Manta TRUST

Maldivian Manta Ray Project

NORTH & SOUTH MALÉ ATOLL | ANNUAL REPORT 2019

Conservation through research, education, and collaboration

- The Manta Trust

MALDIVIAN MANTA RAY PROJECT

WHO ARE THE MANTA TRUST?

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

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

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

MALDIVIAN MANTA RAY PROJECT

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

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

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

THE CONSERVATION CHALLENGE

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

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

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

EXECUTIVE SUMMARY

This report presents data collected by the Manta Trust's Maldivian Manta Ray Project (MMRP) on the reef manta ray (*Mobula alfredi*) population of North and South Malé Atolls in 2019. Data used in this report was collected by MMRP staff and volunteers, and by collaborating tour guides and citizen scientists through the Manta Trust's IDtheManta database.

The geographical atolls of North (NMA) and South (SMA) Malé (collectively, the Malé Region) support a year-round presence of reef manta rays. Manta ray sightings in 2019 conformed to the typical pattern documented in previous years, with the mean number of individuals sighted per survey peaking during the Northeast Monsoon (January – March) at sites along the western edge of the atolls, with another peak occurring towards the end of Southwest Monsoon (September – November), at sites along the eastern edge of the atolls. The current recorded population of reef manta rays in the Malé Region is 823 individuals (17% of the total known Maldives population); recorded at 47 different sites throughout the two atolls. Key findings of this 2019 study include a total of 739 sightings of 229 individual reef manta rays. Eighty-eight percent (*n*=647) of all sightings have been recorded from ten key reef manta ray aggregation sites within the Malé Region.

Ninety-seven percent of all sightings (*n*=720) in 2019 were recorded in NMA, where considerably more research effort was focused during this study. The NMA reef manta ray sub-population is comprised of 92% (*n*=760) of the total recorded regional population, while only 107 individuals (13% of the total recorded regional population) have been documented in SMA to date. The demographics of the NMA sub-population is split almost equally between sexes; with 49% (*n*=373) females, 51% (*n*=386) males, and one individual for which sex could not be determined. The majority (75%) of the NMA sub-population are mature adults (*n*=572), whilst only 2% (*n*=14) are subadults, and 23% (*n*=173) juveniles. However, in 2019, the demographics of individuals sighted that year showed a sex bias; with 54% (*n*=118) males and 46% (*n*=101) females. By contrast, the SMA sub-population demographics overall exhibit a male bias; with 62% (*n*=66) males, and 38% (*n*=41) females. Furthermore, 55% of the recorded SMA population is comprised of juveniles (*n*=55) and subadults (*n*=4), while only 45% (*n*=48) are mature adults. Similar to NMA, in 2019 the demographics of individuals sighted in SMA that year showed a more skewed sex bias than previous years; with 87% of individuals sighted (*n*=13) males, and only 13% (*n*=2) females.

Of the 823 individual reef manta rays recorded in the Malé Region, 88% (*n*=723) 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. Forty-four percent (*n*=338) and 75% (*n*=80) of the recorded reef manta ray sub-populations of NMA and SMA respectively have also been recorded in other geographical atolls throughout the Maldives. This migratory behaviour suggests a large proportion of these

sub-populations are, at least some of the time, highly mobile; travelling hundreds of kilometres throughout the archipelago.

In 2019, courtship and mating behaviour was recorded only four times within NMA. Courtship behaviour took place three times at Boduhithi Thila in early 2019, and once at Lankan Beyru towards the end of the Southwest Monsoon. The courtship behaviour observed earlier in the Northeast Monsoon correlates with the high number of manta ray sightings in January. A total of eight out of the 48 individual adult females (17%) were recorded pregnant throughout the Malé Region during 2019; similar to previous years' sightings (excluding 2018) since 2005.

Within the Malé Region, the most developed and populous area in the Maldives, there has been a constant increase in tourism pressures over the last half a century. In general, the growing numbers of tourists frequenting manta aggregation sites throughout the Maldives shows the importance of these animals to the Maldives' economy. The Manta Trust continue to distribute a 10-step Code of Conduct (available in multiple languages) to tour operators throughout the Malé Region (and in other atolls) to ensure more sustainable manta ray tourism activities are undertaken.

Efforts to conserve the natural heritage of the Malé Region 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 for the Maldives, bringing tens of thousands of people to the country each year to dive and snorkel with them, 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

Located centrally within the Republic of Maldives' 26 geographical atolls, and encompassing the capital island of Malé and the main international airport, North and South Malé Atolls (NMA & SMA) are the most developed and busiest atolls within the country. Malé City is geographically located at the southern edge of NMA, and with a population of approximately 216,000 people, it is among the most densely populated cities in the world. Annually, the Maldives now welcomes well over a million tourists to this tiny island nation, the vast majority of which travel through NMA during their visit. Virtually every island has been developed within the region, and throughout 2019 reclamation of new islands expanded, resulting in significant impacts on the terrestrial and marine ecosystems. NMA is geographically larger (1,565 km²) and more populated than SMA (530 km²); it is comprised of 76 islands and sandbanks (30 resorts and 8 locally inhabited islands), compared to 47 islands and sandbanks (25 resorts and 3 locally inhabited islands) in SMA. In 2019, the hotel industry expanded regionally, with the opening of five new resort islands; two in NMA and three in SMA. Throughout the majority of this report, data from the two geographical atolls has been combined to encompass the entire Malé Region. However, in some instances, the data has been analysed separately to allow comparisons to be made between each atolls' reef manta ray population, and to determine differences or similarities in site use between atolls.

The fluctuating monsoons (seasons) within the Maldives 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 the Malé Region. The monsoons, which dictate the weather in the Maldives, are characterised by their winds, which blow consistently and reverse direction seasonally. The Maldives Northeast Monsoon, or Iruvai, runs from December-March, while the Southwest Monsoon, or Hulhangu, runs from May-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 characterised by more rain and cloud cover, along with reduced underwater visibility and 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 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

Table 1: Ten key reef manta ray (*Mobula alfredi*) aggregation sites within North and South Malé Atolls: pooled into four sub-regional areas for comparative analysis based on their geographical position and population demographics.

Group	Site Name	Atoll	Location	Habitat	Demographic
1	Lankan Beyru	North Malé Atoll	East	Channel	Adults
	Sunlight Faru	North Malé Atoll	East	Inner Reef	
2	Kani Corner	North Malé Atoll	East	Channel	Juveniles
	Lhohifushi Aquarium	North Malé Atoll	East	Channel	
	Gasfinolhu Beyru	North Malé Atoll	East	Outer Reef	
	Thulusdhoo Beyru	North Malé Atoll	East	Outer Reef	
3	Rasfari North	North Malé Atoll	West	Channel	Adults
	Boduhithi Thila	North Malé Atoll	West	Channel	
4	Guraidhoo Falhu	South Malé Atoll	East	Inner Reef	Juveniles
	Guraidhoo Beyru	South Malé Atoll	East	Channel	

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.

To date, reef manta ray sightings have been confirmed at 47 different sites within the Malé Region between 1987-2019. Ten of these sites were classified as key aggregation areas due to the high number of individual manta rays which visited. These primary sites were pooled into four sub-regional groups for comparative analysis based on their geographical position within the region and population demographics (Fig. 1) (Table 1).

2019 was the second year of full-time presence of MMRP staff based in NMA. The MMRP project base in NMA will continue to regularly research and monitor the project's study sites throughout 2020 with the aim of: **(1)** enhancing existing knowledge of this region's manta ray population, **(2)** increasing ocean awareness among the local community and tourists alike, and **(3)** providing recommendations and guidance for the protection of these vulnerable animals and their habitat.

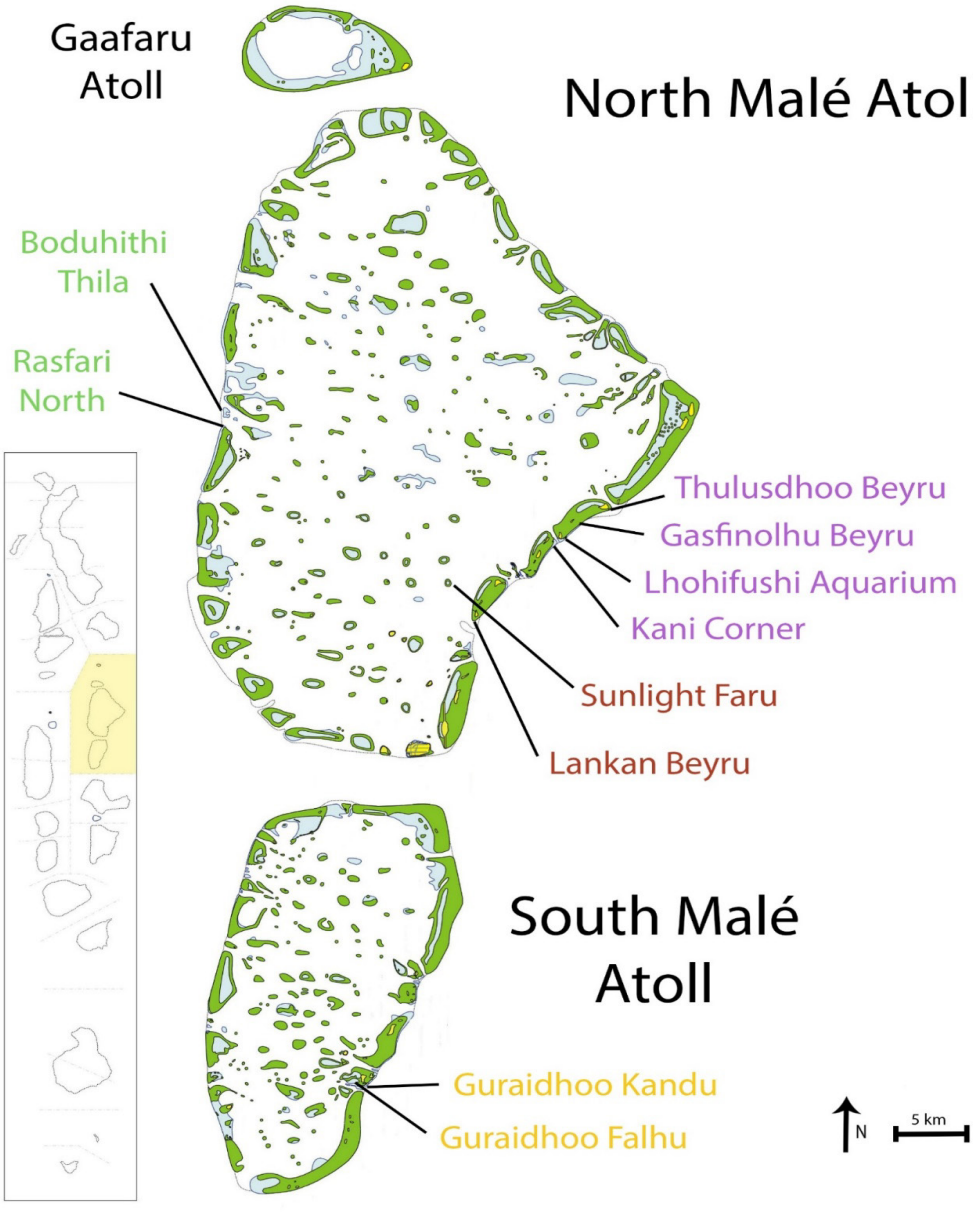

Figure 1: Map of North and South Malé Atolls showing ten key reef manta ray (*Mobula alfredi*) aggregation sites (colour-coded by four sub-regional areas) within the two geographical atolls.

STUDY PERIOD & SAMPLING METHODOLOGY

In 2019, surveys to look for manta rays (*n*=385) were carried out on as many days that conditions and logistics allowed (Fig. 2). Fifty-three percent of the surveys conducted in 2019 (*n*=204) were conducted by MMRP trained researchers on guest excursions with the Euro-divers Meeru dive centre. A detailed briefing was given before every dive or snorkel excursion, including details of the Manta Trust's Code of Conduct and the ten steps on 'How to Swim with Manta Rays'. The remaining forty-seven percent of surveys conducted (*n*=181), were external contributions from collaborating resort marine biologists, dive instructors, or survey data collected from the Manta Trust's 'IDtheManta' submission form. During all surveys (*n*=3,203); location, wind speed and current direction (as well as other environmental weather variables) were noted alongside manta ray numbers, and the manta's prevalent behaviours. Individual manta rays were documented by photographing the unique spot pattern on their undersides (ventral surface). 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 site.

Data for this report was compiled using both sighting and survey data. Sightings were collected by the Manta Trust team in addition to photographs and videos submitted by external contributors. Such contributors, known as 'citizen scientists', can provide important insights into the seasonal movements of many of Malé Region's reef manta ray population. As explained in the Malé Regional Report (1987-2017), a more intense survey method was introduced in 2006, with an increase in survey effort by MMRP staff and volunteers occurring from 2013 onwards (Fig. 2). Throughout certain sections of this report, comparative analysis was only undertaken on these later years where increased survey effort occurred (2013-2019). To account for changes in sampling effort, sightings data between 2006-2019 has been standardised where possible to allow for comparisons to be made between, and within years.

During 2019, survey effort (*n*=385) varied throughout the year (Fig. 3). Generally, the average number of surveys per year (2013-2018) increase from June to November, with a decrease during May and December (the transitional months of change between monsoons) (Fig. 3), when there is usually a reduction in manta sightings at all key aggregation sites. However, in 2019 there was a decrease in the number of surveys undertaken throughout July (*n*=13), August (*n*=16) and September (*n*=14); a result of rougher sea conditions at that time and therefore fewer opportunities to go on guest snorkel excursions. In addition, there was no MMRP researcher present in the field during most of September. Survey effort throughout January to May and December 2019 was much higher compared to the average between 2013-2018. Possibly due to better environmental conditions, resulting in more excursions where surveys could be performed (Fig. 3).

