

1 **The geographic distribution of reef and oceanic manta rays in the south-east Indian and** 2 **south-west Pacific Oceans**

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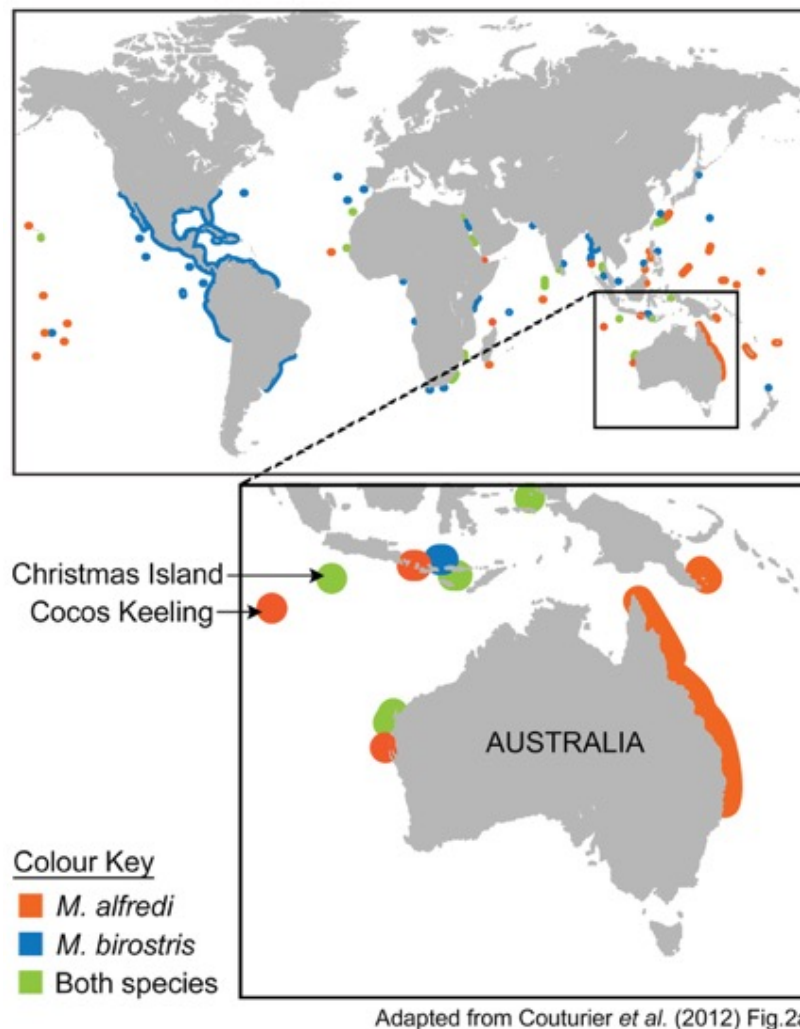
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15 **Abstract:** The reef manta ray, *Mobula alfredi*, occurs in tropical and warm temperate coastal
16 waters, and around islands and reefs in the Pacific and Indian Oceans. Published records that relate
17 to the distribution of *M. alfredi* in the south-east Indian and south-west Pacific Oceans are largely
18 restricted to locations where there is a focus on manta ray ecotourism, with little information from
19 elsewhere. Even less is known about the circumglobally distributed oceanic manta ray,
20 *Mobula birostris*, for which there are few published sighting records. We collated $n = 11,703$
21 sighting records from Australian waters and offshore territories for *M. alfredi* sourced from
22 scientific image databases ($n = 10,715$), aerial surveys ($n = 375$) and online reports ($n = 613$). From
23 collated records, we confirm that the species shows an uninterrupted distribution within Australian
24 coastal waters north of 26°S on the west coast to 31°S on the east coast, with a southernmost record
25 at 34°S . Confirmed locations for *M. birostris* encompass a latitudinal range of $10\text{-}40^{\circ}\text{S}$. Records
26 from more southerly locations relate to warm-water events. Sightings of *M. birostris* were rare,
27 but were confirmed at several geographically separate locations, probably reflecting its preference
28 for offshore waters. The study clarifies the occurrence and range of each species within coastal
29 waters of the south-east Indian and south-west Pacific Oceans, and highlights regions in northern
30 Australia that are of specific interest for future research into possible movements of individuals
31 between international marine jurisdictions.

32 **Keywords:** Aerial survey, citizen science, connectivity, photographic-ID, species distribution
33 range.

