Does tourist behaviour affect reef manta ray feeding behaviour?

An analysis of human and *Manta alfredi* interactions in Baa Atoll, the Maldives

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Supervisor: Annie Murray

Ella Garrud
Y3841390

Manta TRUST

UNIVERSITY of York

Disclaimer

I, Ella Garrud, declare that all aspects of this dissertation are my own original work. I have acknowledged all sources used and have cited these in the reference section.

I declare that my word count is 5,000 excluding project title, disclaimer, acknowledgements, reference list, figure legends, tables and appendices.

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Abstract

The number of tourists travelling to the Maldives specifically to swim with charismatic marine megafauna has increased over recent years. Manta ray tourism in the Maldives is estimated to be worth US$8.1 million annually in direct revenue alone. This type of tourism clearly has significant benefits to the Maldivian economy but there is anecdotal evidence that large numbers of tourists at popular dive and snorkel sites is having a negative impact on reef manta rays' natural behaviour.

This study investigated human and manta ray tourism interactions by collecting video footage (*n* = 431) over a two-month period in Baa Atoll, Maldives at five feeding aggregation sites, to identify and quantify how human in-water snorkelling conduct affected the manta rays' feeding behaviour.

Passively observing the manta significantly decreased the likelihood of causing a strong reaction from the manta. Accidentally obstructing the path of the manta significantly increased the likelihood of the manta displaying avoidance behaviour as did approaching the manta from the front. Tourists positioned between 0 and 3 m of the manta significantly increased the probability of avoidance behaviour from the manta. Diving under/near mantas from the front strongly increased the probability of avoidance behaviour from the manta. Mantas recorded at sites where juveniles are regularly observed also reacted more strongly to human behaviour.

These findings reveal key recommendations: (1) tourists should observe mantas passively, (2) a minimum of 3 m distance should be maintained between human and manta, (3) approach from the side of the focal manta ray, (4) inexperienced snorkelers

should not dive underneath or near manta rays, (5) tourists should not dive in front of mantas, (6) at sites where juveniles are regularly sighted, be more cautious when approaching manta rays. All results and recommendations support the Manta Trust Code of Conduct for Tourism Interactions.

Introduction

Manta rays

The two species of manta ray, reef mantas (*Manta alfredi*) and oceanic mantas (*Manta birostris*), are found in the Maldives (Kitchen-Wheeler, 2010). Reef mantas are found in very large numbers in the Maldives (Anderson et al., 2011); the island nation currently has the largest recorded population in the world, estimated at ~5000 to 6000 individuals, with over 4000 identified to date (Manta Trust, 2016). In the central atolls of North Male, Ari and Baa, the population has been estimated at ~1835 individuals (Kitchen-Wheeler et al., 2011).

Manta rays are large bodied, slow growing cartilaginous elasmobranch fish which are late to mature and have among the lowest fecundity of all elasmobranch species (Dulvy et al., 2014). These life history characteristics leave them highly vulnerable to overexploitation (Dulvy et al., 2014) and they are currently classed as 'Vulnerable to Extinction' on the IUCN Red List of Threatened Species (Marshall et al., 2011). They face a number of anthropogenic threats and are currently subject to bycatch and large targeted fisheries for Mobulid (manta and mobula) species (Whitcraft et al., 2014; Croll et al., 2016; Dewar et al., 2011). Over the past two decades they have been increasingly targeted for their gill rakers, which are sold into the Chinese medicine

market as a traditional pseudo-remedy for many ailments, from asthma to cancer (O'Malley et al., 2016; Heinrichs et al., 2011). There are significant fisheries for manta and mobula gill rakers in Vietnam, Sri Lanka, and India (O'Malley et al., 2016). Historically, there has never been a large targeted fishery for mantas or mobulas in the Maldives, and in 2014 the Maldivian government declared all sharks and rays as protected species (Manta Trust, 2014; Anderson et al., 2011b).

Ecotourism offers a sustainable alternative for generating income from manta rays. It has been found that they are worth significantly more alive than dead (Heinrichs et al., 2011). The estimated global value of the gill raker trade is ~US$11 million and the estimated fisheries value of a single manta ray is US$40 – 500 (Heinrichs et al., 2011). In comparison, a live manta can generate up to US$1 million over its life time (Heinrichs et al., 2011).

Manta ray tourism in the Maldives

The Maldivian economy is almost entirely dependent on its fishing industry and tourism (Anderson et al., 2011, 2011b). In 2015, 1.2 million tourists visited the Maldives (Naish, 2016) and nature based income has been estimated to contribute ~70% of the country's total GDP and this is expected to grow (World Bank, 2010). Many tourists travel to the Maldives primarily to dive and snorkel with large charismatic megafauna such as turtles, whale sharks and manta rays (Riley et al., 2010; Anderson et al., 2011b; Cagua et al., 2014).

Sightings of manta rays in the Maldives are highly seasonal due to the currents caused by the monsoonal winds (Anderson et al., 2011). The southwest monsoon (Hulhangu)

occurs from around May to October with the ocean currents flowing mainly to the east during this time, while the northeast monsoon (Iruvai) lasts from around December to March with the currents flowing mainly to the west (Anderson et al., 2011; Shankar et al., 2002). These currents result in upwelling, which brings up nutrients to the euphotic zone which in turn causes phytoplankton blooms on the downstream side of the atoll chain (Anderson et al., 2011). This seasonally high primary productivity supports high zooplankton biomass which attracts planktivores, including manta rays, to the down stream side of the atolls (Fig. 1) (Anderson et al., 2011).

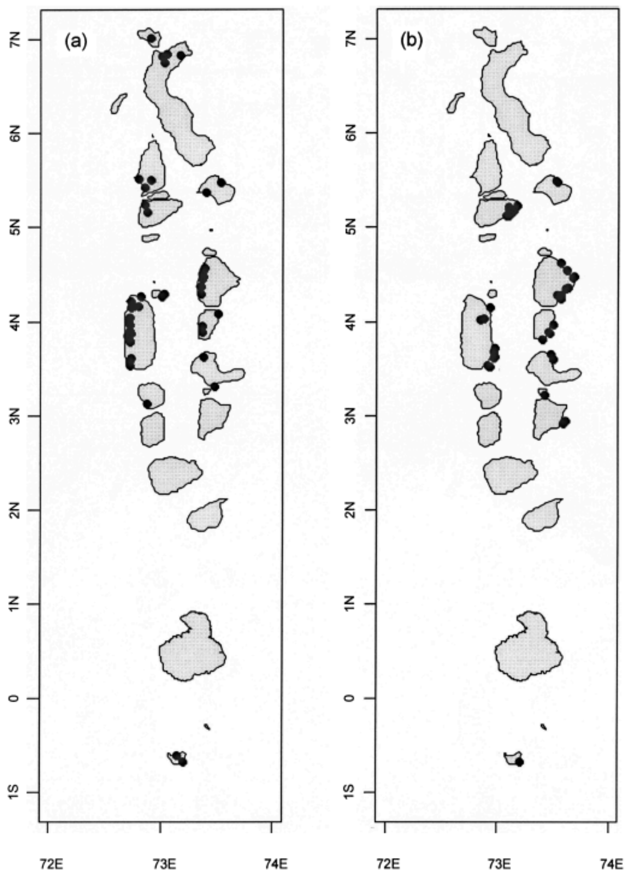

Figure 1: Seasonal distribution of manta rays as reported by divers (each dot represents one dive site, at which mantas are reported to be present in that season). (a) NE monsoon season. (b) SW monsoon season. (Anderson et al., 2011b)

Due to the seasonality of sightings and because mantas tend to aggregate in large groups to feed in areas of high zooplankton abundance, it is moderately easy to predict

where mantas are likely to be seen and, due to this, a large tourism industry based on manta ray watching has developed in the Maldives (Anderson et al., 2011b). The direct global economic impact of manta ray watching is estimated to be US$140 million annually (O’Malley et al., 2013), while in the Maldives manta ray watching is estimate to contribute ~US$8.1 million annually in direct revenue alone (Anderson et al., 2011b).

Ecotourism is based on a number of key tenets: it is non-consumptive, nature based, conservation orientated, has a focus on education and sustainability, promotes ethical and responsible behaviour and raises awareness (Donohoe and Needham, 2006). However, it is possible that the Maldivian manta ray tourism industry could be having a negative impact on manta rays by disturbing their natural behaviours, such as feeding (Venables, 2013), which is contradictive of ecotourism goals. As the number of tourists travelling to the Maldives increases, the risk of negative affects on manta rays will also increase (O’Neill et al., 2004). This has already been observed in the whale shark population in South Ari Atoll; 40% of individuals have been observed with injuries from boat strikes (Collins, 2013). Another study found that 36% of whale sharks in the Indian Ocean bore prominent scars from boat strikes characterised by lacerations, amputations and blunt trauma (Speed et al., 2008).

