



Maldives Manta Conservation Programme

LAAMU ATOLL | ANNUAL REPORT 2022

*Conservation through
research, education, and collaboration*

- The Manta Trust



SIX SENSES
LAAMU



MALDIVES MANTA
CONSERVATION
PROGRAMME

WHO ARE THE MANTA TRUST?



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

The Manta Trust takes a multidisciplinary approach to conservation. We focus on conducting robust research to inform important marine management decisions. With a network of 29 projects worldwide, we specialise in collaborating with multiple parties to drive conservation as a collective; from NGOs and governments, to businesses and local communities. Finally, we place considerable effort into raising awareness of the threats facing manta rays, and educating people about the solutions needed to conserve these animals and the wider underwater world.

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

MALDIVES MANTA CONSERVATION PROGRAMME



Formed in 2005, the Maldives Manta Conservation Programme (MMCP), formerly the Maldivian Manta Ray Project (MMRP), is the founding project of the Manta Trust, and has been a Maldives registered charity since 2022. It consists of a country-wide network of dive instructors, biologists, communities and tourism operators, with more than a dozen MMCP staff based across a handful of atolls, on both resort islands and local islands.

The MMCP collects data around the country's manta population, its movements, and how the environment and tourism / human interactions affect them. Since its inception, the MMCP has identified over 5,500 different individual reef manta rays, from more than 80,000 photo-ID sightings. This makes the Maldives manta population the largest, and one of the most intensively studied populations in the world. The MMCP has also identified more than 830 different individual oceanic manta rays.

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.

OUR PARTNERSHIP WITH SIX SENSES LAAMU



For a decade, Six Senses Laamu has contributed to the research efforts of the Manta Trust and the MMCP, through external submissions of manta ray ID photos. In 2014, a closer partnership began to blossom, with the Manta Trust launching an exciting five-month pilot project in Laamu Atoll. The project focused on investigating the nearby manta aggregation site at Hithadhoo Corner. The pilot phase was so successful that the Manta Trust team were invited back in 2015, this time for an extended period of nine months.

In 2016, a full 12-month partnership between both parties was born, and since then the project has gone from strength to strength. The Manta Trust's MMCP now has a permanent presence on the island, working closely with the resorts' resident marine biologists and sustainability manager, to raise awareness surrounding the unique, yet vulnerable marine environment of Laamu Atoll. The commitment of the resort to protect the environment and develop sustainable practices has made it one of the MMCP's key partnerships. This summary details the research activities carried out by the Laamu Atoll Manta Trust team in 2022.



Photo by Jasmine Corbett

EXECUTIVE SUMMARY

This report is the ninth of its kind in a series that presents data collected by the Maldives Manta Conservation Programme (MMCP), formerly the Maldivian Manta Ray Project (MMRP), on Laamu Atoll's manta ray (*Mobula alfredi* and *M. birostris*) populations, with this report summarising January through December 2022. Since 2005, the MMCP (the founding project of the Manta Trust) has been consistently collecting data on manta rays in the Maldives. Data collection in Laamu Atoll started in 2012, only a short time after Six Senses Laamu opened in 2011. The Manta Trust team are incredibly proud and grateful to continue to have Six Senses Laamu as one of the MMCP's Key Regional Partners.

Laamu Atoll supports year-round manta ray sightings, although sightings historically peak from May to June and again from October to November annually. Two primary aggregation sites have been identified, Hithadhoo Corner in the south of the atoll, and Fushi Kandu in the northeast. Further potential aggregation sites, such as Fonadhoo Beyru, Boduhuraa Beyru (Kurethi) and Maabaidhoo Kandu have been increasingly monitored by the MMCP team in recent years, with Fonadhoo Beyru having been identified as a key aggregation site throughout the last quarter of 2022. All these sites, apart from Maabaidhoo Kandu, are characterised by having distinct cleaning stations, which support frequent cleaning behaviour and seasonal courtship activities.

Key findings in 2022 include a total of 657 confirmed sightings of 81 individual reef manta rays (*M. alfredi*), of which four individuals were new to the Maldives wide database. Hithadhoo Corner continued to support the highest number of confirmed sightings throughout the region ($n=256$), followed by the Eastern outer reef, Fonadhoo Beyru ($n=134$), and the north-eastern channel of Fushi Kandu ($n=117$). Fonadhoo Beyru has been frequently monitored since September 2022 and supported a higher number of manta sightings than Fushi Kandu across the whole year, and a higher number of individuals than Hithadhoo Corner when compared over the same time frame. The number of sightings recorded at other secondary sites in 2022 has increased compared to 2021, with Boduhuraa Beyru alone reaching confirmed sighting numbers of 26, an increase of 1200% compared to 2021 ($n=2$).

As of 2022, *M. alfredi* population demographics of Laamu Atoll constitute 57% female ($n=81$), 41.6% male ($n=59$), and 1.4% ($n=2$) for which sex could not be determined yet. Of the population known to Laamu Atoll ($n=142$), 94% ($n=133$) have been re-sighted, presenting a small but highly residential sub-population. A study investigating manta ray seasonality and behaviour at Hithadhoo Corner revealed that sea temperature was found to be the most significant environmental predictor for manta

ray abundance at the site. Manta ray presence decreased as temperatures neared threshold values of 30°C.

The first ever local ecological knowledge (LEK) surveys investigating Laamu Atoll fishermen's knowledge and perspective on mobulid conservation revealed new potential mobulid ray hotspots in the north of Laamu Atoll and raised concern about the potential

entanglement of manta and devil rays in bait fishing nets. Research projects in 2022 included photo-ID surveys, stereo video photogrammetry (SVP), remote underwater video (RUV) cameras, remote underwater photo (RUP) cameras, aerial surveys, and ultrasound surveys. Furthermore, as well as the LEK surveys mentioned above, a master's thesis project on Laamu's RUP data was conducted analysing 12 months of data collection at Hithadhoo Corner.

MONSOONS & LAAMU ATOLL

Weather patterns in the Maldives are highly influenced by the South Asian Monsoon. There are two defined monsoons (seasons) in the Maldives, characterised by wind direction and speed. The Northeast Monsoon (*Iruvai*) runs from December to March, while the Southwest Monsoon (*Hulhangu*) runs from May to October. April and November are classified as transition months, in which wind speed and direction can be highly variable. As the winds change with each monsoon, so do ocean currents. The islands and atolls within the Maldives act as barriers to these currents, creating regions of deep-water upwelling, which drives nutrient-rich water to the surface. This increases the production of phytoplankton and drives subsequent blooms of zooplankton - the primary food source of manta rays.

The central and northern atolls of the Maldives are "double-chained", with numerous channels dividing the fringing reefs. These characteristics cause plankton to accumulate on either the western or eastern sides of atolls depending on the monsoon, and manta rays migrate accordingly to take advantage of the varying abundances of their zooplanktonic food. Between periods of feeding, manta rays often utilise cleaning stations to clean and engage in

other social interactions.

Located at the southernmost tip of the south-central Maldives, the topography of Laamu Atoll differs from that of the more northern atolls (Fig. 1). Laamu Atoll does not form part of a double chain, and only few (six) channels break the outer reef. While Laamu Atoll experiences strong oceanic currents, water movement through the Atoll is restricted, and no clear seasonal manta ray migration pattern has been documented.

Hithadhoo Corner, located near the southern edge of Laamu Atoll, has historically supported year-round manta sightings, with peaks at the start and end of the Southwest Monsoon. Fushi Kanduu, located on the north-eastern edge of the atoll, appears to be used primarily during transition periods between the switch in monsoons. Both sites have well-defined cleaning stations and support cleaning and courtship behaviours. In 2022, Fonadhoo Beyru, a potential new manta aggregation site, presented high manta ray sightings in the transition period from the Southwest monsoon to the Northeast monsoon (October to December), while Boduhuraa Beyru (Kurethi) supported most sightings during the Northeast Monsoon.



Photo by Miriam Staiger

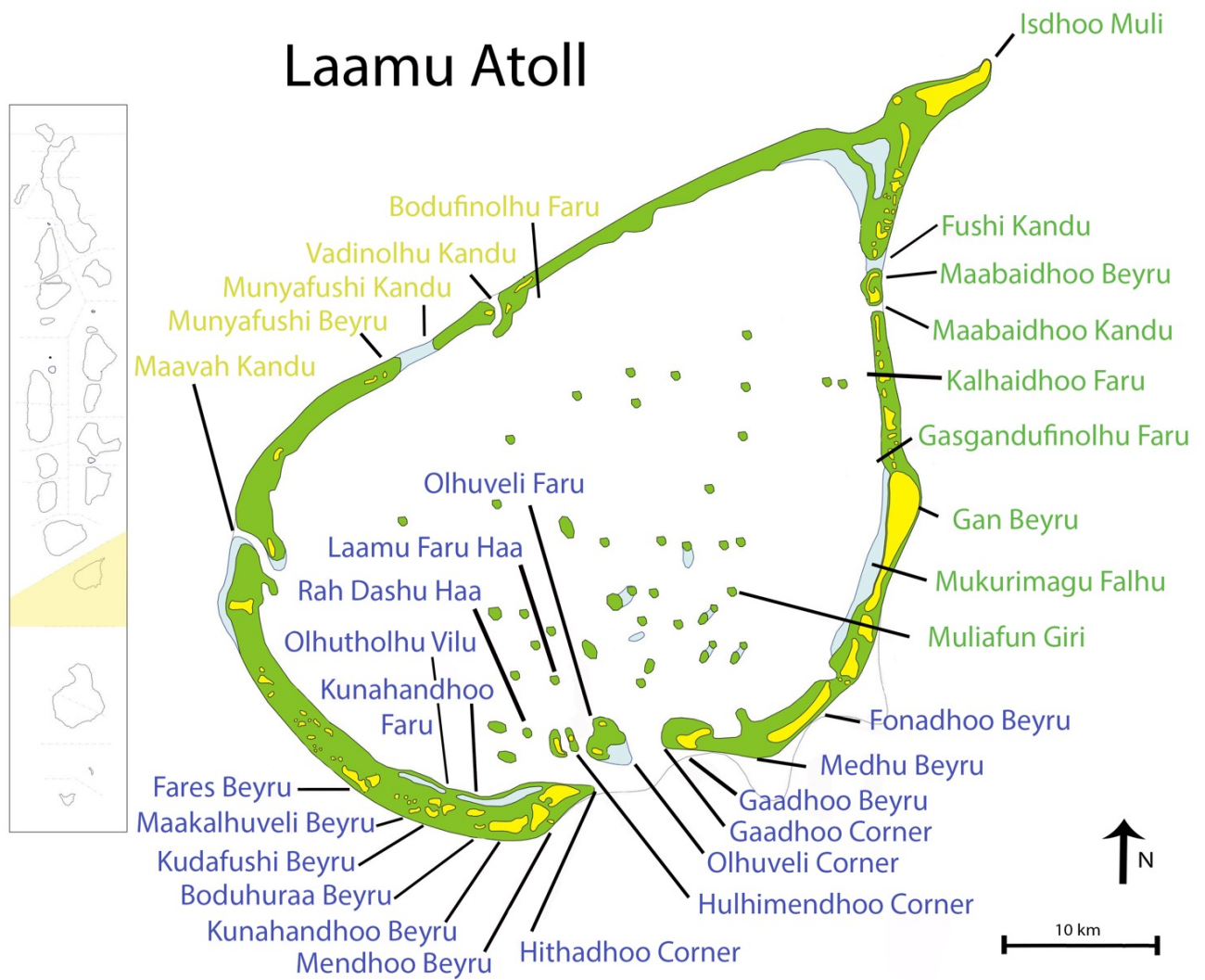


Figure 1: Map of Laamu Atoll showing the thirty-two locations in the atoll where reef manta rays (*Mobula alfredi*) have been observed (2014 - 2022).

SURVEYING & SAMPLING METHODOLOGIES

Throughout the Maldives, the MMCP records sightings of manta rays through photographs of the unique ventral spot patterns of individual manta rays. Since 2013, most sightings data on the local manta population in Laamu Atoll has been collected by the MMCP researchers ($n=5,013$). However, many sightings have also been submitted by resort partners and guides ($n=260$), and outside contributors, including guests ($n=127$). For this report, a sighting is defined as a confirmed photo identification (photo-ID) of an individual manta ray on a given day at a specific location (survey site), unless stated otherwise.

During each survey, information was collected on the location, manta ray abundance, behaviour (e.g., cleaning, courtship, feeding, cruising), duration of encounters, environmental variables (including wind direction, current direction, as well as zooplankton density and composition), and anthropogenic factors (including the number of divers/snorkellers and the number of boats on site). Most data was collected while scuba diving due to the depth of cleaning stations at aggregation sites. In 2022, the overall survey time increased significantly (doubled from the survey effort of 2021) using remote underwater video and remote underwater photo cameras (RUV and RUP, respectively).

For this report, a survey is defined by the start and end time of an activity (such as diving and snorkelling) at a single location. Remote underwater sensing (i.e. RUV and RUP) is included in the survey effort, and a remote survey is also defined by the start and end time of the recording within one day at a single location, hence most RUP surveys are 12 hours long each day (RUPs are programmed to record data from 6am to 6pm). A survey day refers to the number of days when surveys were conducted in the Atoll irrespective of location.

In all reports prior to 2020, surveys were defined by time spent at a single location each day. This meant that if two dives were conducted at one location, collectively the two dives plus the surface interval would be considered as one survey. If there was a long break in-between the morning and afternoon survey effort, the second

visit to the location would be considered as a separate survey. Additionally, remote underwater sensing was previously included within the dive or snorkel surveys, but from 2020 onwards, remote underwater sensing was considered as a separate entity. Whilst data numbers may vary from previous year's reports, the comparison between years will not vary, as all the historical data were re-formatted for the purpose of these reports.

Before April 2015, MMCP researchers were not based in Laamu Atoll during all 12 months of the year, and therefore, data was not recorded on all dives to the manta aggregation sites. For this reason, averages where survey effort could be accounted for only include data between 2016 through 2022. Where possible, data has been standardised for survey effort to provide comparable results by both months and years.

2022 Study Period

In 2022, manta ray surveys ($n=995$) were conducted on a total of 346 days by either the MMCP, Six Senses Laamu staff, or citizen scientists from outside the resort (Fig. 2). This was the highest number of surveys recorded annually to date in Laamu Atoll; a result of the increased usage of remote underwater surveillance, as well as the continued support by the resort dive centre (Deep Blue Divers) contributing survey records every time they visited manta aggregation sites. The Manta Trust Laamu Team were very grateful to receive the highest number of submissions from Deep Blue Divers in 2022 ($n=153$).

In 2022, all surveys conducted at the aggregation sites of Hithadhoo Corner, Fushi Kandu, Boduhuraa Beyru (Kurethi)

and Fonadhoo Beyru were recorded regardless of whether manta rays were observed during the dive or snorkel. For all other locations, surveys were only recorded when manta rays were present, or if MMCP staff participated in the dive.

The Manta Trust staff collected data through a combination of dedicated MMCP research dives ($n=134$), joining Six Senses Laamu (SSLM) activities with guests ($n=231$ dives, $n=6$ snorkels), RUP camera deployment days ($n=403$), and RUV camera surveys ($n=25$). Survey data submitted from contributors outside the resort ($n=10$) was also recorded.

