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Evidence of reproductive and feeding habitat for manta rays off Florida's Atlantic coast

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Abstract Manta rays *Mobula* cf. *birostris* aggregate off the Atlantic coast of Florida each spring, typically March through May. Eighteen courtship events were documented and four zooplankton samples collected opportunistically during boat-based and aerial surveys in 2021–2024. Eighty-three percent of courtship events involved only two individuals, and four stages courtship (initiation, endurance, evasion, pre-copulation positioning) were observed. Breaching events were observed on every day, except one, that courtship events were documented by boat survey. All zooplankton samples were dominated by copepods with bivalve larvae, chaetognaths, and echinoderm larvae also being abundant. Zooplankton biomass ranged from 23.9 to 39.6 mg m^{-3}. These are the first published records of courtship in *Mobula* cf. *birostris*, as well as the first insights into its target surface prey. Identifying potential manta ray critical habitat, such as feeding and reproductive areas, especially in data-deficient regions such as the western Atlantic, is a necessary step for conservation.

Keywords Manta ray · Courtship · Endangered species · Zooplankton · Feeding

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Threatened marine megafauna pose conservation challenges as they are highly mobile and it is impossible to protect them throughout their range. Identifying critical habitats (i.e., nursery, breeding and feeding areas) allows managers to prioritize management in areas that are essential to the conservation of a species (Martin et al. 2017). In south Florida, a potential nursery habitat for manta rays has been described, but little is known about adult habitats and behaviors (Pate and Marshall 2020). Genetic and taxonomic evidence suggests that manta rays in the western Atlantic, including Florida, are a putative new species, *Mobula* cf. *birsotris* (Marshall et al. 2009; Hosegood et al. 2020). There is limited existing knowledge on the ecology, behavior and threats to this putative species, and identifying potential critical habitats is a crucial step in manta ray conservation in the region.

Each spring manta rays aggregate off the coast of central and northern Florida, between Indian River County, FL, and the Florida/Georgia border. Typically, individuals are observed during March of each year in coastal waters off Indian River County, then migrate northward, possibly coinciding with rising water temperatures. While this aggregation has long been known by anglers, who use the manta rays to locate and target cobia, *Rachycentron canadum* (Braun et al. 2024), little scientific study has been conducted on manta rays in the western Atlantic. Research into the spatio-temporal trends and population dynamics of the central Florida manta ray aggregation has been underway since 2021 (Florida Manta

Project unpublished data 2024) using aerial and boat surveys, as well as behavioral observations from a drone (DJI Mavic 2 and 3 Pro) launched from shore or boat.

Aerial surveys were conducted in a Cessna 172 flying two transects (0.5 and 1.5 mi offshore) in Brevard and Volusia counties. Twenty-four aerial surveys were conducted in the months of March and April from 2021 to 2024 (5–7 aerial surveys each year). While there were 21 observations on aerial surveys of smaller mantas rays closely following larger manta rays, we did not include these observations in the results due to the brief window (< 5 s) available to categorize behavior. One observation from an aerial survey is included in the results, as it occurred at the end of a survey when we were able to circle the plane for a few minutes and film the behavior. Thirty-one boat-based surveys were conducted in which we searched for manta rays using the drone or standing on the bow of the boat (3 in April 2021, 1 in January 2022, 8 in March/April 2022, 1 in August 2022, 7 in March/April 2023, and 9 in March/April 2024). If manta rays were found, we documented behavior and took in-water photographs if conditions (i.e., turbidity) allowed. If manta rays were observed feeding (mouths open and cephalic fins unrolled), we took zooplankton samples. Zooplankton sampling effort was often limited due to prioritization of other research activities, such as tagging and photo identification. Citizen science reports of manta rays engaged in courtship behavior are reported in the results as well. Here, we present evidence that the Atlantic coast of central Florida is a reproductive and feeding habitat for manta rays.

