

MARINE RECORD

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Sightings trends and behaviour of manta rays in Fernando de Noronha Archipelago, Brazil



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Abstract

Despite substantial progress in mobulid research over the past decade, knowledge gaps in manta ray ecology and behaviour remain, particularly in the South Atlantic Ocean. Opportunistic photographic and video records of manta rays collected between 2002 and 2019 at Fernando de Noronha Archipelago (FNA) in northeast Brazil provide evidence to support the year-round use of the region by manta rays (believed to be *Mobula* cf. *birostris*). From a total of 130 sighting records, manta rays exhibited feeding behaviour in 36.9% ($n = 48$) of sightings, indicating that the shallow waters surrounding the archipelago are used as feeding grounds. Approximately half of the records (53.8%) corresponded to identified individuals that were re-sighted repeatedly, using the area in different seasons and for several years. Of the compiled records, 69.2% of sightings were of small individuals (≤ 3 m disc width). All identified males had undeveloped claspers and females had no visible mating scars, suggesting a juvenile population. Despite being limited to a small local sample, here we present the first report of manta rays at FNA and provide preliminary evidence of feeding behaviour by juvenile manta rays in Brazil. This information contributes to our understanding of the regional distribution and habitat use of manta rays in Brazilian waters.

Keywords: Citizen science, Elasmobranch, *Mobula* spp., Nursery area, Oceanic island

Introduction

Manta rays (*Mobula* spp.) are planktivorous elasmobranchs that are widely distributed throughout tropical and subtropical oceans (Marshall et al. 2009; Lawson et al. 2017). These rays are primarily encountered in shallow coastal waters, yet their expansive home ranges can include pelagic, offshore habitats (Couturier et al. 2012; Stewart et al. 2018a), remote oceanic islands, pinnacles, seamounts and submerged ridge systems (Kashiwagi et al. 2011; Marshall et al. 2011; Deakos 2012). Manta rays are highly susceptible to overexploitation due to their slow life-history traits. They are long-lived with late-onset of maturity, exhibit low fecundity (typically one pup per litter), and a reproductive periodicity of up to 5 years between pregnancies (Marshall and

Bennett 2010; Couturier et al. 2012; Dulvy et al. 2014). As a result of directed fishing pressure and incidental captures in artisanal and larger-scale fisheries (Croll et al. 2016), manta ray populations have suffered global declines resulting in the two currently recognised species, *Mobula birostris* and *M. alfredi*, being listed as Endangered and Vulnerable to extinction on the IUCN Red List of Threatened Species, respectively (Marshall et al. 2019, 2020). Both species are also listed on Appendices I & II of the Convention on the Conservation of Migratory Species of Wild Animals (CMS) and Appendix II of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES). In Brazil, manta rays have been protected since 2013 by the Interministerial Normative Instruction MPA/MMA N.02. A regulation that prohibits directed fishing, retention on board, transshipment, landing, storage, transport and commercialization of the products or sub-products of

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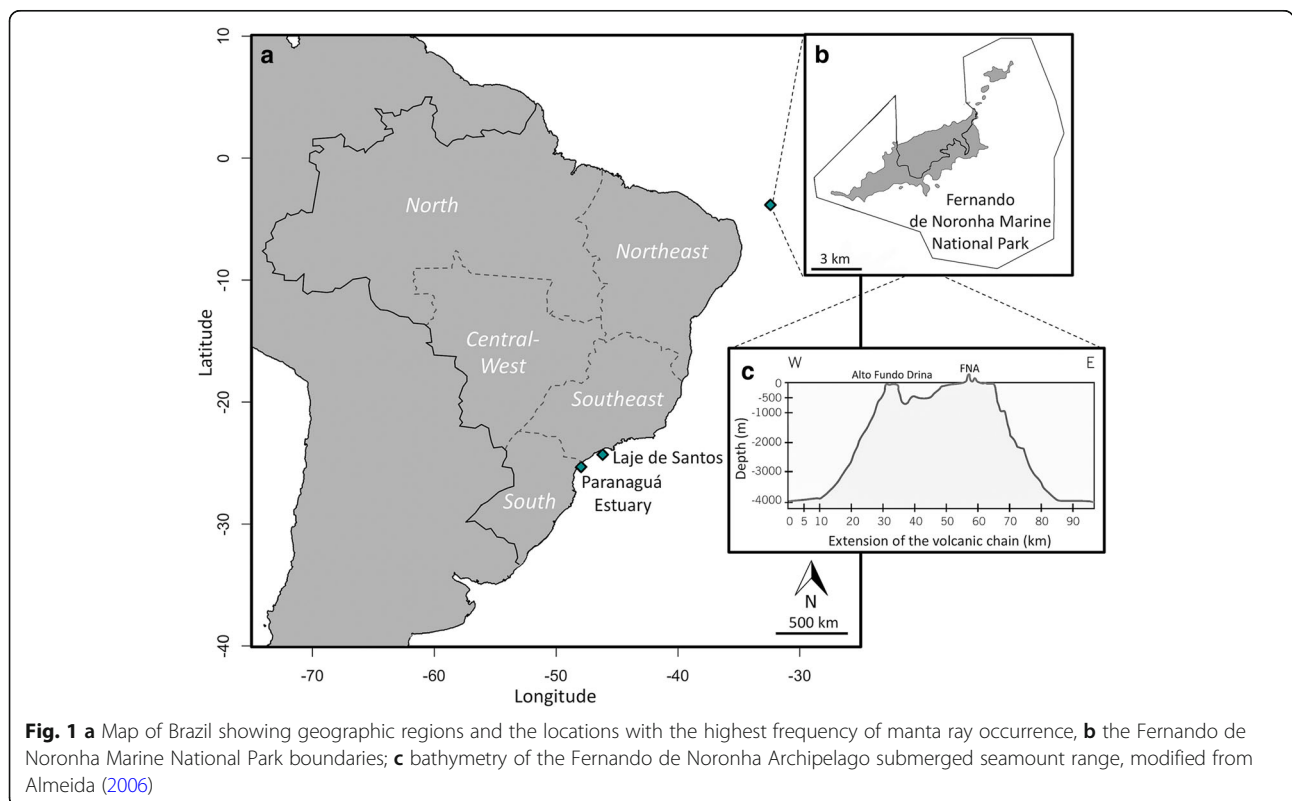
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the family Mobulidae in Brazilian Jurisdictional Waters and across the entire national territory (DOU 2013).

