Manta TRUST

Maldivian Manta Ray Project

RAA ATOLL | 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 first in a series presenting data collected by the Manta Trust's Maldivian Manta Ray Project (MMRP) in the geographical atoll of Raa between 2007 and 2019.

Raa Atoll is a large (1,180 km²) complex atoll, consisting of 95 islands. The atoll is part of the Northern province of the Maldives archipelago. Administratively, Raa Atoll also includes the very small (4 km²) oceanic platform reefs of Alifushi Atoll, which consists of two islands. However, this report does not include Alifushi Atoll due to the lack of manta sightings from this area.

Raa Atoll has a year-round presence of reef manta rays (*Mobula alfredi*), which follow the seasonal abundance of their zooplanktonic prey across the atoll with the changing South Asian Monsoon.

Key findings include 2,482 sightings of 812 individual reef manta rays, recorded at 39 different sites within Raa Atoll between 2007 and 2019. Due to significantly higher survey effort in 2019, enabled by the establishment of the MMRP's first permanent research base in Raa Atoll, more reef manta ray sightings were recorded in 2019 than in any previous year. Thirty-eight percent of the new individuals sighted in Raa Atoll in 2019 (*n*=250) were new to the Maldives population, with 11% of these new individuals being recorded as new-born young of the year.

The Raa Atoll reef manta ray population is split almost evenly by gender, with 434 (53%) females and 374 (46%) males. The gender of the remaining four individuals (1%) remains undetermined. Overall, 61% (*n*=496) of the individuals are adults, 38% (*n*=312) are juveniles, and the stage of maturation for the remaining four individuals (1%) could not be determined. The Maamunagau sub-region in southern Raa Atoll provides suitable habitat for a large sub-population of juvenile reef manta rays (*n*=95), which exhibit high fidelity to this region during the Northeast Monsoon.

Reproductive activity (including visible pregnancies) was recorded in Raa Atoll throughout the study period. 2019 saw the highest number of pregnancies recorded in a single year (*n*=35), with 32% of the adult females sighted that year observed visibly pregnant. Records of courtship activity have not been numerous enough to show any clear trends.

Reef manta rays are highly mobile, often travelling hundreds of kilometres throughout the Maldives. Due to its north-central location, and close proximity to other atolls (particularly Baa Atoll), 65% (*n*=529) of Raa Atoll's reef manta rays have been sighted outside of the atoll. Indeed, reef manta rays from Raa Atoll have been re-sighted in 12 different geographical atolls throughout the Maldives archipelago.

Manta rays are an incredibly important economic resource to the Maldives, bringing tens of thousands of divers and snorkellers to the country every year, and generating millions of USD for the economy annually. Extensive studies by the MMRP show that unregulated tourism can have a negative impact on marine megafauna. The Manta Trust and the MMRP continued to disseminate their 'How

to Swim with Manta Rays' tourism code of conduct in 2019 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 Raa Atoll 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.

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 Raa Atoll.

The South Asian Monsoon is characterized by its wind, which blows consistently and reverses 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 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.

SAMPLING METHODOLOGY & STUDY PERIOD

Sampling Methodology

Manta ray sightings data in Raa Atoll was obtained via photo identification (photo-ID) and was collected throughout the atoll 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 certain location. Surveys were conducted in-water, both on SCUBA and via snorkelling, with sightings recorded at 26 different sites in 2019, and at 22 different sites prior to 2019. Nine of these sites were classified as key aggregation sites due to higher (>40) numbers of manta ray sightings. These key sites were then pooled into five sub-regional groups for comparative analysis based on their geographical position within the atoll and the demographics of the manta rays that frequent the sites (Fig. 1) (Table 1).

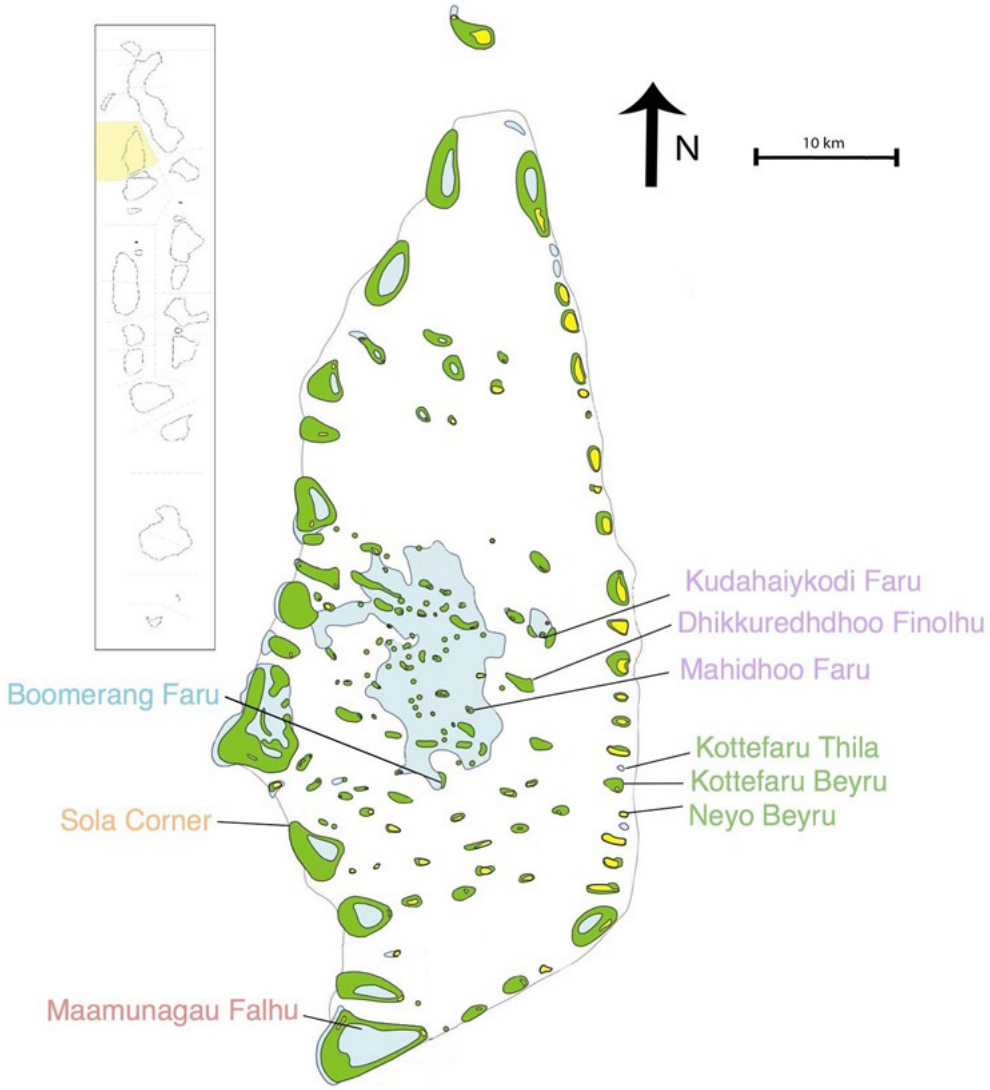


Figure 1: Map of Raa Atoll showing nine of the key reef manta ray (*Mobula alfredi*) aggregation sites (colour-coded by five sub-regional areas) within the geographical atoll. Also shown in the inset box is Raa Atoll in relation to the rest of the Maldives Archipelago.

Table 1: Nine key reef manta ray (*Mobula alfredi*) aggregation sites within Raa Atoll pooled into five sub-regional areas for comparative analysis based on their geographical position and population demographics.

Group	Site Name	Location	Reef Type	Demographic
1	Kottefaru Thila	East	Channel	Adults
	Kottefaru Beyru	East	Outer Reef	
	Neyo Beyru	East	Outer Reef	
2	Kudahaiykodi Faru	Central	Inner Reef	Adults
	Mahidhoo Faru	Central	Inner Reef	
	Dhikkuredhdhoo Finolhu	Central	Inner Reef	
3	Boomerang Faru	Central	Inner Reef	Adults
4	Maamunagau Falhu	West	Lagoon	Juveniles
5	Sola Corner	West	Outer Reef	Adults

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 during all surveys, regardless of whether manta rays were sighted or not. Citizen scientists recorded data only during surveys resulting in a confirmed manta ray sighting. 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.

Pre-2019 Study Period

The MMRP has records of reef manta ray sightings from Raa Atoll as far back as 2007, although the majority of all pre-2019 sightings were reported by citizen scientists as the MMRP researchers conducted only periodic surveys in Raa Atoll prior to 2019. Between 2007 through 2018, only surveys resulting in a confirmed manta photo-ID sighting were recorded, therefore sightings cannot be standardised for effort prior to 2019.

2019 Study Period

During 2019, the MMRP researchers performed a total of 241 surveys. No surveys were conducted between May and August due to the lack of researchers in the region at this time. The MMRP conducted an initial scoping project based at Maamunagau Island from late-January until the end of March, before establishing a permanent research base at the InterContinental Maldives Maamunagau Resort in September 2019. Surveys were also conducted periodically by MMRP researchers based in Baa Atoll during the Northeast Monsoon in 2019.

Throughout 2019, the MMRP researchers carried out surveys on as many days as conditions and logistical operations allowed. The 241 surveys were completed on 98 days at 25 sites, with some surveys accompanied by resort guests. Manta rays were sighted on 59% (*n*=143) of all surveys, with photo-ID data collected on 47% (*n*=114) of surveys.