Eighteen observations of courtship behavior were observed in the months of February ($n=1$, 2024), March ($n=13$, 2021, 2023, and 2024), and April ($n=4$, 2021, 2023, and 2024) in water less than 19 m deep within 8 km of shore of Indian River, Brevard, and Volusia counties (Table 1). Eighty-three percent of events (15 of 18) involved only two individuals, a smaller manta ray following a larger manta ray (Fig. 1A). Sex was only confirmed by in-water observation for four events, where, as expected, the smaller, following manta ray was male (Fig. 1B) and the larger manta ray being pursued was female. Courtship events were observed for up to 73 min (median = 3.2 min) and included four stages (initiation, endurance, evasion, and pre-copulation positioning) of courtship (Stevens et al. 2018, Table 1). In 66.7% of events (12 of 18), only the initiation stage was observed whereby the smaller manta ray was persistently following the larger manta ray at a distance of approximately 1–5 disk widths at cruising speed. During the five events where the stages endurance and evasion were observed, the smaller manta ray sporadically accelerated towards the larger manta ray, which would then perform an evasive maneuver, typically diving, during which the pair would be concealed by the turbid water. The sole observation of pre-copulation positioning was unfortunately short (0.3 min, Table 1) due to the mantas being obscured in extremely turbid water. No copulation events were observed. Videos of all courtship events can be found at https://youtu.be/BsevnINPE7k.

Breaching behavior was also frequently observed off central Florida's Atlantic coast (Fig. 1C). A breaching event was defined as any group of consecutive breaches, as manta rays often breach two or three times sequentially. Breaching behavior is only reported here from boat surveys. Breaching events were observed on every day, except one (3/17/2024, Table 1) that courtship events were documented by boat survey. However, on 3/17/2024, we conducted an aerial survey in the morning and a boat survey in the afternoon, and breaching was observed from the plane, but not from the boat and six breaches were observed on the previous day's boat survey (3/16/2024). The number of breaching events observed during a boat survey where courtship was observed ranged from 0 to 26 (mean = 9.5, Table 1). The maximum number of breaching events documented on a boat survey (45 on 3/27/2023) occurred on the day before two courtship events were observed. Our findings support those from Mozambique where breaching behavior has been found to increase in frequency during courtship and mating periods, with over 90% of breaches occurring within 2 days of reproductive activity (Marshall and Bennett 2010). Table 2 illustrates the observed relationship between feeding, courting, and beaching behavior. Though courting and feeding behavior were observed on the same day, courting individuals were never observed to be feeding, and vice versa. It is important to note that these observations are limited to behavior at the surface, and more data is needed to understand the relationship of these behaviors.

Four surface zooplankton samples were collected in March 2022. A 30-cm diameter, 200-µm-mesh net was towed behind a boat (~ 2 kts) for 4 min with

