Establishing a quantifiable model of whale shark avoidance behaviours to anthropogenic impacts in tourism encounters to inform management actions.

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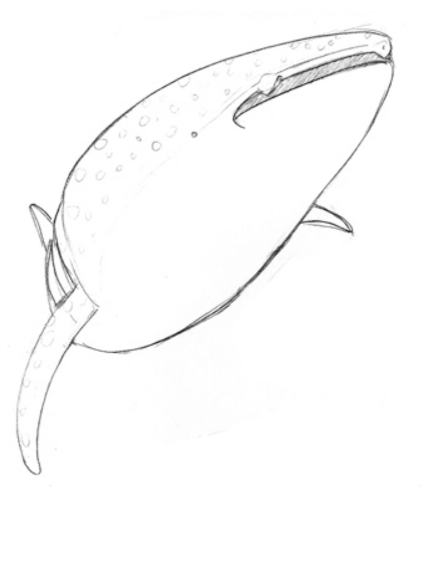

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"Desire is the key to motivation, but it's determination and commitment to an unrelenting pursuit of your goal – a commitment to excellence – that will enable you to attain the success you seek" - ***Mario Andretti***

Abstract

As the world's largest living fish, the whale shark has received much scientific attention in recent years, although despite this a great deal is still unknown on the life history and behavioural ecology of these majestic sharks. Whale shark related tourism has exploded in the last two decades from only a few sites in the 1990s to more than 12 sites internationally, allowing it to become a highly lucrative industry based upon this Vulnerable species. This study assesses the effects of anthropogenic impact on the sharks' avoidance behaviours within modern day tourism encounters, and provides recommendations on how to control and reduce unnecessary disturbance to the species. By means of stereo-photogrammetry, continuous high definition videos of human-animal interactions were recorded and analyzed for behavioural changes against pre-selected independant variables. The use of Stereo-photogrammetry imagery also allowed for the accumulation of repeatable, proximity measurements of swimmer distance to the shark, permitting more precise and accurate results. Avoidance behaviours of 33 individual whale sharks were monitored during typical tourism encounters (n=75). A total of 192 search hours were documented over the collection periods, which incorporated three-aggregation sites spanning the Indian Ocean (the Seychelles, the Philipines & Mozambique). A generalized linear model demonstrated that proximity of swimmers to the shark was found to be significant (p=0.0295) in explaining the probability of the whale sharks showing disturbed behaviour. A proportional odds plot for proximity was developed to give an indication of the animals disturbance level in tourism interactions. At recommended distances of three metres from the sides of the shark, there is on average a 42% chance of disturbance, while at the distance of four metres from the tail area results showed a 31% chance of overall disturbance. The true estimate for either distance is likely to lie between 22-53% respectively with regards to the uncertainty around the mean predictions. Whale shark tourism is viewed as a potential means of protecting this threatened species, while also providing a sustainable livelihood for local communities and tourism providers. Management recommendations presented offer suggestions on how to tackle concerns over proximity distances and links to disturbance. Additionally judgments for future research endeavors into assessing both the impacts of uncontrolled tourism and participants behaviour.

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1. Introduction

There are approximately 1,200 known species of cartilaginous fishes, which form the class *Chondrichthyes* (Campagno, 2001). This class is divided into two subclasses; *Elasmobranchii* (sharks, rays and skates) and *Holocephali* (chimaeras) (Compagno, 1984). The whale shark (*Rhincodon typus,* Smith, 1828) belongs to the order *Orectolobiformes* (carpet sharks) predominantly bottom-dwellers, which are described morphologically to have a range of notable characteristics: a sizeable mouth which is situated well forward of the eyes, five vertical gill slits, a single anal fin, two spineless dorsal fins and barbels on the ventral surface of their head (Campagno, 1988; Norman, 2002). *R.typus* represents the monotypic family *Rhincodontidae* (Rowat & Brooks, 2012) and was first described in science by Dr. Andrew Smith from a 4.6 metre specimen caught off Table Bay, South Africa (Smith, 1828). This original specimen was granted the genus name *Rhiniodon* (Smith, 1828; Compagno, 2001), but the following year it was amended to *Rhincodon* by the same author (Norman, 1999) and to date the holotype remains in the Natural History Museum in Paris (Stevens, 2006). The species is the world's largest living fish-like vertebrate and can attain lengths of well over 14 metres and weights of more then 20 metric tons (Campagno, 2001; Joung, Chen, Clark, Uchida & Huang, 1996; Norman, 2002, Quiros, 2007; Rowat & Brooks, 2012). To date, the largest specimen recorded, was from a Taiwanese fishery record from 1987, which reported the animal to be 20 metres in total length with a weight of approximately 34 metric tons (Chang, Leu & Fang, 1997). A subsequent shark was reported in 2010 from an Indian fisheries record, at a total length of almost 19 metres (Borrell, Aguilar, Gazo, Kumarran & Cardona, 2011).

Independently the whale shark can be characterised by its colossal size, tapering fusiform body type, three prominent longitudinal ridges (carina) that run horizontally along its dorsal flanks, an expansive flattened head with a nearly terminal mouth and a pattern of light spots and stripes over a dark body (Compagno, 1984; Norman, 1999; Norman, 2002; Rowat & Brooks, 2012). Unlike many other shark species, the skin patterns that juvenile whale sharks exhibit, remain unchanged as they mature (Wilson & Martin, 2003). Present research techniques by means of photo identification of the individual skin markings of *R.typus* shows that they can be individually identified using their unique pattern of spots and stripes (Arzoumanian, Holmberg, Norman, 2005), which offers a modern, non-invasive platform to investigate population demographics for the species (Pierce, Mendez-Jimenez, Collins, Rosero-Caicedo, Monadjem, 2010). By using spot recognition software, individual sharks can be consistently identified from one another (Arzoumanian et al., 2005). Commonly, the I^3S (Interactive Individual Identification System; van Tienhoven, Den Hartog, Reijns, Peddemors, 2007) is used to identify whale sharks and any other species that exhibit external body markings. It relies on a unique spot pattern extracted from the segment posterior to the fifth gill slit of each shark, create a "fingerprint" to determine its individuality (Arzoumanian et al., 2005). The methodology, upon which the I^3S software is based, is generic and can be applied in principle to any species that display characteristic skin patterning (Speed, Meekan, Bradshaw, 2007). ECOCEAN (Norman, 2002) utilizes a proprietary pattern matching software for the collection and archiving of whale shark identification photos. ECOCEAN provide a web based portal for cataloging and analyzing whale shark identification photos and is maintained and used by both researchers and interested parties (Arzoumanian et al., 2005), with its main purpose being to gather robust information on the global distribution of the species.

There are a number of theories about the purpose and function of the external body markings of whale sharks; one premise is the distinctive markings may be intended for a dual camouflage purpose (Wilson & Martin, 2003). They postulate that the patterns on the shark's dorsal surface act as a kind of disruptive coloration helping the shark almost unify with its medium, while the coloration on the ventral surface, exhibits counter-shading against the surface water (Rowat & Brooks, 2012; Wilson & Martin, 2003). This counter-shading may also be useful in the neonate stage of development, to conceal them from potential predation (Rowat & Brooks, 2012). Further speculations for these unique body markings are that they might be used during conflicts to exhibit alpha male advantages or exploited during courtship behaviours to attract a potential mate (Baracchi et al., 2012), although the exact role is unknown.

R.typus skeletal composition is a made up of a durable, lightweight, supple cartilage (Campagno, 2001; Gudger, 1915). The species also lack a solid rib-cage structure, which reduces the overall weight of the animal. A sub-dermal complex mesh corset of collagen fibres serves as a flexible external skeleton, that permits the sub-dermal attachment of the locomotory muscles from the backbone in a light and mechanically efficient system (Martin, 2007; Rowat & Brooks, 2012). Unlike bony fish, whale sharks and all members of the elasmobranch family do not possess swim bladders and rely on their extant livers as an aid for buoyancy control (Gudger, 1915). The external characteristics of the species epidermal layer, is comprised of rows of perfectly aligned dermal denticles (Norman, 2000). These external denticles have three longitudinal ridges, the central one forming a sturdy central keel with deep grooves on either side (Bigelow & Schroeder, 1948). These special designed adaptations of the skin serve as a hydrodynamic aid reducing drag and surface-noise production improving the animal's movement in the water, which reduces energy loss during locomotion (Gleiss, Norman & Wilson, 2010).

Generally speaking, the majority of sharks have an unusual combination of biological characteristics such as; slow growth and delayed maturation; long reproductive cycles; low fecundity and long life spans, i.e. K selection features (Compagno, 2001). It is uncertain at what size or age whale sharks become sexually mature, although a number of studies have been made on a variety of possible indicators such as clasper morphology (Norman & Stevens, 2007), vertebral growth rings (Wintner, 2000) and growth rate analysis on captive specimens (Uchida, Toda, Kamei & Teruva, 2000). Clasper morphology may be considered a straightforward non-invasive means of determining probable sexual maturity in male whale sharks (Joung & Chen, 1995). Like many other male species of sharks, immature individuals have short, flexible and often smooth claspers that do not exceed the posterior edge of the pelvic fins. During maturation, clasper growth and calcification occurs and the rate of clasper growth accelerates (Bass, D'Aubery & Kistnasamy, 1975). Males may be considered mature once their claspers extend beyond the pelvic fins (Norman & Stevens, 2007). Studies using growth rings in the vertebrae rely on the theory that the animal leaves permanent markings (growth rings) on the vertebra annually (Cailliet, Radtke. & Welden, 1986). A growth ring is defined as a band pair, comprising of one calcified (opaque) ring and one less-calcified (translucent) band (Norman & Stevens, 2007) (fig.1).

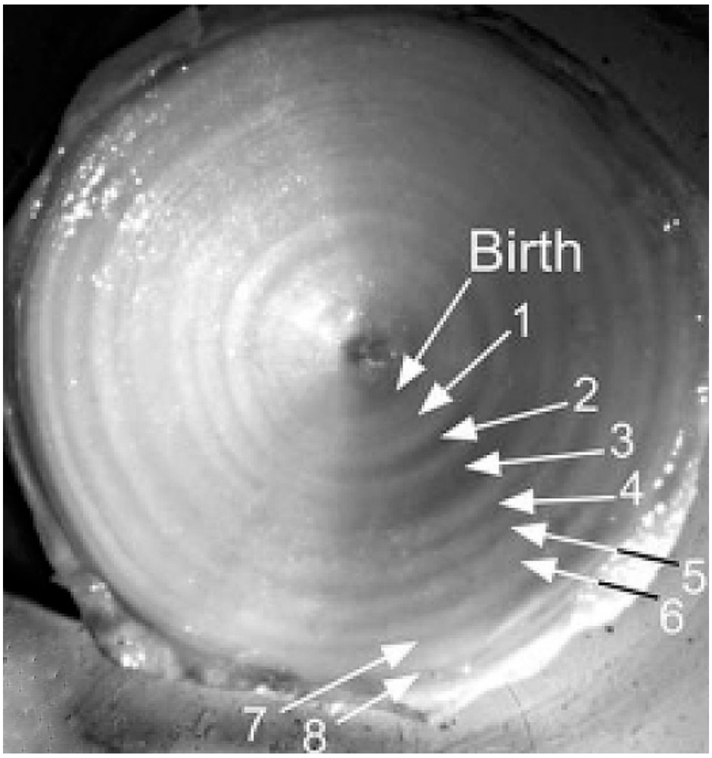


Figure 1: Magnified view of the species vertebra showing both opaque & translucent growth rings. (*Image courtesy Dr. Steven Campana, Bedford Institute of Oceanography, Canada)*

In recent years, there have been many advances in the quantitative study of growth rings to determine age and growth of chondrichthyan fishes, although there is still some controversy over terminology and the methods used to both verify and validate age estimates from chondrichthyan calcified structures, especially edge and marginal increment analyses (Cailliet et al., 1986). However, due to the large size of whale sharks and the limited access to whale shark vertebrae, especially those combined with accurate length measurements, determining growth rates for whale sharks using occasional standing or un-intentional catches, leaves this technique relatively impractical, although initial studies show promising results (Wintner, 2000). Current estimations of whale shark maturity suggest that males mature at ≥9 metres total body length and that females are the same or perhaps larger than males at first maturity, although there is no conclusive evidence to determine exactly when first maturity is reached for the species (Rowat & Brooks, 2012).

Additionally, the longevity of whale sharks is also uncertain and may be as long as 100 years (Campagno, 2001). Currently, the majority of published work on the longevity of whale sharks comes from research derived from measurements taken from captive individuals

(Uchida et al., 2000), within artificial environment conditions, and given the small sample size it poses queries when compared to other wild animals (Chang, Leu, & Fang, 1997; Uchida et al., 2000). A captive whale shark in the Osaka aquarium, Japan grew from four to almost eight metres total length in eight years (Chang, Leu, & Fang, 1997; Rowat, 2008)). A publication by Wintner (2000) examining the growth rings of whale sharks, expressed that a whale shark of around five metres (precaudal length) would be approximately 20 years of age.

Virtually nothing is known about whale shark breeding behaviour and their reproduction cycle, as observations of mating or courtship activities within the species have never been witnessed. Very few cases of juvenile sharks less than three metres in total body length have ever been sited globally (Schmidt et al. 2010). Evidently, only 19 neonate sharks measuring less then 1.5 metres appear in scientific literature (Rowat & Brooks, 2012; Schmidt et al., 2010). Historically, the reproductive cycle of the whale shark has long been under debate, as the species were first thought to be oviparous, based on a single egg case from the Gulf of Mexico that carried a live 37 cm total body length embryo (Schmidt et al., 2010). It was not until 1995 that scientists discovered the species to be a livebearer, with an ovoviviparous mode of development (Joung et al., 1996). Ovoviviparity is the method of reproduction where fertilized eggs develop and hatch within the uterus but gain no additional nutrition from the mother, before being birthed as fully developed live young (Camhi, Fowler, Musick, Brautigam & Fordham, 1998). Undeniable evidence of this came when the Taiwanese fishery caught a 10.6 metre pregnant specimen, internationally known today as "*Megamamma*", which was carrying 304 embryos in her twin uteri, all at numerous life stages (Joung et al., 1996). The largest of the embryos (58-64 cm) were free of their egg cases and had no yolk sac, indicating they were ready to be released (Joung et al., 1996). From this litter, the two largest living embryos were kept alive in captivity for a little over 4 months (Chang et al., 1997; Schmidt et al., 2010). This discovery may well make *R.typus* the most fecund species of all live bearing sharks (Joung et al., 1996).

The species is highly migratory, with individuals sighted in numerous regions across the globe (Rowat & Brooks, 2012). *R. typus* in the main, are solitary animals spending the majority of their lives migrating the tropical and sub-tropical waters, navigating along scent trails that lead to areas of intense productivity, such as coastal upwelling zones (Cliff, Anderson-Reade, Aitken, Charter & Peddemors, 2007). In spite of this solitary lifestyle, these sharks are known to regularly form almost sex-segregated aggregations in coastal waters (Colman, 1997a). These aggregations are generally sporadic and seasonal, and typically lie between latitudes of 30°N and 35°S (Campagno, 2001). From current research it seems to be clear that these aggregations are temporary and often linked to specific productivity events (Wilson, Taylor & Pearce, 2001).

Whale sharks are known to be epipelagic and have been observed in both oceanic and coastal waters (Rowat & Brooks, 2012) while they seem to predominantly prefer sea temperatures of between 25°- 35°C (Colman, 1997; Rowat & Brooks, 2012).
The ability of the species to withstand short-term exposure to colder waters does not seem to be a barrier to the species' movements, as they have been recorded making regular dives into water masses with temperatures of below 10°C (Compagno, 2001). With modern technological advances by means of satellite tagging and tracking devices, research into the species range and dive behavior will become much clearer. With knowledge of the species range, a significant comparison with biophysical factors will help to identify potential areas of occurrence and transitory pathways (Rowat & Brooks, 2012).

This extant shark is one of only three filter-feeding shark species, along with the basking shark (*Cetorhinus maximus*) and the megamouth shark (*Megachasma pelagios*) (Compagno, 2001). Collectively they feed on a wide variety of planktonic (microscopic) zooplankton and nektonic (larger free-swimming) prey (Clarke & Nelson, 1997). Additional prey includes tiny crustaceans, small schooling fishes such as sardines, anchovies and occasionally small tuna and squid (Campagno, 1984). The mouth of *R. typus* is lined with numerous rows of tiny teeth, approximately 300 in each jaw, that apparently play little or no part in their feeding activities (Rowat, 2010). As the eyes of the whale shark are reasonably small they are believed to have relatively poor vision (Compagno, 1984), therefore prey items are almost certainly located primarily by the sharks' olfactory senses (Colman, 1997; Motte et al., 2010). Their well-developed nostrils located on either side of the upper jaw may be able to detect plankton density though the water column, enabling the shark to orientate to follow the most dominant scent trail (Compagno, 1984). During filter feeding, water enters the mouth, passes down into the pharynx, proceeds through the 20 filtering pads exiting between the primary and secondary vanes, passes over the primary gill filaments and into the parabranchial chamber, then finally exiting the external gill slits on either side of the sharks head (Motta et al., 2010; Nelson & Eckert, 2007). This filtering apparatus maximises food intake, meaning that almost nothing but liquid passes back out through the gills (Motta et al., 2010).

To date research has revealed that whale sharks carry out at least three methods of filter feeding (Motte et al., 2010). The most frequently observed behaviour is active surface feeding or surface ram feeding (Clark & Nelson, 1997; Taylor, 2007). When engaged in this, the whale shark swims at the surface of the water with the dorsal surface of its head and upper fins protruding (Motte et al., 2010). The open mouth is lifted to some degree out of the water, and the animal swims at relatively slow speeds ramming the water and food source through its filtering apparatus (Heyman, Graham, Kjerfve & Johannes, 2001; Motte et al., 2010). Whale sharks have been witnessed sweeping their head from side to side as they swim, as a maneuver to capitalise on plankton intake (Colman, 1997).

During suction or vertical feeding, the shark either remains in a relatively horizontal position or will incline themselves in a near vertical position, and almost ceases swimming while creating suction in its pharynx to draw in plankton or small fish with repeated opening and closing of its mouth (Motta et al., 2010; Nelson & Eckert, 2007). Finally, passive feeding or ram feeding is described as the shark swimming slowly through the water with their mouth wide open, sifting the food from the water and every few minutes its mouth will close and the shark will appear to swallow (Heyman et al., 2001). Additionally, the species has been also observed, "coughing" during feeding, which is understood to be a way of back-flushing water through the filtration pads (Taylor, 2007). After this 'coughing', the sharks have been witnessed resuming the same feeding behaviour as prior to the cough (Motta et al., 2010).

The non-aggressive nature of these giant sharks, their aggregation behaviour at specific times of the year, their slow maturation rate and distinctive feeding habits make them very susceptible to targeted and non-targeted fishery impact (Colman, 1997; Taylor, 1994). Traditionally whale sharks were hunted for their liver oil, used for waterproofing wooden boats (Colman, 1997), although in recent years, demands for their meat and fins have increased, creating the international trade that became the main stimulus for new, improved, targeted fisheries (Norman, 2002). As the cartilage fibres in the sharks' fins are apparently not high quality for making soup, the fins are either discarded or sold for display in shark-fin soup restaurants (Chen & Phipps, 2002). In the early 1990s, there was a rapid increase in the demand for whale shark meat, known as "tofu shark" with this being promoted as a delicacy by the Taiwanese restaurant trade (Chen, Liu & Joung, 1997). Rapidly Taiwan became the major market for *R. typus* meat, but the meat was presumably also valued by Chinese communities elsewhere, although lack of trade monitoring hinders identification of other consumer states (Pine, Alava & Yaptinchay, 2007). During the mid-1990s a number of small-scale artisanal fisheries targeting the species existed in a number of countries such as India, Iran, Maldives, Pakistan and the Philippines (Anderson & Ahmed, 1993; Alava et al. 1997b; Hanfee, 2007; Rowat & Brooks, 2012).

Despite a demand for whale shark meat, its increased value and amplified search effort, the catch size declined dramatically and in the start of the 21st century the total Taiwanese catch recorded was 113 animals (Chen, 2002). These significant declines in catch numbers and the increase in demand for Tofu shark lead to the consequent expansion of the Taiwanese fishery into other areas such as India and the Philippines (Hanfee, 2007). Catches continued to decline throughout the entire Indian Ocean region and by 2002 most targeted fisheries for whale sharks had collapsed (Hanfee, 2007; Ziegler, 2010). In 2008, Taiwan prohibited the killing of the whale shark in its state waters as well as the import and export of its meat and other products (RoC, 2007).

Currently the largest non-targeted fishery for whale sharks comes from purse-seine fleets (Rowat & Books, 2012). For many years tuna fisheries have used whale sharks as an indicator of tuna presence and consequently lay their nets around them (Iwasaki, 1970). Recent records from a number of purse seine fleets have shown that the individual whale sharks are usually released from the nets alive (Amande et al., 2010; Chassot, Amande`, Chavance, Pianet & Dedo, 2009; Rowat & Brooks, 2012),

The first steps towards international management of marine resources was the United Nations Convention on the Law of the Sea (UNCLOS) (UNCLOS, 1982; Ziegler, 2010); this provided a foundation for the conservation and management of all fisheries and other uses of the seas, but to date no management initiatives under this convention have included *R. typus* (Rowat & Brooks, 2012). In 2000 the species was classified as 'Vulnerable' by the International Union for Conservation of Nature and Natural Resources (IUCN) (IUCN, 2010;

Norman, 2002). This classification was supported by the data collected from the Indian Ocean fisheries, mainly around India and the Philippines, which showed declining catch records during and following the collapse of their targeted fisheries (Hanfee, 2007). Based on these precedent fishery records, further population decline was projected or suspected in the future due to the species‘ slow recovery rates by comparison with other shark species, subsequent to new and continued targeted fisheries and as a result of by-catch (Norman, 2000). Additional use of the fisheries records, led to the species being included on Appendix II of the Convention of Migratory Species of Wild Animals (CMS) (CMS, 1999) and Appendix II of CITES, the Convention of Trade in Endangered Species (CITES, 2002; Schmidt et al., 2010; Rowat & Brooks, 2012). On a national level, the conservation and safeguard of the species depends heavily on the fundamental understanding of transitory pathways, these sharks have a tendency to use (Ziegler, 2010).

2. Literature review

Chapter overview:

The need for a literature review is essential to offer a comprehensive understanding of both the modern day whale shark tourism industry and to justify the use of a sophisticated stereo photogrammetry measurement system used to formulate results. As these two subject areas are very diverse in their own respect, two independent reviews are presented in this chapter to allow a much broader understanding of firstly, the whale shark tourism industry from its initial development to the practices currently enforced today, and finally the fundamental principles of photogrammetry and stereo-photogrammetry and its present use as a tool for extracting robust and reliable measurements for the modern marine scientist in the underwater environment.

2.1 A Review of shark related tourism with an emphasis on the development of Whale shark (*Rhincodon typus*, Smith 1828) associated tourism.

2.1.1 Introduction to tourism

Tourism involving human-wildlife interactions appears to be escalating, as people continue to seek out authentic encounters with wild animals in their natural habitats. Globally, wildlife based tourism is one of the fastest growing forms of tourism (Muloin, 1998; Reynolds & Braithwaite, 2001) and generates a substantial revenue for local businesses and communities. The term wildlife generally covers all forms of fauna and flora, from terrestrial to marine organisms, while in popular use, wildlife may be used to refer to animals in the their natural habitat (Tapper, 2006).

The conservation of a species based on their role in the upholding of healthy marine ecosystems has failed to halt the global decline in a number of shark populations and approximately 100 million sharks are killed every year from targeted and non-targeted fishery pressure (Vianna, Meekan, Pannell, Marsh, Meeuwig, 2011; Compagno, 2005). Furthermore, over the last two decades key shark populations have decreased by up to 90% worldwide and many are now considered to be at risk of extinction (Compagno, 2005). Shark fisheries and markets in South East Asia are expanding rapidly, with new targeted fisheries being actively developed and the trade in and value of shark products are increasing to cover the growing demand for traditional and non-traditional uses of sharks (Vianna et al., 2011; Ziegler, 2010) such as; the utilisation of the species liver oil for water proofing boats against wood deterioration, the use of shark fins in traditional food dishes and availability of their skin and dentures for sale in the retail sector.

To begin to understand whale shark related tourism a basic clarification of "*shark tourism*" as a whole is necessary. Shark tourism is widespread throughout tropical, subtropical and temperate marine ecosystems and gives rise to controversy because there is little consensus regarding its management (Vignon, 2010). Encounters between humans and sharks take place in both captive and natural environments. However some interactions in the wild may rely on attracting the animal to the tour operators vessels by means of baiting or the development of habituation to humans to increase the likelihood of a sighting or interaction. These contrived experiences may sit between semi-captive and natural encounters (Orams, 2002*)*. In the last two decades, many shark species have been exploited for tourism activities, but the main species that are predominantly used are those sharks that are more often than not top marine predators or large charismatic species, which pose no threats to humans (Fowler, Reed & Dipper, 2002).

Shark tourism is separated into a number of categories that define the different encounter or interaction procedures by which humans interact with sharks. Areas, such as South Africa have become recognised for their the great white shark (*Carcharodon carcharias*) the same way as Florida and the Caribbean have for their tiger sharks (*Galeocerdo cuvier*), bull sharks (*Carcharhinus leucas*) and Caribbean reef sharks (*Carcharhinus perezi*). With the wide spread distribution of pelagic predatory sharks and the large filter feeding species, the industry has now harmonised an awareness of the migratory movements and seasonal feeding patterns of these desired fauna. Tourism involving sharks is a way in which communities are given an opportunity to benefit from their natural, local resource, and a way for them to see that the species is more valuable alive, rather than opting for a one time economic benefit of harvesting sharks for their body parts (Fowler et al., 2002).

Finally, certain species are popular with tour operators due to their status as ”*wildlife icons*” (Lück & Higham, 2008). These tend to possess a certain degree of charismatic properties such as attractiveness and approachability that in turn makes them safe and appealing to humans of all abilities and experience. Despite the attraction of approachable non-threatening species, dangerous predatory species still attract large numbers for the ‘thrill’ of close encounters.

