Department of Environment and Geography

University of York

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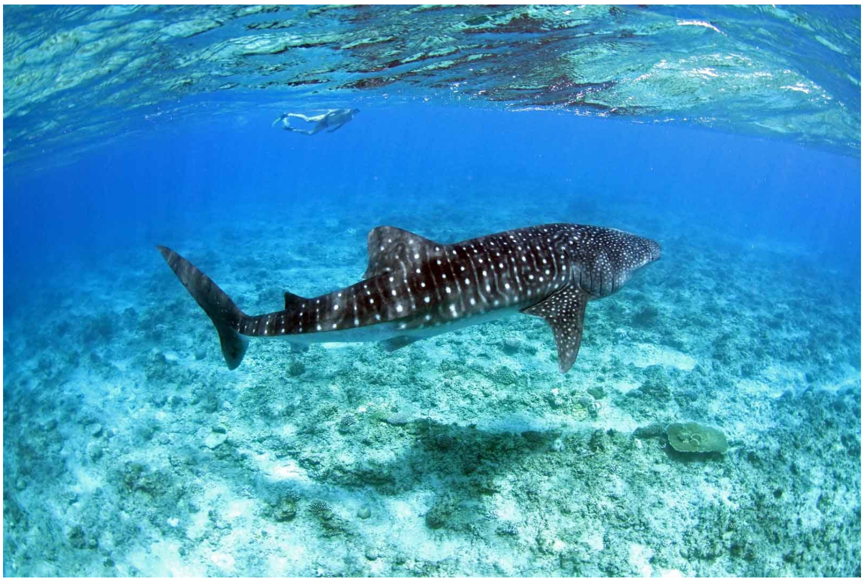
Monitoring and Enforcing the South Ari Atoll Marine Protected Area in the Maldives



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Dissertation submitted in part fulfilment of the MSc Marine Environmental Management, University of York

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DISCLAIMER
I, Nastazia Femmami, declare that the work submitted in this dissertation is the result of my own work and investigation and all the sources I have used have been indicated by means of completed references.

ACKNOWLEDGEMENTS

I would like to thank the Maldives Whale Shark Research Programme for suggesting this project, and in particular, James Hancock and Richard Rees for suggesting research, answering all my questions, sending me all the data and documents I requested and giving me feedback on my written drafts, along with Clara Canovas-Perez. A huge thank you to Dr. Bryce Beukers-Stewart for his time, encouragement and precious help all along this project. And a very special thank you to Dr Julie Hawkins and Professor Callum Roberts for their help and support when I needed it.

ABSTRACT

The South Ari atoll Marine Protected Area (SAMPA) in the Maldives, is a long strip of water spanning 42km^2, designated in 2009 as a measure to protect its year-round aggregation of whale sharks *(Rhincodon typus)* and ensure the sustainability of the local ecotourism that offers the opportunity to swim with this iconic species. However, since its creation neither management plan nor enforcement measures have been implemented. Likely as a consequence, 79% of SAMPA resident whale sharks show signs of injuries mainly due to boat strikes, while unregulated activities and overcrowding at encounters threaten the safety of swimmers and negatively affect visitors' satisfaction. A management plan is therefore urgently needed for regulating whale shark activities in SAMPA. This study explored existing regulations and new technologies that could be implemented to manage, monitor and enforce SAMPA. In this context, combining a zonation system with an alternate access day system and a licensing system of tour operators would enable a limit on the number of vessels visiting the MPA at the same time, and subsequently reduce the risk of injuries for both whale sharks and swimmers. Mandatory 10-knot vessel speed limits also appear essential for significantly reducing the risk of boat strikes on whale sharks. Furthermore, modern technologies such as GPS tracker devices and drones could be used by rangers to monitor vessel speed compliance and perform aerial surveillance respectively. Finally, close cooperation between all stakeholders, as well as education of operators and visitors, is crucial to foster self-enforcement. The present study primarily focused on informing managers and stakeholders of potential measures to be defined in the future management plan for SAMPA. However, measures outlined are also replicable in any other MPA facing similar issues in the Maldives and beyond.

INTRODUCTION

Marine megafauna defines large, late maturing, long lived marine species such as sharks, rays, sea turtles, cetaceans and other large marine mammals (Teh et al., 2018). Many of these species are globally threatened by diverse anthropogenic threats, such as overexploitation, by-catch, prey depletion, destruction of habitats and pollution, which has led to severe population declines worldwide over the last decades (Schnitzler et al., 2019; Wallace et al., 2013; Worm et al., 2013; Lotze and Worm, 2009; Bearzi et al., 2008; Lewison et al., 2004). At the same time, ecotourism consisting of activities of observation and interaction with marine megafauna has become increasingly popular since the 1980s, thereby contributing to local economies and incentivising legal protection of the targeted species (Anderson et al., 2014; Cisneros-Montemayor et al., 2013; O'Malley et al., 2013). However, in places where appropriate management is lacking, these ecotourism activities can have detrimental effects on the targeted populations through repeated disturbance (Trave et al., 2017; Haskel et al., 2015; Anderson et al., 2014). The whale shark *(Rhincodon typus)* is one such species. It is one of the most watched shark species in the world, engaging approximately 100,000 tourists and generating a global revenue estimated at USD 42 million in 2007 (Haskel et al., 2015; Dearden et al., 2008). The whale shark is the world's largest species of fish and one of the three large pelagic filter feeding shark species (Copping et al., 2018; Rowat and Brooks, 2012). It is estimated that the global whale shark population decreased by 50% in the last 75 years and in 2016 the species was classified as 'Endangered' on the IUCN Red List of Threatened Species. (Pierce and Norman, 2016; Rezzolla et al., 2010). It is a migratory species that inhabits tropical and warm temperate waters throughout the oceans (fig.1; Anderson et al., 2014). Whale sharks also form large seasonal aggregations at several locations worldwide, coinciding with local increases in prey availability such as coral and fish spawning events or zooplankton blooms (Anderson et al., 2014). Many of these aggregation events occur in coastal areas, which has led to the development of the popular ecotourism that offers the opportunity to swim with whale sharks (Anderson et al., 2014; Gallagher and Hammerschlag, 2011). Important whale shark tourism sites include the Maldives and especially the South Ari atoll which uniquely has a year-round aggregation (Cagua et al., 2014). Tour operators take advantage of this naturally occurring phenomenon by leading whale shark excursions, and in 2013, whale shark tourism in South Ari atoll alone, generated over USD 9 million, with 78,000 tourists participating in whale shark tours (Cagua et al., 2014).

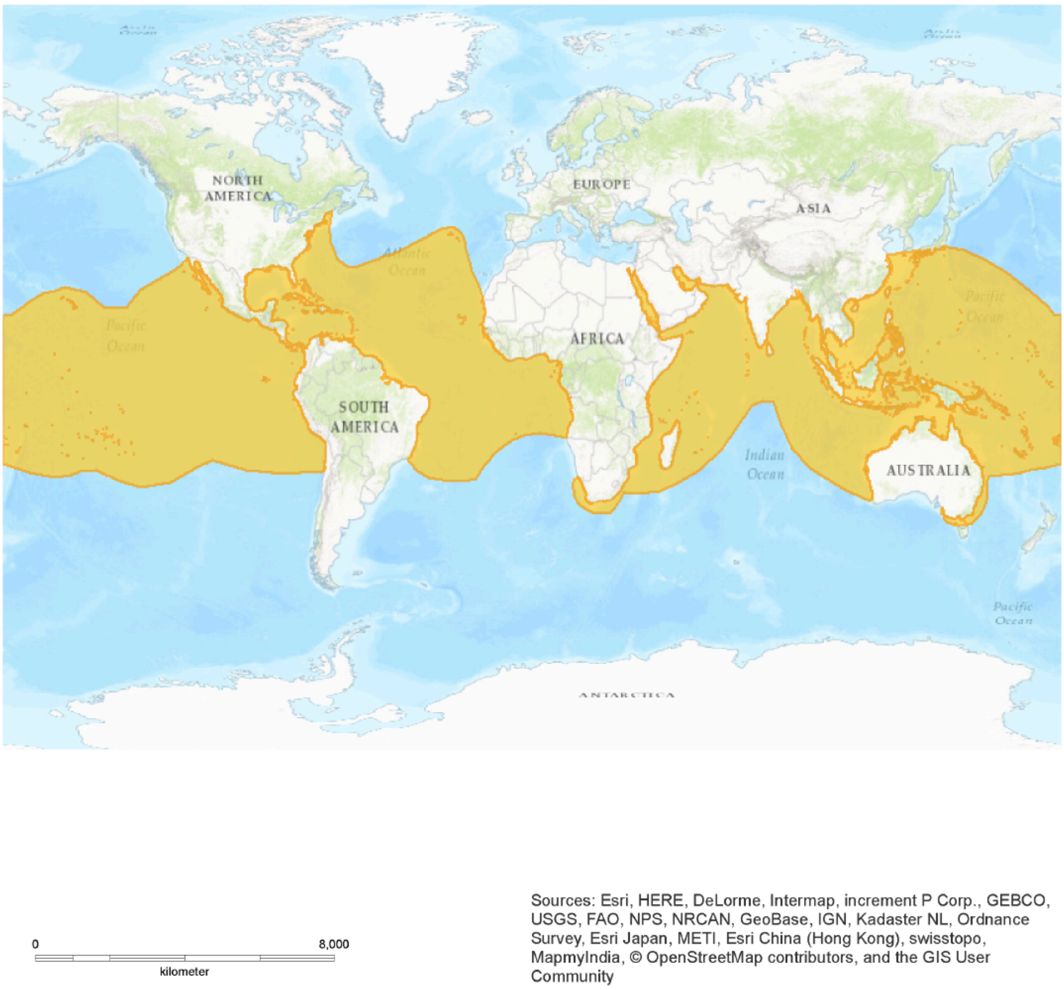


Figure 1. Whale shark *(Rhincodon typus)* distribution map (Pierce and Norman, 2016)

