Manta TRUST

Maldivian Manta Ray Project

ARI ATOLL REGION | ANNUAL REPORT 2019

Conservation through research, education, and collaboration

- The Manta Trust

MALDIVIAN MANTA RAY PROJECT

WHO ARE THE MANTA TRUST?

The Manta Trust is a UK and US-registered charity, formed in 2011 to co-ordinate global research and conservation efforts around manta rays. Our vision is a world where manta rays and their relatives thrive within a globally healthy marine ecosystem.

The Manta Trust takes a multidisciplinary approach to conservation. We focus on conducting robust research to inform important marine management decisions. With a network of over 20 projects worldwide, we specialise in collaborating with multiple parties to drive conservation as a collective; from NGOs and governments, to businesses and local communities. Finally, we place considerable effort into raising awareness of the threats facing mantas, and educating people about the solutions needed to conserve these animals and the wider underwater world.

Conservation through research, education and collaboration; an approach that will allow the Manta Trust to deliver a globally sustainable future for manta rays, their relatives, and the wider marine environment.

MALDIVIAN MANTA RAY PROJECT

Formed in 2005, the Maldivian Manta Ray Project (MMRP) is the founding project of the Manta Trust. It consists of a country-wide network of dive instructors, biologists, communities and tourism operators, with roughly a dozen MMRP staff based across a handful of atolls.

The MMRP collects data around the country's manta population, its movements, and how the environment and tourism / human interactions affect them. Since its inception, the MMRP has identified over 4,942 different individual reef manta rays, from more than 70,000 photo-ID sightings. This makes the Maldives manta population the largest, and one of the most intensively studied populations in the world. The MMRP has also identified nearly 710 different individual oceanic manta rays.

The long-term and nationwide data collected by the MMRP has allowed researchers to record and identify key patterns within this population over time. Not only does this invaluable information improve our understanding of these animals, but it informs their ongoing management and protection both in the Maldives, and around the world.

THE CONSERVATION CHALLENGE

In the last two decades, manta and mobula rays have faced increasing threats from both targeted and bycatch fisheries, due in part to a growing trade in Asia for their gill plates. The gill plates are what these rays use to filter zooplankton from the water. In Traditional Asian Medicine, it is believed these gill plates will filter the human body of a variety of ailments when consumed in tonic. There is no scientific evidence to support this claim.

Unregulated and badly managed tourism is also negatively affecting manta rays, while climate breakdown, reef degradation and pollution is reducing the manta's food supply and suitable habitat.

Manta and mobula rays are particularly vulnerable because of their aggregating behaviour and conservative life-history; they grow slowly, mature late in life, and give birth to few offspring. These traits make it very easy to wipe out entire populations in a relatively short period of time. With protection in place, populations are still slow to recover.

EXECUTIVE SUMMARY

This report is the second in a series presenting data collected by the Manta Trust's Maldivian Manta Ray Project (MMRP) in the geographical atolls of Ari, Rasdhu, and Thoddu (collectively the Ari Atoll Region - AAR) between January and December 2019.

Key findings include a total of 1,274 sightings of 445 individual reef manta rays, recorded at 37 different sites in the AAR in 2019. Reef manta ray sightings had continued to follow an increasing trend from 2014 – 2018, however less sightings were reported, and less individual manta rays were recorded in 2019 than any prior year during which MMRP staff were present year-round in the region. Even though there was consistent survey effort throughout the region by the MMRP and supporting resorts and liveaboards, the decline in individuals sighted will require continued investigation to determine possible reasoning. As only nine percent of the individuals sighted were new to the Maldives population in 2019, and 81% have been re-sighted in the Maldives, it is likely that the vast majority of manta rays in the AAR have now been recorded.

Reproductive activity was observed less frequently in the AAR in 2019 compared with previous years, with only seven percent of all mature females seen pregnant in 2019; this is much less than the 30% seen in 2018. In addition, 14 new manta pups, or 2019 "young of year", were recorded in the AAR, which is slightly less than the recorded 17 manta pups in 2018. Courtship activity in 2019 did not coincide with the transitional period between the Monsoons; which has historically been the recorded trend across Maldives. Instead, courtship behaviour peaked in February, and could be attributed to more favourable conditions and a peak in manta sightings noted at this time.

Reef manta rays are a highly mobile species, often travelling hundreds of kilometres throughout the Maldives. Due to its central location and proximity to other atolls, forty-two percent (n=605) of the AAR's reef manta ray population has been sighted outside of the region, compared to only 29% of the total recorded Maldives' reef manta ray population (n=4,941). Indeed, reef manta rays from the AAR have been re-sighted in 16 different geographical atolls.

Manta rays are an incredibly important economic resource to the Maldives, bringing tens of thousands of divers and snorkellers to the country each year, and generating millions of USD for the economy annually. This is especially true in the AAR, with more tourists and tourist boats recorded by the MMRP in 2019 than in any year prior. Extensive tourism studies conducted by the MMRP and the Maldives Whale Shark Research Programme (MWSRP) show that unregulated tourism can have a negative impact on marine megafauna. In 2019, the Manta Trust's MMRP continued to disseminate its 'How to Swim with Manta Rays' tourism code of conduct to as many involved tourism operators as possible. Operators and tourists will continue to be equipped with the tools and information they need to make their excursions as sustainable as possible.

Efforts to conserve the natural heritage of the AAR and manage the increasing human impacts upon the environment are encouraging, providing much to look forward to in 2020 and beyond. However, it is crucial that active research into manta rays and other marine life continues in order to monitor the effects of both tourism and environmental change. Being able to pinpoint the reasons for any observed trends in, or threats to, the Maldives manta ray population is crucial for the ongoing management and protection of these animals.

THE ARI ATOLL REGION

Geographically, the Ari Atoll Region (AAR) is comprised of three atolls: Ari, Rasdhu, and Thoddu (administratively, Alifu Alifu and Alifu Dhaalu Atolls). Ari Atoll is a very large (2,259 km²) complex atoll, consisting of 91 islands, and is the 18th largest geographical atoll in the world. Rasdhu Atoll is much smaller (62 km²) and is defined as an oceanic faro, as it consists of six islands with only a few channels along the atoll's outer rim. Thoddu Atoll is the smallest of the three (5 km²) and is an oceanic platform reef, not a true atoll. It consists of the single island of Thoddu and has no lagoon system. All three atolls are part of the northern section of the central Maldives archipelago; Thoddu Atoll is located 10 km north of Rasdhu Atoll, which is located 8.5 km to the northeast of Ari Atoll. Analysis throughout the report refers to this combined area as the Ari Atoll Region (AAR).

The AAR has a year-round presence of reef manta rays (*Mobula alfredi*) and whale sharks (*Rhincodon typus*), with both planktivorous species following the seasonal movement of their food across the atolls with the changing South Asian Monsoons. The chance to see these charismatic megafauna species, along with easy accessibility to Malé, has resulted in the AAR becoming one of the most popular tourist destinations in the Maldives. The high tourist presence in the region means that the majority of data collected by the MMRP, including in 2019, came from engaged citizen scientists. These tourists, dive guides, snorkel leaders, and marine biologists have submitted many photo identification (photo-ID) images to the MMRP. The year 2019 also served as the second annual term whereby the MMRP was able to continuously survey manta rays on both the eastern and western sides of Ari Atoll, leading to a much better understanding of the region's manta population.

UNDERSTANDING THE MONSOONS

Seasonal variance and weather patterns within the Maldives are dictated by the South Asian monsoon. The fluctuating monsoons (seasons) play an important role in determining manta ray distribution and, thus, an understanding of the monsoons is critical to the analysis of manta ray sightings in the AAR.

The South Asian monsoons are characterized by their winds, which blow consistently and reverse direction seasonally. The Maldives Northeast Monsoon, or Iruvai, generally runs between December and March, and the Southwest Monsoon, or Hulhangu, between May and October; the months of April and November tend to serve as the transitional periods between the changing seasons. However, the monsoons sometimes change earlier or later than normal. The Southwest Monsoon tends to be characterized by higher levels of rainfall and cloud cover, and stronger wind speeds resulting in rougher seas.

The strong monsoonal winds create oceanic currents that flow either from the northeast towards the southwest (Northeast Monsoon) or from the southwest towards the northeast (Southwest Monsoon). The atoll systems of the Maldives, rising 2,000 meters off the sea floor, act as a barrier to the oceanic currents, displacing the water as it flows around and through the atolls, creating areas of deep-water upwelling along the leeward side of each atoll. These upwellings bring nutrient rich water within reach of the sun, enabling the photosynthetic phytoplankton to flourish, which, in turn, generates a bloom of zooplankton that feeds on the phytoplankton. Zooplankton is the food source for manta rays and whale sharks, and tends to be concentrated in specific areas by the movements of lunar currents into and out of the atolls, via numerous channels. These sites are where we are most likely to observe feeding planktivorous megafauna and, in the case of reef manta rays, where these animals frequent cleaning stations in close proximity to their plankton-rich feeding areas.

The manta rays migrate seasonally to utilize feeding and cleaning areas on the monsoonal down-current edge of the atolls. Therefore, research efforts are focused on the western edges of the atolls during the Northeast Monsoon and on the eastern edges during the Southwest Monsoon. Within the AAR, these seasonal changes of zooplankton and manta ray abundance are observable in Ari Atoll. However, due to the differing topographies of the oceanic faro of Rasdhu Atoll, and the oceanic platform reef of Thoddu Atoll, manta sightings at these atolls do not follow as closely the same seasonal patterns observed throughout the larger, more complex, atoll systems of the archipelago.

SAMPLING METHODOLOGY & STUDY PERIOD

Manta ray sightings data in the AAR were obtained via photo-ID and was collected throughout the AAR both by full-time MMRP researchers and citizen scientists (tourists, local dive guides, snorkel leaders, and marine biologists). Individual manta rays that were sighted in the water were documented by photographing the unique spot patterns on their ventral surface, allowing for identification of individuals. In the context of this report, a sighting is defined as a confirmed photo-ID of an individual manta ray on a given day in a specific location. Surveys were conducted in-water, both on SCUBA and via snorkelling, with sightings recorded at 76 different sites in Ari, Rasdhu, and Thoddu Atolls across all survey years. Twenty-one of these sites were classified as key aggregation sites due to higher (≥50) number of manta ray sightings (Fig. 1 & Table 1).

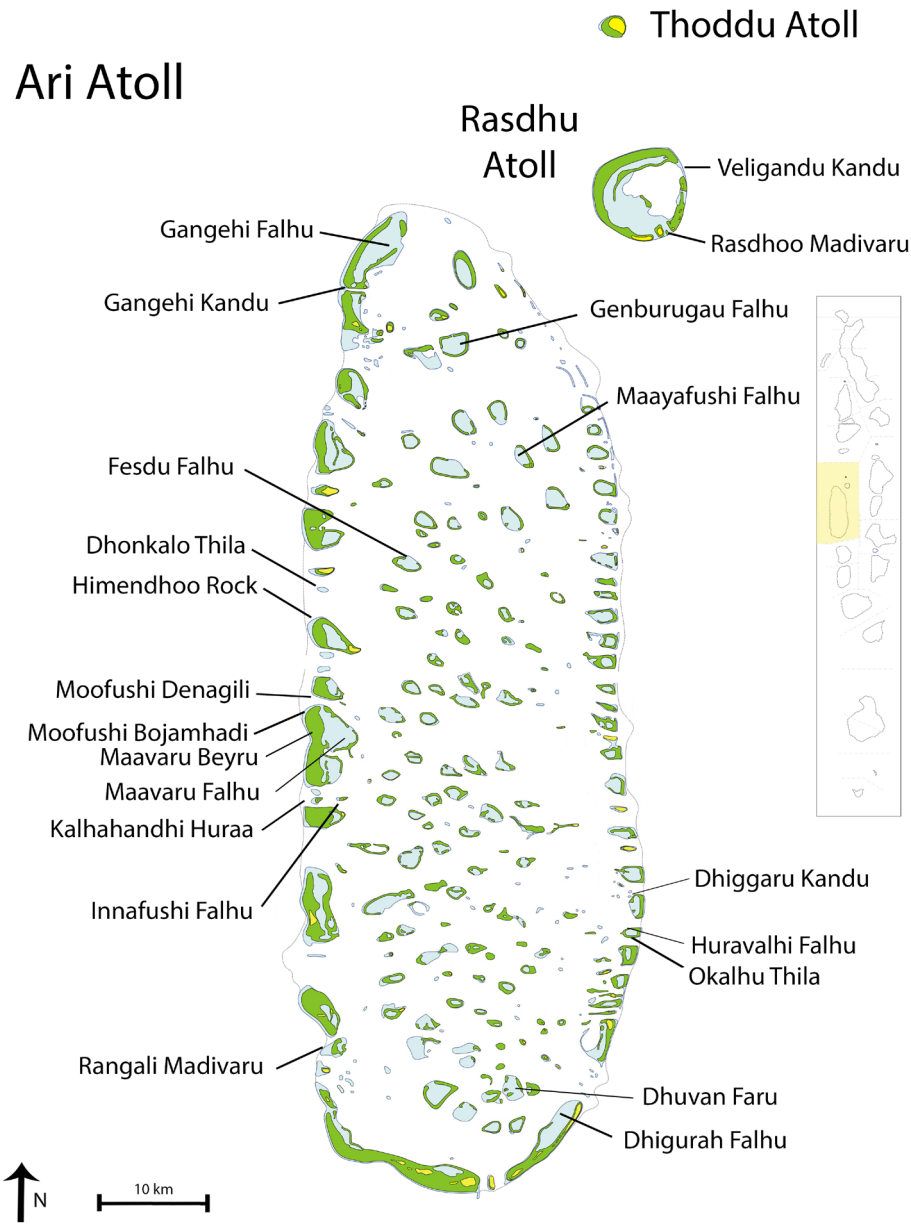


Figure 1: Map of the Ari Atoll Region (AAR) showing twenty-one of the key reef manta ray (*Mobula alfredi*) aggregation sites within the three geographical atolls (Ari, Rasdhu, and Thoddu) across all survey years. Also shown in the inset box is the AAR in relation to the rest of the Maldives Archipelago.

Table 1: Reef manta ray (*Mobula alfredi*) aggregation sites with ≥50 sightings across all survey years (*n*=21) in the three geographical atolls of the Ari Atoll Region (Ari, Rasdhu, and Thoddu).