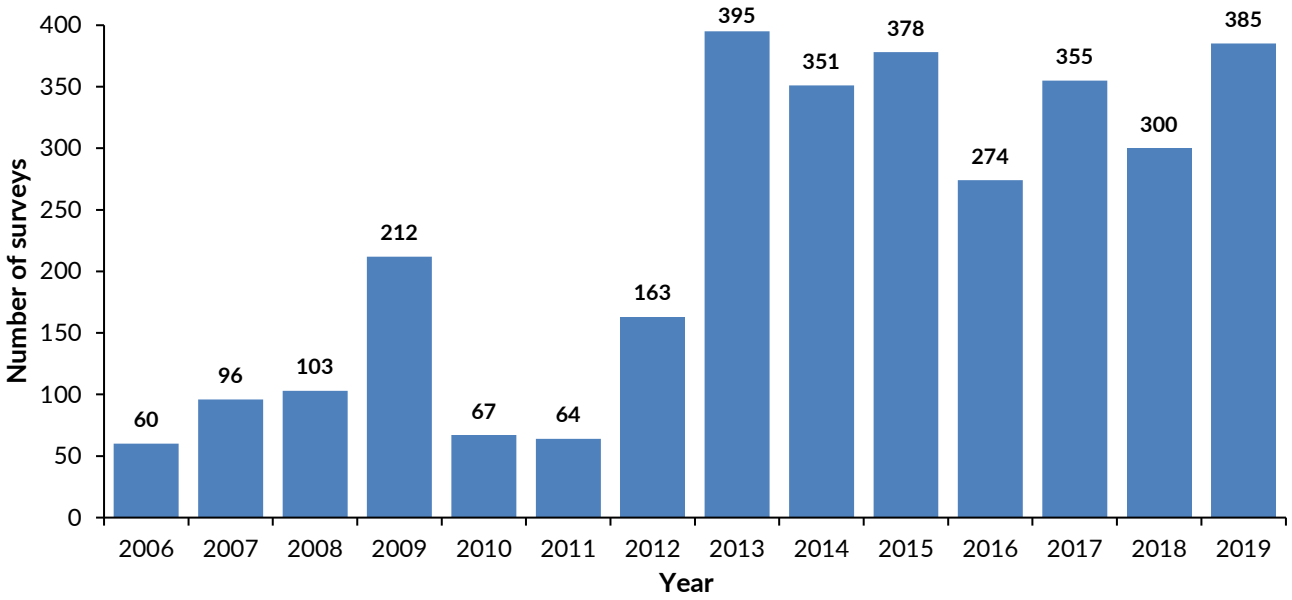

Figure 2: Number of surveys (*n*=3,203) undertaken annually in North and South Malé Atolls.

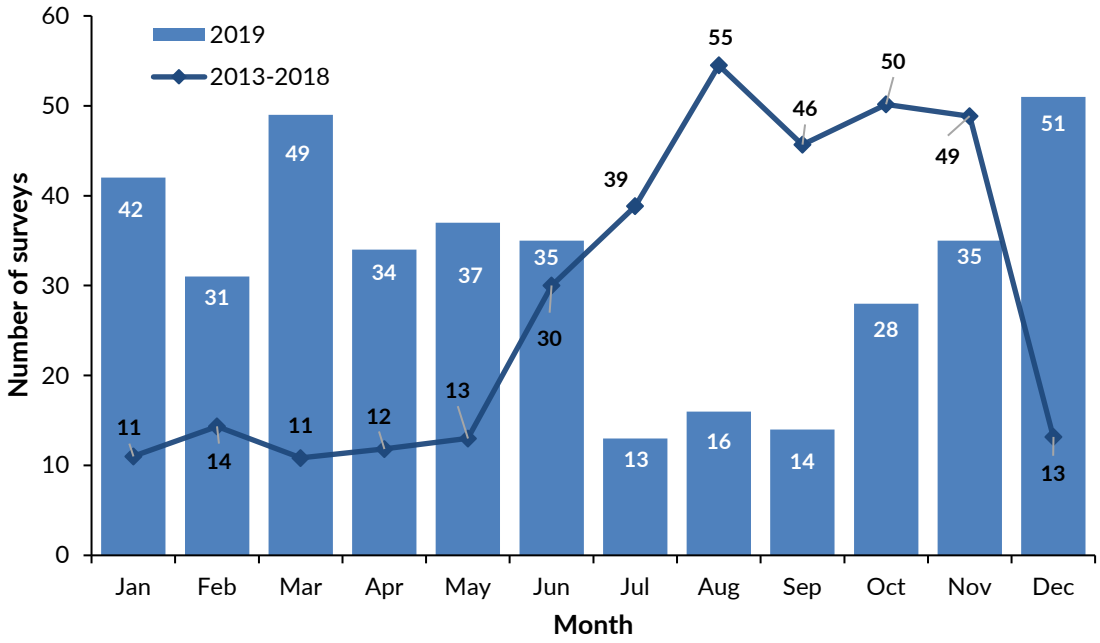

Figure 3: Number of surveys (*n*=2,438) undertaken monthly in North and South Malé Atolls (2013-2019).

Between 2013 and 2019, survey effort also varied between the four key aggregation areas (Fig. 4) (Table 1). Throughout this period, the majority (55%) of surveys (*n*=1,120) were carried out at Lankan Beyru and Sunlight Faru (Group 1). Survey effort within this key area remained relatively consistent throughout the years, with a slight decline during 2017 (Fig. 4). Moreover, significant survey effort at Rasfari North and Boduhithi Thila (Group 3), only began in 2017. In 2019, survey effort at Rasfari North and Boduhithi Thila (Group 3) was almost equal to the effort conducted at Lankan Beyru and Sunlight Faru (Group 1). Together, these areas represented the locations where the majority (91%) of surveys were conducted in 2019 [Group 1 (48%) and Group 3 (43%)]. This increase was a result of an increased number of collaborating tour operators located on the western edge of NMA, plus increased efforts by MMRP staff based in NMA throughout the year.

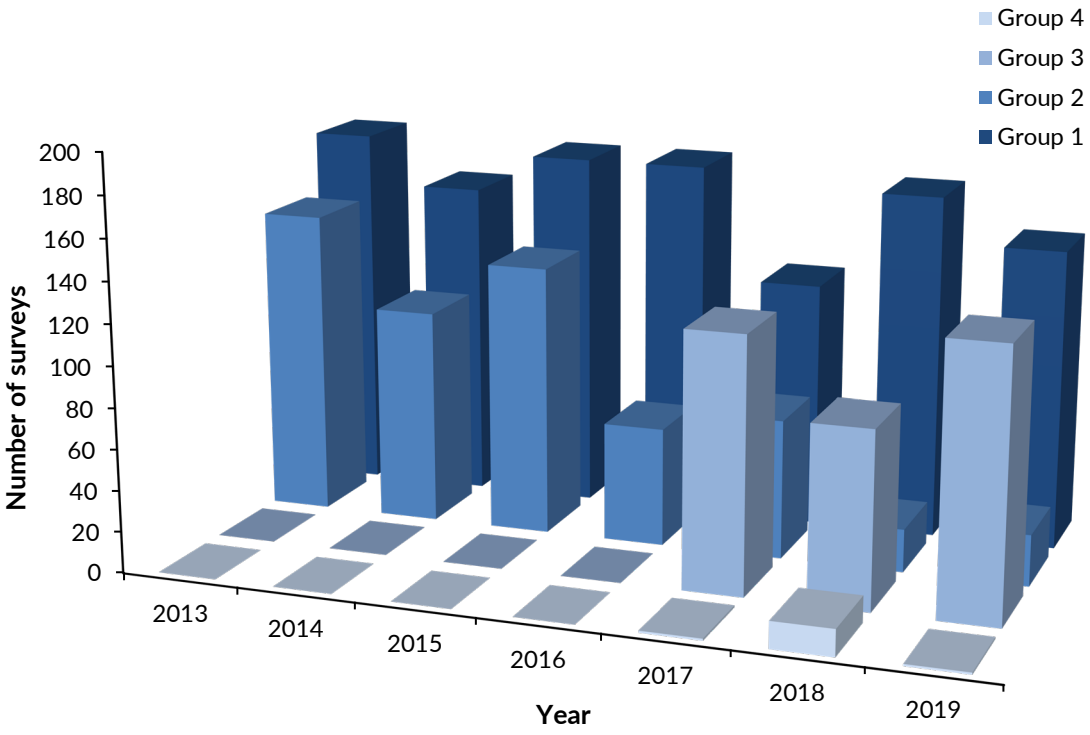

Figure 4: Number of surveys (*n*=2,033) undertaken annually at the four key reef manta ray (*Mobula alfredi*) aggregation areas.

In addition to the surveys conducted within the four key aggregation areas, two new aggregation sites were frequented as a result of permanent MMRP presences on the east side of NMA. These include: Meerufenfushi Falhu, which accounted for 5% of surveys in 2019, and Dhiya Adi Kandu, which accounted for 4% of surveys carried out this year. Both regions are located along the middle and upper eastern edge of NMA respectively. More consistent monitoring of these locations by MMRP researchers in the future will hopefully help to elucidate any trends in manta ray sightings frequency here and qualify their status for inclusion as key aggregation areas.

REEF MANTA RAY SIGHTINGS

North and South Malé Atolls

A total of 8,842 sightings were recorded at 47 different sites throughout the Malé Region from 1987-2019. Fifty-eight percent (*n*=5,101) of these sightings were recorded between 2013-2019, the period of focus throughout this report.

In 2019, a total of 739 reef manta ray sightings were recorded in the Malé Region (Fig. 5). The data shows a decrease (27%) in reef manta ray sightings compared to the previous year (*n*=1,007 in 2018), but similar to that recorded in 2015 and 2017 (Fig. 5). In general, years of increased manta ray sightings have previously been recognised during years of high average wind speeds. In 2019, the average annual wind speeds dropped (*n*=14.9 km/h), which may have contributed to the lower sightings (see Environmental Variables section of this report).

A monthly breakdown of manta sightings across previous years (2006-2018), when standardised for effort, shows that the mean number of individuals sighted per survey typically peaks during the Northeast Monsoon months of January-March, with another peak occurring towards the end of Southwest Monsoon, during the months of September-November (Fig. 6). These peaks reflect the increased activity recorded at manta ray cleaning stations during these months. Reef manta ray sightings in 2019 followed a similar trend, with the typical peak in sightings recorded at the start of the Northeast Monsoon during the month of January (*n*=150), and a second increase in sightings observed towards the end of the Southwest Monsoon; with sightings rising in September and reaching a high in November 2019 (*n*=129) before dropping again in December (*n*=88) (Fig. 7).

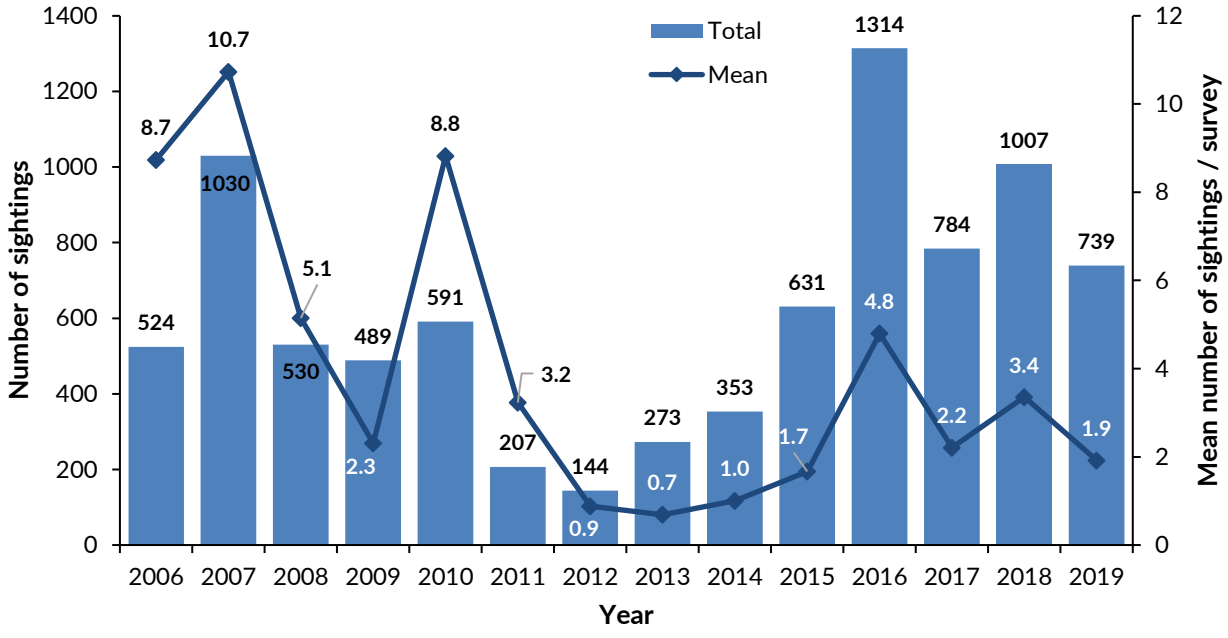

Figure 5: Annual sightings of reef manta rays (*Mobula alfredi*) in North and South Malé Atolls, and the mean number of sightings per survey.

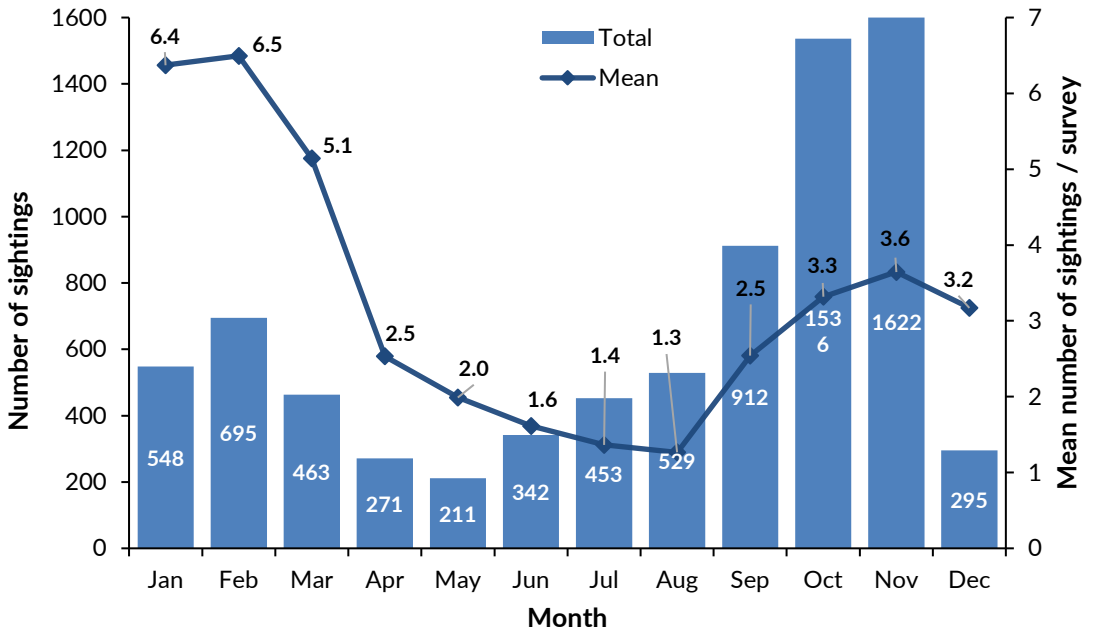

Figure 6: Monthly sightings of reef manta rays (*Mobula alfredi*) in North and South Malé Atolls, and the mean number of sightings per survey (2006-2018).

