Manta TRUST

Maldivian Manta Ray Project

LHAVIYANI ATOLL | ANNUAL REPORT 2021

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 29 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 manta rays, 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 more than a dozen MMCP staff based across a handful of atolls, on both resort islands and local islands.

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 MMCP has identified over 5,500 different individual reef manta rays, from more than 80,000 photo-ID sightings. This makes the Maldives manta population the largest, and one of the most intensively studied populations in the world. The MMCP has also identified more than 830 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 fifth of its kind in a series that presents data collected by the Manta Trust's Maldivian Manta Ray Project (MMRP) on Lhaviyani Atoll's reef manta ray (*Mobula alfredi*) population from January to December 2021.

Reef manta rays are sighted in Lhaviyani Atoll year-round but are recorded more frequently toward the end of the Southwest Monsoon (Oct - Nov) and during the Northeast Monsoon (Jan – Apr). During these months, favourable environmental conditions created by the monsoon winds generate an abundance of phytoplankton and zooplankton, which in turn, influences manta ray abundance locally.

The MMRP collected reef manta ray surveys on 227 days throughout 2021. Key findings of the MMRP in Lhaviyani Atoll during 2021 include a total of 220 sightings of 104 different manta rays. Of these individuals, each manta ray was observed 2.1 times on average. The mean daily number of reef manta ray sightings for 2021 was 0.97, with peaks in daily manta ray sightings seen during the months of January, February, and April. A Residency Index (RI) was calculated to gauge the extent of movement amongst those frequenting the region. The RI for 2021 (0.49) was lower than all other survey years, owing to increased number of surveys collected in 2021 (*n*=433).

As of 2021, the population demographics of Lhaviyani Atoll comprises 51% females (*n*=226), 47% males (*n*=213), and 2% (*n*=10) of individuals for which the sex could not be determined. Overall, 51% (*n*=227) of individuals are adults, 4% (*n*=17) sub-adults, 45% (*n*=203) juveniles, and the maturation stage for the remaining 0.4% (*n*=2) of the population could not be determined. Of these Lhaviyani Atoll manta rays (*n*=449), 82% (*n*=369) have been re-sighted and 41% (*n*=183) have been seen in at least one other geographical atoll in the Maldives.

Of the 210 new reef manta rays added to the MMRP database from across the Maldives in 2021, 8% (*n*=16) were documented in Lhaviyani Atoll, which is a slight increase from the previous year (*n*=10, in 2020). The number of pregnancies recorded in Lhaviyani Atoll during 2021 was the same as in 2020 (*n*=1), with just one pregnancy recorded. This female was estimated to be in the 2nd trimester of pregnancy.

Efforts to conserve the natural heritage of Lhaviyani Atoll and manage the increasing human impacts upon the environment are encouraging, providing much to look forward to in 2022 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. Manta rays are an incredibly important economic resource for the Maldives, bringing tens of thousands of people to the country each year to dive and snorkel with them 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 PERIOD & SAMPLING METHODOLOGY

Manta ray sightings data in Lhaviyani Atoll was collected by both regional 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 identification (photo-ID) of an individual manta ray on a given day at a specific location (survey site). Surveys were conducted in-water, both on SCUBA and via snorkelling, with sightings recorded at 41 different sites across all years.

During each survey performed by MMRP researchers, individual manta ray sightings were documented via photo-ID, and data on the location, manta ray numbers, and predominant behaviours were recorded. Details on 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) were also noted during each survey. Surveys were collected on all trips, regardless of whether manta rays were sighted or not.

Between 2004 and 2016, prior to the establishment of a full-time MMRP researcher in Lhaviyani Atoll, data on manta ray sightings were collected mostly through citizen science. Tour guide operators, dive instructors and tourists would look for manta rays on both full and half day surveys. These surveys were also conducted in-water on SCUBA, or while snorkelling. Prior to 2010, only surveys resulting in a confirmed manta ray photo-ID sighting were recorded. It is unknown how many surveys were conducted annually prior to 2010. However, thereafter all data has been standardised for survey effort where possible to produce comparable results between, and within, years.

2021 Study Period

During 2021, Manta Trust researchers conducted a total of 160 survey trips on as many days that conditions and logistical operations allowed (*n*=133), at 28 different sites. Four of these sites have been classified as key aggregation sites due to higher numbers of individual manta rays sighted in these locations across study years (Fig. 1).

Data was primarily collected by a Manta Trust researcher who was based at Hurawalhi Resort throughout the year. In addition to MMRP survey data, this report utilises data from a further 273 surveys which were undertaken and submitted by external contributors, which include local non-governmental organisations (NGOs), resort dive and water sports staff, as well as citizen scientists. With a total of 433 surveys across 51 sites from Manta Trust and outside submitters combined, 2021 had the highest survey count in the atoll since records began (Fig. 2). Overall, manta rays were sighted on 77% (*n*=333) of all survey trips (*n*=433), and ID photographs collected on 22% (*n*=97) of survey trips.

Survey effort was high across a range of manta aggregation sites in Lhaviyani at the start of 2021. From January until April, survey effort focused on the western Lhaviyani Atoll manta aggregation sites which are all known to be manta ray feeding areas, including Dhanifaru (*n*=44), Felivaru Thila (*n*=31), Kanifushi Falhu (*n*=26), Thin' Gaa (*n*=28), and Veligadu Falhu (*n*=26). Fushifaru Kandu, a key cleaning and feeding site in the northeast of Lhaviyani Atoll, was also visited on 42 survey trips during the first quarter. Survey effort was relatively low between May and August, which coincided with the Southwest Monsoon. From September until December, survey effort focused more heavily on Fushifaru Kandu, which was visited on a total of 106 survey trips. Survey effort was also directed towards manta aggregation sites on the western side of the atoll in November and December to coincide with the return of the Northeast Monsoon, including Dhanifaru (*n*=27), Kanifushi Falhu (*n*=19), and Thin' Gaa (*n*=17).

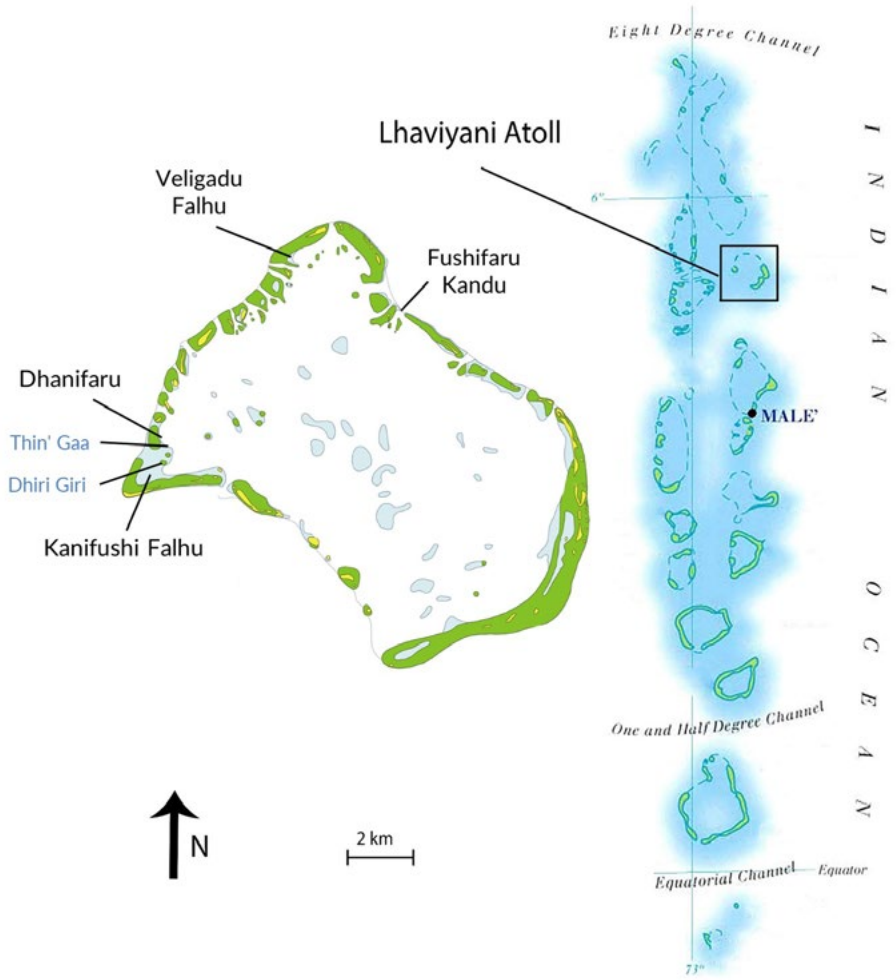


Figure 1: Map of Lhaviyani Atoll, four key reef manta ray (*Mobula alfredi*) aggregation sites (black), and two secondary sites which accounted for a large number of sightings in 2021 (blue). Also shown is Lhaviyani Atoll (black box) in relation to the rest of the Maldives Archipelago.

