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Short Communication

Underestimated threats to manta rays in Brazil: Primacies to support conservation strategies

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ABSTRACT

Manta rays are marine planktivorous elasmobranchs that are distributed worldwide and highly susceptible to overexploitation. Although they are legally protected in Brazil since March 2013, incidental and intentional captures still occur. The sharp population decline following the intensification of targeted fisheries and bycatch highlights the urgent need of manta ray protection. This study provides information on several threats to manta rays (*Mobula birostris* and *M.* cf. *birostris*) in Brazil, including the frequency and geographic extent of the occurrences and their fishing and entanglement with fishing gear. We analysed photo/video records, and the scientific literature reporting mobulids incidence and focused on events of entanglement in fishing gear, intentional and incidental caught of manta rays, obtained from 2000 to 2020. From a total of 270 records of manta rays' occurrences, 70 displayed wounds from anthropogenic activities, including 29 lethal records. Most of the injured individuals were recorded in the State of São Paulo (31.4%; n = 22), followed by Pernambuco (20.0%; n = 14), Rio de Janeiro (10.0%; n = 7), Bahia (8.6%; n = 6), Rio Grande do Norte (7.1%; n = 5), and Espírito Santo (5.7%; n = 4). Despite outnumbered, all manta rays' occurrences in the states of Rio Grande do Norte, Ceará, Sergipe, Pará, Piauí and Santa Catarina showed individuals either captured by fishers, with body scars or dragging fishing artefacts. The majority (61.4%) of injured individuals were recorded after the national protected status was implemented to the family Mobulidae, and all injuries observed were consequences of anthropogenic action. Our results highlight the diverse sources of threat and injuries patterns for manta rays in the nationwide territory and underscore the urgent need for monitoring fishing impacts and promoting effective enforcement of the national regulation for the protection of manta rays in Brazil.

1. Introduction

The sub-class of Elasmobranchii, which includes sharks and rays, is particularly vulnerable to overfishing, comprising mostly long-living species that grow slowly, mature late, and have low reproduction rates (Smallegange et al., 2020); accordingly several species

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are recognised as globally threatened (Dulvy et al., 2014). Severe reductions in elasmobranch populations were recorded in the last decades, resulting in demographic collapses at regional scales (Barausse et al., 2014; Baum et al., 2003; Booth et al., 2020; Marshall et al., 2020).

Manta rays (Family Mobulidae, Order Myliobatiformes) are large planktivorous elasmobranchs with worldwide distribution (Couturier et al., 2012). They represent the world's largest batoids and are highly susceptible to overexploitation. Additionally to other life history characteristics that increase their vulnerability to extinction, manta rays present long gestation with normally a single offspring and an interbreeding interval of 3–5 years (Couturier et al., 2012; Dulvy et al., 2014; Stevens, 2016). Consequently, population declines have been reported in various locations worldwide (Croll et al., 2016; White et al., 2006). The largest member of the family Mobulidae – *Mobula birostris* (Walbaum, 1792) – is listed as *endangered* (EN) to extinction on the IUCN Red List of Threatened Species (Marshall et al., 2020). The species is also listed on Appendix II of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), on Appendices I & II of the Convention on the Conservation of Migratory Species of Wild Animals (CMS), as well as on Annex 1 of CMS - Memorandum of Understanding on the Conservation of Migratory Sharks, which consider the unfavourable conservation status of species. In Brazil, *M. birostris* is classified as *vulnerable* (VU) according to the regional Red List of Brazilian Fauna Threatened with Extinction, which is based on IUCN criteria for regional assessments (ICMBio, 2018). In Brazilian jurisdictional waters and in all the national territory, the family Mobulidae is protected by law through the Interministerial Regulatory Instruction MPA/MMA N.02 of March 13th, 2013, which "prohibits direct fishing, retention on board, transhipment, landing, storage, transport, and any kind of commercialisation of the products or sub-products. If incidentally caught, individuals must be returned to the sea, alive or dead at the time of their capture".

The extensive Brazilian coast harbours a vast diversity of elasmobranch species (Oliveira et al., 2019; Rosa and Gadig, 2014; Vooren and Klippel, 2005; Lessa et al., 1999). Manta rays have been recorded along a wide latitudinal range, including tropical and subtropical locations, from the Brazilian equatorial region (~ 01°N) to southern Brazil (32°S), as well as in the Abrolhos archipelago (central Brazilian coast) and three oceanic systems: Fernando de Noronha archipelago; Saint Peter and Saint Paul's archipelago, and the Rocas Atoll (Bornatowski et al., 2009; Charvet et al., 2018; Cintra et al., 2015; Domit et al., 2017; Jucá-Queiroz et al., 2008; Kotas et al., 2017; Lessa et al., 2008; Luiz et al., 2009; Medeiros et al., 2015; Mendonça et al., 2012, 2018; Nobrega et al., 2009; Siqueira, 2013). Seasonal occurrences of *M. birostris* are known to occur on the southeast and the south coasts of Brazil, during the austral winter at the Laje de Santos Marine Park (PEMLS), State of São Paulo, suggesting favourable environmental conditions (Luiz et al., 2009) and during austral summer at the Paranaguá estuary, State of Paraná, depicturing breaching events (Medeiros et al., 2015). Recently, a juvenile manta ray feeding ground was recognised at Fernando de Noronha archipelago, State of Pernambuco, Brazilian northeast (Bucair et al., 2021).