Brazil is officially divided into five geo-political regions: North, Center-West, Northeast, Southeast and South (Fig. 1a). The vast Brazilian coastline extends over 7367 km along the Atlantic Ocean (Lacerda et al. 1993), comprises tropical and subtropical environments and supports a substantial diversity of elasmobranch species, including mobulids (Amorim et al. 1998; Mazzoleni and Schwingel 1999; Yokota and Lessa 2006; Jucá-Queiroz et al. 2008; Lessa et al. 2008). Manta ray distribution in the South Atlantic Ocean is poorly understood and published studies mostly comprise sporadic occurrences or bycatch reports (e.g. Mazzoleni and Schwingel 1999; Perez and Wahrlich 2005; Yokota and Lessa 2006; Jucá-Queiroz et al. 2008; Afonso et al. 2011; Mendonça et al. 2012; Medeiros et al. 2015). Seasonal occurrences of *M. birostris* have been noted along the south and southeast coasts. Specifically within the *Laje de Santos Marine State Park* (PEMLS), São Paulo during austral winter (Luiz et al. 2009), and the *Paranaguá estuary*, Paraná during austral summer (Medeiros et al. 2015; Medeiros 2016). Manta ray sightings are less frequently recorded along the north and northeast coasts of Brazil, however incidental capture and fisheries landings have been reported by Lessa et al. (1999, 2008), Jucá-Queiroz et al. (2008, 2011) and Cintra et al. (2015).

Mobulids are not considered to be of commercial value in Brazil and there are currently no known target fisheries for manta rays. However, Brazil is recognised as a major supplier of gill plates for the Asian market (Wu 2016; O'Malley et al. 2017) and is cited as a contributing country to global manta ray catch (Camhi et al. 2009). Fisheries landings of manta rays are poorly documented, but they are known to be caught by surface gillnets, longlines, purse seines and harpoons, and kept for their meat and gill plates (Yokota and Lessa 2006; Camhi et al. 2009; Afonso et al. 2011; Couturier et al. 2012; Charvet et al. 2018). Mobulid bycatch is relatively frequent in Brazilian waters and intermittently reported (Mazzoleni and Schwingel 1999; Perez and Wahrlich 2005; Jucá-Queiroz et al. 2008; Cintra et al. 2015).

In order to effectively manage and protect populations of threatened species, particularly migratory species with extensive home ranges, it is important to understand their distribution, habitat usage and movement patterns (Stewart et al. 2018b). Despite a recent increase in mobulid research, critical habitats and home ranges are still being identified for some locations (Stewart et al. 2018a), particularly in South America where little is currently known. Manta rays are commonly monitored at aggregation sites using photo identification (photo-ID), whereby individuals are identified by their unique ventral pigmentation patterns allowing for re-sightings over space and time (Marshall et al. 2011; Couturier et al.



2014). Long-term photo-ID catalogues provide insight into population structure and demographics (Deakos et al. 2011; Marshall and Pierce 2012; Couturier et al. 2014), enable evaluations of residency and movements patterns (Couturier et al. 2011; Deakos et al. 2011; Marshall et al. 2011; Germanov and Marshall 2014), and facilitate the estimation of biological parameters including size at maturity (Clark 2010; Stevens 2016), gestation period, reproductive periodicity, growth and longevity (Marshall and Bennett 2010; Pierce et al. 2018).