34 Introduction

35 The reef manta ray, *Mobula alfredi*, has a broad geographical distribution throughout much of the
36 tropical and subtropical Indo-Pacific region, with the majority of records from relatively shallow
37 waters associated with mainland coastlines, offshore islands, and reefs (Marshall, Compagno &
38 Bennett, 2009; Couturier *et al.* 2012; Stewart *et al.*, 2018) (Figure 1). However, the known
39 distribution of *M. alfredi* is extremely patchy, with most records from dive ecotourism hotspots in
40 Mozambique, South Africa, Maldives, Japan, Guam, the Red Sea, Philippines, New Caledonia,
41 Indonesia and Australia (Figure 1). The distribution of *M. alfredi* could therefore be indicative of
42 highly selective environmental preferences of this species or a consequence of sampling bias.



43 **Figure 1:** Previously published distribution for *M. alfredi* ■ and *M. birostris* ■ or both ■, globally
44 (main) and for the south-east Indian and south-west Pacific Oceans (inset). Note the species' patchy
45 distributions, including the discontinuity between the west and east coasts of Australia. Adapted from
46 Couturier *et al.* (2012).

47 In the south-east Indian and south-west Pacific Oceans, the reef manta ray is thought to occur in
48 shallow tropical and subtropical regions to a southern latitudinal extent of $\sim 30^{\circ}\text{S}$ on the east coast
49 of Australia and $\sim 26^{\circ}\text{S}$ on the west coast (Last and Stevens, 2009; Couturier *et al.* 2012). Similar
50 to the global distribution, the majority of these sighting reports are from subtropical locations
51 where there are large seasonal aggregations of *M. alfredi* and regular ocean-based tourism
52 activities. While *M. alfredi* has been reported widely along the eastern Australian coastline
53 (Couturier *et al.*, 2011; 2014), the occurrence of the species elsewhere remains mainly anecdotal.

54 Few records exist for *M. alfredi* from tropical Australian waters, likely due to a combination of
55 relatively sparse human coastal populations, a large coastline with limited accessibility, regions of
56 high turbidity, and a lack of in-water diving activities due to risks posed by the salt-water crocodile
57 *Crocodylus porosus* and the box jellyfish *Chironex fleckeri*. However, given the adequately warm
58 thermal environment and lack of barriers to movement along Australia's northern coastal habitats,
59 it is possible that *M. alfredi* has an uninterrupted distribution between the sub-tropical regions of
60 both coastlines. Here we collate information from a variety of sources to examine the distribution
61 of *M. alfredi* outside of known aggregation sites in Australian coastal waters. We also collated
62 sighting information for *M. birostris*, which is based on relatively rare photographs of individuals
63 at distinct locations (Figure 1; Couturier *et al.* 2015). Clarification of our understanding of the
64 spatial distribution of these species provides a basis for future research into regional connectivity
65 and conservation of sub-populations, and for evaluation of potential future changes in their
66 geographical occurrence.

67 **Materials & Methods**

68 We collated data on the locations of manta ray sightings from various sources, including image
69 databases used for identification of individual manta rays, aerial surveys, reported online sightings,
70 museum records, and the literature. All research complied with The University of Queensland's
71 Animal Ethics Committee approvals (SBS/319/14/ARC/EA/LEIER, SBS/342/17) and was
72 conducted under the relevant marine park permits (Great Barrier Reef Marine Park Authority
73 Permit G12/35136.1 and G16/37856.1).

74

75 **Manta database records**

76 From birth, *Mobula alfredi* and *M. birostris* possess unique ventral patterning that has facilitated
77 their inclusion in scientific image databases that record unique identifications and track records of
78 individuals through time (Marshall & Pierce, 2012). Encounters with manta rays that have
79 associated identification images are collated in two such image databases (one for the east and one
80 for the west coast of Australia), both actively maintained by *Project Manta* (Couturier *et al.* 2011;
81 McGregor *et al.* 2008). These databases contain images of manta rays encountered by researchers
82 and citizen scientists. The latter contribution forms a large component of the east coast database
83 and derives from social media engagement, or images and metadata submitted to *Project Manta*
84 or other online observation portals such as Eye on the Reef (Dudgeon *et al.* in press; GBRMPA
85 2018). Electronic submission is typically an image of the ventral body surface of a manta ray,
86 along with sighting location, date of capture, and behavioural observations. Each image is
87 scrutinized and matched to the ventral body surface pattern specific to an individual manta ray if
88 that individual has been photographed previously. A novel body surface pattern indicates a
89 previously unrecorded individual, and is assigned a new, unique, identification code.

