Manta TRUST

Maldivian Manta Ray Project

North & South Malé | Atoll Report 1987 - 2017

Conservation through research, education, and colloboration

- 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 globally healthy marine ecosystems.

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 4,750 different individual reef manta rays, from more than 60,000 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 over 700 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 Maldivian Manta Ray Project predominantly on the reef manta ray (*Mobula alfredi*) population of North and South Malé Atolls from 1987 to 2017. Data used in this report was collected by Maldivian Manta Ray Project staff and volunteers, 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 rays frequent these waters throughout the year, with intra-annual peaks in sightings occurring towards the end of the Southwest Monsoon (September-November) at sites along the eastern edge of the atolls, and during the months of January through March during the Northeast Monsoon on the western edge of the atolls. Key findings of this study include a total of 7,084 sightings of 739 individual reef manta rays (17% of the known Maldives population) recorded at 36 different sites throughout the two atolls. Four primary manta ray aggregation areas have been defined within the region, comprised of ten survey sites. Ninety-seven percent (*n*=6,859) of all sightings were recorded between 2006-2017, which was also recognised as a period of increased surveying effort. Throughout the survey period, 2016 saw the highest number of encounters, with 1,309 sightings of 255 different reef manta rays recorded within a single year. The second highest number of sightings were recorded in 2007; with 1,030 sightings of 292 individuals (the highest number of individuals to be recorded within a single year). In 2017, there were only 780 sightings of 228 individuals recorded in both atolls. This 2017 decrease from previous years correlates with an annual drop in average wind speeds, which most likely resulted in less upwelling, and less regional productivity, and therefore feeding opportunities for the manta rays.

Ninety-seven percent of all sightings (*n*=6,858) were recorded in NMA, where considerably more research effort was focused during this study. The NMA reef manta ray sub-population is comprised of 93% (*n*=685) of the total recorded regional population, while only 92 individuals (13% of the total recorded regional population) were documented in SMA during the study. The demographics of the NMA sub-population is split almost evenly between the sexes; with 49% (n=333) females, 51% (n=351) males, and only one individual for which the sex could not be determined. The majority (76%) of the NMA sub-population are mature adults (*n*=518), whilst only 16% (*n*=110) are subadults, and 8% (*n*=56) juveniles. By contrast, the SMA sub-population demographics exhibit a male bias; with 60% (*n*=55) males, and 40% (*n*=37) females. Furthermore, 56% of the recorded SMA sub-population is comprised of juveniles (*n*=20) and subadults (*n*=31), while only 44% (*n*=41) are mature adults.

Of the 739 individual reef manta rays recorded in the Malé Region, 88% (*n*=648) 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-one percent (*n*=279) and 73% (*n*=67) 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.

To date, courtship and mating behaviour has been documented in NMA a total of 76 times. Eighty-seven percent (*n*=66) of these events were recorded along the eastern side of the atoll, at either Lankan Beyru or Sunlight Faru. This behaviour was predominantly observed towards the end of the Southwest Monsoon (October-November), a period recognised throughout the Maldives as the peak reproductive season for manta rays. A total of 127 reef manta rays were recorded pregnant between 2005 and 2017 in the Malé Region. The highest number of pregnancies recorded during a single study year was in 2007, when 49% (*n*=58) of the mature females sighted during that year were observed pregnant. In contrast, only six individuals out of 43 adult females (14%) were observed pregnant throughout the Malé Region during 2017; consistent with the average number of recorded pregnancies documented over the three previous years. Furthermore, for four years from 2010-2013, no pregnancies were recorded anywhere throughout the Malé Region.

Tourism pressures in the Malé Region have increased over the years, with the number of snorkellers or divers, and tourism vessels, increasing steadily from 2013-2017. In response, the Manta Trust created a 10-step Code of Conduct (available in multiple languages). This "How to Swim with Manta Rays" initiative was launched in 2017 and has been readily shared with tour operators throughout the Malé Region and other atolls. The Maldives was the first country to see these interaction guidelines and briefing videos to be used by marine biologists and tour operators, making it a forerunner in initiatives to ensure more sustainable manta ray tourism.

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.

If manta rays are to continue to flourish in the Maldives, it is essential that effective management plans are created and implemented at all manta aggregation sites which are currently within MPAs. Furthermore, many new, and significantly much larger, MPAs are required in the Maldives to protect other key manta aggregation sites. These MPAs are urgently required to help mitigate the rapidly increasing pressures of tourism development, reef fishing, climate breakdown, and habitat destruction.

STUDY AREA & CHANGING MONSOONS

Located centrally within the Republic of Maldives' 26 geographical atolls, and encompassing the capitol 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 140,000 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 Malé during their visit. Virtually every island has been developed within the region, resulting in significant impacts on the terrestrial and marine ecosystems. NMA is geographically larger (1,565 km^2) and more populated than SMA (530 km^2); it is comprised of 76 islands and sandbanks (26 resorts and 8 locally inhabited islands), compared to 47 islands and sandbanks (21 resorts and 3 locally inhabited islands) 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 in close proximity to their plankton-rich feeding areas, and thus, will migrate seasonally to utilise feeding areas and cleaning stations on the monsoonal down-current edge of the atolls. Due to the seasonal migration patterns of the manta rays, research efforts are focused on the west side of the atolls during the Northeast Monsoon, and on the east during the Southwest Monsoon.

To date, reef manta ray sightings have been confirmed at 36 different sites within the Malé Region between 1987-2017. 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).

With the establishment of a new MMRP project base in NMA towards the end of 2017, it is hoped that a year-round presence will;

1.) help to develop our understanding of the manta ray populations frequenting this atoll,
2.) identify additional key aggregation sites, and
3.) assess the importance of these sites over subsequent years.

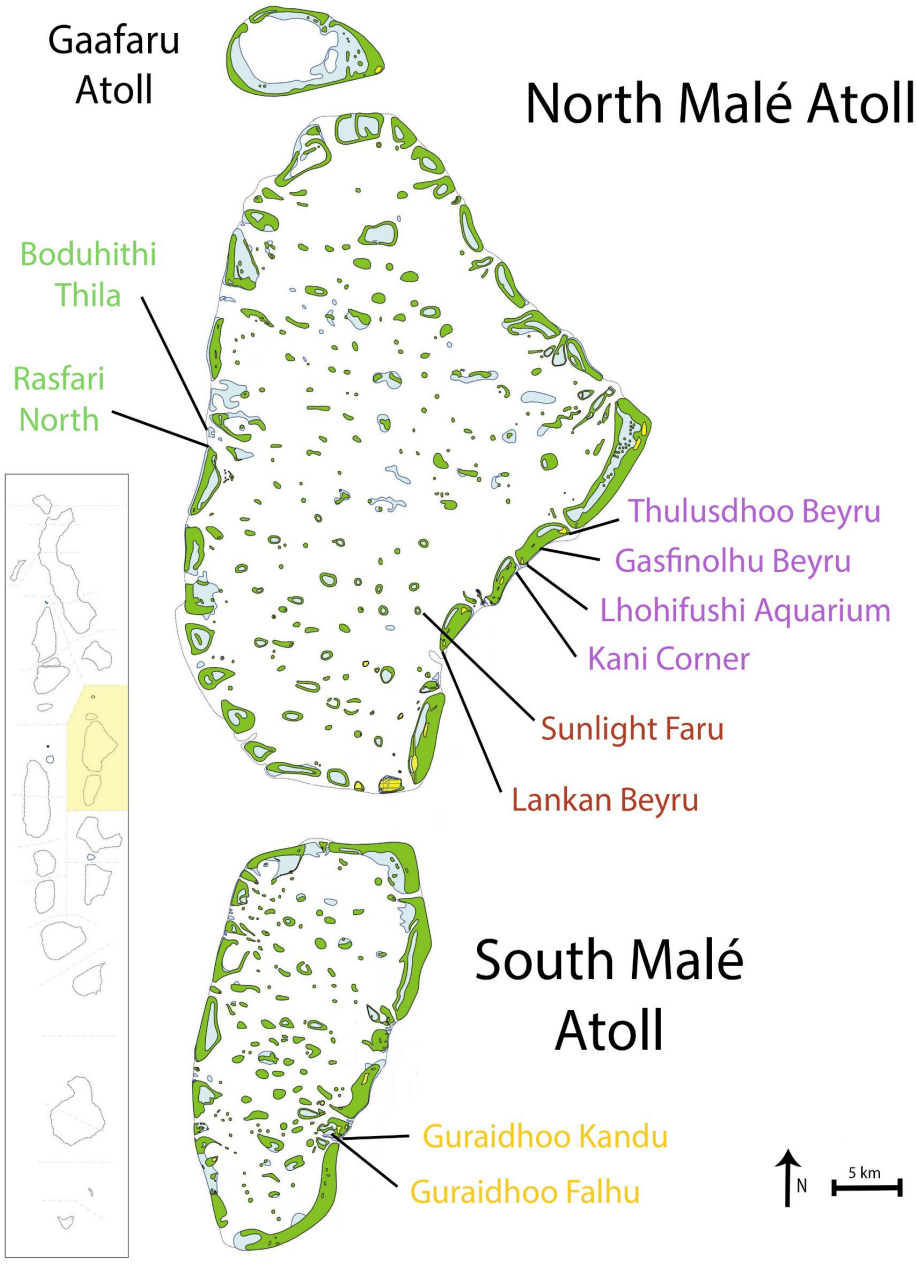


Figure 1: Map of North and South Malé Atolls showing ten of the key reef manta ray (*Mobula alfredi*) aggregation sites (colour-coded by four sub-regional areas) within the two geographical atolls.

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 Sunlight Faru	North Malé North Malé	East East	Channel Inner Reef	Adults
2	Kani Corner Lhohifushi Aquarium Gasfinolhu Beyru Thulusdhoo Beyru	North Malé North Malé North Malé North Malé	East East East East	Channel Channel Outer Reef Outer Reef	Juveniles
3	Rasfari North Boduhithi Thila	North Malé North Malé	West West	Channel Channel	Adults
4	Guraidhoo Falhu Guraidhoo Kandu	South Malé South Malé	East East	Inner Reef Channel	Juveniles

STUDY PERIOD & SAMPLING METHODOLOGY

1987-2005 Survey Period

Between 1987 and 2005, data on manta ray sightings were collected mostly through citizen science contributions. During this period, manta ray numbers and their prevalent behaviours (feeding, cleaning, cruising, *etc.*) were noted, as well as site location and water entry/exit times. Individual manta rays sighted underwater were documented by photographing the unique spot patterns on their undersides (ventral surface). After the foundation of the MMRP in 2005, photo-IDs from each sighting were submitted to the project for identification purposes. In the context of this report, a sighting is defined as a confirmed photo-ID of an individual manta ray on a given day.

Prior to 2006, only surveys resulting in a confirmed manta ray photo-ID sighting were recorded. It is unknown how many surveys were conducted annually prior to 2006. To prevent survey biased results during this time, sightings data from 1987-2005 has been excluded from certain parts of the report.

2006-2017 Survey Period

Between 2006 and 2017, sightings of manta rays throughout the Malé Region were recorded by both MMRP researchers and citizen scientists. From 2006 onwards, a more intense survey method was introduced, with the majority of data collected by MMRP researchers on as many days as conditions and logistical operations allowed. During each survey (*n*=2,518); location, wind speed, current direction, as well as other environmental weather variables were noted alongside manta ray numbers, and the manta's prevalent behaviours.

During this study period, peak surveying effort occurred during the months of June-November (Fig. 2). This increased effort was a result of a higher presence of MMRP staff in the region during the Southwest Monsoon months. The establishment of the Manta Trust's 'IDtheManta' initiative in 2012 resulted in an increasing number of ID-photos being submitted to the Manta Trust's database thereafter. Moreover, an increase in survey effort by MMRP staff and volunteers also occurred from 2013 onwards (Fig. 3). This increase in survey effort is a result of more resorts and dive centres collaborating with the Manta Trust to collect data during excursions. To account for changes in sampling effort, sightings data collected between 2006-2017 has been standardised where possible to allow for comparisons to be made between, and within, years.

During 2017, survey effort (*n*=355) was relatively consistent throughout the year, although decreases in the number of surveys occurred during May and December (the transitional months of change between the monsoons), when there is usually a reduction in manta sightings at all the key aggregation sites (Fig. 4). On the 15th September 2017, the MMRP expanded its research efforts to include a staff member based permanently on Meeru Island Resort and Spa in partnership with Euro-Divers Maldives. The establishment of a new project base on the east of NMA has expanded the project's survey effort, and increased monitoring at key manta sites throughout NMA. This new MMRP research base has resulted in the monitoring of a new manta ray aggregation site (Meerufenfushi Falhu) that attracts juvenile and subadult manta rays to feed during the Southwest Monsoon.

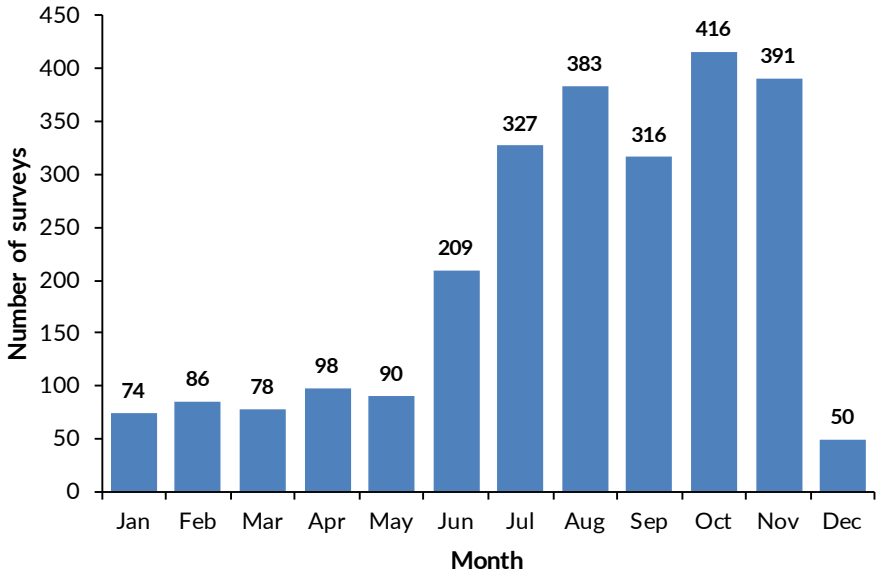


Figure 2: Number of surveys (*n*=2518) undertaken monthly in North and South Malé Atolls (2006-2017).