Site Number	Atoll	Site Name	Atoll Location	Reef Type	Predominant Demographic	No. Sightings
1	Rasdhu Atoll	Veligandu Kandu	Northeast	Channel	Adults	552
2	Rasdhu Atoll	Rasdhoo Madivaru	Southeast	Channel	Adults	58
3	Ari Atoll	Gangehi Kandu	Northwest	Channel	Adults	218
4	Ari Atoll	Dhonkalo Thila	West	Channel	Adults	352
5	Ari Atoll	Himendhoo Rock	West	Channel	Adults	224
6	Ari Atoll	Moofushi Denagili	West	Channel	Adults	103
7	Ari Atoll	Moofushi Bojamhadi	West	Channel	Adults	1753
8	Ari Atoll	Maavaru Beyru	West	Outer	Adults	167
9	Ari Atoll	Kalhahandhi Huraa	West	Channel	Adults	224
10	Ari Atoll	Rangali Madivaru	Southwest	Channel	Adults	1716
11	Ari Atoll	Dhiggaru Kandu	East	Channel	Adults	1616
12	Ari Atoll	Okahlu Thila	East	Inner	Adults	202
13	Ari Atoll	Huravalhi Falhu	East	Channel	Adults	380
14	Ari Atoll	Gangehi Falhu	Northwest	Lagoon	Juveniles	213
15	Ari Atoll	Genburugau Falhu	North Central	Lagoon	Juveniles	251
16	Ari Atoll	Maayafushi Falhu	North Central	Lagoon	Juveniles	273
17	Ari Atoll	Fesdu Falhu	North Central	Lagoon	Juveniles	456
18	Ari Atoll	Maavaru Falhu	West	Lagoon	Juveniles	821
19	Ari Atoll	Innafushi Faru	West	Inner	Juveniles	68
20	Ari Atoll	Dhigurah Falhu	South	Lagoon	Juveniles	1207
21	Ari Atoll	Dhuvan Faru	Southeast	Inner	Juveniles	50

During each survey performed by the MMRP researchers, individual manta ray sightings were documented via photo-ID. In addition, researchers collected data on location, manta ray numbers and behaviour, environmental variables (including wind speed, current direction, and plankton density), and anthropogenic factors (including number of divers/snorkellers, number of boats, and number of paying guests). Data was collected on all surveys, regardless of whether manta rays were sighted or not. Citizen scientists in the AAR recorded data only on surveys where manta rays had been encountered. In addition to submitting sighting photos to the MMRP for identification purposes, citizen scientists noted the trip location, manta ray sighting time, and the manta's prevalent behaviour.

2019 Study Period

During 2019, the MMRP researchers performed a total of 259 surveys (Fig. 2). The marked reduction in survey effort noted between 2018 (*n*=403) and 2019 (*n*=259) is attributed to the closure of two MMRP bases located in Ari Atoll (Athurugau and Thundufushi Islands) in 2018. For the entirety of 2019, the MMRP had researchers based on the east of Ari Atoll at Vilamendhoo Island, with 2019 serving as the second full year of consistent survey effort in the east of the atoll during the Southwest Monsoon.

Throughout the year, the MMRP researchers carried out surveys on as many days as conditions and logistical operations allowed. The 259 surveys were completed on 157 days at 21 sites, and all surveys were accompanied by resort guests. Manta rays were sighted on 59% (*n*=152) of all survey trips, with photo-ID data collected on 81% (*n*=123) of those surveys.

From January until April, survey effort predominantly focused on the western Ari Atoll manta aggregation site of Rangali Madivaru (*n*=65), where both feeding and cleaning manta rays were encountered. During May, survey effort moved to focus on the manta ray aggregation sites in eastern Ari Atoll. Surveys were performed at Dhiggaru Kandu (*n*=39) and Huravalhi Falhu (*n*=32) through to mid-November. Both of these aggregation sites are home to

reef manta ray feeding sites and cleaning stations. With the beginning of the Northeast Monsoon in December, surveys were again performed in west Ari Atoll at Rangali Madivaru (*n*=6). Throughout 2019, surveys were also conducted at the feeding site of Dhigurah Falhu (*n*=50) in southern Ari Atoll. Periodic SCUBA and snorkel surveys were also conducted in the South Ari Marine Protected Area (SAMPA), with a dual focus of manta ray and whale shark sightings.

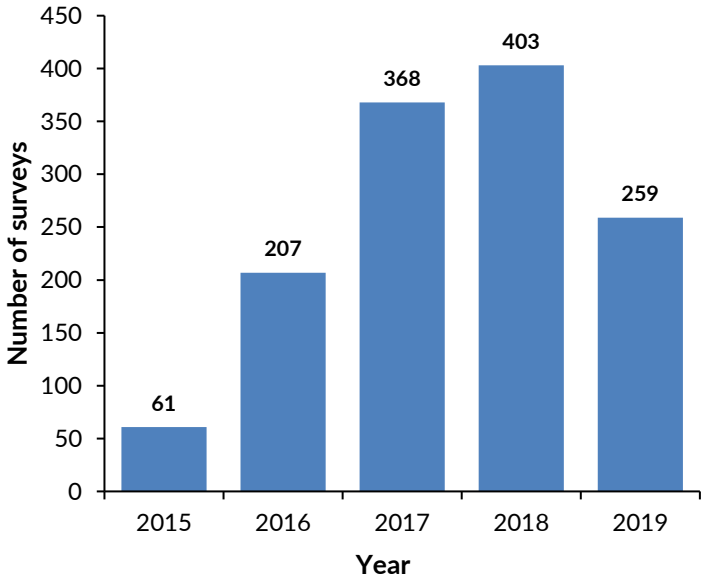


Figure 2: Number of surveys undertaken annually by the Maldivian Manta Ray Project in the Ari Atoll Region.

REEF MANTA POPULATION

Sighting Records

A total of 11,411 sightings of reef manta rays have been recorded across the AAR between 1992 and 2019. Of those sightings, 1,274 were recorded in 2019. The data shows a decrease (33%) in 2019 sightings compared to the previous year (*n*=2,066 in 2018) and is the lowest recorded since 2014 (Fig. 3). When sub-divided by geographic atoll, the majority of sightings were recorded in Ari Atoll (*n*=10,744), followed by Rasdhu Atoll (*n*=625), and with the fewest sightings recorded in Thoddu Atoll (*n*=42). This trend remained consistent in 2019, with 1,164 sightings reported from Ari Atoll, 92 from Rasdhu Atoll, and 18 from Thoddu Atoll.

For the last few decades, the AAR has had a heavy tourism presence through local resorts, guest houses, and liveaboards. The MMRP has relied upon support from this large tourism sector for many manta encounter reports submitted via citizen scientists and local operators. In 2019, 27% of reef manta ray sightings were recorded by MMRP researchers, while the remaining 73% came from citizen scientists. This trend, with the majority of sightings reported by citizen scientists, has remained consistent throughout the MMRP's study time in the AAR, even after the MMRP established permanent researchers based in the region.

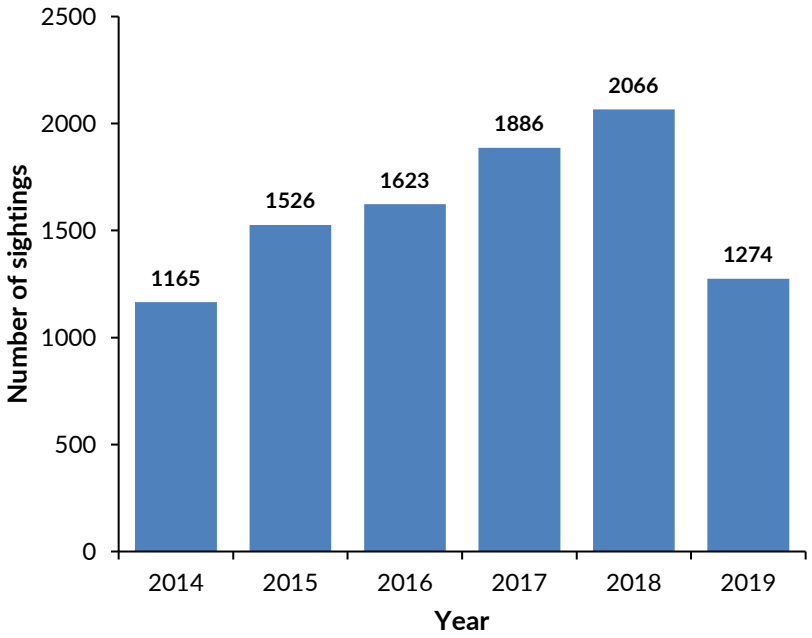


Figure 3: Annual sightings of reef manta rays (*Mobula alfredi*) in the Ari Atoll Region.

In 2019, monthly reef manta sightings were at their lowest in May and June, with more sightings recorded during the first three months of the year (Fig. 4). This was biased by the much higher survey effort in early 2019 due to the tourist demand for manta snorkelling trips at the resorts where the MMRP researchers were based. Therefore, the data collected by the MMRP in 2019 was used to standardise sightings by survey effort (Fig. 5). The standardised data showed three peaks in manta sightings in January, June and December, as well as three troughs in manta sightings in May, September and November. These peaks coincide with periods of expected high productivity, which are believed to occur one or two months following the stronger winds associated with the seasonal transition periods. The decrease in sightings during April-May and November was expected, as these months encompass the transition of the seasonal monsoon when there is usually a reduction in manta sightings at all key aggregation sites throughout the Maldives, while the drop in sightings during September was likely due to variations in local environmental conditions.

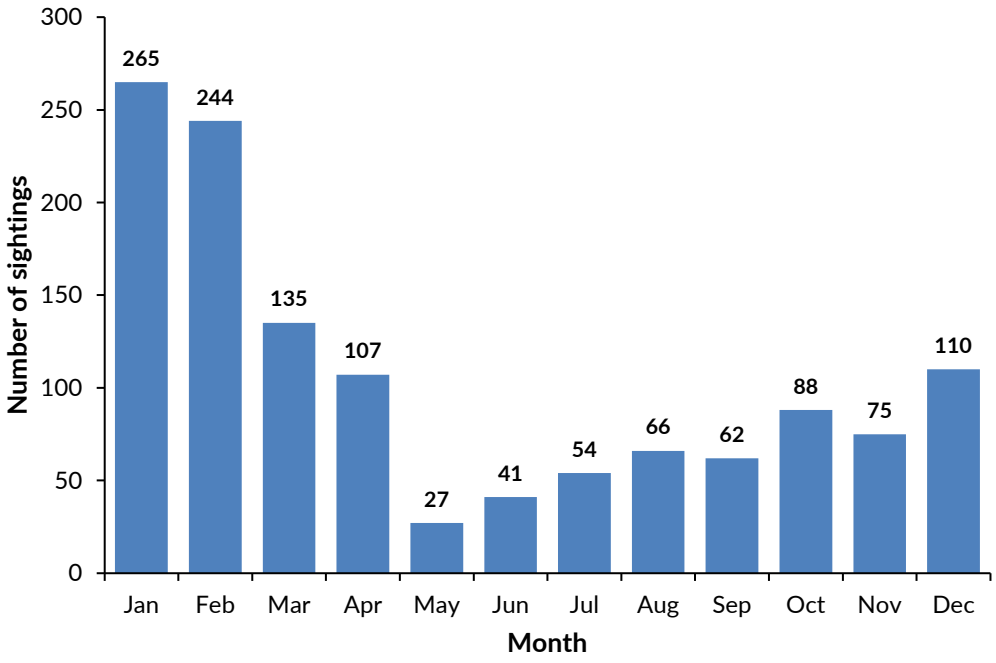


Figure 4: Monthly sightings of reef manta rays (*Mobula alfredi*) in the Ari Atoll Region in 2019 (*n*=1,274).

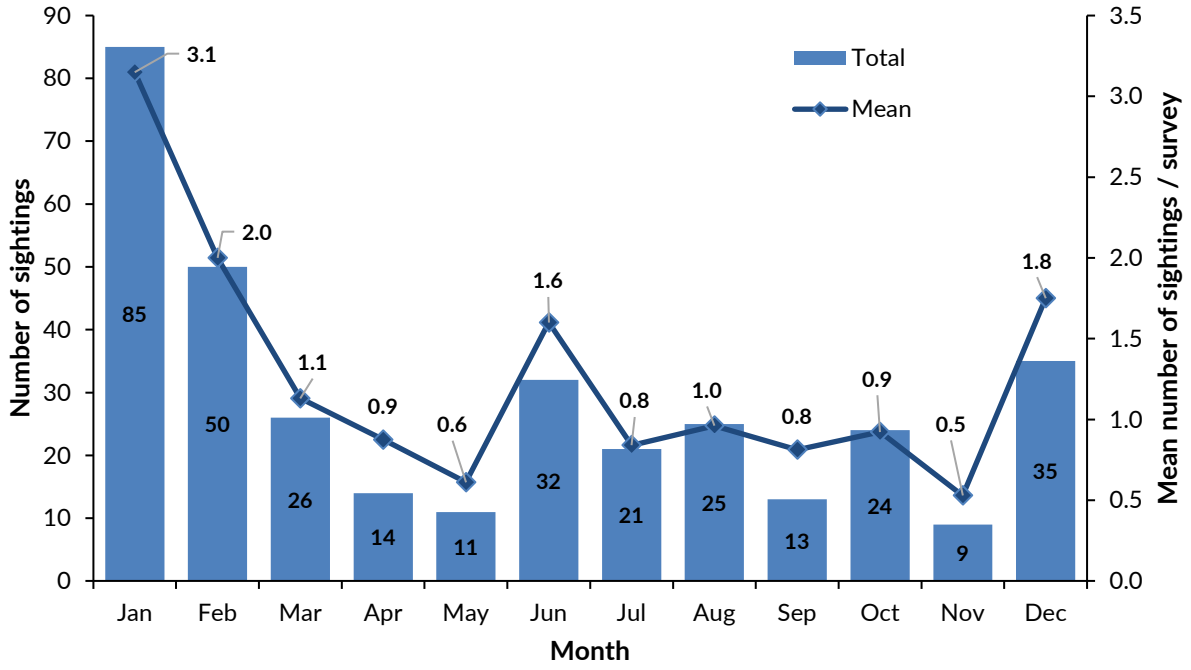


Figure 5: Total monthly sightings of reef manta rays (*Mobula alfredi*) recorded by the Maldivian Manta Ray Project's researchers in the Ari Atoll Region and the mean number of sightings per survey (2019).

Population Demographics

The current recorded population of reef manta rays in the AAR is 1,429 individuals, 29% of the total recorded Maldives population (*n*=4,941). Divided geographically, Ari Atoll has a population comprising 1,318 individuals, Rasdhu Atoll has 163 individuals, and Thoddu Atoll has 23 individuals. Forty-four percent (*n*=627) of these individuals have been recorded in more than one atoll.

The AAR reef manta ray population is split almost evenly by sex, with 706 (49%) females and 711 (50%) males. The sex of the remaining 12 individuals (1%) could not be clearly determined (Fig. 6). The population demographics in AAR show a bias towards adults with 64% (*n*=911) of individuals recorded as adult and 35% juveniles (*n*=506). Without knowing the sex of the 12 unknown individuals, their maturity status could not be determined (Fig. 6).