Manta rays are increasingly targeted by fisheries in several parts of the world, particularly due to the high value of their gill plates that are used in traditional Asian medicine (Couturier et al., 2012; Stevens et al., 2018). Manta ray's products may be used in different ways: the meat serves for human consumption or to be used as bait, the skin can be served dried and deep-fried, and the cartilage is used as a filler for shark-fin soup (Camhi et al., 2009; White et al., 2006). In Brazil, manta rays are not of commercial interest and there are no legal fisheries targeting on them. Nonetheless, manta rays are still captured as bycatch and targeted by illegal fishing. Mazzoleni and Schwingel (1999) reported individuals of *M. birostris* landed at Itajaí Harbor, southern Brazil. Small-scale fisheries off Ceará State, northern Brazil, landed two specimens of *M. birostris* caught at Aracati Bank (Jucá-Queiroz et al., 2008). Santander-Neto and Faria (2020) report two specimens of *M. birostris* landed at Mucuripe Embayment, Fortaleza, Ceará State, by fishing fleet composed of rafts and small motor boats. Afonso et al. (2011), while performing an experiment aiming to reduce the elasmobranch mortality in longlines, captured three individuals of *M. birostris* in Pernambuco State, northeast Brazil. Couturier et al. (2012) indicate that bycatch of mobulids is relatively frequent in south-eastern Brazil. Siqueira (2013), analysed the capture of pelagic longline fishing boats of south/southeast Brazil and recorded 84 individuals of *M. birostris* captured between 2003 and 2006, most of them off the coast of Rio Grande do Sul and Santa Catarina states. Additionally, a trader survey on gill plates in China and south-east Asia conducted by O'Malley et al. (2017), reported that 9.0% of gill plates exports to the Asian market in 2015 was originally from Brazil. The country is the world's eleventh-largest capture producer of chondrichthyans (Dent and Clarke, 2015), but comprehensive assessments and mitigation of the impacts of industrial fishing are hampered by inaccurate records (Barreto et al., 2017) and imprecise nomenclature of elasmobranchs species sold in torn pieces in fishing markets (under the popular Portuguese name of *cação*, which may include species of both, sharks and rays) (Almerón-Souza et al., 2018; Bornatowski et al., 2018, 2015).

In addition to the illegal fishing, incidental capture, strengthened by the large manta ray body size (Pardo et al., 2016), as well as ghost fishing (i.e. the entanglement of animals in derelict fishing gear and marine debris) are serious threats for manta rays (Marshall et al., 2020); they may decrease fitness or contribute to their non-natural mortality (Stevens et al., 2018). Manta rays are large pelagic filter-feeding species (Couturier et al., 2012) that must be in a constant forward motion to breathe. If they are prevented from swimming, as is often the case when become entangled, they soon will be asphyxiated (Stevens et al., 2018). Displays of cruising and feeding behaviour near-surface during daylight, as well as night feeding in shallow waters, enticed by zooplankton vertical migration (Rohner et al., 2017), are commonly observed, which raises the risk of boat strike (McGregor et al., 2019) and make them highly susceptible to entanglement in fishing lines and nets (Croll et al., 2016; Heinrichs et al., 2011). Mobulids captured in gillnets, longlines, trawlers, purse seine, and trap fisheries have been reported throughout their range (Croll et al., 2016). Furthermore, it is not uncommon to observe individuals of manta rays missing body parts (severed) and/or with injuries caused by fishing lines and nets, as well as carrying fishing artefacts (Marshall et al., 2020).

Brazil represents a major knowledge gap for manta ray research. Currently, there are only three scientific publications focused on manta ray population structure and ecology (Bucair et al., 2021; Luiz et al., 2009; Medeiros et al., 2015), with a relatively limited geographic coverage. Mantas ray's threats were never highlighted in previous studies in Brazil, although opportunistically, manta rays are listed in fisheries surveys, landing reports, or even occasional catches reported in local media and newspapers. The recognition of

the national threats is critical for the development of effective local management, for establishing baselines for conservation strategies and decision-making, as well for encouraging further studies in the country. Hence, through the compilation and analysis of a nationwide dataset, this study aims to (i) provide information on the several threats that manta rays are being exposed to and (ii) evaluate the frequency and geographic extent of fishing and entanglement of manta rays with fishing gear in Brazil. This information is critical to raise awareness on the urgent need for more efficient conservation, management, and enforcement actions for manta rays in Brazil.

2. Material and methods

Considering the entire Brazilian coast, the following information were considered: (1) photo and video records from research efforts, (2) images obtained through citizen science, and (3) literature data. All records for the target species were evaluated (n = 270), and potential records of entanglement in fishing gear, intentional and incidental caught of manta rays, obtained from 2000 to 2020, were analysed.