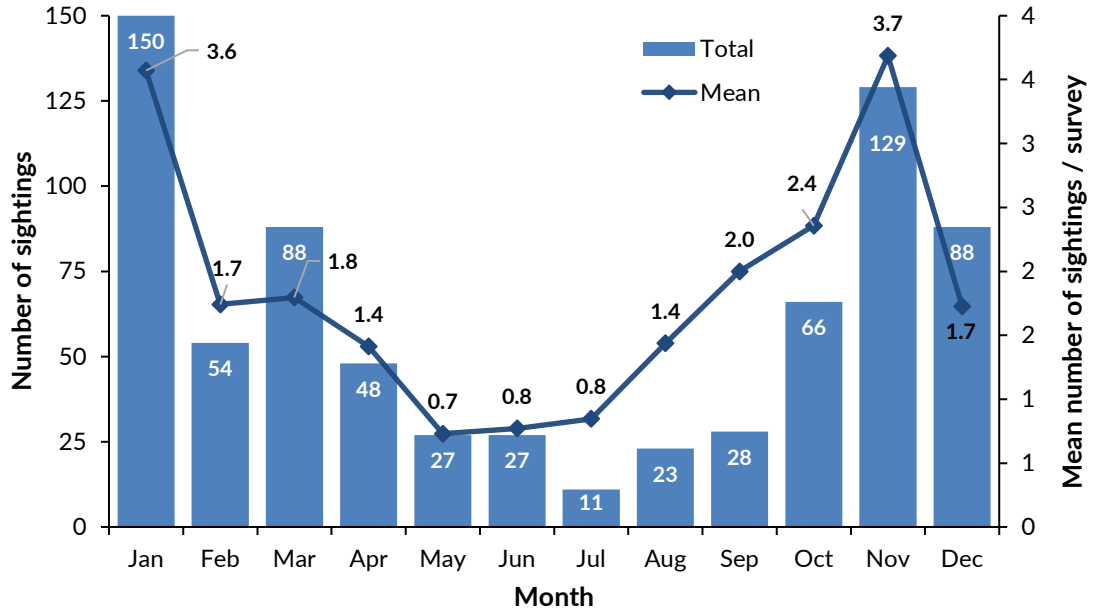

Figure 7: Monthly sightings of reef manta rays (*Mobula alfredi*) in North and South Malé Atolls, and the mean number of sightings per survey during 2019.

During 2019, a total of 229 different individual reef manta rays were recorded in the Malé Region. This accounts for 4.6% of the total recorded Maldives population (*n*=4,941); a slight decrease from 2018 (*n*=252) (Fig. 8). The number of sightings recorded by MMRP researchers and those submitted by citizen scientists were almost equal in their contribution to the overall sightings count in 2019, with MMRP researchers recording 372 sightings (50.3%) and 367 (49.7%) sightings obtained from citizen scientist submissions. This highlights that even with a year-round presence of MMRP staff within the region, citizen science is hugely important in increasing our understanding of the reef manta ray population.

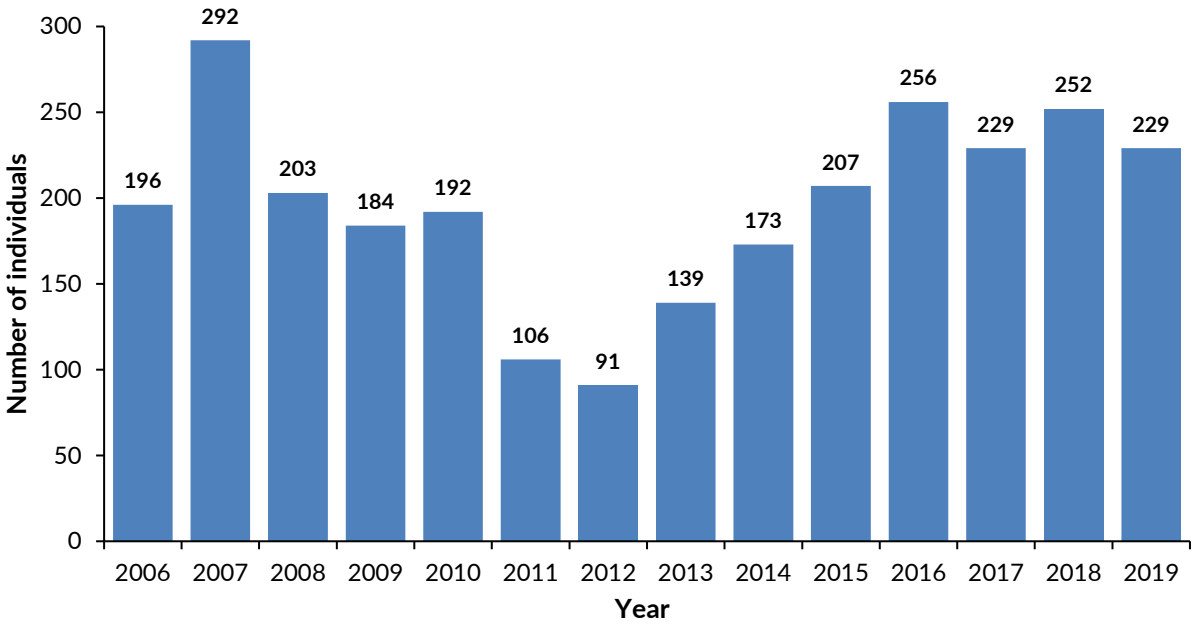

Figure 8: Number of individual reef manta rays (*Mobula alfredi*) recorded annually in North and South Malé Atolls.

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 the Malé Region show the same seasonal movement patterns as the country's other central and northern atolls, with reef manta rays visiting the western aggregation sites during the Northeast Monsoon (December-March) before returning to the eastern aggregation sites during the Southwest Monsoon (May-November) (Table 1 & Fig. 9). Eighty-eight percent (*n*=647) of all 2019 sightings were recorded from the ten key manta ray aggregation sites within the Malé Region (Fig. 1). Variations in site use within the region can be better understood by pooling sightings from these locations into four geographical groups based on their geographical position within the region and population demographics (Table 1).

In 2019, intra-annual sightings conformed to the expected migration patterns in the region. This was evident as the sightings peaked first during the Northeast Monsoon months at Rasfari North and Boduhithi Thila (Group 3), situated on the west of NMA (Fig. 10). From May onwards, sightings at Rasfari North and Boduhithi Thila started to decrease, with a noticeable shift in manta ray site use as sightings gradually increased at Lankan Beyru and Sunlight Faru (Group 1), located on the east of NMA. The other two aggregation groups, which are predominantly utilised as feeding sites by sub-adult and juvenile reef manta rays, are located on the eastern edge of atolls. Despite far few sightings in total noted at these two locations compared to Groups 1 and 3 in 2019, sightings conform to a similar seasonal trend to previous years; peaking between June-November during the Southwest Monsoon, with little to no sightings recorded annually during the Northeast Monsoon (Fig. 10).

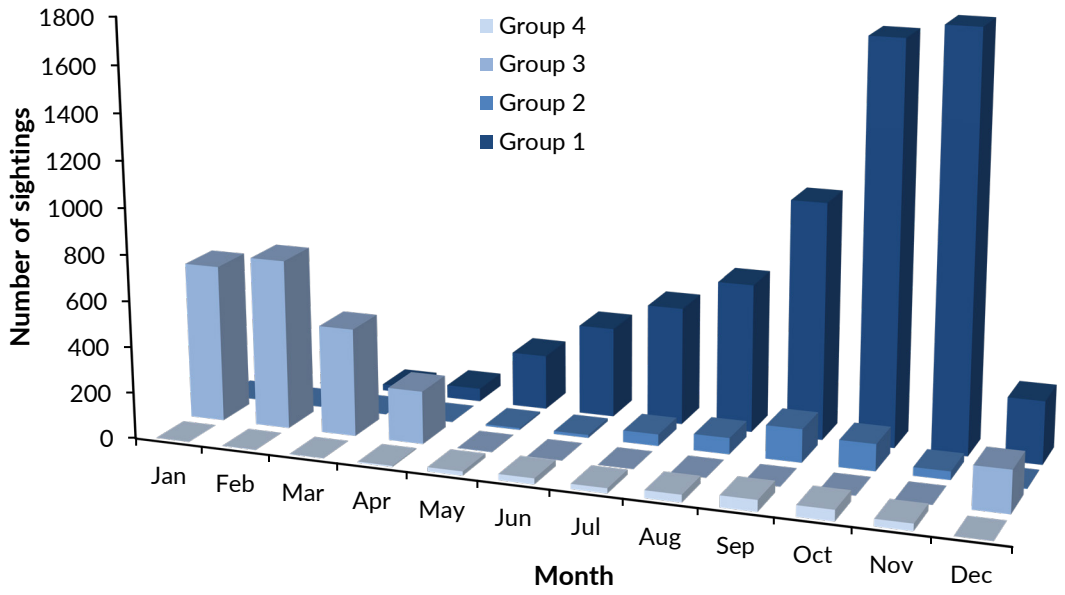

Figure 9: Intra-annual variations in sightings of reef manta rays (*Mobula alfredi*) in North and South Malé Atolls at four key manta aggregation areas (see Table 1) (2005-2018).

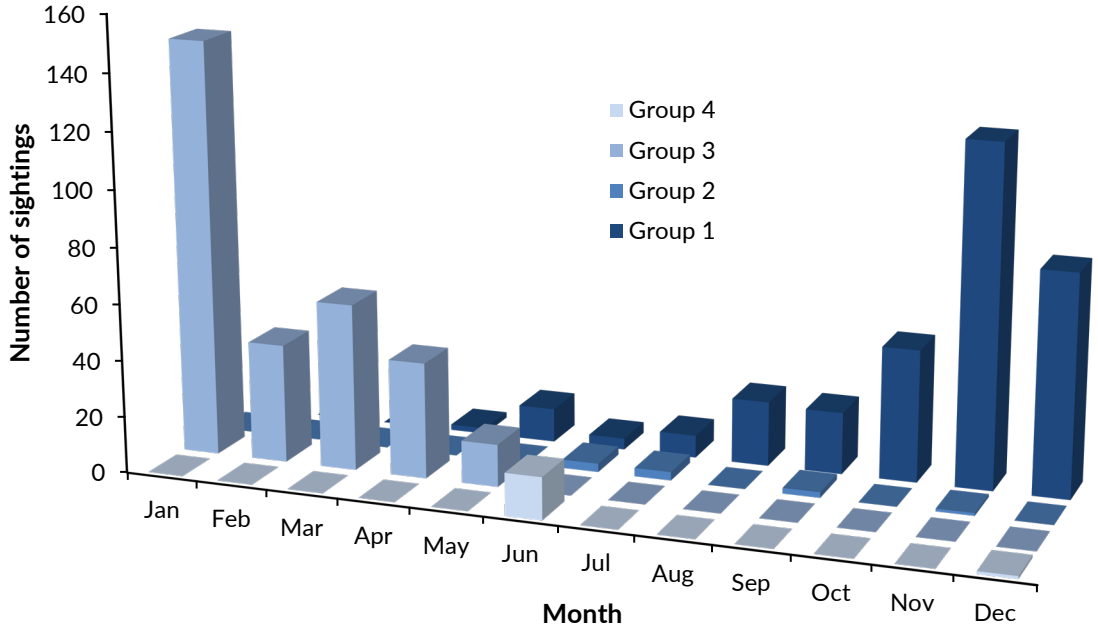

Figure 10: Intra-annual variations in sightings of reef manta rays (*Mobula alfredi*) in North and South Malé Atolls at four key manta aggregation areas (see Table 1) (2019).

Two other aggregation sites (Meerufenfushi Falhu and Dhiya Adi Kandu) were more frequently surveyed as a result of permanent MMRP presence on the east side of NMA. These two sites were within the top ten most visited areas by manta rays in 2019, with most sightings occurring during the Southwest Monsoon. While it is clear that Meerufenfushi Falhu is most active as a feeding site during the Southwest Monsoon, there were three sightings of feeding mantas during the Northeast Monsoon. Dhiya Adi Kandu is predominantly a cleaning site which experienced increased cleaning activity in October (*n*=13). Continued surveillance of these sites is required to determine the sightings trends here and confirm the importance of these locations as key aggregation areas.

The majority of sightings recorded between 2013-2017 occurred at the cleaning stations of Lankan Beyru and Sunlight Faru (*n*=2,437) (Group 1) (Fig. 11). Intensive survey effort at Rasfari North and Boduhithi Thila (Group 3) only began in 2017, but by 2018 the total number of reef manta ray sightings recorded at this key aggregation area (*n*=710) was higher than at Group 1 (*n*=526) for the first time. However, in 2019 the total number of reef manta ray sightings between the key aggregation groups were similar; Rasfari and Boduhithi Thila (*n*=304) and Lankan Beyru and Sunlight Faru (*n*=318) (Fig.11). More consistent monitoring by MMRP researchers in the future will help to identify any trends in manta ray sightings frequency at these key aggregation areas.

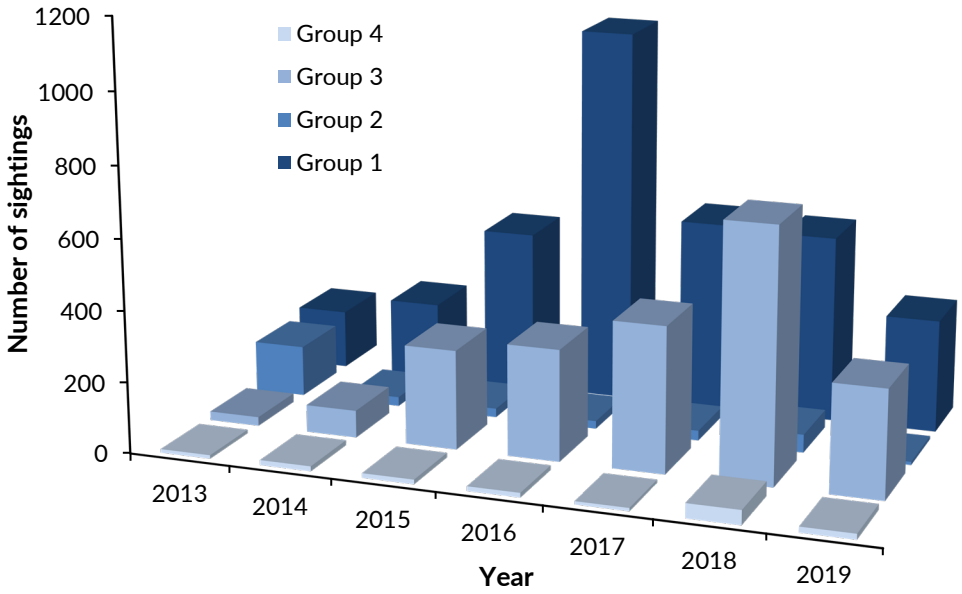

Figure 11: Inter-annual variations in sightings of reef manta rays (*Mobula alfredi*) in North and South Malé Atolls at four key manta aggregation areas (see Table 1).

Population Demographics

The current recorded population of reef manta rays in the Malé Region is 823 individuals, 17% of the total known Maldives population (*n*=4,941). Ninety-seven percent of all sightings (*n*=720) in 2019 were recorded in NMA. The two sub-populations of manta rays have been analysed separately to determine any differences or similarities between populations frequenting these two atolls.