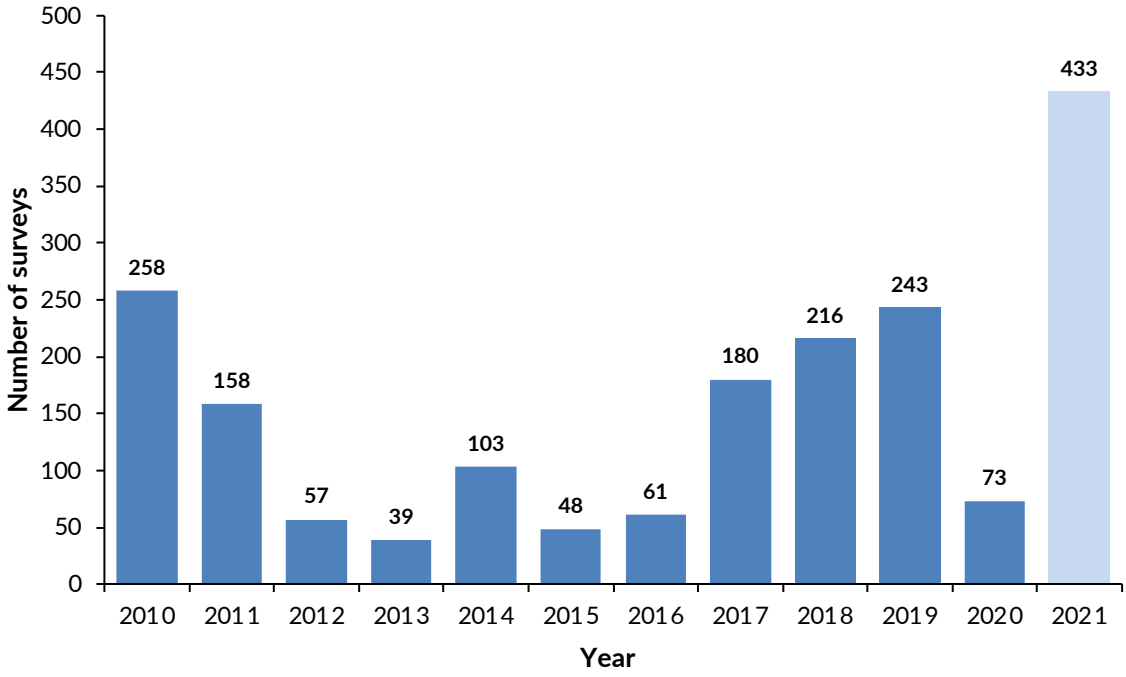


Figure 2: Number of surveys conducted annually in Lhaviyani Atoll.

REEF MANTA RAY POPULATION & SIGHTING TRENDS

Sightings

A total of 2,227 reef manta ray sightings have been recorded in Lhaviyani Atoll between 2004 through 2021, with 1.4 manta rays sighted per survey on average between 2010 and 2021 (when survey data was recorded) (Fig. 3). In 2021, there were 220 sightings of 104 different reef manta ray individuals in Lhaviyani Atoll (Fig. 3); this was a marked increase in sightings compared to the previous year (2020), when the global pandemic halted research activities for eight months.

While there is a certain degree of inter-annual variation across all study years, a general trend in sightings throughout the year can be observed. Sightings in Lhaviyani Atoll tend to peak annually during the months of January to March, then decrease between April and September, followed by a second peak during the months of October to December (Fig. 4). Reef manta ray sightings in 2021 followed a similar trend at the start of the year, peaking in January, February, and April (Fig. 5) to coincide with the Northeast Monsoon. Sightings were low throughout the Southwest Monsoon months of May to September, as expected, but failed to exhibit a second peak at the return of the Northeast Monsoon, with sightings remaining uncharacteristically low throughout October to December (Fig. 5).

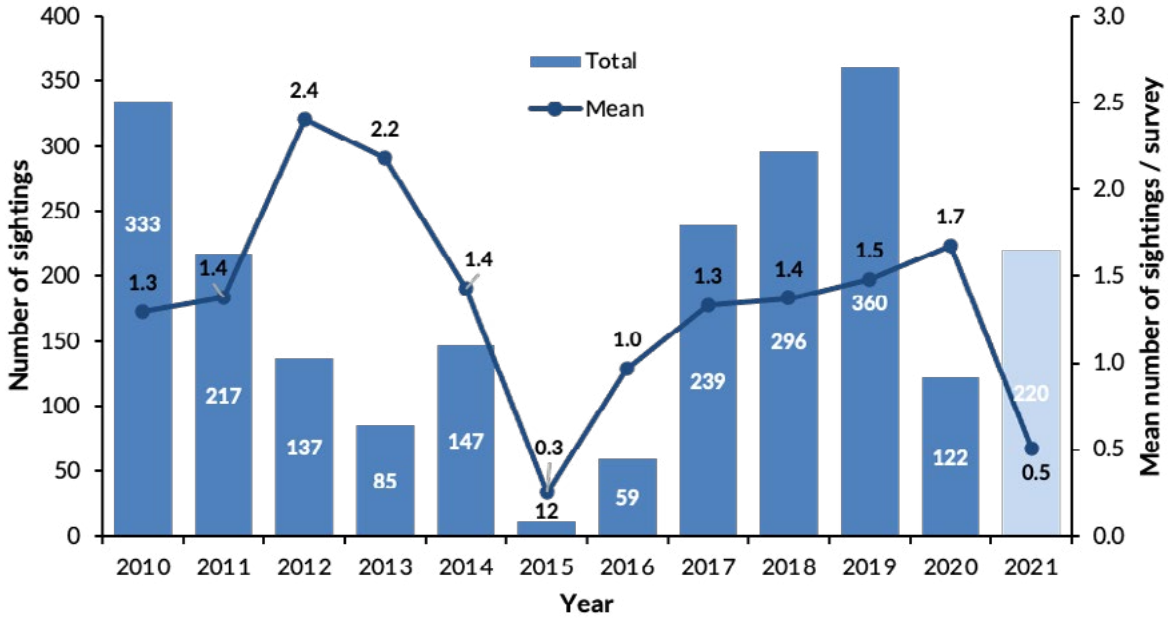


Figure 3: Total annual sightings of reef manta rays (*Mobula alfredi*) in Lhaviyani Atoll, and the mean number of sightings per survey.

The seasonally observed sighting peaks reflect intra-annual variation in site use by reef manta rays around Lhaviyani Atoll. Movements of manta rays around Lhaviyani Atoll are largely influenced by the monsoons of the Maldives (seasons), which drive productivity and, ultimately, variation of manta rays' zooplankton food source in different locations throughout the year. Four key aggregation sites have been previously identified as having the highest number of sightings across study years (2004 – 2021); Fushifaru Kandu, Veligadu Falhu, Dhanifaru, and Kanifushi Falhu (Fig. 1).

In 2021, sightings peaked at the western aggregation sites of Dhanifaru in January and April, at Veligadu Falhu in February, and (to a lesser extent) Kanifushi Falhu in March (Fig. 6). It seems that manta rays sighted at these three locations took advantage of localised abundances in zooplankton, as the majority of individuals were recorded

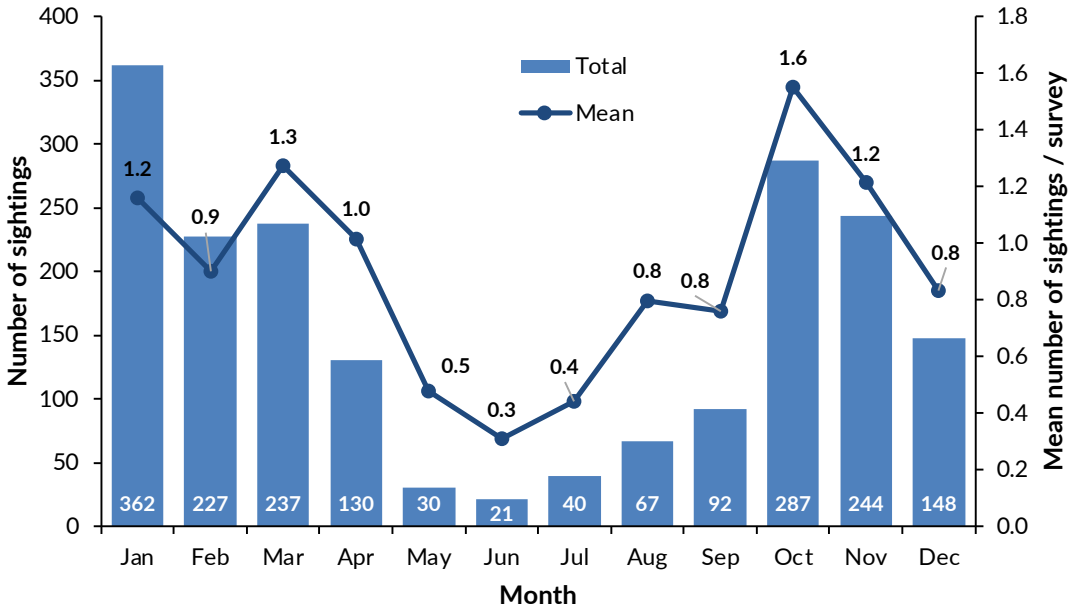


Figure 4: Total monthly sightings and mean number of sightings per survey of individual reef manta rays (*Mobula alfredi*) recorded in Lhaviyani Atoll (2010 – 2021).

