**Protecting the million-dollar mantas; creating an evidence-based code of conduct for manta ray tourism interactions**

Abstract

Tourist experiences with charismatic marine megafauna have become increasingly popular since the 1990's. Manta ray tourism is estimated to contribute US$ 140 million annually to the global economy. The multitudes of tourists interacting with manta rays potentially disturb the animals, yet few studies have examined interactions, and none have quantified the effect of human behaviour on feeding manta rays. Using videos collected at feeding sites in the Maldives, we found that of the 401 independent interactions observed, only 44% complied with existing guidelines for snorkellers during tourism encounters. Human behaviours; accidental obstruction, diving too near/in front, chasing, and approaching from the front, all had a statistically significant negative effect on manta ray behaviour, resulting in feeding cessation. A reduction in foraging will be detrimental due to the transient nature of the manta rays’ zooplankton prey. Interactions within three metres resulted in significantly increased avoidance behaviours. These findings provide a clear evidence-base for the development of a binding code of conduct, with a view to developing legislation in the Maldives and beyond to minimise disturbance of manta rays by tourism. Our key recommendations aim to ensure that the manta ray tourism industry remains sustainable and non-detrimental to the animals’ natural behaviour.

< Link to <https://swimwithmantas.org/> for video abstract >

Keywords: Conservation, Maldives, *Mobula alfredi*, Sustainable tourism, Wildlife tourism.

**Introduction**

Over the last two decades, tourism focused on charismatic marine megafauna; such as whales, turtles, sharks and manta rays has become increasingly popular (O’Malley et al., 2013; Gallagher & Hammerschlag, 2011; Cisneros-Montemayor & Sumaila, 2010; Higham & Luck, 2007; Hoyt, 2001). Globally, the number of marine mammal tourists more than doubled between 1991 and 1998, rising from over four million to nine million participants, with a 12.1% average increase in whale watching figures in the 1990’s (Hoyt, 2001). This figure continued to surge by a further 11.3% between 1998 and 2006, demonstrating ever increasing popularity (Hoyt & Iñíguez, 2008).

While increased tourism and its network of support resources can generate significant economic benefits (O’Malley *et al.,* 2013; Vianna *et al.,* 2012), concerns exist regarding potential negative impacts on the focal species (Anderson *et al.,* 2011; Graham, 2007; Quiros, 2007; Marshall *et al.,* 2011; Kessel et al., 2017). Human impact on marine wildlife can be both direct, such as causing a change to, or stopping, the animal’s natural behaviour, and indirect, by affecting the animal’s fitness by disturbing feeding or cleaning long-term (Quiros, 2007; Sorice *et al.,* 2003). Destructive impacts, including habitat damage and loss (Tisdell & Wilson, 2002), disruption of animals’ natural behaviour (Williams *et al.*, 2002) and human-induced injuries, including boat strikes (Denkinger *et al.,* 2013; Speed et al. 2008), are becoming more common. Such practices do not reflect a safe or sustainable industry, an image commonly used as a selling point by operators advertising an eco-friendlier experience to attract potential consumers. Ecotourism is defined as ‘non-consumptive travel with minimal negative impacts that result in increased conservation and sustainability of natural and sociocultural resources and contributes to the well-being of local people’ (Sirakaya *et al.,* 1999, p. 171).

Manta rays (*Mobula alfredi, M. birostris*) are slow-growing, large-bodied animals that have among the lowest fecundity of all elasmobranchs, i.e. reproduce infrequently (Dulvy *et al.,* 2014a; Stevens, 2016). Their low rate of reproduction, late maturity, and small size of sub-populations makes these species particularly vulnerable to overexploitation in fisheries and extremely slow to recover from depletion (Dulvy *et al.,* 2014b). Manta ray species are listed on Appendix II of the Convention on International Trade in Endangered Species, Appendices I and II of the Convention on the Conservation of Migratory Species of Wild Animals, and classified as “Vulnerable” on the IUCN’s Red list of Threatened Species (Lawson *et al.,* 2017; Marshall *et al.*, 2011). Regional protection for manta rays has been implemented in certain areas. In 2014, Indonesia announced a ban on fishing manta rays, essentially creating the world’s largest manta ray sanctuary (Ministry of Maritime Affairs and Fisheries, 2014). That same year the Maldives included all ray species on its nationwide protected species list, banning the capture, keeping or harming of all ray species (EPA, 2014). The most prominent threats to manta rays globally are directed and by-catch fisheries (Croll et al. 2016; Lawson *et al.,* 2017), primarily driven by increased demand for their gill plates, which are marketed as a pseudo-medicinal health tonic in southeast Asia (O’Malley *et al.,* 2017; Whitcraft *et al.,* 2014).

Manta ray tourism is estimated to contribute US$ 140 million annually to the global economy (O’Malley et al. 2013), but interactions may have a negative effect by disturbing the species’ natural behaviour and degrading their habitat (Venables 2013; Anderson *et al.,* 2011), while potentially reducing fitness, disrupting reproduction and foraging (Colman, 1997; Sorice *et al.,* 2003). Increased human presence has the potential to also induce animal stress (Müllner *et al.,* 2004) and increase the rate of injuries due to higher boat traffic (Cárdenas-Torres *et al.,* 2007; Stevens *et al.,* 2018b). Norman (2005, p. 242-245) noted a reduction in return rate of whale sharks (*Rhincodon typus*) due to tourist stress and aggravation, with Quiros (2007) observing whale sharks’ rapid diving movements and avoidance reactions in response to tourist presence. Constantine (2001) also recorded increased avoidance behaviour by bottlenose dolphins (*Tursiops truncatus*) in the Bay of Islands, New Zealand, in response to increased tourism and swim-with excursions. Giese (1998) examined the impact of tourists approaching Adélie penguins (*Pygoscelis adeliae*) in Antarctica. Approaches of five metres resulted in elevated heart rates and the cessation of incubation behaviour, with such a period of cooling risking chick survival and hatching success. In comparison, approaches of 30 metres had no effect on either incubation behaviour or recorded heart rates of penguins (Giese, 1998). Such stressors highlight the need to monitor and regulate tourism involving wildlife.