Table 1 Description of each courtship event in Central Florida from 2021 to 2024

Date	County	Latitude	Longitude	No. of mantas	Distance from shore (km)	Depth (m)	Water temp (°C)	# of breaching events observed	Courtship stages observed	Survey method	Observation platform	Observation time (min)
3–14-2021	Brevard	27.925395	−80.47512	2	0.8	Not Recorded	Not Recorded	N/A	Endurance, Evasion	Aerial Survey	Plane	4.4
3–14-2021	Brevard	27.884151	−80.45801	2	0.1	Not Recorded	Not Recorded	N/A	Initiation, Endurance, Evasion	Drone from Shore	Drone	5.0
4–21-2021	Volusia	29.262318	−81.01368	2	0.9	Not Recorded	22.4	10	Initiation	Boat Survey	Drone	2.5
3–23-2023	Brevard	28.60796	−80.58664	2	0.6	8.5	21.4	7	Initiation	Boat Survey	Drone	1.8
3–24-2023	Brevard	28.60423	−80.58604	2	0.4	6.9	20.2	9	Initiation	Boat Survey	Drone	0.4
3–28-2023	Volusia	28.89175	−80.7901	2	0.7	9.4	21.2	26	Initiation	Boat Survey	Drone, In-water	2.0
3–28-2023	Volusia	28.87559	−80.77864	2	0.7	9.1	21.4	26	Initiation, Endurance, Evasion	Boat Survey	Drone, In-water	73.0
4–1-2023	Volusia	28.85426	−80.75273	2	1.8	13.2	20.9	4	Initiation	Boat Survey	Drone	4.0
2–15-2024	Indian River	27.78753	−80.40786	2	< 0.1	Not Recorded	Not Recorded	N/A	Initiation	Citizen Science Report	Drone	8.0
3–8-2024	Brevard	28.086604	−80.5618	2	0.1	Not Recorded	Not Recorded	N/A	Initiation	Citizen Science Report	Drone	3.1
3–12-2024	Indian River	27.804033	−80.41369	2	0.4	Not Recorded	Not Recorded	N/A	Initiation	Citizen Science Report	Drone	1.9
3–13-2024	Brevard	28.086604	−80.5618	3	0.1	Not Recorded	Not Recorded	N/A	Initiation	Citizen Science Report	Drone	2.6
3–15-2024	Brevard	28.6225	−80.6054	2	0.1	2.5	20.5	N/A	Initiation, Endurance, Evasion	BOEM Manta Survey	Boat	3.3
3–16-2024	Brevard	28.59986	−80.5847	2	0.1	2.8	20	6	Pre-copulation positioning	BOEM Manta Survey	Boat	0.3
3–17-2024	Volusia	29.01919	−80.87769	3	0.4	6.0	20.3	0	Initiation, Endurance, Evasion	Boat Survey	Drone, In-water	40.0

Table 1 (continued)

Date	County	Latitude	Longitude	No. of mantas	Distance from shore (km)	Depth (m)	Water temp (°C)	# of breaching events observed	Courtship stages observed	Survey method	Observation platform	Observation time (min)
3–21-2024	Brevard	28.53661	−80.48466	2	7.6	10.4	19.9	15	Initiation	Boat Survey	Drone, In-water	42.0
4–7-2024	Volusia	28.951077	−80.83727	2	0.1	Not Recorded	Not Recorded	1	Initiation	Citizen Science Report	Drone	10.7
4–7-2024	Volusia	29.089227	−80.8739	4	4.4	18.2	Not Recorded	1	Initiation	Citizen Science Report	Boat	0.8

Courtship stages from Stevens et al. (2018)

mechanical flowmeter (General Oceanics R2030) to calculate volume of water sampled. Three (samples 2–4, Table 3) were collected within the feeding paths of surface feeding manta rays, which in these three instances were on "color changes" (boundary zones) or tide lines (see example https://www.youtube.com/watch?v=Zo8C900jgIM). Manta rays were classified as surface feeding if their mouth was open with unrolled cephalic fins and their dorsal surface protruded out of the water, a behavior called "barging" by local anglers (Fig. 1D). One surface sample (sample 1, Table 3) was collected in an area with numerous (estimated between 5 and 20) manta rays, but none was observed actively surface feeding; thus, this sample does not necessarily represent prey items for manta rays. Quantifying manta rays this day was difficult, as they were only briefly at the surface, spending much of the time out of view deeper in the water column, and making it impossible to categorize behavior.

Samples were fixed in 10% formalin. Subsamples of 15 mL (5 ml Stempel pipette × 3) were counted and identified using microscopy, following the protocol established by the National Institute of Oceanography (Dhargalkar and Verlecar 2004). Specimens were identified to the lowest taxonomic level possible, ranging from general groups (e.g., chaetognaths, echinoderm larvae) to genera and, in a few cases, to species (see "Zooplankton Identification" in López-Figueroa et al. (2023) for more detailed methodology). To obtain biomass, each sample was placed in a pre-weighed glass Petri dish and dried for 24 h at 70 °C then re-weighed. Plankton biomass was expressed as dry mass per filtered water volume (mg m^{-3}).

