Conservation of reef sharks in the Palau Shark Sanctuary: implications of spatial ecology, socio-economic value and anthropogenic impacts

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Abstract

Despite growing awareness of the widespread depletion of shark populations, conservation arguments based on the ecological importance of sharks for marine ecosystems have been insufficient to prevent or reduce ongoing declines. This suggests that there is a need for holistic conservation strategies that integrate ecological information with a better understanding of relationships between sharks and humans. While negative anthropogenic impacts on sharks (such as fishing) have been relatively well-documented, there is an emerging realization that not all interactions between humans and sharks are necessarily harmful, and in some cases may even be beneficial for both parties.

In 2009, Palau declared the world's first shark sanctuary, an action that recognized the importance of sharks to the national economy and health of the country's marine ecosystems. At the time, the sanctuary was assumed to be an effective strategy to ensure the conservation of sharks. However, it was declared with very little baseline knowledge about the ecology and population status of reef sharks, or with any appraisal of their interactions with humans. My thesis addressed this issue using a multi-disciplinary approach, combining ecological and socio-economic data with citizen science to improve our understanding of the ecology of reef sharks. Through this approach, I explored the effects of interactions between shark and human populations and the potential of these interactions in assisting in the resolution of some of the challenges of shark conservation faced by developing nations.

Using acoustic telemetry, I showed that grey reef sharks (*Carcharhinus amblyrhynchos*) have strong residency at aggregation sites, displaying complex patterns of vertical movement driven by environmental factors. At the same

aggregations, my comparison of telemetry data from tagged sharks with counts of sharks collected by professional dive guides revealed a strong correlation between the two datasets, suggesting that citizen science programs can provide reliable and low-cost data to assist long-term monitoring of shark populations. Through a survey study, I estimated the socio-economic value of sharks as a non-consumptive tourism resource in Palau. I showed that shark diving was a major contributor to the national economy, accounting for 8% of the gross domestic product of the country with distribution of revenues benefiting several sectors of society, while promoting shark conservation from community to national levels. Finally, my assessment of the conservation status of reef shark populations of Palau showed very large differences in shark abundances across the sanctuary with low abundance strongly correlated with indicators of illegal, unreported and unregulated fishing in the remote and unvisited reefs of the sanctuary.

My thesis shows that patterns of shark abundance within the Palau Shark Sanctuary are complex and show evidence of the effects of human impacts. Although the behaviour of humans is generally thought to affect shark populations negatively, my research shows that an alternative scenario, where populations of sharks and humans can both benefit from interactions, is also possible. While a tourism-based conservation strategy may represent an economically attractive scenario for decision-makers, my research also highlights that any broad-scale conservation benefits will be dependent on management strategies that ensure effective enforcement and surveillance over broad spatial scales (100-1000s of km), instead of just at individual tourism sites.

In summary, my thesis presents a framework for assessing the effectiveness of shark sanctuaries highlighting the potential benefits of a tourism-based conservation strategy. This ecological and socio-economic framework can contribute to effective conservation of shark populations, while promoting economic development and assisting the livelihood of local communities in developing countries where marine tourism is viable.

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Acknowledgments

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Publications arising from this thesis

This thesis is submitted as a series of papers, which have been either published or submitted to international peer-reviewed journals. The data chapters presented (Chapters 2 to 5) are formatted in accordance to the requirements of each journal.

I. Vianna G.M.S., Meekan M.G., Pannell D.J., Marsh S.P., Meeuwig J.J., 2012. Socio-economic value and community benefits from shark-diving tourism in Palau: A sustainable use of reef shark populations. *Biological Conservation* 145, 267-277 (Chapter 4)

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The data chapters of my thesis have my supervisors, Prof. Jessica J. Meeuwig (JJM) and Dr. Mark G. Meekan (MGM), as co-authors. While I was the first author for all the chapters of my thesis, Jessica and Mark assisted the planning, data collection, analysis and preparation of the manuscripts for publication. Other co-authors of the papers presented in this thesis are: Prof. David J. Pannell (DJP), Mrs. Sally P. Marsh (SPM), Mrs. Tova H. Bornovski (THB), Dr. Conrad W. Speed (CWS) and Dr. Jonathan L.W. Ruppert (JLWR). The contribution of each co-author for the papers is stated bellow.

Chapter 2- GMSV overall contribution: 70%. MGM provided input in the experimental design (30%), JJM and CWS assisted with the data analysis (30%). MGM, JJM and CWS assisted with structure and content editing of the chapter (30%).

Chapter 3- GMSV overall contribution: 65%. MGM and THB provided input in the experimental design (40%), JJM assisted with the data analysis (30%). MGM and JJM assisted with structure and content editing of the chapter (30%).

Chapter 4- GMSV overall contribution: 70%. MGM, JJM, DJP and SPM assisted with experimental design (30%), DJP and JJM provided input in the analysis (20%), MGM, JJM, DJP assisted with the structure and content editing of the chapter (40%).

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The co-authors have given permission for the manuscripts to be included in this thesis.

Gabriel Vianna
(Candidate)

Prof. Jessica J. Meeuwig
(Coordinating supervisor)

Chapter 1- General Introduction

In 2014, a status assessment estimated that approximately one-quarter of all known species of chondrichthyan fishes (sharks, rays and chimaeras) are under threat of extinction, mostly as a consequence of anthropogenic impacts in marine environments (Dulvy et al. 2014). In particular, fishing for sharks is now a widespread activity, largely responsible for the depletion of populations in virtually all marine environments world-wide (Worm et al. 2013, Dulvy et al. 2014). The intense and unsustainable exploitation of sharks is largely driven by the international trade of shark fins, which supplies a high demand for shark fin soup in Asian markets (Clarke et al. 2007). The pressure on shark populations is further exacerbated by the high fishing mortality in commercial fisheries, where sharks comprise a major component of the by-catch (e.g., tuna and swordfish fisheries; Worm et al. 2013).

The economic drivers of over-exploitation have meant that many countries have ignored arguments that sharks should be conserved because of their intrinsic value and their ecological importance to marine ecosystems. Thus, to date, conservation strategies have had limited influence on decision-makers and their capacity to implement adequate management of shark populations (Worm et al. 2013, Dulvy et al. 2014). This is particularly the case in developing countries, where enforcement capabilities are generally low and the livelihood of coastal communities may depend on the sale of shark products. This highlights the need for alternative approaches that may harness shark conservation to strategies that are economically attractive and effective in assisting the socio-economic development from community to national levels.

In my thesis, I take a multi-disciplinary approach that combines ecological and socio-economic data with citizen science to assess reef shark populations and explore the potential of shark-diving tourism in assisting conservation in the shark sanctuary in Palau. In particular, I focus on improving our understanding of the ecology of reef sharks, the effects of interactions between shark and human populations and the potential of these interactions to assist in the resolution of some of the challenges faced by conservation in Pacific Islands and developing nations.

1.1 Challenges of shark conservation

The removal of sharks can have significant consequences for marine environments (Ferretti et al. 2010; Ruppert et al. 2013), such as the reduction of natural mortality and anti-predator behaviour at lower trophic levels, which in turn can have cascading and potentially negative effects on marine communities (Heithaus et al. 2008, Burkholder et al. 2013, Heupel et al. 2014). On coral reefs, the depletion of shark populations can also decrease the capacity of these systems to cope with natural stressors such as cyclones and bleaching events (Ruppert et al. 2013). These outcomes undermine the resilience of coral reef systems, which may affect ecosystem services and with resulting economic impacts on food security, commercially important fisheries and tourism (Anderson 2001, Myers et al. 2007).

Similar to many other top-order predators, sharks occur in low abundance, have low fecundity, slow growth to maturity and generally produce small litters (typically < 20 pups) (Smith et al. 1998, Worm et al. 2013). These conservative life history traits mean that populations are very vulnerable to overfishing even when relatively well-managed. Given the Data-Deficient status (International Union for the Conservation of

Nature Red List; IUCN) of many shark species (Dulvy et al. 2014), assessments of population status and understanding of demographic patterns are key goals for research. However, monitoring shark populations and assessing the impact of fishing is inherently difficult due to the low abundance and large home ranges common to many species (McCauley et al. 2012). As a consequence, severe declines of shark populations may occur unnoticed and in relatively short periods of time.

Small-scale artisanal shark fishing has been a traditional part of many cultures for centuries (Johannes 1981). Recently, the economic incentives from the shark fin trade have reshaped shark fishing globally, intensifying fishing effort and increasing the pressure on shark populations in coastal and reef habitats (Sebetian and Foale 2006). However, quantifying the impact of these fisheries on shark populations is complicated by the generally limited capacity of the authorities to monitor fishing activity, and the diffuse nature of the activity, with catches landed at many points along coasts (Clarke 2013).

At the same time, large-scale commercial fisheries are now also a major source of shark mortality, either as target species or by-catch (Clarke 2013). Sharks often represent an important component of the catch and many commercial fisheries may retain only the shark fins, discarding the body due to low prices for shark meat (Bromhead et al. 2012). Although illegal in many countries, this practice is still common and represents a major issue for estimates of fishing mortality (Worm et al. 2013). This is further aggravated by widespread illegal, unreported and unregulated (IUU) fisheries, with the result that catch data for commercial fisheries are typically underestimated (Agnew et al. 2009, Worm et al 2013). As a result, there is a major need for fishery-independent and non-destructive datasets on population status and trends that can be collected at low cost for the development of adequate management and conservation strategies.

1.2 Evidence for decline in shark populations

The generally low quality of commercial and artisanal fisheries data suggests that, in many cases, the impact of fisheries on shark populations may be underestimated (Clarke et al. 2006, Worm et al. 2013). Recent estimates of exploitation rates using models that account for uncertainties and the sparse catch statistics shows that global declines in shark populations are mainly a consequence of widespread unsustainable exploration rates (Worm et al. 2014).

On coral reefs, the lack of accurate data on fishing effort and shark mortality is of particular concern as these systems are relatively easy to access from coastal areas and IUU fishing may be diffuse over large coastal areas. Also, due to the poor quality of the data and hyperstability of fisheries, declines in shark populations may be unnoticed in catch data. For example, estimates of abundance using underwater visual surveys at the Great Barrier Reef suggested a large scale depletion of reef shark populations that was not apparent in the catch data, possibly as a consequence of illegal fishing (Robbins et al. 2006, Heupel et al. 2007, Hisano et al. 2011). Similar patterns of depletion of reef shark populations have also been reported by several underwater visual census studies, indicating broad-scale depletion of reef sharks across the Indo-Pacific (DeMartini et al. 2008, Nandon et al. 2012). However, concerns about the estimates of shark abundance generated by underwater visual surveys highlight the need for further studies that may independently validate the reliability of datasets collected by non-scientists for monitoring shark populations (Ward-Paige and Lotze 2011).

1.3 Management and conservation strategies

Due to the conservative life history traits of sharks, sustainable fishing of sharks is only possible under very strict management and enforcement of catch rates, requiring intense monitoring of populations (Walker 1998). Consequently, fishery management of shark populations requires substantial investment in research, enforcement capacity and qualification of personnel. These conditions are not available for most fisheries exploiting shark populations and are particularly rare in fisheries in developing countries (Chapman et al. 2013). As a consequence, examples of sustainable shark fisheries are few and often restricted to species of relatively higher reproductive rates (Walker 1998).