Hithadhoo Corner and Fushi Kandu continued to be the two primary survey sites, with data collected from

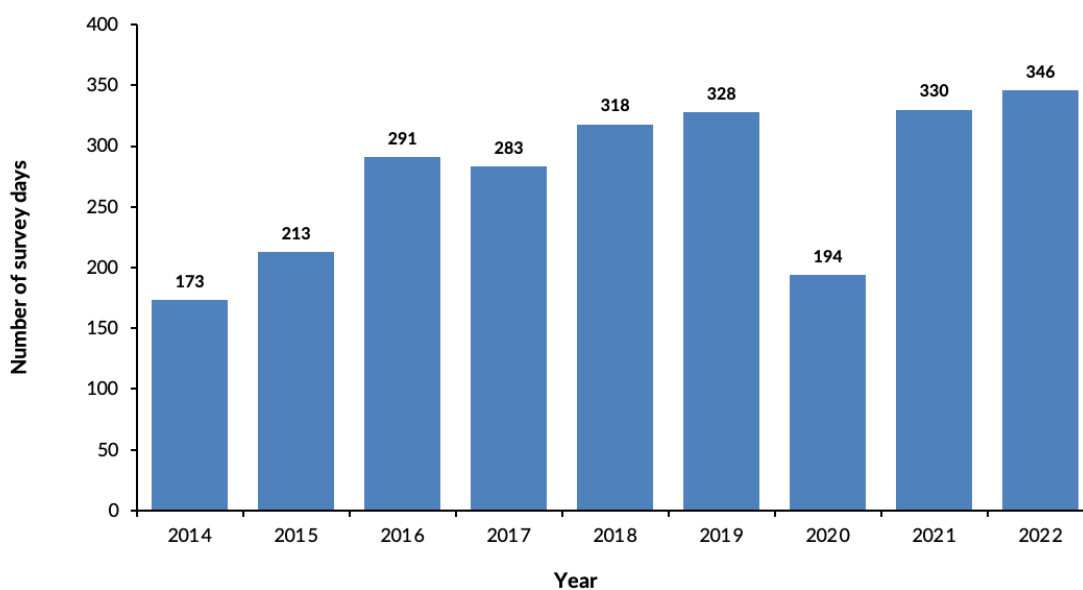


Figure 2: Number of days that surveys were undertaken in Laamu Atoll annually.

Hithadhoo Corner on 309 days, and Fushi Kanduu on 146 days in 2022 (Fig. 3). This was the highest number of survey days on both sites since the start of data collection, due to increased remote underwater surveys. With the goal of extending the survey effort at different study sites, secondary sites Boduhuraa Beyru and Fonadhoo Beyru (later treated as primary site for the purpose of this report due to high sighting numbers) were increasingly surveyed in 2022 accounting for 63 and 45 survey days, respectively.

The MMCP has now collected reports of manta ray sightings from 32 sites in the Atoll and confirmed photo-ID sightings from 17 locations (Fig. 1 and Table 1). Regular monitoring of these sites in the future is necessary to determine the reliability of these locations for supporting manta ray sightings. Overall, manta rays were encountered on 35% ($n=186$) of all dives ($n=539$), and identification photographs were collected during 74% ($n=138$) of dives with manta rays, continuing the trend of increased photo-identification success from the previous year (71% in 2021 and 41% in 2020).

Snorkelling surveys carried out at the two main aggregation sites (Hithadhoo Corner and Fushi Kanduu), or any other snorkel sites where manta rays were identified, were recorded from any resort or MMCP led snorkel trips. Manta rays were observed on 35% ($n=6$) of the snorkel surveys

($n=17$) at these sites, with confirmed identification photos collected for 50% ($n=3$) of the surveys with manta rays present. These figures are not reflective of snorkelling conducted across Laamu Atoll, as it remains rare to see manta rays while snorkelling in the atoll.

Remote underwater photo (RUP) and remote underwater video (RUV) surveys were continuously used to monitor specific manta ray cleaning stations and their use by manta rays in the absence of humans. Of all 995 surveys, 428 (43%) were undertaken using RUVs/RUPs, having nearly doubled the remote underwater survey effort from the previous year ($n=223$, 27%). Prior to 2022, RUP surveys were only conducted at Hithadhoo Corner. However, the receipt of additional equipment this year has enabled RUPs to be deployed at a further three sites – Fushi Kanduu, Fonadhoo Beyru, and Boduhuraa Beyru: contributing 91, 28, and 32 surveys, respectively. A further 245 RUP surveys were collected from Hithadhoo Corner in 2022 and manta rays were observed on 70% ($n=298$) of all remote underwater camera deployments conducted throughout the atoll.

A total of 4130 hours of survey time was recorded over 403 RUP surveys, resulting in an increase of 2117 more hours of data being collected in 2022 compared to 2021. This is in addition to 36 hours of survey time recorded over 25 RUV surveys. A total of 426 confirmed sightings



Photo by Jasmine Corbett

were recorded over these surveys, which constitutes 65% of the total 2022 confirmed sightings ($n=657$), proving the benefits of remote sensing techniques to the Manta Trust's research.

Seventy-one of the 81 individuals sighted throughout 2022 were sighted during RUV and RUP surveys, which was a significant increase from previous years: 2021 ($n=47$) and 2020 ($n=25$). Only ten individuals that were recorded through RUP/RUV were never recorded during any other survey type, such as diving or snorkelling, indicating that most of the individual manta rays sighted (88%) are also observed by divers or snorkellers at some point throughout the year. The highest number of monthly sightings recorded by RUP/RUVs was in May ($n=88$) and November ($n=72$), with the lowest sightings in July ($n=8$) and March ($n=9$).

From 2021 onwards, one RUP system was constantly

deployed on a specific cleaning station (Shallow Block) at Hithadhoo Corner to offer permanent insight into manta ray activity at this site. In 2022, this data was used as part of a year-long study by a Marine Environmental Management master's student, from Exeter University. The thesis assessed the RUP data collected between May 2021 and May 2022 to understand the temporal use of cleaning stations by manta rays, and to determine the effects of environmental variables, such as changing seasons, lunar cycles, tides, and temperatures on manta ray presence at this site. From the camera deployments, 57 individuals were identified across 12 months, of which 40 individuals revisited, indicating strong site-fidelity to Hithadhoo Corner. For more detailed information on the study, the thesis titled "Using remote cameras at cleaning stations to understand the seasonality and behaviour of the reef manta rays (*Mobula alfredi*) of Laamu Atoll, Maldives" by Christopher Wenham is [accessible online](#).

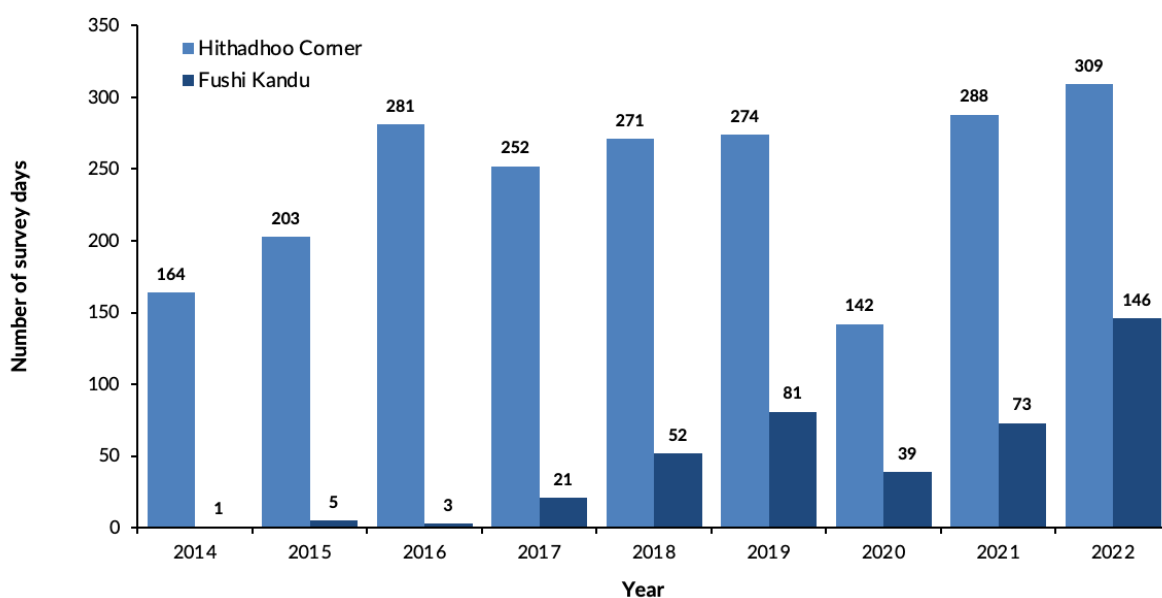


Figure 3: Number of days where surveys were conducted at Hithadhoo Corner and Fushi Kandhu in Laamu Atoll annually.



Photo by Jasmine Corbett

Table 1: Thirty-two sites in Laamu Atoll where reef manta rays (*Mobula alfredi*) have been observed to date; grouped by their geographical location within the atoll.

*Indicates primary study site. Locations in bold indicate locations where manta rays were seen in 2022.

Group	Site Name	Reef Type	Location
1	Fares Beyru	Outer Reef	Southwest
	Maakalhuveli Beyru	Outer Reef	Southwest
	Kudafushi Beyru	Outer Reef	Southwest
	Boduhuraa Beyru	Outer Reef	Southwest
	Kunahandhoo Beyru	Outer Reef	Southwest
	Mendhoo Beyru	Outer Reef	Southwest
	Hithadhoo Corner*	Channel	South
	Hulhimendhoo Corner	Inner Reef	South
	Olhuveli Corner	Outer Reef	South
	Gaadhoo Corner	Channel	South
	Gaadhoo Beyru	Outer Reef	Southeast
	Medhu Beyru	Outer Reef	Southeast
	Fonadhoo Beyru*	Outer Reef	Southeast
	Olhutholhu Vilu	Lagoon	Southwest
	Kunahandhoo Faru	Inner Reef	Southwest
	Rah Dashu Haa	Inner Reef	South
	Olhuveli Faru	Inner Reef	South
Laama Faru Haa	Inner Reef	South	
2	Isdhoo Muli	Outer Reef	Northeast
	Fushi Kandhu*	Channel	Northeast
	Maabaidhoo Beyru	Outer Reef	Northeast
	Maabaidhoo Kandhu	Channel	Northeast
	Kalhaidhoo Faru	Inner Reef	Northeast
	Gasgandufinolhu Faru	Inner Reef	East
	Gan Beyru	Outer Reef	East
	Mukurimagu Falhu	Lagoon	East
	Muliafun Giri	Inner Reef	East Central
3	Bodufinolhu Faru	Inner Reef	Northwest
	Vadinolhu Kandhu	Channel	Northwest
	Munyawushi Kandhu	Channel	Northwest
	Munyawushi Beyru	Outer Reef	Northwest
	Maavah Kandhu	Channel	West

SIGHTING TRENDS

Oceanic Manta Rays

Oceanic manta ray (*Mobula birostris*) sightings in Laamu Atoll remain rare. Thirteen oceanic manta rays have been identified in Laamu Atoll since 2014, at five different sites. The MMCP is working to increase their understanding of this species through research conducted in Fuvahmulah and Addu Atolls, where oceanic manta rays are sighted seasonally in much larger numbers than in other regions of the Maldives. The team in Laamu Atoll last obtained

a Photo-ID of an oceanic manta ray in October 2021 at Maavah Kandhu, which was an outside submission by a guest. No oceanic manta rays were sighted in 2022, but the team will continue to monitor for this species throughout 2023. The remainder of this report refers solely to reef manta rays (*Mobula alfredi*) and any subsequent reference to manta rays refers only to this species.

Reef Manta Rays

Since 2012, a total of 5,403 sightings of reef manta rays have been recorded in Laamu by MMCP researchers, Six Senses Laamu resort staff, citizen scientists, and remote underwater cameras. Between 2015 – 2018, the numbers of confirmed sightings remained consistent, ranging between 727 and 780 sightings per year (Fig. 4). From 2019 onwards there was a significant decline in the number of manta ray encounters, with only 490 confirmed sightings, followed by 118 sightings in 2020, which was the lowest recorded number since the establishment of a permanent research base in Laamu Atoll. However, given the field access restrictions resulting from the Covid-19 pandemic, the low number of sightings recorded in 2020 is unlikely representative of actual visitation numbers. In 2021, sighting numbers ($n=448$) rebounded close to 2019 levels, and in 2022 sightings ($n=657$) reflected similar levels to those recorded in 2015 ($n=727$). The mean number of sightings per survey ($n=1.37$) has also increased since 2021 ($n=1.12$) and resembles sighting records from 2019 (Fig. 4).

Sightings trends in Laamu Atoll were relatively consistent from 2014 through 2018, with peaks in sightings typically recorded annually at the start and the end of the Southwest Monsoon (May to June, and October to November) (Fig. 5). Since 2019, seasonal sighting trends had varied and

sightings per survey were significantly below previous averages (Fig. 6). In 2022, the highest number of sightings occurred in May ($n=107$), followed by October ($n=99$), November ($n=97$) and December ($n=79$) (Fig. 7), indicating that seasonal sighting trends are returning to the initial identified patterns recorded between 2014 – 2018 (Fig. 5). The recorded sightings peak in May 2022 ($n=107$) was however more abrupt than usually observed, with sightings being low either side, both in April ($n=37$) and June ($n=33$) (Fig. 7). Survey effort during these months was relatively consistent, with less dives conducted in May ($n=33$) than in April ($n=46$) or June ($n=37$), suggesting that the sighting observations could be due to rapid fluctuations in environmental conditions. A westerly ($n=71$) / south-westerly ($n=91$) wind direction and outgoing current ($n=12$) dominated in May, while both April and June showed fewer westerly winds ($n=37$ and $n=38$, respectively) and although outgoing currents still dominated in these months, an increase in incoming current was noted for both April ($n=10$) and June ($n=6$). The correlation between manta ray sightings and wind and currents is explored later in the report. In 2022, most sightings were recorded at Hithadhoo Corner (39%, $n=256$), Fonadhoo Beyru (20%, $n=134$), and Fushi Kandhu (18%, $n=117$). These numbers reflect manta ray encounters confirmed through photo-IDs.

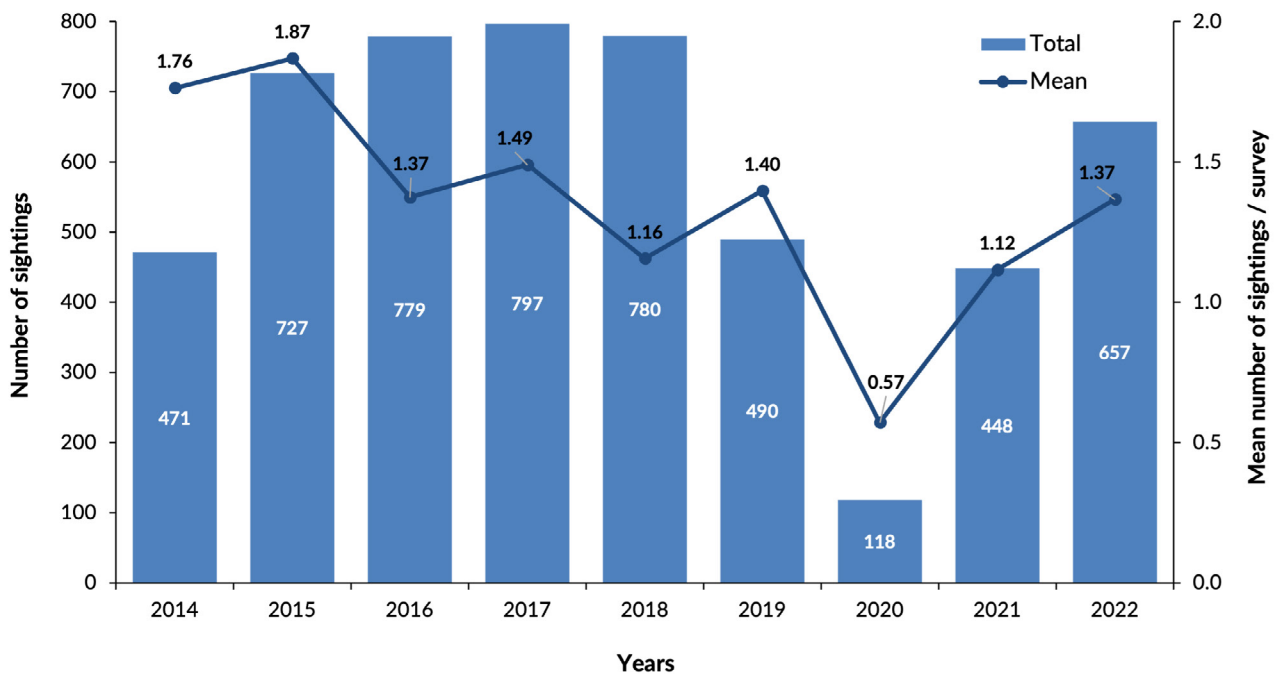


Figure 4: Annual sightings of reef manta rays (*Mobula alfredi*) in Laamu Atoll, and the mean number of sightings per survey.