Like many other marine fish and mammals, manta rays adopt group feeding strategies in order to increase feeding efficiency (Stevens, 2016). These large aggregations of feeding manta rays also attract a large number of tourists. Anderson *et al.* (2011) indicates that manta rays can be interrupted at feeding aggregations by divers and snorkellers, as humans may block the manta rays’ natural feeding routes, startle the manta ray(s) by approaching from behind, or even cause them to stop feeding. Given that aggregations of manta rays are attracted to ephemeral upwellings of zooplankton which disappear with the changing tidal currents, any interruptions to feeding are predicted to decrease food intake. Manta rays are also commonly observed when they visit areas of the reef hosting client fish (commonly various species of wrasse), known as ‘cleaning stations’, to socialise, have ectoparasites, dead or injured skin or mucus removed from their bodies (O’Shea *et al.,* 2010). Humans can also disturb manta ray activities at cleaning stations by approaching the rays too closely, causing the manta rays to leave, and often damaging the fragile coral ecosystem around the cleaning station through poor buoyancy control (Tratalos & Austin, 2001). Cleaning stations are important aggregation sites for this species (Stevens *et al.,* 2018a) and therefore negative impacts on them by humans should be kept to a minimum.

The use of specific guidelines for tourism interactions reduces the negative effect humans have on animals (Brunnschweiler, 2010; Mau, 2008; Pierce *et al.,* 2010), and together with interpretative and educational briefings, can improve tourist’s experience satisfaction (Zeppel & Muloin, 2008; Quiros, 2007). Snorkelling tours in the Ningaloo Marine Park, Australia, set recommended guidelines, limiting boat speed to five knots when within 30 metres, and eight knots when within 100 metres, of manta rays ([www.mantaraycoralbay.com.au](http://www.mantaraycoralbay.com.au)). Snorkellers are advised to form a semi-circle two metres behind manta rays, with spotters positioned behind the group ([www.mantaraycoralbay.com.au](http://www.mantaraycoralbay.com.au)). In Queensland, Australia, divers are advised to maintain their distance, remain calm and still, and allow the manta to control the interaction (Project Manta, 2012). In some areas of the Maldives a code of conduct developed by the Manta Trust is in practice; the in-water recommendations differ to Ningaloo recommendations. The approach buffer zone is set at three metres, and positioning snorkellers to the side of manta rays to remain in their eye line ([www.mantatrust.org](http://www.mantatrust.org)). 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 feeding manta rays.

Situated in the Indian Ocean, the Republic of Maldives is widely recognised as a hotspot for marine wildlife interactions, hosting a high abundance of marine megafauna (Cagua *et al.,* 2014). The direct expenditure on whale shark tourism in the Maldives, for example, increased from US$ 2.3 million per annum in 1993 (Anderson and Ahmed, 1993) to US$ 9.4 million per annum in 2013 (Cagua *et al.,* 2014). 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), it was valued at US$ 15.4 million in 2013 (O’Malley *et al*., 2013). Tourism in the Maldives has grown substantially over the last decade, with over 1.2 million visitors in 2016 alone, with a 28% rise in resort, dive liveaboard and guest house occupancy since 2010 (Ministry of Tourism, 2016). With the increase in tourism over the last decade, the Maldives faces increased pressure on its natural resources, including important *M. alfredi* cleaning and feeding sites (such as Hanifaru Bay in Baa Atoll) which are regularly frequented by this species. Increased manta tourism in Baa Atoll over the last decade is evident by more tour operators providing swim-with encounters each year, and by over 25,000 manta tourists recorded at sites in eastern Baa Atoll during MMRP surveys from 2010-2016 (MMRP, unpublished data).To avoid the risk of damaging this major source of tourist income, manta ray activities need to be monitored across all cleaning and feeding aggregation sites nationwide, rather than through isolated management programmes, such as at Hanifaru Bay. Hanifaru Bay marine protected area (MPA) is regulated by the Maldives Environmental Protection Agency and the Baa Atoll Biosphere Reserve. It became globally famous in 2009 due to media exposure showcasing the feeding aggregations of *M. alfredi* and whale sharks that visit the bay. Regulations now prohibit scuba diving within the Bay, with a limit of 80 snorkellers and five boats at one time (<http://en.epa.gov.mv/regulations>), and a required entrance fee ([www.broffice.gov.mv](http://www.broffice.gov.mv)).

Developed from pilot studies, the Maldives code of conduct will be the basis of this study, testing the specific recommendations; of maintaining a minimum three-metre distance from animals, remaining calm and still throughout interactions, and only approaching animals from the side, specifically avoiding positioning directly behind or in front of manta rays, i.e. in their blind spot. These guidelines were developed in the Maldives following six years of in-water observations, including a three-year pilot study examining manta behaviour during snorkel trips with tourists (see Supplementary Material). To mitigate negative anthropogenic impacts on manta rays, researchers joined resort excursions, providing a pre-encounter briefing specifying the above recommendations - which until now have not been rigorously tested. Purely advisory, these guidelines advise tour operators on the appropriate human behaviours to ensure sustainable human-manta encounters. This study rigorously tests the effect of these guidelines, with the view to providing scientific support for these recommendations which will drive increased protective legislation at manta ray aggregation sites globally. This study aims to link specific human behaviours with the resulting reactions by the manta rays, specifically (1) types of human behaviours during interactions, (2) closest observed distances between manta rays and humans, and (3) direction of human approaches towards animals. Finally, we test inter-site differences in tourist numbers.

**Methods**

***Study Site***

The 26 geographical atolls that compose the Maldives Archipelago are distributed across 870 kilometres (540 miles) from 7° north to half a degree south of the equator in the Indian Ocean. The Maldives territorial waters encompass 90,000 km² of ocean, while the land area is only 300 km², with the highest natural point above sea level recorded at 2.4 metres. The Maldives hosts the world’s largest population of reef manta rays (*M. alfredi*) with over 4,250 identified individuals (Manta Trust, 2014; Stevens, 2016).

This study was conducted in Baa Atoll, northwest of the archipelago’s capital island of Malé. During the south-west monsoon (May through November), monsoonal currents and lunar tides produce a back-eddy concentrating the manta’s zooplankton prey into the body of the bay, attracting the filter feeding megafauna in large numbers (Stevens, 2016), which in turn attract the majority of the tourist excursions.

***Data Collection***

Over a three-year period (2010-2012), a pilot study was conducted by the Manta Trust’s Maldivian Manta Ray Project (MMRP), testing various human approaches and behaviours to examine the resulting response from manta rays, in order to develop the code of conduct for manta ray tourism, published in 2017. The data collection methods used in the pilot study (Supplementary Materials 2-4) were used to establish and implement a protocol for data collection; including human and manta ray test variables and data analysis procedures (Brooks, 2010; Atkins, 2011; Lynam, 2012). Study data were collected across 47 survey days in July and August 2016 as part of the MMRP daily surveys. Data were collected from feeding aggregation sites within Baa Atoll regularly visited by the MMRP research vessel and tourists, including Hanifaru Bay, Reethi Falhu, Veyofushi Falhu, Dhigu Thila, and Andagiri.