It was estimated that between 2006 and 2008 ~143,000 dives and at least 14,000 snorkels aimed at observing manta rays were made annually in the Maldives (Anderson et al., 2011b), and this number has potentially doubled to date (pers. comm., Froman, Project Leader of the Maldivian Manta Ray Project, the Manta Trust, 2016). There is anecdotal evidence that large numbers of snorkelers and divers at

popular and normally productive manta dive sites have caused mantas to move to other sites (Anderson et al., 2011). Two studies have been conducted to assess the effects of human behaviour on manta rays by former University of York MSc Marine Environmental Management students (Atkins, 2011; Lynam, 2012). Neither of these studies identified every individual manta ray and so the results cannot be published due to the high likelihood of pseudo-replication within the data. However, these studies can be used to give an indication of what could be expected from the results of this study. Both studies found the majority of tourist interactions with mantas were passive and caused little to no response from the manta (Atkins, 2011; Lynam, 2012). There are a number of published studies which have analysed human interactions with other marine species (Clua et al., 2010; Frohoff et al., 1995; Müllner et al., 2004; Samuels and Bejder, 1998), but no study has been published which analyses and quantifies the effect of human behaviour on manta ray feeding behaviour in the Maldives in scientific terms.

The Manta Trust has already developed a Code of Conduct to inform snorkelers and divers on how to behave in the water with manta rays (Appendix 1). It was developed by experienced Manta Trust researchers, based on studies and expert observations of manta ray behaviour and their reactions to human interactions and on manta tourism programs worldwide (Manta Trust, 2013). There are other examples of Codes of Conduct around the world for various different marine species, including whale sharks, basking sharks, minke whales and manatees (Mau, 2008; Quiros, 2007; Rowat and Engelhardt, 2007; Pierce et al., 2010). Many of these have been developed based on studies which examined tourism interactions with the focal species in detail.

Aims

The aim of this study is to scientifically quantify manta ray reactions in response to interactions with snorkelling tourists by analysing video footage recorded at feeding aggregation sites in Baa Atoll, the Maldives. The study will examine which type of human behaviour most impacts the mantas' feeding behaviour, and whether the direction of human approach and distance between the human and focal manta ray has any significant affect on the level of disturbance. This study aims to support and reinforce the Manta Trust's existing Code of Conduct with quantifiable results.

Methods

Study Sites

The Maldives is situated in the north-western Indian Ocean and consists of 26 geographical atolls, which are made up of over 2000 reefs and 1190 islands (UNDP, 2014). All data for this study was collected in Baa Atoll (officially South Maalhosmadulu Atoll) which was designated a UNESCO Man and Biosphere reserve in 2011 (Jimenez et al., 2012), and is located in the north-west of the country (Fig. 2).

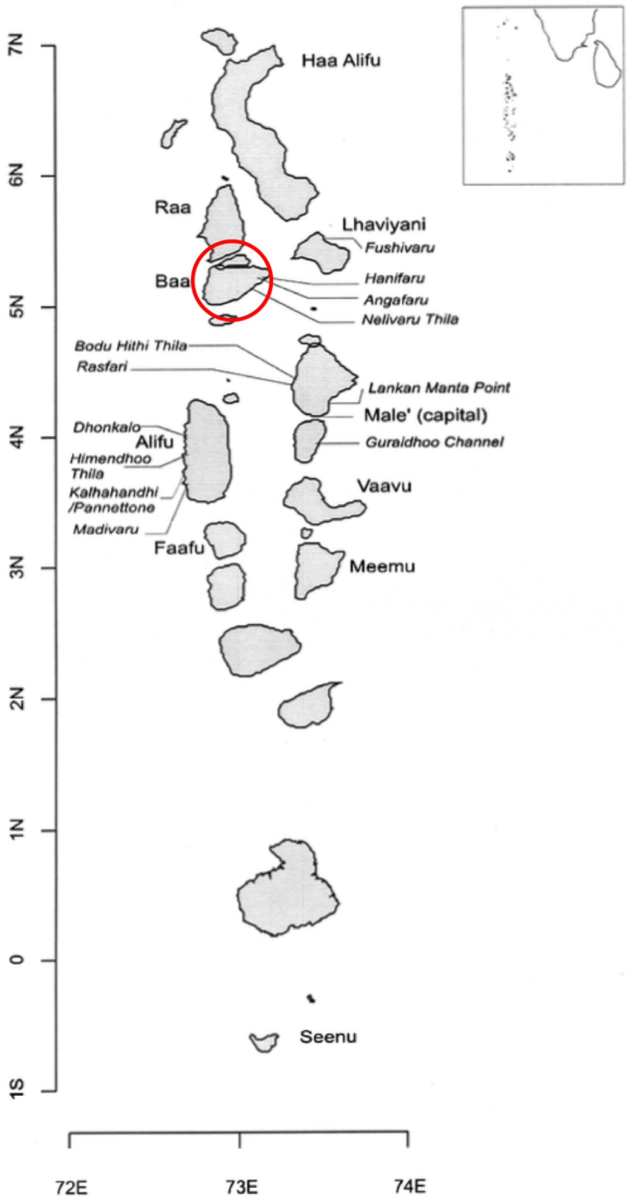

Figure 2: Location of Baa Atoll in the Maldives. Baa Atoll circled in red. (Anderson et al., 2011b)

Data was collected from feeding aggregation sites within Baa Atoll regularly visited by the Manta Trust research vessel; Hanifaru Bay MPA, Reethi Beach, Veyofushi, Dhigu Thila and Andagiri (Fig. 3).

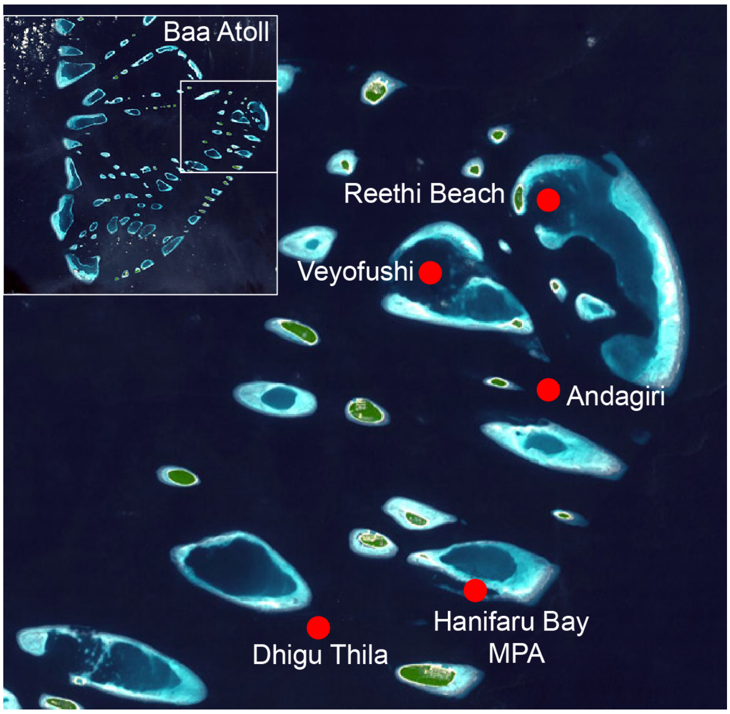

Figure 3: Location of the 5 study sites within Baa Atoll.

Hanifaru Bay is a marine protected area (MPA) which is famous due to the very large feeding aggregations of manta rays it attracts (Brooks, 2010). The bay is uniquely positioned so that during the southwest monsoon, the opposing lunar and monsoonal currents cause plankton rich water to enter the bay (Brooks and Stevens, 2010). Up to 200 reef manta rays have been observed at once in Hanifaru Bay (Brooks and Stevens, 2010), and during this study the largest number of mantas observed was ~80 (pers. obs., 2016). SCUBA diving was banned in Hanifaru Bay from 2012 as it was deemed to be too disruptive to the feeding manta rays (AEC, 2011).

Data Collection

Prior to data collection a test was created to ensure that I could accurately estimate distances between humans and mantas in video footage. A buoyant yellow life jacket was attached to a rope which was held at one end by a second person. The rope was held at 1 m, 2 m, 3 m, 4 m and 5 m lengths successively, and each length was video recorded with the same camera used for data collection, from different angles and distances. Screenshots were then taken from each video at various points. The test comprised of 15 videos and 45 screenshots and involved identifying the distance between the person and the life jacket (Fig. 4). I tested myself everyday until I was scoring consistently more than 90%. Once this was achieved, I tested myself 3 times a week during the two months of data collection to ensure I remained accurate when analysing distances in video footage.