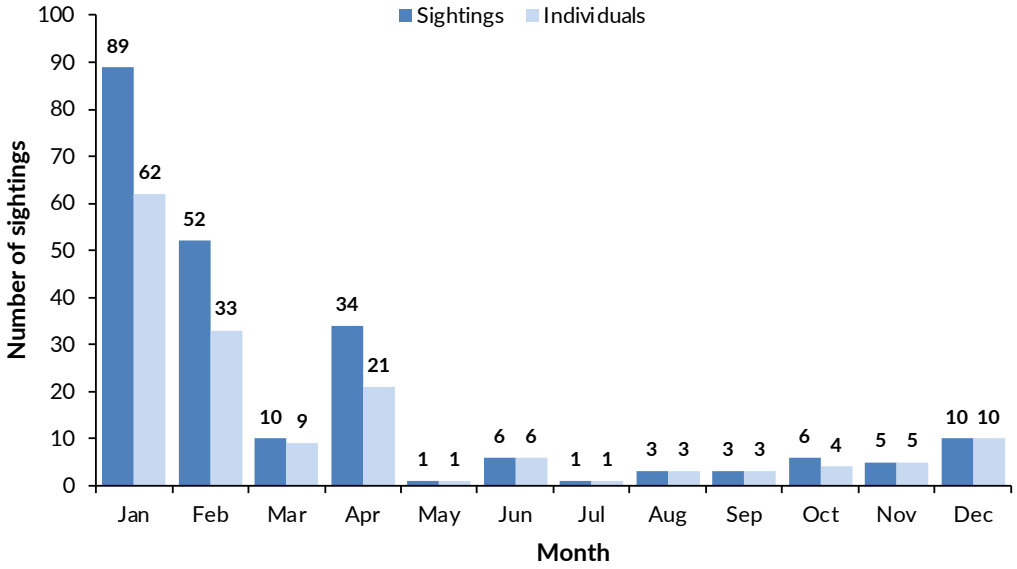


Figure 5: Total monthly sightings and the number of individual reef manta rays (*Mobula alfredi*) recorded in Lhaviyani Atoll (2021).

while feeding. Visitations to these three sites coincided with the Northeast Monsoon, which drives productivity and food availability in the western areas of atolls within the Maldives between December and March each year. The high number of sightings during April here suggests that the Northeast Monsoon may have ended later than usual in 2021.

On the eastern side of Lhaviyani Atoll, sightings peaked at Fushifaru Kandu in January and February (*n*=20) (Fig. 6), when all manta rays were observed cleaning. Manta ray sightings were uncharacteristically low throughout Lhaviyani in the latter months of 2021, however, of the few manta rays that were sighted between September and November (*n*=14), all but one were recorded at Fushifaru Kandu (*n*=13). Of these, ten were recorded as feeding, and three were cleaning. This activity coincided with the end of the Southwest Monsoon, which drives increased food availability in the eastern areas of atolls within the Maldives between May and October each year. Further, towards the end of the season and during the transitional period between the Southwest and Northeast Monsoons, it is typical for manta rays throughout the Maldives to engage in increased cleaning, courtship, and mating activity, with cleaning stations acting as a focal point for these behaviours.

Across all sites, Fushifaru Kandu accounted for the highest number of reef manta ray sightings in Lhaviyani Atoll in 2021 (*n*=34), followed by Dhanifaru (*n*=31), while 21 sightings were recorded at Veligadu Falhu, and 14 at Kanifushi Falhu (Fig. 7). Interestingly, there were also many sightings recorded at Thin' Gaa (*n*=27) and Dhiri Giri (*n*=16) (Fig. 7), two sites located in the western corner of Lhaviyani, in close proximity to Dhanifaru and Kanifushi Falhu (Fig. 1). While Thin' Gaa hosts a small manta cleaning station, most of the manta rays recorded there (*n*=25), and all of those recorded at Dhiri Giri (*n*=16), were engaged in feeding activity. This is unsurprising, as manta ray visitation to these sites predominantly occurred between January and April, when the Northeast Monsoon drives productivity on the western side of the atoll. Thin' Gaa and Dhiri Giri will continue to be monitored throughout 2022 to allow us to assess the reliability of these locations as manta ray aggregation sites. Deployment of underwater cameras at Thin' Gaa cleaning station may help us to gain better understanding of its potential importance for cleaning activity; it is possible that manta rays may opportunistically visit this cleaning site due to its proximity to two of Lhaviyani Atoll's key feeding areas, but that previous survey efforts failed to detect this.

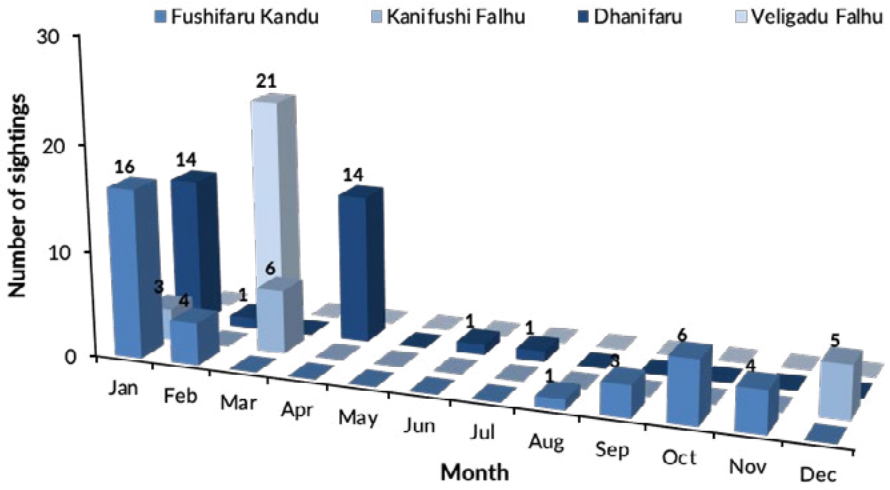


Figure 6: Monthly sightings of reef manta rays (*Mobula alfredi*) at four key aggregation sites in Lhaviyani Atoll (2021).

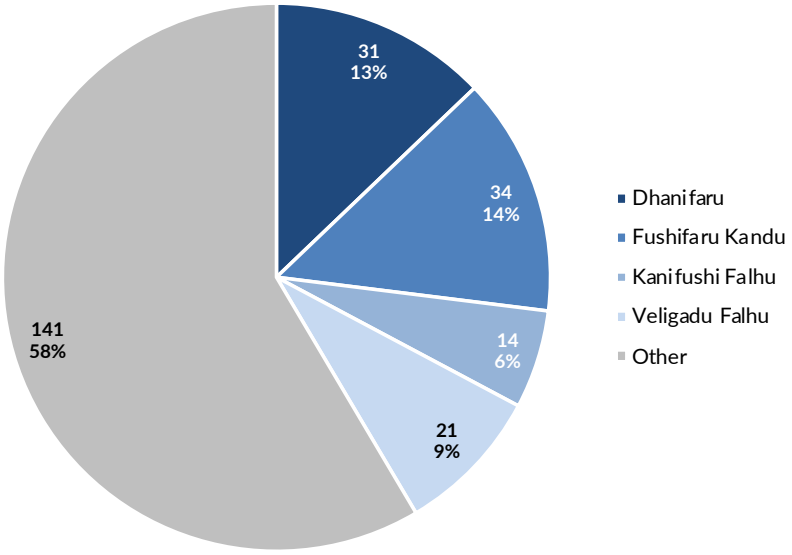


Figure 7: Proportion of total reef manta ray (*Mobula alfredi*) sightings (*n*=220) at different sites in Lhaviyani Atoll (2021).

Population Demographics

During 2021, 25 new reef manta rays were identified in Lhaviyani Atoll, bringing the total recorded population to 449 individuals. The sex ratio of this population is almost even, with 51% females (*n*=226) and 47% males (*n*=213), while sex could not be determined for the remaining 2% of individuals (*n*=10). Age demographics are similarly even; adults account for 51% of the population (*n*=227), 45% are juvenile (*n*=203), and 4% are considered subadult (*n*=17), while maturity could not be determined for the remaining 0.4% of individuals (*n*=2) (Fig. 8). Maturity 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 was 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. All other individuals were classified as juveniles or subadults.

Overall, 70% (*n*=313) of the atoll's population have been sighted more than once in Lhaviyani, and 82% (*n*=369) have been re-sighted either in Lhaviyani or elsewhere in the Maldives. This suggests that most reef of the manta rays that frequent this region have now been discovered.

