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Multiple datasets confirm range extension of the sicklefin devil ray *Mobula tarapacana* in the western North Atlantic Ocean off the eastern USA

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Abstract

The sicklefin devil ray (*Mobula tarapacana*) is a large, pelagic ray which is listed as Endangered by the International Union for Conservation of Nature (IUCN). *Mobula tarapacana* is thought to have a circumglobal, yet patchy distribution, and has not been verified extant off the eastern USA. Here, we report 180 sightings of *M. tarapacana* with a total of 361 individuals, collated across five datasets from aerial survey operations and incidental sightings in the waters off the US East Coast and Gulf of Mexico, between 1996 and 2022. This study extends the northern range of *M. tarapacana* in the Gulf of Mexico to 29°N, and in the Atlantic to 40°N. Seasonal trends were observed off the north-eastern coast of the USA, with *M. tarapacana* only present in the summer months. Measurements from high resolution digital aerial imagery found *M. tarapacana* off the New York coast to be adults and subadults with an average disc width of 268 cm (± 25 , range 232–316 cm). This study provides important spatial and temporal data for management, as well as informing areas for future research on *M. tarapacana* in the western Atlantic.

Introduction

Mobulid rays were largely under-studied during the 20th century, and despite progress in the last decade, large knowledge gaps in their life history and ecology still exist (Stewart *et al.*, 2018). The family Mobulidae previously consisted of 11 species in two genera, but taxonomic and genetic evidence now suggest the family be consolidated into a single genus of nine species (Notarbartolo di Sciarra *et al.*, 2019; Hosegood *et al.*, 2020). All species are planktivorous with some of the most conservative life history strategies and slowest population growth rates of all elasmobranchs (Dulvy *et al.*, 2014; Rambahiniarison *et al.*, 2018). Mobulids are primarily threatened by interactions with fisheries, both as bycatch and direct capture (Croll *et al.*, 2016). Trade in and demand for mobulid gill plates in Asian markets has driven targeted fisheries around the world, especially in Africa and Asia (Ward-Paige *et al.*, 2013; Croll *et al.*, 2016). The conservation status of mobulid rays was recently assessed by the IUCN and all species were categorized as Endangered or Vulnerable to extinction (e.g. Marshall *et al.*, 2019).

Mobula tarapacana (Philippi, 1892) is one of the largest mobulid species, reaching a disc width of up to 370 cm (Marshall *et al.*, 2019). It is known to make regular deep dives of 800 m with maximum depths reaching nearly 2000 m (Thorrold *et al.*, 2014). Most data on *M. tarapacana* comes from research at oceanic island aggregation sites, specifically the Azores, St Helena and the Saint Peter and Saint Paul Archipelago (Sobral & Afonso, 2014; Mendonça *et al.*, 2018; Beard *et al.*, 2021), or from fishing markets in Asia (Lewis *et al.*, 2015; Rambahiniarison *et al.*, 2018).

Mobula tarapacana is thought to have a circumglobal, yet patchy distribution in tropical, subtropical and temperate waters. Establishing clear geographic ranges is essential for accurate assessments and targeted management actions (Lawson *et al.*, 2017). While *M. tarapacana* is reported extant in the Gulf of Mexico (Childs, 1997; Jones *et al.*, 2020) and the Atlantic coast of South America (Notarbartolo-di-Sciarra & Hillyer, 1989), no extant population has been reported off the Atlantic coast of the USA. Recent efforts to evaluate the distribution of the closely related giant manta ray (*Mobula birostris*, Walbaum 1792) revealed numerous sightings of *M. tarapacana* by aerial surveys (Farmer *et al.*, 2022). Here, we provide sightings data from multiple sources that confirm *M. tarapacana* within the western North Atlantic Ocean off the US coast.