As an alternative, marine protected areas (MPAs) can assist conservation by excluding fishing pressure from parts or the entire range of populations. The increasing recognition of the importance of sharks by the governments of small island nations has recently created a conservation movement that seeks to create very large MPAs specifically to protect sharks (PEW Charitable Trusts 2013). Since 2009, such shark sanctuaries have been established in more than ten countries and territories, covering an area of more than 12 million square kilometres of ocean (PEW Charitable Trusts 2013), mostly in the tropical Indo-Pacific region.

Although it is well-recognised that MPAs that are well designed and managed can be effective in conserving biodiversity and marine communities (Edgar et al. 2014), there is a dearth of data to evaluate the effectiveness of the shark sanctuaries as a means of conserving shark populations (Davidson 2012, Chapman et al. 2013, Dulvy 2013). Due to their large size, shark sanctuaries may encompass critical habitats of many shark species including reef and oceanic sharks (Ward-Paige et al. 2012), potentially providing protection over a large part of the home range of individuals. However, the spatial ecology of sharks (e.g., long-term residency, inter-annual and vertical movements) and interactions between sharks and human populations within the new shark sanctuaries are poorly understood. This restricts the ability of managers to design and implement strategies of enforcement and surveillance with appropriate scales that focus on critical areas for shark populations. For this reason, there is a need for studies that describe the baseline distribution, abundance and status of shark populations within these sanctuaries. Additionally, research on spatial ecology and assessments of the interactions of sharks and human populations are essential to identify potential conflicts but also benefits of these large MPAs.

Due to the generally limited resources available for research in the small island nations of the Indo-Pacific, conservation programs need to adopt alternative methods of sampling that are economically viable and effective in generating datasets of sufficient quality to monitor the status of shark populations. These programs may also be useful to show the value of sharks as a renewable (tourism) rather than extractive (fishing) resource for national economies. This information may also assist in bridging the gap between the ecological and socio-economic outcomes of conservation strategies, and may represent a useful instrument to engage local communities, industry and government in shark conservation strategies.

1.4 Shark diving tourism

In recent decades, marine and coastal tourism have come to occupy a central role in the economy of many island nations in the Indo-Pacific (Narayan 2010). Diving tourism is now a major attraction in many countries, where pristine coral reefs and relatively healthy reef fish populations are easily accessible to tourists. A relatively new development has been an increasing interest by the diving tourist community for underwater interactions with large predators, notably sharks (Gallagher and Hammerschlag 2010). Both in the Indo-Pacific and throughout much of the world, shark diving is now an important industry, generating millions of dollars in revenues and tousands of jobs (Cisneros-Montemayor et al. 2013). This industry potentially provides an alternative source of income for local communities that could otherwise be engaged in shark fishing. Given the potential of this industry, there is a need for rigorous and comprehensive studies that quantify the economic value of sharks, particularly in relation to their value as a fisheries resource. This will allow governments a more informed basis on which to make and support management strategies.

Although the impacts of shark diving tourism still need to be investigated further (Maljkovic et al. 2010), this industry is also a potentially useful platform for the collection of data on shark populations on reefs and may thus assist monitoring and management strategies (Ward-Paige et al. 2010, 2011, Ward-Paige and Lotze 2011). Such citizen science programs that use shark population data collected by non-scientists are growing in popularity (Huveneers et al. 2009, Brunnschweiler and Baensch 2011), which indicates the need for a clear understanding of the quality of the data collected by relatively untrained observers and the potential of these datasets to assist the monitoring of shark populations.

1.5 Palau Shark Sanctuary

Palau was the first country in the world to create a nationwide shark sanctuary (2009), prohibiting the possession and trade of sharks and shark parts within its Exclusive Economic Zone (EEZ) (UN 2009). Similar to other small island nations in the Indo-Pacific, the economy of Palau is largely dependent on tourism, and shark diving is a major attractor of tourists to the country. As a consequence, the shark sanctuary in Palau was implemented to safeguard an important element of the economy (UN 2009). However, the extent of the socio-economic importance of sharks as a non-consumptive resource to the economy of Palau is yet to be quantified. Moreover, there are no data available about the distribution, abundance, spatial ecology and use of habitats by the reef shark populations within the sanctuary. This lack of knowledge prevents any assessment of the effectiveness of the shark sanctuary in Palau and ultimately the understanding of effectiveness of shark sanctuaries in conserving shark populations in general.

1.6 Objective and aims

The overall objective of my thesis is to assess the ecology and status of shark populations in the Palau Shark Sanctuary, exploring the potential of shark-diving tourism to: 1) provide a relatively low-cost platform for the collection of data to monitor shark populations (i.e., citizen science) and 2) represent an economically attractive model of non-consumptive use of shark populations. To do so, I present a portfolio of approaches that can assist other developing nations in implementing conservation strategies that consider their socio-economic needs and resource limitations. To achieve this objective, the specific aims of my thesis are to:

1) Describe the spatial ecology of reef sharks at aggregation sites in Palau;

2) Investigate the potential of citizen science programs to collect data for the monitoring of reef shark populations;

3) Describe the socio-economic benefits of shark-diving tourism to the local community and national economy; and

4) Assess the status of reef shark populations within the Palau Shark Sanctuary.

1.7 Thesis outline

The thesis is divided into four data chapters. In Chapter 2, I use passive acoustic telemetry to describe aspects of the spatial ecology of grey reef sharks, one of the most common species found on the reefs of the Indo-Pacific (Compagno 1984). In particular, I describe the attendance and movement patterns of female sharks at aggregation sites on the reef. In this chapter, I also describe the vertical movements of sharks on a range of time scales (from hourly to inter-annual), identifying the major environmental drivers influencing these movements. In Chapter 3, I investigate the potential of citizen science to provide data for shark research and population monitoring. To do this, I compare data of shark attendance, collected using passive acoustic telemetry, with counts of sharks collected by professional dive guides at the same sites. Following the comparison of datasets, I use the data collected by the citizen scientists to describe the seasonal patterns of occurrence of the most common species of reef sharks in the main dive sites in Palau, discussing the implications of the use of this methodology in assisting monitoring programs. In Chapter 4, I report the results of a socio-economic study of the value of the shark-diving industry in Palau. This chapter shows the importance of sharks as a non-consumptive resource for the national economy by quantifying annual revenues of the shark-diving industry, tax revenues and income generated to the local community. In Chapter 5, I use underwater visual census conducted on the reefs and atolls across most of the country to assess the status of shark populations four years after the implementation of the shark sanctuary. I also explore the potential causes of variation in density of reef sharks across localities.

While the main body of this thesis focuses on research conducted in Palau, the methods and concepts I develop have also been applied in other Pacific Island states. These studies resulted in a series of three independent technical reports, which are presented as appendices. These described the non-consumptive economic value of the shark diving industries in Palau (Appendix I, constitutes the foundation of Chapter 4), Fiji (Appendix II) and Semporna, Malaysia (Appendix III). For the studies in Fiji and Semporna, the methodology used in Palau was adapted to suit the industry in each location.

Chapter 2- Environmental influences on patterns of vertical movement and site fidelity of grey reef sharks (*Carcharhinus amblyrhynchos*) at aggregation sites

Foreword

Conservation strategies such as marine protected areas and temporal closures need to be based on adequate information about the spatial ecology and use of habitats by the target species. For reef sharks understanding the residency patterns and vertical movements of individuals is fundamental to mitigate the effects of anthropogenic pressures such as fishing, modification of habitats and tourism. This is particularly important at aggregation sites as these often constitute critical habitats for shark populations.

2.1 Abstract

We used acoustic telemetry to describe the patterns of vertical movement, site fidelity and residency of grey reef sharks (*Carcharhinus amblyrhynchos*) on the outer slope of coral reefs in Palau, Micronesia, over a period of two years and nine months. We tagged 39 sharks (mostly adult females) of which 31 were detected regularly throughout the study. Sharks displayed strong inter-annual residency with greater attendance at monitored sites during summer than winter months. More individuals were detected during the day than at night. Mean depths of tagged sharks increased from 35 m in winter to 60 m in spring following an increase in water temperature at 60 m, with maximum mean depths attained when water temperatures at 60 m stabilised

around 29°C. Sharks descended to greater depths and used a wider range of depths around the time of the full moon. There were also crepuscular cycles in mean depth, with sharks moving into shallower waters at dawn and dusk each day. We suggest that daily, lunar and seasonal cycles in vertical movement and residency are strategies for optimising both energetic budgets and foraging behaviour. Cyclical patterns of movement in response to environmental variables might affect the susceptibility of reef sharks to fishing, a consideration that should be taken into account in the implementation of conservation strategies.

2.2 Introduction

Free-ranging marine predators such as sharks live in a three-dimensional environment where they are able to move in both horizontal and vertical planes. In coral reef ecosystems, most studies of the movement of sharks have focused on defining patterns of use of space on a horizontal plane, many with the ultimate goal of contributing to spatial management strategies, such as marine protected areas, to ensure the adequate conservation of shark populations. Such studies show that site fidelity is a common phenomenon in many species, including whitetip (*Triaenodon obesus*), tawny nurse (*Ginglymostoma cirratum*), blacktip (*Carcharhinus melanopterus*), Caribbean (*C. perezi*) and grey reef (*C. amblyrhynchos*) sharks (Barnett et al. 2012; Castro & Rosa 2005; Chapman et al. 2005; Fitzpatrick et al. 2011; Nelson & Johnson 1980; Papastamatiou et al. 2009). The degree of fidelity appears to vary according to life history stage, availability of resources and area of suitable habitat (Economakis & Lobel 1998; Heupel et al. 2010; Papastamatiou et al. 2009). Strong site fidelity of juveniles to nursery areas is evident in lemon (*Negaprion brevirostris*), blacktip and Caribbean reef sharks and is thought to be due to the advantages of nurseries in terms of predator avoidance and food availability (Garla et al. 2006; Heupel & Simpfendorfer 2009; Morrissey & Gruber 1993). Site fidelity is also common in adult reef sharks, although typically more sporadic when compared to juveniles, which might be partially explained by ontogenetic increases in the size of home ranges (Garla et al. 2006; Heupel et al. 2010). Adult site fidelity is argued to be advantageous for a number of reasons, including mating, feeding, pupping and resting (Speed et al. 2010).

While these studies have contributed to our understanding of the habitat preferences of sharks in reef ecosystems, there is an almost complete lack of equivalent data on the movements of reef sharks in the vertical plane of the water column. In the open ocean, cycles in vertical movement are a fundamental part of the behaviour of predatory species that reflect both changes in physical environments and distributions of prey. For example, pelagic species including swordfish (*Xiphias gladius*), yellowfin (*Thunnus albacares*) and big eye (*T.obesus*) tunas and mako sharks (*Isurus oxyrinchus*) display diel vertical migrations, where they descend to deep water during the day and remain in relatively shallow water at night, a pattern that is thought to follow cycles in the distribution of prey (Dagorn et al. 2000; Sepulveda et al. 2004; Takahashi et al. 2003; Weng et al. 2009). In temperate systems, some coastal species, such as the leopard shark (*Triakis semifasciata*), also show daily vertical migrations and actively use shallow, warm waters in the day and late afternoon to increase the core body temperature to optimise rates of digestion, growth and gestation (Hight & Lowe 2007).