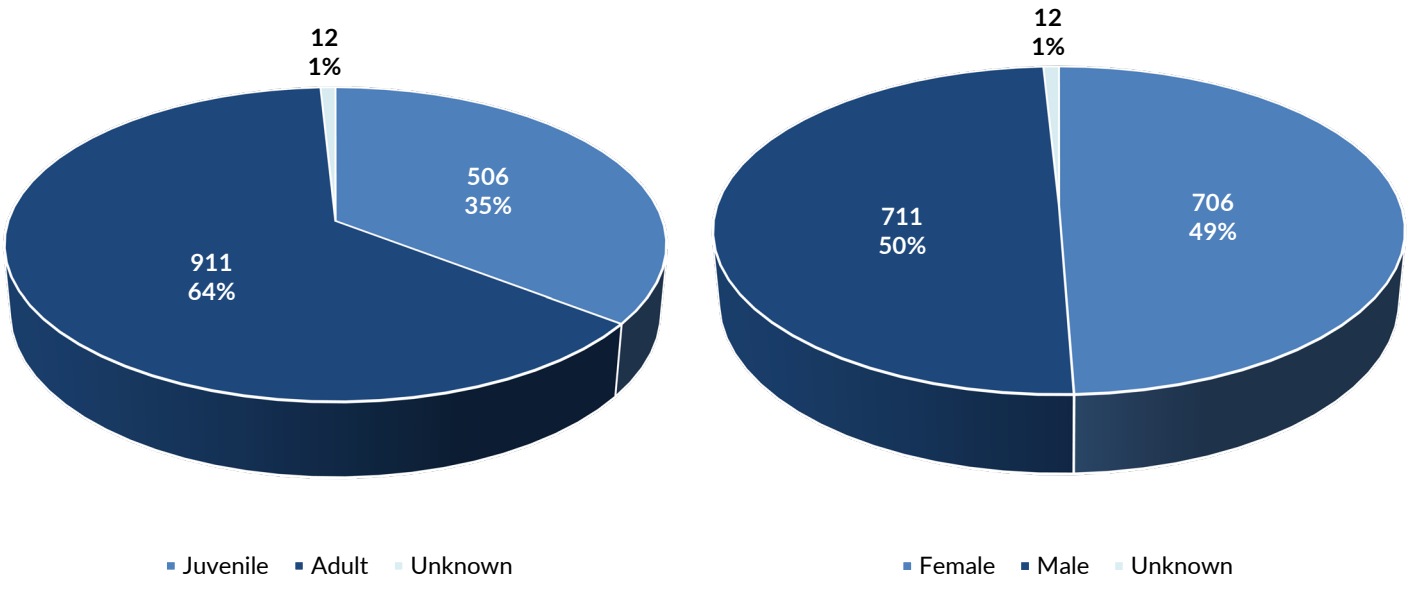


Figure 6: Demographics of the Ari Atoll Region's reef manta ray (*Mobula alfredi*) population (*n*=1,429).

A total of 445 individuals (9% of the overall Maldivian population) were sighted in the AAR in 2019, which is the lowest number of individuals sighted within a single year since the MMRP has had a permanent base in Ari Atoll (Fig. 7). Nine percent (*n*=42) of these individuals were new to the Maldives reef manta ray population (Fig. 7). This is consistent with 2018, and is the lowest percentage of new individuals sighted annually, which was expected, as more of the total population is added to the database each year. To date, 81% (*n*=1,159) of the region's reef manta ray population (*n*=1,429) has been re-sighted in either the AAR or elsewhere in the Maldives, suggesting that the MMRP has recorded the vast majority of the individuals that visit the AAR. Of the 42 new individuals recorded, 14 (31%) were estimated to be "young of the year" (YoY), based on their small disc widths measuring approximately 1.5 metres.

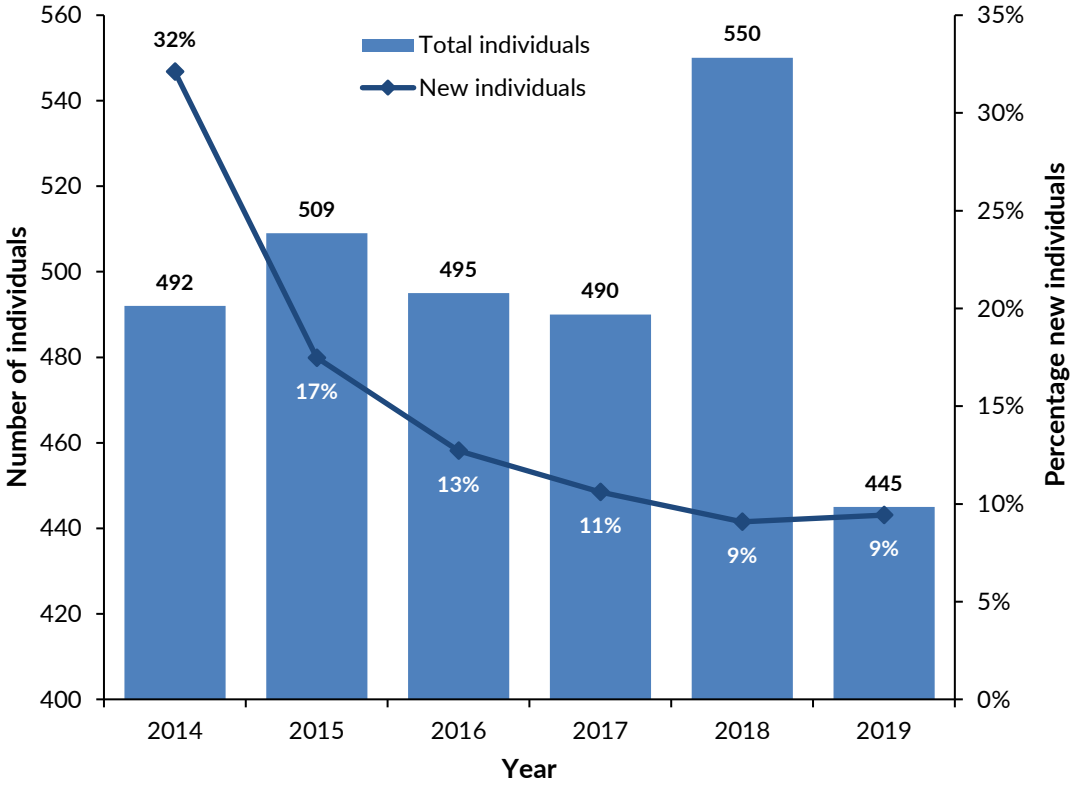


Figure 7: Total number of individual reef manta rays (*Mobula alfredi*) sighted annually in the Ari Atoll Region, and the percentage of those individuals that were newly recorded.

Reproductive Fecundity

In recent years, the MMRP has observed an increase in reef manta ray reproductive fecundity, with higher numbers of pregnant females and new-born pups sighted throughout the Maldives. A total of 110 pregnancies were recorded between 2005 and 2019, with the largest number of pregnant females recorded in 2017 (*n*=20) and 2018 (*n*=29), which represented 31% and 30% respectively of all adult females sighted in the AAR in 2017 (*n*=64) and 2018 (*n*=98) (Fig. 8). A much lower pregnancy rate was recorded in 2019 with only 7% (*n*=6) of the adult females sighted (*n*=83) noted to be pregnant. Of the individuals recorded as pregnant in 2019, two were recorded as pregnant in two consecutive years [Donald (MV-MA-0890) and Blenny (MV-MA-1185)].

Overall, 23% (*n*=324) of the AAR manta population are mature females; the 82 individuals with at least one recorded pregnancy, represent only 25% of the overall population of adult females in AAR. This low reproductive rate, even with the peaks seen in some recent years, indicates a low fecundity for reef manta rays, and reinforces the importance of establishing effective conservation methods to minimize population decline.

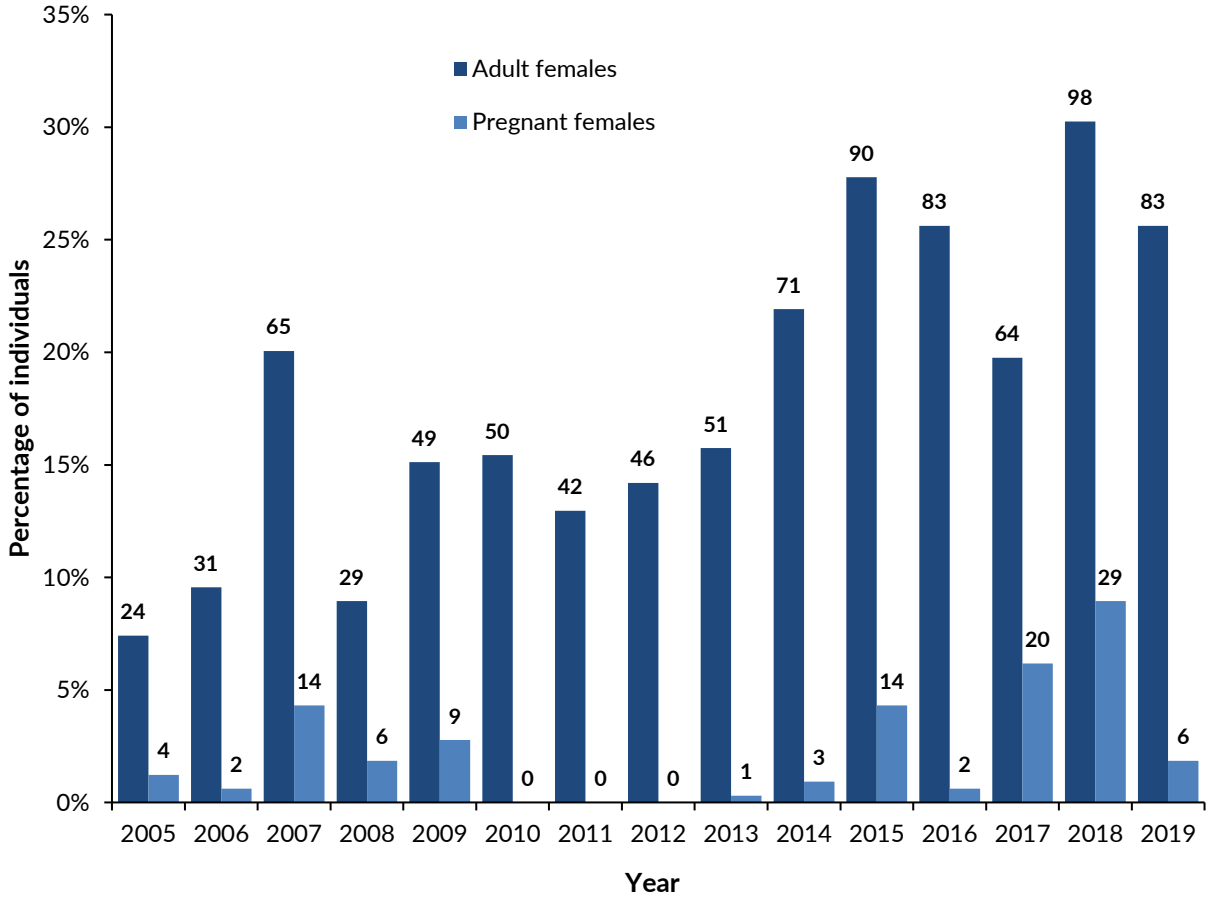


Figure 8: Percentage of the Ari Atoll Region's adult female reef manta ray (*Mobula alfredi*) population (*n*=324) sighted annually, and the percentage of those females that were recorded pregnant in the same year. Actual numbers above bars.

Over the last five years (2015-2019), increased numbers of manta pups, or YoY, have been recorded. In 2019, 14 YoY individuals were recorded in the AAR representing 3% of all individuals recorded that year in the region (*n*=445). Although lower than recorded in 2018 (*n*=17), the number of YoY in 2019 was still consistent with years of increased pup sightings (2015-2018). Only four pups were recorded in the AAR prior to 2015. This increase in sightings of young manta rays is likely attributed to greater research effort, the discovery of manta aggregation areas frequented by juveniles, and the higher number of pregnancies recorded in recent years. With continued research in the AAR, we hope to gain a better understanding of site usage by these young individuals, and develop insight into reproductive periodicity, and factors influencing recruitment rates.

Throughout the Maldives, juvenile and adult manta rays have been observed frequenting different aggregation areas; juveniles tended to be found in sheltered lagoon areas whilst adults were typically seen at cleaning stations and feeding areas in channels and along outer reefs. It is likely that the juvenile manta rays prefer the relative safety provided by shallower, sheltered waters within the atolls.

Between 2015-2019, there were 70 YoY recorded in the AAR; of these mantas, 84% were initially sighted in lagoons (*n*=59) and 16% were sighted at a reef or channel (*n*=11). Of these YoY reef manta rays (*n*=70), 23% were sighted at Dhigurah Falhu (*n*=16), 23% at Genburugau Falhu (*n*=16), 17% at Maavaru Falhu (*n*=12) and 13% at Maayafushi Falhu (*n*=9) leading us to believe these are important aggregation areas acting as nursery grounds for juvenile reef manta rays in the AAR. These sites are heavily visited by tourist boats and, due to their importance to the region's young reef manta ray population, are key sites to manage boat traffic and human presence.

Manta ray courtship and mating behaviour typically peak at certain times of the year throughout the manta rays' global range. Cleaning stations tend to be the focal point for manta courtship behaviour, allowing researchers and knowledgeable citizen scientists to observe and record this behaviour. During 2019, 13 courtship events were recorded, seven of these events were recorded in the peak month of February (Fig. 9). Courtship activity in the AAR did not coincide with the transitional period between the Monsoons which has historically been the recorded trend across Maldives. This could be attributed to more favourable conditions (higher wind speed (Fig. 24)) and a peak in manta sightings (Fig. 5) both occurring in February.

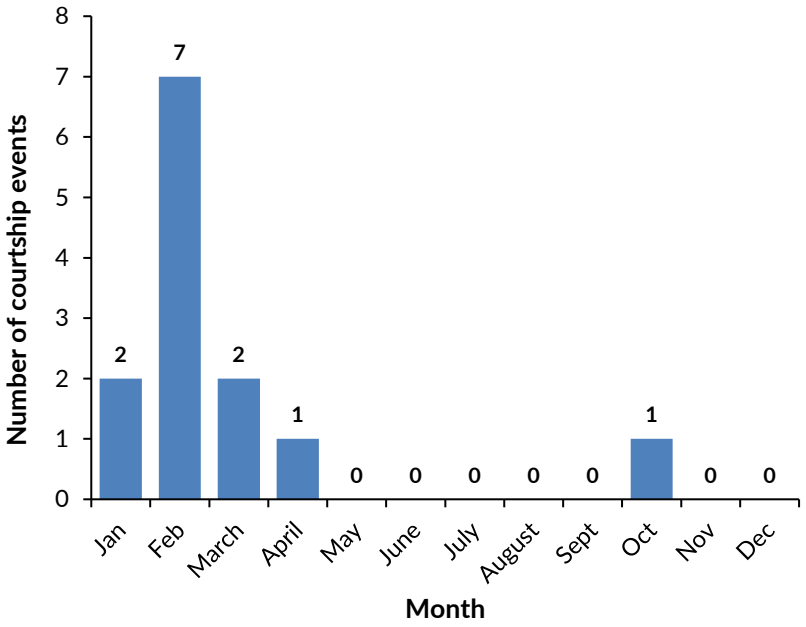


Figure 9: Total number of reef manta ray (*Mobula alfredi*) courtship events recorded throughout the Ari Atoll Region (2019).