Over half of individual zooplankton in all samples were copepods. The surface feeding manta ray samples (samples 2–4, Table 3) were comprised of 68.6, 66.6, and 59.0% copepods, while the behavior unclear sample (sample 1, Table 3) was comprised of 50% copepods. The most abundant taxonomic groups in the four samples were copepods, bivalve larvae, chaetognaths, and echinoderm larvae (Table 3). The two most abundant copepods in feeding samples 2 and 3 were *Labidocera* spp. and *Euterpina acutifrons*. In sample 4, 62% of copepods were *Pontella* spp. and 13% were *Temora* spp. Sample 1 was made up of 46% *Acartia* spp. and 23% copepod nauplii (Table 4). Total biomass of

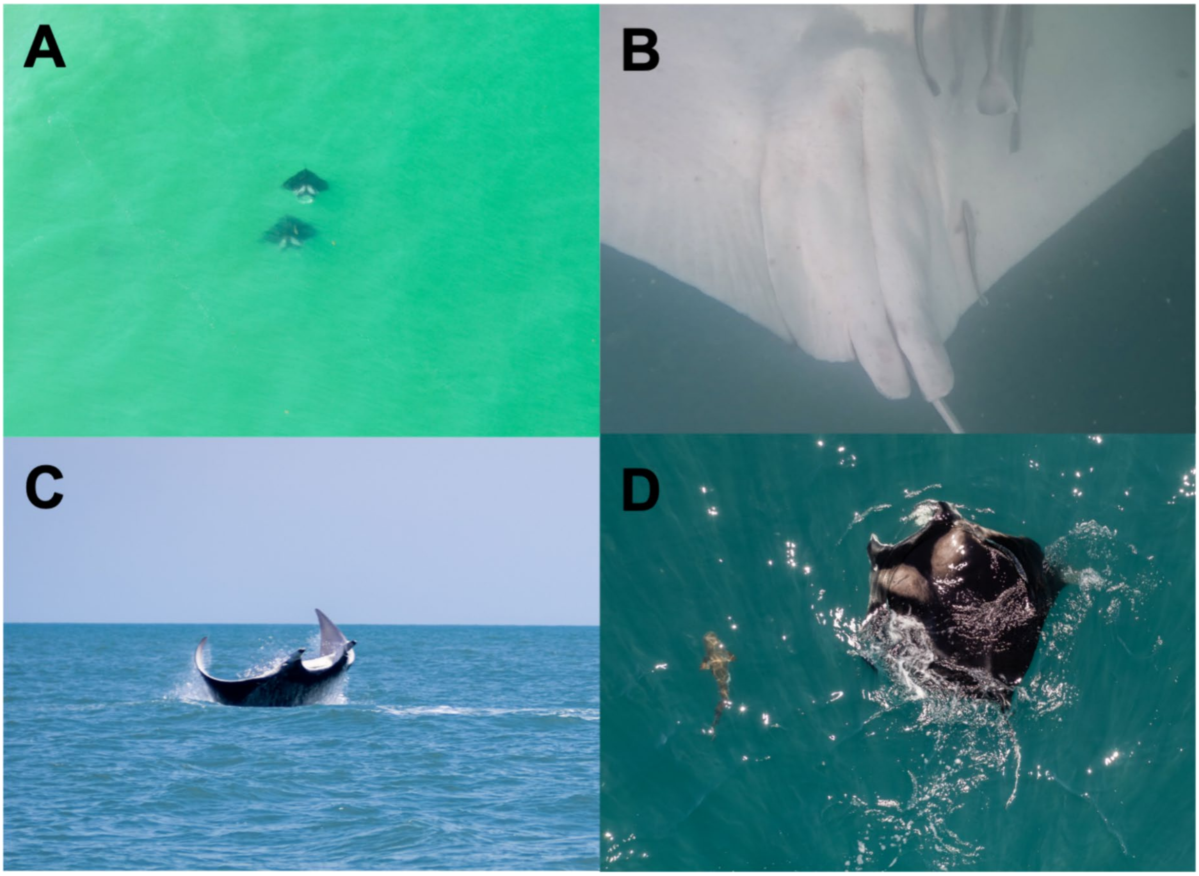

Fig. 1 **A** Courtship behavior with male approaching female manta ray, *Mobula* cf. *birostris*, from behind, March 14, 2021, in Melbourne, FL. **B** Claspers of a mature male manta ray (CFL030) engaged in courtship behavior, March 28, 2023, in Canaveral National Seashore, FL. **C** Manta ray breaching, March 27, 2023, in Canaveral National Seashore, FL. **D** Manta ray surface feeding with dorsal surface out of the water, March 25, 2022, in New Smyrna Beach, FL. Notice the cobia swimming on manta ray's left

Table 2 Florida Manta Project boat survey days (2021–2014) in central Florida where manta ray, *Mobula* cf. *birostris*, feeding and/or courtship behavior was observed and if breaching behavior was observed on those days

	Feeding	Courtship	Both	Neither
Breaching	4	2	5	5
No breaching	4	1	0	5

There was a total of 31 survey days, and on 5 surveys, no manta rays were observed

sample 1 was 35.0 mg m^{-3}, and for the three surface feeding samples (2–4) biomass was 39.6, 23.9, and 27.5 mg m^{-3}.

Copepods were the most abundant taxonomic group at reef manta ray, *Mobula alfredi*, aggregation sites in Australia and the Maldives, with chaetognaths and mollusks also being common (Armstrong et al. 2016, 2021). In the Maldives, *Undinula vulgaris* was the dominant copepod species (Armstrong et al. 2021), while this species was only found minimally in one feeding sample in the present