Here, we use photo and video records contributed by citizen scientists and local underwater media companies to extend the known distribution of manta rays in Brazil. From a 17-year regional dataset, we present evidence of the occurrence of manta rays at Fernando de Noronha Archipelago (FNA), encompassed in a Marine Protected Area (MPA) in the oceanic system of northeast Brazil, and provide preliminary insight into population demographics, seasonality and behaviour of manta rays in the archipelago. This information may serve as a baseline for future manta ray research in Brazil.

Methods

Study area

Fernando de Noronha is a small volcanic archipelago of 21 island and islets in the equatorial South Atlantic, located in the state of Pernambuco in northeast Brazil (3° 51' S, 32° 25' W; Fig. 1a). The archipelago is situated approximately 345 km from the nearest continental coast (*Cabo de São Roque*, RN) and covers a total area of 26 km², 70% of which is encompassed by the Marine National Park of Fernando de Noronha – PARNAMAR (Fig. 1b). The remaining area comprises the Environmental Protection Area (APA - Fernando de Noronha - Rocas - São Pedro and São Paulo). Fernando de Noronha, the largest island in the archipelago (17 km²) is one of the main tourism destinations in Brazil, with nature-based tourism and SCUBA diving being the major motivations for visitors (Brasil 2007). The inhabited island is part of a submerged volcanic chain (Fig. 1c) that rises from a depth of 4000 m along the homonymous fracture zone (Almeida 2006). Small islands and islets surround the main island, emerging from depths of approximately 100 m on the narrow main island shelf (Almeida 2000). Beyond the 100 m isobath, the slope declines steeply to the ocean floor (Fig. 1c). In 2001 FNA was recognized as a UNESCO World Heritage Site. It is considered an area of high biological importance, according to the Brazilian Environmental Ministry (MMA 2002), containing critical feeding and reproductive habitats for fish, sharks, turtles and marine mammals (Cristiano et al. 2020) and hosts many endemic species (Hachich et al. 2015; Outeiro et al. 2019).

The archipelago experiences a warm tropical oceanic climate with two distinct seasons; a rainy season during February to July, and a dry season from August to January (Barcellos et al. 2011; Manso et al. 2011). The ocean surrounding the archipelago is divided into two distinct regions: the 'Inner Sea', adjacent to the northwest coast of the island, which is protected from the currents and winds that come from the south; and the 'Outer Sea' on the island's southeast coast, which faces prevailing waves and wind throughout the year (Cristiano et al. 2020). Predominant winds are southeasterly with an average velocity of 6.6 m/s, with increased wind speeds during July and August (Tchamabi et al. 2017; Cristiano et al. 2020). The mean sea temperature at FNA is 26 °C (Ávila et al. 2018; Figueiredo et al. 2020) and mean salinity is around 36‰ (Assunção et al. 2020; Santana et al. 2020). The region is influenced by the central branch of the South Equatorial Current, which flows westward, and the Equatorial Undercurrent, flowing in the opposite direction (Stramma 1991). The currents interact with the local topography and may induce upwellings events, with the potential to enrich the surface layers of the normally oligotrophic oceanic environment (Wingfield et al. 2011; Tchamabi et al. 2017; Assunção et al. 2020; Leitner et al. 2020). Such events likely increase primary productivity around FNA and provide a suitable oceanic habitat for filter-feeding species, like manta rays.

Data collection

Photo and video records of manta rays from FNA were submitted by the general public (i.e. scuba divers, snorkellers and boat and land-based nature observers). Records included sighting date and location and spanned from January 2002 to November 2019 (see Additional file 1 for additional information). These were compiled into a regional photo-ID catalogue that forms part of the nation-wide Brazilian Manta Ray database – BBM (<https://www.mantasdobrasil.org.br>) and the global online Wildbook database for manta rays 'Manta-Matcher' (Holmberg and Marshall 2020).

Data analyses

Species was determined as per Marshall et al. (2009), classified as *M. birostris*, *M. cf. birostris* - a putative species detailed in Hinojosa-Alvarez et al. (2016), Kashiwagi et al. (2017) and Hosegood et al. (2020), or undetermined species. While *M. cf. birostris* is yet to be officially described, colouration descriptions outlined in Marshall et al. (2009) and Hinojosa-Alvarez et al. (2016) were used for identification. Specifically, mouth colouration, presence of small semi-circular spots below the fifth gill slit, location of ventral pigmentation marks across the abdominal region and pectoral fins, colouration of the ventral pectoral fin margin and the marked pattern of

the dorsal colouration. In footage where the rear of the animal was visible, it was noted whether a small calcified mass was present at the caudal base, situated below the dorsal fin.

Body size (disc width measured between the tips of the pectoral fins) was estimated directly by a trained observer where possible, through comparisons to divers and associated fauna in the contributed images/video. Nevertheless, discrete errors can be associated with imprecise and indirect measurements, and body size should be considered as an estimation here. Sex was determined through the presence or absence of the external male reproductive organ (claspers), as described in Marshall et al. (2011). Life stage (juvenile, sub-adult or adult) was determined through clasper examination for males (size, calcification, scarring and clasper gland structure) and evidence of pregnancy or mating scars for females, as per Marshall and Bennett (2010).