Atoll Residency

Throughout 2019, each individual manta ray was sighted, on average, 2.9 times, which was lower than the 3.8 sightings per individual recorded in 2018 (Fig. 10). The percentage of reef manta rays seen more than once in the AAR in 2019 was 56%, lower than that recorded in 2017 and 2018 (both 62%) (Fig. 10). Because these rates came from sightings recorded by both citizen scientists and MMRP researchers, they did not account for survey effort and might show bias. Therefore, a Residency Index (RI) was calculated for 2016 – 2019 using sightings and survey data collected by the MMRP researchers. The RI is based on the ratio between the number of days each individual was sighted and the total number of surveyed days, in order to determine how often each individual was seen per survey day throughout the year. For example, a RI of 3% means that, on average, each individual was sighted on 3% of the total surveyed days. Within the AAR, the RI in 2019 was 1.4%, which was much lower than that calculated for all previous years (Fig. 11). This was likely a reflection of the decline in the number of individuals sighted in 2019 compared to previous years (Fig. 7). It could also be related to the less favourable conditions in 2019 due to the lower recorded wind speeds compared to 2016, 2017 and 2018 (Fig. 21).

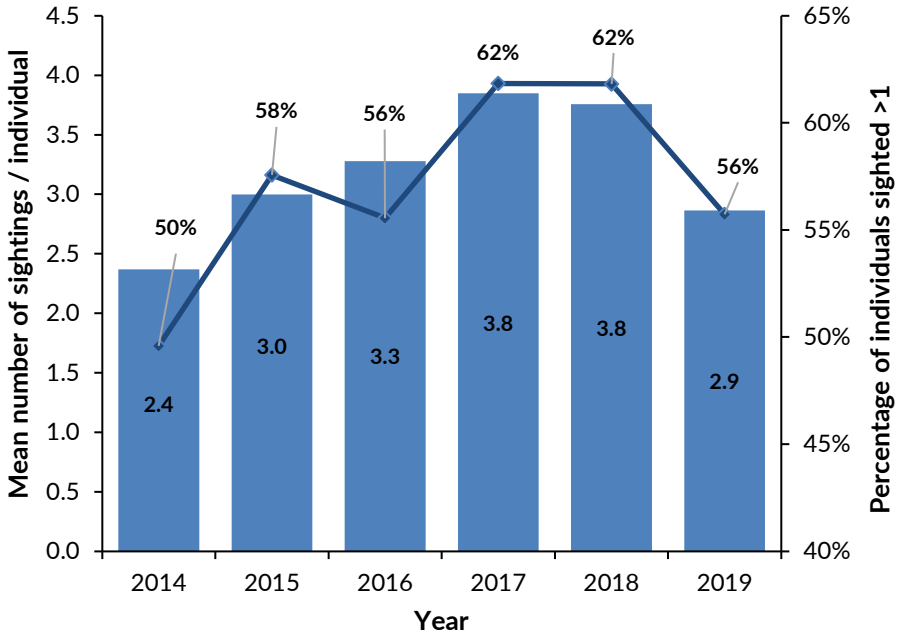


Figure 10: Mean number of sightings per individual reef manta ray (*Mobula alfredi*) in the Ari Atoll Region, and the percentage of individuals sighted on multiple occasions during the same year.

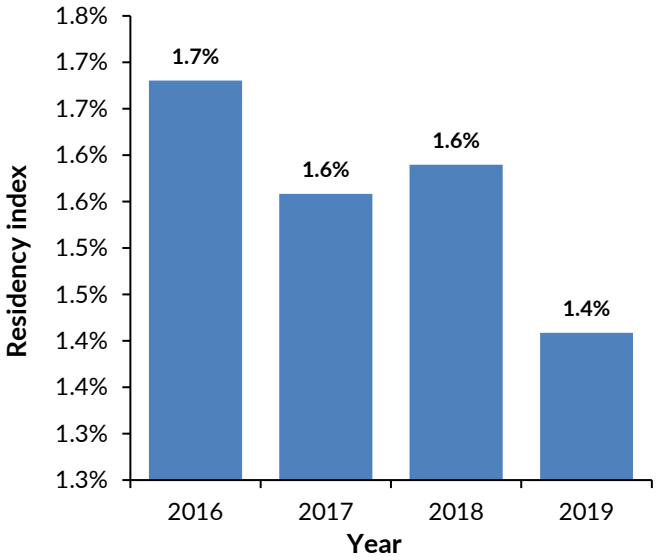
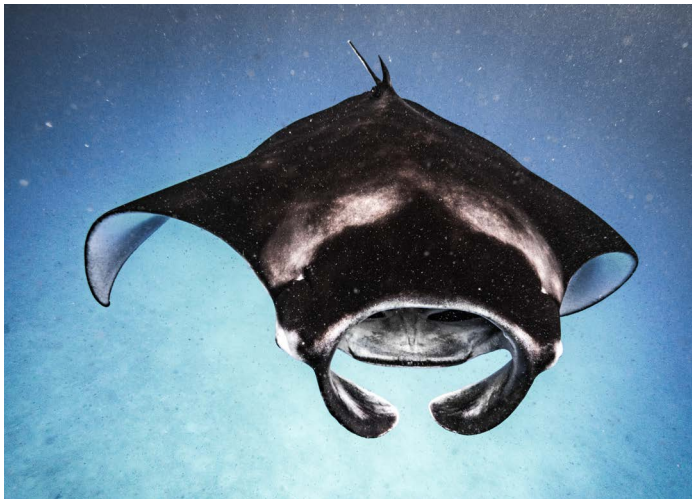


Figure 11: Annual Residency Index (RI) of the reef manta rays (*Mobula alfredi*) recorded by the Maldivian Manta Ray Project's researchers in the Ari Atoll Region. RI is calculated as the average of each individuals' residency score (=number of times sighted annually divided by the total number of surveys).

Intra Atoll Migrations

Reef manta rays in the Maldives migrate seasonally, moving between the eastern and western sides of the atolls with the changing South Asian Monsoon. As detailed in the previous AAR reports, sightings in Ari Atoll have shown the same seasonal movement patterns as the country's other large atolls, with reef manta rays visiting the western aggregation sites during the Northeast Monsoon (December-March) before returning to the eastern aggregation sites during the Southwest Monsoon (May-November). Reef manta ray sightings in Rasdhu Atoll tend to peak during the Northeast Monsoon. However, the only manta aggregation sites (and channels) in the atoll are on the eastern and southern edges of the atoll. It is likely that, due to this small atoll's unique geography, with no channels on the western side of the atoll, the manta rays are utilizing cleaning stations in the channels nearest to their feeding areas, which are likely most productive during the Northeast Monsoon.

Manta ray sightings often show variance within each season, with manta sightings reported earlier in the season at some aggregation sites, and later in the season at others, especially in those aggregation areas frequented by adult manta rays (Table 1 & Figs. 12 & 13). During the Northeast Monsoon, sightings typically occur on the western side of the atoll, with Gangehi Kandu, Moofushi Bojamhadi, Rangali Madivaru, and Veligandu Kandu most active (Fig. 12). Like previous years, in 2019, sightings at Rangali Madivaru and Gangehi Kandu peaked earlier (January) in the Northeast Monsoon than those at Moofushi Bojamhadi and Veligandu Kandu (February) (Fig. 12). With the onset of the Southwest Monsoon, sightings at these westerly locations began to taper off in April with little to no sightings recorded between May to October. From May onwards, a noticeable shift in manta ray site use was recorded as sightings gradually increased at Dhiggaru Kandu and Huravalhi Falhu, located on the east of Ari Atoll (Fig. 13). Manta sightings were recorded in much higher numbers at Dhiggaru Kandu early in the season (May-July) before slowly declining in numbers from August onwards (Fig. 13). On the other hand, sightings at Huravalhi Falhu peaked in October, with lower sightings reported in the other months of the Southwest Monsoon (Fig. 13). Manta sightings at both Dhiggaru Kandu and Huravalhi Falhu were lower in 2019 when compared to recorded sightings in previous years (Fig. 14) despite a high survey effort by MMRP researchers on the eastern side of Ari Atoll.



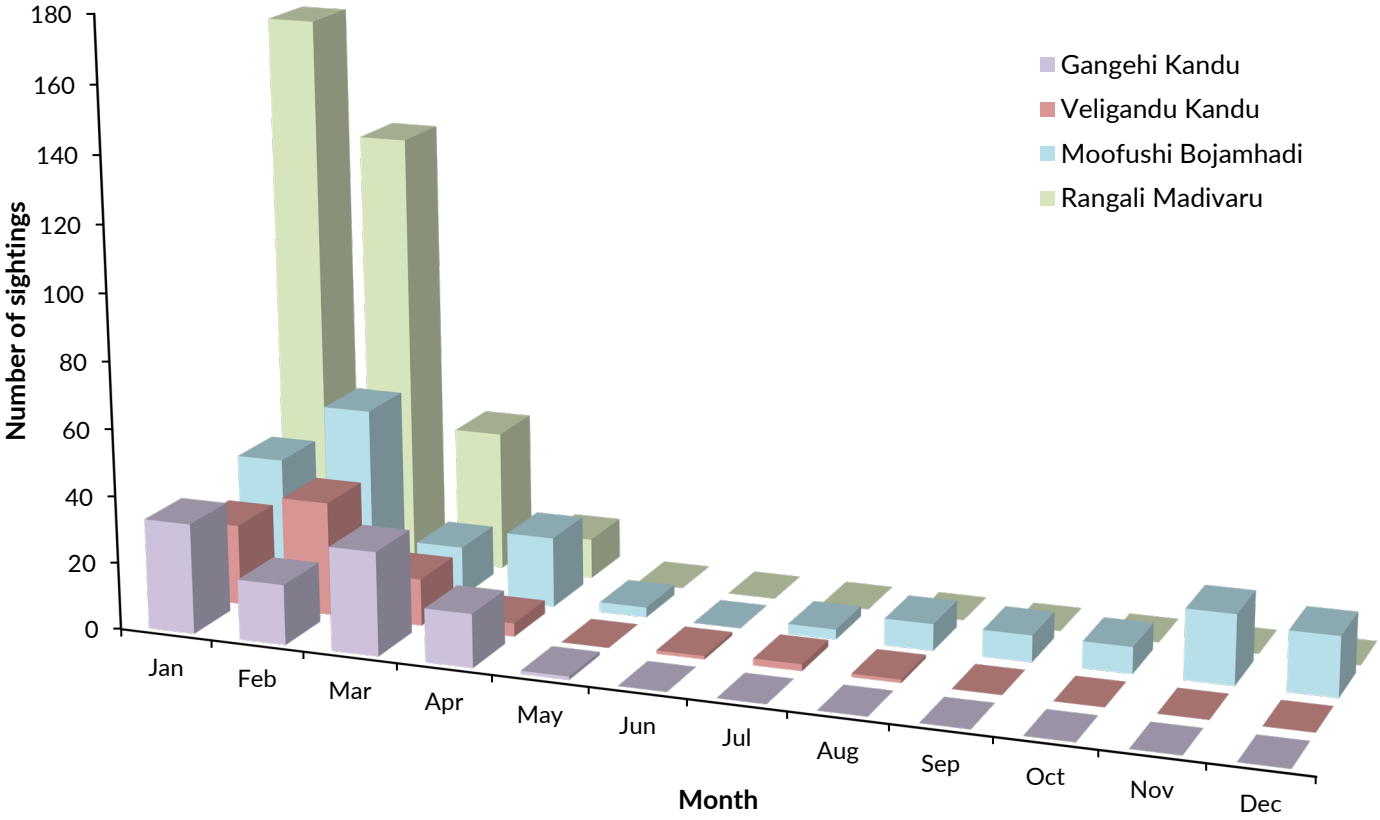


Figure 12: Intra-annual variations in sightings of reef manta rays (*Mobula alfredi*) during the Northeast Monsoon at four key adult aggregation sites in the Ari Atoll Region (2019).

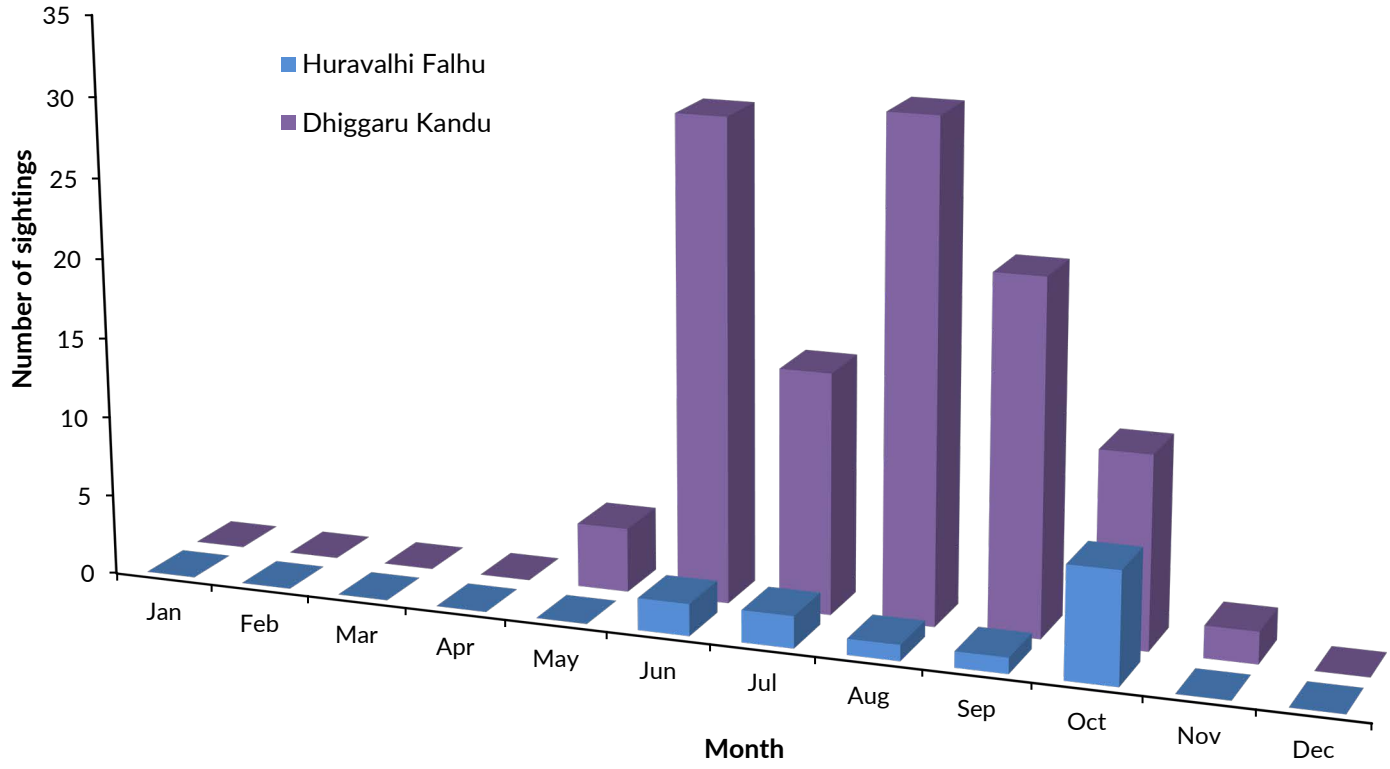


Figure 13: Intra-annual variations in sightings of reef manta rays (*Mobula alfredi*) during the Southwest Monsoon at two key adult aggregation sites in the Ari Atoll Region (2019).