The whale shark has been protected in the Maldives since 1995, and in 2009 the Maldivian government designated the South Ari Marine Protected Area (SAMPA) as a measure to protect and preserve its year-round aggregation (fig.2; Cagua et al., 2014). However, like most other MPAs in the Maldives, SAMPA remains a ‘paper park’, and no management plan has existed or been implemented since its creation (Rasheed et al., 2016). Moreover, Allen (2018) showed that 79% of SAMPA resident whale sharks have signs of injuries mainly due to boat traffic. Those injuries can cause stress and other sub lethal effects that could affect the whale shark population, and according to the Maldives Whale Shark Research Programme (MWSRP - a research-based conservation charity dedicated to studying the whale shark in the Maldives), encounters recorded by the group in South Ari have already gone down by 52% between 2016 and 2018 (EPA, 2019a; Allen, 2018). Furthermore, the unregulated activities and overcrowding at encounters not only threaten the sharks, but also the safety of swimmers (J. Hancock 2019, pers. comm., May 2019). Finally, for the first time in 2018, an article from the Canadian newspaper, The Globe and Mail, reported on the overcrowding and unsustainable practices of whale shark tourism in SAMPA; a reputation that could also negatively impact the industry and subsequently the local economy (Reguly, 2018).

With the number of visitors predicted to increase due to the increasing popularity of whale shark tourism in the Maldives, a management plan is urgently needed for SAMPA and whale shark watching activities carried out there (Rasheed et al., 2016). This project therefore aimed to propose management, monitoring and enforcement measures for SAMPA. The objectives were to investigate existing regulations and new technologies that could be implemented within the MPA. This project could furthermore contribute directly to informing managers and stakeholders, as in April 2019 the first stakeholder consultation meetings took place to discuss the measures to be included in the future management plan for SAMPA (EPA, 2019a; 2019b; 2019c).

METHODS

STUDY LOCATION

Located on the southern fringe of coral reef of the South Ari Atoll (Alif Dhaalu Atoll), SAMPA is the largest Marine Protected Area (MPA) in the Maldives to date (Stevens and Froman, 2019; Cagua et al., 2014). It has a total area of 42 km^2 and extends 1 km seaward from the reef crest stretching between 3°38′10N and 3°32′15N, and 72°42′18E and 72°55′58E (fig.2.; Rasheed et al., 2016). It borders four local community islands (Dhigurah, Maamigili, Dhihdhoo and Fenfushi) and four resort islands (Conrad Rangali, Sun Island, Holiday Island and Diva Maldives) (fig.2.; Rasheed et al., 2016). SAMPA was declared on 5th June 2009 by Directive 138-EE/2009/19 of the Ministry of Housing, Transport and Environment, as a measure to protect and preserve the largest Maldivian aggregation of whale sharks and to maintain the ecosystem for both economic and social benefits (Rasheed et al., 2016; Cagua et al., 2014).

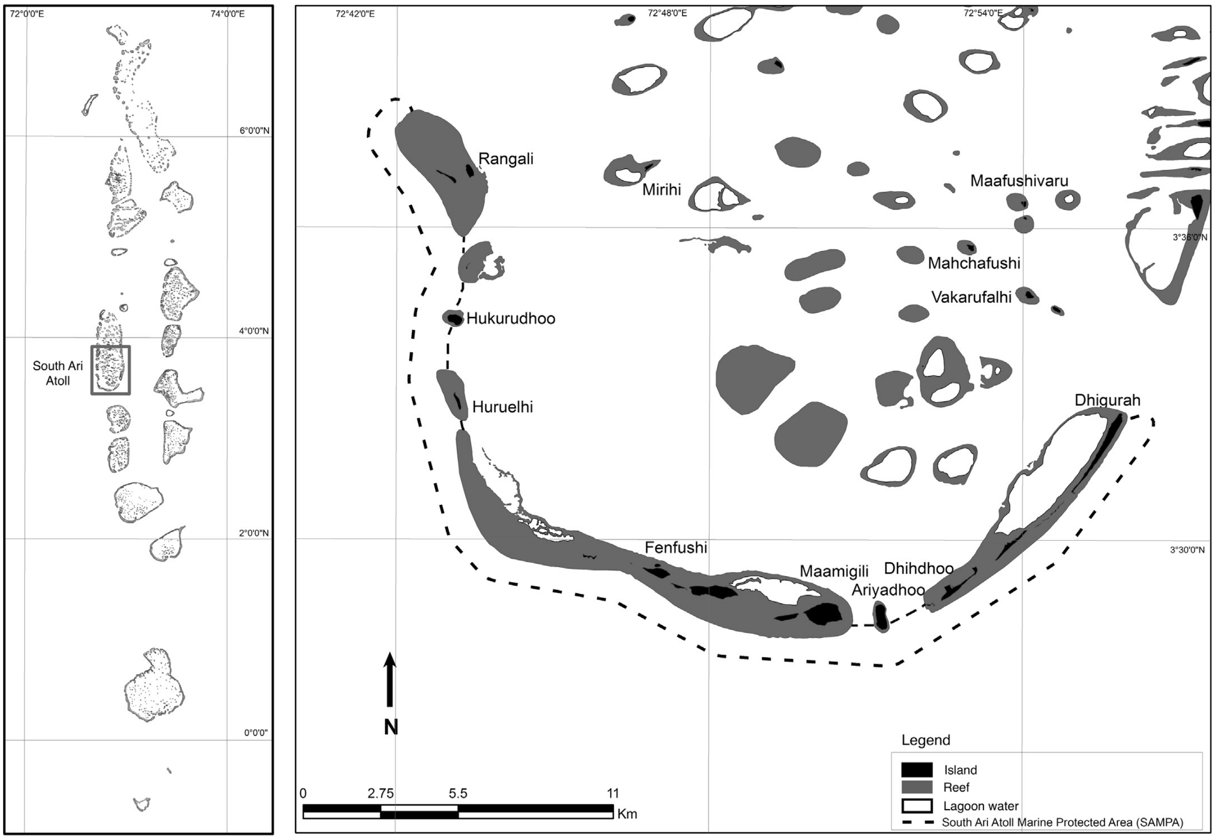


Figure 2. Map of South Ari Atoll Marine Protected Area (SAMPA) (Rasheed et al., 2016).

Whale sharks can be sighted in SAMPA year-round but the locations of sightings move geographically according to opposing Monsoons (fig.3; Mundy, 2017). The MPA boundaries represent the geographical area where whale sharks are most commonly found, and subsequently those most commonly visited by tour operators for whale shark encounters (fig.3; Mundy, 2017; Cagua et al., 2014). Furthermore, the MPA is almost exclusively used by boats looking for whale sharks, with an average of 60 boats entering the MPA everyday (fig.3; J. Hancock 2019, pers. comm., May 2019; EPA, 2019a).