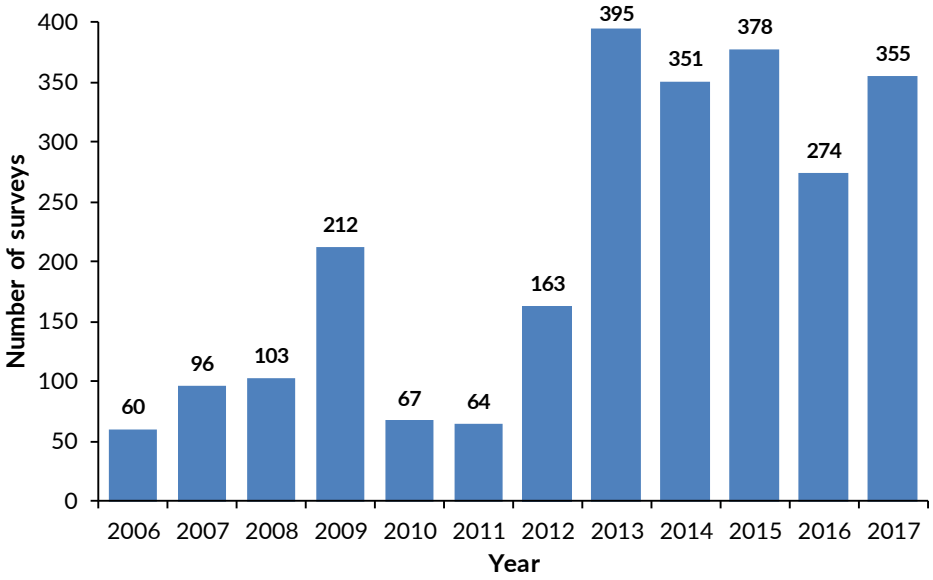


Figure 3: Number of surveys (*n*=2518) undertaken annually in North and South Malé Atolls.

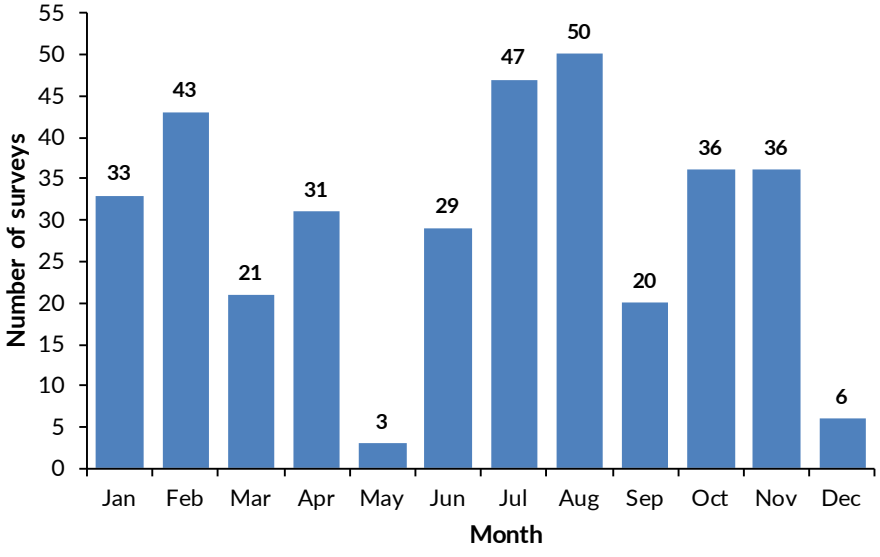


Figure 4: Number of surveys (*n*=355) undertaken monthly in North and South Malé Atolls in 2017.

Sighting Trends

A total of 7,084 sightings were recorded at 36 different sites throughout the Malé Region between 1987-2017. Ninety-seven percent (*n*=6,859) of these sightings were recorded between 2006-2017, which was also the period of significantly increased survey effort.

When standardised for effort, annual sightings of reef manta rays throughout the region have varied over the years (Fig. 5). This variation is likely due to the inter-annual changes in zooplankton abundance - if localised productivity is low during a certain season, manta rays may frequent other atolls where conditions may be more favourable. Throughout the survey period 2006-2017, the peaks in manta ray sightings were observed in 2007 (*n*=1,030), 2010 (*n*=592) and 2016 (*n*=1,309) (Fig. 5). Retrospectively, these three years were also recognised as years of high average wind speeds throughout the Maldives (see Environmental Variable section of this report). As reported in other MMRP reports, higher wind speeds generate increased primary productivity. Therefore, an increase in localised zooplankton abundance is a likely explanation for the increased number of manta ray sightings recorded in the region during these years. In 2017, there were a total of 780 sightings of 228 individuals recorded in the Malé Region. This decrease from the previous year also correlates with a drop in average wind speed.

A monthly breakdown of manta sightings across the survey years 2006-2017, when standardised for effort, show that mean number of individuals sighted per survey peaks annually during the Northeast Monsoon months of December-March, with another peak occurring during the Southwest Monsoon 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 2017 followed a more varied trend, although a noticeable drop in sightings was still observed mid-year during June/July, before peaking again towards the end of the year (Fig. 7). When accounting for survey effort, July produced the lowest average number of sightings per survey (*n*=14). During 2017, only 21% (*n*=161) of sightings were recorded by MMRP researchers or volunteer staff, whilst the majority (79%, *n*=619) were obtained through citizen scientist submissions. This highlights the importance of citizen science in increasing our understanding of the reef manta ray population in the Malé Region. However, more consistent monitoring by MMRP researchers in the future will hopefully help to better elucidate any trends in manta ray sightings frequency observed in the region.

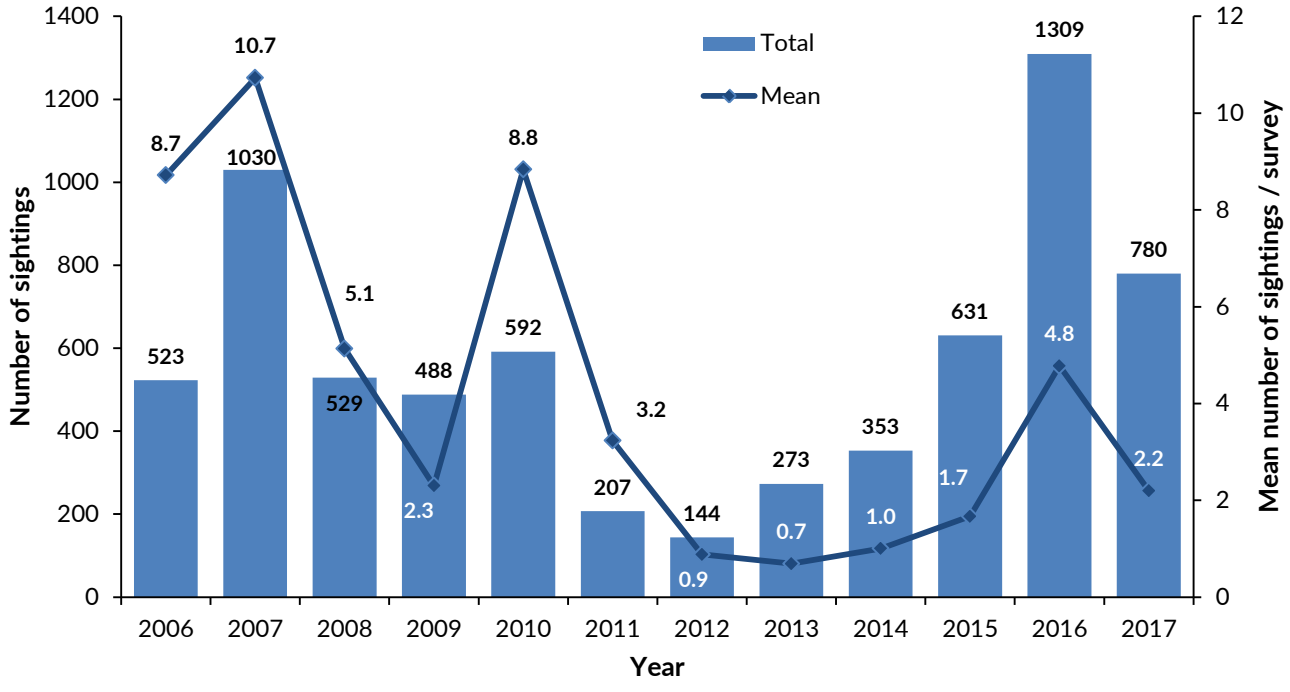


Figure 5: Total annual sightings of reef manta rays (*Mobula alfredi*) in North and South Malé Atolls, and the mean number of sightings per survey.

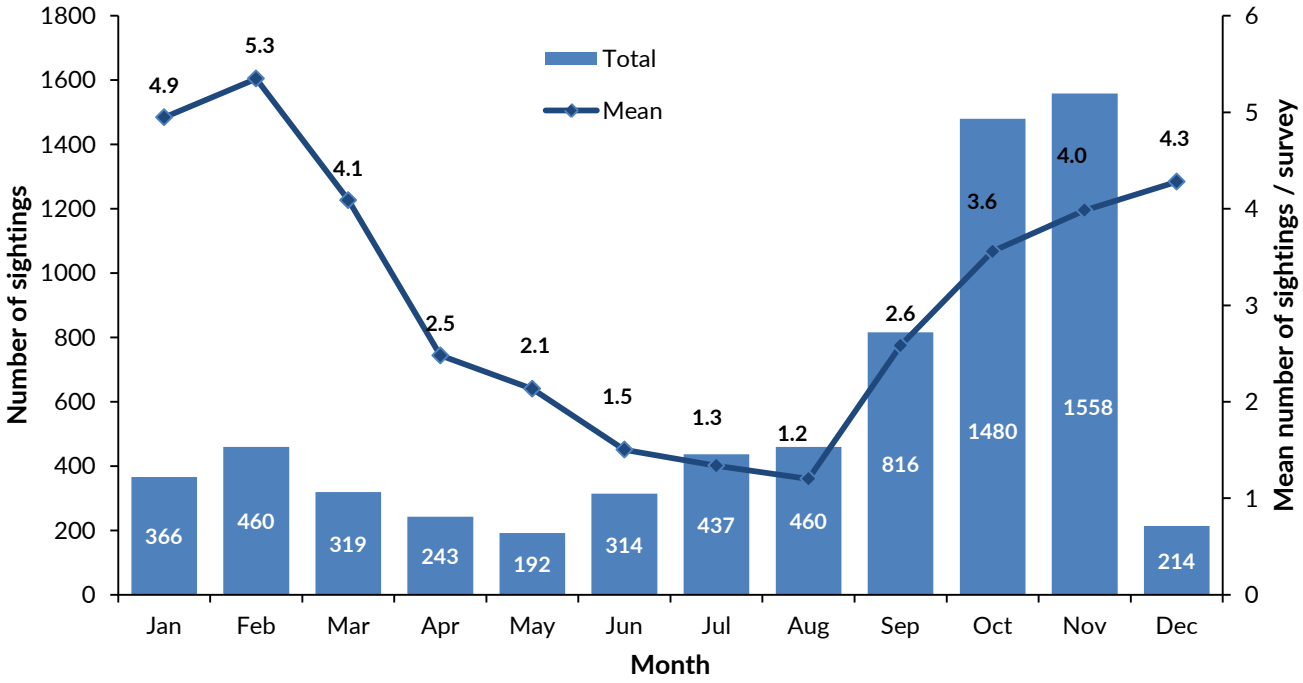


Figure 6: Total monthly sightings of reef manta rays (*Mobula alfredi*) in North and South Malé Atolls, and the mean number of sightings per survey (2006-2017).

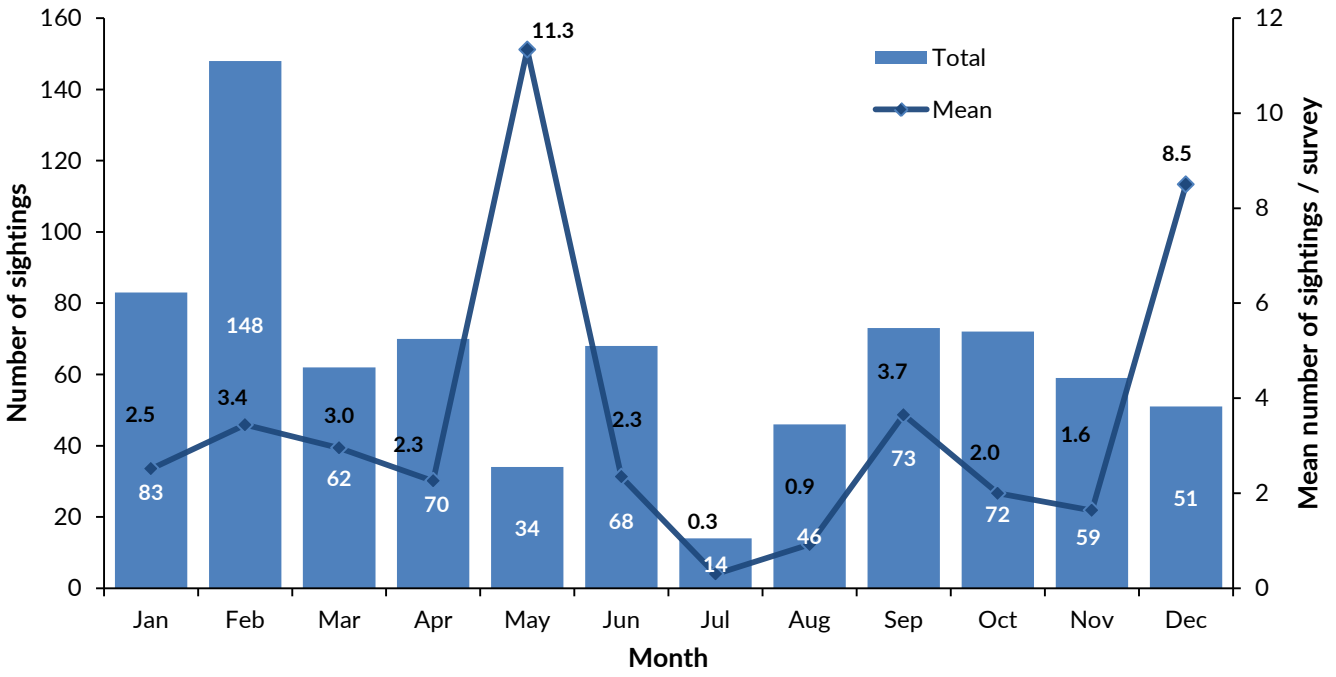


Figure 7: Total monthly sightings of reef manta rays (*Mobula alfredi*) in North and South Malé Atolls, and the mean number of sightings per survey during 2017.

Ninety-eight percent (*n*=6,938) of all sightings from 1987-2017 have been recorded from the ten key reef 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 and reef manta demographic groups (Table 1). Generally, intra-annual sightings between 2005-2017 peaked first during the months of January to April during the Northeast Monsoon at Rasfari and Boduhithi (Group 3), situated on the west of the atoll (Fig. 8). From May onwards, sightings at Rasfari North and Boduhithi Thila started to decrease, with a noticeable shift in manta activity to the eastern edge of the atolls as the manta rays move in response to the changing monsoon conditions. During this period, sightings gradually increase at Lankan Beyru and Sunlight Faru (Group 1), located on the east of the Atoll, peaking in October and November (Fig. 8). Cleaning stations (which are found at all four sites above) are focal areas for courtship and mating activity, and the later months of each monsoon are when this behavioural activity peaks in the Maldives, attracting the greatest number of adult reef manta rays to these cleaning stations.

