OCS Study
BOEM 2021-026

Habitat Use of Oceanic Manta Rays (*Mobula birostris*) in the Vicinity of Marine Mineral Extraction Activities

US Department of the Interior
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DISCLAIMER

Study collaboration and funding were provided by the US Department of the Interior, Bureau of Ocean Energy Management (BOEM), Environmental Studies Program, Washington, DC, under Agreement Number #M20AC100006. This report has been technically reviewed by BOEM, and it has been approved for publication. The views and conclusions contained in this document are those of the authors and should not be interpreted as representing the opinions or policies of the US Government, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

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ABOUT THE COVER

Georgia Aquarium staff conducting *M. birostris* tagging off Marineland, Florida.

ACKNOWLEDGMENTS

This white paper is an effort to assess the risk posed to oceanic manta rays (*Mobula birostris*) due to marine mineral extraction activities, including preventative trawling, by the Bureau of Ocean Energy Management (BOEM) in the sand shoal habitats near Canaveral Shoals, Florida in the Atlantic Southeastern United States (SEUS). BOEM intended for this document to be key reading material to a scientific workshop where BOEM sought to synthesize relevant current data and literature, as well as receive input from experts, in order to attain the necessary information to reduce risks to an ESA-listed species and best inform future mitigation policies. This document also highlights our workshop conclusions and outcomes.

BOEM and Georgia Aquarium are partners on this project, per their cooperative agreement, #M20AC100006. Carrie Kappel, LLC assisted with the planning, coordination, and facilitation of a scientific data gathering workshop, which took place virtually on January 11 and 12, 2021.

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List of Abbreviations and Acronyms

ASV	Autonomous Surface Vehicle
BOEM	Bureau of Ocean Energy Management
CATScam	Custom Animal Tracking Solution camera/accelerometer tag
CITES	Convention on International Trade of Endangered Species of Wild Flora & Fauna
CMS	Convention on Migratory Species
DW	disc width
EEZ	Exclusive Economic Zone
ENM	Ecological Niche Modeling
ESA	Endangered Species Act
FACT	Florida Atlantic Coast Telemetry Network
ft	foot or feet
GAI	Georgia Aquarium
GPS	global positioning system
hr	hour(s)
IACUC	Institutional Animal Care and Use Committee
IATTC	Inter-American Tropical Tuna Commission
IMU	Inertial Measurement Unit
IUCN	International Union for the Conservation of Nature
IUU	illegal, unreported, and unregulated
km	kilometer(s)
kn	knot(s)
LLC	Limited Liability Company
m	meter(s)
mg	milligram(s)
MMP	Marine Minerals Program
MPA	marine protected area
MV	motor vehicle
NASA	National Aeronautics and Space Administration
NOAA	National Oceanic and Atmospheric Administration
NSST	Nighttime Sea Surface Temperature
OCS	Outer Continental Shelf
SEUS	Southeastern United States
SST	Sea Surface Temperature
TSHD	Trailing Suction Hopper Dredge
WCA	Western Central Atlantic

1 An Introduction to *Mobula birostris*

1.1 Biology and Ecology

The giant oceanic manta ray, *Mobula birostris* (Walbaum, 1792), is one of the most charismatic species of megafauna in the world, in large part due to their incredibly large size and gentle presence. Along with all other species of sharks, rays, and chimaeras, *M. birostris* is classified as an elasmobranch, which includes those species with cartilaginous skeletons, and currently contains 1,107 recognized species (IUCN SSG, 2018). This is an incredibly diverse group, with a new species being discovered approximately every 2 weeks on average (IUCN SSG, 2018).

Both oceanic and reef manta rays were categorized as *Manta birostris* until genetic data and newly recognized morphological markers supported the recognition of two species: *M. birostris* and *M. alfredi* (Marshall *et al*., 2009). A more recent taxonomic study suggested that *Manta birostris* and *Manta alfredi* are closely related to the giant devil ray (*Mobula mobular*), with genetic evidence supporting placement of these two species in the genus *Mobula*, thus eliminating the genus *Manta* (White *et al*., 2017; NOAA, 2019; Hosegood *et al*., 2020). The oceanic and reef manta ray are still recognized as two distinct species but are now officially named *Mobula birostris* and *Mobula alfredi*.

Taxonomic history is important because there is a third species of manta that has been identified (*M. cf. birostris*), with its range along the Atlantic Coast, Gulf of Mexico, and Caribbean (Marshall *et al.*, 2009; Hosegood *et al.*, 2020). This third species looks very similar to *M. birostris* and is difficult to identify without genetic testing. A manuscript describing this third species is expected in the near future, but for the purposes of this study, we will refer to the study species as *M. birostris*, though it may prove to be *M. cf. birostris*.

Mobula birostris is the largest species of ray in the world, with an average disc width (DW) between 13–16 ft (Stevens, 2018) and a maximum DW of 23 ft (McClain *et al*., 2015). Similar to other rays, the oceanic manta ray has a dorso-ventrally flattened body shape with the gills on their ventral side; this flattened shape allows for efficient swimming as well as protection from predators (Stevens, 2018). Unlike all other rays, which have ventral mouths, manta rays have terminal mouths. While feeding, mantas unfurl their cephalic lobes in order to efficiently detect and funnel their zooplanktonic prey into their mouths, as seen in **Figure 1**. The primary prey of *M. birostris* is likely to be copepods, chaetognaths, and fish eggs (Graham *et al*., 2012). After gathering a mouthful of food, mantas close their mouths, forcing the water out through rows of tiny rakes called gill plates, and the food is then directed to the esophagus through crossflow (Paig-Tran and Summers, 2014; Stevens, 2018).

Figure 1. *Mobula birostris* feeding.
Photo by Desmond Paroz.

Mobula birostris is a widespread species found throughout the tropical, subtropical, and temperate regions of the world's oceans. Giant oceanic mantas spend a large portion of their time in the open ocean, which makes them more elusive than their close relatives, the reef manta ray (*Mobula alfredi*). This elusive nature has presented logistical obstacles to the study of this species, such that many aspects of their life history remain unknown to science. Based on their close relation to the reef manta, scientists assume the two species have similar ages of maturity (15 years for females; 9 years for males), lifespan (~40 years), and reproduction (one live pup every 2–5 years) (Stevens, 2018). These aspects of life history characterize manta rays as a K-selected species, meaning they are slow to mature, have low reproductive rates with few offspring, and therefore low population growth potential (MacArthur and Wilson, 1967; Pianka, 1970). These life history traits make them highly susceptible to a variety of anthropogenic impacts because populations would be slow to recover.

Mantas are known to aggregate in large numbers (up to 100 individuals) in many areas (e.g., Mexico, Mozambique, Maldives, and Hawaii) for courtship, breeding, and to visit cleaning stations (Anderson *et al.,* 2011; Deakos *et al.,* 2011, Marshall *et al.,* 2011, Graham *et al.,* 2012). Breeding sites are also thought to occur off Ecuador and the Galapagos Islands, due to the presence of apparently pregnant females and mating scars (NOAA, 2019). Mating has rarely been documented within United States waters, but a potential nursery ground was recently described off southeast Florida, from St. Lucie Inlet to Boynton Beach Inlet (Pate and Marshall, 2020). This study also concluded that 98% of the mantas observed were juveniles that displayed a high degree of site fidelity. This newly described area, and the high site fidelity documented therein, could play a crucial role in illuminating additional life history information of this elusive species and assist with determining critical habitat for an early life stage of this species.

