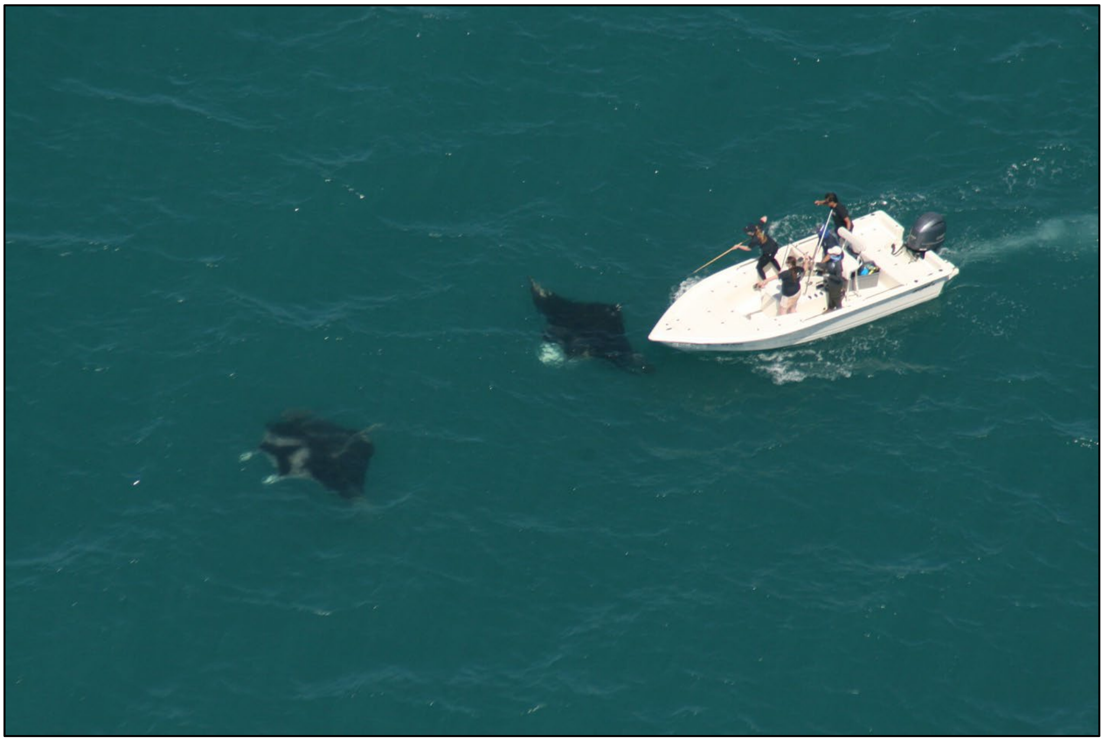
OCS Study
BOEM 2023-068

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



U.S. Department of the Interior
Bureau of Ocean Energy Management
Headquarters, Sterling, VA

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

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DISCLAIMER

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ABOUT THE COVER

Georgia Aquarium staff and volunteers tagging *M. birostris* off Cape Canaveral, Florida.

ACKNOWLEDGMENTS

This final report and project were assisted by support and collaboration with staff at NASA-KSCES, Dr. Steve Kessel at Shedd Aquarium, David Baldwin, Joy Hampp, Terry Clark, Dr. Jeff Carrier, Michael Chamberlain, Dr. Dave Cade, Dr. Josh Stewart at Manta Trust, staff at Marine Megafauna Foundation, and Alasdair Davies at Arribada Initiative.

Summary

The purpose of this study was to understand how movements and site fidelity of endangered oceanic manta rays (*Mobula birostris*) affect the risk of interacting with marine mineral extraction or associated mitigation activities, such as preventative trawling, and inform the Bureau of Ocean Energy Management's (BOEM's) future mitigation policies. The initial study objective was to track animals in the field using a combination of aerial surveys, satellite telemetry, acoustic telemetry, and inertial measurement unit (IMU) payloads to obtain fine-scale habitat use and behavior data. The study faced several obstacles, including impacts from the COVID-19 pandemic, which resulted in the loss of the 2021 field season; the discontinuation of the originally preferred IMU payload; and weather that was unfavorable for field work. As a result of these obstacles, the field initiative was constrained and the total number of tagged animals was significantly reduced, resulting in a limited data set available to achieve the original study objective. However, based on lessons learned during the field campaign, the study was adjusted, and complementary study objectives added to focus on the production of an open-source IMU tag package that can be efficiently attached via active suction to the dorsal surface of a manta ray. The team drew inspiration from a similarly constructed IMU package used by Stewart et al (2019) and the field experience during this study to recognize the importance of advancing the tagging technology and attachment methods for future manta research. The unique skill set and resources of the Georgia Aquarium, in partnership with Arribada Initiative, were leveraged to design and develop a new IMU tag package and conduct iterative attachment trials on manta rays in human care.

In summary, aerial surveys were conducted from March to May 2021 from New Smyrna Beach, Florida to Sebastian Inlet, Florida to determine migration patterns and seasonality of oceanic manta rays off the Southeastern United States, specifically in the vicinity of the Canaveral Shoals sand borrow area to inform the timing of when to capture and acoustically tag animals. In all, 107 mantas were documented–99 in March, 1 in April, and 7 in May. Acoustic tagging fieldwork occurred in March 2022 and resulted in 5 animals being externally tagged with acoustic V16 transmitters. Though the data set is limited, the combination of both aerial and acoustic telemetry data provided some initial insight into the behavior of giant mantas in this region.

Additionally, the fieldwork highlighted several incidental findings related to both capturing and tagging giant mantas that advance the field of science. The fieldwork included an innovative capture method, previously successful on reef manta rays (*M. alfredi*) (Kessel et al., 2017), and applied it to oceanic manta rays (*M. birostris*) for the first time. This new application was successful with smaller animals but highlighted necessary gear modifications to be successful with larger, more powerful animals. Concerns regarding the invasive nature of traditional tagging methods and the challenges associated with capturing, handling, and implanting tags on giant mantas in the wild highlighted the need for more innovative tagging approaches. The team worked with engineers at Arribada Initiative to design a new tag and conduct attachment trials with *M. birostris* in the care of the Georgia Aquarium. Through the in-house trials, we found that modified vacuum cups attached to the head of the animal resulted in the longest retention times (maximum four hours). In addition to the tag design, Arribada Initiative designed a quick-release pole applicator that will allow for tag attachment from a vessel without restraining the animal. As these are open-source designs, they can be used by any academic, government, non-profit, or NGO that would benefit in their scientific endeavors from the designs or their derivatives, including BOEM in their future efforts to study *M. birostris* among other species.

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List of Abbreviations and Acronyms

Short Form	Long Form
ARGOS	Advanced Research and Global Observation Satellite
BOEM	Bureau of Ocean Energy Management
BSS	Beaufort Sea State
DW	disc width
ESA	Endangered Species Act of 1973
FACT	Florida Atlantic Coast Telemetry Array
GAI	Georgia Aquarium, Inc.
IMU	Inertial Measurement Unit
IUCN	International Union for the Conservation of Nature
kn	knots
m	meters
MMF	Marine Megafauna Foundation
MMP	Marine Mineral Program
NCE	No-cost Extension
NOAA	National Oceanic and Atmospheric Administration
nm	nautical miles
OCS	Outer Continental Shelf
OV	Ocean Voyager exhibit at GAI
PAT	Pop-up Archival Tag
PI	Principal Investigator
Psi	pounds per square inch
R&C	Research & Conservation Department at GAI
SPOT	Smart Position Only Tag
SSG	Shark Specialist Group at IUCN
TSHD	Trailing Suction Hopper Dredge
VHF	Very High Frequency

1 Background

1.1 An Introduction to *Mobula birostris*

1.1.1 Biology and Ecology

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

Both oceanic and reef manta rays had been 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*.

This taxonomic history is important because there is a third species of manta that has been identified (*M. cf. birostris*), with a geographic range that extends along the Atlantic Coast, Gulf of Mexico, and Caribbean, perhaps as far south as Brazil (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 currently in preparation, 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 4–5m (Stevens, 2018) and a maximum DW of 7m (McClain et al., 2015). Similar to other rays, the oceanic manta ray has a dorso-ventrally flattened body shape with the gills on the 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 (**Figure 1**). While feeding, mantas unfurl their cephalic lobes to efficiently detect and funnel their zooplanktonic prey into their mouths. The primary prey of *M. birostris* are copepods, chaetognaths, and fish eggs (Graham et al., 2012). During feeding, food is directed to the esophagus through crossflow filtration, while water is directed out through the gills (Paig-Tran and Summers, 2014; Stevens, 2018).

Figure 1. ***Mobula birostris***
Photo credit: Travelosio

Mobula birostris is a widespread species found throughout the tropical, subtropical, and warm 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 (*M. alfredi*). This elusiveness 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 at maturity (15 years for females; 9 years for males), lifespan (~40 years), and reproduction (one live pup per female, 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 intrinsic 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 from disturbance.

Mantas are known to aggregate in large numbers (up to 100 individuals) in many areas (e.g., Mexico, Mozambique, Maldives, and Hawaii). These aggregations may be for feeding, courtship, breeding, or 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 seen on animals in that location (NOAA, 2019). Mating has rarely been documented in U.S. waters, but a potential nursery ground was recently described off southeast Florida, from St. Lucie Inlet to Boynton Beach Inlet (Pate and Marshall, 2020). That study also concluded that 98% of the mantas observed were juveniles that displayed a high degree of site fidelity.

1.1.2 Movements and 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 such significant empirical 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 these traits is important for effective management of the species 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 using 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) towards 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 their biology rife 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 more 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).

1.2 Marine Mineral Extraction

1.2.1 Marine Mineral 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—to assist with beach nourishment, shore protection, and wetland restoration (BOEM, 2020a). Desired 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 2**, to account for future advances in dredge technology (D. Hansen, personal communication, 2021).

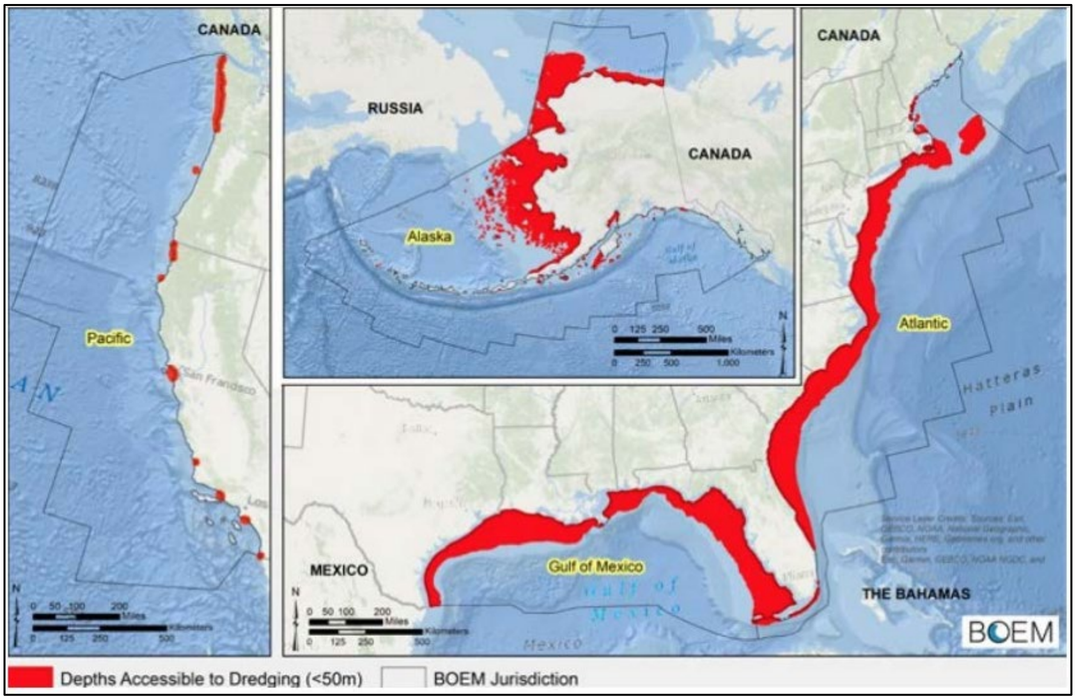


Figure 2. Areas of less than 50 m depth where BOEM MMP operates.

1.2.2 Preventative Trawling

Before and during dredging, relocation trawling may be conducted to mitigate the risk of interaction of trailing suction hopper dredge (TSHD) with Federally protected, Endangered Species Act (ESA) listed sea turtles, which were found to be vulnerable to direct entrainment by dredging operations (BOEM, 2015). Modified shrimp trawling equipment is used to sweep the sea floor to capture and relocate sea turtles. This involves the dragging of a net (dim 15 x 35 ft) along the sea floor behind a trawling boat to capture turtles. Typically, a vessel with two trawling nets is operated in a given area at the same time, and each trawl can be pulled for no more than 40-minutes to prevent serious injuries to captured turtles and speeds must not exceed 3.5 kn, to decrease stress to captured animals (BOEM, 2017). Preventative trawling is often conducted 1 to 3 days before dredging and throughout the duration of dredging operations. 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 and resulted in the development of a cooperative agreement study between BOEM and Georgia Aquarium (GAI) to better understand this overlap and help inform BOEM's future mitigation policies.

