Manta TRUST

Maldivian Manta Ray Project

RAA ATOLL | ANNUAL REPORT 2020

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.

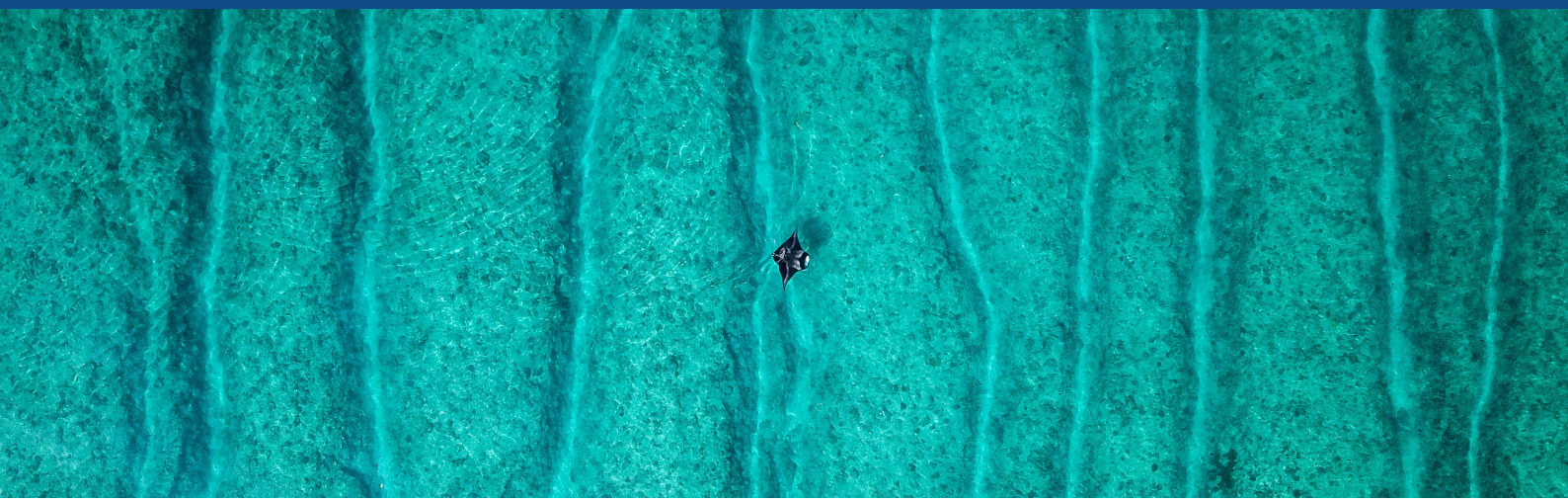
The long-term and nationwide data collected by the MMRP has allowed researchers to record and identify key patterns within this population over time. Not only does this invaluable information improve our understanding of these animals, but it informs their ongoing management and protection both in the 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 presents data collected by the Manta Trust's Maldivian Manta Ray Project (MMRP) on the reef manta ray *(Mobula alfredi)* population of Raa Atoll in 2020. Data used in this report was collected by MMRP staff, collaborating tour guides, and citizen scientists through the Manta Trust's IDtheManta database.

Since the establishment of the MMRP's first permanent research base in Raa Atoll in 2019, there has been significantly higher survey effort within the region. However, due to closure of the collaborating resort from April to November during 2020, researchers were unable to collect further data during this time. Details on the ecology, population demographics, and movements of Raa Atoll's reef manta rays throughout 2020 are provided in this report. However, most of the presented results focus on data collected during the first (January to March) and last (December) months of 2020.

Raa Atoll supports a year-round presence of reef manta rays, which follow the seasonal abundance of their zooplanktonic prey across the atoll with the changing South Asian Monsoon. Key findings include 3,092 sightings of 849 individual reef manta rays, recorded at 40 different sites within Raa Atoll between 2007 and 2020. Twenty-one percent (*n*=37) of the individuals sighted in Raa Atoll in 2020 (*n*=178), were new to the Raa Atoll reef manta ray population. Of the 37 new individuals, 46% (*n*=17) were new to the Maldives population, with one individual being recorded as new-born young of the year.

The demographics of the Raa Atoll regional reef manta ray population (*n*=849) are split almost equally by gender; with 447 (52%) females, 396 (47%) males, and six individuals (1%) for which sex could not be determined. Overall, 61% (*n*=513) of the individuals are mature adults, while 38% are immature: 35% (*n*=301) juveniles and 3% (*n*=29) subadults. The stage of maturation of the remaining six individuals (1%) could not be determined.

The Maamunagau sub-region in southern Raa Atoll provides suitable habitat for a large sub-population of immature reef manta rays (*n*=115), which exhibit high fidelity to this region during the Northeast Monsoon. Demographically, there is a higher presence of juvenile females (*n*=73) than there are juvenile males (*n*=32) within the Maamunagau population. Dissimilarly, the proportion of adults in the Maamunagau population are higher in males (*n*=63) than in females (*n*=21).

Of the 849 individual reef manta rays recorded in Raa Atoll, 86% (*n*=734) have been re-sighted within the region, or elsewhere in the Maldives, suggesting that the vast majority of the individuals which frequent this region have now been identified. Sixty-seven percent (*n*=571) of the recorded manta ray population have been recorded in other geographical atolls throughout the Maldives. This migratory behaviour suggests a large proportion of the population are, at least some of the time, highly mobile; travelling hundreds of kilometres throughout the archipelago.

Throughout the study period, reproductive activity (including courtship events and visible pregnancies) was recorded in Raa Atoll. In 2020, no courtship events were witnessed, and previous annual courtship activity has not been numerous enough to show any clear trends. Only 14% (*n*=3) of the adult female manta rays recorded in 2020 (*n*=21), were observed to be visibly pregnant. Moreover, each of the individual pregnant females were sighted in the first months of 2020 (January to March) and were recorded

in the later stages of gestation (3rd - 4th trimester), suggesting they had become pregnant during 2019.

Tourism pressures in Raa Atoll have remained relatively consistent throughout 2019 and 2020. However, 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 2020 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. 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. 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. 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.

STUDY AREA & CHANGING MONSOONS

Raa Atoll is a large (1,180 km^2) 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 km^2) 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 remains relatively underdeveloped compared to the more central atolls of the Maldives, only opening to tourism in the late 1990s. Most of the data collected in Raa Atoll to date has been collected from the central to southern areas of the atoll. However, future site exploration and data collection in the more northern regions is necessary to gain a better understanding of the entire Raa Atoll reef manta ray population.

Weather patterns within the Maldives are largely dictated by the South Asian Monsoon. This monsoon has two seasons, characterised by their winds, which blow consistently and reverse their direction seasonally. The fluctuating monsoons (seasons) play an important role in determining manta ray distribution. Therefore, understanding the South Asian Monsoon is critical to interpreting the sightings of manta rays in Raa Atoll.

The Maldives Northeast Monsoon, or Iruvai, runs from December to March, while the Southwest Monsoon, or Hulhangu, runs from May to October each year, with the months of April and November acting as transitional periods of change between the two seasons. The Southwest Monsoon is typically characterized by more rain and cloud cover, along with reduced underwater visibility 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 Maldives' islands and atolls, rising 2,000 metres from the sea floor, act as a barrier to these currents, displacing the water as it flows through and around the atolls, creating deep-water upwelling. These upwellings bring nutrient rich water within reach of the sun's rays, enabling photosynthetic phytoplankton to flourish, and generating a bloom of predatory zooplankton that feed on the phytoplankton. Zooplankton is the prey of manta rays and as the strong lunar currents flow through the channels, the concentrated zooplankton is so abundant that the Maldives' waters support the world's largest known population of reef manta rays. It is at these sites where we are likely to observe feeding planktivorous megafauna. Manta rays tend to frequent cleaning stations that are near their plankton-rich feeding areas, and thus, will migrate seasonally to utilise feeding areas and cleaning stations on the monsoonal down-current edge of the atolls. Due to the seasonal migration patterns of the manta rays, research efforts are focused on the west side of the atolls during the Northeast Monsoon, and on the east 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 at a specific location. Surveys were conducted from the research vessel or in-water, both on SCUBA and via snorkelling, with sightings recorded at 40 different sites during the study period 2007 - 2020. Ten 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).

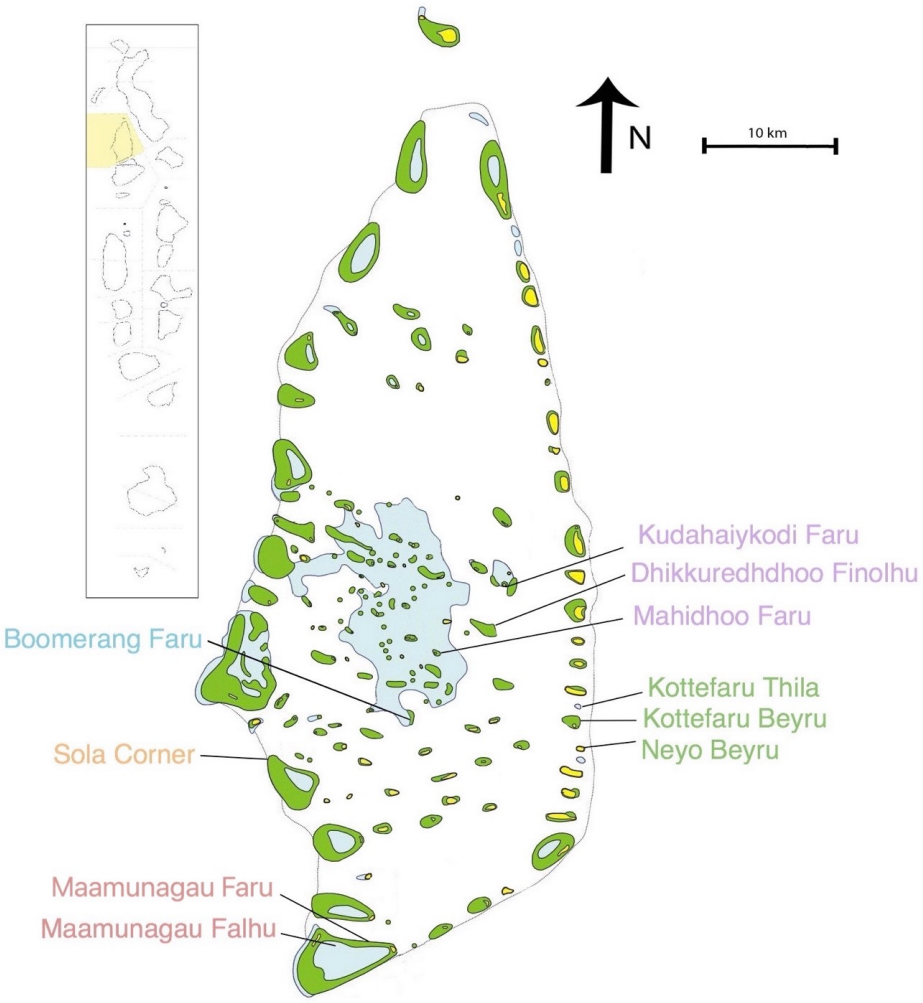


Figure 1: Map of Raa Atoll showing ten of the key reef manta ray (*Mobula alfredi*) aggregation sites (colour-coded by five sub-regional areas) within the geographical atoll. Also shown in the inset box is Raa Atoll in relation to the rest of the Maldives Archipelago.

Table 1: Ten 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	Atoll	Location	Habitat	Demographic
1	Kottefaru Thila Kottefaru Beyru Neyo Beyru	Raa Atoll Raa Atoll Raa Atoll	East East East	Channel Outer Reef Outer Reef	Adults
2	Kudahaiykodi Faru Mahidhoo Faru Dhikkuredhdhoo Finolhu	Raa Atoll Raa Atoll Raa Atoll	Central Central Central	Inner Reef Inner Reef Inner Reef	Adults
3	Boomerang Faru	Raa Atoll	Central	Inner Reef	Adults
4	Maamunagau Falhu Maamunagau Faru	Raa Atoll Raa Atoll	West West	Lagoon Inner Reef	Juveniles
5	Sola Corner	Raa Atoll	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 predominant behaviour, environmental variables (including wind speed, current direction, and plankton density), and tourism data (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 ray's prevalent behaviour.

Study Period

Prior to 2019, nearly all sightings were reported by citizen scientists as the MMRP researchers conducted only periodic surveys in Raa Atoll during this time. 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. The MMRP conducted an initial scoping project based at Maamunagau Island from February to March 2019, before establishing a permanent research base at the InterContinental Maldives Maamunagau Resort in September 2019.

During 2020, surveys to look for manta rays (*n*=317) were carried out on as many days (*n*=86) that conditions and logistical operations allowed. Ninety-five percent of surveys conducted in 2020 (*n*=302) were performed by the MMRP, carried out either by trained researchers (*n*=261) or Remote Underwater Video systems (*n*=41). In addition to the data collected by the MMRP, 15 surveys were also conducted by external parties.

Survey effort has varied throughout the years 2019 and 2020 (Fig. 2). During 2020, more surveys were conducted during the Northeast Monsoon months compared to the previous year (Fig. 2). Only one survey was conducted between April and November 2020 due to the closure of the InterContinental Maldives Maamunagau Resort because of the global pandemic and the resulting lack of researchers in the region at this time.