The other two aggregation groups (Kani Kandu and Guraidhoo Falhu), which are predominantly utilised as feeding sites by sub-adult and juvenile reef manta rays, are located on the eastern edge of the atolls. Despite far fewer sightings in total than groups 1 and 3 between 2005-2017, sightings conform to a similar seasonal trend; peaking between July – November during the Southwest Monsoon, with little to no sightings recorded annually during the Northeast Monsoon (Fig. 8). Generally, this trend in aggregation site usage applies to all years. However, there is also a significant amount of inter-annual variation in reef manta ray sightings between and within these groups. The majority of sightings recorded between 2005-2017 occurred at the cleaning stations of Lankan Beyru and Sunlight Faru (*n*=5,998). At these sites, there was a significant peak in sightings during the years 2007 and 2016 (Fig. 9). These particular years are also recognised as having high recordings of courtship activity, confirming that these sites are reproductive aggregation sites. Sightings at Rasfari North and Boduhithi Thila also increased significantly from 2015 onwards. This increase is, at least in part, due to increased survey effort in recent years. However, as for Lankan Beyru and Sunlight Faru between 2011 and 2014, there was a large decrease in the number of sightings recorded annually. This period is recognised as a time of little/no pregnancies throughout the Maldives. Since these are key sites for courtship and reproduction this period of low reproductive activity may explain the decrease in sightings.

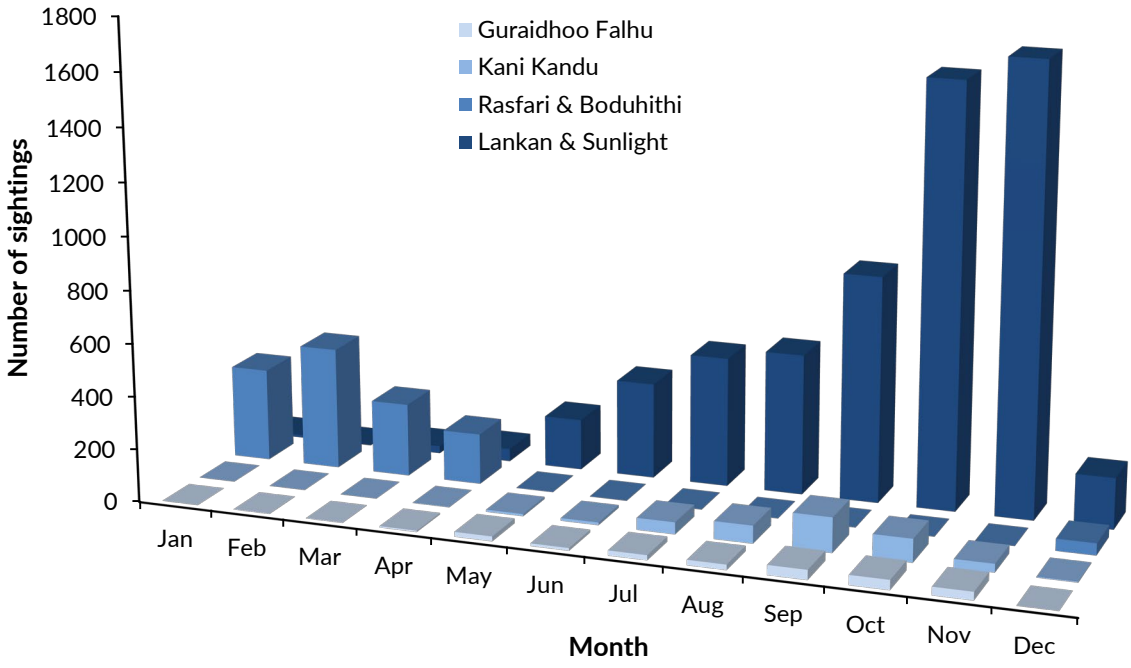


Figure 8: Intra-annual variations in sightings of reef manta rays (*Mobula alfredi*) in North and South Malé Atolls at four key manta aggregation areas (see Table 1) (2005-2017).

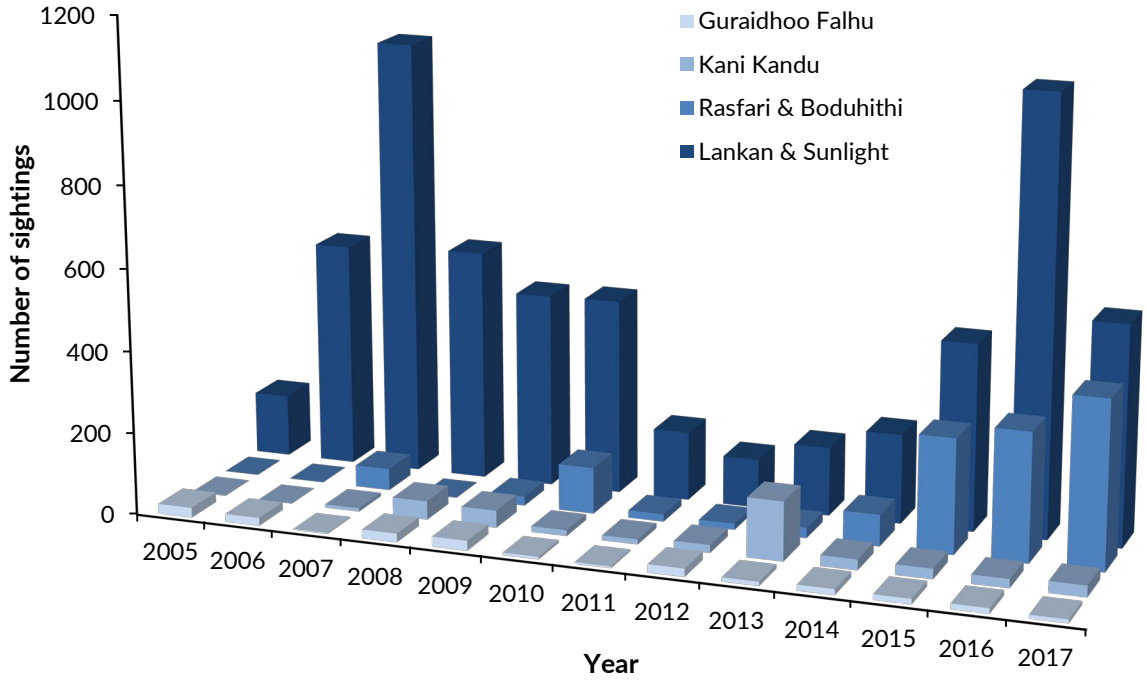


Figure 9: Inter-annual variations in sightings of reef manta rays (*Mobula alfredi*) in North and South Malé Atolls at four key manta aggregation areas (see Table 1).

Population Demographics

The current recorded population of reef manta rays in the Malé Region is 739 individuals, 17% of the total known Maldives population (*n*=4,445). Since the majority (98%) of sightings (*n*=6,858) were recorded in NMA between 1987-2017, 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 population of 685 individuals, accounting for 93% of the overall population in the region. The population demographics in NMA are split almost equally between the sexes; with 49% (*n*=333) females, 51% (*n*=351) males, and one individual for which sex could not be determined (Fig. 10). The population demographics in NMA were biased towards adults, with 76% (*n*=518) of individuals recorded as mature, while 16% (*n*=110) were subadults, and 8% (*n*=56) juveniles (Fig. 10).

In SMA, although the recorded reef manta ray population only consists of 92 individuals (13% of the regional population), the population demographics is different to that of NMA. There is a sex bias; with 60% (*n*=55) males, and 40% (*n*=37) females (Fig. 11). Furthermore, in contrast to NMA, 56% of the recorded population in SMA are immature; with 22% (*n*=20) recorded juveniles, 34% (*n*=31) subadults, and only 44% (*n*=41) recorded as mature adults (Fig. 11). This suggests that SMA supports important aggregation sites for juvenile manta rays- e.g. Guraidhoo Falhu, which is noted as a key juvenile feeding site within the atoll.

As expected, the proportion of newly sighted individual reef manta rays recorded annually has followed a downward trend over the study years as more of the Malé Region population is identified (Fig. 12). As the years have passed, and more data has been collected, sightings of new manta rays have become less frequent. To date, 88% (*n*=648) of the recorded Malé Region 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 2017, of the 228 recorded individuals within the Malé Region, only 32 were new sightings for this atoll. Two of these individuals were estimated to be young of the year, based on their small disk widths (~150 cm). Of the remaining 30 individuals, 13 had never been recorded anywhere else in the Maldives by the MMRP, while the remaining 17 individuals had previously been recorded in other atolls.

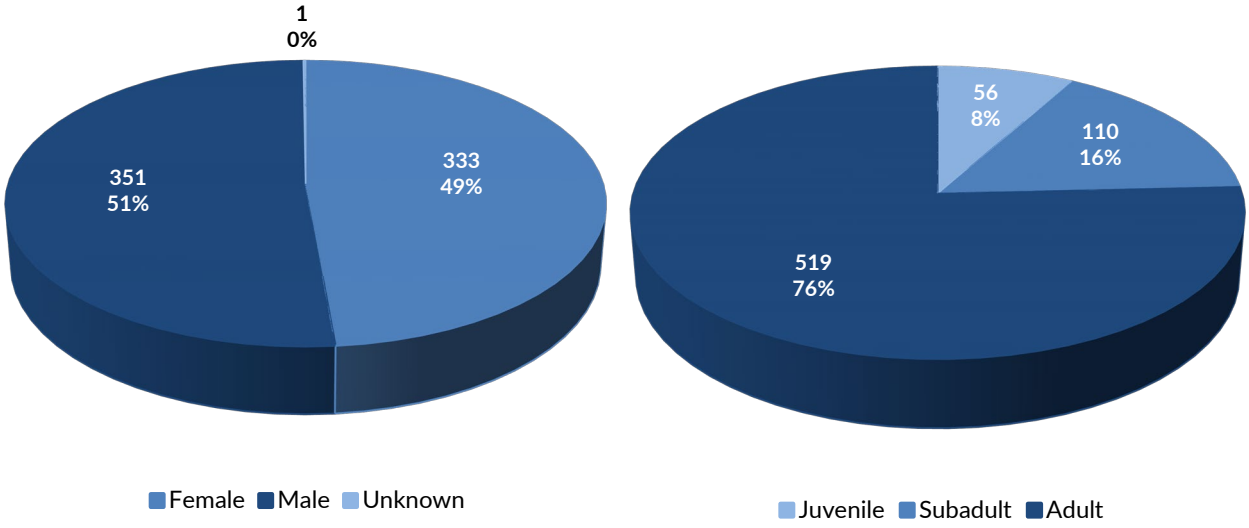


Figure 10: Demographics of the reef manta ray (*Mobula alfredi*) population (*n*=685) recorded in North Malé Atoll (1987-2017).

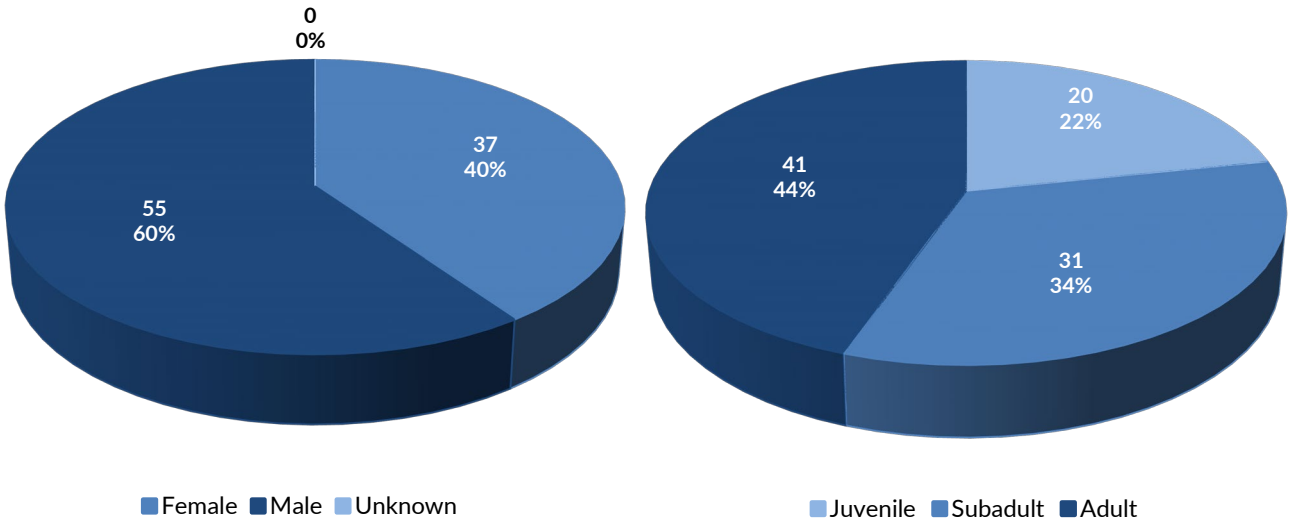


Figure 11: Demographics of the reef manta ray (*Mobula alfredi*) population (*n*=92) recorded in South Malé Atoll (1987-2017).

