing during winter months, although there were consistent overlapping fish calls documented during early morning hours, up to 2,800 Hz.

There were also harmonics in the spectrum from boat/vessel noise visible for mid-frequency and upper-frequency bands, with high intensity ship noise occurring around 0600 on 1 January 2022. For transect 2, there was a larger range in SPD, up to 40 dB was observed for low frequency band < 250 Hz. Also, higher peak PSD values associated with fish chorusing were observed in the mid-frequency band 250–800 Hz. As with July 2020, the median PSD levels were similar to transect 1 across the acoustic spectrum, although in the longer transect 2 there was increased vessel noise that overlapped time of fish chorusing during evening hours, as seen in the LTSA comparative plots.

Transect 3 covered time periods with highest average wind speed (16.7 knots), with 1.7-m waves. There was limited ship noise during this transect, but there was high intensity fish chorusing observed in the 400–800 Hz band, and also overlapping fish calls into the early morning hours. There was a high range of SPD (variability) observed for mid frequencies, with peak levels reaching 100 dB re 1 μPa²/Hz. For transect 4, wind speeds decreased to an average of 8.4 knots, but wave height was 2.0 m. There was increased ship noise as compared with transect 3, particularly at the beginning of the time series, as seen by harmonics at the lower frequencies with RMS average over 80 dB re 1 μPa²/Hz. Fish chorusing was again recorded around sunset, with peak frequencies 300–900 Hz. Overall, range of SPD was lower than transect 3 for mid frequencies, but greater for upper frequencies where increased vessel noise was apparent.

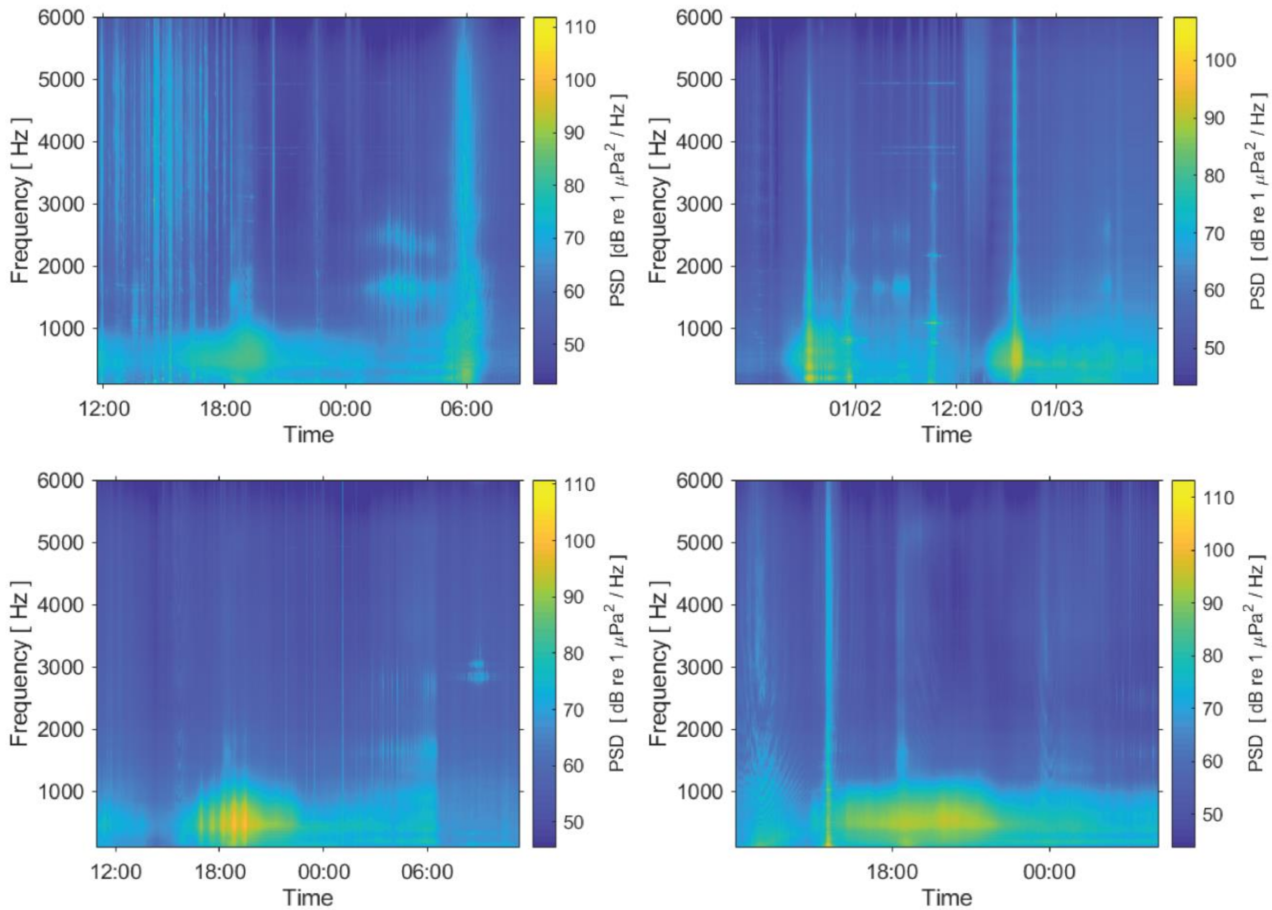


Figure 32. LTSA plots for Wave Glider transects in December 2021–January 2022

Transect no. 1 (upper left), 2 (upper right), 3 (lower left), and 4 (lower right)

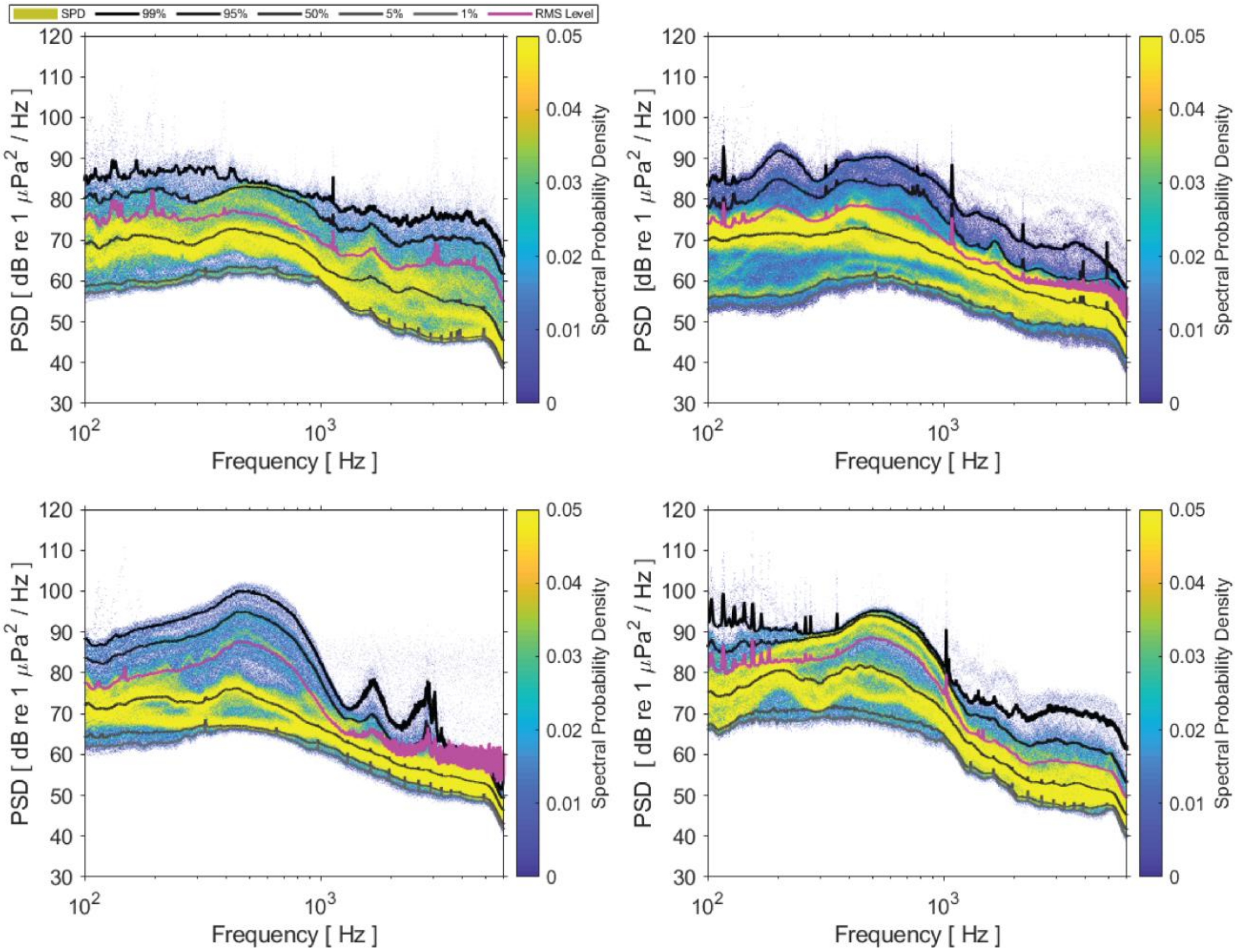


Figure 33. RMS averages and percentiles of the PSD and SPD for Wave Glider transects during July 2020

Transect no.1 (upper left), 2 (upper right), 3 (lower left), and 4 (lower right). Averaging windows are 60 s with exceptions of transect 4 at 45 s.

5.3.3 Dredge Noise

5.3.3.1 Sound Levels at Dredge Site vs. Nearby Reference Site

Analysis of sound levels during dredging by hopper dredge *Liberty Island* is presented for the Station DRE1 recorder adjacent to the CSII dredge area within a 1–2 km range of dredge activity (depending on dredge location), and also for DRE2 recorder that is located to the south and west of the dredge footprint at a distance of approximately 3.5–5.5 km. Results from 1/3-octave analysis (SPL-RMS) are presented for both stations and three separate consecutive days within the frequency bandwidth of 50–10,000 Hz (**Figure 34**).

For the DRE1 site, peak 1/3-octave SPLs of over 120 dB re 1 µPa were recorded in lower frequency bands 50–250 Hz, consistent with larger vessel noise. A peak of 115 dB re 1 µPa at 800 Hz was measured at this station. Greater than 1,000 Hz, average 1/3-octave SPLs averaged less than 110 dB re 1 µPa. For the DRE2 station, average 1/3-octave SPLs were noticeably quieter (i.e., 10 dB) in the 100–250 Hz range, peaking at 110 dB re 1 µPa. There were also two distinct peaks noted at 800 Hz (110 dB re 1 µPa) and at 2,000 Hz (108 dB re 1 µPa). The peak at 800 Hz is a peak harmonic for individual fish calls this time of year and also a discrete energy band associated with smaller vessel noise. The higher peak at 2,000 Hz appeared to be the result of mechanical noise in the recorder mooring. At frequencies higher than mid band (i.e., higher than 2,500 Hz), average 1/3-octave levels were less than 100 dB for the DRE2 station.

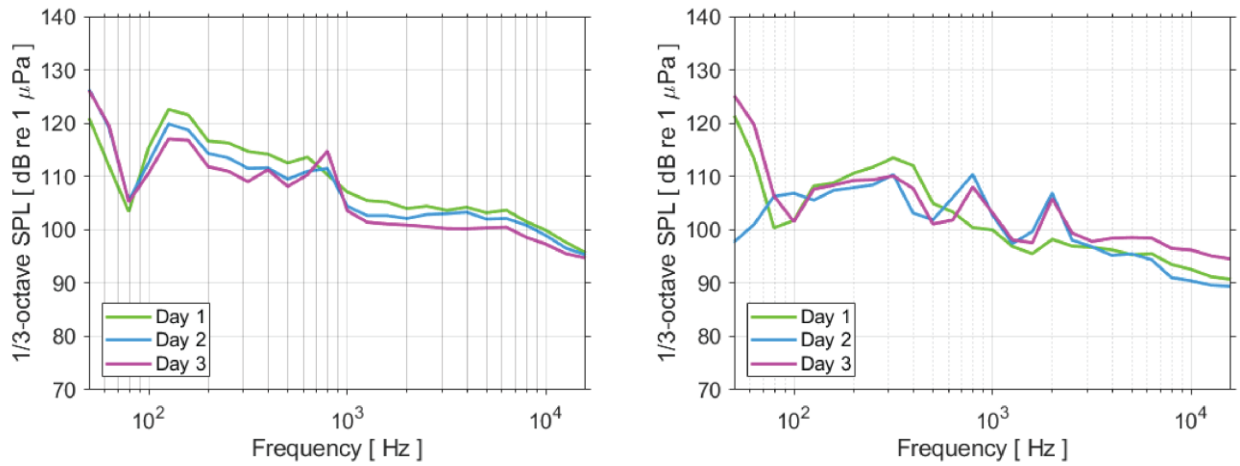
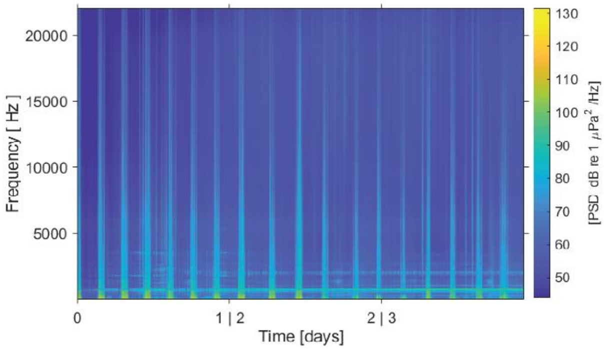


Figure 34. Analysis of 1/3-octave band levels over 3 days of dredging at Station DRE1 (left) and DRE2 (right)

LTSA plots and SPD levels for 3 consecutive days of dredging are shown in **Figure 35**. Note that these are from duty-cycled recordings 3 minutes on and 7 minutes off, and these figures only represent data for the time recording was active. Clear trends in dredge proximity can be seen in the LTSA plot, with vertical bars representing areas of higher intensity when the vessel was closer to the recorder during dredging, and other areas in the plot representing quieter times (above 300 Hz) when the vessel was off-site. Additionally, persistent vessel noise can be noted throughout the duration below 300 Hz, even as the dredge was likely at much further distance from the station. PSD levels peaked from 80 Hz to 200 Hz to over 120 dB re 1 μPa^2/Hz due vessel noise, and this frequency band also contained the largest range for SPD at over 60 dB, showing greater variability in noise intensity. Secondary harmonics are visible from 300–1,000 Hz in the PSD data associated with fish vocalizations, including a large spike in median PSD level to over 90 dB at 800 Hz. Other harmonics from smaller boat vessels are observed in PSD percentiles at frequencies higher than 1,000 Hz, as the range of SPD is lesser at approximately 40 dB. Overall, distribution of the SPD showed highest probability density values representative of the SPL-RMS (mean) PSD.

Broadband noise levels across the spectrum (50–10,000 Hz) are presented in **Table 28**. On average, RMS levels for the DRE1 site were 5–8 dB greater than the DRE2 site. Higher median and mode SPL were observed at DRE2 during Day 2, but comparisons of SEL show higher levels of sound intensity over time for the site closer to the dredge footprint. These RMS levels of broadband cumulative sound are up to 20 dB re 1 μPa^{2}s louder than those observed in the ambient sound data from passive recording stations presented earlier.



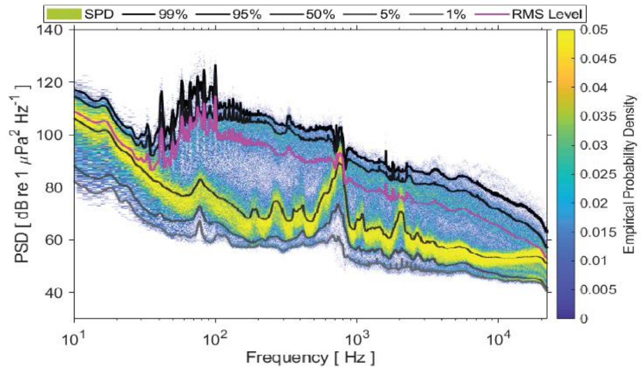


Figure 35. LTSA plot (left), RMS averages and percentiles of the PSD and SPD (right) during 3 consecutive days of dredging

Table 28. Three days of dredging comparison

The distance from the source (dredge) to the recording stations and also the operating parameters of the dredge were variable during this time. On average, the distance for DRE1 was 1,000–2,000 m, and DRE2 was 3,500–5,500 m.