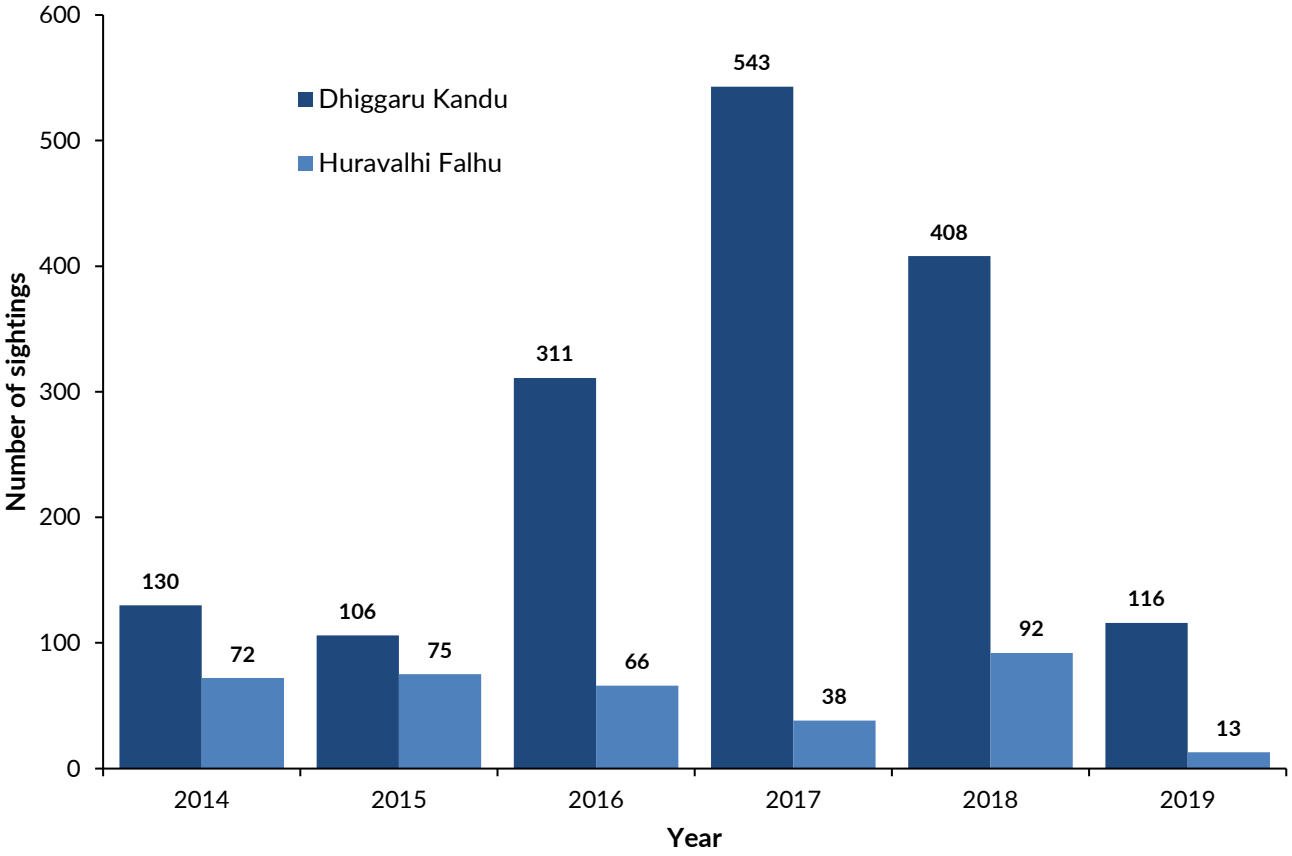


Figure 14: Annual variation in sightings of reef manta rays (*Mobula alfredi*) at Dhiggaru Kandu and Huravalhi Falhu in the Ari Atoll Region (2014-2019).

As the seasons began to shift again at the end of the year, sightings dropped at Dhiggaru Kandu and Huravalhi Falhu in November with a resurgence of sightings recorded on the west of the atoll at Moofushi Bojamhadi, however unlike in previous years, no manta rays were recorded at Rangali Madivaru, Gangehi Kandu, and Veligandu Kandu during November and December 2019 (Fig. 12). This lack of sightings along the west of the atoll and the lower number of sightings recorded at Dhiggaru Kandu and Huravalhi Falhu in 2019 compared to 2018 (Fig. 14), could possibly be attributed to the lower-than-average wind speeds in 2019, particularly noted during the Southwest Monsoon, which is typically a period represented by increased wind speeds (Figs. 21 & 24). Wind speed and current strength have a strong influence on the seasonal abundance of zooplankton, which ultimately influences manta abundance (see "Environmental Variables" for more details).

Both within and between seasons, less variation is seen at juvenile dominated aggregation sites (Table 1 & Fig. 15). In 2019, manta rays were sighted at Dhigurah Falhu in both the Northeast and Southwest Monsoon, with the peak in sightings occurring in December, and again with smaller peaks in April and October (Fig. 15). The more consistent year-round sightings are likely due to the juvenile reef manta ray's habitat preference for sheltered lagoons. Manta ray sightings at Genburugau Falhu in 2019 peaked between September and December (Fig. 15). However, it is problematic to extrapolate clear trends from this data due to the MMRP's reliance upon citizen scientist submission from this site; the involvement of regular citizen scientist from August 2019 onwards and the relative lack of sightings reported prior to 2018. Both Dhigurah Falhu and Genburugau Falhu are large, but sheltered lagoons, providing good habitat for juvenile manta rays. Manta sightings at Fesdu Falhu peaked during the Northeast Monsoon, while sightings at Maayafushi Falhu peaked during the Southwest Monsoon. These areas are unique as most sightings are artificially stimulated through the use of powerful floodlights situated on liveaboards which attract large concentrations of zooplankton at night, and in turn attract the manta rays to feed. The MMRP is reliant upon citizen scientist submissions in these areas, so it is not possible to determine whether trends show true seasonal movements or a change in the frequency of visitors, and floodlight usage, in these areas.

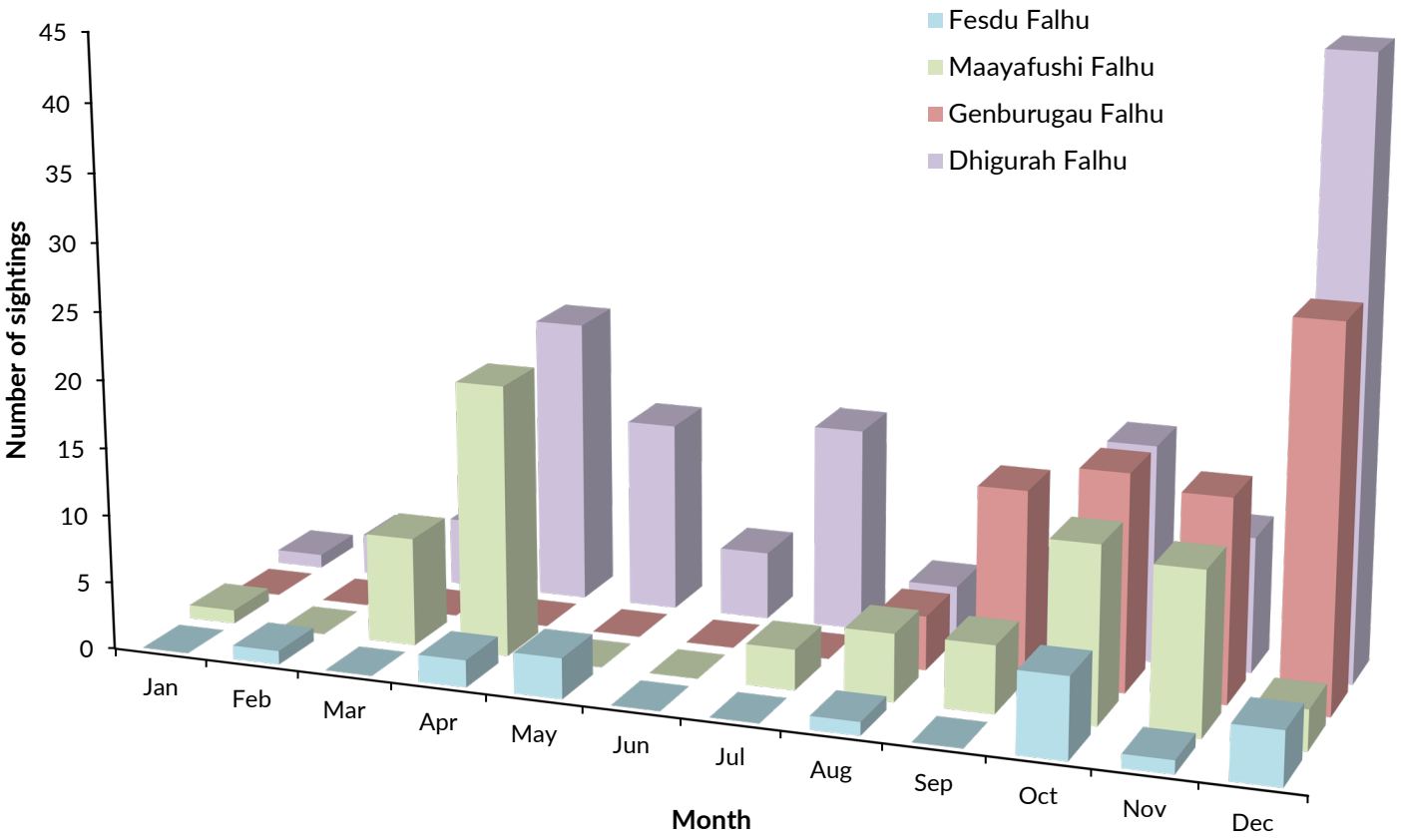


Figure 15: Intra-annual variations in sightings of reef manta rays (*Mobula alfredi*) at four key juvenile aggregation sites in the Ari Atoll Region (2019).

Inter Atoll Migrations

Due to its central location and proximity to other atolls, forty-two percent (*n*=605) of the AAR's reef manta ray population has been sighted outside of the region, compared to only 29% of the total recorded Maldives' reef manta ray population (*n*=4,941). Manta rays from the AAR have been re-sighted in 16 different geographical atolls, with the highest number of re-sightings in Baa Atoll (*n*=368), followed by North Male Atoll (*n*=150) (Fig. 16). After these two atolls, the larger number of re-sightings were recorded in atolls in the central areas of the country, close to the AAR (Fig. 16). This is likely due to a combination of shorter distances and shallower water between atolls (~300 m), providing fewer physical barriers for migration, and greater levels of MMRP survey effort in those areas. Research efforts in 2019 enabled the recording of Homer (MV-MA-0667) and Aurora (MV-MA-0708) for the first time in Ari Atoll. These two manta rays are both adult males and are now in the 1% (*n*=48) of Maldives' reef manta ray population (*n*=4,941) that have been recorded in four different atolls.

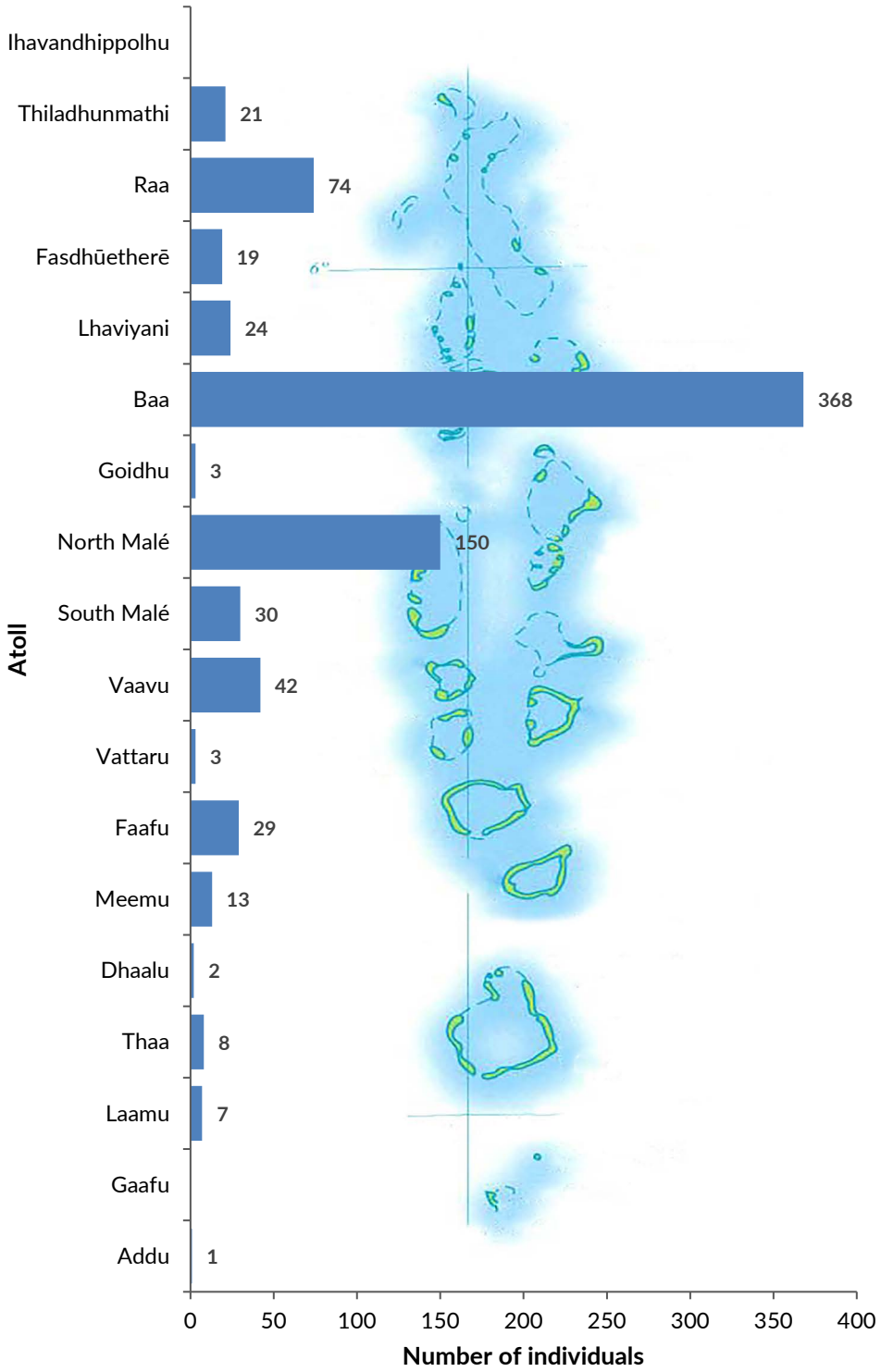


Figure 16: Number of reef manta rays (*Mobula alfredi*) (*n*=605) from within the Ari Atoll Region population (*n*=1,429) which have been recorded in other atolls throughout the Maldives Archipelago. Note – some individuals have been sighted in more than one atoll throughout the Maldives Archipelago.