2.1.2 Whale shark tourism

Seasonal aggregations or regular occurrence of whale sharks (*Rhincodon typus*, Smith 1828) have been reported in a number of known locations, such as Ningaloo Reef (western Austraila) (Norman, 2002), Belize (Graham, 2004), the Seychelles (Rowat & Engelhardt, 2007), the Maldives (Riley, Hale, Harman & Rees, 2010), Kenya (Irvine, 2007), the Philippines (Quiros, 2005), South Africa, Thailand (Islands of the Andaman Sea) (Rowat, 2008), Mozambique (Pierce, Mendez-Jimenez, Collins, Rosero-Caicedo & Monadjem, 2010), Djibouti (Rowat, 2007), The Galapagos (Compagno, 1984), Mexico (Sea of Cortez & Baja California) (Clarke & Nelson, 1997; Ziegler, 2010), Taiwan (Chen, 2002), Pakistan (Rowat & Brooks, 2012) and numerous other regional and international state waters (Colman, 1997). Whale shark related tourism has exploded in the last two decades from only a few sites in the 1990s to over 12 sites internationally and the industry is estimated to be worth US$ 66 million worldwide (Graham, 2004; Ziegler, 2010).

Initial photographic observations of whale sharks were conducted by the naturalist Dr. Geoff Taylor in 1982 (Taylor, 1994; Colman, 1997) from his preliminary surveys at Ningaloo Marine Park, Western Australia (NMNP). From these early studies came proof of the seasonal aggregations of whale sharks to Western Australia; he also investigated a wide range of variables affecting the seasonal occurrence and density of the whale shark at NMNP and their relationship between coral spawning events (Colman, 1997). Taylor's commitment to the understanding of these charismatic fish gave rise to the first localized whale shark tourism industry from the small fishing village of Exmouth, Western Australia (Rowat, 2008). With financial support from the Australian National Parks and Wildlife Service (ANPWS) a three-year aerial survey was executed (Colman, 1997) along the NMNP. The results demonstrated the occurrence of whale sharks along its fringing reef during the autumn months, in harmony with annual mass coral spawning events (Taylor, 1994).

Whale shark interaction tours are believed to have started in 1989 in correlation with these seasonal appearances and up until 1992 (Colman, 1997), the operations were relatively small with only a handful of provincial boats taking curious visitors out to view the sharks. By 1993, increasing regional and international publicity from a series of scientific publications and documentaries fuelled a significant expansion of public interest to interact with these animals (Rowat, 2008).

In 1989, The Department of Conservation and Land Management (CALM) issued a management plan for the state waters of the Ningaloo Marine Park (CALM, 1989) and additionally, along with CALM's management plan, the Australian National Parks and Wildlife Service (ANPWS) in 1990 issued a plan of action for their Commonwealth waters (ANPWS, 1990). Unfortunately both plans were introduced before the outbreak and increased demand for whale shark tourism along the Western Australian coast (Colman, 1997). Ultimately, CALM was tasked with the responsibility to control this growing tourism venture and took initial steps to ensure that this business was being managed equitably and sustainably (Colman, 1997; Norman, 2002).

Before the start of the 1993 season, CALM conducted preliminary research into the existing whale shark industry and from their findings, in co-operation with several dive operators, drafted a trial framework of management controls for the commercial tourism activities with whale sharks and a first version of an in-water code of conduct (Colman, 1997; Norman, 2002; Quiros, 2007; Rowat, 2008) to minimise disturbance to the sharks from the escalating human presence.

Management controls began with licensing, under the Wildlife Conservation Act, of all existing boat operators present in the NMNP zone. The development of this code of conduct came from existing knowledge of the industry, available scientific data, common sense and the national whale-watching guidelines (ANPWS, 1988; Colman, 1997). The first draft banned the touching or riding of the animal and set the minimum distances to the shark and a maximum number of swimmers in an individual encounter. The guidelines also banned the use Diver Propulsion Vehicles (DPV) and prohibited the use of flash photography (Colman, 1997). All recommendations within the code of conduct where aimed to minimise any potential negative impact on the sharks and all licensed operators who participated were required to adhere to the agreed licensing rules and code of conduct guidelines (Rowat, 2008).

Birtles et al. (1996) and Davis & Tisdell (1996) published studies on in-water participants and found that the problem of over-crowding, proximity of swimmer to the shark and the number of persons in the water were especially important in relation to the quality of the in-water experience (Davis, Banks, Birtles, Valentine & Cuthill, 1997).

At the conclusion of the 1995 season, mutual concerns regarding the maximum number of swimmers in close proximity to the shark was expressed. From this concern, CALM proposed a reduction from ten to eight swimmers in the water on any given encounter, although this alteration came with a certain amount of resistance from operators on commercial grounds (Colman, 1997). Further discussion with all parties and the results of the 1995 participants' survey prompted the decision to revise not only the minimum swimmer/shark separation distance, but to review the Code of Conduct once more. Formerly, the Code only required the swimmers to stay a minimum of one metre from the head or body of the shark (Colman, 1997).

Prior to the beginning of the 1996 season, the code was adjusted resulting in the maximum number of swimmers in an encounter lowered from ten to eight and the separation distance of swimmers to shark altered to a minimum of three metres from the head or body of the shark and four metres from the tail (Colman, 1997; Norman, 2002). This revised plan was considered to both benefit the animal and improve the tourism experience, by reducing over-crowding and the risk of unexpected contact with the sharks**.** To the present day, the enforcement of the code of conduct and the management of the industry at NMNP remain the "Best Practice model for this industry" (Norman, 2002).

Following on from the success of Australia's whale shark industry, several other countries that have regular whale shark sightings began to develop their own localised whale shark tourism ventures. In 1996 Belize, the Seychelles and South Africa all showed interest and instigated their own plans for the development of whale shark related eco-tourism. Between October and November of 1996, two pilot project were initiated by the Shark Research Institute (SRI), one in the Seychelles in conjunction with the Association of Professional Divers, Seychelles (APDS) (Rowat, 1997) and the other in South Africa in cooperation with local dive operators (Rowat, 2008). The seasonal appearances of Whale sharks around the coastal waters of Mahé in the Republic of the Seychelles was common knowledge, but until 1996 very little scientific research had been undertaken on their number or migratory movements (Rowat & Engelhardt, 2007). With support of the Minister of Tourism and Transport Seychelles (MTT), the Shark Research Institute and the APDS, a pilot research plan was developed to investigate the frequency and density of the sharks' seasonal visits and whether they could be utilized as a sustainable eco-tourism resource (Rowat, 1997). Initially a tagging project of individual whale sharks around the Islands waters was introduced, as this had been proven to be an effective method for assessing the population of the species (Rowat, 1997; Tyminski, Hueter & De la Parra, 2008). By tagging whale sharks with large fluorescent marker tags it was possible, through repeat sightings, to generate estimates of the local population size and short term movement patterns (Rowat, 1997; Rowat & Gore, 2007).

A study by Newman, Medcraft and Coleman (1997) calculated that a flourishing whale shark tourism industry in the Seychelles, over its short 14 weeks season, could be worth an estimated US$ 3.95 to $ 4.99 million per annum (Rowat, Gore, Meekan, Lawler & Bradshaw, 2008). Another study in 2004 estimated lower revenue of between US $ 1.2 to $ 2.8 million per year derived from 15,000 potential participants (Cesar, van Beukering, Payet & Grandourt, 2004). All parties involved were cautious about the rapid development of a whale shark tourism industry in the Seychelles, so a trial three-year monitoring programme was implemented (Rowat, 2007; Rowat & Engelhardt, 2007) to continue the research on the population status around the countries waters. During this trial period, operators agreed on a code of conduct based on the "Best Practice model" currently used in Western Australia. The best practice model requires in-water participants to be at a minimum distance of three metres from the side and head of the shark and four metres from its tail (Tayler, 1997). It limits the maximum amount of swimmers during a single encounter to eight, and adopts a no touch policy to safe guard not only the animal, prohibit the use of any underwater diver propulsion vehicles (DPV) and forbid flash photography (Norman, 2002). Further regulations concerning operators' safe guard boating protocols setting a maximum boat speed to six knots in the interaction zone and once in the range of one hundred metres of the animal no propellers must be set to neutral (CALM, 1995) (A visual diagram of the code of conduct is presented in Appendix 1). The Government of the Seychelles approved the trial interaction plans; furthermore the growing interest in whale sharks by visitors to the island prompted a more pro-active management approach for their future whale shark industry. In 1997, the Marine Conservation Society Seychelles (MCSS) a non- Governmental and non-profit organization was established. The MCSS created the whale shark monitoring programme Seychelles and continues to stand at the forefront of modern scientific research into these sharks, whilst following the best practice model for interactions with whale sharks (Rowat, 2008).

In South Africa the approach was slightly different for the potential growth of a small whale shark tourism industry. Similar to the Seychelles, a tagging programme was used to try to assess the population status and movements of the species around South African waters. With the cooperation of local dive operators, a project that helped to raise public awareness and involve local communities first hand in a monitoring programme "the whale shark weekends" (Rowat et al, 2008) was launched. This led to the need to raise funds, for the proposed monitoring programme and future industry along its coast (Gifford, 1998; Rowat & Engelhardt, 2007). From the early work around South Africa's southeast coastline, a rudimentary code of conduct was adopted for all participants, based once again on the code of conduct for interacting with whale sharks developed by CALM, Western Australia (Rowat et al., 2008).

In Belize, the local fisherman harvesting mutton snappers (*Lutjanus analis*) from a spawning aggregation on the Gladden Spit during the time of the full moon around April and May each year, have always been aware of the annual visitations of whale sharks to their fishing grounds (Graham, 2001; Heyman, Graham, Kjerfve, & Johannes, 2001). In response to their reports, in 1996 one dive operator and a local community based group 'Friends of Laughing Bird Caye', started co-operating with the local community (Carne, 2007) and together introduced interaction guidelines for in-water activities, again based on the Australian code of conduct (Graham, 2001; Carne, 2008).

Once these guidelines were initiated, the NGO held training courses to re-train local fisherman as whale shark guides (Graham, 2007). In 1998, there were four operators running whale shark tours, and by the beginning of the 2005 season there were estimated to be as many as 26 whale shark tour operators, offering various levels of knowledge and client satisfaction (Carne, 2008). In early 2000 the area around the Gladden Spit was declared a Marine Reserve and the Friends of Nature (FoN), which evolved out of the original community group Friends of the Laughing Bird Caye was born. The FoN was declared a legal non-governmental and non-profit organization in 2002 (Carne, 2008) with its primary objective to safeguard the local industry and to help liaise between operators and the local Government (Carne, 2007).

The industry's fortunes have varied in recent years, as the chance of sighting a whale shark in the reserve was as low as just 20% in 2004, compared to over 80% in 1999 (Carne, 2007). This dramatic decline was possibly due to a number of factors, mainly over-crowding of the site, increased pressure on the sharks, creating guest dissatisfaction, conflict and tension between operators and the flaunting of regulations (Carne, 2007, 2008). By the end of the 2004 season, local government and stakeholders implemented a strategy for the allocation of activity time-slots, through a lottery style approach for all operating vessels (Carne, 2008). This lottery system gave an allocated time slot at the aggregation site to each tour operator throughout the season. The main purpose of the system was to stop the overcrowding in and around the whale shark interaction zone and in theory diffuses the tension among operators (Carne, 2008). Over recent years, whale shark sightings have slowly began to climb once more around the Gladden Spit Marine reserve and further revisions of the regulations in 2007 have given rise to patrol boats to enforce regulations and management of the time slots. Additionally, for the safeguard of the sharks, the government of Belize has passed a fixed penalty of US $5000 for any tourist who touches or harasses the shark (Carne, 2008).

The fishing village of Donsol, in the Sorsogon providence of the Philippines was the next to follow in the utilization of whale sharks for a non-consummative source of income. In January 1998, the discovery of a huge aggregation of whale sharks in and around Donsol bay attracted the attention of the media and local authorities (Quiros, 2007). Following this discovery, local fisherman began hunting these sharks and after the killing of seven sharks in Donsol's waters, local authorities with the assistance of the World Wildlife Fund (WWF) declared Donsol bay, Sorosogon a whale shark sanctuary (Rowat, 2008).

Further, hunting and trading of whale shark meat or fins was banned in the Philippines under the Department of Agriculture Fishery Administrative Order No. 193 (Pine, Alava, Yaptinchay, 2007; Yaptinchay, 1999). The same year the WWF-Philippines started the Whale Shark Research and Conservation Project in Donsol, which had a clear objective to develop a community-based whale shark industry that would directly benefit the local community, while still maintaining sustainability (Quiros, 2005). Due to poor infrastructure in this region and the lack of visitors over the initial years, the sustainability of the project was under threat in Donsol, but by 2004 with continued mounting awareness resulting from media coverage and an international documentary by the National Geographic, the number of tourists rose from 850 in 1998 to over 3000 in 2004, generating US $48,000 in direct revenue that year (Pine et al., 2007; Quiros, 2007).

A number of fishery representatives, local authorities and the WWF met to establish a sustainable management plan for the escalating activities in Donsol. They investigated the practices currently used throughout the whale shark industry and agreed to adopt the Australian rules and regulations that were put in place as a starting platform for the project (WWF, 2011, Bruce, personal communication). To enhance community-based support, local fishermen were re-trained as boat captains and tour guides in a bid to re-direct the revenue back into the local community. By the end of the 2005 season, the upward trend in visitors reflected a number of potential negative impacts for both the whale sharks and the community of Donsol (Quiros, 2007). Concern over adequate enforcement of the regulations, illegal fishing, poaching and the lack of scientific data were some of issues that needed to be assessed as the industry continued to grow (Pine et al., 2007; Quiros, 2005; Rowat, 2008). Over recent years, Donsol has attracted a certain amount of criticism due to negative media attention and dissatisfied clients. New concerns for the operator's negligence of the interaction guidelines could start to threaten the sustainability of the whale shark industry as a socio-economic provider for future generations (Quiros, 2005, 2007).

In Mexico there are two distinct whale shark aggregations and both areas have instigated their own whale shark tourism ventures (Rowat, 2008). Firstly, on the Pacific coast, with the main centre of activities' based at Bahia de los Angeles, Baja California and Bahia de La Paz, Baja California Sur, located in the Sea of Cortes (Rodriguez-Dowdell, Enrıquez-Andrade & Cardenas-Torres, 2007), which is considered one of the most biologically productive areas in the Gulf of California (Alvarez-Borrego, 1983; Rodriguez-Dowdell et al., 2007). Interactions with whale sharks have been operating in this region on a small scale since early 2000 (Rodriguez-Dowdell et al., 2007) with no guidelines or management plans. Mexican whale shark conservation efforts were started by a group of local tour operators from Bahia de Los Angeles, in response to plans for a marina (Rodriguez-Dowdell et al., 2007). With awareness of the potential negative impact of the marina on their local marine life and a blossoming whale shark industry, the group requested that some research on the current status of the populations' size around the Gulf of Mexico be undertaken. In 2001, the Autonomous University of Baja California (UABC) initiated a research program in Bahia de los Angeles in collaboration with the Reserve of the Islands of the Gulf of California RIGC (Rodriguez-Dowdell et al., 2007) and the support of a group of local tour operators. The study focused on population density, distribution, behaviour and other aspects of whale shark ecology (Cardenas-Torres, Enrıquez-Andrade & Rodrıguez-Dowdell, 2007). The main objectives were to provide scientific data on the sharks in the Gulf, to establish a foundation for the direct participation of local tour operators in the management of the industry and develop a proposal for the sustainable future of whale shark tourism (Rodriguez-Dowdell et al. 2007).
For the development of a code of conduct, a survey of tour operators and in-water tourist activities during the 2001 season was conducted. Subsequent to this survey, a meeting with local stakeholders and the steering groups reviewed existing codes of conduct from other regions and adapted these to create a specific code of conduct for Bahia de los Angeles (Cardenas-Torres et al., 2007; Rodriguez-Dowdell et al., 2007). This code was formulated to prevent disturbance or injury to the whale sharks, insuring their seasonal visitations back to the Gulf. The accepted guidelines for their code of conduct were mostly the same as the best

practice model from Ningaloo, but several additional site-specific adaptations were adopted. These included actions such as the separation distance of shark to swimmer was set to 1m from its head or body and 2m from its caudal fin or tail; the code prohibited the use of jet skis in the area of El Rincon and the maximum number of in-water swimmers was set to four (two per side of the shark). Finally, some advisories on minimising avoidance behaviours of the sharks during an encounter were given (Cardenas-Torres et al., 2007). Overall, the local industry, its shareholders and local governments accepted the Code of Conduct (Rodriguez-Dowdell et al., 2007). Prior to the 2003 season, these regulations were formally incorporated into permits for eco-tourism activities on the species (Cardenas-Torres et al., 2007). On completion of the 2003 season, concerns over the lack of inspection and enforcement of the regulations led to the revocation of the regulations prior to the 2004 season (Rodriguez-Dowdell et al., 2007; Rowat, 2008).

A entirely separate aggregation of whale sharks which are used for tourism activities in Mexican waters, are known to congregate around the Yucatan peninsula in the area off Holbox Island, Quinatoo Roo (Cardenas-Torres et al., 2007, Ziegler, 2008). For many years whale sharks migrating in small groups or singly have been reported by fishermen within their fishing grounds on the northeast coast of the Yucatan Peninsula. Although it was not until 2002 from constant media attention of the activities on the Pacific coast and the increasing interest of visitors to swim with these sharks, that the development of a new tourist activity around Holbox Island began (Remolina-Suarez, Perez, Ramirez, Gonzalez-Cano, Parra Venegas, Sabatini et al., 2007). This fast growing activity generated an economic alternative for fishermen who were re-trained as guides and boat captains to keep up with the demand from visitors. Early concerns were soon raised regarding the impact of this amount of tourism pressure on the sharks (Remolina-Suarez et al., 2007) and a meeting between stakeholders and regional government authorities in 2003 resulted in an agreed code of conduct for the protection of this new thriving industry (Remolina-Suarez et al., 2007; Rowat, 2008).

The code of conduct from the activities' on the Pacific coast of Mexico was implemented in Holbox, with the exception of maximum number of swimmers during an encounter lowered from four to two. Over the next two seasons, continuous monitoring and discussions between stakeholders and local authorities led to regional legislation to limit the number of licensed operators for the 2005 season (Cardenas-Torres et al., 2007; Remolina Suarez et al., 2007).

Following this legislation, the task of the enforcement of the regulations and the code were given to the Domino research Project (Remolina Suarez et al., 2007). Project Domino was established during the second quarter of the 2003 season and much of their studies were to investigate aspects such as the sharks' ecology, distribution, as well as management and conservation of the whale shark population around the Atlantic coast. To date, scientific support by private funders has given local stakeholders and project leaders an opportunity to utilize modern tagging methods to estimate annual population magnitude (Tyminski et al., 2008).

Throughout the last decade tourism interactions with whale sharks have become a highly lucrative industry based on upon this vulnerable species (Quiros, 2005; Zeigler, 2008). During the 21st century further localities with habitual whale shark occurrences have themselves formed their own whale shark activities that generate profitable revenue for local communities (Pierce et al., 2010). Now, as the scientific community shift towards new research methods, which begin to access the possible negative impact to the species natural behaviour from tourism, local governments and operators, may need to acquire an overall balance between offering a high quality tourism experience and the potential negative impact their pressure may have on the animals' natural occurrence.

Summary

Over the past two decades, individual shark species have spearheaded the beginning of a new positive outlook for the conservation and management of elasmobranches as a whole. Through tourism encounters with sharks in their natural habitat a greater level of comprehension and understanding of their complex life stages and behavioural agendas, has given scientists a better idea of the potential negative impacts of tourism on these species, that can provides much needed answers for future improvements to current management strategies for these magnificent sharks. Emergences of codes of conduct have benefited this marine tourism activity by providing a baseline to aid in controlling the ever-growing demand from the public sector to experience a one-time encounter with the worlds largest fish.

2.2 A review of stereo-photogrammetry and its use as a tool in marine research

2.2.1 Introduction to photogrammetric systems

Photography in its broadest sense is a process that converts the real three-dimensional world into flat two-dimensional images (Sontag, 1978). The camera is the device that makes this transformation or mapping from three dimensions to two dimensions possible (Gershiem, 1982). The origin of photogrammetry dates back to the mid-1800's, when a French military officer Aime Laussedat developed the first photogrammetric device and techniques (Ackermann, 1996). Photogrammetry in its basic interpretation is the use of photographs to capture measurements, usually by the use of some form of “scale-bar” or known measurement captured in the image for comparison (Rohner, Richardson, Marshall, Weeks & Peirce, 2011). Throughout the 20th century an assortment of conventions, assemblies and institutes for the study of photogrammetry were established, further advancing the capabilities of this technique (Fenton & Kerr, 1997). Recent years have seen fundamental changes in photogrammetric theory and practice, due to both technological changes such as the widespread adoption of digital imagery, and also the emergence of separate fields with strong photogrammetric components such as geographic information systems, computer vision and remote sensing (Shortis & Harvey, 1998). These advancements both in practice and theory have made digital photogrammetry a feasible additional for traditional photography within relevant scientific fields (Robson & Shortis, 1998).

Stereo-photogrammetry essentially reverses the photographic process described above, as it converts or maps a flat two-dimensional images back into a three-dimensional composition (Bellman & Shortis, 2004). Unfortunately, this technique cannot entirely map the 3-dimensional world onto two dimensions, so certain information is lost, primarily the depth (Shortis, Robson & Short, 1996). The basic principle of stereo-photogrammetry can be portrayed similar to the function of binocular vision. Each eye sends slightly different images of an object to the brain, where they are interpreted in terms of depth as well as length and scope (Miskin, 1956). Similarly, if two binocular or stereo-photographs of an object are juxtaposed so that the left eye sees the left photograph and the right eye sees the right photograph, the perception of depth can be as clear as if the object were seen directly (Robson, Shortis & Ray, 1999). By the use of suitable photogrammetric devices and computer-aided software, stereo-photographs can serve as a means to extract measurements of subjects or environments in a range of diverse sectors that utilise photogrammetric components such as; topographic mapping (Sanz-Ablanedo, Rodríguez-Pérez, Arias-Sánchez & Armesto, 2009), architecture (Arias, Ordóñez, Lorenzo, Herraez & Armesto, 2007), archaeology (Bosch, Kulur & Gulch, 2005), police reconstructions (Hellman et al., 1995), medical restoration (Patias, 2002), as well as in space engineering (Li, Zou, Smith & Curran, 1997; Pappa, Black & Blandino, 2003).

This three-dimensional analytical photogrammetry is an established technique that is based around the basic theory of triangulation (Sanz-Ablanedo et al., 2009). Triangulation is a surveying technique in which an area is divided into a series of triangular elements (Drysdale, McElfresh & Snoeyink, 2000) based on a line of known length, so that accurate measurements of distances and directions may be made by the application of trigonometry (Schenk, 1997). Through disparate perspectives obtained by multiple images that have been taken by different cameras from slightly different vantage points (Mavrinac, Chen & Tepe, 2010), so-called "lines of sight" can be plotted from each camera, to points on the photographed object (Mavrinac et al., 2010). These lines of sight, referred to sometimes as rays owing to their optical nature, are mathematically inserted into the images to produce the three-dimensional coordinates of common points of interest, used for extraction of relative measurements of any given subject (Ferrer & Garcia, 2010). On these light-rays, the spatial point is represented by selected pixels in each image and at least two images are necessary in order to reconstruct any three-dimentional point. By selecting two pixels in each image, a projection of the same spatial point is created and from this a three-dimentional point can be easily reconstructed using the camera light-ray's intersections (Shortis, Clarke & Robson, 1995). As such, two pixels create a corresponding pair, which is a basic element for the photogrammetry reconstruction process (Harvey, Shortis, Stadler & Cappo, 2003).

Any stereo-photogrammetry system, which is to be used to obtain accurate, quantitative measurements, must be geometrically calibrated (Brager, Chong, Dawson, Slooten & Würsig, 1999; Harvey & Shortis, Seager & Hall, 2004; Kimley & Brown, 1983). Calibration procedures vary somewhat depending on the field or sector the technique is intended for. In particular, fundamental calibration procedures address the internal characteristics of the cameras, including their principal focus points, radial and decentering distortions in the lenses and their orthogonality and affinity terms (Woods, Docherty & Koch, 1993). Furthermore, the spatial relationship of the two cameras to one another (their angles of orientation) has to be assessed. Ultimately, calibration of any photogrammetric system for use underwater must also take into account the effects of refraction within the various air-glass and glass-water interfaces, which are present when any camera is mounted in a housing for use underwater (Woods et al., 1993).

2.2.2 Photogrammetry as a measurement tool

Prior to the availability of photogrammetry, marine scientists were obliged to restrain individuals for measurement or to use visual estimates to determine the size of an animal in its natural environment (Graham & Roberts, 2007). In the marine context, a number of widespread methods including 'guesstimations' used as a means of obtaining animal size by competent in-water swimmers to at best the nearest half a metre accuracy (Meekan et al., 2006). Other in-water observational techniques used were: comparisons to a known reference object such as a snorkeler (Graham & Roberts, 2007) or a research vessel to estimate size (Hobbs et al., 2009) and the use a of rope marked at known intervals and held at either end by swimmers, while it is strung alongside a mobile subject to determine its relative size (Norman & Stevens, 2007). Such visual estimations were used as a means to estimate the size of larger mobile marine animals in their natural environment without disturbance or the need to remove them from their environment. Whilst visual estimations are effective to some extent, it is still difficult to achieve accurate and precise measurements needed for statistical analysis, with estimated mean errors as high as ~50 cm for experienced researchers in their field (Jeffreys, Rowat, Marshall and Brooks, 2012; Norman & Stevens, 2007). Over the last two decades photogrammetry has been modified and tailored to determine size and body mass dimensions for a whole assortment of marine species. (e.g. Bowhead whales, *Balaena mysticetus* (Koski, Davis, Miller & Withrow, 1992), Killer whales, *Orcinus orca* (Durban & Parsons, 2006), Humpback whales, *Megaptera novaeangliae* (Spitz, Herman & Pack, 2000), Hector's dolphins, *Cephalorhynchus hectori (*Bräger et al., 1999); Scalloped hammerhead sharks *Sphyrna lewini* (Klimley & Brown, *1983),* Bluefin tuna, *Thunnus thynnus thynnus,* (Costa, Loy, Cataudella, Davis & Sardi, 2006) and the growth of coral (Done, 1981)).