The limited information that is available suggests that cycles in vertical movement are also a feature of the behaviour of reef sharks. For example, similar to leopard sharks, grey reef and blacktip reef sharks aggregate in shallow warm waters of sand flats in the afternoon possibly to increase growth and gestation rates (Economakis & Lobel 1998; Speed et al. 2012), while short-term (up to 20 days) tracking suggests that Caribbean reef sharks have a preference for shallow water (<40 m) during the night (Chapman et al. 2007). Whitetip reef sharks do not appear to display diel patterns in depth preferences, but occupy a wider depth range during the night, when actively hunting than during the day when resting (Fitzpatrick et al. 2011; Whitney et al. 2007). Together, these studies suggest a range in patterns of vertical movements by sharks in coral reefs that reflect a variety of ecological drivers.

A better understanding of the ecology of reef sharks in coral reef systems requires the examination of movement and residency patterns on both horizontal and vertical planes. Here, we describe spatial and temporal patterns in the vertical movements and residency of the grey reef shark, one of the most common and abundant sharks on coral reefs across the Indo-Pacific. At our study site in Palau, Micronesia, grey reef sharks tend to form predictable aggregations on outer parts of reef slopes and crests exposed to high current flow. We used acoustic telemetry to describe patterns of spatial and temporal use of aggregation sites by grey reef sharks over multiple years. A combination of acoustic telemetry and environmental data was also used to test the hypothesis that the vertical movements and residency patterns by grey reef sharks were related to environmental variables, notably water temperature. Our study contributes to a better understanding of the ecology of these animals and has implications for the management of sharks at aggregation sites, an important driver for diving ecotourism and the Palauan economy (Vianna et al. 2012).

2.3 Methods

2.3.1 Ethics Statement

This project was conducted under the Republic of Palau Marine Research Permit no. RE-09-26 and the Koror State Marine Research Permit no. 10-204. Shark tagging in 2011 was also conducted under UWA animal ethics permit no. RA/3/100/975, in adherence to provisions contained within the Australian Code of Practice for the Care and Use of Animals for Scientific Purposes.

2.3.2 Study Location

Palau is an archipelago of approximately 300 islands and atolls in the northwest Pacific (7˚N, 134˚W). Our study location was the edge of the main island platform that consists of a large shallow-water lagoon arrayed with small, uplifted limestone islands and a large volcanic island, all of which are enclosed by a 260 km barrier reef (Colin 2009). Grey reef sharks regularly aggregate at sites along the outer reef slope in the southwest (leeward) quadrant of the barrier reef (Figure 2.1) at promontories where the crenulated reef margin juts out into the flow of the prevailing current (Vianna et al. 2012).

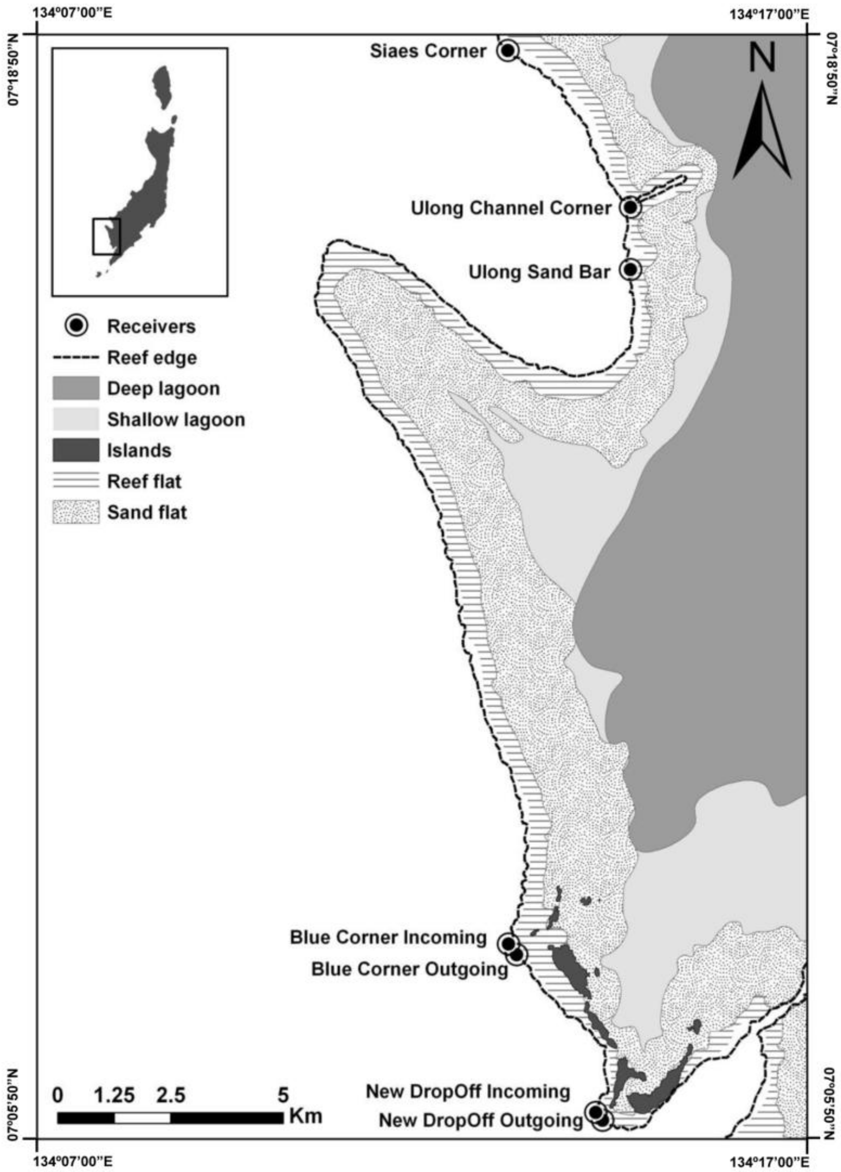


Figure 2.1 Study area in Palau. Outer reef slope of the southwest barrier reef of Palau, showing location of receivers. Top left box indicates the study site in the main island platform. The "shallow lagoon" shade represents depths down to 5 m, while "deep lagoon" areas might reach depths of 20 m.

2.3.3 Acoustic array and shark tagging

We used acoustic receivers (VR2w, Vemco) to monitor the attendance of tagged sharks at five aggregation sites. We moored receivers at depths between 25 and 40 m on the reef wall or slope and downloaded data from them at one to eight month intervals. The acoustic array monitored two areas on the barrier reef characterised by vertical walls and steep slopes (Colin 2009). The receivers were distributed over a linear distance of approximately 6 km in the northern area and 5 km in the southern area (Figure 2.1). The first receiver was deployed in November 2008, with the remainder deployed between May and July 2009.

We used hand reels fitted with baited barbless hooks to catch sharks at each of the receiver deployment sites within an area (Figure 2.1, Table 2.1). Once caught, sharks were brought alongside the boat and restrained within a canvas stretcher, which was then lifted onboard. Sharks were turned upside-down to induce tonic immobility and placed in a holding tank with a constant flow of water into the mouth and through the gills. We recorded the sex, measured the total length (L_T) and surgically implanted an acoustic transmitter into the peritoneal cavity of each shark (Heupel et al. 2006). This tagging procedure typically required less than ten minutes from the moment the shark was caught to the moment it was released. We classified individuals as sexually mature according to the L_T (Last & Stevens 2009). We used a combination of Vemco V16-5H coded tags (power output 165 dB, frequency of 69 KHz) with an estimated battery life of 3.4 years in 2008 and 2009 and V16-6H coded tags (power output 160 dB, frequency of 69 KHz) with an estimated battery life of 10 years in 2011. Ten of these tags were also fitted with pressure sensors that recorded depths to a maximum of 136 m (five V16-5H, deployed in 2008), 204 m (two V16-6H deployed in 2011) or 304 m (three V16-6H deployed in 2011).

We tagged a total of 39 grey reef sharks during November 2008 (*n*=8), May 2009 (*n*=18) and March 2011 (*n*=13). Tagged sharks included 34 adult females (mean L_T= 142 ± 11 cm), four sub-adult females (mean L_T= 124 ± 1 cm) and one sub-adult male (L_T =126 cm). Of these, 17 sharks were tagged in the northern area and 22 in the southern area. Two of the tagged sharks were not detected by the array and one individual was detected for only seven days; data for these sharks were not included in analyses.

In April 2011, we conducted range testing of the receivers in the northern site by deploying a test tag (V16-6H, power output 160 dB, frequency of 69 Khz, fixed delay) and estimating the detection coefficient at intervals of 200 m along transects parallel and perpendicular to the receiver deployment sites. The long-term performance of the receivers was of concern given the large number of tagged individuals in an environment with a complex current regime and reef habitat (Colin 2009). In order to assess performance we used metrics developed by Simpfendorfer et al. (2008) to analyse: (1) code detection efficiency, which provided information on the percentage of tagged animals that had valid detections (consisting of a complete code sequence) and (2) rejection coefficient, which provided an estimate of rejected detections due to incomplete codes detected by the receivers (Simpfendorfer et al. 2008). To estimate levels of biotic and abiotic interference in detection probabilities (Payne et al. 2010), we deployed a control tag on the reef wall in the southern area for a period of 141 days. This tag was located 200 m from the receiver at Blue Corner Incoming (Figure 2.1).

Table 2.1 Residency index and mean number of hours (±SE) grey reef sharks were detected at each monitored site daily (brackets). (*) indicates the site where each individual was tagged, (**) indicates sharks tagged 300 m north of Blue Corner. L_T = total length.

Grey reef shark			Northern area			Southern area			
Tag no.	Gender	L_T (cm)	Siaes Corner	Ulong Channel Corner	Ulong Sand Bar	Blue Corner in	Blue Corner out	New Drop-off in	New Drop-off out
14506	Female	148	0	0	0	5% (4±5.3)	4% (3±2.2)	60% (4±2.6)	67% (7±3.9)*
14507	Female	145	0	0*	100% (19±5.1)	0	0	0	0
14508	Female	126	0	0	0	29% (3±1.9)	74% (22±2.7)*	0	0
14509	Female	144	0	0	0	16% (2±1.1)*	0	0	0
14510	Female	153	2% (1±0.6)	4% (13±6.8)*	39% (7±5.5)	0	0	0	0
15764	Female	146	2% (5±4.1)	100% (13±5.4)*	0	0	0	0	0
15765	Female	144	4% (3±1.9)	100% (9±5.2)*	0	0	0	0	0
15766	Female	145	4% (2±0.8)	85% (3±2.6)*	0	0	0	0	0
15767	Female	133	6% (4±1.8)	96% (22±3.4)*	0	0	0	0	0
15768	Female	140	0	100% (22±2.4)*	0	0	0	0	0
32535	Female	144	0	0	0	5% (4±3.7)	4% (3±2.2)	44% (3±2.1)	48% (21±4.2)*
32536	Female	134	0	0	0	20% (3±3.2)	96% (22±3)*	0	0
32537	Female	130	0	0	0	5% (9±5.7)	4% (5±2.6)	59% (14±5.3)*	46% (4±2.3)
32538	Female	123	0	0	0	73% (3±2)	96% (17±3.8)*	4% (3±1.9)	4% (2±0.9)
32540	Female	130	0	0	0	23% (2±1.5)	96% (22±2.7)*	0	0
32542	Female	141	0	0	0	5% (9±7.3)	4% (2±1.3)	56% (11±3.5)*	50% (8±4.8)
32543	Female	154	0	0	0	42% (4±3.7)	96% (17±4.8)*	0	0
53362	Female	134	0	0	0	61% (21±3.6)*	41% (4±2.5)	3% (4±2.3)	4% (3±1.6)
53365	Female	147	5% (5±5.9)	98% (23±3.3)*	1% (2±0.8)	0	0	0	0
53366	Female	144	0	0	0	28% (4±3.4)*	23% (4±2.6)	34% (4±2.8)	62% (6±4.6)
53367**	Female	139	0	1% (1±0)	0	21% (2±2.8)	89% (23±2.6)	1% (2±2.7)	1% (2±2.1)
53368	Female	139	7% (3±2.3)	98% (21±3.6)*	1% (2±1.1)	0	0	0	0
53369**	Female	145	0	0	0	10% (4±3.5)	89% (22±2.8)	0	0
53370	Female	155	0	0	0	71% (21±3.3)*	62% (5±3.6)*	3% (3±1.7)	3% (2±1.5)
53372	Male	126	80% (6±3.7)*	1% (4±3)	0	0	0	0	0
53373	Female	158	33% (5±4)*	0% (3±1.3)	0	0	0	0	0
53375	Female	157	76% (5±2.9)*	6% (6±6.9)	0	0	0	0	0
53388	Female	146	0	0	0	58% (7±3.5)	72% (7±3.6)*	0	0
53389	Female	149	0	0*	0	0	52% (7±4.7)	0*	0
53390	Female	139	4% (4±2.7)	98% (12±5.1)*	0	0	0	0	0
53391	Female	146	0	0	0	10% (3±2.6)	12% (3±2)	74% (5±3.1)	77% (21±4.5)*
53392	Female	145	16% (4±2.2)	59% (5±4.2)*	93% (9±4.6)	1% (1±0)	2% (1±0)	1% (1±0)	1% (1±0)
53393	Female	123	0	0	0	51% (4±2.3)	86% (14±5.1)*	0	0
53395	Female	143	85% (5±3.3)	27% (6±4.9)*	2% (2±0.7)	0	0	0	0
53396	Female	155	0	0	0	69% (22±3.5)*	40% (3±2.1)	3% (3±2.2)	3% (3±1)
53397	Female	125	2% (3±1.8)	81% (11±8.1)*	0	0	0	0	0