Some longer migrations have also been recorded among the individuals in the AAR. One of the most famous being that reported for Errol (MV-MA-2609), a manta from the Addu regional population and sighted for the first time in Ari Atoll in January 2018. Errol was re-sighted back in Addu Atoll in November 2018. Similarly, in January 2019, a manta from the Laamu regional population [Ké Ké (MV-MA-3431)] was sighted in Ari Atoll for the very first time. By June 2019, Ké Ké had returned to Laamu Atoll.

During 2019, a total of 99 sightings of 76 individuals were recorded at Gangehi Kandu in north-western Ari Atoll. This sub-population appears more transient than the wider AAR population, with 63% (*n*=47) of individuals seen in more than one atoll. Interestingly, of those 47 individuals, 55% (*n*=26) were seen in Baa Atoll. The manta rays recorded in Baa Atoll by the MMRP take advantage of the high productivity in the east of this atoll during the Southwest Monsoon, but much less is known about the whereabouts

of these individuals during the rest of the year. These recent sightings in the AAR, and the high overlap in number of individuals sighted in both Gangehi Kandu and Baa Atoll, suggest many of them migrate south to northern Ari Atoll. For example, Tofu (MV-MA-1696) and Fenna (MV-MA-3416) are two manta rays which are regularly sighted in Baa Atoll during the Southwest Monsoon, particularly in Hanifaru Bay. In 2018 and 2019, these two individuals were two of the most seen manta rays recorded in Gangehi Kandu, with seasonal migratory trends beginning to become evident between North Ari Atoll and Eastern Baa Atoll (Fig. 17). Hanifaru Bay is situated within a marine protected area (MPA) of Baa Atoll's UNESCO Biosphere Reserve, where these rays are afforded greater protection. However, to ensure nationwide protection for these highly migratory and vulnerable species, much more key manta ray habitat must be protected and effectively managed throughout the archipelago.

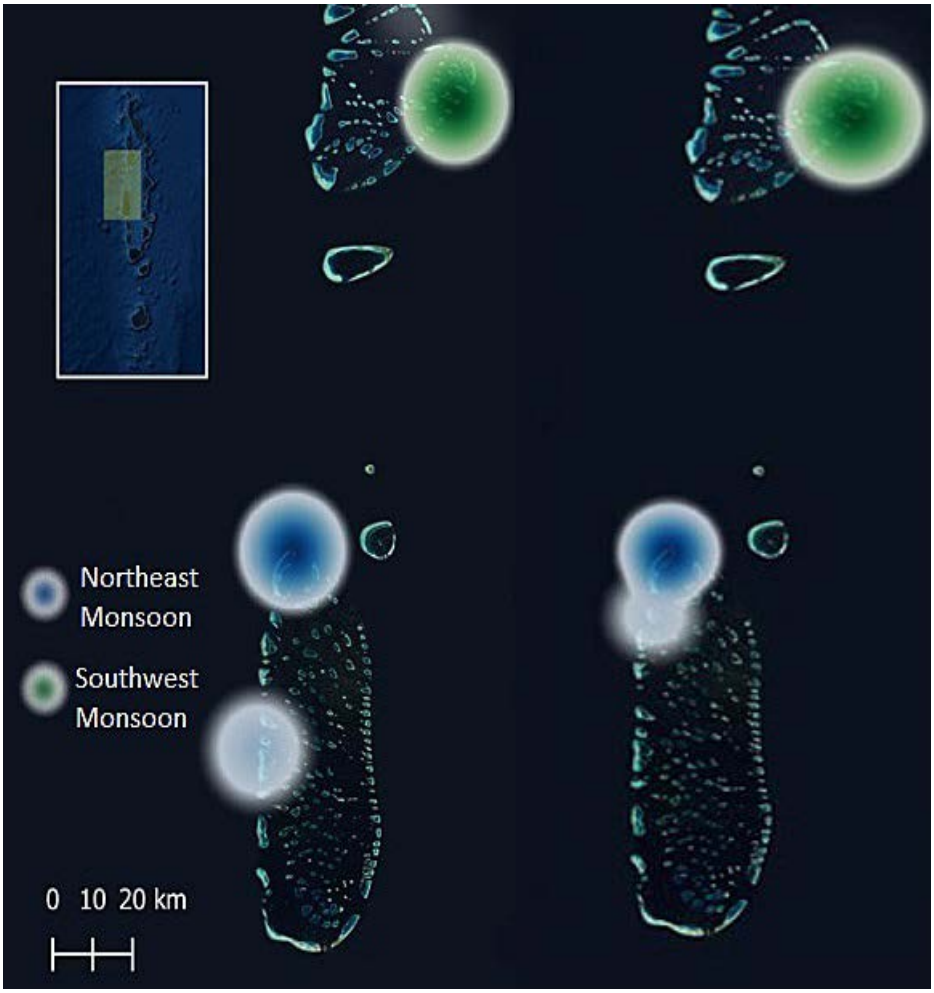


Figure 17: A heatmap of the sightings of the reef manta rays (*Mobula alfredi*) MV-MA-1696 (*n*=78) (left) and MV-MA-3416 (*n*=82) (right) in Ari and Baa Atolls (2005-2019).

Sub-Lethal Injuries

In 2019, a total of 26 new injuries were recorded on individual reef manta rays within the AAR. Of these injuries, 23% (*n*=6) were anthropogenic in origin (e.g., fishing line entanglement, boat strikes, etc.), whilst 23% (*n*=6) were naturally caused injuries (e.g., predatory bites, diseases, deformities, etc.). The remaining 14 sub-lethal injuries originated from an unknown source (Fig. 18). Within the AAR a higher proportion of juvenile manta rays (especially females) had new injuries, compared to adults (Fig. 18). Of the individuals sighted in the AAR in 2019, only 43% were juveniles yet 58% of new injuries were recorded on juvenile manta rays. This is an increase from 2018 where only 37% of new injuries were recorded on juvenile manta rays.

The increase in new injuries on juvenile manta rays from 2018 to 2019 could partially be related to the habitat usage of juvenile individuals and an increase in anthropogenic pressures in these areas. Juvenile reef manta rays tend to feed and clean in sheltered lagoon habitats where they are less exposed to natural predators, but where they can be sighted year-round by tourism operators. This year-round exposure to tourist boats and snorkellers, as well as being potentially exposed to drifting ghost fishing gear, leaves them more susceptible to injuries.

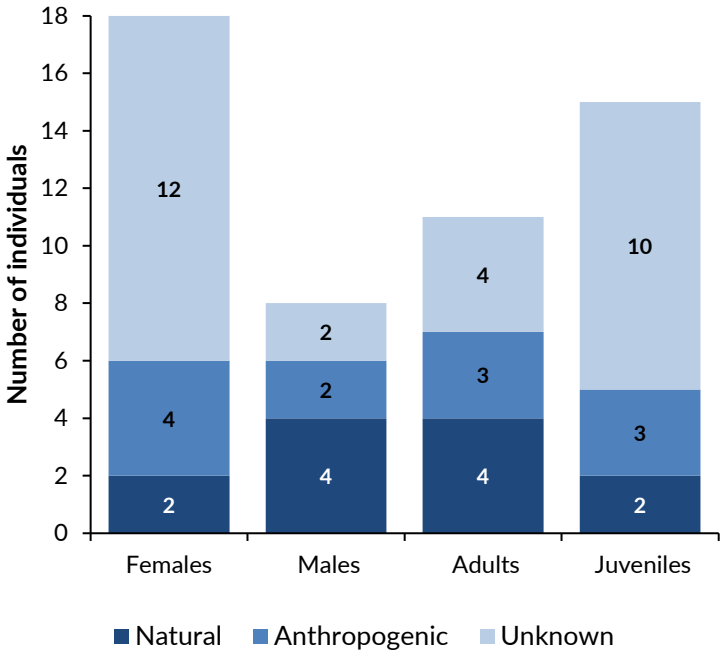


Figure 18: Demographic variations in the number of new sub-lethal injuries (*n*=26) recorded in 2019 on reef manta rays (*Mobula alfredi*) within the Ari Atoll Region population (*n*=1,429), and likely injury origin (natural, anthropogenic or unknown).

ENVIRONMENTAL VARIABLES

Environmental conditions, especially wind and current strength, have a strong influence on the seasonal abundance of zooplankton, which in turn influence manta abundance. On a smaller scale, lunar tidal current strength and direction strongly influence the manta's movements, behaviour, and habitat use.

Small Scale

Tidal currents have the largest influence on daily zooplankton abundance within the atoll channels and lagoons, moving plankton-rich water into and out of the atolls. Manta ray movement, behaviour, and habitat use are influenced by the current direction. Both current direction and predominant manta behaviour were recorded on 140 surveys by the MMRP in 2019 (Fig. 19). Cleaning manta rays were more often encountered (*n*=64) during outgoing currents when zooplankton was less readily available. Feeding manta rays were encountered in low numbers for both incoming (*n*=11) and outgoing (*n*=14) currents, which contrasts to 2018, where feeding manta rays were more often encountered during incoming current (*n*=27), as it is normally the incoming tidal currents that bring an abundance of zooplankton from the upwellings along the atoll's edge. However, variations in site topography and location type (channel, outer reef, lagoon) meant that some areas showed much stronger relationships between current direction and manta activity. For example, at Rangali Madivaru the manta rays typically aggregate where the channel meets the long outer reef. Cleaning manta rays seemed to show a strong preference for outgoing currents (Fig. 20).

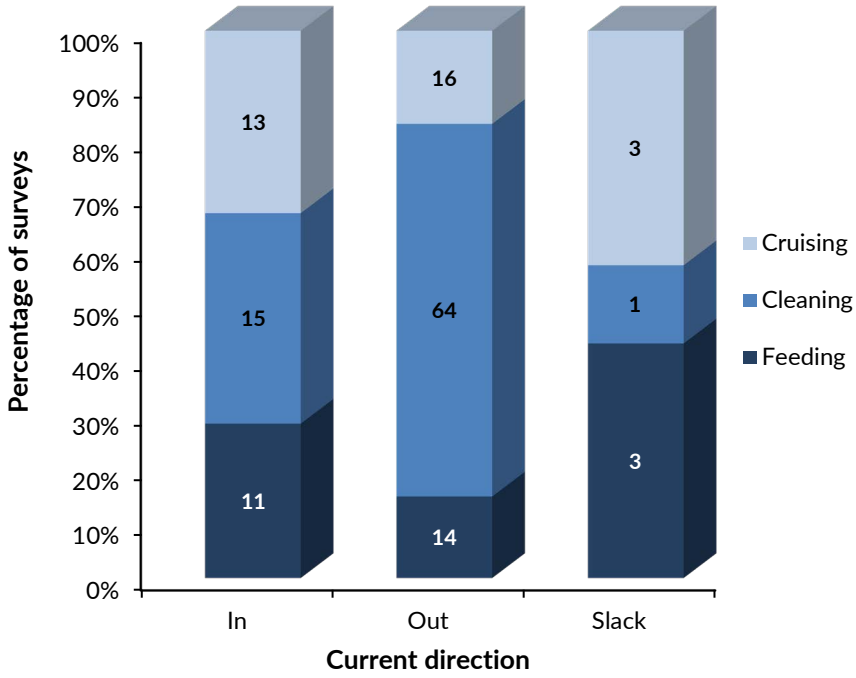


Figure 19: Changes in the behavioural activities of reef manta rays (*Mobula alfredi*) in relation to current direction (In, Out, Slack) through the channels in the Ari Atoll Region during surveys (2019) where manta rays were observed (*n*=140).

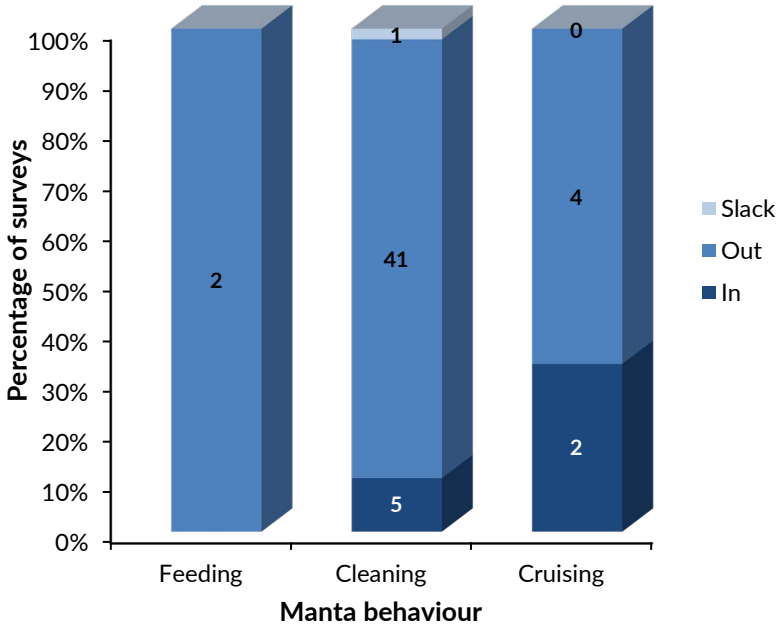


Figure 20: Changes in the behavioural activities of reef manta rays (*Mobula alfredi*) in relation to current direction (In, Out, Slack) through the channels at Rangali Madivaru during surveys in 2019 where manta rays were observed (*n*=55).

With current direction serving as a strong influence on manta behaviour in some locations, it may be a possible driver of intra-seasonal sightings variations. Many manta sightings in the AAR are recorded by MMRP researchers and citizen scientists on cleaning stations, where manta rays are typically encountered on SCUBA. All surveys in the AAR are reliant on guest excursions, which tend to follow schedules that do not account for current variations. Due to this bias, it is possible that sightings are predominantly recorded in areas like Rangali Madivaru at times when divers are present, and currents are favourable to cleaning manta rays.