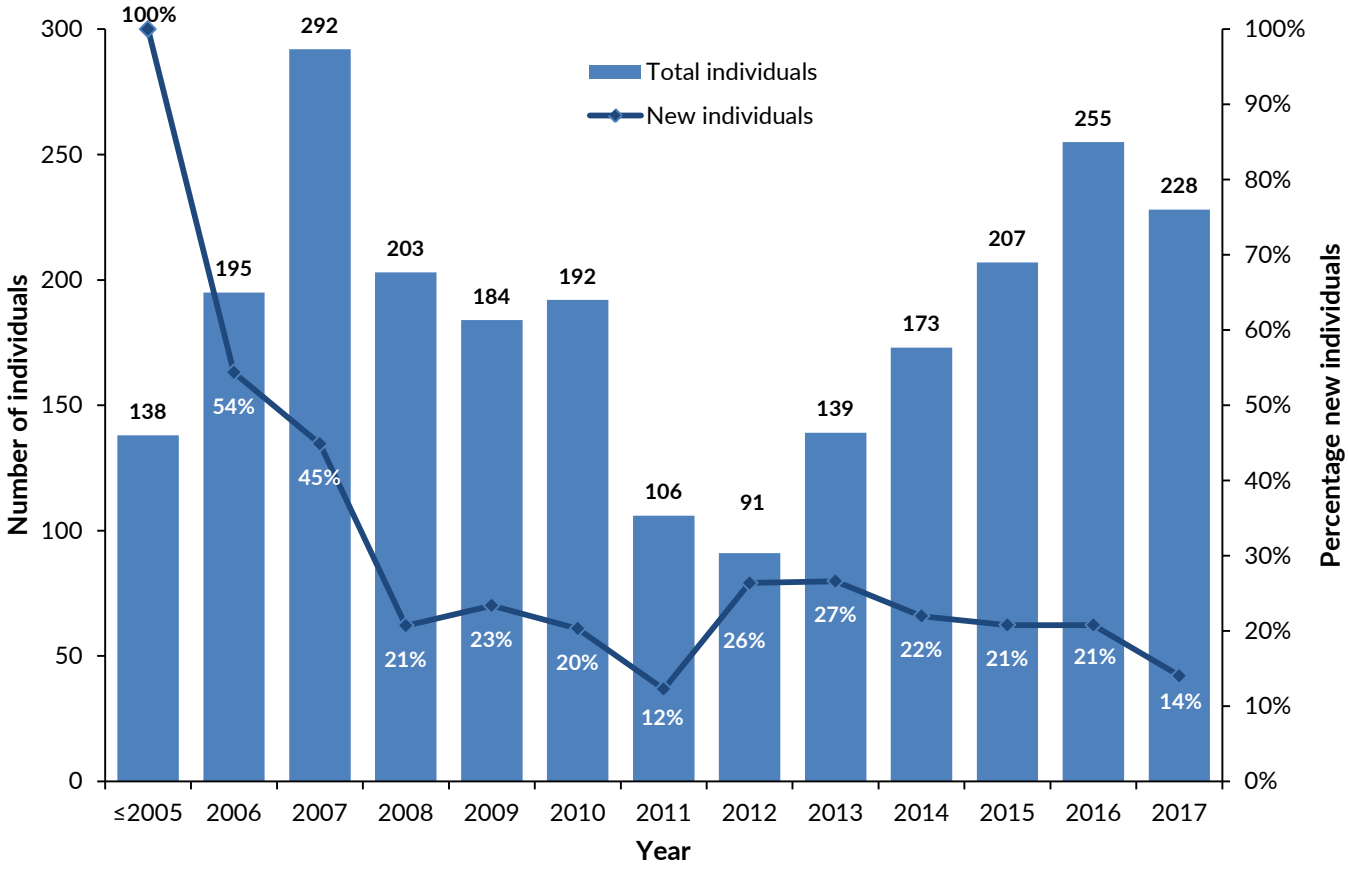
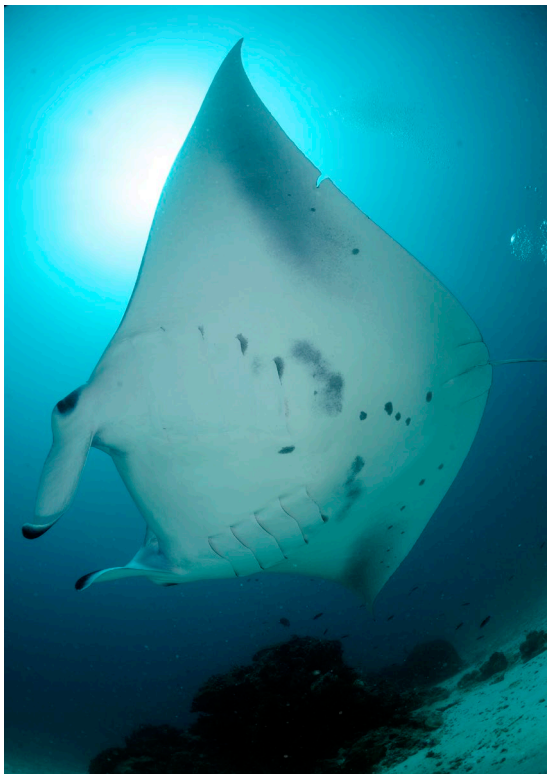


Figure 12: Total number of individual reef manta rays (*Mobula alfredi*) sighted annually in North and South Malé Atolls, and the percentage of those individuals which were newly recorded (1987-2017).

Inter-Atoll Migrations

Forty-one percent (*n*=279) and 73% (*n*=67) of the recorded reef manta ray sub-populations of NMA and SMA respectively have 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. The most common inter-atoll movement records occur between NMA, SMA, and those other atolls closest geographically to the study region. Topping the list of inter-atoll cross migrating records between NMA is Baa Atoll, with 149 individuals with sighting records in both atolls. Ari Atoll comes second, with 102 individuals. In total, reef manta rays that have been recorded in NMA have also been recorded in 14 other geographic atolls (including SMA) (Fig. 13). The recorded sub-population of reef manta rays in SMA are far more transient, with 73% (*n*=67) recorded in nine other atolls, including 38 from NMA (Fig. 14). 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.



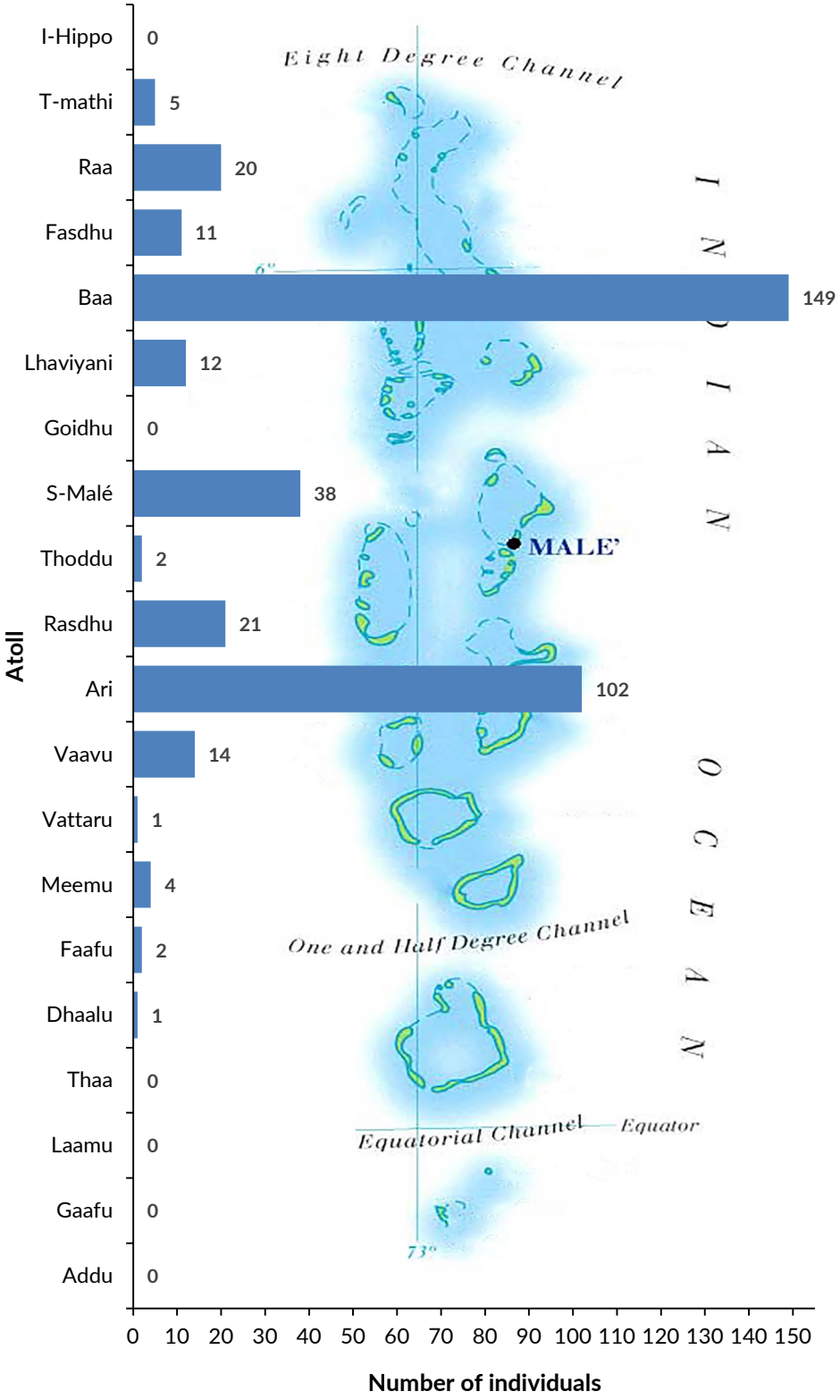


Figure 13: Number of reef manta rays (*Mobula alfredi*) (*n*=279) from within the North Malé Atoll population (*n*=685) which have been recorded in other atolls throughout the Maldives Archipelago. *Some individuals have been sighted in more than one atoll outside North Malé Atoll.

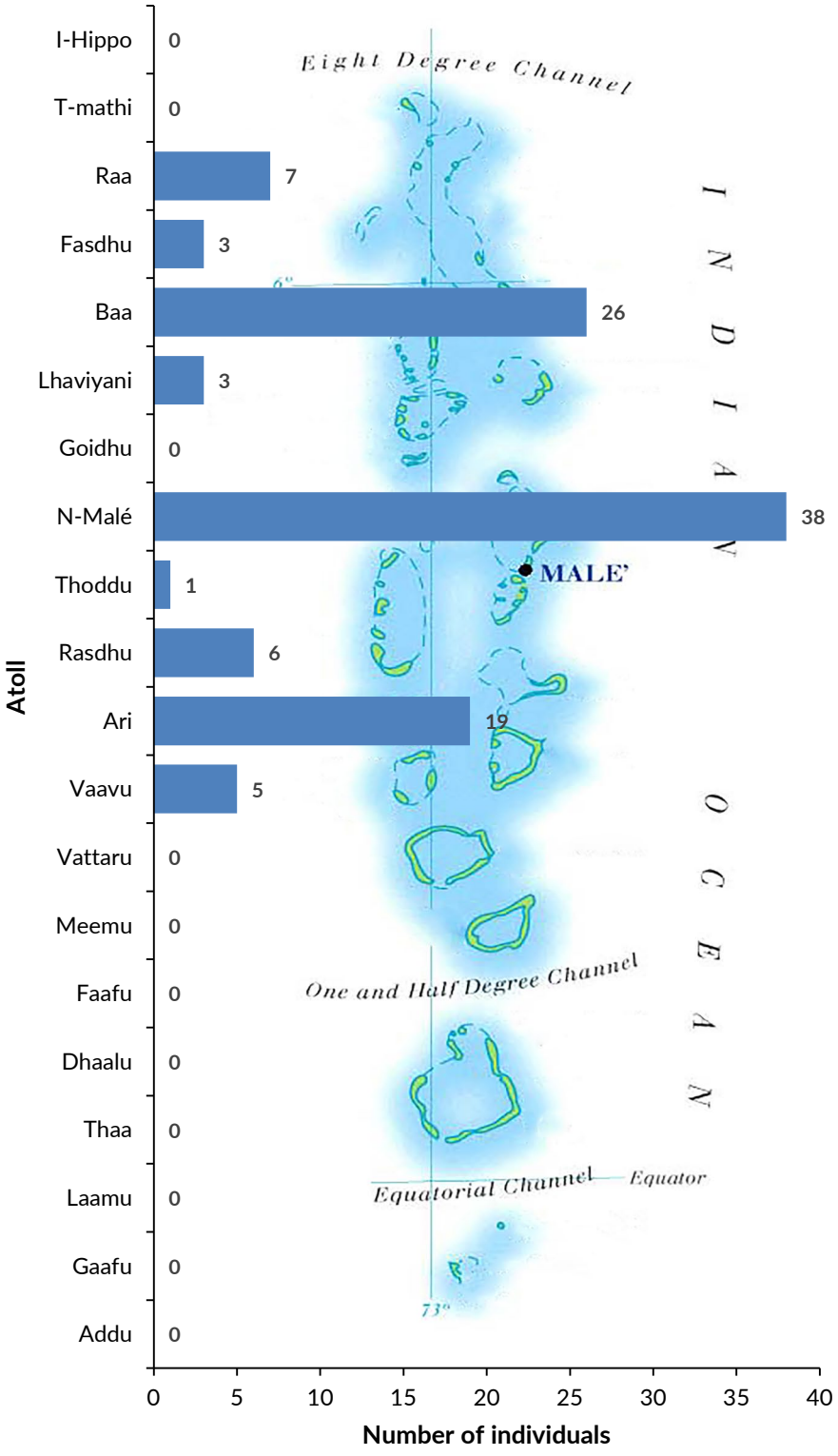


Figure 14: Number of reef manta rays (*Mobula alfredi*) (*n*=67) from within the South Malé Atoll population (*n*=92) which have been recorded in other atolls throughout the Maldives Archipelago. *Some individuals have been sighted in more than one atoll outside South Malé Atoll.

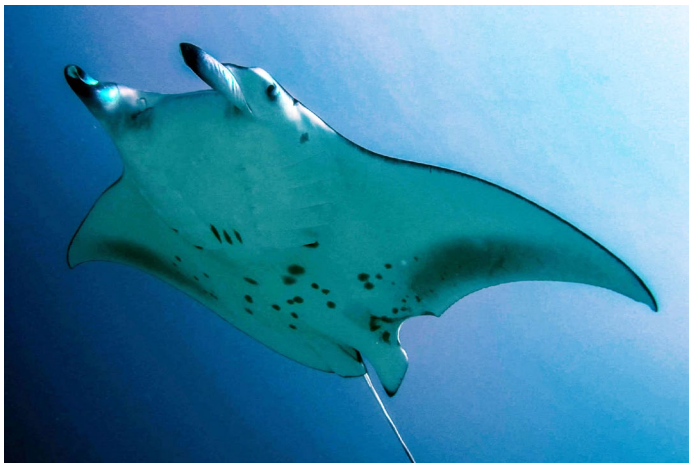
The high degree of migrations by individuals recorded travelling between the atolls is reflective of the wider population. With relatively small distances (10s km) between the atolls in the central and northern regions of the Maldives, and shallow maximum ocean depths (<300m) between most of these atolls, 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.

Site Fidelity

A large proportion (59%) of the reef manta ray sub-population of NMA (*n*=685) have never been recorded outside of this atoll, and 74% of this population (*n*=506) have been recorded on more than one occasion within the atoll. Sixty-nine individuals have been sighted more than 25 times during this study period within the atoll, and 21 individuals more than 50 times. Unsurprisingly, given the reduced survey effort and apparent lower residency rates within the atoll, there have been significantly less re-sightings of the recorded SMA sub-population (*n*=92); where only 47% (*n*=43) of the individual reef manta rays have been sighted on more than one occasion within the atoll. Furthermore, the maximum sightings for any individual within the atoll is 11, with only seven individuals having been sighted more than five times within the atoll. Indeed, only 27% (*n*=25) of the individuals recorded in SMA have been recorded only inside of this atoll.

Many individuals that exhibit high fidelity to the Malé Region also exhibit patterns of specific habitat use within the region, favouring specific sites. For example, MV-MA-0127 (Pelican) is an adult female reef manta ray that has been one of the most sighted individuals in NMA since 2006. To date, Pelican has been recorded a total of 145 times throughout the Maldives, but at only six different survey sites, all within NMA. The vast majority (77%) of these sightings have occurred at Lankan Beyru (*n*=112), while a further 24 sightings (17%) at Rasfari North. This individual spends a large amount of time close to Lankan Beyru during the Southwest Monsoon, and close to Rasfari North on the western edge of NMA during the Northeast Monsoon (Fig. 15). An adult male reef manta ray, MV-MA-0671 (Stumpie), exhibits a slightly different habitat use pattern; sighted 20 times since 2007, Stumpie also visits Lankan Beyru and Rasfari North in NMA. However, almost half (*n*=9) of his sightings have occurred in SMA at Guraidhoo Falhu (Fig. 15).