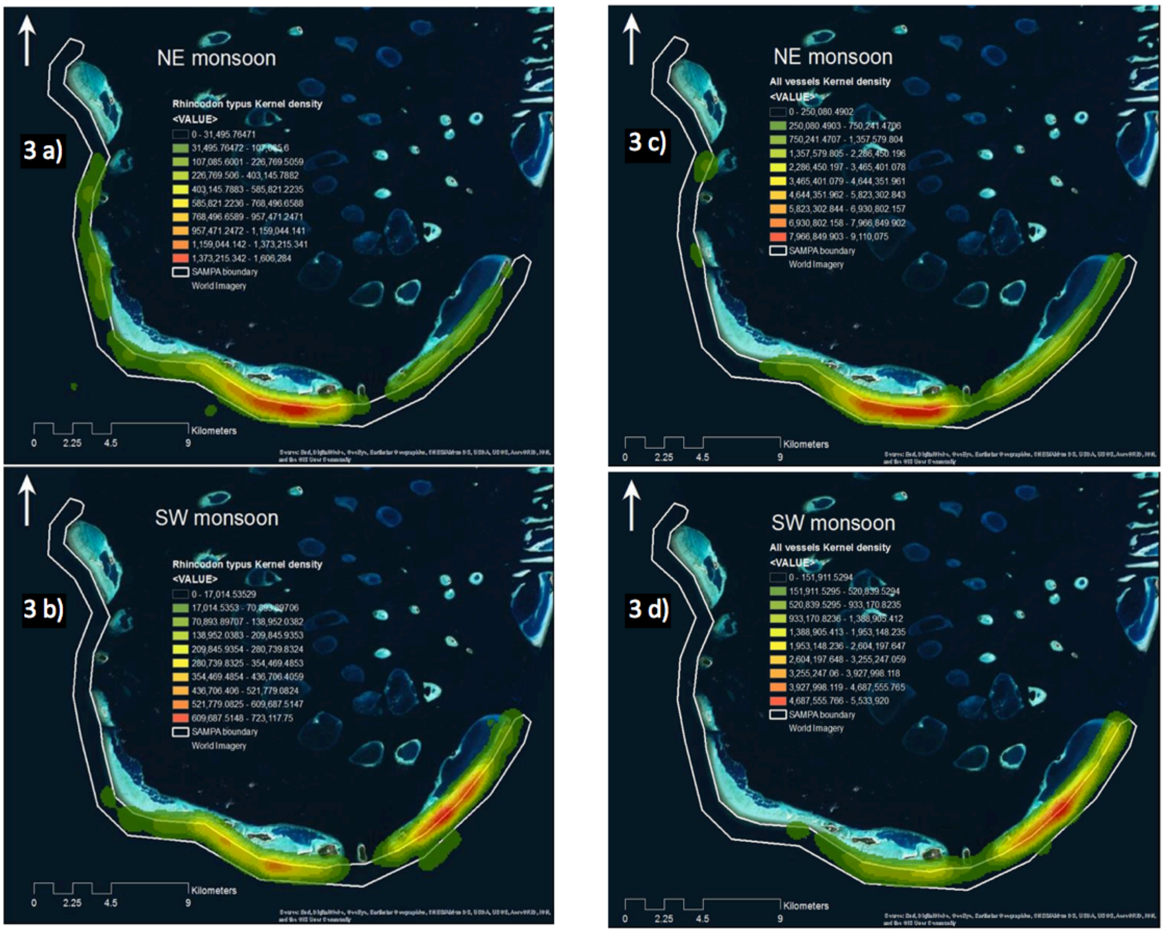


Figure 3. Kernel density counts of whale shark and vessel distributions in South Ari Marine Protected Area. 3a) Whale shark hotspot in the south during the NE monsoon seasons from November 2011 to April 2017. 3b) Whale shark hotspots in the east and south during the SW monsoon seasons from November 2011 to April 2017. 3c) Vessel distribution during the NE monsoon seasons from November 2011 to April 2017. 3d) Vessel distribution during the SW monsoon seasons from November 2011 to April 2017 (Mundy, 2017).

DATA ACQUISITION AND ANALYSIS

Hanifaru MPA Management Plan

Of the 42 protected areas established to date in the Maldives, only Hanifaru MPA, located in Baa Atoll, has a management plan and on-site enforcement measures in place since July 2011 (Stevens and Froman, 2019; MHE, 2011). Those management measures employed in Hanifaru were thus analysed in order to evaluate the replicability of this model in SAMPA.

Whale shark tourism sites around the world

Nineteen whale shark aggregation sites around the world provided by Copping et al. (2018), were analysed in order to identify sites where whale shark tourism activities are carried out. In addition to this list, a literature review was performed to identify locations directly linked to whale shark ecotourism activities, using specific search terms relevant to the research in Science Direct and Google Scholar (Appendix.1a). All relevant articles that mentioned aggregation sites, other than those already listed in Copping et al. (2018), were retained for further analysis. Internet searches (using http://www.google.com) were also performed using specific key word combinations in English, French and Spanish, to retrieve relevant data (Appendix.1a). From these, a database of 20 whale shark aggregation sites was created (Appendix.2). Among those 20 aggregation sites, only 9 sites had official management plans and enforcement measures in place to regulate whale shark tourism activities, and were thus retained for further analysis (tab.1).

Table 1. List of whale shark aggregation sites used for the present analysis and the literature sources where information has been extracted.

Aggregation location	Sources
Australia, Ningaloo Reef	Anderson et al. (2014); DPaW (2013) and Mau and Wilson (2007)
Belize, Gladden Spit	Alicea (2010)
Honduras, Utila Island	Fox et al. (2013) and SERNA-DiBio (2008)
Indonesia , West Papua	Ihsan et al. (2018); Nisa Utami (2015) and WWF (2015)
Mexico, Gulf of California	SEMARNAT (2018) and Ramírez-Macías and Saad (2016)
Mexico, Yucatan Peninsula & Afuera	SEMARNAT (2019)
Philippines, Donsol	Pine (2007); Quiros (2007) and Quiros (2005)
Seychelles, Mahe	Rowat and Engelhardt (2007) and The Marine Conservation Society Seychelles (2009)

Causes of vessel-induced injuries on marine wildlife and potential mitigation measures

With an injury rate of 79%, SAMPA whale shark residents appear to be particularly exposed to the risk of boat strikes (Allen, 2018). In order to identify causes and potential mitigations measures of vessel-induced injuries on marine animals, a literature review was performed using relevant search terms in Science Direct and Google Scholar (Appendix.1b). The key words were chosen because they corresponded to specific species or families of marine animals that swim slowly and/or stay at the surface for long periods of time, making them especially vulnerable to vessel collisions (Appendix.1b; Carillo and Ritter, 2010).

New technologies

Finally, modern technologies can offer high quality performance while remaining affordable. It was therefore explored how new technologies could be used for monitoring and enforcing SAMPA, with a specific focus on GPS tracker devices that could monitor vessel speed compliance, as well as the use of drones to assist rangers in performing aerial surveillance and tour operators in the search of whale sharks. Both a literature review (using Science Direct and Google Scholar) and internet searches (using http://www.google.com) were performed, using relevant key word combinations (Appendix.1c). The analysis also included references obtained in previous research performed for the purpose of the present study, as well as those provided by the MWSRP and Dr Bryce Beukers-Stewart.

RESULTS

HANIFARU MPA MANAGEMENT PLAN

Hanifaru reef was designated as a MPA in 2009 and is a Core Area of the Baa Atoll UNESCO Biosphere Reserve (fig.4; UNESCO, 2015; MHE, 2011). Hanifaru MPA has a total area of 4,68km^2 and is a popular tourism destination for swimming with manta rays and, to a lesser extent, whale sharks (fig.4; Ender, 2016). In 2011, the Maldivian government approved a management plan for the Hanifaru MPA, with the objective of protecting aggregations of manta rays and whale sharks, while providing a sustainable and high quality experience for visitors and supporting the development of local communities (MHE, 2011).

Zonation system

Baa Atoll is a multiple use marine area, where a zonation system defines different zones for different uses in order to minimise detrimental threats and user conflicts (MHE, 2011). The Baa Atoll zonation system comprises three different zones corresponding to the UNESCO World Biosphere Reserve zonation criteria (MHE, 2011). The whole Hanifaru MPA corresponds to a Core Area, where snorkelling is the only activity permitted (MHE, 2011).

Limited number of vessels

Numbers of vessels allowed in Hanifaru MPA are managed through two systems: *a)* a permit system whereby all tour operators must have an official permit to enter Hanifaru Bay; and *b)* an alternate access day system whereby resort vessels and liveaboards can visit Hanifaru MPA according to an alternate day rota schedule determined in advance by the Environmental Protection Agency (EPA) (Ender, 2016; MHE, 2011).

Speed limits

Vessels within 200 meters of the Hanifaru MPA should not exceed 5 knots and vessels within the Hanifaru lagoon shall not exceed 2 knots (MHE, 2011).

Guidelines for megafauna interactions

The management plan also includes mandatory guidelines for megafauna interactions to be followed by all tour operators and visitors during in-water activities (MHE, 2011).

Token fees

In order to be allowed to snorkel in the Hanifaru Bay, each visitor has to purchase a "Hanifaru Token" (Ender, 2016; MHE, 2011). All revenue generated goes to the Baa Atoll Conservation Fund (BACF), a separate fund from the central government in charge of collecting and allocating revenue from visitor fees to fund the management of Hanifaru MPA, such as ranger's salaries, ranger boat and fuel.

Enforcement

In Hanifaru MPA, rangers are responsible for monitoring the implementation of measures defined in the management plan. All rangers must have an official certification granted by the EPA (Ender, 2016; MHE, 2011).

