Do SCUBA divers impact reef manta ray (*Mobula alfredi)* behaviour at cleaning stations? An analysis of diver and manta interactions in the Maldives.

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Disclaimer

I, Nicole Pelletier, declare that all aspects of this dissertation are my original work. I have cited all sources used and have listed these in the reference section. I declare that my word count is 4997 excluding project title, disclaimer, acknowledgements, the Manta Trust Code of Conduct, reference list, Figure legends, Tables and appendices.

Acknowledgments

Firstly, I would like to thank Beth Faulkner and Annie Murray for their encouragement throughout the development and entirety of this summer placement. Their support throughout the project and during statistical analysis was integral to the success of the research and much appreciated!

Thank you to those who helped organize this project for my placement, Dr. Guy Stevens, Dr. Julie Hawkins, Marteyne van Well, Bec Atkins and Tam Sawers. It was an incredible opportunity to be hosted by the Manta Trust and Six Senses Laamu for my summer research project and it would have never possible without your support.

I owe an incredible amount of thanks to Haisham Rasheed, Emma Hedley and Maeva Terrarpon for providing the majority of the video footage I was able to analyse.

Finally, I would like to thank the entire team at Six Senses for hosting my summer placement, being so welcoming and allowing me to get involved in various projects throughout the summer.

Thank you!

Abstract

Reef manta rays (*Mobula alfredi*) are a vulnerable species threatened by targeted and bycatch fishing, as well as unsustainable tourism. Marine tourism is often promoted as a sustainable use of manta rays as a resource; however, minimal research has been conducted on behavioural impacts to manta rays from tourist encounters. To effectively manage tourism practices and minimize disturbance to manta rays, potential impacts on manta ray behaviour must be researched and understood. The Manta Trust, a non-profit organization, developed a code of conduct for scuba diving and snorkelling based on quantifiable research to promote responsible tourism; however, research on scuba diver-manta interactions remains limited. This study aimed to increase available knowledge on scuba diving with reef manta rays through behavioural analysis of video footage from cleaning stations across the Maldives and to determine if the current recommended guidelines are effective at minimizing disturbance by scuba divers. Overall, scuba divers were found to have a minimal impact on reef manta rays at cleaning stations. The main predictors of divers invoking no response from reef manta rays were maintaining a distance greater than three meters from the manta and maintaining a position off of reef cleaning stations. Dive guides can play an essential role in minimizing disturbance to manta rays by sharing the code of conduct recommendations and ensuring that divers follow the guidelines. While immediate disturbance to manta ray behaviour was minimal, this study highlighted the need for research on long term diver impacts to cleaning station habitats.

Introduction

Marine wildlife tourism, specifically tourism focused on observing and interacting with marine megafauna, is a growing industry that can support conservation initiatives and provide socio-economic benefits to countries with highly sought after species such as sharks, manta rays and dolphins (Cisneros-Montemayor and Sumaila, 2010; Trave *et al.,* 2017; Murphy, Campbell & Drew, 2018). While tourism is non-consumptive and many believe wildlife tourism to be eco-friendly, there are potential negative implications from boating, snorkelling and scuba diving that must be managed to ensure the sustainability of species that support the industry (Needham *et al.,* 2017; Trave *et al.,* 2017). Scientific research has established that snorkellers can disrupt the natural behaviours of species such as bottlenose dolphins (*Tursiops spp*.) and whale sharks (*Rhincondon typus*). Research has also shown that boat traffic associated with tourism can increase anthropogenic injury to species such as sea turtles (*Chelonia mydas*) and whale sharks. (Lusseau, 2006; Quiros, 2007; Stensland & Berggren, 2007; Denkinger *et al.,* 2013). Short term responses to disturbance can be quantified and evaluated; however, animals facing high rates of human disturbance may use energy allocated to feeding and reproduction for avoidance behaviours and recovery, causing a reduction in the overall health of a species (Sorice *et al.,* 2003). Habitat loss is of concern as research has shown that scuba divers with poor buoyancy can damage coral reefs that support marine species (Hawkins and Roberts, 1993; Hasler and Ott, 2008). While there are more than 6 million scuba divers worldwide, scientific research is limited on the impacts of recreational scuba divers to marine wildlife (Trave *et al.,* 2017; DEMA, 2013). To best inform management practices and support the conservation of economically valuable and vulnerable species, extensive evidence-based research is needed to develop and test species-specific guidelines for scuba diving encounters. For reef manta rays

(*Mobula alfredi*), a large tourism market exists, but scientific research on the species in regards to diver interactions has been limited.

Reef Manta Rays

Reef manta rays are a long-lived, planktivorous elasmobranch species that can grow to a maximum disc width of four meters (Couturier *et al.,* 2012; Stevens 2016). Individuals have unique ventral markings that allow researchers to track the movements, growth, and life history of these animals through photo identification (Fig. 1) (Marshall and Pierce, 2012).

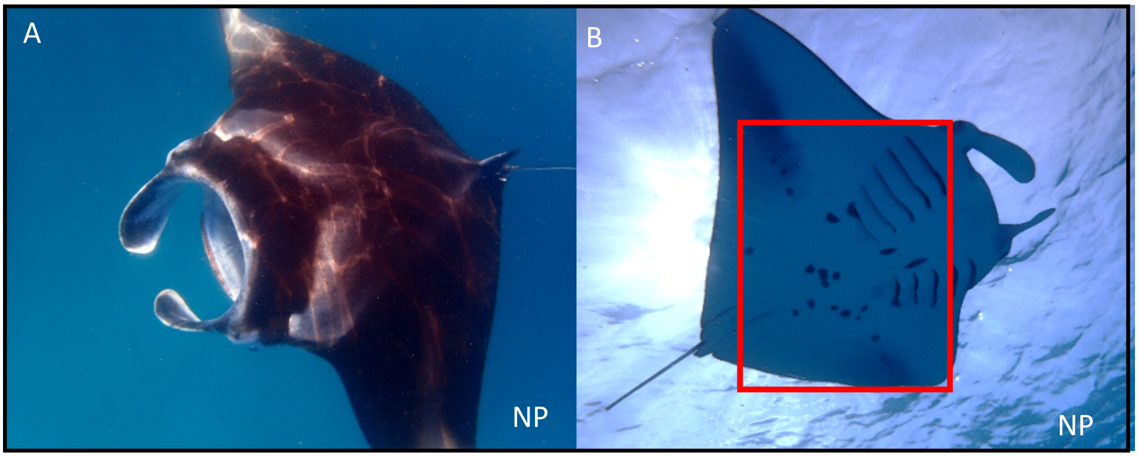

Fig. 1: Image A shows the dorsal side of a reef manta ray. Image B shows the unique ventral spot pattern of the same animal which can be used for photo identification.

Distributed across the Indo-West Pacific, subpopulations of reef manta rays seasonally aggregate to feed at specific locations where their sole food source, plankton, accumulates in abundance (Couturier *et al.,* 2012; Anderson *et al.,* 2011b). Between periods of feeding, reef manta rays frequent "cleaning stations"; specialized regions of coral reefs that support cleaner wrasse assemblages who remove parasites, food remnants and dead skin from other species (Losey, 1972; Kitchen-Wheeler, 2013). For reef manta rays, cleaning stations are also thought to play a role in intra-species socialization and serve as a site to initiate courtship behaviour (O'shea *et al.,* 2010; Stevens, 2016). Feeding behaviour and cleaning station visits are relatively predictable as they are correlated to seasonally-driven concentrations of plankton and habitat requirements (Anderson *et al.,* 2011b). Their behaviour near coral reef habitats supports a large tourism industry but also makes them susceptible to fishing, climate change and unsustainable tourism (Croll *et al.,* 2016; O'Malley *et al.,* 2013; Marshall *et al.,* 2018).

Manta Rays in Demand and Under Threat

The International Union for Conservation of Nature and Natural Resources (IUCN) lists reef manta rays as vulnerable, with populations in decline despite increased legislation to protect the species from trade (CITES, 2014; Marshall *et al.,* 2018). Reef manta rays and oceanic manta rays (*Mobula birostris*) have only been recognized as unique species from one another since 2009 and collectively under the genus Mobula since 2017. With species differentiation only occurring in recent years, the majority of research on manta rays has historically combined both species as they share similar life history characteristics and face many of the same anthropogenic impacts (Marshall *et al.,* 2009; White *et al.,* 2017). Overexploitation in targeted fisheries and bycatch have been the greatest threat to populations as manta rays are K selected, meaning they are late to mature, slow to reproduce and struggle to recover from fishing effort (Deakos *et al.,* 2011; Croll *et al.,* 2016; Stevens, 2016). Their large size, combined with their tendency to aggregate on the surface, increases their susceptibility to targeted fishing as entire populations can be removed over a short period (Croll *et al.,* 2016; O'Malley *et al.,* 2013). Historically, manta rays have not been heavily fished as a food source, and their meat is not often sought after but rather, their gill rakers. In recent years, fishing effort has increased to meet the demand of Asian consumers who believe dried gill plates may cure a variety of ailments despite no scientific evidence of medicinal value (Heinrichs, 2010; Croll *et al.,* 2013; Lawson *et al.,* 2017). In addition to targeted fisheries, manta rays are susceptible to gillnets and purse seines as they can be easily entangled in non-selective fishing gear (Croll *et al.,* 2013).

Often promoted as an alternative to fishing, tourism has proven to be a popular non-consumptive use of the species as a marine resource (Anderson *et al.,* 2011a; O'Malley *et al.,* 2013). Predictable aggregation sites support snorkelling as reef manta rays can be approached easily, and snorkellers can observe reef manta rays while they feed (Anderson *et al.,* 2011a) (Fig. 2). Cleaning behaviour and social interactions at cleaning stations support the diving industry as these habitats can be promoted as 'manta point' diving locations (O'Malley *et al.,* 2013).

