

BRIEF COMMUNICATION**Occurrence and use of an estuarine habitat by giant manta ray *Manta birostris***

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Based on the knowledge of local artisanal fishermen and on direct observations, this study presents evidence that the giant manta ray *Manta birostris* uses the Paranaguá estuarine complex in south Brazil, south-western Atlantic Ocean, in a predictable seasonal pattern. Behavioural observations suggest that the estuary can act as a nursery ground for *M. birostris* during the summer.

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Understanding the habitat requirements of threatened species is essential for implementing effective management and conservation strategies to protect individuals and the area (Hamann *et al.*, 2010). Some large pelagic vertebrates can be distributed across wide areas, by using different marine environments and having a highly migratory behaviour (Block *et al.*, 2011). They can travel thousands of km, sometimes performing transoceanic migrations (Bonfil *et al.*, 2005). These aspects bring some challenges such as knowledge about spatiotemporal patterns of occurrence and critical habitats (Gredzens *et al.*, 2014).

Manta rays (*Manta* spp., Mobulidae, Myliobatiformes) are the world's largest batoids, reaching disc widths (W_D) of up to c. 7 m and weighing more than 1350 kg (Bigelow & Schroeder, 1953; Marshall *et al.*, 2009), but with low fecundity and growth (Marshall *et al.*, 2011a). The genus *Manta* has recently been divided into two species (Marshall *et al.*, 2009): the reef manta ray, *Manta alfredi* (Kreffft 1868), and the giant manta ray, *Manta birostris* (Walbaum 1792). The division is a result of taxonomic and ecological studies that considered habitat use and data on distribution patterns (Marshall *et al.*, 2009). The genus is listed by the International Union for Conservation of Nature (IUCN) as vulnerable to extinction (Marshall *et al.*, 2011a).

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In 2013, it was included in the Appendix II of the Convention on International Trade in Endangered Species of Wild Flora and Fauna (CITES). Furthermore, the directed fishing and marketing of species, products and by-products of Mobulidae have been prohibited in Brazilian waters and national territory (Brasil, 2013).

Manta spp. is known to be migratory and epipelagic planktivores, but in spite of its large size and the growing number of published studies on the genus, their biology is poorly known (Couturier *et al.*, 2012). The species present some degree of habitat segregation (Kashawagi *et al.*, 2011). *Manta alfredi* is a semi-circumglobal and tropical species, which is characterized by occurring in large groups near coral reefs and rocky shores. Several of these established aggregation sites are currently being monitored worldwide (Deakos *et al.*, 2011; Marshall *et al.*, 2011b; Jaine *et al.*, 2012; Kitchen-Wheeler *et al.*, 2012). Furthermore, data show that this species does not occur in the east Pacific and west Atlantic Oceans (Kashawagi *et al.*, 2011).

In contrast, *M. birostris* is a cosmopolitan, more cold-water tolerant, pelagic, solitary and migratory species that is commonly sighted offshore (Marshall *et al.*, 2009; Kashawagi *et al.*, 2011). Notwithstanding their divergent distributions, both species demonstrate habitat fidelity and seasonal aggregation behaviours (Marshall *et al.*, 2009). The oceanic and migratory behaviour of *M. birostris* is based on the rarity with which this species has been observed near the coast (Kashawagi *et al.*, 2011; Rohner *et al.*, 2013) and the seasonality of the few aggregations recorded (Luiz *et al.*, 2009; Rohner *et al.*, 2013). In fact, preliminary studies using pop-off satellite tags, along with international photo-identification projects, have revealed little exchange between regional populations, and it is still uncertain whether *M. birostris* undertakes long-range migrations (Couturier *et al.*, 2012; Graham *et al.*, 2012). Owing to its coastal and residential behaviour, *M. alfredi* is more accessible to researchers and scuba divers than *M. birostris*. In fact, after the split of the genus, it was realized that most of the research carried out until now had been about *M. alfredi* (Couturier *et al.*, 2012). Therefore, despite the increasing scientific attention to manta rays in general, more information is required about the biology and ecology of *M. birostris* to support conservation management.