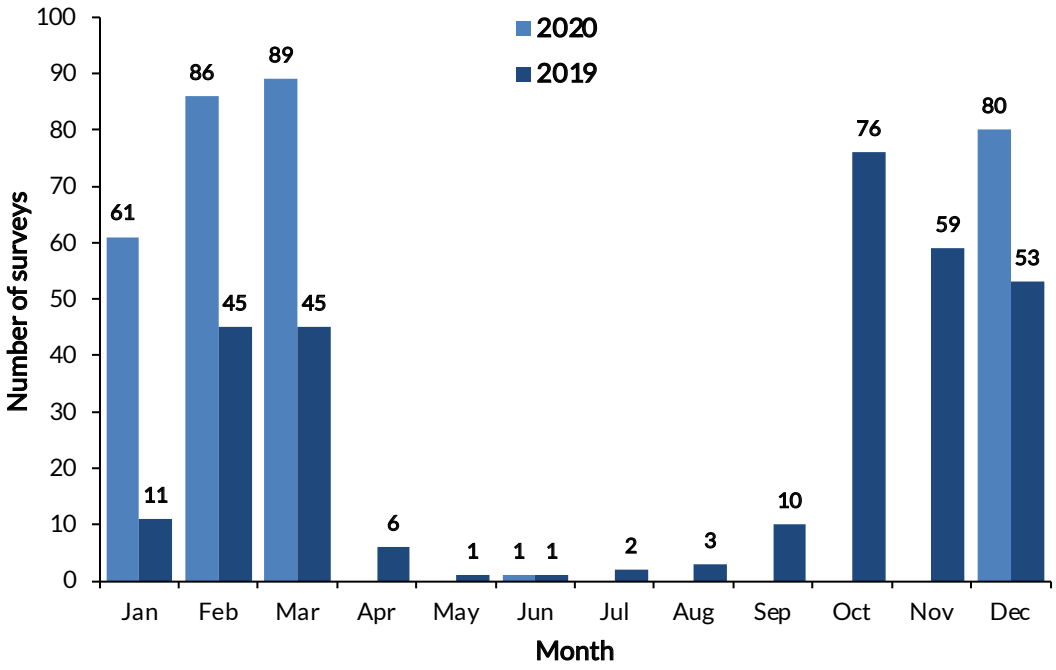


Figure 2: Number of surveys (*n*=629) undertaken in Raa Atoll (2019 - 2020).

REEF MANTA RAY POPULATION

Raa Atoll Sightings Records

A total of 3,092 sightings were recorded at 40 different sites throughout Raa Atoll between 2007 – 2020. Sixty-three percent (*n*=1,958) of all sightings were recorded between 2019 – 2020 due to increased survey effort (Fig. 3).

In 2020, a total of 609 reef manta ray sightings were recorded in Raa Atoll. Ninety-nine percent of the sightings were recorded during January to March (Fig. 4), with MMRP researchers performing regular surveys at this time. Similarly, sightings peaked at the same time during the previous survey year 2019 (Fig. 4). However, with increased survey effort in the region in the latter months of 2019, a second peak was recorded across October to December 2019, which was not evident in 2020. The national pandemic lockdown in 2020 prevented any research efforts from taking place between April to November, and hence no formal comparative analysis could be made between 2019 and 2020 sightings trends noted at this time of the year (Fig. 4). Moreover, due to the absence of MMRP researchers during the national pandemic and the resulting reduction in survey effort, the overall data recorded in 2020 shows a decrease (55%) in manta ray sightings compared to the previous year (*n*=1,349 in 2019) (Fig. 4).

A monthly breakdown of manta ray sightings across 2020, when standardised for survey effort, shows that the mean number of individuals sighted per survey peaked during January (*n*=2.8) and February (*n*=3.0) (Fig. 5). During the previous survey year 2019, the mean number of individuals per survey were overall much higher, peaking in February (*n*=8) and March (*n*=6.3). This is likely due to difference in the monitoring programme and access to resources between the two years. With 2019 being a pilot year for the project, surveys were conducted on days when sightings would be assumed to be higher, comparatively, 2020 surveys were more exploratory and conducted more frequently and continuously with the aim to better understand sighting trends.

When accounting for survey effort, December produced the lowest average number of sightings per survey (*n*=7) in 2020. This decline in sightings compared to December 2019 (*n*=93) is possibly due to the delayed seasonal change (Southwest to Northeast) seen in 2020. Without researchers

based in Raa Atoll for eight months of the year (April to November), full sightings trends could not be determined. However, the initial peak in sightings during the Northeast Monsoon months of January and February coincide with the period of expected high productivity, which tends 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 this time.

During 2020, 96% (*n*=585) of sightings were recorded by MMRP researchers, whilst the remaining records were submitted by citizen scientists. Prior to 2019, the MMRP relied almost solely upon manta ray encounter reports from citizen scientists based at resorts, guest houses, and liveaboards within Raa Atoll. Citizen science remains an important tool for collecting reef manta ray sightings data. However, more consistent, year-round monitoring by MMRP researchers in the future will allow for a better understanding of trends in manta ray sightings in the region.

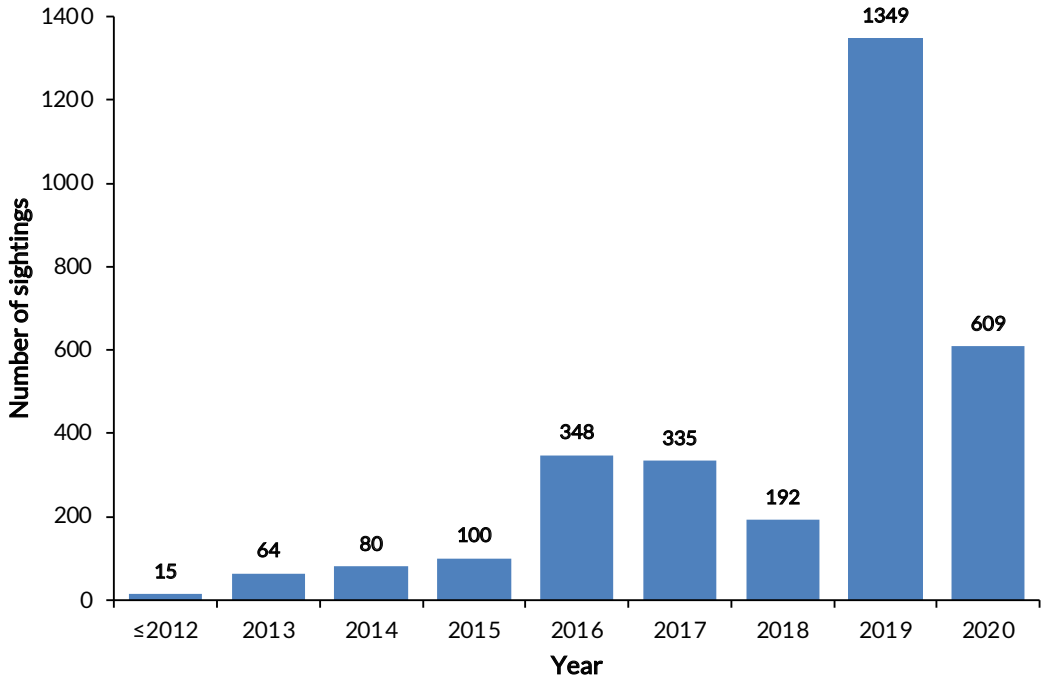


Figure 3: Annual sightings of reef manta rays *(Mobula alfredi)* in Raa Atoll.

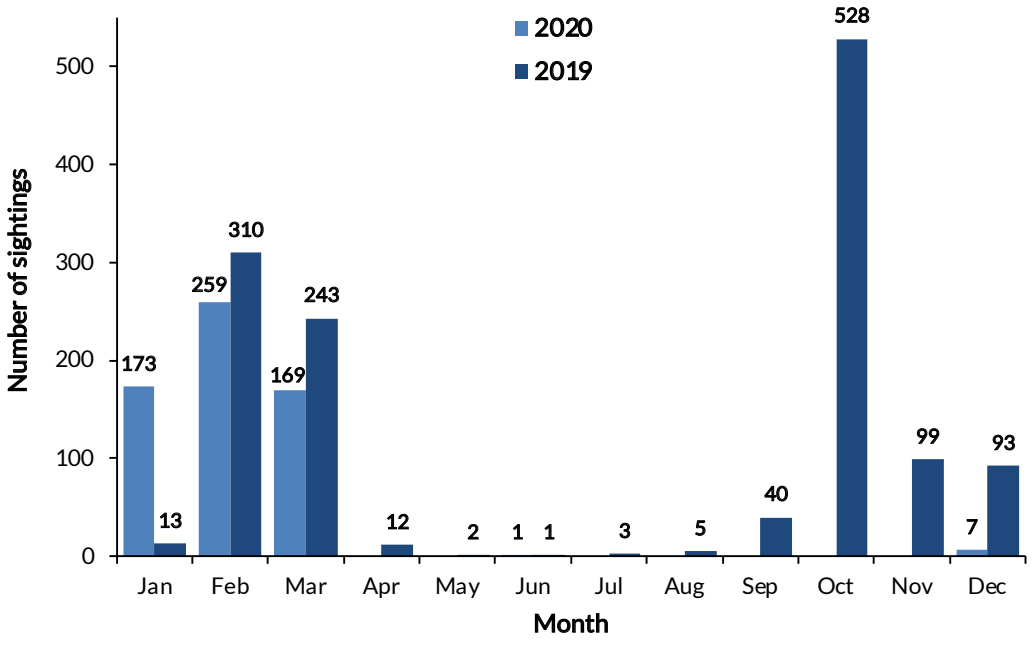


Figure 4: Monthly sightings of reef manta rays (*Mobula alfredi*) in Raa Atoll (2019 - 2020).

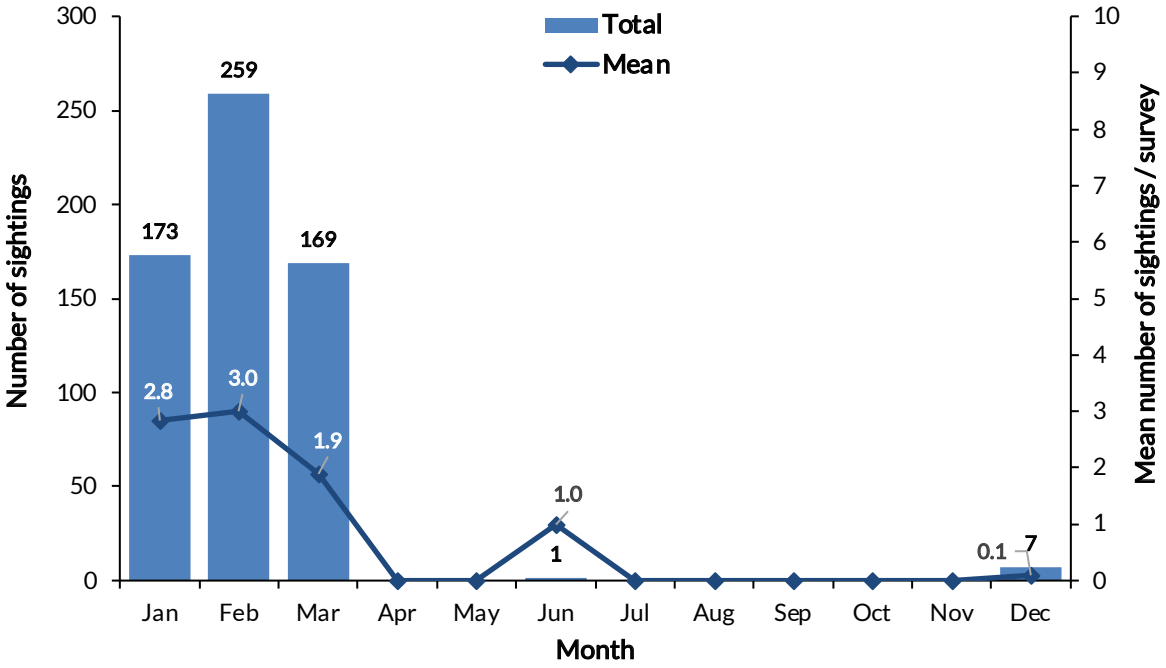


Figure 5: Monthly sightings of reef manta rays (*Mobula alfredi*) in Raa Atoll, and the mean number of sightings per survey (2020).

Raa Atoll Population Demographics

The current recorded population of reef manta rays in Raa Atoll is 849 individuals, 17% of the total recorded Maldives population (*n*=5,041).

The population demographics in Raa Atoll are split almost evenly by gender, with 447 (53%) females, 396 (47%) males, and six individuals (1%) for which gender could not be determined (Fig. 6). Overall, 60% (*n*=513) of the Raa Atoll population are mature adults, while 38% are immature: with 35% (*n*=301) juveniles and 3% (*n*=29) subadults. Without knowing the sex of the six unknown individuals (1%), their maturity status could not be determined (Fig. 6).