2.3.4 Data analysis

We used hourly and daily attendance as metrics to describe the general patterns of site fidelity of sharks at deployment sites of receivers. A shark was considered to be present if two or more detections were recorded in the same day. The use of metrics based on hourly or daily attendance (instead of detections) reduced the effects of differences in detection probability related to the use of tags with different signal outputs. To describe site fidelity, we estimated the residency index as the proportion of monitored days during which a shark attended a given site. We also estimated the mean number of hours detected per day when a shark attended a given site. We classified a shark as “resident” at a site if it had a residency index higher than 0.5 and the mean number of hours detected per day was equal or higher than 12 (i.e., 50% of the total hours available in a day). We considered sharks as inter-annual residents when an animal had an annual residency index equal or higher than 0.5 over consecutive years. We also calculated the daily attendance index as the longest time series of consecutive days each shark attended a monitored site divided by the total number of days the shark was monitored. As time series were often interrupted by downloading of receivers, each portion of the interrupted series was considered to be independent and for this reason, the daily attendance index was likely to be a conservative metric of site fidelity at monitored sites.

We quantified differences in site preferences by calculating the standardised daily attendance as the percentage of sharks tagged in each area attending each receiver on each day. We used ANOVA and a t-test (Zar 1999) to compare site preferences in the southern and northern areas respectively. To determine movement between these areas, we estimated the minimum linear dispersal (Chapman et al.

2005), minimum dispersal time (as the time between the last detection in the residency area and the time of the first detection in the visiting area), and time spent (hours detected) in each visiting event. A shark was considered to be present in the visited area if two or more detections were recorded by the receivers within a period of two hours. For all metrics, mean values and standard deviations (±SD) are reported.

To analyse diel patterns in reef attendance we applied a Fast-Fourier transformation (Chatfield 1996) to the detection frequency of each shark when the individual had a residency index higher than 0.5 (Field et al. 2011). The hourly detection frequencies were corrected to account for variations in the detection probability (Payne et al. 2010). We analysed the northern and southern areas separately, due to preliminary results suggesting that there was limited movement away from the area in which each animal was tagged. We also calculated mean detection frequency of sharks combined per month in each area and employed circular regression to quantify seasonal patterns in attendance (deBruyn & Meeuwig 2001). We corrected the detection frequencies using the correction factors calculated from the data of our control tag (Payne et al. 2010).

We applied a generalised linear model (GLM) with bootstrap sampling to examine the effects of environmental factors on the patterns of depth usage of sharks in 2010, using the mean daily depth of all tagged sharks as the response variable. For this model, water temperature and moon phase were used as explanatory variables. Our temperature dataset consisted of mean weekly water temperature at 57 m depth in the proximity of the monitored sites in both areas (source: Coral Reef Research Foundation, Palau). There was little variation in the temperature between the northern and southern areas, thus we combined data from both for subsequent analyses. We classified the moon phases according to luminosity, where “new” phases had <10% illumination, “half” phases had 11-90% illumination and “full” phases >90% illumination (Dewar et al. 2008). Percentage of illumination was obtained from United States Naval Observatory Astronomical Applications Department (USA Astronomical Application Department website. These data are available at: http://aa.usno.navy.mil/data/docs/MoonFraction.php. Accessed 2012 March 3). We also used circular regression to identify patterns of depth usage in relation to diel cycles. As circular regression has low sensitivity to missing data (deBruyn & Meeuwig 2001), we used the mean depth of the sharks combined per hourly bin over the entire study period for the analysis.

We also used GLMs to establish the relationship between shark attendance and environmental variables within each area. The total number of individual sharks present per hour was the response variable, with tide phase (Tide), month (Month) and time of day (Day/Night; day defined as between 6 am and 6 pm) as the explanatory variables. High and low tide phases were defined as one hour prior to and following the slack tide (O'Shea et al. 2010).

Instantaneous records of shark attendance were aggregated into hourly estimates using a subset function in R (R Development Core Team 2010) that selected 500 values from the data record for each shark. Due to the autocorrelation inherent in the data, the assumption of temporal independence was violated (Burnham & Anderson 2002); we addressed this violation by using a matched-block sampling with replacement technique (Burnham & Anderson 2002). Briefly, this method sub-samples and replaces optimum block lengths from the dataset that maintain some of the autocorrelation structure. Blocks were then joined in a random order to create the uncorrelated bootstrapped sample (Carlstein et al. 1998; Patton et al. 2009; Politis & White 2004). We then applied the model-fitting process to 100 bootstrapped samples and used the median and 95% bootstrapped confidence intervals (2.5 and 97.5 percentiles) of the small sample-corrected Akaike's information criterion (Burnham & Anderson 2002) test statistics: AIC_c, ΔAIC_c (difference between AIC_c of a given model to the model of best fit), $wAIC_c$ (AIC_c weight) and percent deviance explained (%DE) to rank and weight models.

2.4 Results

2.4.1 Receiver performance

Our array of receivers operated continuously during the period of study however, due to technical issues, the receivers from the Blue Corner Incoming and Blue Corner Outgoing sites (Figure 2.1) were not operational from April to November 2010 and March to April 2011, respectively (Figure S2.1). Range testing indicated that there was an overall decrease in the detection coefficient within a 200 m radius of the receivers. All receivers (with the exception of the receiver at Ulong Sand Bar) operated with overall mean code detection efficiency (CDE) above 0.4 for most of the period of the study (Figure S2.2). Following the last deployment of tags in April 2011, there was a considerable decrease in CDE for a number of receivers in both the northern and southern areas. A concurrent increase in the rejection coefficient values (RC) suggests that tag collisions likely contributed to the drop in performance of receivers at this time. We found no cyclical variation of the hourly detection frequencies of the control tag (R^2=0.13, p=0.07), however, the daily detection frequency presented a weak 29-day cycle (R^2=0.17, p=0.02).

2.4.2 General attendance/residency

The receivers recorded a total of 2.3 million detections of 37 sharks over a period of 33 months. Of these, 31 (84%) sharks were detected for 70% to 100% of the monitored weeks. Of the remaining sharks, four were detected daily or weekly for two to 21 months following tagging, although after this time detections ceased. One adult female that was detected at sites on a weekly basis for 14 months after tagging was then not detected for 12 months, after which time she returned to the receiver array and was detected daily for the following two months until the final data download (Table 2.1).

On average, tagged sharks were monitored for 594 ± 370 days (Table 2.2). Twenty individuals (55%) were classified as residents of a given monitored site (Table 2.1). Overall the residency index among the tagged sharks was 0.8 ± 0.2, with a mean daily attendance index of 0.4 ± 0.3 (Tables 2.1 and 2.2). Seventeen of the 26 sharks (65%) tagged in 2008 and 2009 displayed inter-annual residency. On average, individuals were detected for 14 ± 3 hours per day, suggesting that although individuals could have exited the array several times they remained in the vicinity of receivers for extended periods during the day.

Table 2.2 Attendance metrics of grey reef sharks tagged in Palau.

Attendance metrics (*n*=37)	**Mean ± SD**	**Min**	**Max**
Number of days monitored	594 ± 370	13	1114
Number of days detected	483 ± 314	7	910
Maximum number of days continuously detected	191 ± 97	4	343
Residency index	0.8 ± 0.2	0.5	1.0
Daily attendance index	0.4 ± 0.3	0.0	1.0
Mean number of hours detected per day	14 ± 3	1	23

Most sharks were detected regularly at sites adjacent to where they were tagged (Table 2.1). Movement between the northern and southern areas was low and recorded for only four sharks. Of these, two individuals were recorded twice out of the area where they were tagged, while the remaining two sharks attended their non-residency area only once. The mean minimum linear distance of movements of these animals was 17.2 ± 2.1 km and the minimum dispersal time ranged from 10 to 53 hours, but averaged around 13 hours. Attendance time was typically short as most sharks were detected at their non-residency areas for a maximum of four hours. The only male shark tagged by the study was detected in its non-residency area for nine successive hours.

There were significant differences in the standardised daily attendance of sites within each area (t-test northern area: t=-26.7, p<0.01; ANOVA southern area, F=170.6, p<0.01), with Ulong Channel (northern area) and Blue Corner Outgoing (southern area) having higher attendance of sharks than the other sites within the respective area (Figure 2.2).

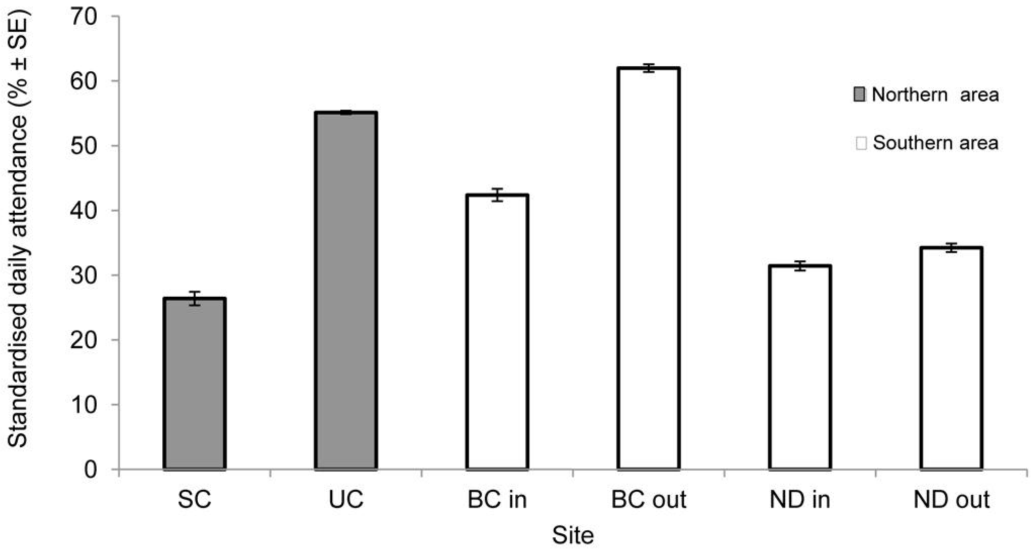


Figure 2.2 Standardised mean daily attendance of grey reef sharks in the monitored areas in Palau. Legends represent receivers at monitored site: SC= Siaes Corner, UC= Ulong Channel, BC in= Blue Corner Incoming, BC out= Blue Corner Outgoing, ND in= New Drop-off Incoming and ND out= New Drop-off Outgoing. Ulong Sand Bar receiver is not included.

