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Photographic identification and citizen science combine to reveal long distance movements of individual reef manta rays *Mobula alfredi* along Australia's east coast

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Abstract

Research into the movement ecology of terrestrial and marine animals is growing globally, especially for threatened species. Understanding how far an animal can move and the extent of its range can inform conservation planning and management. On the east coast of Australia, reef manta rays *Mobula alfredi* are the subject of a photographic identification study, *Project Manta*. In June 2018, videos of reef manta rays from the SS Yongala (19.31° S, 147.62° E), were submitted to the *Project Manta* east coast sightings database. The videos were of two individuals previously identified from North Stradbroke Island (27.42° S, 153.55° E), about 1150 km to the south of the SS Yongala. This represents the greatest point-to-point distance travelled by individual *M. afredi* and extends the latitudinal range for this sub-population on the east coast. This study highlights that citizen science input can provide valuable data to address knowledge gaps in the distribution and population range of marine species. Knowledge of the 1000+ km range movement potential of individual *M. alfredi,* highlights the possibility that regional sub-populations may span jurisdictional zones of more countries than previously considered likely, complicating conservation management of this species.

Keywords: Home range, Animal movement, Population connectivity, Photo-ID, Great barrier reef, Elasmobranch, Dispersal capacity

Introduction

Knowledge of the movement ecology of species, and how far individuals move is important for understanding population structure and for conservation planning and management (Hays et al. 2016). The movements and distributions of non-commercial fish species are generally poorly-understood when compared to commercially important fishes, and other marine megafauna such as sea turtles (Fossette et al. 2010; Houghton et al. 2006; Schofield et al. 2013), cetaceans (Christal and Whitehead 1997; Williams et al. 2009; Cheney et al. 2013) and seabirds (Hennicke and Weimerskirch 2014; Ludynia et al. 2012; Péron et al. 2013).

The reef manta ray *Mobula alfredi,* is a large, pelagic elasmobranch (disc width up to 5 m) found in tropical and subtropical waters of the Indo-Pacific Oceans, often associated with coastlines and coral or rocky reef habitats. This species displays aggregative behaviours at predictable locations that have provided good opportunities to investigate their biology and ecology (Marshall et al. 2011; Dewar et al. 2008; Kitchen-Wheeler et al. 2012). The application of photographic identification (photo-ID) and electronic tagging has shown a relatively high degree of site fidelity to meso-scale geographical regions (Couturier et al. 2018; Braun et al. 2015; Setyawan et al. 2018). One outcome of such site fidelity, could be the formation of local sub-populations, particularly if there are barriers to interchange of individuals with adjacent populations. Currently, there is little evidence of

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contemporary connectivity among regions across the species' distribution (Stewart et al. 2018).

To date, the largest point-to-point movements by individual *M. alfredi* are around 650 km, based on movements along the east coast of Australia (Couturier et al. 2014) and between atolls in the Maldives (Stevens and Peschak 2016). Several other studies have demonstrated shorter movements between locations (Table 1), and studies have yet to demonstrate movements across international boundaries (Stewart et al. 2018).

Mobula alfredi occurs around the Australian coastline in warm temperate and tropical waters, spanning > 7000 km from Shark Bay, WA (25.99 S, 113.79° E), across northern Australia, to the Solitary Islands, NSW (30.21° S, 153.27° E) (Armstrong unpublished data). The longest documented point-to-point movement of an individual reef manta ray from these coastlines was on the east coast, between North-West Solitary Island, NSW to Lady Elliot Island, Qld (24.11° S, 152.71° E), a distance of 650 km (Couturier et al. 2014). This coastline is characterised by shallow continental shelf waters with rocky and coral reefs, forming semi-continuous habitat. Here, through a combination of citizen science and researcher-focused photo-ID surveys, we report on the movements of *M. alfredi* in waters along Australia's east coast and consider how the species' use of what is in effect linear suitable habitat may result in the formation of regional sub-populations.