Methods

We assembled confirmed *M. tarapacana* sightings from: (1) New York State Energy Research and Development Authority (NYSERDA) and Bureau of Ocean Energy Management (BOEM)



aerial digital surveys conducted by Normandeau Associates/APEM; (2) National Oceanic and Atmospheric Administration (NOAA) aerial surveys conducted by Southeast Fisheries Science Center (SEFSC); (3) VACAPES NFC U.S. Navy Monitoring Program aerial surveys conducted by HDR Environmental, Operations and Construction, Inc. (HDR EOC); (4) NOAA Pelagic Longline (PLL) Observer programme data; and (5) incidental sightings by divers and opportunistic samplers. We define ‘sighting’ as the identification of one or more individuals of *M. tarapacana* observed together.

Normandeau associates/APEM NYSERDA and BOEM aerial digital surveys

NYSERDA and BOEM contracted with Normandeau Associates Inc. in collaboration with APEM Ltd to conduct aerial digital surveys to assess the abundance and spatial distribution of birds, marine mammals, sea turtles, cartilaginous fish, and other taxa in areas considered for offshore energy development (Halpin *et al.*, 2009; APEM & Normandeau Associates, 2018, 2019a, 2019b, 2020, 2021; Jervis & Phillips, 2021). NYSERDA conducted offshore aerial digital surveys sampling within the New York Offshore Planning Area, which spans >43,745 km². NYSERDA surveys were conducted four times a year over three years, between August 2016 and May 2019. Eight BOEM aerial digital surveys sampled the offshore waters of North Carolina and South Carolina in 2018 and 2020.

Each resulting dataset consists of high-resolution (1.5 cm at the sea surface) aerial digital imagery. For both survey efforts, images were collected with downward-facing cameras from a flight altitude of 414.5 m. Animal targets were extracted from imagery in the NYSERDA and BOEM data using a combination of detection software and manual review. Two authors (CH, JP) re-evaluated taxonomic identifications of all large rays in Normandeau’s ReMOTe datportal to confirm *M. tarapacana* identification. Characteristics used to identify *M. tarapacana* from other ray species were presence of cephalic fins, relatively large size, uniform olive-green to golden-brown dorsal colouration and the sicklefin shape of trailing edge of pectoral fins (Stevens *et al.*, 2018). Only clear photos where the ray was near the surface and diagnostic features clearly visible were included in the dataset.

To measure disc width (DW) and disc length (DL) of detected *M. tarapacana*, we used the Normandeau ReMOTe data portal’s measuring tool. This measurement tool takes the mean known resolution at the sea surface of the specific camera by which the animal was detected and sums the number of pixels across the user-defined measurement. Measurements are unable to compensate for the unknown depth of the animal and the potential distortion in the image from water refraction, therefore an element of minor error is associated with all subsurface measurements. Measurements (DW and DL) were only taken on photos where the tips of both pectoral fins were clearly visible. However, DW is usually measured at full extension of pectoral fins and we were unable to account for any fin flexion in DW measurements. Any flexion of fins will cause DW to be underestimated, so these DWs can be considered a minimum estimate. DW is plotted against DL and fitted with a linear regression curve. A disc ratio was obtained by dividing DW by DL. All measurements are reported as mean with standard deviation.

NOAA aerial surveys

SEFSC conducts visual aerial surveys in the Atlantic and Gulf of Mexico to assess the spatial distribution and abundance of marine mammals and sea turtles (see Figure 2A, B in Farmer *et al.*, 2022). These aerial survey programmes covered the continental shelf and

the inner continental slope in western Atlantic Ocean waters off the US East Coast, including the Gulf of Mexico, from New Jersey (40°N 74°W) to southern Texas (24.3°N 94.8°W).

While rays were not the target taxa of these surveys, pilots on 1996–1998 Gulf of Mexico surveys noted locations of ‘golden mantas’. Only one photo was available for verification of golden mantas being *M. tarapacana*. Given that these rays were specifically designated as ‘golden’ (uniform brownish colour being an identifying characteristic of the species) and that the photo also confirmed species identification, we are confident that these records are *M. tarapacana*. Similarly, between 2019–2021, observations of *M. tarapacana* were recorded by trained observers with the SEFSC’s Atlantic aerial survey programme (Palka *et al.*, 2021) following training and distribution of a large ray aerial survey guide in 2019 (NOAA Fisheries, 2019).

HDR Environmental, Operations and Construction, Inc.