2.1. Research effort

Data were obtained by researchers (including the first and senior authors) and volunteers of the *Projeto Mantas do Brasil*, an initiative of the non-governmental organisation (NGO) *"Instituto Laje Viva"*, which is dedicated to gather information and promote the conservation of manta ray species in Brazil. Beyond others, the methodology used for this purpose is based on observations, photo-identification, and social and educational initiatives in order to engage society and to support decision-making in favour of the species preservation. Although active throughout the year, field campaign and effort directed by the NGO in the southeast region is mostly restricted to the austral winter (manta ray season). Additionally, occasional field campaigns in the northeast also occur. Finally, the NGO's researchers, volunteers and partners, based especially at São Paulo, Rio de Janeiro, Espírito Santo, Bahia, Pernambuco and Ceará States collect opportunistic data for photo-identification and species occurrence all year round.

All data is compiled into a nationwide photo-ID catalogue, the Brazilian Manta Ray database – BBM (https://www.mantasdobrasil.org.br/), which is under the curation of the *Projeto Mantas do Brasil*. The images allow identification (based on the unique ventral pigmentation patterns), sightings and re-sightings of manta rays over space and time of the different individuals (Marshall et al., 2011).

2.2. Citizen Science contribution

The *Programa Cidadão Cientista*, an initiative of the *Projeto Mantas do Brasil*, aims at raising awareness and training for society to actively contribute to the research and conservation of marine species and the environment. Citizen Science can provide valuable information about the occurrence and distribution of species, especially within countries with wide geographic dimensions, such as Brazil. Although not a traditional data source, citzen science is a remarkably successful tool to understand species distribution and threats (Bonney et al., 2009). Opportunistic records obtained by recreational SCUBA divers, together with reports of captures and landings along the Brazilian coast, with positive identification for manta rays, were considered.

2.3. Scientific literature review

To date, considering the 3 scientific papers regarding the manta ray ecology in Brazil, two of them (Bucair et al., 2021; Luiz et al., 2009) exploit the same database – BBM – as the present study, and the remnant (Medeiros et al., 2015), explored the species behaviour. Therefore, published records (n = 16) of scientific experiments, bycatch, and fishing landings of manta rays in Brazil were considered (see Appendix A for details). For this purpose, general search terms as "manta ray", "mobula", "bycatch", "incidental fisheries", "elasmobranch", "*Manta birostris*", "entanglement", "fishing" and "ghost fishing" were used, as well as the following Portuguese words: "raia manta", "arraia", "jamanta", "raia gigante", "pesca de raia" and "captura de arraia" in *Web of Science*, *Scopus, Google Scholar* and *ResearchGate* platforms.

2.4. Dataset

Species were determined as per Marshall et al. (2009) and 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 unknown (i.e. cases in which the distinction between the two species was not possible). Species discrimination was based on 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, the colouration of the ventral pectoral fin margin, the marked pattern of the dorsal colouration and the presence or absence and size of a calcified mass at the caudal base.

Body size estimates (disc width - DW - measured between the tips of the pectoral fins) were made directly by a trained observer where possible, through comparisons with objects, divers and fauna of known size in the images/videos, and by compiling data published in scientific studies. All records of animals with attached fishing gear, dead or showing evidence for entanglement (i.e. marks, injuries and scars of fishing gear or clutched in mooring lines) were associated with the type of injury and the cause of threat (Fig. 1).

Only images containing metadata (location and date of record) were used. Data were organised by date, location (Brazilian states

and municipalities), animal condition (dead/injured/not injured), fishery type (incidental/intentional/ghost fishing) and injury type (dragging/severed/scar, with associated fishing artefact).

2.5. Data analyses and considerations

The majority (86.3%) of our dataset were obtained from scuba diving (scientific effort of *Projeto Mantas do Brasil* plus citizen science contributions), 6.0% from scientific publications, all regarding elasmobranch fishing and bycatch, and the remaining 4.2% were reports provided by civilians on illegal captures and landings. Beyond the species-specific referred in the scientific literature, in all cases, data was accompanied by images (granting the identification of the species) containing metadata.

Fishery catches that resulted in the animal's death were subsequently associated with the type of capture. The sublethal threats, analysed through image records, were initially divided into natural or anthropogenic causes. The latter were correlated with the potentially used gear/device, considering the wound size, location, and shape. Furthermore, to evaluate the damage extent of injuries and entanglement scars, the body structure of manta rays was divided into: head, central part of the body, pectoral fins (wings) and tail (Fig. 2). Alive specimens with multiple wounds in different body parts were classified as 'multiple' injuries, and dead animals were not associated with injuries to specific body parts. Nevertheless, all injuries (lethal and sublethal) were related to a possible cause and threat.

Despite the expected and known occurrence of manta rays along the entire Brazilian coast, records not included in the BBM, lacking images or with poor quality visual records, unofficial, imprecise, and unpublished information, mostly related to fishery landings and bycatch of mobulid species in Brazil, with no species-level identification, were considered unreliable and not included in our analyses.