NMA has a total known population of 760 individuals which accounts for 92% of the overall population within the region. The population demographics in NMA are split almost equally between sexes with 49% (*n*=373) females, 51% (*n*=386) males and one individual for which the sex could not be determined (Fig. 12). The population demographics in NMA show a bias towards adults, with 75% (*n*=572) of individuals recorded as mature, while 2% (*n*=14) were sub-adults, and 23% (*n*=173) juveniles (Fig. 12). Without knowing the sex of the one unknown individual, the maturity status could not be determined. In 2019, the demographics of individuals sighted within the NMA showed a sex bias; with 54% (*n*=118) males and 46% (*n*=101) females.

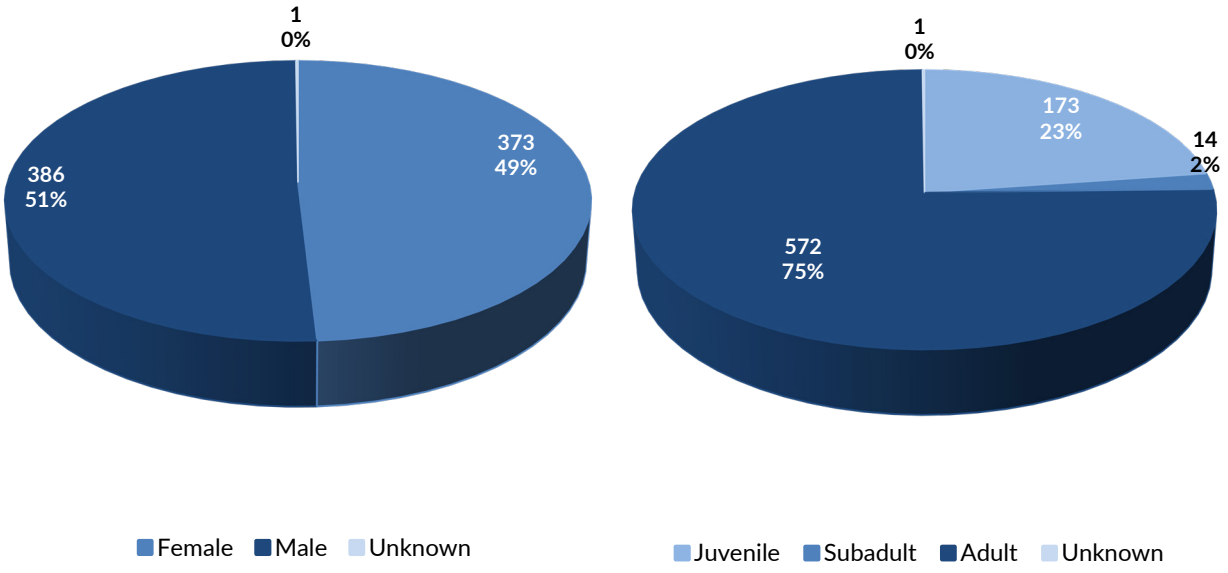

Figure 12: Demographics of the reef manta ray (*Mobula alfredi*) population (*n*=760) recorded in North Malé Atoll (1987-2019).

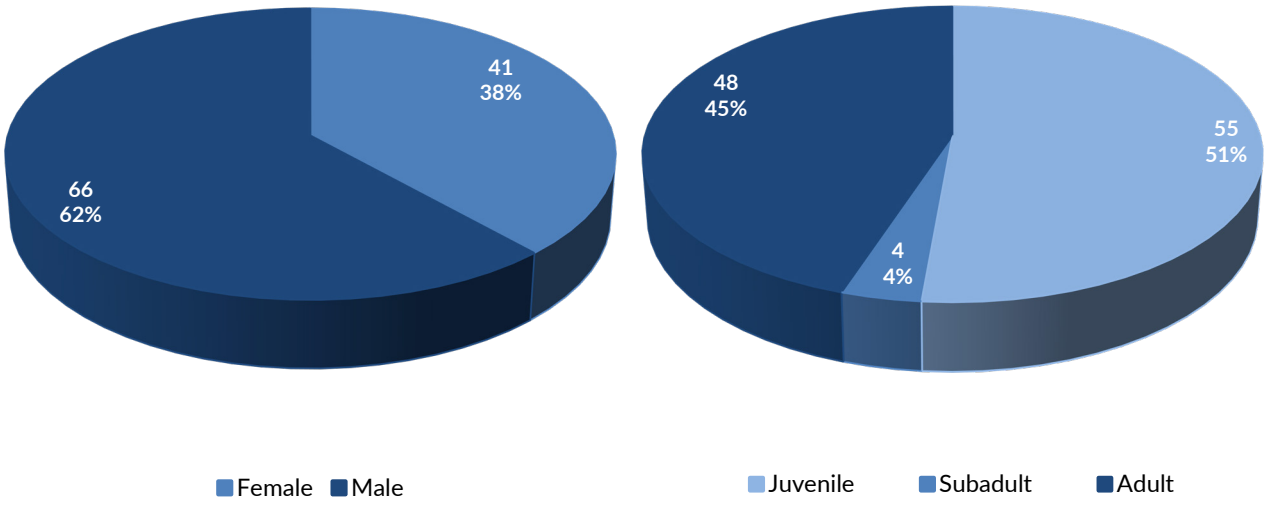

Figure 13: Demographics of the reef manta ray (*Mobula alfredi*) population (*n*=107) recorded in South Malé Atoll (1987-2019).

In SMA, although the recorded reef manta ray population only consists of 107 individuals (13% of the regional population), the population demographics are different to that of NMA. There is a sex bias; with 62% (*n*=66) males and 38% (*n*=41) females (Fig. 13). Furthermore, in contrast to NMA, 55% of the recorded population in the SMA population are immature; with 51% (*n*=55) juveniles and 4% (*n*=4) sub-adults, and only 45% (*n*=48) recorded as mature adults (Fig. 13). This suggest that SMA supports important aggregation sites for immature manta rays- e.g. Guraidhoo Falhu, which is noted as a key juvenile feeding site within the atoll. In 2019, there were two new individuals identified at Guraidhoo Falhu during June, both of which were juveniles. Similar to NMA in 2019, the demographics of individuals sighted showed an increase in sex bias; with 87% (*n*=13) males and 13% (*n*=2) females.

As recorded in the previous Malé Regional Annual Reports, the proportion of newly sighted individual reef manta rays recorded annually has followed a downward trend over the study years as more of the regional population is identified (Fig. 14). To date, 88% (*n*=723) of the Region's reef manta ray population 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 recorded.

In 2019, of the 229 individuals recorded within the Region, 19 were new to the regional population. Six of these individuals were estimated to be young of year based on their small disk widths (~150 cm), and all were recorded at Meerufenfushi Falhu; an apparent juvenile feeding site in NMA. Interestingly, 63% (*n*=12) of new individuals in 2019 were recorded at locations outside the key aggregation areas (Table 1) (Fig. 15), and 42% (*n*=8) of these newly identified individuals were recorded at Meerufenfushi Falhu. This is a reflection of increased survey efforts at this site throughout 2019. In 2018, 60% of new individuals were recorded at Rasfari North and Boduhithi Thila; while in 2019 only 26% (*n*=5) of new individuals were identified here. With a year-round presence of MMRP within NMA, and continued collaborations with resorts and dive operations based on the western edge of the atoll, we can gain greater insight into the population dynamics at these sites and in the Malé Region as a whole.

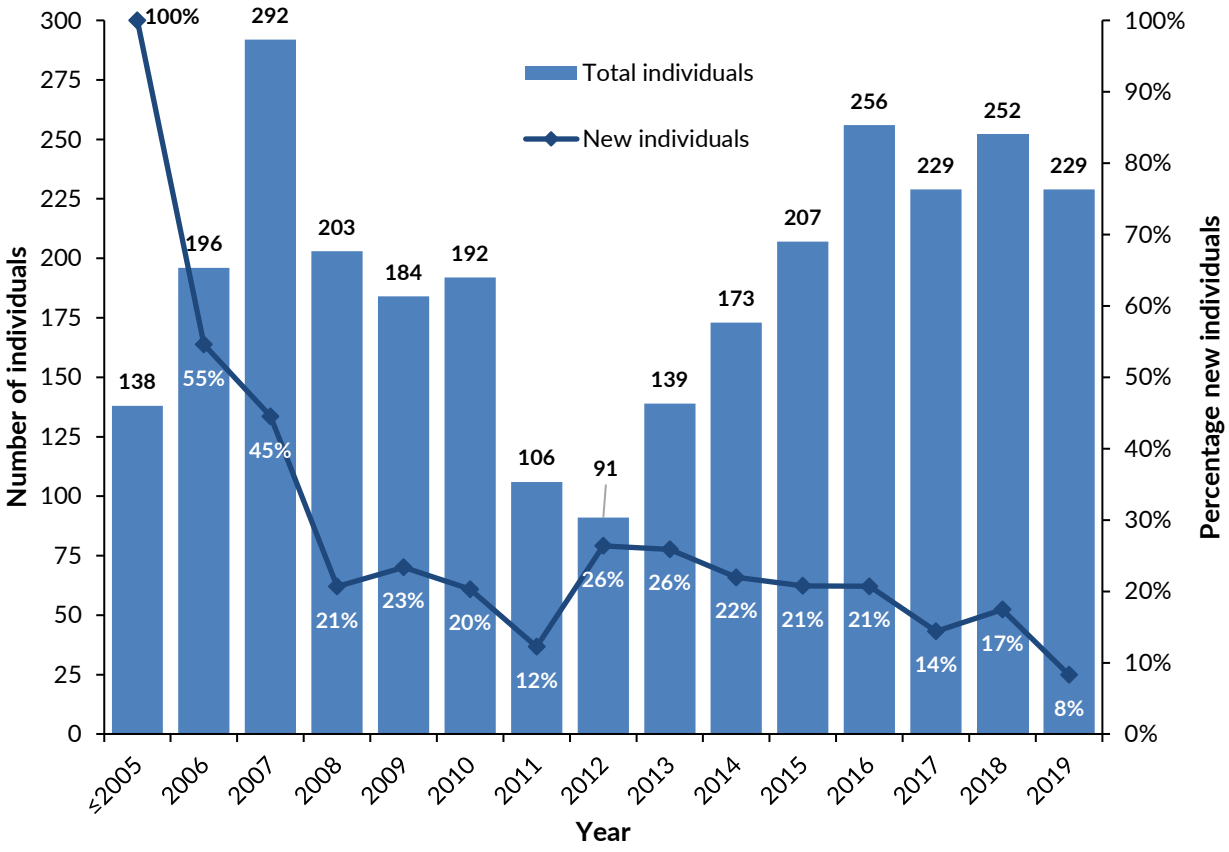

Figure 14: Number of individual reef manta rays (*Mobula alfredi*) sighted annually in North and South Malé Atolls, and the percentage of those individuals which were newly recorded (1987-2019).

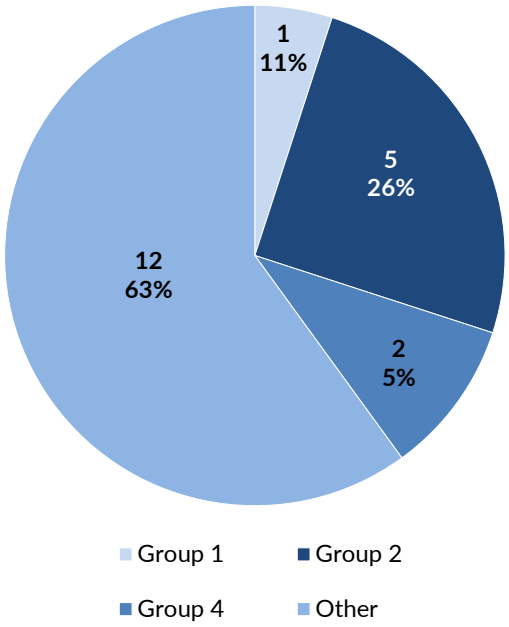

Figure 15: Number of newly recorded individual reef manta rays (*Mobula alfredi*) first sighted at key manta aggregation areas in North and South Malé Atolls (2019).

Inter-Atoll Migrations

Forty-four percent (*n*=338) and 75% (*n*=80) of the recorded reef manta ray sub-populations of NMA and SMA respectively have been recorded in other geographical atolls throughout the Maldives, compared to only 29% of the total recorded Maldives' reef manta ray population (*n*=4,941). As determined in the first Malé Regional Annual Report, this migratory behaviour suggests a large proportion of these sub-populations are, at least some of the time, highly mobile; travelling hundreds of kilometres throughout the archipelago. The most common inter-atoll movement records occur between NMA, SMA, and those atolls closest geographically to the study region. In total, reef manta rays from NMA have been re-sighted in 15 different geographical atolls (including SMA), with the highest number of re-sightings in Baa Atoll (*n*=169), followed by Ari Atoll (*n*=133) (Fig. 16). The recorded sub-population of reef manta rays in SMA are more transient, with 75% of individuals (*n*=80) recorded in nine other atolls, including 44 from NMA (Fig. 17). This suggests less suitable habitat is available for this species within the atoll year-round, but a lack of consistent survey effort is probably also confounding these results.

The high degree of migrations by individuals recorded travelling between the atolls is reflective of the wider population. With relatively small distances (10s km) between the atolls in the central and northern regions of the Maldives, and shallow maximum ocean depths (<300 m) between most of these atolls, there are limited barriers to migration. Indeed, several individuals have also been recorded travelling back and forth between other atolls (i.e. Baa Atoll) and NMA multiple times within a single season. However, these results are also likely influenced by the increased survey effort in these central atolls by the MMRP researchers.