M. birostris has been reported within estuaries on the south-east coasts of the U.S.A. and South America, near the northern and southern limits of their western Atlantic range. Early last century, at Cape Lookout, North Carolina, 11 *M. birostris* including a pregnant female were collected (Coles, 1916). In the Cape Fear Estuary, in the same state, four records of individuals ranging in size from 1.5 to 4.0 m W_D were collected during 1977, 1978, 1981 and 1999 (Schwartz, 2000). In the Indian River Lagoon, on the central coast of Florida, three individuals (1.5–4.0 m W_D) were recorded in 1993 and 1994 (Adams & Amesbury, 1998). Further south, in 2000, a single male was caught off Uruguay, at the mouth of the La Plata River (Milessi & Oddone, 2003). These infrequent observations support the idea that the presence of *M. birostris* in estuaries is generally regarded as accidental incursions of errant individuals (Adams & Amesbury, 1998; Milessi & Oddone, 2003).

In southern Brazil, seasonal offshore aggregations of *M. birostris* have been reported (Bornatowski *et al.*, 2009; Hackradt & Félix-Hackradt, 2009; Luiz *et al.*, 2009). Occurrences in coastal and estuarine areas, however, have also been noted, especially in the Paranaguá estuarine complex, south-western Brazil (PEC; 25° 30' S; 48° 25' W; Fig. 1) (Domit, 2006). The PEC has been part of a world heritage area, United Nations Biosphere Reserve since 1991. It is a large interconnected subtropical estuarine system

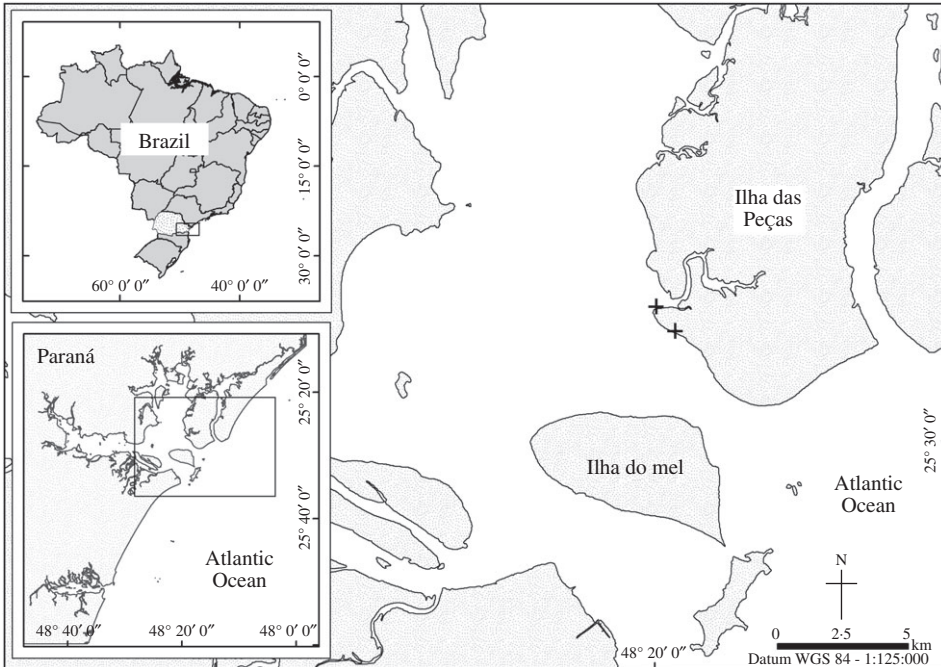


FIG. 1. The Paranaguá estuarine complex in southern Brazil. +, sampling positions.

covering an area of 612 km² and comprises the Paranaguá, Antonina, Laranjeiras and Pinheiros bays. The connection to the ocean is through three channels: Galheta (south mouth), Sueste and Norte (north mouth). The area comprises mangrove swamps, salt marshes and sandy beaches (Lana *et al.*, 2001). The horizontal seaward gradient of mean salinity ranges from 12–29 (summer) to 20–34 (winter) and mean water temperature ranges from 23 to 30° C during the summer and from 18 to 25° C during the winter (Marone *et al.*, 2005). The PEC has mean depth of 4.7 m and a maximum depth of *c.* 30 m. The tidal regime is semi-diurnal (with diurnal inequalities), with a range of up to 2.7 m, an ebb-tide velocity of *c.* 0.85 m s⁻¹ and 1.10 m s⁻¹ during the flood tide (Marone *et al.*, 2005).