Fig. 1. Injuries and scars on manta rays in Brazil. (a) and (b) Severed cephalic fin (photo: Mauricio Andrade and Gustavo Fleury); (c) and (d) irregular scarring possibly from fishing line and nets (photo: Leo Francini and Rawany Porpilho by Dolphin Eye); (e) injuries to pectoral fins caused by incision from fishing lines (photo: Leo Francini). All pictures were granted from the Brazilian Manta Ray database (BBM, https://www.mantasdobrasil.org.br/).

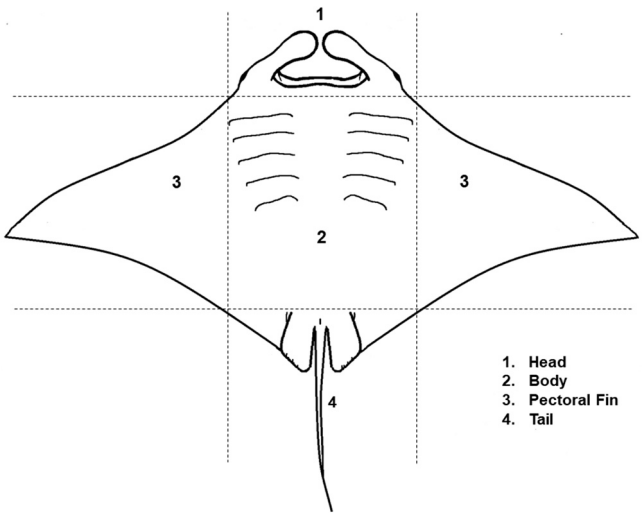

Fig. 2. Diagnostic division of the manta ray body. Manta ray's body structure divided into segments for which injuries were recorded: head (1), central part of the body (2), pectoral fin (3) and tail (4). Illustration by Otto B. F. Gadig.

3. Results

From a total of 270 records of manta rays in Brazil, obtained between 2000 and 2020, the slight majority (54.1%, n = 146) were identified as *M. birostris,* followed by *M.* cf. *birostris* (35.6%, n = 96). The remaining 10.3% were classified as unknown species (i.e inconclusive distinction between the two species) (Fig. 3).

Considering the total dataset, in 25.9% (n = 70) of the records manta rays were wounded to some degree (Table 1). In 41.4% (n = 29) of these, the impact was lethal, with records of dead manta rays on boat decks or whole bodies carried or being sliced on public markets and beaches (Figs. 5 and 7). Intentional captures were recognised as the cause of 51.7% (n = 15) of dead animals, the remaining mostly related to incidental catch. Manta rays showed injuries in different parts of the body (ventral/dorsal surface, head, pectoral fins and tail) in 58.5% (n = 41) of the injured records, although none of them presented signs of natural predation (e.g. shark bites). Therefore, all the animals classified as "injured" in this study showed clear signs of human-induced wounds (e.g fishery, entanglement in fishing gear, or tangle in mooring ropes).