A total of 178 individual reef manta rays (3.5% of the Maldives population) were recorded in Raa Atoll in 2020, which is a substantial decrease compared to the number of individuals sighted in 2019 (*n*=485) (Fig. 7). This reflects the decrease in survey effort and lack of MMRP researcher presence throughout eight months of 2020. During 2019, fifty-two percent (*n*=250) of the individuals sighted were new to the Raa Atoll reef manta ray population. However, in 2020, only 21% (*n*=37) of the individuals sighted were

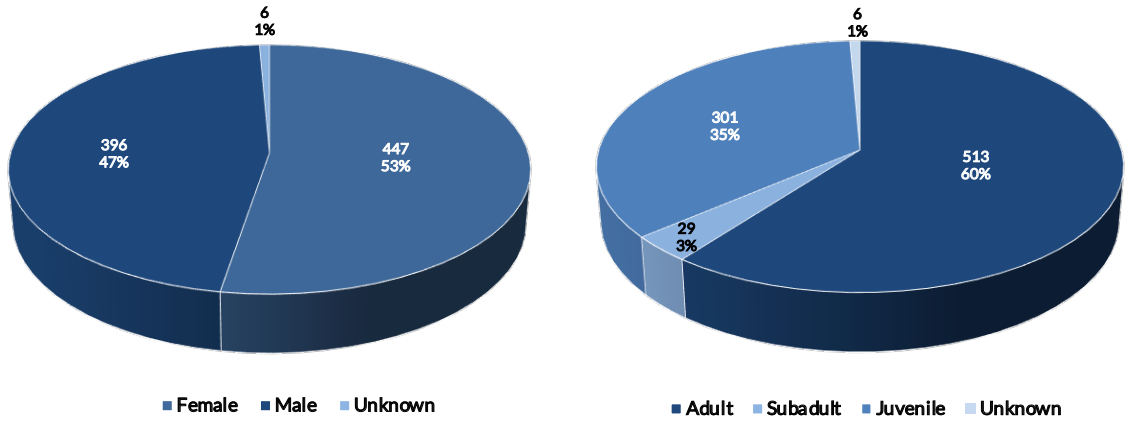


Figure 6: Demographics of the reef manta ray (*Mobula alfredi*) population (*n*=849) recorded in Raa Atoll (2007 - 2020).

new to the population (Fig. 7). In 2019, 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. Comparatively, in 2020, of the 37 new individuals recorded, 46% (*n*=17) had never been recorded elsewhere in the Maldives, while 54% (*n*=20) had previously been recorded in other atolls. Although research effort was restricted in 2020, a downward trend in newly sighted individuals is expected. As years pass and more data is collected, sightings of new manta rays become less frequent.

To date, 86% (*n*=734) of Raa Atoll's reef manta ray population (*n*=849) has been re-sighted in either Raa Atoll or elsewhere in the Maldives, suggesting most of the reef manta ray population which frequent Raa Atoll have now been recorded. Of the 37 new individuals recorded in 2020, one individual was estimated to be young of the year, based on their small disc widths, measuring approximately 150 centimetres.

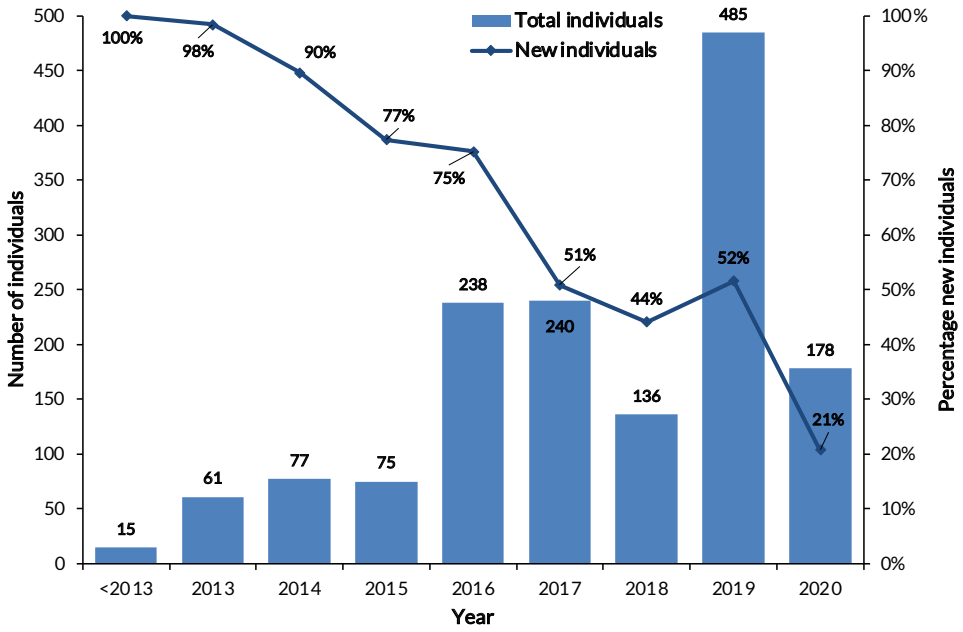


Figure 7: Number of individual reef manta rays (*Mobula alfredi*) sighted annually in Raa Atoll and the percentage of those individuals that were newly recorded.

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 larger atolls, with reef manta rays visiting the western aggregation sites during the Northeast Monsoon (December to March), before returning to the eastern aggregation sites during the Southwest Monsoon (May to November). Ninety-two percent (*n*=2,846) of all sightings from 2007 - 2020 were recorded at the ten key reef manta aggregation sites in Raa Atoll (Fig. 1). Variations in site use can be better understood by pooling sightings from these locations into five geographical groups based on their geographical position within the atoll and population demographics (Table 1).

Since a full year of data collection was not achieved in 2020, sightings from all previous years (2007 - 2020) have been used for preliminary analysis. Overall, intra-annual sightings of reef manta rays mostly conform to the expected migration patterns in the region. This is evident as the sightings peak first during the months of January to April (Northeast Monsoon) at Maamunagau Falhu (Group Four) and Sola Corner (Group Five) situated on the west of the atoll (Fig. 8). From May onwards, sightings at these sites decrease, with a noticeable shift in manta ray site use as sightings gradually increase at the central-eastern sites (Group Two) and eastern sites (Group One) during the Southwest Monsoon, with a peak in sightings at both aggregation groups during the month of October (Fig. 8). Throughout the Maldives, this month is recognised as a time when courtship behaviour is much more frequently observed and may explain the increase in sightings in the region. The remaining aggregation group (Boomerang Faru), located in the centre of the atoll, is predominantly utilised as a feeding site by adult reef manta rays. Despite far

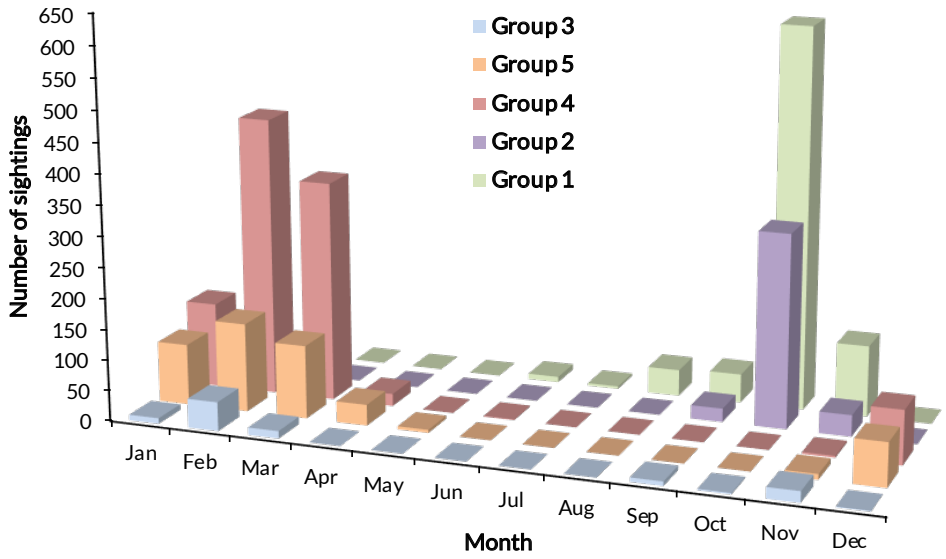


Figure 8: Intra-monthly variations in sightings of reef manta rays (*Mobula alfredi*) at ten key aggregation sites (pooled into five sub-regional areas) in Raa Atoll (2007 - 2020).

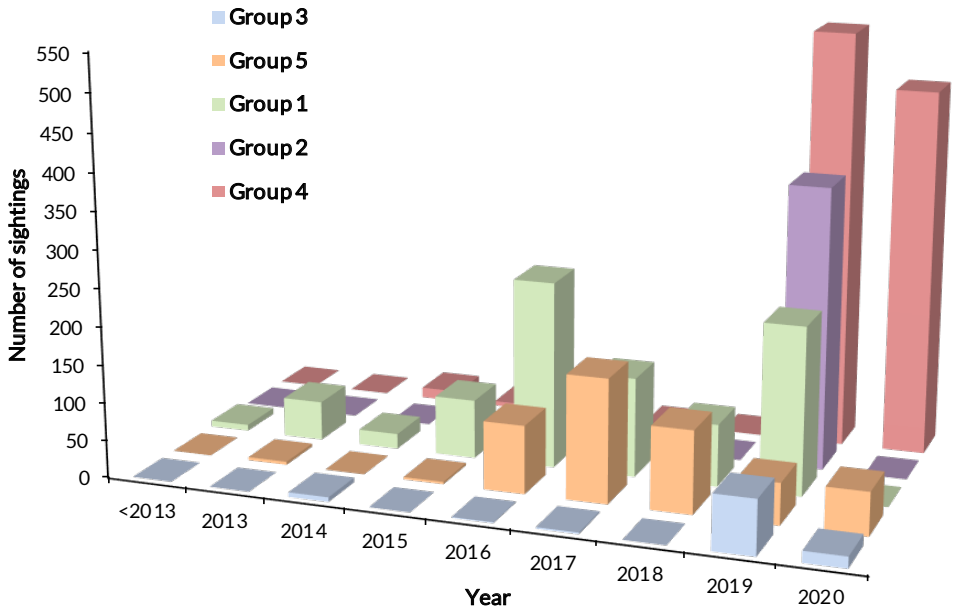


Figure 9: Inter-annual variations in sightings of reef manta rays (*Mobula alfredi*) at ten key aggregation sites (pooled into five sub-regional areas) in Raa Atoll.

fewer sightings in total compared to the other aggregation groups, sightings conform to a different trend, peaking in February (Northeast Monsoon) and November (Southwest Monsoon) (Fig. 8). 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.

Although there is a significant amount of inter-annual variation in reef manta ray sightings between, and within, these regional groups (Fig. 9), this is mostly due to the varying survey effort across previous years. However, the total number of reef manta ray sightings recorded at key aggregation sites Maamunagau Falhu and Maamunagau Faru (Group Four) was higher than all other aggregation groups (n=1,059). This is likely a result of the higher levels of survey effort in this region by MMRP researchers. Ninety-eight percent (n=1,039) of sightings from these sites were collected during 2019 (n=558) and 2020 (n=481). During both survey years, sightings peaked during the month of February (Fig. 10). However, sightings in December were higher in 2019 (n=83) than in 2020 (n=5). Survey effort at

these sites during December was almost identical between 2019 (*n*=36) and 2020 (*n*=35). Therefore, the decrease in sightings in the Maamunagau region during the month of December is possibly due to a delayed change between seasons (Southwest to Northeast) in 2020.

More consistent monitoring by MMRP researchers in the future will hopefully help to elucidate any trends in manta ray sightings at these key aggregation areas.

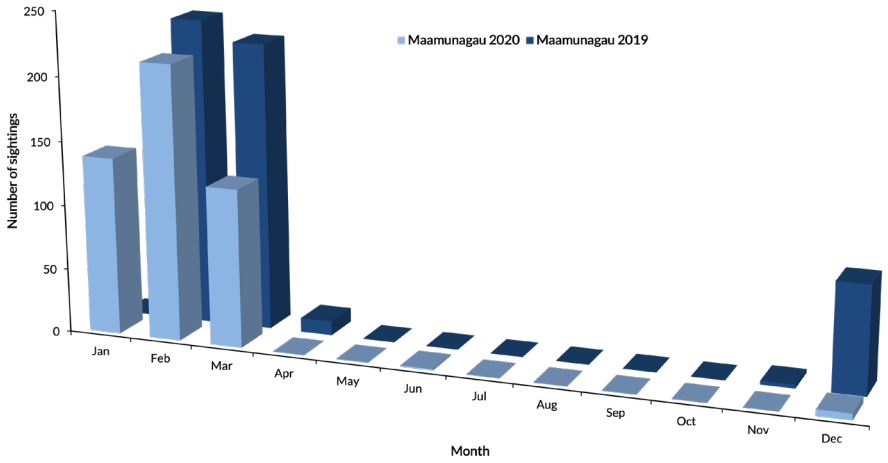


Figure 10: Intra-monthly variations in sightings of reef manta rays (*Mobula alfredi*) at key aggregation sites Maamunagau Falhu and Maamunagau Faru (Group 4) (2019 - 2020).