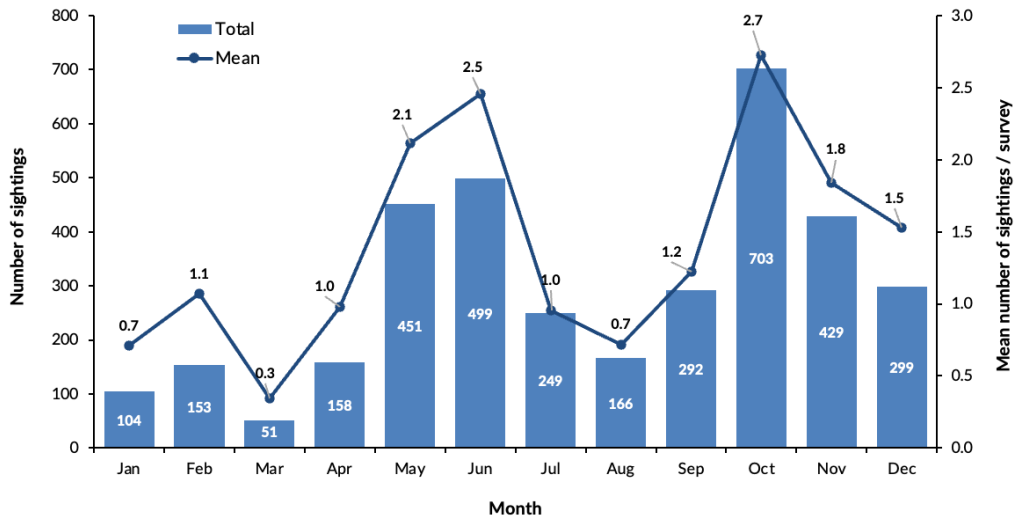


Figure 5: Monthly sightings of reef manta rays (*Mobula alfredi*) in Laamu Atoll (2014 – 2018) and the mean number of sightings per survey.

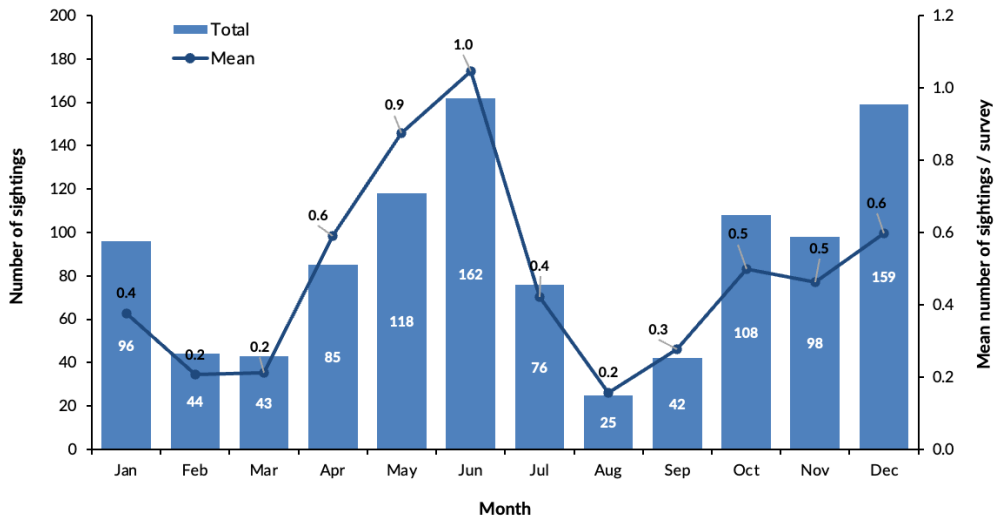


Figure 6: Monthly sightings of reef manta rays (*Mobula alfredi*) in Laamu Atoll (2019 – 2021) and the mean number of sightings per survey.

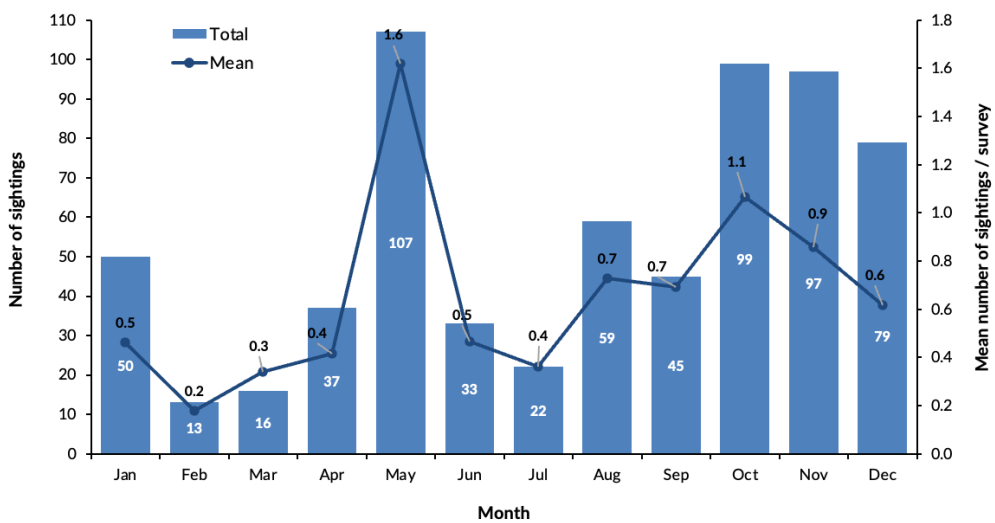


Figure 7: Monthly sightings of reef manta rays (*Mobula alfredi*) in Laamu Atoll (2022) and the mean number of sightings per survey.

Hithadhoo Corner

In recent years, a decrease in manta ray sightings at Hithadhoo Corner was observed (Fig. 8). Between 2014 – 2018 an average of 669 sightings were recorded per year, followed by a steep decline from 396 sightings in 2019 to 340 sightings in 2021. In 2022 sighting numbers have increased slightly ($n=368$) (Fig. 8), however survey effort has also increased from 288 survey days in 2021 to 309 survey days in 2022. When accounting for survey effort across all years, a drop in the mean number of sightings per survey day compared to earlier years was also apparent ($n=1.18$ and $n=1.19$ in 2021 and 2022 respectively, compared to $n=2.89$ between 2014 – 2018) (Fig. 8). It is important to highlight that the total number of sightings across all sites in Laamu has increased since 2019 and is almost back to

initial sighting numbers of 2014 – 2018 (Fig. 4), indicating that the decrease in sightings at Hithadhoo Corner is not representative of the abundance of manta rays within the atoll and that local changes at Hithadhoo Corner might drive the decrease in manta ray sightings.

Peaks in sightings were recorded at Hithadhoo Corner in January, May, and December, with the highest numbers of individuals recorded in May ($n=38$) (Fig. 9). While May is typically known as a month with peak manta ray sightings, the sharp increase from 26 sightings in April to 98 sightings in May and the sudden drop back to 28 sightings in June are an interesting observation, indicating favourable conditions for manta rays on cleaning stations in Hithadhoo Corner

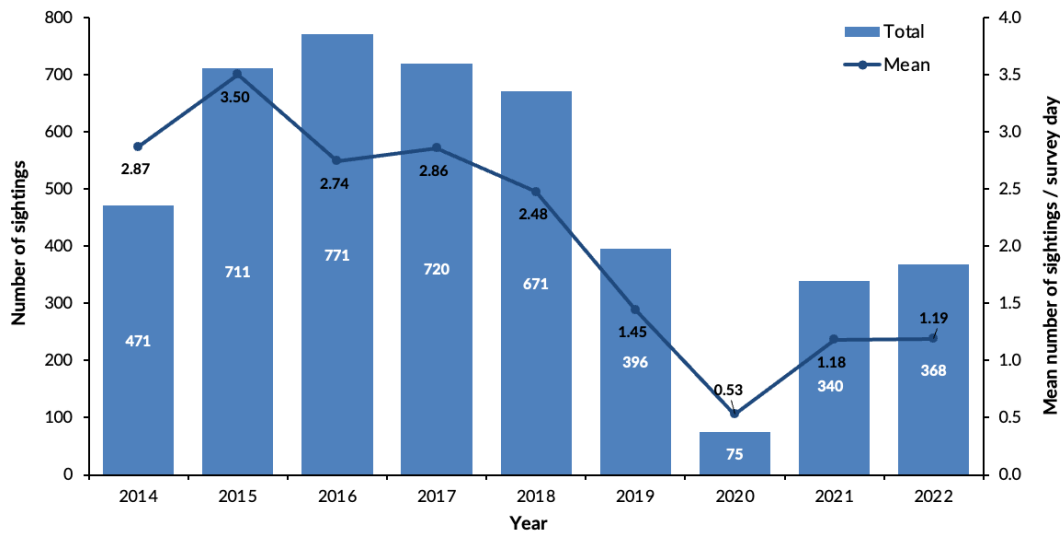


Figure 8: Annual sightings of reef manta rays (*Mobula alfredi*) at Hithadhoo Corner in Laamu Atoll and the mean number of sightings per survey day.

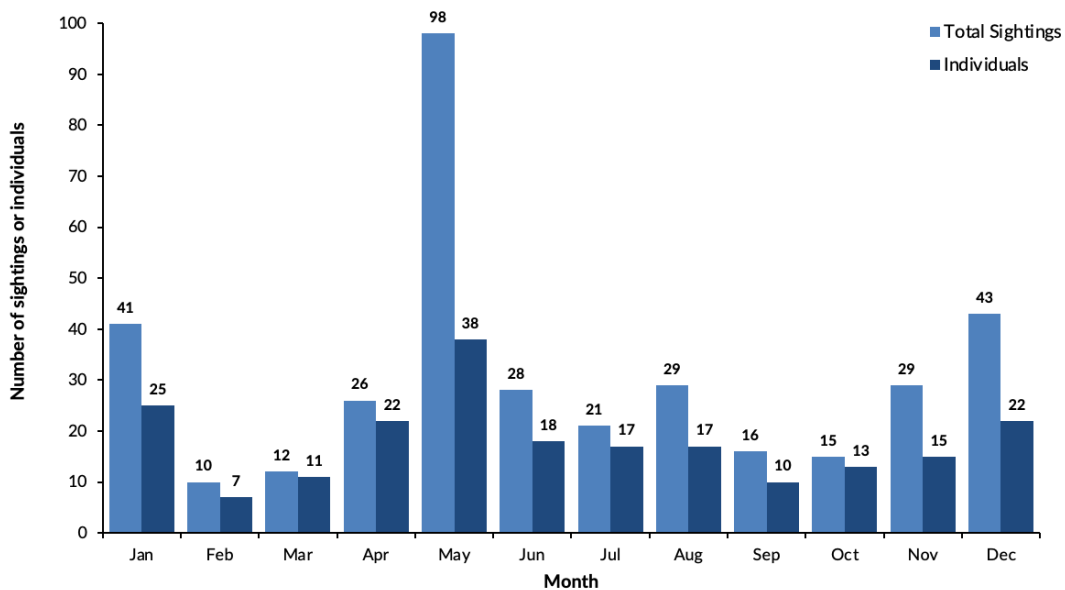


Figure 9: Monthly sightings and the number of individual reef manta rays (*Mobula alfredi*) recorded at Hithadhoo Corner in Laamu Atoll (2022).

or nearby productive feeding areas around this time. It has previously been suggested that manta rays tend to spend more time on cleaning stations when other manta rays are also cleaning. It might indicate that once a certain number of individuals are present at a site due to favourable conditions, other individuals are likely to also visit the site more often during that period, possibly due to higher chances of social interactions, such as courtship. Whether there is a trend of more sudden sighting peaks, and whether these could be due to environmental conditions altering manta ray behaviour will require in depth assessment of various variables over consecutive years.

Seventy-two percent ($n=265$) of sightings recorded at Hithadhoo Corner in 2022 were associated with cleaning behaviour, a decrease of 17% compared to 2021. Cruising behaviour made up 27% of observations ($n=99$) (Fig. 10), which was an increase of 17% from 2021. Courtship only made up 1% of all observed behaviours across the year. The average encounter duration (16 minutes) remained consistent with that recorded in 2021 (17 minutes), showing a slight increase from 2019 (13 minutes), but still a decrease compared to 2014 – 2018, with an average of 23 minutes (Fig. 11). It needs to be highlighted however, that encounter times are sometimes an estimation rather than an exact start and end time.

While SCUBA diving effort at Hithadhoo Corner was highest in years with highest manta sighting numbers (2015 – 2018), with an average of 439 dives per year and 567 sightings per year, the number of sightings during dives suddenly decreased significantly in 2019 ($n=313$) despite relatively consistent survey effort ($n=426$) (Fig.

12), and has since then decreased further to 138 manta ray sightings during dives with only a slight decrease in diving effort (from $n=426$ in 2019 to $n=329$ in 2022). Additionally, 78% percent ($n=222$) of all manta ray sightings at Hithadhoo Corner were recorded through RUV and RUP, signifying the importance of remote camera surveillance, and simultaneously raising the question whether constant diving activities at the site over multiple years, have led to a decrease of manta rays utilising the site when divers are around. Although the total number of individual manta rays visiting Hithadhoo Corner has only decreased slightly from an average of 80 between 2014 – 2018, to 64 individuals in 2022 (Fig. 13), the general decrease in manta ray sightings at Hithadhoo Corner is of concern. Results will therefore directly be communicated with the Hithadhoo Atoll Council and feed into a proposed management plan for the first planned Community Conservation Area (CCA) of the Maldives, called Baaneykolhu CCA, which will include the monitoring, protection, and in-depth study of Hithadhoo Corner, hopefully making it mandatory for all divers visiting this site, not just guests of Six Senses Laamu, to receive code of conduct training on how to dive responsibly with manta rays and other marine life.

Due to the decrease of sightings in Hithadhoo Corner, it has become increasingly important to investigate other potential aggregation sites to understand whether the downward sightings trends are being observed across the atoll or whether it is due to local drivers that affect manta rays' behaviour and site utilisation at Hithadhoo Corner, specifically. For this reason, RUV and RUP survey effort in 2022 expanded with the inclusion of monitoring at three additional manta ray aggregation sites in Laamu.

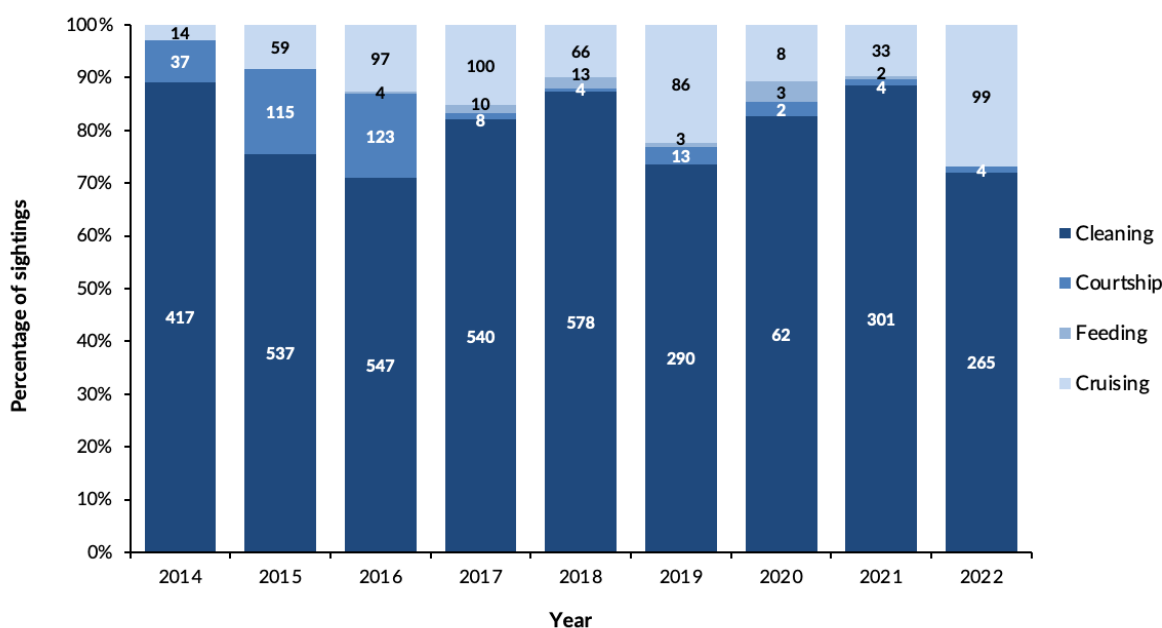


Figure 10: Predominant behaviour recorded during each reef manta ray (*Mobula alfredi*) sighting at Hithadhoo Corner in Laamu Atoll annually. Actual number of sightings above bars.