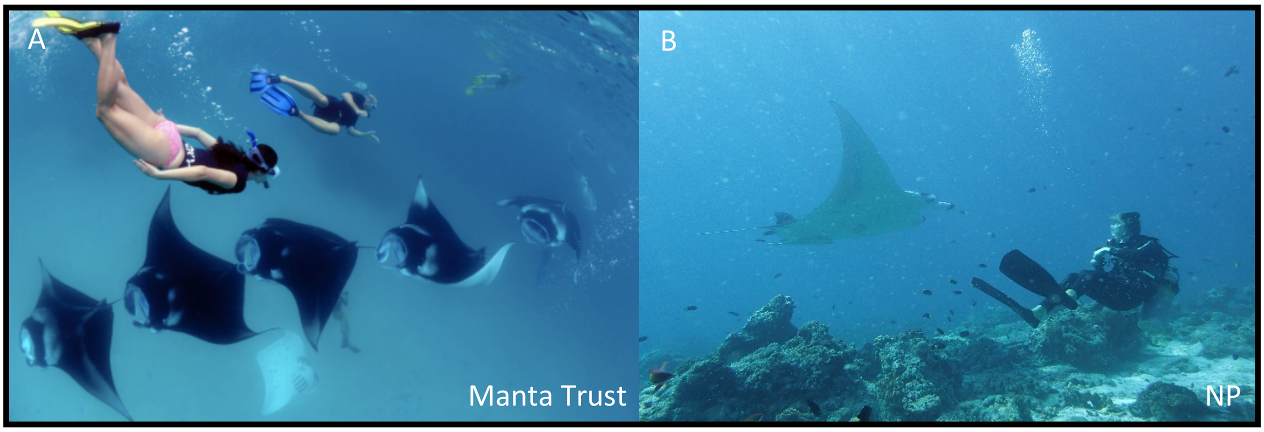

Fig. 2: Image A: Snorkelers at a reef manta ray feeding aggregation site
Image B: A scuba diver interacting with a reef manta ray at a cleaning station.

The limited research available on the value of manta tourism considers both species; however, tourism in different regions is often focused on one species, such as oceanic manta rays on the Pacific coast of Mexico and reef manta rays in the Maldives (O'Malley *et al.,* 2013). O'Malley et al. (2013) identified 200 manta ray dive sites across 23 countries marketed explicitly as `manta sites`. They surveyed tour operators who all recognized that manta rays were in the top five attractions for divers and valuable for their businesses. The direct revenue from manta ray tourism is estimated at more than 73 million USD annually with tourism expenditures related to manta rays totalling more than 140 million USD annually (O'Malley *et al.,* 2013). Tourism has proven to be a valuable use of manta rays as a marine resource; however, the economic studies of manta rays worldwide (O'Malley *et al.,* 2013) and specifically in the Maldives (Anderson *et al.,* 2011a) have raised concerns about potential adverse impacts caused to manta rays by tourists.

Research by previous graduate students on reef manta rays in Baa Atoll, Maldives suggested snorkellers and divers could obstruct the paths of feeding animals, interrupt natural behaviours and cause avoidance behaviours based on their distance and approach toward manta rays (Brooks, 2010; Atkins, 2011; Lyman, 2012, Garrud, 2016). Research on manta ray interactions with diver exhaust bubbles remains limited, with the response from manta rays varied (Brooks, 2010; Atkins, 2011; Lyman, 2012; Kitchen-Wheeler, 2013). There is no primary literature available which investigates scuba diver and manta ray interactions.

Manta Ray Tourism in the Maldives

Located in the Indian Ocean, the Maldives is a hotspot for marine tourism with reef manta rays found in 21 atolls and one of the most sought after species by tourists (Cagua *et al.,* 2014; O'Malley *et al.,* 2013). Manta rays have been protected under legislation in the Maldives since 2014, and the archipelago supports the highest population of reef manta rays worldwide at more than 4000 individuals (Stevens, 2016). While oceanic manta rays are occasionally sighted in the Maldives, the focus of the industry is on tourism with the smaller, well-known reef species of manta ray (Stevens, 2016; O'Malley *et al.,* 2013). Between 2006 and 2008, Anderson et al (2011a) estimated ~143,000 scuba divers visited 91 known manta ray dive sites in the Maldives and valued manta ray tourism at approximately USD 8.1

million annually. Since then, annual tourist arrivals have doubled, and the industry is now thought to contribute ~15.4 million USD to the economy per year (Maldives Tourism Yearbook 2006-2017; O'Malley *et al.,* 2013; Stevens *et al.,* 2018). Despite the high value and potential negative impacts from tourism, diving practices throughout the nation are unregulated and determined by tour operators, except for in Hanifaru Bay (Baa Atoll), a UNESCO World Heritage Site where diving is not permitted (G. Stevens, pers. comm.).

Minimizing Tourism Impacts

In response to high numbers of tourists and to address concerns about diver and snorkeler impacts to manta rays, the Manta Trust, a UK based non-profit organization developed a code of conduct for snorkelling and diving tourism in 2013 (Fig. 3, Appendix I) (The Manta Trust, 2018).

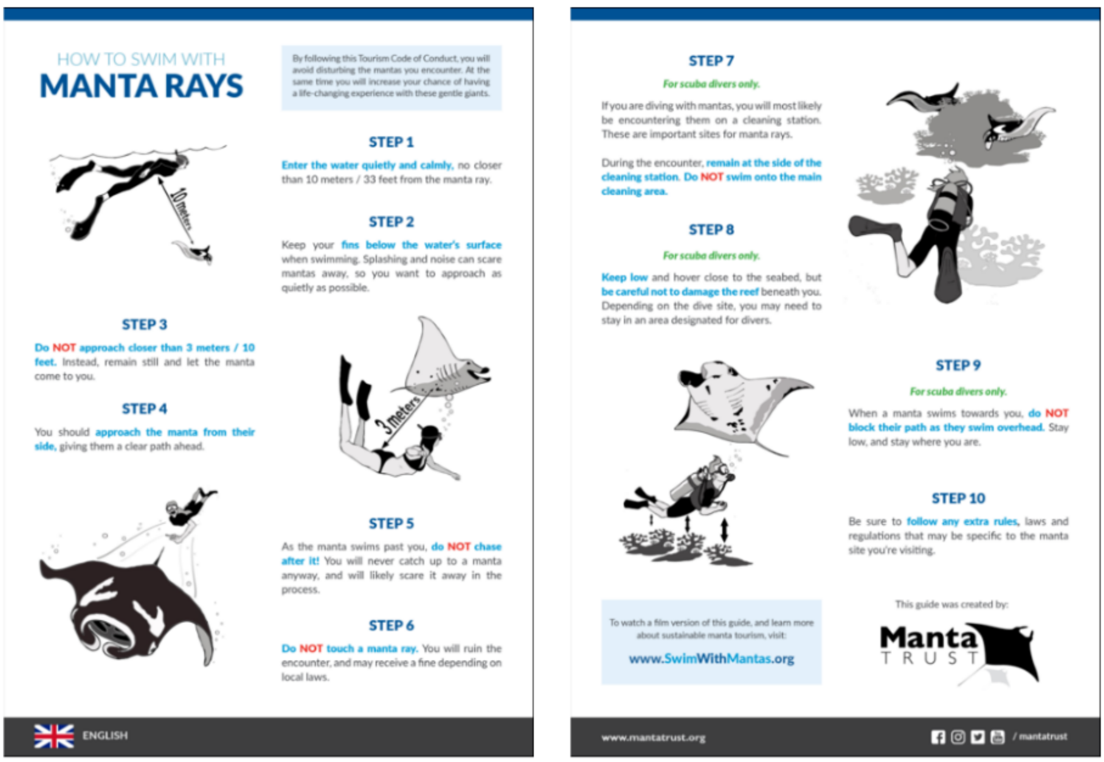

Fig. 3 The Manta Trust Code of Conduct is a research based document that outlines specific recommendations for snorkelling and diving with manta rays.

When used as part of an educational briefing, codes of conduct with specific guidelines for interaction can minimize the negative impacts of humans on the environment and improve the overall experience of guests (Medio *et al.,* 1997; Quiros *et al.,* 2007; Camp and Fraser, 2012). Scuba diving guidelines in the code were developed based on observations by Manta Trust researchers and recommendations from the only studies to quantify reef manta ray-diver interactions in the Maldives (Atkins, 2011; Lyman, 2012). While not enforced by government legislation, the guidelines are in use by multiple tour operators. They have proven effective at reducing the impact of snorkelers to reef manta rays at feeding aggregation sites (Garrud, 2016). The code of conduct is available to all dive tourism operators; however, the recommendations have not yet been tested to show their effectiveness at preventing and reducing disturbance by divers to reef manta rays at cleaning stations.

This study aims to:

- Increase evidence-based research on diver-reef manta ray interactions by quantifying behavioural reactions of reef manta rays to scuba diver at cleaning stations.
- Determine which diver behaviours are most likely to disturb the natural behaviour of reef manta rays at cleaning stations.
- To evaluate whether the recommendations in the code of conduct are effective at minimizing disturbance to reef manta rays engaged in cleaning behaviour.

Methods

This study builds upon prior research conducted on the Manta Trust Code of Conduct. The methodology was based on the "Best Practice Code of Conduct Data Collection Protocol" (Appendix II) and methods used to evaluate the snorkelling code of conduct (Garrud, 2016; Murray, 2018). Only reef manta rays were encountered during the study period; thus, any reference to manta rays throughout the dissertation specifies the reef species.

Study Location

Research was conducted across three atolls of the Maldives, where manta rays were frequently observed, and diving tourism occurred. Data was recorded from six known dive sites, as listed in Figure 4.