1.3 Original Study Objectives

The original study objective was to assess the risk posed to oceanic manta rays (*Mobula birostris*) by marine mineral extraction activities (i.e., dredging), including preventative trawling, in the sand shoal habitats near Canaveral Shoals, Florida in the Atlantic Southeastern United States. To accomplish this objective, the team used a combination of aerial surveys, satellite tags, acoustic transmitters, and IMU payloads to obtain fine-scale habitat use and behavior data of *Mobula birostris*. This combination of data will help BOEM better understand the spatial and temporal overlap of *M. birostris* with BOEM authorized activities and inform mitigation policies to reduce potential interaction between their MMP and the ESA-listed oceanic manta ray.

1.3.1 Satellite Tags

Satellite tags provide broad-scale data of an animal's movement which can be used to better understand seasonality and migration patterns. There are a wide variety of satellite tags and attachment methods for elasmobranchs. For this study, we selected fin-mounted smart position-only (SPOT) tags which would be attached to the dorsal fin of the animal via nylon bolts at four points of attachment. These tags can provide 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. Fin-mounted satellite tag attachment has been proven successful with reef manta rays, *M. alfredi*, in Sudanese Red Sea waters (Kessel et al., 2017). This previous success supported the team's decision to include this method of attachment and to include its lead author, Dr. Steve Kessel, in the research effort.

1.3.2 Acoustic Tags

Acoustic telemetry requires two components – an acoustic transmitter and an acoustic receiver. Animals can be externally or internally tagged with a transmitter that emits unique individual identification numbers in the ultrasound range of 69 KHz. These messages are received and logged by receivers when the animal is close enough for the receiver to detect the transmitter. The Atlantic coast of Florida contains an extensive and well-maintained array of acoustic receivers operated by the Florida Atlantic Coast Telemetry (FACT) network of collaborators. The study included acoustic transmitters in the telemetry methods to take advantage of these resources. We planned to use Innovasea V16 transmitters for both internal and external placement. V16 transmitters were intended for surgical insertion into the body cavity which would have yielded a longer transmission. Alternately, external V16s were to be attached to the wing of the animal via tether.

1.3.3 Inertial Measurement Unit (IMU)

IMU tags allow for data to be collected about animal behavior and habitat use at much finer spatial and temporal scales than either satellite or acoustic telemetry. These tags were equipped with gyroscopes, accelerometers, and magnetometers that allow researchers to understand animal behaviors in three dimensions. These IMUs required us to design a payload that could be attached to the dorsal surface of the animal via active suction or passive suction. Active suction was achieved with compressed air that created a vacuum seal while passive suction was created solely by manual force from a team member.

2 Obstacles and Setbacks

A number of factors combined to interfere with the originally intended objective of this cooperative agreement, leading to the agreed revised modified objective. These factors can roughly be grouped as those related to the COVID-19 pandemic, the discontinuation of our desired tag payload, and fieldwork challenges.

2.1 COVID-19

The 2021 fieldwork season was canceled due to impacts of the COVID-19 pandemic, significantly delaying opportunities to collect samples and deploy tags. To offset this loss, the team tentatively scheduled two rounds of fieldwork for 2022, one in March and one in April for four weeks in total. However, PI schedules were unable to align for the second window to be achieved, which resulted in one two-week fieldwork window being conducted in March 2022 and the April two-week window being canceled. The one-year delay of field season also contributed to the need for a no-cost extension (NCE).

2.2 OpenTag Discontinuation

Originally, the team intended to use Loggerhead Instruments OpenTag for as an IMU payload. This option was an open-source and cost-effective option for the study. However, this tag package was discontinued by Loggerhead Instruments before the work could be completed. After determining no equivalent open-source IMU replacement was available, the team determined the next best option would be to design an IMU tag that would include ORI1300 data logger made by Little Leonardo (Tokyo: Japan). Attaching the IMU for the intended time of deployment was a significant challenge. We modeled our approach after Stewart et al., (2019), who successfully used active suction via compressed air and a vacuum suction cup to attach a tag to the dorsal side of a reef manta ray. Their design was proprietary, but their team kindly provided input for the fundamentals of our design. Arribada Initiative was then hired to engineer the payload on behalf of the project.

An early iteration of the suction cup design proved to be ineffective during fieldwork testing in March 2022. The buoyancy and orientation of the Argos and VHF antennae post-release were not conducive to successful payload recovery. The team identified several design weak spots during fieldwork which were subsequently addressed by Arribada Initiative. Updated designs were tested in-house at GAI with the goal of developing an open-source design that would then be available to future research teams interested in this field of research.

2.3 Fieldwork Obstacles

Before our scheduled March 2022 fieldwork, the team that was contracted to operate as a capture vessel indicated that their vessel would be unable to operate in the sea conditions likely to be present in the study area. This obstacle required the team to abandon their primary capture method of seine netting and rely upon their secondary method of free-hooking, a method that had previously been successful on reef manta rays (Kessel et al., 2017) but had never been used on oceanic manta rays.

Free-hooking proved to be an effective method for capturing smaller animals (<2m DW) but was ineffective for larger animals (>2m DW). This method was likely ineffective for larger animals due to the increased size, weight, and power of the animal. One juvenile animal (1.8m DW) was successfully hooked, captured, sampled, and released. Two adult animals (3.8m; 3.3m DW) were successfully hooked but prematurely broke the fishing gear and escaped. The inconsistency of the free-hooking method prompted the team to begin attaching acoustic transmitters externally via pole spear, as this was the only tag capable of being deployed without restraining the animal. Iterations of gear modifications would likely have made free-hooking a more effective method for larger animals. Particularly, a larger Flemish eye knot may have reduced localized pressure on the monofilament and allowed a larger range of movement for the animal, which may have reduced the frequency of broken fishing lines. Due to the low number of opportunities, the team was unable to deploy satellite and internal acoustic tags and were unable to collect many samples.

In addition to methodological obstacles, the Beaufort Sea State (BSS) did not allow for safe working conditions, resulting in the team being on the water four days out of nine. Several days in the fieldwork window were a BSS of 3 to 4, meaning 0.6–1.3 m waves and 7–16 kts winds. Days on the water averaged a BSS of 2. This type of weather was the maximum strength we could work in and presented difficulties for safely capturing and handling animals.

During the first day of fieldwork activities, the primary vessel began to have engine trouble. As a result, the vessel could only operate with one engine, greatly reducing the distance that could be covered and the speed in which the team could transit. The team changed plans and designated the secondary vessel as the new primary and the original primary as the new secondary. This change allowed the scientific team to be able to cover a greater distance more quickly, maximizing our ability to encounter animals. The engine troubles continued throughout the field period and was eventually resolved by a marine mechanic, but not before significant impact to the fieldwork activity.

3 Fieldwork Operations

3.1 Fieldwork Summary

Fieldwork was conducted from March 21 to March 31, 2022, based out of Port Canaveral, Florida. The fieldwork team consisted of participants from BOEM, GAI, Shedd Aquarium, Stanford University, and volunteers. Two vessels were used for on-water activities and were supported by an aerial team of three who were surveying from a Robinson 66 turbine helicopter. Turbidity in the study area did not allow for frequent sightings from the vessels, requiring constant aerial support for guidance.

The team was on the water for four days, March 25, 26, 28, and 29, 2022. We had 13 encounters with manta rays (mean DW 3.4m), resulting in three successfully free-hooked animals–one of which was processed to completion, and two ending prematurely due to broken fishing gear; one after 62-minutes and the second after 68 minutes. Localized pressure on the monofilament Flemish eye was a likely cause of gear breakage. Increasing the size of the Flemish eye, therefore distributing pressure over a larger area, and allowing for a broader range of hook movement, would potentially decrease the occurrence or frequency of breakage. We deployed five external V16 acoustic transmitters, one by hand spear and four by pole spear from the vessel. Animals were spotted and caught in waters averaging 10.3 m deep.

Fieldwork days had an average SST of 21.63°C; an average air temperature of 20.47°C; and an average wind speed of 3.93m/s. Environmental data corresponding to fieldwork can be found in **Table 1**. All environmental data was downloaded from NOAA’s Station TRDF1 Trident Pier, Florida.

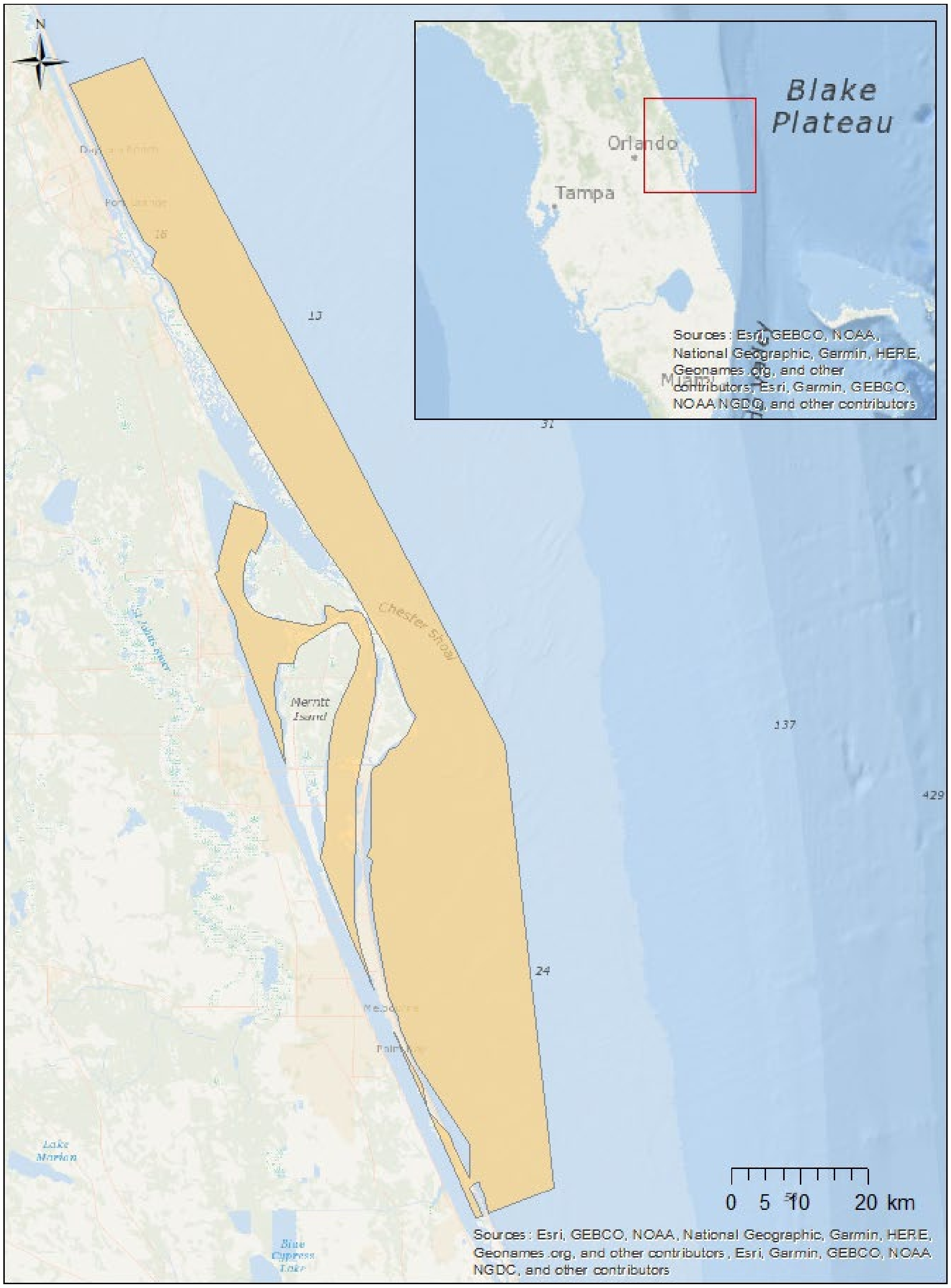
Table 1. Environmental data during fieldwork

Date	Sea Surface Temp (°C)	Air Temp (°C)	Wind Speed (m/s)	*Total Mantas
2022-03-25	24.44	19.80	4.37	13
2022-03-26	19.67	19.67	4.27	9
2022-03-28	21	21	3.90	17
2022-03-29	21.41	21.41	3.18	13

**Mantas sighted by the aerial support team during fieldwork efforts.*

3.1.1 Fieldwork Maps

For fieldwork operations, the aerial support team would scout from New Smyrna Beach south to Port Canaveral, where they would rendezvous with the on-water team. While scouting started at New Smyrna Beach, opportunistic sightings were recorded further north while transiting to the Port Canaveral area. Because of range limitations of the research vessels, the aerial team limited their scouting north to the Kennedy Space Center launch pads and south to Cocoa Beach. The study footprint, fieldwork efforts, and sightings are shown below, and all maps were created using ArcGIS 10.8 software.



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Sources: Esri, GEBCO, NOAA, National Geographic, Garmin, HERE, Geonames.org, and other contributors, Esri, Garmin, GEBCO, NOAA NGDC, and other contributors

Figure 2. Study footprint.