All individuals in both areas showed strong 24 hour cycles in detection frequency (Figure 2.3). A smaller, 12 hour peak was also evident for two thirds of the sharks in the northern area and almost all (88%) of the sharks in the southern area. We also found significant differences in the mean daily detection frequencies per month for all sharks (Table 2.3), indicating that although sharks visited the monitored areas regularly through the year, there was a degree of seasonality, with a higher detection frequencies recorded mainly during summer (June to September) and lower detection frequencies in winter and spring (January to April) (Figure 2.4).

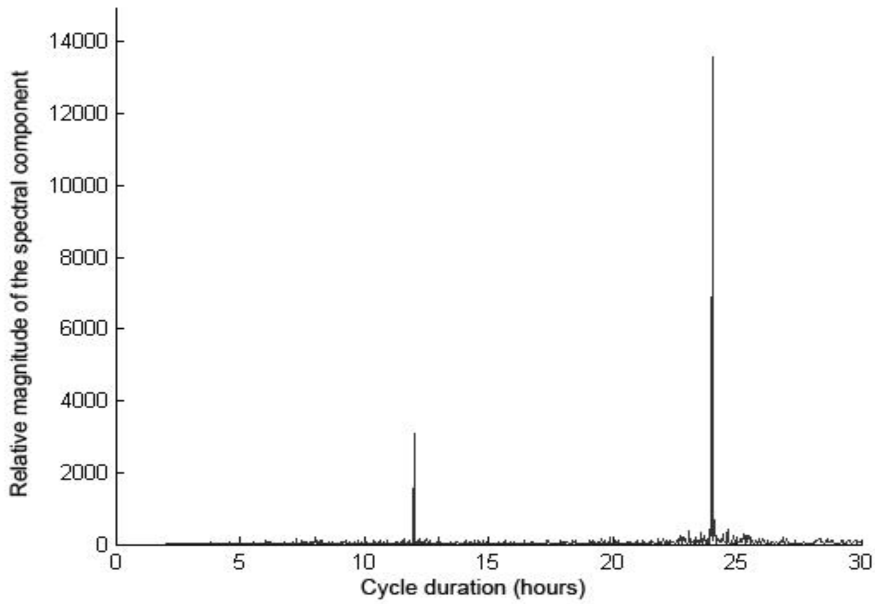


Figure 2.3 Fast-Fourier transformation of hourly detection frequencies of a grey reef shark in Palau. Diel patterns of corrected detection frequencies are represented as peaks of relative magnitude of spectral component. The transformation shows the diel periodicity of detection frequencies of a female grey reef shark (no. 53366, total length=144 cm), a representative example of diel cycles of detection frequencies of the sharks tagged in Palau.

Table 2.3 Summary output of linear regressions of monthly mean detection frequency circular transformed. "Mean" represents mean value of northern and southern areas. SEE= standard error of estimate for the model (liner regression), SE int= standard error of the intercept, SE slope= standard error of slope.

Area	*n*	*p*-value	R^2	SEE	Intercept	SE int	Slope	SE slope
Northern	12	0.0002	0.8	1.0	8.32	0.3	-2.54	0.4
Southern	12	0.017	0.5	1.4	8.17	0.0	-1.74	0.6
Mean	12	0.002	0.6	1.0	8.33	0.3	-1.64	0.0

The GLM analysis indicated that a combination of daily and tidal factors influenced the pattern of reef attendance by sharks (Table 2.4), with more individuals attending the monitored sites during the daytime (Figure 2.5) and at low tide. The top-ranked model for the northern area ($w\text{AIC}_c$ =0.98) included these two variables with an interaction and had the best goodness-of-fit, explaining 19.8% of the deviance in the data. In the southern area, the model that provided the top-ranked fit ($w\text{AIC}_c$= 0.43) included Day/Night and Tide as covariates (Table 2.4) and explained 11.6% of the deviance in the data. In both areas, the amount of deviance explained by Tide was small (0.16% in the north and 0.36% in the south), indicating a greater effect of the daily cycle on the presence of sharks at sites within areas.

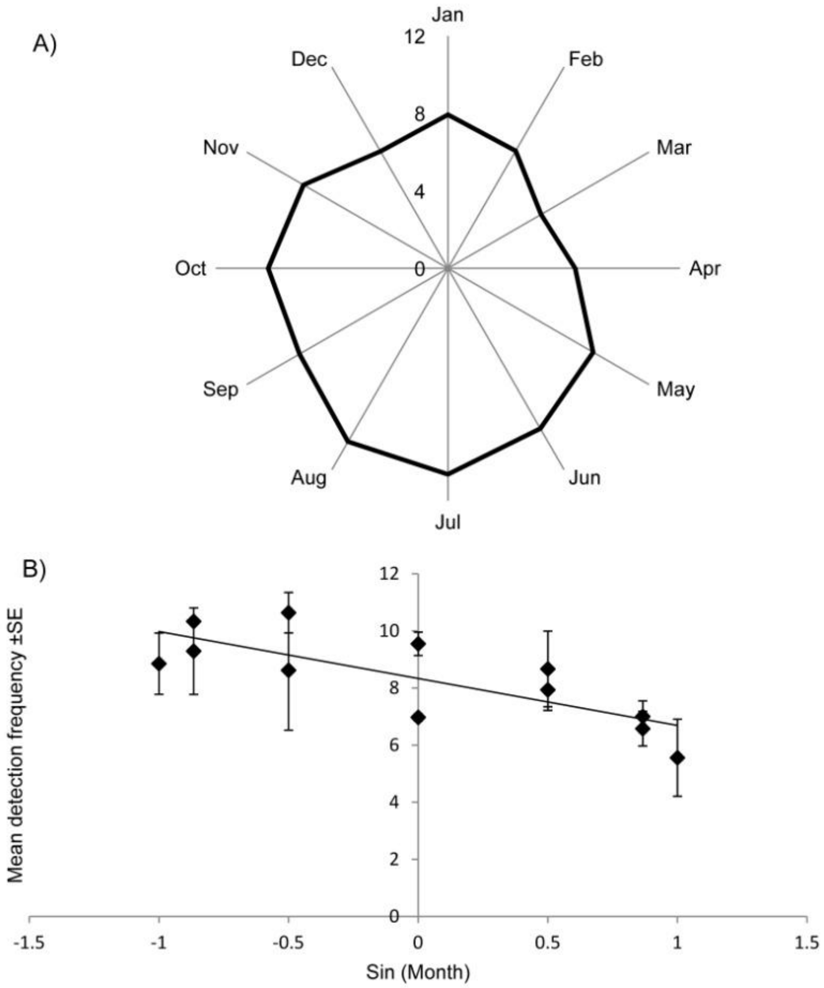


Figure 2.4 Mean detection frequencies of grey reef sharks per month in Palau**.** A) Polar plot of monthly mean daily detection frequency. Months are transformed and expressed as angles, mean daily detection frequencies in a given month (y-axis, areas combined) are represented as distance from the origin. Detection frequencies were corrected by the detection probabilities in each month, calculated from data of a control tag. B) Linear regression representing the mean daily detection frequency per month (areas combined) as a function of sin-transformed months. Equation y=-1.64x+8.33, R^2=0.60.

Table 2.4 Generalised Linear Models ranking results of number of grey reef sharks detected per hourly bin (Indivis as response variable) versus the following explanatory variables: month (Month), phase of the diel cycle (Day/Night), phase of the tidal cycle (Low, Incoming, High, Outgoing) (Tide). Models compared based on Akaike's Information Criteria corrected for small samples (AICc). LL: Maximum Log Likelihood, df: degrees of freedom, dAICc: difference of AICc of a given model to the model with best fit, wAICc: AICc weight and %DE: percentage of deviance explained. Model with best fit highlighted (bold), (*) indicates an interaction between variables.

Area	Model	LL	df	AICc	dAIC*c*	*w*AIC*c*	%DE
Northern	Indivs~1 (Null)	16329.73	1	32661.46	1263.462	0	0
	Indivs~Month	16222.97	2	32449.94	1051.948	0	3.3079
	Indivs~Day/Night	15703.06	2	31410.12	12.123	0.0023	19.4174
	Indivs~Tide	16324.45	4	32656.9	1258.908	0	0.1636
	Indivs~Day/Night+Tide	15698.53	5	31407.07	9.077	0.0106	19.5576
	Indivs~Day/Night*Tide	**15690.99**	**8**	**31397.99**	**0**	**0.9871**	**19.7913**
	Indivs~Tide+Month	16217.77	5	32445.55	1047.555	0	3.469
	Indivs~Tide*Month	16214.47	8	32444.96	1046.963	0	3.5713
Southern	Indivs~1 (Null)	14064.56	1	28131.11	261.630	0.0000	0.0000
	Indivs~Month	14023.44	2	28050.88	181.400	0.0000	3.5262
	Indivs~Day/Night	13933.11	2	27870.22	0.742	0.2990	11.2731
	Indivs~Tide	14060.32	4	28128.65	259.171	0.0000	0.3630
	Indivs~Day/Night+Tide	**13929.74**	**5**	**27869.48**	**0.000**	**0.4333**	**11.5625**
	Indivs~Day/Night*Tide	13927.21	8	27870.45	0.963	0.2677	11.7791
	Indivs~Tide+Month	14019.37	5	28048.76	179.272	0.0000	3.8750
	Indivs~Tide*Month	14018.46	8	28052.94	183.458	0.0000	3.9534