study (sample 2, 5 indv m^{-3}). Zooplankton biomass is higher in areas where manta rays are actively feeding, with prey density thresholds for manta ray feeding behavior ranging from 11.2 mg m^{-3} in Australia (Armstrong et al. 2016) to 53.7 mg m^{-3} in the Maldives (Armstrong et al. 2021). In the Maldives, samples around feeding manta rays ranged from 7.3 to 593.6 mg m^{-3} and samples around non-feeding manta rays ranged from 1.1 and 175.6 mg m^{-3}, with no effect of manta

Table 3 Zooplankton samples collected near manta rays, *Mobula* cf. *birostris* in central Florida in 2022

Date	Sample #	Behavior	# of mantas	Dry weight (mg/m^3)	% Copepods	% Bivalve larvae	% Chaetognaths	% Echinoderm larvae	% Larvaceans	% Other*	Total individuals (indv m^{-3})
3–18-2022	1	Unclear	Many	35.0	50.0	39.2	4.2	0.8	2.5	3.3	665.4
3–25-2022	2	Feeding	2	39.6	68.6	3.8	9.1	7.5	5.3	5.7	826.5
3–26-2022	3	Feeding	2	23.9	66.6	12.8	4.4	6.9	3.4	5.9	2217.0
3–29-2022	4	Feeding	3	27.5	58.8	37.4	1.9	0.0	0.0	1.9	1265.6

*Other groups include Brachyuran Zoea, Caridean larvae, Cyphonautes, Decapod, Fish Larvae Protozoea, Hydromedusa, Mysis, Ostracods, Polychaete Larvae, Pteropods, Round Fish Eggs, Sergestid (Lucifer faxoni), Siphonophore, Stomatopod, Larvae, Veliger Larvae

Each taxonomic group is presented as their percentage of the total individual count. Any taxonomic group comprising less than 2% is included in the Other column. Total individuals were counted from the average three 5-mL subsamples and divided by volume calculated from the tow of the flowmeter

ray abundance (0 to 25 individuals) on biomass (Armstrong et al. 2021). It is important to note that the studies from the Maldives and Indonesia are on a different species of manta ray (*M. alfredi*) and more research is needed to understand how feeding ecology differs between manta ray species. Future studies in central Florida should focus on a greater sampling effort to determine the prey density threshold that triggers feeding behavior, as well as the relationship between environmental conditions, manta ray abundance, and zooplankton density/composition.