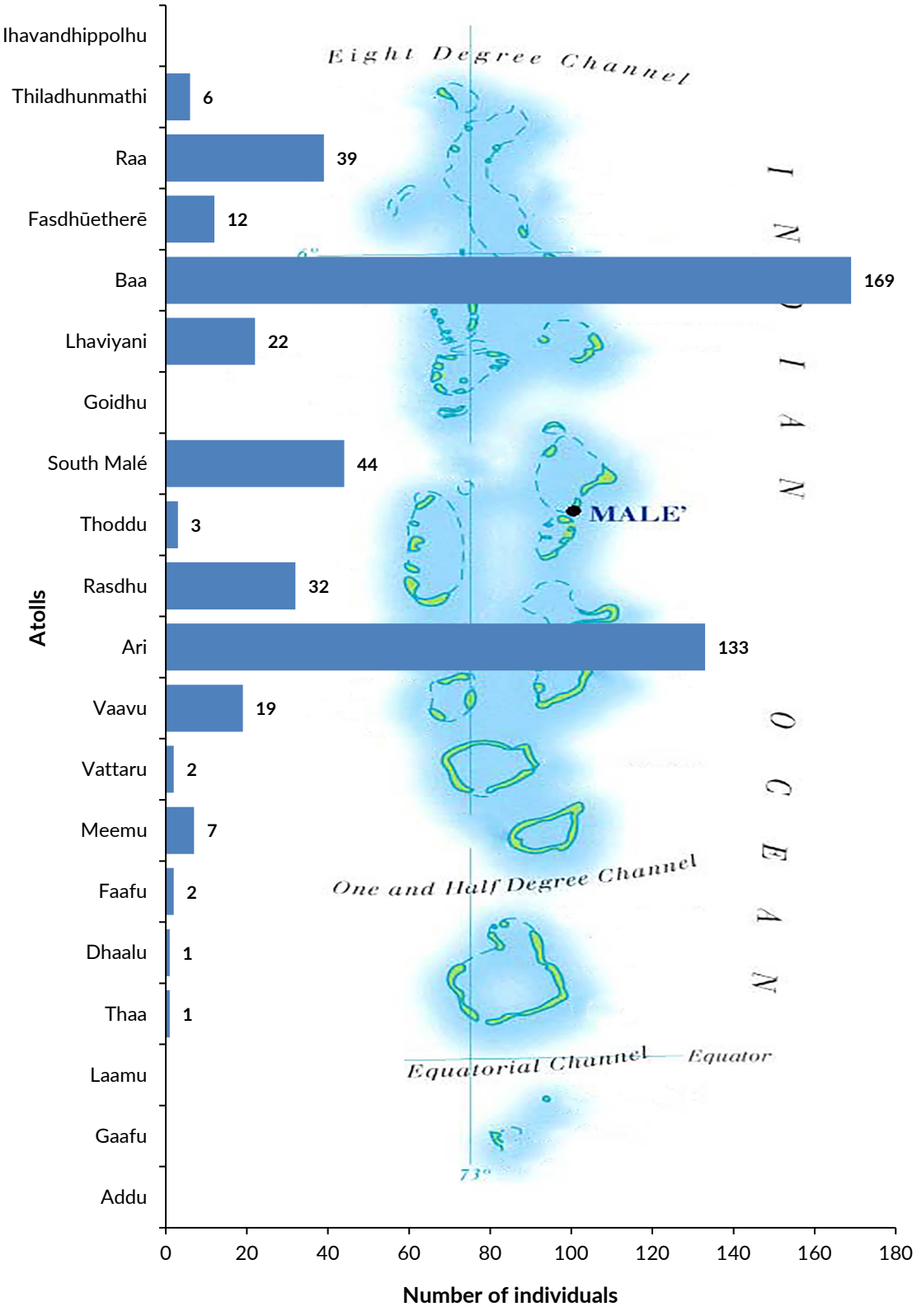

Figure 16: Number of reef manta rays (*Mobula alfredi*) (*n*=338) from within the North Malé Atoll population (*n*=760) which have been recorded in other atolls throughout the Maldives Archipelago. Note: Some individuals have been sighted in more than one atoll outside North Malé Atoll.

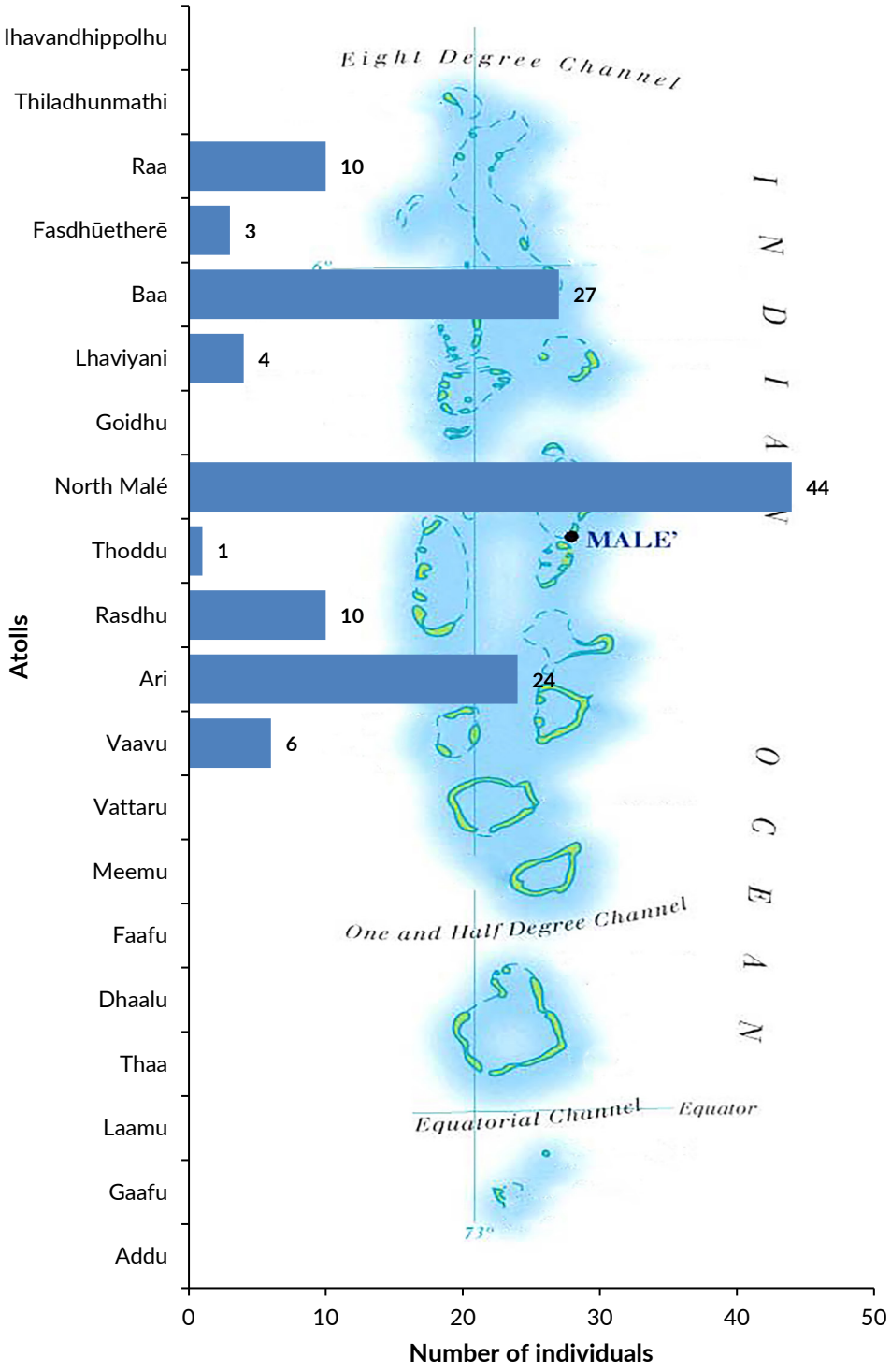

Figure 17: Number of reef manta rays (*Mobula alfredi*) (*n*=80) from within the South Malé Atoll population (*n*=107) which have been recorded in other atolls throughout the Maldives Archipelago. Note: Some individuals have been sighted in more than one atoll outside South Malé Atoll.

Site Fidelity

A large proportion (56%) of the reef manta ray sub-population of NMA (*n*=760) have never been recorded outside of this atoll (Fig. 18), and 44% (*n*=336) have been recorded on more than one occasion within the atoll. Sixty-seven of those individuals have been sighted more than 25 times during the 1987-2019 study period within the atoll, and 20 of those individuals more than 50 times. Unsurprisingly, given the reduced survey effort and apparent lower residency rates within SMA, there have been less re-sightings of the recorded sub-population (*n*=107); where only 25% (*n*=27) of the individual reef manta rays have been sighted only in SMA. Of those 27 individuals, 13 have been sighted more than once while 43% (*n*=46) and 21% (*n*=22) have been recorded within two and three atolls, respectively (Fig. 19).

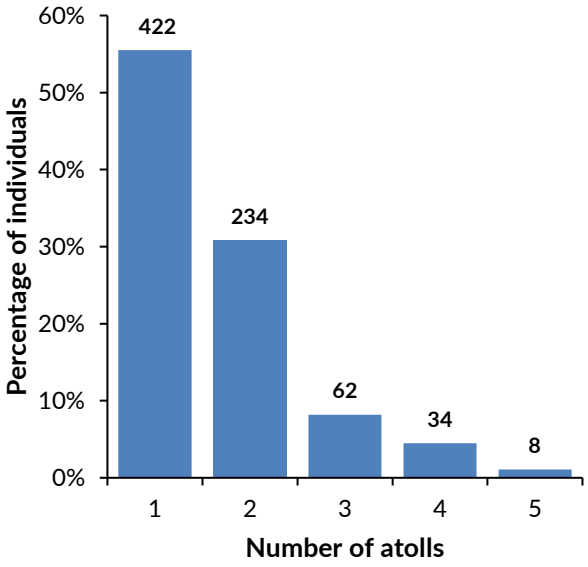

Figure 18: Percentage of the North Malé Atoll reef manta ray (*Mobula alfredi*) population (*n*=760) which have been sighted in one (only North Malé) or more geographical atolls. Actual number of individuals above bars (1987-2019).

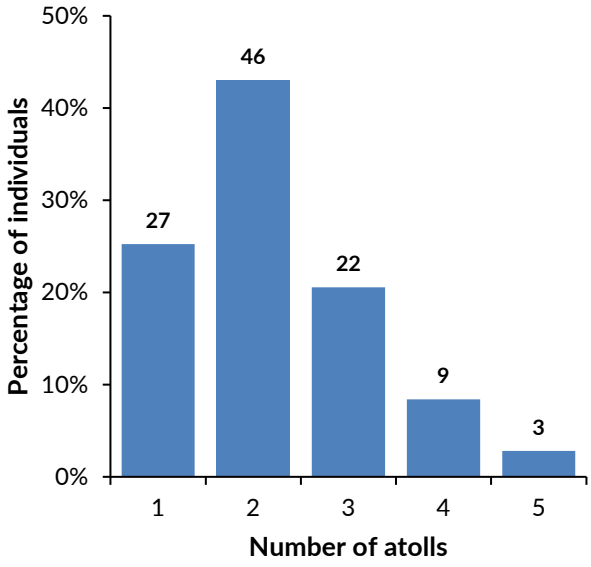

Figure 19: Percentage of the South Malé Atoll reef manta ray (*Mobula alfredi*) population (*n*=107) which have been sighted in one (only South Malé) or more geographical atolls. Actual number of individuals above bars (1987-2019).

Many individuals that exhibit high fidelity to NMA also exhibit patterns of specific habitat use within the atoll, favouring particular aggregation sites. For example, MV-MA-0014 (Freckle Face) is an adult female reef manta ray that has been one of the most sighted individuals in NMA since 2005 (Fig. 20). To date, Freckle Face has been recorded a total of 105 times throughout the Maldives, but at only three different survey sites within NMA. Prior to 2019, the vast majority (76%) of Freckle Face's sightings have occurred at the key manta aggregation area that includes Lankan Beyru (*n*=66) and Sunlight Faru (*n*=2) (Group 1). While the remaining sightings (23%) were all recorded at Rasfari North (Group 3). In 2019, Freckle Face was one of the most sighted individuals in the Malé Region, with a total of 17 sightings across six months. During this survey year, Freckle Face followed exactly the same habitat use pattern as in previous years, with 76% (*n*=13) of sightings at a key aggregation sites within Group 1 and 24% of sightings recorded at key aggregation sites within Group 3 (Fig. 20). The most sighted adult male reef manta ray within the Malé Region, MV-MA-0170 (Shimmer), also exhibits similar habitat use patterns; sighted 69 times since 2006, Shimmer also visits the same two key aggregation areas; Group 1 and Group 3. Prior to 2019, the majority (80%) of Shimmer's sightings have occurred at Lankan Beyru (*n*=48) and Sunlight Faru (*n*=7) (Group 1), with the remaining 20% of sightings recorded at Rasfari North (*n*=13) and Boduhithi Thila (*n*=1) (Group 3). In 2019, Shimmer exhibited similar site use patterns, with 87% of sightings recorded at Lankan Beyru (*n*=13) (Group 1) and the remaining 13% (*n*=2) sightings recorded at Rasfari North (Group 3) (Fig. 21).

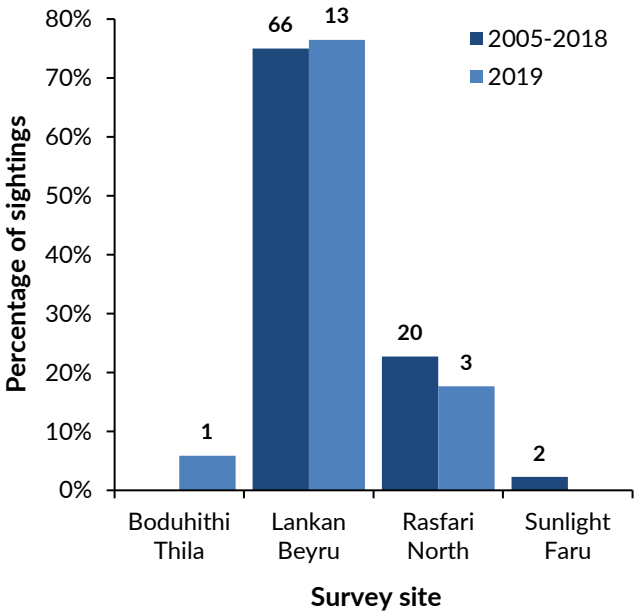

Figure 20: Percentage of the sightings of the reef manta ray (*Mobula alfredi*) MV-MA-0014 (Freckle Face) at different survey sites within North Malé Atoll. Actual number of sightings above bars.

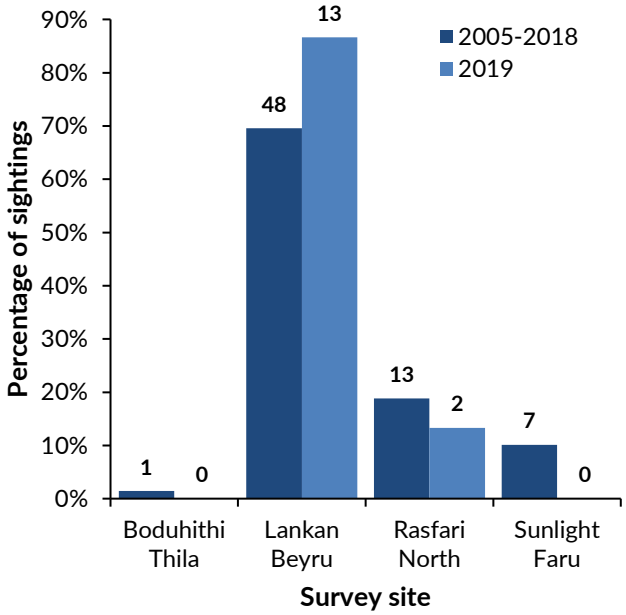

Figure 21: Percentage of the sightings of the reef manta ray (*Mobula alfredi*) MV-MA-0170 (Shimmer) at different survey sites within North Malé Atoll. Actual number of sightings above bars.