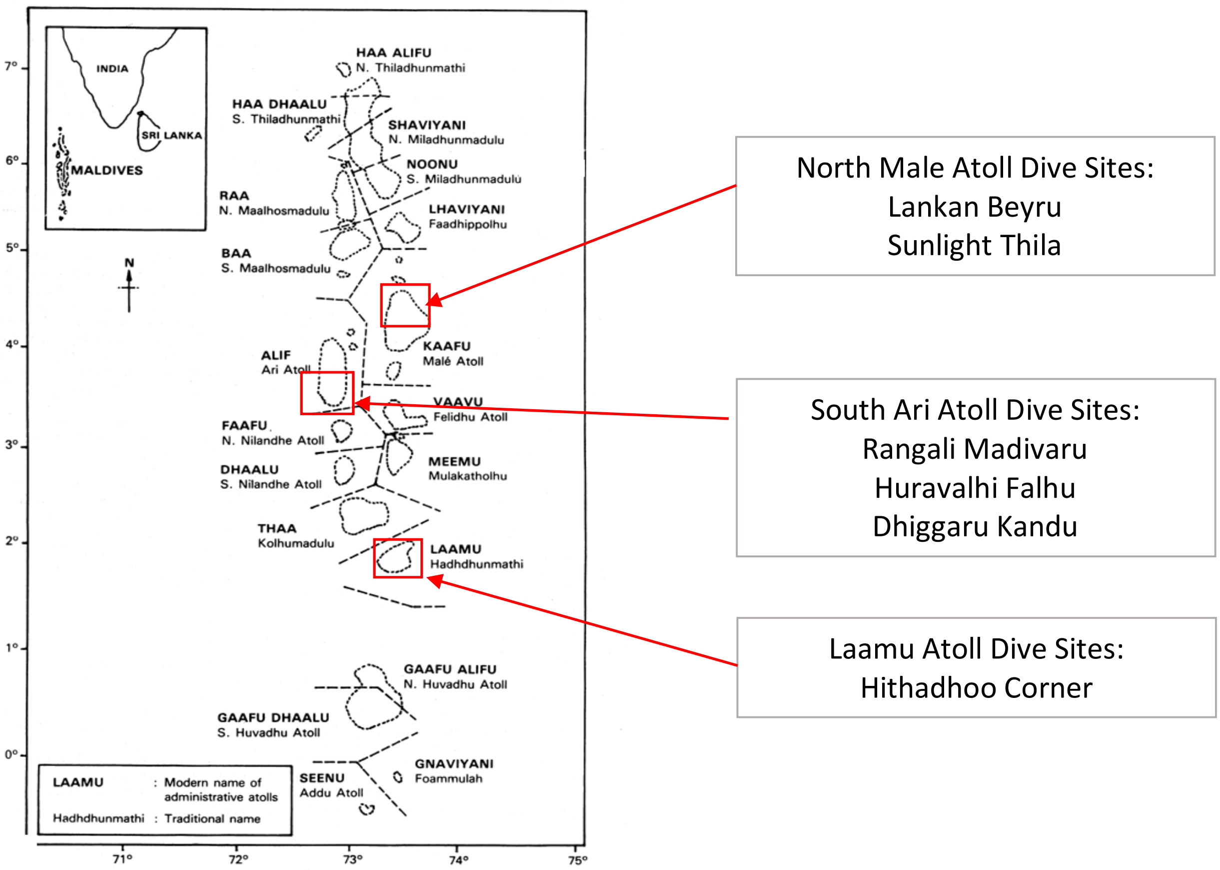

Fig. 4 Atolls and dive site locations where diver- reef manta ray interaction data was collected in the Maldives.
(Basemap from Fisheries and Agriculture Organization- FAO Maldives)

Five dive sites were characterized by large coral reef outcrops (often sp. *Porites*) which support cleaner wrasse and serve as naturally well-defined cleaning stations. One site was an extended outer atoll reef with assemblages of cleaner wrasse but did not have well-defined structures thus cleaning was observed over the reef top and reef crest (Fig. 5).

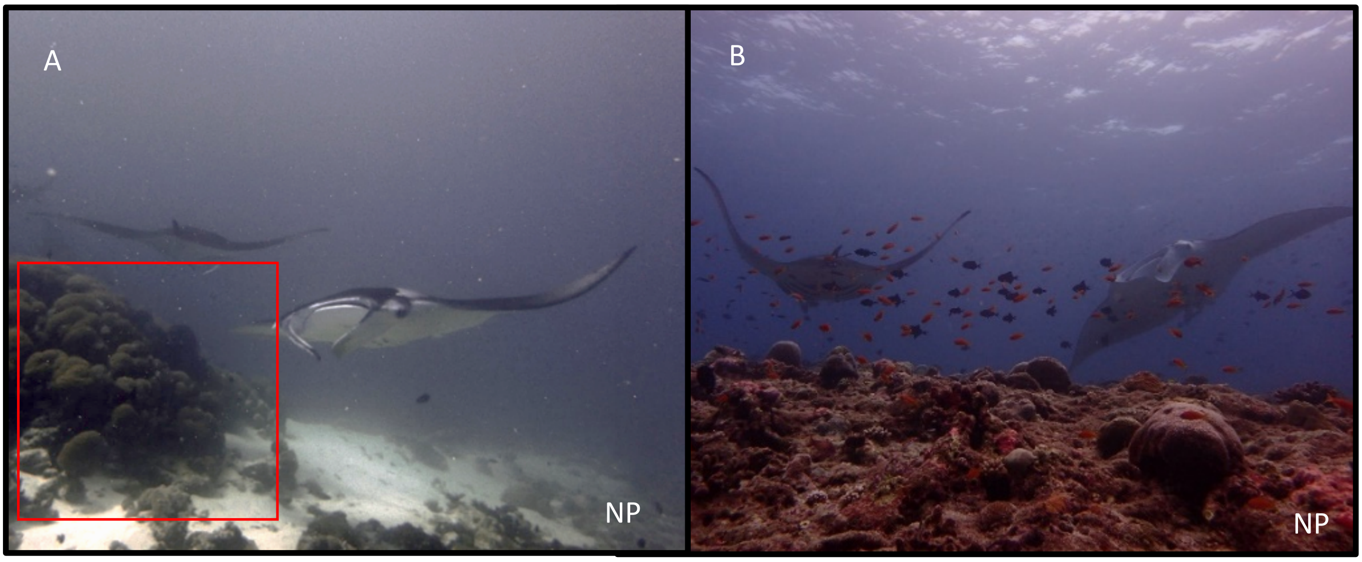

Fig. 5. Image A: Reef manta ray cleaning at a well-defined cleaning station (boxed in red) with surrounding sand substrate.
Image B: Reef manta rays cleaning over the reef top of the outer atoll cleaning station.

Data Collection

Data was recorded by five researchers between March 2018 and August 2018 who followed a set protocol for code of conduct data collection on guest dives (Murray, 2018; Appendix II).

Pre-Dive

During recreational dives with certified divers, a researcher joined guests and provided a briefing on the *Manta Trust Code of Conduct (Appendix I)* for scuba diving. The briefing included the following:

- "Do not approach closer than 3 meters/10 feet. Instead, remain still and let the manta come to you.
- You should approach the manta from the side, giving them a clear path ahead. As the manta swims past you, do not chase after it.
- Do not touch a manta ray.
- During the encounter, remain at the side of the cleaning station. Do not swim onto the main cleaning area.
- Keep low and hover close to the seabed, but be careful not to damage the reef beneath you. Depending on the dive site, you may need to stay in an area designated for divers.
- When a manta swims towards you, do not block their path as they swim overhead. Stay low and stay where you are.
- Be sure to follow any extra rules, laws and regulations that may be specific to the site you're visiting."

Information was also provided about manta ray identification, manta ray biology and the Manta Trust. Divers were informed that video footage and photographs would be taken during the dive for research but not informed of the exact nature of the study as to not alter diver behaviour. If any diver was under 18 or requested not to appear in photographs or video, data was not collected for the project.

During the Dive

While on the dive, resort dive staff led the group and followed a standard practice to position their divers around a cleaning station if manta rays were present (pers. obs.). When manta rays were observed, a researcher photographed the ventral patterns of individuals for later identification. If manta rays were observed for the duration of the dive, the researcher recorded for a maximum of ten minutes. Videos were recorded using a Go Pro Hero 5, Go Pro Hero 6, Olympus TG-4, Canon G16, Canon G9X and Canon SD 700 IS. To anonymize divers, researchers filmed human participants from a distance and focused the video on manta ray behaviour. Additional data recorded included the number of divers at a dive site, the time of the dive, and the number of manta rays observed.

Post-Dive

At each research base, Manta Trust staff used the photographs and the Manta Trust Branchial Gallery, a database containing identification photographs, sex, distinguishing features, and injuries for more than 4,400 individuals to identify each manta ray (Manta Trust, 2018b). The video footage, a list of all manta rays observed, and the metadata from each dive was provided by researchers for analysis. I personally recorded footage following the methodology above from Laamu Atoll between July and August 2018.

Distance

Underwater videos were recorded of distances between 1-10 meters from varying angles using two different cameras to ensure accurate distance estimation in video footage. Thirty-five screenshots were captured from the videos and used to create digital flashcards for study prior to video analysis. To verify distance was being accurately estimated, I tested myself with the flashcards on a weekly basis to ensure I had a 90% rate of accuracy.