The proportion of newly sighted individuals increased from 2020 to 2021 (Fig. 9), accounting for 24% (*n*=25) of individuals sighted, compared to 16% (*n*=13) the previous year. This result contrasts with the downward trend in newly sighted individuals that has been evident in recent years; however, this increase may be due to the very high number of surveys conducted in 2021, particularly in comparison to 2020 when research activities were severely limited due to the Covid-19 pandemic. Dhanifaru was the location which accounted for the largest proportion of manta rays which were new to Lhaviyani's population in 2021, with six individuals sighted for the first time there. The remaining 19 manta rays were sighted for the first time across 15 different sites. Of the 25 new manta rays, 16 individuals had never before been recorded by the Manta Trust, while the remaining 9 had been sighted elsewhere in the Maldives previously. Of the manta rays that were previously unrecorded, none were estimated to be pups born that year.

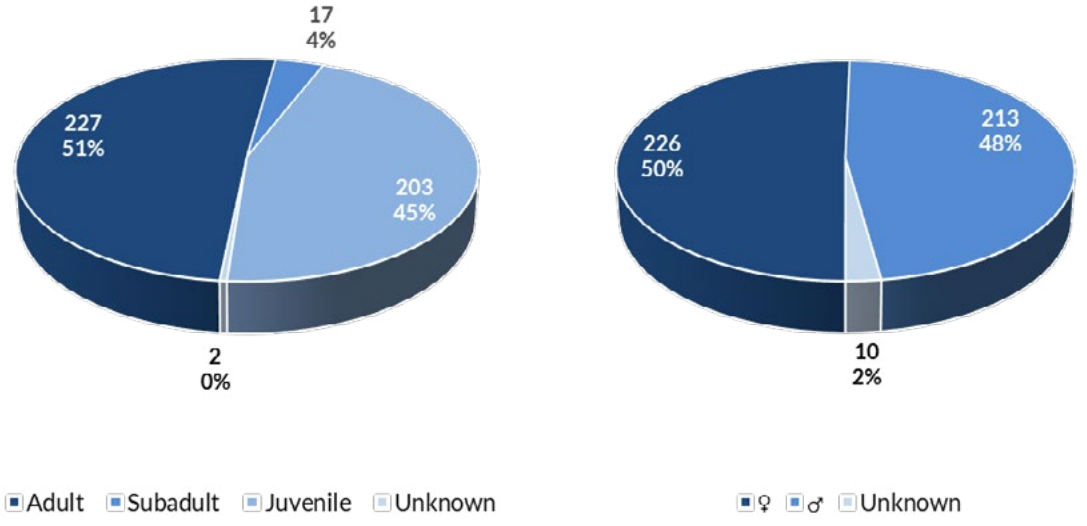
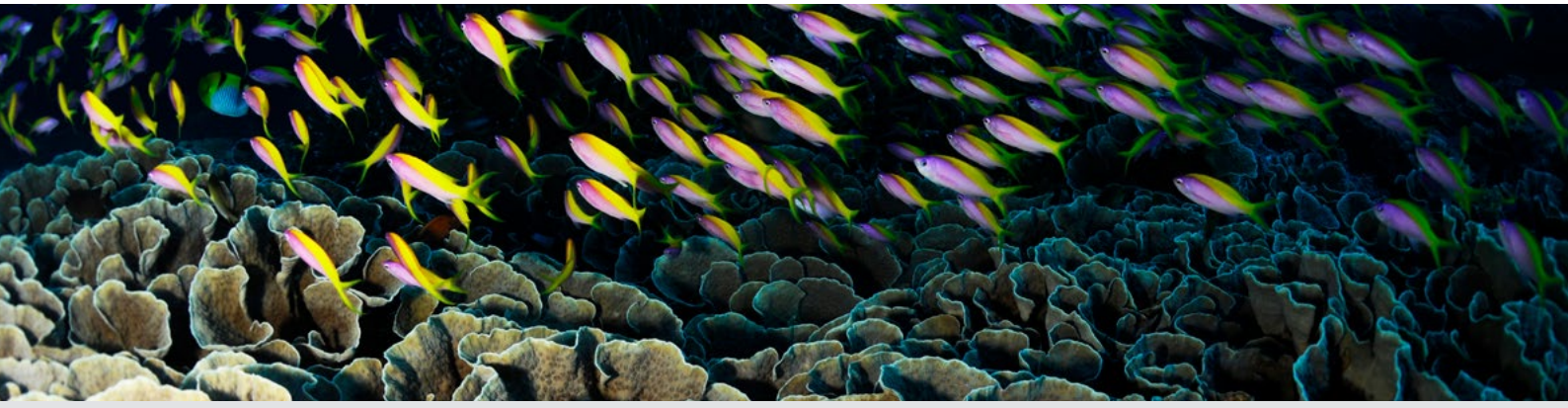


Figure 8: Demographics of the total Lhaviyani Atoll reef manta ray (*Mobula alfredi*) population (*n*=449).



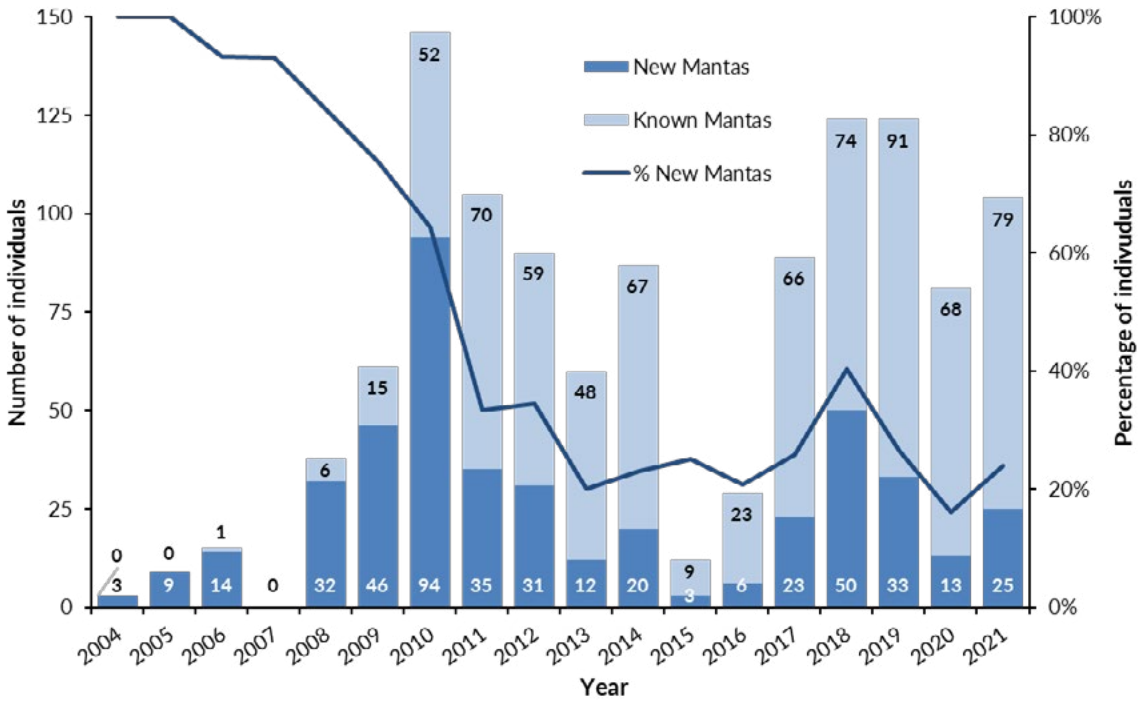


Figure 9: Total number of reef manta rays (*Mobula alfredi*) sighted annually in Lhaviyani Atoll, and the number and percentage of individuals which were newly recorded.

Migrations & Residency

Of the 449 reef manta rays that have been sighted in Lhaviyani Atoll across all study years, 41% (*n*=183) have been recorded by the MMRP in other atolls across the Maldives. Naturally, inter-atoll migrations are most common between atolls which are geographically closest to Lhaviyani Atoll. As of 2021, 116 individuals in the Lhaviyani population have been recorded in Baa Atoll, 37 in Raa Atoll, 31 in Thiladhunmathi Atoll, 23 in Ari Atoll, and 20 in North Malé Atoll (Fig. 10). Each manta ray sighted within the Lhaviyani Atoll population tends to exhibit strong site fidelity, with 88% of individuals only recorded in one (*n*=266) or two (*n*=128) atolls (Fig. 11).

In 2021, individual reef manta rays were sighted 2.1 times each on average and 48% of the recorded population was sighted more than once (Fig. 12). When survey effort is accounted for, the residency index (RI) indicates that each manta ray was recorded on 0.5% of total surveys in 2021, the lowest index recorded across all study years (Fig. 13). The low residency index of manta rays in Lhaviyani in 2021 is likely the result of very high survey effort that year (owing to the large number of external submitter surveys which were included in the dataset), as RI is inversely correlated with number of surveys (Fig. 14). In years with comparable survey effort, a low residency index is a reflection of more transient behaviour, with manta ray movements likely dictated by more favourable conditions elsewhere.