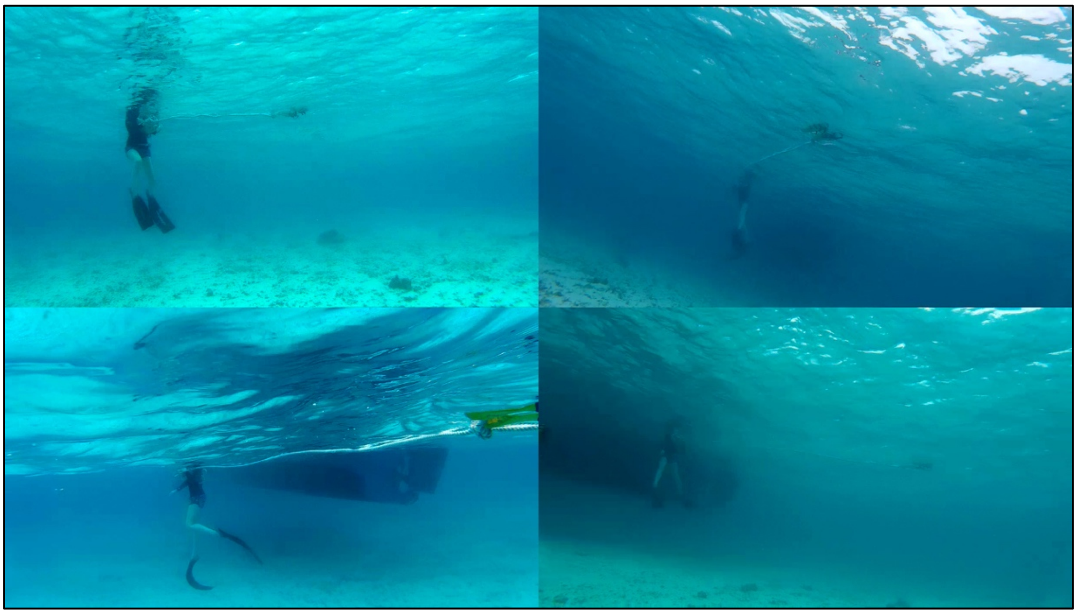

Figure 4: Four screenshots from the test used to improve the accuracy of distance analysis in footage collected for study

Data was collected between July and August 2016. Interactions between snorkelling tourists and feeding manta rays were recorded using an SJCAM SJ4000 camera. At each site, a number of variables was collected including daily weather conditions, wind

and sea state using the Beaufort scale, current direction and strength, types of zooplankton observed, the density of zooplankton, the number of tourist boats and the number of people in the water, including the researcher. Tourists were not made fully aware of the nature of the study to avoid influencing their behaviour. However, they were given the option of opting out of being filmed and were debriefed about the study when possible. To avoid pseudo-replication, footage was only used if the manta ID was clearly visible. Individual mantas were identified by analysing the unique spot pattern on the ventral surface of the manta as per Kitchen-Wheeler (2010) (Fig. 5) and matching them with photographs in the Maldivian Manta Ray Project branchial database, which includes over 4000 individual manta identifications. The database provides the manta's individual ID number, sex, tail length, and information on any injuries or damage to pectoral or cephalic fins.

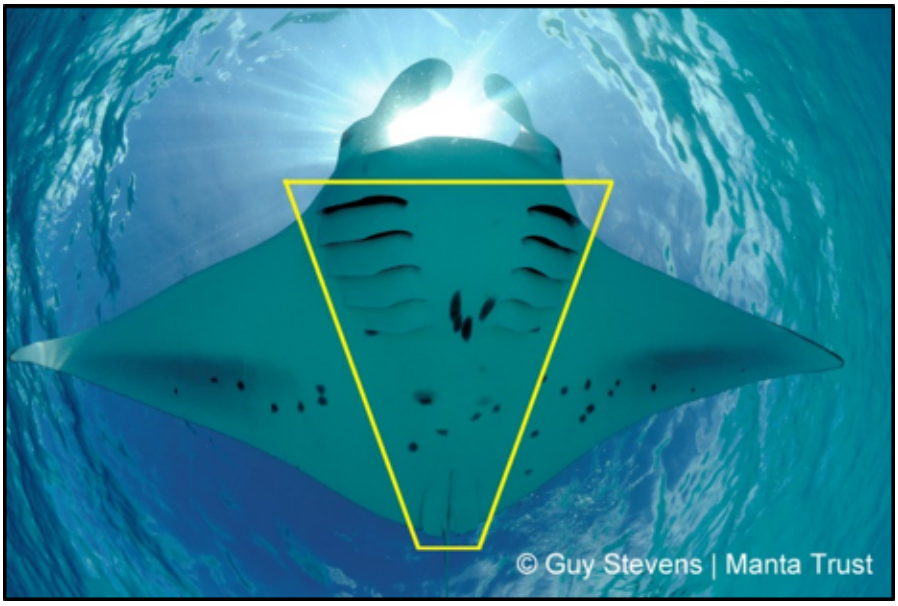

Figure 5: Primary ID area of a reef manta ray (*Manta alfredi*) (Stevens, n.d)

Data Analysis

All video footage was analysed within 48 hours of collection and was assessed to identify the reactions of manta rays in response to tourists' snorkelling behaviour. Each video clip was reviewed multiple times. An interaction was defined as when a tourist and manta became within ≤5 m of each other. For each interaction, 15 variables were recorded, listed in Table 1. The categories of human behaviour, undisturbed manta behaviour and manta response are further explained in tables 2, 3 and 4 respectively. If the same manta ray was recorded multiple times in the same day, just one interaction of each type of human behaviour with that manta was used, the first instance of each recorded behaviour was retained for analysis.

Table 1
Description of variables collected

Variable	Description
ID	Individual manta identification number
Humans	Number of humans viewed in the clip during the interaction
Distance	Distance (m) between manta and human: 0-1 m, 1-2 m, 2-3 m, 3-4 m, 4-5 m
Human behaviour	Interaction type categorised by human behaviour: Passive Observation, Accidental Obstruction, Diving Under/Near, Chasing
Primary direction	Primary direction of human approach: Surface, underneath
Secondary direction	Secondary direction of human approach: Side, front, behind, above, below
Manta behaviour	Undisturbed manta behaviour before interaction: Solo feeding, somersault feeding, chain feeding, cruising.
Manta response	How the manta responded to the interaction: No response, slight course redirection, major course redirection, flight
Stopped behaviour	Did the manta stop its undisturbed behaviour?: Yes, no, unknown
Resumed behaviour	Did the manta resume its undisturbed behaviour?: Yes, no, unknown, NA
Total mantas	Total number mantas at site at the time of interaction
Total humans	Total number of humans at site at time of interaction
Site	Site name: Hanifaru Bay, Andagiri, Veyofushi, Reethi Beach, Dhigu Thila

Table 2
Definitions of human behaviours on an increasing scale of severity from 1 to 4

Human behaviour	Description
(1) Passive observation	Human remains still and flat in the water
(2) Accidental obstruction	Human accidentally obstructs the path of the manta or accidentally touches the manta
(3) Diving under/near	Human dives underneath or near the manta
(4) Chasing	Human actively chases the manta, swimming fast and splashing

Table 3
Definitions of manta response to human behaviour on an increasing scale of severity from 1 to 4

Manta response	Description
(1) No response	Manta does not react to the human behaviour. No extra energy expended by manta.
(2) Slight course redirection	Manta makes a slight change of direction or a small, shallow dive. Minor amount of energy expended by manta.
(3) Major course redirection	Manta makes a large charge of direction or a sharp, deep dive. More energy expended by manta than slight course redirection.
(4) Flight	Manta puts on a sudden burst of speed to exit the interaction. Response behaviour with most amount of energy expended by manta.

Table 4
Definitions of undisturbed manta behaviour

Manta behaviour	Description
Solo feeding	Manta feeds on its own, at the surface or through the water column, ranging in depths
Somersault feeding	Manta performs backwards somersaults through thick patches of plankton with mouth open. Also a solo feeding technique
Chain feeding	Manta feeds while part of a chain of mantas, positioned one after the other. Group feeding technique
Cruising	Manta is cruising or travelling through the water column with closed mouth and cephalic fins curled up

Before any data analysis involving modelling was applied, data exploration as described in Zuur et al., (2010) was carried out to check for normality and skew. The variable ‘number of humans in clip’ was transformed using a square root transformation. Predictor variables were tested for intercorrelation using Pearson’s coefficient *(r).* Collinearity was considered serious if $|r| >= 0.7$ (Dormann et al, 2013). Variance inflation factors (VIF) were also assessed and were considered high if >= 5

as per Marshall et al., (2012).

A Cumulative Link Model (CLM) with a flexible threshold was used to assess whether the number of humans in the video clip, distance between human and manta, type of human behaviour, primary and secondary direction of approach, undisturbed manta behaviour and total number of humans and mantas at the site were significant predictors of manta response. The variables in the model were reduced using combined backwards forwards stepwise selection. Variables were added or removed according to the Akaike Information Criterion (AIC) to create a Minimum Adequate Model. The influence of potential outliers was considered serious if Cook's Distance was near to or greater than 1. A second CLM with flexible threshold was used to assess whether the same 8 variables were significant predictors of mantas terminating their undisturbed behaviour. The same procedure was followed as described above.