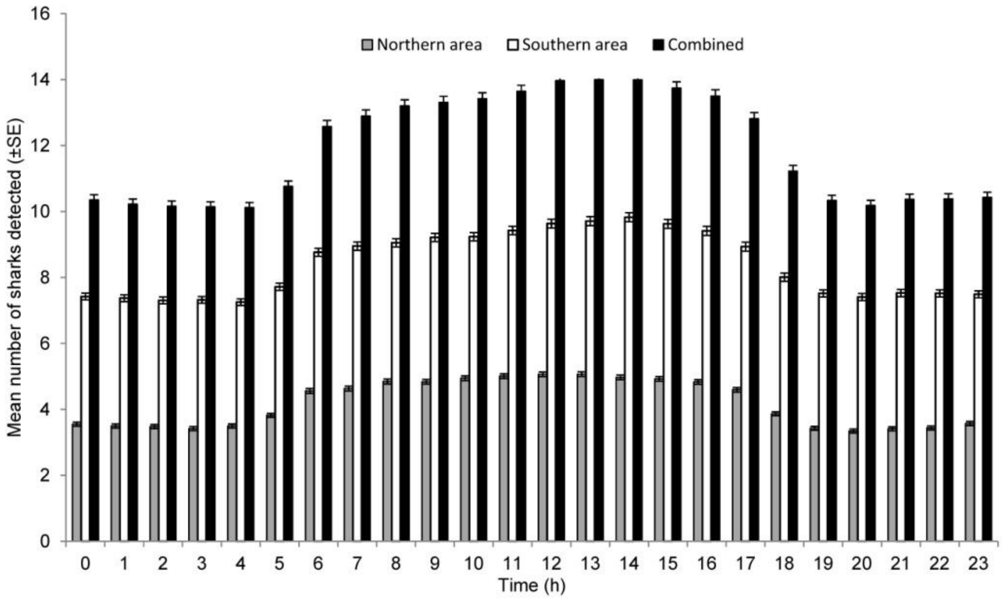
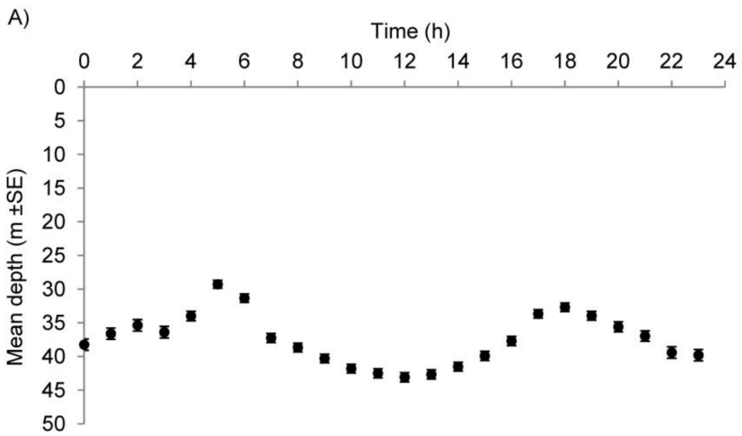


Figure 2.5 Hourly attendance patterns of grey reef sharks at monitored sites in Palau. Mean number of sharks detected in each hourly bin throughout the study period.

2.4.3 Vertical movements

The circular regression revealed a cyclical pattern of depth usage on a daily basis (R^2=0.59, p<0.01) (Figure 2.6). Sharks used shallower waters of around 30 m during dawn (5-6 am) and dusk (6 pm). After sunrise, mean depth gradually increased throughout the morning until noon, when mean hourly depth reached its maximum (~45 m). Mean depth then declined until sunset. A similar, but less pronounced pattern of depth usage occurred at night (Figure 2.6). Overall, there was a tendency for the sharks to use shallower waters during the night (Figure 2.7).



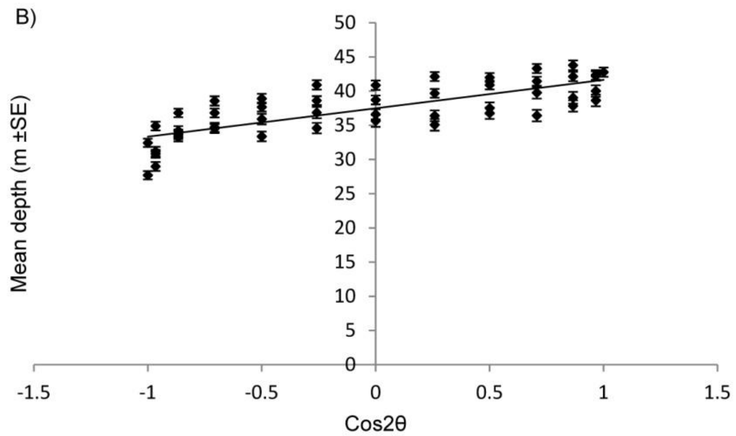


Figure 2.6 Daily pattern of vertical movements by grey reef sharks in Palau. A) Mean hourly depth of grey reef sharks combined. B) Linear regression of mean depth of grey reef sharks combined as a function of Cos2θ-transformed hours. y=4.15x+37.49, R^2=0.59.

GLMs identified water temperature, lunar phase and the interaction between these variables as the strongest influences on patterns in vertical movement of sharks ($_{w}AIC_{c}$=0.51). These two factors and their interaction explained 60.5% of the deviance in the data set (Table 2.5) with temperature having the greatest effect on the mean depth of sharks, explaining 43.0% of the deviance. Water temperature (measured at 57 m) was lowest from January to March when it ranged from 23-25°C. Temperatures then increased to ~29°C and remained constant throughout the remainder of the year. The lower water temperatures in January coincided with use of the shallowest mean depths by sharks. As water temperatures increased at 57 m, sharks occupied deeper waters, averaging 55 m depth from April to August (Figure 2.7). Although there was little change in water temperature from August to December, sharks tended to occupy shallower habitats (mean 45 m depth) at this time.

Table 2.5 Generalised Linear Model ranking results of the average depth of tagged grey reef sharks (with depth sensors) in 2010 (response variable) versus the effect of lunar phase (Moon) and water temperature at 57 metres (Temperature). Models compared based on Akaike's Information Criteria corrected for small samples (AICc). LL: Maximum Log Likelihood, df: degrees of freedom, dAICc: difference of AICc of a given model to the model with best fit, wAICc: AICc weight and %DE: Percentage of deviance explained. Model with best fit highlighted (bold), (*) indicates an interaction between variables.

Model	LL	df	AICc	dAICc	wAICc	%DE
Depth ~ 1 (Null)	-196.464	1	392.928	62.438	0.0000	0.0
Depth ~ Moon	-186.767	2	373.535	43.044	0.0000	18.8
Depth ~ Temperature	-174.273	2	348.547	18.056	0.0001	43.0
Depth ~ Temperature + Moon	-165.278	3	330.556	0.066	0.4917	60.4
Depth ~ Temperature * Moon	**-165.245**	**4**	**330.491**	**0.000**	**0.5082**	**60.5**

Lunar phase also influenced the mean depth of sharks. Depths of sharks at night increased from 40 m during the new moon, to 60 m on the full moon (Figure 2.7). Contrastingly, the mean depth of sharks during the day did not differ with lunar phase, remaining between 45-50 m (Table 2.5).

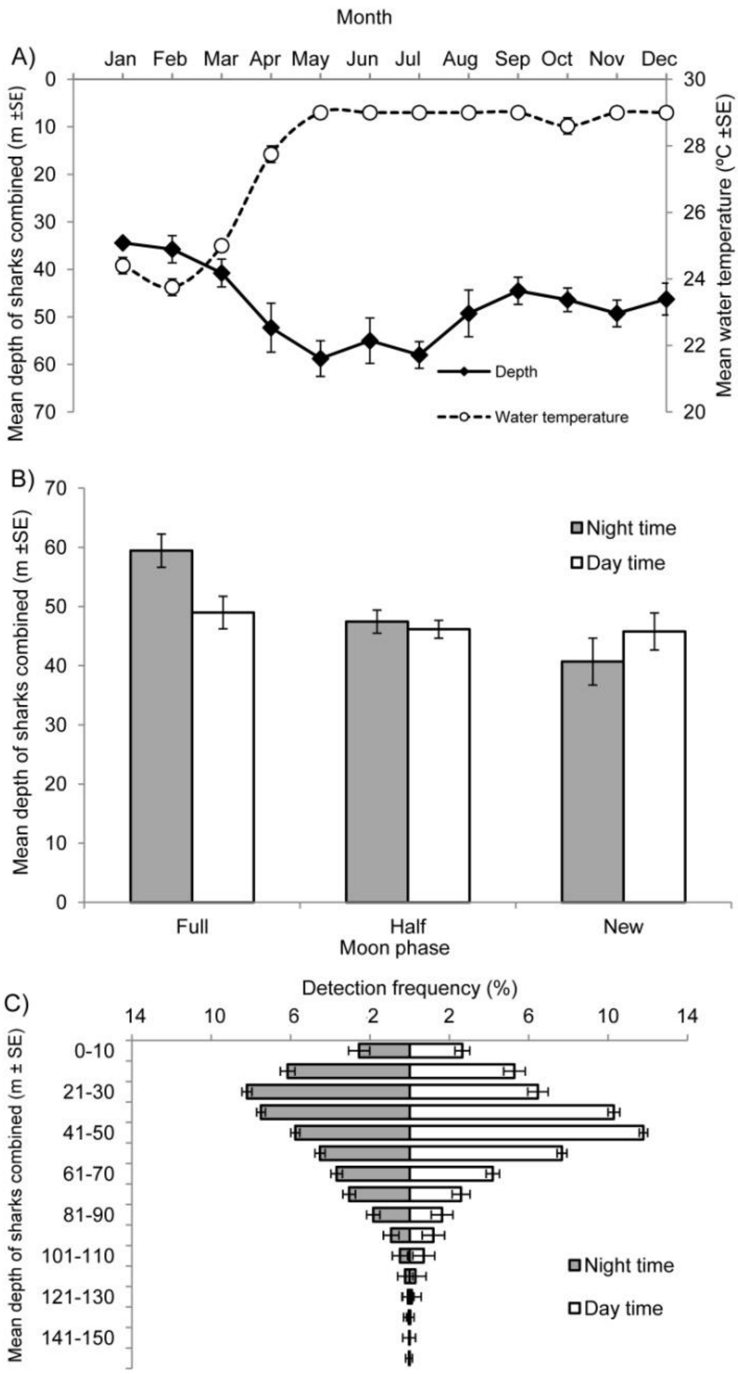


Figure 2.7 Relationship of depth use by grey reef sharks and environmental variables in Palau in 2010. A) Mean monthly depth of grey reef sharks in Palau and mean monthly water temperature at 57 metres B) Mean depth of sharks in a given moon phase C) Detection frequencies of sharks throughout the water column during the day and night.

2.5 Discussion

2.5.1 Site fidelity and horizontal movement

Grey reef sharks in Palau displayed high levels of inter-annual residency, with tagged sharks detected at the same sites along the outer reef slopes for over two years. In both northern and southern areas, most grey reef sharks also displayed residency at the scale of single sites (i.e., residency index higher than 0.5 and attendance for more than 12 hours per day). Unsurprisingly, the highest numbers of sharks detected daily were recorded at the sites where the majority were tagged (Blue Corner and Ulong Channel). There was however, some seasonal variation in attendance in both northern and southern areas, with fewer sharks detected during winter and spring than summer months.