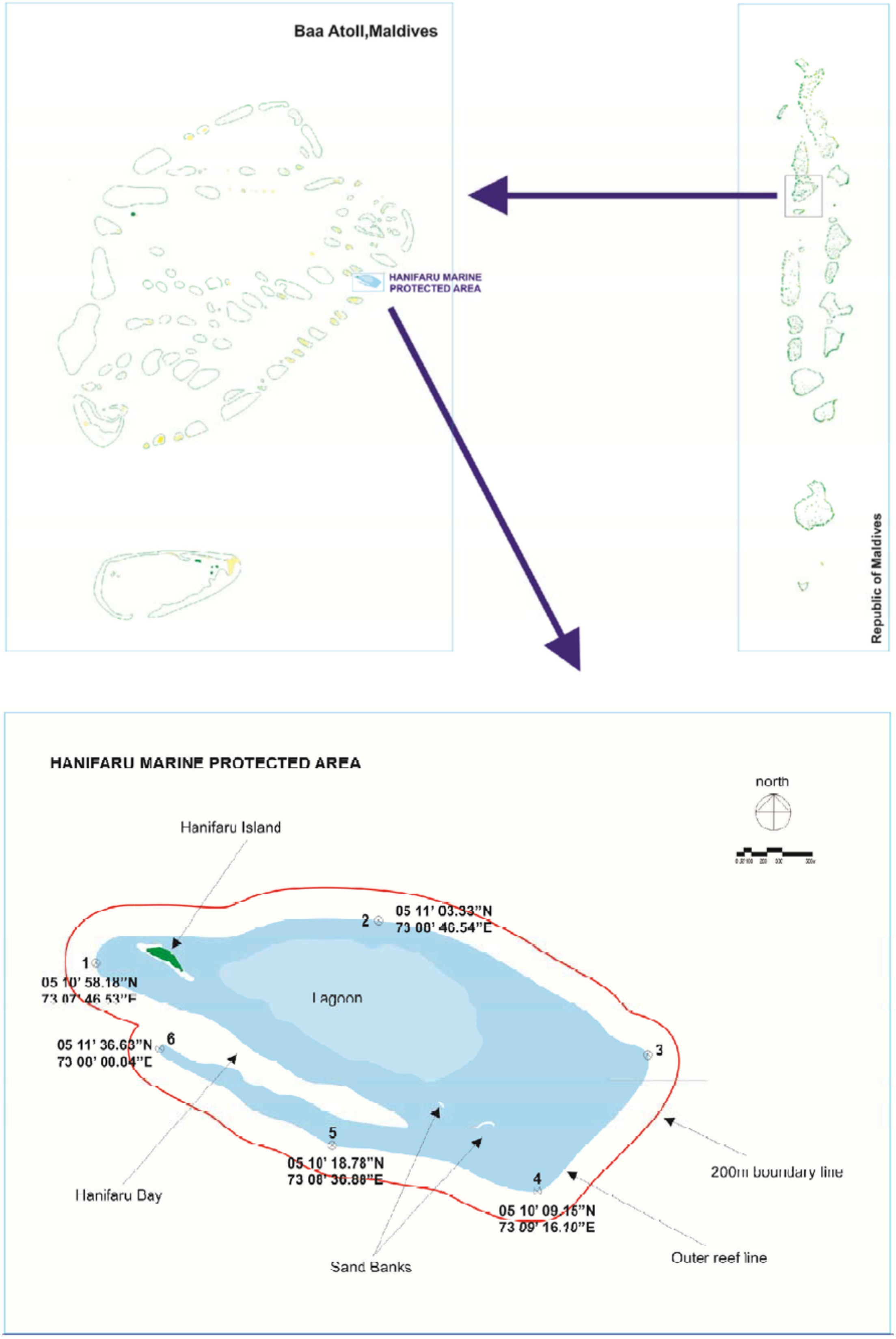


Figure 4. Map of Hanifaru Marine Protected Area, Baa Atoll, Maldives (MHE, 2011).

MAIN MANAGEMENT MEASURES FOR WHALE SHARK TOURISM ACTIVITIES ADOPTED WORLDWIDE

Licensing of tour operators

As in Hanifaru, 7 of the 9 aggregation sites retained for the present analysis have adopted a license system whereby tour operators must have an official license to conduct whale shark tourism activities (Appendix.3). Licences are a regulatory arrangement between a tour operator and authorities that establishes terms of operations that the operator must adhere to at all times (DPaW, 2013). Conditions associated with licences must ensure safety of people and prevent whale sharks from being harmed or disturbed (DPaW, 2013). Conditions of granting licences can concern the size and type of boat, mandatory equipment, mandatory training for industry staff, and the compliance of a code of conduct which covers essential whale shark interaction rules (Appendix.4; DPaW, 2013; Alicea, 2010; SERNA-DiBio, 2008).

Zonation system

Gladden Spit and Silk Cayes Marine Reserve (GSSCMR), in Belize, is a multi-use MPA divided into three different zones to regulate tourism and commercial fishing activities (Alicea, 2010). A specific Whale Shark Zone, where only whale shark interaction activities are allowed, is also designated during the whale shark season and is carefully regulated and monitored (fig.5; Alicea, 2010).

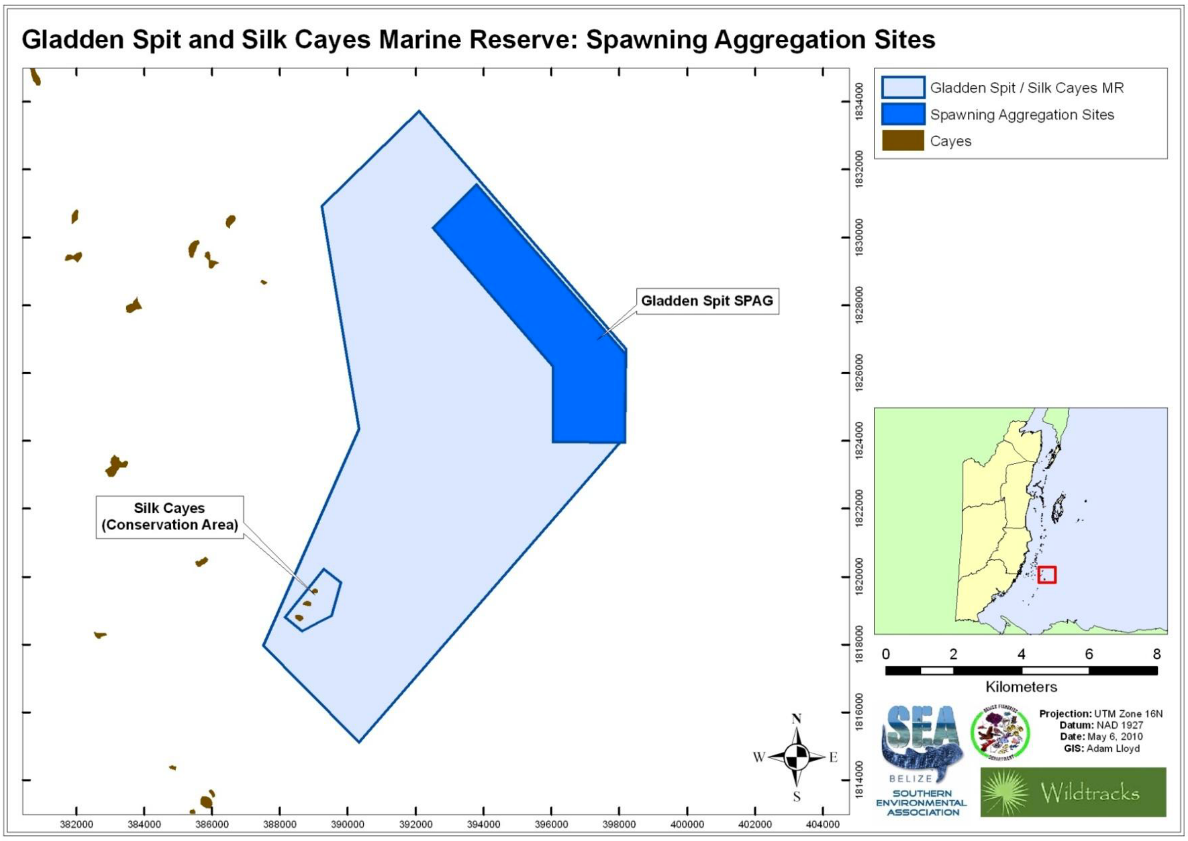
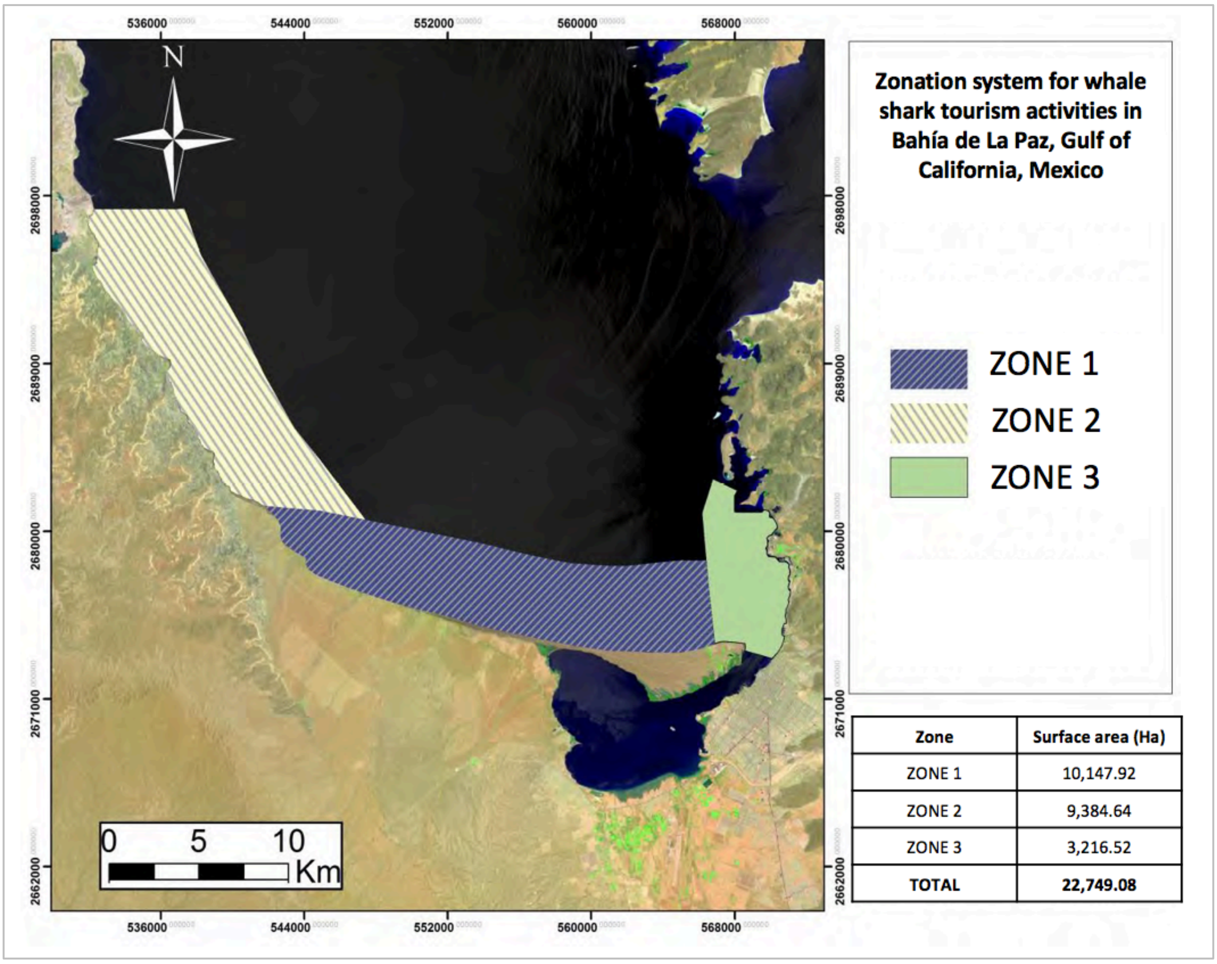