Behaviour was categorised according to descriptions in Jaine et al. (2012). Manta rays were determined to be either cruising (manta ray swimming with cephalic lobes rolled and mouth closed), cleaning (manta ray at a 'cleaning station', maintaining an almost stationary position atop a coral patch for several minutes while being cleaned by cleaner fishes) or feeding (manta ray swimming against the tidal current with mouth open, cephalic fins unfurled and sieving zooplankton from the water). If individuals were seen to exhibit feeding behaviour, the feeding technique (swimming position, individual or coordinated feeding) was categorized as one of the eight feeding strategies presented by Stevens et al. (2018).

Results

Sighting records

A total of 130 manta ray sighting records were compiled from public submissions. The majority of sightings were recorded by recreational SCUBA divers (76.9%, $n = 100$), 6.9% ($n = 9$) of sightings were recorded by snorkellers interacting with manta rays in shallow waters surrounding the main island, and 15.4% ($n = 20$) were from boat and land-based observations. The latter were typically low-quality images in which ventral identification markings could not be clearly distinguished, yet these records contributed evidence of individual and group feeding behaviour in restricted areas. For example, 'Baia dos Golfinhos', a protected site that is inaccessible to the public, where dolphins, rays and sharks can be observed from a prominent cliff. A single fishery record of a deceased individual from the local harbour in 2003 was also included.

Of the total sightings, 69.2% ($n = 90$) were of sufficient quality to carry out species identification using colouration keys. The morphology and colouration of all individuals sighted at *FNA* did not align with either of the

diagnostic characteristics of the two recognized species of manta ray, *M. birostris* and *M. alfredi* described in Marshall et al. (2009). Encountered individuals had pure white faces and ventral markings posterior to the fifth gill slits were typically minimal or absent. Ventral colouration was light with very little shading along the trailing edge of the pectoral fins. Encountered individuals had few and lightly coloured spots or patches on the ventral surface, never medially between the gill slits. In general, the colour pattern most closely resembled the colouration described for *M. cf. birostris*, but with even lighter general colouration than previously reported. Dorsal colouration features included prominent angular white shoulder bar markings, white chevron colouration emanating from the origin of the dorsal fin and prominent white markings at the tips of the pectoral fins (Fig. 2). A small calcified mass was present in all records where the caudal base was visible.

Identified individuals

Manta rays could be individually identified in 65.0% ($n = 85$) of the total sightings. In the remaining 34.6% ($n = 45$) of sightings, an individual could not be positively identified due to the poor quality of the image/video or the absence of ventral markings or injuries. Of the identified rays, 15 different individuals were recognized (10 female and 5 male), 7 of which were sighted on more than one occasion (range = 1–22 sightings, Table 1). In 5 distinct records, individuals could be sexed (1 female and 4 male), but not identified, despite regular colouration of the dorsal surface, ventral markings were absent, thus individual identification could not be confirmed, and these sightings were included as 'No-ID' (Fig. 3a). Individuals were re-sighted within the study area across different seasons and over consecutive years, with two identified individuals (ID-134 and ID-142) sighted in four consecutive years (Table 1). While new identifications occurred regularly, re-sightings of known individuals occurred more frequently in recent years (2015 onwards).

Body size and life-stage

The individuals recorded at *FNA* were small in overall body size (with estimated disc widths of ≤ 3 m, detailed in Additional file 1). One male (ID-134) was sighted in four consecutive years, had small, uncalcified claspers that did not exceed the margin of the pectoral fin upon first sighting in 2016 and was still classified as immature in 2019 (Fig. 3b–e). None of the sighted females had evidence of mating scars on their pectoral fins or visible pregnancy bulges, nor was mating behaviour reported during the study period. Thus, all individuals were classified as immature.