From January until mid-April, survey effort focused on the western Raa Atoll reef manta ray aggregation sites: primarily Maamunagau Falhu (*n*=54), Maamunagau Giri (*n*=6), and Sola Corner (*n*=5). With the return of the MMRP researchers to Raa Atoll in September, survey effort focused on the eastern Raa Atoll reef manta ray aggregation sites: primarily Kudahaiykodi Faru (*n*=16), Kottefaru Thila (*n*=14), Mahidhoo Faru (*n*=13), and Dhikkuredhdhoo Finolhu (*n*=8). With the onset of the Northeast Monsoon in late-November, surveys were again performed in western Raa Atoll, primarily at Maamunagau Falhu (*n*=28), Maamunagau Faru (*n*=14), and Sola Corner (*n*=8). Surveys were performed throughout the year at Boomerang Faru (*n*=24), due to the year-round presence of reef manta rays in this area.

Raa Atoll Sightings Records

A total of 2,482 sightings were recorded at 39 different sites throughout Raa Atoll between 2007 and 2019. Fifty-four percent (*n*=1,349) of all sightings were recorded in 2019, due to increased survey effort (Fig. 2).

Prior to 2019, the MMRP relied upon manta ray encounter reports from citizen scientists based at resorts, guest houses and liveaboards within Raa Atoll. Overall, sixty-three percent (*n*=1,574) of all sightings in Raa Atoll were recorded by MMRP researchers, whilst the remaining records were submitted by citizen scientists. Citizen science remains an important tool for collecting reef manta ray sightings data. However, more consistent monitoring by MMRP researchers in the future will allow for a better understanding of trends in manta ray sightings in the region.

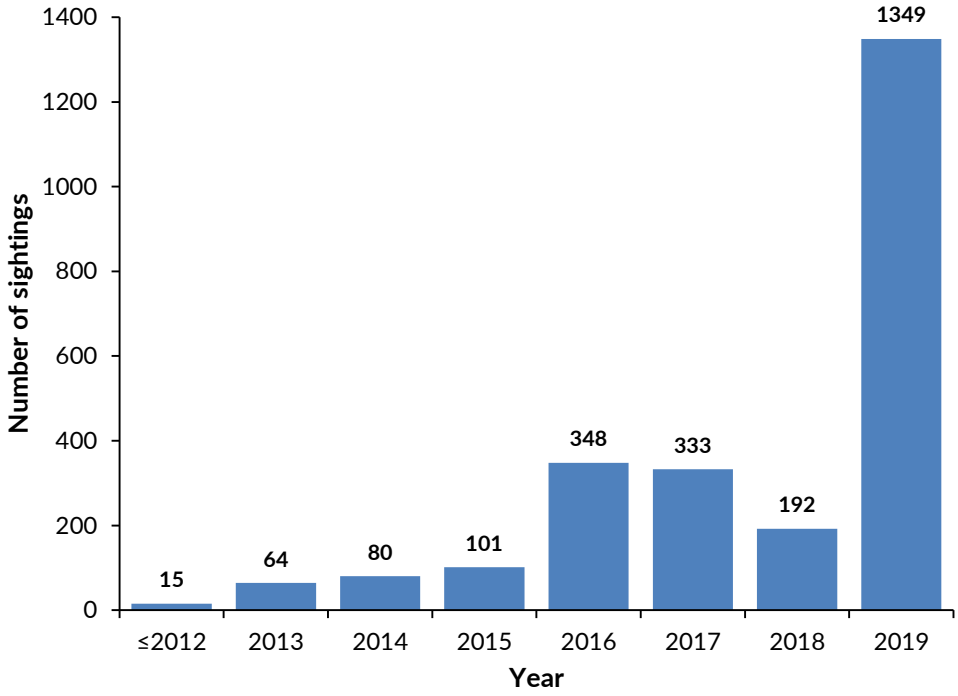


Figure 2: Annual sightings of reef manta rays (*Mobula alfredi*) in Raa Atoll (2007-2019).

In 2019, monthly reef manta ray sightings were at their lowest from May to August, with more sightings recorded during February, March, and October (Fig. 3). This was biased by greater survey effort during those months, with MMRP researchers performing regular surveys between January-March and September-December. Therefore, the data collected by the MMRP in 2019 was used to standardise sightings by survey effort (Fig. 4). The standardised data showed two peaks in manta sightings in February and October, as well as three months with low numbers of sightings in April, November, and December. The decrease in sightings in April and December was expected, as these months encompass the seasonal monsoon changes; the drop in sightings during the month of November is possibly due to the earlier change of season (Southwest to Northeast) seen in 2019. Without researchers based in Raa Atoll for five months of the year (April-August), full sightings trends could not be determined. However, the initial peak in sightings during the Northeast Monsoon months of February and March, and the secondary peak during the Southwest Monsoon in October, coincide with periods of expected high productivity, which tend to occur one or two months following the stronger winds associated with the seasonal transition periods. Higher wind speeds generate increased primary productivity. Therefore, an increase in localised zooplankton abundance is a likely explanation for the increased number of manta ray sightings recorded at these times.

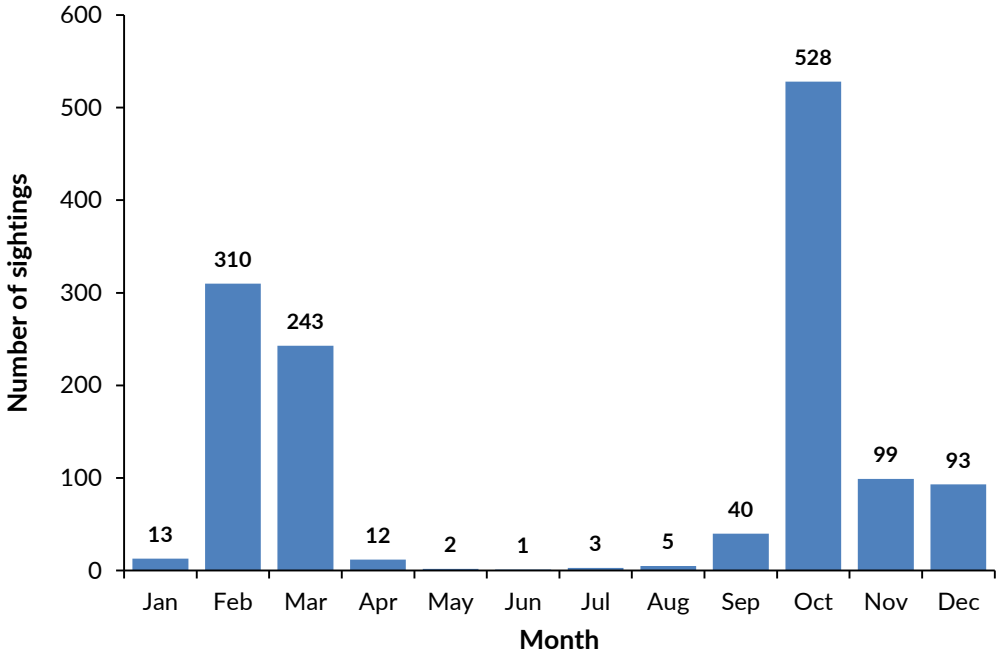


Figure 3: Monthly sightings of reef manta rays (*Mobula alfredi*) in Raa Atoll (2019).

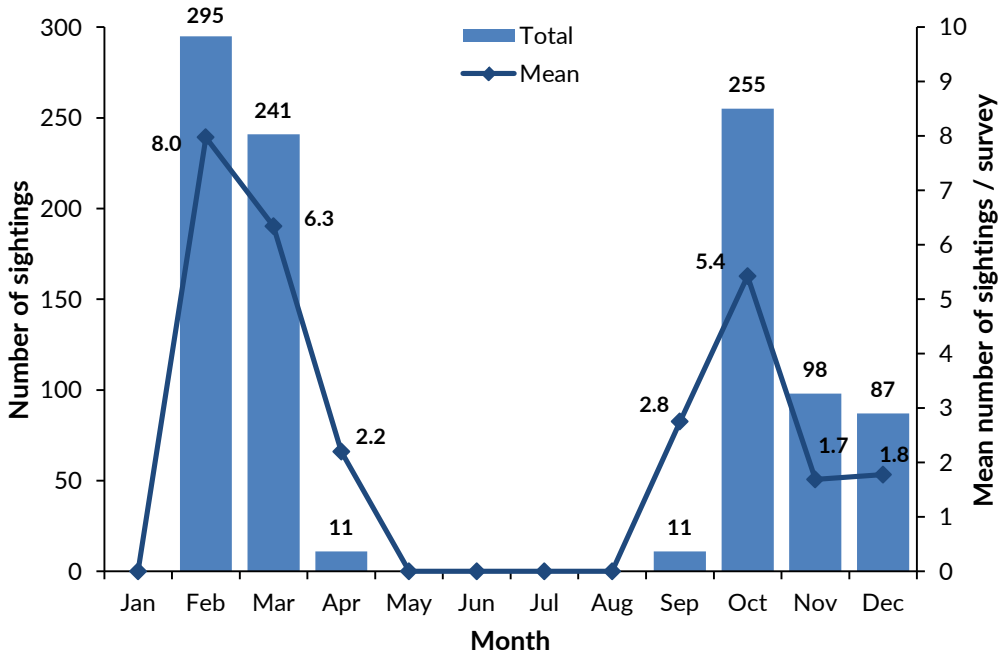


Figure 4: Monthly sightings of reef manta rays (*Mobula alfredi*) recorded by the Maldivian Manta Ray Project's researchers in Raa Atoll, and the mean number of sightings per survey (2019).

Raa Atoll Population Demographics

The current recorded population of reef manta rays in Raa Atoll is 812 individuals, 16% of the total recorded Maldives population (*n*=4,942).

The population demographics in Raa Atoll are split almost evenly by gender, with 434 (53%) females, 374 (46%) males, and four individuals (1%) for which gender could not be determined (Fig. 5). Overall, 61% (*n*=496) of the Raa Atoll population are mature adults, while 38% are immature with 33% (*n*=268) juveniles and 5% (*n*=44) subadults. Without knowing the sex of the four unknown individuals their maturity status could not be determined (Fig. 5).