Our results are consistent with those of Field et al. (2011) and Barnett et al. (2012) who also found strong patterns of site fidelity of grey reef sharks at the remote offshore atolls of the Rowley Shoals (17°19'S, 119°20'E, 250 km from the north-west coast of Australia) and Osprey Reef (13°54'S, 146°38'E, 143 km off the east coast of Australia), but contrast those of Heupel et al. (2010) who found that grey reef sharks displayed relatively low rates of site fidelity on the Great Barrier Reef (GBR, 14°30'S, 145°33'E) (Heupel et al. 2010). In the latter study, some individuals moved 15-18 km over the monitoring period and were detected on a number of reef platforms. Such differences in the degree of site fidelity of this species could be related to the distribution and connectivity of reef habitats. Heupel et al. (2010) noted that the reefs in their array of receivers on the GBR were linked by shallow (20 m depth) passes that may allow easy access for sharks to adjacent reefs. While reef isolation may account for the greater degree of site fidelity of sharks at remote atolls, this does not explain the high degree of site fidelity of grey reef sharks in Palau where sites occurred on a continuous barrier reef that stretched more than 260 km. An additional possibility is that such variation in site fidelity could also be related to the life history traits (for example, sex and maturity) of the tagged animals. At Osprey Reef and in Palau where sharks have a high degree of site fidelity, aggregations of grey reef sharks are almost exclusively composed of females (Barnett et al. 2012, Meekan et al. unpubl data) and as a result, most animals tagged in both areas were mature females. In contrast, Heupel et al. (2010) tagged an equal number of males and females on the GBR. On these reefs females tended to display the strongest patterns of site fidelity, with three of the five tagged females being detected an average of 75% of days during a 150 day monitoring period. In contrast, three of five tagged males were never detected or only monitored for short periods of less than 30 days before disappearing from the study area. The two remaining males were monitored over relatively long times (154 and 167 d) but were only detected on one and 22 (13%) days respectively. Furthermore, the largest movement recorded by their study was undertaken by a male shark that travelled 134 km between atolls in the Coral Sea and the GBR. These results suggest that there may be sex-biased patterns of dispersal and site fidelity in grey reef sharks, a phenomenon that has been recorded in a number of other species, including the shortfin mako (*I. oxyrinchus*), blue (*Prionace glauca*) and hammerhead (*Sphyrna lewini*) sharks (Klimley 1987; Mucientes et al. 2009). Testing this hypothesis will require the tagging of greater numbers of male sharks, which is likely to be a challenge in locations such as Palau where aggregations are dominated by females.

The description of movement and patterns of attendance by acoustic telemetry studies is typically limited by the number and range of the array of receivers that are deployed to track the subject animals. For species such as sharks that are capable of moving large distances, this frequently results in long periods of absence, when tagged animals remain out of range or away from the monitored areas (Chapman et al. 2005; Field et al. 2011; Heupel et al. 2010; Knip et al. 2012). These issues need to be considered when tracking data are used to make assertions regarding home range, use of habitat and connectivity. Our tagged sharks displayed high levels of site fidelity and residency throughout the year, implying that our results are robust despite the limited number of receivers in our array. However, there was some degree of variation in site fidelity of several mature females, which is supported by the observation of movements between the northern and southern areas (a distance of 17.2 km) by three females and the extended period of absence (one year) of a shark from the acoustic array. Although the spatial scale of these movements is consistent with results from studies of grey reef sharks on the GBR (Heupel et al. 2010), in the Coral Sea (Barnett et al. 2012) and earlier work on other Micronesian atolls (McKibben & Nelson 1986) that used an active tracking approach, the limited number of receivers that we deployed means that we may have underestimated the frequency and extent of such movements of tagged sharks. Further expansion of the array of receivers should allow the analysis of fine scale movements of sharks.

2.5.2 Vertical movement and environmental influences

Grey reef sharks displayed diel patterns of vertical movements. The shallowest depths (30 m) were occupied at dawn and dusk, with sharks using progressively deeper waters until noon. An opposite pattern occurred in the afternoon with sharks gradually ascending until dusk. This cyclical pattern of descent and ascent was less pronounced at night. Other studies have shown that grey reef sharks show crepuscular patterns, possibly caused by foraging behaviour (Barnett et al. 2012), thus ascents to shallow reef areas at dawn and dusk in Palau may also be associated with feeding. Crepuscular patterns of vertical movement associated with foraging behaviour are common in many pelagic sharks including shortfin mako, big eye thresher (*Alopias superciliosus*), school (*Galeorhinus galeus*) and megamouth (*Megachasma pelagicos*) sharks (Nelson et al. 1997; Sepulveda et al. 2004; Weng & Block 2004; West & Stevens 2001). This behaviour has been associated with the daily vertical movement of prey items (Rasmussen & Giske 1994). Crepuscular behaviour might also be explained by the active attempts of some species to maintain a preferred isolume (Nelson et al. 1997).

Sharks attained greatest mean depths at midday when sunlight penetrates the water column with minimal reflection and they descended or ascended during the morning and afternoon when reflection at the water surface was greatest. These fine-scale patterns of vertical movement suggest that luminosity might influence the vertical movements of grey reef sharks. Such behaviour has been observed in pelagic sharks, including the megamouth (Nelson et al. 1997), although it is thought to occur over a much greater range of depths (around 100 m) than observed in grey reef sharks (15 m). Archival tags that record both depth and light levels could provide insights into role of luminosity in the vertical distribution of reef sharks.

There were also distinct seasonal patterns of depth use by grey reef sharks in Palau. In winter (January and February), when water temperatures at 60 m attained seasonal lows (23-25°C), sharks tended to utilise shallow waters (mean monthly depths of ~35 m). A steady increase in water temperature at the end of winter and spring (March to May) and displacement of the thermocline to waters below 60 m (Colin 2009) was paralleled by an increase in the range of depths used by sharks from 40 to 60 m. Temperature shifts in the order of 1°C to 4°C are generally enough to produce major responses in fish behaviour and distribution (Crawshaw & O'Connor 1997) and water temperature is an important environmental parameter for grey reef sharks (and many other species of shark) since they can display behavioural strategies that function to maintain optimum body temperature (Economakis & Lobel 1998; Hight & Lowe 2007; Morrissey & Gruber 1993; Speed et al. 2012). In Palau, the shallow water (<15 m) temperatures on the outer reef tend to remain relatively constant throughout the year, while deeper waters (>60 m) may vary by as much as 10°C between seasons (Colin 2009). The seasonal pattern of vertical movement observed in our study suggests that in winter, the optimum thermal habitat of grey reef sharks might be restricted to a smaller surface layer of the water column. Many other sharks are known to display vertical movements driven by thermal preferences and this behaviour has been recorded in laminids including shortfin makos and white (*Carcharodon carcharias*) sharks. These regularly descend to the thermocline to feed, but then return to shallow, warmer waters where they spend the majority of their time (Chatfield 1996; Sepulveda et al. 2004). Similarly, there is evidence that whale sharks (*Rhincodon typus*) spend long periods warming up their bodies in the surface after long deep divers in cold waters (Thums et al. 2013). There is also extensive evidence that coastal, reef and oceanic sharks also use warm waters for behavioural thermoregulation (Economakis & Lobel 1998; Hight & Lowe 2007; Howey-Jordan et al. 2013), a strategy that optimises physiological and metabolic processes (Sims 2003; Speed et al. 2012).

At night, the mean depth inhabited by grey reef sharks increased through the lunar cycle, so that the greatest depths coincided with the full moon. Similar patterns recorded by tagging studies of pelagic species such as swordfish, yellowfin and big eye tuna, suggests that such effects of lunar illumination might be widespread among large pelagic predators (Sims 2003; Speed et al. 2012) (Dagorn et al. 2000; Takahashi et al.

2003; Weng et al. 2009). Fisheries data for a range of other pelagic sharks and tunas also support this idea, although some species such as the black marlin (*Makaira indica)* show the opposite pattern, with catches increasing in shallow waters during the full moon (Lowry et al. 2007). Some coastal sharks also display evidence of lunar influences on depth distributions. For example, the nocturnal patterns of vertical migration of school sharks are depressed during the nights of full moon (West & Stevens 2001), while juvenile white sharks descend to greater depths with higher frequency during the nights of full moon (Weng et al. 2009). Given that greater activity patterns of grey reef sharks during twilight and night hours are thought to be related to foraging behaviour (Barnett et al. 2012; McKibben & Nelson 1986; Nelson & Johnson 1980), it seems likely that the use of deeper waters during the full moon could be a response to equivalent changes in distribution patterns of their prey. In pelagic systems, such reciprocal patterns in distribution of predator and prey species are very common, with cyclical variation in luminosity of the moon driving changes in the depth distribution of mesoplankton at night (Hays 2003; Rasmussen & Giske 1994), which in turn influences the depth distribution of their predators (Dagorn et al. 2000; Hays 2003). Alternatively, or possibly in addition, the increase in depth shown by grey reef sharks may be an anti-predator response where sharks seek to avoid the conditions of increased light nearer the surface that may aid the hunting abilities of larger sharks, both of their own and other species.

The complexity of coral reef habitats presents a range of technical challenges that need to be addressed for accurate interpretation of acoustic monitoring data (Welsh et al. 2012). The analysis of the receiver metrics suggested that the mean performance of our receivers was comparable to earlier work on shark movements in Florida (Simpfendorfer et al. 2008) and Western Australia (Speed et al. 2011). These metrics also showed that the reduction in performance in 2011, followed by partial recovery, was most likely caused by the tagging of additional sharks in March of that year. The increase in collisions of tag transmissions (as a consequence of more tags in the water) increased the rejection coefficient of the receivers, however, we noticed no obvious effects in attendance of sharks that could be attributed to this event. We also observed a drastic decrease of the detection coefficient of the receivers within 200 m, which indicates a relatively short range of detections. We conducted the range testing of the receivers shortly after the tagging event of 2011 and we suspect that the low detection coefficient of the receivers at this time could be partially explained by the collision of tag transmissions due to the increase in numbers of tags in the water. Previous studies of receiver performance indicate that detection ranges in coral reefs environments tend to be low (in the order of a few tens of metres) due to the structural complexity of the habitat Welsh et al. 2012). Despite such problems, the very high number of detections (2.3 million) and consistent shark attendance metrics indicated that our results for patterns of site fidelity were not compromised by the technical limitations of acoustic monitoring.

In summary, our study provides the first long-term view of the vertical movements of grey reef sharks within a coral reef environment. Our results confirm previous suggestions that grey reef sharks display strong levels of site fidelity that persist across years, at least for some components of the population. Patterns of daily attendance of sites and vertical movements varied on diel and seasonal cycles. Diel and lunar changes in vertical movement patterns were possibly related to foraging, while seasonally, sharks avoided cooler water temperatures at depth during winter. A better understanding of the role of sharks in coral reef ecosystems now requires integration of such observations into the development of models of the physiology and behavioural ecology of reef sharks.

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2.7 Supporting Information

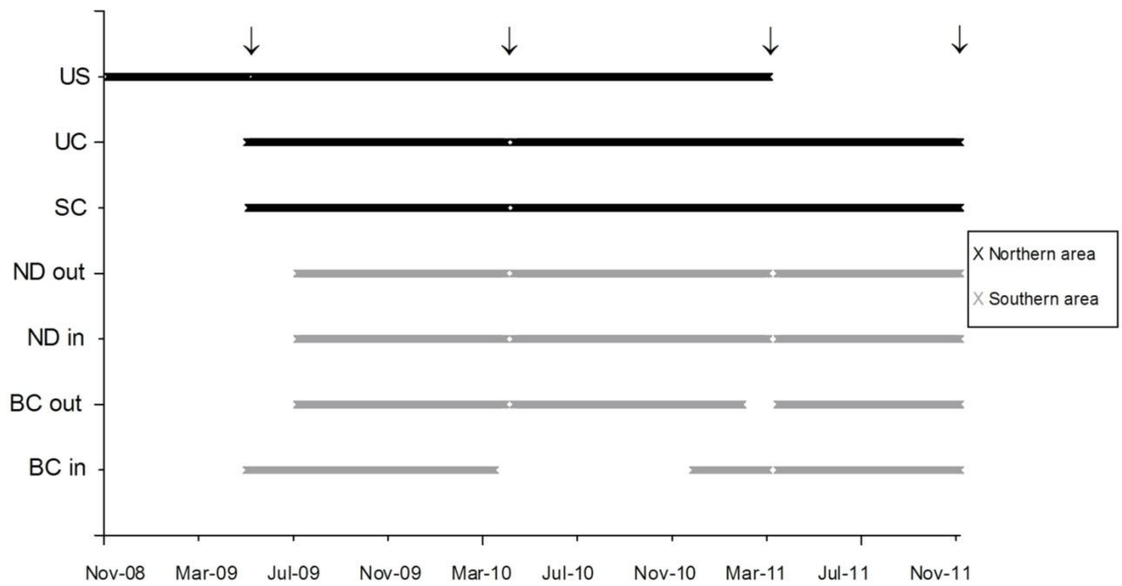

Figure S2.1 Timeline of acoustic receiver operation in Palau. Plot indicates functioning period (x-axis) of each receiver (y-axis), US =Ulong Sand Bar, UC= Ulong Channel, SC= Siaes Corner, ND out= New Drop-off Outgoing, ND in= New Drop-off Incoming, BC out= Blue Corner Outgoing and BC in= Blue Corner Incoming. Arrows indicate download events.