90 **Aerial surveys**

91 Between November 2017 and February 2018, we conducted aerial surveys targeting manta rays
92 on near-shore reefs around Cairns (16.92° S, 145.78° E) and Port Douglas (26.48° S /145.46° E)
93 Queensland, using GLS Aviation (<https://gslaviation.com.au/cairns/>). Sightings including the
94 number of individuals and GPS location were reported by pilots during scheduled flights covering
95 two scenic tourism routes (<https://gslaviation.com.au/cairns/reefhopper>).

96 We also collated data on manta ray presence from population monitoring surveys that targeted
97 marine mammals such as dugongs *Dugong dugon* and various dolphin species. Aerial surveys with
98 sightings of manta rays cover Ningaloo Reef and Shark Bay in Western Australia (Preen *et al.*
99 1997, Hodgson 2007) and the coastline of the Northern Territory (Groom *et al.* 2015, Palmer 2015,
100 Groom *et al.* 2017).

101 **Online sighting records**

102 Additional manta ray location records were found through extensive online searches (Google,
103 www.google.com; YouTube, www.youtube.com). We used species keywords (e.g. manta,

104 reef manta) in combination with specific locations (e.g. Rowley Shoals, Dampier, Broome,
105 Darwin, Weipa, Groote Eylandt, among others), regions (e.g. Northern Territory, far North
106 Queensland) and activity (e.g. snorkelling, fishing, fly fishing), to identify potential sighting
107 records of *M. alfredi* around Australia. The online search yielded results across a variety of sources
108 including the scientific literature, business and personal blogs, fishing forums, local news reports,
109 videos and online image galleries (e.g. Eye on the Reef, GBRMPA; Reef tourism operator image
110 galleries). As there could be misidentifications (e.g. different species of *Mobula* and eagle rays
111 might be reported as *M. alfredi*), sighting reports were classified as those with or without
112 supporting imagery. If imagery to support a manta ray sighting was lacking, reports were only
113 included if accompanying descriptions (e.g. swimming at the surface with mouth open, circling in
114 dense patches of plankton; or body size estimates, e.g. 2 – 4 m disc width) matched known
115 *M. alfredi* behaviours and/or morphology.

116 **Results**

117 In total, we collated 11,703 sighting records for *M. alfredi* in Australian waters from the various
118 data sources. The species showed a near-continuous distribution across northern Australian coastal
119 waters from Shark Bay in Western Australia to the Solitary Islands Marine Park in New South
120 Wales (Table 1; Figure 2). We also found 29 sighting records for the oceanic manta ray *M. birostris*
121 (Figure 2).

122

123 **Table 1:** Collated sightings for *Mobula alfredi* and *M. birostris* in Australian waters summarised by
 124 source.