A total of 485 individual reef manta rays (10% of the Maldives population) were recorded in Raa Atoll in 2019, which is the largest number of individuals sighted within a single year (Fig. 6). This is a reflection of the increase in survey effort in 2019. Fifty-two percent (*n*=250) of these

individuals sighted in 2019 were new to the Raa Atoll reef manta ray population (Fig. 6). Of the 250 new individuals, 38% (*n*=94) had never been recorded elsewhere in the Maldives, while 62% (*n*=156) had previously been recorded in other atolls. If survey effort continues at its current pace, it is expected that the percentage of new individuals recorded will rapidly decrease over the next few years as the remainder of the population is added to the database.

To date, 83% (*n*=670) of Raa Atoll's reef manta ray population (*n*=812) has been re-sighted in either Raa Atoll or elsewhere in the Maldives, suggesting the majority of the reef manta ray population which frequent Raa Atoll have now been recorded. Of the 250 new individuals recorded in 2019, 28 (11%) were estimated to be young of the year, based on their small disc widths, measuring approximately 150 centimetres.

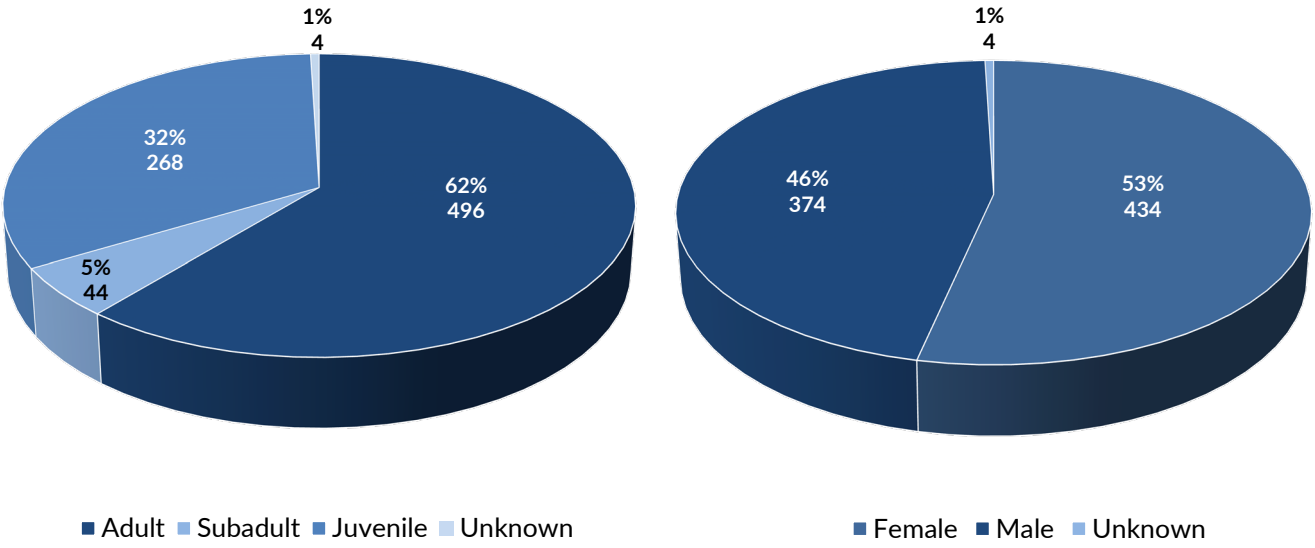


Figure 5: Demographics of the reef manta ray (*Mobula alfredi*) population (*n*=812) recorded in Raa Atoll (2007-2019).

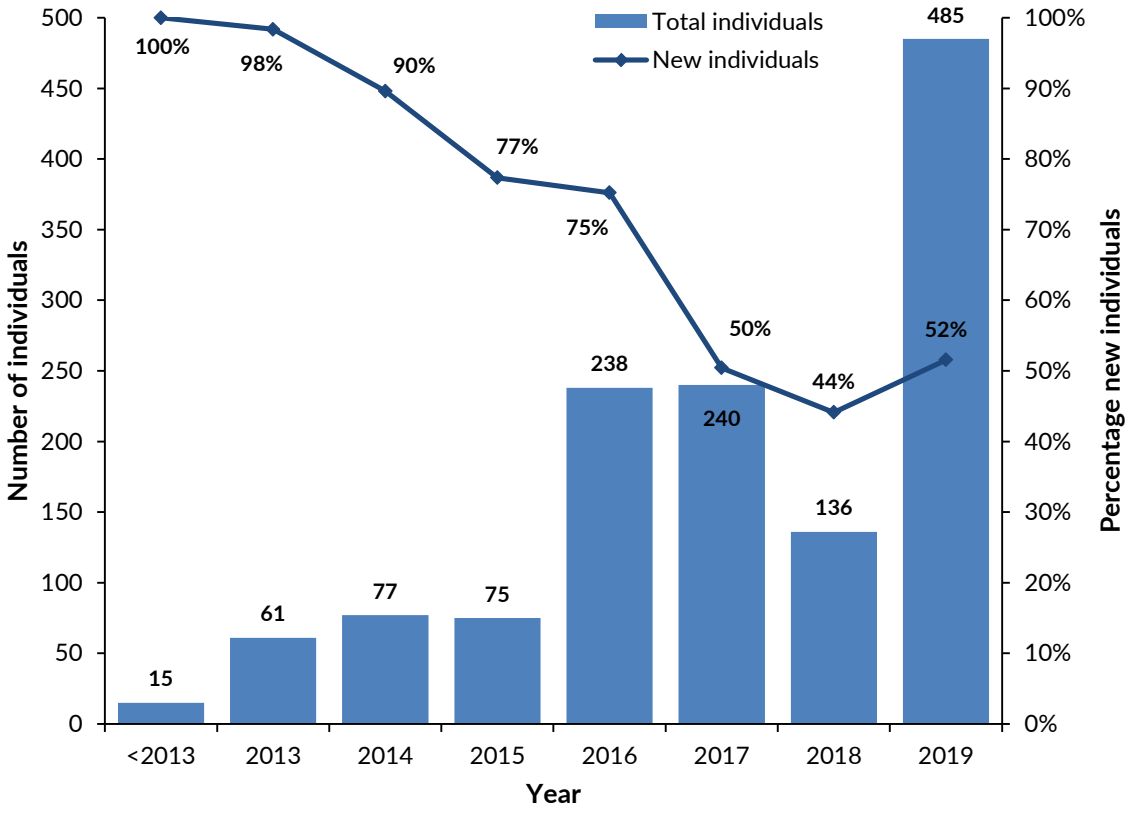


Figure 6: Number of individual reef manta rays (*Mobula alfredi*) sighted annually in Raa Atoll and the percentage of those individuals that were newly recorded (2007-2019).

Maamunagau Sighting Records

The Maamunagau sub-region of Raa Atoll, including the sites of Maamunagau Falhu, Maamunagau Beyru, Maamunagau Giri, Maamunagau Thila, and Maamunagau Faru (hereinafter referred to as Maamunagau), was an area with high survey effort by the MMRP in 2019. Further analysis was performed to understand the reef manta ray population of this sub-region.

Throughout 2019, 568 reef manta ray sightings were recorded in Maamunagau. This was the first year in which large numbers of reef manta ray sightings were recorded in Maamunagau due to increased survey effort by the MMRP researchers based on Maamunagau Island. In total, 108 surveys were performed over 66 days in Maamunagau in 2019, with an average of 8.6 reef manta ray sightings per survey day. Maamunagau is located on the southwestern corner of the atoll, with sightings recorded primarily during the Northeast Monsoon (December-March). As expected, sightings peaked in February and March, and began to rise again in December with the start of the Northeast Monsoon. Survey effort was consistent throughout February and March, and again in December, and, when standardised for survey effort, sightings peaked in February and were lower in December (Fig. 7).

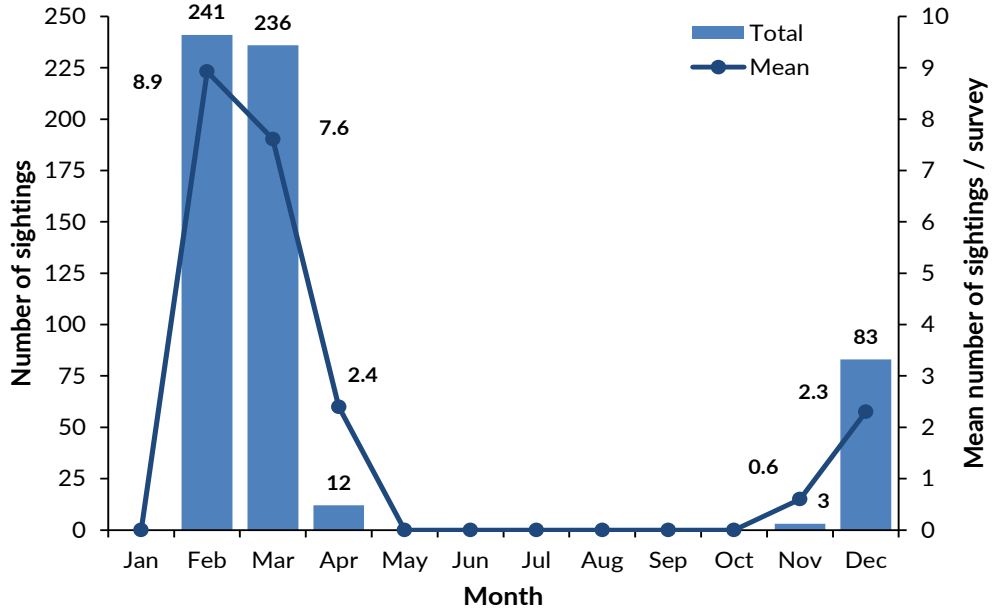


Figure 7: Monthly sightings of reef manta rays (*Mobula alfredi*) at Maamunagau in Raa Atoll recorded by the Maldivian Manta Ray Project's researchers, and the mean number of sightings per survey (2019).