Methods

Photo-ID is an approach that can be applied to any species whose individuals have unique skin patterns or other features that are stable over time (Marshall and Pierce 2012; Bansemer and Bennett 2008; Reisser et al. 2008; Wiirsig and Jefferson 1990). Photographs of animals can provide discrete information about individuals' locations in time and space. Each manta ray has a ventral body surface that has light and dark pigment distributed in a unique pattern, that varies in the number, size, shape, position and density of spots and patches (Marshall et al. 2011; Kitchen-Wheeler 2010). On the Australian east coast, *Mobula alfredi* has been the focus of a photo-ID program (*Project Manta*) since 2007. Images of manta rays from along the coast are submitted for inclusion in the *Project Manta* database by trained researchers performing repeated, intense surveys at specific locations and, more opportunistically, by citizen scientists, such as recreational SCUBA divers, snorkelers, and people within the dive industry (Dudgeon et al. 2016). Images, along with various metadata (including the date and location of image capture), are entered into a searchable database that allows the history of individual rays to be explored.

On 1 June and 29 June 2018, videos of *M. alfredi* were submitted to *Project Manta* by citizen scientists. Two individual reef manta rays were filmed at the wreck of the SS Yongala, a 107 m long, 3,364 t steamer that sank in 30 m of water in 1911 off Townsville, Queensland (19.31° S, 147.62° E). Still images of the two rays from the videos were matched against images in the *Project Manta* east coast sighting database. This northern site of the SS Yongala, and the site to the south (Manta Bommie, North Stradbroke Island) where the individuals had previously been seen, were used to estimate the greatest point-to-point distance moved by each ray, using the marmap package in R (Team 2013; Pante et al. 2018). This estimate excluded possible passage of manta rays through the 70 km long Great Sandy Strait that separates Fraser Island from the mainland, as this includes narrow and very shallow sections, and there have been no records of manta rays in the strait.

Results

As of 29 June 2018, the east coast sighting database contained verified photographic records of 1235 individual *Mobula alfredi*, from 6375 encounters recorded at 31

Table 1 Greatest point-to-point distances moved by individual *Mobula alfredi*

Location	Species	Method	Distance (km)	Study
East Coast, Australia	*M. alfredi*	Photo-ID	650	(Couturier et al. 2014)
Maldives	*M. alfredi*	Photo-ID	650	(Stevens and Peschak 2016)
East Coast Australia	*M. alfredi*	Satellite tag	520	(Jaine et al. 2014)
Komodo NP, Indonesia	*M. alfredi*	Photo-ID	450	(Germanov and Marshall 2014)
Japan	*M. birostris*[a]	Photo-ID	350	(Homma 1997)
Red Sea, Saudi Arabia	*M. alfredi*	Satellite tag	169	(Braun et al. 2015)
Maldives	*M. birostris*[a]	Photo-ID	160	(Kitchen-Wheeler 2008)
Raja Ampat, Indonesia	*M. alfredi*	Acoustic track	100	(Setyawan et al. 2018)
Hawai'i	*M. alfredi*	Acoustic track	63	(Clark 2010)
Hawai'i	*M. alfredi*	Photo-ID	40	(Deakos et al. 2011)

[a]Indicates the species was likely to be *M. alfredi*, but was published as *M. birostris* as these papers pre-date the redescription of the former (Marshall et al. 2009)

unique locations, between the Solitary Islands, NSW in the south, and Tijou Reef, Qld (13.16° S, 143.97° E) in the north. This included 69 individuals identified from north of the SS Yongala (75 encounters), 10 individuals recorded at the SS Yongala site itself (12 encounters), and 1156 individuals from south of the wreck (6288 encounters); with no prior overlap of sightings among these locations (Fig. 1).

Citizen science images of *M. alfredi* from the SS Yongala site taken on 1 June 2018 were matched to reef manta ray individuals coded #736 and #1153 in the database (Figs. 2 and 3). The subsequent sighting at the SS Yongala on 29 June 2018 also matched individual #736, an immature male (Fig. 2). This individual had been sighted 20 times before at Manta Bommie, North Stradbroke Island (27.42° S, 153.55° E) between April 2013 and December 2017. Individual #1153, a sexually mature male (Fig. 3), was previously sighted twice off North West Island (23.30° S, 151.70° E) in April 2017, and once at Manta Bommie in March 2018.