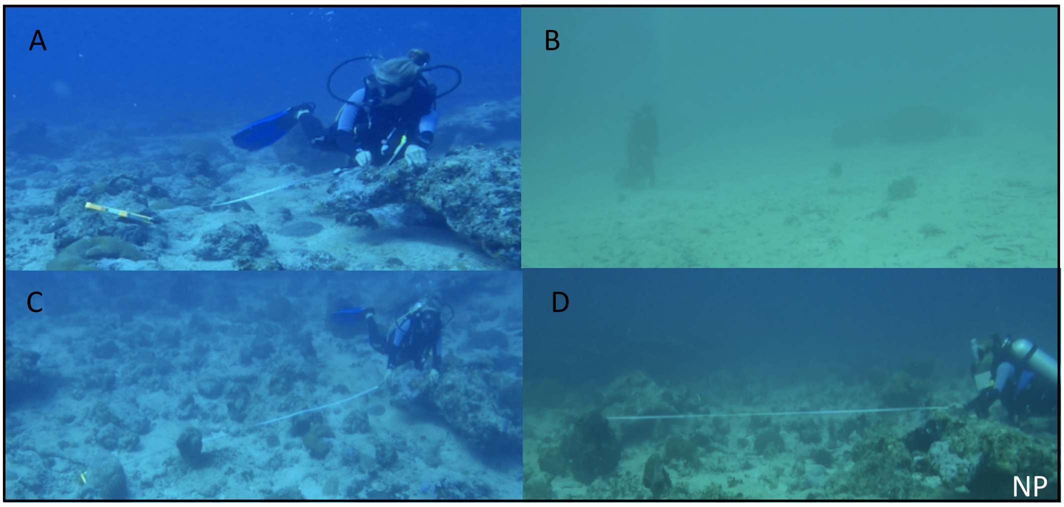

Fig. 6- Screenshots from the distance videos used to practice and test distance estimation. Image A shows a distance of one meter. Images B-C show a distance of three meters using different cameras and angles. Image D shows a distance of 4 meters.

Video Analysis

To be considered relevant for analysis, video clips needed to include the undisturbed behaviour of the manta ray and show scuba divers and manta rays in the same frame within 10 meters of one another. Additionally, footage needed to include the unique ventral pattern of manta rays for the identification of individual animals. Video clips were not used from Lankan Beyru as they did not meet the requirements.

Defining Interactions

The closest distance (0-10 meters) between manta rays and divers in video clips was determined and termed an 'interaction'. If the interaction was between 0-5 meters and a manta ray swam to a distance beyond 5m from the original diver then toward another diver, the video clip was split and recorded as multiple interactions for a manta ray.

Manta Ray Identification

Screenshots were created of the ventral spot pattern of each manta ray for identification. Screenshots were then visually compared to the Manta Trust Branchial gallery images of all manta rays recorded during the dive (Fig. 7) (Manta Trust, 2018b). Each individual was identified to avoid pseudo-replication.

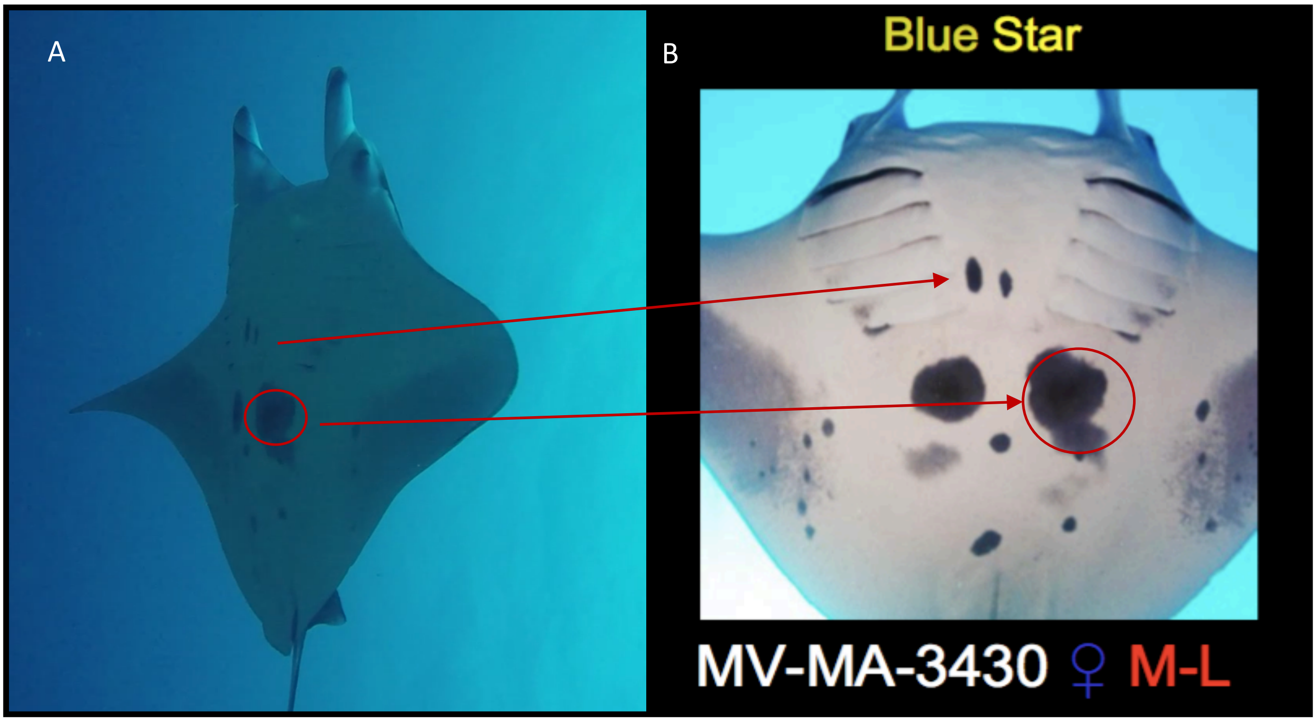

Fig. 7. Image A shows a screenshot taken from a diver-manta ray interaction video of MV-MA-3430. Image B: Manta Trust Branchial gallery image of the same individual.

Manta Ray Response Behaviour

For each interaction, the identification of each manta ray and 14 variables were recorded as potential indicators of manta ray response behaviour as described in Table 1. The variables 'undisturbed manta ray behaviour', 'interaction type', and 'bubble interactions' are further explained in Tables 2-4. If guests were close together at an equidistant from the manta ray, their collective behaviour was considered for the predictor variable. For cameras or videography equipment, the categories incorporated distance and information was recorded based on the closest diver to the manta ray using the camera.

Table 1: Description of manta ray response variables

Identification Number	Manta ray Identification number from branchial gallery
Dive Site	Dive Site Name
Sex	Male, Female
Undisturbed manta behavior	Cleaning/Courtship/Cruising- See Table 2
Site Type	Defined/Outer Atoll Reef Cleaning Station
Divers	Total number of divers at dive site
Mantas	Total number of mantas observed at dive site
Cleaning Station Position	Is/are diver(s) positioned in the same area where mantas are actively cleaning? Yes/No
Interaction Type	Type of interaction recorded between the diver(s) and manta: Passive Observation, Accidental Obstruction, Swimming in front or near the manta, Touching the manta, Swimming onto the cleaning station, Chasing the manta – See Table 3
Diver Position	Position of diver(s) in relation to the manta: Below on Substrate, Midwater, Above the manta
Cameras (photography)	Is a diver within the video clip using a camera to photograph the manta (besides the researcher)? (1) No/ (2) Yes, at least one diver within 3m of the manta./ (3) Yes, by at least one diver more than 3m from the manta
Strobes (photography)	Are strobes being used by any photographers? Yes/No
Video (videography)	Is a diver within the video clip recording the manta (besides the researcher)? (1)No / (2) Yes, by a diver that comes within 3m of the manta / (3) Yes, by a diver remaining more than 3m of the manta
Lights	Are lights being used by any divers recording video? Yes/No
Bubble Interactions	Type of interaction recorded between diver bubbles and the manta: None, Diver and Bubbles, Bubbles, Between Bubbles, Bubble Wall. See Table 4.

Table 2. Undisturbed behaviour of manta rays at cleaning stations

Cleaning	Manta is swimming around cleaning station allowing fish to approach and remove skin and parasites
Courtship	Manta is actively shadowing and following another manta around the cleaning station but not cleaning
Cruising	Manta is cruising by or through the cleaning station area but does not remain at the cleaning station to allow for fish to clean/ Manta is cruising between cleaning stations at a dive site prior to interaction

Table 3. Possible types of interactions recorded between divers and manta rays (Manta Trust, 2018b)

Passive Observation (PO)	Divers remain still in the water and do not interfere with the manta
Accidental Obstruction (AO)	Diver is unintentionally in the path of the manta or accidentally makes physical contact with the manta
Swimming onto the cleaning station (CI)	Diver swims onto the designated cleaning area
Swimming in front or near the manta (FN)	Diver swims near the manta or in front of the manta rather than remaining calm at the cleaning station
Chasing the manta (CH)	Diver quickly moves toward or follows the manta at a cleaning station
Touching the manta (TO)	Diver intentionally touches the manta

Table 4. Possible types of interaction between manta rays and diver bubbles

None	Manta does not have an interaction with bubbles
Diver and Bubbles	Manta swims within 2m of diver and through diver bubbles
Bubbles	Manta is at a distance greater than 2m from diver and swims through bubbles
Between Bubbles	Manta swims over divers but purposefully between streams of bubbles
Bubble Wall	Manta swims within 2m of bubble streams forming a wall but does not pass through bubbles

For each interaction, an overall manta ray response on an increasing scale of severity between 1-4 was determined with 1 being no reaction and 4 representing an avoidance behaviour as described in Table 5.

Table 5. Reef manta ray response to human behaviours on an increasing scale of severity

1- No Reaction	Manta does not react to human behaviour
2- Slight Reaction	Manta has a minor reaction after human behaviour but does not end behaviour and quickly resumes undisturbed behaviour
3- Direction Change	Manta changes swimming direction after interaction with diver but maintains undisturbed behaviour
4- Avoidance	Manta reacts to humans by swimming away or changing behaviour quickly to avoid human

Diver Bubble Interactions

To quantify specific and immediate manta ray responses to bubbles, a 'response to bubble interactions' was recorded as a categorical independent response variable, as described in Table 6.

Table 6. Reef manta ray response to bubble interaction by category

No Reaction	Manta does not change behaviour or appear to react to bubbles
Slight Reaction	Manta reacts with slight change in body positioning or movement
Remains in Bubbles	Manta remains in stream of bubbles for more than 10 seconds
Directional Change	Manta changes swimming direction
Avoidance	Manta quickly swims away from bubbles

Quantified Response

To determine a response level to individual variables, the mean value of the 'manta ray response' was calculated for different levels of predictor variables in R Studio. A mean response of 1 indicated no reaction behaviour and a mean response of 4 indicated the highest severity of response behaviour as detailed in Table 5. Excel was used to calculate standard error and plot mean manta ray response if any category of a predictor variable averaged > 2 (slight reaction). Responses to interactions with bubbles were categorized but unranked as types of interactions and responses varied.