HDR Environmental, Operations and Construction, Inc. (HDR EOC) led VACAPES NFC (Norfolk Canyon) visual aerial surveys as part of the US Navy Monitoring Program in 2018–2019. HDR EOC conducted marine species monitoring surveys beginning in April 2018 through August 2019 in the NFC study area off the coast of Virginia Beach, VA. Twenty-three days of aerial surveys were completed between 9 April 2018–12 August 2019. Survey results were submitted to the OBIS-SEAMAP database (Halpin *et al.*, 2009; Cotter, 2019, 2020). Species identification was confirmed by trained observers (T. Pusser and M. Cotter, pers. comm. to N. Farmer, 5/2022).

PLL Observer data

PLL Observer data were collected by trained fisheries observers aboard pelagic longline vessels in the Atlantic and Gulf of Mexico. Prior to July 2019, fisheries observers did not classify rays according to species; therefore, all pre-2020 *M. tarapacana* observations were verified by associated videos and photos of capture. Beginning in 2020, fisheries observers began identifying and collecting bycatch data on large mobulid rays. Not all of these records included photos, but of the four that did, all were verified as *M. tarapacana* by an author (CJ). Due to issues with confidentiality, location is reported as within particular fishing zones as opposed to exact GPS coordinates (see map of longline fishing areas in Supplemental Figure).

Incidental observations

Incidental observations were sightings reports initially sent to NOAA or the Marine Megafauna Foundation (MMF) as manta rays (*Mobula birostris*), but later identified as *M. tarapacana* based on photographs. All photographs were confirmed as *M. tarapacana* by at least one author. One opportunistic sighting of *M. tarapacana* by a scuba diver was reported to MMF in 2018. A second sighting was initially reported as a ‘manta ray’ by the Gulf Coast Research Laboratory of the University of Southern Mississippi from a plankton survey in the Gulf of Mexico in 2019, but photos later confirmed the species as *M. tarapacana*. Additionally, in 2006 a commercial saturation diver’s downline was entangled by an *M. tarapacana* off Louisiana in the northern Gulf of Mexico (<https://www.longstreath.com/community/incidents/?page=3>). A video of the encounter (<https://www.youtube.com/watch?v=959CWu0w8dc>) was used to confirm the species identification. Finally, a boater observed at least 8 *M. tarapacana* in the Florida Keys in May 2022.

Results

In total, 361 individual *M. tarapacana* were identified from 180 sightings in the five datasets in the waters off the US East Coast and Gulf of Mexico between 1996 and 2022 (Table 1, Figure 1). The majority (88%, $N = 316$) of individuals were seen in June through August. Most sightings (75%, $N = 136$) were of lone individuals, but group sizes ranged up to at least 24 individuals, with small groups of 2–4 individuals being the most common group size (70%, $N = 31$ out of 44 groups observed).

Normandeau Associates/APEM definitively identified 101 *M. tarapacana* individuals in 61 sightings in their aerial digital surveys for NYSERDA and BOEM. In the NYSERDA data, 61 images contained a ray that was definitively identified as *M. tarapacana* (Figure 2A–C). Another 72 images were identified as potentially *M. tarapacana*, but submergence of ray or poor-quality photos prohibited accurate identification. In 10 of the definitively identified images, the ray selected by the software was nearby one or more ray(s). It was only possible to definitively identify 10% (5 of 50) nearby rays as *M. tarapacana*, but given that *M. tarapacana* is often seen in groups (Beard *et al.*, 2021) it is probable that other rays, of similar size and colouration, were the same species. When including these nearby rays, the NYSERDA data identified a total of 101 *M. tarapacana*. The 10 observed groups consisted of 2–21 individuals, with an average of 5 per group (± 5.8 rays).