Two more CLMs were used to firstly, assess whether secondary direction of approach and secondly, whether distance between manta and human affected the mantas' response when looking at the types of human behaviour separately by creating subsets within the dataframe. False discovery rate (FDR) end point adjustment was used to account for multiple testing. Therefore, alpha was adjusted to 0.0375.

Results

431 human and manta interactions were over 47 days in July and August 2016. The most commonly observed human behaviour was passive observations, with 166 interactions, followed by diving under/near with 152 interactions (Fig. 6).

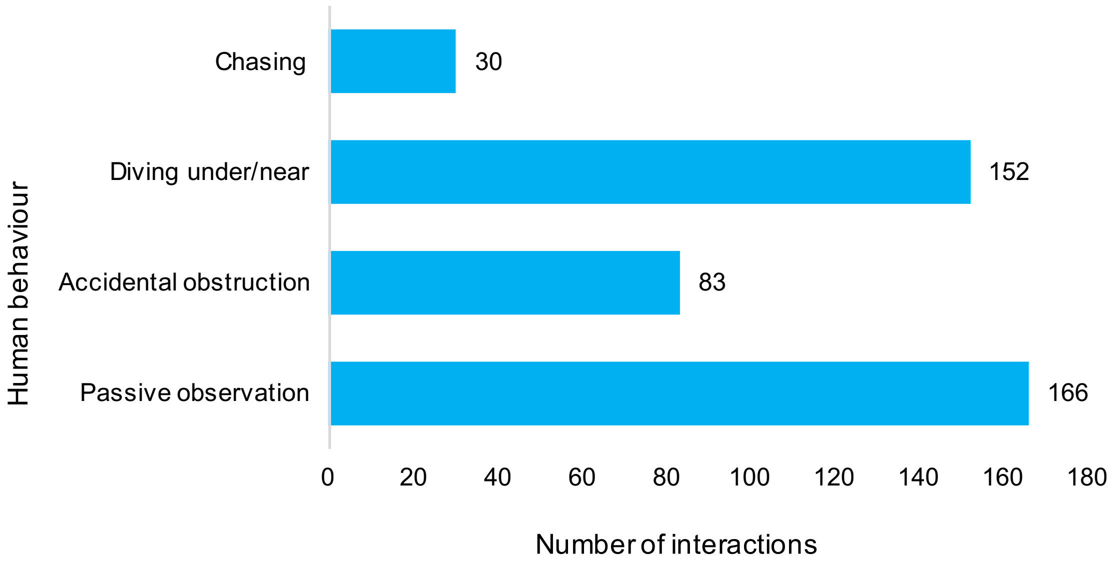

Figure 6: Number of times each human behaviour was observed

Mantas did not respond to human behaviour in 63.6% of observed interactions. Minor course redirection and major course redirection responses were observed in 16.7% and 17.6% of cases respectively. Flight responses were only observed in 2% of observed interactions (Fig. 7).

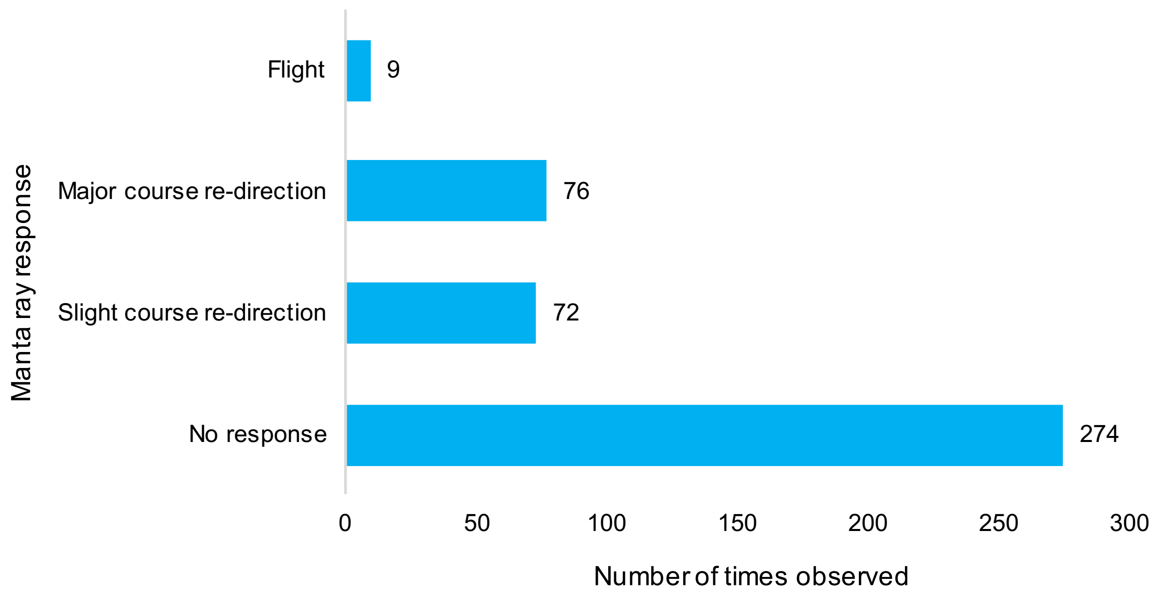

Figure 7: Number of times each manta response was observed

In terms of undisturbed manta behaviour, 364 mantas were observed to be solo feeding, 61 were recorded somersault feeding, one was recorded chain feeding and the remaining were observed cruising/travelling. Therefore, only five out of 431 mantas were observed not to be engaged in feeding behaviour. Manta rays were observed to stop their feeding behaviour in response to human behaviour in 6.73% of cases and, of these, 65% did not resume feeding after the interaction.

The first CLM showed that the type of human behaviour was the strongest predictor of manta response, followed by secondary direction of approach, and then distance between human and manta. Passive observations were found to be statistically significant with a negative trend which shows that mantas are less likely to display avoidance behaviour as a result of a passive interaction. Accidental obstructions were also found to be statistically significant with a positive trend so therefore significantly increase the likelihood of avoidance behaviour displayed by the manta (Fig. 8). Here

avoidance behaviour is defined as any manta response ranging from behaviours 2 – 4 as defined in Table 3.

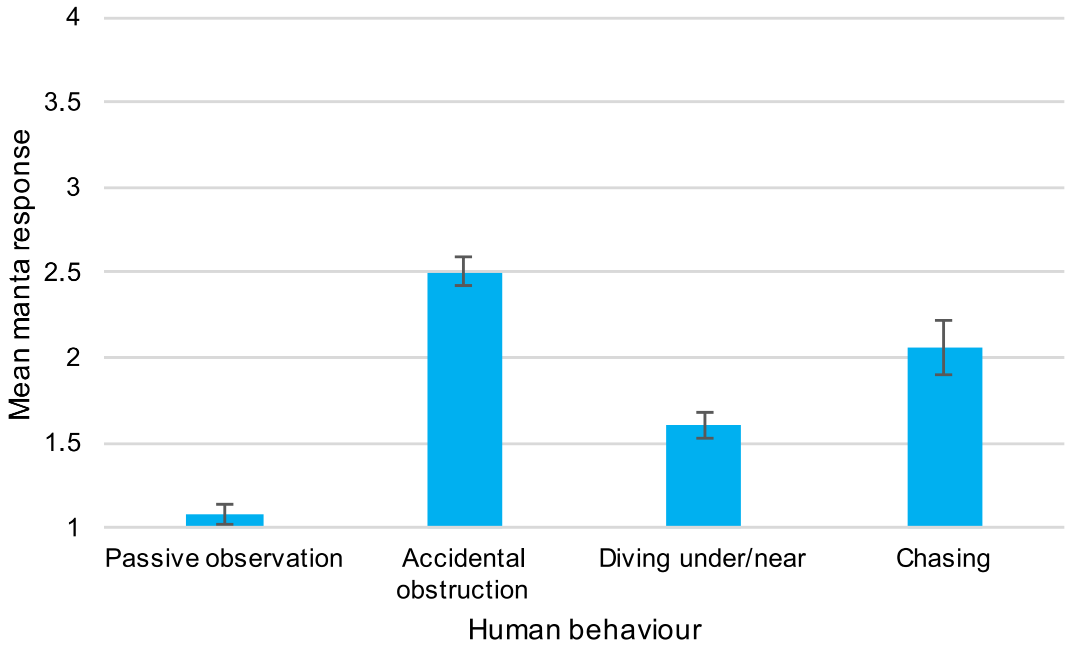

Figure 8: Mean manta response vs. human behaviour (n = 431). Error bars represent standard error (SE), the 95% confidence interval.