Figure 5. Gladden Spit and Silk Cayes Marine Reserve Zones. The Spawning Aggregation Site corresponds also to the Whale Shark Zone during the whale shark season (Alicea, 2010).

In Gulf of California, Mexico, three different zones are temporarily designated during the whale shark season to regulate whale shark tourism activities: Zone 1 is an exclusive whale shark zone where only whale shark interaction activities are allowed; Zone 2 is a conservation area where any tourism activities are prohibited; and Zone 3 is a transit area allowing vessels to enter and exit the whale shark zone and where any other tourism activities are prohibited (fig.6; SEMARNAT, 2018).



Zone	Surface area (Ha)
ZONE 1	10,147.92
ZONE 2	9,384.64
ZONE 3	3,216.52
TOTAL	**22,749.08**

Figure 6. Map of the zonation system set up for whale shark interaction activities in Bahía de La Paz, Gulf of California, Mexico. Zone 1: exclusive whale shark zone. Zone 2: conservation area. Zone 3: transit area. (SEMARNAT, 2018)

Speed limits

The 9 whale shark aggregation sites retained for the present analysis also implemented mandatory speed limits between 10 knots and neutral speed (Appendix.3).

CAUSES OF VESSEL-INDUCED INJURIES ON MARINE WILDLIFE AND POTENTIAL MITIGATION MEASURES

Collision with ships is a key mortality factor for a wide range of large marine animals, especially those like whale sharks who swim slowly and stay on the surface for longer periods of time (Currie et al., 2017; Wiley et al., 2011; Calleson and Frohlich, 2007). This problem is global in scale and includes for example North Atlantic right whales *Eubalaena glacialis* in Canada (Reimer et al., 2016), Florida manatees *Trichechus manatus latirostris* in the United States (Calleson and Frohlich, 2007), sperm whales *Physeter macrocephalus* in the Canary Islands and the Mediterranean (Di-Méglio et al., 2018; Carrillo et al., 2010), dugongs *Dugong dugon* and green turtles *Chelonia mydas* in Australia (Meager, 2016; Hazel et al., 2007), and whale sharks in Mozambique and the Maldives (Speed et al., 2008; Allen, 2018). Not surprisingly, most studies state that fatality rates and severity of injuries to animals struck by boats are related to speed of vessels (Silber et al., 2014; Carrillo and Ritter, 2010; Vanderlaan and Taggart, 2007). A link has been established whereby the probability of death of a whale involved in a collision increases as vessel speed increases (fig.7; Conn and Silber, 2013; Vanderlaan and Taggart, 2007). In this respect, 10-knot speed limits have proved effective for reducing vessel-related large whale deaths (Nichol et al., 2017; Laist et al., 2014; Wiley et al., 2011; Kite-Powell et al., 2007). For example, Vanderlaan and Taggart (2007) found that at 15 knots, 80% of collisions were fatal to whales, and at speeds of 11.8 and 8.6 knots, the percentage of fatal collisions dropped to 50% and 20%, respectively. However, the effectiveness of speed limits depending entirely on vessel-operator compliance, studies suggest that to be effective for protecting marine animals from vessel strikes, speed limits must be mandatory and properly enforced (Laist et al., 2014; Lagueux et al., 2011; Hazel et al., 2007).

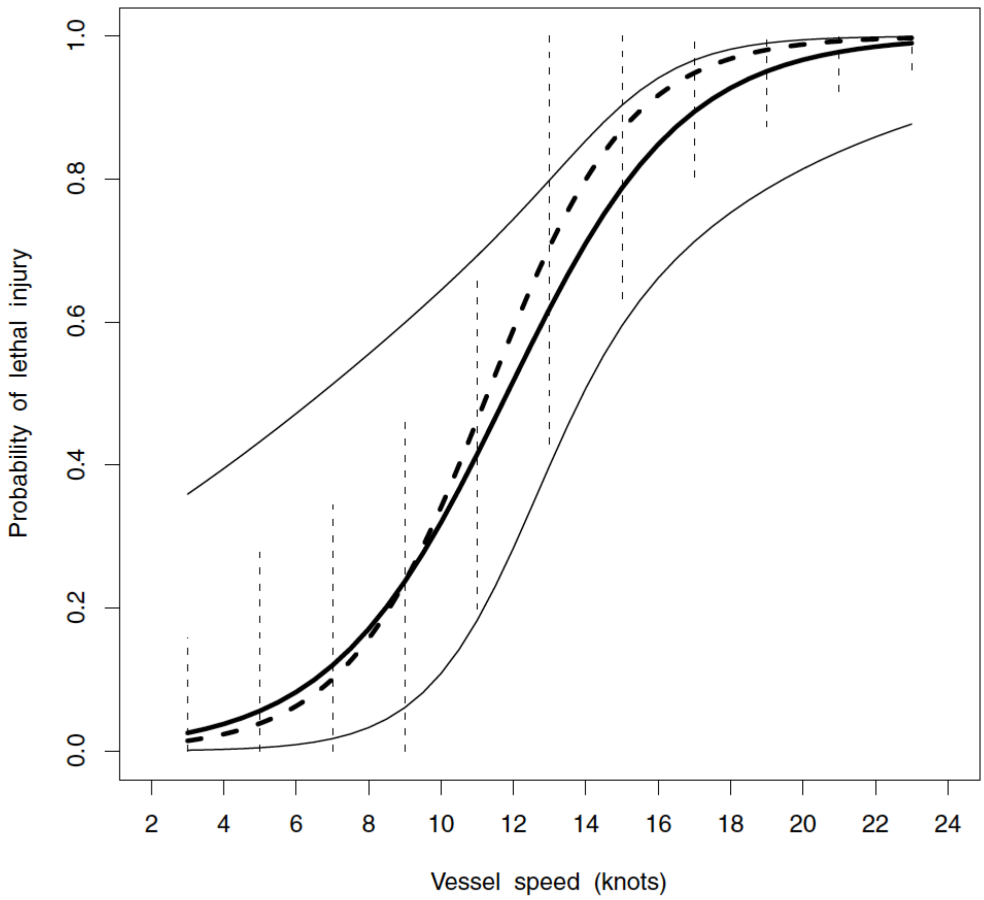


Figure 7. Probability of a lethal injury resulting from a vessel strike to a large whale as a function of vessel speed based on the simple logistic regression (solid heavy line) and 95% CI (solid thin lines) and the logistic fitted to the bootstrapped predicted probability distributions (heavy dashed line) and 95% CI for each distribution (vertical dashed line) where each datum (_) is the proportion of whales killed or severely injured (i.e., lethal injury) when struck by a vessel navigating within a given two-knot speed class (Vanderlaan and Taggart, 2007).

NEW TECHNOLOGIES

GPS tracker devices

At Ningaloo Reef in Australia and in Gulf of California in Mexico, whale shark tour operators are required to equip their boats with a GPS tracker device that automatically transmits GPS coordinates and the vessel speed to a central database, which can thus be monitored for compliance purposes (SEMARNAT, 2018; DPaW, 2013). At Ningaloo Reef, tracking data are stored and data history can be mapped to help compile evidence to support or disclaim complaints received about operations (DPaW, 2013). In Mexico, each operator must follow a strict protocol for entry into and exit from the whale shark observation zone, which consists of radioing for authorization to enter and exit the area, while the GPS tracker device automatically transmits GPS coordinates and the vessel speed, that are instantaneously monitored by a ranger on a computer screen (fig.8; SEMARNAT, 2018). No information about the costs of these technologies could be found. However, Mexican authorities have already expressed their willingness to help expand this technology in other countries facing similar issues of vessel-induced injuries on whale sharks (Meganoticias BCS, 2019).