Data Exploration

Prior to statistical analysis, predictor variables were explored and checked for skew in R Studio using standard data exploration techniques (Zuur *et al.,* 2010). The variable 'total number of manta rays' was transformed with a cube transformation. The distances recorded during interactions were grouped into two categories, 0-3m and 3-10m, to account for the uneven spread of data (Zuur *et al.,* 2010). The variables of 'undisturbed behaviour', 'interaction type', 'bubble interaction type' and 'video lights' were removed prior to statistical analysis due to the possibility that low prevalence (<10) of categories within predictor variables could skew the results of statistical modelling (Harrell, 2001) Intercorrelation of remaining variables was evaluated using Pearson's correlation coefficients and statistical plots; variables were removed if intercorrelation was considered high, $|r| \geq 0.7$ (Dormann *et al.,* 2012). Standard methods were used to calculate variance inflation factors (VIF) and considered high when VIF scores were ≥ 2 (Zuur *et al.,* 2010). Subsets of variables were analysed using Cumulative Link Models (CLM).

Significant Predictors of Manta Response Behaviour

Cumulative link models were used to analyse predictor variables of 'Sex', 'Distance', 'Cleaning Station Position', 'Cameras', 'Strobes', 'Video Cameras', 'Direction', 'Number of Manta Rays' and 'Number of Divers'. Identification of each manta ray was set as the random factor throughout the model analysis. The model was reduced using backwards forwards stepwise selection and compared using the Akaike Information Criterion (AIC) score to determine a minimum adequate model (Crawley, 2014). Predictors were considered significant with a p-value of < 0.05 (Zuur *et al.,* 2010; Crawley, 2014).

Results

A total of 147 human-manta ray interactions were recorded during 32 dives between March and August 2018. Forty-five individual manta rays were identified throughout the study. The mean number of divers was 23 divers/dive (±1.99 SE). The average number of manta rays observed on a dive was 5.38 (±0.59 SE). Female manta rays were observed during 113 of the interactions and male manta rays during 34 interactions. No correlation was found between sex, the total number of divers or manta rays, and manta ray response. Recorded interactions by site location are shown in Figure 8. Mean response at all sites was < 2.

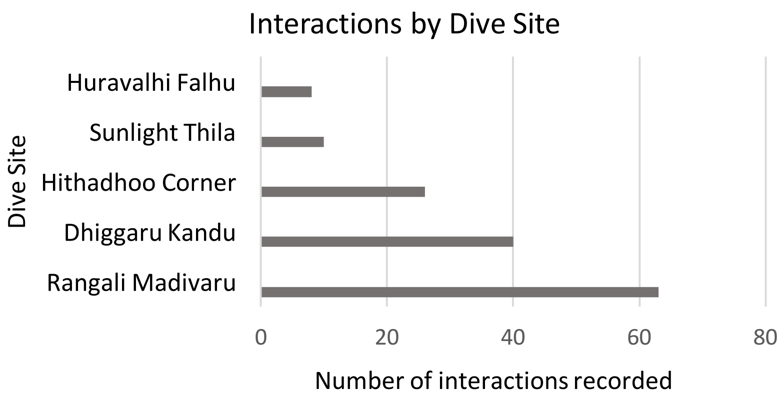

Fig. 8 Number of manta ray-scuba diver interactions recorded at each dive site.

Manta Ray Response Behaviours

Manta rays showed no reaction to divers during 67% of interactions (n=99), followed by directional changes as the next most common response during 22% of interactions (n=32). Slight reaction responses and avoidance behaviours were each observed during eight interactions (Fig. 9).

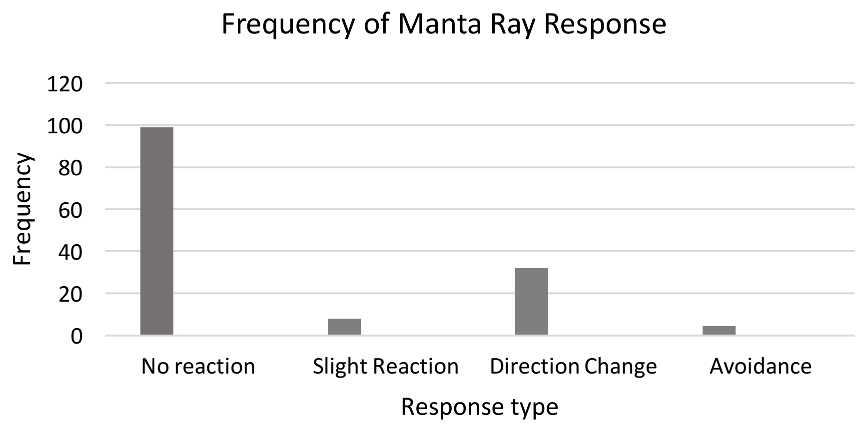

Fig. 9 Number of times each response was recorded from a diver-manta ray interaction across all sites visited in the study.

Mean manta ray response across all interactions was 1.65 (±0.08 SE), signifying a mean response between no reaction and slight reaction to all scuba diver interactions. Only variables where a predictor category had a mean response > 2 (slight reaction) and bubble interactions have been presented in the following sections. Mean response values for all other variables can be found in Appendix III.

Interaction Type

The most commonly observed diver interaction type was passive observation (n=129), followed by accidental obstruction (n=9) and swimming in front of or near the manta ray (n=8). Only one diver was observed purposefully touching a manta ray, and no interactions were recorded where a diver swam onto the cleaning station or chased a manta ray. The mean response to passive observation was 1.55 (±0.08SE) and was highest for accidental obstruction at 2.67 (±0.24SE). Mean response to swimming in front or near the manta ray was 2.13(±.39SE) (Fig. 10). Mean response to touching a manta ray was not analysed as it was based on only one observation of the behaviour.

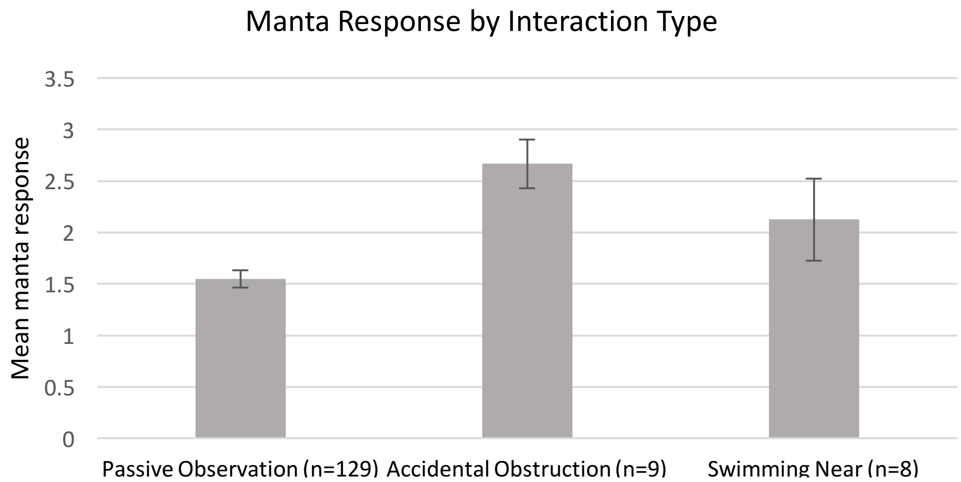

Fig. 10 The mean manta ray response to diver interaction type for 146 of the interactions recorded. The x-axis represents the type of interaction and y-axis shows the mean manta ray response on an increasing scale of severity where 1 is no reaction and 4 is avoidance behaviour. Error bars show standard error to a 95% CI.

Bubble Interaction Type

Sixty-four manta ray and bubble interactions were recorded with the majority of bubble interactions categorized as 'Diver and Bubbles' (n=33) followed by 'Bubble Walls', 'Bubbles' and then 'Between Bubbles' as described in Table 4 and shown in Table 7. Response to bubble interactions varied with the majority of interactions resulting in directional changes and seven interactions where manta rays remained in bubbles signifying a positive reaction. During 100% of interactions with bubble walls, the manta ray changed direction.

Table 7 Bubble interaction matrix shows the total number of response behaviours recorded by interaction type. Bubble interaction types are shown in far left column and response types in the first row.

	No Reaction	**Remains in Bubbles**	**Slight Reaction**	**Direction Change**	**Avoidance**
Diver and Bubbles	11	1	9	7	2
Bubbles	2	6	3	1	
Between Bubbles	1			3	
Bubble Wall				15	

Diver Positioning

Divers were positioned on the reef where manta rays were cleaning during 36% of interactions (n=53) and off the cleaning station during 64% (n= 94) of interactions. All interactions recorded on the cleaning station were recorded at the outer atoll reef site. The mean manta ray response to divers on the cleaning station was 2.15 (±0.16SE), and to divers off the cleaning station was 1.37 (±0.08SE) (Fig. 11).