Modern photogrammetry systems used to investigate size measurements on large free-ranging marine species, are generally mounted from an aerial vantage point on boat platforms or from masts, offering an unobstructed vertical viewpoint (Koski et al., 1992; Spitz et al., 2000). The most frequently used single camera photogrammetric techniques estimate the size of the subject by applying a scaling factor or size indicator to a taken image. A scaling object may be defined as something of known size or length that is present within any photograph (Durban & Parsons, 2006; Jeffreys et al., 2012). Other researchers opted to use an allometric approach to determine the size and maturity of a number of species (Whitehead & Payne, 1981). Allometry designates the changes in relative dimensions of parts of a body that are correlated with changes in overall size (Huxley & Teissier, 1936b). A study by Scott and Winn (1980) estimated the body length of humpback whales from aerial photographs by using non-linear regression analysis of the allometric growth relationships between morphological dimensions and total body length. A shortcoming of this procedure, however, is that humpback whales may present considerable variability in the ratios of partial body lengths to full body length especially from the rostrum to the blowhole (Tomilina, 1967). Whitehead and Payne (1981), using an aerial vantage point photographed southern right whales *(Eubalaena autralis)* from a fixed-wing aircraft. A research boat transporting a white disk of known size ran parallel to the swimming whales to act as a size indicator. With knowledge of the focal length of the camera lens, together with the measured distance to the whale obtained from altimeter readings, the authors were able to compute the dimensions of the field of view of the camera lens and the measurement of the target disc and adjacent whale. Boat-based techniques have also been used to estimate whale size; Gordon (1990) photographed sperm whales *(Physeter macrocephaius)* from a research vessel's central mast. Distance to the whale was estimated from the angle subtended by the whale and the horizon. Gordon then calculated the blowhole-to-dorsal-fin length of the whales from measurements on the images obtained, and from this partial length, extrapolated total body length using inferences from allometric data obtained from dead sperm whales.

More recently, the use of a parallel-laser system as a means of attaining more precise and accurate measurements has been developed (Durban & Parsons, 2006; Rohner et al., 2011). A rudimentary laser metric camera system can be defined as some form of rigid horizontal frame, with two lasers mounted at a known distance either side of a camera (Rohner et al., 2011). The system can be terrestrial or marine-based and merely projects the lasers marks onto the subject's body. This gives the researcher a direct scale indicator, which in turn eliminates the need for any external reference frame or object. The use of laser metric systems and analysis has been applied to study morphological traits for a whole range of subject from; killer whales, *Orcinus orca* (Durban & Parsons, 2006), African elephants *Loxodonta africana* (Shrader, Ferreira & van Aarde, 2006), manta rays *Manta alfredi* (Deakos, 2010) and whale sharks *Rhincodon typus* (Jeffreys et al., 2012).

2.2.3 Stereo-photogrammetry

The 1980s brought forward a new focused approach to the discipline of stereo-photogrammetry within marine science; the use of synchronised still-frame stereo-camera systems that were pre-calibrated before deployment, using stable camera geometry (Fenton & Kerr, 1997). As mentioned previously, stereo calibration measures may vary somewhat depending on the field or sector the systems is intended for, although every system fundamentally follows a series of orthodox pre-calibration steps. Initial effects of refraction must be accounted for as formerly mentioned for any underwater camera system and finally the spatial relationship and alignment or orientation of the two cameras must be established, which can be determined by incorporating the cameras total viewing angle at the optimal filming distance and the size of mounting frame preferred (Woods et al., 1993). All underwater camera systems have some degree of lens barrel distortion and even in small amounts this can cause flawed measurements (Harvey & Shortis, 1998). To assess the amount of barrel or pin-cushion distortion of camera lenses a distortion chequer-board is often used; this is a calibration instrument consisting of a rigid board printing with alternate black and white squares with precisely aligned corners. As a rule of thumb, the board is filmed in water and positioned in front of the stereo-camera system to completely fill both cameras line of sight, establishing the maximum amount of re-correction. The final step for pre-calibration is to register the images from the two cameras in a three-dimensional space (Kimley & Brown, 1983). The general approach that has been widely adopted for this phase is the use of a three-dimensional control frame with a number of known positions marked as reference points. These calibration instruments address two main areas; firstly the complete internal characteristics of the two cameras, covering their principle focus points to their orthogonality and affinity terms and, secondly, the relative orientation of the two cameras to one another (Harvey & Shortis, 1998).

These geometrical advancements and calibration protocols have enabled scientists to lower the overall margin of error for assessing length measurements compared to conventional single camera photogrammetry techniques. Providing more accurate and precise data to formulate robust results of a variety of mobile species which are challenging to observe, such as individuals that live close to the bottom of the water column (epibenthic) and those species that live at or near the surface of the ocean (pelagic fish). Ultimately, for the first time the biomass and population distributions of any sampled species can be confidently estimated (Abdo et al., 2006). As technological advances evolved, the 1990s brought the first use of digital video image sequences, expanding further the versatility and the efficiency of data acquisition (Harvey et al., 2003), which in turn reduced the processing time needed for pre-calibration tasks and post calibration analysis. As we move into the 21st century, underwater stereo-photogrammetry is used in numerous environments from a variety of platforms. Marine animals are now surveyed from aerial observations by fixed wing aircraft, cameras mounted on boats, stationary rigs deployed to deep depths of the ocean and from manually or remotely operated camera set ups (Harvey, Fletcher, Shortis & Kendrick, 2004).

2.2.3.1 Underwater visual census & the introduction of manually operated systems

Since the introduction of self-contained underwater breathing apparatus (SCUBA) to marine science, researchers have been surveying population densities of a variety of mobile species in the marine environment by underwater visual census (UVC) techniques (Kimley & Brown, 1983). The use of SCUBA divers, as a direct means to survey was largely due to them being considered non-destructive, quick to deploy, relatively inexpensive and primarily an effective means to collect valuable information of fish density in a specific area with little or no scientific equipment (Kulbicki, 1998). Initial surveys involved divers using underwater dive slates to record a number of in-water variables ranging from species identification, population counts and density estimations of the surrounding habitat (Dibble, 1991). The inherent drawbacks of this surveying technique are time limitations under water due to the build up of gases in the human body (Pelosi, Proietti, Della-Morte, Magalini and Bondoli, 1981) and the inherent inability of the observer to notice all specimens in the survey zone which may be due to human disturbance causing the animal to disappear or show cryptic behaviour (Losey, 2003). In addition, the temperature of the water may affect the duration of the survey as well as the biases or errors if the assessor surveys outside a transit area or survey grid (Riegl, Purkis, Keck & Rowlands, 2009). As a result of these limitations and human errors, direct UVCs often underestimate the abundance and density of a population, which potentially leaves results lacking reliability (Harvey, Fletcher & Shortis, 2002).

A study by Bortone and Martin (1991) was the first of its kind to use a photogrammetric approach to standard UVC surveys. The study incorporated the use of a diver operating a single video camera system whilst observing and counting fish over the top of the camera housing (Harvey et al., 2002). This method of video surveying relied on counts of the number of fish that pass through a very limited field of view. The study indicated that while the advantage of video provided a permanent visual record of the surveys helping to aid in species identification, the overall field of vision was much smaller than that of the human eye. Therefore, without the aid of additional lenses for a wider field of view, a lower number of species and individuals are recorded using this method compared to visual observation (Bortone & Martin, 1991). Harvey et al. (2002) advanced the use of photogrammetric techniques further through the introduction of the first marine stereo-video system to aid UVC surveys. In addition to recording general abundance data and habitat condition, the stereo-video cameras were able to accurately measure fish length, thus removing the significant restraint of visual size estimations (Shortis & Harvey, 1998). Since accurate information on length, width and height of fish, and the distance between individual fishes can be calculated from stereo systems, this methodology has been used in a variety of research fields for obtaining genuine metamorphic measurements of free-swimming marine mammals and fish (Bräger et al., 1999; Kimley & Brown, 1983; Koski et al., 1992; Spitz et al., 2000).

In New Zealand, Bräger et al. (1999) developed a study to gather information on social structure and group composition of a population of Hector's dolphin (*Cephalorhynchus hectori*) which are a rare endemic species living in coastal-waters around New Zealand. Their research incorporated a stereo-camera system to aid in collecting accurate size measurements of these miniature dolphins for the use in steps for national conservation. The system was mounted onto a stable aluminum tripod and fastened on the portside bow of the research vessel. The cameras were set to gather vertical stereo-photographs of the free-swimming dolphins as they rode the wake on the bow. The study provided an overall comprehensive record of body length measurement of Hector's dolphins and was claimed to be of low cost and simple to operate. Bräger et al. (1999) also expressed that the stereo-photographs are excellent for short-term identification of individual animals, because body scar information can be viewed in three dimensions.

Work completed by Kimley and Brown (1983) on three-dimensional positions of schooling scalloped hammerhead sharks (*Sphyrna lewini*) in the Gulf of California may be considered as one of the first in-water diver operated stereo studies. The study describes in detail how the use of a horizontal side by side stereoscopic camera system can provide accurate and reliable information on whether scalloped hammerhead sharks of different size, remain in the same position and distance to neighbouring sharks, within a school on a daily basis. Results from their study demonstrated that although single camera surveying techniques are useful for qualitatively describing two-dimensional spatial relationships of small free-swimming specimens, the use of a three-dimensional system can provide quantitative data with precision, in the accuracy of repeated measurements on the same individuals.

Arguably the principal drawbacks of opting for an underwater stereo-video system as an assemblage assessment tool may be the initial expense of setting up some of the more technological advanced equipment (e.g. cost of cameras, housings, calibration measures and analysis software) and the systems possible inability to measure the total abundance of individuals in an area, which creates problems when trying to give a true estimate of the entire population.

2.2.3.2 Stereo Baited Remote Underwater Video Stations (sBRUVS) & Habitat mapping

Remote capture techniques have an advantage over conventional UVC techniques because they can be used to examine species or habitats at depths beyond the reach of standard SCUBA apparatus. Stereo baited remote underwater video stations (sBRUVs) are one type of remote sampling that is becoming more prevalent in recent studies, as it is considered to be a non-destructive, non-intrusive sampling technique that can be deployed to variable depths in an assortment of habitats, including those with complex topography (Willis & Babcock, 2000). There are variations in this sampling technique, but the principle is generally the same as in single camera BRUVs: bait is used to attract fish and the observations are recorded by a camera system. Modern construction consists of at least two high-resolution video cameras mounted in individual underwater housings and aimed at a container or bag filled with bait source (Harvey & Shortis, 1998). Usually the bait holder is positioned either out in front of the cameras line of sight for horizontal viewing or alternatively directly beneath the cameras for vertical viewing (Cappo, Speare & De'ath, 2004). A rigid frame is fabricated around the cameras to provide stability during deployment and survey periods, which protects the cameras from accidental movement from impact or collisions, which would affect the calibration, resulting in flawed data (Harvey et al., 2004). Most sBRUV systems are normally calibrated in shallow waters using the same pre-calibrations steps as previously described for manually operated stereo-camera systems.

Being a non-destructive and non-intrusive sampling technique, sBRUV sampling can be implemented in fragile environments (eg. marine protected areas or nursery grounds) allowing for the bait trail to attract larger mobile species including top-level predators (Cappo et al., 2004). With sampling in marine protected areas with larger top-level animals the studies may provide a way to measure the effectiveness of protection provided by the managed area (Polunin & Roberts, 1993). A widespread study by Ellis and DeMartini (1995) found that the sBRUV sampling technique offered a useful alternative to bottom long-line sampling for estimating abundance of juvenile pink snapper (*Pristipomoides filamentosus)*. Furthermore, their study with the use of sBRUVs over conventional single BRUVs provided the accurate measurements of size of individuals within the population, providing information to construct a population demographic model for the study area. A study by Cappo et al. (2004) that explained patterns of fish biodiversity in inter-reef waters around the Great Barrier Reef Marine Park (GBRMP) eastern Australia was the first comprehensive study to deploy a fleet of replicate units. The main aim of his study was to demonstrate the advantage of stereo BRUVs over single camera units. The advantage stereo units offered was the possibility of comprehensive measurements to be taken of individuals within the population, which provided a means to develop a more accurate population demographic model. This ‘biologically-informed’ stratification of a single area can provide an insight to unique spatial patterns of species richness, abundance and assemblage structure (Pitcher et al*.*, 2007), a tool useful in construction of management plans for conservation.

The use of stereo-photogrammetry in marine habitat mapping provides an efficient non-destructive means for measurement in environments with limited accessibility (Sanchez, Serrano & Gomez Ballesteros, 2009). Throughout the last decade a more detailed approach by marine geologists has driven the need for reliable knowledge of the global distribution and nature of benthic habitats, required to support effective marine management (Coggan & Diesing, 2011). Currently, the primary survey tool for fine scale mapping of the ocean floor is a towed camera platform that records high-resolution digital still images and / or video along transects (Sanchez et al., 2009). Remotely Operated Vehicles (ROVs) and submersibles are another common remote platform that are usually self-powered rather than towed; they are capable of working to depths of up to 1500m and are normally connected to the vessel via a fiber-optic communication link (Coggan & Diesing, 2011; Williams, Barker, Kloser, Sherlock, Bax, 2005). The main advantage of stereo-camera systems for habitat mapping is the availability of three-dimensional data (Drap et al., 2006). Whilst length measurements are the primary means for many surveys, surface areas and volumes can also be accurately estimated (Telem & Filin, 2010). Therefore, rather than making assumptions of the seabed topography from a single camera's perspective, the actual surface topography can be measured (Coggan & Diesing, 2011).

Recent publications by Harvey et al. (2004) and Shortis et al. (2009) have begun to raise concern that topography measurements may have inaccuracies resulting from the calibration of the system being completed in shallow water and the actual recorded imagery coming from a greater depth (Shortis et al., 2009). As a general rule of thumb, stereo-camera towed sled calibrations are carried out at depths of one to three metres for operational convenience. Once calibrated at this depth the stereo-cameras may subsequently be deployed to depths of up to 2,000 metres where conditions of considerably increased water pressure and decreased temperature may deform the cameras housings and view ports, which will adversely affect camera calibration and accuracy of the stereo measurement (Shortis, Seager, Williams, Barker & Sherlock, 2007). On typical stereo-photogrammetry towed bodies or sleds, as with sBRUVS, the cameras are mounted in a rigid frame like structure with each camera covered by its own robust housing (Coggan & Diesing, 2011). The framework around the set up offers duel support by means of protection for the cameras against collisions and, secondly, ensures the stability of the imagery and the relative orientation of the cameras to one another

(Harvey et al., 2003). Deployments are typically between 30-60 minutes in duration, producing transects of one to three kilometers in span (Harvey et al., 2003), but, if required, the sleds can be towed continuously for several hours (Williams et al., 2005) subject to the limitations of the power source used. The paired cameras observe the sea floor at a diagonal projection from a height of one to three metres as the towed body "flies" above the ocean floor (Williams et al., 2005). Some of the more technically advanced systems are equipped with global positioning systems so that measurements can be accurately geo-located. The sleds are also equipped with sensors that record depth, pressure, pitch, roll, water temperature, conductivity and fluorescence of the surrounding habitat (Shortis et al., 2009).

Summary

Throughout marine science the adoption of simple approaches to underwater measurement problems continue to be the most successful, and increased task or equipment complexity has a much greater tendency to incline towards failure (Harvey et al., 2004). Stereo-photogrammetry is a sophisticated, non-invasive technique that allows the use of digital imagery to estimate accurate three-dimensional measurements of objects and surfaces that are largely unobtainable using standard photographic practices. Present scientific publications in this sector have confirmed stereo-photogrammetry techniques and applications are not highly sensitive to human error, subjectivity or sampling bias, and are able to achieve robust results in a challenging environment. As there are such a number of diverse uses for stereo-photogrammetric techniques within the entire marine environment; therefore, it is crucial that research objectives are clear so that the most fitting technique and analysis are chosen.

3. Research Rationale & Objectives

During the 21st century as many as 15 global localities with regular whale shark occurrences have formed whale shark tourism activities, which generate profitable revenue for local communities and tourism operators (Pierce et al., 2010; Quiros, 2005). Tourism generated by the whale shark industry alone is estimated to be worth US$66 million worldwide and expected to grow as developing countries begin to capitalize on the profit margins of this valuable fish (Graham, 2004). Concerns are growing over the degree of consideration given to this expanding industry, its potential impacts on whale shark ecology, and not least of all the exploitation of the carrying capacity of the species by unregulated tourism (Quiros, 2007). Local governments and tourism managers are under constant pressure to find a functional balance between a high quality tourism experience, and the possible negative impacts these activities may have on the animals' natural occurrences at specific coastal sites (Ziegler, 2010).

To date, previous studies undertaken on whale shark behaviour and the potential impact of whale shark tourism, have yet to develop a means of generating quantifiable results that are not subjective to the influence or presence of an in-water observer. This concern has raised a number of problems when attempting to provide scientifically robust data, which can be used to offer recommendations for the assessment and improvement of current codes of conduct and conservation measures for the species.

A pioneer study by Norman (1999) in association with the department of conservation and land management (CALM) in Western Australia, aimed to develop a rudimentary means to classify whale sharks' primary repertoire of characteristic avoidance behaviours. Some of which included eye rolls, diving, banking, change in swimming speed, degree of mouth opening, and coughing or gill flushing. Using visual in-water observations, he constructed a list of fundamental short-term and long-term behavioural changes from a range of external factors, associated with tourism encounters at Ningaloo marine national park, Western Australia (NMNP). His study comprised of a survey of over 300 individuals, spanning a 3-year period between March-June in correlation with the annual arrival of these congregating sharks. The majority of these sighting were witnessed within a 1-2 Km radius of the reef crest between the area of Tantabiddi and Turquoise bay, lying in waters approximately 10-30 metres in depth. General observations of the sharks' behaviours were recorded and divided into a number of categories, with each encounter individually analyised. Along with the primary collection of behavioural data, individuals were inspected for scars or irregular adaptations to the external appearance of the sharks body and fins. Furthermore, modern photo identification techniques were used to individually identify one shark from another with relatively similar markings.

This study was the first attempt at determining whether there are noteworthy indications that ecotourism may present a negative impact on the population of whale sharks in Western Australia. A reduction in the duration of interaction time between human and sharks over the three successive years, suggests that over the short survey period alone *R. typus* may have become slightly less tolerant of the ecotourism industry at NMNP. Throughout this preliminary work the absence of controlling elements was an issue, so instead of determining cause and effect relationships between human and whale shark behaviours, only associations, or groupings of certain types of behaviors were examined. In general, the research did demonstrate that while the long-term consequences of human impact on whale sharks were yet to be fully understood, the need to develop a protocol to record the sharks behavioral responses to short-term anthropogenic impact from controlled or uncontrolled tourism was a priority for future research. Norman's work did however provoke concern for recommendations to be made, for reducing the potential harmful effects of this blossoming industry to the Department of Conservation and Land Management (CALM).

Quiros (2007) continued this area of study by developing a system for recording whale shark avoidance behaviours and their relationship to human presence, with her research in Donsol in the Philippines. The key aim of her study was to examine general tourist compliance to existing codes of conduct for whale shark interactions and to assess the impacts of tourist activities on the seasonal shark population. From three survey periods in 2004 and 2005 that lasted between 4 and 12 days, observers collected behavioral data in two categories: behaviour of swimmers and tour operators, and behaviour of whale sharks. The tour operator variables included: number of boats present within 50 metres of the shark, boat approach, path obstruction by the boat, boat crowding and number of swimmers during each encounter. The in-water tourist variables monitored were: touching of the animal, flash photography, path obstruction and proximity to the whale shark. To access the compliance of tourists to the code of conduct, observers noted for each encounter whether or not the regulation was enforced. Additionally, information was gathered on the duration of each interaction, boat orientation to the shark, and the presence or absence of injuries to the sharks body or fins.

Quiros developed the first numerical scale to categorise disturbance levels shown by an individual shark to the pre-selected human stressors. Whale shark disturbance behaviours were classified on a gradient line from neutral to disturbed. Neutral behaviours included; feeding, swimming in repeated circles and no response to any in-water activity. Behaviours classified as disturbed included; diving away from a swimmer, change in swimming direction, and banking (a known avoidance response (Norman, 1999)). The study detailed each classified response into sub categories; so the sharks dive response and change of direction was each divided in to four individual cases covering all possibilities. Individual dive responses were instant dives, steep dives, gradual dives and parabola diving (diving up and down in the water column at regular intervals). Changes of shark direction sub categories were abrupt change, gradual change, swimming in circles and violent shuddering. Overall Quiros's study was successful in identifying key events or factors that might trigger an avoidance response. From her 2004 analysis it is clear that the key events that affected whale sharks' behaviours with the most significance were: path obstruction by boats and swimmers, proximity to the animal, and first-time daily sighting of the shark (e.g. the first in-water encounter of an individual). Additionally, analysis from the data collected during the 2005 season showed that while proximity and path obstruction still remained elevated as a driving factor, touching of the shark by a swimmers and the in-water dive behaviour of tourists showed increasing negative disturbance to the animal.

The issue of human error and biases associated with in-water visual sampling techniques raises concerns as to the possible influence of the observer in data collection. As the observer would themselves be counted as an in water swimmer within the encounter code, their presence may also contribute to the behavioural response. Clarification of this subjection is difficult, but given that the study aimed to study tourist compliance to the code of conduct and investigate all that occurs within it, it follows therefore the observer must be incorporated.

This thesis aims to collect statistically robust data on the possible effects of anthropogenic impact on avoidance behaviours shown by whale sharks within tourism encounters, and to develop recommendations on how to integrate these findings into management plans to reduce any negative impact on the species. By means of novel methodology and the utilisation of a custom-made stereo-photogrammetry system, continuous high definition video of the entire human-animal interaction will be recorded. The use of video data will allow for all behavioural changes of the animals to be captured and assessed relative to a number of known external variables. Stereo-photogrammetry gives the study a quantifiable and reliable means to extract stereoscopic measurements, which would be otherwise unobtainable from any other two-dimensional photogrammetric system. This advantage allowed for the accumulation of repeatable, proximity measurements of any given swimmer to the shark, permitting precise and accurate results, to clarify if there is any relationship between proximity and level of avoidance displayed.

As previous behavioural studies on the species have failed to remove the influence of an the observer from the results, a unique in-water protocol will be developed and applied, allowing the observer to be positioned outside the currently accepted interaction guidelines adopted by all research localities. Additionally, this approach will provide quantifiable data collection techniques not used prior to this study and remove the predicament of the observer interference to the shark's behaviour. The research question to be evaluated within the presented study is to determine whether or not the whale sharks' overall behavioural outcome during tourism encounters, is affected by any of the pre-selected anthropogenic variables.

Modern technological advancements in whale shark science such as the widespread use of digital photography, satellite tagging systems, and associated environmental data collection techniques, have shown significant improvements to various areas of research such as whale shark identification, distribution and their biology. These enhancements have accelerated the availability of essential information on the species aggregation size, migratory routes, environmental cues and rudimentary growth estimations (Norman, 2002; Rowat & Gore, 2007). In spite of these recent innovations, the use of a robust, reliable and easily applied methodology for assessing the possible negative effects of tourism on the world's largest fish remains incomplete.

Aim & Objectives for this project are:

To assess the effects of tourism interactions on whale shark behaviors at a number of known aggregation sites adopting a minimal disturbance protocol, and to further provide a recommendation on how to integrate these findings into management plans.

1. Develop a robust, reliable and inexpensive Stereo-Photogrammetry system for the use in gathering specific data.
2. Integrate a research protocol to observe whale shark interactions with minimal impact or influence on the animal's natural behaviour.
3. Quantitatively measure proximity of swimmers to the shark and record the degree of avoidance response shown.
4. Develop a statistically valid model to evaluate if whale sharks' avoidance behaviours are related to factors associated with human presence.
5. Provide a recommendation on how to integrate these findings into management plans to reduce anthropogenic impacts on the species.

4. General Materials & Methods

4.1 Study area

The study assessed populations of whale sharks that aggregate seasonally at three global sites. Field sites were individually chosen due to the differences in intensity of whale shark tourism within each unique locality. Furthermore, the selected sample sites occur in the Indian Ocean region and peak seasons exist along a timeline allowing a staggered study timeframe suitable for the research.

1) The island of Mahé in the republic of Seychelles 4° 40′ 0″ S, 55° 28′ 0″ E (fig.1). The island itself is situated on a shallow plateau in the western Indian Ocean. Its unique location creates a passage for the Southern Equatorial Current (SEC) that forms a boundary between subtropical low nutrient waters from the south and warmer more nutrient-rich waters from the northeast (Rowat, Gore, Meekan, Lawler & Bradshaw, 2009). For several months of the year trade winds blow across the Mahé plateau resulting in localized blooms of plankton, which lead to the seasonal appearances of whale sharks (*Rhincodon typus*) and other planktivores such as giant Manta rays (*Manta birostris*).

2) Praia do Tofo in the Inhambane providence, Mozambique 23°51′20″S, 35°32′53″E (fig.2). Tofo is situated in the southeast part of Mozambique and lies adjacent to the Inhambane shelf approximately 400 km northeast of the country's capital city, Maputo (Pierce et al., 2010). Unlike many other documented aggregation sites for whale sharks and other mega fauna, the Mozambique Channel and Tofo, may be considered one of the only places globally where whale sharks and other planktivores species can be seen year round (Rohner et al., 2012). Early ideas about the causes of this phenomenon are the effects of ocean bathymetry along the coastline, with upwelling appearing to be primarily driven by the interaction of pole ward-propagating mesoscale eddies within the narrow shelf.

3) The small fishing village of Donsol in the Sorsogon province, Philippines 12° 54′ 28.8″ N, 123° 35′ 52.8″ E (fig.3). Every year the rich mangroves surrounding Donsol bay produce localized growth of microscopic plants and animals, which flow into the surrounding rivers and into Donsol bay. Once entering the bay, local bathymetry and current gyres drag and trap the plankton into huge blooms, encouraging the seasonal arrival of whale sharks in large numbers.