1.2 Movements & Habitat Use

Many of the life history characteristics we attribute to *M. birostris* are inferred from their close relative, the reef manta ray, *M. alfredi*, and, while these species most likely do share similarities in their life history, it is difficult to properly implement conservation planning for a species with species-specific knowledge gaps. Reproduction, life span, migration, and habitat use are a few of the knowledge gaps pertaining to this species, all of which can have adverse impacts on conservation management initiatives; ongoing research into this cryptic species is important for effective management both globally and locally.

A better understanding of manta ray movements is crucial to defining critical habitat use, overlap with anthropogenic activities, and then managing these interactions accordingly. A study off northern Peru aimed to do this through the use of satellite tags (Andrzejaczek *et al*., 2021). Three mantas were tagged and all three exhibited reverse diel vertical migration, conducting vertical movements that were significantly deeper at night compared to daytime. An overall preference for surface habitats (< 2 m) was observed, as well as fine-scale behaviors where individuals predominately remained in coastal surface waters throughout the day and oscillated up and down through a highly stratified water column at night. Two of the three mantas did not exceed a maximum depth of 85 m, while the third manta spent 0.65% of its time at depths >100 m, reaching a maximum depth of 648 m (Andrzejaczek *et al.,* 2021). The results of the study suggested that coastal vertical movements were a result of a combination of foraging at depth and thermal recovery near the surface. Although the study was specific to northern Peru, the results may be indicative of behaviors and movements that may be expected of oceanic mantas off the Southeastern United States (SEUS), albeit in more shallow water due to the depth limitations of the continental shelf waters in that region.

Broad-scale migratory movements among oceanic manta rays are poorly understood in general, but researchers have documented a few instances of long-distance migration, most of which were attributed to foraging at seasonal upwelling events. Giant mantas tagged near Isla de la Plata, Ecuador, between 2010 and 2012 revealed some movements south towards Peru, while other animals were making migrations of up to 1,500 km (straight-line distance) from Isla de la Plata to the Galapagos Islands. That study was also the first to establish population connectivity between mainland Ecuador and the Galapagos Islands for oceanic manta rays (Hearn *et al*., 2013).

Habitat use of manta rays remains an area of life history riddled with knowledge gaps. Large numbers of juveniles have been caught by gill-net fisheries in offshore pelagic waters around Sri Lanka, landed by fishermen in Brazil and Indonesia, and observed in oceanic habitats off Mexico (Stewart *et al.*, 2016; Stewart *et al.*, 2018). Stewart *et al* (2017) suggested that adult and juvenile oceanic manta rays use similar pelagic habitats, but that juveniles may not travel inshore where adults are commonly observed, due to increased predation risk. Stable isotope analyses of tissue samples from adults and juveniles off Peru, Sri Lanka, and the Philippines provided evidence that this species may not experience an ontogenetic shift in feeding behavior or trophic level, with adults and juveniles sharing similar habitats and prey (Stewart *et al.*, 2017).

1.3 Threats

In 2020, the International Union for the Conservation of Nature (IUCN) classified *Mobula birostris* as "Endangered," highlighting the increased threat of extinction that this species faces (Marshall *et al.*, 2020). Giant mantas are targeted by both industrial and artisanal fisheries utilizing a variety of capture methods such as harpoons, drift nets, purse seine nets, gill nets, trawls, and longlines. This species is easy to target due to its large size and slow swimming speed. *M. birostris* is primarily targeted for meat and gill plates; the latter is highly valued among Southeast Asian medicinal markets. Typically, their meat is consumed locally, in either fresh or dried forms, but the demand in Asia for gill plates is a direct reason for the increased fishing pressure and observed rapid population declines (Stevens, 2018). The demand for mobulid rays, including *M. birostris*, is documented in recorded landings, which are typically a conservative estimate due to illegal, unreported, and unregulated (IUU) fishing. From 2000 to 2007, the global landings of manta and devil rays increased from 900 tons to 3,300 tons (Trends in Global Shark Catch, 2009). In addition to targeted fisheries, bycatch is a frequent threat for this species. According to the Inter-American Tropical Tuna Commission (IATTC), an average of 135 *M. birostris* individuals per year was recorded as bycatch from purse seine vessels from 1993–2015 (Miller and Klimovich, 2017; Marshall *et al.*, 2020).

The drastic increase of *M. birostris* landings and bycatch has resulted in severe population declines. Among well-studied populations in Mozambique and Costa Rica, a 94% and 81% decline were documented over a 15-year and 21-year period, respectively (White *et al.*, 2015; Rohner *et al.*, 2017). Both of these timeframes are less than a generation length (29 years) and, therefore, cause for concern. Based on current trends, it is suspected that the global population of *M. birostris* will decline by 50–79% over the next three generations (87 years) (Marshall *et al.*, 2020). These unsustainable declines prompted international efforts to manage this species through listings with the Convention of Migratory Species of Wild Animals (CMS), Convention on International Trade of Endangered Species of Wild Flora and Fauna (CITES), and the Endangered Species Act of the United States (ESA) (CMS, 2011; CITES, 2014; NOAA, 2019).

Manta rays face additional anthropogenic threats, such as recreational boating, recreational fishing, and divers. Pate and Marshall (2020) found that 46% of the mantas in their study were injured: 30% presumably from boat propellers, 30% from fishing line, 27% from an unknown cause, and 12% from shark bites (Pate and Marshall, 2020). All documented propeller injuries were on the dorsum, with one documentation of a propeller cutting through the ventral side as well, while 80% of fishing line injuries occurred on the pectoral fins. A female manta mortality occurred outside of their study site after the manta ray was entangled in a vessel exclusion line (steel cable) and drowned.

The overlap of manta rays and anthropogenic activities have also been documented for SCUBA divers. Mantas are usually a highlight for divers, but accidents resulting in harm to the diver or manta have happened. In 2006, a professional diver using surface supply for air was deployed for platform maintenance. As he began his ascent, at approximately 150 ft deep, a large manta ray became entangled in the dive hose and rapidly pulled the diver to the surface. The diver was rushed to a decompression chamber but ultimately died (E. Hoffmayer, personal communication, 2021). Although instances like this are incredibly rare, it may warrant future studies in order to mitigate risks for both manta rays and people.

1.4 Listing *Mobula birostris* on the Endangered Species Act

Mobula birostris was listed as “Threatened” on the ESA in 2018 (NOAA, 2018). Five factors are taken into consideration prior to the listing of a species:

1. Present or threatened destruction, modification, or curtailment of its habitat or range
2. Overutilization of the species for commercial, recreational, scientific, or educational purposes
3. Disease or predation
4. Inadequacy of existing regulatory mechanisms
5. Other natural or manmade factors affecting its continued existence

The listing determinations are based solely on the best scientific and commercial information available; no economic impacts are considered in this process (NOAA, 2020). The petition listing process begins with a petition from an organization or individual requesting that a species be listed as endangered or threatened; be reclassified; or be delisted. The process following the receipt of that petition is shown in **Figure 2** (NOAA, 2020). In addition to the petition process, NOAA can implement a self-initiated process to examine the status of a species, and this process does not have the same statutory deadlines as the petition process. The self-initiated process is shown in **Figure 3** (NOAA, 2020).