Despite equivalent survey effort in the autumn and winter months (Figure 2F in Farmer *et al.*, 2022), *M. tarapacana* were only observed during July and August in NYSERDA surveys. Twenty-nine rays were observed in August 2016, 24 in August 2017 and 8 in July and August of 2018. Twenty-two (36%) of photos were appropriate to take measurements of DW and DL. Mean DW was 268 cm (± 25 ; range 232–316 cm), mean DL was 196 cm (± 16 , range 165–222 cm) and mean disc ratio was 1.4 (± 0.1 , range 1.2–1.6; Figure 3). The relationship between DW and DL was described by the following linear regression equation (Figure 3):

$$DW = 1.0593 \times DL + 60.551 \quad (r^2 = 0.4989)$$

In the BOEM aerial digital survey data, 2 *M. tarapacana* individuals in separate sightings were definitively identified, with another 6 rays identified as potentially *M. tarapacana*. Both definitively identified rays were observed in the afternoon of 25 May 2018. Only a photo of a single individual was good enough to allow measurement and this ray had a DW of 272 cm, DL of 205 cm and disc ratio of 1.3.

NOAA Fisheries SEFSC Gulf of Mexico marine mammal aerial surveys reported 12 sightings of *M. tarapacana* with a total of 27 individuals (Figure 2D). All observations were of a solitary individual, except for a group of 15 observed in July 1996 and a pair of *M. tarapacana* observed in March 1997. All sightings occurred in the months of March (42%, $N = 5$) or July (58%, $N = 7$). Another solitary individual was observed in December 2019 off the Atlantic coast of Florida by the SEFSC programme.

Trained observers with HDR EOC reported 70 sightings of *M. tarapacana* with a total of 188 individuals. Observations were noted April through October with most (60%, 42 of 70 sightings) noted in June (Table 1). Forty-four per cent (31 of 70) of sightings by HDR EOC were of more than one *M. tarapacana* with groups sizes ranging from 2–24 (average of 2.7 ± 3.7 rays).

The PLL Observer programme reported 31 *M. tarapacana*. Fourteen individuals were incidentally captured in the Mid-Atlantic Bight, 2 in the South Atlantic Bight, 3 in the North-east Coastal, 7 in the Florida East Coast and 5 in the Gulf of Mexico (Table 1).

A single *M. tarapacana* was observed on 10 July 2018 at 10:00 am by a scuba diver in Jupiter, Florida, USA (Figure 2E, F). The

ray was at a depth of 40 m and the surrounding water temperature was measured at 27.8°C. The ray circled the diver for less than 2 minutes and then departed to the south. A second incidental observation was made during a NOAA plankton survey in the Gulf of Mexico on 30 May 2019. Additionally, a single *M. tarapacana* became entangled at 61 m depth in a commercial diver's downline for ~30 s at West Delta 104 offshore Louisiana on 2 September 2006, just a week after a diver was killed by rapid ascent during a similar incident with a large ray (<https://www.longstreath.com/community/incidents/?page=3>). Finally, a group of at least 8 *M. tarapacana* were observed by a boater on 7 May 2022 in 134 m water depth off Marathon in the Florida Keys (Figure 1).

Discussion

While *Mobula tarapacana* is assumed to have a circumglobal distribution, there is a lack of data confirming this (Marshall *et al.*, 2019). This study expands the known range of *M. tarapacana* further north in the western Atlantic, spanning from Florida to offshore of New York. While *M. tarapacana* has previously been reported in the Gulf of Mexico (Childs, 1997; Jones *et al.*, 2020), we also include additional confirmation of this with the PLL Observer data, SEFSC aerial visual survey data and a recorded interaction with a commercial saturation diver. The previous northernmost confirmed record of *M. tarapacana* in the western Atlantic was from the north-western Gulf of Mexico, specifically the Flower Garden Banks off the coast of Texas (28°N, Childs, 1997), though the Azores population resides at 38°N. Our data slightly extend the northern range of *M. tarapacana* in the Gulf of Mexico to 29°N, and in the Atlantic to 40°N. In the Pacific, the northernmost record is Japan (45°N, Tomita *et al.*, 2013).