To test the code of conduct, interactions between tourists and feeding manta rays were recorded using an SJCAM SJ4000 camera. At each site, a number of variables were collected: current strength, the density of zooplankton, the number of tourist boats, and the total number of people in the water during the observation period (including the researcher). To avoid pseudo-replication, footage was only used if the manta was clearly identifiable. Individuals are identified by examining the unique spot-pattern on the ventral surface; matching this pattern with catalogued photographs in the regional branchial database allows for individual identification and sexing (Marshall & Pierce, 2012).

***Video Analysis***

All video footage was analysed by the primary researcher and was assessed to identify the reactions of manta rays in response to tourist behaviour. Prior to data analyses, a test was created to ensure that researchers could accurately estimate distances between humans and manta rays in video footage. A buoyant yellow life jacket was attached to a rope which was held at one end by a research assistant. 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. The researcher was tested on distance estimation every day until consistently scoring more than 90%. Once this was achieved, testing was conducted three times a week during the two months of data collection to ensure accurate readings when analysing distances in video footage.

During the training period, two researchers reviewed each video until both consistently scored videos the same. The remaining video clips were reviewed multiple times by the same researcher to ensure an accurate analysis of the manta behaviour and to ensure uniformity. Following pilot study observations and initial results, the following test criteria were chosen: an interaction was defined as when a tourist and manta came within ≤5 metres of each other. Distance (<1 m, 1-2 m, 2–3 m, 3–4 m, 4–5 m) was estimated to the closest metre (using a maximum distance of 5 m to define an interaction) (Brooks, 2010; Atkin, 2011 & Lynam, 2012). The categories of human behaviour, avoidance and cessation behaviours are further explained in Tables 1, 2 and 3 respectively.

Table 1. Definitions for human behaviour observed during interactions

|  |  |
| --- | --- |
| **Human behaviour** | **Definition** |
| **Passive observation** | *Humans remain still and flat in the water* |
| **Accidental obstruction** | *Human accidentally obstructs the path of the manta ray or accidentally touches the manta ray* |
| **Diving too near/in front** | *Human dives too close or directly in front of the manta ray* |
| **Chasing** | *Human actively chases the manta ray, swimming fast and splashing* |

Table 2. Definitions for manta ray reaction behaviours observed during interactions.

|  |  |  |
| --- | --- | --- |
| **Manta ray reaction** | **Definition** | **No. observations** |
| **No response** | *Individual continues with current behaviour* | 255 |
| **Slight reaction** | *Minor direction changes to move away from obstruction* | 68 |
| **Direction change** | *Distinct direction changes to avoid obstruction* | 69 |
| **Avoidance** | *Complete alteration of behaviour to avoid obstruction* | 9 |

Table 3. Definition for manta ray cessation behaviour observed during interactions.

|  |  |  |
| --- | --- | --- |
| **Cessation reaction** | **Definition** | **No. observations** |
| **Yes** | *Manta ray stopped their original behaviour due to human interaction* | 360 |
| **No** | *Manta ray continued their original behaviour despite human interaction* | 27 |

*Statistical Analysis*

A Cumulative Link Mixed Model (CLMM) was used on the ordinal data to examine the effect of predictor variables on the manta response variable using individual manta-ID as the random effect. A CLMM with a flexible threshold was used to test whether the variables (Human Behaviour, Distance, Position of Human, Direction of Human Approach, Site, Sex and Undisturbed Behaviour) were statistically significant predictors of ‘Manta Response’. Variables which were not statistically significant in the initial model were tested individually; if they proved non-statistically significant, they were not controlled for in future models. As such, the variables ‘Sex’ and ‘Undisturbed Behaviour’ were dropped. As interactions were recorded at a feeding site, a second CLMM was used to test whether the remaining five variables were statistically significant predictors of ‘Cessation of Feeding’ across observations (Table 3). The sample size was 387 as 14 records of cessation could not be confirmed. Non-statistically significant variables were removed from the model using stepwise regression; the final model included ‘Human Behaviour’ and ‘Direction of Approach’. The same procedure was followed as described above. The total number of people recorded at each site per day was calculated and a Kruskal-Wallis test used to test for statistical differences in tourist visitation per site, per day.

**Results**

A total of 401 independent human-manta interactions were recorded during July and August of the 2016 south-west monsoon in eastern Baa Atoll. Videos were collected six days a week, at five sites across the data collection period. Passive interactions (n = 158) were the most common human behaviour recorded, while the most intrusive of human behaviours, chasing (n = 20), was the least recorded. Across the 401 interactions, tourists, who should be briefed on in-water conduct prior to interactions were observed within one metre or closer to the animals during 30.1% of observations, and were recorded observing the recommended three metres or more rule during 44.1% of interactions.

The ‘Human Behaviour’ variable had the strongest influence on manta response, with accidental obstruction, diving too near/in front, and chasing statistically significant in higher levels of response (see statistical outputs in Table 4a, Figure 1a-d). Estimated distances of 3 - 4 m and 4 - 5 m elicited significantly greater responses, but with a negative trend, meaning that manta rays were less likely to display higher levels of response (i.e. avoidance or flight) in such interactions (Figure 1e). Human approaches from underwater were significantly less likely to cause a response in manta rays compared to surface approaches (see in Table 4c). The variable ‘Direction of Human Approach’ was also statistically significant, with approaches from the front resulting in higher levels of manta response (see in Table 4d, Figure 1f). ‘Site’ proved an important influence on manta behaviour, with animals at Veyofushi Falhu exhibiting a statistically significant difference in disturbance behaviour than manta rays at Hanifaru Bay (see in Table 3e).

In relation to cessation of feeding, ‘Human Behaviour’ had the most influence on manta behaviour: accidental obstruction, diving too near/in front and chasing were statistically significant, with positive associations showing that they resulted in higher levels of response (see in Table 5a, Figure 2a). Although not statistically significant, compared with human approaches from the side (i.e. within their eye-line), manta rays were more likely to stop feeding when approached from the front (see in Table 5b, Figure 2b).