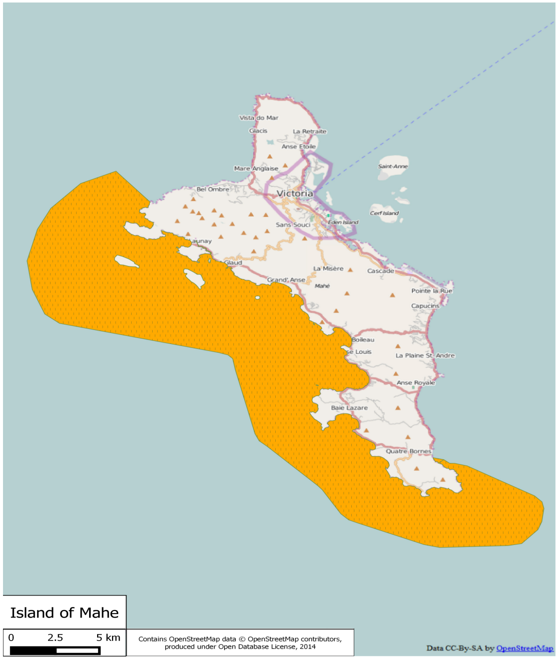


Figure 2: Island of Mahé, Seychelles showing search zone

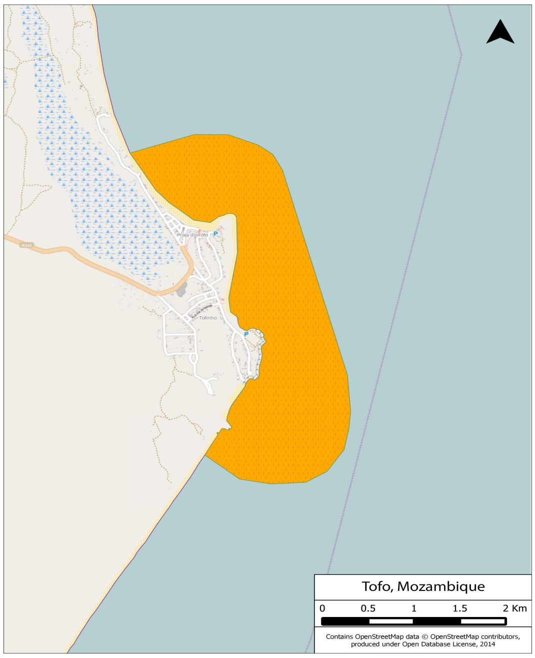


Figure 3: Praia do Tofo, Mozambique showing search zone

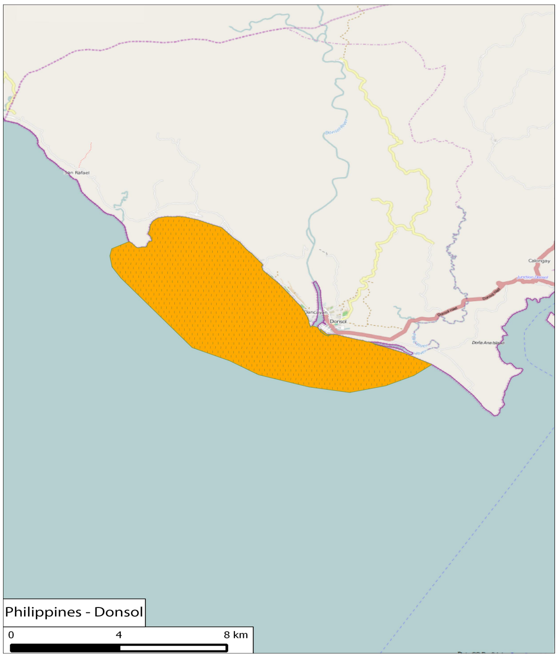


Figure 4: Donsol, Philippines showing search zone

4.1.1 Support basis for research

Over the course of the field research, numerous Non-Governmental Organizations (NGO's) and private individuals donated various supporting elements to assist in gathering data and formulating the results.

4.1.2 Seychelles

On the Island of Mahé in the republic of the Seychelles, the whale shark interactions are run in conjunction with the Marine Conservation Society Seychelles (MCSS) and its current marine research, which has been in operation since 1997. Their whale shark research programme has been ongoing-since their inception under the supervision of Dr. David Rowat (Chairman of MCSS). During the duration of the monitoring period, the researcher was based at the MCSS field office courtesy of Dr. David Rowat.

Every morning (weather permitting) during peak season of August through October, aerial surveys were executed around the Island of Mahé to locate and record the position of aggregating whale sharks and any other large marine fauna, as well as comprehensive observations of the fishing practices in use around the islands coastline. Aerial surveys are conducted by a delta-wing micro-light aircraft (Aquilla II, Solo Wings, South Africa) by experienced pilots trained in aerial survey techniques (Rowat, 2008), using recognized aerial survey protocols adapted for this specific area (e.g., McClellan, 1996). If sharks were present during the morning survey flight, the daily research vessel was prepared and departed from Beau Vallon Bay (North West area of Mahe), which transported tourists and the research team to the relevant interaction areas. The boat was a ten metre high-speed catamaran manned by a skipper; three MCSS team members and a maximum of fourteen paying clients. Before leaving the shore all tourists, were given an introduction on whale sharks in Seychelles and a stringent run through of the current interaction guidelines for in-water encounters with these sharks. The maximum search time for these trips was three hours, with all trips supported by the Micro-light aircraft via a VHFair-band radio link.

4.1.3 Mozambique

In Mozambique the whale shark encounter trips were made in conjunction with the continuous research being carried out by the Marine Mega-Fauna Foundation (MMF). Their current marine research program has been on going since 2003 under the supervision of Dr. Andrea Marshall and Dr. Simon Pierce. During the survey period the researcher was based at a residency of MMF courtesy of Dr. Simon Pierce.

Daily encounter trips, *"Ocean safaris",* were run in alliance with the Peri-Peri dive company, Tofo, aboard their inflatable eight and a half metre Zodiac dive craft, fitted with twin Yamaha 85 engines and manned with a skipper, a guide, one researcher from MMF and a maximum of twelve paying guests per trip. Survey excursions launch from Tofo beach and head south along its coastline. Over the last ten years the sighting data attained by MMF, shows this specific stretch of the coast provides most whale shark sightings, so a zig-zag search pattern has been adopted along that area to maximize the chance of encountering a shark or any other mega fauna. As a general rule the ocean safaris' launch at 11:00 am and are normally two hours in duration covering approximately 20km. Before leaving the dive centre, all guests are shown a whale shark interaction introduction video produced by MMF, covering basic biology of the whale shark and demonstrating the current encounter code for interacting with the sharks in Mozambique's waters. After the video, a boat launching procedure briefing is given (surf launching) and finally a safety briefing for the boat.

4.1.4 Philippines

In Donsol, the whale shark tourist encounter trips were run from the Donsol Tourism office in cooperation with the World Wildlife Fund (WWF) and their research efforts, which have been ongoing since 1998. During the survey period, the researcher was based at the WWF field office in Donsol town courtesy of the project coordinator and was granted an access card from the WWF to board tourist vessels as a researcher. From February till May each year, boat trips with paying clients head out into Donsol bay from 7:00 am till 12:00 noon, in search of aggregating sharks. The boats are traditional Philippines style "Pangas" equipped with a single Yamaha 60 engine.

They are generally manned by two crewmembers (spotters), one boat captain, a researcher and a maximum of six paying clients. The maximum time allowed in the interaction zone for a tourist trip was three hours, from leaving the shore to returning back to the tourist office.

4.2 Whale shark Photo Identification

All whale sharks encountered within this study were individually identified using the I^3S Interactive Individual Identification System (van Tienhoven et al., 2007), which uses the unique spot pattern from the segment, posterior to the fifth gill slits of each shark, too create a "finger print" to determine its individuality (Arzoumanian, Holmberg & Norman, 2005; Pierce et al., 2010) (fig.5). Individual identification of each shark allowed sex, previous encounter history and general scaring classification to be taken into consideration when analysing the results. After all analysis was completed, each photographed shark was updated to global and individual databases and used for population demographics. The use of the I^3S software ensured that similarly marked individuals could be consistently identified and their behavioural responses to human encounters confidently compared (Arzoumanian et al., 2005; van Tienhoven et al., 2007).

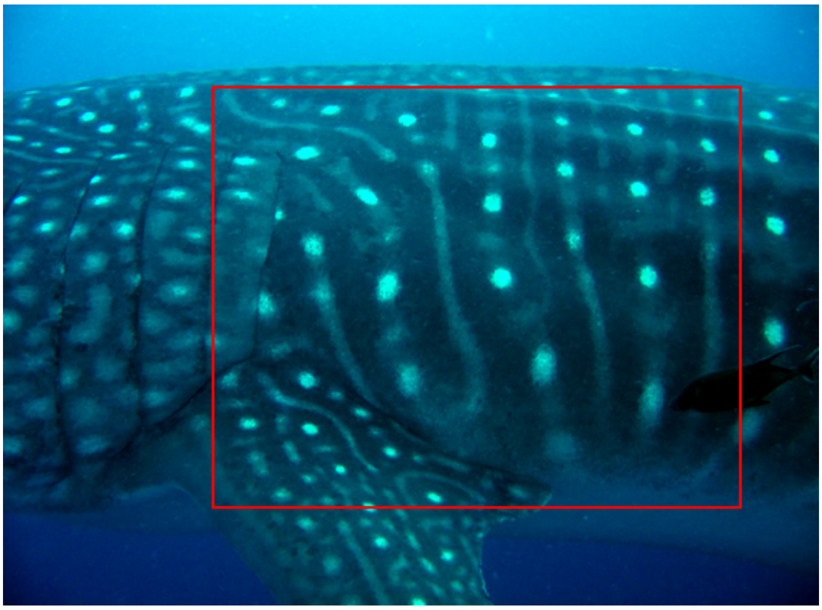


Figure.5. Unique spot pattern used for identification "fingerprint" of individual whale sharks

4.3 The Underwater Stereo-Camera system

To aid in the collection of the shark avoidance behaviours to anthropogenic disturbance and to enable the accurate collection of proximity measurements between the animal and swimmer, an underwater stereo-video system was used, which also improved reliability over visual estimates. Underwater videogrammetric systems offer two advantages over conventional single video cameras techniques. Firstly, they allow accurate measurements, which are difficult to obtain from a single camera. Secondly, the overall margin of error is less compared to other estimation techniques, thus providing more quantifiable data to formulate robust results.

The underwater stereo system used for the study was comprised of two commercially available Go-Pro HD Hero2 extreme-sports video cameras, which were housed in the standard Go-Pro underwater housings and set-up as a stereo pair. The selection of these types of cameras was due to their compact size, high definition video output, ease of mounting and the field of view available from the lenses and camera. The standard Go-Pro domed housing lenses were changed and replaced with Oculus flat lenses to help with the removal of image distortion in water. The cameras were mounted on an aluminium box – section tube 1 m x 40 mm x 3 mm with custom made mounting brackets at either end. The underwater housings were attached to the frame's brackets by Go-Pro standard flat surface adhesive mounts and supported by additional custom-made aluminium brackets with neoprene nonslip ends to prevent housing movement. Cameras were detachable from the main frame by quick release mechanisms, leaving only the mounting brackets securely fixed (Fig. 6).

Go-Pro cameras do not have the facility for master-slave synchronization, so a laser pointer served as a simple means of synchronising the recording time of left and right cameras from which measurements would be extracted (Harvey et al., 2003; Brager et al., 1999). The laser pointer was attached to the center position of the frame by a simple bracket mount. The lasers used were commercially available "underwater diver pointers" (model DIVE-1, Z-Bolt ®, Technologies, Inc. Oregon, USA) powered by 2x AA battery's with a max output of 5 mW. To obtain synchronization using the laser, firstly the cameras were switched to record mode, then with the laser turned on, the stereo-camera system is run past a flat surface a with an obvious visual mark. This allowed both cameras to record images of the laser as it crossed the mark enabling exact time synchronisation. This method of synchronising the cameras before entering the water ensured that the video footage from each camera could be matched to the exact frame to produce the stereo image needed for analysis (Brager et al., 1999). The visual marker cues could be seen on both cameras from a minimum distance of 50 cm from the frame.

Throughout the analysis visual cues were established in each video clip and manually synchronised so both videos were at the exact frame, then locked together via a lock synchronisation procedure within the stereo analysis software. Video footage was recorded in the standard Go-Pro MP4 format for the duration of the project to standardise the video files. The cost to produce the apparatus including HD cameras and underwater housing was approximately £600.

Figure 6: Underwater Stereo-Camera System

4.3.1 Operation of the System in water

To operate the underwater camera system during an encounter a specially designed in-water protocol was developed (fig.7). The observer entered the water with the camera system turned on and synchronized, and positioned themselves with as little disturbance as possible at a distance of at least 4 m behind the shark. This position was outside the minimum limit of the encounter code recommendations adopted by all survey localities and out of sight range of the shark, generally behind all in-water participants. This original protocol aimed to minimise the influence of the researcher being a contributing factor to the disturbance of the sharks' natural behaviours. Furthermore, the observer was able to benefit from an overall view of the whole encounter as it developed.

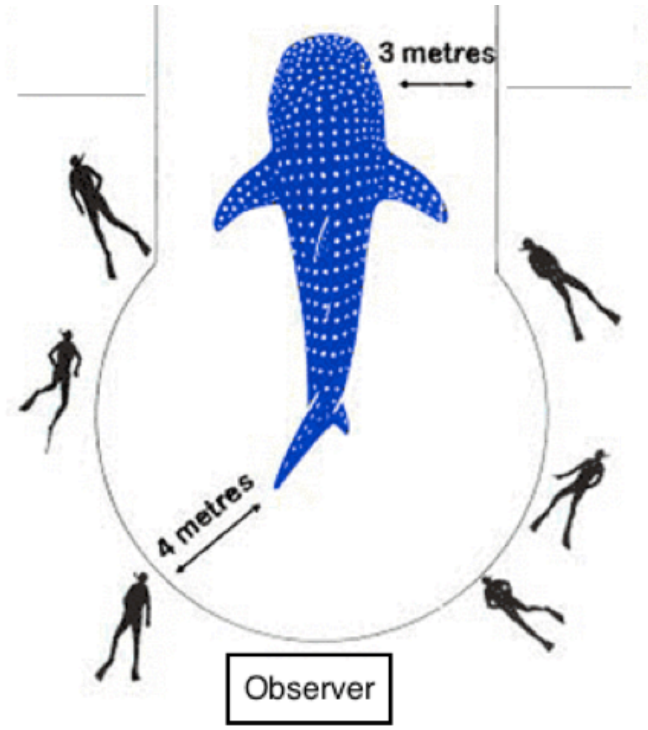


Figure 7: Specially designed in-water protocol showing location of observer (adapted from CALM, 2003)

The camera system was operated with both hands at full arms reach in front of the observer; this allowed a constant camera-system alignment and the removal of any possible intrusion of body parts entering the cameras field of view. During each encounter the observer moved from side to side along a horizontal axis to capture continuous video of the proximity of all in-water swimmers on either side of the sharks body and tail, whilst observing the behavioural responses of the shark. A research assistant from the relevant survey localities collected identification photos, sex and relevant scaring data of the animal for later analysis. If a research assistant was not present, once the shark had moved away from swimmers, either by accelerated swimming or diving, the observer followed the shark and collected the appropriate data. Each encounter was recorded and saved as a different video clip; consequently manual synchronization with the visual cue was established before entering the water on each occasion.

4.4 Calibration Procedures

4.4.1 Calibration of the system

In order to be used for accurate, quantitative measurement any photographic system must be geometrically calibrated (Brager, Chong, Dawson, Slooten & Würsig, 1999; Harvey, Fletcher, Shortis & Kendrick, 2004). In particular, the calibration procedure addresses the internal characteristics of the cameras, including their principal focus points, radial and decentering distortions in the lenses and their orthogonality and affinity terms. Furthermore, the spatial relationship of the two cameras to one another their angles of orientation have to be assessed (Harvey et al., 2004). Throughout survey periods, the system and cameras were inspected daily for damage, movement of the housings, system bracket alignment and angle of the cameras. The system was routinely calibrated every seven days similar to other systems (Woods, Dockerty & Koch, 1993), or whenever it was knocked or dropped unintentionally to ensure the alignment of the apparatus and reliability of data.

4.4.2 Vidsync software

The calibration procedures presented here are those of a freely available software program; VidSync 1.2 (vidsync.sourceforge.net; Neuswanger, pers. comm.), which was used in the calibration of the stereo-photogrammic system and formulation of the results presented. Moreover, it calculated quantitative measurements of proximity. For use of the software, individual videos from two cameras are uploaded into VidSync and footage from the each camera is synchronised using a lock synchronisation procedure within the program. Using video footage of a calibration object (calibration quadrant), the software calculates projective transformations from two surfaces of the calibration instrument. During analysis for every proximity measurement taken, the user manually clicks the proximal point of one object (a swimmer) to the nearest point of the other (the shark) and the software calculates a line through those two points to represent the line-of-sight for the first camera. Next it intersects the line from the second camera to triangulate the position of the marked points in 3-

Dimentions, and then computes the proximity length based on the 3-Dimentional distance between the two points.

4.4.3 Camera spatial relationship and alignment

Any stereo-video system requires the spatial relationship between the two cameras and their orientation to be determined to achieve quantifiable results (Kimley & Brown, 1983; Spitz, Herman & Pack, 2000). The spatial relationship and alignment of the cameras for the study was obtained from literature reviews of previous work carried out on other large ocean ranging sharks and cetacean, and then tailored to suit the individual requirements of the project. First, a specific field of view and optimal distance was calculated to achieve the stereo parameters needed to capture and record valid data for analysis. Preliminary field tests of the selected Go Pro cameras viewing angles, and coverage were used to verify and test a range of possible camera separation distances and orientations. Tests comprised of stereo photographs taken from the system at a fixed position, at the desired optimal distance of 6 m. A series of camera separation distances and camera orientations were tested ranging from 0° to -3°. Consequently, the distance between the centre points of the camera lenses were set at 90cm, with the cameras' angle of view set at Go-Pro's standard 127° (standard medium setting on Hero2 models). Finally, the camera's orientation was set at an inward angle of 1° towards one another, to attain the angle of convergence required to achieve the range and optimal distances needed for data collection. Prior to and following the conclusion of every encounter trip, the underwater system was routinely checked for movement or damage to supporting brackets that hold the cameras. If any movement of damage was found to exist in the supporting brackets or camera-housings the data was deemed flawed and was not used in the analysis.

4.4.4 Distortion correction chequer-board

Lens radial distortion, often called pin-cushion or barrel distortion, is a source of image distortion and induced vertical parallax (Woods et al., 1993). All underwater camera systems have some degree of lens barrel distortion and even in small amounts this can cause flawed measurements in photogrammetry. To assess the amount of barrel distortion on the stereo camera system, a custom-made distortion chequer-board was produced. The specifications of the board were a 1 m x 1 m x 4 mm sheet of white acrylic (perspex) plate, printed with 2 cm x 2 cm alternating black and white squares with precisely aligned corners (Fig. 8). The chequer-board was large enough to completely fill each camera's screen when positioned far enough from the camera to be in focus. The individual square dimensions were intended to be large enough to be distinct from one another at the filming distance and small enough that in the calibration program a reference 'plumb-line' can be drawn that is comprised of a large enough number of points to assure a good circle fit (Woods et al., 1993). This is based on the insight that the locus of a distorted straight line becomes the arc of a circle (Strand & Heyman, 2005). To ensure the precision and accuracy of the chequer-board a professional sign printer was used for printing.

Figure 8: Distortion Correction chequer-board

Lens distortion tests were conducted in Beau Vallon Bay, Mahé. The chequer-board was bolted to the back of the calibration quadrant and lowered into the water. The quadrant was held in position two metres below the water surface by floatation aids attached to the top edge. An assistant held the quadrant, to ensure it remained motionless whilst being filmed. During testing the cameras were set to record and were individually positioned in front of the chequer-board at a distance of 50 cm, the optimal distance to ensure it completely filled the full field of view. Vidsync tests each individual cameras lens separately for barrel distortion; so no synchronisation is necessary at this stage.

The first step of the lens distortion calibration is to import the relevant video clips into Vidsync. Once both clips are imported, they are saved as a working project to allow the user to begin the distortion calibration steps. Each video clip can be played-back independently to get a clear full screen shot of the chequer-board. When identified, an automatic routine inserts "plumb-lines" onto the selected screen shot of the calibration squares. Plumb-lines are defined by the program as the vertical and horizontal lines that lie along the outer edges of the squares of the chequer-board (Neuswanger, Hughes, Wipfli & Kelly, 2010). If some are not exactly aligned along the outer edges of the squares, the user may manually nudge them into alignment using the keyboard arrow keys. A magnification option in the working window allows for more precision. The plumb-lines at this stage are the distorted lines seen by the cameras lenses. These lines are referred to as "Uncorrected" overlays within Vidsync (Fig. 9). Once these are exactly aligned to the corners of the squares both horizontally and vertically, the program will allow automatic correction factors to be calculated.

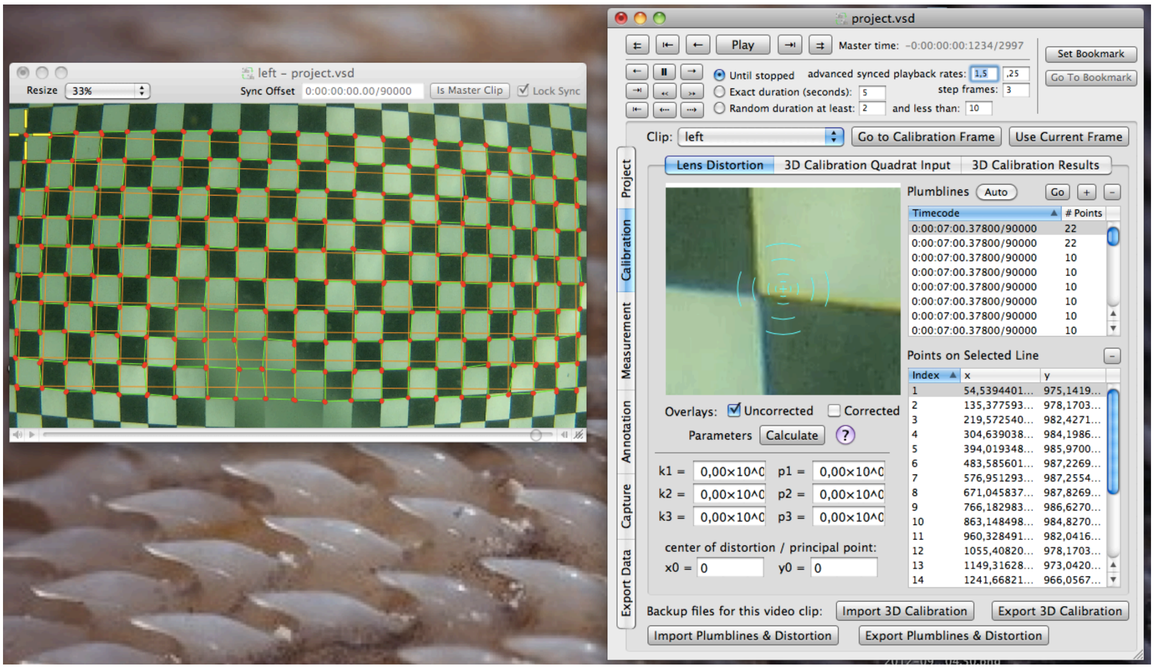


Figure 9: Screen shot from Vidsync showing working window & uncorrected overlays from the lens distortion calibration procedure

In some cases, the Auto plumb-lines option will be incapable of recognizing the squares on the chequer-board and a manual approach must be used to create custom plumb-lines to suit. For a more detailed explanation of the procedures necessary for manual correction refer to Neuswanger et al. (2010).

These steps are repeated for the second camera and saved.

During survey periods the lenses and cameras were not changed or disrupted so that the lens distortion calibration was only evaluated at the beginning of a survey period and once again at the end.

4.4.5 Calibration Quadrant

The next step in calibration is to register the images from the two cameras in a three-dimensional space. The general approach adopted for this calibration is the use of a three-dimensional control frame with a number of known positions marked as reference points. These calibration instruments address two main areas, first the complete internal characteristics of the cameras, from their principle focus points to their orthogonality and affinity terms, and secondly, the relative orientation of the two cameras to each other (Harvey & Shortis, 1998).

For the side-by-side stereo-camera system used, a uniquely designed calibration quadrant was fabricated. The quadrant was a durable 1 m x 1 m cube framework made of 5 mm squared aluminium tube. Mounted on both the front and back surfaces of the cube, were 4 mm acrylic (perspex) plates; with the front surface plate clear and the back surface plate solid white (Fig. 10). Both plates were bolted to the sides of the quadrant and were perfectly aligned in parallel with one another, to ensure that both could be individually marked with reference points to create a known 3-Dimentional coordinate system which was used during the calibration process.

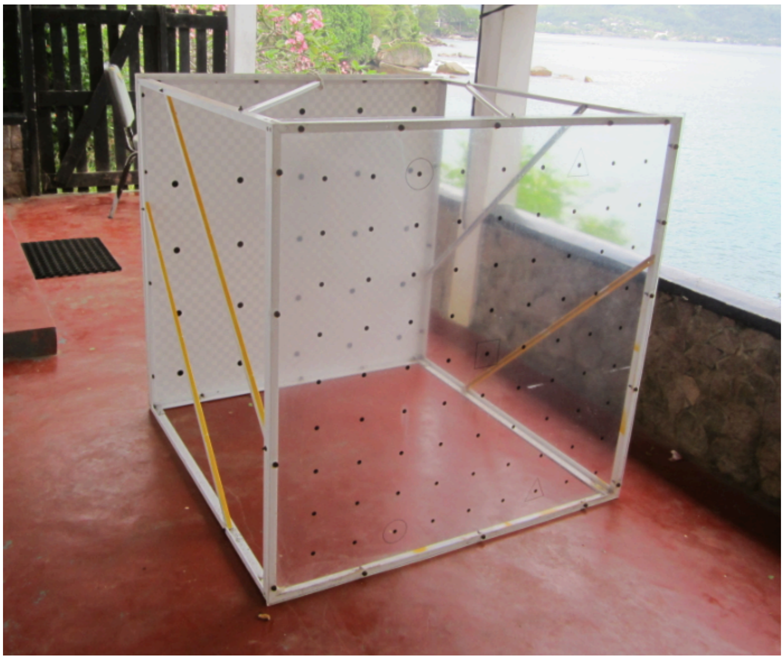


Figure 10: Calibration quadrant complete with 3-Dimentional coordinate system

Numerous variations exist for the number and location of the reference points needed to create a 3-Dimentional coordinate system for stereo-camera calibration. These are dependent on a number of diverse variables including the specifications of the quadrant, its material and its purpose (Hughes & Kelly, 1996). However, the majority adopt a regular grid method to locate the 3-Dimentional coordinates with a minimum of four known points on each surface. Any calibration quadrant should have sufficient points on each side that if several are obscured, enough remain available to ensure that the calibration result is not overly sensitive to errors at any single point.

For this study the quadrant was marked with twenty-five known reference points on the back surface plate along a 20 cm regular grid outline. The front surface plate was marked with eighty-one known reference points along a 10 cm grid outline. Providing that all reference points on both surfaces are recognised in the identical coordinate system and that each camera has a clear view of both the parallel surfaces, calibration is achievable.