Tourists approaching from the front of the manta increased the likelihood of a severe response from the manta (Fig. 9), whereas approaching the manta from underneath rather than the surface decreased the likelihood of the manta displaying avoidance behaviour. Mantas recorded in both Veyofushi and Reethi Beach were found to react more strongly to human interactions. Distances of 0 – 1, 1 – 2, and 2 – 3 m between human and manta were found to elicit a more severe response from the manta. Distances of 3 – 4 and 4 – 5 m between human and manta were not found to be significant predictors of the mantas response (Fig. 10). See Table 5 for detailed results.

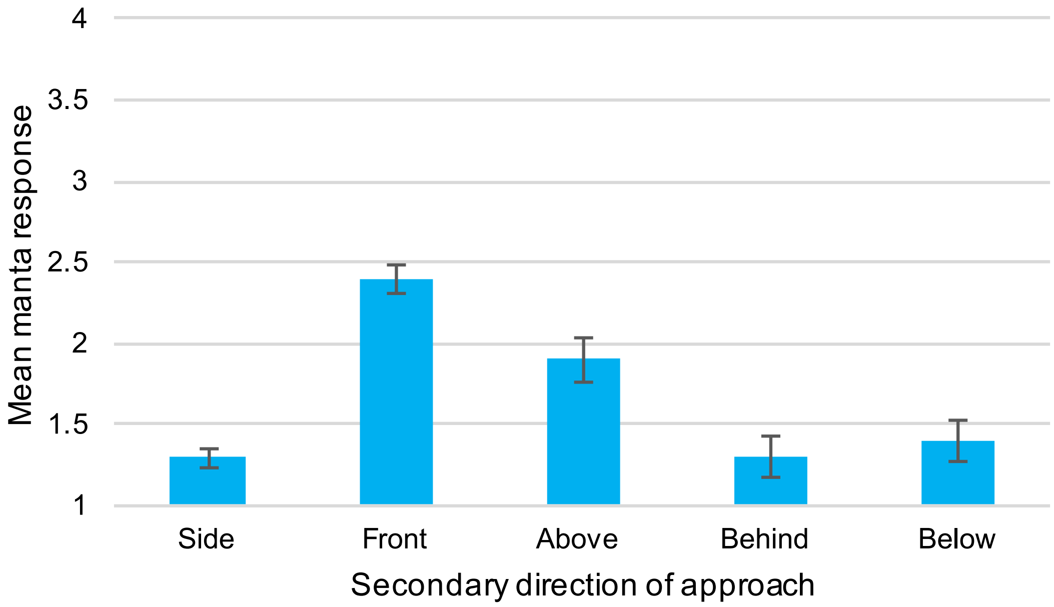

Figure 9: Mean manta response vs. secondary direction of human approach (*n* = 431). Error bars represent standard error (SE), the 95% confidence interval.

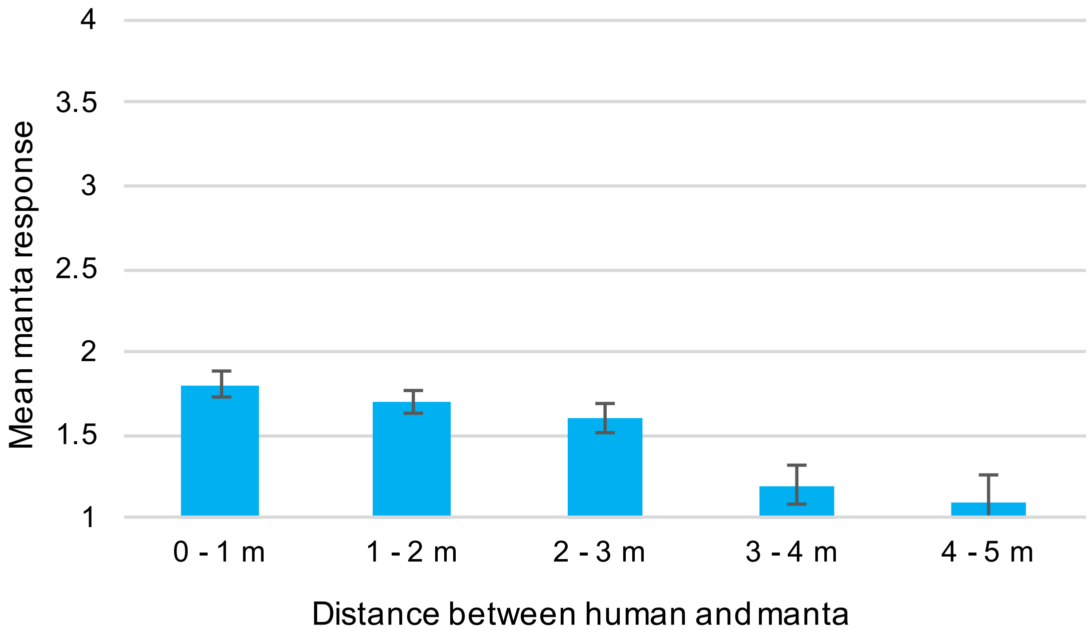

Figure 10: Mean manta response vs. distance between human and manta (*n* = 431). Error bars represent standard error (SE), the 95% confidence interval

Table 5
Cumulative Link Model of manta response versus 8 predictor variables. Statistics include the probability of deviation from a slope of zero (*p*), direction of the trend (positive +, negative –), confidence intervals to a 95% level. Bold type indicates significant variables (alpha = 0.0375). Where no *p* values appear, these variables were not included in the minimum adequate model after backwards forwards stepwise reduction. See methods for explanation of variables.

Model	Predictor variables tested	*p* value	Standard error	Confidence intervals 2.5%	97.5%
Response CLM	Humans	------------			
	Interaction:				
	Passive observation	**1.15e-14 –**	**0.4074**	**-3.996**	**-2.387**
	Accidental obstruction	**0.014153 +**	**1.2831**	**0.302**	**2.643**
	Diving under/near	------------			
	Chasing	------------			
	Distance:				
	0 – 1 m	**0.008438 +**	**0.8388**	**0.747**	**4.173**
	1 – 2 m	**0.009898 +**	**0.8399**	**0.704**	**4.132**
	2 – 3 m	**0.011476 +**	**0.8442**	**0.664**	**4.108**
	3 – 4 m	0.179838 +	0.8853	-0.394	3.214
	4 – 5 m	------------			
	Primary direction:				
	Surface	------------			
	Underneath	**0.009067 –**	**0.3162**	**-1.449**	**-0.206**
	Secondary direction:				
	Side	------------			
	Front	**8.15e-08 +**	**0.3404**	**1.162**	**2.5**
	Behind	0.069857 +	0.3812	0.529	2.028
	Above	0.057455 +	0.4969	-0.008	1.956
	Below	------------			
	Undisturbed manta behaviour:				
	Surface feeding	------------			
	Barrel roll feeding	0.139763 +	0.6691	-2.376	0.271
	Cruising	------------			
	Total humans	------------			
	Total mantas	------------			
	Location:				
	Hanifaru	------------			
	Andagiri	0.10607 +	1.3080	-1.057	4.542
	Veyofushi	**0.00160 +**	**0.5021**	**0.604**	**2.578**
	Reethi Beach	**0.00394 +**	**0.3654**	**0.335**	**1.771**
	Dhigu Thila	------------			

The second CLM results shows that location relates most strongly to whether the observed manta stopped its previously undisturbed behaviour in response to the human interaction, followed by primary direction of approach, then type of interaction and then finally distance between manta and tourist. The results show that mantas

recorded in Reethi Beach were more likely to stop their behaviour. Mantas are more likely to stop their behaviour following an accidental obstruction and when the distance between human and manta is 1 m or less. See Table 6 for detailed results.

Table 6
Cumulative Link Model of stopped behaviour versus 8 predictor variables. Statistics include the probability of deviation from a slope of zero (*p*), direction of the trend (positive +, negative –), confidence intervals to a 95% level. Bold type indicates significant variables (alpha = 0.0375). Where no *p* values appear, these variables were not included in the minimum adequate model after backwards forwards stepwise reduction. See methods for explanation of variables.

Model	Predictor variables tested	*p* value	Standard error	Confidence intervals 2.5%	97.5%
Stopped feeding CLM	Humans	------------			
	Interaction:				
	Passive observation				
	Accidental obstruction	**0.012876 +**	**0.5927**	**0.302**	**-2.644**
	Diving under/near	------------			
	Chasing	------------			
	Distance:				
	0 – 1 m	**0.023466 +**	**0.4217**	**0.129**	**1.792**
	1 – 2 m	------------			
	2 – 3 m	------------			
	3 – 4 m	------------			
	4 – 5 m	------------			
	Primary direction:				
	Surface	------------			
	Underneath	**0.009067 –**	**0.5609**	**-2.562**	**-0.344**
	Secondary direction:				
	Side	------------			
	Front	------------			
	Behind	------------			
	Above	------------			
	Below	------------			
	Undisturbed manta behaviour:				
	Surface feeding	------------			
	Barrel roll feeding	------------			
	Cruising	------------			
	Total humans	------------			
	Total mantas	------------			
	Location:				
	Hanifaru	------------			
	Andagiri	------------			
	Veyofushi	------------			
	Reethi Beach	**0.000507 +**	0.5907	**0.918**	**3.251**
	Dhigu Thila	------------			

The third CLM results show that if a tourist dives under/near a manta from the front, it significantly increases the probability of the manta displaying avoidance behaviour (p = 1.54e-05, SE = 0.308). The remaining secondary directions of approach were not found to be statistically significant in relation to the individual human behaviours (Figure 11).