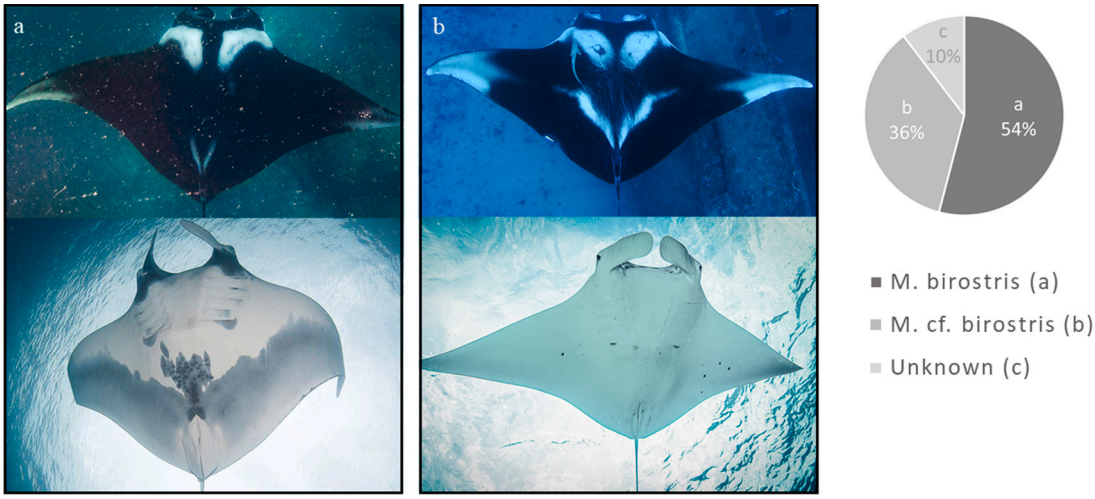

Fig. 3. Distinctive colouration patterns of *M. birostris* and *M.* cf. *birostris*. (a) *M. birostris* with regular colouration pattern, dorsal surface (top) and ventral marks (bottom), and (b) common colouration exhibit for *M.* cf. *birostris*, well defined dorsal marks (top) and light colour on the ventral surface, with pigmentation spots on pectoral fins and abdominal region (bottom). The pie chart gives the proportion of occurrences for (a) *M. birostris*, *(b) M.* cf. *birostris*, and unknown (i.e. the distinction between the two species was not possible). Photo credits and description: (a) State of São Paulo (© Leo Francini), at Parcel Dom Pedro in 2016 (top) and Queimada Grande in 2014 (bottom); (b) State of Pernambuco, at Recife in 2018 (top - ©Rawany Porfilho/Dolphin Eye) and Fernando de Noronha archipelago in 2017 (bottom - ©Nayara Bucair/All Angle Images). All images were granted from the Brazilian Manta Ray database (BBM, https://www.mantasdobrasil.org.br/).

Table 1
Summary of the total record, by species and animal condition (healthy, injured or dead).

	Total (n)	Not injured	Injured	Dead
Mobula birostris	146	110	23	13
Mobula cf. *birostris*	96	78	11	7
Unknown	28	12	7	9
Total	270	200	41	29

Among the wounded animals (injured and dead), 31.4% occurred off the coast of São Paulo state (SP, n = 22), followed by Pernambuco (PE, 20.0%; n = 14), Rio de Janeiro (RJ, 10.0%; n = 7), Bahia (BA, 8.6%; n = 6); Rio Grande do Norte (RN, 7.1%; n = 5), and Espírito Santo (ES, 5.7%; n = 4). The remaining occurrences were reported for the states of Pará (PA), Ceará (CE), Piauí (PI), Sergipe (SE), and Santa Catarina (SC) (Fig. 4).

The states of PA, PI, CE, RN, SE, BA, ES and SC had relatively high proportions of wounded individuals (Fig. 4), with manta rays being either killed by fishers, enmesh or trapped in fishing gear (net or trap fishery), displaying scars on their bodies or dragging entangled fishing gear. A total of 26 manta ray specimens captured under artisanal fishery were recorded to be mainly impacted by gillnets. For the records in which manta rays were accidentally trapped and entangled in the fishing net or line, the animals were captured and occasionally dragged to the beach, killed, and had their bodies sliced for a possible trade, sharing and/or consumption. Local statements allege the meat sold for up to R$5,00–R$6,00/kg (local currency). Fig. 5 features an event of a manta ray incidentally captured by gillnet, in which the fishermen claimed lack of boat structure to support the animal release. After capture, the animal was towed to the beach, where it was sliced into pieces. Fig. 5d and e reveals the remaining animal discards, comprising the head and the manta ray intact gill plates.

By analysing the injuries and entanglement scars, it was possible to address the impact of fishing on different body parts of manta rays and to infer the type of fishing gear causing the wounds. Injuries were most frequent on the pectoral fins (20.0%; n = 14), followed by the head (mainly on the cephalic fins; 11.4%; n = 8), tail (2.8%; n = 2) and central part of the body (both on dorsal and ventral sides; 2.8%; n = 2). Wounds induced by fishing lines were characterised by incisive and linear marks (Fig. 1e), occasionally causing truncations, mutilation (i.e. cutting off animal's body parts) or disfigurements (Fig. 1a). These latter types of injuries were observed primarily on the head and pectoral fins of the manta rays. Entanglement with fishing nets caused multiple wounds, mostly on the central part of the body. It was not possible to distinguish a particular body part affected by injuries in 62.8% (n = 44) of the cases, due