Maamunagau Population Demographics

Based on records collected in 2019, the reef manta ray population of Maamunagau consists of 153 individuals. Of these individuals, 47 (31%) were new to the MMRP database. The Maamunagau reef manta ray population is comprised of 54% (*n*=82) females, and 46% (*n*=71) males. The area is home to a large percentage of juvenile reef manta rays; 62% (*n*=95) of individuals sighted in 2019 were juveniles (Fig. 8).

Overall, 62% (*n*=95) of individuals recorded at Maamunagau were sighted more than once, with an average of 3.71 sightings per individual. When split by demographic, juvenile reef manta rays exhibit higher site fidelity to Maamunagau than adults. On average, each juvenile individual was recorded 4.38 times, compared to only 2.62 times for each adult. A residency index (RI) was calculated for the Maamunagau population to determine how often each individual was seen throughout the year. The RI is based on the ratio between the number of days each individual was sighted, and the total number of surveyed days. For example, a RI of 3% means that, on average, each individual was sighted on 3% of the total surveyed days. Juvenile reef manta rays showed a much higher residency, with a RI of 6.63%, compared to a RI of 3.97% for adults.

Of the individual reef manta rays sighted in Maamunagau in 2019, 14% (*n*=21) were estimated to be new-born young of the year, and 20% (*n*=31) were believed to have been less than five years old. The large number of sightings and re-sighting rates of juvenile reef manta rays in Maamunagau, combined with the prevalence of many new-born pups, indicates that Maamunagau serves as nursery habitat for these young individuals. Juvenile reef manta rays are likely utilising Maamunagau due to the large sheltered lagoon, which offers these smaller individuals greater protection from predation and ample foraging opportunities.

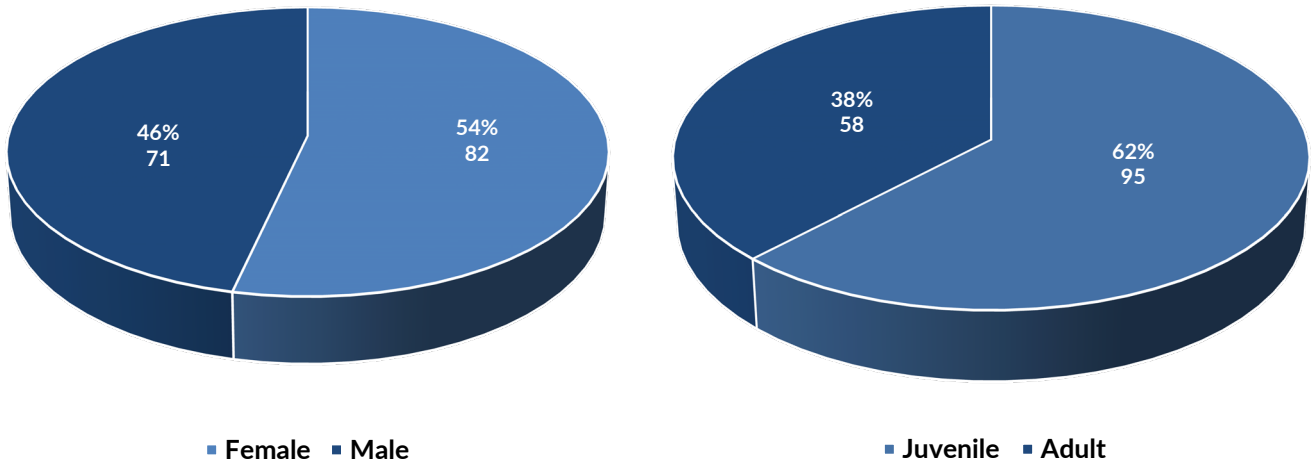


Figure 8: Demographics of the reef manta ray (*Mobula alfredi*) population (*n*=153) recorded at Maamunagau in Raa Atoll (2019).

Reproductive Fecundity

In the last four years, the MMRP has observed a cyclical increase in reproductive fecundity, with higher numbers of pregnant females and new-born pups sighted throughout the Maldives. A total of 64 individual female manta rays in Raa Atoll were recorded pregnant between 2007 and 2019, with the largest number of pregnant females recorded in 2019 (*n*=35) (Fig. 9). This represented 32% of all adult females sighted in Raa Atoll in 2019 (*n*=111). Much lower pregnancy rates were recorded in all previous years, but the increase in pregnancies recorded in 2019 is most likely a result of increased survey effort. Overall, 25% (*n*=199) of the recorded Raa Atoll population are mature adult females. The 64 females recorded pregnant at least once represents only 32% of the overall population of adult females. This low reproductive rate is consistent with trends observed throughout the Maldives, suggesting a very low fecundity for this species. With such a conservative life history strategy, it becomes vital for the survival of this species to minimise anthropogenic threats. Effective measures include the establishment of functional marine protected areas (MPAs) and the adherence to sustainable tourism activities at key manta ray aggregation sites.

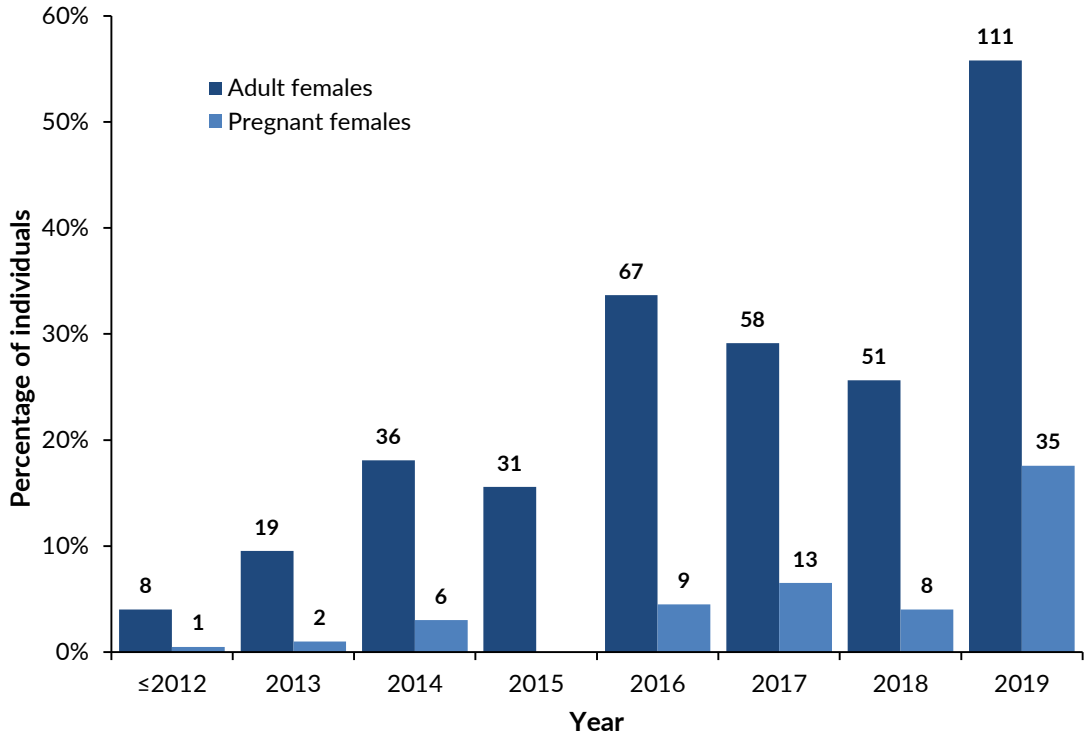


Figure 9: Percentage of Raa Atoll's adult female reef manta ray (*Mobula alfredi*) population (*n*=199) sighted annually, and the percentage of those females that were recorded pregnant in the same year. Actual numbers above bars (2007-2019).

Throughout their range globally, reef manta ray reproductive activity often peaks at particular times of the year. In the Maldives, courtship behaviour and mating are much more frequently observed during the months of October and November, and again in March and April, when the country's two monsoons transition from one to the other. Throughout the day, adult manta rays spend a significant amount of their time cleaning, with female manta rays often spending several hours each day cruising around a favoured cleaning site. Therefore, cleaning stations often become the focal point for courtship and mating activity. It is thought that receptive females release pheromones in order to signal to a potential mate their readiness to reproduce. To date, only seven courtship events have been documented in Raa Atoll, involving 28 individuals. Overall, courtship activity in Raa Atoll peaked in October and November, with three and two events recorded, respectively (Fig. 10). These peaks in courtship activity coincided with the transitional period between monsoons, matching the general timing of courtship activity recorded throughout Maldives. Further study by trained observers, able to recognize and record courtship activity, will help to further understand seasonal courtship trends in Raa Atoll.