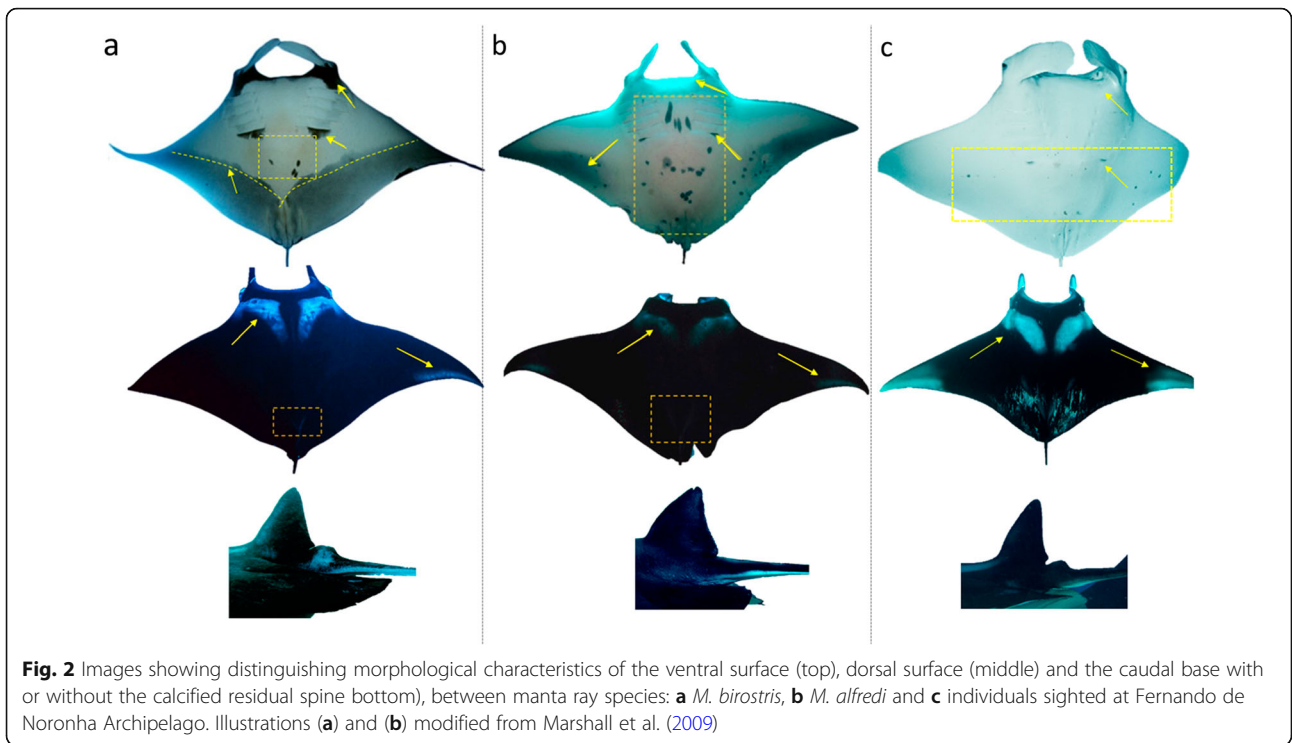


Table 1 Yearly sightings frequency of manta rays at Fernando de Noronha Archipelago from 2002 to 2019

ID (sex)	Total number of sightings per year													Total
	2002	2003	2004	2005	2009	2011	2012	2014	2015	2016	2017	2018	2019	
110 (F)	1													1
134 (M)										11	6	3	2	22
138 (F)									1	2	5			8
142 (F)									1	6	2	2		11
144 (F)								2		5	2			9
147 (F)	1													1
149 (F)		1												1
150 (F)			1											1
151 (F)			1											1
155 (M)										1	4			5
156 (F)										1				1
157 (F)						1								1
159 (F)												1		1
161 (M)													17	17
163 (M)													5	5
No-ID				1	2		1		10	11	4	9	7	45
Total	2	1	2	1	2	1	1	2	12	37	23	15	31	130

Individual identification code (ID) and sex (M Male, F Female) are presented. Unidentified individuals (No-ID) consistent with species morphology and colouration were catalogued. The years 2006, 2007, 2008, 2010 and 2013 were excluded due to the absence of records of manta rays at FNA

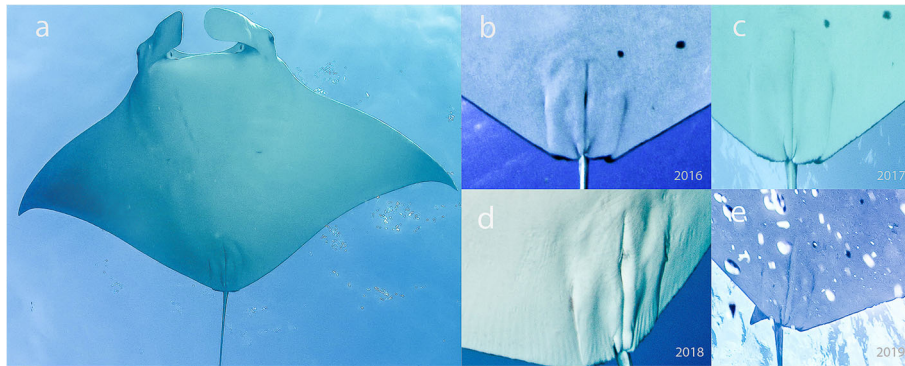


Fig. 3 Examples of manta ray colouration and life-stage at Fernando de Noronha Archipelago, **a** light-coloured individual without ventral marks, **b-e** clasper development from 2016 to 2019 (ID-134). Photos credits: **a** Juliana Viana, **b** Thaiza Bucair, **c** Tati Vasconcelos, **d** Zaira Matheus, and **e** Nayara Bucair

Behaviour

Manta rays were exhibiting feeding behaviour in 36.9% ($n = 48$) of records. According to the categories of feeding strategies described by Stevens et al. (2018), the manta rays at FNA displayed *Somersault Feeding* (Fig. 4a, b and c) and *Surface Feeding* (Fig. 4d and f). Coordinated feeding was observed with small groups of up to three individuals feeding in close proximity at the same time (Fig. 4e and f). Manta rays exhibited cruising behaviour in 37.6% ($n = 49$) of records, and behaviour could not be determined in the remaining 24.6% ($n = 32$)

of records. None of the records depicted manta rays at reef cleaning stations, nor was cleaning behaviour identified in any of the contributed images or video.