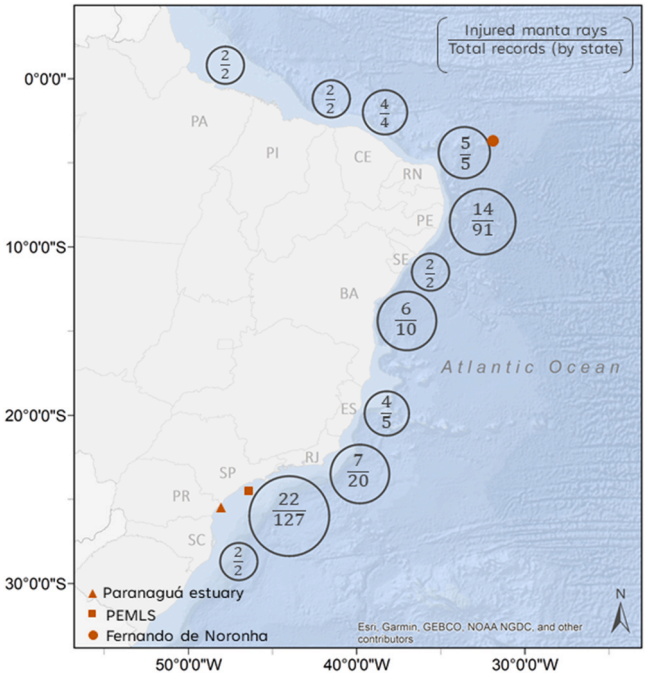

Fig. 4. Occurrences of Manta ray in Brazil, highlighting injured animal per total records by State. The number of fishing/entanglement events recorded for manta rays across the Brazilian coastal states. Circle sizes are proportional to the magnitude of the impact (lethal and sublethal). The number of injured animals per total number of records per state are given inside the circles. Regions of regular and known occurrences are highlighted in the map (Paranaguá estuary, PEMLS - Laje de Santos Marine Park, and Fernando de Noronha archipelago). PA = Pará, PI = Piauí, CE = Ceará, RN = Rio Grande do Norte, PE = Pernambuco, SE = Sergipe, BA = Bahia, ES = Espírito Santo, RJ = Rio de Janeiro, SP = São Paulo, PR = Paraná, and SC = Santa Catarina.

Fig. 5. Lethal threats to manta rays in Brazil. (a) Manta ray being sliced at an urban beach in Vila Velha (ES) – 2016. (b and c) Animal handling on the beach with the presence of fishermen and other civilians. (d and e) Remaining body parts (the head and the branchial filaments) discarded by local fishermen.

to lethal impacts or the occurrence of multiply scars and injuries all over the body.

Ghost fishing, a well-known hazard for manta rays, was also revealed in our results, with records of animals trapped in fishing gear adrift in the ocean (Fig. 6). Among the injured records, 34.3% (n = 24) of occurrences included animals that were dragging some kind of fishing gear, mainly on the edge of pectoral fins and cephalic fins, generally associated with profound scars (suggesting incisive line cuts) and amputation of body parts. In 12 different occasions, manta rays were dragging fishing gear (hook/line or fishing net) attached to the body. In some of these entanglement events, the rescue was possible (Fig. 6c), but without the certainty of the animal's survival and/or extension of damage.

4. Discussion

Threats to the manta ray populations in Brazil are real, although, due to lack of data, are still underestimated. Our results highlight the different sources of threats that manta rays are subject to in Brazilian waters, even with protective national and international legislation in place. Considering the entire dataset, 25.9% of the individuals displayed injuries from anthropogenic effects (fishery, bycatch, or ghost fishing). The pattern of injuries varied along the Brazilian coast. In locations with a greater number of sightings (São Paulo, Rio de Janeiro and Pernambuco states), the injures were mostly related to ghost fishing. In the remaining states, most injuries

Fig. 6. Featured ghost fishing images. (a) Manta ray observed with fishing net entangled on the cephalic fin at Laje de Santos – São Paulo (2007); (b) Manta ray carrying a portion of fishing net in the cephalic fin at Abrolhos - Bahia (2016); and (c) manta ray entangled in boat bridle rope. All pictures were granted by the Brazilian Manta Ray database - BBM (https://www.mantasdobrasil.org.br/).

were related to fishery captures that resulted in death, with 61.4% of the cases occurring after the formal protection of mobulids started in Brazil.

In our dataset, most individuals were identified as *M. birostris* (54.1%). In 35.6% of the records, the individuals matched with the characteristic of the putative new species *M.* cf. *birostris* (n = 96), yet to be described, proposed by Marshall et al. (2009) and supported genetically by Hinojosa-Alvarez et al. (2016) and Hosegood et al. (2020). Thus, our study provides evidence for the occurrence of the putative new species of manta ray in the Southwestern Atlantic, primarily in northeast Brazil (Pernambuco, Bahia, Rio Grande do Norte and Sergipe), yet with inchoate records in the southeast region (Espírito Santo and São Paulo). In the remaining 10.3% of the records, the distinction between the two species was not possible due to the lack of two or more characteristics (like ventral pigmentation spots setting, dorsal and ventral colouration patterns and the calcified mass on the base of the caudal fin), with individuals therefore classified as unknown.

Natural mortality of manta rays appears to be low and opportunistic, with shark predation as the most probable cause (Couturier et al., 2012). Sightings of shark attacks on living manta rays are rare, although shark-inflicted bite marks may be frequent in certain regions. Studies on signs of shark predation in reef manta ray populations were estimated at 76.0% in Inhabane, Mozambique (Marshall and Bennett, 2010), 33.0% in Maui, Hawaii (Deakos et al., 2011), and 2.7% in the Ningaloo Coast, Western Australia (McGregor et al., 2019), with most evidence of shark bites recorded for the posterior edge of the pectoral fins. A comparison with sublethal shark bite observations from other studies suggests no records of manta rays with shark-inflicted bite injuries in our 20-year dataset, considering both, juveniles and adults individuals of manta rays. The lack of bite injuries on manta rays may be associated with the low density of sharks along the Brazilian coast caused by decades of overfishing (Luiz and Edwards, 2011; Morais et al., 2017). Therefore, all injuries and threats observed here were considered as consequences of anthropogenic actions.