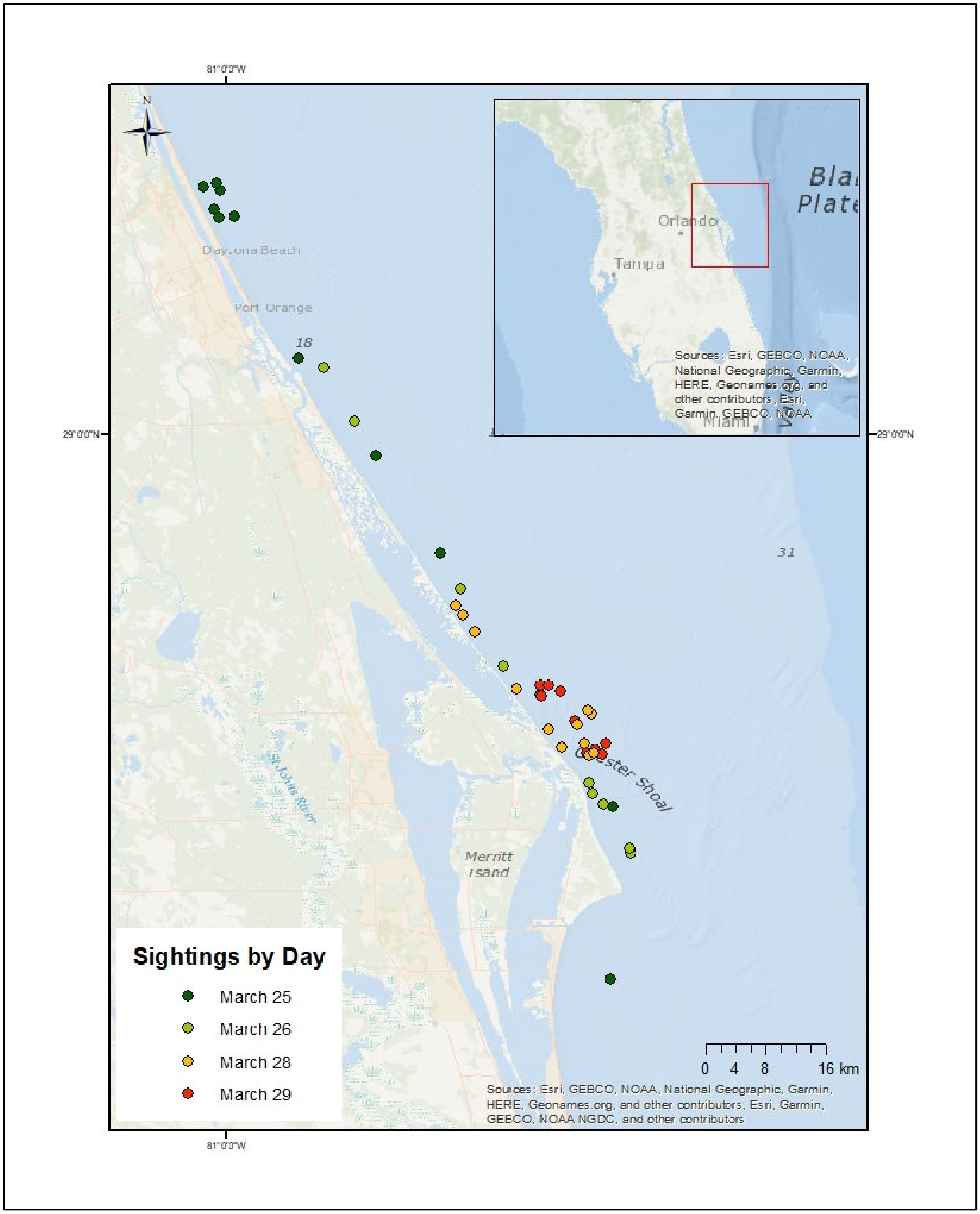

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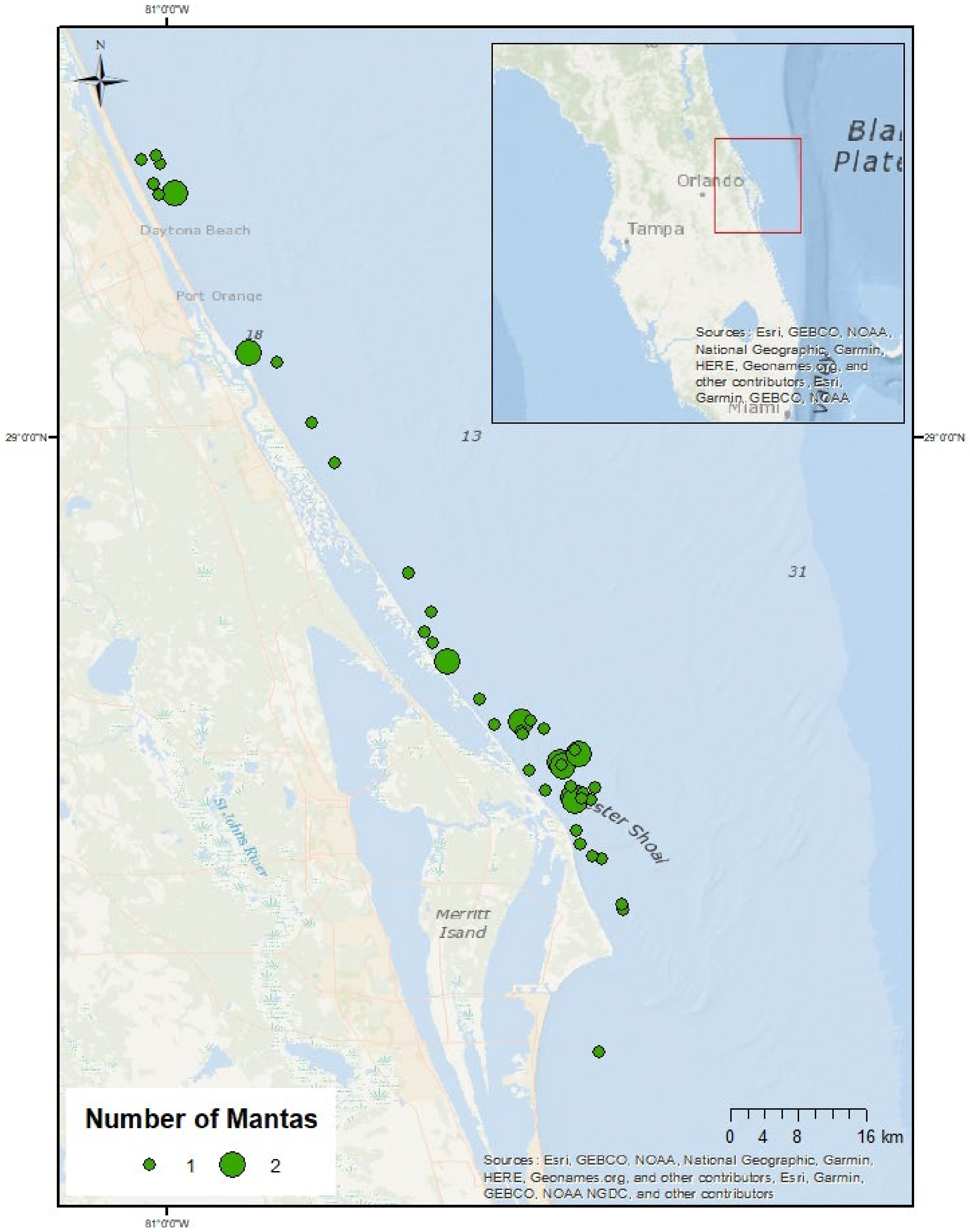
Figure 4. Fieldwork sightings by day.



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Sources: Esri, GEBCO, NOAA, National Geographic, Garmin, HERE, Geonames.org, and other contributors, Esri, Garmin, GEBCO, NOAA NGDC, and other contributors

Figure 5. Number of mantas per sighting during fieldwork efforts.