Site	Sample	RMS Level	Median SPL	Mode SPL	SEL
DRE1	Day 1	129	112	136	174
DRE1	Day 2	127	113	112	171
DRE1	Day 3	125	117	117	169
DRE2	Day 1	121	110	109	166
DRE2	Day 2	123	121	121	167
DRE2	Day 3	120	115	114	164

NOTE: RMS Level, Median SPL, Mode SPL Units: dB re 1 μPa; SEL Units: dB re 1 uPa^2 sec

5.3.3.2 Baseline Ambient Sound Levels for Both Sites Immediately Post-Dredging and 3-Months Post Dredge (3-day Comparisons)

Results from 1/3-octave analysis (SPL-RMS) are presented for both DRE1 and DRE2 for 3 consecutive days during the post-dredge period in **Figure 36**. For both sites, average 1/3-octave levels of both stations were quieter in the low frequency band 100–250 Hz as compared with dredge periods, with levels peaking at just over 100 dB re 1 µPa. For the DRE1 station, there was also a large spike observed in the mid-frequency band at corresponding to a peak of 115 dB re 1 µPa at 600–800 Hz. This was consistent with regular fish vocalizations this time of year, and also overlap with a discrete energy band of smaller vessel engine noise (mostly during daytime hours). This recreational and fishing vessel noise was observed regularly in recordings both during and after dredging. In the upper-mid band (1,000–2,500 Hz) and frequencies greater than 2,500 Hz, 1/3-octave SPLs averaged between 90–100 dB re 1 µPa (SPL-RMS) for both stations. Comparative PSD levels in the 50–200 Hz frequency band during the post-dredge period were almost 20–25 dB quieter than during the dredge period, averaging 75–85 dB re 1 µPa^2/Hz (**Figure 37**).

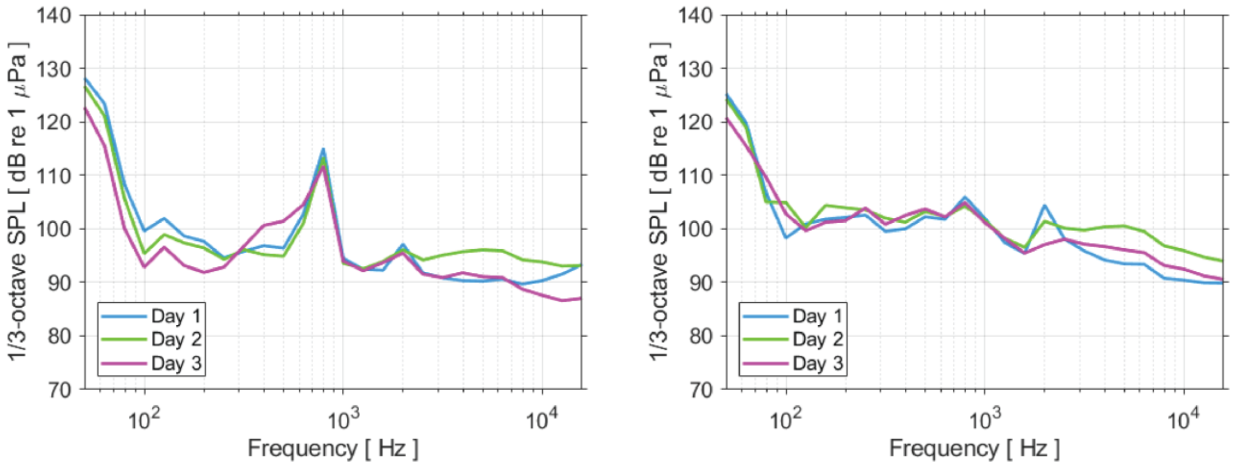


Figure 36. Results of 1/3-octave analysis over 3 separate days during the post-dredge period for DRE1 station (left) and DRE2 station (right)

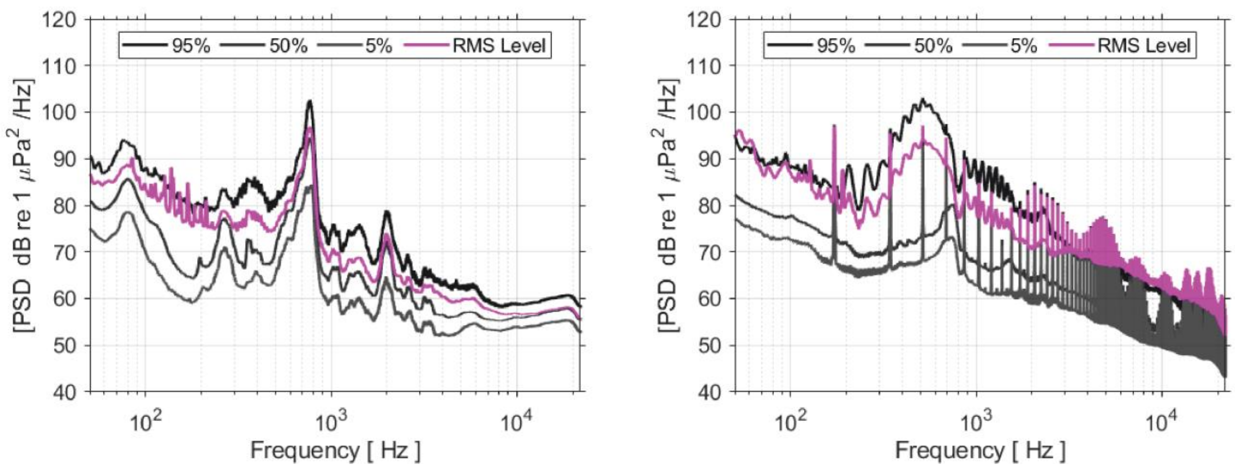


Figure 37. Comparative PSD levels for one representative day at the DRE1 station during the post-dredge period (left) and 3-months post dredge (right)

Data represent SPL-RMS, 5%, 50%, 95%.

Results from 1/3-octave analysis (SPL-RMS) are presented for both DRE1 and DRE2 for 3 consecutive days occurring 3 months after the dredge period in **Figure 38**. For both sites, average 1/3-octave levels for both stations were quieter in the low frequency band 100–250 Hz as compared with dredge periods, with average levels peaking at just over 100 dB re 1 µPa for the DRE1 station, and 108 dB re 1 µPa for DRE2. In both stations, there was also a large spike observed in the mid-frequency band corresponding to a peak of almost 118 dB re 1 µPa at 500–600 Hz, mostly due to intense fish chorusing in spring months, that was not seen earlier in the year during and immediately after dredging. Also, these frequencies overlap with discrete energy bands associated with smaller vessel engine noise. In the upper-mid band (1,000–2,500 Hz) and frequencies greater than 2,500 Hz, average 1/3-octave SPLs were mostly between 95–100 dB re 1 µPa for both stations. As with the post-dredge period, comparative PSD levels in the 50–200 Hz frequency band 3 months post-dredge were almost 20–25 dB quieter than during the dredge period, averaging 75–85 dB re 1 $\mu Pa^2/Hz$ (**Figure 38**).

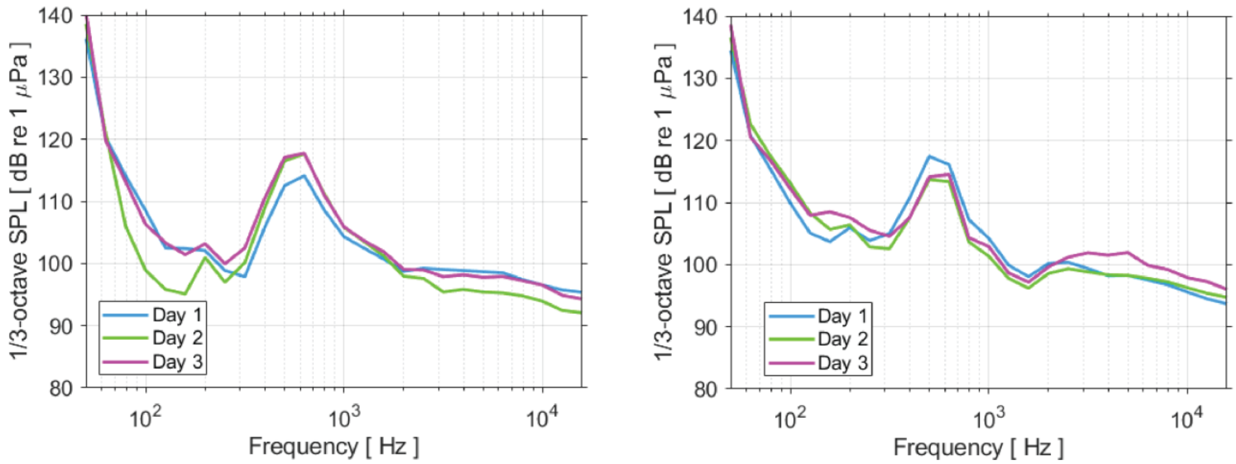


Figure 38. Results of 1/3-octave analysis over 3 separate days 3 months post dredge for DRE1 station (left) and DRE2 station (right)

5.3.4 **Biological Soundscape**

5.3.4.1 Common Biological Sounds on the Canaveral Shoals

This study characterized biological sounds including fish chorusing for passive fixed stations across several months and moon phases and from Wave Glider surveys. Data were available for Station DRE2 from February through early August, for DRE2 February through June, and CON for June and July. Fish chorusing was characterized by overall sound intensity and by manual scores from review of audio files for individual, overlapping, and multiple species calls. Calls were classified to the lowest taxonomic level although vocalizations of many fish on the east Florida continental shelf remain uncatalogued. To classify calls, audio call extractions were cross-referenced with reputable online sources, including Discovery of Sound in the Sea (URI Graduate School of Oceanography 2021), Fishbase.org, and Cornell Sound Library (Cornell University 2021). Specific fish calls were also compared with published literature including (Luczkovich et al. 1999; Ramcharitar et al. 2006; Locascio and Mann 2011; McIver et al. 2014; Rice et al. 2016; Monczak et al. 2017; Ricci et al. 2017).

The overlap of ship noise in the low and mid bands with fish chorusing was noted on many occasions. Other biological and anthropogenic noises were also noted and catalogued as part of the review process. Other biological sounds included snapping shrimp that resulted in a flattening or upward trend in the ambient spectrum above 2,000 Hz in several recordings, and a variety of marine mammal (cetacean) calls that were documented in the high-frequency band (2,500–20,000 Hz). A summary of mammal vocalizations for a subset of audio is also presented below.

5.3.4.2 Fish Chorusing at CSII and Chester Shoals February–July 2018

A total of 2,352 3-minute manually reviewed files were associated with peak moon phase dates running from 19 February–31 July 2018. This equates to the following for number of representative hours that were scored in 2018: DRE1 (n = 196; 19 Feb–31 Jul); DRE2 (n = 160; 19 Feb–24 Jun); and CON (n = 81; 01 Jun–31 Jul). Overall, fish chorusing appeared common and fairly diverse (2+ species) at stations DRE2 and CON (**Figure 39**). Scores of 2 and 3 were fairly equivalent at DRE2 across months, with scores of 4 noted in all months with the exception of March. Scores of 3 were most common at the CON station for June and July. In contrast, fish chorusing appeared less common and diverse at station DRE1. Individual calls were most commonly seen from February–May (score = 1) with chorusing intensity increasing in June and peaking in July where an intensity score of 3 was the most common (**Figure 39**). A score of 4 was not documented for station DRE1. A score of 2 appeared more commonly at DRE1 2 months earlier than other stations for hours that occur before sunset (April rather than June), while hours after sunset continued to follow the earlier overarching trend where mean intensity scores of 2–3 became more common in June (**Figure 40**).

No overall trends in chorusing intensity and species diversity were initially apparent at station DRE2 with respect to a specific moon phase, with all chorusing intensities present during each phase at similar levels (**Figure 41**). When viewing the intensity of fish chorusing by moon phase before and after sunset, this lack of a trend persists for hours occurring before sunrise with the exception that a mean intensity score of 0 was not documented on a new moon phase (**Figure 41**). Fish vocalizations were more common during the new and first quarter moon phases (scores of 1–2 most common) in comparison to the full and third quarter moon phases (scores of 0–1 most common) for hours that occurred after sunset (**Figure 42**). It should be noted that all intensity score levels were still present during each moon phase.

In contrast to station DRE2, a higher average number of fish vocalizations and species diversity was found at station CON with a mean intensity score of 2 or higher most common for all moon phases (**Figure 41**). Vocalizations and species diversity were greatest in the 3rd quarter, also in contrast to station DRE2. Mean intensity scores of 0 were only found in the 1st quarter moon phase. For hours prior to sunset, fish vocalizations appeared to diminish during the full moon, with individual calls and some overlapping calls (scores = 1–2) present, but very few hours of chorusing (scores = 3+) (**Figure 42**). Overlapping calls and chorusing were more common in the remaining three phases with the 3rd quarter being the only phase with hours that had a mean intensity score of 4 (3+ species chorusing). Chorusing of 2+ species was more common after sunset (score = 3–4) across all phases, with the 3rd quarter again the most likely phase to have 3+ species chorusing within a given reviewed hour (**Figure 42**).

Station DRE1 remained quieter with no calls or just individual calls for all moon phases except during the 3rd quarter where mean intensity scores of 0–3 appeared equally common, similar to station CON (**Figure 41**). For hours occurring before sunset, mean chorusing intensity remained fairly steady over all moon phases with a potential increase from score 2 to score 3 more common in the 1st quarter and Full moon phases (**Figure 42**). Vocalizations were slightly less on average after sunset with a mean intensity score of 1 being the most common across all moon phases. Chorusing was not as prominent at station DRE1 after sunset, but still occurred (**Figure 42**).

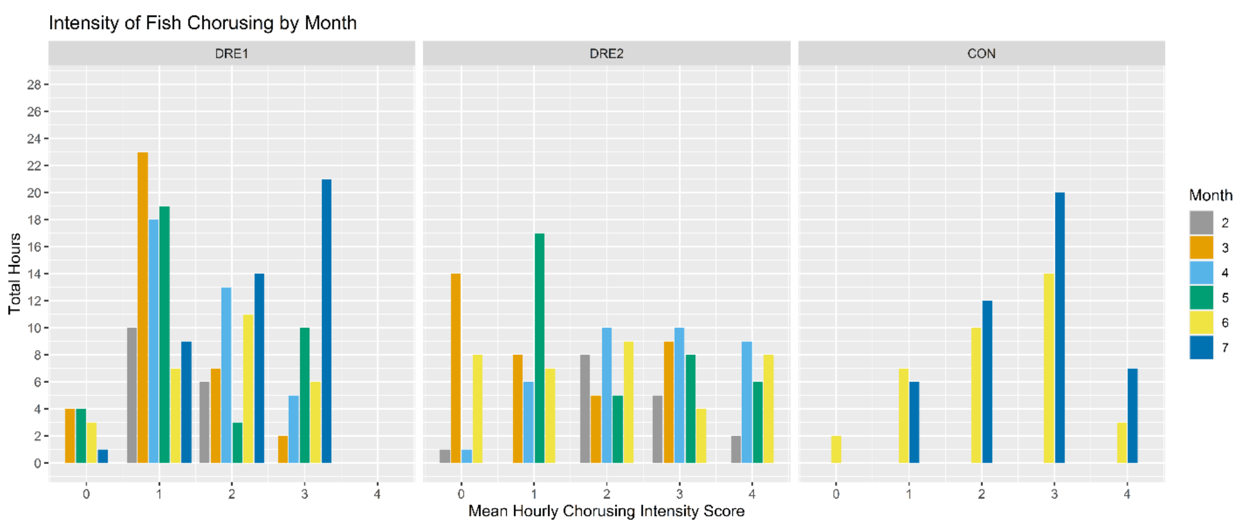


Figure 39. Mean hourly intensity of fish chorusing by month (Feb–July) for sites DRE1, DRE2, and CON