Analysing the geographic extent of fishing and entanglement of manta rays in Brazil, considering the injured animals (n = 70), 47.1% of the records were from the southeast coast (comprising the states of São Paulo, Rio de Janeiro, and Espírito Santo), and were mostly associated with ghost fishing and incidental capture. Except for two occurrences recorded in the south region, the remaining 50.0% correspond to occurrences in the Brazilian north and northeast region, which were largely associated with incidental and intentional capture (including animals incidentally trapped in gillnets that were further landed, for supposedly trading), with records of dismemberment of the animal's body parts, as well as whole specimens upraised in fishing markets in smaller and secluded regions. Most lethal records were associated with unique individuals landed by small artisanal fishing boats/structures.

Size estimates of animals, published or performed through the comparison with objects of known size in images, indicated that manta rays captured and/or landed in the north and northeast coast of Brazil had disc widths no larger than 3 m. When observed, the male reproductive organ was consistent with undeveloped clasper, indicating immature individuals. This latter result corroborates the occurrence of a manta ray juvenile population in an oceanic system in northeast Brazil (Bucair et al., 2021), as well as the occurrence of juvenile *M. birostris* reported at Caiçara do Norte – RN (Yokota and Lessa, 2006), and along the inner continental shelf of the Ceará State (Jucá-Queiroz et al., 2008, DW = 2,07 m). The rare records from the north region include a report at Pará State (Cintra et al., 2015, DW = 2,80 m), and occurrences at Piauí State (Nobrega et al., 2009, DW = 1,97-2,36 m). This information demonstrates the high fishing pressure to which immature individuals are subjected and highlight the need to understand the possible consequences to demography of manta rays in Brazil.

The higher number of records for the states of São Paulo and Pernambuco (n = 22 and n = 14 from 127 and 91 records, respectively), may reflect the fact that sightings are likely higher due to the intense scuba dive practice in both areas and the regular seasonality of manta rays occurrence in São Paulo (Luiz et al., 2009), as well as the high elasmobranch research effort at the Pernambuco state (Afonso et al., 2011; Lessa et al., 1999; Mendonça et al., 2018, 2012). Scarcity of data for other locations does not mean that manta rays are not under threat, but rather reflect low sampling effort.

The vast extent of the Brazilian coastline and the increasing fishing pressure due to the emerging demand for manta ray products suggest that the threats identified in this study are probably underestimated. The majority (86.3%) of our dataset were obtained from scuba diving (scientific effort of *Projeto Mantas do Brasil* plus citizen science contributions), which is restricted to relatively small sampling areas where diving tourism is popular, mostly in the southeast and northeast Brazil. Even so, anthropogenic effects were detected. Parton et al. (2019), underscores the current importance and contribution of a methodical social network to monitor pelagic species and highlights the family Mobulidae as one of the 14 most reported and affected species by anthropogenic marine debris (e.g. ghost fishing).

Entanglement of manta rays with derelict fishing gear (e.g. "ghost nets") are not uncommon (Marshall et al., 2020). Once trapped, the individuals can carry fishing gears for years, causing body cuts and maiming or severed body parts. Depending on the fishing gear (especially ghost nets) it can prevent or hinder the ray to swim properly, which limits feeding, breathing and can eventually lead to death (Parton et al., 2019). Despite having a strong tradition in fisheries (including the diversity of resources, the extensive coast, and social aspects involving small and medium scale fisheries and coastal communities), Brazil is still deficient regarding information about surveillance, enforcement, direct impacts of fishing on manta rays, as well as indirect impacts of fishing-related debris in marine species (Link et al., 2019). Considering our results, 58.5% (n = 24) of the alive but injured animals recorded, were from manta rays either trailing hook, line, and/or net or with body scars and cut-offs possibly caused by fishing gear. Currently, the long-term and the true scale of these impacts on individuals that survive entanglement (e.g. gillnet and mooring ropes) or fishery with direct confrontation with fisherman (e.g. harpoon, hook and line, including cut-offs to preserve fishing gears) are not known; nor whether foraging and swimming efficiency is impaired and if there are any impacts on fecundity (Germanov et al., 2019). Thus, future studies are warranted.

In 21,4% (n = 15) of the records, it was not possible to distinguish a particular body part affected by anthropogenic activities. Lethal reports were largely (n = 29) associated with intentional and incidental capture. Most incidental catches were associated with

longline or fishing net. The fishery classified as intentional, in which animals are brought (towed) to land (or onboard) and then killed and torn into pieces to be traded or shared, comprised 51.7% (n = 15) of the captured animals. However, the representativeness of this practice is plausibly underestimated. Intentional fishing is illegal and raises concern. Most of the captures and entanglement records (61.4%; n = 43) considered here occurred after the implementation of the regulation that protects manta rays in Brazil (Interministerial Regulatory Instruction MPA/MMA N.02 of March 13th, 2013), with clear evidence for the occurrence of prohibited activities such as manta rays being captured, dragged alive to land or onboard to be further sliced in pieces in public areas (Fig. 7; see Appendix A for details).