Table 4. Cumulative Link Mixed Model of Avoidance Behaviours versus five 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. (*n* = 401). \*\* Denotes a *p*-value of <0.01.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| ***Model*** | ***Predictor variables*** | ***Logistic coefficient*** | ***p-value*** | ***Standard error*** | **95% CI** | |
| *a)* | *Human behaviour* |  |  |  |  |  |
|  | Passive interaction |  |  |  |  |  |
|  | Accidental obstruction\*\* | 3.237 | 3.11e-10 | 0.5144 | 2.23 – 4.25 | |
|  | Diving too near\*\* | 3.255 | 4.09e-09 | 0.5536 | 2.17 – 4.34 | |
|  | Chasing\*\* | 3.816 | 3.38e-07 | 0.7481 | 2.35 – 5.28 | |
|  |  |  |  |  |  |  |
| *b)* | *Distance* |  |  |  |  |  |
|  | < 1 m |  |  |  |  |  |
|  | 1 - 2 m | - 0.053 | 0.868 | 0.3192 | -0.68 – 0.57 | |
|  | 2 - 3 m | - 0.173 | 0.658 | 0.3916 | -0.94 – 0.59 | |
|  | 3 - 4 m\*\* | - 1.516 | 0.00599 | 0.5517 | -2.60 - -0.43 | |
|  | 4 - 5 m\*\* | - 3.737 | 0.00291 | 1.2552 | -6.20 - -1.28 | |
|  |  |  |  |  |  |  |
| *c)* | *Position of human* |  |  |  |  |  |
|  | Surface |  |  |  |  |  |
|  | Under animal\*\* | - 1.349 | 0.00768 | 1.3492 | -2.34 - -0.36 | |
|  |  |  |  |  |  |  |
| *d)* | *Direction of human approach* |  |  |  |  |  |
|  | Side |  |  |  |  |  |
|  | Front\*\* | 1.956 | 4.34e-06 | 4.594 | 1.12 – 2.79 | |
|  | Behind | 0.741 | 0.198 | 1.287 | -0.39 – 1.87 | |
|  | Above | 1.002 | 0.056 | 1.910 | -0.06 – 2.03 | |
|  | Below | - 0.678 | 0.234 | -1.190 | -1.79 – 0.44 | |
|  |  |  |  |  |  |  |
| *e)* | *Site* |  |  |  |  |  |
|  | Hanifaru Bay |  |  |  |  |  |
|  | Andagiri | 2.550 | 0.074 | 1.787 | -0.25 – 5.35 | |
|  | Veyofushi Falhu | 1.246 | 0.03339 | 2.127 | 0.10 – 2.39 | |
|  | Reethi Falhu | 0.798 | 0.071 | 1.805 | -0.07 – 1.67 | |
|  | Dhigu Thila | - 0.758 | 0.516 | -0.649 | -3.04 – 1.53 | |

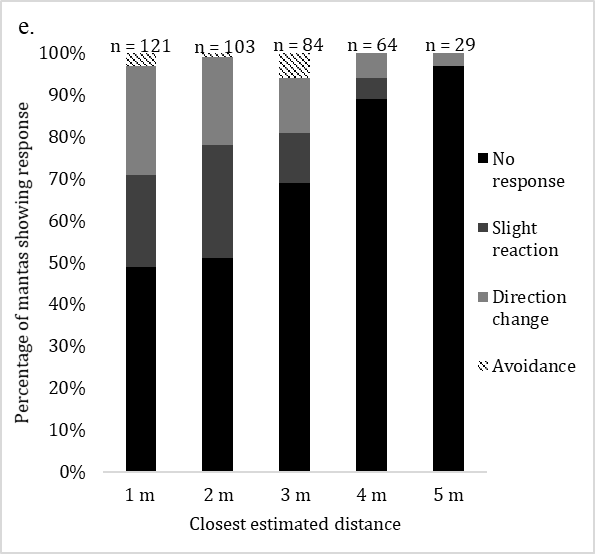
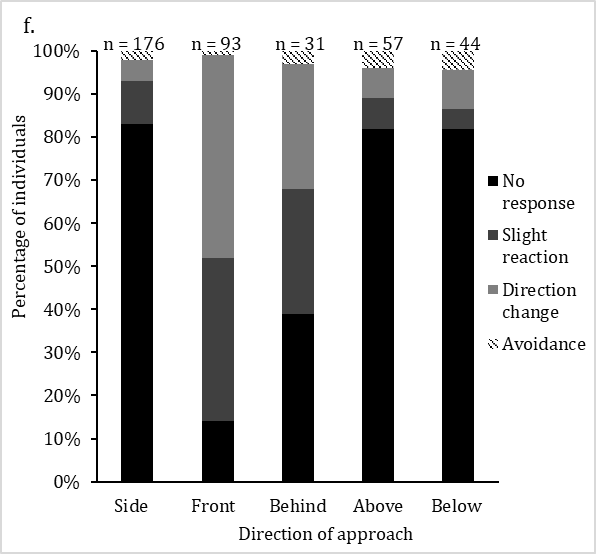
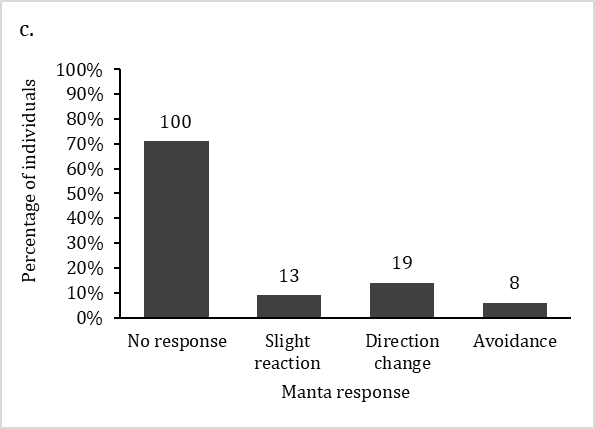
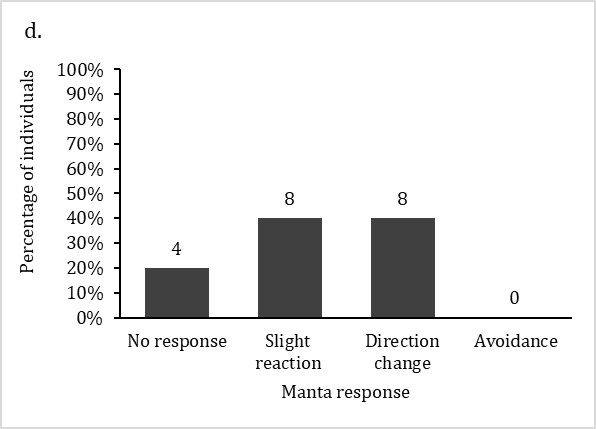
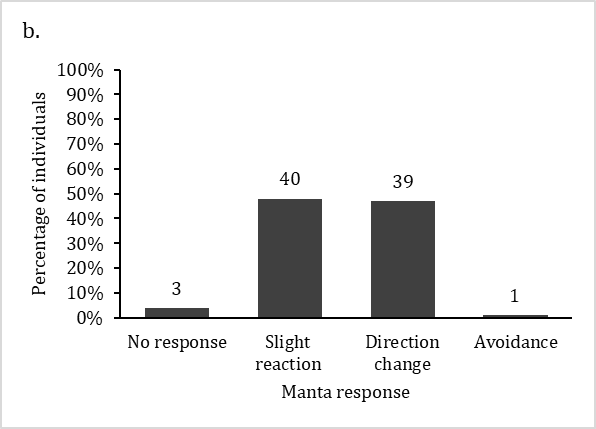
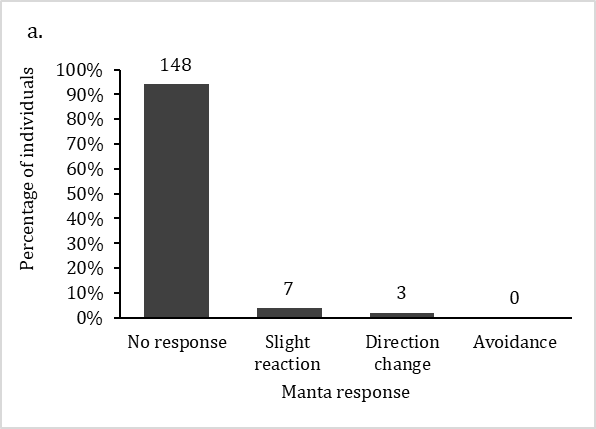