Site use also varies between the different life stages of the reef manta ray demographics. For example, juveniles and sub-adults are sighted more often inside the atolls in protected lagoonal areas, presumably as a predator avoidance strategy. As the individuals grow, they are sighted more in the channels and outer reef aggregations sites. All reef manta rays in the Maldives are grouped into four life stages (LS) based on their size (disc width, DW) and external indictors of sexual maturity (such as the presence of mating scars on females, or the calcification of the males' claspers). LS1=150-230 cm DW, LS2=240-260 cm, LS3=270-310 cm, and LS4=320-370 cm. Size at maturity varies between sexes, but on average female reef manta rays mature at about 320 cm (LS4) DW, while males mature at about 270 cm (LS3). All LS1&2 individuals are juveniles or sub-adults. Two individuals, MV-MA-0018 (Wendy), a female, and MV-MA-1627 (Weiner), a male, have been re-sighted within the Malé Region more than a dozen times since they were first documented as LS1 individuals in 2005 and 2009 respectively. During the initial years of their recorded sightings, both individuals were only observed in SMA at the juvenile aggregation sites of Guraidhoo Falhu and Olhuveli Falhu. Over the following decade, as these individuals grew into LS2 and then LS3 manta rays, both began frequenting the adult aggregation sites in NMA, such as Lankan Beyru (Fig. 16). By 2015, Weiner's claspers had fully calcified and he was considered to be a mature male, regularly sighted at Lankan Beyru during the Southwest Monsoon thereafter. In 2017, Wendy was still considered a subadult female, when she was sighted twice feeding in Guraidhoo Falhu, and twice at the cleaning station at Lankan Beyru (Fig. 16).



MV-MA-0018 (Wendy), a female manta first sighted in North Malé Atoll in 2005.

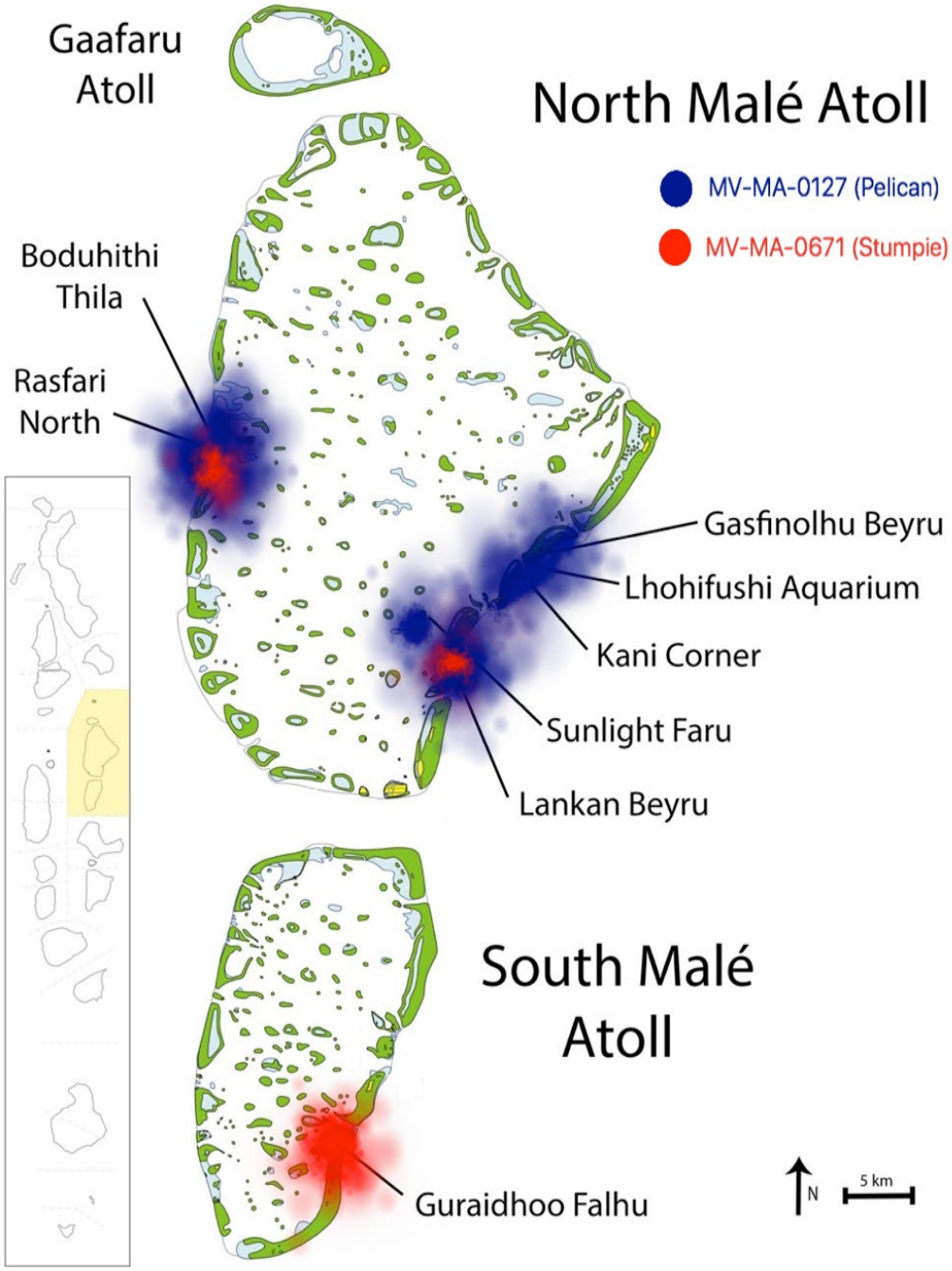


Figure 15: A heat map of the sightings (*n*=165) of two reef manta rays (*Mobula alfredi*) in North and South Malé Atolls between 2006-2017.

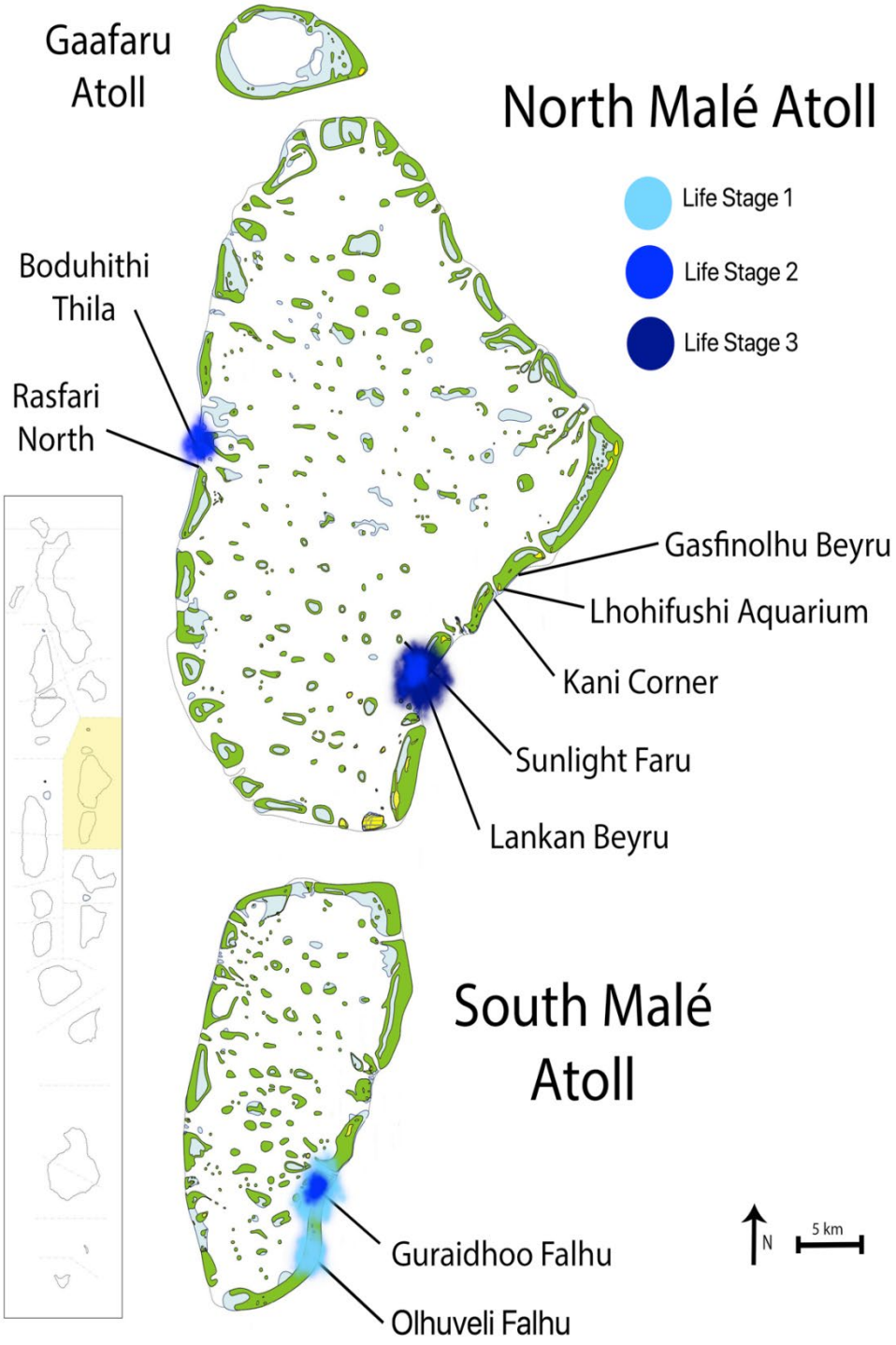


Figure 16: A heat map of the sightings (*n*=35) at each life stage of two reef manta rays (*Mobula alfredi*), MV-MA-0018 (Wendy) and MV-MA-1627 (Weiner), in North and South Malé Atolls between 2005-2017.

Without utilising more sophisticated tracking methodologies, such a telemetry studies, it is difficult to create a more detailed picture of how habitat use varies within the demographics, or the degrees to which 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 2017, each manta was observed on average 3.4 times within the Malé Region, a slight decrease compared to 2016 (*n*=5.1), but still higher than in most previous study years (Fig. 17). To account for variations in survey effort, an average Residency Index (RI) was calculated for each year post-2006 based on the ratio between the number of days each individual was sighted and the total number of surveyed days. Therefore, the RI of 4.6% calculated in 2010 highlights that, on average, each individual was sighted on 4.6% of the total surveys, the highest RI across all years (Fig. 18). In contrast, the RI result for 2017 (1%) is similar to that of all years from 2012 onwards, but considerably lower than all years prior (Fig. 18). It is unknown what has caused this decrease in residency rates in recent years, but hopefully increased surveying effort and the establishment of a permanent Manta Trust researcher within the atoll will help to identify an explanation for this trend. It is hypothesised that although manta rays might frequent the important cleaning sites during the courtship months, more favourable conditions elsewhere have attracted manta rays to neighbouring atolls in search of food. There is also the possibility that the level of development, resulting in increased boat traffic, and increased snorkeller and diver pressures at the manta ray's aggregation sites, has affected the rays' 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.

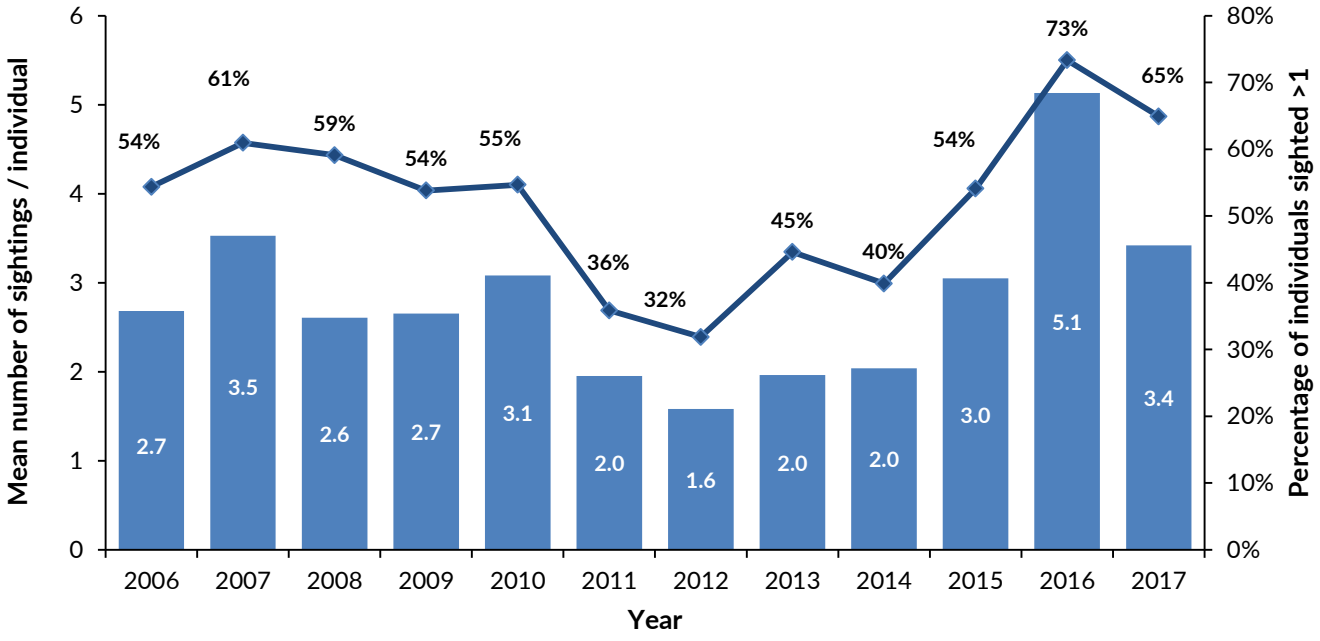


Figure 17: Mean number of sightings per individual reef manta ray (*Mobula alfredi*) in North and South Malé Atolls, and the percentage of individuals sighted on multiple occasions during the same year.

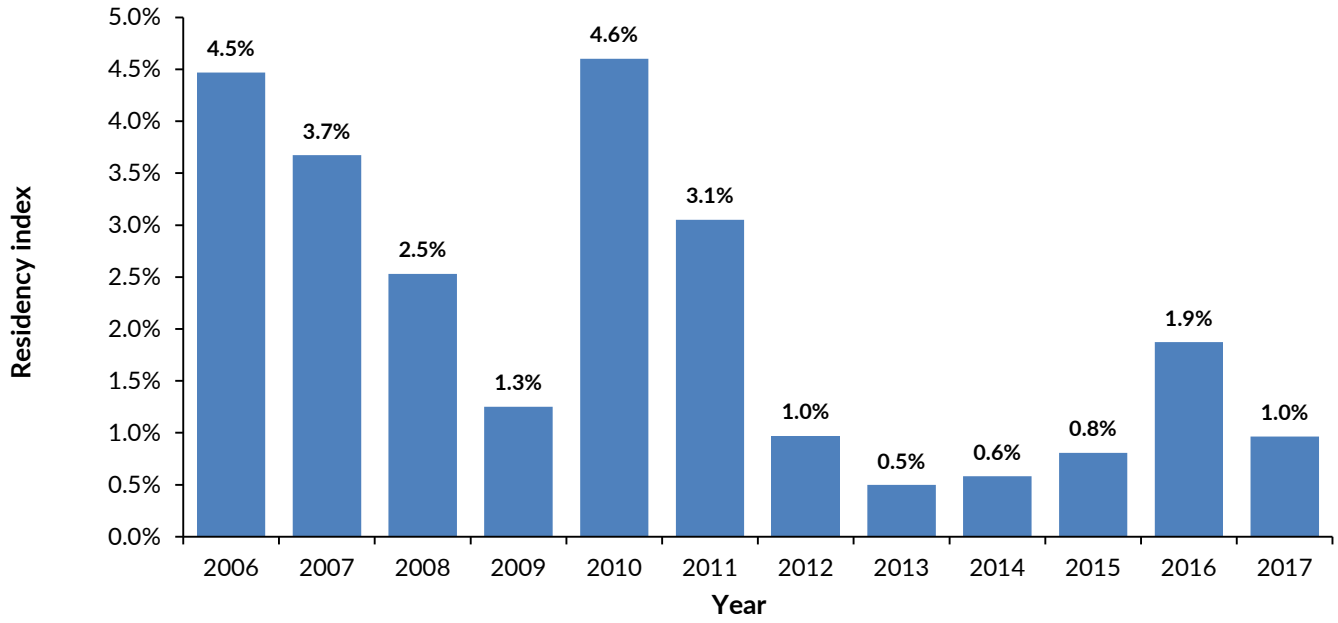


Figure 18: Annual Residency Index (RI) of the reef manta rays (*Mobula alfredi*) in North and South Malé Atolls. RI is calculated as the average of each individuals' residency score (= number of times sighted annually divided by the total number of surveys).