Maamunagau Sighting Records

The Maamunagau sub-region of Raa Atoll is comprised of six survey sites; Maamunagau Falhu, Maamunagau Faru, Maamunagau Beyru, Maamunagau Finolhu, Maamunagau Giri, and Maamunagau Thila (hereinafter referred to as Maamunagau) (Fig. 11). The large number of sightings and re-sightings of juvenile reef manta rays in Maamunagau, combined with the prevalence of many new-born pups recorded in 2019, indicated that Maamunagau serves as nursery habitat for these young individuals. To better understand the population of reef manta rays in this sub-region, survey efforts continued at these sites in 2020 (*n*=185), allowing further analysis to be performed.

In 2020, a total of 522 reef manta ray sightings were recorded at four of the Maamunagau sites: Maamunagau Falhu (*n*=449), Maamunagau Faru (*n*=32), Maamunagau Finolhu (*n*=29) and Maamunagau Beyru (*n*=12). The data shows a slight decrease (8%) in sightings compared to the previous year (*n*=568 in 2019). A monthly breakdown of reef manta ray sightings across 2020, when standardised for survey effort, shows that the mean number of individuals sighted per survey peaked during the month of February (*n*=220), and were significantly lower in December (*n*=5) (Fig. 12).

Survey site Maamunagau Falhu accounted for ninety-five percent (*n*=540) of the reef manta ray sightings (*n*=568) in the Maamunagau sub-region in 2019, and eighty-six percent (*n*=449) of sightings (*n*=522) in 2020. This area was predominately utilised by feeding manta rays (Fig. 13). Despite fewer sightings recorded, the primary behaviour observed at survey sites Maamunagau Faru and Maamunagau Beyru was also feeding, whereas Maamunagau Finolhu and Maamunagau Giri had multiple sightings of cleaning manta rays (Fig. 13). Manta rays tend to frequent cleaning stations that are near their plankton-rich feeding areas. To better understand the use of these cleaning stations by the Maamunagau reef manta ray population, remote underwater video surveys (RUVs) were used by the MMRP researchers based on Maamunagau Island; positioned at the two cleaning sites of Maamunagau Finolhu and Maamunagau Giri.

Remote underwater video surveys are commonly used in research to monitor specific areas and their use by different marine life whilst humans are absent. Twenty-two percent (*n*=41) of the surveys conducted within Maamunagau in 2020 (*n*=185) were collected using RUVs. A total of 28 sightings of 19 individuals were recorded over the 41 RUV

Figure 11: Map of Maamunagau in Raa Atoll, showing the six reef manta ray *(Mobula alfredi)* survey sites within the sub-region.

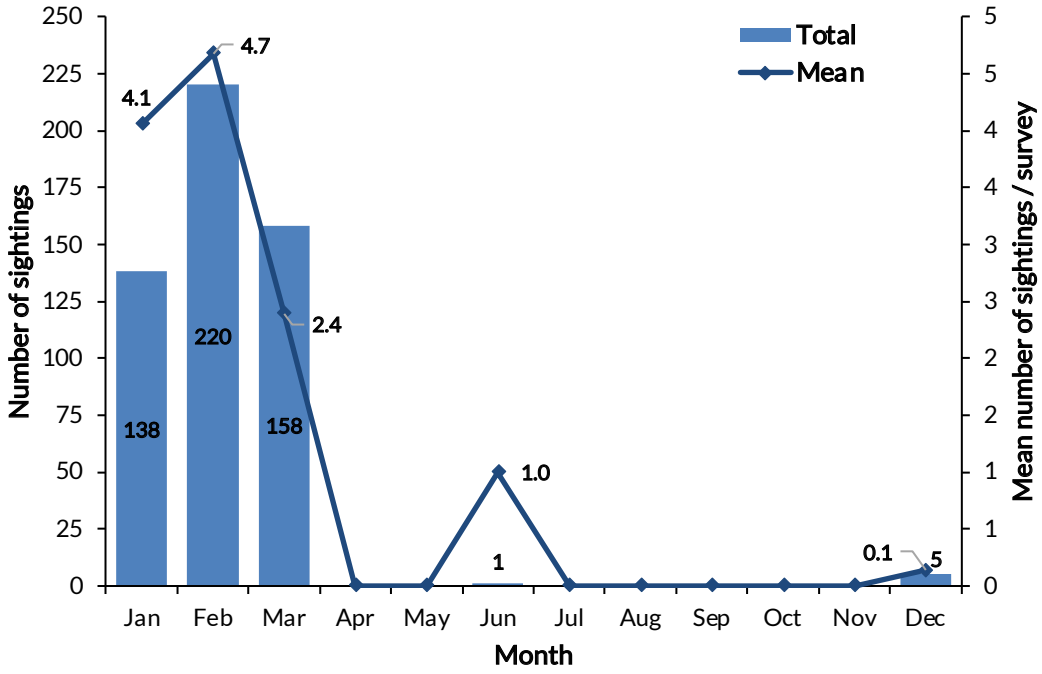


Figure 12: Monthly sightings of reef manta rays *(Mobula alfredi)* at Maamunagau in Raa Atoll, and the mean number of sightings per survey (2020).

surveys, which makes up 5% of the total Maamunagau sub-regional sightings (*n*=522). Ninety-six percent (*n*=27) of these sightings were recorded at Maamunagau Finolhu, where the only observed behaviour was cleaning. Seven individuals that were recorded cleaning at Maamunagau Finolhu on RUV surveys were also seen that day feeding within Maamunagau Falhu via human observation. Moreover, six individuals were recorded by the RUVs on more than one occasion, suggesting that they returned to the same cleaning station (Maamunagau Finolhu) across multiple days.

Of the 19 individuals recorded, all except one manta ray had been recorded during human observations somewhere within Maamunagau (Finolhu or Falhu) throughout 2020. However, there was one individual that would have gone unknown without the deployment of a RUV, proving the value of this method when monitoring manta ray cleaning stations and aggregation sites.

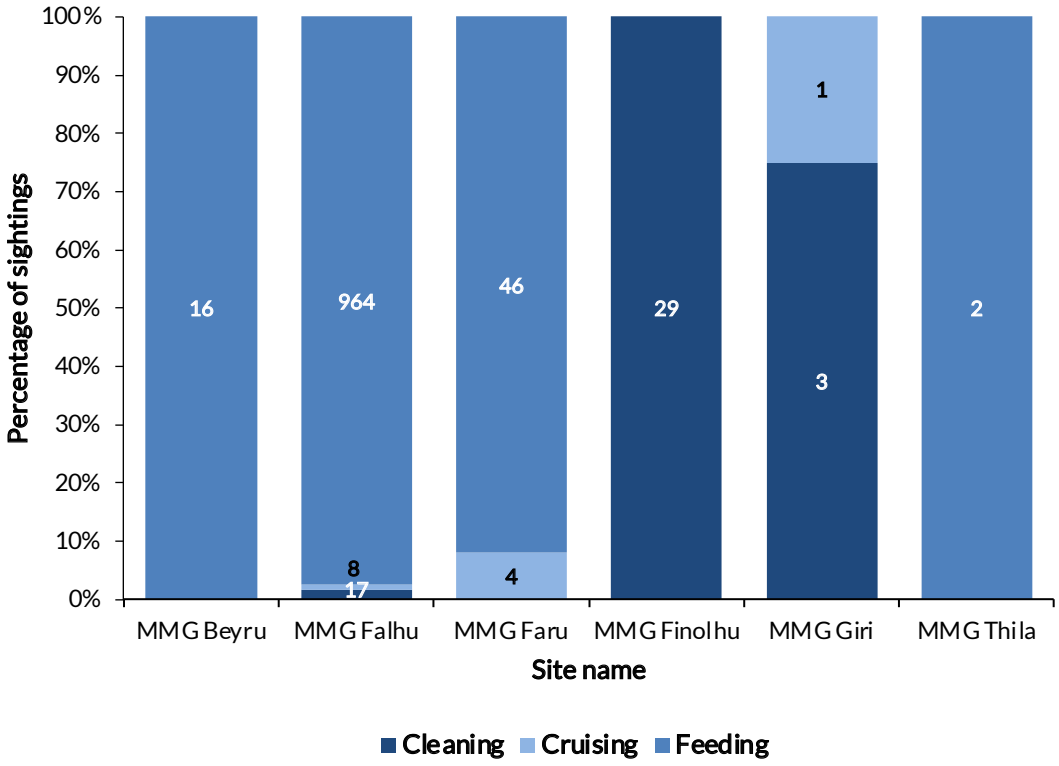


Figure 13: Reef manta ray *(Mobula alfredi)* sightings at the six survey sites within the Maamunagau (MMG) subregion of Raa Atoll. Distribution categorised by primary behaviour recorded at each survey site. Actual numbers within bars (2019 - 2020).

Maamunagau Population Demographics

Data collected during the years of increased survey effort 2019 and 2020 have been used to assess the reef manta ray population of Maamunagau. Data shows that the Maamunagau population consists of 200 individuals, accounting for 24% of the overall Raa Atoll population (*n*=849). Of these individuals, 37% (*n*=74) were recorded in Maamunagau during both 2019 and 2020 survey years, while 40% (*n*=79) were only sighted in 2019, and 24% (*n*=47) only in 2020, with 13 of these individuals being new to the MMRP database.

The population demographics of Maamunagau are split almost equally between sexes, with 48% (*n*=96) females, 52% (*n*=103) males, and one individual for which sex could not be determined (Fig. 14). The sub-regional population has a higher percentage (58%) of immature individuals than the wider Raa Atoll population (38%), with 53% (*n*=105) juveniles and 5% (*n*=10) subadults (Fig. 14). Maturation was defined by the presence of mating scars and visible pregnancies in females, and by the enlargement and calcification of claspers in males. Furthermore, if an individual is estimated to be at, or larger than, the known size at maturation for this species in the Maldives (320 - 330 cm disc width for females, 270 - 280 cm disc width for males), adult status was also assigned.

Further analysis of the available data shows that there was a higher presence of juvenile females (*n*=73) than juvenile males (*n*=32) within the Maamunagau population (Fig. 14). Dissimilarly, the proportion of adult males (*n*=63) was higher than that of females (*n*=21) (Fig. 14). Despite a higher number of juvenile female individuals compared to their male counterparts in the Maamunagau population, sightings from the first three months of 2020 (*n*=516) show a similar ratio of juvenile female and male manta rays (Fig. 15). There is, however, a definite bias towards adult males compared to females (Fig. 15). It is possible that this higher presence of adult males frequenting the Maamunagau region can be explained by males having a higher affiliation to lagoonal feeding grounds than females. Similar findings have been observed in other areas of the Maldives. However, continued research efforts by MMRP researchers in future years will help to elucidate this trend.

In 2020, a total of 121 individuals were recorded within Maamunagau. Demographics of individuals sighted in Maamunagau in 2020 showed the same general trends as the overall sub-population, with 43% (*n*=52) females, 56% (*n*=68) males, and a higher percentage (61%) of immature individuals. Overall, 54% (*n*=65) of the individuals recorded in 2020 were sighted more than once, with an average of 4.31 sightings per individual. When split by demographic, juvenile manta rays exhibit higher site fidelity to Maamunagau than

adults. On average, each juvenile was recorded 5.4 times, compared to 2.54 times for each adult. Furthermore, the maximum sightings for any individual recorded within Maamunagau in 2020 was higher in juveniles (*n*=20) than adults (*n*=9). To account for survey effort, a residency index (RI) was calculated to determine how often each individual reef manta ray was seen throughout each survey 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, an RI of 3% means that, on average, each individual was sighted on 3% of the total surveyed days. The RI for juvenile reef manta rays in 2020 (6.75%) was higher than the RI for adults (3.18%).

Of the individual reef manta rays sighted in Maamunagau in 2020, one was estimated to be new-born young of the year, and 23 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, in both 2019 and 2020, indicate 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.

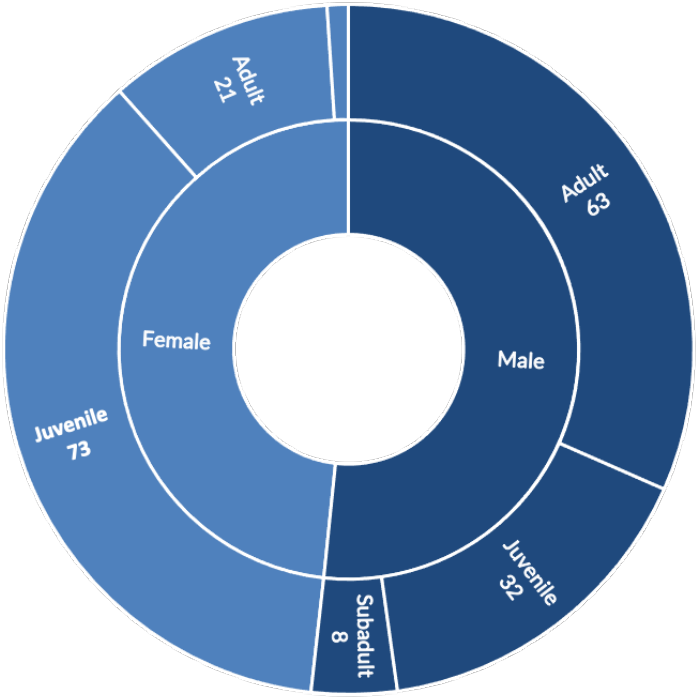


Figure 14: Maturity status of the reef manta ray *(Mobula alfredi)* population (*n*=200) at Maamunagau in Raa Atoll categorised by gender (2019 - 2020).

