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Records of bentfin devil ray, *Mobula thurstoni*, in a marine protected area in Brazilian Equatorial Atlantic: implications for the species' distribution and local conservation strategies

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Abstract The bentfin devil ray (*Mobula thurstoni*) is a migratory elasmobranch species with a wide distribution range. Despite the recent increase in mobulid research, critical habitats and home ranges are still being identified for these threatened species. In the present study, photo and video records opportunistically gathered by SCUBA diving effort were used to identify individuals and habitat usage by *M. thurstoni* in a marine protected area in the western equatorial Atlantic Ocean, Fernando de Noronha Archipelago (FNA). The bentfin devil ray was identified in five distinct records, in different years and sites around the archipelago. All the males showed developed claspers, suggesting mature individuals using the area. The UNESCO heritage site of FNA is considered an area of high biological importance, containing essential habitats for several species of fish, turtles and marine mammals. However, habitat usage by devil ray species is poorly reported in the region; therefore, the present study presents the first report of *M. thurstoni* at FNA, which adds the fifth mobulid ray species recorded in the region. Additionally, these results correspond to the second record of living specimens of *M. thurstoni* in Brazilian jurisdictional waters, highlighting new information on the species' distribution and the home range of mobulids in Brazil.

Keywords Endangered species · Conservation · Distribution · Mobulidae · Oceanic island

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Introduction

Manta and devil rays (Myliobatiformes: Mobulidae) comprise a distinct group of about ten species (Hosegood et al. 2020) of medium to large size migratory epi-pelagic filter-feeding elasmobranchs, mostly occurring worldwide (Notarbartolo-di-Sciara 1987; Couturier et al. 2012). The bentfin devil ray *Mobula thurstoni* (Lloyd, 1908) has one of the wider distributions of all the mobulids, circumglobally distributed in temperate, tropical and subtropical regions of the Atlantic, Indian and Pacific Oceans (Couturier et al. 2012; Lawson et al. 2017; Marshall et al. 2019). The species occurs in neritic and oceanic waters, including around oceanic islands, pinnacles and seamounts (Gadig et al. 2003; Mendonça et al. 2012; Marshall et al. 2019), usually related to highly productive upwelling areas (Marshall et al. 2019). As a filter-feeder species, *M. thurstoni* forage on zooplankton patches, including small shrimp, crabs and fish (Notarbartolo-di-Sciara 1987, 1988; Stewart et al. 2017). Although able to adapt and shift diet according to the food availability (Couturier et al. 2012), the bentfin devil rays have specialized feeding habits, which comprise mostly euphausiids species (Gadig et al. 2003; Rohner et al. 2017; Mukharror et al. 2018).

Like other mobulid rays, *M. thurstoni* is harmless to humans, attaining a maximum disc width (DW) of 1.97 m (Rambahiniarison et al. 2018). Several of its population characteristics and other life-history traits remain uncertain (Stewart et al. 2018), but the species is recognized to be highly susceptible to overexploitation, especially due to its life-history traits, including slow growth and low reproductive rate, normally with one live-born pup per litter every 1–3 years (Marshall et al. 2019). The global increase of gill plates trade has resulted in the population decline of many mobulid species (Zeng et al. 2016; Marshall et al. 2019). The bentfin devil ray is targeted by fisheries in the Philippines, Indonesia, Sri Lanka, Peru, the Republic of Guinea and Mexico, as well as a representative bycatch component of artisanal and industrial fisheries in several locations worldwide (Marshall et al. 2019). Accordingly, *M. thurstoni* is currently listed as Endangered by the IUCN Red List of Threatened Species (Marshall et al. 2019). In Brazil, *M. thurstoni* is classified as Vulnerable according to the Red Book of Brazilian Fauna Threatened with Extinction (ICMBio 2018), and is protected by law in national territory under the Inter-ministerial Regulatory Instruction MPA/MMA N.02 of March 13, 2013, which prohibits direct fishing, retention on board, landing, storage, transport and trade of the products/sub-products of mobulid rays.

The ecology and distribution of *M. thurstoni* are poorly documented in Brazil, where the species was first recorded caught in the inshore area of São Paulo coast (Gadig et al. 2003), southeast Brazil, although the species is most likely listed in former fishing reports under *Mobula* sp. or misidentified as a different mobulid species, especially *M. hypostoma* and *M. mobular* (Gadig et al. 2003; Charvet et al. 2018). The records of living specimens, additionally to a pregnant female caught by longline, were documented in the vicinity of the oceanic archipelago of Saint Peter and Saint Paul—SPSP (Mendonça et al. 2012; McCallister et al. 2020), mid-equatorial Atlantic Ocean. Landings of the bentfin devil ray have been recorded in the states of São Paulo (Gadig et al. 2003; Casas et al. 2006; Rotundo et al. 2019), Rio Grande do Sul (Vooren and Oddone 2019), and Ceará (Jucá-Queiroz et al. 2008; Santander-Neto and Faria 2020).