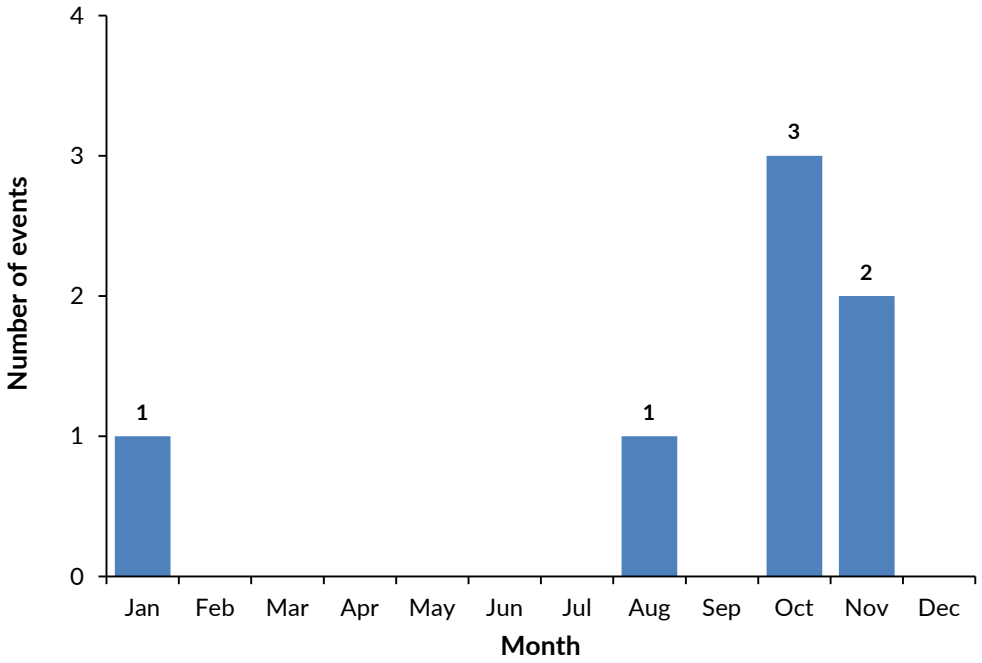


Figure 10: Number of reef manta ray (*Mobula alfredi*) courtship events recorded throughout Raa Atoll (2007-2019).

Atoll Residency

Throughout 2019, each individual manta ray was sighted on average 2.8 times, which was higher than the sightings per individual recorded in previous years (Fig. 11). The percentage of reef manta rays seen more than once in Raa Atoll in 2019 was also much higher than previous years, with a 60% re-sighting rate (Fig. 11). To account for variations in survey effort, an average residency index (RI) was calculated for 2019 using sightings and survey data collected by MMRP researchers. The RI of 2.59% calculated in 2019 highlights that, on average, each individual was sighted on 2.59% of the total surveyed days. However, until several more years of consistent and increased survey effort have been undertaken, a clearer understanding of the reef manta ray population residency in Raa Atoll cannot be attained.

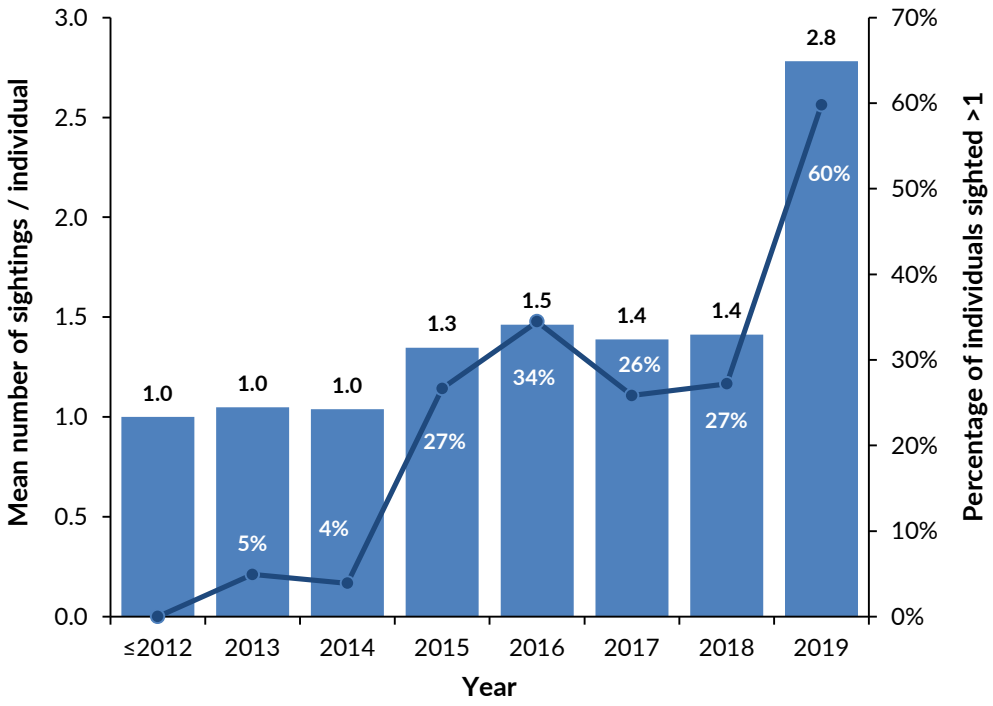


Figure 11: Mean number of sightings per individual reef manta ray (*Mobula alfredi*) in Raa Atoll, and the percentage of individuals sighted on multiple occasions during the same year (2007-2019).

Intra-Atoll Migrations

Reef manta rays in the Maldives migrate seasonally, moving between the eastern and western sides of the atoll with the changing South Asian Monsoon. Overall, sightings in Raa Atoll show 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). Ninety-two percent (n=2,274) of all sightings from 2007-2019 were recorded at the nine key reef manta aggregation sites in Raa Atoll (Fig. 1). To investigate variations in seasonal site use, sightings from these locations were pooled into five sub-regional groups for analysis (Table 1). Reef manta ray sightings mostly conformed to the expected migration patterns in the region, evident in the sighting peaks at the western sites (groups four and five) during the Northeast Monsoon, and the peak at the eastern sites (group one) and eastern-central sites (group two), during the Southwest Monsoon (Fig. 12). However, sightings at Boomerang Faru (group three) showed small peaks in February and November, indicating this site is likely utilised year-round by reef manta rays (Fig. 12). Boomerang Faru is a centrally located inner reef where the predominant recorded manta ray behaviour is feeding. It is likely that, due to its central position, zooplankton is brought into this site by incoming currents during both seasons, with manta rays taking advantage of this productive area throughout the year.

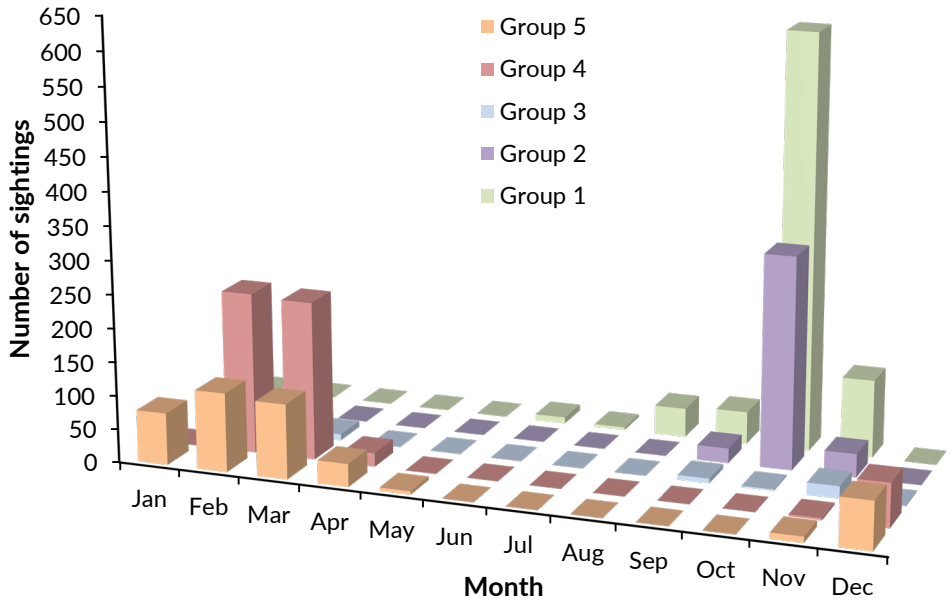


Figure 12: Intra-annual variations in sightings of reef manta rays (*Mobula alfredi*) at nine key aggregation sites (pooled into five sub-regional areas) in Raa Atoll (2007-2019).

Inter-Atoll Migrations

Due to its north-central location, and close proximity to other atolls, 65% (*n*=529) of the recorded reef manta ray population of Raa Atoll have been recorded in 12 other geographical atolls throughout the Maldives, suggesting a high mobility within the population (Fig. 13). The most common inter-atoll movement occurs between those atolls closest geographically to the study region. With the highest number of re-sightings recorded in neighbouring Baa Atoll (*n*=472), followed by Ari Atoll (*n*=92). This is likely due to the relatively small distances (10s km) between the atolls in the central and northern regions of the Maldives, along with the shallow maximum ocean depths (<300m) between these atolls, limiting barriers to migration. Indeed, several individuals have also been recorded travelling between other atolls, particularly Baa and Raa Atolls, multiple times within a single season. However, these results are also likely influenced by greater levels of MMRP survey effort in these atolls.

In total, 204 individuals were sighted in both Raa and Baa Atolls during 2019. In 2019, forty-three percent (*n*=141) of the individuals recorded in Raa Atoll during the Southwest Monsoon (*n*=331) were also recorded in Hanifaru Bay during the same season. With a relatively small distance (30 km) between Hanifaru Bay (which is situated on the eastern edge of Baa Atoll) and the eastern reef manta ray aggregation sites of Raa Atoll, several individuals were recorded moving between the atolls relatively frequently. October offered the highest levels of activity, with 31 individuals recorded moving between Raa Atoll and Hanifaru Bay within the month. The shortest time recorded between inter-atoll sightings by any individual was four days.

In addition to the aforementioned intra-seasonal movements between Hanifaru Bay and Raa Atoll in 2019, 26% (*n*=57) of the individuals recorded in Raa Atoll during the Northeast Monsoon (*n*=223) were also recorded in Hanifaru Bay during the 2019 Southwest Monsoon. It is known that reef manta rays in Baa Atoll take advantage of the high abundance of prey in the east of this atoll during the Southwest Monsoon, but much less is known about the whereabouts of these individuals throughout the rest of the year. This study suggests many of these Baa Atoll individuals migrate to Raa Atoll to forage on the western side of the atoll during the Northeast Monsoon.