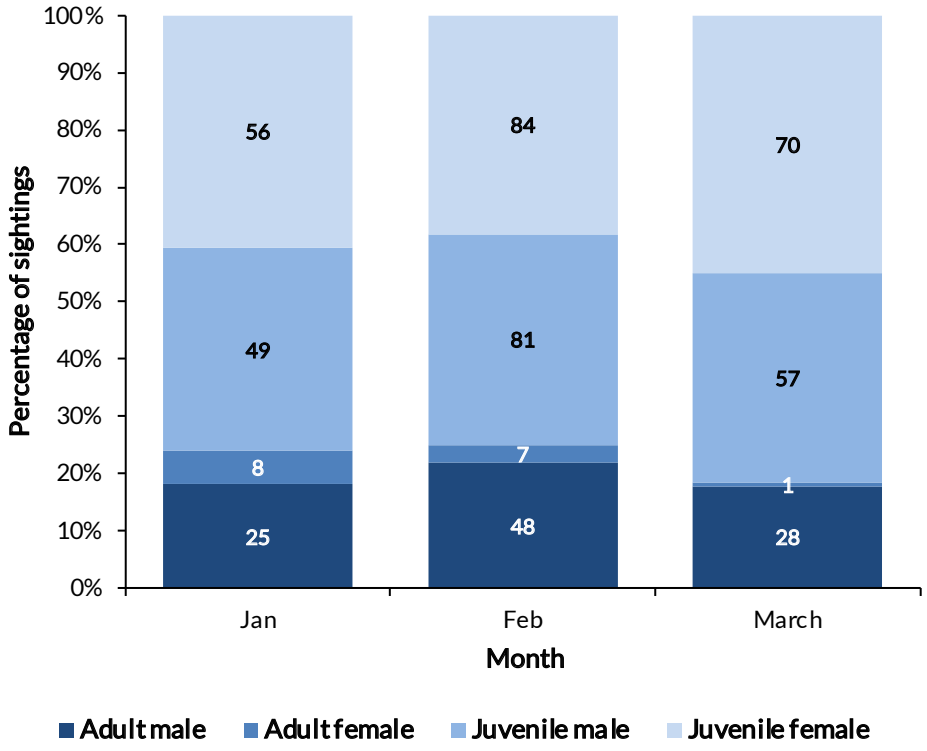


Figure 15: Reef manta ray *(Mobula alfredi)* sightings distribution categorised by maturation status during the first months of intensive surveying effort in Maamunagau in Raa Atoll. Actual numbers within bars (2020).

Atoll Residency

To date, 60% (*n*=506) of the Raa Atoll population have been recorded on more than one occasion within the atoll. Sixty-five of those individuals have been sighted more than 10 times throughout the study period (2007 – 2020), and 11 of those individuals more than 20 times.

Without utilising sophisticated tracking methodologies, such as telemetry, it is difficult to create a detailed picture of how individual reef manta rays utilise their habitat within Raa Atoll. However, increased surveying effort by the MMRP in 2019 and 2020 has allowed for some broad preliminary analysis. Throughout 2020, each individual manta ray was observed on average 3.4 times within Raa Atoll (Fig. 16), a slight increase compared to 2019 (*n*=2.8). The percentage of reef manta rays seen more than once in Raa Atoll in 2020 was lower than 2019, but higher than all other previous years, with a 45% re-sighting rate (Fig. 16). To account for survey effort, a Residency Index (RI) was calculated for 2020, based on the ratio between the number of sightings per individual manta ray and the total number of surveyed days. The RI for 2020 (3.98%) was higher than that noted in 2019 (2.12%). The higher residency of manta rays in Raa Atoll during 2020 is likely a result of the increased focus on surveying sub-regional aggregation area Maamunagau during the Northeast Monsoon months, and the lack of data collected at other aggregation sites throughout the remainder of the year. Maamunagau has already been highlighted as a site with higher fidelity. 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.

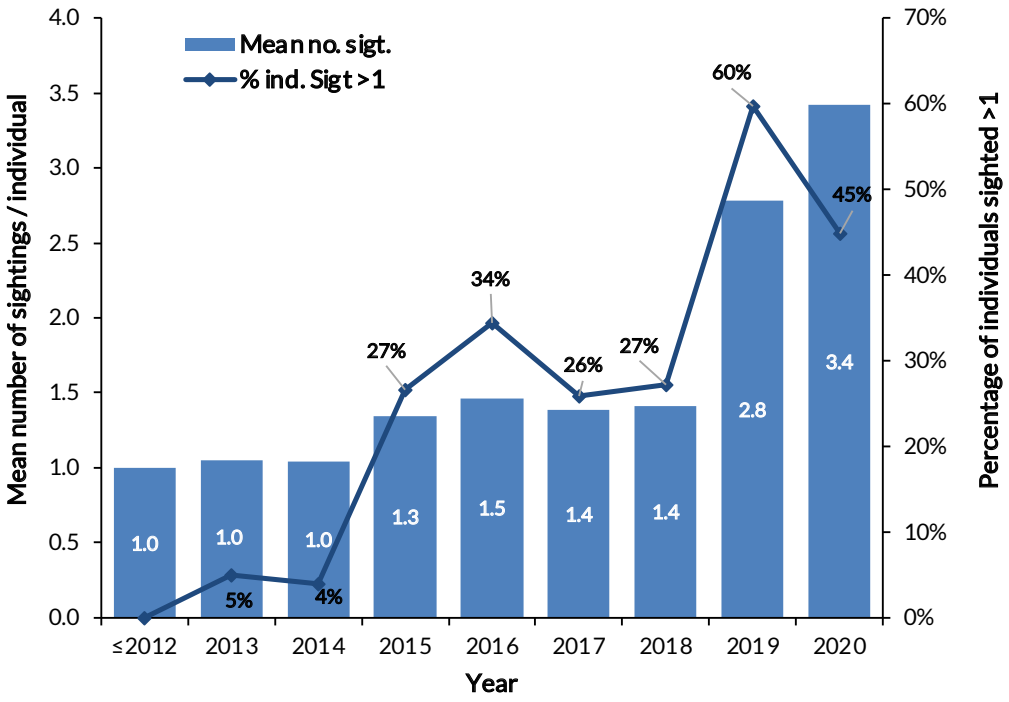


Figure 16: Mean number of sightings per individual reef manta ray *(Mobula alfredi)* in Raa Atoll, and the percentage of individuals sighted on multiple occasions during the same year.

Inter-Atoll Migrations

Due to its north-central location, and proximity to other atolls, 67% (*n*=571) of the recorded reef manta ray population of Raa Atoll have been recorded in 15 other geographical atolls throughout the Maldives, suggesting high inter-atoll mobility within the Maldives population (Fig. 17). Forty-two percent (*n*=357) of the Raa Atoll population have been recorded in two atolls (Fig. 18). 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*=505), followed by Ari Atoll (*n*=98) (Fig. 17). 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.

Throughout 2020, inter-seasonal movement between Baa and Raa Atoll conformed to similar trends as previously recorded. In total, 53 individuals that were sighted in Raa Atoll (*n*=178) during the 2020 Northeast Monsoon months were previously recorded in Baa Atoll during the 2019 Southwest Monsoon. Sixty-eight percent (*n*=36) of these individuals were recorded in Hanifaru Bay in 2019, before being sighted in Raa Atoll in 2020. Moreover, 44 individuals were recorded in both Raa and Baa Atoll throughout 2020, of which 95% (*n*=42) were recorded in Hanifaru Bay in 2020 after being sighted in Raa Atoll earlier that year. Data shows that 36 individuals were recorded across all three seasons (Baa Atoll Southwest Monsoon 2019, Raa Atoll Northeast Monsoon 2020, and Baa Atoll Southwest Monsoon 2020). 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 that some Baa Atoll individuals migrate to Raa Atoll to forage at sites along the western side of the atoll during the Northeast Monsoon.

Without year-round survey effort in Raa Atoll throughout 2020, additional intra-seasonal analysis cannot be performed. However, with the presence of MMRP researchers based on Maamunagau Island in Raa Atoll, it is hoped that year-round survey effort will be possible in the future, and 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.

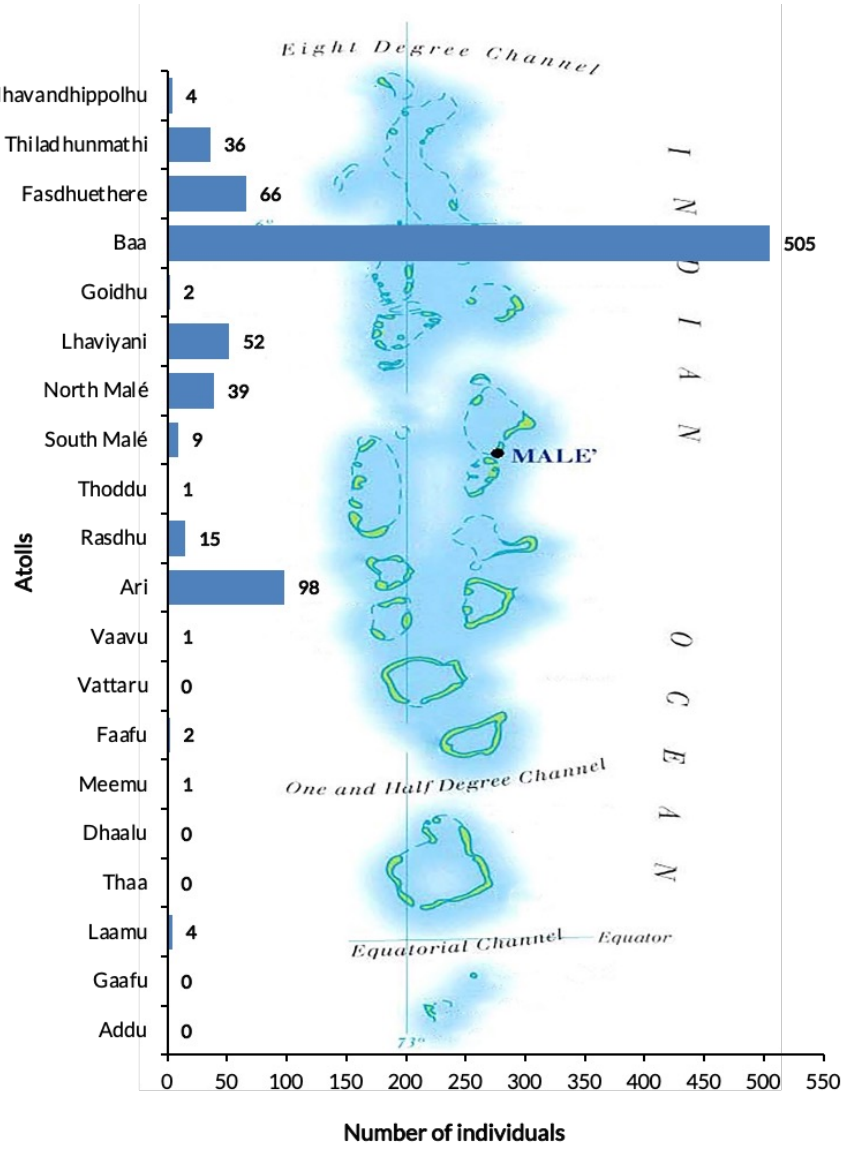


Figure 17: Number of reef manta rays *(Mobula alfredi)* (*n*=571) from within the Raa Atoll population (*n*=849) which have been recorded in other geographical atolls throughout the Maldives Archipelago. Note – some individuals have been sighted in more than one atoll.

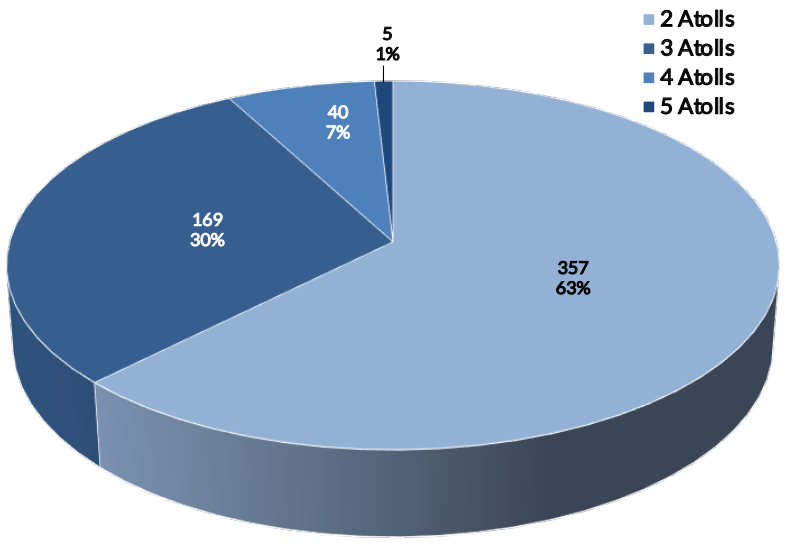


Figure 18: Total number of atolls each individual reef manta ray from the more transient Raa Atoll population (*n*=571) have been sighted in (2007 - 2020).