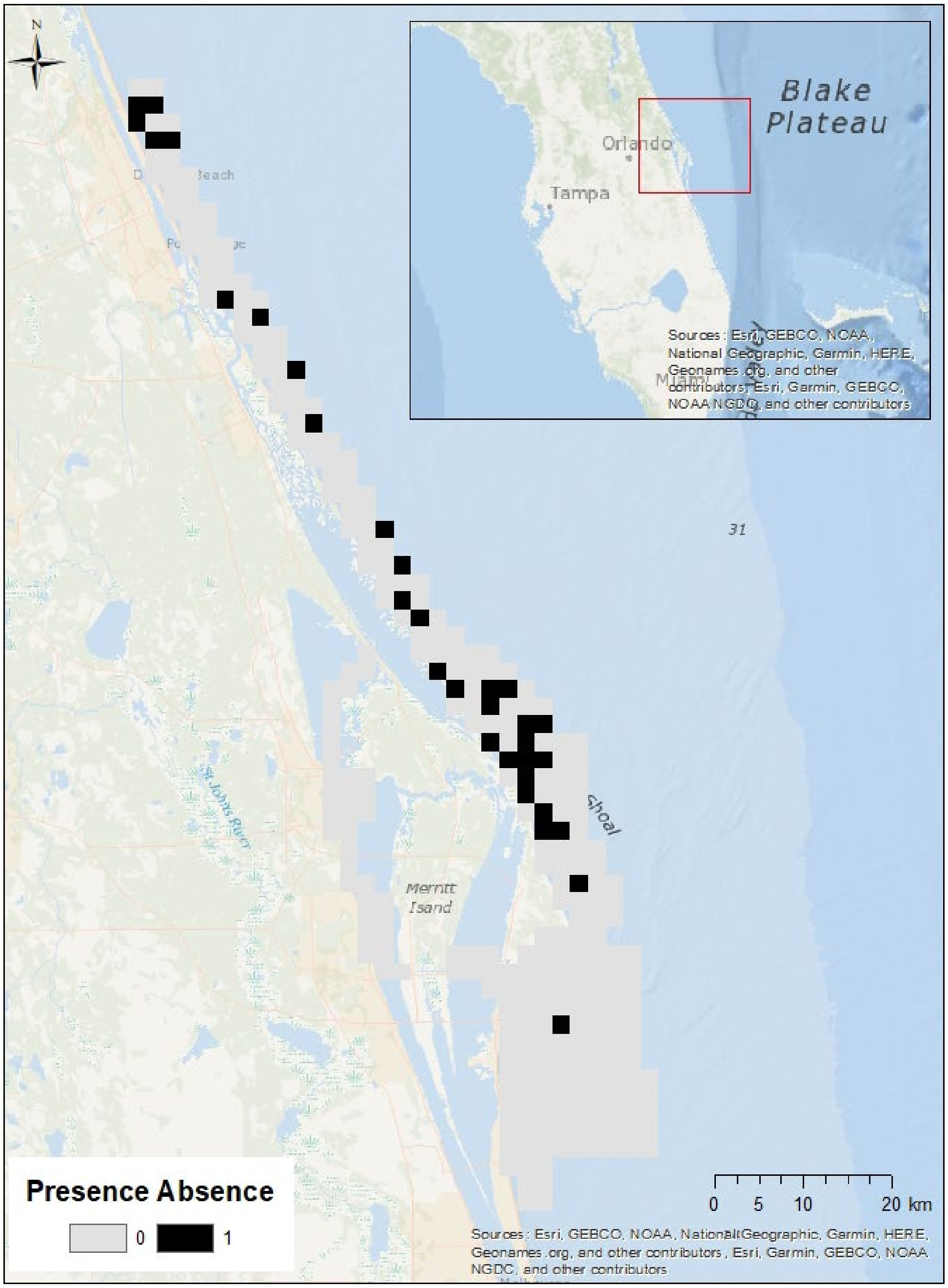

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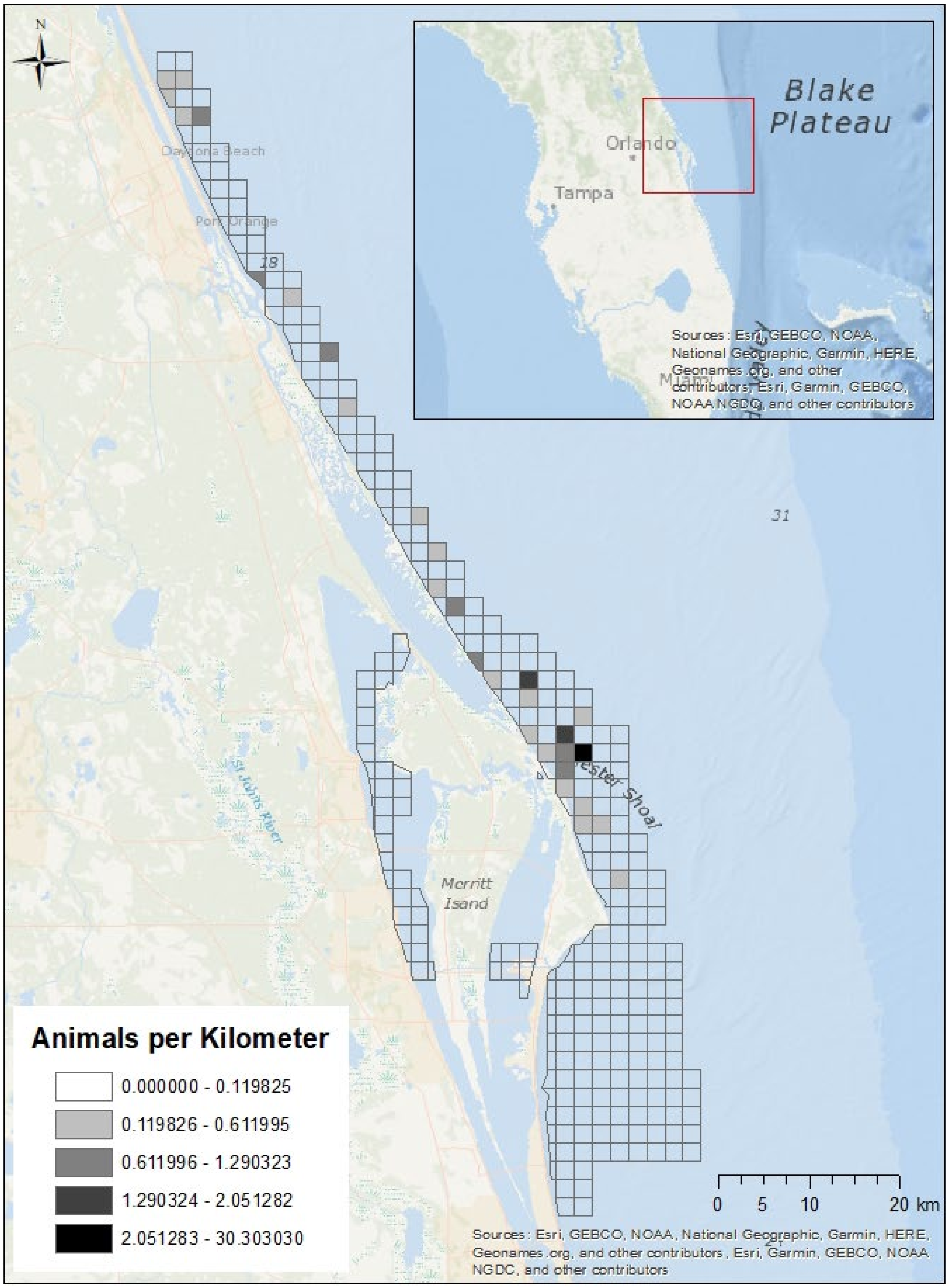
Figure 3. Manta presence absence during fieldwork.



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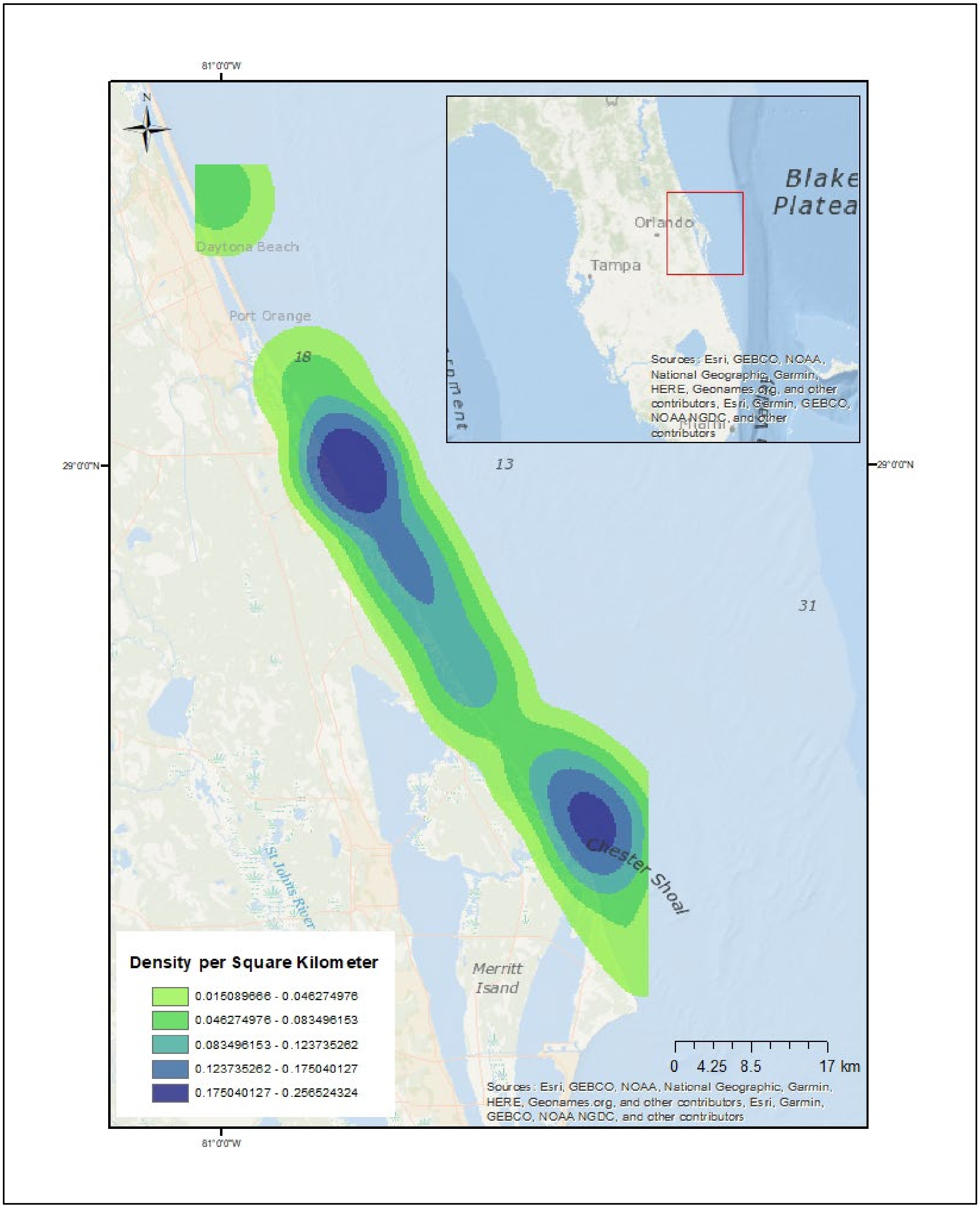
Sources: Esri, GEBCO, NOAA, National Geographic, Garmin, HERE, Geonames.org, and other contributors, Esri, Garmin, GEBCO, NOAA NGDC, and other contributors

Figure 4. Fieldwork sightings per unit effort.



Sources: Esri, GEBCO, NOAA, National Geographic, Garmin, HERE, Geonames.org, and other contributors, Esri, Garmin, GEBCO, NOAA NGDC, and other contributors

Sources: Esri, GEBCO, NOAA, National Geographic, Garmin, HERE, Geonames.org, and other contributors, Esri, Garmin, GEBCO, NOAA NGDC, and other contributors

Figure 5. Fieldwork heat map.

3.2 Aerial Surveys

3.2.1 Survey Outcomes

Aerial surveys were conducted in the Spring of 2021 and 2022 to better inform the team about when and where mantas may be most abundant. The aerial survey and fieldwork support team consisted of Joy Hampp, an observer with 13 years' experience; Terry Clark, an observer with four years' experience; and David Baldwin, a pilot with two years' experience. All fieldwork support and 12 of 14 aerial surveys were conducted in a Robinson 66 turbine helicopter. Two aerial surveys in June 2022 were flown in a Cessna Skymaster. Our team worked in conjunction with Marine Megafauna Foundation (MMF) to share aerial survey information to better inform both organizations. The survey range extended from Ponce Inlet to the north and Sebastian Inlet to the south. Flights were conducted at 0.5 nm and 1.5 nm from shore. Our access to Cape Canaveral restricted air space was inconsistent and represents a bias in our survey data, as certain surveys had to shift transect lines further offshore than other surveys to avoid restricted space.

Six flights were flown in 2021 and 2022, respectively. In 2021, three flights were conducted in March, one in April, and two in May. The highest concentration of mantas occurred in March, with individuals sighted throughout the survey boundaries. For 2021, 107 mantas were documented, with 99 sightings occurring in March, 1 in April, and 7 in May. In 2022, one flight was conducted in January, March, April, and May, and two in June. Surveys did not maintain their standard schedule due to fieldwork assistant from the aerial survey team. For 2022, 67 mantas were documented, with 1 sighting in January, 47 in March, 1 in April, 7 in May, and 11 in June.

Aerial survey days had an average SST of 22.95°C; an average air temperature of 23°C; and an average wind speed of 3.42m/s. Environmental data corresponding with aerial surveys and the number of mantas recorded can be found in **Table 2**. All environmental data was downloaded from NOAA's Station TRDF1, Trident Pier, Florida.

Table 2. Environmental data from aerial surveys

Date	Sea Surface Temp (°C)	Air Temp (°C)	Wind Speed (m/s)	Mantas Recorded
2021-03-01	22.29	22.90	4.05	24
2021-03-14	N/A	N/A	N/A	64
2021-03-23	18.47	18.47	2.06	11
2021-04-29	24.81	24.81	3.59	1
2021-05-11	26.47	26.47	2.77	5
2021-05-25	24.64	24.64	3.01	2
2022-01-24	9.43	9.43	2.74	1
2022-03-18	22.55	22.55	2.38	47
2022-04-27	24.26	24.26	3.38	1
2022-05-06	27.26	27.26	5.86	7
2022-06-02	26.04	26.04	3.01	10
2022-06-09	26.18	26.18	4.80	1
Total Mantas	-	-	-	174

**A survey was conducted on 2021-03-14 but no environmental data was available from Station TRDF1.*

3.2.2 Survey Maps

Survey efforts and sightings are shown below, and all maps were created using ArcGIS 10.8 software.

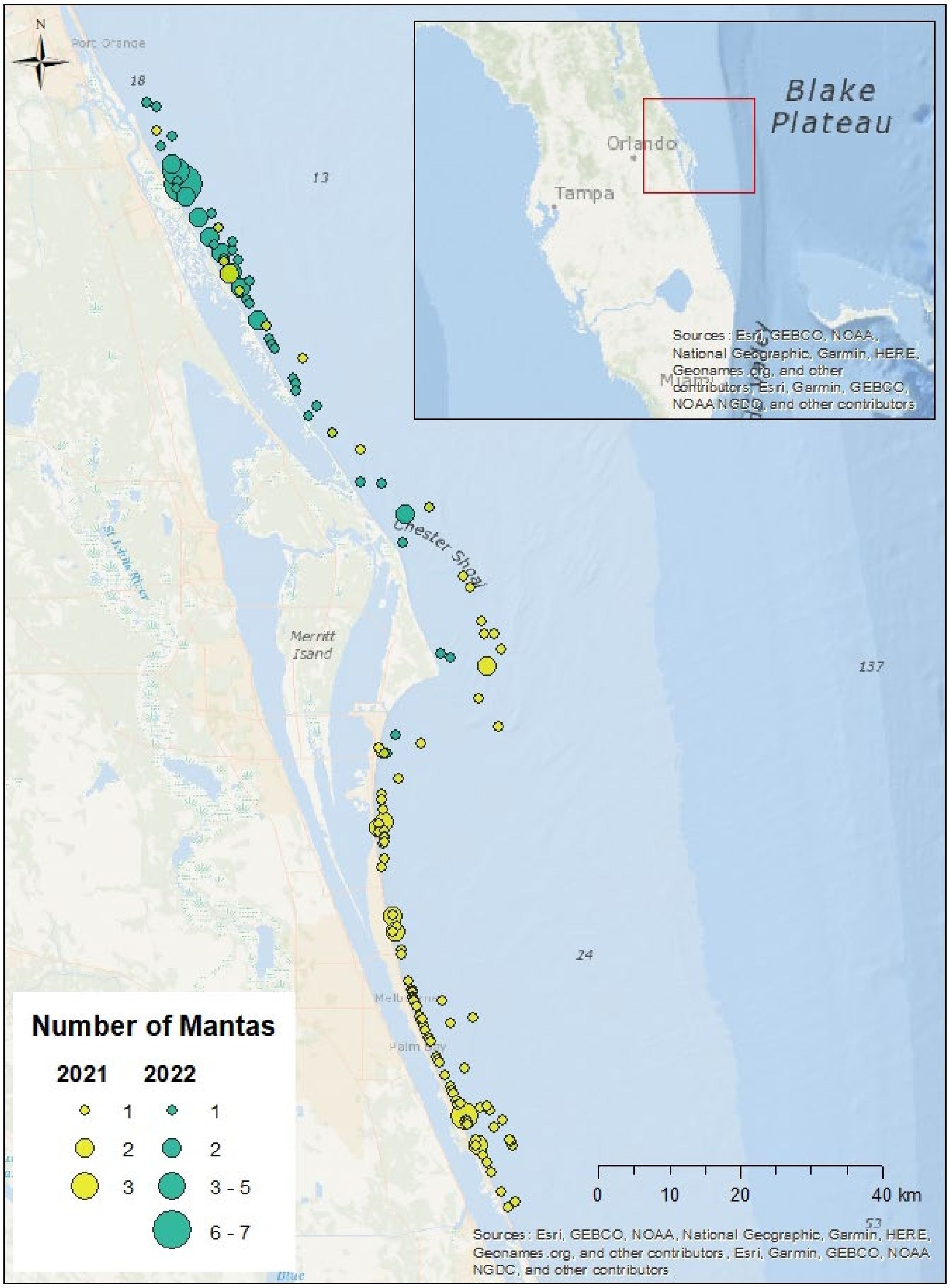


Figure 6. Aerial survey number of mantas per sighting by year.