Within Lhaviyani Atoll, fidelity of reef manta rays to different aggregation sites varies between individuals. Four key hotspots have been identified (as described previously): Dhanifaru and Kanifushi Falhu (both sheltered lagoons to the west of the atoll), Fushifaru Kandu (a key cleaning station to the northeast), and Veligadu Falhu (an elongated sandbank to the northwest). Of the manta rays that frequent these four key sites (*n*=394), 52% (*n*=203) have been recorded at one of the locations only, indicating variation in site preference among individuals. Indeed, these sites appear to be utilised by different age and sex demographics within the population (Fig. 15). Across study years, Dhanifaru and Kanifushi Falhu were visited by a relatively large proportion of juvenile manta rays, which may be because young individuals tend to prefer more sheltered lagoon areas. Meanwhile, most of those individuals recorded at Fushifaru Kandu and Veligadu Falhu were adults. Interestingly, Veligadu Falhu was favoured by males (61%), whereas 58% of individuals sighted at Fushifaru Kandu were female. The preference of mature manta rays, and of female manta rays, to Fushifaru Kandu is unsurprising given that adults commonly visit cleaning

stations which act as focal points for courtship activity and are typically dominated by females which invest more time in cleaning than males.

Overall, these findings highlight the importance of surveying across different sites and support the protection of multiple areas around the atoll in order to protect different demographics of reef manta rays and their habitats. Of the four key sites described, only Fushifaru Kandu is currently designated as a marine protected area (MPA), with protective legislation banning fishing in 1,400 ha of the surrounding area. However, there is no enforcement or monitoring of regulations in this area, and it is not made clear what the guidelines are for this specific area. In December of 2017, a proposal for the creation of two new MPAs at Veligadu Falhu and Dhanifaru was presented to the Lhaviyani Atoll Council by a MMRP researcher in collaboration with Naifaru Juvenile, another local NGO. The proposal was unsuccessful; however, before moving to create new MPAs within Lhaviyani Atoll, it is necessary that regulations are being enforced and monitored in existing protected areas.

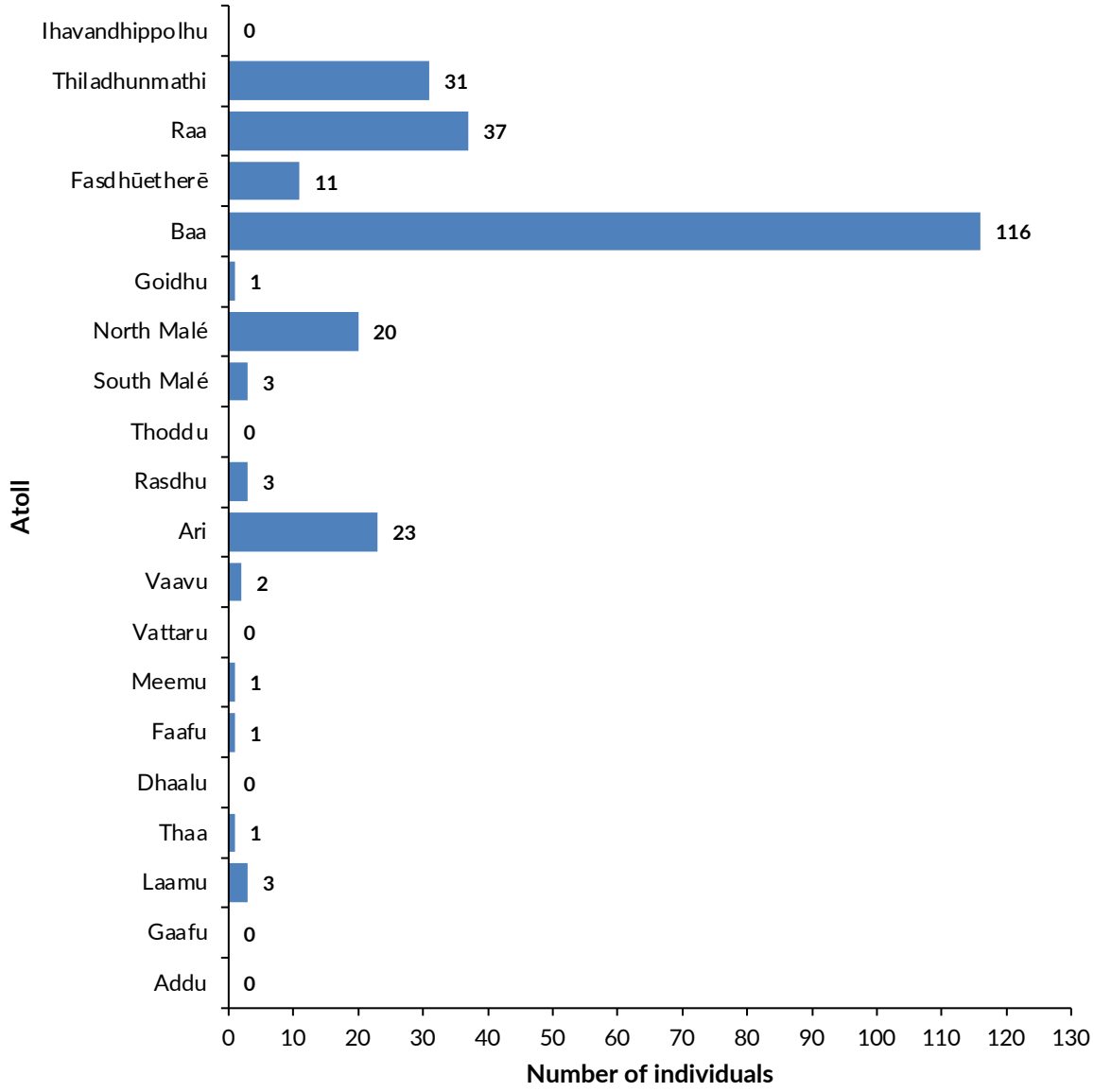


Figure 10: Number of reef manta rays (*Mobula alfredi*) (*n*=183) from within the Lhaviyani Atoll population (*n*=449) which have been recorded in other atolls throughout the Maldives Archipelago. Note — some individuals have been sighted in more than one atoll outside Lhaviyani Atoll.

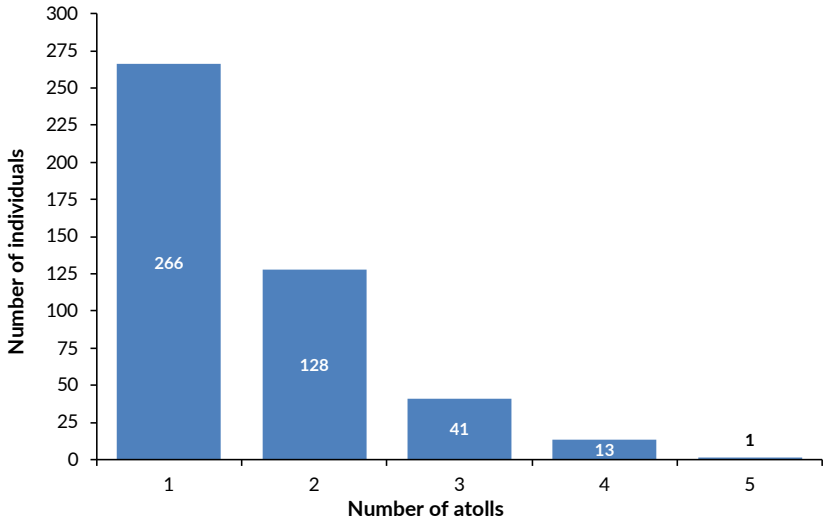


Figure 11: Number of geographical atolls each individual reef manta ray (*Mobula alfredi*) in the Lhaviyani Atoll population (*n*=449) has been recorded in.

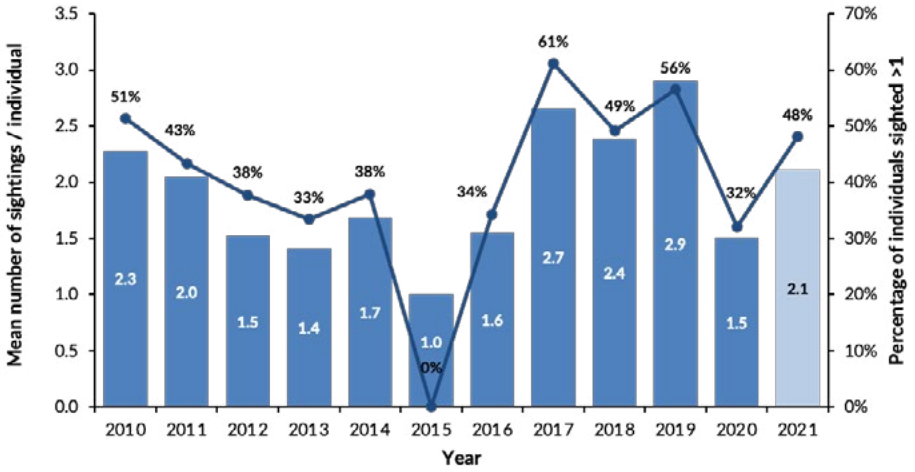


Figure 12: Mean number of sightings per individual reef manta ray (*Mobula alfredi*) in Lhaviyani Atoll, and the percentage of individuals sighted on multiple occasions during the same year.