Throughout their range globally, reef manta ray reproductive activity often peaks at specific 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, with mature males aggregating at these sites in search for sexually receptive females. 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. 19). These peaks in courtship activity coincided with the transitional period between monsoons, matching the general timing of courtship activity recorded throughout Maldives. In contrast to the last five years, no courtship activity was recorded during 2020 (Fig. 20). However, this is likely due to the absence of MMRP researchers during the months when courtship might be expected.

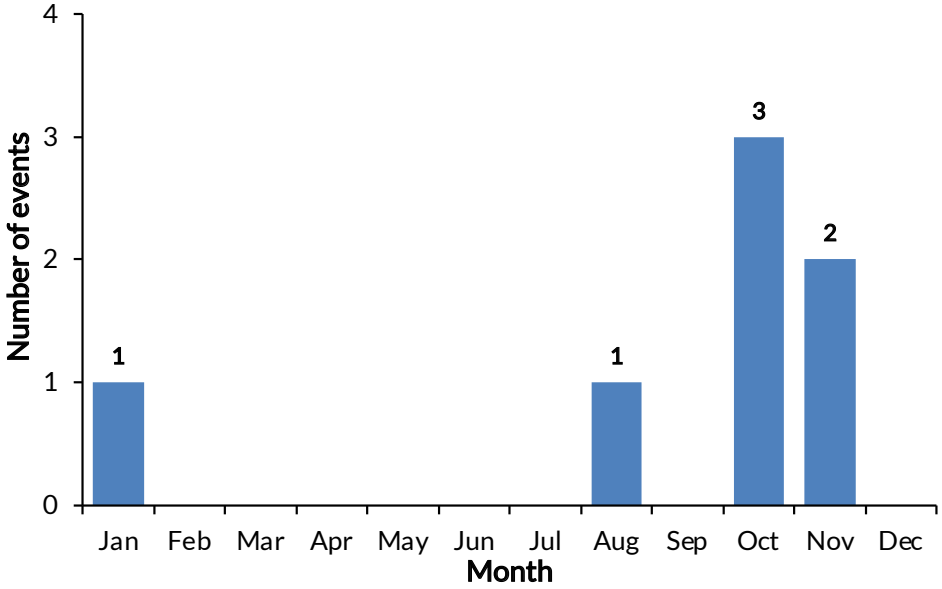


Figure 19: Number of reef manta ray *(Mobula alfredi)* courtship events recorded throughout Raa Atoll (2007 - 2020).

Throughout the Maldives, the MMRP has observed a cyclical fluctuation in reproductive fecundity, with higher numbers of courtship events reflecting higher numbers of pregnant females in the following year. Without consistent data collection from Raa Atoll, it is not possible to draw definitive conclusions. However, the low incidence of courtship activity recorded within the atoll in 2019 (*n*=1 event of 7 individuals), does correlate to the low number of pregnancies recorded in 2020 (*n*=3) (Fig. 20). Further research by trained observers which are able to recognize and accurately document courtship activity will help to better understand seasonal courtship trends in Raa Atoll.

Overall, 24% (*n*=200) of the recorded Raa Atoll population are mature adult females, of which 33% (*n*=66) have been recorded to be visibly pregnant at some point during the study period (2007 – 2020). The highest number of pregnant females was recorded in 2019 (*n*=35), a stark difference to the low incidence of pregnancies recorded in 2020 (*n*=3) (Fig. 21). The number of mature adult females recorded was also much lower in 2020 (*n*=21) compared to 2019 (*n*=111) (Fig. 21), most likely due to the variation in survey effort between the two years.

With a gestation period of one year, manta ray pregnancies become easily visible at about six months into the pregnancy. Of the three individuals observed to be pregnant in the region in 2020, all of them were already in the later stages of gestation (3rd or 4th trimester) at the beginning of the year, suggesting they had also been pregnant throughout the later months of 2019. This low incidence of pregnancies reported in 2020 highlights the overall very slow reproductive rate for this species. With such a low fecundity it becomes vital for the survival of these animals to minimise anthropogenic and natural impacts. Effective measurements include the establishment of functional marine protected areas (MPAs) and the adherence to sustainable tourism activities at key manta ray aggregation sites.

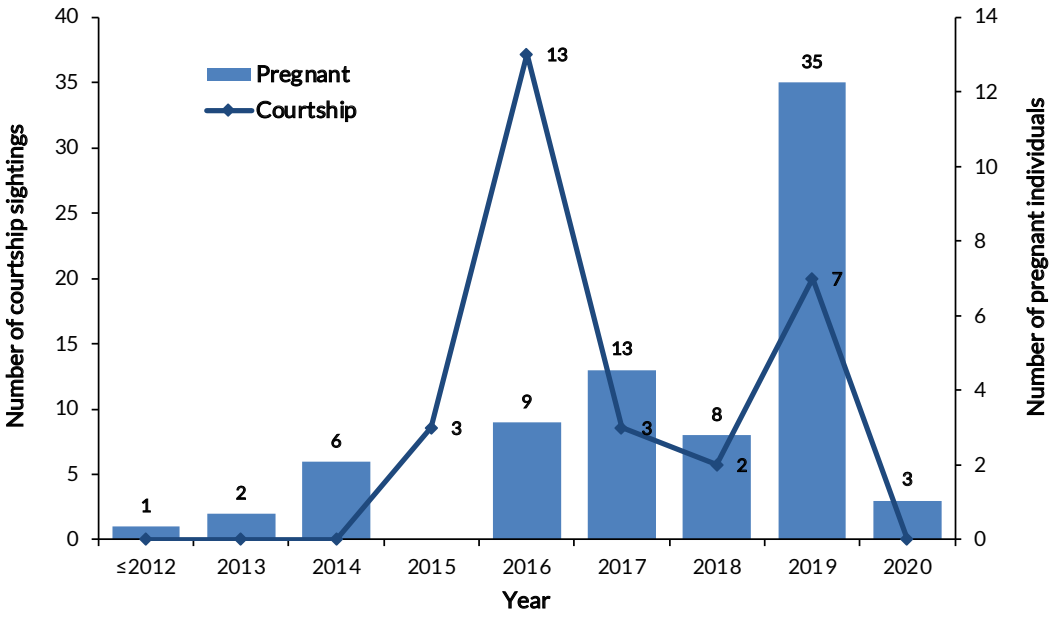


Figure 20: Number of reef manta ray *(Mobula alfredi)* sightings where courtship was the predominant behaviour observed annually in Raa Atoll, and the total number of pregnant females recorded in that same year.

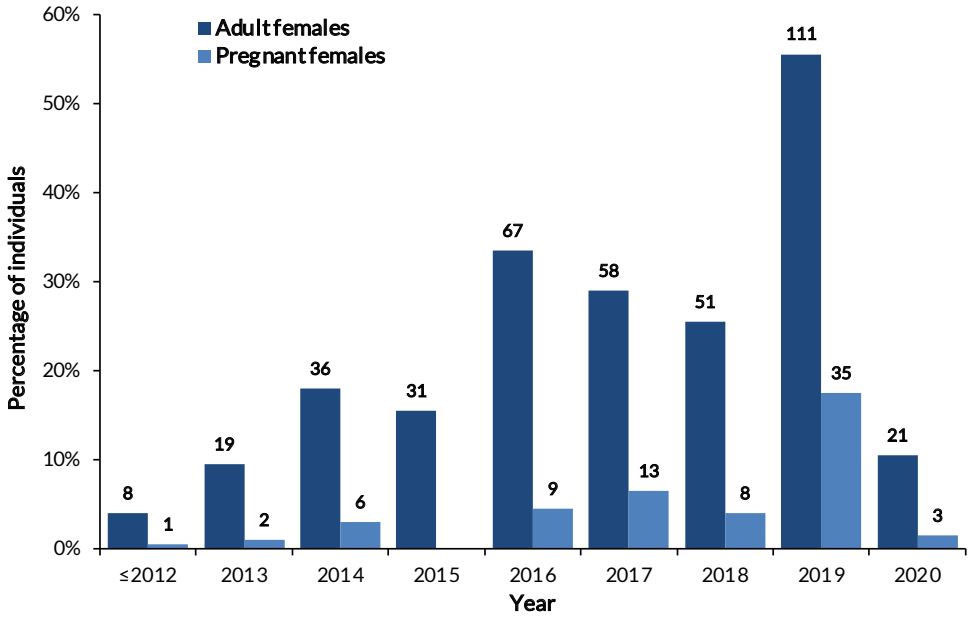


Figure 21: Percentage of Raa Atoll's adult female reef manta ray *(Mobula alfredi)* population (*n*=200) sighted annually, and the percentage of those females that were recorded pregnant in the same year. Actual numbers above bars.

Sub-Lethal Injuries

Of the 849 individual reef manta rays recorded to date in Raa Atoll, 35% (*n*=300) have sub-lethal injuries. Of the injured individuals, 84% (*n*=252) have only one injury, 15% (*n*=44) have two recorded injuries, and four individuals (1%) have three injuries. Overall, 340 separate injuries were recorded, 60% (*n*=205) of which resulted from natural origins (e.g., predatory bites, diseases, deformities, etc.), whilst 24% (*n*=81) resulted from anthropogenic origins (e.g., fishing line entanglement, boat strikes, etc.). The remaining 54 sub-lethal injuries originated from an unknown source (Fig. 22).

Demographically, instances of injuries are slightly higher in females than in males, with 56% (*n*=190) of all injuries reported on females, and the remaining 44% (*n*=150) on males (Fig. 22). Injuries were also more prevalent in adults (*n*=219) compared to juveniles (*n*=121), which is

unsurprising since adult reef manta rays are older and more likely to have encountered both anthropogenic and natural threats more often than juveniles during their lifetime.

Across all individuals sighted within Raa Atoll, the most common cause of injury (for both adults and juveniles) was from predatory bites (*n*=169), followed by fishing line entanglement (*n*=63) (Fig. 23). Other natural sources of injury, such as deformity, infections, disease, and parasites, were less frequent, comprising 6% (*n*=21) and 4% (*n*=15) of injuries, respectively. Additional anthropogenic injuries included those caused by boat strike (*n*=16), the majority of which were inflicted upon adult manta rays (*n*=13). Only two rope or net entanglement injuries were recorded within the population (Fig. 23).

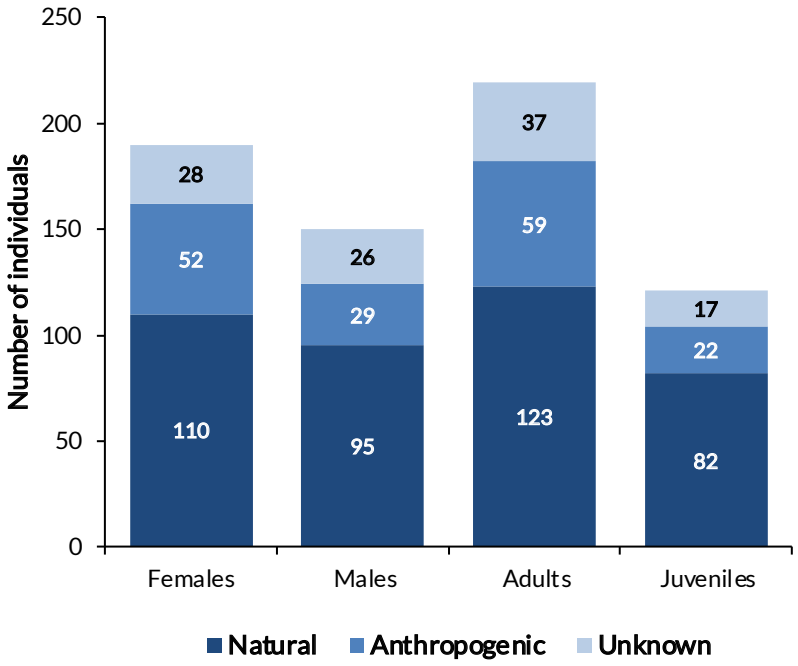


Figure 22: Demographic variations in the number of sub-lethal injuries (*n*=340) recorded on reef manta rays *(Mobula alfredi)* within the Raa Atoll population (*n*=849), and the likely injury origin (natural or anthropogenic).

Of all manta ray injuries recorded in the Raa Atoll population, the most common body area inflicted by injury (66%) are the manta ray's pectoral fins (Fig. 24); a similar finding to other MMRP atoll annual reports. This is most likely because manta rays cannot see well directly behind them, making them vulnerable to attacks from predators (mainly large sharks) within the anterior pectoral fin region. This region of the body is also where entangled fishing line often causes the most damage. The proportion of individuals with injured pectoral fins remains relatively consistent between sexes and maturity statuses of the Raa Atoll population (Fig. 24).

In total, 34 new injuries were recorded in the Raa Atoll reef manta ray population in 2020. New injuries followed similar trends to that of the whole Raa Atoll population, with 50% (*n*=17) of injuries resulting from natural origins, whilst 21% (*n*=7) resulted from anthropogenic origins, and the remaining 29% (*n*=10) originated from an unknown source. Most injuries were attributed equally to predatory bites (*n*=7) and deformities (*n*=7), followed by fishing line (*n*=4) and infection, disease, and parasites (*n*=3) (Fig. 25). The proportion of new injuries recorded in 2020 were almost even between adult and juvenile reef manta rays (Fig. 25).