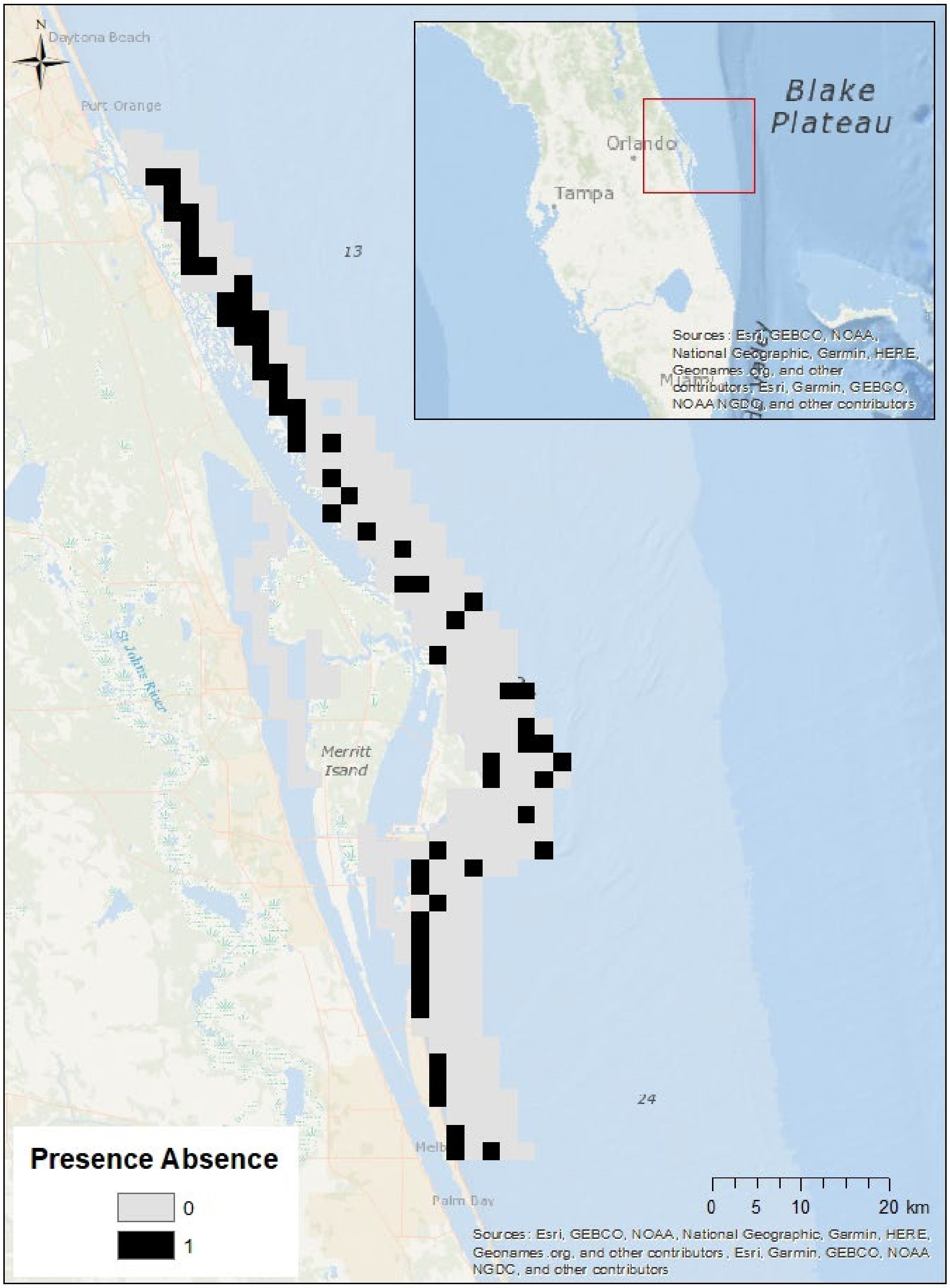
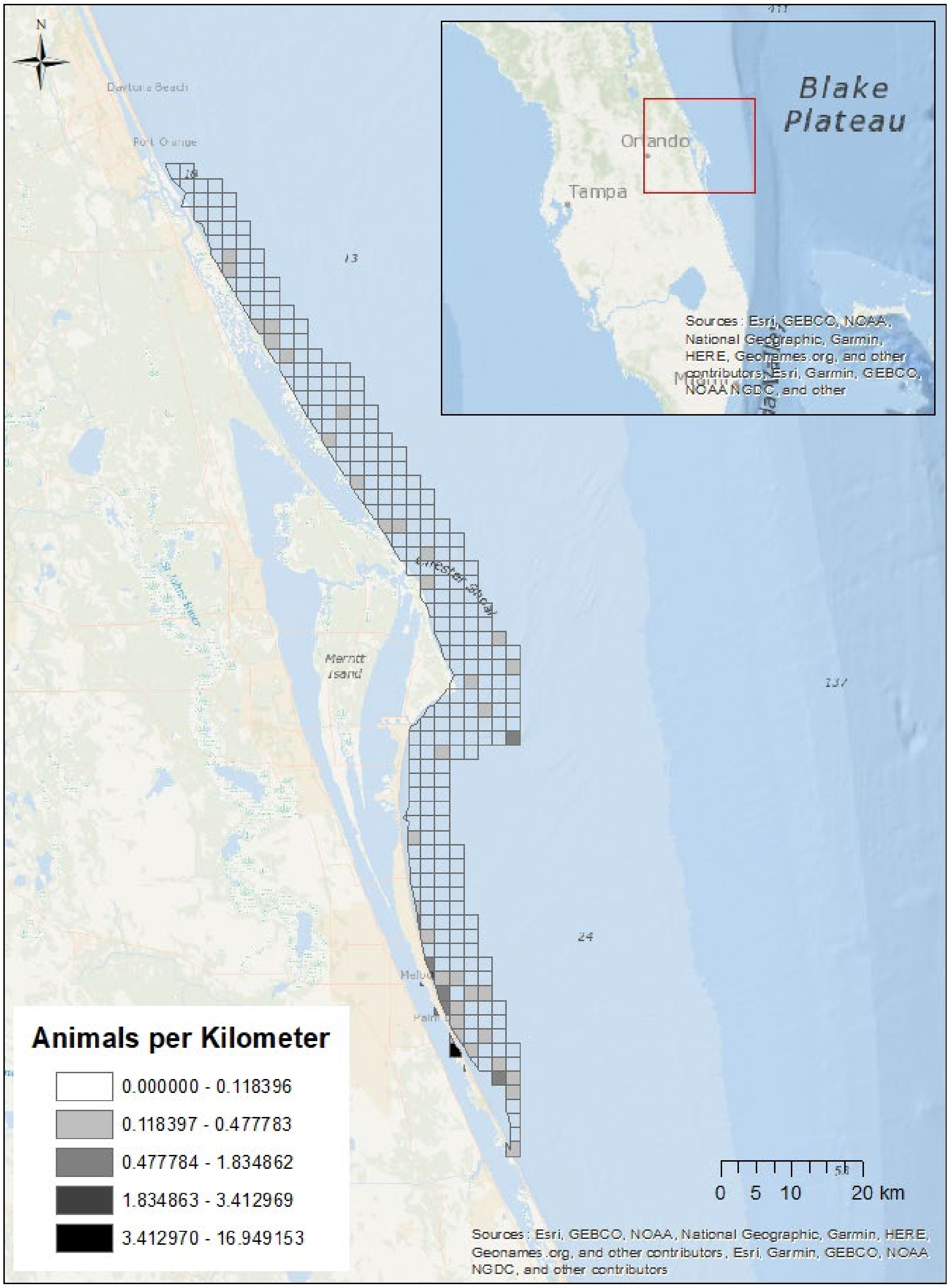


Figure 7. Manta presence and absence during aerial surveys.



Sources: Esri, GEBCO, NOAA, National Geographic, Garmin, HERE, Geonames.org, and other contributors, Esri, Garmin, GEBCO, NOAA NGDC, and other

Sources: Esri, GEBCO, NOAA, National Geographic, Garmin, HERE, Geonames.org, and other contributors, Esri, Garmin, GEBCO, NOAA NGDC, and other contributors

Figure 8. Aerial survey sightings per unit effort.

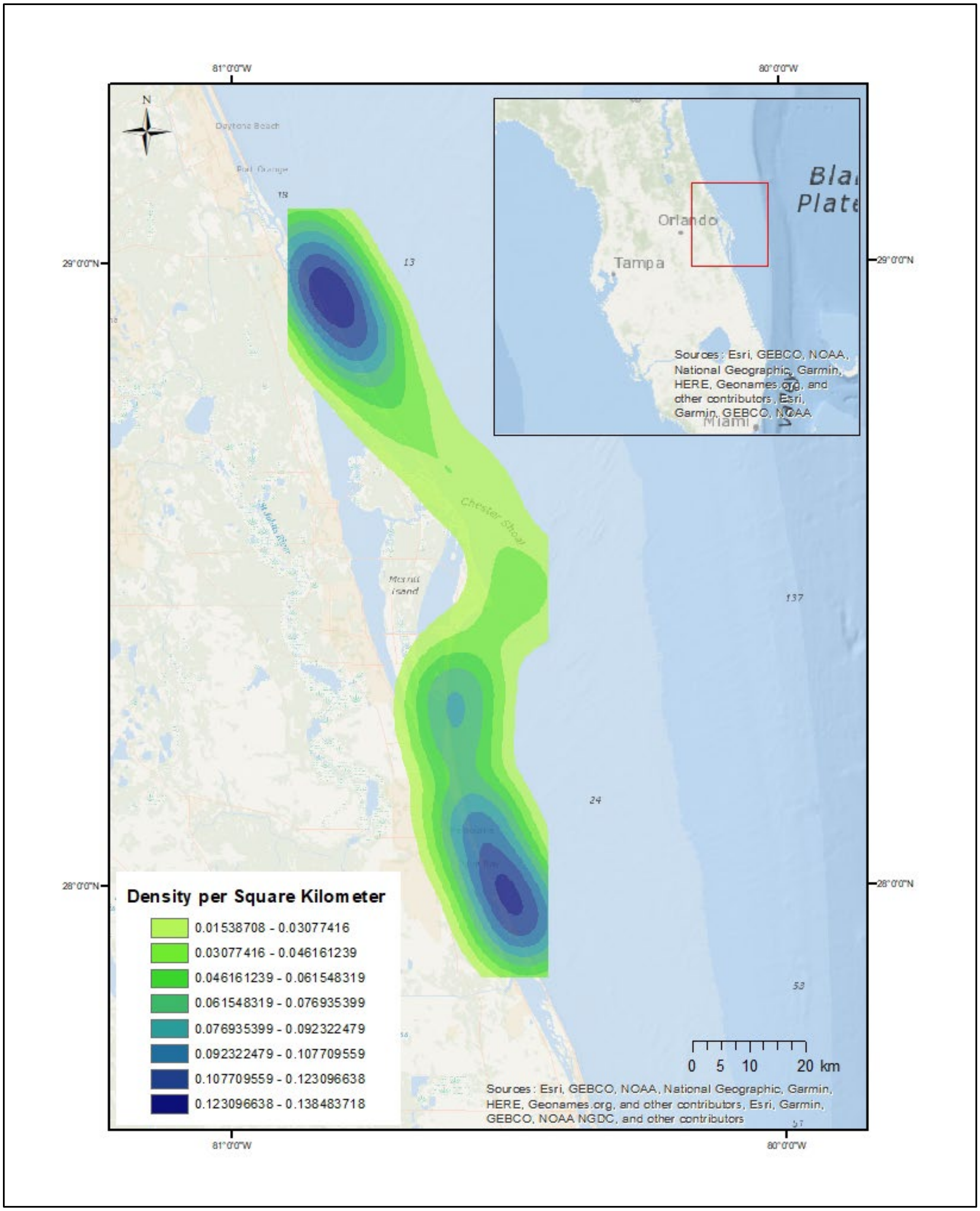


Figure 12. Aerial survey heat map.

3.3 Acoustic Tag Data

The team successfully tagged five animals with high powered V16 external acoustic transmitters with a randomized rep rate of 80 to 160 seconds. Four free-swimming animals were tagged via pole spear from a vessel, and one was tagged by hand after capture. Due to the transmitters being externally attached, we anticipate the retention time to be approximately 3–4 months. The receivers were downloaded in June 2022 and indicated four of the five tagged animals were detected throughout April, May, and June. Two of the mantas were first detected the same day they were tagged; the others were first detected 13 and 54 days later. Detections per receiver can be found in **Figure 13** and **Figure 14**. Tagging locations relative to receivers can be found in **Figure 15**. Acoustic data for individual mantas can be found in **Table 3**. The receivers will be downloaded again during spring or summer of 2023 after official completion of the project; these data will be submitted to BOEM as a separate supplement.