Considering the species' distribution and habitat usage as crucial information to effectively manage and protect populations of threatened species, the present study provides data on the occurrence of *M. thurstoni* at Fernando de Noronha Archipelago (FNA), an important marine protected area in Brazil. Additionally, it also summarizes information on the species' distribution and insights regarding the diversity of mobulids in a marine protected area in the Brazilian northeast and the incidence of endangered species.

Materials and methods

Study area

The FNA (03°51′S–32°25′W) is composed of 21 islands and islets of volcanic origin in northeast Brazil (Fig. 1), located approximately 350 km from the nearest continental coast of the Rio Grande do Norte State. The archipelago covers a total area of 26 km^2, 70% of which is encompassed by the Marine National Park of Fernando de Noronha – PARNAMAR, and the remaining area comprises the Environmental

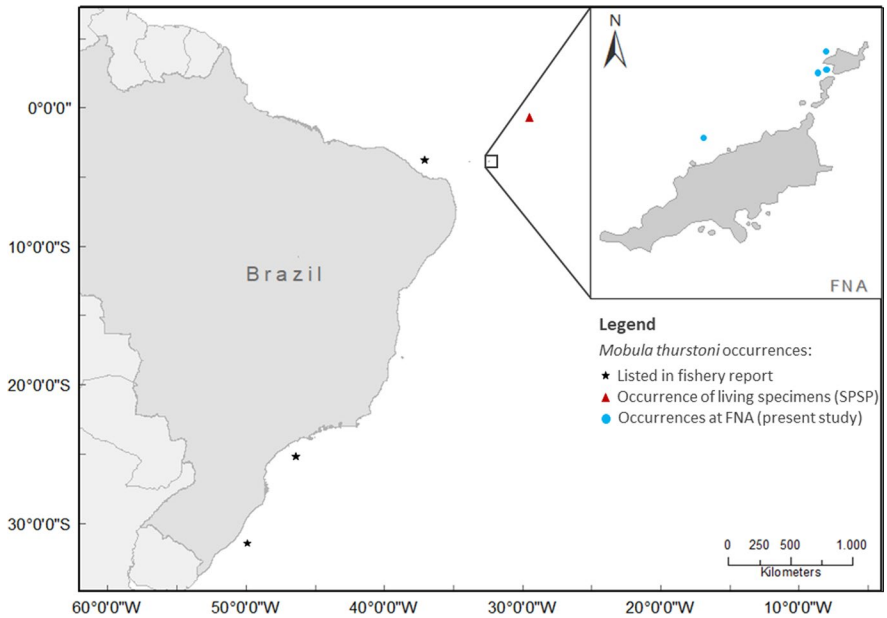

Fig. 1 Map of Brazil, underlining the location of Fernando de Noronha Archipelago (FNA); black stars indicate the previous known published records of *Mobula thurstoni* associated with fishing reports along the Brazilian coast; red star indicates the single site in Brazilian jurisdictional waters with previous records of living *Mobula thurstoni*; blue circles indicate the locations of occurrences at FNA. From bottom to top, the previous occurrences references are the following: Rio Grande do Sul (Vooren and Oddone 2019), São Paulo (Gadig et al. 2003; Casas et al. 2006), Ceará (Jucá-Queiroz et al. 2008; Santander-Neto and Faria 2020) and Saint Peter and Saint Paul Archipelago (Mendonça et al. 2012; Hazin et al. 2018; McCallister et al. 2020)

Protection Area (APA—Fernando de Noronha—Rocas—São Pedro and São Paulo). In 2001, the archipelago was recognized as a UNESCO World Heritage Site and is considered an area of high biological importance, containing critical feeding and reproductive habitats for fish, sharks, turtles and marine mammals (Cristiano et al. 2020). The region experiences a warm tropical oceanic climate with two distinct seasons, a rainy season from February to July, and a dry season from August to January (Barcellos et al. 2011; Manso et al. 2011). The mean sea temperature 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 mobulid rays.

Data

Photo and video records of moulid species from the FNA taken by local SCUBA divers were analysed. Only records with identification compatible with *M. thurstoni* and containing metadata (i.e. date and location) were considered in the present study.