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 mantas 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. It is thought that receptive females release pheromones in order to signal to a potential mate their readiness to reproduce. To date, courtship activity has been documented in the Malé Region during a total of 76 events, involving 175 different individuals. Eighty-seven percent (*n*=66) of the time, these courtship and mating events occurred at either Lankan Beyru or Sunlight Faru cleaning stations in NMA.

A total of 127 reef manta rays were recorded pregnant between 2005 and 2017 throughout the Malé Region. In 2007, the highest number of pregnancies were recorded, when 49% (*n*=58) of the mature females sighted during that year were observed to be pregnant (Fig. 19). Throughout the study period, a total of 83% (*n*=105) of the pregnancies were recorded at Lankan Beyru and Sunlight Faru, which is likely a result of increased survey effort at these two sites by trained observers (MMRP staff). Closer analysis of the core adult female population (*n*=50) which most frequently visited Lankan Beyru and Sunlight Faru between 2005 and 2017 show that the highest number of pregnancies were also recorded in 2007, when 76% (*n*=37) of these adult females were observed pregnant (Fig. 20).

Interestingly, no pregnancies were recorded at all during the years 2010-2013 (corresponding with the low number of sightings reported post 2010, a trend noted throughout the Maldives). And in 2017, only six pregnancies were recorded throughout the Malé Region, consistent with the average number of recorded pregnancies documented over the previous three years (Fig. 19). This overall low reproductive rate, of just 16% of the core adult females recorded pregnant at Lankan Beyru and Sunlight Faru annually, on average, is consistent with trends observed throughout the Maldives by the MMRP. These results suggest a very low fecundity for this species in the Maldives, with each adult female gestating on average only once every six years in the Malé Region. With such a conservative life history strategy, it becomes vital for the survival of this species to minimise anthropogenic threats. Effective measures include the establishment of functional MPAs, and the adherence to sustainable tourism activities at key manta ray mating, cleaning and feeding sites.

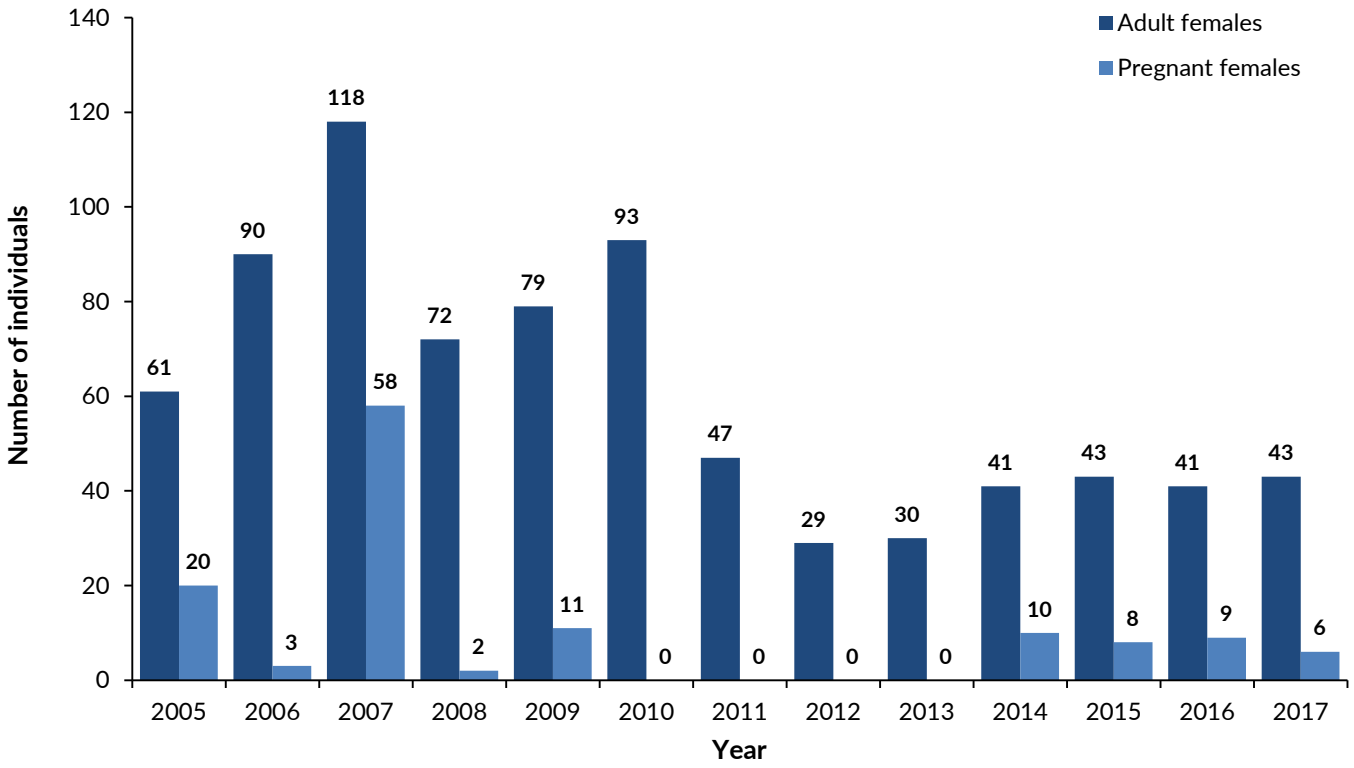


Figure 19: Total number of adult female reef manta rays (*Mobula alfredi*) sighted annually in North and South Malé Atolls, and the total number of those females which were recorded pregnant in the same year.

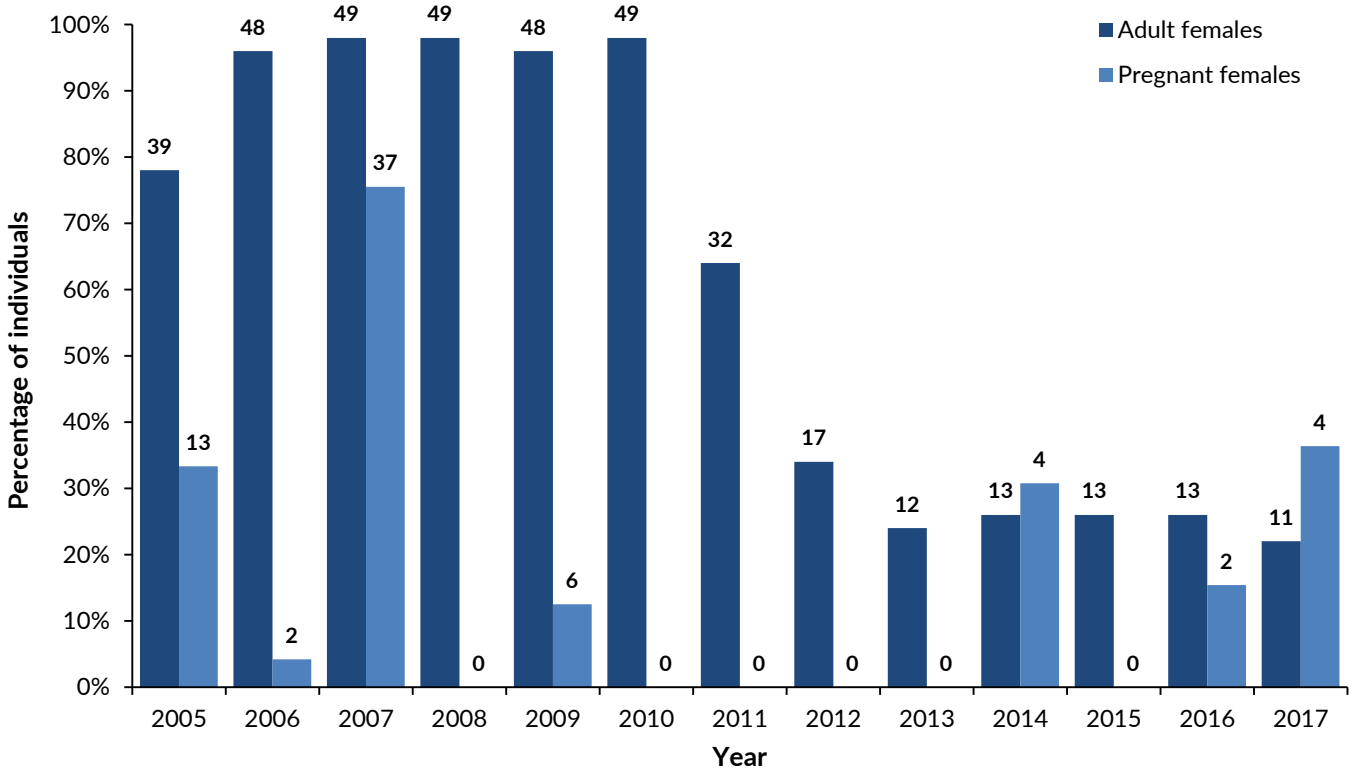


Figure 20: Percentage of Lankan Beyru and Sunlight Faru's core adult female reef manta ray (*Mobula alfredi*) population (*n*=50) sighted annually, and the percentage of those females which were recorded pregnant in the same year. Actual numbers above bars.

Sub-Lethal Injuries

Within the NMA sub-population of reef manta rays (*n*=685), 39% (*n*=264) have some form of sub-lethal injury; much higher than the national average of 29%. Overall, 306 separate injuries were recorded; with some individuals (*n*=37) having more than one injury. Demographically, instances of injuries are roughly the same between females and males, but much higher in adults than juveniles (Fig. 21). This increase in instances of injuries to the adults is unsurprising, as these individuals are older, and therefore likely to have encountered threats more often than juveniles during their life. Comparatively, 30% (*n*=28) of the SMA reef manta ray population (*n*=92) have some form of sub-lethal injury, with a total of 30 separate injuries recorded. Overall, the injury incidence between the sexes is similar to those recorded within the NMA sub-population, although a higher proportion of the juveniles were injured than the adults when compared to NMA (Fig. 22).

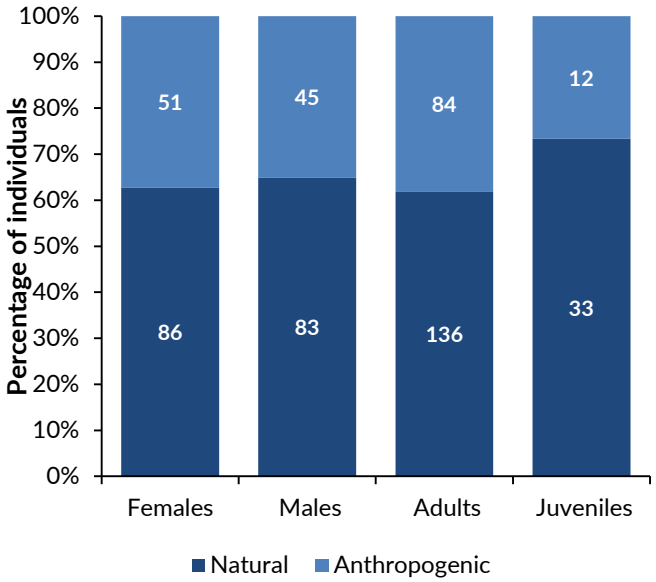


Figure 21: Demographic variations in the number of sub-lethally injured (*n*=264) reef manta rays (*Mobula alfredi*) within the North Malé Atoll population (*n*=685), and the likely injury origin (natural or anthropogenic). Actual number of injuries on bars.

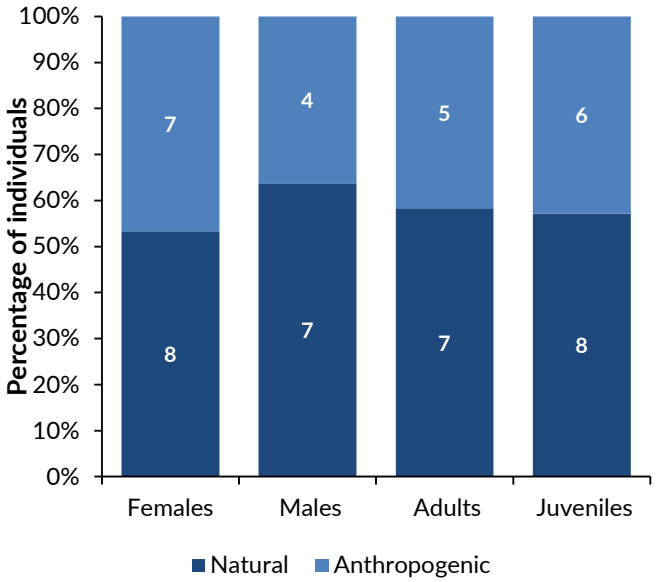


Figure 22: Demographic variations in the number of sub-lethally injured (*n*=28) reef manta rays (*Mobula alfredi*) within the South Malé Atoll population (*n*=92), and the likely injury origin (natural or anthropogenic). Actual number of injuries on bars.

Naturally caused injuries (e.g. predatory bites, diseases, deformities, etc.) recorded in the NMA sub-population account for 55% (*n*=169) of all recorded injuries, whilst 31% (*n*=96) had anthropogenic origins (e.g. fishing line entanglement, boat strikes, etc.). The remaining 41 sub-lethal injuries originated from an unknown source (Fig. 23). Comparatively, in SMA, injury origins are similar; with 50% (*n*=15) of injuries arising from natural sources, 37% (*n*=11) anthropogenic, and the remainder (*n*=4) originating from an unknown source (Fig. 24). The slightly higher incidences of anthropogenic originated injuries in SMA can be explained by the greater number of injured juveniles proportionally compared to NMA. The most common cause of natural injuries across both sub-regions in adults and juveniles were from predatory bites, while the most common cause of anthropogenic injuries was from fishing lines. The level of boat strikes injuries in both atolls is also a concern, however this is especially concerning in SMA at Guraidhoo Falhu, where the manta rays often feed in the shallow waters.

MV-MA-0339 (Zorro) with dorsal scars from boat propeller strike at Rasfari North, North Malé Atoll.