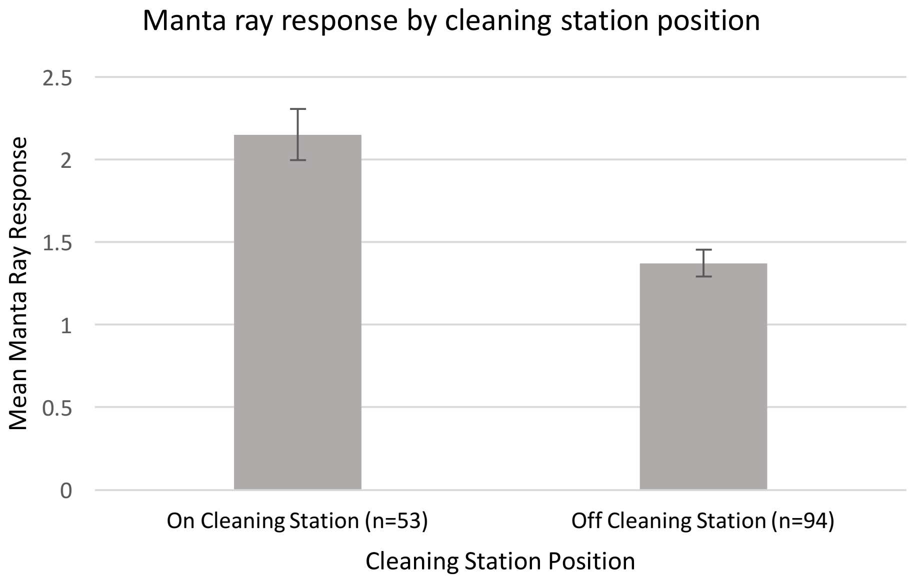

Fig. 11 The mean manta ray response to cleaning station position for all interactions recorded. The x-axis shows whether divers were positioned on or off the cleaning station and the y-axis shows the mean manta ray response on an increasing scale of severity where 1 is no reaction and 4 is avoidance behaviour. Error bars show standard error to a 95% CI.

Distance

Eighty-five interactions were recorded at a distance between 0-3 meters, and sixty-two interactions were recorded between 3-10 meters. No reaction was observed during interactions when divers were greater than 6 meters from a manta ray. When grouped, the mean manta ray response of both 0-3 meters and 3-10 meters was < 2 however, interactions between 1-2 meters had a mean response of 2.25 (±0.19SE) and between 2-3 meters, a response of 2 (±0.21SE) (Fig. 12).

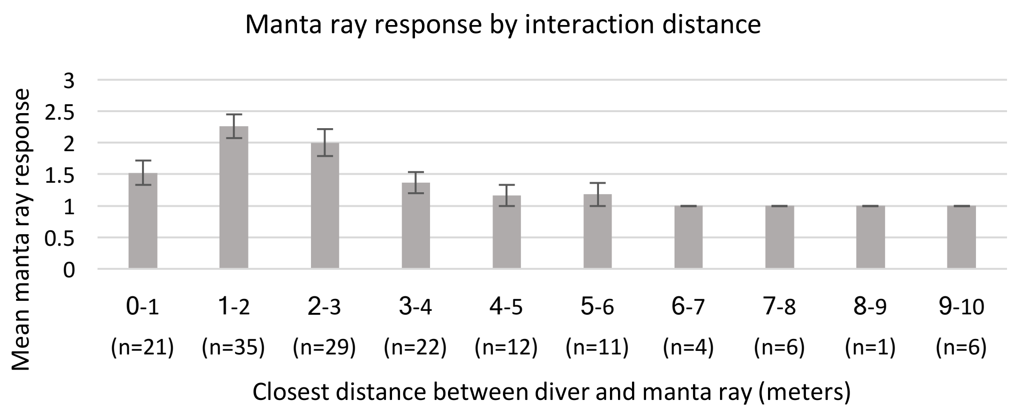

Fig. 12. The mean manta ray response to distance for all interactions recorded. The x-axis shows the distance between the closest diver and reef manta ray during an interaction and the y-axis shows the mean manta ray response on an increasing scale of severity where 1 is no reaction and 4 is avoidance behaviour. Error bars show standard error to a 95% CI.

Photography and Videography

Cameras were observed within 3 meters of a manta ray during 21% of interactions (n= 31) and beyond 3 meters during 28% of interactions (n =41). Video cameras were observed within 3 meters of a manta ray during 21% of the interactions (n=32) and beyond 3 meters during 32% of interactions (n=47). Strobes were only observed flashing during 12 interactions, and video lights were recorded during eight interactions. Mean response to all photography and videography variables was <2 except for when video cameras were used within three meters of the manta ray, where the mean response increased to 2.25 (±19SE) (Fig. 13).

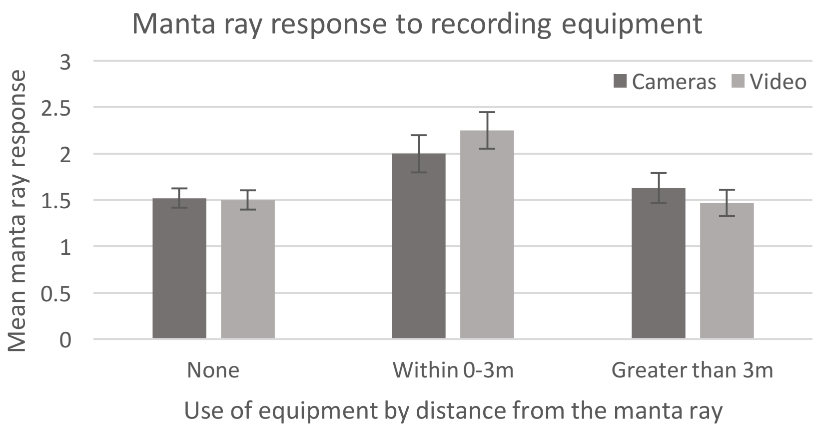

Fig. 13. The mean manta ray response to recording equipment for all interactions. The x-axis shows the use of cameras and video cameras by distance during an interaction and the y axis shows the manta ray response on an increasing scale of severity where 1 is no reaction and 4 is avoidance behaviour. Error bars show standard error to a 95% CI.

The Cumulative Link Model showed that 'distance' was the strongest predictor of manta ray response followed by 'cleaning station position' (Table 8). Statistically significant ($p<0.05$) negative relationships were found for both diver positioning off the cleaning station (p = 0.004529) and distances between 3-10m (p = 0.002550) which shows that manta rays were less likely to demonstrate negative response behaviours when divers met these conditions.

Table 8: Cumulative Link Model showing non-intercorrelated predictor variables analysed for significance toward predicting a manta ray response. P values are shown for predictor variables included in the minimum adequate model. Bold predictors were found to be statistically significant. Variables listed in grey were tested in the original model before backwards forwards stepwise selection. Plus (+) indicates a positive relationship and minus (-) indicates a negative relationship.

Model	Predictor variables tested	*p value*	Standard error	Confidence Intervals 2.5%	97.5%
	Sex:				
Manta Ray	Male	--	--	--	--
Response CLM	Female	--	--	--	--
	Distance				
	0-3m	--	--	--	--
	3-10m	**0.002550 -**	**0.07632**	**-1.6089**	**0.5332**
	Cleaning Station Position:				
	On	--	--	--	--
	Off	**0.004529 -**	**0.08143**	**-1.5557**	**0.5480**
	Cameras				
	None	--	--	--	--
	Within 3 meters	--	--	--	--
	Beyond 3 meters	--	--	--	--
	Strobes				
	Yes	--	--	--	--
	No	--	--	--	--
	Video Cameras:	--	--	--	--
	None	--	--	--	--
	Within 3 meters	--	--	--	--
	Beyond 3 meters	--	--	--	--
	Direction:				
	Below on Substrate	--	--	--	--
	Midwater	0.595192 +	0.16351	0.4529	0.8524
	Combined Group	0.052763 +	0.35165	1.2589	0.6500
	Number of Manta Rays	--	--	--	--
	Number of Divers	0.108511+	0.92843	0.0373	0.0232

Discussion

The majority of divers were observed following the code of conduct recommendations and had minimal impact on manta ray behaviour. Predictor variables differed from previous studies, which prevented a full comparison of interactions; however, the overall low response in this study was consistent with the findings of prior research on scuba diver and manta ray interactions (Atkins, 2011; Lyman, 2012). The most significant predictors of causing no disturbance, 'distance' and 'cleaning station position', are both addressed in the current code of conduct recommendations (Manta Trust, 2018a). The evidence gained from this study demonstrates that the guidelines are effective at minimizing disruption to manta ray cleaning behaviour.

Throughout this study, Manta Trust researchers provided the dive briefing on best practices; however, for the majority of divers in the Maldives, the briefing is provided by dive guides (pers. obs.). Dive guides play an integral role in minimizing scuba diver impact on manta behaviour as they provide information about best practices and can determine a dive groups' position in relation to cleaning stations. When participating in snorkelling activities, tourists are not necessarily near their guide; however, for scuba diving, divers are encouraged to remain behind the guide and follow their lead throughout the dive (pers. obs.) In a study of diver interactions with grey nurse sharks, Apps *et al.,* 2015 found dive staff to be highly influential in determining a behaviour of a dive group and acknowledged that clear communication from guides led to divers following recommendations (Apps *et al.,* 2015; Barker *et al.,* 2011). When divers were positioned off the cleaning station and did not approach manta rays within three meters, lower levels of disturbance were observed in this study.

Proximity to animals has been shown to be an important factor when surveying guests on satisfaction with encounters (specifically snorkelling with Whale Sharks) however a commitment to conservation practices and education about code of conduct recommendations can also increase guest satisfaction (Ziegler *et al.,* 2012; Apps *et al.,* 2015). Apps *et al.,* 2015 found the primary reason for scuba divers intending to approach nurse sharks was to gain a better view however, close approaches scared animals and disturbed their behaviour at a dive site which ended encounters. While guests want to have close encounters with harmless animals such as manta rays, interactions at distances of 0-3 meters resulted in increased behavioural response during the study and indicates that divers may have an impact on natural behaviour.

At distances of greater than six meters from the manta ray, no reactions were observed; however, it can be difficult for divers to see and photograph animals from this distance, particularly in poor visibility. Dive guides must balance guest satisfaction with best practices, and it may not be possible or practical for guides to keep their group six meters from a manta ray. Overall, it appeared as though guides were following recommendations for maintaining distance, and most of the 0-3 meter interactions were recorded when manta rays approached dive groups rather than divers swimming toward manta rays**.** The recommendation from the Manta Trust to not approach manta rays within three meters is an effective guideline for minimizing impact. By following this guideline, divers can have the opportunity to interact with manta rays while minimizing the possibility of disturbing natural behaviour.