Despite year-round effort of NYSERDA aerial digital surveys, *M. tarapacana* were only observed in the summer months of July and August. Average water temperature in July and August for this time period were 22.8°C and 23.9°C, respectively (NOAA buoy 44025: 40.251°N 73.164°W). Additionally, pelagic longline captures only occurred in the North-east Coastal (NEC) fishing area during August and September. Further south in the Mid-Atlantic Bight (MAB) and off the coast off Virginia and North Carolina, *M. tarapacana* were only observed in the months of April through October. Similar seasonal trends are found in the Azores where *M. tarapacana* are only found in the boreal summer months with water temperatures ranging from 17.7–20.7°C (Morato *et al.*, 2003; Sobral & Afonso, 2014), and satellite tagged *M. tarapacana* all moved south from the Azores after the summer aggregation (Thorrold *et al.*, 2014). Though *M. tarapacana* can tolerate cold water (4°C) on deep dives (2000 m), they bask in warm, daylight waters before and after doing so (Thorrold *et al.*, 2014).

No seasonal trends were detected off the southern coast of the USA, with *M. tarapacana* being observed in both summer and winter months. *Mobula tarapacana* are sighted year-round in St Helena in the South Atlantic Ocean where temperatures range between 19°C (winter) and 25°C (summer, Brown *et al.*, 2019). *Mobula tarapacana* are also sighted year-round in the Saint Peter and Saint Paul Archipelago (SPSPA, an island group 3000 km north-west of St. Helena), but were more frequently sighted in the months of January–June. (Mendonça *et al.*, 2018). These months of higher frequency *M. tarapacana* sightings in the SPSPA were attributed not to water temperature, but to probable greater food availability (Mendonça *et al.*, 2018). The degree to which *M. tarapacana* movements in the western Atlantic are driven by temperature and/or productivity could be clarified with satellite telemetry and distribution modelling.

Table 1. Total *Mobula tarapacana* individuals from: (1) Bureau of Ocean Energy Management (BOEM) aerial digital surveys and New York State Energy Research and Development Authority (NYSERDA) and other aerial surveys conducted by Normandeau Associates/APEM, (2) VACAPES NFC U.S. Navy Monitoring Program aerial surveys conducted by HDR Environmental, Operations and Construction, Inc (HDR EOC), (3) Incidental sightings by divers and opportunistic samplers, (4) National Oceanic and Atmospheric Administration (NOAA) aerial surveys conducted by Southeast Fisheries Science Center (SEFSC), and (5) NOAA NEFS Pelagic Longline (PLL) Observer programme data [by fishing area: Mid-Atlantic Bight (MAB), South Atlantic Bight (SAB), Northeast Coastal (NEC), Florida East Coast (FEC) and Gulf of Mexico (GOM)]

Source	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total	Years
APEM/Normandeau Associates					2		3	98					103	2016–2018
BOEM					2								2	2018
NYSERDA							3	98					101	2016–2018
HDR EOC				2		139	24	20		3			188	2018–2019
Incidental					9		1		1				11	2006, 2018–2019, 2022
NOAA Fisheries Aerial Survey			6				21					1	28	1996–1998, 2019
<i>Gulf of Mexico</i>			6				21						27	1996–1998
<i>Atlantic</i>												1	1	2019
PLL Observer programme	1		1	1	4	3	1	6	7	3	4		31	2006–2010, 2012, 2014, 2016–2018, 2020
FEC						2	1				4		7	2009–2010, 2012, 2014
GOM			1	1	3								5	2007–2008, 2014, 2018
MAB						1		4	6	3			14	2006, 2012, 2016–2017, 2020
NEC								2	1				3	2012, 2020
SAB	1				1								2	2016, 2020
Total	1	0	7	3	15	142	50	124	8	6	4	1	361	