Species identification was determined following the diagnostic features provided by Notarbartolo-di-Sciara (1987), Gadig et al. (2003), Casas et al. (2006) and Stevens et al. (2018): remarkable subterminal mouth; short cephalic fins; head dorsally depressed; short-necked appearance; nuchal region between the origins of pectoral fins with a rectangular light grey area; presence of a dermal mid-dorsal ridge from nuchal area to dorsal fin; thick black band on the top of the head that stretches from eye to eye; prominent double curvature of anterior margin of pectoral

fins; tail base dorsally depressed; tail size equal to or longer than DW; absence of caudal spine; white spot on the dorsal fin tip; bluish dark dorsal colouration pattern, with purple hues; white triangular small area located about midway between the origin and the apex of the pectoral fins; ventral surface with a narrow subtriangular bronze (silver-brown) sheen along the anterior margin of the pectoral fins; and a white hue along the leading edge of anterior margin of the pectoral fin, fading towards apex.

Sex was identified based on the presence or absence of the male external reproductive organs (claspers). Whenever possible, the maturity stage (juvenile, sub-adult and adult) of the individuals was analysed based on reproductive mating scars and pregnancies in females, and development of clasper in males (Notarbartolo-di-Sciara 1988; Casas et al. 2006).

Results

Devil rays were positively identified as *M. thurstoni* in five distinct records ($n = 5$), in different years and sites around the FNA (Fig. 2), here listed in chronological order. A mature male of *M. thurstoni* was recorded on May 17, 2011(Fig. 2a), swimming close to the bottom, with a damaged tail, and developed clasper that surpasses the margin of the pelvic fins. On January 31, 2012 (Fig. 2c–d), a mature male was sighted at the dive site of *Cagarras* (maximum depth of 35 m). The specimen was swimming in the middle