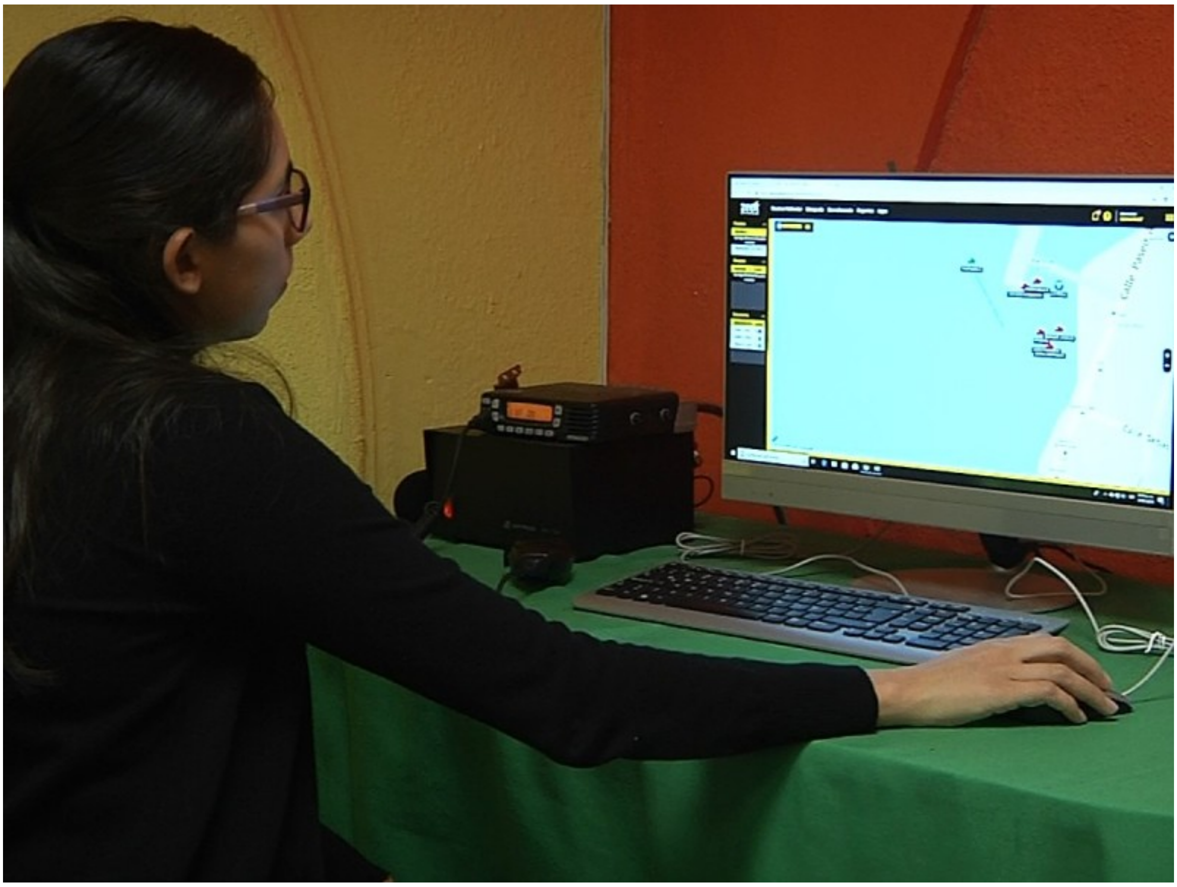


Figure 8. Ranger monitoring whale shark excursion vessels in Gulf of California, Mexico, through radio and GPS tracking data displayed on a computer screen (Cervantes, 2019).

Similar technologies are also used in developing countries for monitoring small- scale fisheries. For example, solar-powered vessel tracking systems have been tested in Timor Leste since 2018, for automating and monitoring artisanal fisheries (fig.9; Pelagic Data Systems, 2019; Layzell, 2018). A similar project will also be soon implemented by the Blue Marine Foundation and the Six Senses Resort, in Laamu atoll in the Maldives, to monitor local fishermen (S. Hashim 2019, pers. comm., April 2019).

Figure 9. Pelagic Data Systems' solar-powered vessel tracking system (Pelagic Data Systems, 2019).

Finally, mobile applications can also provide similar services. For example, *FollowMe Tracker* is a real-time vessel tracking mobile application available to download in App Store and Google Play in the Maldives, which has been developed to enable people to track public boats (GooglePlay, 2019). Features include boat location, trace route and vessel speed information (fig.10).

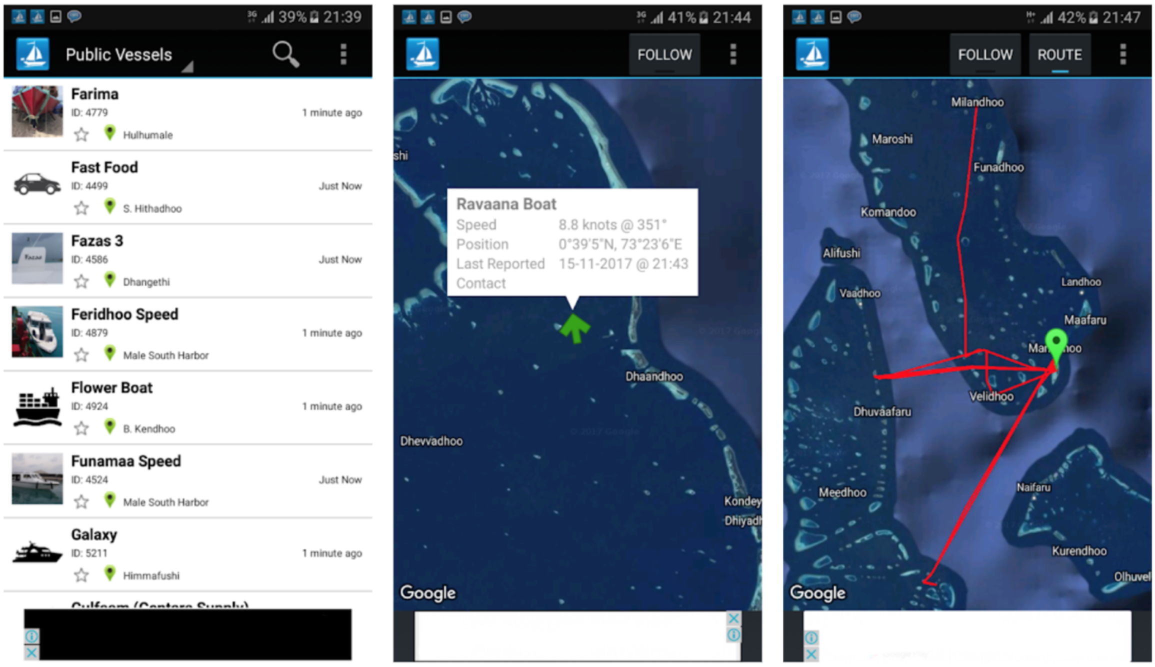


Figure 10. Screenshots of *FollowMe Tracker* mobile app, real-time vessel tracking mobile application available to download in the Maldives (GooglePlay, 2019).

Use of drones

At Ningaloo Reef, Australia, spotter planes and light aircraft are used by local authorities to perform aerial surveillance and monitor whale shark interactions (DPaW, 2013; Davis and Banks 1997). Spotter planes are also used by tour operators to locate whale sharks and guide the mother ships towards them (DPaW, 2013; Davis et al., 1997). This facilitates whale shark encounters by making searching more efficient and dispersing operators among a greater number of sharks (Cagua et al., 2014; Catlin and Jones, 2010). New technology like drones could provide similar services at least cost. For example, use of drones is growing rapidly in marine science and conservation, as they provide on-demand remote sensing capabilities at low cost and with reduced human risk (Johnston Lab, 2019; Werth et al., 2019).

DISCUSSION

SAMPA is a long strip of water of 42km^2 covering remote, commercial (i.e., resorts) and inhabited areas (fig.2). Large parts of the MPA are away from any potential land based monitoring and there are unlimited access points on the fore-reef side, making entry control difficult (fig.2). Furthermore, multiple stakeholders, from South Ari and other atolls, with variable economic interests and means, must be considered when deciding on management options (Rasheed et al., 2016; Cagua et al., 2014). Management, monitoring and enforcement measures must therefore address these difficulties while ensuring both the conservation of whale sharks and prosperity of the associated tourism industry in SAMPA. Based on the above results, here are some practical solutions that could be implemented in SAMPA, considering its needs and means.

ZONATION SYSTEM

As SAMPA is a multiple use marine area, the Environmental Protection Agency (EPA) already suggested the implementation of a zonation system whereby different uses and activities would be undertaken in different zones (EPA 2019a, 2019b and 2019c; Rasheed et al., 2016). Here are some recommendations for its design. Mundy (2017) showed that the areas where whale sharks are most commonly found, and subsequently the most commonly visited by tour operators, are geographically delimited into two distinct areas within the MPA boundaries (fig.3). Those areas should therefore be highly protected and monitored, to ensure that tourism activities are sustainable and prevent whale sharks from being harmed or disturbed. To this end, as for Hanifaru MPA, those two areas should be designated as Core areas, where only non-damaging and non-extractive uses are allowed (MHE, 2011). Those areas should be accessible only by authorized tour operators for whale shark excursions and only snorkelling activities should be allowed (i.e., no SCUBA diving or fishing activities) (fig.10). In addition, the IUCN and the MWSRP stated that whale sharks are also frequently sighted in the lagoon and channels (EPA, 2019a). Those sensitive areas should therefore be designated as Buffer zones subject to specific rules such as speed limits, in order to minimize the risk of boat strikes on whale sharks (fig.10). Finally, as in Bahia de La Paz, in Mexico, conservation areas, where any activities are prohibited, should be implemented in SAMPA (SEMARNAT, 2018). Such conservation areas appear necessary in SAMPA where whale sharks are subject to tourism activities and boat traffic throughout the year (Mundy, 2017; Cagua et al., 2014). This would allow whale sharks to find refuge in highly protected areas where they can recover from injuries and/or tourism activities. Conservation areas could take the form of geographic areas specifically designated for this purpose, or closed periods/days during which any tourism activity would be prohibited in the MPA (tab.2).