With future year-round survey effort in Raa Atoll, comparison between years, along with more detailed inter and intra-seasonal movement comparisons, can be made to further understand the relationship between these two atolls. Importantly, Hanifaru Bay is situated within an MPA, and is part of the Baa Atoll UNESCO Biosphere Reserve, providing great protection for these rays. However, the level of movement between these atolls shows the importance of the nationwide protection for these highly migratory and vulnerable species, and the need for more key manta ray habitat to be protected and effectively managed throughout the archipelago.

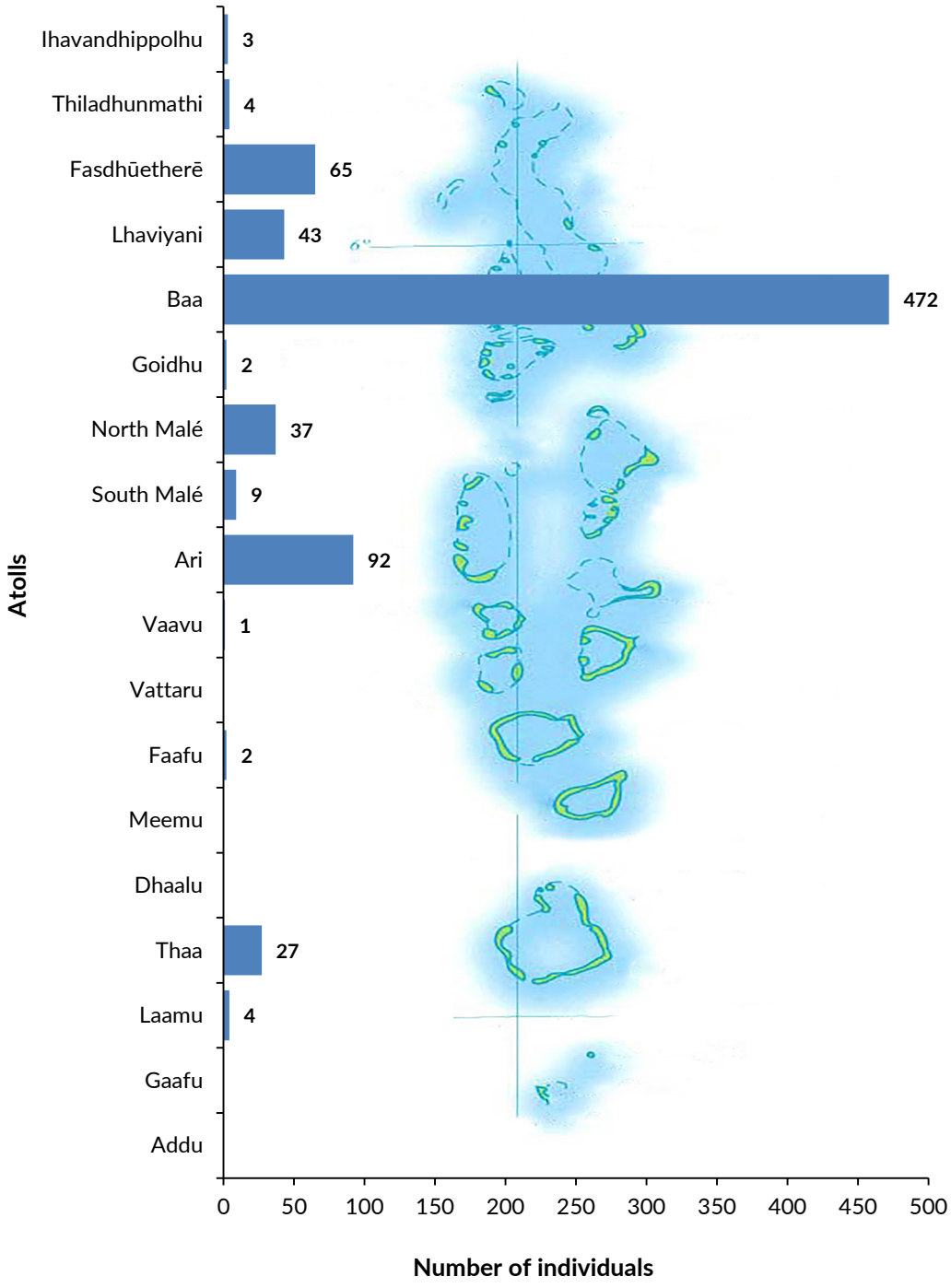


Figure 13: Number of reef manta rays (*Mobula alfredi*) (*n*=528) from within the Raa Atoll population (*n*=812) which have been recorded in other atolls throughout the Maldives Archipelago.
Note – some individuals have been sighted in more than one atoll.

Sub-Lethal Injuries

Of the 812 individual reef manta rays recorded to date in Raa Atoll, 33% (*n*=272) have sub-lethal injuries. Of the injured individuals, 10% (*n*=29) have multiple injuries recorded. Overall, 68% (*n*=178) of all injuries are of natural origin, with the remaining 32% (*n*=85) stemming from anthropogenic causes (Fig. 14). The predominant natural source of injury was predatory bite, comprising 51% (*n*=156) of all recorded sub-lethal injuries (Fig. 15). Other natural sources of injury were deformity and infection, disease and parasites, comprising 4% (*n*=12) and 3% (*n*=10) of injuries, respectively. The primary anthropogenic threat to reef manta rays was fishing line, comprising 24% (*n*=72) of all recorded sub-lethal injuries (Fig. 15). Anthropogenic injuries from boat strike and rope or net entanglement comprised 4% (*n*=12) and <1% (*n*=1) of injuries, respectively (Fig. 15).

Demographically, instances of injury were slightly higher in females than in males, with 59% (*n*=180) of all injuries

reported on females, and the remaining 41% (*n*=125) on males (Fig. 14). However, this partially reflects the overall population demographics in Raa Atoll, with 53% female and 46% male individuals. Injuries were more prevalent on adults than juveniles; 64% (*n*=194) of sub-lethal injuries were recorded on adults, whilst the remaining 33% (*n*=111) were on juveniles (Fig. 14). This is unsurprising, as the adult individuals are older and therefore more likely to have encountered threats during their lifetimes.

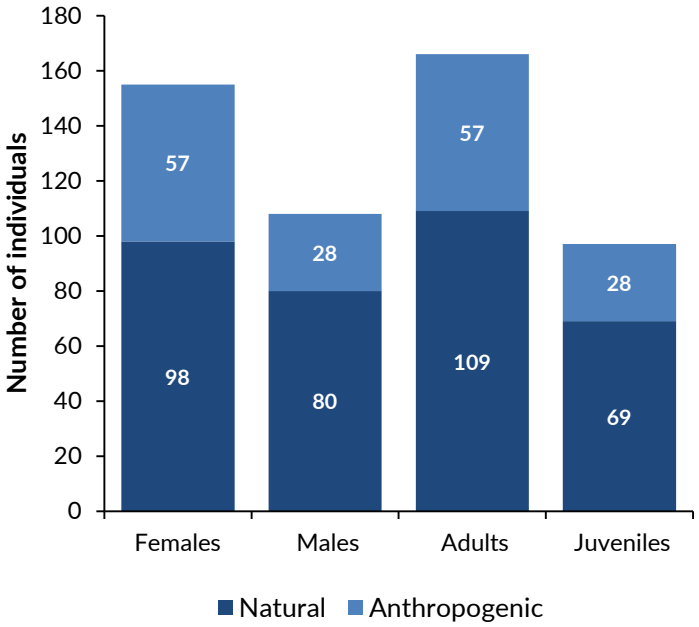


Figure 14: Demographic variations in the number of sub-lethal injuries (*n*=305) recorded on reef manta rays (*Mobula alfredi*) within the Raa Atoll population (*n*=812), and the likely injury origin (natural or anthropogenic).

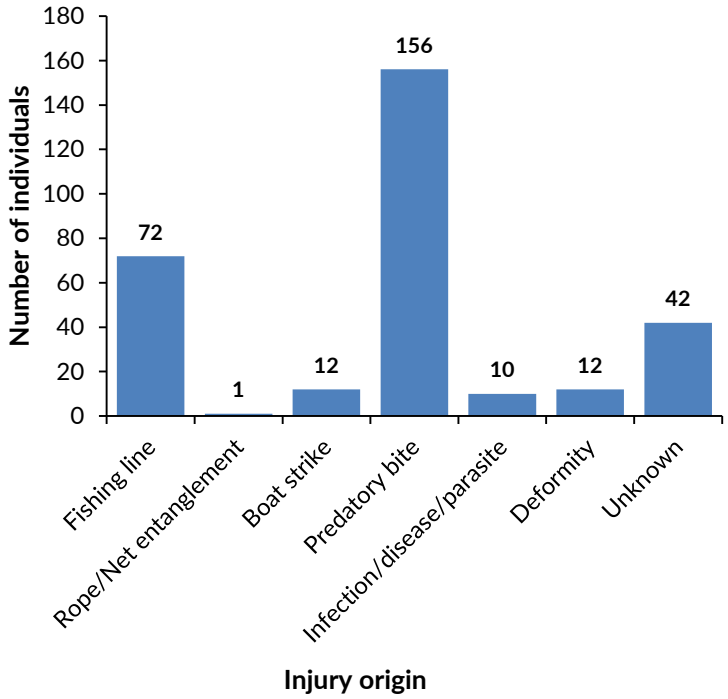


Figure 15: Variations in the origin of sub-lethal injuries (*n*=305) within the injured reef manta ray (*Mobula alfredi*) population of Raa Atoll (*n*=272).