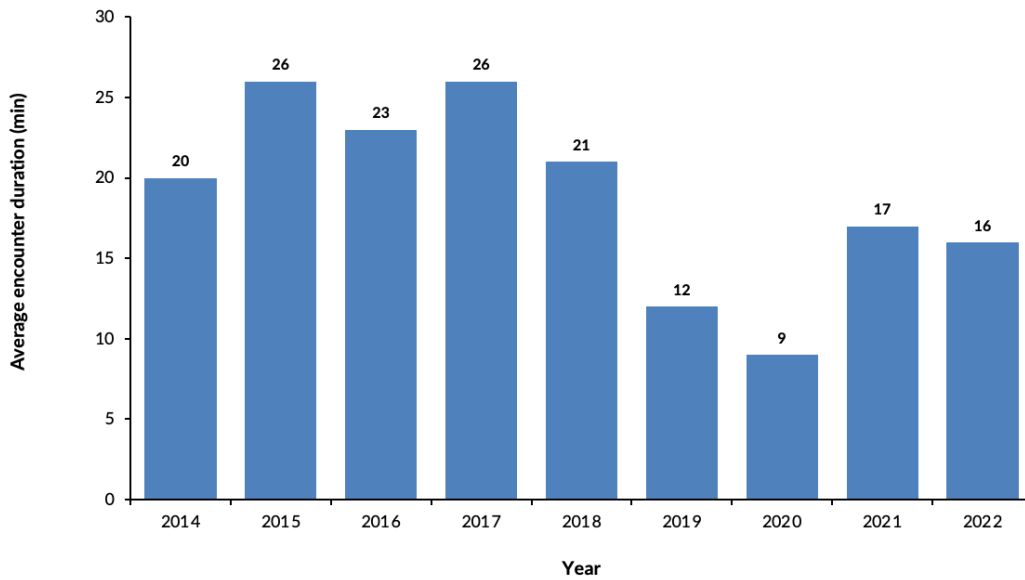


Figure 11: Average duration (minutes) of reef manta ray (*Mobula alfredi*) encounters recorded by divers at Hithadhoo Corner in Laamu Atoll annually.

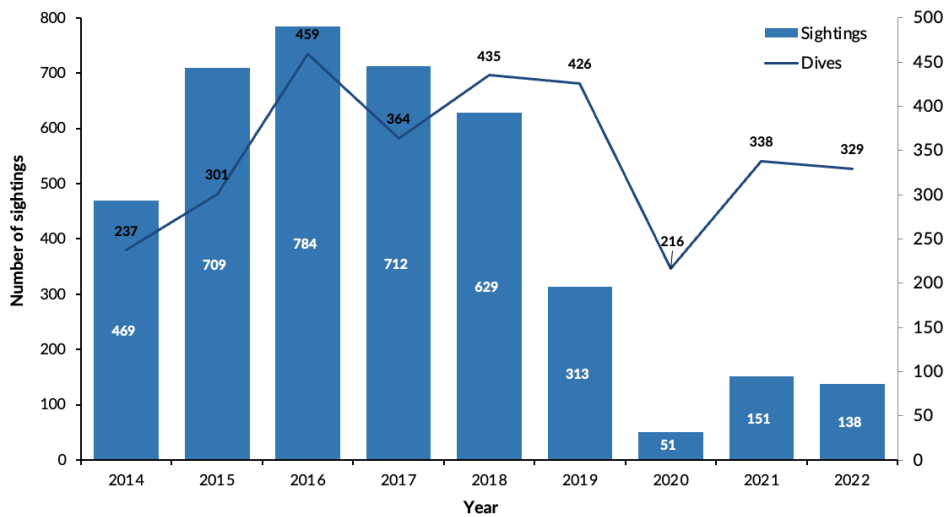


Figure 12: Number of reef manta rays (*Mobula alfredi*) sighted during SCUBA dives at Hithadhoo Corner with number of SCUBA dives conducted annually.

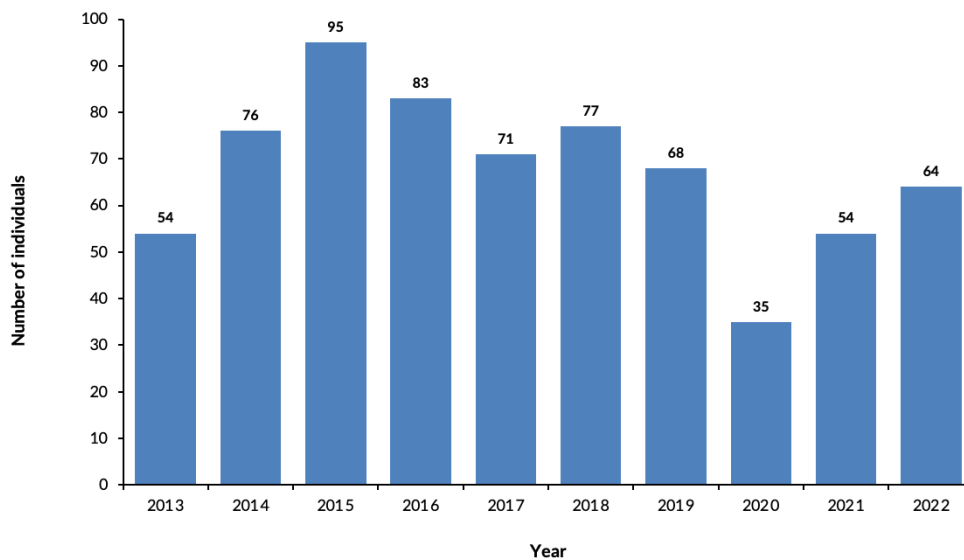


Figure 13: Number of individual reef manta rays (*Mobula alfredi*) identified at Hithadhoo Corner annually.

Northeastern Channels

In 2018, Fushi Kandu was identified as a second key aggregation site based on preliminary surveys conducted in previous years, since then survey effort has increased from 52 surveys in 2018 to 73 surveys in 2021. In 2022, surveys at Fushi Kandu reached a new record of 146 survey days. This increase was possible due to a combination of more regular visits to the site by the resort's dive centre and the implementation of remote underwater camera systems at the cleaning station in Fushi Kandu. Since its first recognition as an aggregation site, the recorded sightings at Fushi Kandu have nearly doubled from 111 sightings in 2018 to 210 sightings in 2022. The average number of sightings per survey day in 2022 ($n=1.4$) has decreased since 2021 ($n=1.9$) yet are higher than in 2019 and 2020 ($n=0.6$ and $n=1.3$, respectively) (Fig. 14).

Maabaidhoo Kandu, a channel located just ~2km south of Fushi Kandu, recorded five sightings across nine survey days in 2022. To calculate sightings per survey day at these sites, the approximate number of manta rays observed was used when there were no confirmed sightings, as data for these sites remains limited.

In 2022, 37 individuals were collectively recorded from 122 confirmed sightings from the north-eastern channels. Manta ray sightings at these channels were recorded from April to June and again from August to December, with October representing the month with the most confirmed sightings ($n=33$) and the highest number of individuals ($n=23$) (Fig. 15). Compared to 2021, where manta ray sightings slowly increased from May ($n=3$) to December

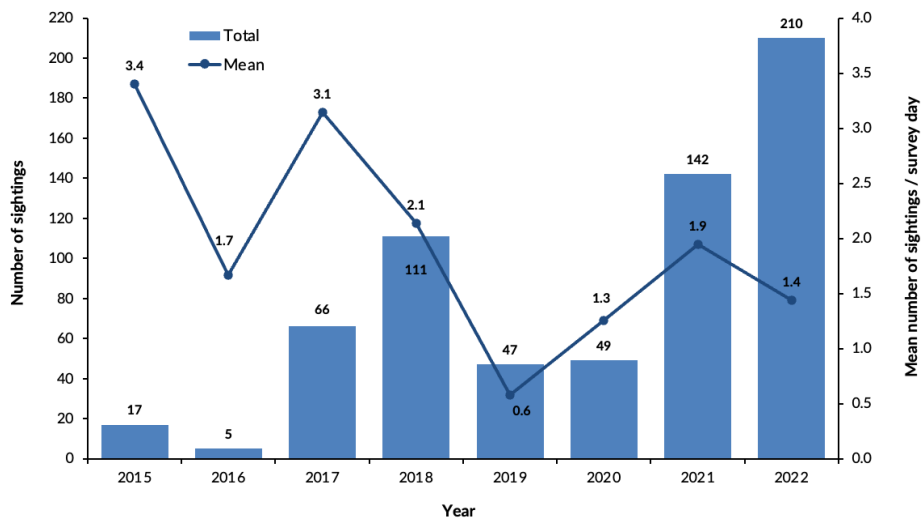


Figure 14: Annual sightings of reef manta rays (*Mobula alfredi*) at Fushi Kandu in Laamu Atoll, and the mean number of sightings per survey day.

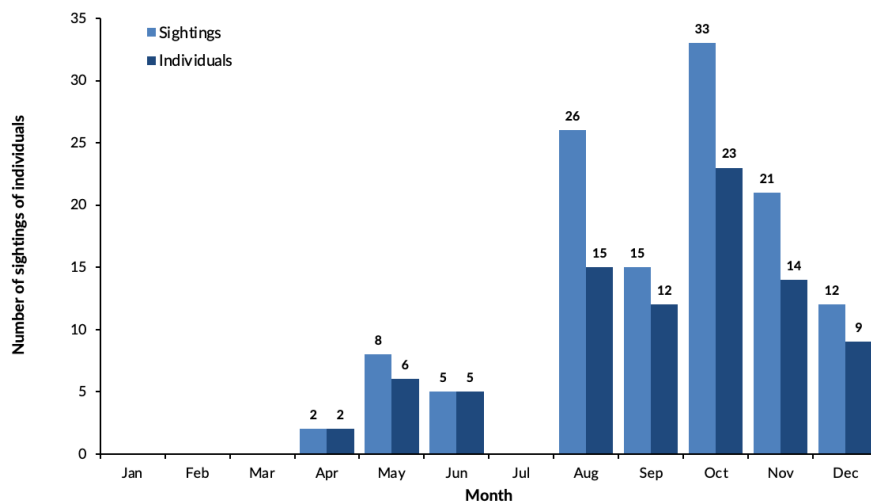


Figure 15: Monthly sightings and the number of individual reef manta rays (*Mobula alfredi*) recorded at Fushi Kandu and Maabaidhoo Kandu in Laamu Atoll (2022).

Photo by Jasmine Corbett



($n=46$), sightings in 2022 showed low numbers between April ($n=2$) and June ($n=5$), followed by a sudden increase in sightings in August ($n=26$), leading into a second peak in October ($n=33$) until sightings dropped slowly in December ($n=12$). Sighting numbers at Hithadhoo Corner were higher in December ($n=43$), but lower during the times where Fushi Kanduu experienced peaks in August and October, with 17 and 13 sightings, respectively.

The highest numbers of individuals sighted per survey occurred at Fushi Kanduu in October ($n=6$), a decrease compared to the highest number of individuals identified at this site during a survey in 2021 ($n=11$). Of the 142 individuals known to Laamu Atoll, 91% ($n=129$) have been

sighted at Hithadhoo Corner, and 49% ($n=70$) at the north-eastern channels. There are only nine individuals that have been sighted at the north-eastern channels, but not at Hithadhoo Corner; three of which were new to Laamu Atoll in 2022. As the peak sighting months for Hithadhoo Corner and the north-eastern channels are similar overall (Fig. 16), and since most of the individuals sighted at the north-eastern channels have also been seen at Hithadhoo Corner, the most plausible hypothesis remains; that Fushi Kanduu and Hithadhoo Corner represent key aggregation sites of a single manta ray population within Laamu Atoll. Individuals likely move along the outer atoll reef to travel between these sites. This hypothesis is further supported through the results obtained from Fonadhoo Beyru, an outer reef

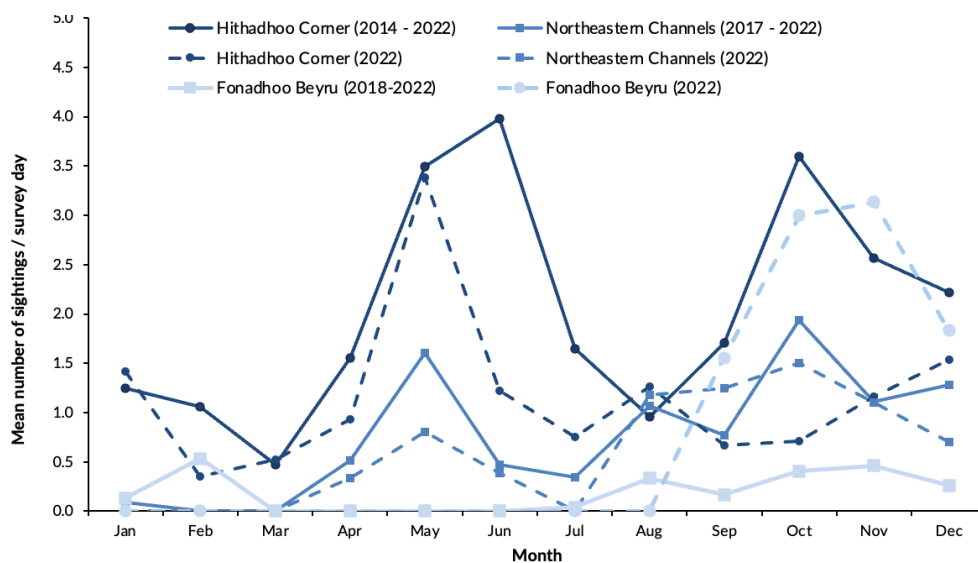


Figure 16: Mean number of reef manta ray (*Mobula alfredi*) sightings per survey day at Hithadhoo Corner, the north-eastern channels and Fonadhoo Beyru in Laamu Atoll.

located between Fushi Kandu and Hithadhoo Corner, and where significant manta ray sightings were recorded from September to December 2022, with a peak of sightings in October ($n=51$).

Total sightings since 2014 from the north-eastern channels ($n=430$) are steadily increasing, but remain comparatively low, mainly due to the lower frequency of research visitation to these sites. The highest proportion of sightings at north-eastern channels was recorded during the Southwest Monsoon (15%, $n=64$) and westerly winds (13%, $n=57$), whilst few sightings (6%, $n=24$) were recorded during the Northeast Monsoon (Fig. 17). Similarly, in 2022 the highest proportion of sightings were recorded during the Southwest Monsoon, or during the transition between

Northeast and Southwest monsoons, with the highest proportion of sightings recorded during westerly winds (63%), followed by sightings during north-westerly winds (18%) and south-westerly winds (15%).