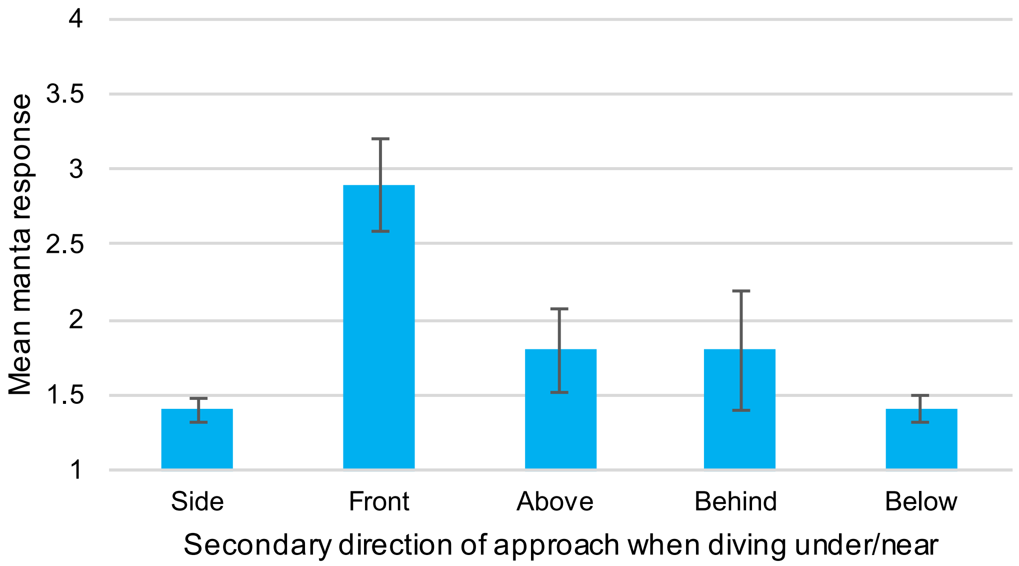

Figure 11: Mean manta response vs. secondary direction of human approach when diving under/near manta (n = 152). Error bars represent standard error (SE), the 95% confidence interval.

The fourth CLM results found that when tourists dive under or near mantas at distances of 0 – 3 m this significantly increases the likelihood of avoidance behaviour from the manta (0 – 1 m: p = 0.00698, SE = 0.745, 1 – 2 m: p = 0.0459, SE = 0.354, 2 – 3 m: p = 0.0259, SE = 0.582). The distances of 3 – 4 m and 4 – 5 m were not found to be statistically significant in predicting manta response in relation to individual human behaviours.

Discussion and Conclusion

Manta ray and other marine megafauna tourism needs to be conducted in such a way to ensure limited negative impact on the focal animal (Curtin, 2011). It needs to operate and be managed sustainably while also meeting tourists' expectations (Sorice et al., 2003). This study shows that the majority of interactions between humans and mantas do not result in manta rays displaying avoidance behaviour, or in mantas stopping their feeding behaviour at feeding aggregation sites in Baa Atoll. The results are comparable to those found by Atkins (2011) and Lynam (2012) and show relative consistency in behaviour of both humans and mantas over these years. The main recommendation that can be drawn from this study is that tourists should observe manta rays passively, whilst lying horizontal and still in the water, without splashing, as this reduced the likelihood of avoidance behaviour from mantas. Accidental obstructions on the other hand, significantly increased the probability of mantas displaying avoidance behaviour, as did tourists being within a distance of 0 – 3 m from the focal manta, and approaching the manta from the front. In comparison, tourists positioned underneath the manta, rather than approaching them from the surface, significantly decreased the likelihood of mantas displaying avoidance behaviour. This can most likely be explained by mantas' field of vision; they will not be able to see a tourist that is positioned underneath and will therefore not react to their presence (Marshall and Bennett, 2010; Deakos et al., 2011).

Regarding accidental obstructions, 82 out of 83 occurred when human and manta were within 3 m of each, and 70 out of 83 occurred when tourists were positioned in front of the manta. This again highlights the importance of people not moving into the path of mantas and trying to maintain at least a 3 m distance between themselves and

the mantas. However, it is difficult to recommend a way in which to do this, as these disturbances were not intentional. Accidental obstructions are difficult for tourists to avoid as mantas will often swim repeatedly through patches of plankton, changing direction to remain close to the thickest patches, which can result in tourists then being in the path of the feeding manta ray with little time to take evasive action (pers. obs., 2016). Nevertheless, tourists could be made aware of this before entering the water, which may encourage them to remain 3 m away from, and stay to the side of, the mantas.

Analysis of the affect of direction of approach and distance between human and manta in relation to the separate human behaviours, found that diving under/near the manta from the front, and at a distance of 0 – 3 m between human and manta very strongly increased the probability of the manta reacting with avoidance behaviour. These results reinforce the importance of keeping a respectable distance between human and manta and the importance of not obstructing the path of feeding manta rays. From this it can be recommended that inexperienced snorkelers should refrain from diving under/near mantas completely. These tourists will be unable to hold their breath for a long time in comparison to experienced snorkelers or freedivers, and will therefore be more likely to make an uncontrolled ascent (Race and Orams, 2013; Barker, 2003). During this process they may be less likely to look around for approaching manta rays and therefore be more likely to surface close to or in front of a feeding manta ray, which will result in disturbance to the animal. Inexperienced snorkelers are also more likely to make splashes at the surface of the water when initiating a freedive, which could potentially disturb mantas (Lynam, 2012).

Mantas recorded at Reethi Beach and Veyofushi were found to react significantly more strongly to human behaviour. This could be due to more juveniles being recorded at both of these sites than the others. Reethi Beach and Veyofushi are shallow and sheltered sites so provide better protection from predators, making them favourable sites for juveniles (Murray, 2013). Juvenile mantas are smaller than adults and have had less time to become acclimatised to the presence of humans (Deakos et al., 2011; Murray, 2013; pers. comm., Froman, Project Leader of the Maldivian Manta Ray Project, the Manta Trust, 2016), which could contribute to them reacting more strongly, as the human presence may be experienced as a potential threat. For example, one juvenile individual was recorded at Reethi Beach reacting with a flight response to a passive observation from a tourist.

Although certain factors were found to be significant predictors of whether mantas stopped their feeding behaviour, very few recorded mantas were actually observed to stop feeding. This means that the mantas are, in general, not being disturbed to a level affecting their consumption of zooplankton. There is a theory discussed by researchers that manta rays are less prone to disturbance when they are engaged in activities critical to maintaining their health, however this needs further research in order to be proven (Lynam, 2012).

It was expected that the more tourists there were at a site, the greater the mantas would be disturbed. For example, Pierce et al. (2010) found that whale sharks reacted more strongly to human presence when multiple boat loads of people were in-water with the sharks, in comparison to single boat encounters. However, neither the number of people involved in the interaction or at the site were found to be significant predictors

of manta response. This could be explained by the possibility that mantas at Hanifaru Bay, where the largest number of people were recorded, the mantas have become habituated to human presence (Lück, 2008). However, further research needs to be conducted in order to ascertain whether this has taken place.

There is evidence from a number of studies that briefings given to tourists before they engage in ocean going activities can reduce potential negative impacts on the natural resource they are exploiting (Toyoshima and Nadaoka, 2015; Medio et al., 1997; Harriott, 2002). For example, Toyoshima and Nadaoka (2015) found that divers who received an environmental briefing before SCUBA diving were less likely to make damaging contact with the reef. Therefore, if tourists are given a briefing before interacting with manta rays, this could cause them to behave more responsibly in the water and therefore reduce the disturbance to the mantas. The Manta Trust uses its Code of Conduct to give briefings to tourists engaged in manta ray tourism at all resorts at which they are based (pers. obs., 2016; pers. comm., Froman, Project Leader of the Maldivian Manta Ray Project, the Manta Trust, 2016). However, it is currently unclear whether other resorts in the Maldives give satisfactory briefings to guests who visit the sites from this study (pers. comm., Froman Project Leader of the Maldivian Manta Ray Project, the Manta Trust, 2016; pers. comm., Murray, Research Officer of the Maldivian Manta Ray Project, the Manta Trust, 2016). It is therefore recommended that the Manta Trust start an initiative to train staff at resorts and dive operations around the Maldives that conduct swim-with manta excursions to give appropriate briefings to their guests using the Manta Trust Code of Conduct, in order to reduce potential disturbance to manta rays.