Seasonality of sightings

Considering our dataset, the majority (90.7%, $n = 118$) of reported sightings at FNA occurred between 2015 and 2019. Manta ray sightings in FNA occurred across every month of the calendar year. When examining total monthly sightings reported across all years, overall sightings increased from June to October, befitting the



Fig. 4 Examples of feeding behaviour observed at Fernando de Noronha Archipelago, **a, b** and **c** somersault feeding, **d** and **f** surface feeding, **d** and **e** co-ordinated feeding. Photos credits: **a** Wilker Brasileiro, **b** and **c** David Luis de Andrade, **d** and **f** Rafael Pinheiro, and **e** Mayla Y Doo

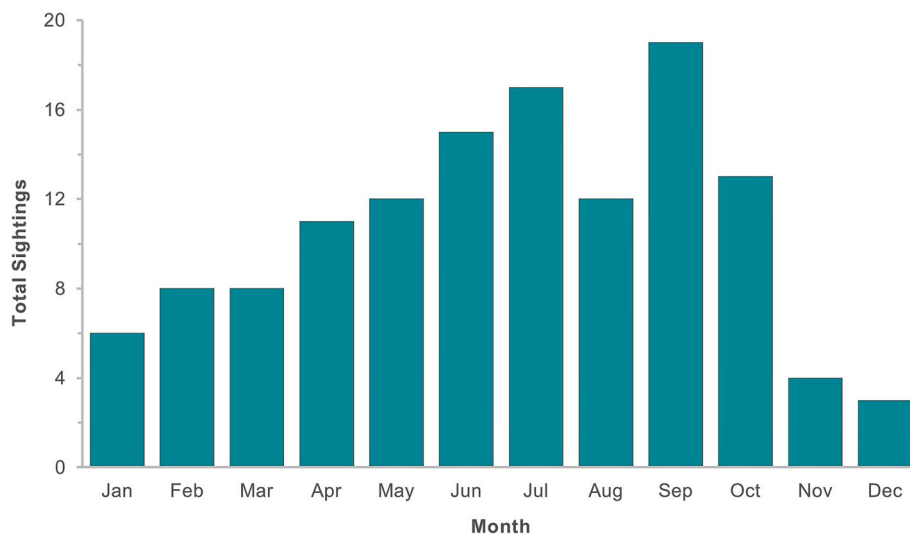


Fig. 5 Sightings frequency of manta ray at Fernando de Noronha Archipelago, considering the period between 2002 and December 2019, summarizing total sightings per month across all the years

transition of the rainy and dry seasons (Fig. 5). Unlike the general trend observed in previous years, an increased number of sightings were reported in the summer months (December – February) of 2016–2017 and 2019. Considering the mean sightings per month across the study period, excluding the years with no records of manta rays in *FNA*, the seasonality shows no clear pattern (see Additional file 1 - Table 2).

Discussion

Regardless of significant progress in mobulid research over the past decade, knowledge gaps surrounding the distribution and habitat use of mobulid species still exist. This is particularly true for lesser-studied regions like South America, notably Brazil which boasts an extensive coastline and suitable habitat for mobulid rays. Region-specific information is critical to understanding habitat use and seasonality of these species, particularly for the development of effective local management and conservation strategies. Identifying aggregation sites and the related animal behaviour is especially important for locations where sightings are sporadic and the drivers behind habitat use and movements are poorly understood. Here, through the examination of images and video contributed by citizen scientists, we present the first report of manta rays at *FNA* and provide preliminary information on population demographics, behaviour and habitat usage.

While the majority of manta rays sighted at *FNA* were consistent with the initial descriptions of *M. cf. birostris*, which has a known distribution exclusively in the western Atlantic Ocean, our observations cannot be considered conclusive without genetic confirmation and the

collection of other diagnostic samples. Manta rays sighted in the region appear to be exclusively juvenile individuals, something that is rare in monitored manta ray aggregations in other locations. There is a distinct paucity of data on the early life stages of manta rays; birthing grounds remain unknown and only a few nursery habitats have been identified to date (Stewart et al. 2018a). Specifically, Flower Garden Banks in the Gulf of Mexico (Stewart et al. 2018b) and the inshore waters off Florida (Pate and Marshall 2020) were recently recognised as important juvenile habitat for the putative third manta ray species. Reef manta ray nursery habitats have also been identified in Nusa Penida (Germanov et al. 2019), and Raja Ampat (Setyawan et al. 2020), Indonesia. Considering the criteria established for shark and ray nursery areas by Heupel et al. (2007, 2019), our results suggest that *FNA* is a potential nursery area and an important juvenile habitat for *M. cf. birostris*.