Table 3. Transmitter data for acoustically tagged mantas

ID	Tag Date	First Detection Date	Last Detection Date	Total Number of Days Detected	Total Stations Where Detected (X of 12)	Total Amount of Detections
59705	2022-03-25	2022-03-25	2022-06-14	4	6	33
59706	2022-03-26	2022-05-17	2022-05-17	1	3	7
59710	2022-03-26	2022-03-26	2022-03-28	2	5	24
59713	2022-03-29	2022-04-11	2022-04-13	3	3	125

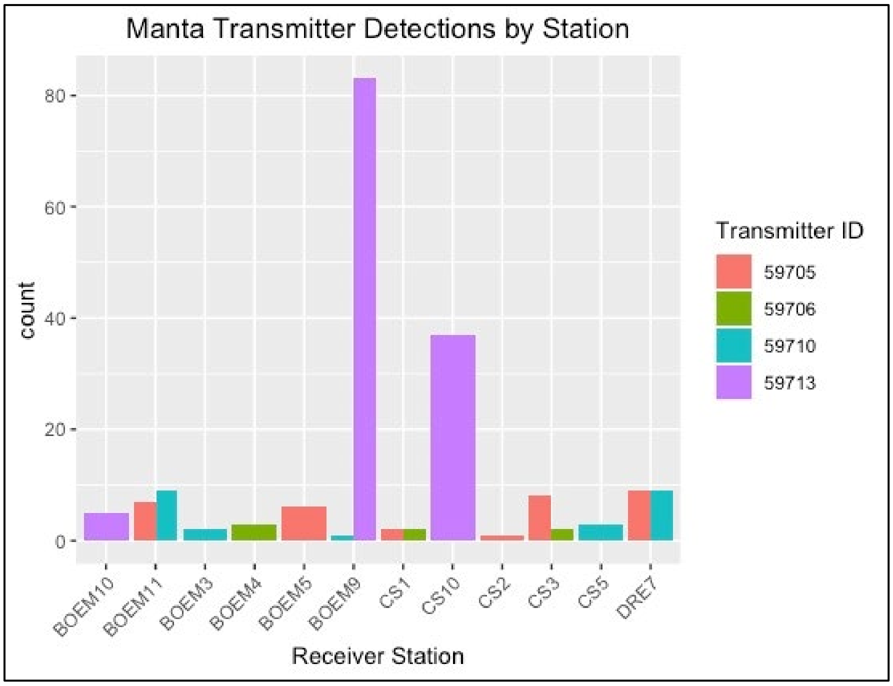
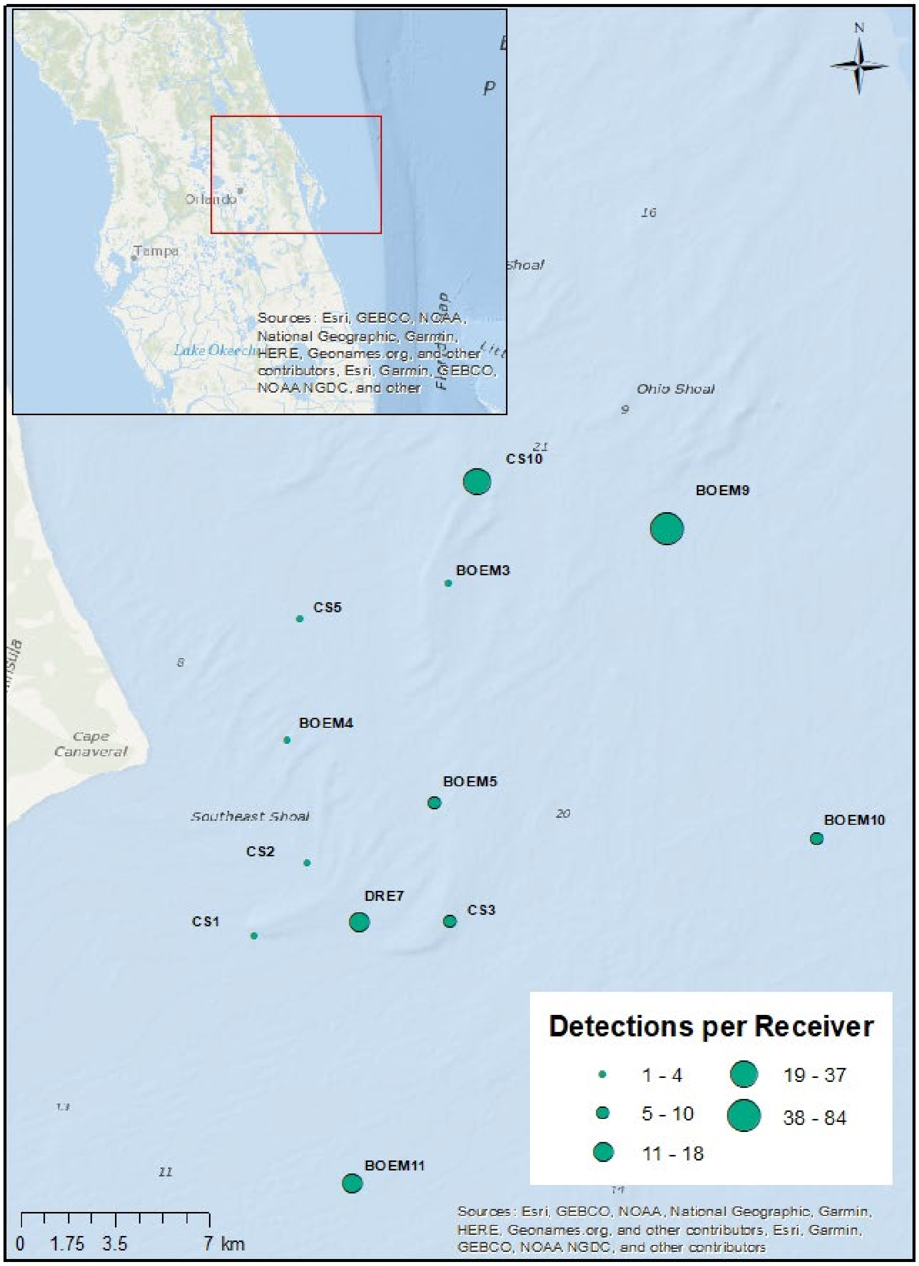


Figure 9. Transmitter detections by station.



Sources: Esri, GEBCO, NOAA, National Geographic, Garmin, HERE, Geonames.org, and other contributors, Esri, Garmin, GEBCO, NOAA NGDC, and other

Sources: Esri, GEBCO, NOAA, National Geographic, Garmin, HERE, Geonames.org, and other contributors, Esri, Garmin, GEBCO, NOAA NGDC, and other contributors

Figure 10. Amount of detections per receiver.

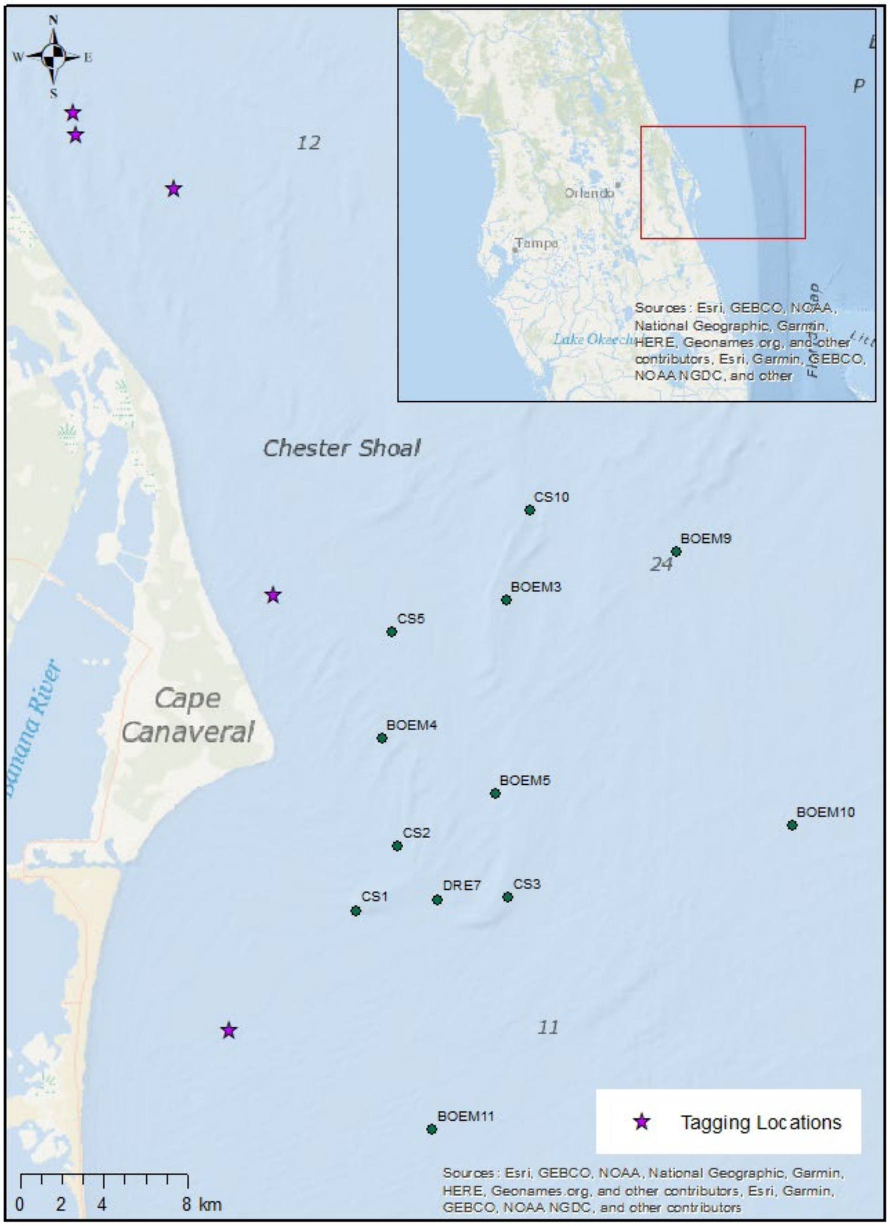


Figure 11. Tagging locations in relation to receivers.

4 Inertial Measurement Unit (IMU) Overview

4.1 Shifting to an IMU Focus

For reasons described in Section 2, the team modified the objective to improve the design of the IMU tag payload and attachment method. From fieldwork experiences highlight in Section 4.3, the team provided feedback to Arribada Initiative. This feedback and input were used to iterate the design, which would then be tested on aquarium animals housed at GAI to iterate towards successful application and retention on the animal. Testing at GAI provided a controlled environment that allowed the team to improve upon the tag and attachment design with each successive deployment to determine the optimal placement and configuration for success in the field. The final design is open-source and is available through Arribada Initiative to any person or organization who would benefit from this design.

4.2 Initial Design

We began working with Arribada Initiative in October 2021 to design an IMU tag that would attach to the dorsal surface of a manta ray. Initial designs included an Argos satellite tracker, Little Leonardo ORI-1300 IMU, and a VHF tag, enclosed in a custom-designed hydrodynamic rectangular case that was 3D printed. This initial design, **Figures 16 and 17**, would then attach to a metal plate incorporated into a vacuum cup that could then be attached to the animal via active suction driven by compressed air. The metal plate within the vacuum cup added substantial weight to the payload package, which made floatation and orientation difficult. The initial design was significantly modified for an updated design that addressed floatation, orientation, and improved hydrodynamic flow.

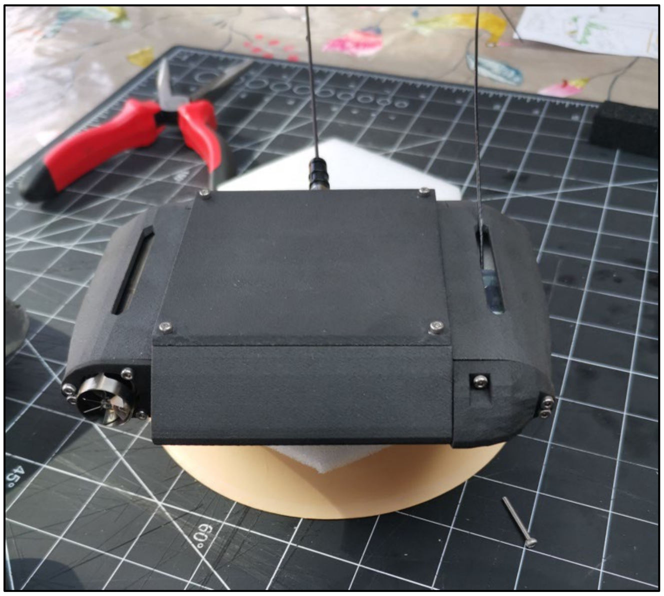


Figure 12. Initial tag design, front view.