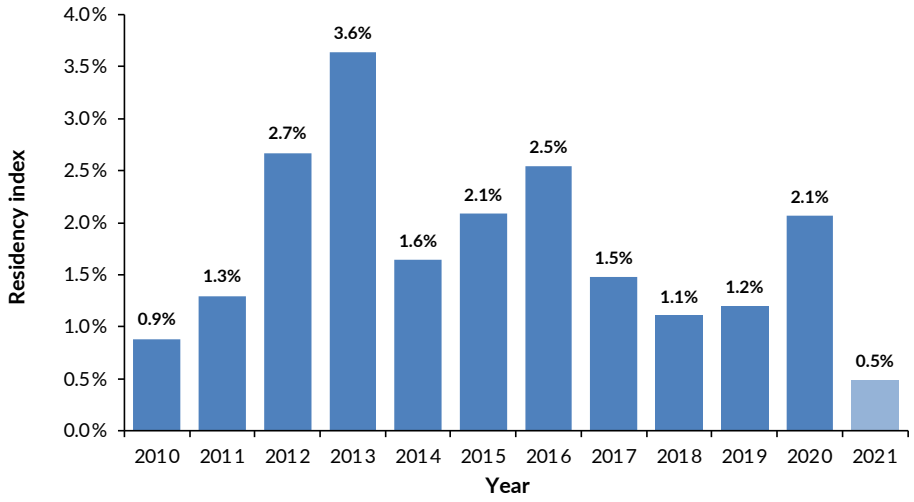


Figure 13: Annual Residency Index (RI) of reef manta rays (*Mobula alfredi*) in Lhaviyani Atoll. RI is calculated as the average of each individuals' residency (number of times sighted annually divided by the total number of surveys).

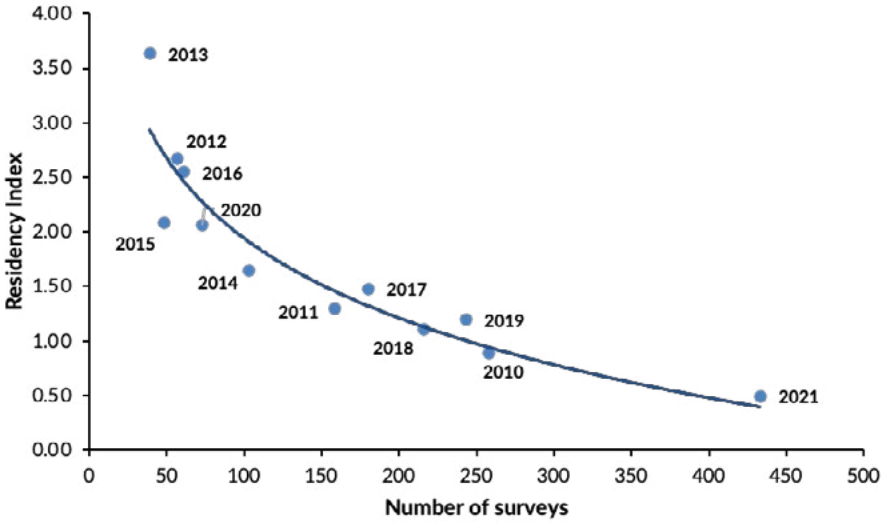


Figure 14: Relationship between the number of surveys conducted and the Residency Index of reef manta rays (*Mobula alfredi*) recorded within a study year in Lhaviyani Atoll (2010 – 2021).

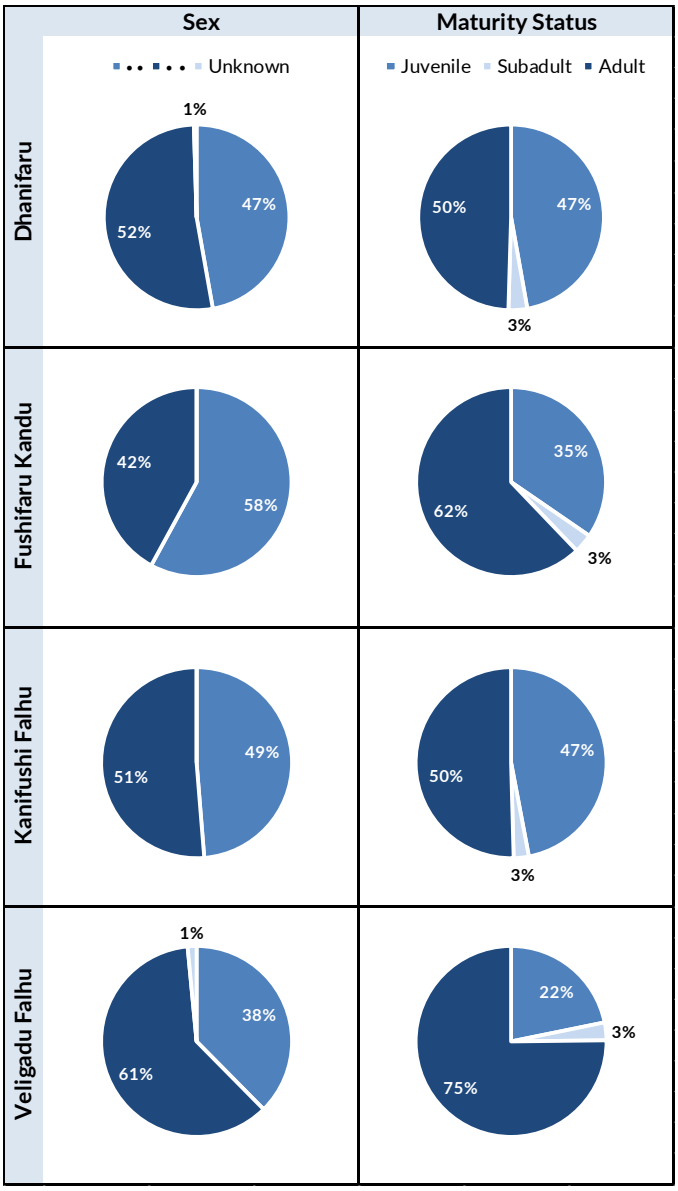


Figure 15: Demographics of the reef manta rays (*Mobula alfredi*) recorded at the four key aggregation sites in Lhaviyani Atoll (2004 – 2021).

Pregnancies & Courtship Observations

The Lhaviyani reef manta ray population comprises a total of 77 mature females, 11 of which were sighted during 2021. Of these, only one was observed pregnant (Fig. 16). On average, only 14% of mature females sighted annually between 2004 and 2021 have been observed pregnant, indicating very low fecundity within the population, which is consistent with reproductive rates of manta rays elsewhere in the Maldives. Indeed, of the 18 females that have been observed pregnant in Lhaviyani Atoll across the study period, only three individuals have been recorded pregnant more than once, two of which have been recorded pregnant in three different years (Table 1). Furthermore, there are very few records of courtship behaviour in Lhaviyani Atoll, with no courtship events documented in 2021.

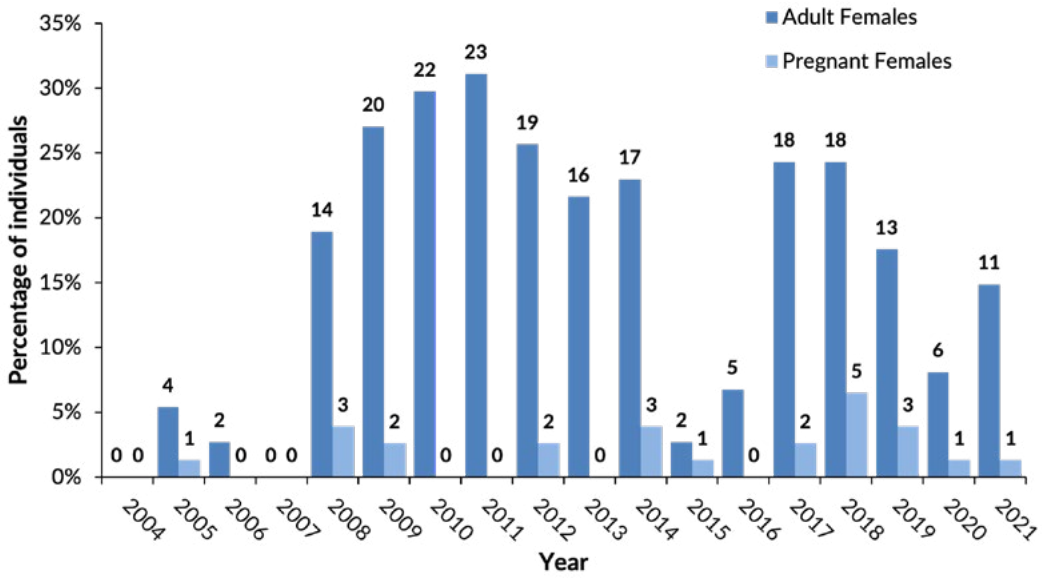


Figure 16: Percentage of Lhaviyani Atoll's adult female reef manta ray (*Mobula alfredi*) population (*n*=77) sighted annually, and the percentage of those females which were recorded pregnant in the same year. Actual numbers above bars.