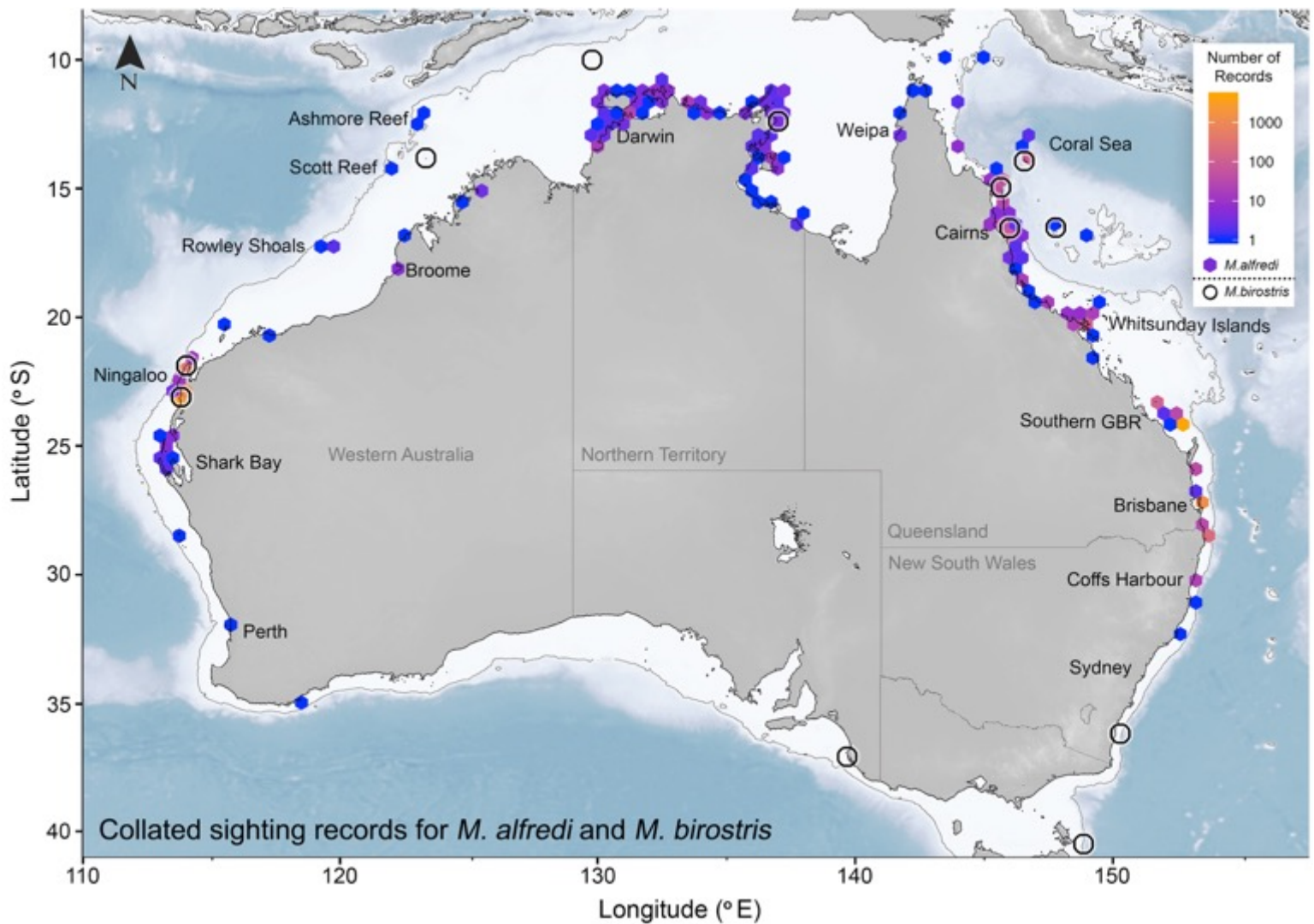
Sighting Record Source	<i>Mobula alfredi</i>	<i>Mobula birostris</i>
Manta ray identification database	10,715	16
<i>Project Manta</i> East coast database	6480	2
<i>Researcher</i>	1826	
<i>Citizen Scientist</i>	4200	
<i>Researcher & Citizen Scientist</i>	454	
<i>Project Manta</i> West coast database	4235	14
<i>Researcher</i>	2127	
<i>Citizen Scientist</i>	2108	
Aerial Observations	375	2
<i>Marine Mammal Survey</i>	255	2
<i>Manta Survey</i>	120	
Online sighting reports	613	7
<i>No supporting media</i>	492	2
<i>Supporting media (e.g. image, footage)</i>	121	5
Museum records	0	1
Total	11,703	26

125 **Manta database records**

126 Over 90% of the collated sighting records were sourced from the two manta identification
 127 databases maintained by the *Project Manta* research group ($n = 10,715$) (Supplementary). The east
 128 coast database contained ~55% ($n = 6,480$) of the sightings, with *M. alfredi* observed between 13-
 129 31°S. However, 91% of those reports were from just two locations (Lady Elliot Island = 71%;
 130 North Stradbroke Island = 20%).

131 Along Australia's west coast, photographic observations of manta rays are largely restricted to the
 132 Ningaloo coastline where on-water recreation and aquatic ecotourism activities occur year-round
 133 (Smallwood *et al.* 2011, Venables *et al.* 2016). Outside of the Ningaloo Reef region, vast tracts of
 134 coastline are uninhabited and inaccessible for tourism activity. The west coast database contained
 135 36% ($n = 4,235$) of Australia's sighting records, with all but three sightings from the Ningaloo
 136 coastline, between 21.6°S to 23.5°S. Citizen science submissions constituted 64% ($n = 4200$) and
 137 50% ($n = 2108$) of east and west coast database entries respectively. There were 16 database

138 records for *M. birostris*, 14 of which were from the Ningaloo Reef region, with the remaining two
139 from the Great Barrier Reef and Coral Sea.