The observations suggest that the overall seasonality at the north-eastern channels of Fushi Kandu and Maabaidhoo Kandu is consistent with observations from the MMCP's study sites in the central atolls, whereby eastern sites experience higher numbers of sightings during the Southwest Monsoon and western sites during the Northeast Monsoon. This hypothesis is supported by the increased sightings of manta rays at western sites during the Northeast Monsoon in 2022 and indicates a potential correlation between monsoons and sightings.

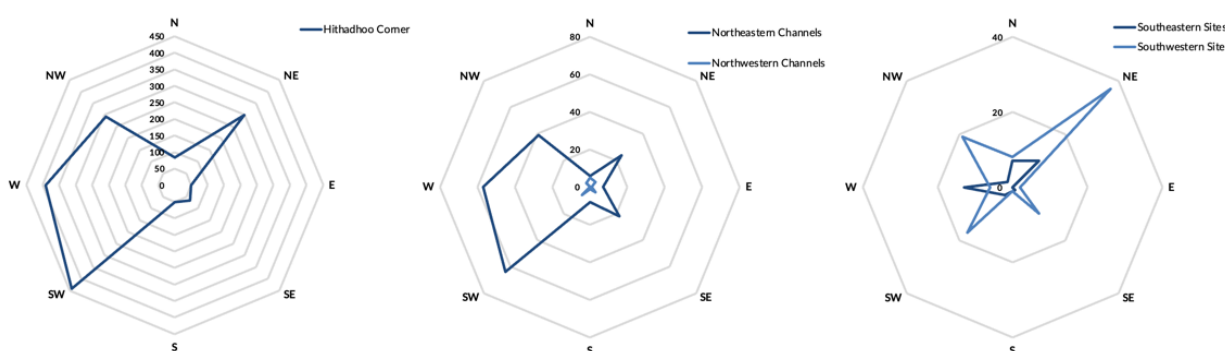


Figure 17: Number of reef manta ray (*Mobula alfredi*) sighting records in relation to the prevailing wind direction at Hithadhoo Corner, the northeastern channels, the northwestern channels, the northeastern and southwestern sites in Laamu Atoll (2014 - 2022).

Fonadhoo Beyru

Since the beginning of the Manta Trust's research in Laamu Atoll, Fonadhoo Beyru was only surveyed 51 times, with a total of 54 (unconfirmed) manta ray sightings, the vast majority being recorded in 2018 ($n=43$). Of these sightings, 19 were confirmed sightings through photo-ID, all of which were recorded in February. Since 2018, only a few surveys per year were conducted at this site. Historically, identified manta rays sighted at Fonadhoo Beyru have been reported to be feeding. Only one record is available from 2019 in which a manta ray was sighted cleaning. In September 2022, sightings of manta rays utilising a small, deep (~26m) cleaning station were reported and the Manta Trust subsequently started RUP system deployments at Fonadhoo Beyru, thereby increasing survey effort at this site by a further 45 days from September onwards.

Throughout the final quarter (September - December) of 2022, a total of 208 (unconfirmed) manta ray sightings

were recorded at Fonadhoo Beyru. Of these, 134 sightings (64%) were confirmed through photo-ID, with 85% ($n=114$) of those being obtained through RUP ($n=27$) and RUV ($n=1$). The primary observed behaviour for identified manta rays at Fonadhoo Beyru was cleaning (91%, $n=122$), followed by cruising (5%, $n=6$), courtship (4%, $n=5$), and feeding (<1%, $n=1$). Due to the cleaning station being at a depth of ~26m, survey time during dives is limited, therefore these observations reiterate the importance and benefits of utilising RUPs and RUVs.

Prior to 2022, Fonadhoo Beyru was treated as a secondary site. Due to the surveys at Fonadhoo Beyru being incredibly successful in 2022, with the number of individuals ($n=46$) visiting the site between September and December exceeding the number of individuals recorded at Fushi Kandu ($n=35$) across the whole year, Fonadhoo Beyru was treated as primary site for the purpose of this

report. Comparing the number of individuals sighted at Fonadhoo Beyru ($n=46$) with the number of individuals at Hithadhoo Corner ($n=35$) throughout the same time from September to December, this site also accounted for nine additional individual manta ray sightings compared to the number of individuals observed at Hithadhoo Corner ($n=35$). Considering that Fonadhoo Beyru was surveyed on less days ($n=44$) than Hithadhoo Corner ($n=98$) throughout this time frame, this observation suggests that some manta rays seek out other cleaning stations more frequently than Hithadhoo Corner. Whether this is due to environmental factors, such as depth of the cleaning station and hence potentially lower sea temperatures, or due to anthropogenic reasons, it will have to be investigated further. It is yet to be determined as to whether this observation noted in 2022 is a seasonal anomaly or if similar trends are observed in subsequent years. The MMCP will continue survey effort at this site to gain further insight into manta ray visitation patterns at this site.

Despite Fonadhoo Beyru having provided more confirmed manta ray sightings ($n=134$) than Hithadhoo Corner ($n=81$) across the same time frame, it is important to note that the cleaning station at Fonadhoo Beyru is a lot smaller than the cleaning station at which the team deploys the RUP

systems at Hithadhoo Corner (Shallow Block). This results in a bigger area that manta rays can utilise at Hithadhoo Corner and hence it is easier for the RUP to also miss certain manta ray photo-IDs (i.e., a manta encounter is still highly likely to be recorded but photo-IDs cannot always be obtained because the manta was located too far away from the camera). At Fonadhoo Beyru there is a much smaller possibility the RUP misses a manta ray sighting due to the small size of the cleaning station and the positioning of the RUP.

It is worth noting that between September and December 2022, 19 individuals that were sighted at Fonadhoo Beyru were not recorded in Hithadhoo Corner, and 28 individuals that were recorded in Fonadhoo Beyru were not recorded in Fushi Kanduu during that time. These observations could indicate that Fonadhoo Beyru serves as a key aggregation site throughout this time, potentially facilitating a preferred area of habitat use for some manta rays in Laamu Atoll. Five individuals that were recorded at Fonadhoo Beyru were never recorded on any other site throughout 2022. More regular surveying of Fonadhoo Beyru is recommended in 2023 to detect sighting and movement trends over a full annual term.



Photo by Jasmine Corbett

Secondary Sites

Ninety-one reef manta ray encounters were reported at an additional eight survey sites in 2022 (eight sites less than in 2021), with 36 of these sightings being confirmed through photo-ID. Most sightings were recorded at Boduhuraa Beyru (66%, $n=60$), followed by Munyafushi Beyru (17%, $n=15$), and Mendhoo Beyru (12%, $n=11$), also known as Hithadhoo West. All sites are outer reefs, with Boduhuraa Beyru being the only site with distinct cleaning stations that have been identified so far. Of all secondary sites, Mendhoo Beyru and Boduhuraa Beyru have historically provided the most consistent sightings, with 30% ($n=144$) and 29% ($n=139$) of secondary site sightings respectively. Due to its remoteness, Munyafushi Beyru is a site that has never been surveyed before. The 15 unconfirmed sightings recorded in February 2022 were an outside submission from a trusted local dive instructor who observed the manta rays during a surface feeding event. February is a month with typically low sightings of manta rays on frequently surveyed study sites, such as Hithadhoo Corner and Fushi Kandu, and this observation supports the hypothesis that manta rays likely frequent the western sites of the atoll during the Northeast

Monsoon. The recorded sightings at Boduhuraa Beyru were dominant in January ($n=22$) and April ($n=19$) and, on a smaller scale, at Mendhoo Beyru during March ($n=7$) and December ($n=3$). These records suggest that manta rays predominantly frequent this site during the Northeast Monsoon. Interestingly, sightings at western channels continue to be low, with only two sightings recorded in Vadinolhu Kandu in January and no sightings in Maavah Kandu throughout 2022. Inner reef sightings were also low, with a total of two sightings, one at Olhuveli Faru in February and one at Laama Faru Haa in April. In 2022, 53% ($n=19$) of the confirmed sightings from secondary locations were of cleaning behaviour, 36% ($n=13$) of cruising, and 8% ($n=3$) of feeding activity.

Generally, sightings on the southwestern side of the Atoll increased during the Northeast Monsoon. However, data from secondary sites, particularly from sites further afield in the north of the Atoll, remains limited and additional research is needed to determine if sightings in these areas are linked to environmental conditions.

Environmental Influences

Throughout the Maldives, site usage by manta rays has been linked to wind direction, which changes with the seasons. Research in Laamu Atoll has been on-going since 2014, but the wind has never been considered a key variable in determining site use, as Hithadhoo Corner was the only aggregation site identified until 2018, and the site supports year-round encounters. However, preliminary analysis of the Laamu Atoll data since 2014 on the approximate number of manta rays observed at a site in relation to wind direction has revealed that sightings at Hithadhoo Corner generally are recorded under all wind conditions, but typically peak when winds are blowing from the southwest and west (Fig. 17). Sightings recorded in 2022 appeared to follow this trend, with the highest encounters recorded during westerly winds.

At the north-eastern channels of Fushi Kandu and Maabaidhoo Kandu, sightings also peak when winds are blowing from the southwest and west (Fig. 17). Very few sightings have been recorded at Fushi Kandu or Maabaidhoo Kandu during the Northeast Monsoon, which suggests these sites may be used more seasonally. However, data collection at these sites is still comparatively low compared to Hithadhoo Corner. In other areas of the Atoll, there may also be correlations, particularly on the southern outer edges of the Atoll where sightings peaked when winds were from the northeast (Fig. 17). While the

topography may be somewhat different in Laamu Atoll to the more northern atolls, manta ray site usage in the Atoll appears to still be heavily influenced by wind direction. As sightings in the Atoll decrease during the Northeast Monsoon, it is likely that the manta rays are using sites on the western edge of Laamu (which are rarely visited by the Manta Trust and Deep Blue Divers teams) or are utilising western sites within Thaa Atoll; the closest atoll to Laamu. Understanding the influence of wind in Laamu Atoll is important as it informs conservation management and allows the MMCP to prioritise survey areas depending on the prevailing wind direction and monsoon. Data from further sites remains limited and further research is needed during both monsoons to determine the environmental influence on sightings trends at these locations.

Christopher Wenham's thesis project, as introduced above, assessed RUP data collected between May 2021 and May 2022 to understand the temporal use of cleaning stations by manta rays, and to determine the effects of environmental variables, such as changing seasons, lunar cycles, tides, and temperatures on manta ray presence at this site. Temperature was found to be a significant environmental predictor for manta ray abundance at Hithadhoo Corner. Manta ray presence decreased as temperatures neared threshold values of 30°C. Generally, visitation rates were higher during the first quarter of the moon phase, however

moon phase was not a significant predictor. Tidal phase showed no significant effect, however more manta rays were seen during low tide, which might be attributed to optimal feeding conditions in nearby areas at high tide. The highest abundance of manta rays were recorded at Hithadhoo Corner at the beginning or end of monsoons, suggesting these transition months provide the most favourable conditions for the utilization of this aggregation site by the reef manta rays.

Although current has always been assumed to be a factor influencing manta ray activity patterns, no formal analysis has been conducted to support theories. In Laamu Atoll, the current direction is considered a key variable and therefore is typically recorded for all dive or snorkel surveys. An assessment of the data recorded between 2014 – 2022 revealed that most manta ray sightings at channel sites

occur during outgoing current (Fig. 18) (67% and 55% at Hithadhoo Corner and the north-eastern channels, respectively). The least chance of sighting manta rays on dives at channel sites was noted to be when the current is slack. Manta rays sighted at channel sites are primarily observed being cleaned, which might indicate that manta rays feed at other locations during incoming currents when zooplankton rich water gets pushed closer to the surface and concentrated in the reef systems of the atolls. It is possible that when currents are changing, and therefore a slack current prevails, manta rays leave their current site and change their behaviours from feeding to cleaning behaviour. In December 2022, current meters were installed by the MUI at Hithadhoo Corner and Fushi Kandu with the aim of collecting more robust and accurate current data to better understanding sighting trends of megafauna in correlation to ocean currents at channel sites.

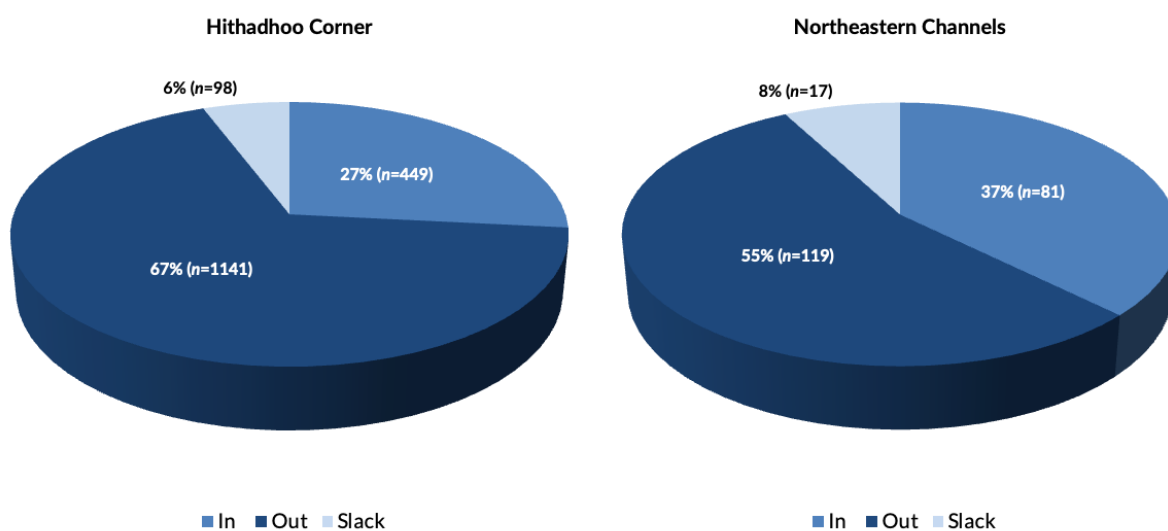


Figure 18: Number of reef manta ray (*Mobula alfredi*) sighting records in relation to the current direction at Hithadhoo Corner and the north-eastern channels in Laamu Atoll (2014 – 2022).

POPULATION DEMOGRAPHICS

As of the 31st of December 2022, 142 individual reef manta rays (81 females, 59 males, and two individuals of unknown gender) have been identified in Laamu Atoll, comprising 2.5% of the known Maldives population. At study locations further north in the Maldives, the ratio of female to male manta rays observed is roughly 50:50. Although it is apparent that in recent years there has been a shift in ratio towards a more equal gender distribution, Laamu Atoll still appears to support a slightly female dominated (57%) and mostly adult (54%) population (Fig. 19). When looking at the number of sightings of females and males

each year, females are also sighted more frequently than males (Fig. 20). This is to be expected as most sightings in Laamu Atoll occur around cleaning stations, which are commonly visited by adult manta rays, and are typically dominated by females, who invest more time in cleaning than male individuals. If more feeding sites and juvenile aggregation areas were to be identified within Laamu Atoll, the population demographics could likely reflect the national average more closely.