Table 1: Annual sightings of 18 mature female reef manta rays (*Mobula alfredi*) in Lhaviyani Atoll which have been recorded as being pregnant. Years where the individual was observed as being pregnant are highlighted in dark blue. (*MV-MA-1975 was pregnant once, spanning from 2018 to 2019.)

ID	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
MV-MA-0040		1																
MV-MA-0041		1			4	2	8	4	6		2		2	6	15	12	2	7
MV-MA-0042		1			1				2	1	4			7	6			
MV-MA-0937					1	1	1	3	2		2			7	3	2	4	2
MV-MA-0939					1		2	2	1		3	1		6				
MV-MA-1090							1								1			
MV-MA-1184					1		1	2						2	1			
MV-MA-1185					1													
MV-MA-1186					2												1	
MV-MA-1412						1			1		1							
MV-MA-1419						2	2											
MV-MA-1421						1		3			4			6	3	7		3
MV-MA-1424						1	1	4	1									
MV-MA-1975								1		2				2	3	3*	1	
MV-MA-2798									2									
MV-MA-3161										1	1				4			
MV-MA-3162										1			1			2	1	
MV-MA-3233											1							
Total pregnant	0	1	0	0	3	2	0	0	2	0	3	1	0	2	5	3	1	1

Sub-lethal Injuries

During each photo-ID sighting, data on any injuries of the reef manta rays was also recorded. Within the Lhaviyani Atoll reef manta ray population, 64% (*n*=289) have no significant or permanent sub-lethal injuries, while the remaining 36% (*n*=160) have been recorded with sub-lethal injuries. Of those, 20 individuals had more than one injury. Over half (63%) of injured individuals in the Lhaviyani reef manta ray population have injuries from natural origins (*n*=100), 27% (*n*=43) have injuries caused by anthropogenic impacts, and 19% (*n*=30) of injured individuals have an injury for which the origin could not be clearly identified (Fig. 17). The sex ratio of injured individuals is evenly split between males (49.5%, *n*=79) and females (49.5%, *n*=79), with a further two (1%) injured individuals for which sex could not be determined. Adults accounted for 61% (*n*=97) of injured individuals, 4% were subadults (*n*=6), and 36% were juveniles (*n*=57).

Naturally caused injuries included deformity (*n*=5), and predatory bites (*n*=96). Injuries caused due to anthropogenic impact to manta rays included boat strikes (*n*=4), fishing line (*n*=38), and entanglement in fishing nets (*n*=1) (Fig. 18). Ghost nets and discarded fishing gear are regularly encountered in Lhaviyani Atoll, which may explain the large number of injuries caused by fishing lines in the region. Of the 160 manta rays recorded with injuries, 88% (*n*=140) had injuries inflicted upon their pectoral fins, 15% (*n*=24) on the tail and dorsal areas, 9% (*n*=14) on the cephalic fins, 3% (*n*=4) on the gill slits, and 4% (*n*=7) on the pelvic fins (Fig. 19).

In 2021, ten manta rays were recorded with new injuries in Lhaviyani Atoll. Of these, two had a naturally caused predator bite injury on their pectoral fin, and another had a fishing line injury on its pectoral fin. The injuries of the seven other manta rays were located on the pectoral fins (*n*=3), tail (*n*=2), pelvic fins (*n*=1), and dorsal surface (*n*=1), however the causes of these injuries could not be determined.

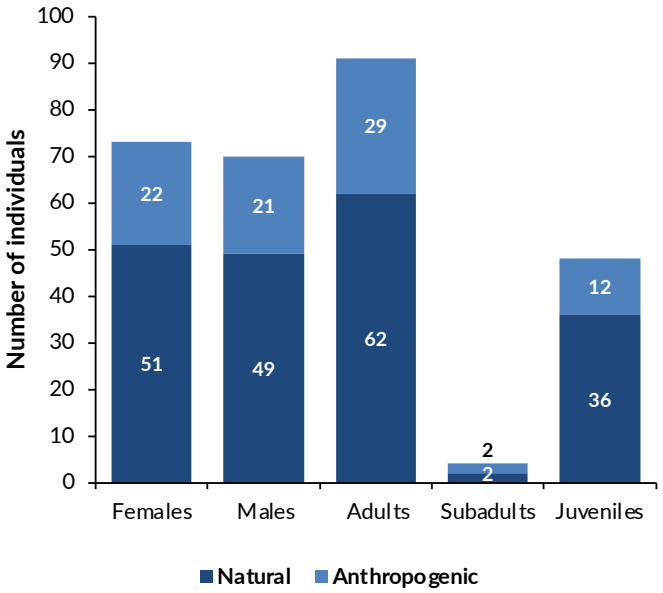


Figure 17: Demographic variations in the likely origin (natural or anthropogenic) of sub-lethal injuries within the injured reef manta ray (*Mobula alfredi*) population of Lhaviyani Atoll (*n*=160). Note — some individuals have more than one injury.

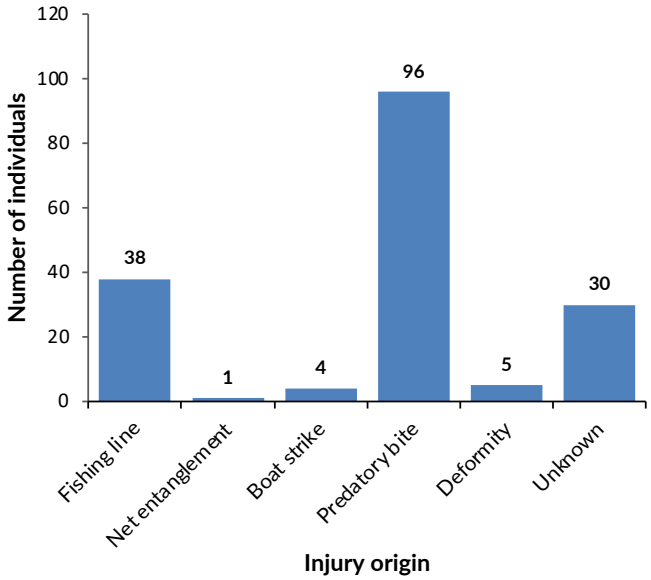


Figure 18: Variations in the origin of sub-lethal injuries within the injured reef manta ray (*Mobula alfredi*) population of Lhaviyani Atoll (*n*=160). Note — some individuals have more than one injury.

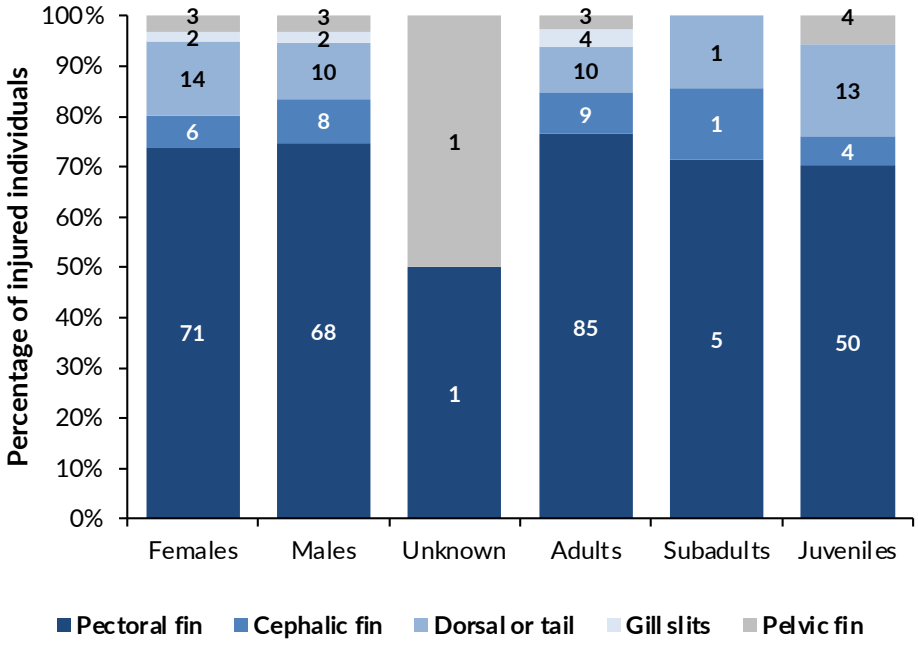
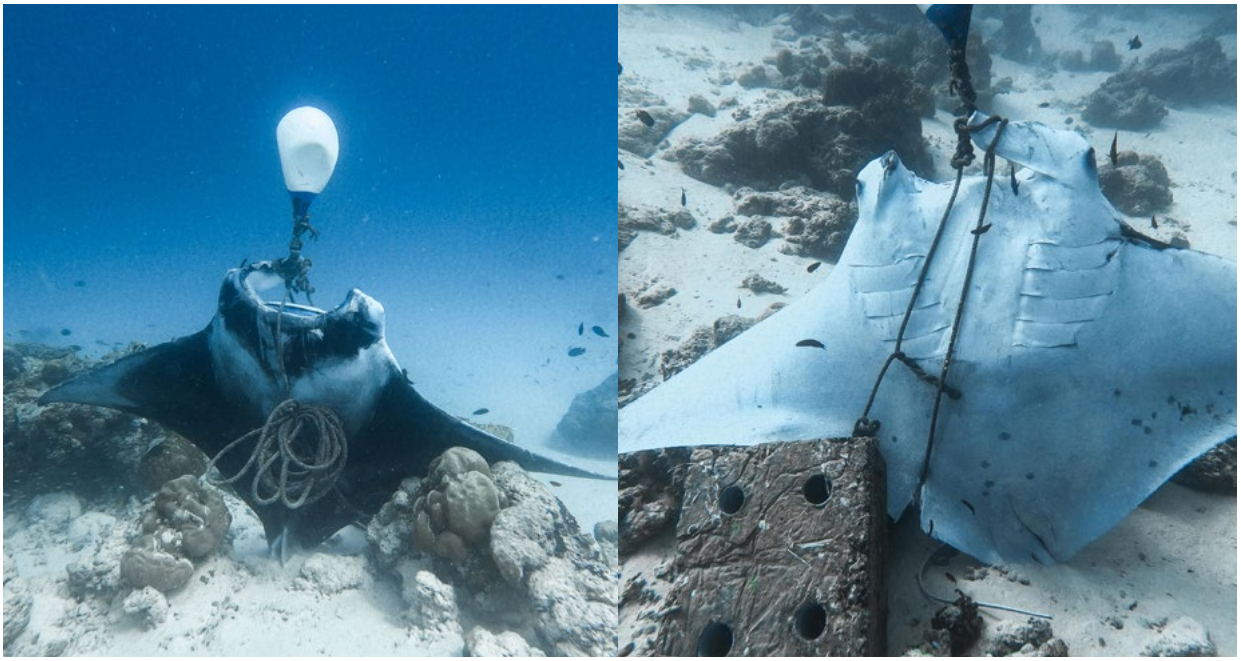