There were a number of limitations involved in this study that need to be considered. There was an uneven data spread within certain variables. Firstly, data collected at study sites were unevenly spread; 309 interactions were recorded at Hanifaru Bay, whereas six were recorded at Andagiri, 41 at Veyofushi, 65 at Reethi Beach and 10 at Dhigu Thila. Secondly, 30 cases of chasing were recorded out of 431 interactions. From my observations during data collection, chasing can be a very intrusive way of interacting with manta rays, so it was expected that this behaviour would increase the likelihood of mantas displaying avoidance behaviour. However, my results did not find chasing to be a statistically significant predictor. This could be due to the relatively small number of recorded instances. However, the small amount of observations could also indicate that the majority of tourists are well behaved when in-water with mantas.

Initially, a fifth category of human behaviour was classified for data collection entitled intentional obstruction. This was defined as a human intentionally moving into the path of, or intentionally touching, a manta. However, I did not record any of this behaviour so the category was removed from analysis. Although it would be expected from personal observations, and results from other studies analysing marine megafauna tourism interactions, that this behaviour would increase the likelihood of avoidance behaviour from the manta (Venables, 2013; Norman, 1999; Quiros, 2007; Waayers et al., 2006), this study is unable to assess whether this is the case.

Finally, this study only collected data from manta ray feeding aggregation sites where snorkelers are present, and so the results cannot take into account manta and human interactions at manta cleaning stations or interactions with SCUBA divers. It is recommended that a further study be conducted in order to analyse these factors.

In conclusion, the majority of human and manta interactions result in no response or behaviour change from reef manta rays in Baa Atoll, the Maldives. Very few mantas recorded in the study stopped their feeding behaviour due to an interaction with a tourist. However, as the number of tourists visiting the Maldives to swim with manta rays increases, as does the risk of disturbance to the animals (O'Neill et al., 2004). The precautionary principle should be used in the management of tourists at popular snorkel and dive sites where mantas are sighted, in order to limit any possible long term negative affects of tourism interactions (Heyman et al., 2010; Lusseau and Hingham, 2004; Fennell and Ebert, 2004). It should be mandatory for tourists to receive effective behavioural briefings before they enter the water with manta rays. The Manta Trust could initiate this by providing training to staff at resorts and tour operators in the Maldives that conduct swim-with manta ray excursions.

Recommendations that can be made from this study for responsible and sustainable manta ray tourism at feeding aggregation sites visited by snorkelers are: (1) observe mantas passively, remaining still in the water without splashing or touching the mantas, (2) a minimum distance of 3 m should be maintained between human and manta, (3) approach from the side of the focal manta ray, (4) inexperienced snorkelers should not dive under or near manta rays, (5) tourists should not dive in front of mantas, (6) at sites where juveniles are regularly sighted, be more cautious when approaching manta rays. All these recommendations should be included in briefings and all of these support and reinforce the Manta Trust Best Practice Code of Conduct for Tourism Interactions. Enforcement of this Code of Conduct is vital in order to reduce the level of disturbance to manta rays to ensure the continuing sustainability of swim-with manta tourism (Barker and Roberts, 2004). Swim-with ecotourism can be

a long term way in which to sustainably utilise the manta ray population of the Maldives while significantly benefitting the local economy, and providing a viable alternative to fishing.

References

Anderson, R., Adam, M. and Goes, J. (2011). From monsoons to mantas: seasonal distribution of *Manta alfredi* in the Maldives. *Fisheries Oceanography*, 20(2), pp.104-113.

Anderson, R., Adam, M., Kitchen-Wheeler, A. and Stevens, G. (2011b). Extent and Economic Value of Manta Ray Watching in Maldives. *Tourism in Marine Environments*, 7(1), pp.15-27.

Atkins, R. (2011). *Manta ray (Manta alfredi) tourism in Baa Atoll, Republic of Maldives: human interaction, behavioural impacts and management implications*. MSc Thesis for University of York. Unpublished data

AEC (Atoll Ecosystem Conservation Project). (2011). *Management Plan for Hanifaru Marine Protected Area Baa Atoll, Maldives*. [online] Male: Ministry of Environment, Energy and Water, B. Atoll, Maldives, pp.1-23. Available at: http://www.epa.gov.mv/images/stories/publications/Hanifaru%20Management%20Plan%20-%20English%20(July%2020-2011).pdf [Accessed 16 Sep. 2016].

Barker, N.H.L. (2003). *Economic and Socio-economic impacts of dive and snorkel tourism in St Lucia, West Indies.* Doctoral Thesis for University of York.

Brooks, K. (2010). *Investigating Tourism at Hanifaru Bay Marine Protected Area, Maldives*. MSc Thesis for University of York. Unpublished data

Brooks, K. and Stevens, G. (2010). *Developing Tourism at Hanifaru Bay Marine Protected Area (MPA)*. A short report for the Ministry of Environment, Maldives; EPA and AEC Project. Male: Maldivian Manta Ray Project, Manta Trust, pp.1-12.

Cagua, E., Collins, N., Hancock, J. and Rees, R. (2014). Whale shark economics: a valuation of wildlife tourism in South Ari Atoll, Maldives. *PeerJ*, 2, p.e515.

Cisneros-Montemayor, A. and Sumaila, U. (2010). A global estimate of benefits from ecosystem-based marine recreation: potential impacts and implications for management. *J Bioecon*, 12(3), pp.245-268.

Clua, E., Buray, N., Legendre, P., Mourier, J., & Planes, S. (2010). Behavioural response of sicklefin lemon sharks Negaprion acutidens to underwater feeding for ecotourism purposes. *Marine Ecology Progress Series*, *414*, 257-266.

Collins, N. (2013). Advocacy for Marine Management: Contributions to a Policy Advocacy Initiative in the Maldives. *Capstone Collection*. Paper 2608

Croll, D., Dewar, H., Dulvy, N., Fernando, D., Francis, M., Galván-Magaña, F., Hall, M., Heinrichs, S., Marshall, A., Mccauley, D., Newton, K., Notarbartolo-Di-Sciara, G., O'Malley, M., O'Sullivan, J., Poortvliet, M., Roman, M., Stevens, G., Tershy, B. and White, W. (2015). Vulnerabilities and fisheries impacts: the uncertain future of manta and devil rays. *Aquatic Conserv: Mar. Freshw. Ecosyst.*, 26(3), pp.562-575.

Curtin, S. (2011). Maldives, Manta Rays and Tourism: Controlling the 'Swim With' Phenomenon. *Marine Tourism in Less Developed Countries: Wednesday 2 March 2011.*, Centre for Tourism in Islands and Coastal Areas, University of Kent, Canterbury, UK.

Deakos, M., Baker, J. and Bejder, L. (2011). Characteristics of a manta ray Manta alfredi population off Maui, Hawaii, and implications for management. *Marine Ecology Progress Series*, 429, pp.245-260.

Dewar, H. (2002). Preliminary report: Manta harvest in Lamakera. *Report from the Pfleger Institute of Environmental Research and the Nature Conservancy*, 3.

Dormann, C.F., Elith, J., Bacher, S., Buchmann, C., Carl, G., Carré, G., Marquéz, J.R.G., Gruber, B., Lafourcade, B., Leitão, P.J. and Münkemüller, T. (2013). Collinearity: a review of methods to deal with it and a simulation study evaluating their performance. *Ecography*, *36*(1), pp.27-46.

Dulvy, N., Pardo, S., Simpfendorfer, C. and Carlson, J. (2014). Diagnosing the dangerous demography of manta rays using life history theory. *PeerJ*, 2, p.e400.

Fennell, D. and Ebert, K. (2004). Tourism and the Precautionary Principle. *Journal of Sustainable Tourism*, 12(6), pp.461-479.

Frohoff, T. G., & Packard, J. M. (1995). Human interactions with free-ranging and captive bottlenose dolphins. *Anthrozoos: A Multidisciplinary Journal of The Interactions of People & Animals*, *8*(1), 44-53.

Froman, N. (2016). *Project Manager of the Maldivian Manta Ray Project, the Manta Trust*. Personal Communication. niv@mantatrust.org

Harriott, VJ. 2002. Marine tourism impacts and their management on the Great Barrier Reef. CRC Reef Research Centre Technical Report No 46. CRC Reef Research Centre, Townsville.