Figure 1. Comparison of reef manta ray (*Mobula alfredi*) responses to differing human behaviour: (a.) passive observation, (b.) accidental obstruction, (c.) diving too near, (d.) chasing, in response to estimated closest distance between human and manta ray (e.), and in response to direction of human approach (f). Numbers above bars represent sample size.

Table 5. Cumulative Link Mixed Model of Cessation of feeding versus two 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. (*n* = 387). \*\* Denotes a *p*-value of <0.01.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| ***Model*** | ***Predictor variables*** | ***Logistic coefficient*** | **p*-value*** | ***Standard error*** | ***95% CI*** | |
| *a)* | *Human behaviour* |  |  |  |  |  |
|  | Passive interaction |  |  |  |  |  |
|  | Accidental obstruction\*\* | 19.200 | 6.20e-06 | 4.249 | 10.87 – 41.26 | |
|  | Diving too near\*\* | 18.814 | 4.54e-05 | 4.614 | 9.77 - 27.86 | |
|  | Chasing\*\* | 21.304 | 3.87e-05 | 5.177 | 11.16 – 31.45 | |
|  |  |  |  |  |  |  |
| *b)* | *Direction of human approach* |  |  |  |  |  |
|  | Side |  |  |  |  |  |
|  | Front | 1.111 | 0.527 | 1.283 | -2.33 – 4.55 | |
|  | Behind | 2.830 | 0.185 | 1.062 | -1.36 – 7.02 | |
|  | Above\*\* | 18.900 | 2.84e-07 | 2.406 | 11.25 – 25.13 | |
|  | Below | -0.045 | 0.985 | 0.306 | -4.81 – 4.72 | |
|  |  |  |  |  |  |  |

Figure 2. Percentage of interactions which resulted in cessation of feeding (Stopped) or no change in feeding (No effect) in response to a. Human behaviour: (Passive Observation; Accidental Obstruction; Diving too near/in front; Chasing). b. Direction of human approach: (Side; Front; Behind; Above; Below). (n = 387). Numbers on bars represent sample size.

Tourist numbers differed significantly across the five sites (see Figure 3), with Hanifaru Bay recording a median number of 70 tourists per day, while Reethi Falhu averaged only four daily, Kruskal-Wallis; H = 200.87, *p* = <2.2e-16.

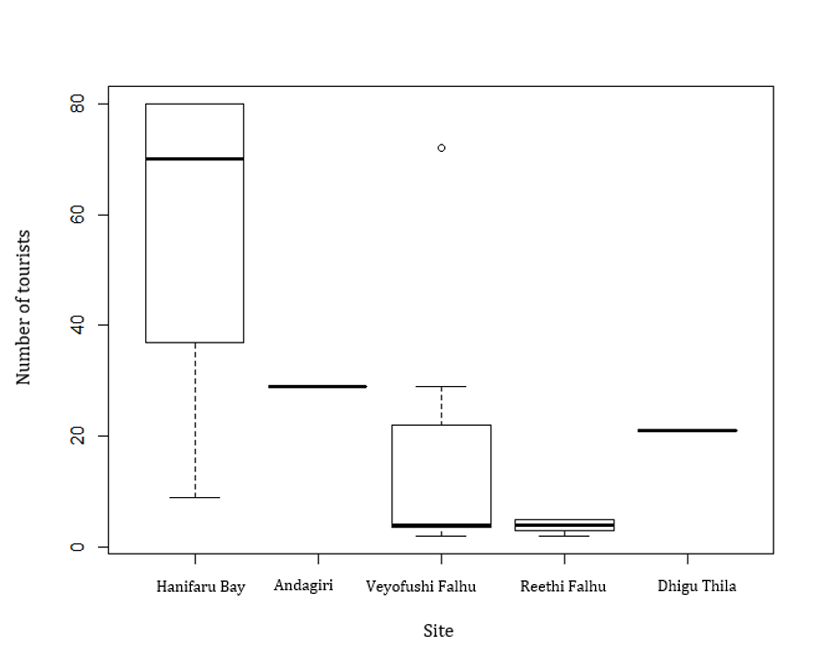


Figure 3. Total number of tourists per site per day. The boxplot shows the medians,

interquartile ranges (box), upper and lower quartiles (whiskers) and outliers (circles). Kruskal-Wallis test shows a significant difference between the number of humans per site,

H = 200.87, p = <2.2e-16. (*n* = 402).