Large Scale

Wind strength and direction strongly influences seasonal upwelling – playing an important role in determining zooplankton abundance over longer timescales, typically monthly to seasonally. Average overall wind speed in 2019 (9.3 km/h) was considerably weaker than those in previously recorded years in the AAR (Fig. 21). In order to look at the relationship between manta ray sightings and wind speed, data collected by MMRP researchers in 2016, 2017, 2018, and 2019 was used for analysis. Overall, a weak positive correlation (R^2=0.03) was found between average monthly wind speeds and daily manta sightings (Fig. 22). Similarly, the data from 2019 showed a moderate positive correlation (R^2=0.52) between these two variables (Fig. 23). When manta ray sightings and average wind speeds were compared on a monthly basis, manta sightings tend to increase the same month or one month after wind speeds increase, likely due to the time taken between increased primary productivity and the blooms of zooplankton to occur. Wind speeds in 2019 peaked in January and February, and again in June and December. Wind speeds were at their lowest in March and April, and again in October and November. In response to the peaks in wind speed, manta ray sightings were higher in January and February, and again in June and December (Fig. 24). In previous years there has been a slight delay in peaks in sightings reacting to the higher wind speed, which may also explain the lack of significant correlation when analysing monthly wind speeds and monthly manta sightings between 2016 and 2019.

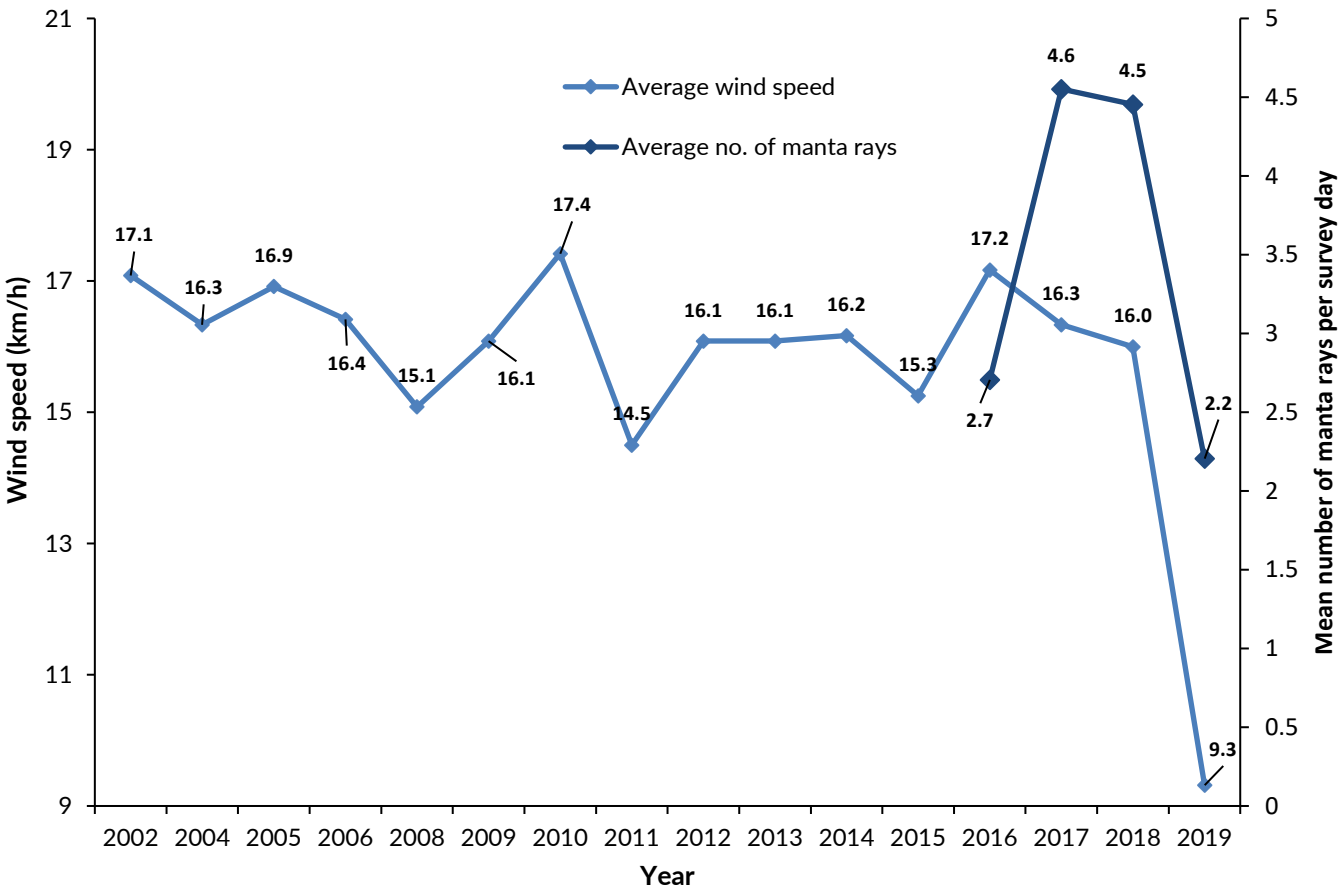


Figure 21: Mean yearly wind speed (km/h) and mean number of reef manta ray (*Mobula alfredi*) sightings per survey day by the Maldivian Manta Ray Project researchers in the Ari Atoll Region.

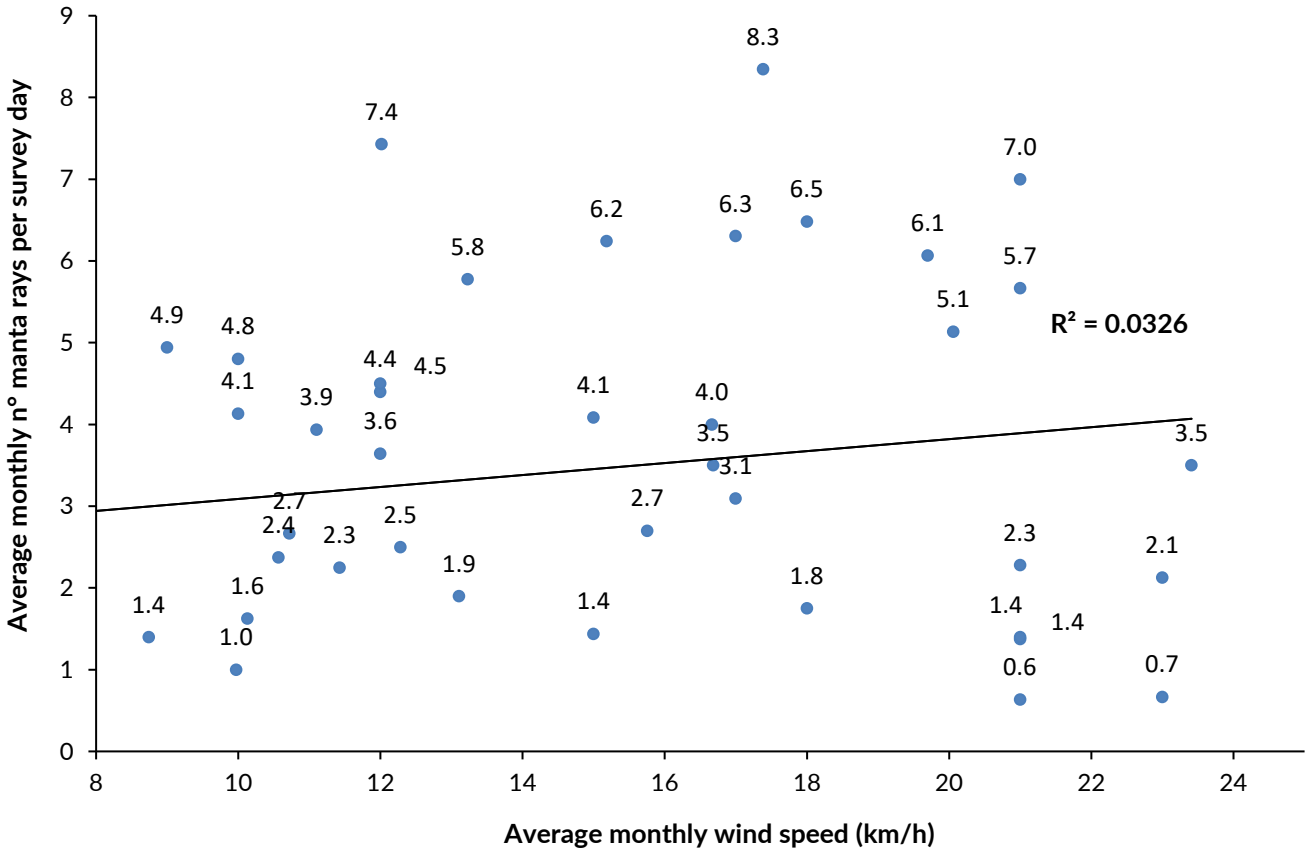


Figure 22: Mean monthly wind speed (km/h) and the mean monthly number of reef manta ray (*Mobula alfredi*) sightings recorded per survey day by the Maldivian Manta Ray Project researchers in the Ari Atoll Region (2016-2019).

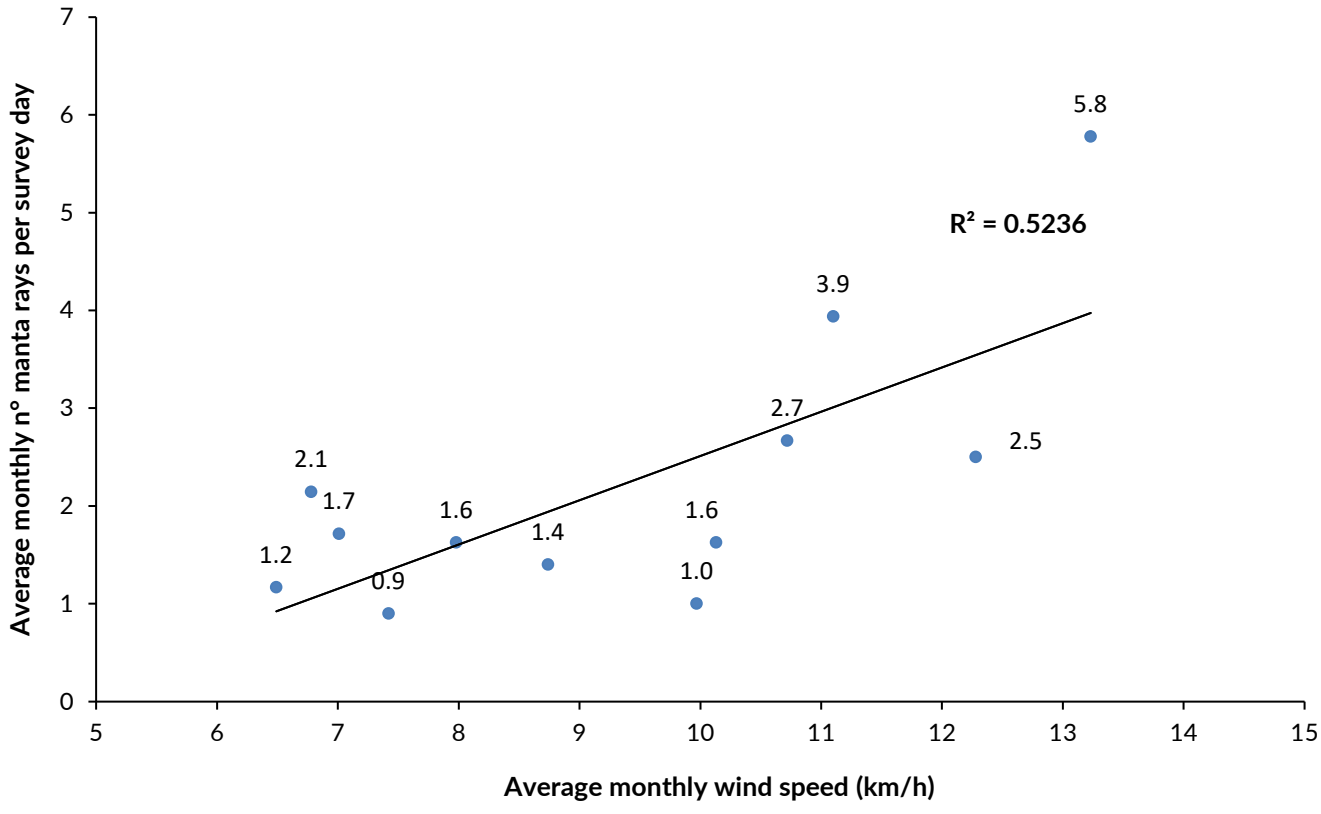


Figure 23: Mean monthly wind speed (km/h) and the mean monthly number of reef manta ray (*Mobula alfredi*) sightings per survey day by the Maldivian Manta Ray Project researchers in the Ari Atoll Region (2019).

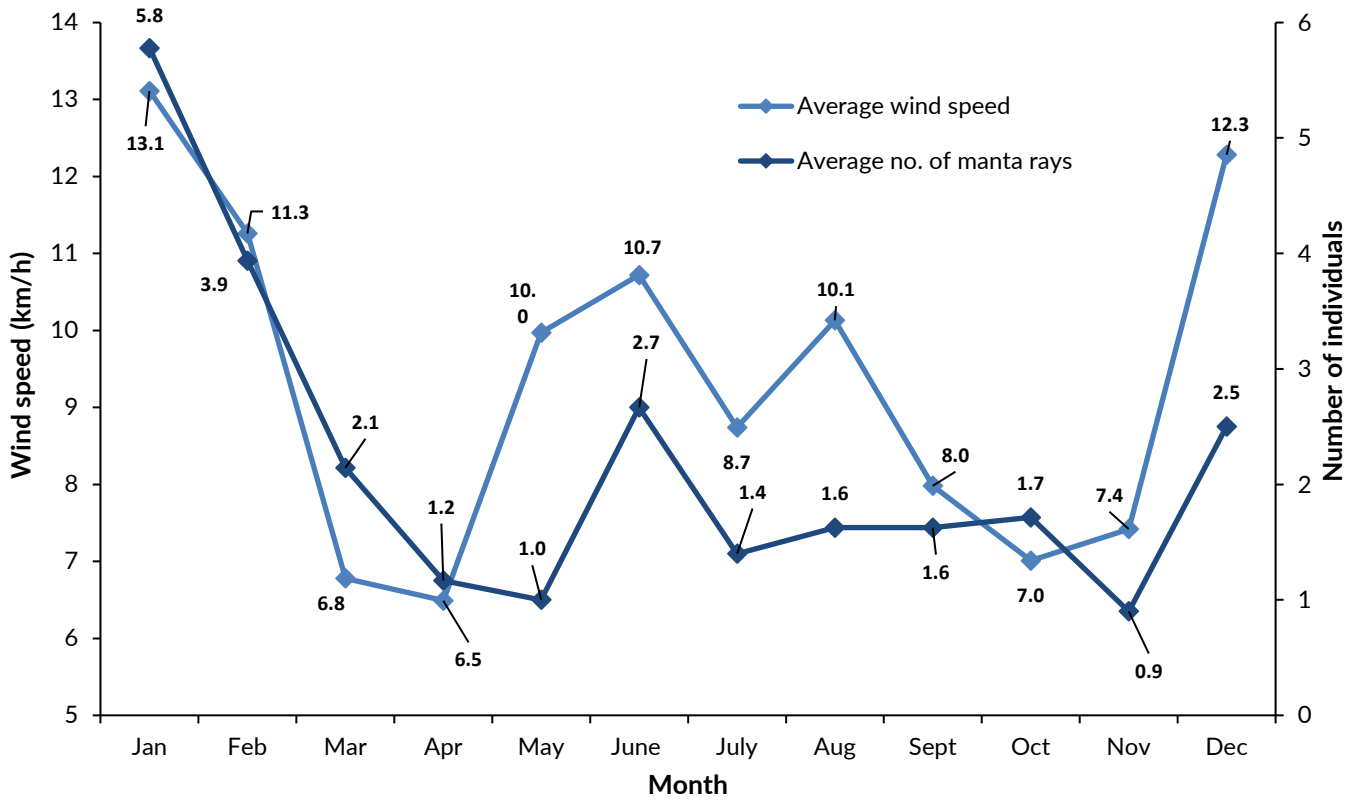


Figure 24: Mean monthly wind speed (km/h) and mean number of reef manta ray (*Mobula alfredi*) sightings per survey day by the Maldivian Manta Ray Project researchers in the Ari Atoll Region (2019).