Turbid waters and low visibility (often estimated as less than 1.5 m), in our study area, limit behavioral observations to the surface, making in-water observations difficult, and sometimes impossible. Manta rays can often be initially located, but only remain on the surface briefly before diving out of sight. The use of technology, such as satellite tags and accelerometers, has the potential to provide information on behavior beneath the surface. Also, sampling zooplankton throughout the water column would provide insights into prey density distribution and possibly feeding behavior.

Manta rays were listed as a threatened species on the U.S. Endangered Species Act in 2018, yet there is still insufficient data to designate critical habitat (NOAA 2018, 2019). Identifying a potential seasonal reproductive and feeding habitat is a key step towards the conservation of Florida's manta rays. Furthermore, taxonomic and genetic evidence suggests that the manta rays observed off Florida are a putative third species (*Mobula* cf. *birostris*, Marshall et al. 2009; Hosegood et al. 2020). Little is known about the ecology, behavior, and threats to this species. Here we report on the first published records of courtship in *M.* cf. *birostris*, as well as first insights into its target surface prey.

A specialized fishery exists off this coastline wherein anglers target the seasonal manta ray aggregation to locate and catch cobia (Fig. 1C). This fishery has become increasingly popular with the rise of social media, and the harassment and foul-hooking of manta rays are often reported (Braun et al. 2024). Fishing near manta rays has the potential to disrupt feeding and reproductive behavior, and even cause injury or mortality due to boat strike (Strike et al. 2022). Due to the difficulty of in-water photography in the turbid waters of central Florida, data is not available for the

Table 4 Summary of the most abundant copepods in each zooplankton sample from central Florida, including percent of total copepods made up by three most abundant species combined

Date	Sample #	% comprised of 3 most abundant copepods	Three most abundant species/genera/life stage
3–18-2022	1	80	*Acartia* spp. (46%), Copepod nauplii (23%), *Euterpina acutifrons* (11%)
3–25-2022	2	58	*Labidocera* spp. (21%), *Euterpina acutifrons* (20%), *Corycaeus* spp. (17%)
3–26-2022	3	75	*Labidocera* spp. (27%), *Euterpina acutifrons* (20%), *Oithona* spp. (15%)
3–29-2022	4	83	*Pontella* spp.(62%), *Temora* spp. (13%), *Oithona* spp. (8%)

percentage of adult manta rays with boat strikes. However, in south Florida, boat strike injuries are observed on 8% of juvenile manta rays (Pate unpublished data 2024). Additionally, an ongoing sand mining project off Brevard County, FL, occurs in the vicinity of where manta rays have been observed feeding and courting (Iafrate et al. 2022). It is essential to understand the importance of these waters to this manta ray aggregation to mitigate the impacts of mining exploration, construction, and development.

These initial observations warrant future study to determine the importance of this area to manta ray feeding and reproduction, as well as characterization of the environmental influences that affect manta ray presence and behavior. More zooplankton samples, possibly with stable isotope analysis, are needed to accurately describe manta ray feeding ecology in the region. In addition to ongoing aerial surveys to quantify spatio-temporal distribution, continued boat and drone surveys are needed to document behavior. A potential nursery habitat for juvenile *M.* cf. *birsotris* has been described ~ 200 km south of this area (Pate and Marshall 2020); therefore, determining the genetic connectivity and relatedness of adult and juvenile manta rays along Florida's Atlantic coast using population genetics/genomics would be a useful next step. The spring aggregation of adult manta rays in Florida represents a unique opportunity to study a data-poor population of a putative new species in an area (western Atlantic) where manta ray and mobulid research are notably scarce. This study is an important step in filling the substantial knowledge gaps that exist on the putative new species in the western Atlantic.

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Data availability Data will be made available on request.

Declarations

Animal ethics No approval of research ethics committees was required to accomplish the goals of this study.

Competing interests The author declares no competing interests.

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