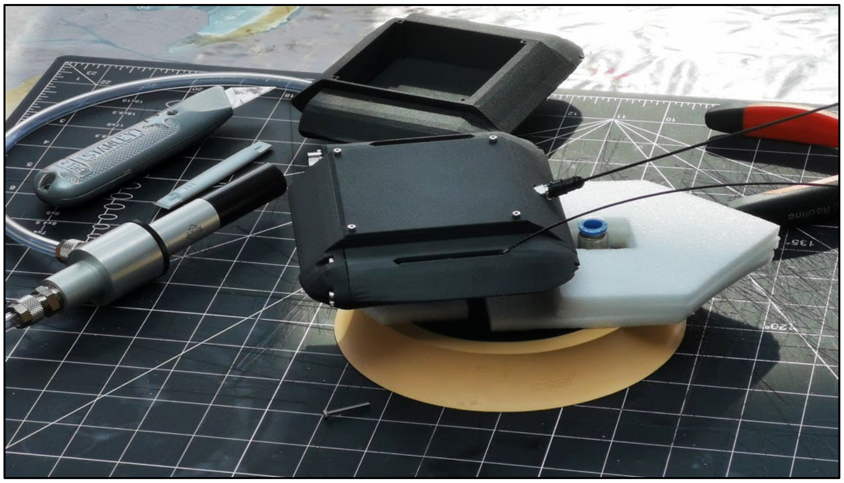


Figure 13. Initial tag design, side view.

4.3 Feedback for Arribada Initiative

The research team provided Arribada Initiative with feedback gained from fieldwork. The primary concern was the lack of proper flotation and orientation to ensure the VHF tag and Argos satellite system can properly communicate to allow for recovery and the feedback that the additional foam needed to be incorporated into the overall design rather than an external addition, as that made the tag weak and prone to breakage. As the initial tag required hands on the animal for attachment, and due to increased difficulty with successful capture, the team requested that Arribada Initiative design a quick release pole which could successfully attach the tag without requiring capture. Additionally, the team informed Arribada Initiative that the design needed to be more hydrodynamic to increase retention time.

4.4 Re-Design

4.4.1 Adjustments for Flotation

Arribada Initiative subsequently redesigned the initial tag to be more hydrodynamic and stable. The new design, known as “the tadpole”, includes a foam “tail” for better flotation and orientation in the water column. This tail also helps to provide stabilization during attachment. The “tail orients perpendicular to the water and allows the VHF tag to be detected by the antennae for retrieval.

4.4.2 Elimination of Weak Connective Points

The newer design incorporates syntactic foam encased in 3D printed housing. By updating the design, multiple weak points between the tag and the vacuum suction cup were eliminated resulting in a stronger and more stable design that could withstand harsher elements of fieldwork. The newer design sits directly on the vacuum cup, in contrast to the initial design, which had a gap between the payload and the cup, allowing drag and pressure to weaken the connective point and potentially break the tag from the cup. The elimination of this gap, in addition to the overall design change, significantly improved the hydrodynamic properties of the tag package.

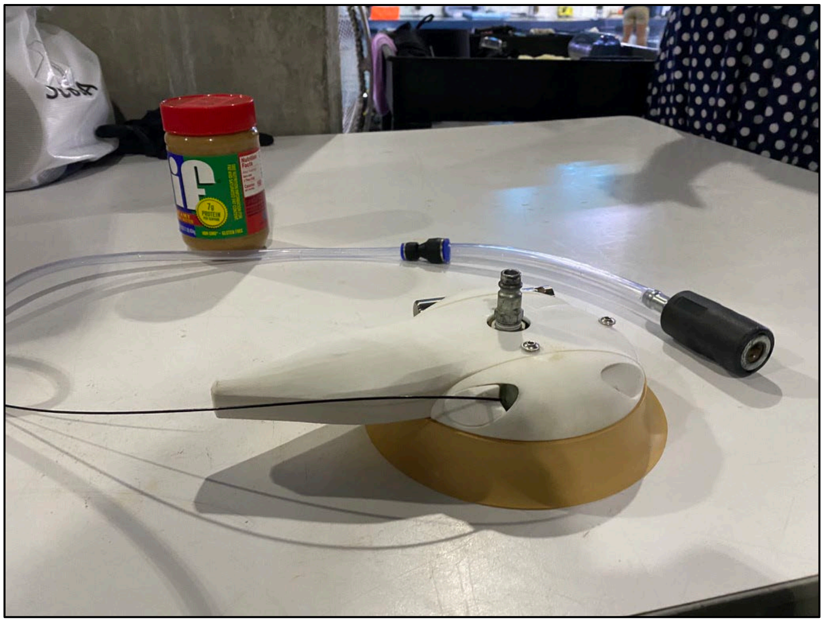
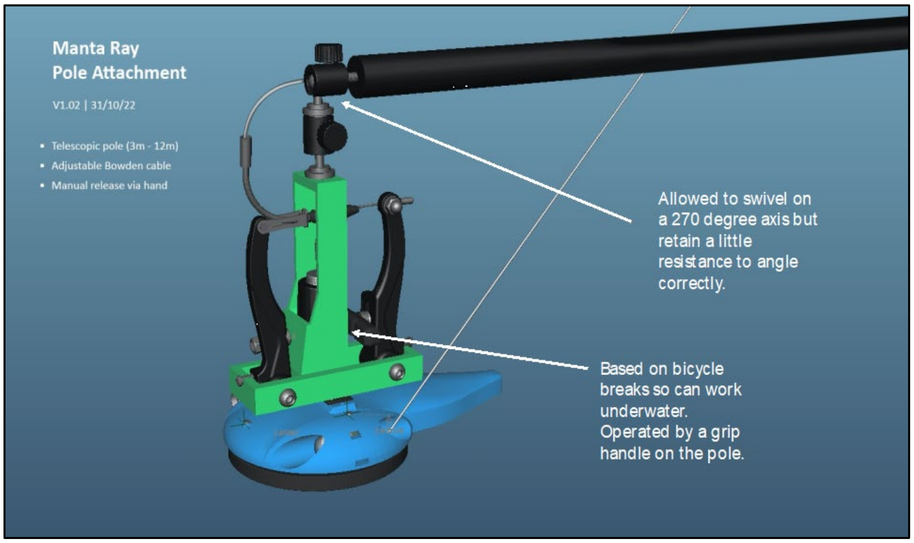


Figure 14. Updated tag design.

4.4.3 Pole Application

A telescopic carbon fiber pole was designed to allow for a “hands off” attachment method (**Figure 19**). This pole is adjustable from 3m-12m length and equipped with a handle that can be secured on the pole in a comfortable position for the user. The end of the pole was equipped to hold the fully constructed tag and employed modified bicycle breaks attached to the handle to allow the user to trigger a release of the tag once in contact with an animal. This design incorporates ball bearings which allows the tag to swivel approximately 270 degrees to allow flexibility for attachment. Once the user triggers the handle, the modified bicycle break will release the hose tail coupler which will release the payload from the air hose that is supplying compressed air to achieve a vacuum seal. For the work described in this cooperative agreement, the first iteration of the pole was also the final design submitted, however, future iterations are likely.



Manta Ray
Pole Attachment

V1.02 | 31/10/22

- Telescopic pole (3m - 12m)
- Adjustable Bowden cable
- Manual release via hand

Allowed to swivel on a 270 degree axis but retain a little resistance to angle correctly.

Based on bicycle breaks so can work underwater. Operated by a grip handle on the pole.

Figure 15. Pole attachment design.

4.5 In-house Testing

4.5.1 First Round of In-house Testing

Tag testing was conducted in early March 2022 at GAI before fieldwork. Project partners from GAI, BOEM, and Arribada Initiative were present for testing using the first tag prototype (**Figures 16 and 17**). The goal of this initial testing was to determine if passive suction was feasible and what, if any, lubricant would help with increase tag retention on manta rays. Passive suction is when the payload is applied by manual pressure only. The team decided to test three types of lubricants (**Table 4**): petroleum jelly, Manuka honey, and creamy peanut butter on *Mobula hypostoma*, a smaller but morphologically similar species to *M. birostris*. Lubricants were first applied to the dorsal side of an animal to determine if any adverse skin reaction would be detected and to test viscosity of each substance in combination with the animal's skin (n=8). Vaseline did not adhere; Manuka honey would adhere for approximately five seconds; creamy peanut butter adhered for approximately ten seconds. No adverse skin reactions were observed. We excluded Vaseline from future trials due to its inability to adhere to the animal's skin. To mimic the textured dorsal surface of *Mobula birostris*, we tested passive and active suction on a rough cutting board. Passive suction with peanut butter adhered to the cutting board for approximately 50 seconds and remained attached while an aquarist moved the cutting board throughout the water column to create a small degree of drag. Active suction with peanut butter adhered to the cutting board for over 60 seconds and remained attached when the team placed it in front of a high flow hose (max 435 psi) to mimic an animal swimming at higher speeds. We attempted to passively attach the vacuum suction cup with peanut butter to a male manta ray in GAI's collection. The vacuum cup did not attach and immediately slid off the dorsal surface.

Table 4. Sealant testing on *Mobula hypostoma*

Type of Suction	Lubricant Used	Duration
None, dorsal skin application	Vaseline	0, would not adhere
None, dorsal skin application	Manuka honey	5 seconds
None, dorsal skin application	Creamy peanut butter	10 seconds
Passive, animal application (*M. hypostoma*)	Manuka honey	10 seconds
Passive, animal application (*M. hypostoma*)	Creamy peanut butter	15 seconds
Passive, cutting board	Creamy peanut butter	50 seconds
Active (venturi), cutting board	Creamy peanut butter	60+ seconds
Passive, animal application (*M. birostris*)	Creamy peanut butter	0, would not adhere

4.5.2 Second Round of In-house Testing

A second round of testing was conducted at GAI in August 2022 with project partners from GAI, BOEM, and Arribada Initiative. This testing used a revised tag prototype based on feedback provided to Arribada Initiative. The revised prototype was lighter in weight and more hydrodynamic compared to the initial design. Testing was conducted on August 8 and August 9, 2022, to assess tag flotation and orientation, resulting in the addition of more weight (73 g) to the front of the tag. The tag was suctioned to the bottom of a holding pool where it stayed attached for approximately three hours before removal.

Table 5. Tag orientation tests prior to animal application

Date	Payload Components	Time In	Time Out	Notes
2022-08-08	IMU only	9:55am	9:56am	Floats flat, slight lean to IMU side
2022-08-08	VHF and IMU	10:10am	10:11am	Floats flat, balanced; 32g weight added to back resulted in ~5-degree tilt
2022-08-08	VHF and IMU	10:54am	10:55am	73g add; tail oriented out of water more than previously
2022-08-08	VHF and IMU	11:07am	10:09am	73g with additional foam for increased buoyancy and orientation
2022-08-09	VHF, IMU, Argos	8:29am	11:28am	Active suction bottom of holding pool to test vacuum seal

After holding pool tests, the team attempted to attach the payload to male manta ray E10023, a *Mobula birostris* at GAI. These attempts were conducted by GAI's Ocean Voyager husbandry team who have developed behavioral training techniques that allow for opportunities for attachment. The first successful attachment was August 10, 2022. The attachment was placed to the left side of the dorsal ridge and had a retention time of approximately 12 minutes. This deployment did not include any lubricant sealant. The attachment resulted in a distinct mark on the animal from the center ring of the vacuum cup. To better distribute pressure on the animal's dorsal surface, the team decided to remove the inner and outer rings from the vacuum cup prior to the next attempt. The next attempt, with both rings removed, was placed in the same location, and had a retention time of approximately 30 minutes. This attachment resulted in a less noticeable, more evenly distributed marking on the dorsal surface. The second round of in-house testing resulted in two successful attachments and a detailed outline of steps moving forward. The team decided GAI's Research & Conservation (R&C) team, in partnership with the OV husbandry team, would continue in-house testing to refine the attachment method and design as much as possible for successful field deployment in the future.

Figure 16. First *M. birostris* application.

4.5.3 Long Term In-house Testing

GAI's R&C team worked with the husbandry team to establish a schedule for tagging attempts. Every two weeks was the original schedule agreed upon. After the second round of in-house testing, the next attempts were conducted on September 8, 2022 and September 27, 2022. Mechanical issues with the tag became apparent after the September 8 attempt, when the payload had significantly reduced suction and could not achieve a seal on the animal. GAI ordered two new AE-VDF-250 venturi pumps from Air Engineering Controls Ltd. (East Sussex: UK) to resolve the issue. The new pumps arrived and were added to the payload before the next attempt. The September 27 attempt was unsuccessful and led to the team conducting additional tests to better document suction and retention.

During these tests, it was determined that the epoxy used to hold the hose tail coupler adapter in place had weakened substantially and was leaking air, ultimately resulting in pressure loss and the inability for the payload to remain on the animal. Arribada Initiative determined it would be best to remove the epoxy and replace that connection with a stainless-steel bolt to strengthen the overall design. Additionally, the hose tail coupler interior had begun to show signs of rust and needed to be replaced with a stainless-steel alternative. The original hose tail coupler was replaced with a stainless steel S1 ESI 071808HE 8mm hose tail coupler from the company Prevost Corp. (Greenville: USA); Prevost Corp also created the nickel-plated hose tail coupler originally used. Arribada Initiative altered the tag to incorporate these new additions. The updated tags with stainless-steel bolts arrive to GAI on November 1. Bin testing was conducted on November 2, 2022 and November 3, 2022 to confirm suction and retention prior to deployment. A 24-hour bin attachment was achieved.