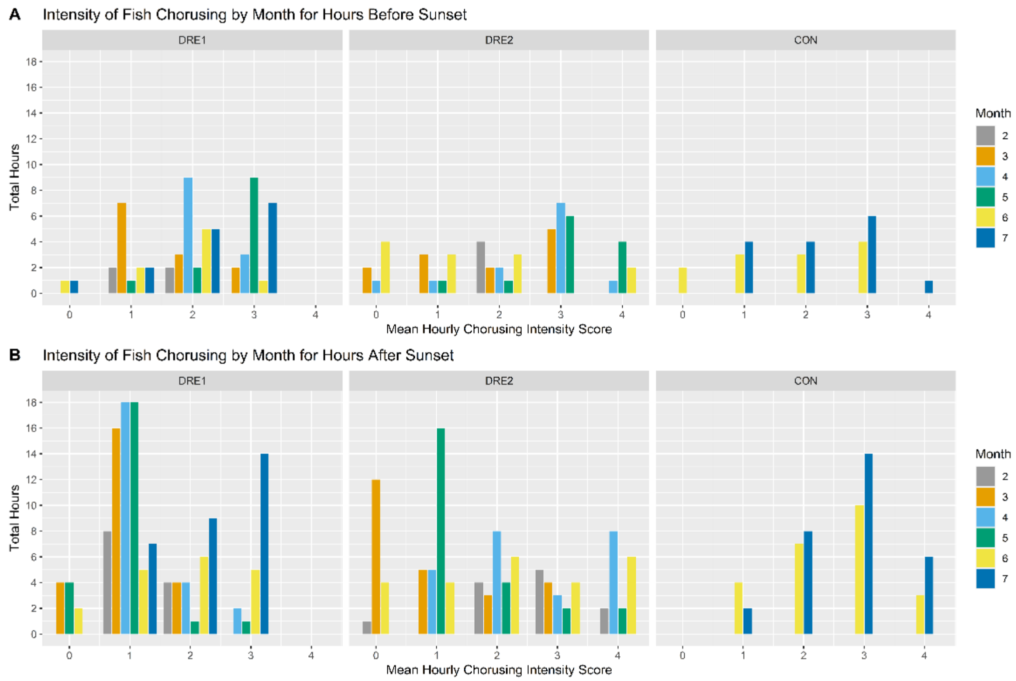


Figure 40. Mean hourly intensity of fish chorusing by month for sites DRE1, DRE2, and CON for 2 hours before (A) and 8 hours after (B) sunset

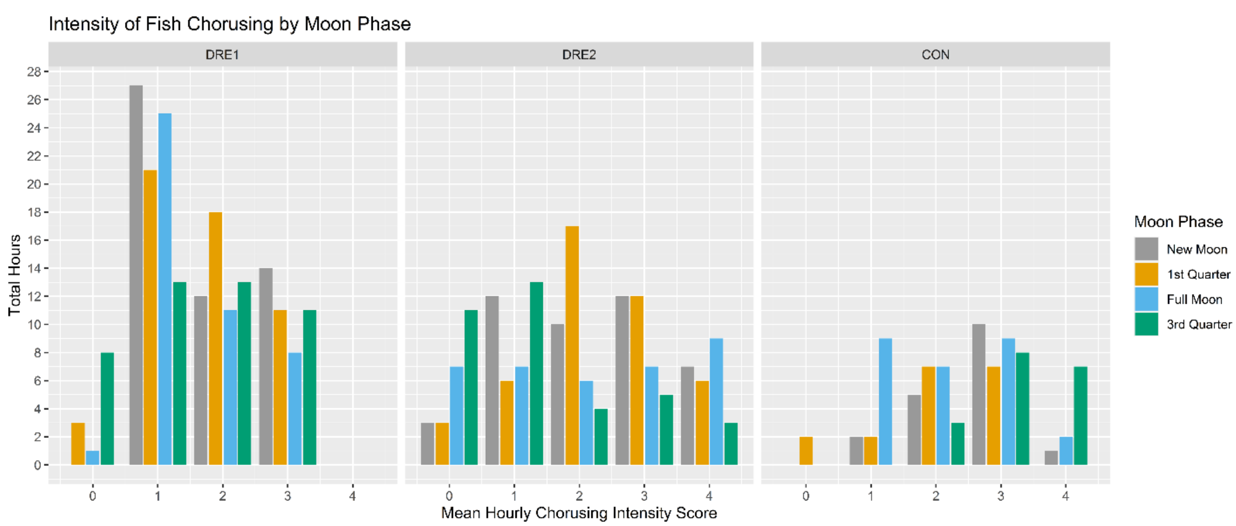


Figure 41. Mean hourly intensity of fish chorusing for sites DRE1, DRE2, and CON in relation to moon phase

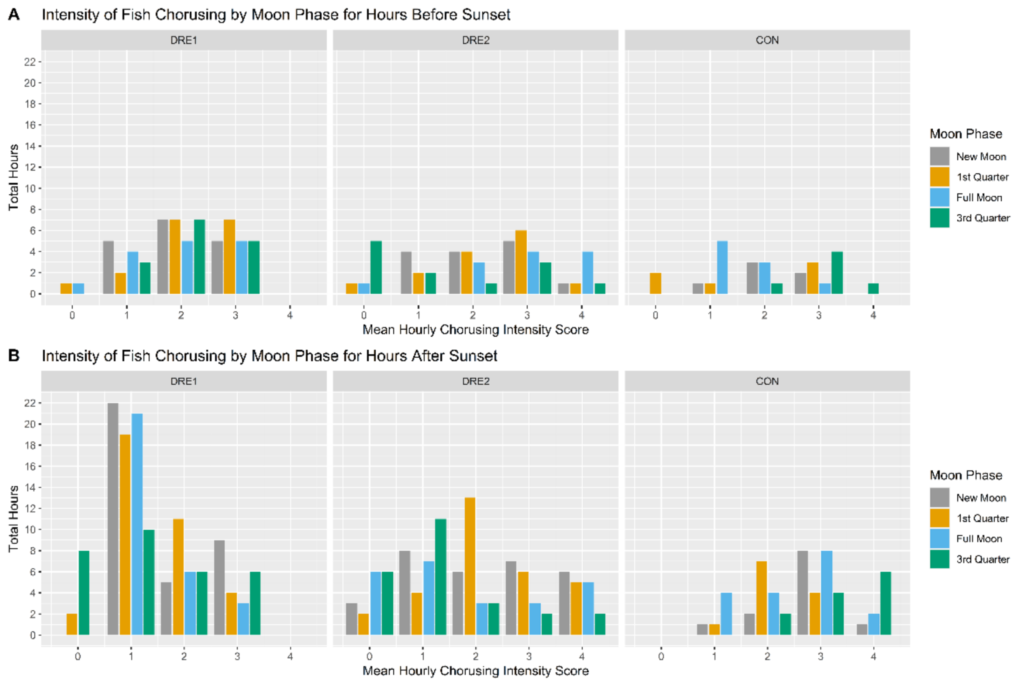


Figure 42. Mean hourly intensity of fish chorusing by moon phase for DRE1, DRE2, and CON in relation to moon phase for before (A) and after (B) sunset in 2018

5.3.4.2.1 Relative Chorusing Intensity and Hours

Analysis of PSD levels for representative datasets showed that equivalent scores (intensity) for Chester Shoal and Canaveral Shoal did not have the same sound pressure levels, as shown for SPL-RMS, 1%, 5%, 50% (median), 95%, 99% (**Figure 43**). At peak level fish chorusing frequencies (300–700 Hz), CON SPL-RMS levels were 85 dB re 1 µPa^2/Hz and 90 dB re 1 µPa^2/Hz that corresponded to scores 3 and 4, respectively. In contrast, DRE1 averaged 105 dB re 1 µPa^2/Hz (score 3) for this lower frequency band corresponding to the most intense choruses from fishes in the family Sciaenidae and Atlantic midshipman (family Batrachoididae) that was not as locally intense. There was a decrease of 10 dB in PSD levels at 700 Hz seen in all three comparative plots indicative of the upper peak frequency for Sciaenidae fish chorusing. Overall, the midshipman chorusing PSD levels in the 700–1,200 Hz band were quieter than those observed on the Wave Glider, likely due to differences in habitat and/or structure for aggregations. At higher frequency bands (>2,500 Hz) more indicative of vessel noise, PSD levels peaked at approximately 70 dB re 1 µPa^2/Hz for CON, as compared to 85 dB re 1 µPa^2/Hz for station DRE1, although the range from low-high percentiles was much greater for station DRE1.

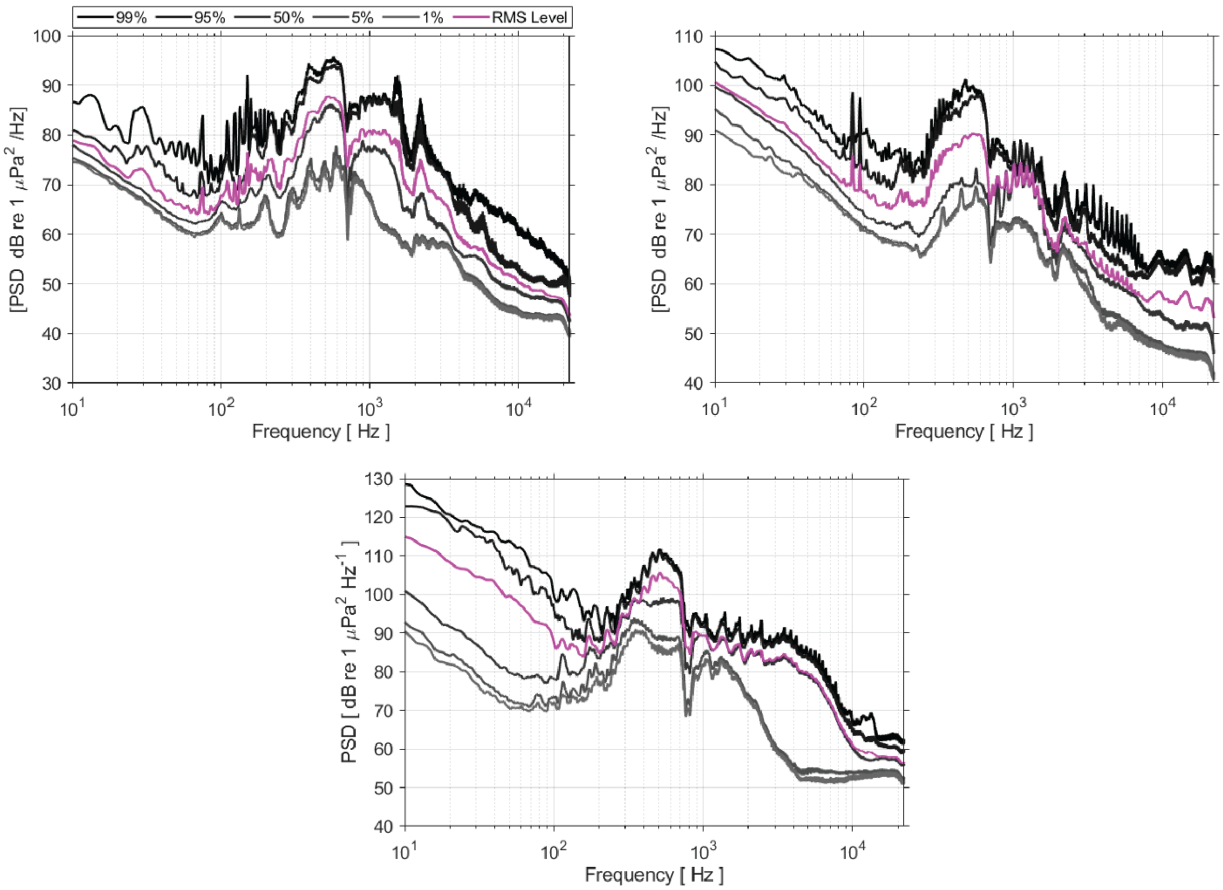


Figure 43. Comparative PSD levels (SPL-RMS, 1%, 5%, 50%, 95%, 99%) for representative datasets of scores of fish chorusing intensity

Data are shown for CON in June (Score 3); CON in July (Score 4); and DRE1 in July (Score 3)

5.3.4.3 Fish Species Identified in Acoustic Recordings

As part of the manual review of audio files, nine different types of calls were identified from possibly six different families of fish. Additionally, two other distinct types of fish calls and chorusing were documented but not classified. The most documented fish calls and chorusing on all three stations were from Sciaenidae, Batrachoididae, and Ophidiidae (**Table 29**). Within these families, known fish species that were identified include Atlantic midshipman, oyster toadfish, and black drum. Several species were identified to the Sciaenidae family, but not specifically confirmed due to unique call characteristics. Other common calls were possibly from Serranidae, Ariidae, and Triglidae families.

Table 29. Family and acoustic parameters for typical examples of the most common fish calls identified in the analysis

Family	FF	PF	Duration (sec)
Sciaenidae	-	-	-
Black Drum (*Pogonias cromis*)	108	108	0.4
Unconfirmed Sciaenidae A	118	590	chorus
Unconfirmed Sciaenidae A	172	560	0.3
Unconfirmed Sciaenidae B	345	1,315	0.025
Unconfirmed Sciaenidae C	113	226	0.3
Ophidiidae	-	-	-
Unconfirmed Ophidiidae	500	1,500	0.04
Batrachoididae	-	-	-
Oyster Toadfish (*Opsanus tau*)	118	118	0.4
Atlantic Midshipman (*Porichthys plectrodon*)	194	1,012	chorus
Atlantic Midshipman (*Porichthys plectrodon*)	211	850	0.2

FF = fundamental frequency (Hz); PF = peak frequency (Hz)

5.3.4.4 Marine Mammal Vocalizations

Examination of a subset of audio files for marine mammal vocalizations revealed the presence of odontocetes (toothed whale; most likely dolphins) at all three stations. The presence of species with vocal ranges above 22.05 kHz could not be confirmed, as usable data is equivalent to the Nyquist frequency or half the sampling rate (44.1 kHz). No mysticete (baleen whale) vocalizations were detected. Vocalizations included whistles, clicks, and various types of burst pulses (all as defined in (Jones et al. 2019). The number of active vocalizers varied between stations, with three or more actively vocal individuals most common at station CON (n =7 of 8). Station DRE2 was consistent with two active vocalizers for all files reviewed (n = 3), while station DRE1 appeared to be the quietest with most files showing one or two actively vocal individuals (n = 6 of 8). Further analysis is required to see if these trends are truly representative for each station.

Whistles (n = 467) ranged from 1,935 Hz to the upper limit or Nyquist frequency (22.05 kHz) across all stations, the true upper limit for the odontocete specie(s) presently unknown (**Figure 44**). Closer examination revealed a difference in frequencies utilized between sites, with the largest range (~ 20.1 kHz) and lowest frequencies (1,935 Hz) heard at station DRE1. Station CON followed with a range of ~ 19.8 kHz (lowest 2,228 Hz) while station DRE2 exhibited the smallest range in frequencies (~ 19 kHz) and highest minimum of 2,991 Hz. Whether these differences are related to station specific environmental parameters (ambient sound levels, prey/predator sensory system, etc.) or individual/species vocal preference will require further investigation. Clicks (n = 77) ranged from 1,173 Hz to the Nyquist frequency, the true upper limit unknown due to sampling limitations (**Figure 44**). Burst pulses (n = 109) ranged from 175 Hz to the Nyquist Frequency (**Figure 44**).