The final ruling for *M. birostris* was issued on January 22, 2018, resulting in a listing of “Threatened” due to overutilization for commercial purposes (NOAA, 2018). Due to the immense fishing pressure and incidental bycatch throughout their range, coupled with declines in sightings and landings, a listing of the oceanic manta ray was deemed necessary. In the 2018 decision, NOAA acknowledged there was considerable uncertainty regarding current abundance of oceanic manta rays, but the available data indicated that the species was likely to become endangered throughout significant portions of its range (NOAA, 2020).

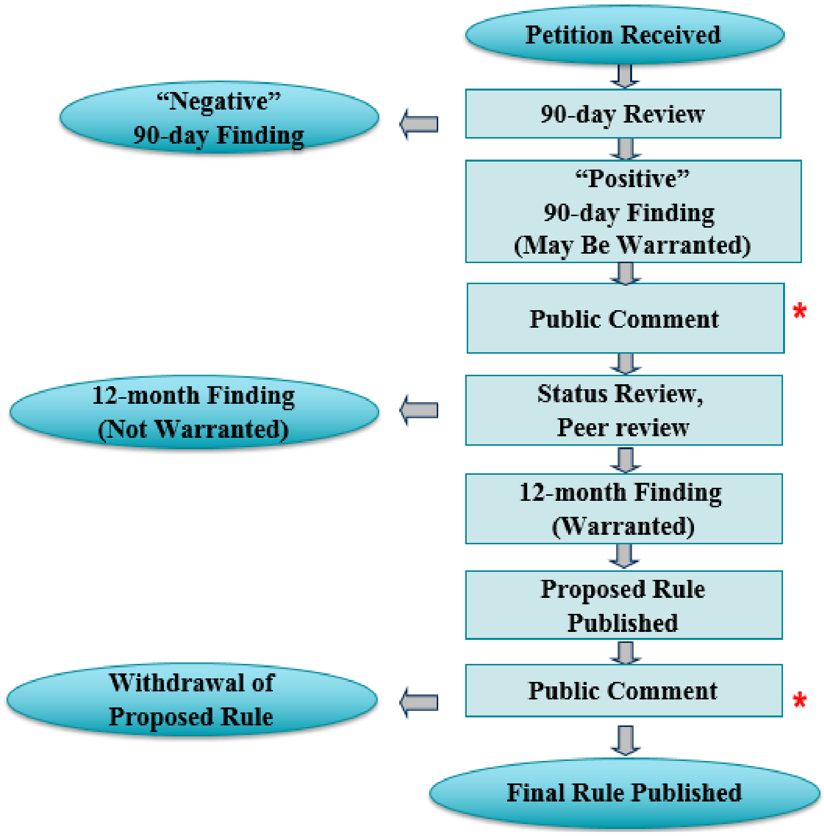

Figure 2. Step by step petition process for listing a species on the Endangered Species Act.

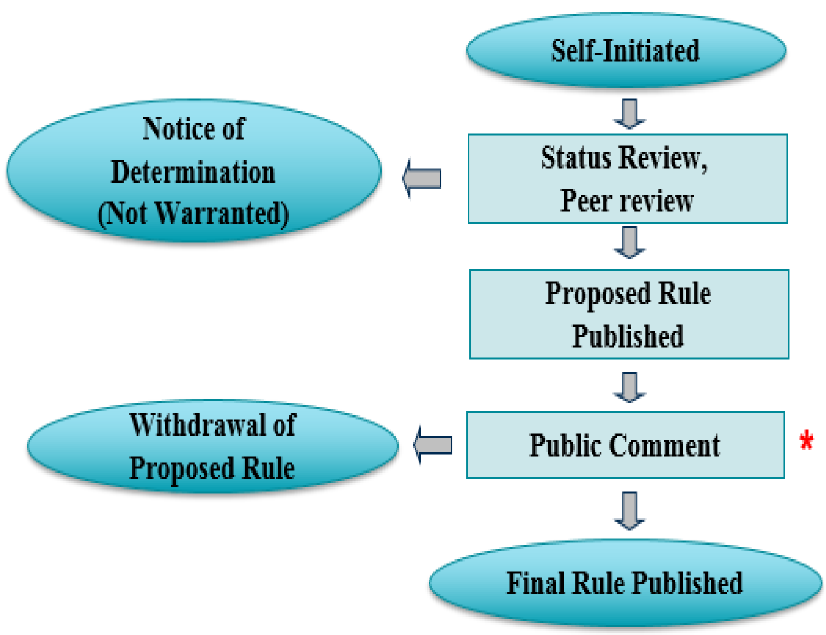

Figure 3. Step by step self-initiated process of listing a species on the Endangered Species Act.

2 Overview of Relevant Research

2.1 Telemetry

Telemetry is one of the most valuable approaches when it comes to filling knowledge gaps for a variety of terrestrial and marine species. By using tags equipped with a variety of sensors, scientists can better understand animal movements and behaviors. Tag selection varies based on the questions being investigated and the type of data being collected. Some of the most common are satellite and acoustic tags. Satellite tags are attached externally and use satellites from the CLS/ARGOS array to relay live or archived location information. Some satellite tags can also collect additional data, such as depth, light, and temperature (Wildlife Computers Inc., 2020), which further informs movements and behaviors. Acoustic tags are attached externally or implanted internally and need to be accompanied by a fixed network of acoustic receivers deployed in the study area, which detects coded ultrasonic signals from each tag as animals move through the array. These two common tag types have provided a plethora of data pertaining to manta rays, including site fidelity and restricted movements (Stewart *et al.*, 2016), habitat preferences for relatively shallow water (Graham *et al.*, 2012), and a lack of overlap among core habitat preferences and marine protected areas (MPA) in the Western Central Atlantic (WCA) (Garzon *et al.*, 2020). Telemetry is useful for effective conservation planning because it demonstrates where animals spend their time, information that can then be related to any threats that may result from those spatial preferences (e.g., shipping lanes, fishery activities).

2.2 Habitat Modeling

Habitat modeling is a useful tool for better understanding variables that may influence the presence or absence of a species. *Mobula birostris* habitat use in the WCA was recently analyzed by Garzon *et al.* (2020) using a type of habitat modeling called ecological niche modeling (ENM, also known as species distribution modeling). Their model indicated a seasonality between coastal and offshore habitat preference, with depth, bathymetric slope, chlorophyll-α, and nighttime sea surface temperature (NSST) as the four driving variables. Garzon *et al.* (2020) observed a coastal core habitat preference in the spring-summer and an open ocean preference during autumn-winter. Their model determined chlorophyll-α to be the most important factor influencing the species movements. Although this study used *M. birostris* locations from satellite detections, online databases, and social media records as inputs for the model, they were unable to take three-dimensional depth use into account, and the authors acknowledged that three-dimensional data from sources such as an open-source inertial measurement unit (IMU) would be helpful for more accurate predictions (Garzon *et al.*, 2020).