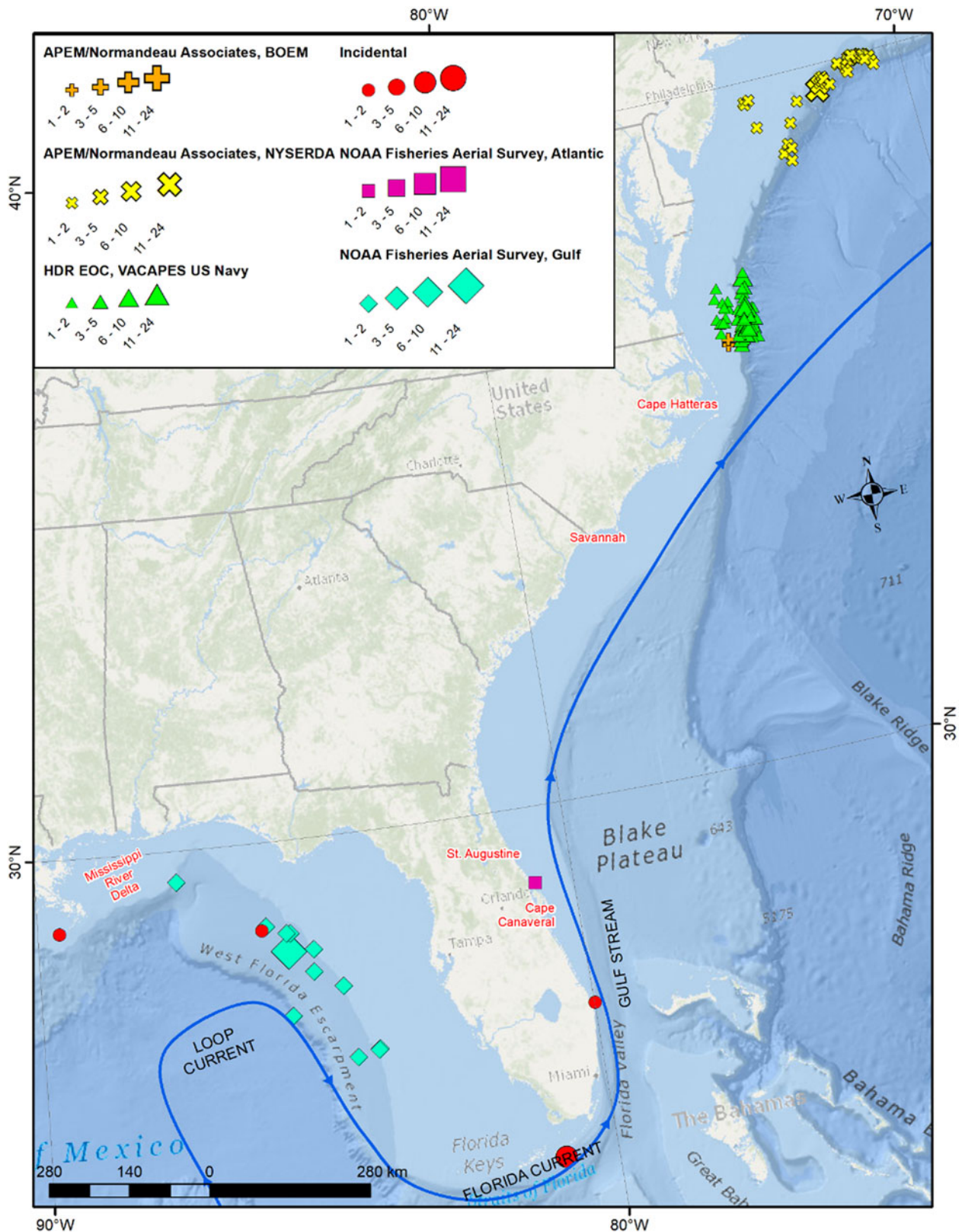


Figure 1. *Mobula tarapacana* locations from confirmed aerial survey and incidental sightings, scaled to the number of individuals sighted. Pelagic Longline Observer data excluded to protect confidentiality.

Accurately measuring mobulid rays *in situ* is difficult without capture, and many studies estimate in-water size by comparison of an object of known length (Mendonça *et al.*, 2018, 2020). Precise measurements can be more reliably collected on DL than DW due to the difficulty in getting a photo when pectoral fins are at exact full extension. The DW can then be estimated

from a DW–DL relationship, such as that provided in the Results section above (Figure 3). However, caution should be taken when applying this equation to *M. tarapacana* measurements due to the moderate (0.5) correlation coefficient.