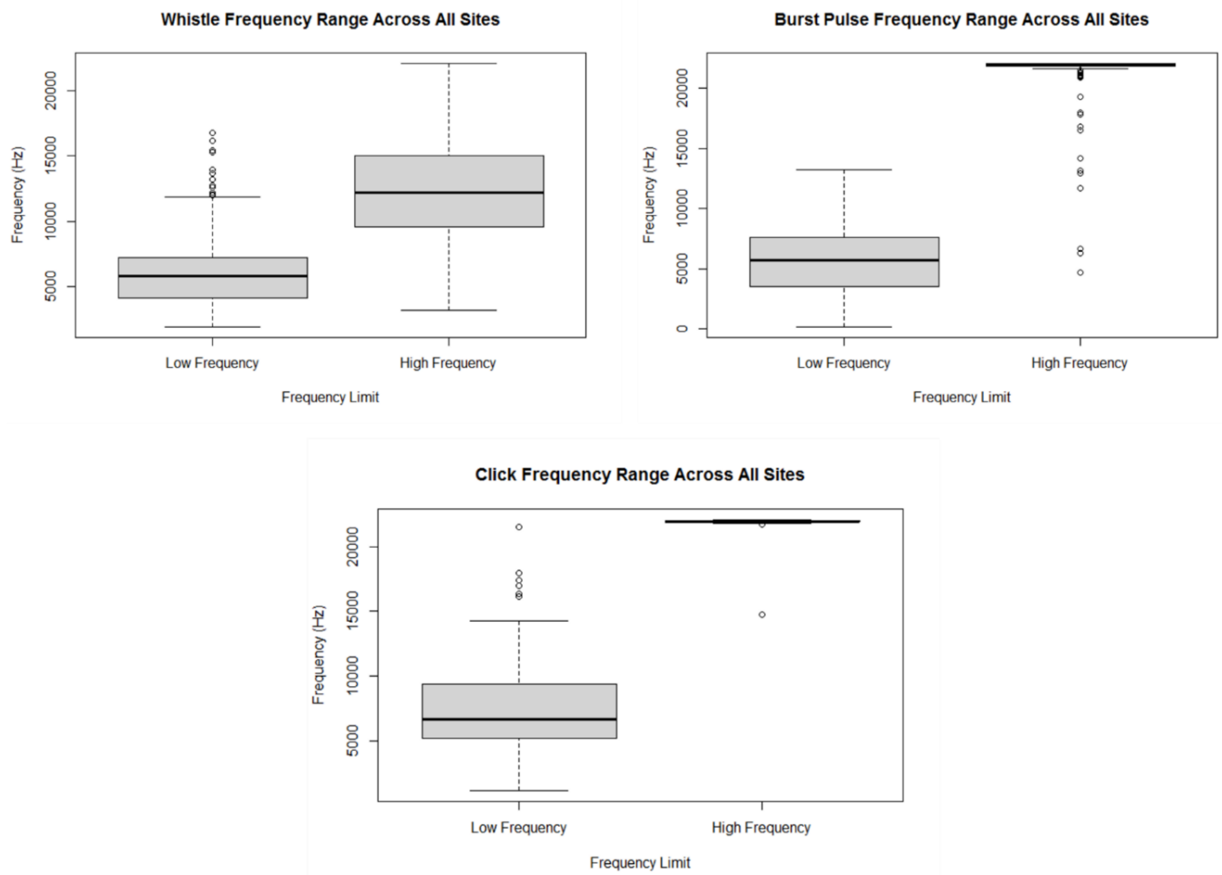


Figure 44. Frequency range of marine mammal vocalization types including whistle (upper left), burst pulse (upper right), and click (center bottom) from April to July 2018

Sample size is representative of number of selected vocalization groups or bouts that varied in duration but covered to overall frequency range of the bout

5.3.4.5 Summary of Fish Chorusing Activities from Wave Glider Surveys

Trends in biological noise can be seen in the LTSA plots from the Wave Glider survey in July 2020 (**Figure 28**). There was an increase in the SPL of fish vocalizations that were observed each night after 1800 (sunset was approximately 20:20), representing species from multiple families including Sciaenidae, Triglidae, and Batrachoididae. Two distinct fish choruses that increase in sound pressure levels at different times were observed in the data, particularly for transects 5 and 6. This was more prominent then observed in the passive acoustic fixed-station data on Canaveral Shoals that is summarized below. The first chorus was comprised of multiple species dominated by sciaenids and peaks in SPL approximately one hour after sunset. Further analysis shows that the second chorus peaks approximately 3 hours after sunset and is dominated by very loud persistent hums that were acoustically similar to published reports on the plainfin midshipman (*Porichthys notatus*) that occurs in the Pacific Ocean, indicating these choruses are likely from the Atlantic midshipman (*Porichthys plectrodon*), a fish species that is known to be present in the region but with no other known documentation of recordings. After dominating the soundscape, persistent fish chorusing began to taper off at hours 0100–0200, with limited individual calls heard during the day.

Unique trends in biological noise can also been in LTSA plots from the Wave Glider survey that occurred 31 December 2021–5 January 2022 (**Figure 32**). Notably, there were not two distinct fish choruses as observed in July 2020. There was an increase in SPL of fish vocalizations each night a couple of hours before and after 1,800 (sunset was approximately 17:30). As with July 2020, this was a multi-species chorus comprised of mostly Sciaenidae and Batrachoididae. Most dominant calls were observed in the mid-frequency bands (300–900 Hz) from Sciaenidae. Following this primary chorus, individual fish calls, including Atlantic midshipman, were observed into the early morning hours. There was some partitioning in fish calls observed, particularly between those documented at the 400–800 Hz band and other "clicks" observed at 1,400–2,800 Hz. However, the Atlantic midshipman calls were limited to "growls," and the high intensity "grunts" and "hum" were not documented. This survey does confirm the presence of fish chorusing during the winter months, with individual calls observed at numerous hours throughout the day. As with July 2020, the intensity and relative activity appeared to vary considerably by habitat, a subject worthy of future investigation.

5.3.4.6 Suspected Recording of Atlantic Midshipman (*Porichthys plectrodon*) Calls and Chorusing in the US South Atlantic

The distinct grunts and chorusing of the Atlantic midshipman were first identified during review of data for the late evening hours from the Wave Glider Acoustic Survey 1 in July 2020. Data for late evening hours (after 1800) was reviewed more closely to characterize the fish grunt calls that have not been previously documented. The spectrogram of the grunt calls (**Figure 45**) show approximately 1 s between calls, and 80–100 ms for an individual animal call. During the chorusing or "hum" (**Figure 31** and **Figure 46**), there is a prominent harmonic stack that has been observed with plainfin midshipman off the West coast (McIver et al. 2014). One of the key authors of that study reviewed audio files from Canaveral and helped to identify the species heard vocalizing.

The frequencies observed for the chorus hum in this study are higher than those observed with the plainfin midshipman (84–104 Hz) in Southern California. However, researchers have observed 5 Hz increase in fundamental frequency per 1° C increase in water temperature for the west coast plainfin species. The water temperature off Cape Canaveral in summer July 2020 was approximately 18° C greater than documented in (McIver et al. 2014). Given this information, the fundamental frequency would be expected to be higher in the warmer waters, although actual increases dependent upon water temperature are likely species-specific. Further analysis for these calls off Cape Canaveral is warranted to examine the positive relationship between water temperature and fundamental frequency and will be the subject of future work.

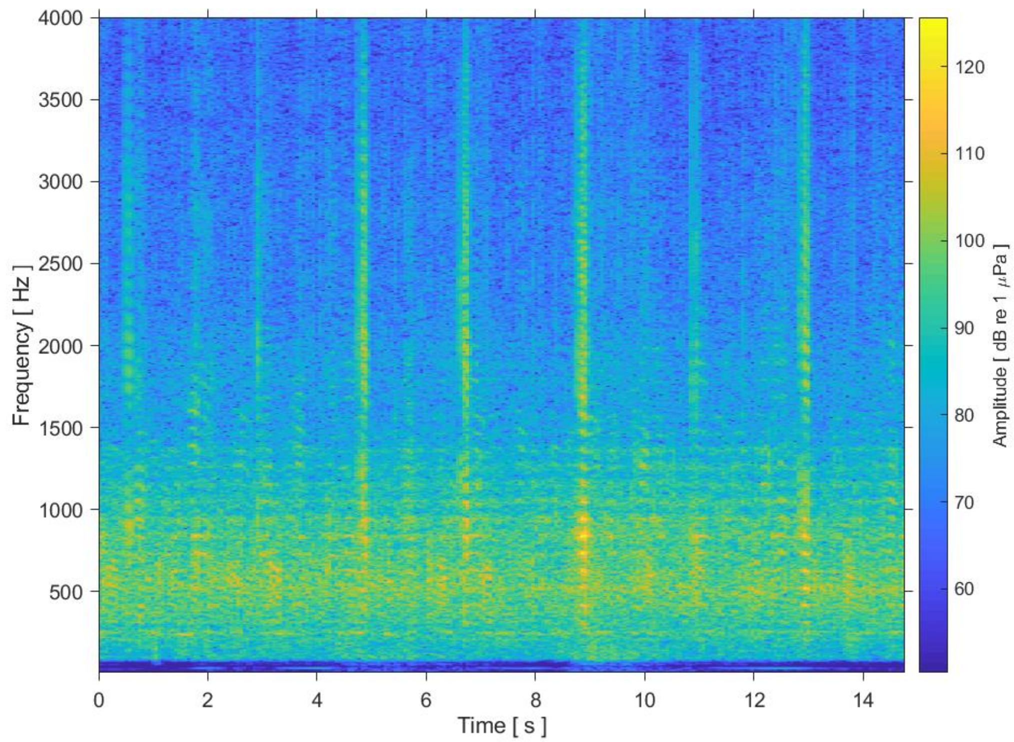


Figure 45. Spectrogram of fish grunt calls recorded by the Wave Glider

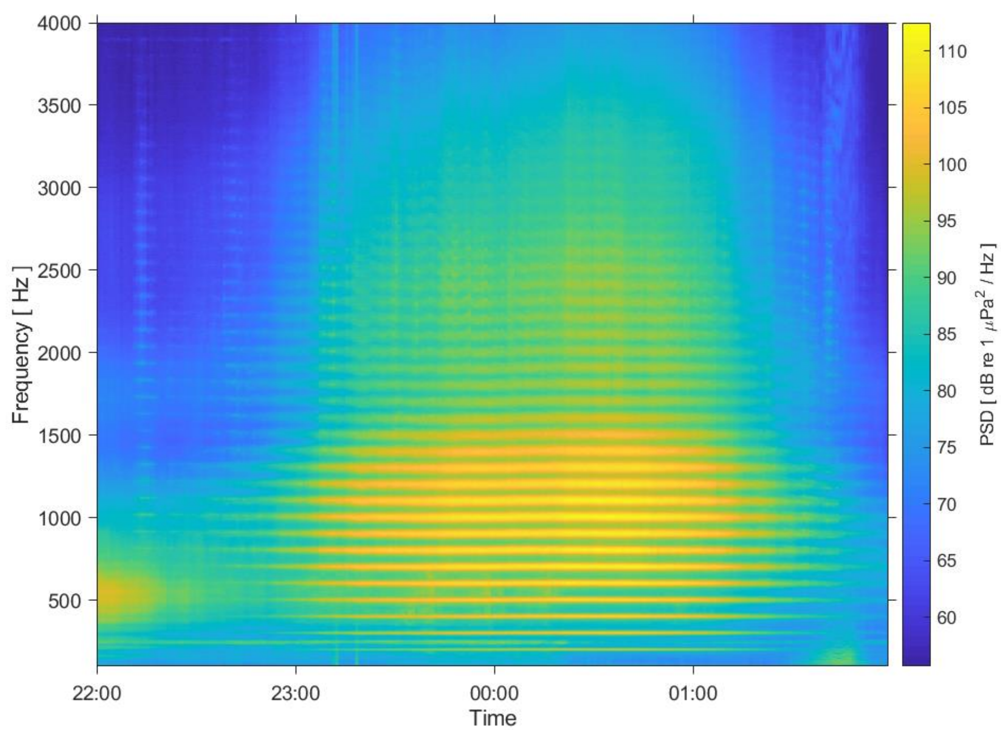


Figure 46. Four-hour spectral average plot recorded by the Wave Glider beginning 24 July

5.4 Discussion

5.4.1 Trends in Ambient Sound Recordings

Ambient sound levels in the low frequency band were observed to range from 75–90 dB re 1 μPa^2/Hz. Narrowband peaks in PSD levels in the low frequency band were seen in all three stations and are indicative of persistent larger ship noise in the study area. Larger vessels that regularly occur in the area include cargo ships, cruise ships, and tugboats. Mid-frequency PSD levels were found to be noticeably higher (10–15 dB) in mid-June as compared with later June. This appeared to be the result of intense sciaenid chorusing heard on all stations for different times of the month, and indicative of the temporal differences in biological noise dependent upon time of day, moon phase, and month. At higher frequencies, PSD levels were found to be quieter but indicative of harmonics from smaller recreational or commercial vessel noise, particularly for DRE1 and DRE2 stations closest to Port Canaveral. Boat noise was observed to be more transient in these recordings. Sea state was low for both periods at 0.8 and 1 m, likely limiting the amount of wind-driven noise typically observed in recordings around 1,000 Hz (Haxel et al. 2019).

Analysis of ambient noise from the Wave Glider survey in July 2020 showed average PSD levels for the low frequency band comparable to the passive fixed stations, although peaks were quieter at approximately 85 dB re 1 μPa^2/Hz. The glider survey also provided an opportunity to evaluate PSD levels for higher sea states and wind speed approximately 6 m below the surface, from the sub of the Wave Glider. Although PSD levels in the mid-frequency band for the transects were dominated by noise from Atlantic midshipman chorusing, analysis of representative daytime hours in transect showed median levels greater than 70 dB re 1 μPa^2/Hz for sea state on average 1.4 m, with wind speeds over 9 knots. As with data from stationary recorders, persistent noise from smaller vessels was observed in the high-frequency band. Although loudest noise levels from both large, slow-moving vessels and those more likely recreational and commercial fisherman are documented throughout the spectrograms, the relative higher intensity of biological noise for dusk and night hours is clearly visible. These findings highlight the importance of consideration for fish spawning aggregations on or near shoal complexes during the spring and summer months.

5.4.2 Noise from Dredge Operations

Dredge noise from fixed-station sound recorders was analyzed by 1/3-octave levels for comparison between sites and with other studies. Noise levels by octave were louder across all three bands (low frequency [< 250 Hz], mid frequency [250–2,500 Hz], and high frequency [> 2,500 Hz]) for the station closer to dredging (DRE1) for the analysis period consisting of three active dredging days. Closer review of data shows that the DRE2 station was only louder than the DRE1 station during transit of the dredge that moved off the shoal to the south for offload of sand. Dredging occurred in approximately 2-hour cycles for dredge of sand, offload, and vessel return to the area. LTSA plots from the DRE1 station also highlight the persistent nature of noise in the local area during active dredge activity. Even during times the dredge is not on site, the low frequency noise from ship movement increases the anthropogenic noise levels for these lower bands above ambient levels. The high PSD levels observed in the low frequency band are also likely due to cruise ships and other large vessels transiting the area, and overlap with those frequencies of greatest sensitivities (100–400 Hz) for fish (Reine et al. 2014).

Acoustic analysis of data from the post-dredge period and 3 months post-dredge period showed key differences in 1/3-octave SPLs for the 100–250 Hz frequency band as compared with the dredge period. Recordings from the DRE1 station were on average 15–20 dB quieter during these post-dredge periods, while recordings from DRE2 were 5–10 dB quieter due to the lack of persistent dredge vessel noise in closer proximity. Differences at higher frequency bands were less distinct than those observed at low and mid frequencies associated with large vessel engine noise that also overlap key bands for fish vocalizations. Individual fish calls were catalogued from the DRE1 site during active dredging, and overlapping individual calls were also noted during times of quieter ship noise. Also, there was no apparent difference in fish vocalization activity at DRE1 during as compared to just after dredging, although chorusing is limited during this time of year (February). However, more diverse vocalizations were observed at the DRE2 station for the same dates. This did appear to be an overall trend, as higher activity related to fish chorusing was observed at this undisturbed station (DRE2) overall as compared to the dredge location (DRE1) as discussed below.

Sound levels from dredging as presented by 1/3-octave analysis were compared with a similar study aimed at characterizing underwater sounds from TSHDs during sand mining off Wallops Island, Virginia (Reine et al. 2014). One of these dredges was the *Liberty Island*, the same dredge vessel analyzed in this Canaveral study and provides for a unique comparison of sound levels in two different study areas. In this report, levels were found to be similar for a lower listening depth of 9.1 m (similar to the DRE1 station off Canaveral) and upper listening depth of 6 m. Ambient levels across several sites was 117 dB re 1 μPa on average. Received levels or SPL-RMS of dredge sediment removal noise across all bands was within 1 dB of ambient levels at 1.55 km, and equivalent at approximately 1.75 km. At 150 m from the source, peak frequencies for 1/3-octave SPL levels were centered around 200 Hz, 500 Hz, and 1.1 kHz. SPL levels fell to 125 dB re 1 μPa at 2.1 km, approximately 5 dB above ambient. During vessel transit, SPL for the *Liberty Island* was documented from approximately 123–127 dB re 1 μPa at a distance of 1,000–2,000 m.

Comparatively, measured average ambient broadband sound levels for Canaveral stations ranged from 109–122 dB re 1 $\mu Pa^2/Hz$ for periods before and after dredging, as recorded at DRE1 (11-m depth). Recordings were taken from 1,000–2,000 m (DRE1 station) but do provide a baseline estimate for relative sound pressure levels. At this distance, broadband received level ranged from average 125 to 129 dB re 1 μPa. Dredge noise levels (broadband SPL) were found to be above max ambient levels by 3–7 dB, as compared to estimated attenuation to ambient at approximately 1,075 m seen in (Reine et al. 2014). However, audio files were not analyzed to correlate with timestamps for the actual dredge position in this study. Overall, maximum SPL levels for sediment removal or vessel transit at 1,000–2,000 m were similar to the previous study off Wallops Island. Many variables can influence sound levels in the acoustic environment including bottom type, depth, recorder position, and positioning of the dredge vessel, but measurements off Canaveral show the intermittent, increased sound pressure levels in the local area (within 2 km) associated with dredging in this region.