The mobulid fishery is considered unsustainable and populations are declining on a global scale due to both, targeted fisheries and indirect anthropogenic threats (Andrzejaczek et al., 2020). The demand for gill plates has fuelled an international trade that is supplied by the largely unmonitored and unregulated target and incidental fisheries around the world (Lawson et al., 2017). Camhi et al. (2009) cite Brazil as one of the countries that contribute to the target fishery of manta rays with the use of harpoon and gillnet. Wu (2016) and O'Malley et al. (2017) referred to Brazil as one of the representativeness of gill plates suppliers for the Asian market. Fisheries catches of manta rays are poorly documented in the Brazilian territory, but they are known to be taken by surface gillnets, longlines, purse seines and harpoons, and kept for their meat and gill plates. However, the species are still treated as with no commercial value and not fishery targets in Brazil. The rising demand of the products for gill plates and meat (O'Malley et al., 2017; Ward-Paige et al., 2013), associated with unregulated bycatch, unreported and unregulated fishing in Brazilian jurisdictional waters, contribute to local and global population declines and support the illegal wildlife trade that elevates the risk of the species to extinction. Context-dependent and adaptive management solutions are important for manta ray populations conservation and recovery. Brazil urgently needs to restructure its fishery information collection systems, management strategies and labelling regulations for fish commercialisation (Barreto et al., 2017; Martins et al., 2018).

Alarming records of mobulid species incidentally caught were reported mainly to the Brazilian south and southeast region (Mas et al., 2015; Perez and Wahrlich, 2005; Siqueira, 2013). This evidence highlights the impact of incidental capture on mobulids in Brazilian jurisdictional waters. Nevertheless, unprecise identification and misidentification of the family Mobulidae are problematic, which makes it difficult to assess species distribution and seasonality patterns, fishing pressure, and the real extent of threats to specific species.

Bornatowski et al. (2018) emphasise the threats of the misclassification of ray's species in fisheries, as well as mislabeling of elasmobranch species sold under a unique trade name (cação), which puts in risk several threatened species. In general, at the national territory, the common names of "raia manta", "raia diabo", and "jamanta" were observed to be used for 6 different species of mobulids (*M. mobular, M. hipostoma, M. tarapacana, M. thurstoni, M. birostris* and the proposed *M.* cf. *birostris*). The inaccurate nomenclature, associated with the deficient dissemination of information regarding the protected status of mobulids in Brazil (especially for remote localities and artisanal fishing grounds), as well as the lack of enforcement, hamper the effort for conserving the species. Proper characterisations and quantification of manta ray's fishing practices, bycatch, entanglement, the impact on individuals and populations are critical for effective regional management of mobulid populations (Stewart et al., 2018). Threats to manta rays in Brazilian jurisdictional waters are plausibly intense and is still poorly documented, even though they are protected by the national directive and supported with international recommendations.

Knowledge of manta ray's population size and distribution along the Brazilian coast are scarce. Even though primarily, our results highlight the occurrence and local threats to manta rays in almost all coastal states in Brazil, including catches with gillnets, longline, harpoon and trawl. Underlining the fishing pressure considering both, directed and incidental captures, as well as entanglement as great threats and harm to the species. Captures of small size manta rays reported along the north and northeast coast of Brazil implies an even greater concern. However, factors including illegal, unreported, and unrecorded fisheries suggest that manta ray captures and landings in Brazil are likely to be significantly higher than what we could assume.

The conservation of species and natural ecosystems ensures the sustainability of natural resources. Manta rays, as large-size filter-feeding species, are considered secondary consumers that ingest large quantities of plankton and small pelagic fish (Couturier et al., 2013). Together with other giant planktivorous elasmobranchs, they can provide high socio-economic benefits through ecotourism and also have an important ecological role as a concentrated food source to the deep ocean ecosystems as carcasses (Burgess et al., 2016).

The declining trend of manta ray populations is concerning (Marshall et al., 2020). The multitude of threats and the degradation of the marine and coastal environments associated with high fishing pressure, entanglement and incidental capture may affect the species survival and the ecosystem balance. Our data highlight the presence of different types of injuries and threats that currently affect manta ray species in the Brazilian national territory, highlighting the need for monitoring of fishing impacts and more effective enforcement of the national regulation for the protection of manta rays in Brazil.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Fig. 7. Manta ray fishing in Brazil. (a) Salvador - Bahia, 2014; (b) and (d) Salvador -Bahia, 2020; (c) Vila Velha- Espírito Santo (2016); (e) Sergipe, 2019; (f) Sergipe, 2020. All pictures compiled and granted by BBM (Brazilian Manta Ray database).

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Appendix A. Supplementary data

The complementary data to this article include the dataset to assist in the result interpretation, as well as data replicability. The

spreadsheet is organised by: Date; Local (State and specific site when applicable); Species; Animal Condition (dead/injured/not injured); Injury Location - Body part (i.e. head/central body/pectoral fin/tail/multiple/ or dead); Fishery Type (intentional/incidental/ghost fishing, the latter was classified within 'dragging', 'severed', or 'scar'); Fishing Artefact (hook/line, net, longline, harpoon, or undefined); and identification (BBM_ID/Literature Reference).

Appendix B. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.gecco.2021.e01753.

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