140 **Figure 2:** Collated sighting records for *Mobula alfredi* and *M. birostris* in Australia, with data sourced
141 from scientific literature, image databases, aerial surveys, museum records, and online reports. *Mobula*
142 *alfredi* sightings are aggregated across a 0.5° gridded area and are represented by hexagonal cells,
143 where colour is indicative of the sighting count (from 1 to >1000) per cell. Sightings of *M. birostris*
144 are represented by open black circles and are indicative of location only (not count, due to the limited
145 number of observations). Note that data from Cocos Keeling Island and Christmas Island are not
146 shown. The unbroken grey line off the coast of Australia represents the 500 m isobath.

147 **Aerial records**

148 Although aerial records represented just 3% ($n = 375$) of the total Australian manta ray sighting
149 records, they filled in much of the previously unsampled area in northern Australia. Mobulids,
150 most likely *M. alfredi*, were seen along the Northern Territory coastline, with additional localized
151 coverage and reports from Western Australia and Queensland (Supplementary). For aerial surveys
152 targeting manta rays, 95 *M. alfredi* were observed on 48 scenic reef flights by GSL aviation and
153 25 *M. alfredi* from 3 research specific flights covering near-shore reefs of Cairns and Port Douglas.
154 Northern Territory marine megafauna monitoring surveys (between 2014-2016) contributed 211
155 sighting records. Two of these records from the Northern Territory were identified by aerial
156 observers as likely sightings of *M. birostris*. Similar aerial surveys covering the Ningaloo and
157 Shark Bay regions in Western Australia (1989, 1994, 2007) contributed 44 records.

158 **Online records**

159 Online sighting reports (5%; $n = 613$) provided evidence of manta ray presence in some areas that
160 were not encompassed by the identification databases or aerial surveys (Supplementary). While
161 80% of those records lacked supporting media, the vast majority of observations were from within
162 the Great Barrier Reef Marine Park where experienced tourism operators have a good knowledge
163 of local species and *M. alfredi* is found; species identity was assumed to be correct given these
164 circumstances. The remaining 20% of records with accompanying images that confirmed the
165 identification of individuals as *M. alfredi* were generally near ‘remote’ towns (e.g. Weipa,
166 Queensland), where there are on-water activities such as fishing. Seven records of *M. birostris*
167 were found, five of which had supporting media to confirm the identification.

168 The most southerly records of *M. alfredi* on the west coast were from Coojee Beach, Perth
169 (32.1°S) – with supporting image evidence – and Cheynes Beach, Albany (34.9°S) – without
170 image-based confirmation of identity. On the east coast, the most southerly confirmed records are
171 from South West Rocks, NSW (30.9°S). There were a few possible sightings of *M. alfredi* further
172 to the south, but these, and a single record from Sydney Harbour in 1868, are excluded due to
173 uncertainties about the species involved. Sightings were also recorded from Australia’s offshore
174 remote territories in the Indian Ocean where presence of *M. alfredi* (Cocos Keeling Island) and
175 *M. birostris* (Christmas Island) are confirmed.

176 Discussion

177 By combining multiple data types, we produced the most comprehensive distribution map for
178 *M. alfredi* within the south-east Indian and south-west Pacific Oceans, providing a significant
179 update on the published species distribution. Rather than having highly selective environmental
180 preferences that cause a patchy distribution, we consider that *M. alfredi* has a near-continuous
181 distribution throughout Australia's tropical and subtropical coastal waters southwest to about
182 Shark Bay, Western Australia, and southeast to the Solitary Islands, New South Wales. We also
183 confirm that *M. birostris* is found on all coasts of Australia, including in temperate waters of
184 Tasmania (Couturier *et al.* 2015), but is much less common than *M. alfredi*.

185 The southerly range limit for *M. alfredi* is similar on both east and west Australian coasts. Australia
186 is unique in being the only continent with warm poleward-flowing currents on both coasts: the
187 East Australian Current in the east (Ridgway & Godfrey 1997) and the Leeuwin Current in the
188 west (Godfrey & Ridgway 1985). These currents set the southern range of various mobile species
189 (Couturier *et al.* 2011, Dudgeon *et al.* 2013, Payne *et al.* 2018). Many tropical marine fauna reach
190 the southern limit of their range, and many temperate fauna reach their northern limit, at latitudes
191 of ~25°S to ~30°S on Australia's east and west coastlines (Gomon *et al.* 2008, Last & Stevens,
192 2009, Blair *et al.* 2014).