5.4.3 Biological Soundscape on Canaveral Shoals, Identification of Key Species, and Relationship to Other Findings

Based on manual review of files, fish chorusing was least common and diverse at the DRE1 station; intensity scores of 3 or more species were not noted. Chorusing activity peaked in July for this station closest to the dredge area. By contrast, greater intensity and diversity was noted at DRE2 and CON stations where scores 2–4 (including chorusing by three or more species) were noted almost every month of review. Peak levels of multi-species chorusing were April for DRE2 (July not available), dominated by sciaenid chorusing and more distant Atlantic midshipman. In comparison, peak levels were in noted in July for CON (although only June–July were available). Interestingly, the greatest intensity and diversity was documented at the CON station associated with Chester shoals. The reasons for this are not entirely clear but could be based on habitat variables such as clearer water on Chester shoals, greater diversity of sediment, and a lesser disturbed area. There were also the clearest trends for multi-species chorusing after sunset, and also in the third quarter moon phase noted at this location.

Acoustic recordings of Atlantic midshipman represent a unique finding of this study. Trawl data collected by the University of Florida confirms the occurrence of Atlantic midshipman in the study area (pers comm. Deb Murie). Chorusing of this species was prominent for periods after sunset in all stations.

However, often these vocalizations were not “locally intense” as the fish aggregations were not located in or directly adjacent to the shoal habitat. Additionally, midshipman chorusing was notably louder as recorded during Wave Glider surveys, providing additional information that this species is vocalizing in areas either “inter-shoal” or slightly offshore of the Chester and Canaveral shoal complexes. Although there was clear partitioning of the sciaenid and the midshipman fish chorusing in time especially as observed in glider recordings, there also appeared to be spatial distinction as noted from sound pressure levels during manual review. Finally, while there is overlap in the frequency bands for these two types of choruses, there is some level of frequency partitioning as seen in the LTSA glider figures, and loudest levels for midshipman were noted closer to 1,000 Hz.

5.4.4 **Advantages and Limitations of Wave Glider Acoustic Surveys**

The Wave Glider has several advantages for soundscape surveys. Central to these is the ability to have an autonomous audio recording platform with greater spatial coverage. The vehicle allows for persistent surveys of large areas that otherwise would be too costly and difficult (Pagniello et al. 2019). This greater coverage allows for the opportunity to identify specific areas of interest and/or new spawning aggregations, as was done with Atlantic midshipman in this study. With supplemental use of a motion-isolating tow cable and tow fish, the audio data is very clean with limited self-noise and provides continuous recording data that is suitable for advanced analysis such as auto-detection of animal calls or machine learning in soundscapes. An additional advantage of the Wave Glider is the ability to simultaneously record atmospheric, oceanographic, and habitat data with audio recordings. This is crucial to understand the sources of ambient noise for a region and to better characterize the acoustic habitat for different animals, and how that may change in a variety of environmental conditions.

Key limitations of the Wave Glider for soundscape surveys are data storage and susceptibility to extreme ocean conditions. Onboard data storage for continuous recordings is limited without more complex solutions and can be costly. Solving this limitation can lead to increased temporal coverage and valuable datasets for more efficient cataloguing of the soundscape. The glider is a capable platform in high sea states, even those produced by hurricane force winds, but as documented in this chapter periods of low sea states and high currents create difficult scenarios where the thruster is required to safely maneuver the glider, creating additional noise in audio recordings. These are unpredictable challenges even with careful mission planning.

5.4.5 **Lessons Learned and Best Practices for Acoustic Data Collection**

Lessons learned for passive acoustic fixed stations is to not overestimate the battery and/or storage capacity for sound recorders. These limitations are important to consider and plan for with deployment and recovery times to minimize times with no data available. Also, duty-cycled recordings are great for long-term averages and ambient noise level estimates. However, for analyses on a finer scale such as dredging or any other potential stressor, continuous recordings allow for much greater resolution of sound level fluctuations, and also any other sources of noise to be considered when comparing sites. Finally, unique to this study, the domination of fish chorusing after sunset and during night hours for midshipman made it very difficult to examine potential diel trends in other sources of ambient noise off Canaveral.

Several data gaps related to fish chorusing are now even more apparent after this study. One of these is trying to characterize unidentified species calls, including one type that was found to be numerous individuals and intense choruses. This species could not be identified to family, and more research is needed. Additionally, there is a notable data gap for identifying key habitats of occupancy particularly for the newly discovered aggregations of Atlantic midshipman. These intense choruses were noted at a distance in several recordings and are likely occupying distinct bottom types different from Sciaenidae. Increasing our understanding of this spatial portioning, in addition to temporal and frequency partitioning, will help to better summarize what species are chorusing when and where off Canaveral. This in turn will help to better understand and predict potential vulnerability to anthropogenic noise and other activities.

6 Study Conclusions

This study utilized several diverse yet complimentary sampling techniques to document the abundance and behavior of federally managed fish and sea turtles associated with the Canaveral Shoals, including autonomous monitoring strategies that have historically been minor components of sand shoal surveys. This novel approach was driven by the growing recognition that many of the fish and sea turtle species of greatest management interest, while poorly represented in previous shoal surveys due to their generally larger sizes and high mobility, are nonetheless quite common on shoals in the US South Atlantic and Gulf of Mexico. As with smaller sedentary species, large fish and turtles are undoubtedly impacted by sand borrow activities to a degree, but our coarse understanding of their life history makes it difficult to identify or mitigate for specific risks. The present study was made possible through continued improvements in automated sampling systems. Fixed-station acoustic telemetry tags and receivers, satellite transmitters, inertial measurement units, uncrewed ocean gliders, and ocean sound recorders are all powerful tools for expanding the duration and geographic scope of observations on the open continental shelf. At over 6 years in duration, this study was also rather long. Due to cost and logistical constraints, previous shoal surveys have often consisted of intense but shorter duration sampling bouts that do not fully document the (often considerable) seasonal and interannual trends in fish and sea turtle abundance and movement.

This study at Cape Canaveral, including the initial findings presented in Iafrate et al. (2019), and complemented by the concurrent benthic community assessments by Murie and Smith (2022), collectively represents one of the most comprehensive surveys of a sand shoal ecosystem in the US South Atlantic to date. Monitoring is now largely complete (although additional tracking of giant manta ray movements is planned; see Herman et al. 2021), providing an appropriate time to consider several important questions. For example, what have we learned regarding fish and sea turtle use of the Canaveral Shoals that we did not know before the start of the study in 2013? How broadly can these results be applied to other sand shoals in the southeastern US? How will findings help refine management of OCS dredge operations? And finally, what important knowledge gaps remain and how can they best be addressed?

6.1 Recent Species and Habitat Insights

Longline and acoustic tracking efforts over periods of 5 and 6 years, respectively, confirmed that a diverse contingent of federally managed fishes associate with the Canaveral Shoals. Coastal sharks were a particularly conspicuous component of the local fish fauna, collectively present in large numbers year-round. Adult red drum, a sportfish of great economic and cultural significance to the region, was also common much of the year except during fall, when they moved generally north and inshore to spawn. Perhaps most unexpectedly, federally listed smalltooth sawfish (see Graham et al. 2021) and Atlantic sturgeon were both more regular visitors to the Canaveral region than previously known, with some individuals returning in consecutive years. In contrast, members of the economically important reef fish complex, such as snappers and groupers, while susceptible to baited hooks and a subject of several acoustic tracking studies in east and south Florida, were rarely detected during longline and telemetry monitoring of the core study area, although acoustically tagged goliath grouper did intermittently traverse the shoals.

At the community level, there appeared to be greater variation in the large fish assemblage across seasons than across depths. Perhaps this is not a great surprise. While sand shoals offer more vertical relief than the sand-mud plains that surround them, the overall depth difference is small relative to the full range of depths available on the east Florida shelf. Notably, in a recent modeling study by Pickens and Taylor (2020) encompassing the US South Atlantic and Gulf of Mexico, proximity to shoals was less important than oceanographic conditions (e.g., temperature, salinity, chlorophyll) or distance from other habitats when predicting the abundance of many fishery species including penaeid shrimp, sharks, seabass, and snapper. Locally, there were also only subtle differences in the assemblage of acoustically tagged fish between the active CSII sand dredge site and a nearby control site, with most species detected in relatively equal numbers near each area. The reason(s) for this remain unclear, but many of the larger fish species selected for acoustic tagging feed opportunistically in the water column, so their presence may not be strongly influenced by the level of dredge-related disturbance to benthic communities. Moreover, trawl sampling by Murie and Smith (2022) found no significant differences in the numerical abundance or community composition of small benthic fishes between dredged and undredged portions of the CSII borrow site (although fish biomass was higher in undredged sections), suggesting that the benthic prey species quickly recolonize an area after dredge disturbance.

No species targeted in this study strongly associated with the shallowest shoal ridges. In fact, deeper water on the flanks of the shoals, particularly areas characterized by high turbidity and soft sediments, appeared more important for many sharks, red drum, and loggerhead turtles based on utilization distribution maps produced from telemetry data. Shoal margins, with their undulating seafloor topography, have been shown to offer important microhabitats for small fish and invertebrates in other regions (Diaz et al. 2003; Vasslides and Able 2008). Murie and Smith (2022) provided local confirmation of this pattern, demonstrating that the shoal margins (classified as swales in their trawl survey) had higher fish and invertebrate abundance, biomass, and diversity than adjacent ridges, and thus may serve as productive foraging grounds for larger fish species and omnivorous loggerheads. Anecdotally, however, shoal ridges are at least ephemerally valuable for certain managed fish species. Spanish mackerel, for example, form large schools on shoal ridges locally as they quickly pass by during seasonal migrations and are targeted there by commercial gillnet fishermen. Aggregations of federally endangered giant manta ray form on offshore shoal sites, notably Hetzel Shoal and the Bull, during periodic cold-water upwelling events, a behavior that was already widely known in the fishing community and will hopefully be documented in detail during upcoming BOEM-sponsored manta ray studies.

Certain behavioral traits were shared across taxonomically diverse fishes in the Canaveral region. For example, most acoustically tagged species exhibited low site fidelity, generally being detected at any single location for less than an hour on average before moving on. Moreover, there was regular exchange of fish with adjacent non-shoal habitats. Sharks, red drum, and cobia tagged on the shoals—as well as sawfish, cownose rays, tarpon, goliath grouper, and others tagged elsewhere—moved freely between the shoals and offshore reef tract; red drum were also regular visitors to the adjacent IRL. Most fish and sea turtles acoustically tagged near the Canaveral Shoals also eventually undertook extensive seasonal migrations. The highly collaborative FACT Network documented several hundred instances of fish migrating great distances along the coast. Northward spring movements to Georgia and the Carolinas were particularly common, and fish tagged as far as Nova Scotia, Bahamas, and Mexico visited the Canaveral region on many occasions. Satellite tagging also revealed that female loggerhead and green turtles typically disperse hundreds of kilometers from Cape Canaveral after summer nesting is complete.

The local ocean soundscape was rich and temporally dynamic, comprising environmental, biological, and anthropogenic sound components. In this coastal environment, vessel noise regularly contributes to a higher SPL than the ambient soundscape, reflecting the high activity of cruise ships, commercial vessels, and recreational fisherman in the project area. Interestingly, the biological component of the sound spectrum was elevated above ambient levels throughout much of the recordings; snapping shrimp were ubiquitous, and nocturnal fish spawning vocalizations were widespread, especially in spring and summer. Six different families of vocalizing fish were catalogued, and two temporally and spatially distinct fish choruses were apparent. The first is a well-known multi-species chorus beginning around sunset, with a second chorus composed primarily of Atlantic midshipman beginning several hours later. Greater intensity and diversity of fish chorusing were documented near an undisturbed control site relative to the active dredge site although many of the same species were documented at both sites. The importance of Cape Canaveral's sand shoals to fish spawning aggregations was previously unknown prior to this work.

6.2 Relevance to Other Sand Shoal Sites

It is difficult to extrapolate patterns in marine species abundance and diversity from single shoal surveys (i.e., case studies) over wide areas of the continental shelf, or even to other sand shoals that share similar defining qualities. Even subtle differences in physical habitat and oceanographic conditions can result in distinct species assemblages across closely spaced shoals, a point demonstrated in previous studies (e.g., Kaiser et al. 2004, Brooks et al. 2005) and now locally at Cape Canaveral (Murie and Smith 2022). In other words, the habitat value of sand shoals at Cape Canaveral likely differs from sand shoals in other areas and will also vary through time and across species.

One could logically argue, however, that a species' *behavior* is more consistent across wide areas, and that understanding this behavior helps when assessing potential impacts to that species from offshore dredging. Small burrowing fishes, for example, are often sedentary and face the greatest risk from dredge entrainment and habitat disruption, while larger fish species (generally speaking) have an increasing ability to overcome dredging activities and to eventually locate other suitable habitat patches. The traits observed in most priority fish and turtle species at Cape Canaveral (e.g., sharks, drum, cobia, mackerel, and sea turtles), namely high mobility, low site fidelity, and use of multiple habitat types, likely help mitigate the potential negative effects of dredging at the CSII sand borrow site because they naturally spend limited time at that location. There were even indications of high mobility in demersal rays and Atlantic croaker. Moreover, because most of these species are highly migratory with reduced site fidelity, the same individuals are almost certainly utilizing other shoals in the region, also presumably for short periods of time.

For sea turtles, satellite tagging also suggested that loggerheads may have been foraging for benthic prey on or near the Canaveral Shoals during the summer nesting season. Loggerheads also spent more time along the US southeast coastline after nesting was complete, with several individuals passing over or near other mapped sand shoals as they moved towards winter feeding grounds after nesting. Sand shoals may therefore be proportionally more valuable habitat for adult female loggerheads than green turtles in this region. This difference may be unimportant at this time since both species are federally listed and managed similarly, but this distinction may become more meaningful to management if the listing status of either species changes in the future.

One study conclusion that clearly has wide application to other shoals regardless of location is the value of automated sampling platforms. The integrated sampling approach that included acoustic telemetry, passive sound recorders, satellite and IMU tags, and ocean gliders all provided new insight on animal abundance and behavior at Cape Canaveral that traditional sampling never could. While rarely used during dedicated shoal surveys in the past, all these technologies are now relatively mature and should be given consideration as core components of future sand shoal monitoring studies.

6.3 Implications for Dredge Site Management

Several specific findings from the study may have relevance to future dredge site management at other sites in the southeastern US. For example, acoustic telemetry revealed the occasional presence of Atlantic sturgeon and smalltooth sawfish in the Canaveral Array including at CSII, suggesting that dredging effects on these ESA-listed species should be evaluated at sites in east Florida. Both are strict benthic feeders and may be susceptible to dredge-induced habitat alteration but were thought to be rare in the region. That said, both species also exhibited low site fidelity when at Cape Canaveral, and sawfish (detected late spring and summer) are also partially protected by reduced dredging activity in summer designed to protect sea turtle nesting. Evidence is also available that federally listed manta rays periodically gather on offshore shoals during summer cold-water upwellings, an event witnessed by the study authors on several occasions but never described in detail. These gatherings may simply be an attempt to avoid colder water farther offshore, but further research is required to confirm the nature and geographic extent of this habitat association, and their specific use of the CSII dredge site.

From a habitat perspective, elevated turbidity and sedimentation is considered a detrimental byproduct of coastal dredging with the potential to smother nearby reefs, interfere with the feeding and reproduction of many marine species, and potentially invoke an avoidance response (Michel et al. 2013). In interviews conducted by Tomlinson et al. (2007), turbidity from dredging at Cape Canaveral was a concern, with some fishermen linking it with reduced water quality and increasing sedimentation of offshore reefs, both of which were thought to affect fish landings (although many also recognized that maintenance dredging of the Canaveral navigation channel, not sand borrow activities, was often the primary turbidity source). Regardless, in the present study, areas of high turbidity appeared to be preferred by several target fishes including sharks and red drum. These findings would suggest that short-term turbidity increases from dredging operations may not be as detrimental in areas like the Canaveral Shoals that are already naturally turbid much of the year, especially if turbidity plumes are short-lived, are not associated with the release of contaminants, and do not overlap sensitive hard bottom habitat.

Finally, this study highlights the intermittently high noise footprint during dredging above typical ambient sound levels. Even though animals residing outside of a busy port like Canaveral may be habituated to frequent vessel noise, the persistent nature could potentially have other implications, including masking. Noise can mask biologically important sounds between animals (including prey, predators, and conspecifics) and remains an important consideration for dredge site management, particularly in proximity to fish spawning aggregations.