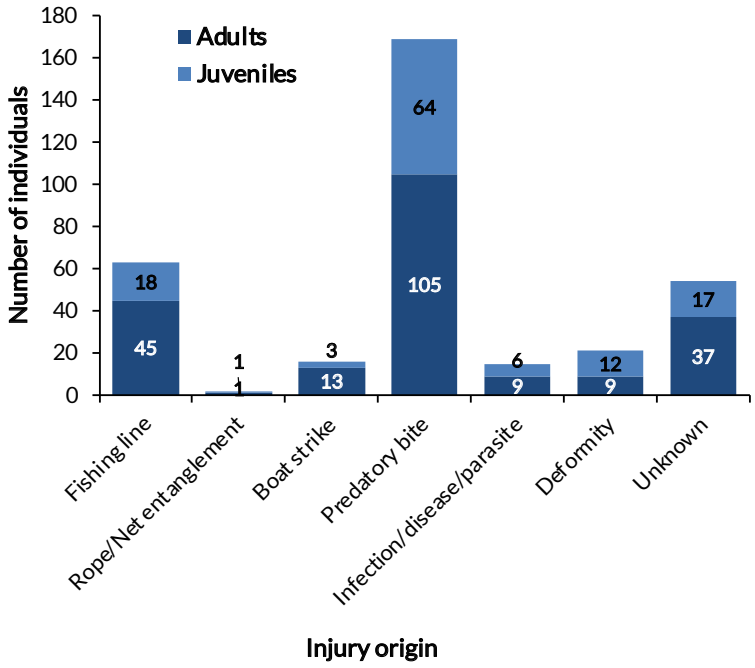


Figure 23: Demographic variations in the likely origin of sub-lethal injuries (*n*=340) within the injured reef manta ray *(Mobula alfredi)* population of Raa Atoll (*n*=300).

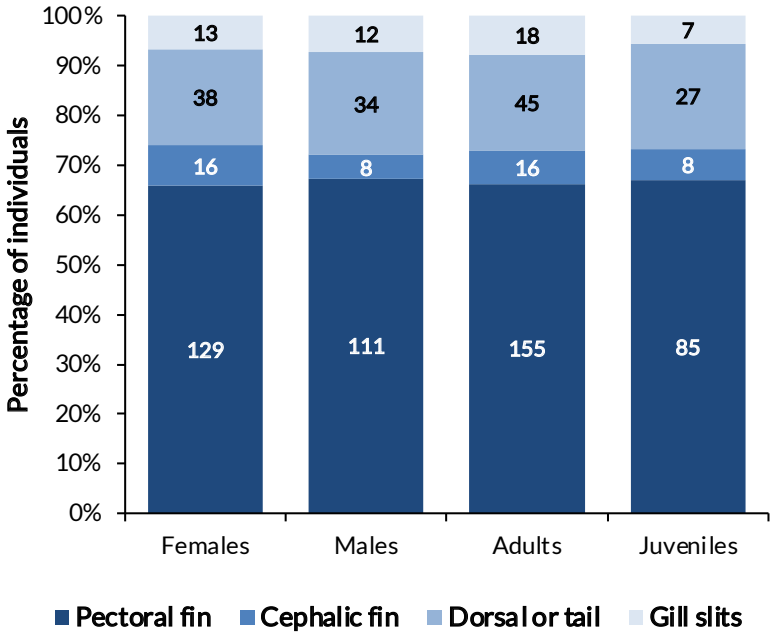


Figure 24: Demographic variations in the location of recorded sub-lethal injuries (*n*=340) within the reef manta ray *(Mobula alfredi)* population of Raa Atoll. Actual numbers within bars.

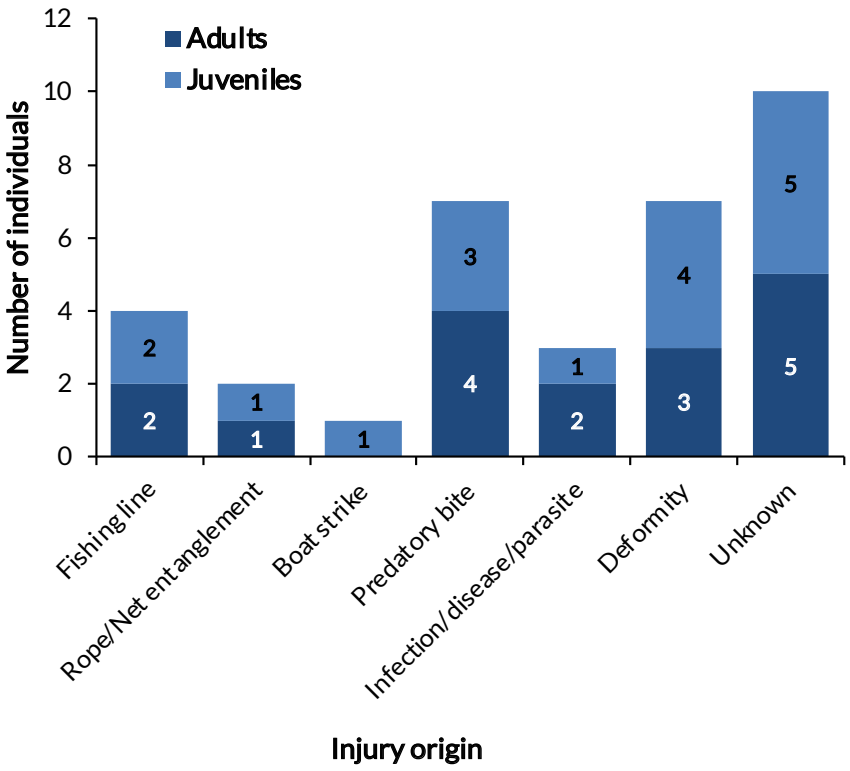


Figure 25: Demographic variations in the likely origin of newly recorded sub-lethal injuries (*n*=34) within the reef manta ray *(Mobula alfredi)* population of Raa Atoll (2020).

ENVIRONMENTAL VARIABLES

Environmental conditions, particularly wind and current strength, have a strong influence on the seasonal abundance of phytoplankton, and therefore zooplankton availability, which in turn is likely to influence manta ray abundance. Weather data for 2020 and previous years were sourced from the Maldives meteorological department and have been analysed together with sightings records to determine whether any correlation exist between manta ray sightings and wind speed. Due to the lack of survey records, inter-annual analysis could not be accurately assessed for all years prior to 2019. An initial comparison between survey years 2019 and 2020 revealed a higher average wind speed in 2020 (*n*=17.8km/h) compared to 2019 (*n*=15km/h). However, there was a slight decrease in the average number of manta ray sightings per survey day in 2020 (*n*=5.6), compared to 2019 (*n*=6.2).

Closer analysis of wind speed and manta ray activity towards the end of 2019 and throughout 2020 shows that wind speed began to rise towards the end of 2019, increasing from 12km/h in November to 20km/h in December 2019 (Fig. 26). Wind speeds were highest during January and February 2020, before dropping to much lower levels in March. Reef manta ray sightings followed expected trends, with the highest number of sightings recorded per survey (*n*=10.4) during February 2020 (Fig. 26). The spike in wind speed at the end of 2019, followed by continuous high winds in the beginning months of 2020, follows similar trends to those seen throughout the Maldives, with manta sightings increasing one or two months after an increase in wind speed. This is likely due to the natural time lag between increased primary productivity and zooplankton blooms. Throughout the later months of 2020, wind speed peaked again during the months of September and October, with speeds of 21km/h and 22km/h respectively. These speeds are significantly higher when compared to the same months in 2019 (Fig. 26). Following these months, wind speeds dropped in November to 11km/h. This sharp decline likely affected the manta ray sightings in December 2020, with an all-time low of 0.4 sightings per survey day. It is possible that because of the dramatic drop in wind speed recorded in November compared to September and October, the normal process of seasonal change and zooplankton build up was delayed in 2020, in turn delaying

the migration of reef manta rays through the Maldives. This would explain the lack of manta ray sightings in December 2020, with December acting as the transitional period of change between the two seasons (typically observed in November). Without researchers in Raa Atoll during the latter months of the Southwest Monsoon (September – November), full sightings trends could not be determined for this period. However, unlike in 2019, manta ray sightings did not increase during the month of December 2020. Despite this, an overall positive correlation (R2=0.1306) was found between average wind speed and daily manta sightings in 2020 (Fig. 27). 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.

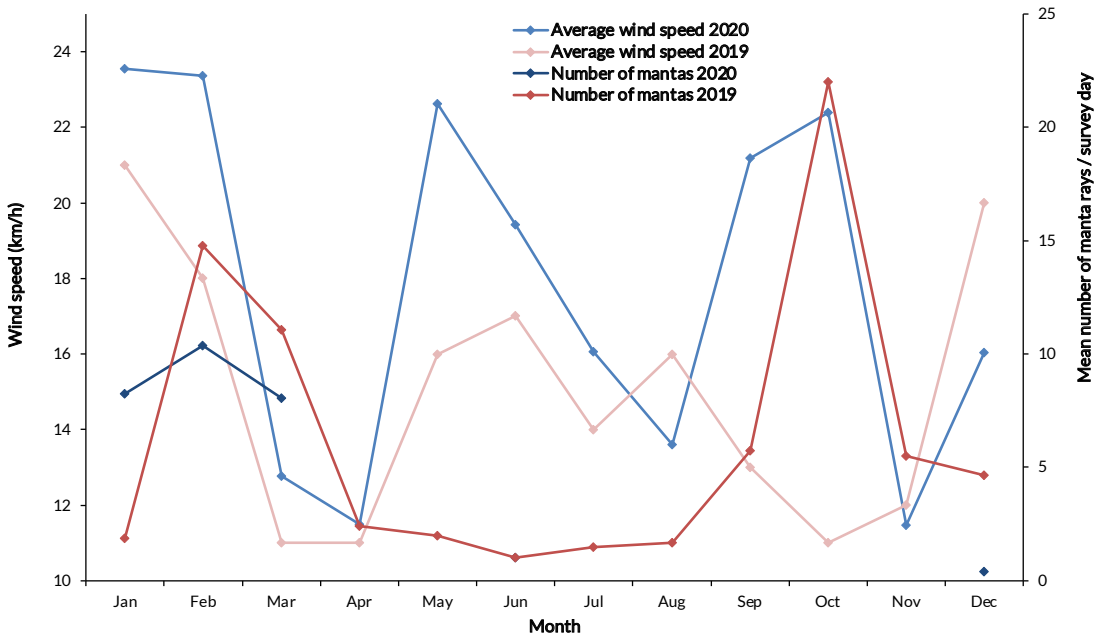


Figure 26: Mean monthly wind speed (km/h) and mean number of reef manta ray *(Mobula alfredi)* sightings per survey day by in Raa Atoll (2019 - 2020).

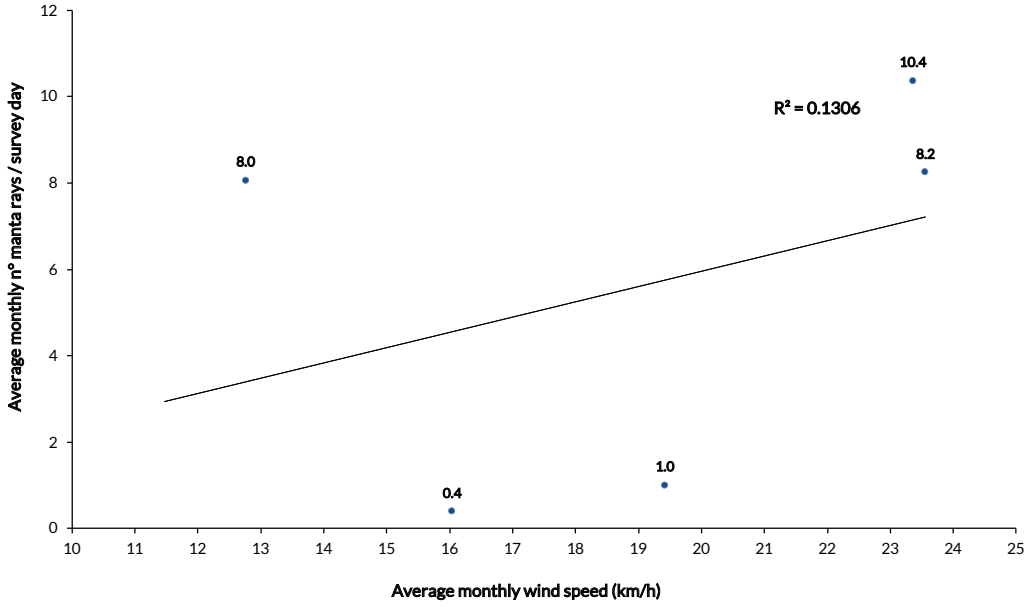


Figure 27: Mean monthly wind speed (km/h) and the mean monthly number of reef manta ray *(Mobula alfredi)* sightings recorded per survey day in Raa Atoll (2020).