The water inside the estuary is turbid, precluding underwater observations of *Manta* spp. Approaches based on assessing local ecological knowledge of resource users are a promising method for accessing long-term data on species distributions (Beaudreau & Levin, 2014). Thus, in order to investigate the temporal and spatial patterns of *Manta* spp. in the area, 20 local artisanal fishermen, aged between 28 and 73 years, living in a small fishing community (Vila das Peças; population 300) were interviewed. The interviews consisted of a semi-structured questionnaire designed to elicit perceptions on the distribution and behavioural aspects of *Manta* spp. inside the PEC. They were asked if they had seen *Manta* spp. in the PEC and to indicate, on a nautical chart (visual ethnographic method), the location and period (month and year). In addition, questions about interactions between fishing and *Manta* spp. were made.

The fishermen described *Manta* spp. as being big and heavy and locally known as 'jamanta'. They reported individuals that were larger than a 5 m W_D . All respondents

described the colour of *Manta* spp. as being black on the dorsal and white on the ventral surfaces, and added further details that match the description of *M. birostris*, as follows: ‘It has white spots on the head with a black cross in the middle’. Sixteen fishermen also reported the occurrence of a smaller ray, which they called ‘jamantinha’. The fishermen claim jamantinha are *Manta* spp. juveniles or adults of other mobula genera. Reports of older fishermen asserted that *Manta* spp. have regularly visited the PEC for at least the past 30 years, and typically between October and May, with peak occurrence in January, February and March (austral summer). Fishermen often associated the occurrences in that area with warm sea surface temperatures and believed that gravid *Manta* spp. enter the area in the summer to give birth. All interviewees had reported sightings of breaching events, which included both partial and complete emergence of *Manta* spp. from the water, followed by a subsequent drop in a belly-up position (backward somersaults).

After the interviews, field sampling was performed including directed observations during the reported periods of greatest *Manta* spp. occurrences in the PEC. Land-based observations were made by one observer on the *Ilha das Peças*, at random times between 0800 and 1800 hours, from December 2011 to May 2012, and between January and May 2013, comprising 257 and 181 h of observations, from two points of observation during 2011–2012 and one point in 2013. The number of *M. birostris* sightings was 99 during 2011–2012 and 147 in 2013. The sightings per unit of observation effort peaked in March during 2011–2012 and in February 2013, forming a gradual bell-shaped pattern of increase and decline in both years (Table I and Fig. 2).

Breaching events were the only behaviour recorded during the directed observational effort (Video S1, Supporting Information). The sightings mainly occurred between 10 and 1000 m distance from the coast (73%), but some sightings occurred up to 3000 m (27%). This behaviour comprised both partial and complete emergence from the water, of unique (37%) or sequential breaches (63%), repeating the operation in <30 s, one (60%) or two (3%) times. Most sightings involved backward somersaults; only three sightings were forward somersaults with a drop in the belly-down position (Fig. 3). Photo-identification to verify the number of individuals using the area and site fidelity was not possible. On two occasions on 19 February 2013, however, three *M. birostris* breached at the same time, indicating that more than one individual was in the area at the time.