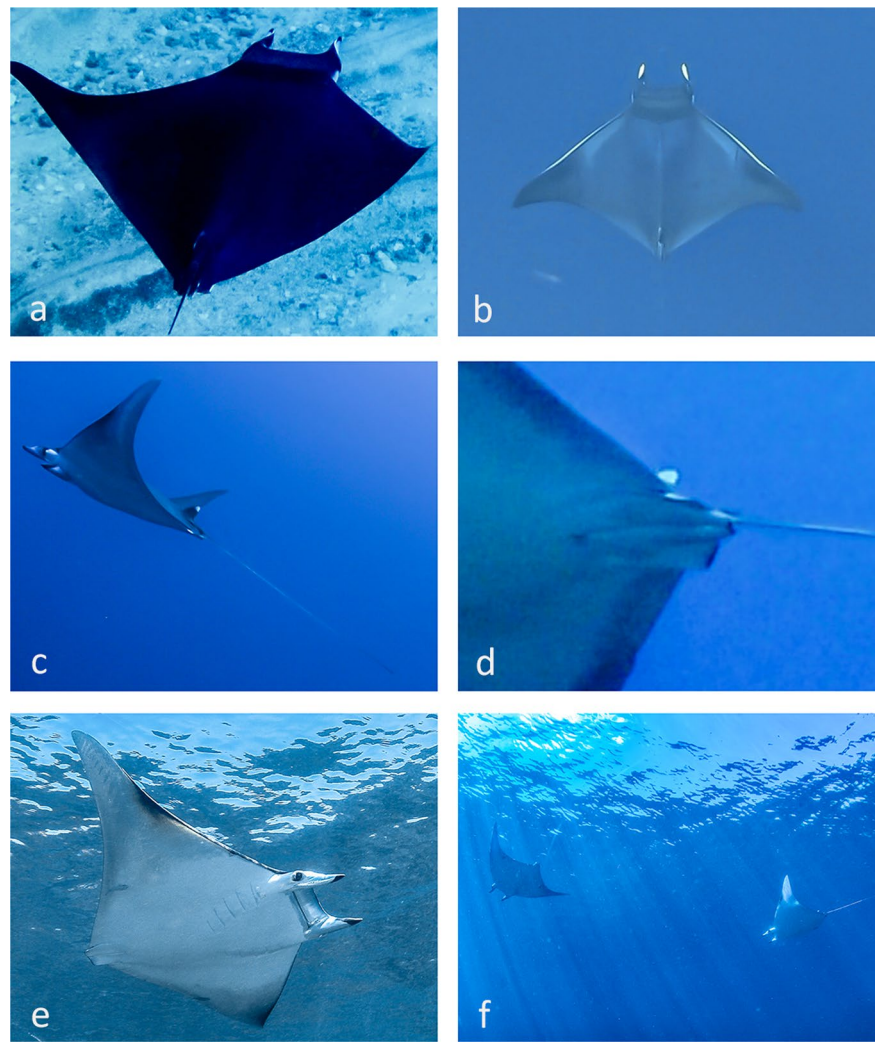

Fig. 2 Records of *Mobula thurstoni* at Fernando de Noronha Archipelago. **a** Individual male cruising close to the bottom (photo by *Barracudas Imagens*, 2011); **b** an adult male swimming in the water column at *Cabeço Dois Irmãos* (photo by Francisco da Costa, 2021); **c–d** a mature male cruising at *Cagarras* embayment (photo by Camila Barreto/*Barracudas Imagens*, 2012) and **e–f** two individuals (one female) cruising together (photo by Geovana M. Gonçalves/*Ciliares Foto e Video*, 2021)

of the water column. On May 23, 2021 (Fig. 2b), an adult male bentfin devil ray was sighted at the dive site of *Cabeço Dois Irmãos* (maximum depth of 52 m), cruising alone around the 20 m depth. Lastly, on July 01, 2021, two individuals (Fig. 2e–f) were sighted cruising together in shallow waters at the *Ressurreta* point (maximum depth of 10 m). The latter individuals exhibited different behaviour from the previously sighted, swimming near divers for several minutes. One of them was a female (Fig. 2e), with a damaged tail and a well-defined ventral colouration pattern. The remarkably intense silvery pattern of the preoral and cephalic fins described by Gadig et al. (2003) could be observed in all the records.

Discussion

The present records highlight and confirm the occurrence of the bentfin devil ray in the Brazilian northeast oceanic waters, at a location where it was not previously reported. These new occurrences contribute to the knowledge of mobulid rays distribution in the South Atlantic Ocean, remarkably in the western equatorial Atlantic, where a few specimens were known to date (Jucá-Queiroz et al. 2008; Santander-Neto and Faria 2020). The disclosure of the representative records of living specimens at FNA underlines the species' distribution in the Brazilian jurisdictional waters and corroborates earlier unpublished data of the species occurrence in the area (O. Gadig, pers. comm. 2011).

Despite not observing any specific adult behaviour, such as mating or parturition, it was possible to determine the adult life stage for most individuals. All individuals identified as males had well-developed claspers, indicating advanced stages of maturity and development. This observation corroborates the occurrence of adult specimens of *M. thurstoni* reported in the adjacent Brazilian oceanic system of SPSP (Mendonça et al. 2012; Hazin et al. 2018; McCallister et al. 2020). The similarity in species diversity, life stages and environmental conditions may support the connectivity between the two areas for many groups, especially migratory and filter-feeding species. Nevertheless, future studies using non-lethal methods are needed to verify and monitor the behaviour and habitat usage of *M. thurstoni* at FNA.

This first occurrence of *M. thurstoni* at FNA adds the fifth mobulid rays species recorded in this very small tropical archipelago, along with *M. tarapacana*, *M. mobular*, *M. birostris* and *M.* cf. *birostris* (Soto 2001; Bucair et al. 2021a), representing 50% off all world known mobulid species to date. This richness is equal to or higher than many geographically wider world areas where the mobulid fauna is well known, like Australia, Borneo, the Mediterranean and the Caribbean Sea (Last et al. 2016; Stevens et al. 2018). The local oceanographic conditions together with food availability may favour the occurrence of filter-feeding species in the region, since oceanic islands and seamounts may also play as wildlife corridors for different marine species, facilitating the migration and dispersal of these organisms by providing areas for feeding and settlement (Hilty et al. 2020). The oceanic system of FNA is part of a transverse fracture zone of volcanic seamounts, located at the oriental extremity of the volcanic chain (750 km long), with an E-W orientation alignment that projects towards the coast of the Ceará State (Almeida 2006; Castro 2010). At the opposite end of the fracture zone, which extends off the continental shelf of the Ceará State, the occurrence of *M. thurstoni* was also reported (Jucá-Queiroz et al. 2008; Santander-Neto and Faria 2020), suggesting that this region may play an important role as a migratory corridor for the species.

The highly productive SPSP, adjacent to FNA (627 km distant), is a biologically important area of Brazil's northeast region, with a high richness of mobulids (*M. tarapacana*, *M. birostris*, *M. thurstoni* and putatively *M. hypostoma* and *M.* cf. *birostris*), coupled with favourable habitat for filter-feeding species, with approximately twice the zooplankton biomass compared to FNA (Campelo et al. 2019). The SPSP has been identified as an important habitat for the *M. tarapacana* and *M. thurstoni* (Mendonça et al. 2012, 2018, 2020; Hazin et al. 2018; McCallister et al. 2020).