A previous study aimed at modeling *M. birostris* distribution off the northeastern Yucatan Peninsula determined that primary production was the most influential variable affecting distribution, followed by distance to the coast (Hacohen-Domené *et al*., 2017). Primary production was the most influential variable from July to August, when manta observations were highest, but distance to coast followed by sea surface temperature (SST) became most influential factors starting in September. Their maximum entropy model (Maxent) also determined that most manta aggregation sites occur in shallow waters close to the coast, with low bottom slopes. Predictive modeling for distributions and habitat preferences is an efficient and effective approach to better understanding species biology and ecology, which directly impacts management strategies and protective measures at the local and global level. It is a helpful tool for piecing together the entire picture of a species' life history that may otherwise be difficult to study.

2.3 Site Fidelity & Migration

Site fidelity and migration for oceanic manta rays are still poorly understood relative to other marine megafauna species, but studies have documented that both broad and small-scale migrations are part of their life history (NOAA, 2019). Broad-scale migration seems primarily due to foraging that correlates with seasonal upwellings and SST (Luiz *et al.*, 2008; Couturier *et al.*, 2012; Girondot *et al*., 2014; Sobral and Afonso, 2014; De Boer *et al.,* 2015; Armstrong *et al.,* 2016; Hacohen-Domené *et al.,* 2017). An SST range of 25.1 to 30.06° Celsius and surface chlorophyll-α concentration range of 0.14 to 0.76 mg/m^3 seem to occur with increased manta presence (Graham *et al*., 2012). Through satellite tagging, broad migrations of over 1,000 km have been documented from Ecuador to the Galapagos Islands, and from Mozambique to South Africa (Marshall *et al*., 2011; Hearn *et al.,* 2013). Additional migratory destinations include the Azores, French Guiana, the Gulf of Mexico, Brazil, and the SEUS (Luiz *et al*., 2008; Graham *et al.*, 2012 Sobral and Afonso, 2014; Girondot *et al*., 2014; Webb, H., unpublished data). However, the origins and migratory routes for the mantas at many of these locations remain unknown (NOAA, 2019).

A 2018 study examined genetic diversity of manta rays at Isla de la Plata, Ecuador from 2010 to 2013 (Sotelo, 2018). Twenty-four individuals were sampled in 2013 and compared to 57 individuals that were sampled from 2010–2012. The study found a moderately high degree of genetic diversity, comparable to other species known to undertake long-distance migrations. The study concluded that the 2013 samples represented a different population than the individuals sampled from 2010–2012. The authors noted that copepod density peaked two months later in 2013 than in previous years, which may be a factor in a different manta population foraging compared to previous years. The results also suggested that manta rays may migrate in family groups and may not consistently visit the same areas (Sotelo, 2018).

Although there are documented broad-scale migrations, other studies have also confirmed high degrees of residency and site fidelity. Six manta rays were tagged in the Gulf of Mexico (four females, one male, one juvenile), and their movements were tracked for a maximum of 64 days. The tracks showed no clear migratory route, with the majority of the tracks more than 20 km from shore, in water depths of less than 50 m, and with a distance of 116 km traveled from the original tagging location. The study concluded that these mantas forage on a large spatial scale (~100 km) that is too far offshore and too wide-ranging to be protected within Mexico's MPA networks. Their data highlighted a high degree of site fidelity and association with frontal zones (Graham *et al*., 2012).

Seasonal sites for the oceanic manta ray have been documented around the world, including the Yucatan Peninsula, French Guiana, and sites in the Indian Ocean, but many knowledge gaps still remain regarding migration and site fidelity (Dewar *et al*., 2008; Anderson *et al*., 2011; Kashiwagi *et al*., 2011; Graham *et al.,* 2012; Girondot *et al*., 2014). It is evident that broad and small-scale migrations are important to this species, and, although environmental cues such as SST and primary production seem to be a factor correlated with manta presence, many unknowns persist as to why some populations display broad migratory patterns while others do not. Further research is needed to better understand these life history traits and why there appears to be such variability among populations.

3 Marine Mineral Extraction

3.1 Marine Minerals Program Background

The Bureau of Ocean Energy Management (BOEM) Marine Minerals Program (MMP) partners with communities to address issues such as erosion along coastal beaches, dunes, barrier islands, and wetlands (BOEM, 2012**).** To accomplish this, BOEM is the Federal entity authorized to manage and lease minerals from the Outer Continental Shelf (OCS). The MMP leases non-energy minerals—such as sand, gravel, and/or shell resources—in order to assist with beach nourishment, shore protection, and wetland restoration (BOEM, 2020a). Leased minerals are removed from the OCS by dredge, then usually pumped to shore using a temporary pipeline. Dredging for sand usually occurs in areas < 30-m depth, though BOEM often buffers this depth to 50 m for studies, as highlighted in **Figure 4**, to account for future advances in dredge technology (D. Hansen, personal communication, 2021).