ENVIRONMENTAL VARIABLES

Environmental conditions, especially wind and current strength, have a strong influence on the seasonal abundance of zooplankton, which, in turn, influence seasonal plankton abundance. Lunar tidal currents bring plankton-rich water into and out of the atoll daily, via the channels along the outer rim.

It is expected that daily manta ray movement, behaviour, and habitat use is influenced by the current direction. Both current and predominant manta behaviour were recorded on 98 surveys by the MMRP in 2019, mostly at channel and outer reef sites. Of these surveys, 82 were conducted during an outgoing current, and only 12 surveys were carried out during an incoming current. In addition, the majority of surveys encountered feeding manta rays (*n*=60), with only a few surveys recording sightings of cleaning (*n*=11) and cruising (*n*=11) manta rays. Overall, on incoming currents, feeding was the dominant behaviour. However, on outgoing currents, feeding was also the predominant behaviour recorded (Fig. 16). When examining behaviour, manta rays were observed cleaning more often on outgoing currents than on incoming currents. Due to the low numbers of surveys recorded and the dominance of both feeding behaviour and outgoing currents during survey days, further data collection is required to clearly determine overall trends. In addition, further data collection will allow for the assessment of trends on a sub-regional level, assessing differences due to reef type, dominant habitat usage, and reef location. Too few surveys were conducted in 2019 to perform assessments on individual sites.

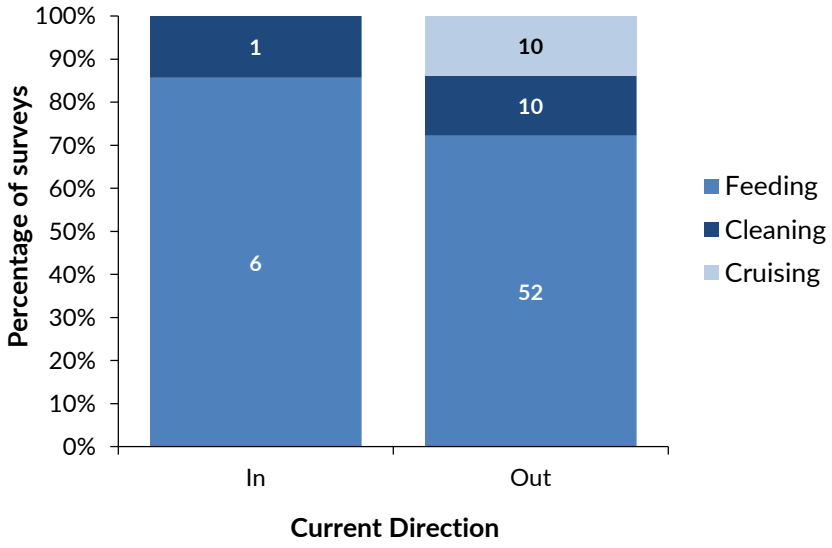


Figure 16: Changes in the behavioural activities of reef manta rays (*Mobula alfredi*) in relation to current direction (In, Out) through the channels in Raa Atoll during surveys (2019) where manta rays were observed (*n*=98).

Wind strength and direction strongly influence seasonal upwelling, playing an important role in determining seasonal zooplankton abundance, as stronger winds generate more upwelling and, therefore, primary productivity. Due to lack of survey records pre-2019, analysis was only performed on data collected during 2019. Overall, a weak negative correlation (R^2=0.09) was found between average wind speed and daily manta sightings (Fig. 17). When manta ray sightings and average wind speed were compared on a monthly basis, manta sightings tended to increase one or two months after an increase in wind speed, likely due to the natural time lag between increased primary productivity and zooplankton blooms (Fig. 18). Wind speeds were highest in January and February, dropping to much lower levels in March. Reef manta ray sightings followed the expected trend and were at their highest in February and March (Fig. 18). Wind speeds increased again during the Southwest Monsoon months from May until August, with manta ray sightings peaking in October (Fig. 18). Without researchers in Raa Atoll between mid-April and mid-September, full sightings trends could not be determined. With future year-round study in Raa Atoll, comparisons between years, along with more detailed monthly comparisons, can be assessed to further understand the relationship between seasonal wind trends and manta ray sightings in Raa Atoll.

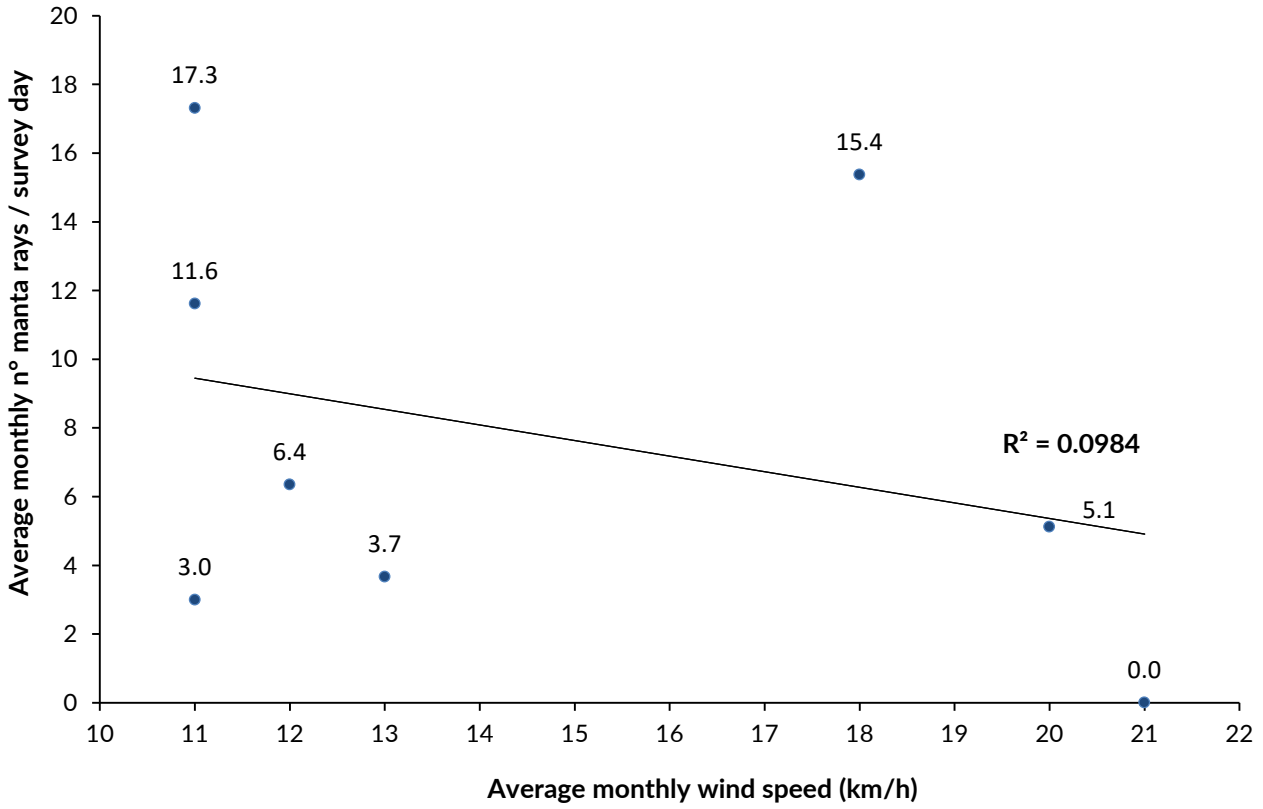


Figure 17: Mean monthly wind speed (km/h) and the mean monthly number of reef manta ray (*Mobula alfredi*) sightings recorded per survey day by the Maldivian Manta Ray Project researchers in Raa Atoll (2019).

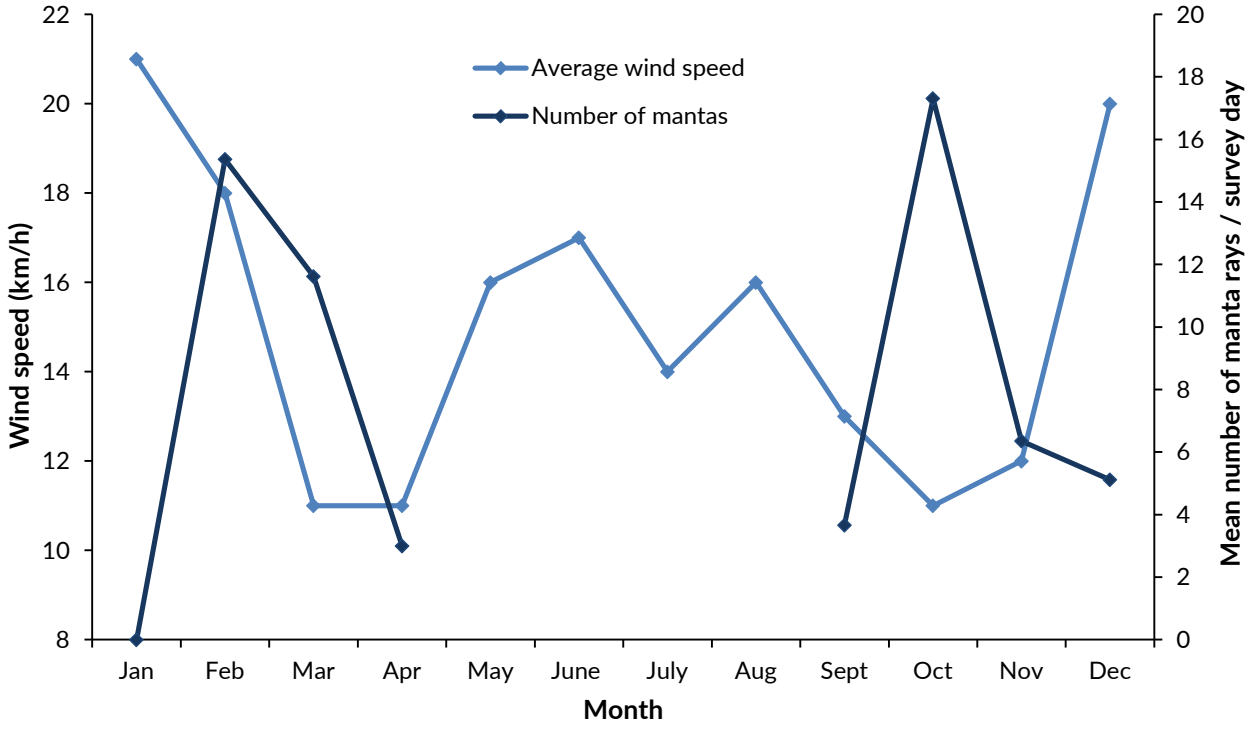


Figure 18: Mean monthly wind speed (km/h) and mean number of reef manta ray (*Mobula alfredi*) sightings per survey day by the Maldivian Manta Ray Project researchers in Raa Atoll (2019).