193 Given the few records of *M. alfredi* at locations further south than Coffs Harbour (~25°S) or Shark
194 Bay (~30°S) on the east and west Australian coasts, respectively, it is likely that sightings south
195 of these regions are unusual forays into normally cold-temperate environments and not part of their
196 normal distribution. For example, manta rays (probably *M. alfredi*) reported as far south as
197 Cheynes Beach (34.9°S, Albany, WA) coincided with an exceptional 'marine heatwave', when
198 sea surface temperatures peaked at up to 5°C warmer than normal (Feng *et al.* 2013), and
199 temporary range extensions of many marine fishes were recorded (Pearce & Feng 2013).

200 This study identified locations within Australia's northern waters where *M. alfredi* have not been
201 reported previously, including the coastline of the Northern Territory, the northern coasts of
202 Western Australia and Queensland. Both reports and confirmed photographic identifications at
203 remote Australian offshore territories of Christmas Island (*M. birostris*) and Cocos Keeling islands
204 (*M. alfredi*), located ~1500 and ~2000 km offshore respectively. Our findings of manta ray

205 distribution at the Cocos Keeling Islands and Christmas Island support those of Kashiwagi *et al.*
206 (2011), with evidence for only *M. alfredi* at Cocos Keeling Islands and *M. birostris* at Christmas
207 Island. These results differ to the distribution presented by Couturier *et al.* (2012) for Christmas
208 Island, where both species were reportedly present.

209 The near-continuous distribution for *M. alfredi* raises questions about regional population
210 structure. It is well-established that *M. alfredi* exhibits strong migratory behaviour, with
211 movements of up to 500 km not uncommon (Couturier *et al.* 2011, Germanov and Marshall 2014,
212 Jaine *et al.* 2014) and recently movements of at least 1150 km have been demonstrated (Armstrong
213 *et al.* 2019). Photo-identification and tagging studies show that individual rays have an affinity for
214 particular sites and regions (Braun *et al.* 2015, Couturier *et al.* 2014, Kessel *et al.* 2017, Marshall
215 *et al.* 2011). However, most studies have focused on populations separated by large distances
216 and/or by regions of deep water (Deakos *et al.* 2011). The shallow continental shelf of northern
217 Australia may facilitate broad-scale connectivity along the expansive coastline, given an apparent
218 absence of barriers to movement. Whether *M. alfredi* move between Australia and its northern
219 neighbours is currently unknown. Our study presents a single record from Ashmore reef, located
220 ~135 km south of Indonesia's southernmost islands, Rote and Pulau Ndana. Distances between
221 Ashmore Reef, the southernmost Indonesian islands, and the Australian mainland, fall within the
222 known range of reef manta movement capacity (<500 km). Further collaborative work would be
223 necessary to determine the potential for exchange of Australian genetic stock with that of
224 Indonesian manta rays.

225 This study provides evidence that *M. alfredi* is distributed across nearly two-thirds of Australia's
226 coastline and adjacent islands and reefs. The species' distribution is predominantly restricted to
227 warm waters north of ~30°S. Unusual events in which warm water extends further south than
228 normal appear to be accompanied by temporary southerly range extensions. Although records are
229 scarce, we provide the first map of *M. birostris* occurrence in Australian waters and confirm that
230 this species is found on all coasts. Due to the proximity of some sightings to international marine
231 jurisdictions and the species' capacity to traverse the separating distances, future collaborative
232 work is necessary to determine whether international movements occur.

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234 Environment and Natural Resources for providing access to the dugong aerial survey data; GSL
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243 data collection. The figures were produced by A.J.A and all authors contributed to manuscript
244 creation. All authors have seen and approved the final manuscript.

245 **Significance Statement:** Published records relating manta ray (*Mobula alfredi* & *M. birostris*)
246 distribution in the south-east Indian and south-west Pacific Oceans are largely restricted to manta
247 ray focused ecotourism localities, with little information from elsewhere. This study clarifies the
248 occurrence and range of manta rays within coastal waters of the south-east Indian and south-west
249 Pacific Oceans, demonstrating the value of citizen science and non-traditional data sources (social
250 media and online videos) for understanding species distributions.

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