Of the 142 known individuals, 57% were photographed

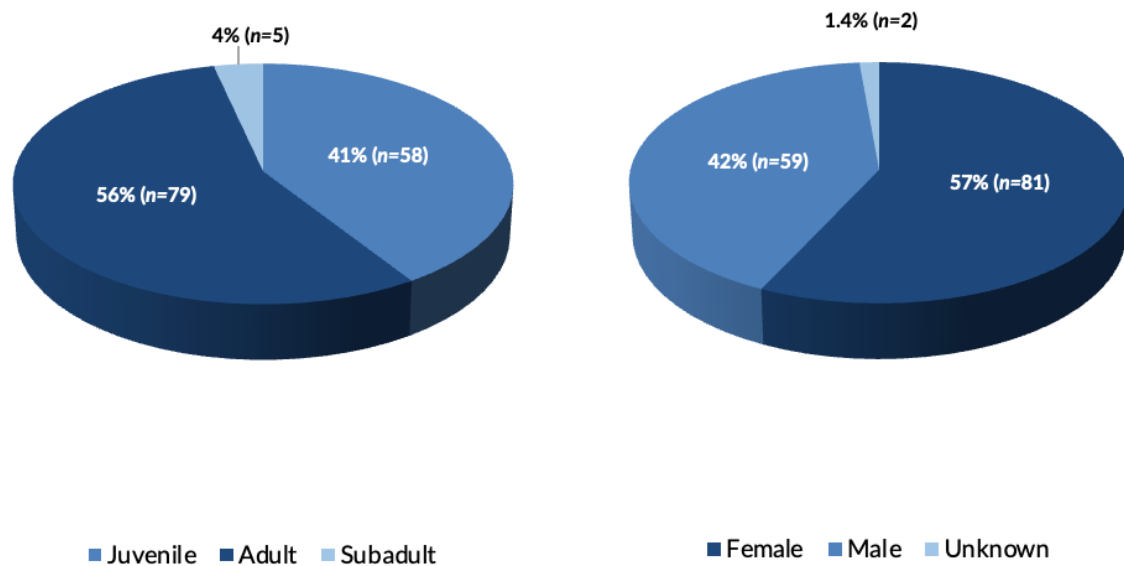


Figure 19: Demographics of the Laamu Atoll reef manta ray (*Mobula alfredi*) population (n=142).

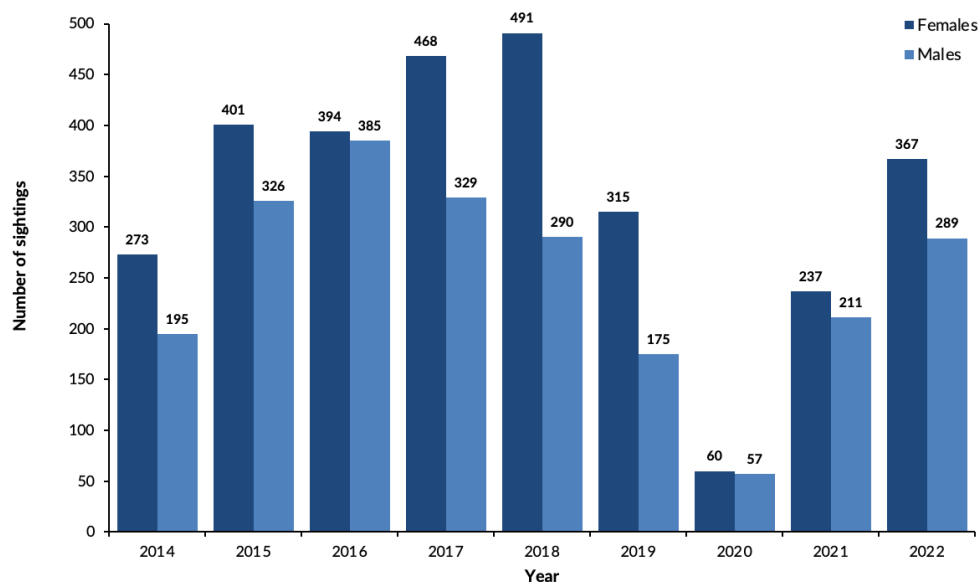


Figure 20: Number of female and male reef manta rays (*Mobula alfredi*) sighted annually in Laamu Atoll.

in 2022 (n=81), an increase from recent years [n=67 in 2021 (49%) and n=53 in 2020 (40%)], and a return to pre-2020 numbers with an average of 84 individuals sighted each year between 2014 and 2019 (Fig. 21). Of the 81 individuals sighted throughout the year, 17 were not sighted at Hithadhoo Corner, reiterating the importance of surveying other sites to get a more holistic view of manta ray population size.

Four new individuals were recorded in Laamu Atoll, all of which were new to the Maldives. All these individuals were identified as juveniles, three of which were males and one where sex could not be determined yet. All three new males were first sighted in Fushi Kandu, with the 4th new

individual first being sighted in Hithadhoo Corner.

Between 2015 – 2018, the percentage of individual males sighted had remained consistent at 40 to 41% per year. In recent years there has been a shift in ratio towards a more equal ratio, because of below-average sightings of individual female manta rays. In 2022, 47% (n=38) of individuals recorded were male, and 53% (n=43) were female (Fig. 22). This shift in ratio is due to a decrease in individual female manta rays recorded in Laamu Atoll; i.e., 43 females in 2022 compared to 57 females in 2015. It is however worth noting that of all female manta rays recorded in Laamu Atoll, ten individuals have only been documented in the Atoll during one research year since the

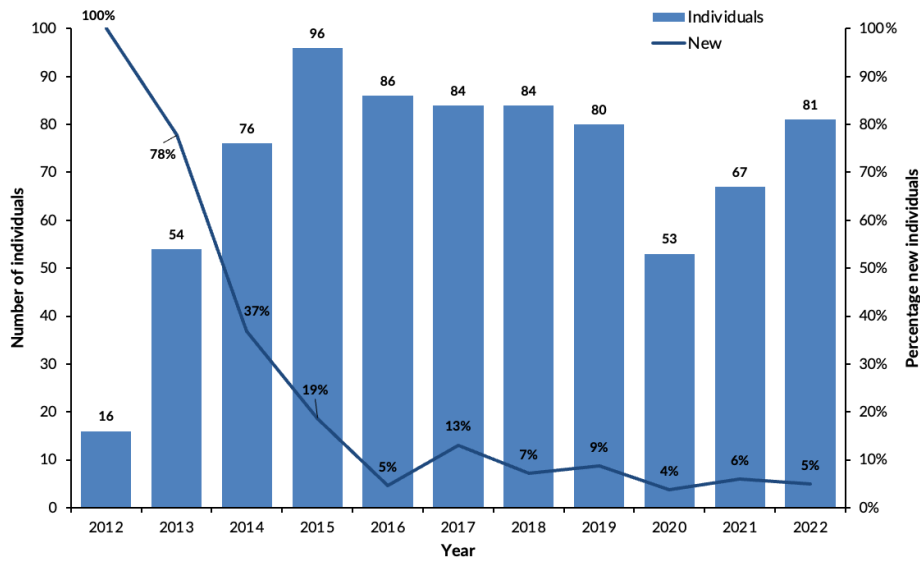


Figure 21: Number of reef manta rays (*Mobula alfredi*) sighted annually in Laamu Atoll and the percentage of those individuals that were newly recorded.

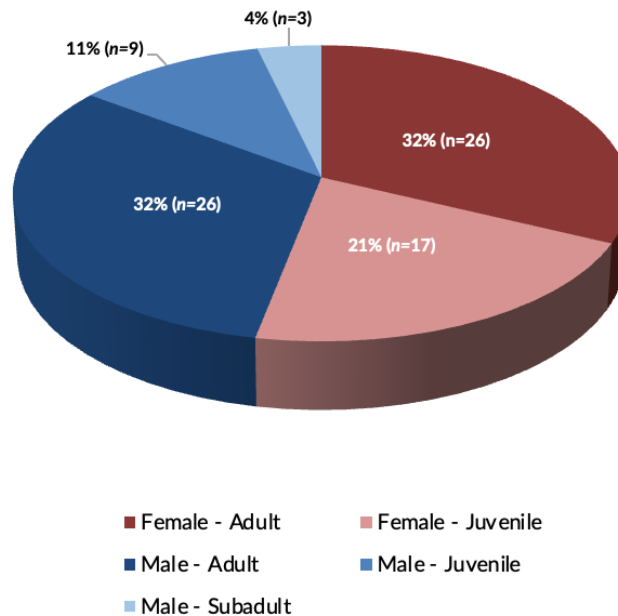


Figure 22: Demographics of the Laamu Atoll population of reef manta rays (*Mobula alfredi*) sighted in 2022.

start of records in 2012, suggesting that there is a small percentage of individuals that might not utilize Laamu Atoll as permanent habitat, or that these individuals have died.

The maturity status in manta rays can be determined by the presence of mating scars or visible pregnancies in females, or by the enlargement and calcification of claspers in males. If visual features are not apparent, the size and historical sightings records of individuals can also be considered to estimate maturation. If an individual was estimated or measured to be at least 320 cm (centimetres) disc width

in females, or 270 cm disc width in males, they were considered as adults. Research on measuring manta rays is currently being conducted in Laamu Atoll as part of a PhD study with Cambridge University. More information about measuring manta rays is also available in the project activities report.

Maturation demographics in 2022 remained in line with previous years. Sixty-four percent of individuals sighted in 2022 were adult manta rays ($n=52$) and 32% were juveniles ($n=26$), with demographics of the overall population

appearing relatively consistent. From 2016 to 2019 there was a steady increase in the proportion of juveniles recorded in Laamu Atoll (Fig. 23). This may be the result of young recruits utilising the study sites after a period of population fecundity. However, it could also indicate that the study sites in Laamu Atoll are utilised more by adults when conditions are favourable for courtship. Another possibility, and the most likely hypothesis, is that research effort in recent years has diversified focus to collect data from more varied manta ray aggregation sites, opportunistically capturing younger individuals in the process, which are less

likely (less often) to frequent the cleaning stations at sites like Hithadhoo Corner. Interestingly, this pattern was not followed in 2020, with an increase in adults and decrease in juveniles recorded. Survey effort drastically reduced in 2020 and a lower variety of sites were visited, reducing the opportunity to encounter new juveniles. Although eight new individuals have been identified in Laamu Atoll between 2021 and 2022, the ratio has remained consistent with that reported in 2020, with a slight increase of sub-adults being recorded (4%) in 2022 (Fig. 23).

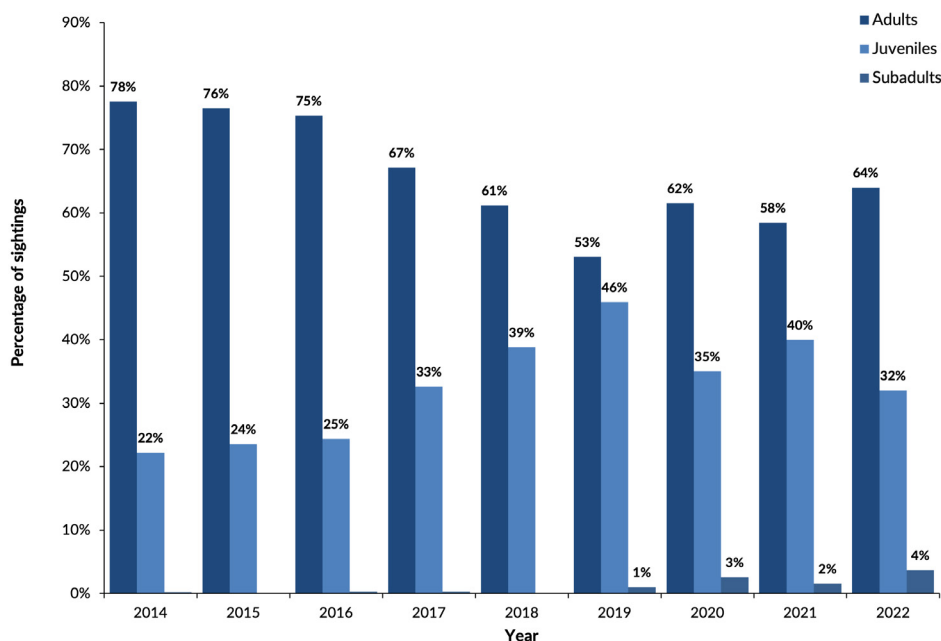


Figure 23: Percentage of confirmed sightings of juvenile, subadult, and adult reef manta rays (*Mobula alfredi*) in Laamu Atoll between 2014 and 2022.

MIGRATION & RESIDENCY

The population of reef manta rays in Laamu Atoll is small, yet highly resident. Individuals show high site fidelity and are rarely sighted elsewhere in the Maldives. The number of sightings per individual ($n=8.11$) in 2022 increased compared to 2021 ($n=6.69$) and was similar to the number of sightings recorded per individual between 2015 – 2018 (average of 8.85 sightings per individual) (Fig. 24). The proportion of manta rays observed on more than one occasion (89%) increased by 31% from 2021. This proportion of individual manta rays being sighted on more than one occasion was comparable with that recorded between 2014 and 2019 (an average of 86%) (Fig. 24) and suggests that, compared to 2020 and 2021, the Manta Trust was able to survey habitats that manta rays utilised throughout the year. It also needs to be noted that up until recently the survey

effort was extremely focused on Hithadhoo Corner, which historically might have been the preferred habitat for manta rays, however data in recent years suggests that this might be changing. Trends in site fidelity will only become clear upon further years of research.

To account for variations in survey effort, an average residency index (RI) was calculated for each year based on the ratio between the number of times each individual manta ray was sighted and the total number of surveyed days (e.g., an RI of 5% means that, on average, each manta ray was sighted on 5% of the total surveyed days). Changes in RI can be linked to environmental fluctuations or changes in survey effort within each year. Up until 2020, the average RI in Laamu Atoll had been decreasing, from

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Changes in RI can be linked to environmental fluctuations or changes in survey effort within each year. Up until 2020, the average RI in Laamu Atoll had been decreasing, from 3.6% in 2014 to 1.15% in 2020. In 2021, the RI increased to 2.5%, but has shown a slight decline again in 2022 to 2.3% (Fig. 25). This could be explained by the increased survey effort conducted in 2021 and 2022 - in both years the lengths of survey times increased significantly due to more remote surveys (RUPs and RUVs), which in turn increased the likelihood of recording manta rays at some point throughout the day, thereby increasing the number of individuals on average being recorded within one survey day.

While a determination of the exact movements of individual manta rays is not possible with the current research techniques (photo-ID), it appears that the Laamu Atoll manta ray population exhibited more transient behaviour in recent years, perhaps searching for more favourable conditions elsewhere. Despite Hithadhoo Corner still facilitating the most manta ray sightings throughout the year compared to other sites, significant decreases in sightings at this site over the years suggest that manta rays have started to utilise other sites more frequently. This hypothesis is supported by the high sighting rates obtained from Fonadhoo Beyru. To determine how often manta rays are utilising additional sites, and why, it is necessary



Photo by Jasmine Corbett

to increase the survey effort in unexplored areas of Laamu Atoll. Increasing numbers of exploratory dives presents logistical challenges and would mean a decrease in dives at Hithadhoo Corner. The decreased sightings at this crucial aggregation site have, however, provided significant justification to survey other sites more consistently, while the usage of RUP at Hithadhoo Corner provides almost continuous monitoring of the site without the need for daily research dives.

Up until the end of 2021, 16 individuals (11% of Laamu

Atoll's population) have been recorded elsewhere. Some individuals have been sighted in more than one atoll outside Laamu Atoll, resulting in 46 recordings of these 16 individuals across 11 other atolls in the Maldives (Fig. 26). The majority of these individuals have been recorded in Baa Atoll ($n=6$) and Raa Atoll ($n=4$) since 2014. The 2022 analysis for the collective dataset from all research bases in the Maldives is still in process, so the figures for Laamu Atoll manta rays sighted in other atolls in 2022 will be published in the 2023 report.

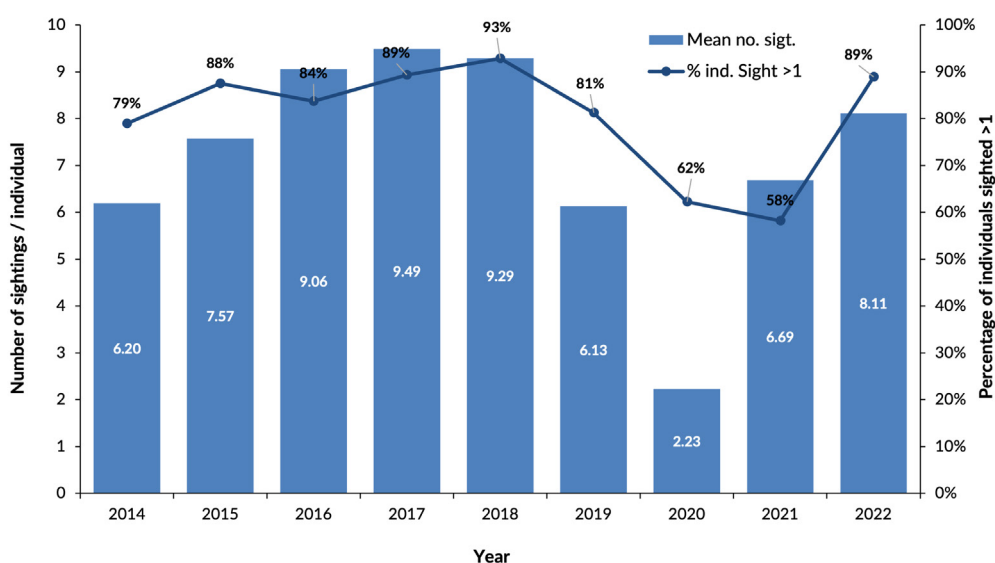


Figure 24: The mean number of sightings per individual reef manta ray (*Mobula alfredi*) annually in Laamu Atoll and the percentage of those individuals sighted more than once.