Heyman, W., Carr, L. and Lobel, P. (2010). Diver ecotourism and disturbance to reef fish spawning aggregations: It is better to be disturbed than to be dead. *Marine Ecology Progress Series*, 419, pp.201-210

Jimenez, H., Bigot, L., Bourmaud, C., Chabanet, P., Gravier-Bonnet, N., Hamel, M., Payri, C., Mattio, L., Menou, J., Naeem, S., Rilwan, Y., Sattar, S., Scott, L., Shiham, A., Vigliola, L. and Andréfouët, S. (2012). Multi-taxa coral reef community structure in relation to habitats in the Baa Atoll Man and Biosphere UNESCO Reserve (Maldives), and implications for its conservation. *Journal of Sea Research*, 72, pp.77-86.

Kitchen-Wheeler, A. (2010). Visual identification of individual manta ray (Manta alfredi) in the Maldives Islands, Western Indian Ocean. *Marine Biology Research*, 6(4), pp.351-363.

Kitchen-Wheeler, A., Ari, C. and Edwards, A. (2011). Population estimates of Alfred mantas (Manta alfredi) in central Maldives atolls: North Male, Ari and Baa. *Environ Biol Fish*, 93(4), pp.557-575.

Lück, M. (2008). *The encyclopedia of tourism and recreation in marine environments*. Wallingford, UK: CABI.

Lusseau, D. and Higham, J. (2004). Managing the impacts of dolphin-based tourism through the definition of critical habitats: the case of bottlenose dolphins (Tursiops spp.) in Doubtful Sound, New Zealand. *Tourism Management*, 25(6), pp.657-667.

Lynam, B. (2012). *The impacts of tourism on a population of manta rays, Baa Atoll, Republic of Maldives.* MSc Thesis for University of York. Unpublished data

Manta Trust, (2014). *The Maldives announces all ray species now added to the Maldives Protected Species List*. [online] Available at: http://www.mantatrust.org/wp-content/uploads/2012/03/Maldives-Protection-for-all-Ray-Species-Manta-Trust-Maldivian-Manta-Ray-Project-Save-Our-Seas-Foundation-5th-June-2014.pdf [Accessed 17 Aug. 2016].

Manta Trust, (2016). *Maldives | Manta Trust*. [online] Mantatrust.org. Available at: http://www.mantatrust.org/in-the-field/maldives/ [Accessed 3 Aug. 2016].

Marshall, A. and Bennett, M. (2010). The frequency and effect of shark-inflicted bite injuries to the reef manta ray Manta alfredi. *African Journal of Marine Science*, 32(3), pp.573-580.

Marshall, A., Kashiwagi, T., Bennett, M., Deakos, M., Stevens, G., McGregor, F., Clark, T., Ishihara, H. and Sato, K. (2011). *Manta alfredi (Coastal Manta Ray, Inshore Manta Ray, Prince Alfred's Ray, Reef Manta Ray, Resident Manta Ray)*. [online] Iucnredlist.org. Available at: http://www.iucnredlist.org/details/195459/0 [Accessed 17 Aug. 2016].

Marshall, A.R., Willcock, S., Platts, P.J., Lovett, J.C., Balmford, A., Burgess, N.D., Latham, J.E., Munishi, P.K.T., Salter, R., Shirima, D.D. and Lewis, S.L. (2012). Measuring and modelling above-ground carbon and tree allometry along a tropical elevation gradient. *Biological Conservation*, *154*, pp.20-33.

Mau, R. (2008). Managing for Conservation and Recreation: The Ningaloo Whale Shark Experience. *Journal of Ecotourism*, 7(2&3), p.208.

Medio, D., Ormond, R. and Pearson, M. (1997). Effect of briefings on rates of damage to corals by scuba divers. *Biological Conservation*, 79(1), pp.91-95.

Müllner, A., Eduard Linsenmair, K., & Wikelski, M. (2004). Exposure to ecotourism reduces survival and affects stress response in hoatzin chicks (*Opisthocomus hoazin*). *Biological Conservation*, *118*(4), 549-558.

Murray, A. (2013). *A study of the social interactions of Manta Rays in the Baa Atoll, Maldives.* MSc Thesis for University of York. Unpublished data

Murray, A. (2016). *Research Office at the Maldivian Manta Ray Project, the Manta Trust*. Personal Communication. annie@mantatrust.org

Naish, A. (2016). Tourist arrivals reach 1.2m in 2015. *Maldives Independent*. [online] Available at: http://maldivesindependent.com/business/tourist-arrivals-reach-1-2m-in-2015-121424 [Accessed 16 Sep. 2016].

Norman, B.M. (1999) *Aspects of the biology and ecotourism industry of the whale shark Rhincodon typus in North-Western Australia.* Masters by Research thesis, Murdoch University

O'Malley, M., Lee-Brooks, K. and Medd, H. (2013). The Global Economic Impact of Manta Ray Watching Tourism. *PLoS ONE*, 8(5), p.e65051.

O'Malley, M., Townsend, K., Hilton, P., Heinrichs, S. and Stewart, J. (2016). Characterization of the trade in manta and devil ray gill plates in China and South-east Asia through trader surveys. *Aquatic Conserv: Mar. Freshw. Ecosyst.*.

O'Neill, F., Barnard, S. & Lee, D., 2004. Best practice and interpretation in tourist/wildlife encounters : A wild dolphin swim tour example. *Wildlife tourism research report series: no. 25*, pp.1-70

Pierce, S., Méndez-Jiménez, A., Collins, K., Rosero-Caicedo, M. and monadjem, A. (2010). Developing a Code of Conduct for whale shark interactions in Mozambique. *Aquatic Conserv: Mar. Freshw. Ecosyst.*, 20(7), pp.782-788.

Quiros, A. (2007). Tourist compliance to a Code of Conduct and the resulting effects on whale shark (*Rhincodon typus*) behavior in Donsol, Philippines. *Fisheries Research*, 84(1), pp.102-108.

Race, S. and Orams, M (2013). Marine tourism gone wild: Visitation to New Zealand's most popular marine reserve [online]. In: Fountain, J. (Editor); Moore, K (Editor).*CAUTHE 2013: Tourism and Global Change: On the Edge of Something Big*. Christchurch, N.Z.: Lincoln University, 2013: 663-675

Riley, M., Hale, M., Harman, A. and Rees, R. (2010). Analysis of whale shark Rhincodon typus aggregations near South Ari Atoll, Maldives Archipelago. *Aquat. Biol.*, 8, pp.145-150.

Rowat, D. and Engelhardt, U. (2007). Seychelles: A case study of community involvement in the development of whale shark ecotourism and its socio-economic impact. *Fisheries Research*, 84(1), pp.109-113.

Samuels, A., and Bejder, L. (1998). A pilot study of habitual interactions between humans and wild bottlenose dolphins near Panama City Beach, Florida. *A Report to the Marine Mammal Commission, Bethesda, Maryland, USA,* pp.13

Shankar, D., Vinaychandran, P.N. and Unnikrishnan, A.S, (2002) The monsoon

currents in the north Indian Ocean. *Prog. Oceanogr*. 52, pp.63–120.

Sorice, M., Shafer, C. and Scott, D. (2003). Managing Endangered Species within the Use/Preservation Paradox: Understanding and Defining Harassment of the West Indian Manatee (Trichechus manatus). *Coastal Management*, 31(4), pp.319-338.

Speed, C., Meekan, M., Rowat, D., Pierce, S., Marshall, A. and Bradshaw, C. (2008). Scarring patterns and relative mortality rates of Indian Ocean whale sharks. *Journal of Fish Biology*, 72(6), pp.1488-1503.

Stevens, G. (n.d.). *Primary ID area of reef manta ray*. [Photograph].

UNDP. (2014) *Maldives Human Development Report 2014*. The Ministry of Finance and Treasury and the United Nations Development Programme in the Maldives, 2014. Print. Bridging the Divide: Addressing Vulnerability, Reducing Inequality.

Venables, S. (2013). *Short-term behavioural responses of manta rays, Manta alfredi, to tourism interactions in Coral Bay, Western Australia*. Perth: Murdoch University.

Waayers, D., Newsome, D. and Lee, D. (2006). Research Note Observations of Non-Compliance Behaviour by Tourists to a Voluntary Code of Conduct: A Pilot Study of Turtle Tourism in the Exmouth Region, Western Australia. *Journal of Ecotourism*, 5(3), pp.211-222.

Whitcraft, S., O'Malley, M., & Hilton, P. (2014). The Continuing Threat to Manta and Mobula Rays: 2013-14 Market Surveys, Guangzhou, China.

World Bank. (2010). *Climate Change in the Maldives*. [online] Available at: http://www.worldbank.org/en/news/feature/2010/04/06/climate-change-in-the-maldives [Accessed 20 Apr. 2016].

Zuur, A.F., Ieno, E.N. and Elphick, C.S. (2010). A protocol for data exploration to avoid common statistical problems. *Methods in Ecology and Evolution*, *1*(1), pp.3-14.

Appendices

Appendix 1: Manta Trust Best Practice Code of Conduct for Tourism Interactions.