In-water calibration was conducted in Beau Vallon Bay, Mahé. (see earlier description of methodology). Before entering the water both cameras were turned on and set to record. When the cameras were recording the laser was turned on and the system was run past the visual mark to obtain synchronisation cues. The system is to be positioned in front of the cube and perpendicular to the front surface with, ideally, the quadrant surfaces occupying most of the cameras' field to ensure more quantifiable results. Trials indicated that the optimal distance for filming was approximately one meter away from the instrument, dependent on the water visibility**.**

The calibration clips from both cameras were imported into the Vidsync software and, each clip was played back independently until the visual cues were recognised. Once this was done for both camera clips, the two clips are locked at the appropriate frame to synchronise the two video feeds. From this point both the videos are played as one corresponding clip. The video streams were played to an appropriate screen shot where the quadrant was visible in both cameras and filled the majority of the field of view. Once an appropriate screen shot has been found the calibration process was started (Fig.11).

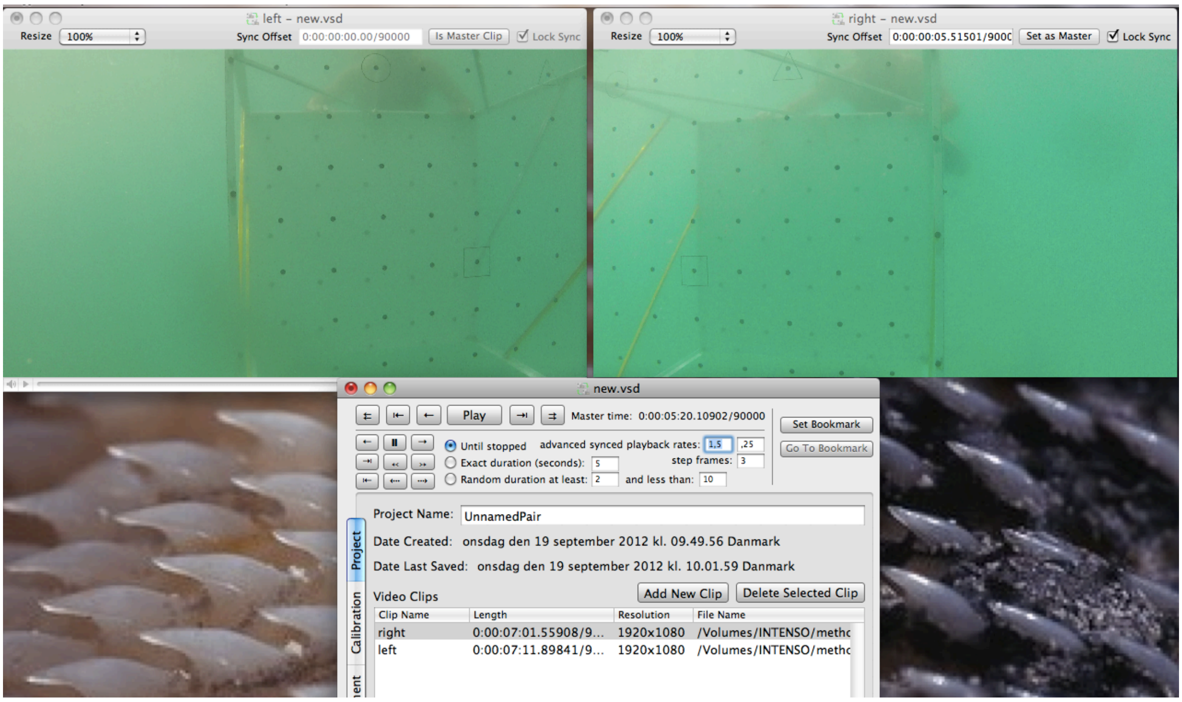


Figure 11: Vidsync screenshot of initial calibration procedure

The unique dimensions of the calibration quadrant and specifications of the 3-Dimentional coordinate system are first manually entered into the program. Once cube dimensions and coordinate system have been input into Vidsync, they can be exported and saved as a Vidsync file for forthcoming data analysis and calibration testing.

When the cube coordinate system has been re-imported into Vidsync, calibration of the left camera is started first. All the known reference points on the back surface are manually marked, after which all the known points for the front surface are similarly marked (fig.12).

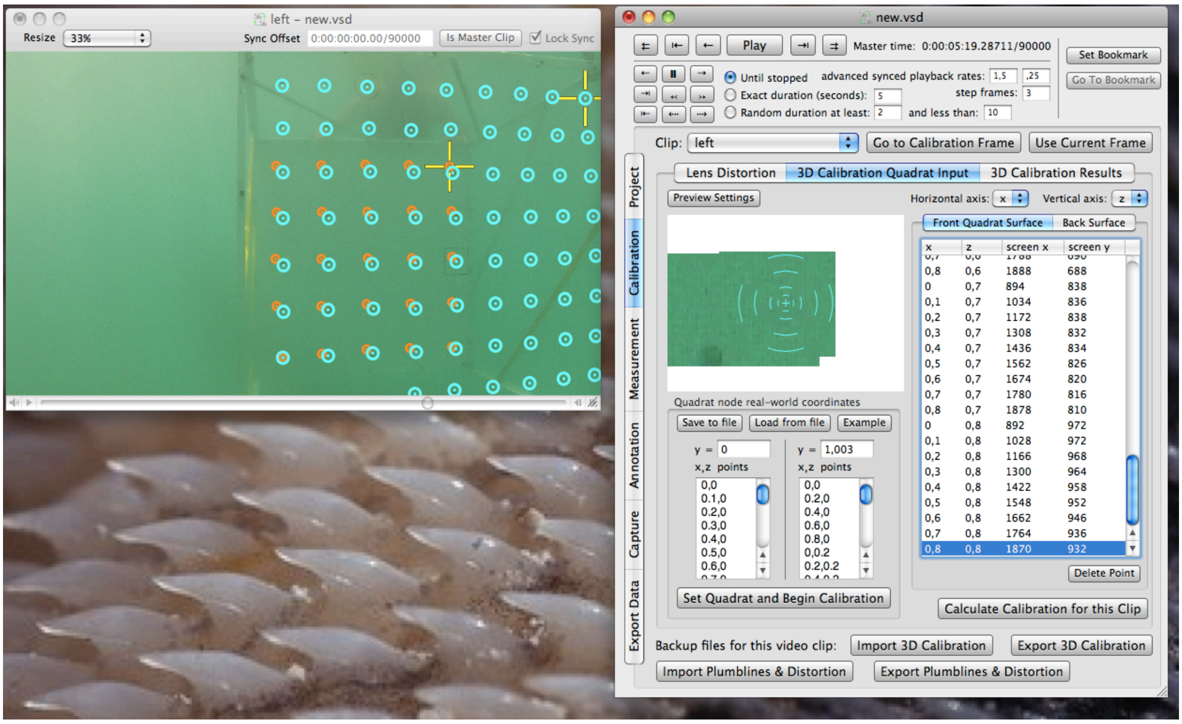


Figure 12: Vidsync sceenshot of marked reference points on both parallel surfaces of calibration quadrant

When all known reference points seen on the current calibration frame have been marked and nudged into alignment, vidsnyc will automatically perform the 3-Dimentional calibration. The calibration results are provided in matrices with residuals that measure how well the theoretical two dimensional quadrant coordinate systems match the points recorded. These are called the “world” residuals within Vidsync. In short, the world residuals are the distances between the intended coordinates of the dots on your calibration quadrant and the three dimensional positions calculated from the clicks you made on those specific reference dots during calibration (Neuswanger et al., 2010). The final world residuals reported by VidSync are the averages of those values across the front surface of the calibration quadrant and the back surface of the calibration quadrant. Software producers mention for the best quantifiable results, the world residuals must be less then 0.5 cm (Neuswanger et al., 2010) (fig.13).

Following these results a refraction correction test must be carried out on the calibrated frame. Vidsync uses the refraction correction to compensate for the effect of refracting light on the reference dots on the two parallel surfaces and recalculates their true position for the specifications of the calibration instrument.

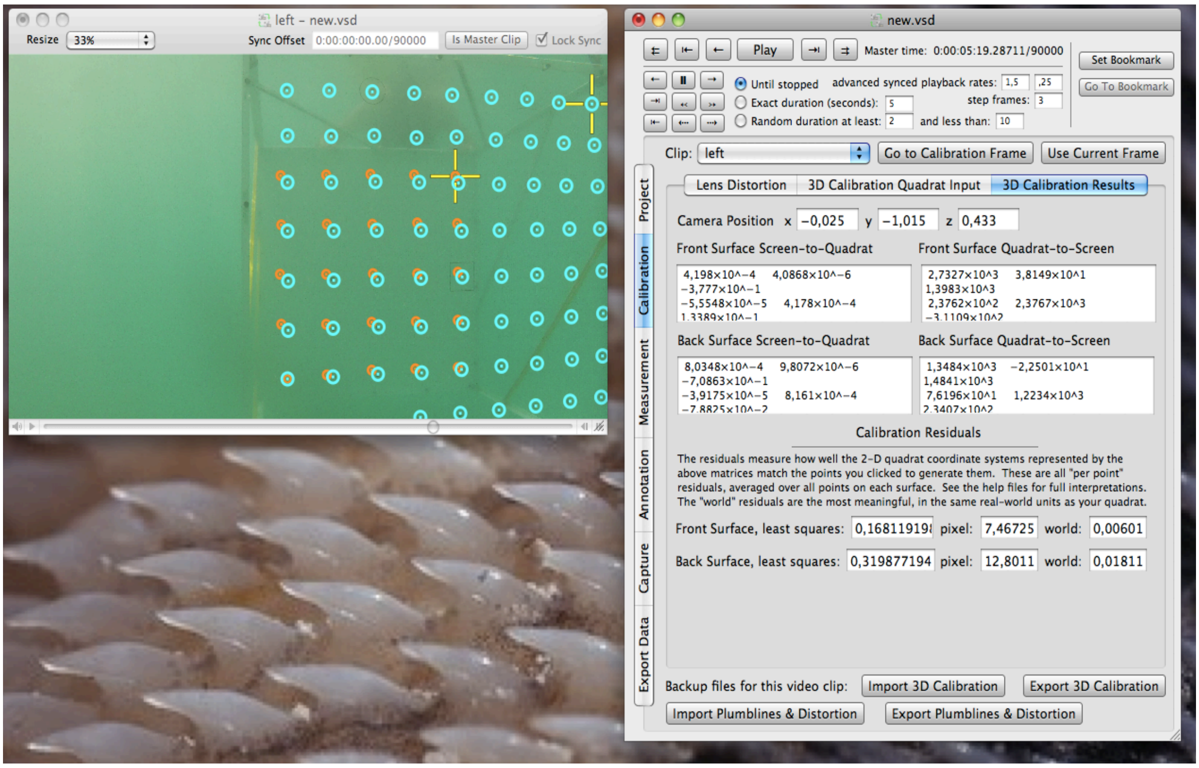


Figure 13: Vidsync screenshot of calibration results

Vidsync offers a number of options to suit the cube specifications. Firstly, the thickness of the front quadrant surface material was adjusted to 4 mm, which is in the same length units as the quadrant node real-world coordinates. Next, the refractive index of the quadrant material was adjusted to acrylic (perspex). Vidsync has a database of a number of useful materials and their known index values. For the material used in the project, the front surface index value was set to 1.491 for acrylic while the refractive index for the medium was set to salt water, with a value of 1.342. After all values have been set the data is saved and exported to the master vidsync folder.

The whole calibration process is then repeated for the right camera to conclude the correction procedures.

4.5 Measuring the accuracy and precision of the stereo–photogrammetry system

When a system is used for making exact measurements of distance, it is important to establish the variability in the accuracy and precision of all measurements made. Panfili et al. (2002) defined "accuracy" as "the closeness of the estimate of a quantity to its true value" and further defines "precision" as "the closeness of repeated measurements of the same quantity."

The stereo photogrammetric system used was continually validated throughout the research using repeated measurements of an object of known length in-water at a series of changing angular positions, as tests for the system's ability to obtain stereoscopic measurements within a field environment. When possible, multiple repeated measurements on individual whale sharks were obtained at each study site to give a representation of the systems performance in a constantly changing environment. Repeatability (r) can be explained as the capability to obtain consistent results when calculating identical measurement with the same instrument (Harvey & Shortis, 2004; Spitz et al., 2000). Repeatability of the stereo-photogrammetry system was calculated from an index of precision and accuracy obtained from a one-way analysis of variance (ANOVA).

4.6 Data Collection

Overall data collection was dependent on the availability of sharks seen daily and / or an adequate number of paying tourists, for successively operating whale shark encounter trips at all surveyed sites. Generally speaking most encounter or search trips lasted approximately three hours in total length and in the main surveyed exclusively coastal areas. Surveys were conducted from tourism-focused vessels, in compliance with locally preferred codes of conduct for whale shark interactions. The availability of aerial support in the Seychelles allowed for a complete search pattern along its coastal areas, while other sites relied exclusively on boat-based survey techniques.

Upon locating a whale shark, the researcher entered the water alongside paying clients and recorded all seen behavioural observations of the animal and the in-water participants. Using both visual signals on the videos and standard dive slates, the information was collected for later analysis. The total length (TL) of the shark was estimated visually to the nearest half metre and the sex identified by the presence or absence of claspers on the pelvic fins. Also the total number of swimmers, boats and various environmental characteristics were documented on the recording sheet. Analysis of the video recordings established the existence and location of any injuries or external scars to the shark, which were noted and categorised as "major", "minor" or "intact" following the definitions of Speed et al. (2008a). Identification of the individual sharks was accomplished through photo-identification software techniques, processed by the researcher within both global and nationwide databases. To standardise data collection, all field observations were made by the same researcher. To eliminate confusion when analysing data, multiple swim groups or different boats of people swimming with the same individual shark, during one encounter were considered as one single interaction or encounter.

4.6.1 Monitoring avoidance behaviours

Avoidance behaviours of the whale sharks' were divided into two basic categories: 1) dive behaviours 2) directional changes and accelerated swimming behaviours. The individual types of dive behaviours were further separated based on the observed behaviours: instant dives, sharp dives, gradual dives and parabola diving. Directional changes and accelerated swimming were also sub-divided, based on speed and the type of activity such as: direct change, gradual change, swimming in circles towards / away from swimmers and banking (*sensu* Norman, 1999). Accelerated swimming of the shark was classified as a disturbed behaviour and was demonstrated as a shark increasing its current swimming speed, as a means to try to move away from an in-water swimmer, boat or other unseen variables. A detailed description of the individual categories of behaviours is given in table.1

Table 1. Description of the Individual categories of behaviour within the study

Dive Responses	Directional changes / Accelerated swimming
• Instant dives were defined as an immediate dive from the animal less than five seconds after the start of an encounter. The start of the encounter was defined as the time when the swimmers enter the water • Sharp dives was defined as a dive with an angle in excess of 20° • Gradual dives were a shallow slow dive from the shark at an angle less then 20° • Parabola dives were when the shark swam up and down through the water column in a consistent rhythm. This manner of behaviour within marine mammal research is termed “porpoising”	• Direct change in direction was demonstrated by the animal turning between 45° and 90 ° in less than two seconds after the start of the encounter • Gradual changes were when the animal exhibited a directional change of 45° or less • Swimming in circles divided into two groups: 1) Sharks swimming towards a swimmer. This behaviour was classified as an increased level of curiousness towards a swimmer or boat and recorded as a neutral behaviour. 2) Swimming in circles away from a swimmer, classified as an avoidance response. • Banking is when the shark turns its dorsal surface to the swimmer as a defense mechanism for protection of its soft ventral surface and to amplify its overall size (*sensu* Norman, 1999)

To quantify these behaviours for analysis, an ordered numerical grading scheme was developed and applied commonly to all whale shark encounters. This ordered scheme was used to provide a simple behavioural classification, which rates the severity of a behavioural change by the shark during the interactions. Set along a gradient they ranged from a score of "0" the shark showing no disturbance or possible positive behaviours, to a score of "3" the shark exhibiting direct avoidance behaviours to an in-water event. The assignment of each grade to each type of behaviour is shown in table.2.

Table 2. The individual grades of severity allocated to each type of behaviour

Response Grade	Behaviour Classification
0	No response No change in direction Swimming in circle towards swimmers Feeding Parabola diving
1	Gradual dive Gradual change in direction Circling away from swimmers
2	Sharp dive Accelerated Swimming
3	Instant dive Banking Multiple of two behaviours*

* Incidents when the shark exhibiting two individual behavioural changes at once was given the severity grade "3" a clear avoidance to an in-water event. An example of this multiple grouping is if the shark exhibits banking behaviours towards a swimmer and simultaneously makes a sharp dive. This association of behaviour's demonstrates a deliberate discontent to its immediate surroundings and a prompt action to move away from it.

4.6.2 Data Processing

Throughout the analysis phase all multiple encounters with the same individual were disregarded and only first time sightings were used within the statistical model. This aided to eliminate any pseudoreplication, which can typically occur when the number of observations or the number of data points are treated inappropriately as independent replicates (Hurlbert, 1984). Recordings with technical faults due to camera failure or missing synchronising cues were further disregarded from the analysis. Accounts where the shark showed a curious or approaching behaviour to swimmers, resulting in the animal inadvertently "*spooking*" itself were removed from the data set, as the study solely aimed to examine the avoidance behaviours of *R.typus* to a number of pre-selected variables. In the course of the analysis recordings were played back and during each individual encounter a proximity measurement and a behavioural grade were recorded every five seconds from the beginning of the encounter until the end. The encounter conclusion was defined as the point when the shark was out of view or swimming range of the participants. This five second interlude was selected due to the noticeable length of time it takes *R.typus* to exhibit a behavioural change, allowing the recordings to represent a correct explanation of the behavioural action at the time of measurement.

Proximity measurements were recognised as the nearest point of the closest swimmer to the shark at the time of measurement. Scar description, sex of the shark and field location were given a numbered code, which was used as a standard categorical factor unit within the analysis model. At the end of each encounter an average proximity distance and avoidance behavioural grade were calculated and assigned to each in-water encounter.

4.7 Statistical Analysis

The effect of the numbers of swimmers, number of boats, shark size (m), sex of the animal, scarring information, field location, and proximity distances (m) were observed, upon the occurrence of changes in the whale sharks behaviour and examined using a Generalised Linear Model in the statistical program R-Studio: a powerful and integrated user interface environment for R (version 0.95.265).

Disturbed / Undisturbed classification of the whale sharks behavioural status within the encounter, was used as the response variable, using a binomial error structure with the logit link function. Table 3 illustrates the starting model construction. The model was refined using a standard stepwise deletions procedure, removing the least insignificant terms. The Akaike information criterion (AIC) score was used as a measure of how well a model fits a data at hand. The Akaike Information Criterion is a way of selecting a model from a set of models. The chosen model is the one that minimizes the Kullback-Leibler distance between the model and the truth (Burnham & Anderson, 2002). It's based on information theory, but a heuristic way to think about it is as a criterion that seeks a model that has a good fit to the truth but few parameters. It is defined as

$$\mathbf{AIC = -2\,(\,\ln\,(\,likelihood\,))+2\,K}$$

where the likelihood is the probability of the data given a model and K is the number of free parameters in the model. The expected best model is the one with the smallest AIC scores.

Table 3. Generalised linear model construction

Dependent variable and model type	Independent variables
Disturbed / Undisturbed interaction Error structure = Binomial Link function = Logit	Size class No of Persons Scars Proximity

4.8 Statistical modeling

Following the selection of the covariates available (see above), a generalised linear modelling (GLM) approach was used to model the behavioural response *B* of whale sharks as a function of their characteristics (fish length *L* and number of scars *S*) and the environment (number of persons in the water *N* and proximity between swimmers and whale sharks *P*). The covariates *L*, *S*, and *N* were modelled as factors and the proximity *P* was considered as continuous variable. A length limit of 4.5 m was used to distinguish between smaller and larger juvenile whale sharks. Fishes characterised by scars were considered to have experienced several encounters with boats. A reference number of eight persons in the water according to the current regulation size (Colman, 1997) were considered for factorising *N*. No interaction was considered in the model. The response variable *B* was coded as a Boolean (0 for undisturbed and 1 for disturbed) and assumed to follow a Binomial distribution following

$$\mathbf{g(B_{0/1}) – L + S + N + P + \varepsilon_{0/1}}$$

where *g* is the logit link function which transforms the expectation of the response variable to the linear predictor and $\boldsymbol{\varepsilon_{0/1}}$ are the model residuals assumed to be binomially distributed.

To test the hypothesis $\mathbf{H_0: \beta1=\beta2=0}$ a comparison was made between the final refined model and a reduced model that only contained an intercept term. A likelihood ratio test comparing the full and reduced models was performed using the ANOVA function with the additional option test = "Chisq". Chi-square is a statistical test commonly used to compare observed data with data we would expect to obtain according to a specific hypothesis. The chi-square test tests the null hypothesis, which states that there is no significant difference between the expected and observed result. Interpretation of the Chi-squared value showed the p-value of p=0.001. As the P-value is <0.005 there is a rejection of the H_0 at 5% and for all sample sites H_1 was accepted. Table. 4 shows the summary of the analysis of deviance table for the remaining variables. Additionally, the GLM summary output is presented (table.5) showing parameter estimates and standard error values.

5. Results

Two hypothesis were tested:

- (H_0) The sharks' behavioural outcome during tourism interactions has no relationship to the in-water activities of swimmers
- (H_1) The sharks' behavioural outcome during tourism interactions is dependant on the in-water activities of swimmers

5.1 Data summary

Field data was collected between April 2012 – April 2013 from all three-aggregation sites with the number of observations resulting in: the Seychelles (53%), Mozambique (3%) and the Philippines (44%). A total of 192 search hours were documented over the collection periods, resulting in 75 in-water human-shark encounters from tourism-orientated vessels. Due to the lack of suitable data from the field site Tofo, Mozambique, it was removed from the analysis and not referred to in the results.

A sum of 33 individual whale sharks was positively identified using the interactive individual identification software (I3S) (van Tienhoven et al., 2007). Of these identified sharks 24 were male (72%) and 4 were female (13%). The lack of suitable identification photographs for all in water encounters meant that some sharks lacked identification and were coded as "unknown" in the analysis. Throughout the total field collection 5 sharks (15%) fell into this category.

From the 75 shark encounters, 60 ended by the shark actively diving away from the swimmers (80%), leaving the remaining 15 encounters concluding by the shark accelerating its swimming speed and gradually moving away from swimmers (20%). Generally, swimming speed of *R. typus* when not engaged in feeding was rarely too fast for tourists to sustain within the interaction zone. Observations at all sample sites showed that whale sharks do feed during interactions, by both suction and flow-through mechanisms. Although, during all surveying periods accounts of feeding behaviours were significantly low and therefore feeding as a variable in itself was removed.

5.1.1 Data Description

Due to the overall lack of individual animals in the study resulting in a relatively small dataset, therefore a number of independent variables were removed from the analysis owing to unbalanced distribution or confounding effects, resulting in the "parsimony principle" of science being adopted. In short, the principle of parsimony is one of simplicity, suggesting that that the simplest explanation is probably the most likely (Seasholtz & Kowalski, 1993). In practice, electing to move with the weight of the evidence available to us from the observed dataset. This will probably seem very obvious, but it is essential that scientists have a philosophically justified method of choosing between explanations of our data (Seasholtz & Kowalski, 1993). Observational data plots between the numbers of boats verses the number of swimmer (fig.14) showed that the two variables to be highly correlated, which was to be expected.

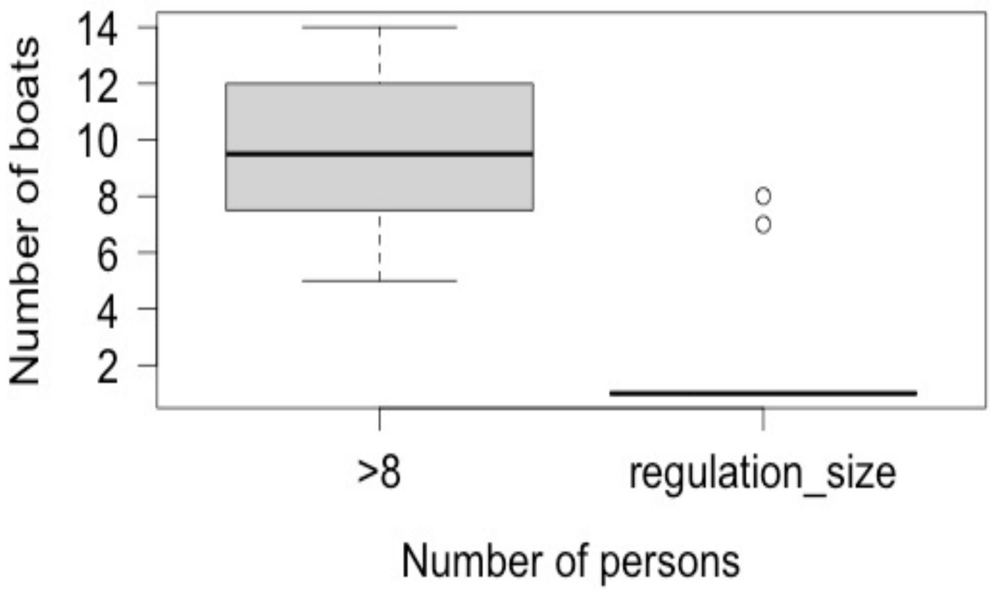


Figure 14. Data observation boxplot of the distribution of the number of swimmer vs number of boats in the interaction zone. Regulation size equals or less than 8 persons in the water (Colman, 1997)

The above plot validates that the number of boats within the interaction zone is highly correlated to the number of persons in an interaction so co-linearity. This makes rational sense as tourism-operated vessels are supported and restricted entirely by the demand of paying guests. This observation initiated the removal of the number of boats variable from the analysis, allowing the main focus to be pushed on a more quantifiable understanding of the effect of the in-water behaviours' of swimmers. Sexual identification of the individual sharks was further removed, due to the unbalanced distribution of grouped individual classes (fig.15) and the lack of examples of both sexes at all sampling sites.