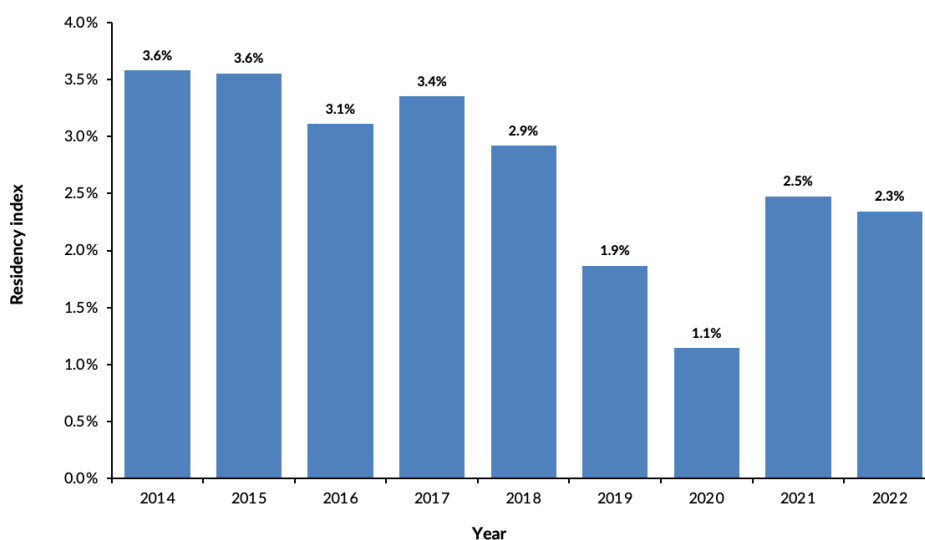


Figure 25: Residency Index (RI) of the reef manta rays (*Mobula alfredi*) sighted annually within Laamu Atoll. RI was calculated as the average of each individual's residency score (equal to the number of times sighted annually divided by the number of surveyed days in the atoll).

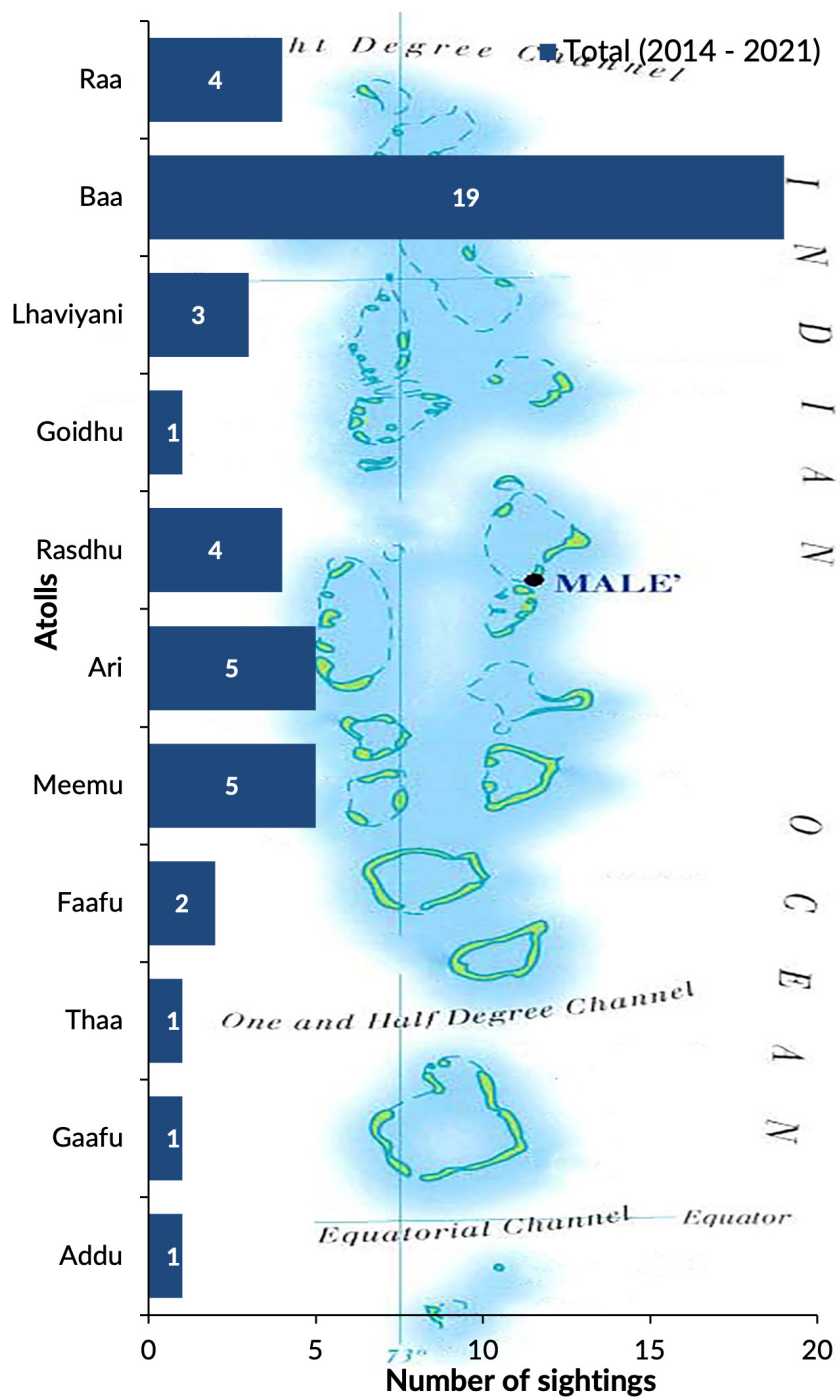


Figure 26: Number of sightings ($n=46$) of reef manta rays (*Mobula alfredi*) from the Laamu Atoll population which have been sighted in other atolls throughout the Maldives. Note - some individuals have been sighted in more than one atoll throughout the Maldives Archipelago.

PREGNANCIES & COURTSHIP

Prior to 2018, Laamu Atoll was considered to support a bi-annual courtship season (May – June and October – November). Following minimal courtship behaviour in 2018 ($n=4$ sightings) but high pregnancy records ($n=73$ sightings of $n=16$ individuals), 2019 saw a slight increase in courtship behaviour ($n=15$ sightings of $n=14$ individuals) with pregnancy records greatly reduced (Fig. 27). This could be due to a combination of lower sightings in 2019, and individuals recorded as pregnant in 2018 having given birth

and in a period of recovery between gestation periods. In both 2020 and 2021, courtship behaviour was extremely low, with only two and six sightings recorded, respectively (Fig. 27). Courtship activity and gestations are often cyclical, with periods of significant increased fecundity, often followed by years of little or no reproductive activity in the population. These cycles are thought to be linked to ocean productivity and since female manta rays invest a great deal of energy in gestation, they can only reproduce

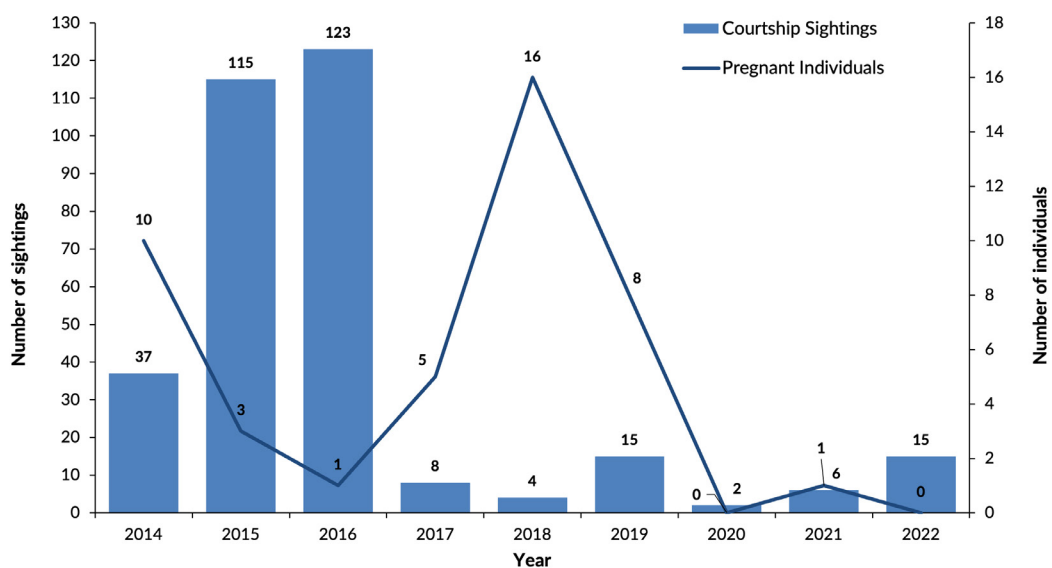


Figure 27: Number of sightings annually during which courtship was the primary behaviour, and the number of individual reef manta rays (*Mobula alfredi*) which were recorded pregnant annually.

when food availability is above average. In recent years, Laamu Atoll is likely experiencing reduced productivity, which could be the reason for the lack of reproductive activity in recent years.

Following zero pregnancies in 2020, just one pregnancy was recorded in 2021. In 2022, the sightings of courtship behaviour increased ($n=15$ sightings). Despite seven females having shown mating scars in 2021, no pregnant females were observed in 2022. The recorded regular sightings of these individuals throughout the year suggests that mating in these females has not yet led to pregnancies, as signs of pregnancy would have likely been noticed during the second half of the year. Unsuccessful mating is natural and of no concern unless this develops into a trend with no pregnancies being recorded in the upcoming years, despite consistent sightings of courtship and mating scars.

All courtship sightings were recorded towards the end of the year during October and December, with no other courtship observations between May - June, suggesting that Laamu Atoll does not currently support a bi-annual courtship season. Seventy-eight percent of all adult females sighted in Laamu have been observed pregnant before ($n=29$), with 38% ($n=11$) of those recorded with more than one pregnancy (Table 2). Pregnant manta rays in their 4th and final trimester were last recorded in 2018, with the last earlier-trimester pregnancy recorded in 2021.

The data suggests that Laamu Atoll manta rays are still between reproductive cycles. Since the average fecundity for female reef manta rays in the Maldives is thought to be one pup every seven years, the current absence of pregnancies seen since 2018 in Laamu manta rays, will only become concerning if this trend continues. However, while

Table 2: Number of individual adult female reef manta rays (*Mobula alfredi*) and the recorded pregnancies in Laamu Atoll. Numbers within each cell indicate the number of sightings, empty cells indicate zero sightings, dark highlighted cells indicate years of pregnancies.

Table 2 (2014 - 2022)									
ID	2014	2015	2016	2017	2018	2019	2020	2021	2022
MV-MA-0035	1	5		1		1			
MV-MA-0258	8	5	13	22	11	12		3	11
MV-MA-1090	4	8	10	5	2	6			4
MV-MA-1446	13	18	7	16	13				
MV-MA-2411	9	4	2						
MV-MA-2412	8	6	10	11	1	3	2	3	9
MV-MA-2413	1	2	2						
MV-MA-2414	10	19	17	25	17	10	1	12	9
MV-MA-2552	8		9	9	7	1	1	3	10
MV-MA-2765				1					
MV-MA-2808		4	1		2	3	1		1
MV-MA-2810	4	5	2	2	1	3	2	2	5
MV-MA-2812	7	14	22	20	23	20	3	14	8
MV-MA-2911	7	11	7	8	11	9		10	11
MV-MA-2912	5	13	23	12	9	4	1	7	8
MV-MA-2913	13	5	18	29	20	15	6	14	29
MV-MA-2918	9	5	2	6	4		2		5
MV-MA-2922	2	8	11	9	12	4	1	8	10
MV-MA-2923	3	4	3	3	4	4		3	9
MV-MA-2924	6	15	1						
MV-MA-2925	2		1	2					
MV-MA-2927	9	11	5	7	4	2	1	16	25
MV-MA-2928	1	3	1						
MV-MA-2930	3	2	2	3	5			1	10
MV-MA-2971	1	3	1			1			3
MV-MA-2972	4	11	17	10	12	11	6	9	9
MV-MA-3002	21	27	7	15	17				
MV-MA-3221	3	3	5	1	6	4	2	3	6
MV-MA-3426	6	6	13	5	10	5		6	13
MV-MA-3428	1	2	4	3	6	1		1	4
MV-MA-3430	11	17	23	33	33	21	3	3	1
MV-MA-3433	1	5	1	2	6	1	2	1	6
MV-MA-3600	4	16	13	20	12	12			3
MV-MA-3602	8	8	2						
MV-MA-3754		3	6	4	25	10	3	17	30
MV-MA-3878		3	6	38	45	16	6		
MV-MA-4007			2	3	3			1	5
Individuals pregnant	10	3	1	5	15	10	0	1	0
Adult females sighted	32	33	35	30	28	25	17	21	26
% pregnant of all adults	27%	8%	3%	14%	41%	27%	0%	3%	0%

short term fluctuations in reproductive activity are natural, a weakening of the South Asian Monsoon, linked to the climate crisis, is resulting in more years of below average productivity in the Maldives, which may have significant consequences for the long-term viability of the Maldives reef manta ray population. The Manta Trust will continue to survey for manta ray behaviour to identify whether a low fecundity trend continues across several years.

It is also worth noting that in total, 32 females have not been sighted since 2019 or earlier, with 15 “newer” females having only been sighted in Laamu since 2017 and onwards. This might indicate either a natural shift in females moving away to new sites or unstudied sites, or, more likely, the natural death of older females and introduction of juvenile females maturing into habitats of adult reef manta rays. Only one of the females that hasn’t been sighted in Laamu for several years was pregnant when last sighted,

suggesting that there is no reason to believe that pregnant manta rays move away from Laamu Atoll to give birth and not return to the Atoll.

In 2019, Six Senses Laamu, the Manta Trust, IMV Imaging, and the University of Cambridge released the first images of pregnant and non-pregnant reef manta rays using the world’s first contactless underwater ultrasound scanner. In 2022, only two scans were obtained due to interactions and behaviour patterns of manta rays not being favourable for conducting any ultrasound scans. The team is however hopeful that 2023 will present more possibilities to obtain scans, particularly of pregnant manta rays. For additional information about the ultrasound scanner, please see the project activities report. A paper on the obtained ultrasound images across the Maldives since the beginning of the project will be published in the second quarter of 2023.

SUB-LETHAL INJURIES

Of the 142 identified individuals in Laamu Atoll, 33% ($n=47$) have been recorded with at least one sub-lethal injury, with a total of 51 injuries now documented in Laamu Atoll. Of the 51 injuries, 49% ($n=25$) were of natural origin, 33% ($n=17$) of anthropogenic origin, and 18% ($n=9$) of unknown origin. Of the 47 injured individuals, 30 were females and 17 were males (Fig. 28), with some individuals ($n=4$) having obtained more than one injury. Note that a single injury can result in multiple body parts being injured, therefore the

total number of injury locations ($n=53$) exceeds the number of injury events ($n=51$). Thirty-four (64%) of the recorded injuries took place on pectoral fins, 15% ($n=8$) to the manta rays' cephalic fins, 11% ($n=6$) to the pelvic fins, claspers, or tail, 6% ($n=3$) to their head and 4% ($n=2$) were to the body and back (Fig. 29).