Without utilising more sophisticated tracking methodologies, such a telemetry studies, it is difficult to create a more detailed picture of how individual reef manta rays exhibit site fidelity. However, the increased surveying effort by the MMRP from 2006 onwards does allow some broad preliminary analysis. Throughout 2019, each manta ray was observed on average 3.2 times within the Malé Region (Fig. 22), a slight decrease compared to 2018 (n=4.0). To account for survey effort, a Residency Index (RI) was calculated for each year based on the ratio between the number of days each individual was sighted and the total number of surveyed days (e.g. an RI of 3% means that on average, each individual was sighted on 3% of the total survey days). The RI for 2019 (0.84%) was lower than that noted in 2018 (1.33%), and similar to that of all years from 2012 onwards (Fig. 23). The low residency of manta rays in the Malé Region in recent years is likely the result of higher survey effort, as RI is inversely correlated with number of surveys (Fig. 24), and a reflection of more transient behaviour, with manta ray movements likely

dictated by more favourable conditions elsewhere. There is also the possibility that the level of human development, resulting in increased boat traffic, and increased snorkeller and diver pressures at the manta ray's aggregation sites, has affected the ray's residency. The impacts of increasing noise pollution, reef degradation, and the physical disturbances which all result from these development activities have yet to be evaluated in detail.

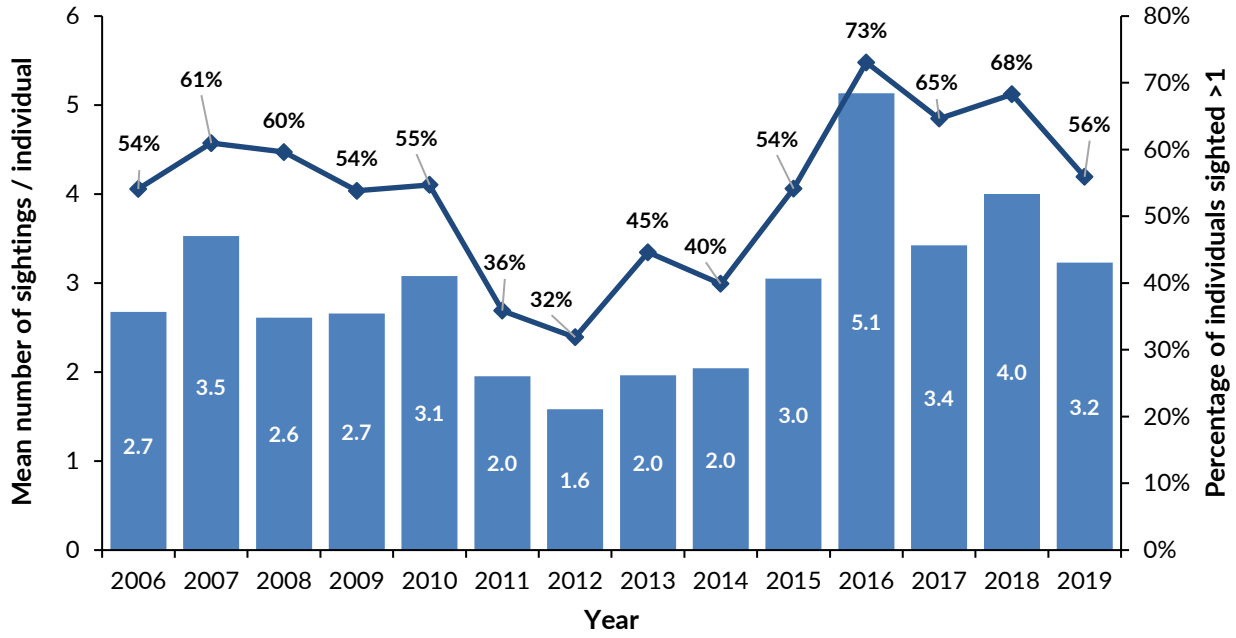

Figure 22: Mean number of sightings per individual reef manta ray (*Mobula alfredi*) in North and South Malé Atolls, and the percentage of individuals sighted on multiple occasions during the same year.

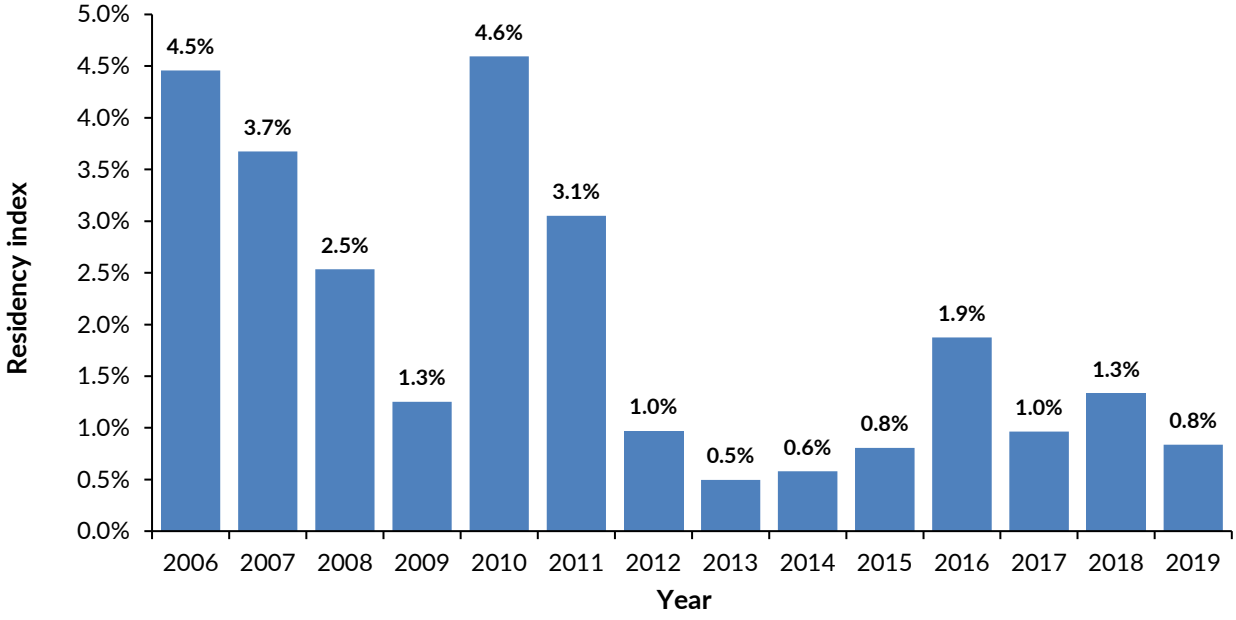

Figure 23: Annual Residency Index (RI) of the reef manta rays (*Mobula alfredi*) in North and South Malé Atolls. RI is calculated as the average of each individuals' residency score (= number of times sighted annually divided by the total number of surveys).

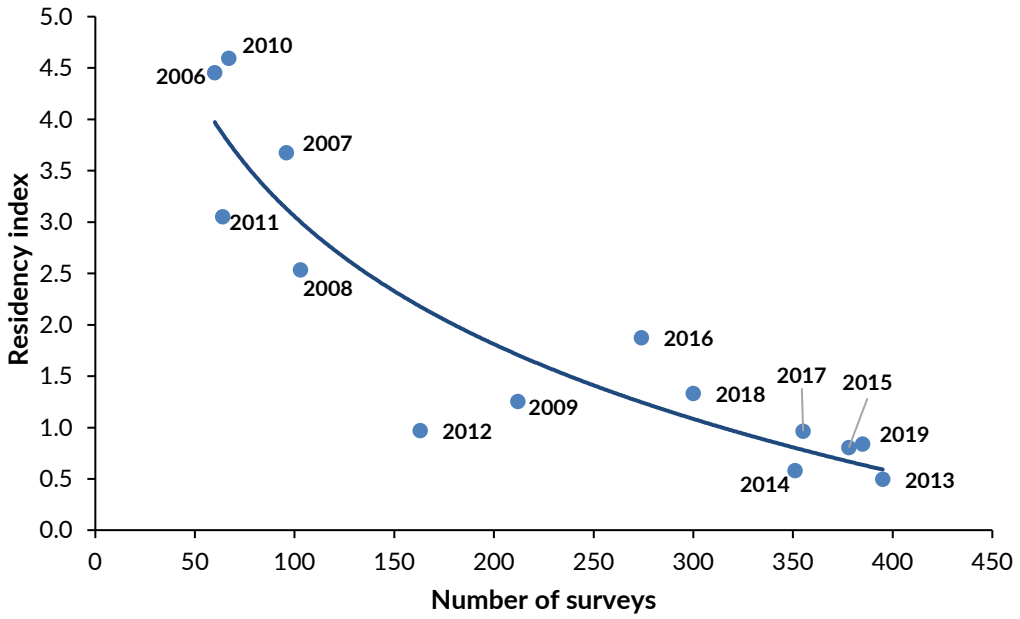

Figure 24: Relationship between the number of surveys conducted and the residency index of reef manta rays (*Mobula alfredi*) recorded within a study year in North and South Malé Atolls (2006-2019).

Courtship & Reproduction

Throughout their range globally, manta ray reproductive activity often peaks at particular times of the year. In the Maldives, courtship behaviour and mating are much more frequently observed during the months of October and November, and again in March and April, when the country's two monsoons (seasons) 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. Cleaning stations therefore often become the focal point for courtship and mating activity, with mature males aggregating at these sites in search for sexually receptive females.

In 2019, relatively low incidences of courtship events were recorded at cleaning stations, with only four events involving a total of 23 individual manta rays displaying courtship behaviour (Fig. 25). Three of these courtship events were observed during the Northeast Monsoon at key aggregation site (Boduhithi Thila) and the fourth courtship event occurred at Lankan Beyru, during the Southwest Monsoon. The courtship event at Lankan Beyru was a remarkable recording, which involved 17 different males and two females, and concluded with a rarely witnessed copulatory event.

In 2019, 48 adult female manta rays were sighted in the region, and 17% (*n*=8) of these individuals were visibly pregnant (Fig. 26). This is in stark contrast to 2018, when a reported 31% of the adult females sighted were noted to be pregnant (Fig. 26). It should however be highlighted that the number of pregnancies recorded in 2018 was far higher than the average incidence of pregnancies recorded throughout the study period (Fig. 26). Moreover, courtship behaviour was at the lowest, with only two reported events through 2018, hence the decrease in pregnancies recorded in 2019.

With a gestation period of one year, manta pregnancies become easily visible at about six months into the pregnancy. Of the eight individuals observed to be pregnant in the region in 2019, 75% (*n*=6) were already in the later stages of gestation (3rd-4th trimester) towards the end of the year. The low incidence of pregnancies reported in 2019 highlights the overall very slow reproductive rate for this species, which on average sees only 14% of the mature females reproducing annually. 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 MPAs and the adherence to sustainable tourism activities at key manta ray mating, cleaning and feeding sites.

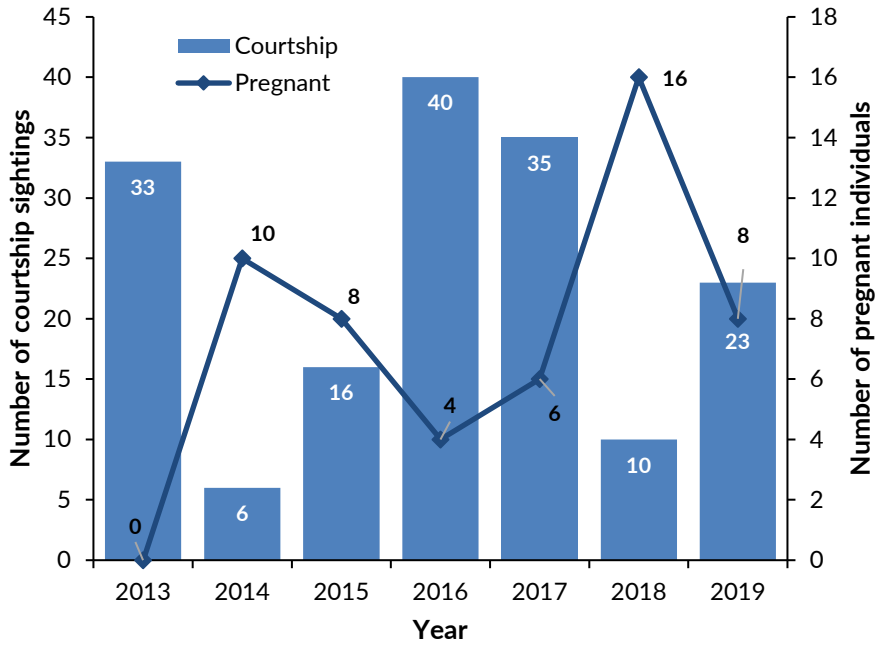

Figure 25: Number of reef manta ray (*Mobula alfredi*) sightings where courtship was the predominant behaviour observed annually in North and South Malé Atolls, and the total number of pregnant females recorded in that same year.

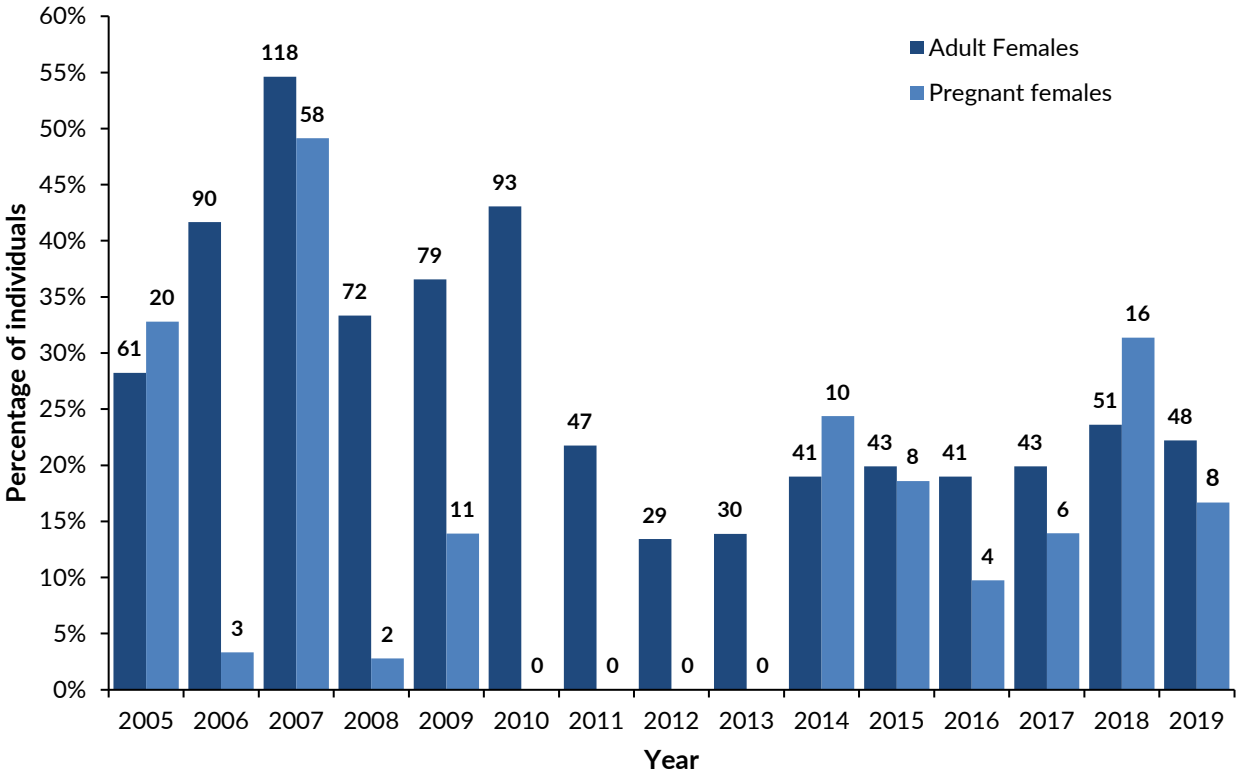

Figure 26: Percentage of the total adult female reef manta rays (*Mobula alfredi*) identified regionally which were sighted annually in North and South Malé Atolls, and the percentage of those females that were recorded pregnant in the same year. Actual number of individuals above bars.