6.4 Remaining Knowledge Gaps

There are several avenues of research that would expand on findings—and limitations— of this study to further inform OCS dredging activities. For example, a deeper understanding of the composition of fish spawning choruses would be a second means for evaluating dredging impacts to benthic fish communities. Dozens of fish families are soniferous, including economically valuable Serranidae (grouper and seabass), Carangidae (jacks), and Sciaenidae (drum and croaker), but vocalizations of most species have not yet been catalogued in the US south Atlantic region. The distribution of soniferous fishes, if identifiable to the species level, could help assess biodiversity across sites with differing levels of disturbance or even to locate and avoid sensitive reef habitat. Passive acoustics could also help identify what type of habitat the Atlantic midshipman is occupying, an often-dominant vocalizer at Cape Canaveral that burrows during the day but appears to occur over different bottom types than other chorusing fishes. Finally, in this study, dredging (winter) did not overlap peak spawning aggregations (spring and summer). A greater emphasis on documenting the immediate impact of dredging on fish chorusing at other times of the year would be informative.

Other behavioral responses of fish in the vicinity of an active dredge also have never been attempted. Monitoring localized movement through IMUs or appropriately designed acoustic telemetry arrays could reveal the immediate avoidance or displacement responses, and the duration of any behavioral changes. The feasibility of installing telemetry monitoring equipment on the dredge itself should also be assessed. The response from most of the highly mobile species tagged in this study is likely to be temporary or subtle, but dredging could invoke greater behavioral shifts for resident benthic species, such as small-bodied flatfish, lizardfish, and sea robins. Assessing baseline patterns of normal behavior prior to disturbance would be important to this analysis.

In this study, dive behavior calculated from IMU tags were examined for nesting and post-nesting female loggerhead turtles. Sea turtles are also present on the shoals at other times of the year but are more difficult to collect. Additional deployments of IMU tags outside of nesting season, and from males, would provide further detail on the habitat use, foraging, and movement of turtles on the shoals. IMUs can also be used for finer-scale classification of dive types, calculation of flipper beats to help distinguish between resting and swimming behavior, and summarizing overall daily activity budgets (Wilson et al. 2017). Correlating spatial movements with finer scale IMU data has potential to provide valuable insight on turtle habitat use, particularly for animals that likely stay in the study area longer outside of nesting season.

A finer-scale analysis of potential behavioral response of fishes to active dredging also represents a knowledge gap. Examination of localized movement could provide an indication on potential responses (such as avoidance or displacement) and the duration of such changes to behavior. Investigation of the feasibility of installing telemetry monitoring equipment on the dredge itself would be worthwhile. The response from most of the highly mobile species tagged in this study is likely to be temporary or muted but could have greater implications for more resident benthic associated species, such as small-bodied flatfish, lizardfish, and sea robins. These species may occur over sand and mud bottoms, and likely occur year-round in the habitats of Canaveral Shoals, as well as other shoal habitats throughout the region. Assessing baseline patterns of normal behavior prior to disturbance would be important to this analysis and also would provide a comparison with coastal pelagic finfish and sharks.

Environmental DNA (eDNA), or free-floating DNA that is passively shed into the water column by all organisms, is now regularly being used to detect rare and cryptic marine species and for assessments of species diversity. With further improvements, eDNA sampling may also provide ecological inferences regarding population size, biomass, and even genetic diversity within a species (Barnes and Turner 2016). eDNA could be used on sand shoals to detect the presence of ESA-listed species and assess species assemblages across habitats, seasons, and levels of benthic disturbance. At Cape Canaveral, for example, eDNA could be eventually used to detect local use of smalltooth sawfish and Atlantic sturgeon, and to compare species richness between shoal, nearshore, and offshore reef communities. That said, in open coastal settings, eDNA may originate from well beyond shoals of interest. The value of eDNA for making management decisions largely depends on understanding the origin, transport mechanisms, and persistence of genetic material in the water column, information that is often not readily available.

Finally, although sand dredging for shoreline renourishment commonly has important environmental benefits (such as stabilizing dunes used by nesting turtles or rebuilding eroding wetlands), sand placed on beaches can also alter seafloor morphology and result in short-term impacts to benthic organisms required by fish, crabs, and shorebirds (Greene 2002). In east Florida, the surf zone fish community is diverse and supports economically valuable species including pompano, bluefish, drum, and snook. At Cape Canaveral, specifically, longshore troughs, shoreline features which could be at least temporarily altered by beach renourishments, appear to be critical winter habitat for young lemon sharks (Reyier 2014), and this region is now classified as a HAPC for the species. Biological monitoring is generally required for beach nourishment projects, but data on fish behavior are limited. (Peterson and Bishop 2005) noted that only 33% of beach nourishment surveys included a fish monitoring component, due in part to challenges in monitoring their abundance and movement. Acoustic telemetry, passive sound recorders, and other autonomous sampling approaches now provide to means to assess the site fidelity and behavior of fish in surf zone habitats—not just offshore borrow areas—and should be considered as monitoring options for future beach renourishment projects.

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Appendix A. Maps of Oceanographic Conditions Measured by the Wave Glider