During each of the surveys conducted in 2020, wind direction was recorded using the online weather forecast platform Windguru (www.windguru.cz/173263). Wind directions recorded between January and March reveal variability throughout these Northeast Monsoon months (Fig. 28). Wind directions were classified into eight main directions, combining multidirectional winds into their main category. As expected during the Northeast Monsoon, winds coming in from the general east direction dominated from January to March contributing to 35% – 59% of wind direction readings during this time (Fig. 28). The beginning of the season (January and February) was marked with distinctly higher easterly and north-easterly readings followed by a decrease during March. Although easterly readings in March were higher than any other direction, the percentage of readings from the south and west directions were present during March, but not in the previous two months. In comparison, the average number of manta ray sightings per day peaked in February (*n*=10.4), during which time winds from the east were notably higher than any other direction. Whereas January and March had slightly lower but relatively equal average manta ray sightings per day (*n*=8.2 and 8.0), respectively, but also relatively equal percentages of wind direction readings from the Northeast and East as well (Fig. 28). As a force acting in combination with increased wind speed, wind directions dominating from the east and northeast may additionally influence the favourable conditions which result in an increase in manta ray sightings during the first few months of the calendar year. Without any survey data recorded during the Southwest Monsoon 2020, full annual trends could not be determined. However, surveys from December 2020 show that winds coming from the east were much lower compared to the previous seasons' Northeast Monsoon months (January to March 2020), with readings of winds from Southwest and Northwest also recorded during this month (Fig. 28). This suggests that the Northeast Monsoon had not fully started yet, supporting the theory that there was a delayed seasonal change witnessed in 2020.

Tidal currents bring plankton-rich water in to, and out of, the atoll lagoons via channels along the outer rim of the atoll daily. Therefore, it is expected that tidal currents also influence the manta rays' movement, behaviour, and habitat use. To further determine any correlations between current direction and manta ray behaviour, survey data from 2020 included the variables current direction, current speed, and primary observed behaviour. Of the 317 surveys recorded in 2020, manta rays were present on 43% (*n*=137) of these occasions. On 45% of these surveys when manta rays were present (*n*=61), the current was outgoing, during which time the predominant behaviour observed was feeding (*n*=46) (Fig. 29). In contrast, on the fewer occasions when cleaning behaviour was recorded in 2020 (*n*=22), it was almost equally recorded during incoming and outgoing currents (Fig. 29). Similar trends were recorded when assessing sub-regional aggregation site Maamunagau. In total, manta rays were present on 45% (*n*=83) of the surveys recorded in Maamunagau in 2020. On 41% of these surveys when manta rays were present (*n*=39), the current was outgoing, during which time the predominant behaviour observed was feeding (*n*=34).

Overall, the most common behaviour displayed by the reef manta ray population in Raa Atoll was feeding, constituting 60% (*n*=82) of all surveys when manta rays were recorded present in 2020 (*n*=137). Indeed, of the 609 photo-ID sightings of reef manta rays recorded in 2020, 86% (*n*=522) were of individuals feeding.

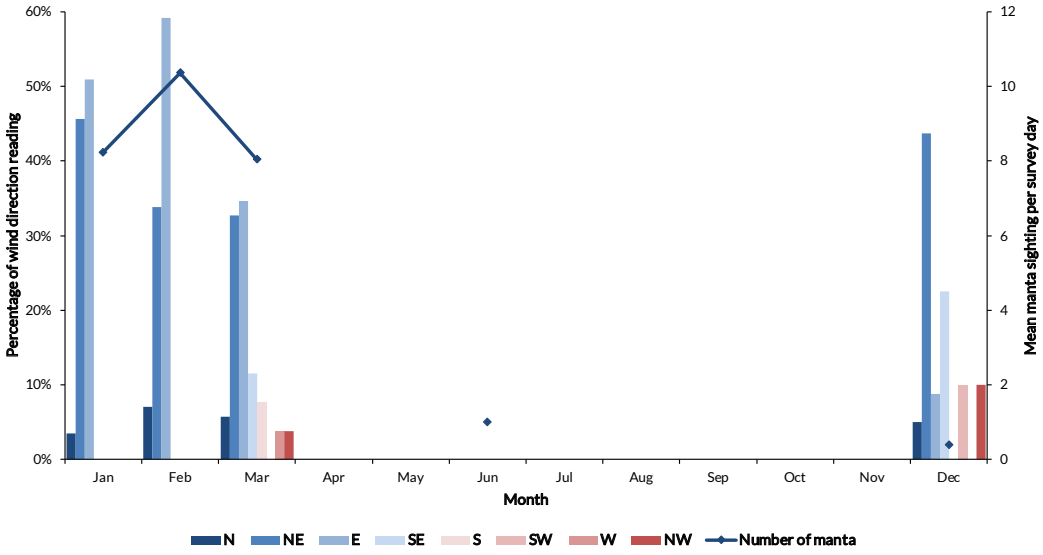


Figure 28: Monthly breakdown of the percentage of Raa Atoll wind direction readings from the online weather forecast platform Windguru, and the average number of reef manta ray *(Mobula alfredi)* sightings per survey day (2020).

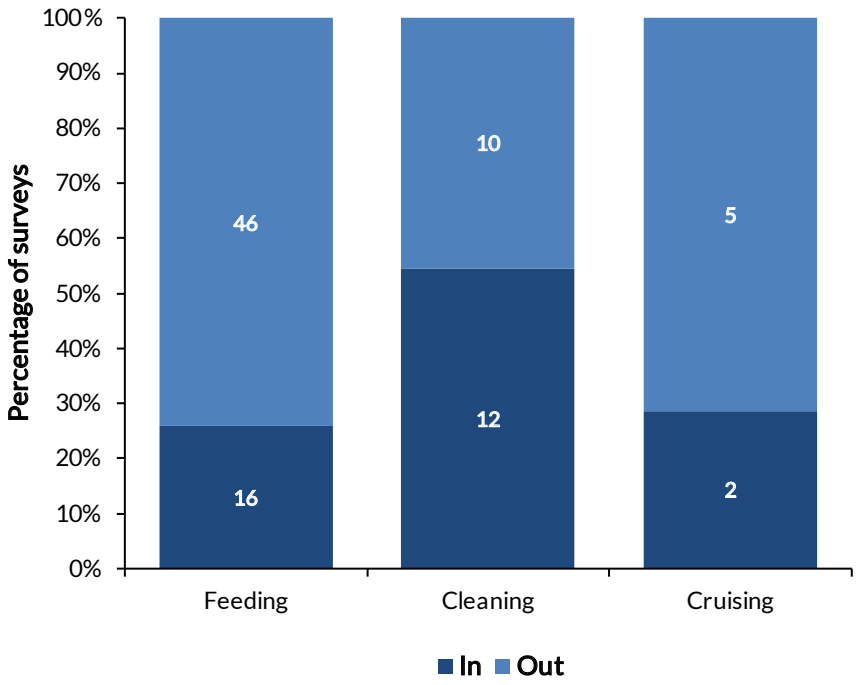


Figure 29: Changes in the behavioural activities of reef manta rays *(Mobula alfredi)* in relation to current direction (In, Out) through the channels in Raa Atoll during surveys (2020) where manta rays were observed (*n*=137).

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. Virtually all manta ray sightings in Raa Atoll are of reef manta rays, with no recorded sightings of an oceanic manta ray in 2020. To date, there is only one recorded sighting of an oceanic manta ray in Raa Atoll, which was recorded in 2017 during the Northeast Monsoon at Sola Corner, an outer reef feeding, and cleaning site, commonly frequented by reef manta rays.

Whale sharks *(Rhincodon typus)* are another species of large, filter-feeding elasmobranch, with similar life history characteristics and overlapping habitat use to reef manta rays in the Maldives. The Maldives Whale Shark Research Programme (MWSRP) monitor the Maldives whale shark population, using photos and videos of a whale shark's unique spot pattern to identify individuals. Whale shark sightings are uncommon in Raa Atoll, with no confirmed photo-ID sightings recorded to date.

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 a total of 13 resorts in operation, one of which opened in 2020. 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 2020 showed that, on average, 1.3 boats were present per survey (including the MMRP research boat) (Fig. 30), and an average of 3.9 snorkellers and divers per survey (Fig. 31). In general,

there were more snorkellers (*n*=953) than divers (*n*=248) recorded in 2020 (Fig. 32). Fifty-four percent (*n*=510) of the snorkellers recorded in 2020 were utilising the Maamunagau sub-regional sites. These findings are almost identical to those recorded in 2019, suggesting that a consistent level of tourist operators utilise the reef manta ray aggregation sites for guest activities within Raa Atoll. Continued monitoring by the MMRP at these sites aims to assess the effects tourism is having on the manta ray population and their habitats in the region, and to ensure that tourism practices continue to be sustainably managed.

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.

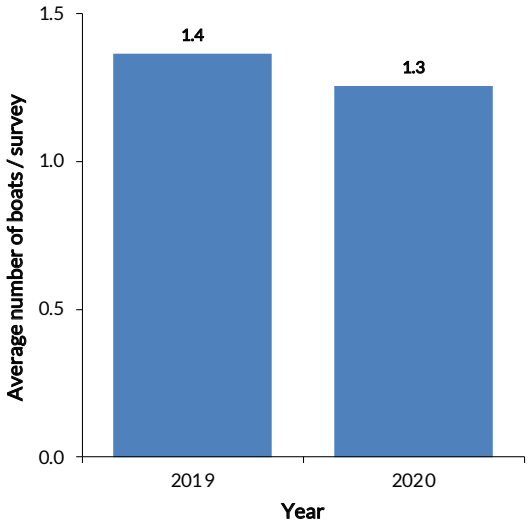


Figure 30: Mean number of marine vessels recorded per survey (*n*=547) in Raa Atoll.

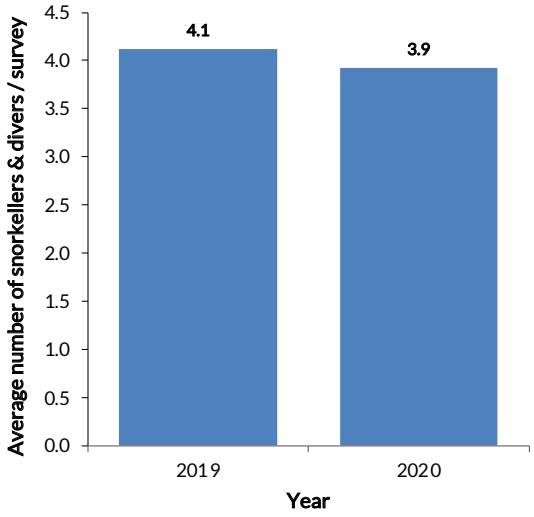


Figure 31: Mean number of snorkellers and divers per survey (*n*=547) in Raa Atoll.

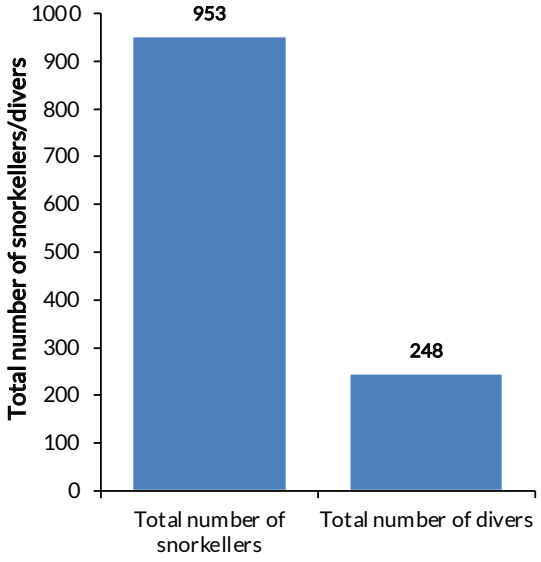


Figure 32: Total number of snorkellers and divers recorded in Raa Atoll (2020).

MANAGEMENT CHANGES & INITIATIVES

The Maldives' government have not designated any new MPAs within Raa Atoll since 1999. To date, only one MPA exists in Raa Atoll. Situated in south-western corner of the atoll, Villingilee Thila (also known as Fenfushi Giri) was designated protection in 1999. No manta ray sightings have been recorded within this MPA. However, the size of the protected area is extremely small (2.7km^2), and manta rays have been recorded feeding just north of the MPA at Fenfushi Faru. In addition, 1.5km south of the MPA sits the Maamunagau sub-region, recognised as one of the key manta aggregation sites in Raa Atoll, with particular importance for juvenile reef manta rays that utilise Maamunagau as a nursery feeding ground. Although the designation of this existing MPA is important, it is currently only protected on paper. If manta rays are to continue to flourish in the Maldives, it is urgently required for the MPA to be significantly expanded to encompass the entire Maamunagau sub-region, and for effective management plans to be created, implemented, and enforced. Such an MPA would help to mitigate the negative impacts of increasing tourism numbers in Raa Atoll, in particular the pressures on the juvenile reef manta ray population within Maamunagau. In the meantime, 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

INTERCONTINENTAL HOTELS & RESORTS

INTERCONTINENTAL MALDIVES MAAMUNAGAU RESORT

As our primary supporter in Raa Atoll, the InterContinental Maldives Maamunagau Resort has been incredibly supportive of the Manta Trust and MMRP. We hope this partnership continues to prosper for years to come.

EPA

MARINE RESEARCH CENTRE

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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