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 spend more time away from reefs in open ocean. The vast majority of manta ray sightings in Raa Atoll are of reef manta rays, with only one recorded sighting of an oceanic manta ray. This sighting was recorded in 2017 during the Northeast Monsoon at Sola Corner, an outer reef feeding and cleaning site frequented by reef manta rays.

Whale sharks (*Rhincodon typus*) are another species of large, filter-feeding elasmobranch, with similar life history characteristics and habitat use to manta rays. The Maldives Whale Shark Research Programme (MWSRP) monitor the Maldives whale shark population. Much like manta rays, each whale shark can be identified using photo-ID's of its unique spot pattern. Whale shark sightings are uncommon in Raa Atoll, with no confirmed sightings registered in the MWSRP database. In 2019, The MMRP team in Raa Atoll recorded one sighting of a whale shark in eastern Raa Atoll at Kottefaru Thila. However, the team were unable to collect a positive photo-ID to confirm the sighting of this individual.

MANTA RAY TOURISM

Many tourists visiting the Maldives participate in snorkel and dive excursions during their stay, hoping to see marine megafauna, including manta rays. Tourism in Raa Atoll is increasing, with five new resorts established in 2019. However, tourist related pressures in Raa Atoll (for now) remain lower than at many other manta aggregation sites throughout the Maldives.

Survey data collected by the MMRP in 2019 showed that, on average, 1.3 boats were present per survey (including the MMRP research boat), and there was an average of 4.1 snorkellers and divers per survey. In general, there were more snorkellers (*n*=848) than divers (*n*=145) recorded in 2019 (Fig. 19).

Manta rays and their habitats are important to the Maldives' economy, evident in the increasing numbers of tourists frequenting manta ray aggregation sites throughout the country. Guests based in local guesthouses, resorts, and on liveaboard dive vessels throughout the country help to generate tens of millions of USD for the local economy via manta ray dive and snorkel excursions annually, providing further incentive to protect these ecologically vulnerable species. In response to the growing interest in manta tourism, and the negative impacts that result from unregulated wildlife tourism, the Manta Trust published its first Best Practice Code of Conduct (CoC) in 2014, with an updated CoC released in late 2017. The Best Practice CoC is aimed at minimising tourism activities' impact on the natural behaviour of manta rays. The 2017 update included the launch and distribution of a 10-step guide for "How to Swim with Manta Rays", complemented by a snorkelling and SCUBA diving briefing video. Together, it is hoped these materials will deliver a pertinent message on sustainable tourism - how to get the most out of your experience with the manta rays while ensuring that interactions do not disturb or negatively impact the animals. The Manta Trust's CoC has been implemented by dozens of operators, both in Raa Atoll and throughout the Maldives.

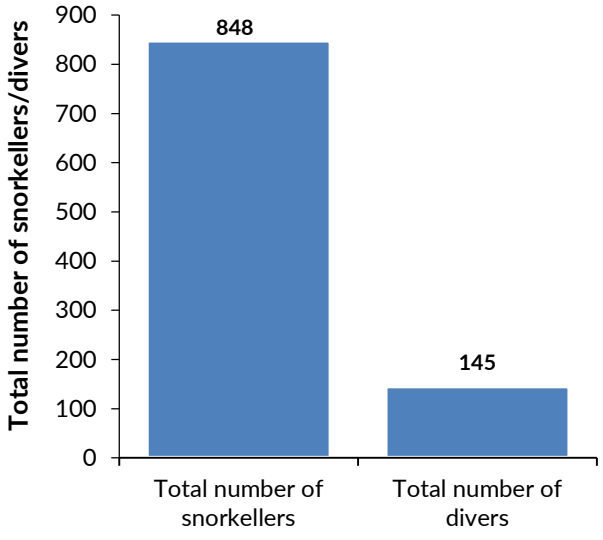
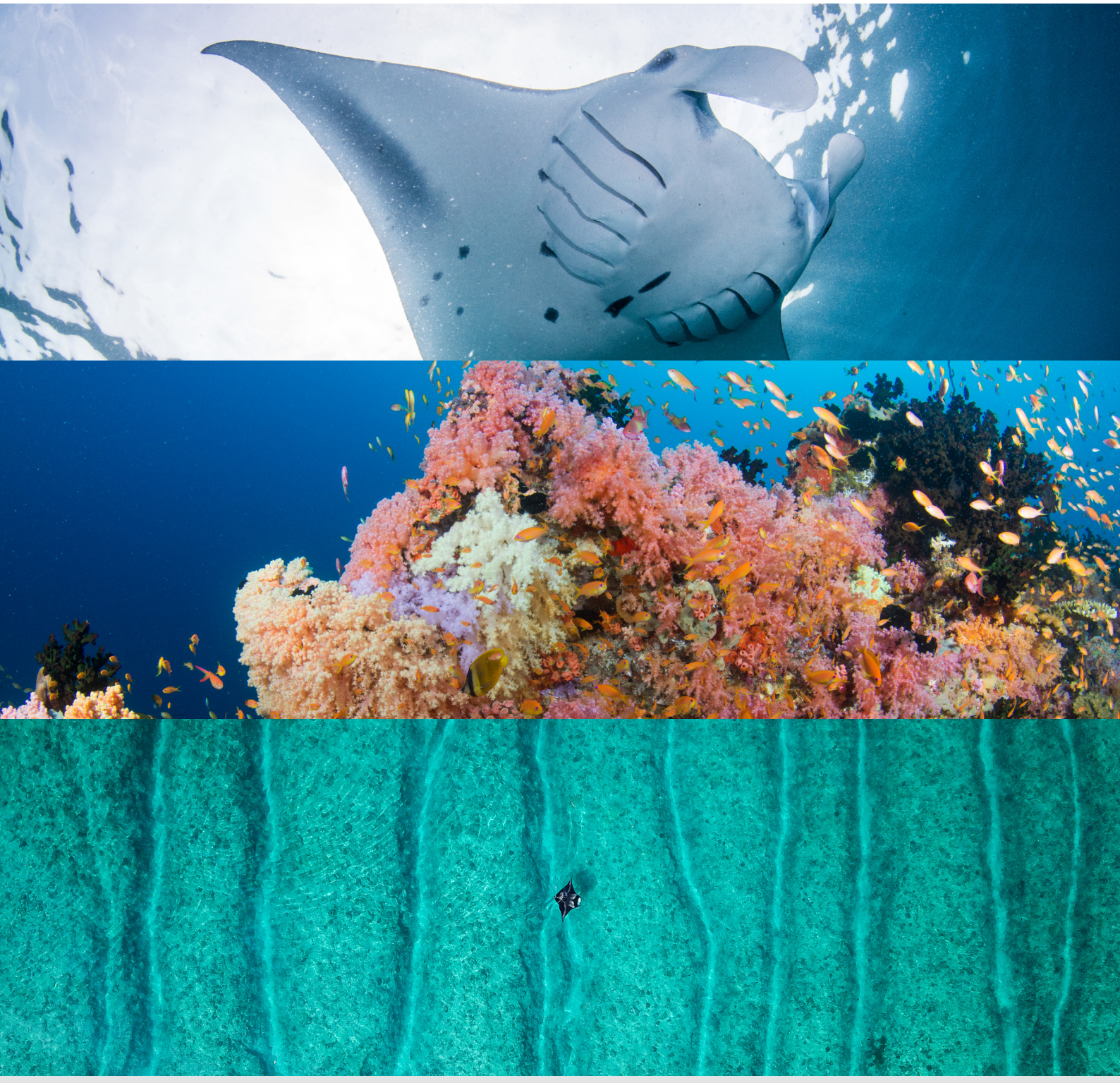


Figure 19: Total number of snorkellers and divers recorded in Raa Atoll (2019).

MANAGEMENT CHANGES & INITIATIVES

Raa Atoll is currently home to only one MPA. The Maldivian government declared Vilingili Thila (in southern Raa Atoll) as an MPA in 1999. This very small protected area (only 0.2 km²) was selected for protective status for its diversity of fish life and healthy population of anemones and associated anemone fish. No manta ray sightings have been recorded within this MPA. As tourist numbers in Raa Atoll grow, the expansion of protected areas, particularly to include key manta ray aggregation sites, along with effective MPA management, becomes increasingly important. In addition, the MMRP will continue to disseminate the Manta Trust's Best Practice Code of Conduct (CoC) to various operators in Raa Atoll, hopefully with the support of the Maldivian government, to minimise the impact of tourism activities on the natural behaviour of manta rays.



This report was made possible thanks to

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.

This report was compiled on behalf of the MMRP and the Manta Trust by:

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