Mobula tarapacana mature at a DW of 270–280 cm for females and 240–250 cm for males (Rambahinirison *et al.*,

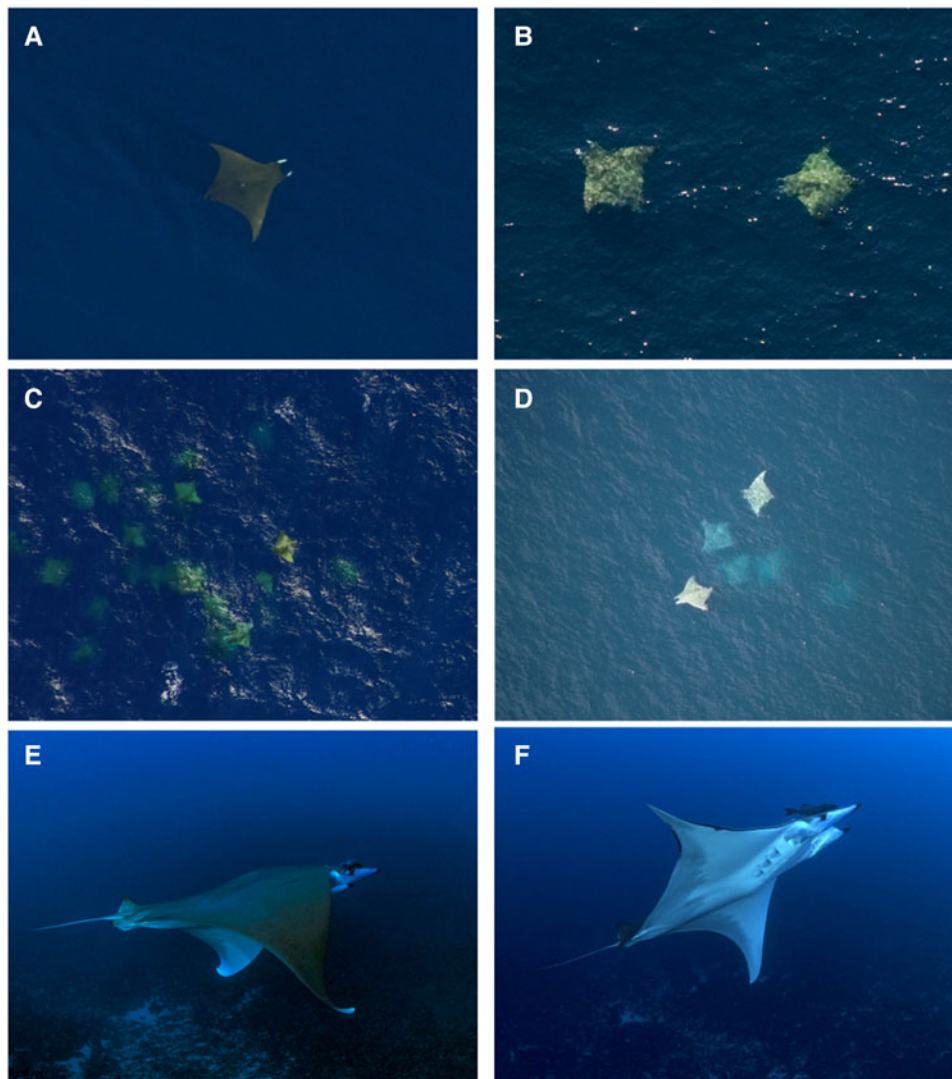


Figure 2. Photos of *M. tarapacana* from NYSEERDA aerial surveys (A, B and C), SEFSC marine mammal aerial survey (D), and Florida scuba diver Jeff Joel (E and F).

2018; Stevens *et al.*, 2018). While we were unable to determine sex from aerial digital survey data, 77% ($N = 17$) of the rays for which measurements were possible had DW greater than 240 cm. Minimum DW measured was 232 cm. These DWs indicate that the *M. tarapacana* offshore of New York are adults and sub-adults; however, it is important to note that we were only able to measure rays in 22 (36%) of the photos in the NYSEERDA