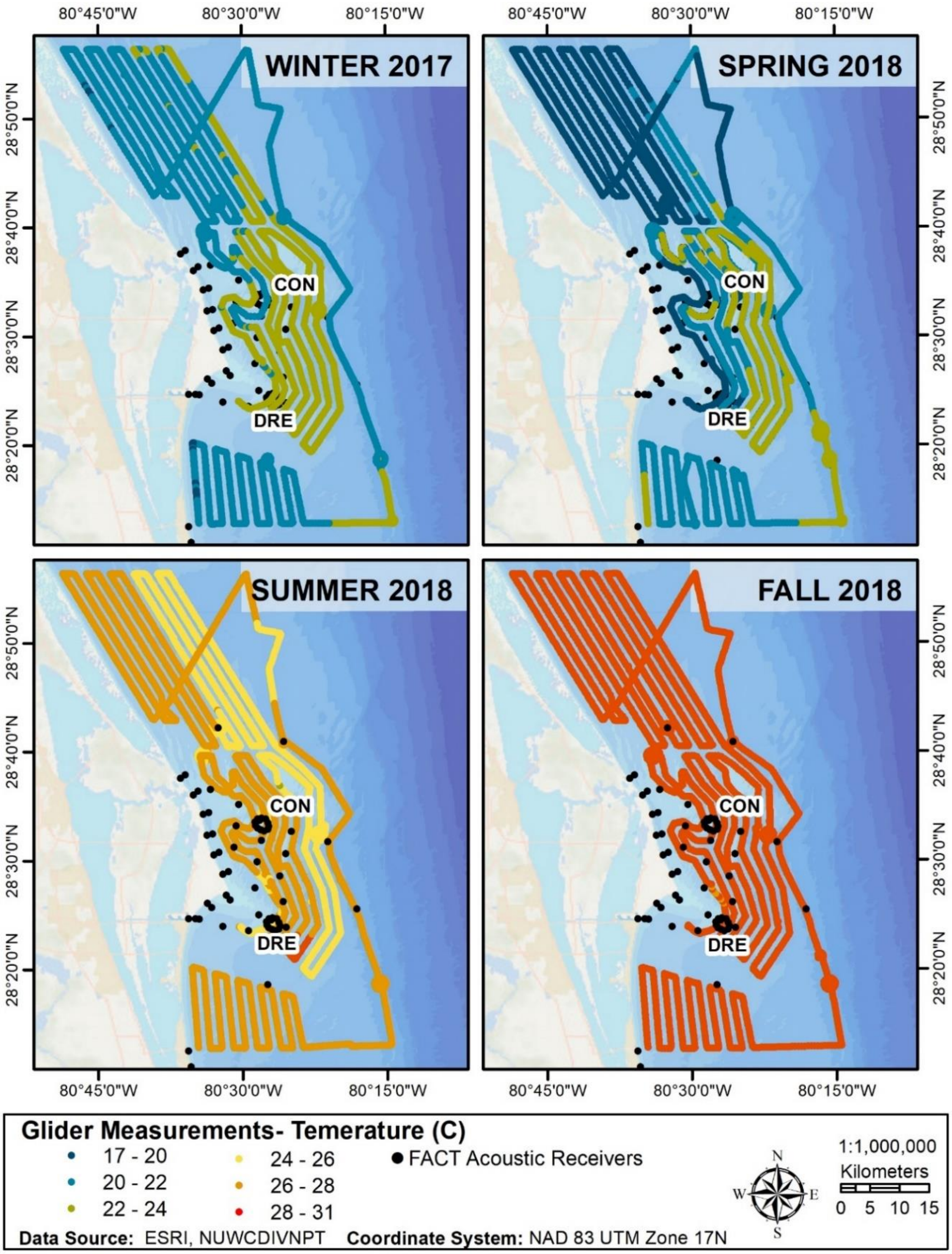

Figure A-1. Spatial variation in surface water temperature, Deployments 1–4

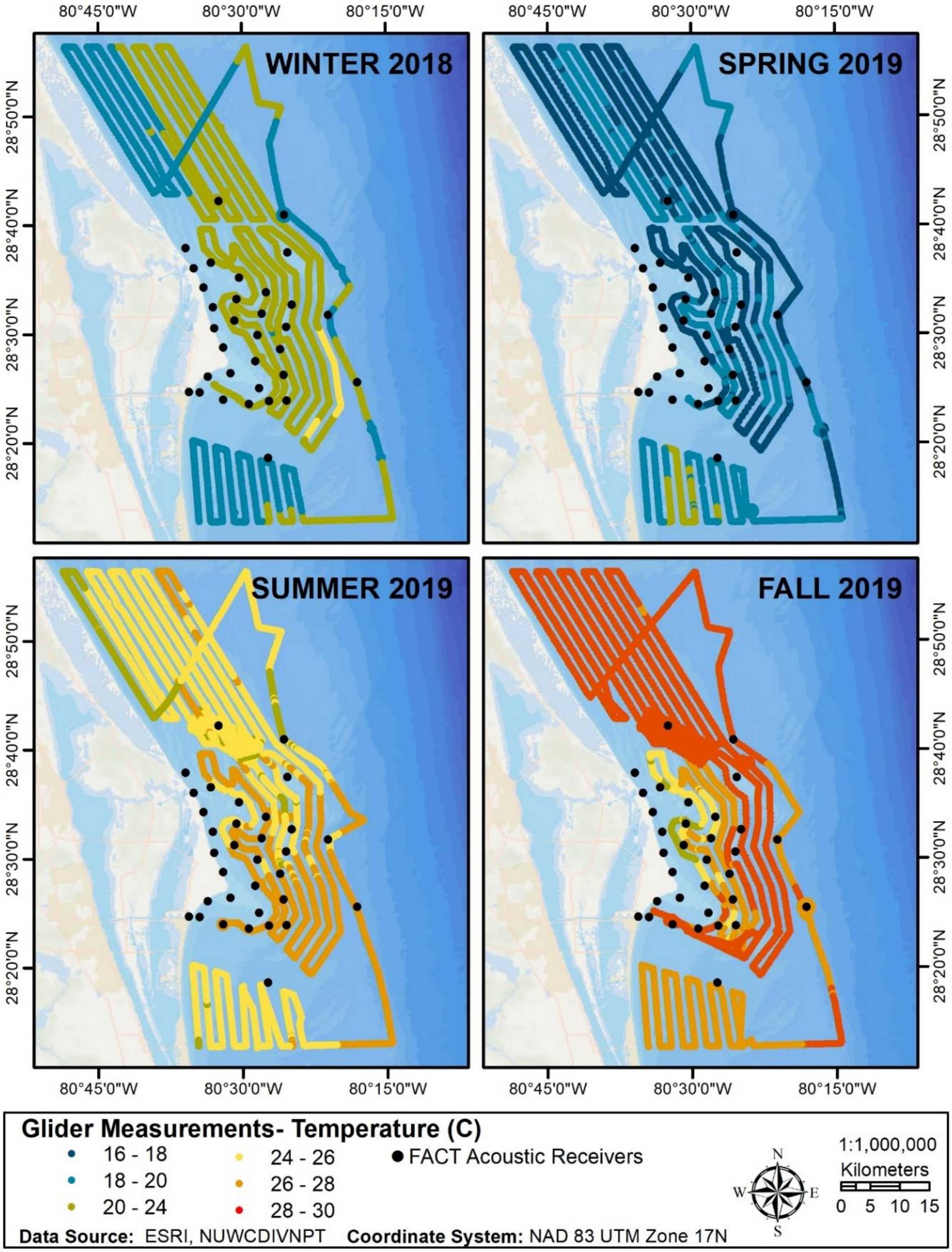

Figure A-2. Spatial variation in surface water temperature, Deployments 5–8

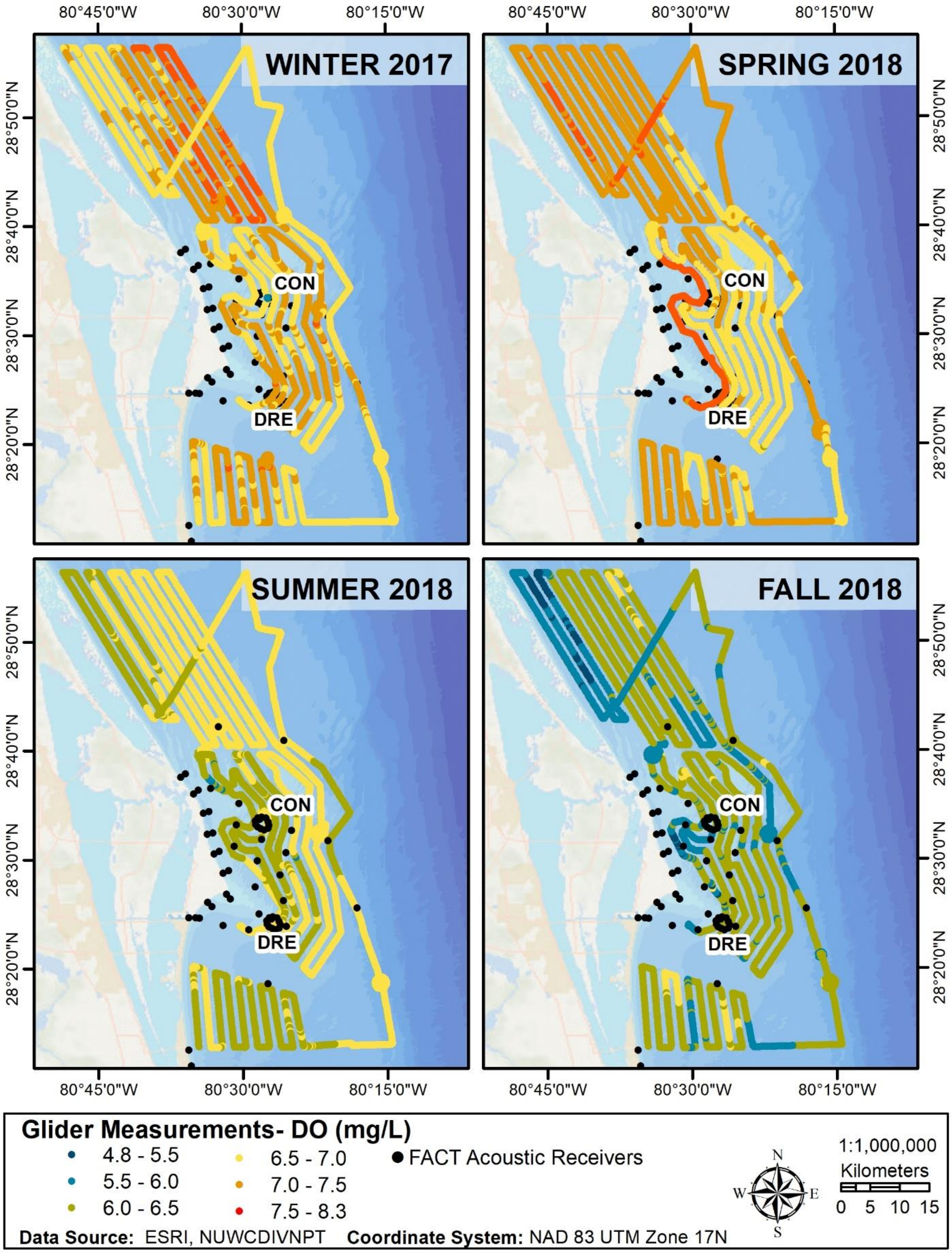

Figure A-3. Spatial variation in dissolved oxygen, Deployments 1–4

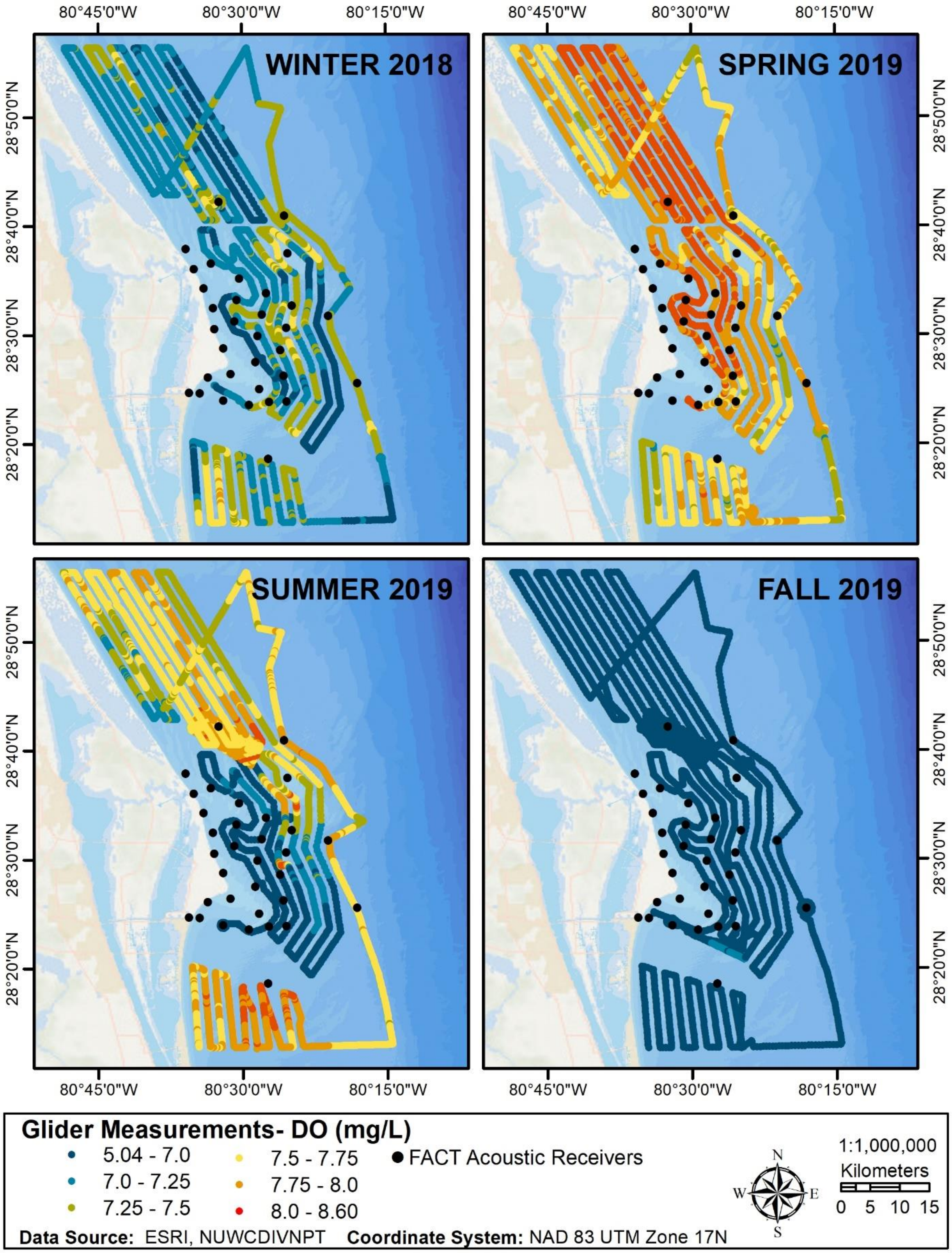

Figure A-4. Spatial variation in dissolved oxygen, Deployments 5–8

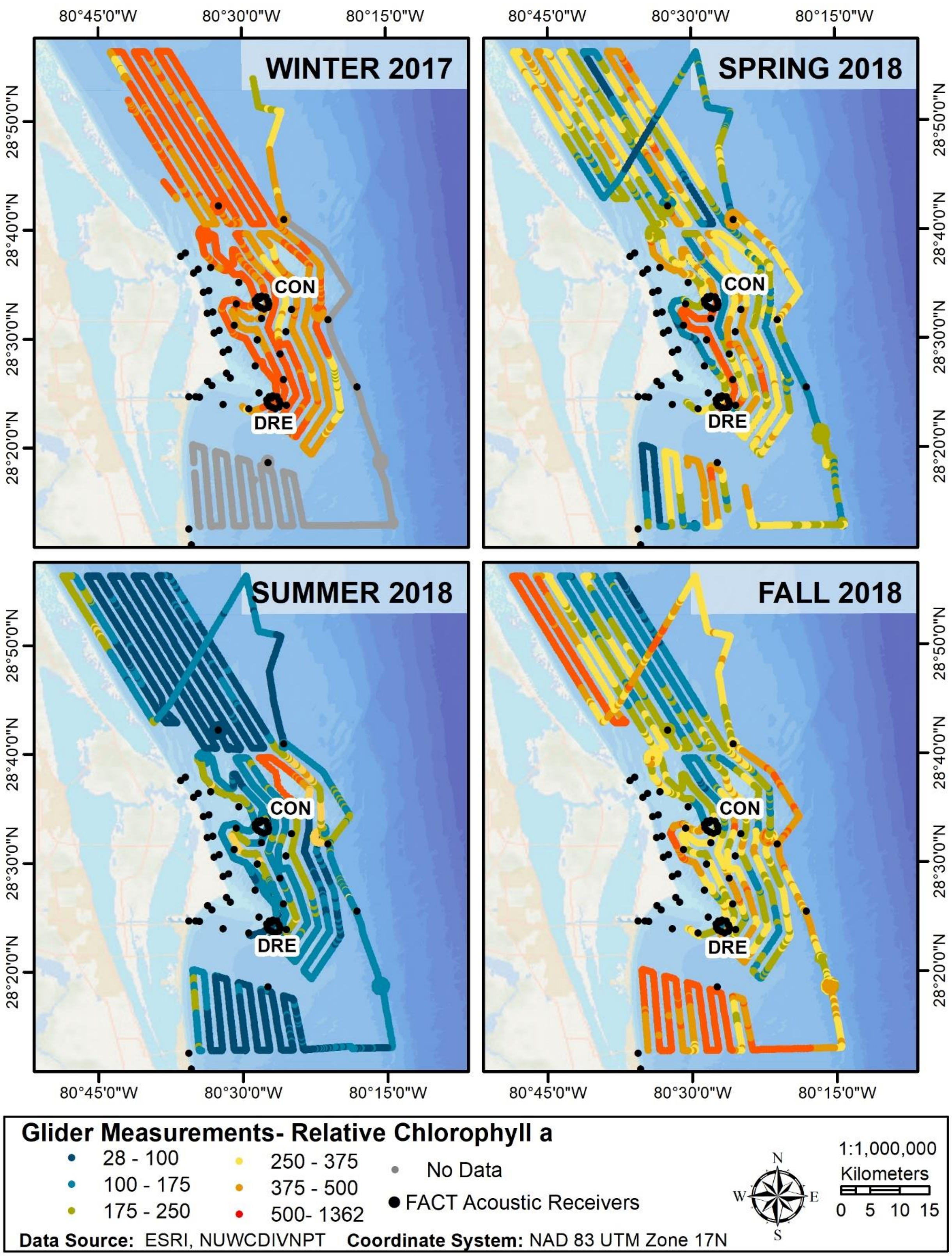

Figure A-5. Spatial variation in relative chlorophyll, Deployments 1–4

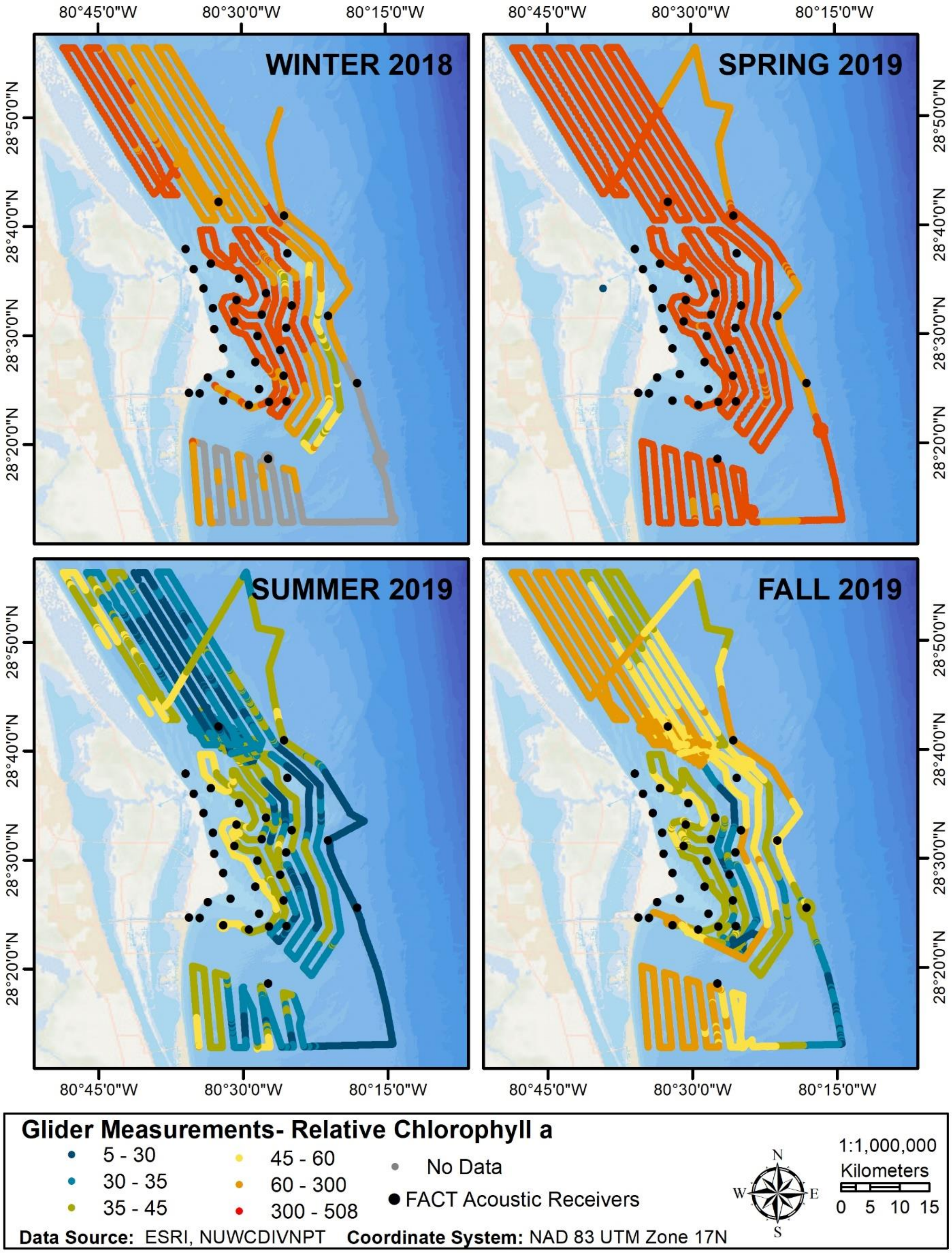

Figure A-6. Spatial variation in relative chlorophyll, Deployments 5–8

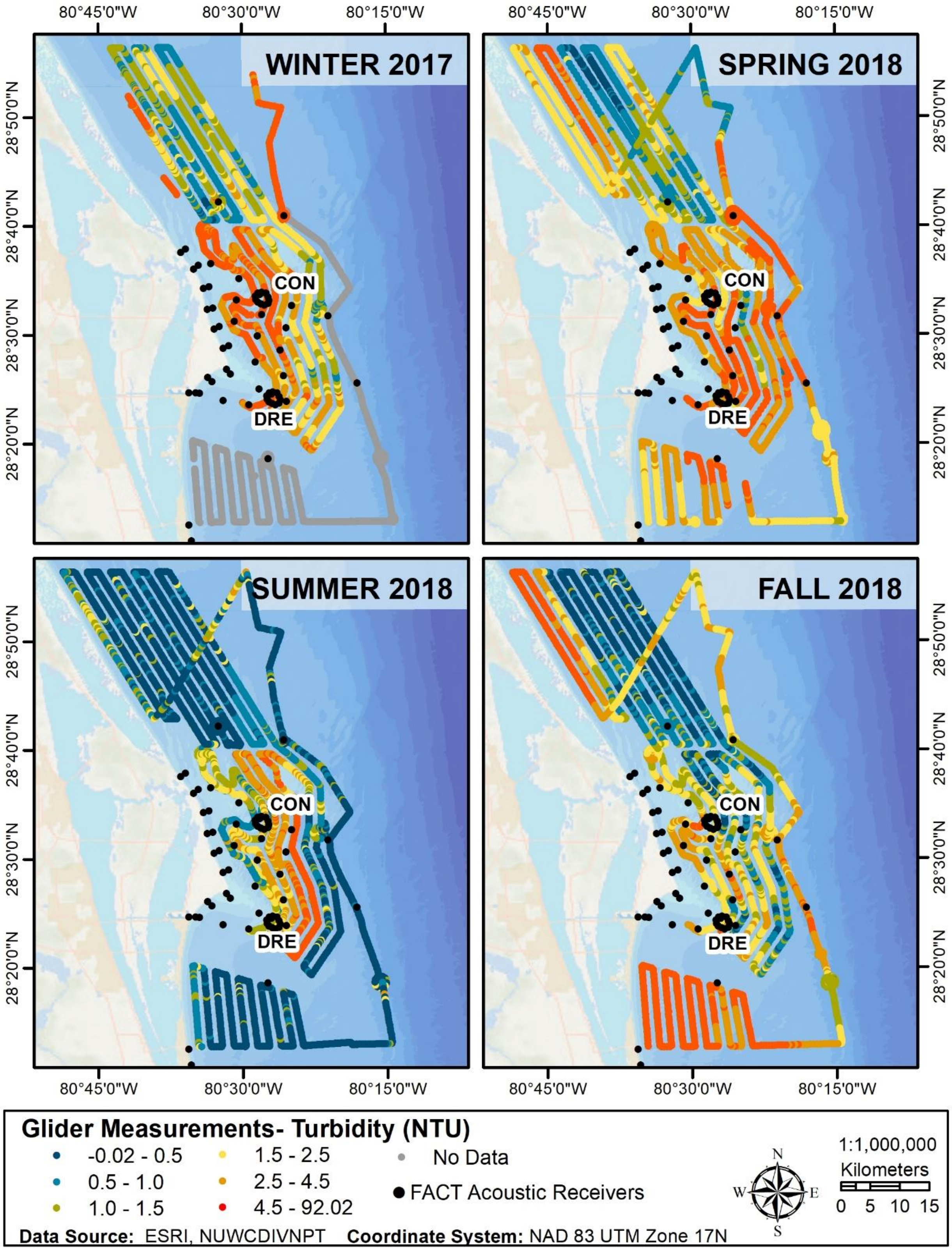

Figure A-7. Spatial variation in turbidity, Deployments 1–4

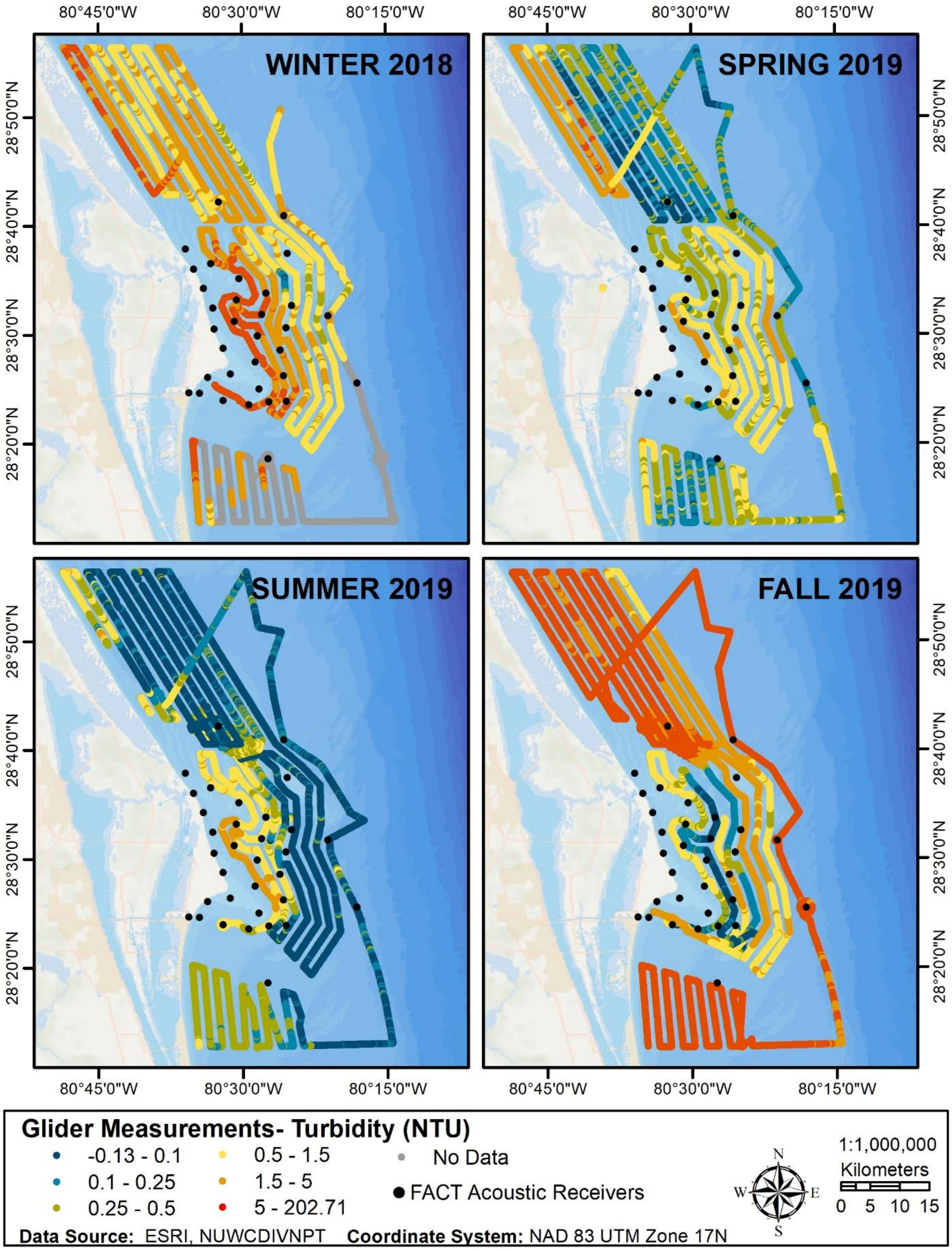

Figure A-8. Spatial variation in turbidity, Deployments 5–8

Appendix B. Habitat Conditions Recorded by the Wave Glider During Animal Encounters

Table B-1. Summary habitat conditions recorded by the Wave Glider (all locations surveyed) and at animal encounter locations. Values are mean (SD). Suspect animal encounters are not included.