Thirty-two percent ($n=15$) of all injured individuals ($n=47$) have obtained their injuries from entanglement in fishing

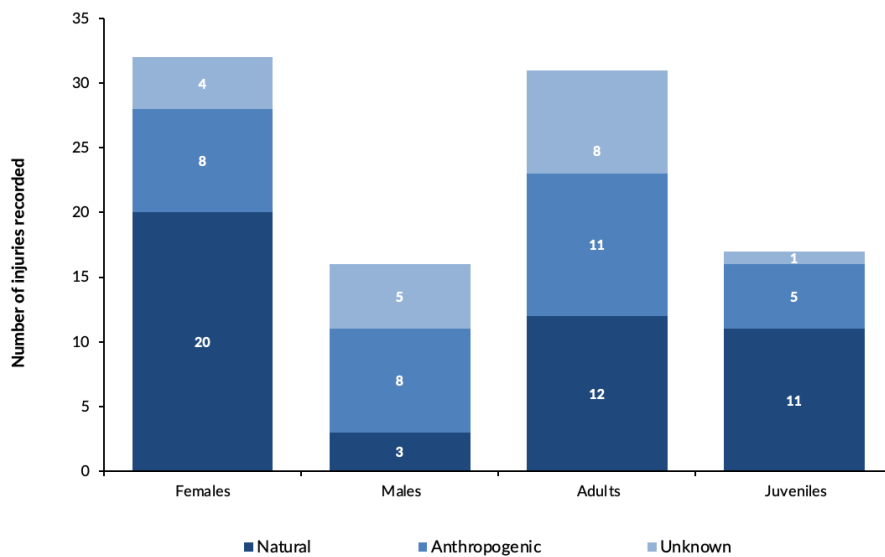


Figure 28: Demographic variation in the likely origin (natural, anthropogenic, or unknown) of sub-lethal injuries ($n=51$) within the injured reef manta ray (*Mobula alfredi*) population of Laamu Atoll ($n=47$).

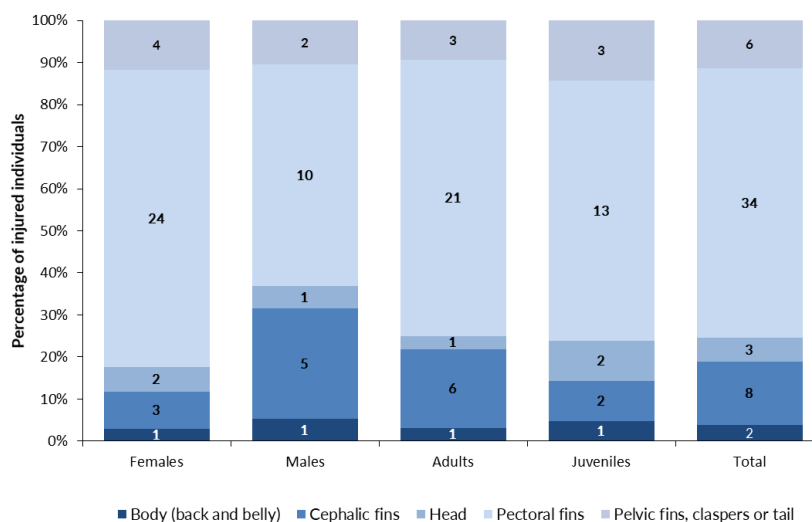


Figure 29: Variations in the location of sub-lethal injuries ($n=51$) within the injured reef manta ray (*Mobula alfredi*) population of Laamu Atoll ($n=47$). Actual number of individuals on bars. Note that a single individual can obtain injuries on multiple locations.

line (Fig. 30). Most fishing line entanglements have caused injury to the pectoral fins of individuals ($n=10$), but there have also been injuries of concern to the cephalic fins or head (eyes and mouth) ($n=6$). Despite Laamu Atoll having six newly designated Marine Protected Areas (MPAs) and Six Senses Laamu actively discouraging fishing at key manta aggregation sites, such as Hithadhoo Corner, fishing continues at this site. Although active fishing is rarely observed, the MMCP regularly removes fishing line from the reef and cleaning stations at Hithadhoo Corner and Fushi Kanduu. Without observing individuals becoming entangled, it is however difficult to determine where manta rays get entangled in fishing gear. The planned Baaneykolhu CCA foresees a restriction of fishing at Hithadhoo Corner and management plans are currently being prepared by the Blue Marine Foundation and Maldives Resilient Reefs.

The Manta Trust have provided feedback on the protection plans and will be supporting the community with the necessary scientific advice, such as when the site is most active with manta ray visitations and therefore vulnerable to any anthropogenic impacts occurring within the vicinity of this site.

No new boat strike injuries have been recorded in Laamu Atoll in 2022. With only one recorded boat strike injury, the low prevalence of this injury type in the Atoll is likely due to the low level of tourism and boat traffic. However, boats have been observed to drive over the top of dolphins without slowing down, indicating that injuries inflicted through careless driving might increase in the future. Code of conduct driving patterns are enforced by Six Senses Laamu boat staff. However, to limit harmful piloting within

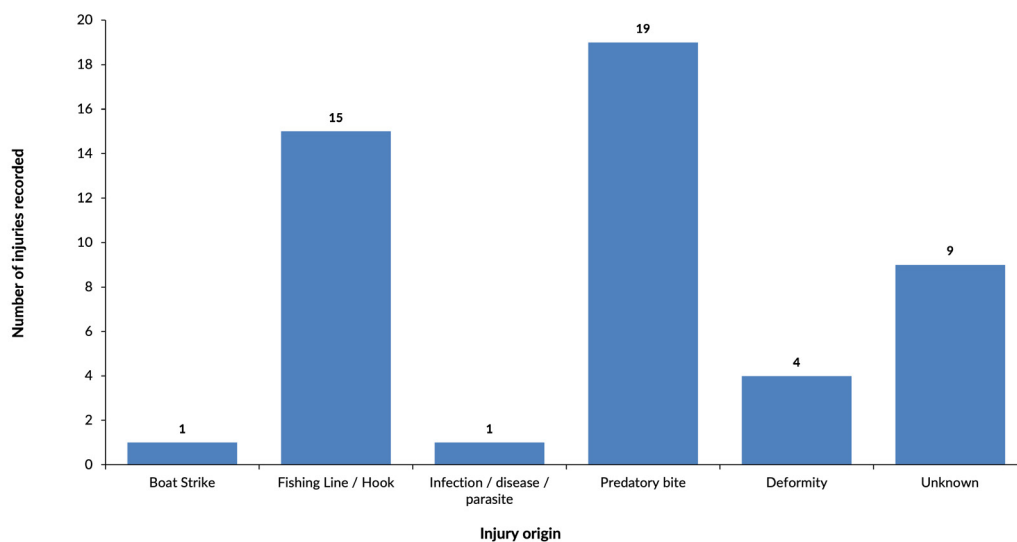


Figure 30: Variations in the origin of sub-lethal injuries ($n=51$) within the injured reef manta ray (*Mobula alfredi*) population of Laamu Atoll ($n=47$).

Laamu Atoll, dedicated zones with low speed limits will be necessary. The Manta Trust urges boat pilots to be vigilant, particularly near the aggregation sites of Hithadhoo Corner, Fushi Kanduu, Fonadhoo Beyru, and Boduhuraa Beyru, and look out for marine megafauna which may be at the surface.

Predatory bites were inflicted upon 40% ($n=19$) of all injured individuals. Interestingly, 90% ($n=17$) of these manta rays were female. Infection/disease/parasites made up 2% ($n=1$) of all injured individuals.

FISHERMAN INTERVIEWS

Since the start of the MMCP's partnership with Six Senses Laamu in 2014, the Project's research efforts have primarily focused on in-water surveys. In 2019, the project broadened its reach and conducted their first interviews with Laamu Atoll's fishermen to gain a greater understanding of current and historic manta and devil ray (mobulid) sightings in the

region. From the preliminary studies, the team developed a new, more detailed, questionnaire which was used in an Atoll wide research study, which was introduced in 2022.

In 2022, between April and May, the Manta Trust's MMCP team and a master's of science student from the University

of Exeter visited all 11 inhabited islands of Laamu Atoll to obtain more in-depth local knowledge about manta rays from the community. The study aimed to explore whether the local ecological knowledge (LEK) obtained through interviews with fishers could be used to inform manta and devil ray conservation management in Laamu Atoll, and subsequently whether this could be expanded to a national scale. This is the first time a study like this has been conducted in Laamu Atoll.

During the study, the team was able to conduct face-to-face interviews with 123 fishermen, with the questionnaire examining five key fields of information: 1) background information, 2) fishing practice employed and primary catch, 3) knowledge about native marine species and mobulids, 4) Knowledge about the mobulid occurrence and threats faced by the group, and 5) knowledge of measures for mobulid protection and attitude towards conservation.

The answers from the fishermen's interviews were used to map the distribution of mobulids in Laamu Atoll according to the fishermen's sightings (Fig. 31), to identify the potential anthropogenic threats these animals face and understand local attitudes towards conservation. From analysing this data, the study found evidence for potential new research sites not previously considered as mobulid hotspots. Figure 31 shows the stated mobulid hotspots according to LEK. Some of the highlighted areas are located further than the MMCP's usual study sites, but are of high interest to the team and will be targeted for surveys in 2023, if logistics allow.

When fishermen were asked if they thought manta rays should be protected, 96% said 'yes'. When these participants were asked why, the words 'tourism', 'tourist(s)', and 'visitor(s)' were most frequently recorded in responses, with 34% stating this as a reason. The local attitudes towards mobulids and conservation efforts appeared to be mostly positive in Laamu Atoll. When asked what they would like to gain from conservation programmes, 53% answered that tourism is something they hoped to gain. Only 2% of participants answered 'yes' when asked if manta or devil rays had ever been caught intentionally in the Maldives. However, 42% of fishers ($n=52$) stated they had caught manta or devil rays unintentionally in their gear. Out of these 42%, the majority (75%, $n=39$) stated devil rays would rarely get caught, but 19% ($n=10$) stated that this happens often. Fishermen explained that most of these catches happen while using a net (69%, $n=36$) used for bait fishing. Despite most fishermen (94%, $n=116$) stating they would release the caught mobulids when possible, entanglement in bait fishing nets could indicate an activity of potential conservation concern for mobulids, and we recommend further investigation by fisheries targeted conservation groups. Overall, the survey highlighted positive attitudes towards manta ray conservation work. The findings have helped the team to better understand the local ecology and attitudes towards conservation strategies and the Manta Trust's MMCP team would like to thank the involved community members for their incredible support in this project. For more information, the master's thesis "The Use of Fishers' Local Ecological Knowledge (LEK) in Mobulid Conservation, Maldives" by Hannah Cocks is [accessible online](#).

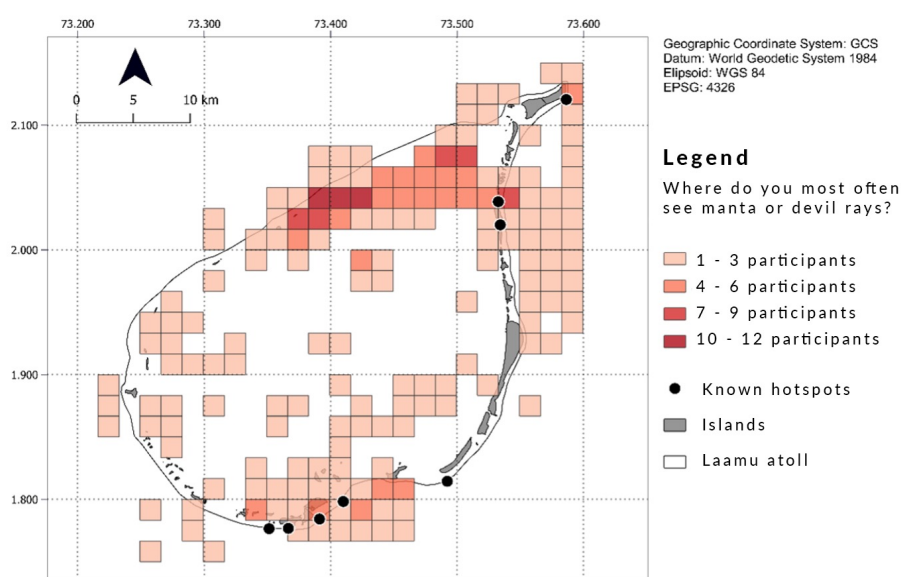


Figure 31: Laamu Atoll divided into grid squares with darker squares indicating locations at which most fishermen recorded to most often see mobulids. Known reef manta ray (*Mobula alfredi*) hotspots identified by the Manta Trust are indicated.

CONCLUSIONS

In 2022, the Manta Trust's MMCP team was able to extensively study Laamu Atoll's manta ray population at several sites around the Atoll. The team recorded shifts in encounter locations, identified Fonadhoo Beyru as an important aggregation site, and successfully completed the first in depth local ecological knowledge survey with Laamu Atoll's fishermen. Two students conducted their MSc research thesis with the team in Laamu Atoll, one study focusing on the fishermen surveys and one assessing the long-term remote camera data from Hithadhoo Corner. The local ecological knowledge surveys with fishers highlighted a need for further investigation of mobulid entanglements in bait fishing methods due to the concerning frequency of mobulid entanglement in fisher nets. Furthermore, it identified a possible new manta ray hotspot in the north of Laamu Atoll for which further exploration in these less surveyed sites is recommended.

Fewer manta ray sighting numbers to those recorded during earlier years of data collection, a continued decrease in recorded reproductive activity and the decrease of mean sightings at Hithadhoo Corner is of concern and might be an indication of a change in habitat health, localized zooplankton abundance or human influence. While the Manta Trust's MMCP team will continue to brief all the Resort's divers in codes of conduct before every dive at Hithadhoo Corner, it is recommended that code of conduct dive training is also implemented as a mandatory measure for all liveaboards diving at this key aggregation site. This is currently planned to be incorporated into the management plans for the Baaneykolhu Community Conservation Area. While the decrease in reef manta ray visitations recorded

at Hithadhoo Corner could be due to natural inter-annual fluctuations in the ecological needs of the manta population, an in-depth analysis of cleaning station health is recommended to create a baseline understanding of current coral health, cleaner wrasse abundance, general species richness, and interactions of manta rays on various cleaning stations. This assessment, repeated over time, could help us understand whether these sites are still providing the same service, or how particular environmental/anthropogenic impacts are influencing the health of these sites, as well as help us understand the importance of the health of the coral reef and cleaner fish community to the visitation patterns of the manta rays.

Following another year of evidence that supports the hypothesis that Laamu Atoll's reef manta ray sub-population is relatively small and exhibits high site fidelity, the protection of their key habitats has once again been proven to be of paramount importance. With tourism continuing to grow in the Maldives, and manta rays facing increasing threats worldwide, all factors impacting manta ray populations should be taken into consideration.

We would like to express our continued gratitude to Six Senses Laamu for showing unwavering support for the Manta Trust's MMCP and its team in Laamu Atoll. By working alongside the Maldives Underwater Initiative team, and working with various local stakeholders, and central government agencies, we hope to continue and develop protection of both manta rays and the wider biodiversity of the Atoll for years to come.



Photo by Jasmine Corbett

This report was made possible thanks to



MALDIVES MANTA
CONSERVATION
PROGRAMME

MALDIVES MANTA CONSERVATION PROGRAMME (MMCP)

The MMCP, formerly known as 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 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.

The MMCP and the Manta Trust are happy to share with the Maldives government any data collected as part of this study.



SIX SENSES

LAAMU

SIX SENSES RESORT LAAMU

The MMCP expresses its sincere appreciation for the ongoing partnership between Six Senses Laamu Resort and the Manta Trust. Without their support, this important work would not have been possible. The Manta Trust and the MMCP are looking forward to a continued and successful partnership with Six Senses Laamu.



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