Additional research effort at both the eastern and western manta aggregation sites over the next several years should help to further elucidate the relationship between food availability, the strength of monsoonal winds, and manta ray sightings. It is possible that these variables all fluctuate with long-term, natural weather cycles within the Maldives but, more concerning, these changes may also be linked to the global climate crisis.

WHALE SHARK & OCEANIC MANTA RAY SIGHTINGS

The reef manta rays' close relative, the oceanic manta ray (*Mobula birostris*), can grow to over six metres in disc width and tend to spend much more time away from reefs in the open ocean. The vast majority of manta sightings in the AAR are of reef manta rays, with only eight oceanic manta ray sightings recorded in the region to date. There were no recorded sightings of oceanic manta rays in the AAR in 2019.

Whale sharks (*Rhincodon typus*) are another species of large, filter-feeding elasmobranchs, with similar life history characteristics and habitat use to manta rays. The AAR region, specifically South Ari Atoll, is host to a semi-resident whale shark population. This region is believed to be a nursery ground for the sub-adult whale sharks which aggregate there. The Maldives Whale Shark Research Programme (MWSRP) monitor this population of whale sharks, along with the wider Maldives whale shark population. Much like manta rays, each whale shark can be identified by photo-ID of its unique spot pattern. In 2019, the MMRP researchers, along with guests who accompanied them on excursions from Vilamendhoo Island, were able to contribute a total of 28 whale shark sightings to the MWSRP to support their research efforts.

MANTA RAY TOURISM

The Ari Atoll Region is one of the nation's most popular tourist destinations with tens of thousands of visitors snorkelling and diving during their stay, and many choosing this area due to their desire to encounter marine megafauna. During surveys, the MMRP collected data on anthropogenic pressure. Since 2016, the average number of boats recorded per survey has steadily increased from 1.6 in 2016, to 2.2 in 2018, and has since doubled in 2019 to 4.4 boats per survey (Fig. 25). The rise in use of technology and social media has also meant that tourist operators are often connected via online networks resulting in tourist boats gathering at manta 'hotspot' aggregations at the same time. Similarly, the average number of snorkellers and/or divers per survey has increased since data collection began, with a big jump in numbers recorded between 2018 and 2019. It has steadily increased from 9.2 people per survey in 2016, to 18.1 in 2018, to 29.8 people per survey in 2019.

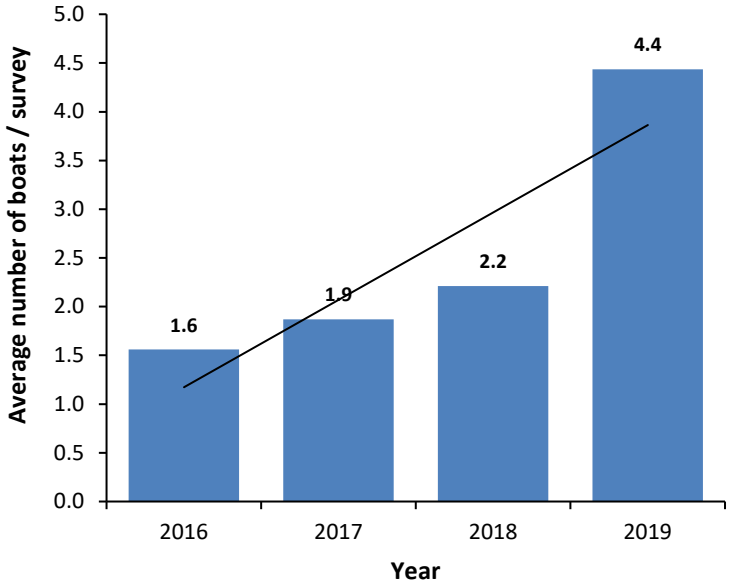


Figure 25: Mean number of boats per survey recorded by the Maldivian Manta Ray Project researchers in the Ari Atoll Region.

Interestingly, the data from 2016 – 2019 showed a strong negative correlation (R^2=0.7) between mean number of guests (snorkellers and/or scuba divers) per survey and the mean number of reef manta ray sightings per survey (Fig. 26). It is possible there is a connection between the increase in tourism pressure and the decline in manta ray sightings, however further investigation would be needed to confirm a relationship as there is relatively data to support this trend now.

The increasing tourist pressure on these key manta aggregation sites shows the importance of these areas to the Maldivian economy, and emphasizes the need for proper protection and tourism management. Manta tourism from guests based in local guesthouses, resorts, and on dive liveaboard boats generates an estimated $15 million USD annually. However, if tourism pressure continues to increase, manta rays will be more heavily subjected to anthropogenic related injuries, such as boat strikes, and it is possible that they will be forced to abandon these disturbed aggregation areas. The Manta Trust released updates to its Best Practice Code of Conduct (CoC) in 2017, and throughout 2018 and 2019 continued to distribute the CoC tools to any tourism operators, both in the AAR and throughout the Maldives, who were not previously aware of the guidelines and tools available to them. We hope to further disseminate the CoC to all tourism operators nationwide, ideally with the support of the Maldives government.

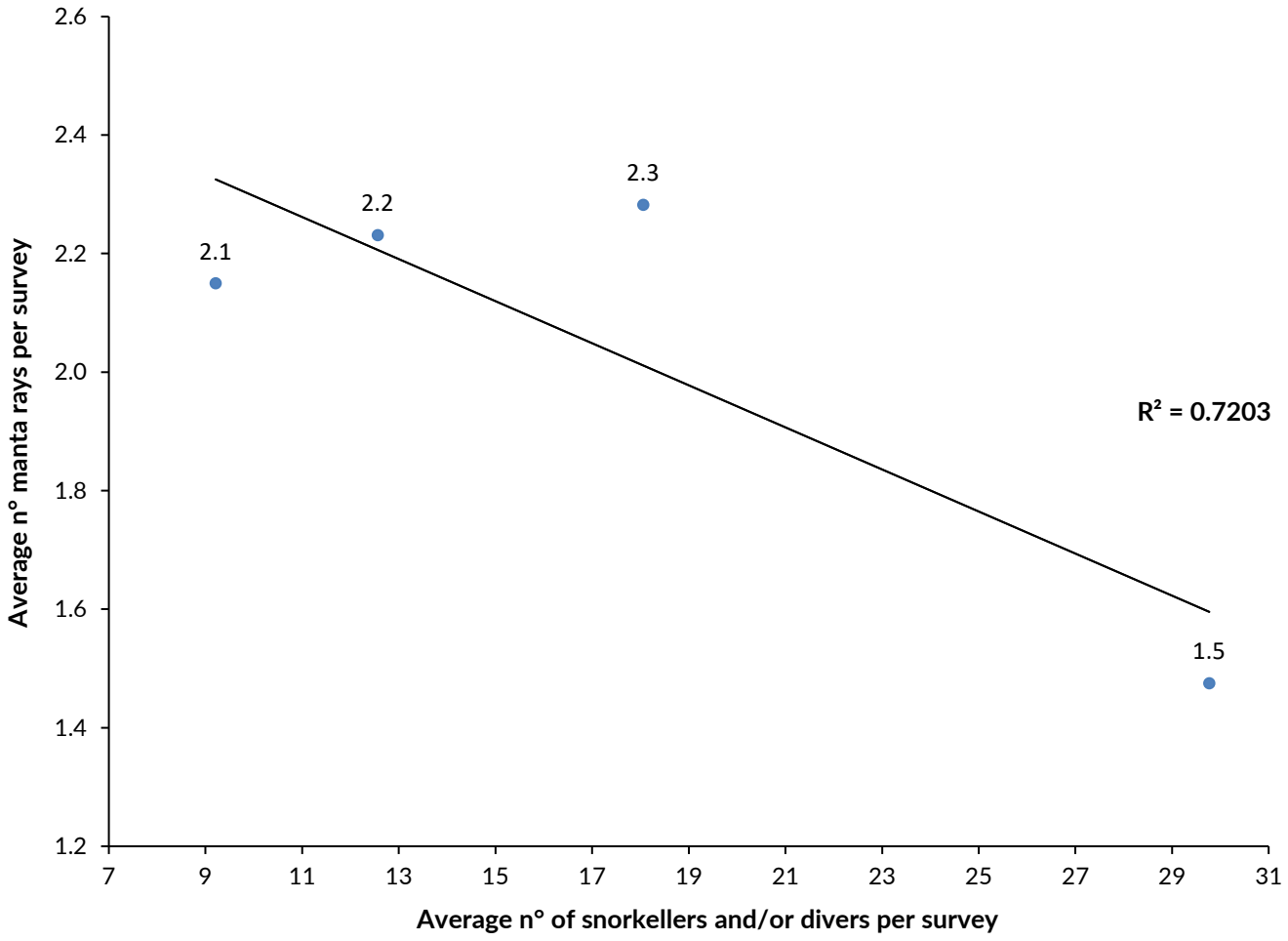


Figure 26: Mean number of snorkellers and SCUBA divers per survey, and the mean number of reef manta ray (*Mobula alfredi*) sightings per survey recorded by Maldivian Manta Ray Project researchers in the Ari Atoll Region (2016-2019).

MANAGEMENT CHANGES & INITIATIVES

In October 2018, the Maldives government created an MPA at Rasdhoo Madivaru in the southeast of Rasdhu Atoll. The designation of this MPA is in addition to two other known manta ray aggregation sites in the AAR which are currently within MPAs: one at Rangali Madivaru and the other covering the whale shark aggregation area along the southern edge of Ari Atoll (South Ari Marine Protected Ari, or SAMPA). Although the MPA at Rasdhu Atoll was designated due to the presence of hammerhead sharks, the protected status of this area will also afford protection to the visiting manta rays. Rasdhoo Madivaru is a feeding and cleaning area for reef manta rays, although not frequently, and it is also the location of the only two oceanic manta sightings from Rasdhu Atoll.

Although the designation of Rasdhoo Madivaru, along with Rangali Madivaru and SAMPA, as protected areas is an important step, they are currently only protected on paper. Without the implementation of effective management plans and on-site enforcement, these biologically and economically important areas will remain highly susceptible to the threats inherent to unsustainable tourism and fishing pressure. As tourist numbers continue to grow in the AAR, the implementation of effective MPA management along with the expansion of protected areas to other key manta aggregation sites becomes increasingly important.

ARI ATOLL MARINE EDUCATION PROGRAMME

The MMRP team based on Vilamendhoo Island was pleased to collaborate with the Maldives Whale Shark Research Programme (MWSRP) to deliver their Moodhu Kudhin, or "Children of the Sea", environmental education programme at Dhangethi School. This programme held two sessions involving students in grades six, seven, and eight, and included a combination of classroom-based theory and practical training through interactive games activities and field trips. The programme was run with the aim of increasing students' understanding of, and engagement with, their local marine environment and local marine megafauna. Students at Dhangethi School do not have the option in secondary school to complete courses in fisheries or marine science, making the programme the only exposure some students will have to marine conservation. The MMRP team contributed a classroom-based lesson on biology, ecology and conservation of the locally prevalent manta rays, and some interactive activities which had the students immersed in some of the MMRP research techniques. The team also assisted in-water for a snorkelling and water-safety lesson, and aboard the MWSRP research dhoni. The field trip served to increase student engagement and give students a chance to see the ecosystems and marine megafauna that was discussed during the classroom session. It also gave the students the opportunity to partake in collecting the identification data and environmental variables alongside the research teams at the MWSRP and the MMRP. The MMRP is extremely grateful to the MWSRP, Vilamendhoo Island Resort & Spa, EuroDivers Maldives, and the Dhangethi School teachers, administration, students, and parents, without whom the programme would not have been possible.

This report was made possible thanks to

EURO DIVERS MALDIVES AT VILAMENDHOO ISLAND RESORT

As our primary supporter in Ari Atoll, Euro Divers Maldives at Vilamendhoo Island Resort has been incredibly supportive of the Manta Trust and MMRP. We hope this partnership continues to prosper for years to come.

MALDIVES GOVERNMENT AUTHORITIES

The Manta Trust is grateful for the opportunities provided by the Ministry of Environment and Energy, the Ministry of Fisheries, Marine Resources and Agriculture, the Environmental Protection Agency, and the Marine Research Centre. All data was collected in accordance with the relevant permit requirements of the aforementioned governing bodies.

The Manta Trust would also like to extend a warm thank you to all the other resorts, guest houses, liveaboards, dive centres and watersports teams as well as the marine biologists and citizen scientists who have supported our research and submitted sightings.

The MMRP and the Manta Trust are happy to share with the Maldives government any data collected as part of this study.

MALDIVIAN MANTA RAY PROJECT (MMRP)

The MMRP is highly regarded within the scientific community. It is the largest and one of the longest running manta ray research programmes in the world. We would welcome the opportunity to continue to work with the Maldives government and our other partners for the long-term management and conservation of these species in Maldivian waters.

The opportunities that the Manta Trust's MMRP have in the Maldives are unparalleled. Working in an area that is home to the largest aggregation of reef manta rays in the world, our research continues to expand every year. We are humbled by the thought of being able to further pursue our research programmes alongside the Maldives government. The opportunity we have to learn about manta rays in the Maldives is unique and has many implications on a global scale for manta ray conservation.

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