Species	No. Animals	Depth (m)	Shore Distance (km)	Temp (°C)	DO (mg/l)	Chlorophyll (RFU)	Turbidity (RFU)	CDOM (RFU)
Wave Glider	**-**	**16.8 (4.0)**	**12.2 (6.6)**	**23.7 (3.7)**	**7.0 (0.6)**	**300.4 (203.6)**	**47.3 (58.8)**	**153 (148.1)**
Blacktip shark	47	16.2 (3.9)	10.8 (5.2)	20.3 (1.2)	7.2 (0.4)	490.1 (225.0)	48.5 (38.7)	312.0 (88.4)
Blacknose shark	22	16.2 (5.5)	11.0 (7.3)	22.7 (4.2)	7.0 (0.6)	330.7 (153.4)	53.5 (43.9)	180.8 (143.3)
Red drum	18	13.2 (3.0)	7.0 (3.5)	22.1 (3.1)	7.0 (0.4)	217.7 (160.4)	56.3 (31.4)	119.3 (74.6)
Finetooth shark	15	16.6 (2.0)	7.4 (3.5)	19.8 (0.8)	7.3 (0.3)	475.8 (215.0)	45.4 (23.7)	294.9 (48.4)
Cobia	14	18.6 (4.4)	15.8 (5.8)	21.7 (1.6)	7.3 (0.3)	496.6 (309.6)	25.4 (8.5)	288.2 (175)
Red snapper	13	-	-	-	-	-	-	-
Sharpnose shark	8	16.0 (2.4)	13.4 (4.7)	25.2 (3.5)	6.7 (0.5)	303 (192.4)	34.4 (29.9)	122.8 (116.9)
Tarpon	6	14.1 (3.7)	5.2 (4.3)	25.4 (4.4)	6.5 (0.6)	597.3 (227.1)	141.4 (100.7)	222.8 (190.1)
Bonnethead shark	5	16.3 (3.1)	6.6 (4.0)	19.0 (1.0)	7.4 (0.4)	516.2 (157.9)	41.6 (22.3)	350.8 (64.4)
Goliath grouper	4	19.8 (2.3)	14.8 (5.3)	21.0 (2.1)	7.1 (0.3)	334.3 (167.5)	62.4 (57.5)	241.9 (151.5)
Cownose ray	3	13.2 (1.6)	9.9 (5.2)	19.4 (0.9)	7.3 (0.3)	479.1 (271.3)	26.4 (10.1)	318.6 (121.3)
Loggerhead turtle	2	13.5 (2.1)	6.9 (3.6)	27.8 (1.0)	6.3 (0.1)	467.9 (313.9)	113.8 (98.2)	68.2 (38.7)
Smooth butterfly ray	2	8.0	1.1	29.8	6.7	300.0	42.7	84.3
Tiger shark	2	19.8 (0.8)	15.6 (6.1)	26.5 (2.1)	7.1 (0.8)	144.4 (100.4)	15 (14.8)	47.4 (28.8)
Bull shark	1	12.0	12.0	20.7	7.2	787.2	56.6	359.6
Gulf flounder	1	13.0	10.3	21.2	6.5	-	-	-
Lemon shark	1	7.0	8.4	17.9	7.8	147.8	10.7	463.1
Smalltooth sawfish	1	12.0	6.1	27.0	6.5	75.0	10.8	38.9
White shark	1	21.0	25.9	18.2	7.7	77.9	8.0	209.7
Whitespotted eagle ray	1	14.5 (3.5)	11.0 (2.8)	20.3 (0.5)	7.4 (0.2)	663 (28.6)	35.3 (12)	297.9 (114.6)
Mean (All Species)	**-**	**15.9 (4.1)**	**10.4 (5.9)**	**21.6 (3.2)**	**7.1 (0.5)**	**399.5 (235.6)**	**94.0 (343.4)**	**232.9 (137.9)**

Appendix C. Spectrogram Examples of Select Marine Mammal and Fish Vocalizations

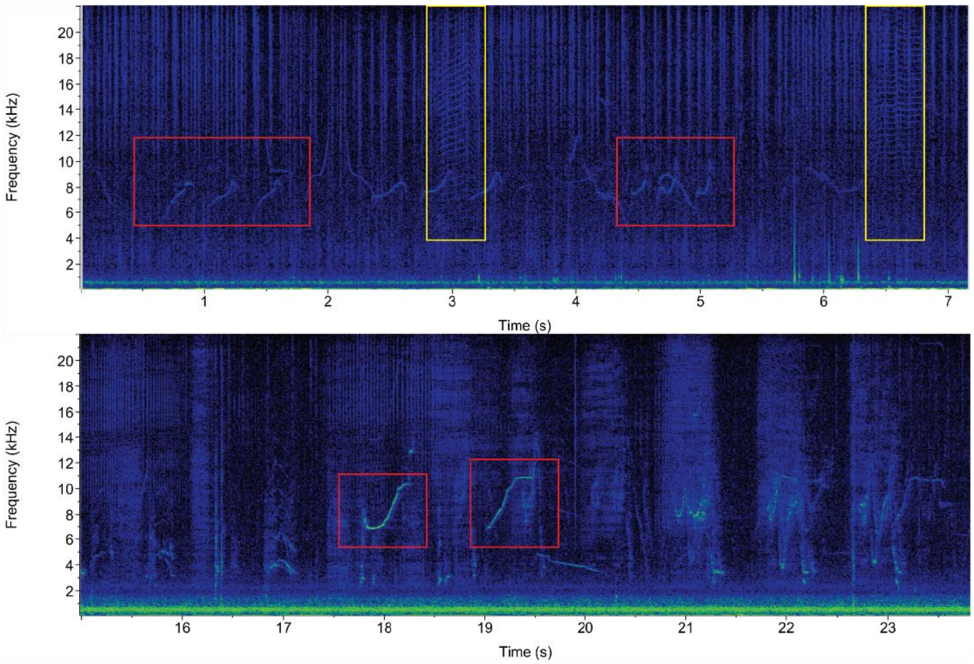

Figure C-1. Spectrogram for common odontocete (most likely a type of dolphin) vocalizations: Echolocation clicks (vertical lines in top figure), whistles (red box), and burst pulses (yellow box). Spectrogram parameters (top): window type = Hann; window size = 1,050 samples; overlap = 90%, discrete Fourier Transform (dFT) = 2,048; sample rate = 44kHz. Spectrogram parameters (bottom): window type = Hann; window size = 1,050 samples; overlap = 90%, dFT = 2,048; sample rate = 44kHz.

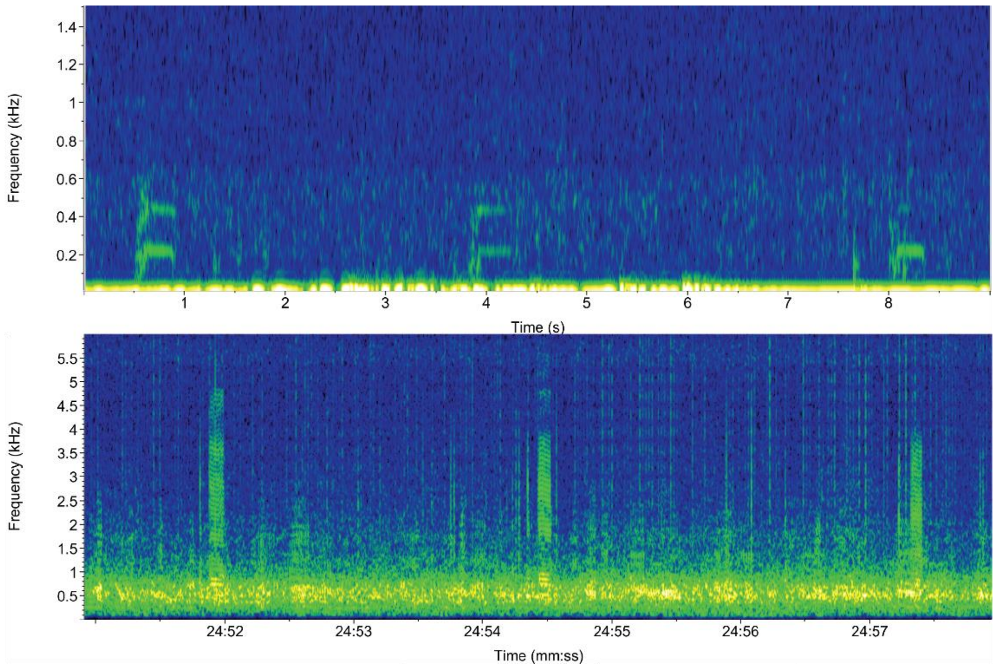

Figure C-2. Spectrogram for individual calls of the oyster toadfish (top), and another common vocalizing species from family Sciaenidae (bottom).
Spectrogram parameters (top): window type = Hann; window size = 1,489 samples; overlap = 90%, dFT = 2,048; sample rate = 44kHz. Spectrogram parameters (bottom): window type = Hann; window size = 2,639 samples; overlap = 90%, dFT = 4,096; sample rate = 44kHz.

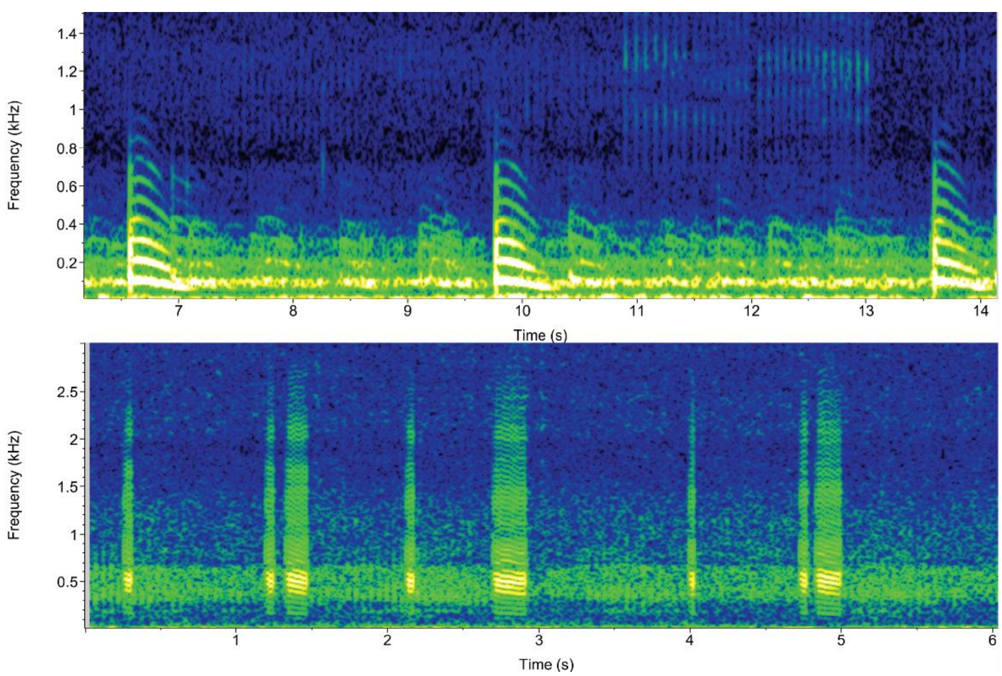

Figure C-3. Spectrogram from individual black drum calls with other sciaenid calls interspersed at 11–13 seconds (top). Individual grunts of Atlantic midshipman (bottom).
Spectrogram parameters (top): window type = Hann; window size = 3,053 samples; overlap = 90%, dFT = 4,096; sample rate = 44kHz. Spectrogram parameters (bottom): window type = Hann; window size = 312 samples; overlap = 90%, dFT = 512; sample rate = 12kHz.

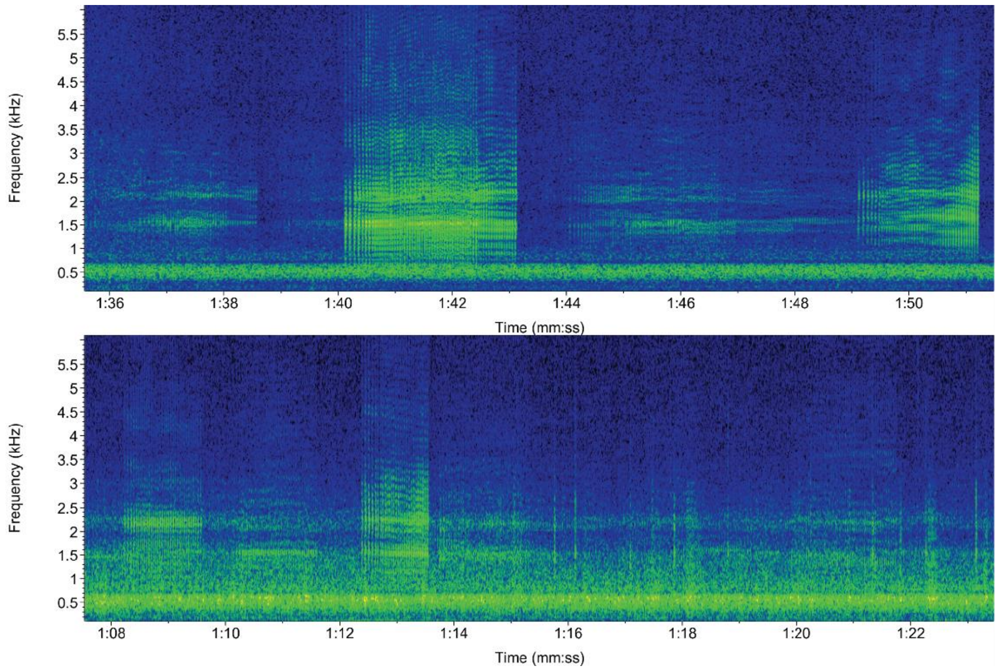

Figure C-4. Spectrogram for overlapping calls of fish from Sciaenidae (top), and multiple species chorusing from Sciaenidae and Batrachoididae families (bottom).
Spectrogram parameters (top): window type = Hann; window size = 2,466 samples; overlap = 90%, dFT = 4,096; sample rate = 44kHz. Spectrogram parameters (bottom): window type = Hann; window size = 1,609 samples; overlap = 90%, dFT = 2,048; sample rate = 44kHz.

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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).