Figure 17. Vacuum cup varieties: (L to R) intact, inner ring removed, inner and outer ring removed.

An attachment on the left wing was conducted on November 8, 2022 with the new venturi pumps and modified tags. The attachment was successful, but the team observed the tag detach when the animal maneuvered his wing to a steep angle to avoid other animals in the exhibit. The attachment prior to the wing movement was seven minutes. The team re-attached for a second deployment and had a successful ten-minute attachment. On November 10, 2022, the team conducted another deployment, but this attachment was moved from the left wing to the center of the head, anterior to the dorsal ridge, hereby referred to as "forehead". This deployment lasted 37 minutes. A second attachment on the forehead was attempted on November 22, 2022 and this deployment lasted for 28 minutes. After this deployment it was noted that the tag had small amounts of blood on the vacuum cup. An attachment to the central anterior part of the head was conducted on December 1, 2022 with a modified vacuum cup where both inner rings were removed. This attachment lasted for 38 minutes. Due to staff scheduling and animal health exams, further attachments were postponed until after the holidays.

An attachment to the central anterior part of the head with a modified vacuum cup with both inner rings removed was successful on January 11, 2023. The attachment lasted 54 minutes. After this attachment, our two longest retentions were each on the forehead with vacuum cups without inner rings and were applied without peanut butter. As a result of longer attachments, our next attachments on January 18 and 19, 2023, were also to the forehead, however, our January 18 attempt was with a fully intact vacuum cup without peanut butter. E10023 visibly responded to the fully intact cup being applied and according to the husbandry team, behaved differently than previous tactile interactions. The intact cup fell off quickly (<1 minute) and left a noticeable ring from the inner most circle. The team decided to swap vacuum cups for the modified cup without the inner rings and to attempt another attachment. This attachment went normally but only lasted approximately two minutes. The reduced mucus layer from the first attachment may have contributed to the shortened retention time for the second attachment. The attempt on January 19 was to the forehead with the modified cup missing both rings and no peanut butter. This attachment went as usual from a behavioral standpoint and was successful but also quickly detached after approximately two minutes. Two more attempts were conducted on February 7, 2023 and February 8, 2023, each with modified cups placed on the forehead without peanut butter and resulted in short attachments (<2-minutes).

The decrease in attachment time may have been a result from a reduced mucus layer. Stewart et al., (2019) documented similar findings of reduced mucus on the dorsal surface adversely impacting tag attachment and retention times. The team decided to take a 36-day break from tagging to allow the regeneration of the mucus layer. This timeframe was decided on due to schedule availability and due to the 54 minute attachment success after a 42-day break. An attachment was conducted on March 15, 2023 with a clean (no peanut butter) modified cup missing both inner rings and was placed on the forehead. This attachment lasted for approximately four hours and documented behaviors not previously recorded, including feeding and barrel rolls.

4.5.4 Findings and Results

Table 6. Data of successful payload attachments

Date	Peanut Butter (Y/N)	Total Time (min)	Location	Cup Details	Notes
2022-08-10	N	12	Left wing	Intact	-
2022-08-11	N	30	Left wing	Both rings removed	-
2022-11-08	Y	7	Left wing	Inner ring removed	Detached due to wing angle
2022-11-08	Y	10	Left wing	Inner ring removed	-
2022-11-10	Y	37	Head	Inner ring removed	-
2022-11-17	N	5	Head	Inner ring removed	Weak suction
2022-11-22	N	28	Head	Inner ring removed	Small amount of blood on suction cup
2022-12-01	N	38	Head	Both rings removed	
2023-01-11	N	54	Head	Both rings removed	Successful attachment after 42-day break*
2023-01-18	N	<1	Head	Intact	Attached as usual but quickly released; clear marking left from inner vacuum ring

Date	Peanut Butter (Y/N)	Total Time (min)	Location	Cup Details	Notes
2023-01-18	N	2	Head	Both rings removed	Quickly released, may have been due to reduced mucus layer from earlier attempt
2023-01-19	N	2	Head	Both rings removed	Good suction but may have released more quickly due to reduced mucus layer from previous day
2023-02-07	N	<1	Head	Both rings removed; new vacuum cup	Immediately went for a second attempt after first failed, animal was not receptive
2023-02-08	N	<1	Head	Both rings removed; old, modified cup	-
2023-03-15	N	240	Head	Both rings removed	Successful 4-hour attachment after 36-day break*

*Day of last deployment and referenced deployment are included in the sum of days.

The team conducted 18 in-house attachment attempts, 14 of which resulted in successful attachment (**Table 6**). The longest attachment was 240 minutes and the shortest was <1-minute. Of the 14 attachments, 6 (42%) had durations of +20 minutes, and 5 of those 6 (83%) +20-minute attachments were located on the forehead and without the addition of peanut butter. The overall average duration was 33.3 minutes. The average duration for a modified vacuum cup missing the inner ring was 17.4 minutes (-1.4 minutes below overall) and for a modified vacuum cup missing both rings was 52.4 minutes (+19.1 minutes above overall). The median of overall attachments was 11-minutes. Our two longest attachments occurred after a 42-day and 36-day hiatus, resulting in a 54-minute and a 4-hour attachment, respectively. These records, in conjunction with the findings of Stewart et al., (2019), support the hypothesis of mucus levels being an important variable for attachment success and increased retention time.

4.6 Application and Future Use

4.6.1 Final Design

The final design (**Figure 18**) is the third iteration which includes a stainless-steel metal bolt in lieu of the epoxy, easier attachment of the IMU and VHF components, a "tail" for stability and orientation, and the ability to change vacuum suction cup skirts more easily. This is the design that was used for the majority (n = 13 of 18) of our in-house testing attempts and had the highest number of long-term (>20-minute) deployments (n=5). Aquarium trials resulted in the longest retention times using a clean (no peanut butter) modified vacuum cup with both inner rings removed attached to the forehead.

4.6.2 Application for Researchers

Successful video camera deployment on cetaceans has been documented many times in the literature (Iwata et al., 2021; Pearson et al., 2017; Aoki et al., 2015) but a similar application for elasmobranchs is significantly less common. Stewart et al. (2019), demonstrated success with a similarly designed tag that was attached using a small J-shaped hook to hold the tag package onto the skin. With the completion of our open-source design, a greater number of researchers will be able to access the tools needed to conduct elasmobranch IMU research, with the possibility of our design being built upon for application to non-elasmobranch species. Similar designs being proprietary creates an obstacle for researchers that can hamper their ability to answer questions related to habitat use. Our hope is for this design to immediately benefit fellow batoid researchers, with the potential to be modified for other groups and species as needed.

5 Study Deliverables

The study deliverables are outlined in **Table 7**, where the extended due date column highlights extensions that resulted from the NCE. The original due date was based on grant allocation happening in June 2020; however, allocation did not occur until August 2020 which resulted in the team deciding to immediately shift all original due dates by two months to accommodate the new timeframe.

Table 7. Study deliverables

Item	Original Due Date	Revised Date	Date delivered
Post-Award "kickoff" meeting (virtual)	Within four weeks of award	-	9/9/2020
Post-Award "kickoff" meeting summary	Within one week of kickoff meeting	-	9/16/2020
Draft Project Management Plan	Aug 15th, 2020	-	11/1/2020
Final Project Management Plan	Within two weeks of receiving comments on draft from BOEM	-	11/23/2020
Pre-workshop white paper draft	No less than two weeks prior to planning workshop	-	1/8/2021
Planning workshop	Start date no later than Oct 15, 2020	-	1/11/2021
Post-workshop review of white paper	No later than Nov 15	-	2/22/2021
Final draft of white paper	Within two weeks of receiving comments from BOEM	-	3/1/2021
Quarterly Progress Reports	Quarterly on 1st of month	-	The 15th of every quarter
Quarterly Conference Calls	Quarterly or as needed	-	The last Monday of every month
GIF Communications Deliverables	One GIF prior to fieldwork commencing, remaining throughout the project at least 100 days prior to the project's conclusion	8/30/2022	8/30/2022
Draft Final Report	No less than 4 months prior to scheduled end of cooperative agreement	1/30/2023	1/30/2023
Final Report	No less than 30 days prior to scheduled end of agreement	3/31/2023	3/31/2023

5.1 White Paper

A comprehensive white paper outlining the goals and objectives of the study was published in March 2021. The white paper was a deliverable (Deliverable 8) for the project and was a collaborative effort among GAI and BOEM partners. The paper detailed our cooperative agreement study and goals and served as an examination of the oceanic manta rays life history, threats, and biology and ecology. The white paper laid out our study's efforts to assess the risk posed to oceanic manta rays (*Mobula birostris*) due to marine mineral extraction activities, including preventative trawling, by BOEM in the sand shoal habitats near Canaveral Shoals in the Southeastern U.S. We were able to use this white paper as a reference for partners that helped with our fieldwork efforts and data analysis.

5.2 Public Relations Coverage

5.2.1 Social Media

GAI's Communications and Public Relations team joined the research team during fieldwork to capture footage for a project summary video (subtask 4e). Interviews were conducted with both GAI and BOEM representatives to provide input into the goals and operations of the fieldwork being conducted and the overall study. The video was submitted to and approved by BOEM on May 11, 2022. BOEM and GAI published the video in tandem to their social media platforms on May 20, 2022[1]. Overall views and engagement from GAI's video across Facebook, Twitter, LinkedIn, and YouTube totaled 10,970 views and 891 engagements (e.g., likes, comments, shares, etc.).

5.2.2 GIF Production

GAI's Content Management team created 3 GIFs relevant to the study (Deliverable 11; Task 4). Each GIF focused on a different aspect of the project, including fieldwork, aquarium tag testing, and institutional collaborations across the study. GIFs were included as a deliverable to succinctly summarize complex aspects of the project. The GIF medium allowed for easily and quickly sharable content, which potentially increases audience reach and therefore may increase awareness of this study and the partnership of GAI and BOEM, among others. These GIFs were submitted to BOEM on August 31, 2022.

5.3 GAI Lesson Plan

GAI's Education team created a lesson plan highlighting this study and coastal marine management (Subtask 4a). The lesson plan is for the third-grade level and can be found on the GAI website[2] . Publishing the lesson plan on the GAI website, will have increased visibility and accessibility, because it is free for teachers to download and use for their courses. The plan includes a project summary, information about BOEM as an agency, a detailed explanation of acoustic transmitters and how they operate, as well as a variety of activities including using an image to determine how many manta rays would be detected by an acoustic receiver to a word search. The lesson plan was published on GAI's website on December 8, 2022.

5.4 Open-Source IMU Package

The open-source IMU vacuum cup design and pole applicator (NCE revised deliverable based on Task 3) are available for use by any academic, government, non-profit, or NGO that would benefit from the design or its derivates in their scientific endeavors. The design is built around the Little Leonardo ORI1300 IMU. If other IMUs are to be used, the payload design would need to be modified to accommodate different sized tags. Similarly, the VHF component is built around the Advanced Telemetry Systems F1835B transmitter. The vacuum cup and pole were submitted to BOEM on March 31, 2023.

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[1] The video can be viewed here: https://www.youtube.com/watch?v=3tmkvSg8YmA

[2] See https://www.georgiaaquarium.org/wp-content/uploads/2022/12/BOEM-Lesson-plan.pdf

6 Study Financials

This project cost $563,504.07 across the two-year study. Details on expenses by year and category can be found in **Table 8**. GAI contributed $253,321.13 in matching funds toward the project.

Table 8. Study financials by year

Year	Equipment and/or Supplies	GAI Match	Travel	Payroll	Total
2020	$2,148.00	$0	$0	$31,543.94	$33,691.94
2021	$43,309.19	$123,297.05	$0	$80,426.75	$247,032.99
2022	$94,322.65	$130,024.08	$12,694.22	$45,738.19	$282,779.13
Study Total	$139,779.84	$253,321.13	$12,694.22	$157,708.88	$563,504.07

7 Conclusion

This study significantly advanced the methods available to study the behavior and habitat use of manta rays. Through fieldwork and aerial surveys, we were able to enhance our understanding of migratory times and spatial range within the SEUS which can help inform BOEM's MMP's future mitigation policies. The decision to modify the objective to designing an open-source IMU tag and suction attachment method allowed the team to produce a tangible result that has been through several iterative rounds of improvement already. Additional iterations should converge on an optimal design for manta rays and platform that can be modified for addressing similar questions in a range of other species. BOEM still aims to determine oceanic manta ray habitat use in the vicinity of marine mineral extraction, and this new design can be deployed in future BOEM studies to shed light on these unknown behaviors and habitat uses.

The open-source IMU outcome from this study will provide a resource that may help advance our understanding of an elusive and important endangered species, as well as provide a foundation upon which future modifications can be made for application to additional species. Our hope is that the flexibility and adaptability of the team may result in a technological design that assists future studies and conservation efforts pertaining to a variety of species in addition to *M. birostris*.

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