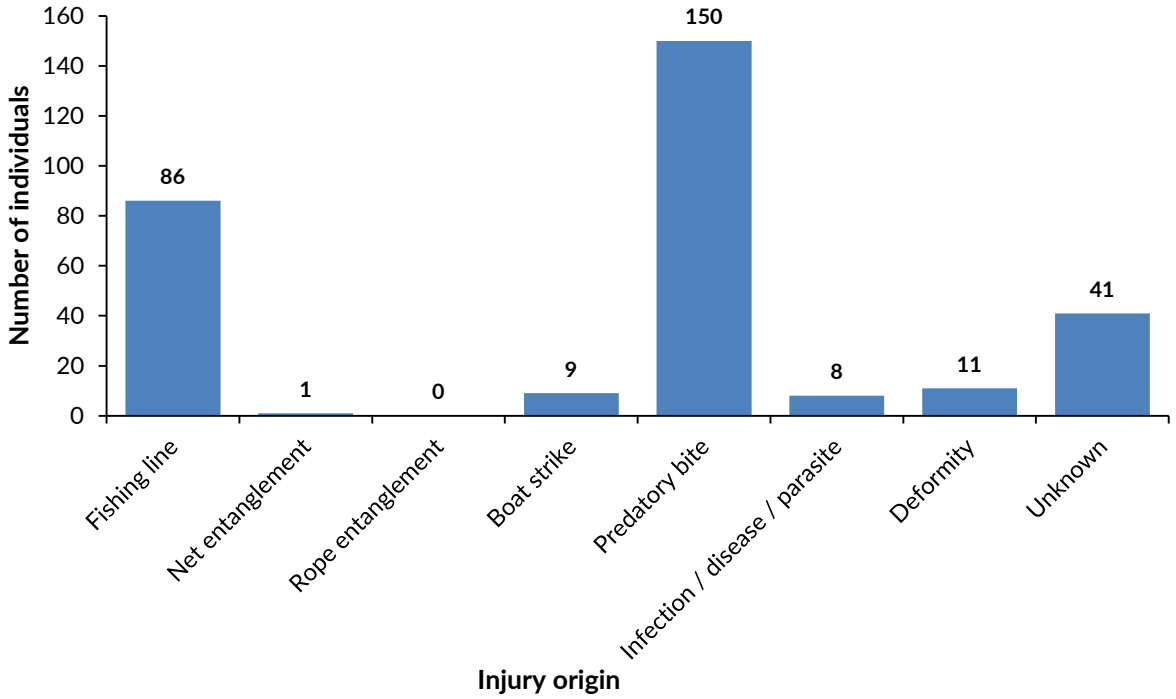


Figure 23: Variations in the origin of sub-lethal injuries (*n*=306) within the injured reef manta ray (*Mobula alfredi*) population of North Malé Atoll (*n*=264).

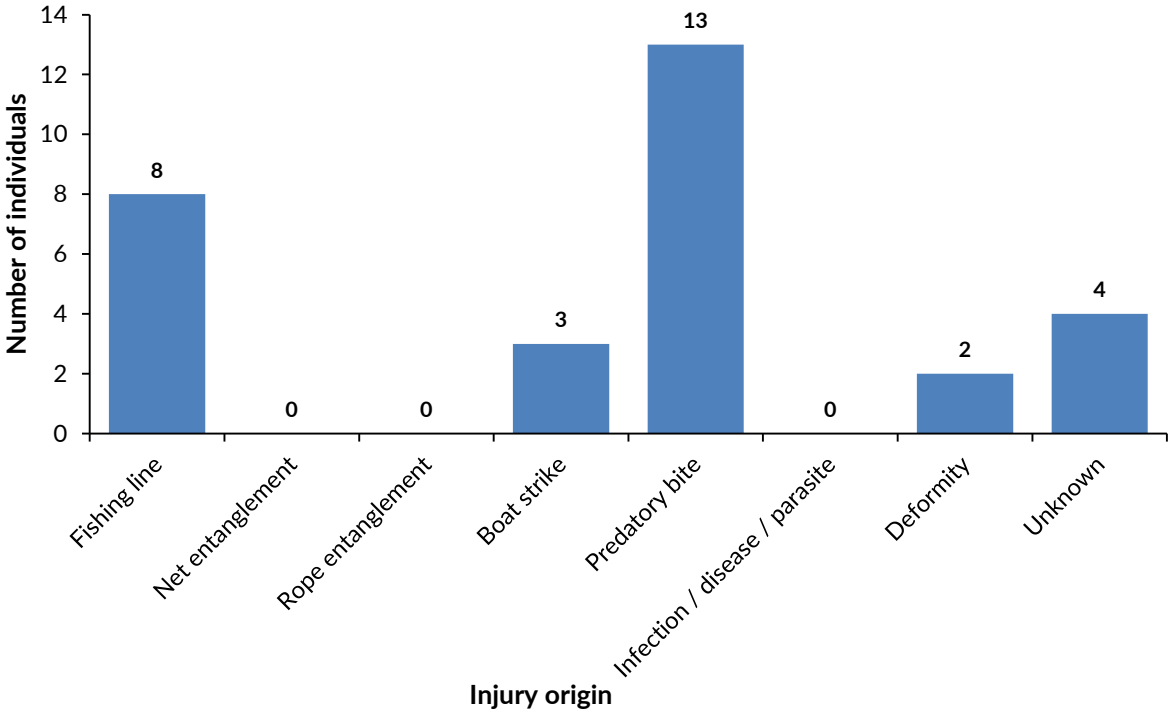


Figure 24: Variations in the origin of sub-lethal injuries (*n*=30) within the injured reef manta ray (*Mobula alfredi*) population of South Malé Atoll (*n*=28).

Of all manta injuries recorded, the most common body area inflicted by injury across both NMA (69%) and SMA (75%) are the manta ray's pectoral fins; 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 injuries from predators (mainly large sharks) within the anterior pectoral fin region. This region of the body is also where entangled fishing line often causes the most damage. The proportion of individuals with injured pectoral fins remains relatively consistent between the sexes, and maturity status, of the population within the Malé Region (Figs. 25 & 26).

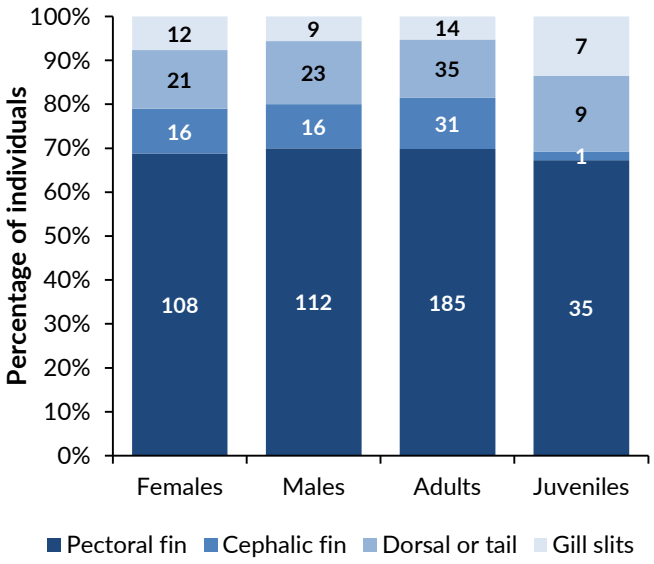


Figure 25: Demographic variations in the location and number of sub-lethal injuries (*n*=306) within the injured reef manta ray (*Mobula alfredi*) population of North Malé Atoll (*n*=264). Actual number of injuries on bars.

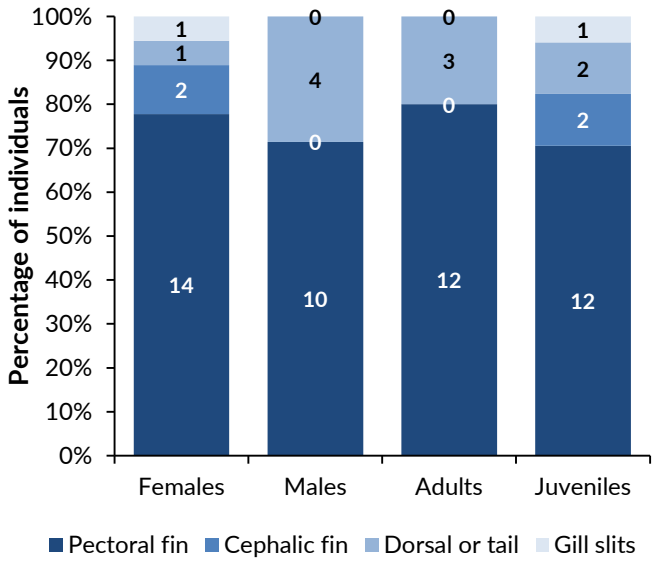


Figure 26: Demographic variations in the location and number of sub-lethal injuries (*n*=30) within the injured reef manta ray (*Mobula alfredi*) population of South Malé Atoll (*n*=28). Actual number of injuries on bars.

MARINE PROTECTED AREAS

The Maldives' government have designated eight Marine Protected Areas (MPAs) within NMA, and two within SMA. Reef manta rays have been sighted at five of these MPAs between the years 1987-2017: Thanburudhoo Thila, Nassimo Thila, and Rasfari in NMA, and at Embudu Falhu and Guraidhoo Kandu in SMA. Guraidhoo Kandu and Rasfari were both designated protected areas in 1995. Both areas are key reef manta ray aggregation sites, accounting for 2% (*n*=181), and 19% (*n*=1,307), of the total sightings (*n*=7,084) recorded to date in the Malé Region (1987-2017) (Fig. 27).

The MPA of Guraidhoo Kandu covers an area of approximately 2 km^2, including both the outer reef and inner lagoon 'Guraidhoo Falhu'. This lagoonal area is an important feeding and cleaning site for juvenile reef manta rays (Fig. 28). However, while protected on paper, there is no management plan for this site, and the impacts of development pressures (such as speedboat traffic) need to be addressed. A lack of government management at Rasfari is also an increasing problem, especially at the northern area of this MPA, where the manta rays aggregate to feed, clean and mate (at Rasfari North and Boduhithi Thila). The MPA is relatively large, covering an area of approximately 25 km^2; encompassing both the uninhabited island of Rasfari, and all surrounding reef and lagoon areas. Rasfari North is a shallow reef crest (2-5 m) outside the atoll which is an important aggregation site for adult reef manta rays throughout the Northeast Monsoon (Fig. 28). Its shallow depth 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. Unfortunately, however, there is no management plan in place to regulate tourism at this site, resulting in 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. As at nearly all other MPAs in the Maldives, there is also no effort to prevent fishing inside these areas, further threatening the rays as a result of bycatch entanglement.

Lankan Beyru and Sunlight Faru together account for 76% (*n*=5,276) of all the reef manta ray sightings from 1987 to

2017, yet concerningly, these sites are not part of any MPA. Predominately, these sites are utilised by adults during the Southwest Monsoon for cleaning and courtship behaviour, although feeding does also occasionally occur at the surface (Fig. 28). Due to their close proximity to Malé, and reliability of sightings, these sites are among the most visited (and most famous) manta ray aggregation sites in the world, yet some of the least protected.

If manta rays are to continue to flourish in the Maldives, it is essential that effective management plans are created and implemented at all manta aggregation sites which are currently within MPAs. Furthermore, many new, and significantly much larger, MPAs are required in the Maldives to protect other key manta aggregation sites. These MPAs are urgently required to help mitigate the rapidly increasing pressures of tourism development, reef fishing, climate breakdown, and habitat destruction.

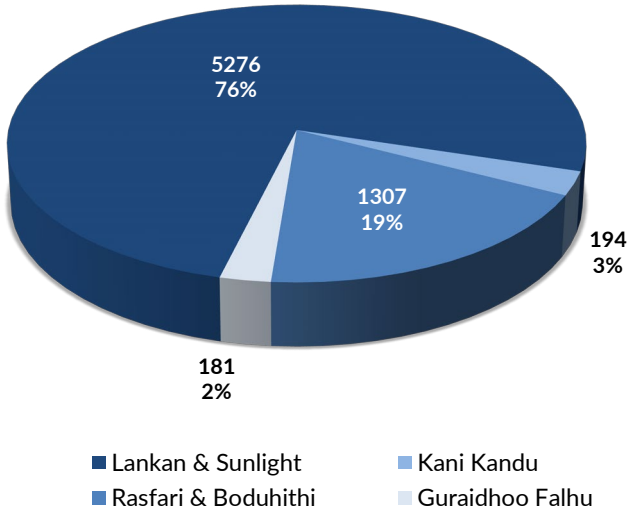


Figure 27: Proportion of the total reef manta ray (*Mobula alfredi*) sightings at the four key aggregation areas (see Table 1) in North and South Malé Atolls (1987-2017).

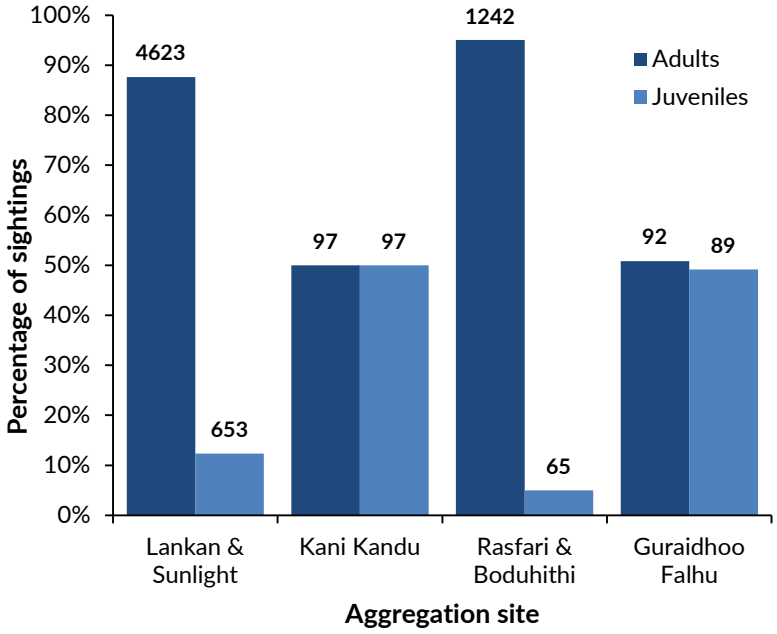


Figure 28: Demographic variation in the number of sightings of reef manta rays (*Mobula alfredi*) at the four key aggregation areas (see Table 1) in North and South Malé Atolls (1987-2017). Actual numbers on bars.

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. With limited survey data collected prior to 2006, only sightings from 2006-2017 have been analysed together with recorded environmental variables to determine whether any correlation exist between manta ray sightings and weather conditions. Historic weather data for these years were sourced from the Maldives meteorological department. The highest average annual wind speeds were recorded in 2007, 2010 and 2016, measuring 17.1 km/h, 17.4 km/h and 17.2 km/h respectively (Fig. 29). As previously stated, the same years (2007, 2010 and 2016) correlated with higher number of manta sightings per survey throughout the region (Fig. 5). This correlation of higher average wind speed and increased manta ray sightings is consistent with MMRP findings recorded throughout the Maldives.