Images of these two reef manta ray individuals in the database showed that they had been at Manta Bommie, North Stradbroke Island prior to their sighting at the SS Yongala. The shortest distance between the two sighting locations, without crossing land, is 1150 km (Fig. 1). Manta ray #1153 moved between these two sites within a 3-month period at a speed of at least 12.7 $km.d^{-1}$, and manta ray #736 within a 7-month period at a speed at least 5.5 $km.d^{-1}$.

Discussion

The observations here extend the longest verified movement of an individual *Mobula alfredi* between two locations, from 650 km (also from the east coast of Australia; Couturier et al. 2014) to 1150 km. Interrogation of the east coast photo-ID database had revealed a well-defined sub-population of *M. alfredi* between the Solitary Islands in the south and the Capricorn Bunker Group in the southern Great Barrier Reef (Couturier et al. 2011). The latitudinal extent of this group of rays now extends to the SS Yongala in the north (Fig. 1).

As reef manta rays are large-bodied, pelagic rays with a wide tropical and subtropical distribution in the Indo-Pacific, they could potentially move vast distances.

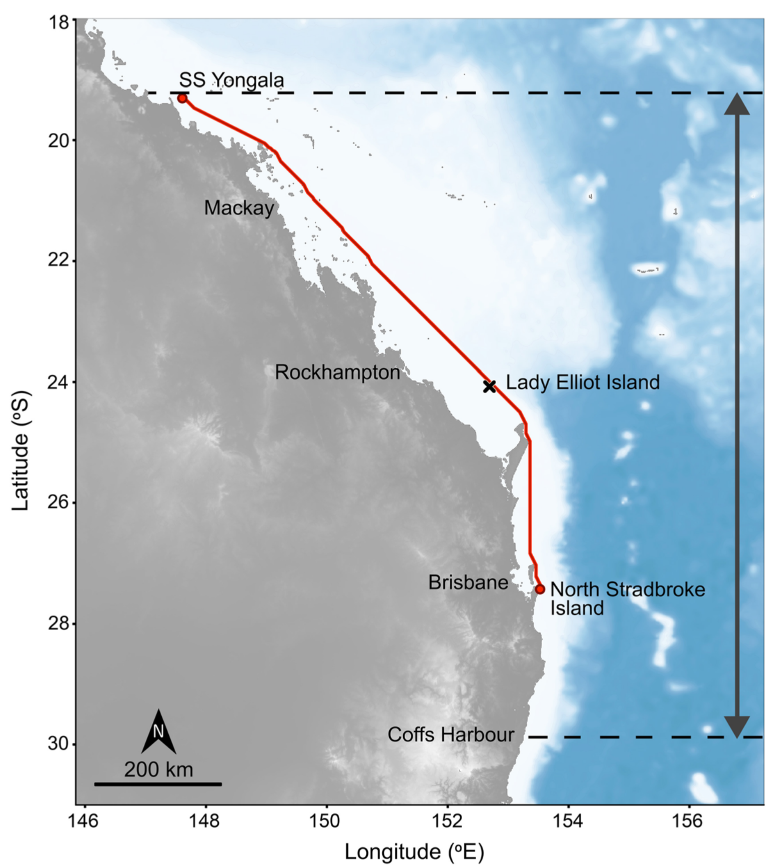

Fig. 1 The largest point-to-point movement for an individual reef manta ray *Mobula alfredi*. The red line presents the shortest straight-line movement between the wreck of the SS Yongala and North Stradbroke Island (1150 km). The arrow on the right indicates the latitudinal range of the regional sub-population of *M. alfredi* on this coastline as at 29 June 2018