TABLE I. Frequency of *Manta birostris* sightings by month in Paranaguá estuarine complex, southern Brazil, during the 2011–2012 and 2013 fieldwork campaigns

2011–2012	Sightings	Effort (h)	Sightings h ⁻¹	2013	Sightings	Effort (h)	Sightings h ⁻¹
December	0	43	0.00	–	–	–	–
January	1	58	0.02	January	16	40	0.40
February	8	28	0.29	February	111	42	2.64
March	79	70	1.13	March	13	35	0.37
April	10	38	0.26	April	5	28	0.18
May	1	20	0.05	May	2	36	0.06
Total	99	257	1.7	Total	147	181	0.81

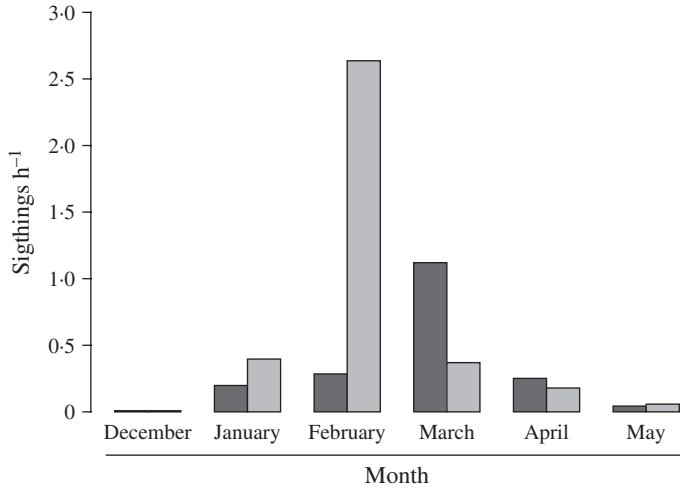


FIG. 2. Bell-shaped pattern of sightings of *Manta birostris* per unit of observation effort during 2011–2012 (■) and in 2013 (□)

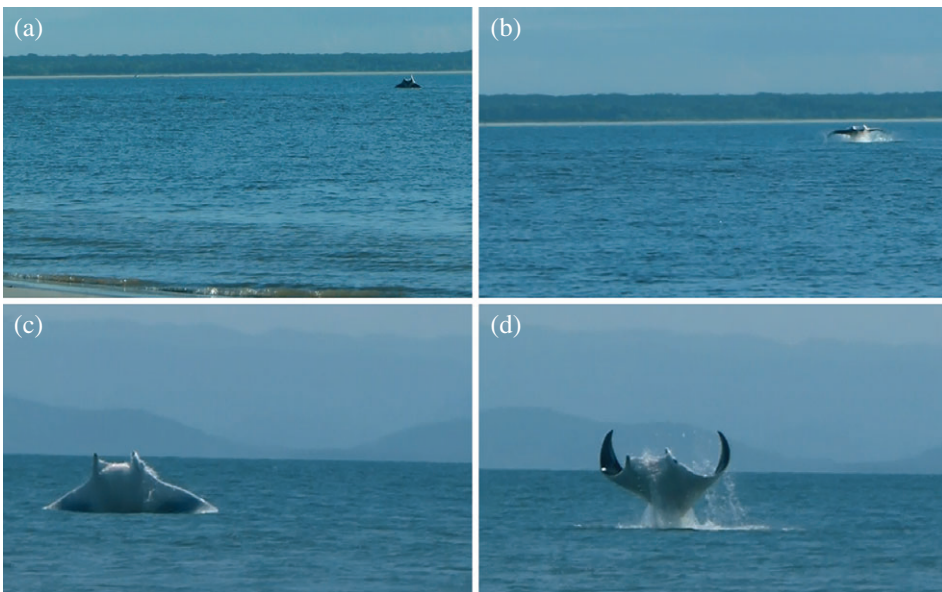


FIG. 3. *Manta birostris* performing breaching behaviour in the Paranaguá estuarine complex, southern Brazil: (a, b) backward somersault and (c, d) forward somersault.

The turbidity of estuarine waters makes *Manta* spp. hard to see if they are not breaching, so the present results can be alternatively interpreted as seasonal breaching behaviour. Reports from fishermen, which are based on different types of observations, including records of bycatch, damage to fishing gear and sightings, support the hypothesis that the presence of *M. birostris* occurrences inside the estuary is seasonal.

For instance, as *M. birostris* are of no economic value to fishermen, they restrict the use of gillnets and longlines between December and May, which they call ‘manta ray season’, so as to avoid accidental catches, which cause damage to the fishing gear.