Closer analysis of wind speed and manta ray activity intra-annually shows a reduction in wind speed from January to April, which correlates with the decrease in number of manta sightings (Fig. 30). However, during the beginning of the Southwest Monsoon, as wind speeds increase, manta ray sightings do not begin to increase until towards the end of the Southwest Monsoon, when average wind speeds have plateaued or declined. This could be due to the majority of manta ray sightings in the Malé Region occurring at cleaning stations rather than feeding aggregation sites. During the time when wind speeds are high and upwellings are greater, the reef manta ray population in Malé Region are potentially spending more time feeding in atoll channels, and less time visiting cleaning stations.

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 determine any correlations between current direction and a given behaviour, survey data from 2015 onwards included the variables; current direction, current speed, and primary observed behaviour. Out of the 1,007 surveys recorded between 2015-2017, manta rays were present on fifty-three percent (n=531) of occasions. On forty percent of these occasions (n=214), the current was outgoing, during which time 72% of individuals (n=155) were observed to be primarily cleaning (Fig. 31). In contrast, on the rare occasion feeding behaviour was recorded (n=38), it was more prevalent during an incoming current (Fig. 31).

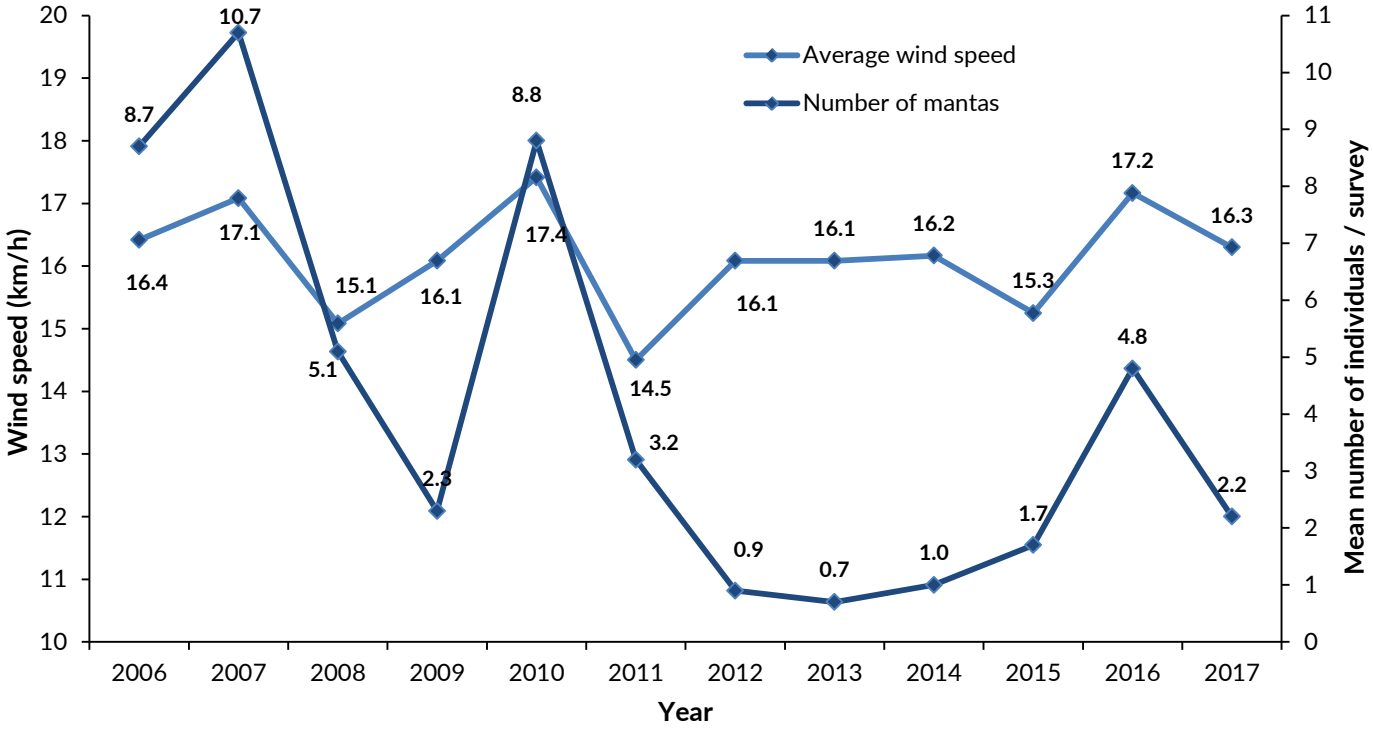


Figure 29: Mean annual wind speed (km/h), and the mean number of reef manta ray (*Mobula alfredi*) sightings per survey in North and South Malé Atolls.

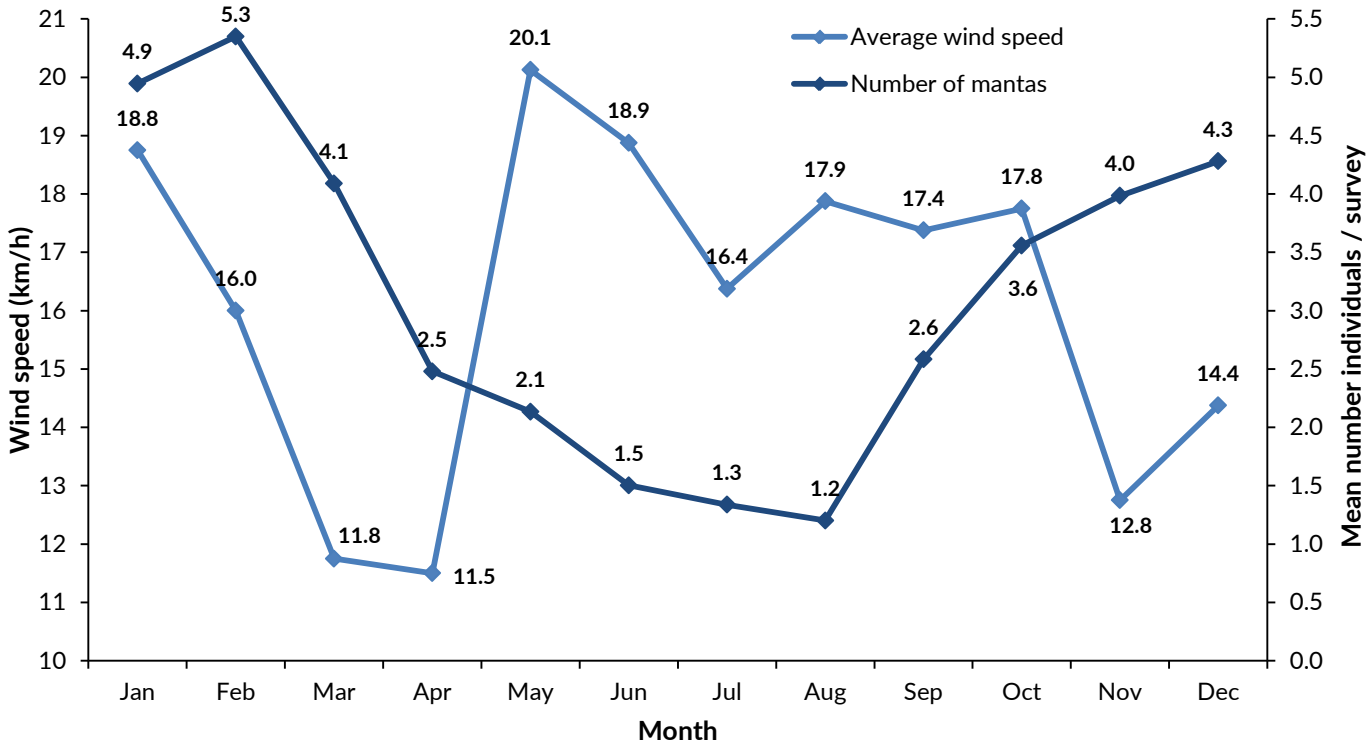


Figure 30: Mean monthly wind speed (km/h), and the mean number of reef manta ray (*Mobula alfredi*) sightings per survey in North and South Malé Atolls (2006-2017).

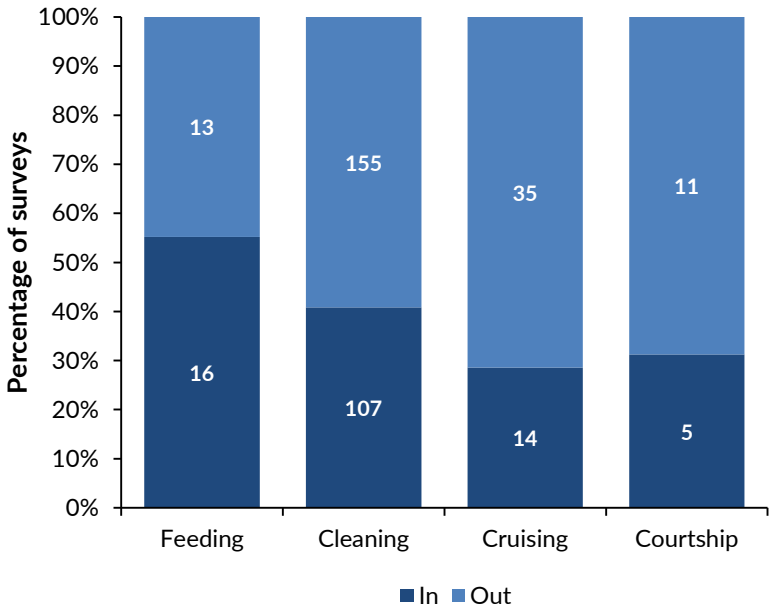


Figure 31: Changes in behavioural activity of reef manta rays (*Mobula alfredi*) in relation to current direction (In, Out) through the channels of North and South Malé Atolls during 2015-2017 surveys (n=1,007).

Overall, the most common behaviour observed by the reef manta ray population of the Malé Region was cleaning; constituting 81% (*n*=416) of all recorded 'manta present' surveys between 2015-2017. Further evidence supporting this claim can be seen from the 7,084 sightings recorded between 1987-2017; of which eighty-seven percent (*n*=6,187) of all sighted manta rays were recorded to be cleaning.

OCEANIC MANTA RAY SIGHTINGS

Oceanic manta rays (*Mobula birostris*) are larger than their reef relatives, capable of growing up to seven metres in wingspan, they truly are giants of the ocean. Across the Maldives, sightings of this species are much less frequent than those of the reef manta ray; with a total of 378 sightings of 368 identified individuals between 1996-2017.

Some atolls have much higher sightings than others, the highest being Fuvahmulah Atoll. In the Malé Region, sightings of oceanic manta rays are uncommon, with only nine sightings of eight different individuals recorded to date. Out of the eight identified individuals within the Malé Region, seven were new to the Manta Trust's MMRP database, while the ninth was a re-sighted individual. Across the Maldives entire population of oceanic manta rays, re-sightings are rare (*n*=10), however, two of these re-sightings occurred in NMA. The first individual (MV-MB-0069) was sighted twice over a one-week period in 2014 off the western edge of the atoll. However, more interestingly, the second (MV-MB-0211) resulted in the first cross-atoll re-sighting for this species in the Maldives. This individual was recorded first in Ari Atoll in 2016, and subsequently sighted a year later at Rasfari North in NMA.

MANTA RAY TOURISM

The Malé Region is one of the most popular tourist destinations within the Maldives. Many of the visiting tourists' snorkel and dive during their stay, hoping to see marine megafauna, such as a manta ray. Survey data collected by the MMRP since 2013 shows a general increase annually in the average number of tourist boats recorded per survey (Fig. 32), and the average number of snorkellers and divers per survey also increasing (Fig. 33).

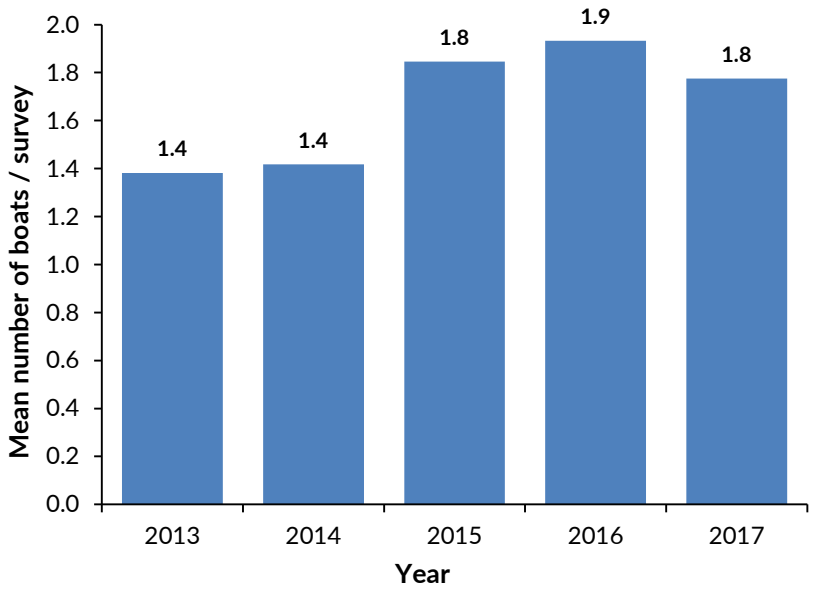


Figure 32: Mean number of tourism vessels per survey (*n*=1,449) in North and South Malé Atolls.

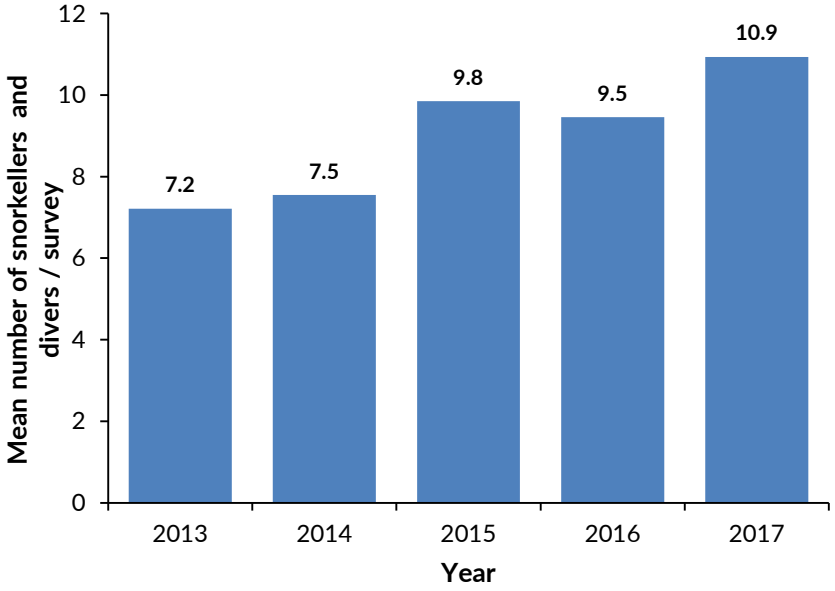


Figure 33: Mean number of snorkellers / divers per survey (*n*=1,449) in North and South Malé Atolls.

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

This report was made possible thanks to

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 scienteists 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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