In general, manta rays demonstrate site affinity to feeding areas, cleaning stations, and reproductive sites (Couturier et al. 2011; Kashiwagi et al. 2011; Harris et al. 2020). Preliminary indications are that young of the year and juveniles may display more intense site fidelity, even permanent use of specific habitats, during the first years of their lives (Heupel et al. 2007; Stewart et al. 2018b; Pate and Marshall 2020). The frequent re-sighting events observed around *FNA* could be associated with the majority of juvenile individuals using the area. Manta rays are known to aggregate in and migrate to areas of high productivity to gain access to productive feeding grounds. Feeding ecology studies suggest that in addition to surface feeding, the majority of their nutrition may come from foraging in deep-water mesopelagic

environments, explaining their tendency to frequent shallow waters with close proximity to deep oceanic regions (Burgess et al. 2016), aligning with the conditions occurring at *FNA*. Other planktivorous species are also sporadically observed in the *FNA* region, including sicklefin devil rays (*M. tarapacana*), spinetail devil rays (*M. mobular*), whale sharks (*Rhincodon typus*) (Soto 2001), and seasonally humpback whales (*Megaptera novaeangliae*) (Tischer et al. 2020), suggesting local environmental conditions and food availability are favourable for filter-feeding species.

Areas of high productivity adjacent to *FNA* like the *Alto Fundo Drina* (23 km west of the archipelago, ~50 m depth), the *Rocas Atoll* (145 km west of *FNA*), and Saint Peter and Saint Paul Archipelago (SPSP, 627 km northeast of *FNA*) are biologically important areas of Brazil's northeast region. SPSP has been identified as an important habitat for planktivorous species like sicklefin devil rays (Mendonça et al. 2018, 2020) and whale sharks (Macena and Hazin 2016), and comparatively described with approximately twice the zooplankton biomass than *FNA* (Campelo et al. 2019). Furthermore, Mendonça et al. (2012) reported sporadic sightings of *M. birostris* at the SPSP archipelago during a mobulid survey in 2010/2011 ($n = 6$, estimated disc width = 3.0–4.5 m).

Our results highlight preliminary information regarding the occurrence of manta rays in *FNA*. The underlying reasons for these occurrences remain unclear and more comprehensive studies are required to better understand manta ray habitat use in the region. Considering the total monthly sightings across our 17-year dataset, a higher frequency of sightings occurred during austral winter. Within this period, reported sightings were lowest in August, which may be related to increased wind, typical of this time of year at *FNA* (Manso et al. 2011; Silva et al. 2016). These conditions increase surface chop, and rough seas limit surface visibility and restrict access to several dive sites (especially on the windward side of the island).

Sighting frequencies increased from 2015 onward, which may be a consequence of increased tourism in the archipelago or the more frequent use of underwater cameras and enhanced awareness of citizen science. In the last decade, the *FNA* has seen a vast increase in the number of tourist and residents (Afonso et al. 2019; Cristiano et al. 2020), in conjunction with a large tourism ecological footprint (Feitosa and Gómez 2013; Lopes et al. 2017). Potential negative impacts of tourism include harassment of marine animals, eutrophication, marine litter increase, light/sound pollution, introduction of exotic species, erosion and sediment loading on coral reefs (Feitosa and Gómez 2013; Canteiro et al. 2018). Marine wildlife tourism is prominent in the archipelago with SCUBA diving being one of the major

tourist activities (Outeiro et al. 2019), likewise over three-quarters of manta ray sightings were recorded during SCUBA dives. While the increase in sightings since 2015 could be explained by an expansion in dive effort (i.e. frequent dives with a greater number of divers), local operators report consistent dive routines throughout the years.

Fluctuations in local environmental variables may also play a representative role in the observed increase of sightings. Variability in zooplankton biomass (Campelo et al. 2019), and coral bleaching (Leão et al. 2019; Longo et al. 2020) related to thermal stress and extreme events (like *El niño*) have been reported in the Brazilian oceanic islands, particularly in *FNA* and SPSP. Yet determining the influence of environmental factors on manta ray sightings in *FNA* was beyond the scope of our study and would require in-depth monitoring of sightings and environmental conditions.

Over the course of this study, manta rays were sighted with entanglement injuries from fishing gear. Prior to 2015, only two individuals were recorded with healed scars potentially caused by fishing line. Remarkably, in 2019 manta rays were observed feeding at night in the harbour (*Porto de Santo Antônio*) on zooplankton attracted by artificial lights affixed to the jetty. Although it provides additional opportunity for manta ray watching, the animals were feeding in an area of high boat traffic and a fishing zone. Consequently, these sightings were followed by reports of wounded manta rays, mainly hook and line injuries, as well as entanglements in boat mooring lines. Given the lack of current data and the potential for increased impacts on manta rays using the waters of *FNA*, it is an opportune time to begin more rigorous and structured research into manta rays in the region.