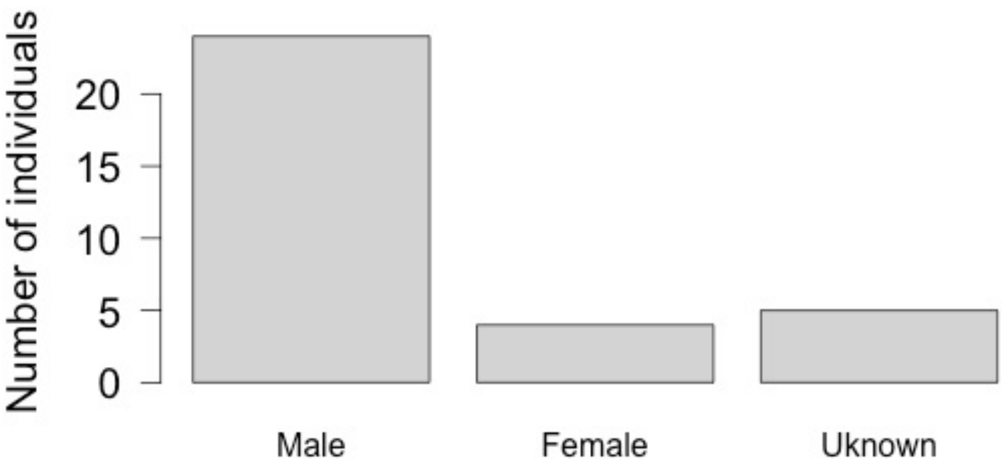


Figure 15. Number of whale sharks observed according to sex

This was expected, as most coastal aggregations of *R. typus* are sex segregated and dominated by juvenile males (Norman, 2002; Rowat & Brooks, 2012).

Identification of the individual sampling area as an independent variable was removed, as collected data showed disproportionate extremes of uncontrollable, environmental factors at sampling sites, which were not taken into account during this study such as, extreme weather conditions, levels of water visibility and availability of boats. Finally, figures 16 & 17 illustrate the uneven distribution in both the numbers of persons and numbers of boats classes at both sites.

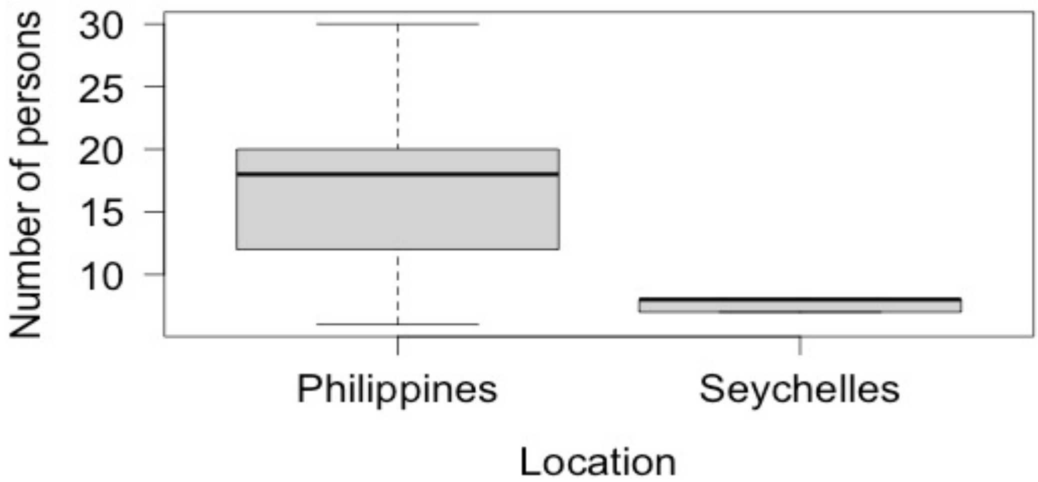


Figure 16. Data observation boxplot of the distribution of the number of persons according to the individual sampling area.

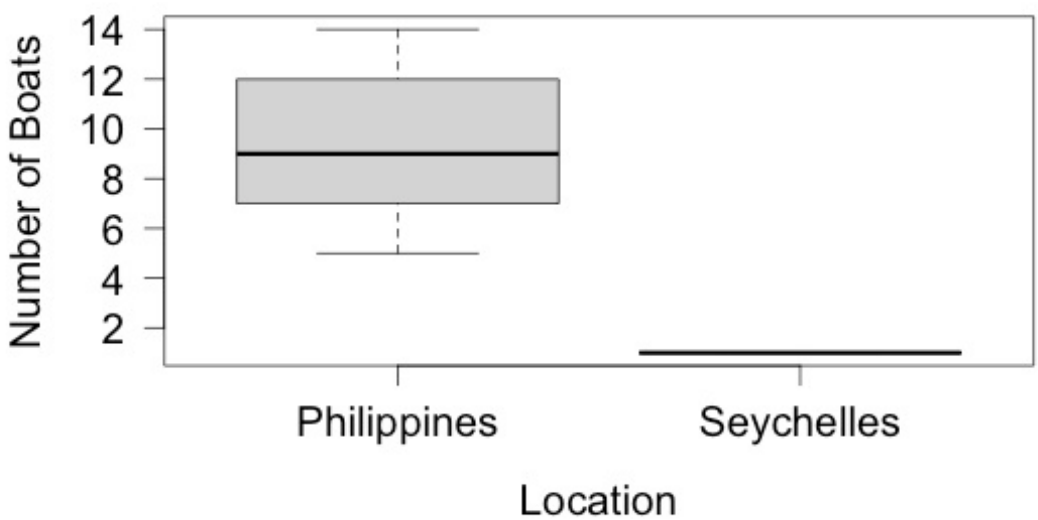


Figure 17. Data observation boxplot of the distribution of the numbers of boats according to the individual sampling areas

5.2 Generalised Linear Model Output

Analysis of the generalised linear model output table (table.4) presents evidence that whale sharks are disturbed by the presence of swimmers that are too close to them. The proximity of swimmers to the shark was found to be significant (p-*value* 0.0295) in explaining the probability of the whale sharks to show a disturbed behaviour. All other predicators in the final model showed no significance in explaining the outcome. Although not significant (p-value = 0.11), the decrease in the number of persons in the water from >8 to a number compliant with regulation size was found to have a negative effect on the probability of disturbance (mean parameter value = -2.064; Table 5).

Table 4. Summary of Analysis of deviance table. Df = degrees of freedom. * indicates P-value < 0.05

Final model

	Df	**Deviance**	**Residual Df**	**Residual deviance**	**P-value**
Null model			32	44.252	
Proximity (P)	1	4.737	31	39.515	0.0295*
Number of persons (N)	1	2.572	30	36.942	0.1088
Size class (L)	1	0.918	29	36.024	0.3379

Table 5. GLM Summary output of final model

	Estimate	**Std. Error**	**z value**	**Pr(>|z|)**
(Intercept)	1.1658	0.9755	1.195	0.2321
Proximity (P)	-0.1053	0.3159	-0.333	0.7389
No.persons (N)	-2.0645	1.1531	-1.790	0.0734
Size.class (L)	-0.7686	0.8746	-0.879	0.3795

Similarly, the response of size on whale shark response was inconclusive in the model (p-value = 0.34) but the parameter estimate (-0.77; Table 5) suggested that small whale sharks might be less disturbed by swimmers than large ones.

A proportional odds predictions plot for proximity was developed to give an indication of the disturbance level of *R. typus* at the current code of conduct advised distances of three metres from either side of the shark and four metres from the shark tail (Norman, 2000). At a distance of three metres from the shark, there is on average a 42% chance of disturbance, while the advised distance of four metres at the rear of the shark showed a 31% chance of disturbance to the shark (Fig. 18). The true estimate for either distance may however possibly lie between 21-53% respectively with regards to the uncertainty around the mean predictions.

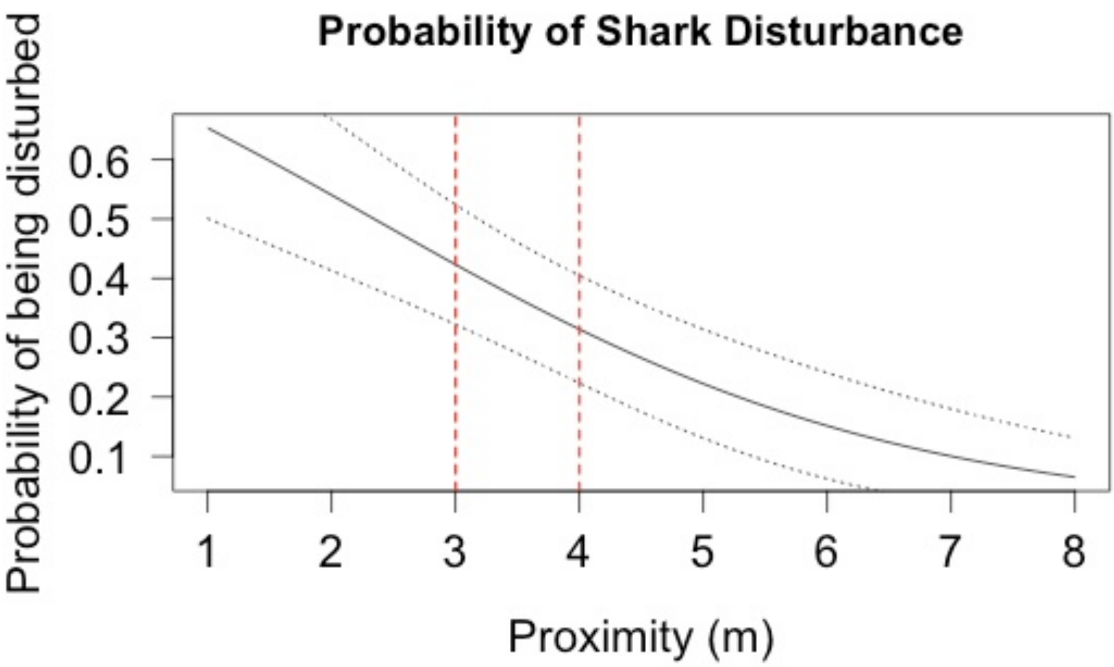


Figure 18. Probability plot of proximity as an indicator of shark disturbance at currently accepted code of conduct distances. Black solid line indicates mean model predictions. Black dashed lines indicate standard error. Vertical red lines show the 3 m and 4 m reference distances

5.3 Precision and Accuracy Validation Results

Over the course of the research, 25 individually identified whale sharks were repeatedly measured at a series of six different angular positions to gain a robust repeatability (r) value for the system's ability in a changing field environment. Repeatability of the system was calculated from a one-way analysis of variance (ANOVA) using a series of repeatability calculations presented below. Overall r value for the stereo-photogrammetry system was 0.999. This explains that about 99.9% of the variation is due to differences among individuals, not repeated measurements of the same individual, which can only happen if individuals are consistent. Table 6 shows the output summary table for the ANOVA single factor test.

Table 6. Summary output of ANOVA single factor analysis. SS = sum of squares, Df = Degrees of freedom, MS = Mean square, F = Fisher statistic

ANOVA

Source of Variation	*SS*	*Df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	72604.32	24	3025.17983	17992742.84	0	1.604
Within Groups	0.021	125	0.000168133	0		0
Total	72604.34	149				

In the output table from the ANOVA, is the important information that is used to calculate the overall repeatability of the stereo camera system. The analysis of variance tests provides a statistical assessment of whether or not a significant amount of the total variation is found by examining differences between the different groups (individuals) relative to the amount of variation within the groups. The output is presented into a number of columns the SS and MS represent the sum of squares and mean sum or squares due to the source.

The Df is a degrees of freedom, the *F* column, is the Fishers statistic, calculated by taking the ratio between mean sum of squares to the error mean sum of squares using a simple calculation (F = MSB/MSE). The P-value is a statistical value used to determine if there is any relationship in a dataset and used in the likelihood of finding a difference between the groups. From the output table there is almost a zero chance that there is a true difference between groups (*p-value* = 0). With such a significantly low P-value, directly assuming and provisionally stating that the groups are different and the variation is due to differences among individuals not repeated measurements of the same individual, which can only happen if individuals are consistent. Usually in scientific research, if the chance is 5% or less (p-value = < 0.05) we say it is statistically significant. Fundamental calculations and the formula to attain a repeatability value are simplified below in a step-by-step break down. Repeatability formula

$$\mathbf{r = S^2A/(S^2 + S^2A)}$$

where $\mathbf{S^2A}$ represents the between group variance and $\mathbf{S^2}$ is the within group variance. The $\mathbf{S^2}$ signifies the sum of squares that are associated with the specified sources of variation, which are divided by their degrees of freedom to give the mean squares values (Lessels & Boag, 1987). Within this test design the $\mathbf{MS_B}$ is the within group variation (MS_B = 0.000168133) and to symbolises the value for the variation among individual groups $\mathbf{MS_A}$ was assigned (MS_A = 3025.17983).

Next we use the following equation to determine the between group variance

$$\mathbf{S^2A = (MS_A - MS_B)/\boldsymbol{n}}$$

within this second equation $\boldsymbol{n}$ characterises the weighted number of repeated measures per individual group and for this validation test n = 6. For the presented data set, the final calculations for the repeatability value are presented formally here:

$S^2 = MS_B =$ **0.00016**

$S^2A = (MS_A - MS_B)$ /n = (3025.17983 – 0.000168133) /6 = **504.1966102**

r = $S^2A/(S^2 + S^2A)$ = 504.1966102 / (0.000168133 + 504.1966102) = **0.999999667**

r = **0.999999667**

6. Discussion

Quantative behavioural studies on large, migratory, marine mega-fauna will always be challenging. Their complex lifestyles and continually altering environmental factors affect the means to successfully interact with these species in their natural environment (Orams, 2002). In recent years the advances in stereo-photogrammetry methods have attracted the marine biologist to develop uses for this technique in their own relevant marine sectors, where there are advantages over conventional single camera photogrammetry measurement methods (Harvey et al., 2004). Scientific publications (Harvey et al., 2003: Shortis et al., 2007) have confirmed that current stereo photogrammetry techniques and applications are not highly sensitive to human error, subjectivity or sampling bias, and are unable to achieve robust results in a challenging environment (Harvey & Shortis, 1998; Harvey et al., 2003). Preliminary studies by Harvey & Shortis (1996) provided an early indication of the advantages of stereo-camera systems over single camera techniques. They demonstrated that the accuracy and precision of a prototype stereo-video system, combined with strict reliability measurement and calibration guidelines, provides an increased incentive to pursue this technique and deploy remote stereo-video systems. This is considered to be in preference to remote single cameras for underwater measurement use. A further study by Harvey et al (2003) compared the accuracy and precision of underwater measurements taken from single and stereo-video camera systems. Their results undoubtedly illustrated / showed that a stereo photogrammetry system was substantially more accurate and precise in determining underwater length measurements, in comparison to the tested single camera system. In addition, these results provided evidence to show that it was also possible to accurately measure the length of a known measurement instrument over a greater range of rotation with improved accuracy, compared to single video camera systems. Abdo et al (2006) examined the efficiency of measuring marine species. They demonstrated this by using simple laboratory trials to show that the stereo photogrammetry techniques, do not show any biases to observer experience, equipment operation and camera projection.

As technological advances have evolved, the use of digital video image sequences has undoubtedly helped expand the versatility and the efficiency of data acquisition (Harvey et al., 2003). Geometrical advancements and computer aided calibration protocols have enabled scientists to not only lower the overall margin of error of a remote stereo camera system, but dramatically reduced the processing time needed for pre-calibration tasks and post calibration analysis (Kimley & Brown, 1983: Shortis & Harvey, 1998). Modern, sophisticated stereo photogrammetry set ups, have now progressed to a point where the initial costs to develop a reliable unit is considerately expensive and almost brands them inaccessible for fundamental research. The need to develop a reliable, low-cost, easy to operate system, which can withstand the daily wear and tear of a constantly changing marine environment is of high demand. This was a critical objective for this study, as current available products where beyond the financial scope for the research.

Currently, the most scientifically recognised "complete" stereo photogrammetry package or system is the readily available platform from SeaGIS Ltd, Australia (SeaGIS, 2012). SeaGIS Ltd is an Australian based company specialising in measurement science software, hardware and services (Abdo et al., 2006; Shortis et al., 2009). They presently offer software products including a range of photogrammetric camera calibration, measurement and event logging software, with a core focus on underwater ecology and biological applications (SeaGIS, 2012). Their hardware products include calibration instruments and a range of collapsible underwater stereo camera systems all of which can be customized. Thus ensuring that the most suitable technique and analysis are provided (SeaGIS, 2012). The average price for a complete SeaGIS system comprising of calibration instruments, collapsible camera system and analysis software is approximately AUD15600 exclusive of cameras (J, Seager, Personal communication, January, 10, 2014). The primary objective for this study to develop a robust, reliable and inexpensive stereo-photogrammetry system for the use in gathering specific data at an affordable price was achieved and validated by a precision and accuracy validation test. A flawless side-by-side stereo camera system, and fundamental calibration instruments were constructed from easily obtainable materials and the choice to opt for small, high definition, GoPro extreme sports cameras, offered high quality video imagery at an affordable price. This innovative attitude of using a set of small, lightweight, high definition extreme sports cameras for scientific research might have been a forward thinking approach, but the choice was clearly justified by both the overall usability of the cameras internal functions, their affordability and the level of video quality. The further advantage of GoPro's specially designed, easy to attach abrasive mounting plates, is that it provided an excellent platform for securely attaching the cameras, both at the desired distance and orientation on the systems frame. This was done without disturbance, and in reviewing the manufacturers testing information provided showed that the mounts adhesive compound is capable of securing a standard GoPro Hero camera to the wings of an airplane going at speeds of over 200mph (GoPro representative, Personal communication, January, 14, 2014).

Computer aided software used in the calibration and data analysis was a concern when designing the research goals as current software packages are high-priced and require an high level of technical ability to operate (Harvey et al., 2004; SeaGIS, 2012). The availability of the new, freely available, software program VidSync 1.2 (vidsync.sourceforge.net; Neuswanger, pers. comm.), provided an alternative to additional and expensive calibration software. This enabled straightforward, easy to use calibration procedures for any photogrammetric system and data analysis tools. This means the system is capable or formulating a wide variability of results (Neuswanger et al., 2010). When any newly constructed system is designed for the use of making true measurements of distance, it is important to establish the variability in the accuracy and precision of all measurements made (Harvey & Shortis, 2004; Panfili et al., 2002). As the camera system presented in this research was a the first of its kind to use both extreme sports cameras for gathering scientific data, and to use freely available software during the analysis phase, it was essential to provide the level of precision and accuracy through a validation test. To do this, a unique precision and accuracy validation test involving collecting repeated measurements was employed. Measuring the distance between two visible spots on individually identified whale sharks, at a series of changing angular positions, it gave an excellent representation of the system's ability to obtain accurate, and precise stereoscopic measurements in a constantly changing marine environment. A repeated measures test is a form of experimental design in which observations are made on the same units at two or more points in time (Carrasco, Phillips, Puig-Martinez, King, Chinchilli, 2013). Overall repeatability for the prototype stereo system was calculated from an index of precision and accuracy obtained in a one-way analysis of variance and results showed a score 0.999. Repeatability, often symbolised as r, can be explained as the capability to obtain consistent results when calculating identical measurement with the same instrument (Harvey & Shortis, 2004; Spitz et al., 2000). It ranges on a gradient from 0 to 1 and expresses the proportion of variation in a trait that is due to differences among individuals rather than repeated measurements of the same individual, which can only happen if individuals are consistent (Lessels & Boag, 1987). Therefore, if the average individual is consistent, then the average within individual variation will be low. This will make the ratio of among individual variation to within individual variation (the repeatability) high (Lessels & Boag, 1987). Harvey & Shortis (1996) study on stereo-video measurements of sub-tidal organisms, published repeatability results for their prototype stereo camera system with an overall r score of 0.954, or 95.4% during validation tests. Therefore, an output repeatability score of 0.999 or 99.9% validates that virtually every part of the measurement variation has been explained and ultimately provides convincing evidence that this original, low cost stereo-photogrammetry camera system can provide robust repeatable measurements, which are comparable with current, more lavishly high-priced competitor setups and applications.

Analysis of the collected data from this study found that the proximity of swimmers to individual whale sharks during tourism interactions was significant (p-*value* 0.0295) in determining the overall behavioural outcome of the animal. These findings concur with the previous work by Quiros (2007) on the species, at an identical sampling site of Donsol, Philipines. Quiros's study aimed to assess tourist's compliance to the existing code of conduct and the resulting effect on whale shark behaviours. Her results indicated that proximity of swimmers to the shark during interactions was a significant predictor of whale shark directional change. This may be perceived as a clear avoidance response of the animal. The author further noted that the species showed significant increases in disturbance when swimmers dived in the direction towards the animal (Quiros, 2005, 2007). Although the present study did not incorporate a set variable for swimmers diving activities, incidences of sudden decline in the proximity between swimmer and shark significantly affected the magnitude of disturbance among individual sharks (pers. obs). According to a management study by Davis et al. (1997), which examined whale shark tourism in the Ningaloo Marine Park, Western Australia, they raised many questions concerning the separation distances of swimmers to the animal during swim-tours. Conversely, relatively small separation distances between swimmer and shark, coupled with the fact that boats passed sharks from one operator to the next in a rotation pattern, means that there is potential for negative impacts to the sharks by accidental collisions in to the shark, or path obstruction by boats, leaving the authors with the notion that this may require constant specialised monitoring (Davis et al., 1997). These common findings certainly support the understanding, that participants swim behaviours, which is somewhat controlled for in the currently accepted code of conduct for interacting with whale sharks, need to be fundamentally enforced to avoid disturbance or sudden behavioural adjustment of the sharks (Norman, 1999; Quiros, 2005).

A publication by Constantine. (2006) on the increased avoidance of wild bottlenose dolphins (*Tursiops truncates)* during wild-swim-tours, published results that revealed the animal's avoidance responses to swimmers increased respectively from 22% to 31% over several sampling seasons. In addition, that the animals response was found to vary according to swimmer placement, increasing dramatically when swimmers were placed in the animals path of travel. The author supplementary disclosed results that the operators' success with swim attempts, defined as at least one dolphin located within 5 m of at least one swimmer, decreased from 48% to 34% after three consecutive seasons. Similar studies from British Columbia by Williams, Trites & Bain. (2002) focusing on the behavioural responses of killer whales (*Orcinus orca*) to the proximity distances of whale-watching boats. This work produced canonical correlations between whale behaviour and vessel proximity, which suggest that the disregarding of interaction guidelines, or not adequately enforcing them, would result in higher levels of disturbance to the wild animals. Further related studies by Amante-Helweg (1996) & Scarpaci, Dayanthi & Corkeron (2003) on opportunistic swim-tours with large marine fauna, provided evidence that commercial operators licensed to offer "Eco-tourism" interactions, fail to follow the regulations. Whilst these regulations exist to reduce the likelihood of any possible negative impact on the animals, disregard for them is a failure of the tourism provider, and not solely the participants actions. A year later Scarpaci et al (2004) aimed to compare the level of compliance to three regulations; boat approach, interaction length and proximity of swimmer to dolphins, to determine the overall success of an experience. Their results revealed that compliance cannot be assumed, as many tour operators appear to comply better with conditions that are easily quantified. The authors expressed that further studies are needed to determine the statistical power required, to detect changes in tour operator behaviour to conditions in their permits. This will inform agencies whether the changes they have implemented to improve compliance levels are actually working. As a whole, tourism providers and any licensed operator might further enforce proximity concerns by developing new in-water protocols, which position swimmers properly at the onset or by more detailed pre-swim briefings (Davis et al., 1997; Quiros, 2007).

Although the effects of the remaining independent variables; individual size class of the shark and the number of person within an encounter, were not significant as a factor in determining the behavioural outcome, further examination of the output summary table (table.5) of the final model showed that both their coefficient estimates are of a negative value. Generally, in logistic regression models the regression coefficients represent the change in the logit for each unit change in the predictor (Bull, Mak & Greenwood, 2002). A negative coefficient estimate may indicate that there is an inverse relationship between our variables conveying that as one variable increases, the other variable decreases (Rahayu, Zain, Embong, Juwari, Purnami, 2012). Although, the negative sign in a coefficient estimates denotes only the directionality of the relationship, not the strength (Bull et al., 2002), these negative coefficient in the summary table may indicate that the individual size of whale sharks or the number of persons within an single encounter, may be significant in determining the behavioural outcome. It is reasonable to assume that a further study using a considerably larger dataset might conclude this. Speculations that smaller juvenile whale sharks might be more curious that larger juveniles may need to be investigated in further studies, as data interpretations from this study showed increased occurrences of positive behaviour amongst smaller individuals (pers. obs). At present there is no existing research to compare observations of curious or positive behaviour towards in-water participants and an overall need to determine the true behavioural traits of small juvenile shark over significantly larger juveniles.

The lack of significance in the statistical analysis may well stem from the small sample size and suggestions for further investigation are proposed, to elucidate both the effects of individual animal size and numbers of persons in the water on determining the behavioural changes of the species during tourism interactions. The power of any test of statistical significance is defined as the probability that it will reject a false null hypothesis (Cuevas, 2013). Statistical power relates to the likelihood that a study will detect an effect when there is an effect there to be detected. If statistical power is high, the probability of making a Type II error, or concluding there is no effect when, in fact, there is one, is reduced (Ferrari & Cribari-Neto, 2004). Statistical power might be improved by a meta-analysis approach, merging comparable datasets on observations of whale shark behavioural responses from within tourism encounters. Preliminary results from this innovative study undoubtedly disclose that with a basic understanding of the principles behind stereo photogrammetry, its basic set up and calibration procedures, the above-described inexpensive stereo-photogrammetry camera system and technique is a powerful tool for the marine scientist. The benefits are not limited to remotely determine not only the proximity of an in water swimmer to a desired species, but spread along the whole sector as a useful instrument for gathering a number of in water measurement information, including relative position of in water animals, their size and spatial distance to one another.

7. Management recommendations

With any wild animal and especially so with vulnerable species, any human contact in their natural environment must be weighted in terms of long-term positive and negative impact (Orams, 2002). Similar to other marine tourism activities, whale shark tourism participants do not form a homogeneous group and, subsequently, have differing attitudes towards appropriate in-water guidelines and disclose a full variety of swimming abilities, which in turn creates unique and challenging management concerns. A study by Catlin & Jones. (2010) on the maturation of the whale shark tourism industry in Western Australia, provides evidence that over recent years this blossoming tourism activities in Ningaloo national marine park (NNMP), had a greater distribution of participants age, personal abilities, tolerance to over-crowding and a much larger emphasis on the non-wildlife components of the experience making management recommendations somewhat more complex. Coastal aggregations of whale sharks are centered on feeding activities, and any slight disturbance to the sharks has the potential to reduce the sharks' chances of survival in the long-term, by diverting their energies from feeding to avoidance behaviour (Colman, 1997; Norman, 1999). Any marine-based tourism offers opportunities for economic, educational and environmental benefits but is not without risks to participants, animals and the environment and if the benefits of this sector are to be harnessed it will require an increasing focus upon law and policy governing the industry (Amante-Helweg, 1996). Quiros (2005) evaluated the conservation and community benefits of "Ecotourism" from whale sharks', both in the Philippines and Belize. The authors research offered suggestions that a successful long-term approach is contingent on several factors: overall impacts to the whale sharks and the environment must be properly managed, direct conflicts among stakeholders must be relieved through better management practices with benefits spread more equitably and the two sites must continue to receive active NGO and government support.