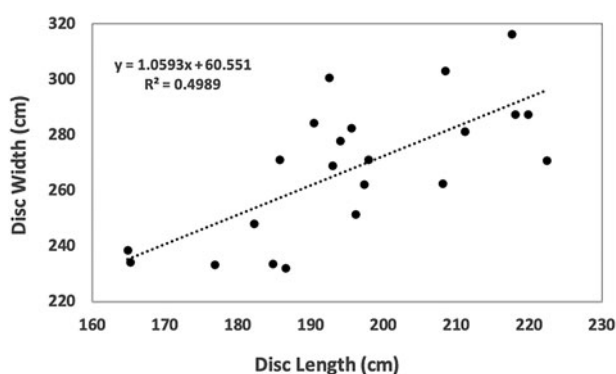


Figure 3. *Mobula tarapacana* ($N = 22$) disc width plotted against disc length. Measurements are from NYSEERDA aerial photo data, measured using the Normandeau data portal measuring tool.

dataset. In addition, while we only used photos that clearly showed body margins of the ray and that appeared to be at or near full extension of the pectoral fins, there is likely some measurement error due to the subsurface location of the rays and the bending of the pectoral fins.

While most studies of *M. tarapacana* occur in remote ocean island groups, this study elucidates a potential seasonal population of *M. tarapacana* for future study off the coast of the continental USA, specifically New York. Future studies of *M. tarapacana* in the western Atlantic should examine whether the offshore area off New York may represent an important foraging or reproductive habitat, as well as describe their horizontal and vertical migrations and habitat use. Genetic and telemetry studies should also investigate the connectivity between eastern and western Atlantic populations of *M. tarapacana*.

Understanding spatial distribution is key to management and conservation of endangered species. This study provides insight into where *M. tarapacana* may overlap with fisheries and are at greater bycatch risk. Prior to July 2019, fisheries observers in the USA did not classify mobulid ray bycatch according to species. With future bycatch data accurately representing mobulid species catch, we can quantify which fisheries affect *M. tarapacana*, and make management decisions accordingly. Also, recent advances in the distribution modelling of manta rays (Farmer *et al.*, 2022) can be applied to *M. tarapacana* to further elucidate

environmental drivers of species distribution. This may increase efficiency for research programmes and potentially reveal areas likely to contain previously undiscovered *M. tarapacana* aggregations.

This study highlights how incidental observations and observer data can provide important data on rare, vulnerable and difficult to study species. Recently, similar methods were used to describe the spatio-temporal distribution of *Mobula mobular* in the Eastern Atlantic (Lezama-Ochoa *et al.*, 2020), as well as *Mobula thurstoni* habitat use in a marine protected area in Brazil (Bucair *et al.*, 2022). We hope this encourages other researchers and managers to examine regional databases for information on other data-poor species.

Supplementary material. The supplementary material for this article can be found at https://www.iccat.int/Documents/CVSP/CV055_2003/n_4/CV055041576.pdf

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Author contributions. JP formulated the research question, JP, JRW, CJ, CH and NF all collected data and designed the study, JP and CH analysed the data and JP wrote the manuscript. All authors read and approved of the manuscript.

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Competing interests. All authors declare that they have no competing interests.

Data availability. Data collected by Normandeau-APEM are freely available. Imagery may be reviewed on the Normandeau ReMOTe web site (https://remote.normandeau.com/remote_about.php). All other aerial digital data may be found at the links below:

NYSERDA:

Digital Aerial Baseline Survey of Marine Wildlife in Support of Offshore Wind Energy – OPA 2016

<https://seamap.env.duke.edu/dataset/1817>

Digital Aerial Baseline Survey of Marine Wildlife in Support of Offshore Wind Energy – WEA 2016

<https://seamap.env.duke.edu/dataset/1818>

Digital Aerial Baseline Survey of Marine Wildlife in Support of Offshore Wind Energy – OPA 2017

<https://seamap.env.duke.edu/dataset/1994>

Digital Aerial Baseline Survey of Marine Wildlife in Support of Offshore Wind Energy – OPA 2018

<https://seamap.env.duke.edu/dataset/2073>

BOEM:

Ecological Baseline Studies of the U.S. Outer Continental Shelf Option Year 1

<https://seamap.env.duke.edu/dataset/2065>

Ecological Baseline Studies of the U.S. Outer Continental Shelf Option Year 2

<https://seamap.env.duke.edu/dataset/2161>

Other data are available on request due to privacy/ethical restrictions.

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