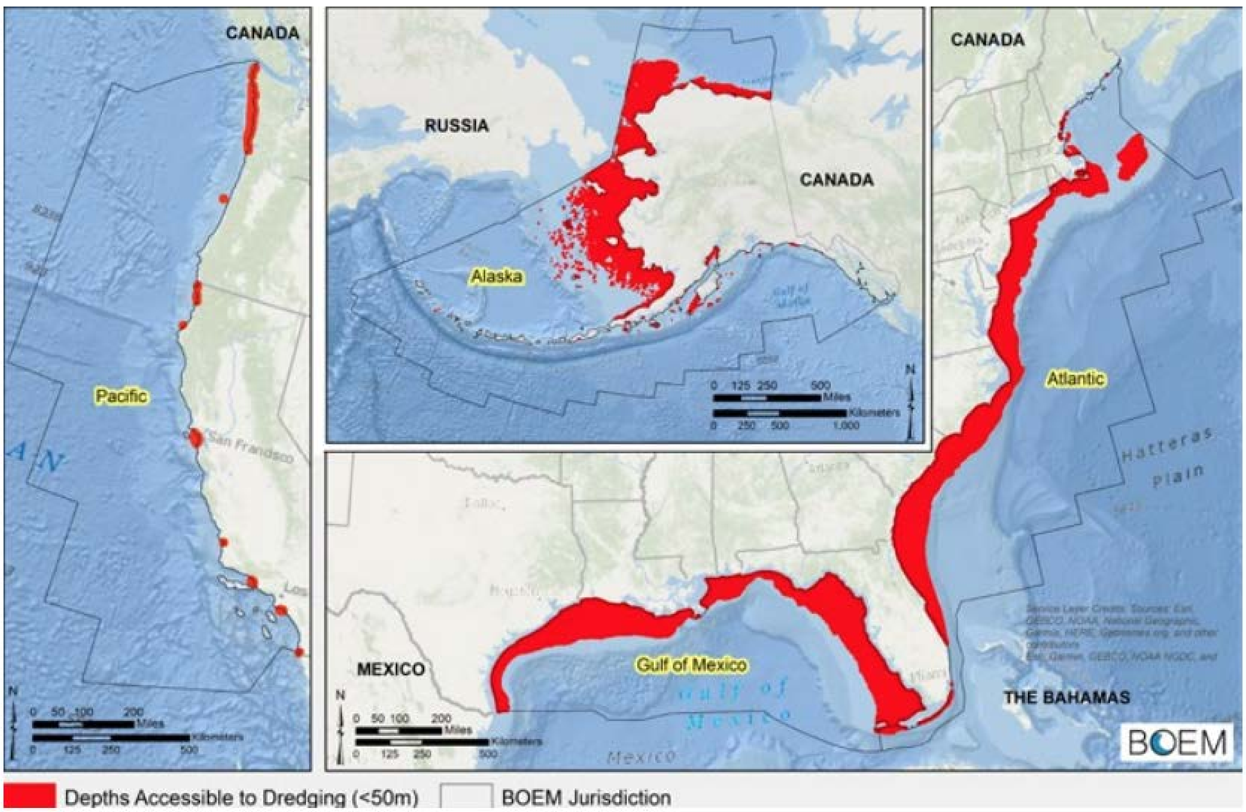

Figure 2. Areas of less than 50-m depth, where BOEM MMP operates.

3.2 Sand Dredging

Sand dredging is the method most commonly used to renourish beaches in the SEUS, including in the Canaveral Shoals area of Florida. A trailing suction hopper dredge (TSHD), shown in **Figure 5**, is the equipment most often used in this area. TSHD vessels operate at 3–5 km hr^{-1} (1.5–3 kn) while an onboard dredge pump creates suction that is transmitted through 1–3 pipes leading to each pipe's draghead, each of which is 1.5–4 m in width and lies on the seafloor (Michel *et al*., 2013). Sand is suctioned through the trailer arm pipe and into the hopper, which is located in the hull of the ship. After suction, the dredge moves to a stationary in-water pump-out station to pump sand to shore via pipelines. An illustrative visualization of the TSHD (https://www.youtube.com/watch?v=nfhUCoJX5Vg) demonstrates the equipment in operation; however, U.S. techniques differ somewhat.

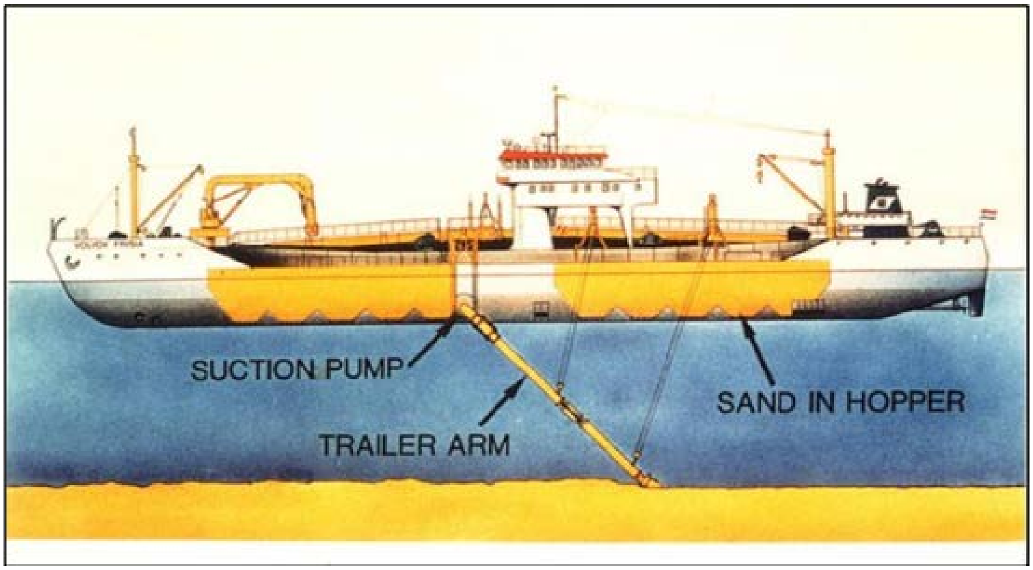

Figure 3. A trailing suction hopper dredge (TSHD) and its primary components for operation.

3.3 Potential Environmental Impacts

Sand dredging can result in a variety of impacts to the environment, including increased noise, alterations to the food web, increased suspended sediment, sedimentation of the seafloor, and loss of prey (Kim *et al*., 2008; Suedel *et al*., 2008; Wenger *et al*., 2017). The environmental impacts most likely to affect manta rays are turbidity, removal of prey, and noise (D. Hansen, personal communication, 2021). The MMP has an environmental stewardship program that functions to assess impacts, identify knowledge gaps, and conduct research in order to minimize impacts and guide mitigation efforts (BOEM, 2020a). Unintentional interactions with species, especially slow-growing species with low-fecundity, can have an adverse impact on local populations. In order to fully consider potential impacts, BOEM's environmental stewardship has two core focus areas: environmental assessments and environmental science. Environmental assessment evaluates impacts from activities at public, Federal, state, and tribal government levels (BOEM, 2020b), whereas environmental science is to obtain the best available data and information about environmental resources. These two core foci combine to form an assessment that determines what new science, if any, is still needed (BOEM, 2020b).

Through project assessments, BOEM determined that activities related to MMP leases, such as dredging and trawling, may interact with ESA-listed manta rays. BOEM is therefore executing research to help determine the risk of potential impacts to manta rays and considering ways to minimize or mitigate these interactions.

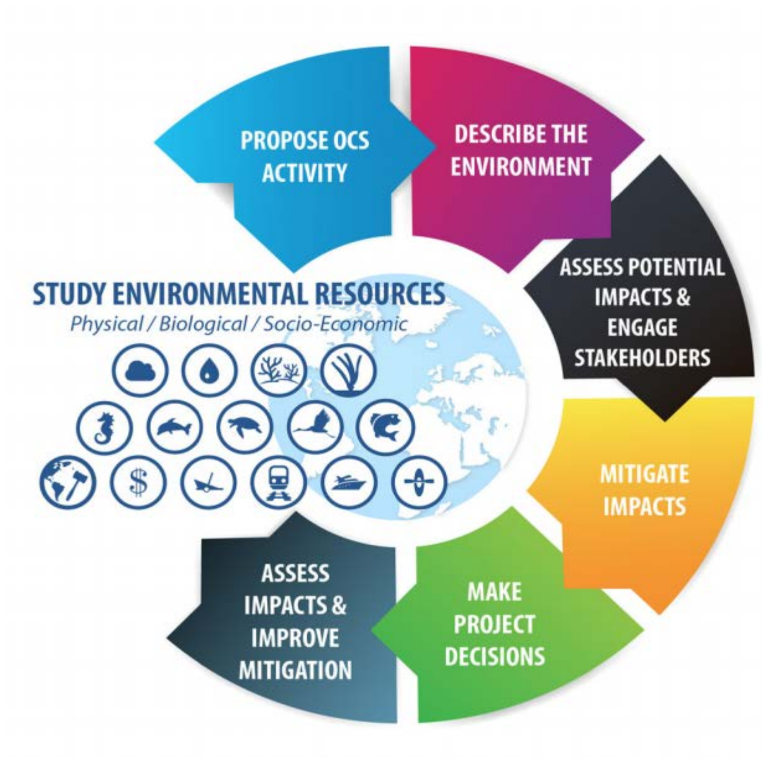

Figure 4. BOEM Environmental stewardship graphic highlighting environmental assessment process.