Breaching behaviour is relatively common among *Manta* spp. (Rayner, 1986; Homma *et al.*, 1999). This behaviour may be related to mating displays, parturition, removing attached remoras (Echeneidae), playing and acoustic communication (Homma *et al.*, 1999; Deakos, 2010; Marshall & Bennett, 2010). Breaching events were also recorded in Cape Lookout Estuary, North Carolina (Coles, 1916). Other reports of *Manta* spp. in estuarine waters of the northern hemisphere include pups, juveniles and adults between 1.5 and 4.0 m W_D (Adams & Amesbury, 1998; Schwartz, 2000). In Mozambique, 90% of the observed breaching events occurred during the period of courtship and mating (Marshall & Bennett, 2010), suggesting that breaching may be linked to the reproductive behaviour of *M. alfredi*. Events of pregnancy occurrences, however, were monitored using photo-identification and individual re-sighting and no parturition was observed in the wild.

Manta spp., as with all Myliobatiform stingrays, have a characteristic viviparous reproductive mode called lipid histotroph. The placenta is not formed, but the uterine mucosa develops glandular trophonemata, responsible for lipid-rich secretions of histotroph or uterine milk, enabling the embryo to increase in size significantly during gestation (Wyffels, 2009; Tomita *et al.*, 2012). *Manta* spp. give birth to a single pup, after a gestation period estimated at 1 year (Marshall & Bennett, 2010). The only pupping event documented occurred in Okinawa Churaumi Aquarium, Japan (Uchida, 1994). Knowledge about the development and growth of neonate rays, as well as on the location of mating, birthing and nursery habitats of *Manta* spp., is poor (Uchida, 1994; Deakos, 2010; Marshall & Bennett, 2010).

Inshore waters and estuaries act as nursery areas for many sharks and rays and seasonal migration into these areas is common during the warmest temperatures (White & Potter, 2004; White & Sommerville, 2010; Cerutti-Pereyra *et al.*, 2014). This nursery area, for many elasmobranchs, provides for juveniles abundant food resources and protection from predators to maximize growth and survival (Simpfendorfer & Milward, 1993; Heupel *et al.*, 2007; Grubbs, 2010). The PEC may provide protection from predators, and has warmer waters during the summer (23 to 30°C) associated with high productivity. In sampling by another scientific project on 14 March 2012, the water temperature was 28°C and the average salinity was 30. The zooplankton community in the region is poorly known, but recent data indicate that in the summer, there is a high abundance of the marine–euhaline copepod *Euterpina acutifrons*, across the *Ilha das Peças* (B. Salvador, pers. comm.). It is possible that *M. birostris* have been using the PEC for nursery ground. The identification of nursery habitat types should require at least a comparison of the densities of early life-history stages in other nearby habitat types (Pauly & Yáñez-Arancibia, 2013) and further studies focusing on the early life-history stage of *M. birostris* within the PEC are necessary to confirm the hypothesis.

The understanding of ontogenetic shifts in habitat use is critical to the effective management and conservation of *Manta* spp. populations, especially if habitats used by juvenile individuals occur in coastal and estuarine waters, which are most vulnerable to anthropogenic degradation (Courrat *et al.*, 2009). Coastal development, mangrove destruction, port construction, dredging and pollution jeopardize nearly one-third of threatened sharks and rays (Dulvy *et al.*, 2014). Despite the existing records of *Manta*

spp. within estuaries, these were not cited by the recent reviews on the conservation of *Manta* spp. (Marshall *et al.*, 2011a; Couturier *et al.*, 2012).

By integrating knowledge of local fishermen and scientists, it was possible to show that *M. birostris* are using the PEC, in southern Brazil, in a predictable seasonal pattern. Based on the available behavioural evidence, the PEC is suggested as a nursery ground for *M. birostris*, although more studies using different methods are necessary to confirm this hypothesis. These results reinforce the importance to update the biological and ecological information of *M. birostris* on the international datalog (Red list of IUCN) and to include approaches for estuarine and coastal management.

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Supporting Information

Supporting Information may be found in the online version of this paper:
Video S1. *Manta birostris* performing breaching behaviour in the Paranaguá estuarine complex, southern Brazil.

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