However, knowledge of mobulids' population size and distribution along the Brazilian coast is scarce (Gadig and Sampaio 2002; Couturier et al. 2012; Stewart et al. 2018). Most incidences of bentfin devil rays are related to fishing landing and bycatch reports (Gadig et al. 2003; Casas et al. 2006; Jucá-Queiroz et al. 2008; Mas et al. 2015; Rotundo et al. 2019; Chelotti and Santos 2020; Santander-Neto and Faria 2020). Related to the need to enhance the knowledge

concerning mobulids in Brazil, recent studies focusing on ecology, biology and conservation were conducted by Luiz et al. (2009), Medeiros et al. (2015, 2021), Mendonça et al. (2018, 2020) and Bucair et al. (2021a, b). However, further effort and resources are crucial to substantiate the ecology of endangered mobulid species along the Brazilian coast.

Beyond the scarce information on living individuals, the identification of manta and devil rays has proven problematic, mainly due to the external resemblance of the various species (Couturier et al. 2012; Stevens et al. 2018). In Brazil, these batoids are referred to as "manta", "jamanta", "jamanta-mirim", "raia-diabo", "boca-de-gaveta", indicating the wide distribution of this group along the entire Brazilian coast, comprising at least six species of world mobulid fauna (Gadig and Sampaio 2002). Despite the lack of adequate data on the population parameters for most mobulid species in Brazil, regional taxonomic issues are relatively well solved. The first records of two large mobulids in the western Atlantic were based on Brazilian specimens of *M. mobular* (Gadig and Sampaio 2002, as *M. japonica*) and *M. thurstoni* (Gadig et al. 2003). Nevertheless, inaccurate records of mobulid species are common, particularly in field campaigns and fishery reports, where *Mobula* sp. or common names are used. Likewise, *M. thurstoni* is commonly confused with other species, especially *M. mobular* due to the dark mark on the back and bluish hue on the dorsal body surface and white tip of dorsal fin (Stevens et al. 2018). The inaccurate nomenclature and the use of a unique common term to refer to different species of elasmobranchs are underlined by Barreto et al. (2017) and Bornatowski et al. (2018); therefore, comprehensive assessments, species' distribution, threats and mitigation are hampered by imprecise records. Species-level records, especially of living individuals and their respective habitats, are extremely important to better understand the species' distribution and occurrence, as well as a strategic tool for effective conservation efforts.

The recognized occurrence of six mobulid species along the Brazilian coast endorses the high biodiversity and species richness in the country since there are currently ten acknowledged species worldwide. However, Brazil represents a major knowledge gap for mobulid ray research related to population parameters and distribution, and most data are from fishing records (many without species-level identification and inaccurate capture site). The water surrounding the FNA may constitute an important ecological area for mobulids, favouring the migration process, food resource or protection. Nevertheless, further studies are needed to better understand the habitat usage by the species. Methodologies such as satellite monitoring studies and citizen science approaches may represent great opportunities to obtain important data on these endangered species, especially in protected and monitored regions with high tourist activity, such as FNA.

Despite punctual, local occurrences are crucial to building worldwide distribution patterns and support effective management strategies for species conservation. Therefore, the occurrence of *M. thurstoni* at FNA accentuates the pressing need for validation of regional studies. Although preliminary, the data presented herein extend the known distribution area of *M. thurstoni* along the Brazilian coast and corroborate the richness of mobulid species in the Marine National Park of Fernando de Noronha, highlighting the importance of marine protected areas for species conservation. Also, the information presented herein is critical to raising awareness of the urgent need for directed studies, conservation and management actions for mobulid rays in Brazil.

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Author contribution NB designed and directed the study, wrote the manuscript, participated in the fieldwork, compiled, analysed and interpreted the data, edited the photos and assisted in figure development; SM edited the manuscript, assisted with the data interpretation and analyses and supported figure development; CA edited the manuscript and assisted with the data interpretation and analyses and figure development; BSR edited the manuscript and analysed the dataset; OBFG edited the manuscript, analysed the dataset and assisted in species identification. All authors read and approved the final manuscript.

Data availability The datasets generated and/or analysed during the current study are not publicly available due to photographic credits but are available from the corresponding author on reasonable request upon permission of the third party involved.

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 by citizen scientists and local companies, which allowed the use of the given images for scientific and educational purposes.

Competing interests The authors declare no competing interests.

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