**Discussion**

For wildlife tourism to be sustainable, it must be conducted according to the principles of ‘ecotourism’, in which interactions are intended to exert minimal negative impact on the focal animal (O’Malley *et al.,* 2013). However, increasing concern exists about the negative effect of tourism interactions on species, particularly when no clear management guidelines are in place (Anderson *et al.,* 2011; Graham, 2007; Quiros, 2007; Marshall et al 2011 (from Venables, 2013)). Our data suggests that certain human actions impact manta ray behaviour negatively during interactions. Distance between human and manta, human behaviour, and the position of snorkellers all significantly affected the manta ray’s response (Table 4), which reflects the Manta Trust’s code of conduct recommendations. Interactions at a distance of four or five metres resulted in significantly less avoidance behaviour by the manta rays, showing that allowing the animals more distance, decreases disturbance. During approaches within three metres, the likelihood of avoidance behaviour was 31% but reduced to just 3.4% for interactions between four to five metres. Approaches from the front were also significantly more likely to result in disturbance, which can be explained by the snorkeller blocking the direction of travel and presenting a barrier to the future movement of the manta ray. Approaches from above were also significantly more likely to cause cessation of feeding entirely. Manta rays are unable to see directly above and behind, while their downward, lateral and forward vision is good (Deakos, 2010). Therefore, they are more likely to feel threatened and react adversely to an unidentified object approaching from these directions, hence it is recommended to approach from the side to avoid startling the animal.

Accidental obstructions, diving too near/in front and chasing encounters all proved significantly disturbing, causing more cessation of feeding during interactions than passive interactions. Manta ray reactions to the presence of humans were recorded to be higher at sites exploited less by tourism activities compared with sites with more tourists (e.g. Hanifaru Bay), possibly due to lower tourist numbers and non-habituated manta rays, although this variable needs further study.

During our study, snorkellers (who are recommended to be briefed on conduct prior to in-water interactions) passively observed the focal manta rays in only 158 of the 401 interactions (39.4%), with the majority of all tourism interactions therefore showing second-rate compliance to the recommended distance for in-water conduct. Accidental obstructions were observed on 83 interactions (20.7%), for instance by touching or blocking the pathway of the manta ray’s travel, but troublingly, during 140 encounters (34.9%), snorkellers were observed deliberately diving near manta rays, while attempting to film or photograph themselves with the animals (#MantaSelfie).

An avoidance response by the manta ray was observed on 36.7% of observations, including behaviour such as slight reaction, direction change or avoidance. A similar result was found from a study in Ningaloo Reef, Western Australia, where feeding *M. alfredi* displayed a behavioural response to snorkellers classified as disturbance in 34.1% of tourism interactions (Venables, 2013). Venables (2013) also found that surface splashing by snorkellers significantly increased the likelihood of manta ray behavioural responses. As demonstrated in this study, passive, quiet observations appear to minimise avoidance responses by manta rays.

A further concern during in-water interactions is that human presence stops an animal’s natural behaviour. Human behaviour was a statistically significant factor in the change of manta ray behaviour, with accidental obstructions, diving too near/in front and chasing all proving statistically significant (Table 4). Race and Orams’ (2013) study in Goat Island Marine Reserve, New Zealand found that less experienced snorkellers were unable to hold their breath for long periods of time, a factor which could apply to the human behaviour recorded during this study. A lack of snorkeller experience would also explain the quick bolt action of free-divers back to the surface, with little awareness of the manta rays swimming above and around them, which was regularly observed in this study. Such erratic movement and the crossing and blocking of the manta ray’s path has the potential to interrupt their natural behaviour and potentially reduce feeding activity. Another consideration is the impact of human presence at specific sites. For example, the manta rays at Veyofushi Falhu demonstrated significantly increased avoidance reactions compared to other sites. One theory to explain this result is the variation in human visitation between sites and therefore the level of manta habituation to human presence. At Veyofushi Falhu there was a median number of four visitors per day, compared to 70 at Hanifaru Bay (Figure 3).

Regionalised action is being taken to encourage sustainable tourist practices, with Australia establishing government approved guidelines for interacting with manta rays (Ningaloo Marine Interactions, 2018). Swim-with manta ray interactions at Hanifaru Bay MPA are regulated by the Maldives Environmental Protection Agency and the Baa Atoll Biosphere Reserve, leading to many tour operators providing tourists with pre-encounter briefings. However, over half of observed interactions showed snorkellers breached these code of conduct recommendations, highlighting the importance of monitoring encounters and having in-water guides and enforcement personnel to regulate tourist behaviour. Penalties for tourist infractions are employed for whale shark interaction in Oslob, the Philippines, ranging from fines up to PHP 2,500 (USD 48.10), to imprisonment (Craven, 2012). Previous ecotourism studies have found there to be significant changes in diver behaviour following environmental briefings, with reduced physical contact and damage recorded (Toyoshima & Nadaoka, 2015; Medio *et al.,* 1997; Worachananant *et al.,* 2008; Camp & Fraser, 2012; Krieger & Chadwick, 2013). Even more effective was dive leader intervention, which reduce a non-compliant diver behaviour more successfully than briefings alone. For this to be effective, a smaller, more manageable group size is recommended, which is defined as ‘small enough so that dive/trip leaders can supervise all members of the group adequately’ (Barker and Roberts, 2004, p. 481-489).

Regulating tourism interactions and conducting pre-encounter briefings are key measures with the potential to minimise the effect of humans during tourism interactions (Brunnschweiler, 2010; Mau, 2008; Pierce et al 2010), and together with interpretive material can increase tourist satisfaction with the experience (Zeppel & Muloin, 2008; Quiros, 2007). All findings from our study support the recommendations provided by the Manta Trust’s Best Practice code of conduct for interacting with manta rays (see Supplementary Material, S. 1, [www.mantatrust.org](http://www.mantatrust.org) & [www.swimwithmantas.org](http://www.swimwithmantas.org) ).

Further research should investigate the effect of tourism interactions at manta ray cleaning stations as this research only considered feeding aggregations. The next step will be to extend this study to firstly, look at the long-term impacts from disturbance to feeding if it continues. Secondly, statistically test whether *M. alfredi* are more likely to show tourist avoidance behaviour when cleaning versus feeding. Thirdly, examine SCUBA interactions and diver behaviour with manta rays. Preliminary results from previous pilot studies have shown a similar pattern to our study, with SCUBA diver approaches made from the front, above, below and behind causing higher animal disturbance responses than approaches from the side, passive interactions and encounters over three metres (see Supplementary Material). Diver bubbles may also block easy access to cleaning stations, the presence of people may potentially shorten the time spent cleaning, and poor buoyancy control can damage the coral reef.