Sub-Lethal Injuries

Of the 823 individual reef manta rays recorded in the Male Region, 40% (*n*=328) have some form of sub-lethal injury. Within the NMA sub-population of reef manta rays (*n*=760), 2% (*n*=15) were recorded with a new sub-lethal injury in 2019 (Fig. 27). Overall, 16 separate injuries were recorded, 31% (*n*=5) of which were injuries caused from anthropogenic origins (e.g. fishing line entanglement, boat strikes, etc.), whilst 44% (*n*=7) were naturally caused injuries (e.g. predatory bites, diseases, deformities, etc.). The remaining four sub-lethal injuries originated from an unknown source (Fig. 27). Within NMA a higher proportion of adult manta rays had these new injuries, compared to juveniles (Fig. 27). This increase in instances of injuries to the adults is unsurprising, as these individuals are sighted more frequently and visit sites on the outer reefs and channel where they are exposed to sharks and possible fishing pressure. Comparatively, 3% (*n*=3) of the SMA reef manta ray population (*n*=107) were recorded with a new sub-lethal injury in 2019, with a total of three separate injuries recorded. However, injury origins differ slightly; with 66% (*n*=2) of injuries arising from anthropogenic sources and the remaining (*n*=1) originated from an unknown source.

Of all manta injuries recorded in 2019, the most common body area inflicted by injuries in NMA (60%) are the manta ray's pectoral fins (*n*=9); a similar finding to other MMRP atoll study 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.

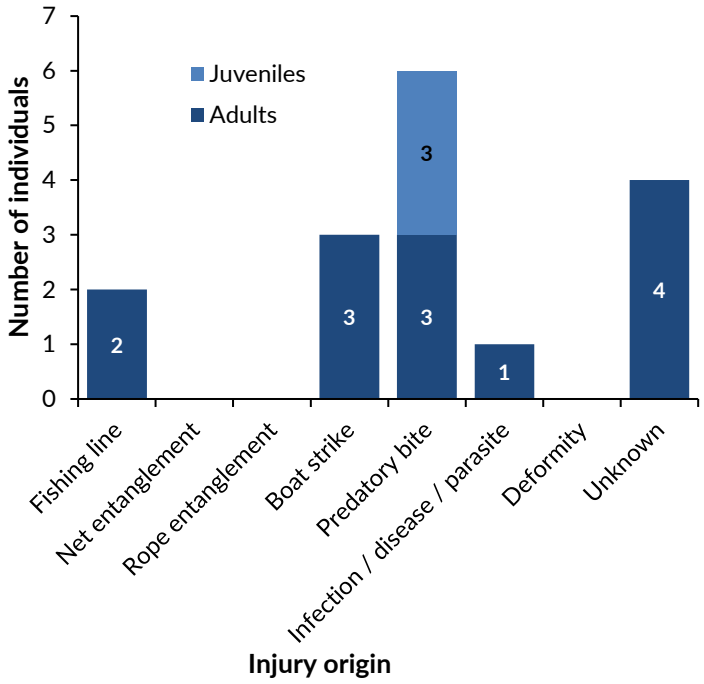

Figure 27: Demographic variations in the number of newly recorded sub-lethal injuries (*n*=16) within the North Malé Atoll reef manta ray (*Mobula alfredi*) population (*n*=760) in 2019, and the likely origin of the injuries.

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 abundance. Weather data for 2019 and previous years were sourced from the Maldives meteorological department and have been analysed together with sighting records to determine whether any correlation exist between manta ray sightings and wind speed. In 2019, average annual wind speeds (*n*=14.9km/h) decreased compared to previous years (*n*=15.5km/h), correlating with a decrease in the average number of manta ray sightings per survey (*n*=1.8) compared to 2018 (*n*=3.4) (Fig. 28). This correlation of fewer sightings and decreased wind speeds follows the trend witnessed in previous years.

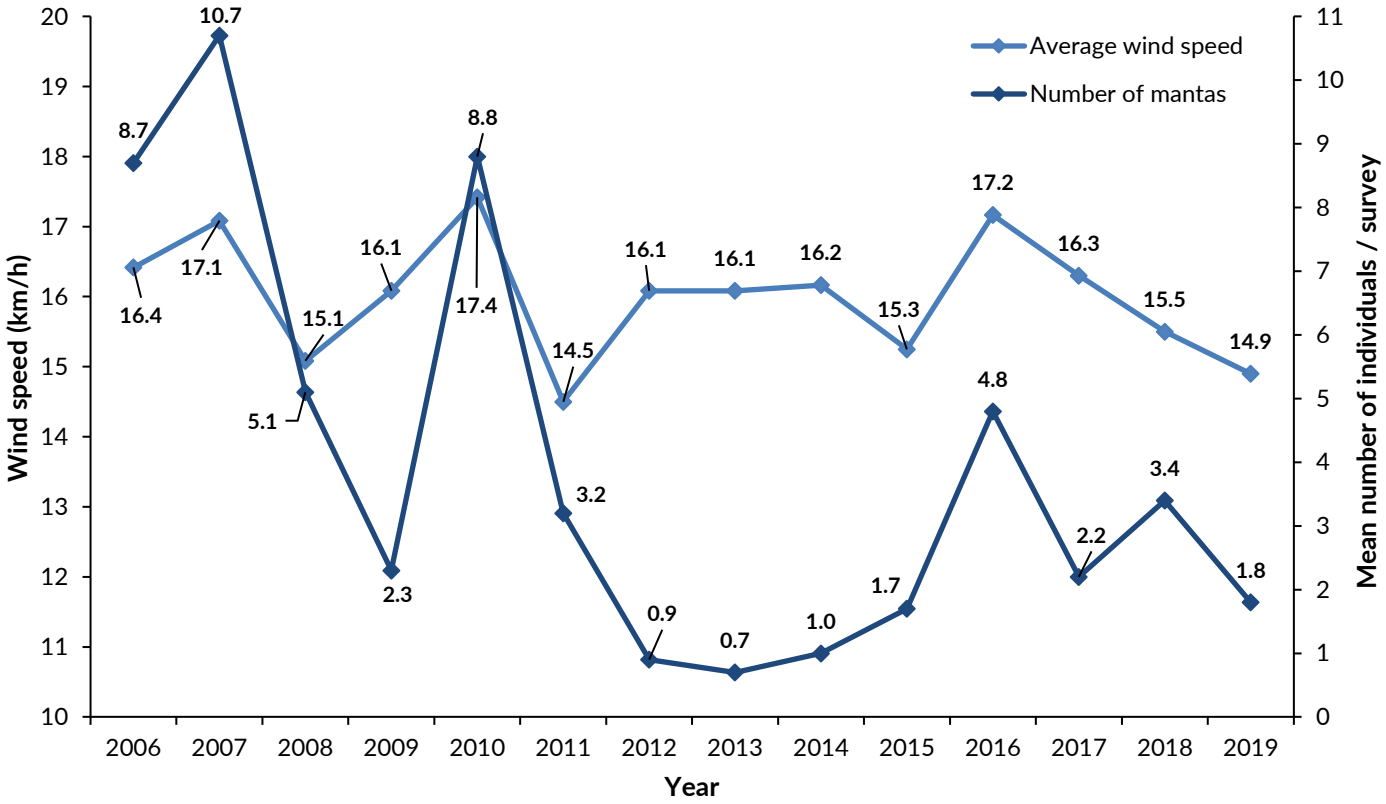

Figure 28: Annual mean wind speed (km/h), and the mean number of reef manta ray (*Mobula alfredi*) sightings per survey in North and South Malé Atolls.

Closer examination of wind speed and manta ray activity towards the end of 2018 and throughout 2019 shows that wind speed began to rise towards the end of 2018, increasing from 11km/h in November to 14km/h in December 2018, and reaching a high of 21km/h during the month of January in 2019. January was also one of the months with the highest number of manta ray sightings recorded per survey (*n*=3.6) during 2019 (Fig. 29). The spike in wind speed noted in January was followed by a marked drop in speed, reaching an average of 11km/h during the months of March and April. This was met by an associated drop in average manta ray sightings (*n*=1.8 and *n*=1.4 sightings per survey during the months of March and April respectively) (Fig. 29).

With the onset of the Southwest monsoon, wind speed escalated during the month of May (16km/h) and remained relatively stable until September when another dip in the average speed was recorded (12km/h) (Fig. 29). This contrasts with previous years, where wind speed is seen to remain steady or increase during the second half of the Southwest Monsoon (August-November) (Fig. 30). In general, sightings of reef manta rays within the Maldives tend to increase one or two months after stronger wind speeds, which generate increased primary productivity, and in turn leads to increased localised zooplankton prey for manta rays. Although a slight increase was recorded in the average number of manta ray sightings between the months of July to November 2019, this was still relatively

low compared to previous study years. As a force acting in combination with increased wind speed, it may be pertinent for wind direction to dominate from west or south westerly direction thereby influencing the favourable conditions which result in an increase in manta ray sightings during these months of the Southwest Monsoon.

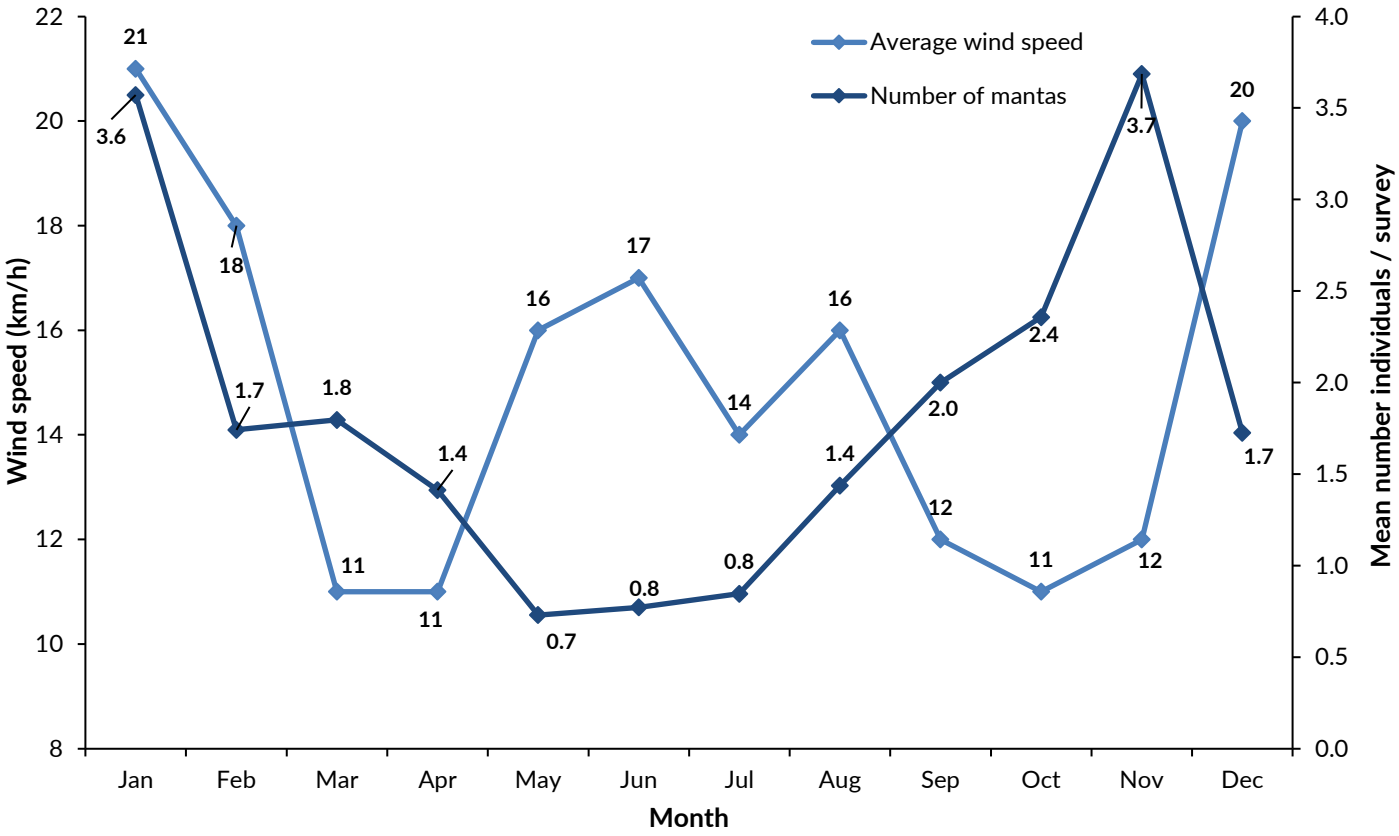

Figure 29: Monthly mean wind speed (km/h), and the mean number of reef manta ray (*Mobula alfredi*) sightings per survey in North and South Malé Atolls during 2019.