Figure 10. Map of the proposed zonation for South Ari atoll MPA. Core areas corresponding to the areas where whale sharks are most commonly found, and subsequently the most commonly visited by tour operators (Mundy, 2017). Buffer zones corresponding to channels and the lagoon where whale sharks are frequently sighted (EPA, 2019a).

ALTERNATE ACCESS DAY SYSTEM

In SAMPA, boat activity varies throughout the week and vessel types encountered in the MPA also vary per weekday (fig.11; Cagua et al., 2014). Vessels encountered included liveaboards, resort vessels and guest house vessels (fig.11; Cagua et al., 2014).

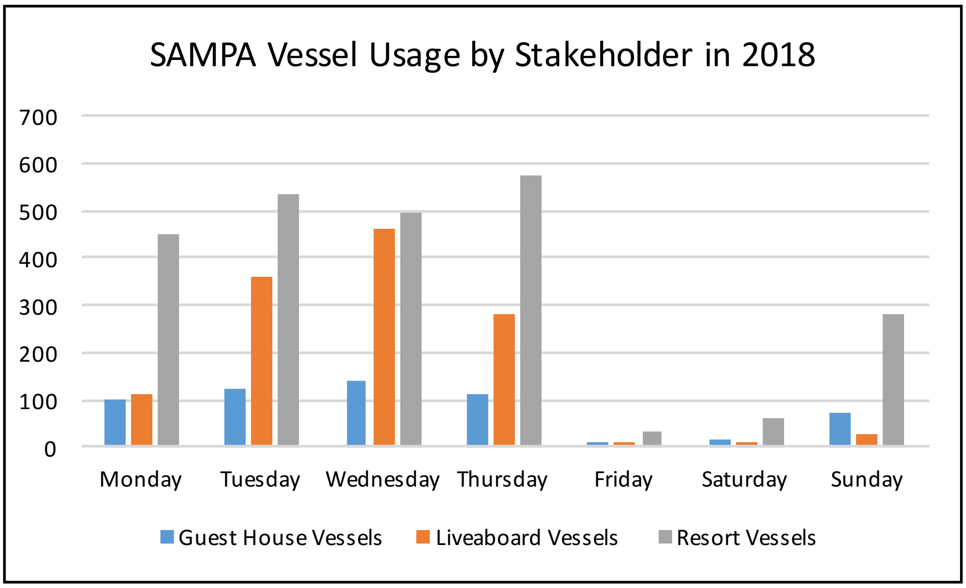


Figure 11. Total number of boats recorded in South Ari atoll MPA (SAMPA) throughout the year 2018, according to the type of vessel and the different days of the week. Data from Fridays and Saturdays are skewed as the MWSRP does not generally perform surveys on these days (Hancock 2019, unpublished data).

Liveaboards appear to be mostly present in SAMPA from Tuesday to Thursday than the rest of the week, while resort vessels visit the MPA more frequently from Sunday to Thursday. However, the presence of guest house vessels was relatively constant during the week. Fridays and Saturdays are the quietest days, but data from these days are skewed as the MWSRP does not generally perform surveys on Fridays and Saturdays (J. Hancock 2019, pers. comm., June 2019). In view of the above weekly distribution of vessel usage in SAMPA, an alternate access day system would limit the number of boats visiting the MPA on a same day and consequently minimize the boat-traffic associated risks (Allen, 2018; Ender, 2016; MHE, 2011). An example could be to focus resort operations from Saturday to Monday since liveaboards visit the MPA more frequently from Tuesday to Thursday (fig.11; tab.2). Guest house vessels could share the MPA with liveaboard vessels from Tuesday to Thursday, as the latter are less numerous than resort vessels (fig.11; tab.2). Finally, as suggested above, Friday being the quietest day, it could be designated as a 'Conservation Day', during which any tourism activities would be prohibited (tab.2).

Table 2. Proposed alternate day rota schedule whereby guest house vessels, liveaboard vessels and resort vessels would be allowed to access South Ari atoll MPA for whale shark excursions.

Weekdays / Vessel type	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Guest House Vessels		✔	✔	✔	Conservation (closed) Day		
Liveaboard Vessels		✔	✔	✔			
Resort Vessels	✔					✔	✔

LICENSING OF TOUR OPERATORS

As whale sharks are a protected species in the Maldives and given the negative impacts boats can cause to whale sharks, it is necessary to restrict the number of operators providing whale shark excursions and define the conditions in which those activities must be carried out (Cagua et al., 2014; DPaW, 2013). To this end, licensing of tour operators has been widely implemented in almost all whale shark tourism sites globally, including in Hanifaru (SEMARNAT 2019 and 2018; DPaW, 2013; MHE, 2011; Alicea, 2010; SERNA-DiBio, 2008). Conditions associated with licences must ensure the sustainability of whale shark tourism activities and the safety of people, for example by limiting the size of boats allowed to enter the MPA for whale shark interaction tours and adopting codes of conduct for boats and swimmers (Appendix.4; DPaW, 2013). In addition, a licensing system could create a sense of ownership and generate self-enforcement, while encouraging license holders to report any illegal activity to the relevant authorities, especially in a place like SAMPA where all stakeholders know each other (J. Hancock 2019, pers. comm. May 2019).

TOKEN FEE

As in Hanifaru, a token fee system should be implemented in SAMPA whereby each visitor has to purchase a token to be able to participate in whale shark excursions in SAMPA (Ender, 2016; MHE, 2011). Revenue generated should then be used to fund the management of the MPA, as well as local community projects. A separate fund representing all stakeholders, should be created and would be in charge of collecting and allocating all revenue generated from SAMPA entrance fees (Ender, 2016).

SPEED LIMITS

Most studies state that the risk of vessel-induced injuries to marine animals increases as vessel speed increases (Vanderlaan and Taggart, 2007). Regarding whale sharks specifically, all managed whale shark tourism sites analysed, including Hanifaru, implemented speed limits between 10 knots and neutral speed (Appendix.3.; MHE, 2011). Similar speed limits should therefore be implemented in SAMPA to lower the risk of boat strikes on whale sharks.

ENFORCEMENT

As in Hanifaru, official certified rangers should be assigned to SAMPA. They would be responsible for monitoring the implementation of measures defined in the management plan and reporting breaches of any measures to relevant authorities (Ender, 2016; MHE, 2011). In April 2019, the IUCN already stated that 4 rangers will be assigned to SAMPA (EPA, 2019a).

STAKEHOLDER INVOLVEMENT AND EDUCATION

Developing industry and community support for whale shark interaction management is critical to the effectiveness of the management plan (Giakoumi et al., 2018; DPaW, 2013; Pine, 2007; Rowat and Engelhardt, 2007; Thomas and Middleton, 2003). Therefore, close cooperation between all stakeholders at the initial stages of the development of the management plan, would allow a better understanding and cohabitation between conservation and socio-economic interests, thereby fostering a sense of ownership, acceptance of the need for restrictions (e.g., speed limits) and generating self-enforcement (Giakoumi et al., 2018; Reimer et al., 2016; DPaW, 2013; Thomas and Middleton, 2003). Workshops, social-auditing, feedback mechanisms, regular discussions, public consultations, and educational approaches could all be valuable approaches to engage stakeholders and promote cooperation (Giakoumi et al., 2018; DPaW, 2013).

Education is also crucial to complement the enforcement work of rangers (DPaW, 2013). Education can ensure that visitors and stakeholders have a sound understanding of the conservation and management issues associated with whale sharks, and thus generates self-enforcement (DPaW, 2013). Educational strategies could include provision of interpretive materials (e.g., brochures, interactive mobile application, laminated codes of conduct for display on vessels, in hotels and dive centres), public presentations and events (e.g., Whale Shark Festival), and whale shark interaction training courses for industry staff (DPaW, 2013; Pine, 2007; Rowat and Engelhardt, 2007). If the government does not have the resources for implementing training programs for stakeholders, the MWSRP as an Non

Governmental Organisation (NGO), could be accredited by the government to provide training, as has happened with the Southern Environmental Association (SEA) in Belize (SEA, 2019).

USE OF DRONES

Overcrowding and dense boat traffic are the main issues in SAMPA, and with the number of visitors expecting to increase, there is a growing need to reduce crowds of boats and people in the water, as well as improve whale shark interaction practices (Allen, 2018; Reguly, 2018; Rasheed et al., 2016; Cagua et al., 2014). With a transmission range of 7 km, an average of 27 minute-flight time and a live video transmission functionality, the use of drones by both rangers and tour operators could be an effective way to perform aerial surveillance and disperse boats among a greater number of sharks (DJI, 2019). Monitoring by air would provide rangers with an additional view of interactions that may not be so clear from their vessels, while the use of drones by operators would increase guests' chances to spot a whale shark and enable to avoid crowds. Nowadays, powerful drones are available to the general public and cost between £450 and £1,350 (DJI, 2019).