3.4 Preventative Trawling

Prior to dredging, relocation trawling may be conducted to mitigate the risk of interaction of THSD with federally protected, ESA-listed sea turtles, which were previously found to be vulnerable to direct entrainment by dredging operations (BOEM, 2015). Trawling is often conducted 1 to 3 days prior to dredging. Trawling tow times are required to be less than 42 minutes and must not exceed 3.5 kn, in order to decrease stress to captured animals (BOEM, 2017). Preventative trawling is a highly focused activity in space and time that can result in overlap and increase risk of interaction with non-targeted species, such as manta rays. In the SEUS, manta rays have been observed in the vicinity of trawling activities in 2017 and 2018 (BOEM, 2018). Although there are no records of mantas being captured in BOEM preventative trawls, the trawls are the same type used by shrimp trawlers throughout the SEUS, and mantas have been documented being captured in these trawls. Significant injury and death have been documented from these captures (C. Horn, personal communication, 2021). As a result of *M. birostris* being listed on the ESA, an interagency cooperation, identified in Section 7 of the ESA, provides the mechanism by which Federal agencies ensure their actions do not jeopardize the existence of any listed species (BOEM, 2017). For this reason, a better understanding of any potential spatial and/or temporal overlap between *Mobula birostris* and BOEM's activities is warranted.

4 Cooperative Study with BOEM and Georgia Aquarium (GAI)

4.1 Study Objectives & Background

The objective of this study is to understand how movements and site fidelity of ESA-listed *Mobula birostris* affect the risk of this species interacting with BOEM's marine mineral extraction or associated mitigation activities in the SEUS. Elucidating habitat use patterns and current life history gaps for this species will allow BOEM to implement appropriate future mitigation policies accordingly. Previous information about *M. birostris* off the SEUS is not sufficient for understanding the drivers of movement or residency patterns and therefore is not sufficient for informing mitigation policies. Although there are many knowledge gaps surrounding *M. birostris*, including migration and site fidelity, they are regarded as a broadly migratory species, which also means that highly localized impacts on manta rays may have regional or international impacts for this species. For this reason, a better understanding of SEUS manta ray habitat use, fine-scale movements, and migrations is crucial. To accomplish the objectives of the study, we will be using a combination of techniques including satellite, acoustic, and IMU telemetry, as well as BOEM's Liquid Robotics wave glider, Autonomous Surface Vehicle (ASV) *Melvin*, an autonomous aquatic vehicle that provides a platform for prolonged data acquisition with real-time relay in coordination with National Aeronautical and Space Administration (NASA) Ecological Services. We plan to deploy 30 acoustic, 10 satellite, and 10 IMU tags for this study with a goal that some manta rays will carry multiple tag types simultaneously.

Figure 5. Wildlife Computers fin-mounted satellite SPOT/SPLASH tag.

4.2 Satellite Telemetry

Satellite tags are capable of providing location data when the animal breaks the surface, and the tag is able to communicate to a land-based station through the ARGOS satellite network. Satellite tags have also been successfully used for regional and ocean basin scale studies (Gunn and Block, 2001). These tags are able to provide near real-time location data and, in the case of SPLASH tags, the type of satellite tag that will be used in this study, can relay additional behavioral information such as depth of diving behavior and water temperature at the surface as well as at depth. From analysis of these data, we will develop a clearer understanding of where these animals move, both at the surface and throughout the water column. We will be attaching a satellite tag similar to the Wildlife Computers fin-mounted SPOT/SPLASH tag, seen in **Figure 7**, to the dorsal fin using nylon bolts at four points of attachment, a method that has previously proven successful for reef manta rays, *M. alfredi*, in Sudanese Red Sea waters (Kessel *et al.,* 2017). Using the bolt-mounting method, we anticipate a tag mission length of approximately one year, which should provide one complete annual movement pattern.

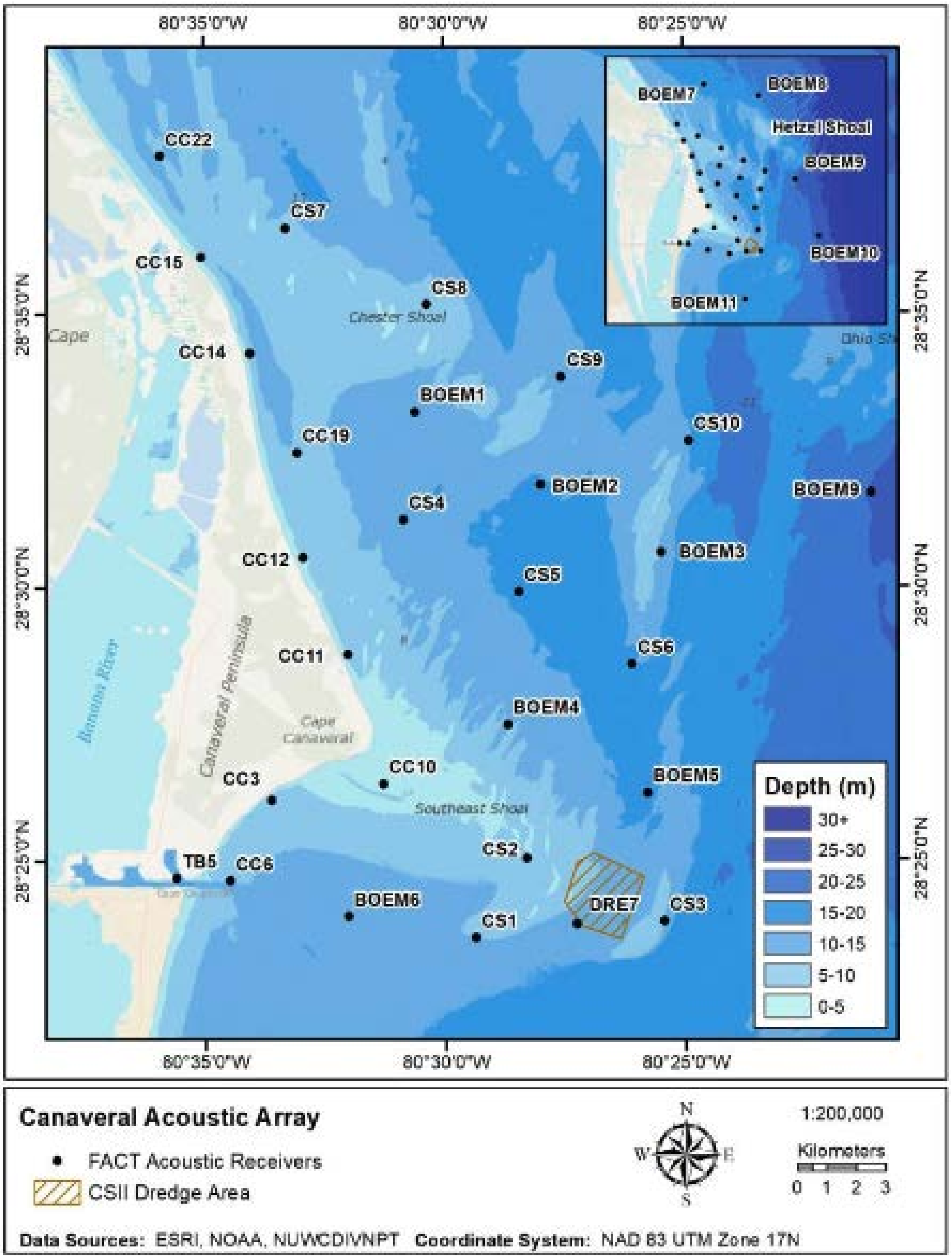

Figure 6. Canaveral acoustic array.