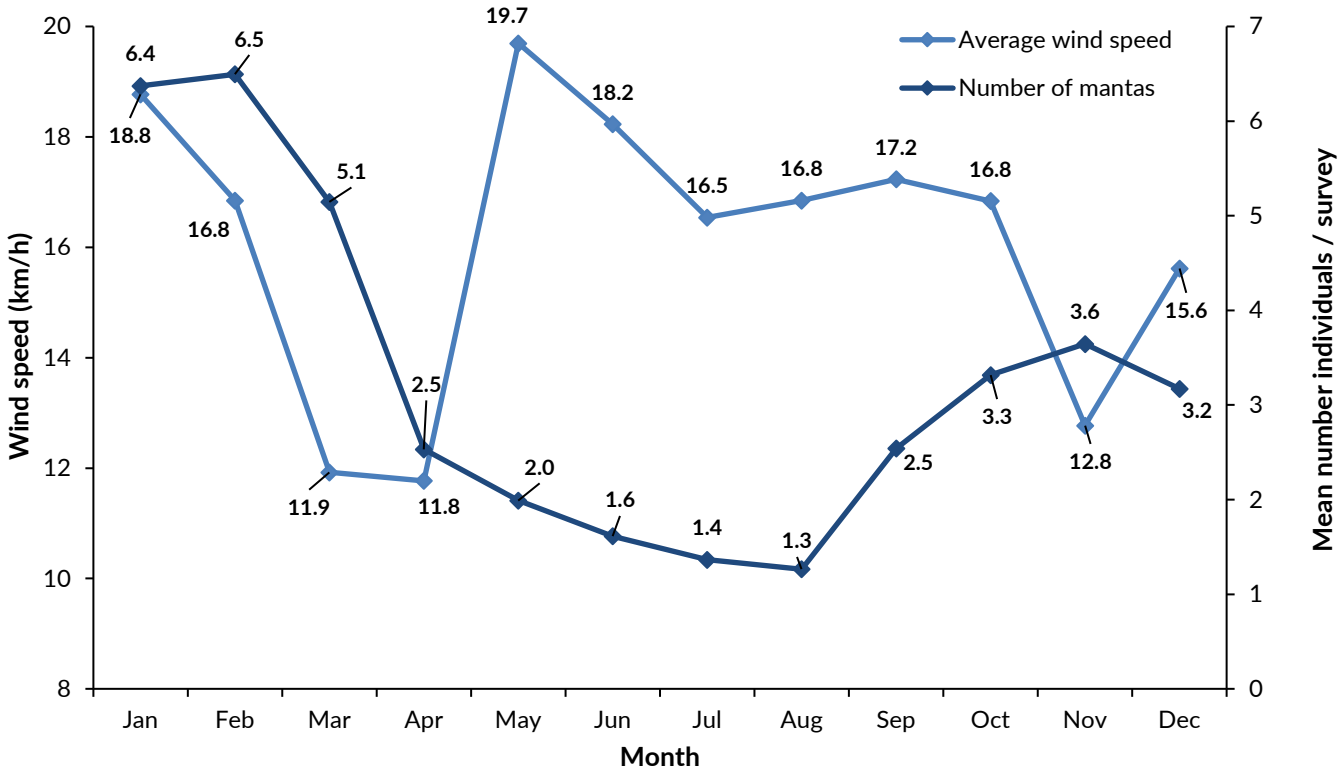

Figure 30: Monthly mean wind speed (km/h), and the mean number of reef manta ray (*Mobula alfredi*) sightings per survey in North and South Malé Atolls during (2006-2019).

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' movements and habitat use. In order to further determine any correlations between current direction and a given behaviour, survey data from 2019 included the variables current direction, current speed and observed primary behaviour. Out of the 385 surveys recorded in 2019, manta rays were present on seventy-four percent (*n*=284) of surveys. On fifty-six percent of these surveys (*n*=160), the current was outgoing, during which time the predominant behaviour observed (60%) was cleaning (*n*=96) (Fig. 31). In contrast, on the fewer occasions when feeding behaviour was recorded in 2019 (*n*=40), it was primarily noted on an outgoing current (Fig. 31).

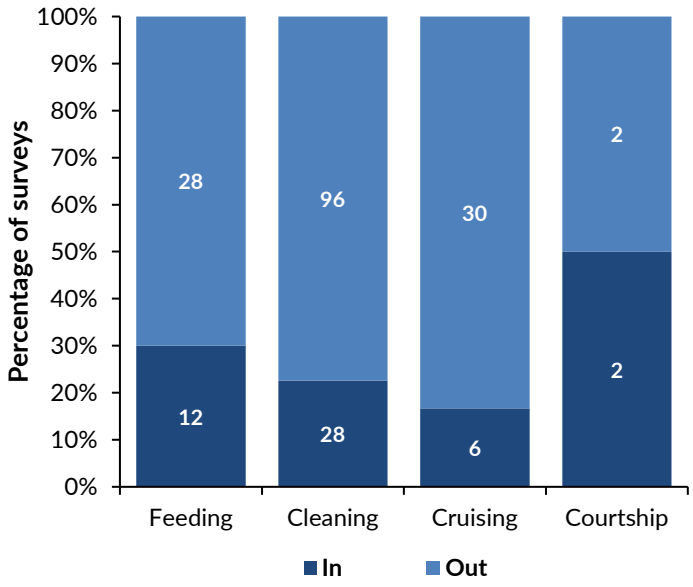

Figure 31: Changes in behavioural activity of reef manta rays (*Mobula alfredi*) in relation to current direction (In, Out) through the channels of North and South Malé Atolls during 2019 surveys (*n*=385).

MANTA RAY TOURISM & MARINE PROTECTED AREAS

The Malé Region is one of the nation's most popular tourist destinations, with numerous visitors snorkelling and diving during their stay, hoping to see marine megafauna, such as manta rays. During surveys, the MMRP collected data on anthropogenic pressures. The average number of boats recorded per survey has steadily increased over the years. In 2019, there were slightly less snorkellers/divers and boats recorded per survey compared to 2018, but tourist pressure remained consistent or slightly higher than all years prior to 2018 (Figs. 32 & 33). This drop in snorkeller/diving pressure and boat traffic noted between 2018 and 2019 may be attributed to surveys being undertaken by MMRP staff at less known manta ray aggregation sites which are further away from resorts and guesthouses.

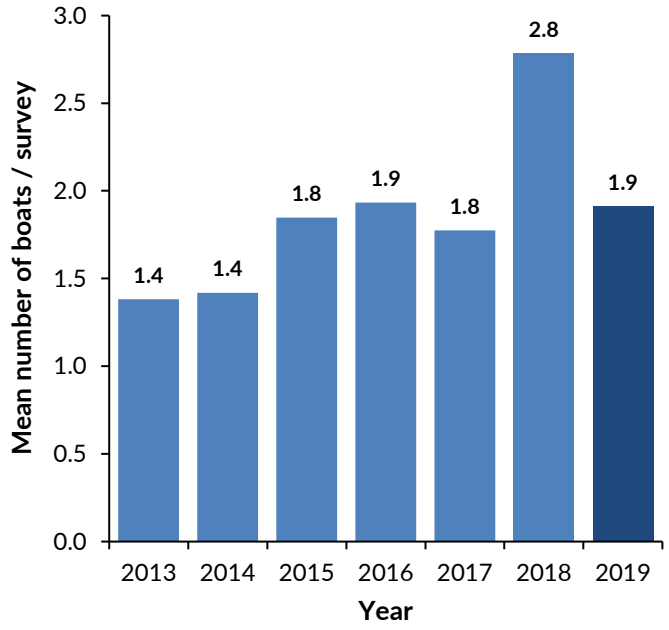

Figure 32: Mean number of tourism vessels per survey (*n*=2,080) in North and South Malé Atolls.

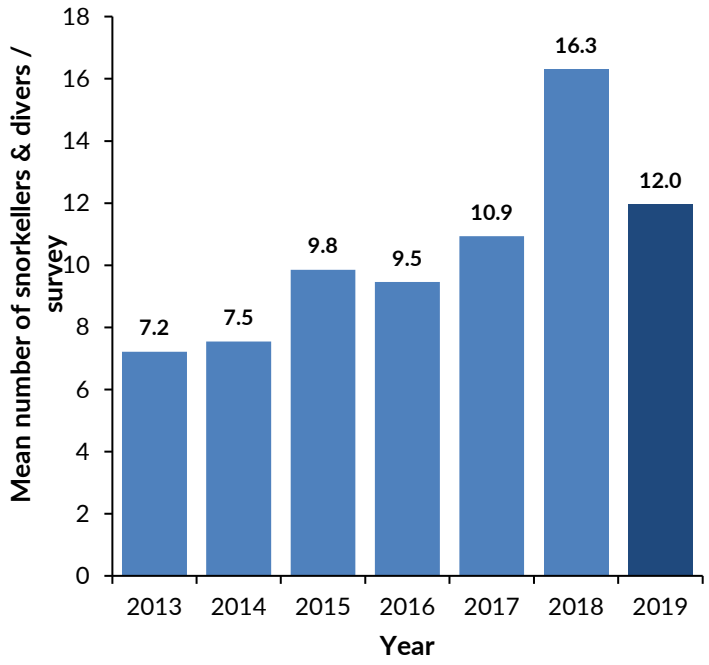

Figure 33: Mean number of snorkellers and divers per survey (*n*=2,080) in North and South Malé Atolls.

The tourist pressure noted at the original key manta aggregation sites highlights the importance of these areas to the Maldivian economy and emphasises the need for proper protection and tourism management. To date, the two most popular and famous destinations for swimming with manta rays in NMA are Rasfari North; a designated Marine Protected Area (MPA), and Lankan Beyru; which is not afforded protection in any way. During 2019, survey data on anthropogenic pressures were collected for the second year within Rasfari MPA (as well as Boduhithi Thila) (Fig. 34).

The MPA of Rasfari is relatively large (25km²), encompassing both the uninhabited island of Rasfari, and all surrounding reef and lagoon areas. However, while protected on paper, there is no management plan for this site, which is an increasing concern. Especially at the northern area of this MPA, where adult manta rays aggregate to feed, clean and mate (at Rasfari North and Boduhithi Thila). Rasfari North is a shallow reef crest (2-5m), which allows for spectacular, up-close encounters with cleaning and courting manta rays for both snorkellers and SCUBA divers, attracting thousands of tourists to the area each year. In 2019, an average

of 3.6 boats, 19.1 snorkellers, and 1.2 SCUBA divers were recorded per survey at Rasfari North (Fig. 34). The presence of SCUBA diving activity at this site is of particular concern, due to increased disturbance on top of the manta ray cleaning station by the divers. Rasfari MPA would benefit from being a snorkelling-only zone. Moreover, with no management plan in place to regulate tourism at this site, there are unsustainable levels of pressure on the aggregating rays. Jet skis, speedboats and sea scooters (Sea-bobs) regularly drive over the top of cleaning manta rays, and in some instances motorised vessels are used to "herd" manta rays back in the direction of guests. Tourists also touch and chase the rays on a regular basis. In addition, there is no effort to prevent fishing inside these areas, further threatening the rays as a result of bycatch entanglement.

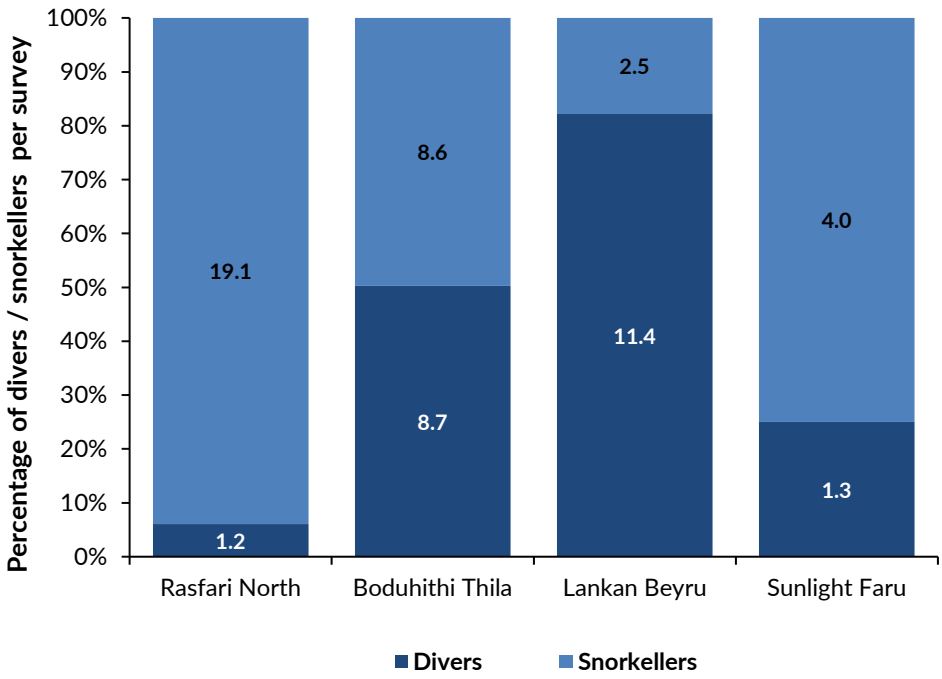

Figure 34: Variation in the mean number of snorkellers and SCUBA divers present per survey (*n*=250) at four key reef manta ray (*Mobula alfredi*) aggregation sites in North Malé Atoll during 2019. Actual numbers within bars.

Due to their close proximity to Malé, and reliability of sightings, Lankan Beyru (and Sunlight Faru) are also among the most visited (and most famous) manta ray aggregation sites in the world, yet some of the least protected. In 2019, an average of 2.4 boats, 2.5 snorkellers, and 11.4 SCUBA divers were recorded per survey at Lankan Beyru (Fig. 34). This high level of diving activity at this site is a major cause for concern because of the importance of this aggregation site to the reef manta ray population. With hundreds of divers visiting this site daily during the 'manta season', no regulations on the number of divers or boats, no site use regulations or enforcement thereof, and constant boat traffic above the cleaning station area, there are likely to be devastating implications for the long-term health of this population if these activities remain unmanaged.

Manta tourism from guests based in local guesthouses, resorts, and on dive liveaboard boats, generates an estimated $15 million USD annually. However, if tourism pressure continues to increase, manta rays will be more heavily subjected to anthropogenic related injuries, such as boat strikes, and it is possible that they will be forced to abandon these disturbed aggregation areas. In response to the growing interest in manta ray 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 that 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 the Malé Region and throughout the Maldives.

NORTH MALÉ ATOLL MARINE EDUCATION PROGRAMME

The first Manta Trust marine education programme "Moodhu Madharusaa" was conducted in NMA in 2019. The MMRP team on Meeru Island was able to conduct a 20-hr education programme at Dhiffushi School. Eight sessions were run, involving 24 students in grades nine and ten, and included a combination of classroom-based theory sessions and practical training through interactive games activities and field trips. The programme was run with the aim of increasing students' understanding of, and engagement with, their local marine environment, and inspiring them to work to conserve their island and local reefs. Programme topics included the basic biology and ecology of Maldives marine ecosystems and locally prevalent marine megafauna, the climate crisis understanding and awareness, waste and pollution, and conservation actions that students can implement to take care of their island environment. In addition, practical sessions (creating re-useable bags), and field trip activities (three snorkelling sessions and an island clean-up), served to increase student engagement and give students a chance to see the ecosystems and issues discussed during the classroom sessions. For some students this was their first time to experience snorkelling and many gained in-water confidence throughout the snorkelling sessions. Following the programme's final exam, the three top scoring students were awarded the prize of Discover Scuba Diving with EuroDivers on Meeru Island.

The Manta Trust was also pleased to host the students of Dhiffushi School at the 2019 Baa Manta Festival, held on Eydhafushi Island, Baa Atoll. This festival served as a perfect addition to the eight-session programme and gave students additional chances to learn about the marine conservation efforts throughout the Maldives. The MMRP is extremely grateful to Meeru Island Resort & Spa, EuroDivers Maldives, and the Dhiffushi School teachers, administration, students, and parents, without whom the programme would not have been possible.

This report was made possible thanks to

EURO DIVERS MALDIVES AT MEERU ISLAND RESORT

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

MALDIVES GOVERMENT 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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