From this preliminary study, results unmistakably reveal that although the long-term anthropogenic effects of this ever-growing industry cannot be measured, the short term effect of negligent activities of participants and operators clearly has some effect on the avoidance behaviours expressed by the animals during current tourism interactions. Examining the statistical analysis presented, we can directly say that a preliminary recommendation to managing directors and tour operators must be to pay close attention to proximity distances between sharks and swimmers, and ensure a complete understanding for the current in-water code of conducts at individual sites. This recommendation does not come as a surprise, as previous publications and opinions by Norman (1999) and Quiros (2007) offer additional weight to investigate this recommendation on a global scale and determine its importance and degree on the effects to avoidance behaviours of the species. As it stands today, the current best practice code of conduct or interaction guidelines developed by CALM, western Australia for whale shark interactions (CALM, 2003), are still considered the first and best line of defence to help minimise short-term negative impacts on the species from negligent participants actions. Future management objectives, should now aim to improve the mandatory understanding of these guidelines at all tourism sites, prior to embarking on an encounter trip, and perhaps independent site-specific consequence for negligent actions by means of a financial loss or removal from tourism activities might improve participants' actions. An innovative approach to support this philosophy was instigated in Belize prior to the start of the 2007 whale shark season (Carne, 2008). Enforcement by means of patrol boats observing site-specific regulations and issuing fixed penalty fines of US $5000 for any tourist who touches or harasses the shark were implemented (Carne, 2008). Following this tactic, recent years have shown a steady increase in whale shark numbers once more around the Gladden Spit Marine reserve, Belize. Subsequently, an improved level of both tourist satisfaction and hostility among licensed operators has followed (Carne, 2008).

A study on Humpback whales (*Megaptera novaeangliae*) by Kessler & Harcourt (2010) on swim tours in Tonga, had a direct focus on the sustainability of this industry as recent years has raised concerns over its potential impact on the animals involved. Their aim was to examine the relationship between the existing Tongan Government draft regulations and Tonga Whale Watching Operator Association guidelines, which control the industry and visitor expectations. Their results offered direct recommendations expressing that operators and governments must work hand in hand to ensure compliance with regulations, appropriate management fees charged, and that visitors should be engaged in environmental education and research agendas concerning the impacts of swimming with humpback whales.

The availability of informative presentations to all participants pre and post experience aims to not only improve the visitors direct knowledge of the industry, but also the critical threats that the species is facing from uncontrolled, nonchalant tourism activity by participants and operators alike. To date, the majority of whale shark tourist sites offer elementary briefing of the trip followed by explanations of the in-water regulations. However, providing a satisfying wildlife experiences, whilst endeavouring to protect the species and/or its environment can become a difficult task (Quiros, 2007). A study by Ziegler, Dearden, Rollins (2012) published a very comprehensive study to try to understand the motivations and satisfactions of whale shark tour participants on Isla Holbox, Mexico, in order to assess the success of this industry, in meeting customer expectations. An IP analysis using the importance and satisfaction mean scores and the iso-rating line method, identified several areas of relative concern with respect to environmental and setting attributes, over-crowding and tour services. Key issues with false advertising, lack of educational information, personally observed crowding in the water, and tour cost were among the most significant in tarnishing the overall guest experience.

A new innovative notion to involve participants in a "citizen science" role might be a unique approach to improve conservation efforts and drive participants to behave in a united way. By empowering the participants with simple observation tasks, photo Identification collection and to become visually aware of other participants unacceptable actions, offers them the chance to act as civilian enforcers. Hidalgo-Ruz & Thiel (2013) examined a citizen science sampling approach during their work on the accumulation of large and small plastic debris on beaches in the southeast pacific coastline of Chile. This unique project was supported by school children and from all over Chile who documented the distribution and abundance of small plastic debris on Chilean beaches. To validate the data obtained by the participants, all samples were recounted in the laboratory. The results showed that the students were able to follow simple instructions and generate reliable data collection. The use of citizen science has been around to some degree in whale shark research, since the introduction of ECOCEAN (Norman, 2002) the web based portal for cataloging and analyzing whale shark identification photos. ECOCEAN offers the general public and scientists a chance to enter photographs of the species from opportunistic encounters in the wild helping to build a complete population model of whale sharks free of charge.

The adoption of citizen science in further gathering of whale shark participant's in-water behaviours, might present a new angle of approach against whale shark disturbance from negligent activities and provide the citizen with a psychological enticement to safe guard the species for future generations.

Future recommendations for behavioural investigation on the species should now begin to address in detail issues related to boating scheduling, boat traffic and orientation of vessels within shark interaction zones. Although the impact or disturbance of boats with not examined in this study, previous studies by Davis et al (1997) and Quiros (2007) both offer suggestions to further recognise and investigate the disturbance of path obstruction and encounter approach by boats on the species.

A study by Stamation et al (2010) investigated the short-term responses of humpback whales to whale-watching vessels during their southward migration along the south coast of New South Wales (NSW), Australia. It presented an insight into the species behavioural changes exposing that while some individuals showed obvious signs of horizontal avoidance (moving away from vessels), others approached, initiating interactions. Results validated that humpback whales were more likely to avoid a vessel moving within the permitted 100 metre approach limit, than vessels outside the limit and pods containing calf's showed increased sensitive to the presence of vessels than non-calf pods. Recommendations provided explained that management of the humpback whale-watching industry should adopt a conservative approach and aim to improve the overall knowledge of long-term impacts of multiple exposures to vessels to begin to understand and inform management providers of the effects of whale-watching activities. A more recent study by Kessler & Harcourt (2013) further investigated the regulation compliance trends for the management of whale watching activities in Sydney, Australia. The study compared commercial and recreational vessel compliance with key features of the whale watching regulations between two independent annual seasons, 2007 and 2010 and results showed that Low compliance, with its concomitant increase in risk of harm to whales, risks undermining the ability of the regulatory framework to minimise impacts on whales. The authors recommend that the industry now needs to go beyond developing rules just for boat behaviour around the species, and provide more consideration to how these rules are enforced on a seasonal basis and whether additional management measures, such as operator permits, might provide protection and safe guard the whales from over exhaustion of increases avoidance. A precautionary approach in the whale shark industry should aim to enforce or regulate the number of boats within specifically designed interaction zones, which will subsequently lower opportunities for path obstruction, accidental collisions with the animal and provide adequate exit paths for disturbed animals.

A universal coordination of swimmer entry procedures at all tourism sites focusing on slow and controlled entries into the water will further help to minimise noise disturbance, water movement and sudden "*shock*" appearance to the sharks' environment by participants. All species of sharks have acute sensory biology and the lateral line sensory systems that run along their flanks (Compagno, 1984) allows them to sense water displacement of objects around them. Suggestions for independent studies assessing whale sharks' visual capabilities in a captive or natural environment might expand on existing knowledge of the distance and range *R.typus* views approaching objects. Fully understanding these senses will aid management officials to develop both boat and swimmer water protocols. The future management plan to designate no swim areas or free line of sight zones for the animal during interactions, offers a dramatic decrease in the chance of sudden behavioural of the shark, removing the event of a rapid diving behaviour and increased swimming speed resulting in potential contact with swimmers or boats causing injury. Ultimately, tourism directors need to communicate with one another through species specific conferences, public meetings and research trips to restore equilibrium between offering a respectable tourist experience with minimal risk of possible negative impact to the marine environment and species from their activities.

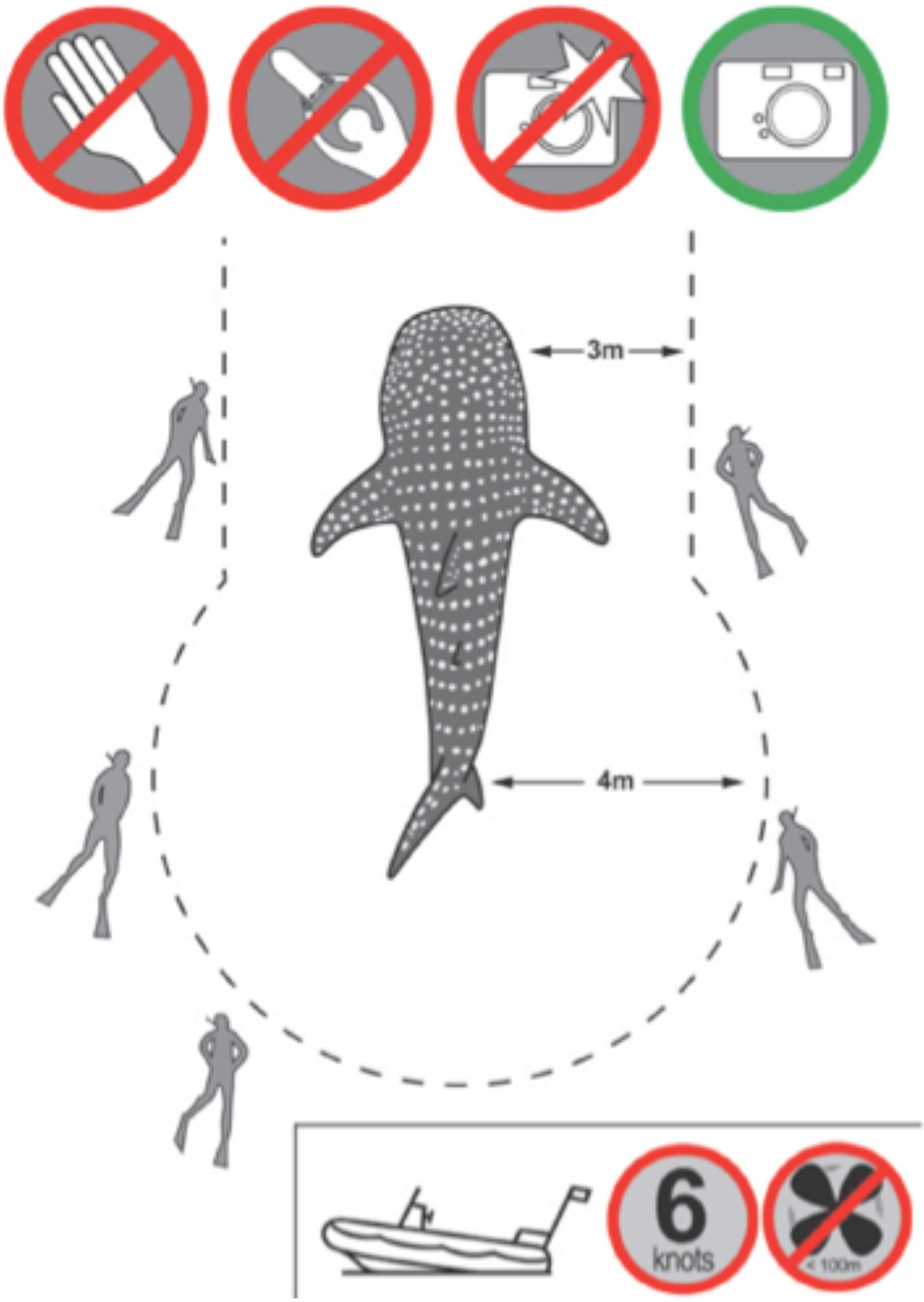
8. Conclusions

Modern stereo-photogrammetric techniques have reached a rather sophisticated stage in their ability to describe and monitor a range of aspects of the animals' ecology and behaviour (Osborn, 1997). Furthermore, the incorporation and availability of high definition video techniques within the sector are greatly enhancing its efficiency and usage in a complex and constantly changing marine environment. Although given this advantage, it is surprising that stereo-photogrammetric techniques are not more widely exploited in biological studies. Quantifiable results from this study together with support from the validation tests clearly show that an easy to operate, relatively cheap and robust in-water stereo camera system can be used as a tool to effectively obtain quantifiable results using fundamental calibration procedures in this specialised marine sector.

Research on whale sharks relies on the hard work and dedication of researchers. Unfortunately, the number of scientists that devote their lives worldwide to the protection of these magnificent creatures is still very low compared to other marine taxonomic groups like cetaceans. The more scientists studying whale sharks across the world and sharing their findings, the better our understanding will be of these inquisitive giants. While our understanding of the species has greatly increased since 1828, there is still so much more to learn. The continued development of new research techniques, as well as the increased awareness of this species among the public, is certainly a step in the right direction towards uncovering the mystery of the world's largest fish and understanding the best way to protect it. Finally, the investment of research to monitor and examine the currently available in-water code of conduct for future management adjustments may hold the key to sustainable tourism with these iconic ocean gypsies.

Appendix

Best practice in-water code of conduct for interacting with whale sharks (*R. typus*) developed and implemented by the department of conservation and land management, Australia (CALM, 1995).



References

Abdo, D. A., Seager, J. W., Harvey, E. S., McDonald, J. I., Kendrick, G. A. & Shortis, M. R. (2006). Efficiently measuring complex sessile epibenthic organisms using a novel photogrammetric technique. *Journal of Experimental Marine Biology and Ecology*, *339*(1), 120-133.

Ackermann, F. (1996). Experimental tests on fast ambibuity solutions for airborne kinematic GPS positioning. *International Archives of Photogrammetry and Remote Sensing*, *31*(6), 1-6.

Alava, M. N. R., Yaptinchay, A. A., Acogido, G., Dolar, M., Louella, L., Wood, C. J., et al. (1997b). Fishery and trade of whale shark (*Rhincodon typus*) in the Philippines. Abstract. In: *13th meeting of the American Elasmobranch Society*.

Alvarez-Borrego, S. (1983). Gulf of California. In: Ketchum, C. B. H. (Eds.), *Estuaries and Enclosed Seas*. *Elsevier, Amsterdam,* (pp.427-449).

Amande, M. J., Ariz, J., Chassot, E., Molina, A. D., Gaertner, D., Murua, H., et al. (2010). Bycatch of the European purse seine tuna fishery in the Atlantic Ocean for the 2003–2007 period. *Aquatic Living Resources,* 23, 353–362.

Anderson, R. C. & Ahmed, H. (1993). Shark Fisheries of the Maldives. Rome: Ministry of Fisheries and Agriculture, Maldives, and Food & Agriculture Organization.

ANPWS. Australian National parks & Wildlife Service. (1988). Whale watching guidelines. Austalian National Parks and Wildlife Services, *Commonwealth of Australia, Canberra*, *pamphlat*.

ANPWS. Australian National parks & Wildlife Service. (1990). Ningaloo Marine Park (Commonwealth Waters) Plan of Management. Australian National Parks and Wildlife Service. *Commonwealth of Australia, Canberra,* 31.

Arena, G., Barea, L. & Defeo, O. (1994). Theoretical evaluation of trap capture for stock assessments. *Fisheries Research*, *19,* 349-362.

Arias, P., Ordóñez, C., Lorenzo, H., Herraez, J. & Armesto, J. (2007). Low-cost documentation of traditional agro-industrial buildings by close-range photogrammetry. *Building Environment Journal*, *42,* 1817-1827.

Arzoumanian, Z., Holmberg, J. & Norman, B (2005). An astronomical pattern-matching algorithm for computer-aided identification of whale sharks Rhincodon typus. *Journal of Applied Ecology, 42*, 999-1011.

Baracchi, D., Petrocelli, I., Cusseau, G., Pizzocaro, L., Teseo, S. & Turillazzi, S. (2012). Facial markings in the hover wasps: quality signals and familiar recognition cues in two species of Stenogastrinae. *Animal Behaviour, 85*(1) ,203-212

Bass, A. J., D'Aubery, J. D. & Kistnasamy, N. (1975). Sharks of the east coast of southern Africa. IV. The families Odontaspidae, Scapanorhynchidae, Isuridae, Cetorhinidae, Alopiidae, Orectolobidae and Rhiniodontidae. *Investigational Report 39*. Oceanographic Research Institute, Durban.

Bellman, C. & Shortis, M. R. (2004). A classification approach to finding buildings in large-scale aerial photographs. *International Archives Photogrammetry and Remote Sensing*, *35*(B3), 337-342.

Bigelow, H. B. & Schroeder, W. C. (1948). *Fishes of the Western North Atlantic*. Yale, CT: Sears Foundation for Marine Research, Yale University

Birtles, A., Cuthil, M., Valentine, P. & Davis, D. (1996). Incorporating research on visitor experiences into ecologically sustainable management of Whale shark tourism. *Proceedings of the ecotourism association of Australia, National Conference, Alice Springs*, 1995, (eds). Richins, H., Richardson, J. & Crabtree, A.

Boland, G. S. & Lewbel, G. S. (1986). The estimation of demersal fish densities in biological surveys using underwater television systems. *Oceans*, *86,* 9-13.

Borrell, A., Aguilar, A., Gazo, M., Kumarran, R. P. & Cardona, L. (2011). Stable isotope profiles in whale shark (*Rhincodon typus*) suggest segregation and dissimilarities in the diet depending on sex and size. *Environmental Biology of Fishes,* 92, 559-567.

Bortone, S. A. & Martin, T. (1991). Visual census of reef fish assemblages: a comparison of slate, audio and video recording devices. *Northeast Gulf Shelf*, *12,* 17-23.

Bosch, R., Kulur, S. & Gulch, E. (2005): Non-metric camera calibration and documentation of historical buildings. *Proceedings of the XX International Symposium of the International Committee for Documentation of Cultural Heritage (CIPA)*, *Torino, Italy, September 2005*, (pp. 142-147).

Bräger, S., Chong, A., Dawson, S., Slooten, E. & Würsig, B (1999). Combined stereo-photogrammetry and underwater-video system to study group composition of dolphins. *Helgolnd Marine Research, 53*, 122-128.

Bull, S.B., Mak, C. & Greenwood, C.M.T. (2002). A modified score function estimator for multinomial logistic regression in small samples. *Computational Statistics & Data Analysis, 39*(1), 57-74.

Cailliet, G. M., Radtke, R. L. & Welden, B. A. (1986). Elasmobranch age determination and verification: a review. (pp. 345–360). *In*: T. Uyeno, R. Arai, T. Taniuchi & K. Matsuura (ed.) Indo-Pacific Fish Biology: Proceedings of the Second International Conference on Indo-Pacific Fishes, Ichthyological Society Japan, Tokyo.

CALM. Department of Conservation & Land Management (1989). Ningaloo Marine Park Management Plan 1989-1999. *Department of Conservation and Land Management, Perth*, 74.

Camhi, M., Fowler, S., Musick, J., Brautigam, A. & Fordham, S (1998). Sharks and their Relatives: Ecology And Conservation, Occasional paper of the IUCN Species survival commission, 20.

Cappo M., Speare P. & De'ath G. (2004). Comparison of baited remote underwater video stations (BRUVS) and prawn (shrimp) trawls for assessments of fish biodiversity in inter-reefal areas of the Great Barrier Reef Marine Park. *Journal of Experimental Marine Biology and Ecology, 302*, 123-152.

Cardenas-Torres, N., Enrıquez-Andrade, R. & Rodrıguez-Dowdell, N. (2007). Community-based management through ecotourism in Bahia de Los Angeles, Mexico. *Fisheries Research*, *84*, 114-118.

Carne, L. (2007). Whale shark tourism at gladden split marine reserve Belize, *Central America*. *In The First International Whale Shark Conference: Promoting International Collaboration in Whale Shark Conservation, Science and Management*. *Conference Overview, Abstracts and Supplementary Proceedings* (Irvine, T. R & Keesing, J. K, (eds), *CSIRO Marine and Atmospheric Research*.

Carne, L. (2008). Monitoring & Management of whale sharks tourism at Gladden spit 6 the silky cayes Marine reserve, Belize. *Presentation for Friends of Nature at Holbo, Mexico*.

Carrasco, J.L., Phillips, B.R., Puig-Martinez, J., King, T.S., Chinchilli, V.M. (2013). Estimation of the concordance correlation coefficient for repeated measures using SAS and R, *Computer Methods and Programs in Biomedicine*, 109 (3), 293–304.

Cesar, H., van Beukering, P., Payet, R. & Grandourt, E. (2004). Evaluation of the Socio-economic impacts of marine ecosystem degradation in the Seychelles, *Ministry of Enviroment, Victoria, Seychelles*.

Chang, W. B., Leu, M. Y. & Fang, L. S. (1997). Embryos of the whale shark, *Rhincodon typus*, early growth and size distribution. *Copeia* 1997, 444–446.

Chassot, E., Amande, M. J., Chavance, P., Pianet, R. & Dedo, R. G. (2009). Preliminary results on tuna discards and bycatch purse seine fishery of the eastern Atlantic. *Collective Volume Of Scientific Papers,* 64, 1054-1067.

Chen, C. T., Liu, K. M. & Joung, S. J. (1997). *Preliminary Report on Taiwan's Whale Shark Fishery*. Taipei: TRAFFIC East Asia.

Chen, V.Y. (2002). Whale shark utilization and management in Taiwan. Paper presented during the Shark Conference 2002: Sustainable Utilization and Conservation of Sharks. *WildAid-National*.

Chen, V. Y. & Phipps, M. J. (2002). Management and Trade of Whale Sharks in Taiwan. Taipei: TRAFFIC East Asia.

CITES. (2002). Convention of International Trade in Endangered Species. Amendments to Appendices I and II of the Convention. In *12th Conference of Parties to CITES, Santiago, Chile*. Geneva: Convention on International Trade in Endangered Species.

Clarke, E. & Nelson, D.R. (1997). Young whale sharks, Rhincodon typus, feeding on a copepod bloom near La Paz, Mexico. *Environmental Biology of Fishes*, 50, 63-73.

Cliff, G., Anderson-Reade, M. D., Aitken, A. P., Charter, G. E. & Peddemors, V. M. (2007). Aerial census of whale sharks on the northern KwaZulu-Natal coast, South Africa. *Fisheries Research,* 84, 41-46.

CMS. (1999). Convention of migratory Species. *Annex III- Species Added to Appendices I and II by the Sixth Meeting of the Con- ference of the Parties, Cape Town, South Africa*. Bonn: Convention on the Conservation of Migratory Species of Wild Animals.

Coggan, R. & Diesing, M. (2011). The seabed habitats of the central English Channel: a generation on from Holme and Cabioch, how do their interpretations match-up to modern mapping techniques?. *Continental Shelf Research, 31,*132-150.

Colman, J. (1997). Whale shark interaction management, with particular reference to Ningaloo marine park 1997–2007.*Western Australian Wildlife Management Program. Department of Conservation and Land Management, Perth.*

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

Compagno, L.J.V. (1984). *FAO species catalogue. Vol. 4. Sharks of the world. An annotated and illustrated catalogue of shark species known to date*. FAO Fish Synopsis 125, *Vol. 4*, Pt. 1, Hexanchiformes to Lamniformes. Rome, Italy.

Compagno, L.J.V (1988). Sharks of the Order Carchariniformes. *Princeton University press*. (pp. 486).

Compagno, L.J.V (2001). Sharks of the world, An Annotated and illustrated catalogue of shark species known to date. *FAO species catalogue for fishery purposes,* No1, Volume 2.

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

Costa, C., Loy, A., Cataudella, S., Davis, D. & Sardi, M. (2006). Extracting fish size using dual underwater cameras. *Aquacultural Engineering, 35***,** 218-227.

Antonio Cuevas. (2013). A partial overview of the theory of statistics with functional data, Journal of Statistical Planning and Inference, (in press, April, 2013)

Davis, D. C. & Tisdell, C. (1996). Managing marine tourism resources in Ningaloo marine park, Western Australia. *Proceedings of the 1996 World Congress on Coastal and Marne Tourism, Honolulu, Hawaii, 19-22 June 1996*.

Davis, D., Banks, S., Birtles, A., Valentine, P. & Cuthill, M. (1997). Whale sharks in Ningaloo Marine Park: managing tourism in an Australian marine protected area. *Tourism Managent, 18*, 259-271.

Deakos, M.H. (2010). Paired-laser photogrammetry as a simple and accu- rate system for measuring the body size of free-ranging manta rays Manta alfredi. *Aquatic Biology, 10*, 1-10.

Dibble, E. D. (1991). A comparison of diving and rotenone methods for determining relative abundance of fish. *Transactions of the American Fisheries Society*, *120,* 663-666.

Done, T. J. (1981). Photogrammetry in coral reef ecology: a technique for the study of change in coral reef communities. *Fourth International Coral Reef Symposium*, *Manila*, 315-320.

Drysdale, R. L., McElfresh, S. & Snoeyink, J. S. (2000). On exclusion regions for optimal triangulations. *Discrete Applied Mathematics, 109*, 49-65.

Drap, P., Seinturier, J., Scaradozzi, D., Gambogi, P., Long, L. & Gauche, F. (2006). Photogrammetry for virtual exploration of underwater archeolgical sites. *XXI International CIPA Symposium, 1st-6th October, Athens, Greece*.

Durban, J. W. & Parsons, K. M. (2006). Laser-metrics of free-ranging killer whales. *Marine Mammal Science, 22*(3), 735-743.

Fenton, S. & Kerr, R. (1997). Accident scene diagramming using new photogrammetric technique. *SAE Publications, V* (1237), 970944, *Accident Reconstruction: Technology and Animation, VII*, 29-40.

Ferrer, J. & Garcia, R. (2010). Bias reduction for stereo triangulation. *Electronics Letters, 46*, (25), 1120-1121.

Ferrari, S & Cribari-Neto, F. (2004). Beta Regression for Modelling Rates and Proportions, Journal of Applied Statistics, 31(7), 799-815.

Fowler, S. L., Reed, T. M. & Dipper, F. A. (2002). The IUCN Species Survival Commission: elasmobranch biodiversity, conservation and management. *Proceedings of the International Seminar and Workshop, Sabah, Malaysia, July 1997, IUCN SSC Shark Specialist Group. IUCN, Gland, Switzerland and Cambridge, UK. Xv*+258.

Gernshiem, H. (1982). Origins of photography. *Publisher Thames & Hudsen (New york, N.Y), Volume 1*.

Gifford, A. (1998). Report on the third and fourth whale shark tagging and survey programs. May 1, 1995 to April 30, 1997. *Shark research Institute (SA), Durban*.

Gleiss, A., Norman, B. & Wilson, R. (2010). Moved by that sinking feeling: variable diving geometry underlies movement strategies in whale sharks. *Functional Ecology, 25,* 595-607.

Graham, R. T. (2001). Research and conservation of whale sharks and reef fish spawning aggregation in Belize. W*hale shark newsletter, Summer, University of York*.