Our study rigorously tested the guidelines provided in the Manta Trust’s code of conduct, supporting the guidelines provided to tour operators for human-manta interactions. In conclusion, this study makes clear recommendations for in-water interactions with feeding manta rays; (1) maintain a distance of three metres or more when approaching manta rays, (2) remain passive throughout interactions avoiding splashing, touching or chasing animals, (3) if approaching animals, always approach from the side, within the manta ray’s field of vision, (4) only experienced snorkellers should attempt to free dive near manta rays, and (5) avoid diving directly in front of manta rays. These recommendations should be given to all tourists before taking part in any in-water interactions with manta rays. Tour guides should be vigilant about monitoring and enforcing these recommendations throughout the encounter. Creating nationwide government legislation and effective enforcement based on these recommendations in countries where manta ray tourism activities exist is the next step towards making in-water manta ray encounters a true ecotourism activity. Once achieved, these activities can become a safe and sustainable alternative to fishing these vulnerable species, with long-term financial gains for the local economy and tourism trade.

**Declaration of Interests**

The authors declare that they have no competing interests and that that this study is our original work and contains no material previously written or published. The content of this paper is the sole responsibility of the authors.

**References**

Anderson, R. C., & Ahmed, H. (1993). The shark fisheries of the Maldives. *FAO, Rome, and Ministry of Fisheries, Male, Maldives*.

Anderson, R. C., Adam, M. S., Kitchen-Wheeler, A. M., & Stevens, G. (2011). Extent and economic value of manta ray watching in Maldives. *Tourism in Marine Environments*, *7*(1), 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.

Baa Atoll UNESCO Biosphere Reserve Maldives, 2012. [Online] Available at: http://www.broffice.gov.mv/en/index.php/news-events/24-hanifaru-protection-and-preservation-regulation-2012-r-23-go-into-effect-from-26th-april-2012. [Accessed 13th September 2018]

Barker, N. H., & Roberts, C. M. (2004). Scuba diver behaviour and the management of diving impacts on coral reefs. *Biological Conservation*, *120*(4), 481-489.

Brooks, K., (2010). Investigating tourism in Hanifaru Bay marine protected area, Maldives. MSc Thesis for University of York. Unpublished data.

Brunnschweiler, J. M. (2010). The Shark Reef Marine Reserve: a marine tourism project in Fiji involving local communities. *Journal of Sustainable Tourism*, *18*(1), 29-42.

Cagua, E. F., Collins, N. M., Hancock, J., & Rees, R. (2014). *Visitation and economic impact of whale shark tourism in a Maldivian marine protected area* (No. e360v1). PeerJ PrePrints.

Camp, E., & Fraser, D. (2012). Influence of conservation education dive briefings as a management tool on the timing and nature of recreational SCUBA diving impacts on coral reefs. *Ocean & coastal management*, *61*, 30-37.

Cárdenas-Torres, N., Enríquez-Andrade, R., & Rodríguez-Dowdell, N. (2007). Community-based management through ecotourism in Bahia de los Angeles, Mexico. *Fisheries Research*, *84*(1), 114-118.

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

Colman, J. G. (1997). A review of the biology and ecology of the whale shark. *Journal of Fish Biology*, *51*(6), 1219-1234.

Constantine, R. (2001). Increased avoidance of swimmers by wild bottlenose dolphins (*Tursiops truncatus*) due to long‐term exposure to swim‐with‐dolphin tourism. *Marine Mammal Science*, *17*(4), 689-702.

Craven, S. (2012). Whale Sharks of Oslob. A report on the status of the whale shark watching tourist industry in Tan-awan, Oslob, Cebu. [Online] Available at: <http://www.moalboal.net/moalboal/images/pdf/oslob-physalus-report.pdf> [Accessed 10th April 2018]

Croll, D.A., Dewar, H., Dulvy, N.K., Fernando, D., Francis, M.P., Galván‐Magaña, F., Hall, M., Heinrichs, S., Marshall, A., Mccauley, D. and Newton, K.M. (2016). Vulnerabilities and fisheries impacts: the uncertain future of manta and devil rays. *Aquatic Conservation: Marine and Freshwater Ecosystems*, *26*(3), pp.562-575.

Deakos, M. H. (2010). Ecology and social behavior of a resident manta ray (*Manta alfredi*) population off Maui, Hawai'i. *Dissertation Abstracts International*, *72*(05).

Denkinger, J., Parra, M., Muñoz, J. P., Carrasco, C., Murillo, J. C., Espinosa, E., Rubianes, F. & Koch, V. (2013). Are boat strikes a threat to sea turtles in the Galapagos Marine Reserve? *Ocean & coastal management*, *80*, 29-35.

Dulvy, N. K., Fowler, S. L., Musick, J. A., Cavanagh, R. D., Kyne, P. M., Harrison, L. R., Carlson, J.K., Davidson, L.N., Fordham, S.V., Francis, M.P. & Pollock, C. M. (2014a). Extinction risk and conservation of the world’s sharks and rays. *Elife*, *3*, e00590.

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

EPA, M., 2014. Ministry of environment and Energy. Laws and Regulations. [Online] Available at: <http://en.epa.gov.mv/regulations>. Accessed 24th October 2018.

Gallagher, A. J., & Hammerschlag, N. (2011). Global shark currency: the distribution, frequency, and economic value of shark ecotourism. *Current Issues in Tourism*, *14*(8), 797-812.

Giese, M. (1998). Guidelines for people approaching breeding groups of Adélie penguins (*Pygoscelis adeliae*). *Polar Record*, *34*(191), 287-292.

Graham, R. T. (2007). Whale sharks of the western Caribbean: an overview of current research and conservation efforts and future needs for effective management of the species. *Gulf and Caribbean Research*, *19*(2), 149-159.

Higham, J. E., & Lück, M. (Eds.). (2007). *Marine wildlife and tourism management: Insights from the natural and social sciences*. CABI.

How to swim with Manta Rays. 2017. [Online] Available at: <https://swimwithmantas.org/>

[Accessed 30th October 2017].

Hoyt, E. (2001). Whale watching 2001: worldwide tourism numbers, expenditures, and expanding socioeconomic benefits.

Hoyt, E., & Iñíguez, M. (2008). The state of whale watching in Latin America. *WDCS, Chippenham, UK*.