As of 2011, Rangali Madivaru was one of the most valuable manta ray dive sites in the Maldives (Anderson *et al.,* 2011a), which signifies that tourism has been popular at the site for several years. In the Maldives, manta rays are often resident to certain atolls (Stevens, 2016) and frequently re-sighted at the same cleaning stations, including Rangali Madviaru. Divers positioned on the cleaning station were only observed at this site where the cleaning station is undefined. It may have been difficult for guides to know where to position their divers particularly when the dive site was crowded (>23 divers- calculated based on average number of divers across all sites) and space was limited thus divers were positioned close together where manta rays were cleaning (Needham *et al.,* 2017; Zhang and Chung, 2015). Diver position resulted in seven of the nine accidental obstructions when manta rays appeared to be confined to an area between divers for cleaning. No avoidance behaviours resulted from accidental obstruction, nor did the interaction type cause manta rays to cease cleaning. A higher mean response at the site was anticipated given the close distances observed between divers and manta rays; however, the site response was less than 'slight reaction'. The Manta Trust code of conduct guidelines advise divers remain off cleaning stations and this guideline was followed by divers recorded at all locations except Rangali Madivaru. Overall, divers were not shown to have a large impact on manta rays at the cleaning stations and this may be due to divers remaining off cleaning stations. The development of this guideline was based on observations of researchers and should continue to be followed. Additional recordings and analysis may provide increased evidence for this guideline should divers be observed on cleaning stations at sites where the habitat is well defined.

Research on habituation for elasmobranch species is minimal, however, habituation could be a plausible explanation for the low response at specific sites in this study (Kimber *et al.,* 2014). With the high numbers of divers recorded at sites such as Rangali Madivaru, it’s possible increased exposure to divers over time may have altered the manta rays' perception of divers as a threat, therefore, minimizing response at particular cleaning stations. Despite their complex brain structure, learning capabilities in manta rays have not been well researched, and no literature is available on habituation in the species (Ari, 2011). Increased observations of individual manta rays subject to different types of human interaction may provide information about whether individual manta rays have increased tolerance toward divers.

Kitchen-Wheeler (2013) described manta rays using bubbles for cleaning, which was comparable to what was observed during seven interactions where manta rays remained in streams of diver bubbles. Brooks (2010) Atkins (2011) and Lyman (2012) all reported avoidance behaviours from manta rays interacting with bubbles; however, avoidance was only observed in this study during two interactions where the diver exhaled within 2 meters of the manta ray. Large groups of divers close together unknowingly formed walls of bubbles. When manta rays approached within two meters, all were observed to change direction, but no animals exhibited an avoidance behaviour. Bubble curtains, human-developed walls of bubbles, have been researched as a method to control invasive species, exclude fish species from habitats and decrease impacts of acoustic pollution on cetaceans (Dawson *et al.,* 2006; Bennett *et al.,* 2017; Dähne *et al.,* 2017). In the case of bubble walls caused by divers, they were not a purposeful obstruction but may have been viewed as a barrier and could limit a manta ray's ability to enter or leave a cleaning station using a specific route.

This research only evaluated the immediate response of manta rays to diver behaviour and did not investigate potential long term impacts caused by diver behaviour or habitat degradation. While the study was not designed to record diver contact with the reef, this is mentioned in the code of conduct, and the videos were evidence that diver contact rates to the reef were high. Cleaning stations are a vital habitat for manta rays. If reefs are degraded through overuse or poor buoyancy control, reef manta rays may need to change habitats in order to meet their cleaning requirements (Hawkins and Roberts, 1993; Osada, 2010; Couturier *et al.,* 2012). The average number of divers at sites in South Ari and North Male was 26 individuals with a maximum number recorded of 45 divers during one dive. Multiple divers were recorded standing on the reef, holding on to live corals or laying on top of the coral, which is cause for concern due to the immediate degradation of coral but also the carrying capacity of these habitats (Hawkins and Roberts, 1993; Hawkins *et al.,* 1999). A position near the substrate is recommended when manta rays approach, however, divers are advised to be careful of the substrate below them (Manta Trust, 2018a). On all dives, regardless of the site being known for manta rays, guides need to stress the importance of maintaining good buoyancy to help conserve the habitats that support marine biodiversity.

The number of divers was not found to be a significant predictor of a manta ray response however, a reduction in the number of divers would have a positive impact on reducing bubble walls, overcrowding at dive sites, and habitat degradation. Crowding has been shown to have a negative influence on guest satisfaction, and one way to manage diver numbers is through user limits (Sorice *et al.,* 2007; Hasler and Ott, 2008). A diver limit could be added to the code of conduct if it becomes part of a comprehensive marine management plan that includes marine protected areas, limits on diver access, and certification programs for guides. These management techniques have proven effective at regulating marine tourism and improving sustainability in Sipadan, Malaysia, and Isla Holbox, Mexico (Musa, 2002; Sipadan, 2018; Ziegler *et al.,* 2012). Management measures such as the creation of marine parks and limits to diver access require government support but could improve guest satisfaction at dive sites in the Maldives and increase the willingness of guests to pay for scuba diving activities (Peters and Hawkins, 2009; Needham *et al.,* 2017, Murphy et al. 2018).

Limitations

All previous data collection on the code of conduct took place in Baa Atoll during July and August, considered to be manta ray high season, thus snorkelling activities were frequently observed (Brooks, 2010; Atkins, 2011; Lyman, 2012; Garrud, 2016). With scuba diving, data could only be collected over a short duration (maximum 60 minutes) when guests were visiting a manta ray dive site and if manta rays were located. Manta rays were not observed on every guest dive, and for Laamu Atoll, July and August were low season for manta ray encounters. Data collection for this study should continue to increase the number of manta and scuba diver interactions analysed.

Observations of certain sub-variables were minimal; thus additional work is needed to test the significance of predictors on manta ray response. In future research, camera and video camera types should be recorded and analysed independently as there may be a more significant response to cameras of a specific size. No recommendation was made on lights or strobes based on the evidence of this study as they were only recorded in a few video clips.

Conclusion

Analysis of the 147 diver-manta ray interactions presented in the study vastly increases the amount of data available on reef manta ray behaviour in regards to scuba divers. It provides the first quantifiable research on bubble interactions and camera usage in the presence of manta rays. Temporal and spatial distribution of data has also been expanded as videos were collected over six months and from multiple atolls in the Maldives. This study provided evidence-based research that supports the continued use of the guidelines currently recommended in the code of conduct for scuba diving and highlighted areas that need to be further researched in future studies.

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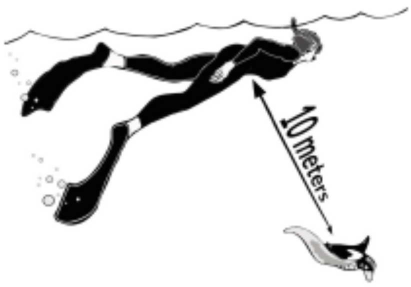
Appendix 1: Manta Trust Code of Conduct

HOW TO SWIM WITH
MANTA RAYS

By following this Tourism Code of Conduct, you will avoid disturbing the mantas you encounter. At the same time you will increase your chance of having a life-changing experience with these gentle giants.



STEP 1

Enter the water quietly and calmly, no closer than 10 meters / 33 feet from the manta ray.

STEP 2

Keep your **fins below the water's surface** when swimming. Splashing and noise can scare mantas away, so you want to approach as quietly as possible.

STEP 3

Do NOT approach closer than 3 meters / 10 feet. Instead, remain still and let the manta come to you.

STEP 4

You should **approach the manta from their side,** giving them a clear path ahead.

STEP 5

As the manta swims past you, **do NOT chase after it!** You will never catch up to a manta anyway, and will likely scare it away in the process.

STEP 6

Do NOT touch a manta ray. You will ruin the encounter, and may receive a fine depending on local laws.

ENGLISH

STEP 7

For scuba divers only.

If you are diving with mantas, you will most likely be encountering them on a cleaning station. These are important sites for manta rays.

During the encounter, **remain at the side of the cleaning station. Do NOT swim onto the main cleaning area.**

STEP 8

For scuba divers only.

Keep low and hover close to the seabed, but **be careful not to damage the reef** beneath you. Depending on the dive site, you may need to stay in an area designated for divers.

STEP 9

For scuba divers only.

When a manta swims towards you, **do NOT block their path as they swim overhead.** Stay low, and stay where you are.

STEP 10

Be sure to **follow any extra rules**, laws and regulations that may be specific to the manta site you're visiting.

To watch a film version of this guide, and learn more about sustainable manta tourism, visit:

www.SwimWithMantas.org

This guide was created by:

Manta TRUST

Appendix II: Protocol for Code of Conduct Data Collection

A protocol for data collection on the science behind manta interactions: A Code of Conduct for Manta Ray Tourism

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Reef Manta Ray, *Mobula alfredi*, Tourist Touching, Hanifaru Bay, Baa Atoll, Maldives © Guy Stevens, Manta Trust 2010

1. Introduction

Situated in the Indian Ocean, the Republic of the Maldives is widely recognized as a hotspot for marine wildlife interactions and ecotourism, hosting a high abundance of whale sharks, sea turtles and manta rays (Cagua *et al.,* 2014). The direct expenditure on whale shark tourism has increased from US$ 2.3 million per annum in 1993 (Anderson & Ahmed, 1993) to US 9.4 million per annum in 2013 (Cagua *et al.,* 2014). However, the need for improved tourism management is apparent as visitor numbers have escalated to 72-78 million per annum (Cagua *et al.,* 2014), there are increased anthropogenic injuries to individuals (MWSRP, 2013) and 40% of whale sharks in South Ari show injuries from boat strikes (Bott *et al.* unpublished as seen in Collins, 2013). Tourism directed at swimming with manta rays in the Maldives has also increased greatly; estimated to contribute US$ 8.1 million in direct revenue in 2010 (Anderson *et al.,* 2011) and the direct economic impact approximately US$ 15.4 million in 2013 (O'Malley *et al.*, 2013).