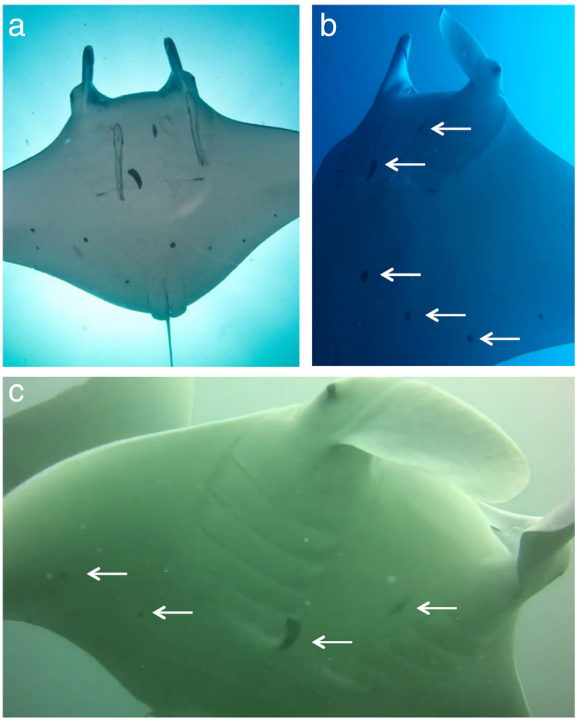

Fig. 2 Images of reef manta ray #736, an immature male; **a** Reference image; and images submitted from SS Yongala on (**b**) 29 June 2018 and **c**) 1 June 2018. Arrows indicate matching spot pattern (photo credit: **a** John Gransbury, **b** Cam Risbey and **c** Laura Billett)

However, previous studies have documented maximum point-to-point movements of < 650 km (Table 1), and demonstrated high site fidelity and restricted movements (Dewar et al. 2008; Couturier et al. 2018; Setyawan et al. 2018; Kessel et al. 2017). In contrast, other pelagic elasmobranchs have longer point-to-point movements, such as the tiger shark *Galeocerdo cuvier* (3,500 km) (Lea et al. 2015), blue shark *Prionace glauca* (4,500 km) (Vandeperre et al. 2014), white shark *Carcharodon carcharias* (10,000 km) (Bonfil et al. 2005), and whale shark *Rhincodon typus* (15,000 km) (Guzman et al. 2018). A satellite tagged individual of the larger manta ray species, *M. birostris* (disc width up to 7 m) moved 1500 km between mainland Ecuador and the Galapagos Islands (Hearn et al. 2014). However, similar to the reef manta ray, the majority of studies for *M. birostris* have found this species undertakes relatively short distance point-to-point movements (< 300 km) (Stewart et al. 2016; Graham et al. 2012).

Why *M. alfredi* appears to have relatively small directional excursions, and consequently small population ranges is uncertain. Soft barriers to dispersal, such as deep water, may play a role. For example, the volcanic islands of Hawai'i are separated by deep waters, and there is no evidence of connectivity between populations that are only ~ 150 km apart (Deakos et al. 2011). However, in the Maldives, individual *M. alfredi* have transited deep waters (~ 2000 m) (Stevens and Peschak 2016) and as such, depth alone does not appear to be a barrier to movement. A recent report of the first *M. alfredi* to be seen in the eastern Pacific Ocean, off the coast of Costa Rica, extends the known geographical distribution for the species (Arauz et al. 2019). It is unknown whether this individual migrated from islands 6,000 km to the west, or whether it is part of a previously undocumented population, as the individual had not been identified anywhere else before this sighting (it was not in the global MantaMatcher database of ~ 9839 individual rays) (Town et al. 2013). In the current study, the northward range extension of a regional (eastern Australian) *M. alfredi* sub-population is supported by the positive match via photo-ID of two individuals from North Stradbroke Island sighted at the SS Yongala.