Kessel, S. T., Elamin, N. A., Yurkowski, D. J., Chekchak, T., Walter, R. P., Klaus, R., Hill, G. & Hussey, N. E. (2017). Conservation of reef manta rays (*Manta alfredi*) in a UNESCO World Heritage Site: Large-scale island development or sustainable tourism?. *PLoS One*, *12*(10), e0185419.

Krieger, J. R., & Chadwick, N. E. (2013). Recreational diving impacts and the use of pre-dive briefings as a management strategy on Florida coral reefs. *Journal of Coastal Conservation*, *17*(1), 179-189.

Project Manta (2018). [Online]. Available at: <https://sites.google.com/site/projectmantasite/home/diving-with-mantas--code-of-conduct> [Accessed 13th September 2018].

Lawson, J. M., Fordham, S. V., O’Malley, M. P., Davidson, L. N., Walls, R. H., Heupel, M. R., Stevens, G., Fernando, D., Budziak, A., Simpfendorfer, C.A. & Ender, I. (2017). Sympathy for the devil: a conservation strategy for devil and manta rays. *PeerJ*, *5*, e3027.

Lynam, R., (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). [Online]. Conservation. Available at: <http://www.mantatrust.org/> [Accessed 28th December 2014].

Marshall, A., Bennett, M. B., Kodja, G., Hinojosa-Alvarez, S., Galvan-Magana, F., Harding, M., Stevens, G. & Kashiwagi, T. (2011). Manta birostris. The IUCN Red List of Threatened Species 2011: e. T198921A9108067.

Marshall, A. D., & Pierce, S. J. (2012). The use and abuse of photographic identification in sharks and rays. *Journal of Fish Biology*, *80*(5), 1361-1379.

Mau, R. (2008). Managing for conservation and recreation: The Ningaloo whale shark experience. *Journal of Ecotourism*, *7*(2-3), 213-225.

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

Ministry of Maritime Affairs and Fisheries, 2014; Decree Number 4/KEPMEN-KP/2014 issued by Ministry of Maritime Affairs and Fisheries. Available at: <http://birdsheadseascape.com/download/legislation%20and%20legal%20documents/KEPMEN-KP%204:2014%20Perlindungan%20Manta.pdf> [Accessed 9th April 2018]

Ministry of Tourism. (2016). Statistics, Monthly Updates. [Online]. Available at: <http://www.tourism.gov.mv/statistics/arrival-updates/> [Accessed 1st November 2017].

Ningaloo Marine Interactions. (2018). [Online] Available at: <http://www.mantaraycoralbay.com.au/wp-content/uploads/2015/02/Manta-Ray-Management-poster.pdf>. [Accessed 4th April 2018].

Norman, B.M., (2005). Whale Shark. In: Fowler, S. L. (Ed.). (2005). *Sharks, rays and chimaeras: the status of the Chondrichthyan fishes: status survey* (Vol. 63). IUCN, Gland, Switzerland, pp. 242-245.

O’Malley, M. P., Lee-Brooks, K., & Medd, H. B. (2013). The global economic impact of manta ray watching tourism. *PloS one*, *8*(5), e65051.

O'Malley, M.P., Townsend, K.A., Hilton, P., Heinrichs, S. and Stewart, J.D., 2017. Characterization of the trade in manta and devil ray gill plates in China and South‐east Asia through trader surveys. *Aquatic Conservation: Marine and Freshwater Ecosystems*, *27*(2), pp.394-413.

O’Shea, O. R., Kingsford, M. J., & Seymour, J. (2010). Tide-related periodicity of manta rays and sharks to cleaning stations on a coral reef. *Marine and Freshwater Research*, *61*(1), 65-73.

Pierce, S. J., Méndez‐Jiménez, A., Collins, K., & Rosero‐Caicedo, M. (2010). Developing a Code of Conduct for whale shark interactions in Mozambique. *Aquatic Conservation: Marine and Freshwater Ecosystems*, *20*(7), 782-788.

Quiros, A. L. (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), 102-108.

Race, S., & Orams, M. (2013). Marine tourism gone wild: Visitation to New Zealand's most popular marine reserve. *CAUTHE 2013: Tourism and Global Change: On the Edge of Something Big*, 663.

Sirakaya, E., Sasidharan, V., & Sönmez, S. (1999). Redefining ecotourism: The need for a supply-side view. *Journal of Travel Research*, *38*(2), 168-172.

Sorice, M. G., Shafer, C. S., & 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), 319-338.

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

Stevens, G. (2016). Population demographics, habitat use and life history characteristics of the reef manta ray (*Manta alfredi*) in the Maldives. PhD thesis, The University of York, viewed 5th October 2017. [Online] Available at: [<http://etheses.whiterose.ac.uk/16981/>].

Stevens, G.M., Hawkins, J.P. and Roberts, C.M., (2018a). Courtship and mating behaviour of manta rays Mobula alfredi and M. birostris in the Maldives. *Journal of fish biology*.

# Stevens, G., Fernando, D., Dando, M & Notarbartolo di Sciara, G. (2018b). Gui.de to the Manta and Devil Rays of the World. Princeton University Press.

Tisdell, C., & Wilson, C. (2002). Ecotourism for the survival of sea turtles and other wildlife. *Biodiversity and Conservation*, *11*(9), 1521-1538.

Toyoshima, J., & Nadaoka, K. (2015). Importance of environmental briefing and buoyancy control on reducing negative impacts of SCUBA diving on coral reefs. *Ocean & Coastal Management*, *116*, 20-26.

Tratalos, J. A., & Austin, T. J. (2001). Impacts of recreational SCUBA diving on coral communities of the Caribbean island of Grand Cayman. *Biological Conservation*, *102*(1), 67-75.

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

Vianna, G. M. S., Meekan, M. G., Pannell, D. J., Marsh, S. P., & Meeuwig, J. J. (2012). Socio-economic value and community benefits from shark-diving tourism in Palau: a sustainable use of reef shark populations. *Biological Conservation*, *145*(1), 267-277.

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

Williams, R., Trites, A. W., & Bain, D. E. (2002). Behavioural responses of killer whales (*Orcinus orca*) to whale-watching boats: opportunistic observations and experimental approaches. *Journal of Zoology*, *256*(2), 255-270.

Worachananant, S., Carter, R. W., Hockings, M., & Reopanichkul, P. (2008). Managing the impacts of SCUBA divers on Thailand's coral reefs. *Journal of Sustainable Tourism*, *16*(6), 645-663.

Zeppel, H., & Muloin, S. (2008). Conservation and education benefits of interpretation on marine wildlife tours. *Tourism in Marine Environments*, *5*(2-1), 215-227.