4.3 Acoustic Telemetry

Acoustic telemetry requires two components—an acoustic transmitter and an acoustic receiver. Animals can be externally or internally tagged with a transmitter with individual identification numbers, which will be logged by receivers when the animal is close enough for the receiver to detect the transmitter. Receivers must be regularly maintained, and the data downloaded. The Atlantic coast of Florida has an extensive array of acoustic receivers near Canaveral Shoals, shown in **Figure 8**, as well as the Florida Atlantic Coast Telemetry (FACT) network of collaborators. We will take advantage of this existing array by using Vemco V16 and V9 acoustic transmitters, seen in **Figure 9**. V16 transmitters will be surgically implanted into the coelom (body cavity) of juvenile manta rays via a small (~ 2 cm) incision on the ventral side of the animal; this incision will be closed with sutures. Implanted transmitters have a battery life of up to 10 years, and a surgical insertion will make it possible to track movements as the juveniles grow and mature into adulthood, including any ontogenetic changes in habitat usage. Adult manta rays will be externally tagged with a V9 transmitter on their dorsal side using a pole spear and an intradermal dart tag. Superficial tag attachment methods, similar to our proposed V9 attachment for adult manta rays, result in a shorter tag duration due to animals shedding tags. For that reason, we anticipate the V9 to have a shorter mission length of 800–900 days.

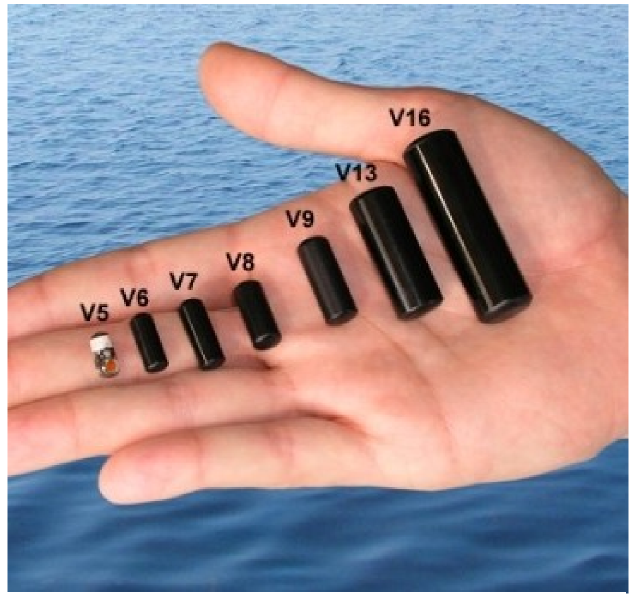

Figure 7. Vemco acoustic transmitters.

4.4 Inertial Measurement Unit (IMU) Telemetry

An IMU is an electronic device used to measure acceleration, pitch, roll, and heading. Tri-axial IMU's are composed of three accelerometers, three gyroscopes, and often a magnetometer (Larey *et al.*, 2019). They were initially developed for navigational systems; however, bio-logging IMUs have been miniaturized for consumer application and most recently used to quantify body orientation and motion in a range of diverse taxa (Cade *et al.*, 2020). With the use of GPS positions as geo-reference points for the start and finish, animal tracks between positions can be estimated using IMU to integrate speed, pitch, and heading changes. Fine-scale behaviors and habitat use, such as foraging and feeding, vertical movement, social interactions, stress resulting from capture, response to stimuli, physiology, and reproduction, can be differentiated and correlated with temporal and spatial parameters (Thomson and Heithaus, 2014; Tyson *et al.*, 2017; Cade *et al.*, 2020).

Figure 8. Loggerhead Instruments Open Tag IMU.

We will use Arduino-based open IMU tags (Loggerhead Instruments), as seen in **Figure 10**, to determine fine-scale behavior and CATScam IMU tags (CATS Inc.), which incorporate high-definition video, to verify correlations between specific behaviors to their signatures in IMU data. We plan to attach these tags on the animal's dorsal surface using suction cups aided by peanut butter, a method that has previously proven effective and successful (Stewart *et al.*, 2019). We will overlay animal habitat use and fine-scale behavior with preventative trawling and other mitigation activities to generate spatially explicit heat maps that allow us to better understand potential risk.

5 Workshop

5.1 Workshop Summary

A virtual data gathering and synthesis workshop was conducted January 11–12, 2021, with the assistance of Carrie Kappel, LLC, as facilitator. Experts from academia, government, and non-profits convened in order to summarize where knowledge about *M. birostris* currently stands and to better understand any ongoing research and how it may be informative or useful for the upcoming cooperative research study at Canaveral Shoals. Several presentations were given to stimulate discussions about various aspects of the study, including the topics of tagging, habitat modeling, animal handling, and environmental data collection. A collaborative shared notes document contains the workshop minutes as well as saved video recordings of both days. The workshop was productive and yielded recommendations from experts that may not have been considered otherwise. By the end of the workshop, it was agreed to postpone our fieldwork until Spring 2022 due to the impacts of the Covid-19 pandemic in relation to the timing of potential field work.

5.2 Aerial Surveys

Despite postponing boat-based fieldwork operations, we will begin in 2021 our aerial survey efforts, which will establish a baseline of manta abundance within the study site. These baseline data will be informative for future fieldwork planning. We will be collaborating with the non-profit Marine Megafauna Foundation (https://marinemegafauna.org/) to combine our respective aerial survey efforts in order for both organizations to benefit from additional sightings data. Approximately one flight will be flown every 10 days, for a total of 13 flights, weather and shuttle launches permitting, from late February/early March to the beginning of May. During previous survey efforts, manta numbers in this area have been highest in March, with a continued presence through April. We will also be recording environmental data such as sea state, glare, and SST to find any potential correlations between those environmental factors and manta presence/absence.

Based on workshop discussions, it was recommended that aerial observations also happen simultaneously with fieldwork to aid with spotting mantas and directing boat operators to their location. Most likely, we will use a drone based on a fieldwork vessel in order to gain this vantage point and relay approximate animal locations to the fieldwork team. This additional perspective is likely to increase our chances of capturing and handling mantas to deploy tags, but some of the fieldwork crew will need to be trained to pilot a drone for this to be a feasible option.