Graham, R.T. (2004). Global Whale shark tourism: a "golden goose" of sustainable and lucrative income. *Shark news, 16*, 8-9.

Graham, R. T. (2007). Interactive planning and adaptive management of whale shark tourism in Belize: global implications of lessons learnt from 1998 and 2004. *In: Irvine T.R., Keesing, J.K (eds) The first international Whale Sharks Conference: Promoting international Collaobration in Whale Shark Conservation, Science and Management. CSIRO Marine and Atmospheic Research, Australia.*

Graham, R. & Roberts, C. M. (2007). Assessing the size, growth rate and structure of a seasonal population of whale sharks (Rhincodon typus, Smith 1828) using conventional tagging and photo identification. *Fisheries Research journal, 84*(1), 71-80.

Gudger, E. W. (1915). Natural history of the whale shark *Rhincodon typus* Smith. *Zoological: New York Zoological Society, 1,* 349-389.

Hanfee, F. (2007): Indian whale shark fishery. In *The First International Whale Shark Conference: Promoting International Collaboration in Whale Shark Conservation, Science and Management* (Irvine, T. R. & Keesing, J. K., eds), p. 74 Perth: CSIRO Marine and Atmospheric Research, Australia.

Harvey, E.S. & Shortis, M.R. (1996). A system for stereo-video measurement of sub-tidal organisms, Marine Tehcnology Society Journal, 29, 10-22.

Harvey, E.S. & Shortis, M.R. (1998). Calibration stability of an underwater stereo-video system: Implications for measurement accuracy and precision. *Marine Technology Society Journal,* 32(2), 3-17.

Harvey, E., Fletcher, D. & Shortis, M. (2002). Estimation of reef fish length by divers and by stereo-video: a first comparison of the accuracy and precision in the field on living fish under operational conditions. *Fisheries Research, 57***,** 255-265.

Harvey, E. S., Shortis, M. R., Stadler, M. & Cappo, M. (2003). A comparison of the accuracy of measurements from single and stereo-video systems. *Marine Technology Society Journal, 36*(2), 38-49.

Harvey, E. S., Fletcher, D., Shortis M. R. & Kendrick, G. A. (2004). A comparison of underwater visual distance estimates made by SCUBA divers and a stereo-video system: Implications for underwater visual census of reef fish abundance. *Marine and Freshwater Research, 55,* 573-580.

Harvey, E. S., Shortis, M. R., Seager, J. W. & Hall, N. (2004). Refining non-intrusive stereo video techniques & protocols for SBT transfers. *Report on AFMA Research Contract Number R03/1428. Australian Fisheries Management Authority Research,* 1-*37.*

Hellman, R., Oliver, W. R., Arthur, S., Chanceller, A. A., Soltys, M., Cullip, T., et al. (1995). Three-dimensional reconstruction of a bullet path: validation by computed radiography. *Journal of Forensic Sciences, JFSCA, 40*(2), 321-324.

Heyman, W., Graham, R., Kjerfve, B. & Johannes, R. E. (2001). Whale sharks *Rhincodon typus* aggregate to feed on fish spawn in Belize. *Marine Ecology Progress Series,* 215, 275-282.

Hidalgo-Ruz, V & Thiel, M. (2013). Distribution and abundance of small plastic debris on beaches in the SE Pacific (Chile): A study supported by a citizen science project, Marine Environmental Research, 87–88, 12-18.

Hobbs, J.-P. A., Frisch, A. J., Hamanaka, T., McDonald, C. A., Gilligan, J. J. & Neilson, J. (2009). Seasonal aggregation of juvenile whale sharks (*Rhincodon typus*) at Christmas Island, Indian Ocean. *Coral Reefs, 28,* 577

Hughes, N,. & Kelly, L. (1996). New techniques for 3-D video tracking of fish swimming movements in still or flowing water. *Fish Aquatic Science*, 53, 2473-83.

Hurlbert, S.H. (1984). Pseudoreplication and the design of ecological field experiments. *Ecology Monography, 54*(2), 187-211.

Huxley, J. S. *& Teissier, G. (*1936b). *Terminologie et notation dans la description de la croissance relative. Comptes rendus séances soc. biol. fil, 121934-937.*

Irvine, T. R. (2007). International collaboration in science, conservation and sustainable tourism of whale sharks. *Fisheries Research 84*, 1-3.

IUCN,International Union for the Convention of Nature & Natural Recourses. (2010). *IUCN Red List of Threatened Species, Version 2010.04*. Gland: International Union for the Conservation of Nature and Natural Resources. Available at http://www. iucnredlist.org/apps/redlist/details/19488/0.

Iwasaki, Y. (1970). On the distribution and environment of the whale shark, *Rhincodon typus*, in skipjack fishing grounds in the western Pacific Ocean. *Journal of the College of Marine Science Technology, Tokai University, 4,* 37-51 (in Japanese with English abstract).

Jeffreys, G. L., Rowat, D., Marshall, H. & Brooks, K. (2012). The development of robust morphometric indices from accurate and precise measurements of free-swimming whale sharks using laser photogrammetry. *Journal of the Marine Biological Association of the United Kingdom, Journal of the Marine Biological Association of the United Kingdom,* 1-12.

Joung, S. J. & Chen, C. T. (1995). Reproduction in the sandbar shark, *Carcharhinus plumbeus*, in the waters of northeastern Taiwan. *Copeia, 3,* 659-

665.

Joung, S,J., Chen, C,T., Clark, E., Uchida, S. & Huang, W.Y.P. (1996). The whale shark, Rhincodon typus, is a livebearer: 300 embryos found in one “megamamma” supreme. *Environmental Biology of Fishes, 46*, 219-223.

Kessler, M & Harcourt, R. (2013). Whale watching regulation compliance trends and
the implications for management off Sydney, Australia, *Marine Policy*, 42, 14-19

Kimley, A.P. & Brown, S.T. (1983). Stereo-photography for the field biologist, measurement of lengths and three-dimensional positions of free-swimming sharks, *Marine biology, 74,* 175-185.

Koski, W. R., Davis, R. A., Miller, G. W & Withrow, D. E. (1992). Growth rates of bowhead whales as determined from low-level aerial photogrammetry. *Report to the International Whaling Commission, 42*, 491-499.

Kulbicki, M. (1998). How the acquired behaviour of commercial reef fishes may influence the results obtained from visual censuses. *Journal of Experimental Marine Biology & Ecology*, *222,* 11-30.

Last, P.R. & Stevens, J.D. (1994). *Sharks and Rays of Australia*. CSIRO, Hobart.

Lessels, C.M. & Boag, P.T. (1987). Unrepeatable repeatabilities: a common mistake. *Auk 104*, 116-121.

Li, R., Li, H., Zou, W., Smith, R. G. & Curran, T. A. (1997). Quantitative photogrammetric analysis of digital underwater video imagery. *IEEE Journal of Oceanic Engineering, 22*(2), 364-375.

Losey, G. S. Jr. (2003). Crypsis and communication functions of UV-visible coloration in two coral reef damselfish, *Dascyllus aruanus* and *D. reticulates, Animal Behaviour, 66*(2), 299-307.

Lück, M. & Higham, J. (1998). Marine wildlife and tourism management: Insights from the natural and social sciences. CABI. 1, 19-91.

Mavrinac, A., Chen, X. & Tepe, K. (2010). An automatic calibration method for stereo-based 3D distributed smart camera networks. *Computer Vision and Image Understanding, 114*, 952-962.

McClellan, D. (1996). Aerial surveys for sea turtles, marine mammals and vessel activity along the southeast Florida coast, 1992-1996. Report No. 390, *NOAA, NMFS-SEFSC*.

Meekan, M. G., Bradshaw, C. J. A., Press, M., McLean, C., Richards, A., Quasnichka, S., et al. (2006). Population size and structure of whale sharks (Rhincodon typus) at Ningaloo Reef, Western Australia. *Marine Ecology Progress Series, 319,* 275-285.

Nelson, J. & Eckert, S. (2007). Foraging ecology by whale sharks (Rhincodon typus) within Bahia de los Angeles, Baja California Norte, Mexico. *Fisheries Research, 84*, 47-64.

Neuswanger, J., Hughes, N. F., Wipfli, M. S. & Kelly, L. H. (2010). Improved 3D video analysis methods with application to wild juvenile chinoock salmon foraging behavior. *Presentation for the international symposium Advances in the Population Ecology of Stream Salmonids in Luarca, Spain. 17th - 22th May, 2010.*

Newman, H. E., Medcraft, A. J. & Coleman, J. G. (1997). Whale shark tagging and ecotourism elasmobranch biodiversity, Conservation and Management. *International seminar and workshop, IUCN, Sabah, Malaysia.*

Miskin, E. A. (1956). The application of photogrammetric techniques to medical problems. *Photogrammetric Record, 2*, 92-110.

Motta, P. J., Maslanka, M., Hueter, R. E., Davis, R. L., Parra, R. D., Mulvany, S. L., et al. (2010). Feeding anatomy, filter-feeding rate, and diet of whale sharks *Rhincodon typus* during surface ram-filter feeding off the Yucatan Peninsula, Mexico. *Zoology, 113*, 199-212.

Muloin, S. (1998). Wildlife tourism: the physiological benefits of whale watching. *Pacific Tourism Review. 2*, 199-213.

Norman, B.M. (1999). Aspects of the biology and ecotourism industry of the whale shark *Rhincodon typus* in northwestern Australia. Unpublished MPhil Thesis, Murdoch University, Australia.

Norman. B.M. (2000). The 2000 IUCN Red List of Threatened Species. *IUCN*, Gland, Switzerland and Cambridge, UK.

Norman, B. (2002). *Review of Current and Historical Research on the Ecology of Whale Sharks* (Rhincodon typus)*, and Applications to Conservation Through Management of the Species*. Freemantle: Western Australian Department of Conservation and Land Management

Norman, B. N. & Stevens, J. D. (2007). Size and maturity status of the whale shark (*Rhincodon typus*) at Ningaloo Reef in Western Australia. *Fisheries Research, 84*, 81-86.

Orams. M. B. (2002). Feeding wildlife as a tourism attraction: A review of issues & impacts. *Tourism management, 23,* 281-293.

Osborn, J. (1997). Analytical and digital photogrammetry. In: Parrish JK, Hamner WM (eds) Animal groups in three dimensions. *Cambridge University Press*, Cambridge, (pp. 36-60).

Panfili J., de Pontual H., Troadec H. & Wright P.J. (eds) (2002). Manual of fish schlerochronology. *Ifremer-IRD coedition, Brest, France*, (pp.466).

Pappa, R. S., Black, J. T. & Blandino, J.R. (2003). Photogrammetric measurement of gossamer spacecraft membrane wrinkling. *Proceedings of the SEM Annual Conference and Exposition on Experimental and Applied Mechanics*, Charlotte, NC, USA.

Patias, P. (2002). Medical imaging challenges photogrammetry, *ISPRS Journal of Photogrammetry & Remote Sensing, 56*, 295-310.

Pelosi, G., Proietti, R., Della Morte, F., Magalini, S. I. & Bondoli, A. (1981). Decompression sickness: a medical emergency. *Ressuscitation, 9*(3), 201-209.

Pierce, S.J., Mendez-Jimenez., A, Collins, K., Rosero-Caicedo, M. & Monadjem, A. (2010). Developing a Code of Conduct for whale shark interactions in Mozambique. *Aquatic Conservation, 20*, 782-788.

Pine, R., Alava, M.N.R. & Yaptinchay, A.A. (2007). Challenges and lessons learned in setting-up a community-based whale shark ecotourism program: The case in Donsol, Philippines. In: T.R. Irvine and J.K. Keesing. (Eds). 2007. *The First International Whale Shark Conference: Promoting International Collaboration in Whale Shark Conservation, Science and Management Conference Overview, Abstracts and Supplementary Proceedings*. CSIRO Marine and Atmospheric Research, Australia, (pp. 36-44).

Pitcher, C. R., Doherty, P., Arnold, P., Hooper, J., Gribble, N., Bartlett, C., et al. (2007). Seabed Biodiversity on the Continental Shelf of theGreat Barrier Reef world heritage area, *AIMS/CSIRO/QM/QDPIF CRC Reef Research Task Final Report*. 320.

Polunin N. V. C. & Roberts, C. M. (1993). Greater biomass and value of target coral-reef fishes in two small Caribbean marine reserves. *Marine Ecology Progress Series, 100*, 167-176.

Quiros, A. (2005). Whale shark "ecotourism" in the Philippines and Belize: evaluating conservation and community benefits. *Tropical Resources Bulletin, Yale University,* 24, 42-45.

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,* 102-108.

Rahayu, S.P., Zain, J.M., Embong, A., Juwari. & Purnami, S.W. (2012). Logistic Regression Methods with Truncated Newton Method. *Procedia Engineering, 50*, 827-836.

Remolina-Suarez, J. F., Perez., Ramirez, J. J., Gonzalez-Cano, J., Parra Venegas, R., Sabatini, N.B., et al. (2007). Whale shark management strategies, with the participation of local stakeholdes in Yum Balam, Mexico. . *In The First International Whale Shark Conference: Promoting International Collaboration in Whale Shark Conservation, Science and Management*. *Conference Overview, Abstracts and Supplementary Proceedings* (Irvine, T. R. & Keesing, J. K., eds), *CSIRO Marine and Atmospheric Research*, 31-35.

Reynolds, P. C. & Braithwaite, D. (2001). Towards a conceptual framework for wildlife tourism. *Tourism management, 22,* 31-42.

Riegl, B., Purkis, S. J., Keck, J. & Rowlands, G. P. (2009). Monitored and modeled coral population dynamics and the refuge concept. *Marine Pollution Bulletin, 58*(1), 24-38.

Riley, M. J., Hale, M.S., Harman, A. & Rees, R.G. (2010). Analysis of whale shark *Rhincodon typus* aggregations near South Ari Atoll, Maldives Archipelago. *Aquatic Biology,* 8, 145-150.

Robson, S & Shortis, M. R. (1998). Practical influences of geometric and radiometric image quality provided by different digital camera systems. *The Photogrammetric Record, 16*(92), 225-248.

Robson, S., Shortis, M. R. & Ray, S. (1999). Vision metrology with super wide angle and fish-eye optics. *Videometrics VI, SPIE, 3641*, 199-206.

RoC (2007). Agriculture Law Notice No. 0961320771: Regulation on Prohibition for Possession of Whale Shark Meat. *Fisheries Law Article 44.1, 44.2, 46* (Agriculture, C. O., ed.). Tapei: Government of Taiwan.

Rodriguez-Dowdell, N., Enrıquez-Andrade, R. & Cardenas-Torres, N. (2007). Property rights based management: whale shark ecotourism in Bahia de los Angeles, Mexico. *Fisheries Research, 84*, 119-127.

Rohner, C.A., Richardson, A.J., Marshall, A.D., Weeks, S.J. & Pierce, S.J. (2011). How large is the world's largest fish? Measuring whale sharks Rhincodon typus with laser photogrammetry. *Journal of Fish Biology, 78(*1), 378-385.

Rohner, C.A., Weeks, S.J., Richardson, A.J., Pierce, S.J., Magno-Canto, M.M., Feldman., et al. (In press) (2012). Oceanographic influences on a global whale shark hotspot in southern Mozambique. *Deep Sea Research, Part II.*

Rowat, D. (1997). Seychelles whale shark tagging project–pilot project report. *Phelsuma, Nature Protection Trust of Seychelles* 5, 77–80.

Rowat, D., Meekan, M. G., Engelhardt, U., Pardigon, B. & Vely, M. (2007b). Aggregation of juvenile whale shark (*Rhincodon typus*) in the Gulf of Tadjoura, off Djibouti. *Environmental Biology of Fishes, 80*, 465-472.

Rowat, D. (2007). Occurrence of whale shark (Rhincodon typus) in the Indian Ocean: a case for regional conservation. *Fisheries Research, 84*, 96-101.

Rowat D. & Gore M. (2007). Regional scale horizontal and local scale vertical movements of whale sharks in the Indian Ocean off Seychelles. *Fisheries Research, 84,* 32-40.

Rowat, D. (2008). Population dynamics and behavior of Whale shark (Rhincodon typus, Smith 1828) in coastal waters of the Seychelles. Unpublished doctoral dissertation paper, Marine Biological Station, Millport. University of London.

Rowat D., Gore M.A., Baloch B.B., Islam Z., et al. (2008). New records of neonatal and juvenile whale sharks (Rhinccodon typus) from the Indian Ocean. *Environental Biology of Fishes, 82*. 215-219.

Rowat, D., Gore, M., Meekan, M R., Lawler, I.R. & Bradshaw, C.J.A. (2009). Aerial survey as a tool to estimate whale shark abundance trends. *Journal of Experimental Marine Biology and Ecology, 368*, 1-8.

Rowat, D. (2010). *Whale sharks*: An introduction to the world's largest fish from one of the world's smallest nations The Seychelles. *Plus Two Design Ltd*.

Rowat D. & Brooks, K. (2012). A review of the biology, fisheries and conservation of the whale shark *Rhincodon typus*. *Journal of fish biology, 80,* 1019-1056.

Sanchez, F., Serrano, A. & Gomez Ballesteros, M. (2009). Photogrammetric quantitative study of habitat and benthic communities of deep Cantabrian Sea hard grounds. *Continental Shelf Research, 29*, 1174-1188.

Sanz-Ablanedo, E., Rodríguez-Pérez, J. R., Arias-Sánchez, P. & Armesto, J. (2009). Metric potential of a 3D measurement system based on digital compact cameras. *Sensors, 9*, 4178-4194.

Scarpaci, C., Dayanthi, N. & Corkeron, P.J. (2003). Compliance with regulations by "Swim-with-dolphins" operations in Port Phillip Bay, Victoria, Australia. *Environmental Management, 31*, 342–347.

Scarpaci, C., Carol., Nugegoda., Dayanthi., Cockeron, P.J & Peter, J. (2004). No detectable improvement in compliance to regulations by "Swim-with dolphin" operators in port Philip Bay, Victora, Australia, *Tourism in Marine Environments*,1(1), 41-48.

Schenk, T. (1997). Towards automatic aerial triangulation. *ISPRS Journal of Photogrammetry & Remote Sensing, 52*, 110-121.

Schmidt, J., Chen, C., Sheikh, S.I., Meekan, M., Norman, B. & Shoou-Jeng Joung. (2010). Paternity analysis in a litter of whale shark embryos. *Endangered Species research,* 12, 117-124.

Scott, G, P. & Winn, H.E. (1980). Comparative evaluation of aerial and shipboard sampling techniques for estimating the abundance of humpback whales *(Megaptera novaeangliae)***.** Contract report to U.S. Marine Mammal Commission

Seasholtz, M.B. & Kowalski, B. (1993). The parsimony principle applied to multivariate calibration. *Analytica Chimica Acta, 277*(2), 165–177.

Shortis, M. R., Clarke, T.A. & Robson, S. (1995). Practical testing of the precision and accuracy of target image centring algorithms. *Videometrics IV, SPIE, 2598*, 65-76.

Shortis, M. R., Robson, S. & Short, T. (1996). Multiple focus calibration of a still video camera. *International Archives of Photogrammetry and Remote Sensing, 31*(5), 534-539.

Shortis, M. R. & Harvey, E. S. (1998). Design and calibration of an underwater stereo-video system for the monitoring of marine fauna populations. *International Archives Photogrammetry and Remote Sensing*, *32*(5), 792-799.

Shortis, M. R., Robson, S. & Beyer, H. A. (1998). Principal point behaviour and calibration parameter models for Kodak DCS cameras. *Photogrammetric Record, 16*(92), 165-186.

Shortis, M. R., Seager, J. W., Williams, A., Barker, B. A. & Sherlock, M. (2007). A towed body stereo-video system for deep-water benthic habitat surveys. *Eighth Conference on Optical 3-D Measurement Techniques, A. Grun and H. Kahmen (Eds),* ETH Zurich, Switzerland, ISBN 3-906467-67-8, Volume II, (pp 150-157).

Shortis, M. R., Seager, J. W., Williams, A., Barker, B. A. & Sherlock, M. (2009). Using stereo-video for deep-water benthic habitat surveys. *Marine Technology Society Journal, 42*(4), 28-37.

Shrader, A. M., Ferreira, S. M. & van Aarde, R. (2006). Digital photogrammetry and laser rangefinder techniques to measure African elephants. *South African Journal of Wildlife Research, 36***,** 1-7.

Smith, A. (1828). Description of new, or imperfectly known objects of the Animal Kingdom, found in the south of Africa. *African Commercial Advertiser,* 3, No. 145.

Sontag, S. (1978). Photography. *Communications Booknotes, Volume 10*(1).

Speed, C. W., Meekan, M. G. & Bradshaw, C. J. A. (2007). Spot the match – wildlife photo-identification using information theory. *Frontiers in Zoology,* 4, 1-11.

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

Spitz, S. S., Herman, L. M. & Pack, A. A. (2000). Measuring sizes of humpback whales (*Megaptera novaeangliae*) by underwater videogrammetry. *Marine mammal science, 16*(3), 676-681.

Stevens, J.D. (1996). Sharks and Rays of Australia*, CSIRO Publishing*; 2nd Revised edition.

Stamation, K.A., Croft, D.B., Shaughnessy, P.D., Waples, K.A., Briggs, S.V. (2010). Behavioral responses of humpback whales (*Megaptera novaeangliae*) to whale-watching vessels on the southeastern coast of Australia. *Marine Mammal Science*, 26(1), 98-122.

Strand, R & Haymen, E. (2005). Correcting Radial Distortion by Circle Fitting, *In the Proceedings of the British Machine Vision Conference, Oxford, UK, 2005*

Spitz, S.S., Herman, L.M. & Pack, A.A. (2000). Measuring Sizes of humpback whales (*Megaptera novaeangliae*) by underwater videogrammetry. *Marine mammal science*, *16*(3), 676-681.

Tapper, R. (2006). Wildlife watching and tourism: a study on the benefits and risks of a fast growing tourism activity and its impacts on species. *Published by the United Nations Environment Programme (UNEP) and the Secretariat of the Convention on the Conservation of Migratory Species of Wild Animals (CMS)*, Bonn, Germany.

Taylor, G. (1994). Whale Sharks: Marine wildlife conservation and community-based ecotourism. Angus & Roberston Publishers, Sydney. Yaptinchay, A.A.

Taylor, G. (2007). Ram filter-feeding and nocturnal feeding of whale sharks (*Rhincodon typus*) at Ningaloo Reef, Western Australia. *Fisheries Research,* 84, 65-70.

Telem, G. & Filin, S. (2010). Photogrammetric modeling of underwater environments, *ISPRS Journal of Photogrammetry and Remote Sensing, 65*, 433-444.

Tomilina, G. (1967). Mammals of the U.S.S.R. and adjacent countries. 9: Cetacea. *Israel Program for Scientific Translations, Jerusalem.*

Tyminski, J., Hueter, R. & De la Parra, R. (2008). The vertical movements of whale sharks tagged with pop-up archival satellite tags off Quintana Roo, Mexico. *Proc. of 2nd International Whale Shark Conference, Holbox, Quintana Roo, Mexico, 15-20 July 2008.*

Uchida, S., Toda, M., Kamei, Y. & Teruva, H. (2000). The husbandry of 16 whale sharks Rhincodon typus, from 1980 to 1998 at the Okinawa expo aquarium, *In abstract of the American Elamsobrach Society 16th annual meeting*, La Paz, Mexico.

UNCLOS, (1982). United Nations Convention on the Law of the Sea. In *Division for Ocean Affairs and the Law of the Sea.* New York, NY: United Nations. Available at: http://www.un.org/depts/los/convention_agreements/texts/unclos/unclos_e.pdf/.

Van Tienhoven, A.M., Den Hartog, J.E., Reijns, R.A. & Peddemors, V.M. (2007). A computer-aided program for pattern-matching of natural marks on the spotted raggedtooth shark Carcharias taurus. *Journal of Applied Ecology, 44*(2), 273-280.

Vianna, G. M. S., Meekan, M. G., Pannell, D. J., Marsh, S. P. & Meeuwig, J. J. (2011). 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.

Vignon, M. (2010). Impact of shark-feeding tourism on surrounding fish populations off Moorea Island (French Polynesia). *Marine and Freshwater Research,* 61(2), 163-169.

Whitehead, H & Payne, R. (1981). New techniques for assessing population of right whales without killing them. Mammals of the seas, (eds), J G. Clark, *FAO Fisheries Series, 5, volume 3*. Rome: Food and Agriculture Organisation of the United Nations.

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.

Williams, A., Barker, B., Kloser, R., Sherlock, M. & Bax, N. (2005). Applying video data to spatial management in a deep-water fishery off SE Australia. *Presented paper, American Fisheries Society 135th Annual Meeting, Anchorage, Alaska*.

Willis T. J. & Babcock, R. C. (2000). A baited underwater video system for the determination of relative density of carnivorous reef fish. *Marine and Freshwater Research, 51,* 755-763.

Wilson, S.G,. & Martin, R.A. (2003). Body markings of the whale shark: Vestigial or functional?. *Scientific publications, 24*(2), 115-134.

Wilson, S. G., Taylor, J. G. & Pearce, A. F. (2001). The seasonal aggregation of whale sharks at Ningaloo Reef, Western Australia: currents, migrations and El Nino ˜ / Southern Oscillation. *Environmental Biology of Fishes, 61*, 1-11.

Wintner, S. P. (2000). Preliminary study of vertebral growth rings in the whale shark, *Rhincodon typus*, from the east coast of South Africa. *Environmental Biology of Fish, 59,* 441-451.

Woods, A., Docherty, T. & Koch, R. (1993). Image Distortions in Stereoscopic Video Systems. *Proceedings of SPIE*, Volume 1915, *Stereoscopic displays and applications IV*, Page 1.

World Wildlife Fund field office muncupality Donsol, Sorogon providence, 2011: Personal Interview with R, Bruce, Project Coordinator WWF Philippines. Discussion on the meeting between stakeholders and governmental officials and the development of a suitable code of conduct for Donsol. *Municipal Government, Donsol*.

Yaptinchay, A. A. (1999). Marine wildlife conservation and community-based ecotourism. In: Proceedings of Conference-Workshop on Ecotourism, Conservation and Community Development, November 7–12. *VSO Publication,*
Tagbilaran City, (pp. 90–99).

Ziegler, J. (2008). Assessing the sustainability of whale shark tourism: a global perspective, *2nd International Whale Shark Conference July 15-20, 2008*.

Ziegler, J. (2010). Assessing the sustainability of whale shark tourism: a case study of Isla Holbox, Mexico. Unpublished masters of Science dissertation, University of Victoria.