The *Instituto Chico Mendes de Conservação da Biodiversidade* (ICMBio) is responsible for the regulation of protection, preservation, and conservation of biodiversity of Federal Conservation Units, and manage the *FNA* (PARNAMAR/APA). The current directive of *FNA* remains equivalent to date (with regulated diving sites and control of the number of people and boats entering the protected area), although, there are likely more people in the water in recent years. Guidelines and formal codes of conduct (Murray et al., 2019) are highly recommended for manta ray interaction, aiming to minimize disturbance to manta ray population, especially regarding juvenile individuals and sensitive nursery habitats.

The current study presents an opportunistic and preliminary investigation into manta rays using the inshore area around *FNA*. However, more in-depth and comprehensive research is required, including regular structured surveys to monitor sightings, estimate abundance and assess the drivers of mobulid presence in the region, as

well as investigations into regional feeding ecology. The initial results presented herein may assist in the development of effective and early management and conservation strategies until larger scale monitoring programs can get underway.

Conclusion

With only two peer-reviewed scientific publications focusing on manta ray ecology in the Brazilian territory available at the time of writing (Medeiros et al. 2015; Luiz et al. 2009), Brazil represents a major knowledge gap for manta ray research. Local manta ray ecology and population demographic studies contribute relevant scientific information to the current global knowledge of manta ray populations and their overall distribution. This study provides new information on manta rays in northeast Brazil, at a location that was not previously known to have consistent sightings. Although preliminary, our findings identify *FNA* as feeding ground for juvenile manta rays. Furthermore, the inshore area of *FNA* may potentially represent a nursery habitat for young-of-year and juvenile manta rays identified as *M. cf. birostris*. This information has important implications for the management of *FNA* park waters and encourages follow-up studies in the region.

Supplementary Information

The online version contains supplementary material available at <https://doi.org/10.1186/s41200-021-00204-w>.

Additional file 1: Table S1. *FNA* dataset. Database of manta ray sightings at *FNA* (January 2002 to November 2019). An auxiliary spreadsheet with detailed description of manta ray sightings, organized by date, species, pigmentation, gender, DW, maturity, behaviour, location, dive site, data acquisition, Id, and data relevant information, at Fernando de Noronha archipelago. Undefined patterns and characteristics were categorized as 'Ud'. **Table S2.** Summary. Resume of the dataset of manta ray sightings at *FNA* (January 2003 to November 2019). An auxiliary spreadsheet with resumed information of manta ray sightings at *FNA*, organized by year and month, highlighting total sightings per month and year, with mean, standard deviation, and standard errors).

Acknowledgements

The authors would like to thank the reviewers for their constructive feedback on earlier versions of the manuscript, all divers, photographers, and subaquatic media companies who donated pictures and videos for this purpose, particularly, *All Angle Images*, *Barracudas Images*, and *Ciliares Foto and Video*. In particular, we're immensely grateful to *Projeto Mantas do Brasil* (sponsored by Petrobras and the *Fundação Grupo Boticário for Nature Protection*) for granted access to the Brazilian Manta Ray database, and for induce manta ray research in Brazil. A special thanks to Jayson Huss (volunteer of *Projeto Mantas do Brasil*) for gathering and compiling the manta ray records in Fernando de Noronha Archipelago. As well as to volunteers and researchers involved, and specifically for all collaborators and professional photographers in the region. Without your incredible contribution, these results could not be achieved.

Authors' contributions

NB designed and directed the study, wrote the manuscript, conducted the fieldwork, compiled, analysed and interpreted the data, edited the photos and assist in figures development, SKV edited the manuscript, assisted with

the data interpretation, and created the figures, ADM edited the manuscript and assisted with the data analyses, APB edited the manuscript, compiled and analysed the dataset. All authors read and approved the final manuscript.

Funding

Not applicable. This research has been developed with no funding support.

Availability of data and materials

The freely presented datasets analysed during the current study are available in the Brazilian Manta Ray database – BBM (<https://www.mantasdobrasil.org.br/banco-brasileiro-de-mantas/bbm0001c>) and the WildMe Wildbook Manta Matcher online database (<https://mantamatcher.org>).

Declarations

Ethics approval and consent to participate

Not applicable. However, all procedures and images records were obtained in accordance with the Fernando de Noronha Marine National Park regulations.

Consent for publication

Consent has been provided from citizen scientists, photographers and local underwater media companies. Which allowed the use of the given images for scientific and educational purposes.

Competing interests

The authors declare that they have no competing interests.

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Received: 19 September 2019 Accepted: 18 March 2021

Published online: 16 April 2021

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