5.3 Tagging Methodology

By using aerial surveys, we will be able to better plan our fieldwork activities for Spring 2022 to deploy tags. We plan to deploy 10 satellite tags, 10 IMU tags, and 30 acoustic tags throughout the duration of the study. As previously mentioned, satellite tags will be attached to the dorsal fin via a bolt-on method that proved successful during a study of *Mobula alfredi* in the Red Sea (Kessel *et al*., 2017). We expect this method to provide a mission length of approximately one year. IMU tags will be applied to the dorsal side of a wing with a suction cup aided by smooth peanut butter, a method that was effective in a previous manta ray study (Stewart *et al*., 2019). IMU tags will have short mission lengths of approximately 3–5 days, due to the high resolution of data that they collect, which results in data payloads that exceed the capacities of ARGOS satellite bandwidth. Acoustic tags will be surgically inserted in juveniles and externally attached in adults. We anticipate a maximum mission length of 10 years for implanted tags, based on Vemco V16 battery life, and a shorter mission length of 800–900 days for externally attached tags (Vemco, 2021).

During the workshop IMU presentation, participants began a discussion about the benefits of using manta rays in the GAI collection to conduct method development studies to improve the chances of success during subsequent field operations. We plan to explore this opportunity and hope to attach IMU tags to at least one of the manta rays in the Ocean Voyager exhibit and collect simultaneous behavioral observational data to ground truth the sensor data gathered by the IMU tag. There are no published data for manta ray wingbeat detections via IMU (D. Cade, personal communication, 2021). If we can detect wingbeats via IMU and validate those detections with observational data, it will help with better determining behavioral IMU data from wild tagged manta rays. We will submit two applications to the GAI Institutional Animal Care and Use Committee (IACUC) in order to begin the approval process for using in-house animals and wild animals as part of this research project.

Workshop discussions included the potential method of free-hooking mantas. Dr. Steve Kessel used this method for his Red Sea studies with *M. alfredi* and found it to be effective and potentially less injurious than other capture methods, such as seine netting (Kessel *et al.*, 2017). For this method, a hook is thrown in front of a manta ray in order to catch the animal. Once hooked, the manta is able to swim and tire itself, making handling safer for both the animal and the researchers. The animal is immediately released after sampling and based on previous observations, does not seem to be affected by the method; animals were observed exhibiting usual behaviors, such as feeding, soon after capture and release (S. Kessel, personal communication, 2021). We plan to include this method in our project IACUC application, as it seems the most feasible form of capture for adult mantas, which will likely take place in deeper water than for their juvenile counterparts.

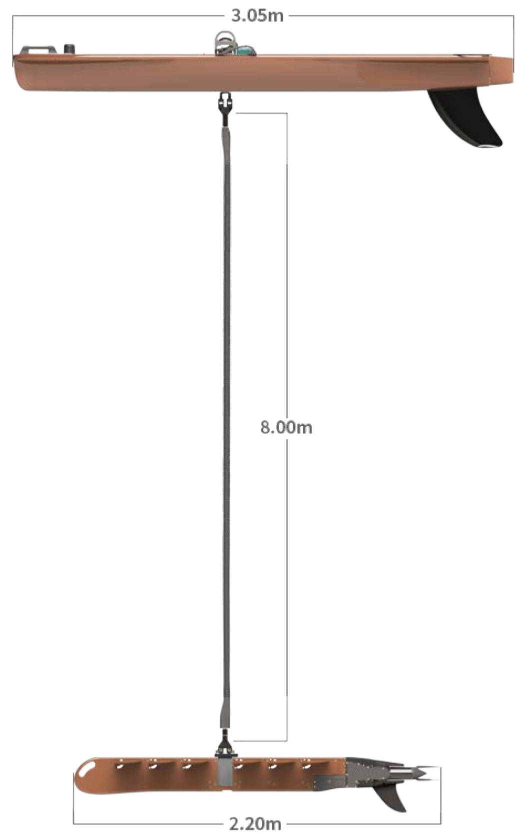

Figure 9. Liquid Robotics Wave Glider Model

5.4 Liquid Robotics Wave Glider

The use of BOEM's *ASV Melvin*, a wave glider produced by Liquid Robotics (**Figure 11**), allows for extended sampling range to assist with this study. The ASV is powered by waves and solar energy and follows pre-determined survey transects to collect a variety of environmental data. Equipped with an array of sensors, ASVs have been widely used for environmental monitoring tasks such as passive acoustic monitoring for cetaceans and fish tracking (Carlson, 2015; Bittencourt *et al.*, 2018).

While on a mission, the wave glider is able to stream data via satellite and is piloted by trained personnel via a web browser interface. The variety of sensors used, collectively referred to as the scientific payload, can include a Vemco acoustic receiver and temperature, oxygen, chlorophyll, turbidity, and passive acoustic recorders (Liquid Robotics, 2018). This tool affords the ability to monitor movements beyond the boundaries of the fixed receiver array, collect environmental data, and characterize surrounding soundscapes. As of our workshop, *ASV Melvin* has detected 20 different acoustically tagged species, such as sharks, cobia, and mantas, and has recorded 320 animal encounters (B. Ahr, personal communication, 2021). The average deployment is 25 days with an average speed of 1.2 kn (B. Ahr, personal communication, 2021). By using *ASV Melvin*, we will acquire additional fine-scale data to better understand habitat characteristics where mantas may be found. Three GAI staff will be trained to pilot the *ASV Melvin* and will plan to begin using the wave glider in 2021.

5.5 Workshop Conclusions

After the workshop, it was clear a combination of tag types (acoustic, satellite, IMU) would yield the greatest amount of data, but because of extended battery life and the manta life stages that may be included as a result, we determined a need for emphasis on acoustic tags. In addition to the multiple life stages they may capture, they are more cost effective than their satellite and IMU counterparts. Our goal is to deploy all three tag types and collect both spatial and behavioral data, but due to available acoustic telemetry infrastructure, such as *ASV Melvin*, the Canaveral acoustic array, and FACT network, a priority will be given to acoustic tags.

During our fieldwork postponement, we plan to attach IMU tags to manta rays housed at GAI in order to refine attachment methodology as well as establish baseline data points that can be validated with behavioral observations. We will use the attachment methodology of a suction cup aided by smooth peanut butter, a method proven successful in previous studies (Stewart *et al.*, 2019).

Prior to commencing fieldwork, additional conversations are needed to better understand specific data requirements for desired outputs, such as habitat modeling. Further discussions with experts at Canaveral Shoals and BOEM will clarify specific data requirements for statistical analysis, modeling outputs, and management needs.

6 Conclusion

Due to our fieldwork postponement, next steps will be training GAI staff to pilot the *ASV Melvin*; proceed with testing IMU tag attachment on manta rays housed at GAI; begin the permitting process at the national level to ensure accessibility to Canaveral Shoals National Seashore; and begin aerial surveys to determine seasonality of *M. birostris* in our study site to better guide our fieldwork planning for Spring 2022.

The combination of technology and expertise in the project will facilitate a unique opportunity to better understand fine-scale drivers of manta ray movement and ecology, and though this data will be used to implement future BOEM mitigation policies, it will also help advance our current scientific understanding of an elusive, endangered, and poorly understood species. Our hope is to meet our project goals while collecting quality data that may assist future studies and conservation efforts pertaining to this endangered species.

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Department of the Interior (DOI)

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

Bureau of Ocean Energy Management (BOEM)

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

BOEM Environmental Studies Program

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