Figure 19: Variations in the location and number of sub-lethal injuries within the injured reef manta ray (*Mobula alfredi*) population of Lhaviyani Atoll (*n*=160) and their demographic variation. Actual number of individuals on bars.

Fatalities

Boat mooring and buoy lines have been widely used in the Maldives for decades. However, as the number of these lines greatly increases throughout the country due to tourism development, they are increasingly posing a serious threat to the reef manta ray population. Very sadly, one reef manta ray became entangled in such a mooring line in Lhaviyani Atoll in 2021. The mooring line in question was poorly configured, with a large amount of slack line in which the manta ray became entangled. Since manta rays are obligate ram ventilators and need to swim constantly to "breathe", the manta ray asphyxiated and died prior to being discovered. The individual was an adult male with a disc-width of approximately 280cm. This male was previously known to the MMRP database, first recorded in Lhaviyani Atoll in 2011, and given the name "Tambourine".

This tragic incident, and the similar fatality which occurred in Lhaviyani in 2018, have highlighted the importance of ensuring that all mooring and buoy lines in the Maldives are modified to reduce the risk of manta ray entanglements. To aid these efforts, the Manta Trust has developed a few simple action items which can be undertaken to help prevent future manta ray entanglements, and guidance on how to respond in the event of an entanglement. These can be found on the Manta Trust website (https://www.mantatrust.org/resources). The MMRP team based at Hurawalhi Island Resort have secured all mooring lines around the resort and have urged all resorts within Lhaviyani Atoll to do the same.



ENVIRONMENTAL VARIABLES

Within Lhaviyani Atoll, site use by manta rays appears to be linked to wind direction, which changes with the monsoons. Wind direction was recorded on 151 of the 160 surveys conducted by resident Manta Trust researchers in 2021, and on 159 of the 273 surveys conducted by external contributors. Notably, north-easterly monsoon winds accounted for the largest proportion of sightings at all four key manta ray aggregation sites in Lhaviyani Atoll: Dhanifaru (n=14), Fushifaru Kandu (n=17), Kanifushi Falhu (n=5), and Veligadu Falhu (n=21) (Fig. 20). Winds of the Northeast Monsoon drive upwelling and primary productivity on the outer edge of the atoll between December and March each year. When combined with tidal currents, this produces localised abundances of zooplankton within the western side of Lhaviyani during this time and drives manta ray feeding activity at the western aggregation sites (Dhanifaru, Kanifushi Falhu, and Veligadu Falhu). On the eastern side of Lhaviyani, manta rays sighted at Fushifaru Kandu during north-easterly winds were all observed cleaning (n=17); it is possible that manta rays took advantage of this nearby cleaning station between feeding events at the western sites.

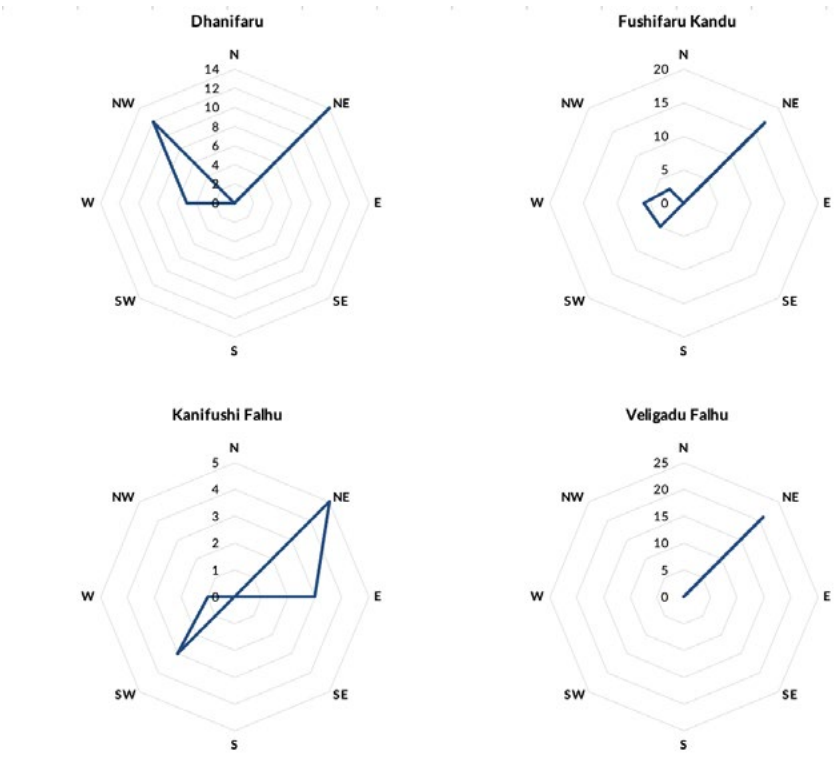


Figure 20: Total number of reef manta ray (*Mobula alfredi*) sightings in relation to prevailing wind direction at four key aggregation sites in Lhaviyani Atoll (2021). Data was obtained from surveys where wind direction was recorded (*n*=310).

TOURISM ACTIVITIES

The MMRP strive to improve the sustainability of manta ray tourism activities in Lhaviyani Atoll, and in 2021, the MMRP researchers continued to collect tourism related data within the region. On average, there were 1.5 boats recorded at each site visited (multiple sites may have been visited within a single survey trip), which was similar to boat numbers recorded in 2020 (1.6 per site). There was an average of 7.8 snorkellers recorded per survey trip in 2021, compared to 5.1 snorkellers per survey trip in 2020; this increase was likely due to the gradual recovery of tourism following the global pandemic (Fig. 21).

As manta ray excursions continue to become more popular with visitors to the atoll, MMRP researchers have continued to encourage sustainable tourism practices to be administered. During 2021, the MMRP team organised a series of informative presentations aimed at those leading swim-with-manta-ray tourism initiatives. The information sharing events provided education on manta ray biology, ecology, the history of the MMRP, the research the MMRP conducts in the Maldives, and the best Codes of Conduct (CoC) for interacting with manta rays in the water (https://swimwithmantas.org/). The aim was to provide marine users with the necessary tools to conduct sustainable manta ray tourism activities, in order to safeguard against negative ramifications of human-manta ray interactions and ensure the conservation of the Maldives manta ray population. The information sharing events were a success.

Beyond educating marine users it is crucial to the conservation of the Maldives manta ray population that there is improved monitoring of diver and snorkeller manta ray tourism activities at manta sites (and other protected areas) in Lhaviyani Atoll. Wide distribution of the CoC and the "How to swim with mantas" guidelines across all dive centres and liveaboard vessels that operate in Lhaviyani Atoll is becoming increasingly important, as new resorts and guest houses are opened and more tourists join manta excursions each year. All tourists who joined manta snorkel excursions or dives from Hurawalhi Resort in 2021 were properly briefed by the MMRP's Manta Trust researcher and/or the Prodivers staff on how to behave in water.

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.

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