GPS TRACKER DEVICES

To be effective in protecting whale sharks, vessel speed limits must be well monitored and enforced (Laist et al., 2014; Lagueux et al., 2011; Hazel et al., 2007). The Maldivian government should therefore explore all GPS tracker options that could assist rangers in monitoring speed of vessels within the MPA boundaries, including cooperating with the Mexican and Australian authorities to explore the replicability of their electronic monitoring systems in SAMPA (SEMARNAT, 2018; DPaW, 2013). As in Gulf of California, Mexico, the implementation of a protocol for entry into SAMPA combining GPS tracker system and radio communication, could facilitate entry control within the MPA boundaries. (tab.2.; SEMARNAT, 2018).

CONCLUSION

This study proposes management, monitoring and enforcement measures that could be implemented in SAMPA in order to protect the whale shark population and ensure the prosperity of the associated tourism industry. This document could therefore serve to inform managers and stakeholders of potential measures to be defined in the future management plan for SAMPA. Furthermore, measures outlined in the present study show how modern and affordable technologies such as GPS tracker systems and drones, could help address logistic and economic constraints for monitoring and enforcing a MPA. Finally, the present study highlights that management and enforcement are crucial for the effectiveness of a MPA like SAMPA. In that respect, the proposed measures could be replicated in any other MPA facing similar issues in the Maldives and beyond.

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APPENDIX 1. List of search terms used for the different literature reviews performed for the present analysis.

Appendix 1a. Search terms used for the literature review (using Science Direct and Google Scholar) and internet searches (using http://www.google.com) performed to retrieve relevant data about whale shark aggregation sites around the world.

Source	Search terms
Science Direct and Google Scholar:	‘whale shark’, ‘*Rhincodon typus’*, ‘aggregation’, ‘tourism’, ‘tourist’.
www.google.com	***English***: ‘whale shark tourism’, ‘swim with whale shark’, ‘dive with whale shark’, ‘whale shark tour’ and ‘whale shark excursions’. ***French:*** ‘tourisme requin baleine’, ‘où nager avec le requin baleine’, ‘plonger avec le requin baleine’, ‘excursions requin baleine’. ***Spanish***: 'turismo tiburón ballena', 'nadar con el tiburón ballena', 'bucear con el tiburón ballena', 'excursiones con el tiburón ballena'.

Appendix 1b. Search terms used for the literature review (using Science Direct and Google Scholar) performed to retrieve relevant data about causes and potential mitigations measures of vessel-induced injuries on marine animals.

‘vessel’, ‘boat’, ‘collision’, ‘strike’, ‘injuries’, ‘death’, ‘whale shark’, ‘basking shark’, ‘manta ray’. ‘marine mammals’, ‘cetaceans’, ‘manatee’, ‘turtles’

Appendix 1c. Search terms used for the literature reviews (using Science Direct and Google Scholar) and internet searches (using http://www.google.com) performed to retrieve relevant data about new technologies that could be used for monitoring and enforcing SAMPA.

GPS tracker system: ‘electronic monitoring’, ‘electronic monitoring system’, ‘EMS’ ‘vessel’, ‘boat’, ‘speed’, ‘GPS’, ‘tracker’, ‘vessel speed’, ‘monitoring vessel speed’, ‘compliance’.

Drones: ‘drones’, ‘tourism’, ‘scientific expeditions’, ‘scientific research’, ‘monitoring MPA’, ‘aerial surveillance’, ‘MPA’, ‘drone footage’, ‘marine animal’.

APPENDIX 2. List of main whale shark aggregation sites worldwide, with information regarding aggregation periods, the presence or not of whale shark tourism activities at each site, and the literature sources where information has been extracted.

Aggregation location	Aggregation period	Whale Shark tourism activities	Sources
Australia, Ningaloo Reef	March to July	✔	Anderson et al. (2014); DPaW (2013) and Mau and Wilson (2007)
Australia, Christmas Island	November to January	N/K	Meekan et al. (2009)
Belize, Gladden Spit	March to July	✔	Alicea (2010)
Djibouti, Gulf of Tadjoura	October to February	N/K	Rezzolla and Storai (2010) and Rowat et al. (2007)
Galapagos	June to November	✔	Heam et al. (2014); and Galapagos Whale Shark Project (undated)
Honduras, Utila Island	March to April	✔	Fox et al. (2013) and SERNA-DiBio (2008)
India, Gujarat	Winter monsoon (November to February)	✖	Tata Group (2017); Vaidayanathan (2016); Matwal et al. (2014); Kumari and Raman (2007); Joshi et al. (2005) and Kulkami (2005)
Indonesia	December & March	✔	Ihsan et al. (2018); Nisa Utami (2015) and WWF (2015)
Madagascar, Nosy Be	October to December	✔	Diamant et al. (2016) and Madagascar Whale Shark Project Foundation (undated)
Mexico, Gulf of California	September to February	✔	SEMARNAT (2018) and Ramírez-Macías and Saad (2016)
Mexico, Yucatan Peninsula & Afuera	April to September	✔	SEMARNAT (2019)
Mozambique, Tofo Beach	Year-round aggregation with a September/October peak	✔	Haskel et al. (2015); Tibiriçá, et al. (2011); Pierce et al. (2010) and Marine Megafauna Foundation (undated)
Philippines, Donsol	Sighted year-round with a March/April peak	✔	Pine (2007); Quiros (2007) and Quiros (2005)
Qatar, Al-Shaheen Oil Field	April to October	✖	Robinson et al. (2017) and Robinson et al. (2013)
Saudi Arabia, Al-Lith	February to May	✔	Hozumi et al. (2018) and Berumen et al. (2014)
Seychelles	August to October	✔	Rowat and Engelhardt (2007) and The Marine Conservation Society Seychelles (2009)
Taiwan	March to June	N/K	Cruz et al. (2013)
Tanzania, Mafia Island	October to March	✔	WWF (2018) and Rohner et al. (2015)
USA, Northern Gulf of Mexico	June to August & October	N/K	McKinney et al. (2017) and The University of Southern Mississipi (undated)

N/K: Not Known
✔: Whale shark tourism activities carried out at the corresponding aggregation site
✖: No whale shark tourism activities

APPENDIX 3. Summary of management measures for whale shark tourism activities adopted in the 9 whale shark tourism sites that have official management and enforcement measures in place and retained for the present analysis.

Aggregation locations	Licensing/permit system	Zonation system	Vessel speed restrictions	Code of conduct	Training for industry staff	Monitoring and enforcement procedures	Sources
Australia, Ningaloo Reef	✔	✖	8 knots max in the contact zone (i.e., a radius of 250m of any whale shark)	✔	✔	Boat ramp inspections, industry vessel placements, covert operations, aerial surveillance and boat patrols.	Anderson et al. (2014); DPaW (2013) and Mau and Wilson (2007)
Belize, Gladden Spit	✔	Whale Shark Zone set up during the whale shark season	No more than 2 knots when approaching a whale shark	✔	✔	All boats should check-in with SEA rangers stationed inside the reef before proceeding to the Whale Shark Zone.	Alicea (2010)
Honduras, Utila Island	✔	N/K	2 knots max in the 'contact zone' . Neutral at 10m from a whale shark or when there are swimmers in the water.	✔	N/K	N/K	Fox et al. (2013) and SERNA-DiBio (2008)
Indonesia, West Papua	✔	N/K	10 knots max at 1km from the lift net (e.i., area where boats must dock for whale shark encounters) 2 knots max at 50m from the lift net.	✔	N/K	Teluk National Park Authorities operate controls.	Ihsan et al. (2018); Nisa Utami (2015) and WWF (2015)
Mexico, Gulf of California	✔	Implementation of three different zones: an exclusive whale shark zone (zone 1), a conservation area (zone 2) and a transit area (zone 3)	8 knots max in zone 3; 7 knots max in zones 1 and 2; and 3 knots max in any zone in presence of a whale shark.	✔	✔ Condition for obtaining a permit: mandatory training and certification for guides and captains.	Radio protocol: for entry into and exit from the observation zone. GPS tracker system: for monitoring position and vessel speed.	SEMARNAT (2018) and Ramírez-Macías and Saad (2016)
Mexico, Yucatan Peninsula & Afuera	✔	Whale shark excursion zone set up during the whale shark season	3 knots max in the whale shark excursion zone. Neutral in presence of a whale shark.	✔	✔ Condition for obtaining a permit: mandatory training and certification for guides and captains.	Operators must Inform on a daily basis (before 8:00pm) the relevant authorities about departure scheduldes planned for the following day	SEMARNAT (2019)
Philippines, Donsol	N/K	✖	N/K	✔	✔	N/K	Pine (2007); Quiros (2007) and Quiros (2005)
Seychelles, Mahe	N/K	✖	8 knots in the contact zone a (i.e., radius of 200m of any whale shark) and 2 knots at 50m from any whale shark.	✔	N/K	N/K	Rowat and Engelhardt (2007) and The Marine Conservation Society Seychelles (2009)

N/K: Not Known
✔: yes
✖: no

APPENDIX 4. Conservation and Land Management (CALM), Western Australia, whale shark interaction codes of conduct for swimmers and vessels (DPaW, 2013).