1.1 The Purpose of monitoring the impact of human interactions on manta rays

Anecdotal reports indicate that manta rays' natural activities can be disturbed by divers and snorkelers present at aggregation sites. Humans may block the manta's natural feeding path, startle the manta by approaching from behind, or even cause them to stop feeding or cleaning (Anderson *et al.,* 2011). Humans can also disturb activities at cleaning stations by approaching too closely, leading the manta rays to leave, and often disturb the fragile coral ecosystem that constitute the cleaning station through bad buoyancy (Tratalos & Austin, 2001.). The use of specific guidelines for tourism interactions has been shown to minimise the negative effect of humans on animals (Brunnschweiler, 2010; Mau, 2008; Pierce *et al.,* 2010) and together with interpretive and educational briefings can improve tourist satisfaction with the experience (Zeppel & Muloin, 2008; Quiros, 2007). However, few studies have examined the effect of tourism interactions on manta rays in detail and no study has analysed and quantified the effect of human behaviour on cleaning manta rays in scientific terms. **The aim of this study is to investigate human-manta ray tourism interactions, using videos collected in the Maldives, to identify whether human behaviour causes changes in the cleaning behaviour of manta rays.**

This protocol is designed to provide the Manta Trust's Maldivian Manta Ray Project (MMRP) staff with a clear guide to collecting human/manta interaction data for the SCUBA Code of conduct study. This document will specify the necessary data aspects needed to ensure a clear and representative view of manta interactions.

1.2 Practical Considerations

There are a number of practical considerations when planning a monitoring programme. These include personnel, safety and insurance.

1.2.1 Personnel

Ideally observers should have considerable SCUBA experience and a clear personal understanding of the Manta Trust's Best Practices Code of Conduct so that they also complying with the in-water recommendations. Observers should also have the ability and organisational skills so that they are able to make adequate records, collect clear and representative data without influencing or biasing data.

1.2.2 Safety

Observers must be aware of the risks involved in SCUBA diving, as stated in the Liability Release & Assumption of Risk form. All observers must complete and sign the Liability Release & Assumption of Risk form before entering the project (Appendix 1).

2. Methods

2.1 Equipment and Set-up

Cameras

Prior to surveys staff must prepare the necessary camera equipment. Any camera used needs to have the time settings adjusted to **Malé time**, i.e. one hour earlier than resort time. **The observer must ensure that all primary and spare batteries for each individual camera are fully charged and memory cards clear prior to leaving the resort.** Spare batteries should also be packed in the dry bag to avoid running out of charge whilst on surveys.

2.2 Site Map

To aid analysis and Code of Conduct recommendations, please provide a map of the dive site, clearly marking the designated cleaning station/s, marked with depth measurements and key topographic features. This will allow us to designate 'Safe Zones' for divers during interactions and establish the location of cleaning stations.

2.3 Interactions

The aim of this study is to capture and analyse human/manta interactions, but what is an interaction? **For the purpose of this study an interaction is defined as an encounter when "a human and manta ray become within a 5 m distance of each other".** Researchers should dedicate **10 minutes** per dive to collecting human/manta interactions. To avoid biasing both human and manta behaviour, researchers should wait for all divers to be assembled and positioned at the cleaning station before filming begins. Position yourself close to the divers and beside the cleaning station as this will allow you to pan the camera around, following the path of the manta and capturing all the behaviour. **IMPORTANT** The camera should remain focused on the manta **NOT** divers for the duration of their visit to the cleaning station, but ensure camera angle allows human behaviour to be included in the frame, i.e. zoom out if necessary. If there are a large number of mantas on the dive, remain focused on the cleaning station. Extra interactions whilst cruising can also be collected but the priority will be during cleaning interactions. It is **VITAL** that a clear ID shot of the manta involved in the interaction is recorded (Figure 1); if it is not possible to capture the ID during the interaction itself, then ensure that this is collected before or after or by another diver.

Figure 1: An ideal ID shot which shows the unique spot-pattern on the ventral surface (Reef Manta Ray, *Mobula alfredi*, Fushi Faru, Lhaviyani Atoll, Maldives © Guy Stevens).

2.4 Data Collection

It is vital that in order to avoid manipulating behaviour, snorkelers and divers should not be made aware of the nature of the study before the interaction.

The primary purpose of this study is to evaluate the reactions of manta rays according to specific human behaviours therefore videos should also clearly show the **mantas primary reaction**. Reactions are categorised on a scale from 1 – 4; No reaction (1); Slight reaction (2); Direction change (3) and Avoidance (4), as defined in Table 1 below. For the purpose of analysis, all video data should clearly show **human behaviour** which will be grouped into eight primary categories; Passive Observation (PO); Accidental Obstruction (AO); Swimming onto the cleaning station (CI) Swimming in Front/Near manta (FN); Chasing (CH); Touching (TO); Bubbles (BU) and Diver and Bubbles (DB) as defined in Table 2 below. Another key variable to be tested is the impact of **cameras and diver behaviour on manta behaviour**. This will be tested separately using the following criteria; Use of photo/video camera (Yes/No); For video cameras, lights were used or not (Yes/No); for photos, strobes were used or not (Yes/No); Behaviour of diver using the camera, e.g. diver pushed the camera in the path of the manta OR diver remained calm and still beside the cleaning station, maintaining distance between the camera and the manta OR diver lost buoyancy and touched the reef. Footage should also show the **position of divers in the water column relative to the focal manta ray** (identified manta in the interaction) and **relative to the reef**. These are categorised as; Positioned Below on the substrate (BL); Mid-water (MW) and Above (AB). Videos will be used to record the estimated distance between divers and the manta. Footage will also establish whether the manta ceases to clean following the interaction or not (Yes/No), leaves the cleaning station or not (Yes/No) and if so, whether it returns to the cleaning station within 60 seconds or not (Yes/No).

If the observer notes any behaviour, interaction or event which may prove relevant to the study they should make a note of this on the data slate and the time that it occurred, for example a large pod of dolphins entered the survey area.

Table 1: Definitions for manta reactions observed during interactions.

Manta reaction	Label	Definition
No reaction	1	*Individual continues with current behaviour*
Slight reaction	2	*Minor direction change to move away from obstruction*
Direction change	3	*Distinct direction change to avoid obstruction*
Avoidance	4	*Complete alteration of behaviour to avoid obstruction*

Table 2: Definitions for human behaviour observed during interactions.

Human behaviour	Label	Definition
Passive observation	PO	*Human remains still in the water, allowing the manta to continue on its usual path*
Accidental obstruction	AO	*Human unintentionally moves into the path of or accidentally touches the manta*
Swims onto the cleaning station	CI	*Diver swims directly onto the designated cleaning station*
Swimming in front/near	FN	*Human swims in a direction which crowds the manta, i.e. too close to the manta or blocking its path*
Chasing	Ch	*Human moves towards or follows the manta during the interaction*
Touching	To	*Human intentionally touches the manta ray during the interaction*
Bubbles	Bu	*Diver bubbles hit the manta.* ***Also note:*** *in front or underneath the manta*
Diver AND bubbles	DB	*A diver comes within a 2-metre distance AND releases bubbles which hit the manta*

In order to avoid replication in the data, observers should try to avoid filming multiple interactions involving the same animal. Therefore, making a mental note of the ID will enable observers to collect a broad sample of the manta rays which are aggregated.

Data slate

During surveys a daily log of activities should be recorded at each site, noting each vessel (including the research *dhoni*) at the site and the number of tourists and guides (hereafter called "group") entering the water. A more detailed record should be taken of the research vessel activity; name of site, dive start and finish time, peak encounter time, approx. number of manta, visibility, impairments to visibility, plankton density and type, current strength, manta breaches, and number of divers in the water.

Additional data to be collected on the dive

- Number of divers at the cleaning station.
- Amount of time the mantas remains cleaning at the station.
- Total number of mantas per dive.
- Total number of divers per dive.

2.5 Equipment Maintenance

On arriving back at the resort after surveys all cameras should be rinsed in order to remove any salt from the housing and stored in the office. With dry hands, observers should remove the camera from the housing and place the battery to charge every day even if the camera has had minimal use. Once a week all cameras should be cleaned and the O-rings greased. All spare batteries should be checked on a weekly basis and charged if necessary.

2.6 Data Storing

Data should be sorted and filed on the day of collection.

Each video clip should be assigned and labelled with a clip number which will correspond with the data collection spreadsheet. The clip number should relate to the location, date and clip number, for example, the first video clip filmed at Hithadhoo Corner on the 1st May 2018 should be labelled **HC_2018_05_01_01.** At the end of each survey all video clips should be saved and backed up on a designated external hard drive. To maintain an organised storage system, the data folder should be clearly divided and labelled by month, day, site and observer name, for example **May** -> **1st May 2018, Hithadhoo Corner Bay, Annie.** When footage has been saved and backed up the observer should clear the footage from the memory card to ensure there is enough memory to record subsequent interactions.

Contact Information

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Appendix III- Variables with a mean response less than 2 (slight reaction).

Variable	n=	Mean Response	Standard Error
Undisturbed Behaviour			
Cleaning	131	1.618	±0.082
Cruising	15	2.017	±0.357
Courtship	1	1	±0
Site Location			
Rangali Madivaru	63	1.968	±0.141
Hithadhoo Corner	26	1.115	±0.078
Huravalhi Falhu	8	1.125	±0.125
Sunlight Thila	10	1.8	±0.326
Dhiggaru Kandu	39	1.575	±0.153
Site Type			
Defined	84	1.414	±0.089
Outer Atoll	63	1.968	±0.141
Direction			
Below	119	1.647059	±0.091
Midwater	17	1.3636	±0.163
Combined	11	1.882353	±0.351
Sex			
Male	34	1.823	±0.172
Female	113	1.602	±0.091
Video Lights			
Present	8	1.750	±0.366
Absent	139	1.647	±0.085
Strobes			
Present	12	1.750	±0.329
Absent	135	1.644	±0.085