This study highlights the utility of citizen science contributions to photo-ID databases. Using citizen scientists, we identified the unusual movements of two individuals from within a large population of many hundreds of *M. alfredi*. Citizen scientist involvement offers a way to increase observer effort in remote locations, such as the extensive coastal waters of northern Australia. In total, 67% of the photographic records in the *Project Manta* database in eastern Australia have been contributed by citizen scientists. In less populated and more remote regions, including northern QLD, up to 100% of sightings are sourced from citizen scientists (Dudgeon et al. 2016). Photo-ID databases are commonly used to track the movement of animals, including manta rays (Marshall et al. 2011; Homma 1997; Deakos et al. 2011; Kitchen-Wheeler 2010; Couturier et al. 2011), but there are several challenges associated with their use. Photo-ID is restricted to in situ observations, and the geographic and temporal cover provided by citizen scientists is unregulated, which can result in data collection bias.

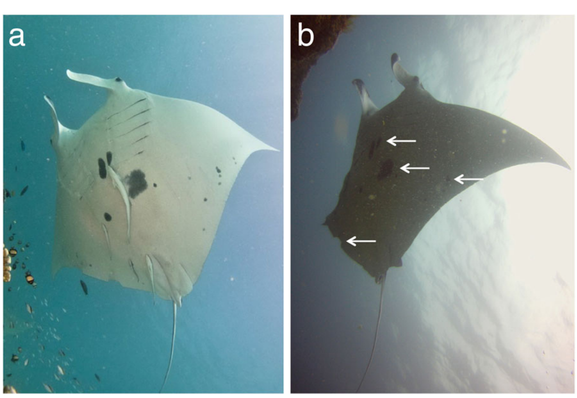

Fig. 3 Images of reef manta ray #1153, a sexually mature male; **a** Reference image and **b** image submitted from SS Yongala on 1 June 2018. Arrows indicate matching spot pattern and tissue loss (likely bite wound) to right pectoral fin (photo credit: **a** John Gransbury and **b** Ariela Schnitman)

In northern Australia, the *Project Manta* database has opportunistic sightings of *M. alfredi* (75 encounters north of the SS Yongala, in comparison to 6300 encounters further south). The under-representation of sightings in the north is due to a lack of researcher directed surveys in this region, sparse human population, and prevalence of saltwater crocodiles *Crocodylus porosus* and box jellyfish *Chironex fleckeri* (Caldicott et al. 2005; Harrison et al. 2004). Electronic tagging offers an alternative approach to tracking animals, but generally provides short-term information and is expensive, limiting the number of animals that can be tracked (Stewart et al. 2018). However, molecular approaches based on analysis of tissue biopsies have the potential for exploring connectivity between different regions (Dudgeon et al. 2012).

Conclusions

For reef manta rays, this extended movement capability adds complexity to the management of this threatened species, as it may cross jurisdictional boundaries. In Indonesia, individuals have travelled between locations up to ~ 450 km apart, moving between protected waters and regions of higher fishing risk (Germanov and Marshall 2014). Given the long-distance movement of reef manta rays observed in this study, there is likely to be increased population connectivity among regions. In northern Australia, relatively shallow coastal waters could potentially allow unobstructed movement of *M. alfredi* across international jurisdictions that offer different levels of protection and exposure to targeted fisheries. Greater harnessing of citizen science, in conjuction with international collaboration and data sharing, could provide valuable information to assess these long distance multi-jurisdiction movements.

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Authors' contributions

AOA, AJA, MB and CD designed and conducted the study. AOA, AJA and KT collected the data. AOA, AJA, MB and CD analysed the data. AOA, AJA, MB, AR, KT and CD interpreted the data and compiled the manuscript. All authors read and approved the final manuscript.

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Availability of data and materials

Data is contained in the *Project Manta* east coast database which is not currently available online. This information can be provided by the corresponding author upon reasonable request.

Ethics approval and consent to participate

Approval was obtained from The University of Queensland Animal Ethics Committee (SBS/319/14/ARC/EA/LEIER and SBS/342/17).

Consent for publication

Consent has been provided from contributing photographers: John Gransbury, Cam Risby, Ariela Schnitman and Laura Billett.

Competing interests

The authors declare that they have no competing interests.

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