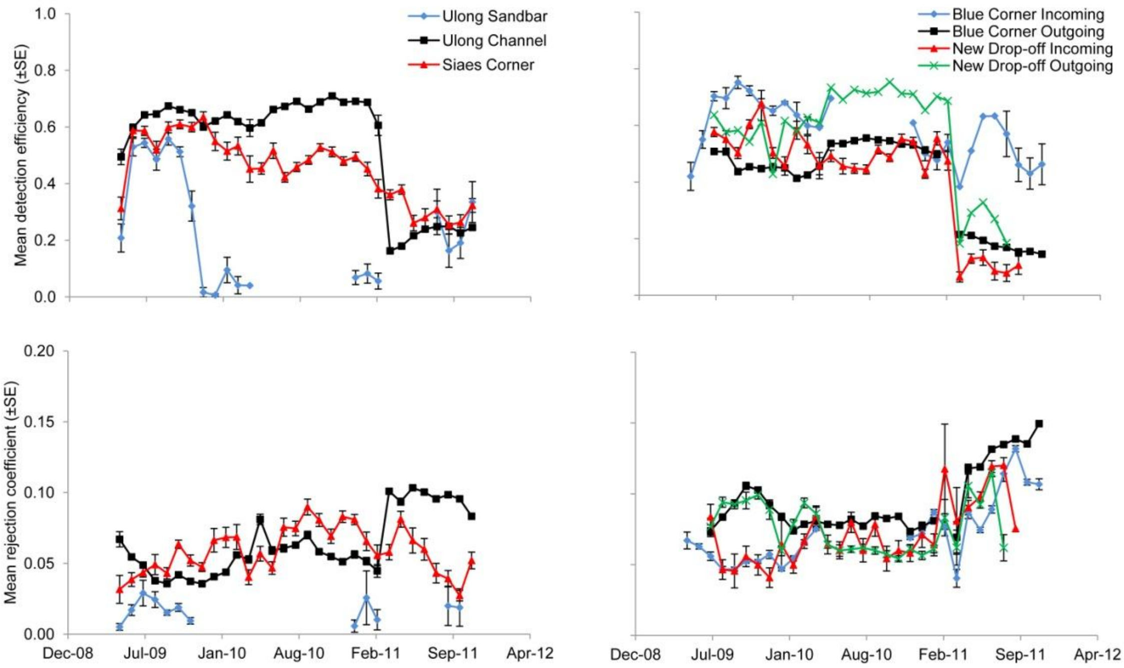

Figure S2.2 Metrics of receiver performance during grey reef shark acoustic monitoring period in Palau. Graphs describe the detection efficiency (top) and rejection coefficient (bottom) of receivers in the northern (left) and southern area (right) of the study site.

Chapter 3- Acoustic telemetry validates a citizen science approach for monitoring sharks on coral reefs

Foreword

Acoustic telemetry is an important tool for the study of ecology and behaviour of sharks, which has assisted the understanding of the spatial ecology and use of habitat by sharks. However, the high costs and logistic constrains associated with this technology usually means that telemetry studies of sharks are often restricted to a small part of the populations within a fraction of the range of monitored animals. Therefore, there is a need for the development of alternative techniques of population monitoring that can be easily applied over large areas, sampling larger parts of shark populations at lower costs.

3.1 Abstract

Citizen science is promoted as a simple and cost-effective alternative to traditional approaches for the monitoring of populations of marine megafauna. However, the reliability of datasets collected by these initiatives often remains poorly quantified. We compared datasets of shark counts collected by professional dive guides with acoustic telemetry data from tagged sharks collected at the same coral reef sites over a period of five years. There was a strong correlation between the number of grey reef sharks (*Carcharhinus amblyrhynchos*) observed by dive guides and the telemetry data at both daily and monthly intervals, suggesting that variation in relative abundance of sharks was detectable in datasets collected by dive guides in a

similar manner to data derived from telemetry at these time scales. There was no correlation between the number or average depth of sharks recorded by telemetry and the presence of tourist divers, suggesting that the behaviour of sharks was not affected by the presence of divers during our study. Data recorded by dive guides showed that current strength and temperature were important drivers of the relative abundance of sharks at monitored sites. Our study validates the use of datasets of shark abundance collected by professional dive guides in frequently-visited dive sites in Palau, and supports the participation of experienced recreational divers as contributors to long-term monitoring programs of shark populations.

3.2 Introduction

Many shark species are experiencing unsustainable rates of mortality due to fishing, a phenomenon that is driving population declines globally (Worm et al. 2013). Despite this emerging crisis, our knowledge of the distribution, abundance and ecology of many species is generally poor. In 2014, an assessment of the extinction risk of 1,041 species of elasmobranchs concluded that almost half (487 species) were categorised as "Data Deficient", meaning that a lack of information prevented any firm conclusions being drawn on their population status and trajectories (Dulvy et al. 2014). This has occurred at a time when there is increasing evidence of the importance of sharks as top-down regulators of the structure and function of marine ecosystems (Ferretti et al. 2010) and recognition of their current and potential value as a non-consumptive resource that supports local economies through ecotourism (Vianna et al. 2012).

The assessment and monitoring of shark populations through fishery-independent techniques presents considerable challenges due to the naturally low population densities and relatively large home ranges common to most species (McCauley et al. 2012; Richards et al. 2011). The large scale (tens to hundreds of km) and long-term (years to decades) monitoring programs that can be required to document the status of populations are thus expensive, particularly if they involve in-water activities such as SCUBA diving. For this reason, development of these initiatives is often beyond the means of governments of developing countries or organisations with interests in the conservation of sharks. Thus, there is an urgent need for the creation and adoption of simple, standardised and low-cost methods for monitoring shark populations (Ward-Paige & Lotze 2011).

Data collected by the public can provide a cost-effective means of monitoring populations of wild animals (Goffredo et al. 2010). Such “citizen science” initiatives are growing in popularity as alternatives to conventional scientific sampling as they offer the opportunity to gather large datasets at reduced cost (Bernard et al. 2013; Silvertown 2009). In the marine environment, this approach is particularly useful for the study of conspicuous animals and megafauna inhabiting coastal areas and coral reefs, where data obtained from the public are relatively easy to collate. This approach has been used to describe the distribution and ecology of many species, including green and hawksbill turtles (*Chelonia mydas* and *Eretmochelys imbricata*), minke whales (*Balaenoptera acutorostrata*) and manta rays (*Manta alfredi*) (Bell et al. 2008; Higby et al. 2012; Jaine et al. 2012). Sharks have also been the target of many of these initiatives, with projects based on data collected by recreational snorkelers and divers used to investigate patterns in distribution, demographics, abundance, habitat use, movement and the effects of environmental and anthropogenic factors (Davies et al. 2012; Hussey et al. 2013; Huveneers et al. 2009; Meekan et al. 2006; Speed et al. 2008;

Ward-Paige & Lotze 2011; Ward-Paige et al. 2010). Structured programs where data are gathered by recreational participants have also been used to provide baseline data and monitor spatial and temporal trends in abundance, which can then be used to design and assess the efficiency of conservation measures (Hussey et al. 2013; Jaine et al. 2012).

Recreational divers and snorkelers have been used to collect data on elasmobranchs in two principal ways: firstly, by recording counts of animals seen during a dive (Brunnschweiler & Baensch 2011; Huveneers et al. 2009; Ward-Paige et al. 2010a) and secondly, by taking identification photos that can then be used in mark-recapture modelling to estimate trends in abundance and demography (Marshall & Pierce 2012; Meekan et al. 2006). The latter approach focuses on those species that have distinctive patterning or scars that allow animals to be identified individually, such as whale sharks (*Rhincodon typus*), manta rays and white sharks (*Carcharodon carcharias*), but is unsuitable for the many reef and pelagic sharks that generally lack any persistent features that might be used to distinguish individuals. For these species, counts by divers provide one of the simplest means to monitor numbers.

Traditional approaches to underwater visual surveys involve standardized techniques that focus on quantifying the area sampled and the abundance and length of individuals within the sample space (MacNeil et al. 2008; McCauley et al. 2012). Such rigorous protocols are a feature of science-based diving programs, but are not necessarily applied during recreational diving. For this reason, datasets of counts collected by recreational divers do not usually generate the data necessary for calculations of total abundance, density and biomass as area-based metrics (McCauley et al. 2012; Ward-Paige et al. 2010a). It is also recognised that other issues may potentially compromise the quality of recreational datasets, such as rounding bias, misidentification and inflation of estimates (Bernard et al. 2013; Brunnschweiler & Baensch 2011; Ward-Paige & Lotze 2011). Although simulation and comparative studies have suggested that recreational divers may indeed be able to report shark numbers in an accurate and reliable manner (Ward-Paige et al. 2010a; Ward-Paige & Lotze 2011), there is a need for independent validation of this approach in the field.

Acoustic telemetry can provide a means to address these issues and validate datasets generated by citizen science approaches. Arrays of acoustic receivers are now commonplace in many coastal marine environments that are inhabited by marine megafauna such as sharks (Heupel et al. 2006). Acoustic tags can be deployed on animals without causing modification of behaviour and will report their presence whenever they are in range of the array (Heupel et al. 2006). The presence/absence data generated by these tags are commonly used to monitor the attendance of individuals tagged at the monitored sites (Heupel et al. 2006), and provide an index of relative abundance that can be used to identify trends in the populations over time. In places where citizen science initiatives and arrays overlap, acoustic telemetry can be used to assess the validity of citizen science datasets.

In our study, we compared datasets of shark relative abundance collected by professional dive guides with tagging data generated by passive acoustic telemetry at the same sites on coral reefs in Palau, Micronesia. We aimed to determine if the observations reported by dive guides produced comparable estimates of relative abundances and temporal patterns in numbers of sharks as those obtained from presence/absence data derived from acoustic tagging and monitoring. We also used the telemetry data to investigate the effect of the presence of tourist divers (i.e., observer effect) on the relative abundance and depth use by sharks. Finally, we analysed our citizen science dataset in order to identify environmental correlates of patterns of relative abundance of sharks at dive sites.

3.3 Methods

3.3.1 Ethics Statement

This project was conducted under the Republic of Palau Marine Research Permit no. RE-09-26 and the Koror State Marine Research Permit no. 10-204. Shark tagging in 2011 was also conducted under UWA animal ethics permit no. RA/3/100/975, in adherence to provisions contained within the Australian Code of Practice for the Care and Use of Animals for Scientific Purposes. Participants of the shark counts were aware of the use of these data for research and provided written consent for the use of the data collected. This project has been assessed as exempt from ethics review by the Human Research Ethics Office of the University of Western Australia (protocol code: RA/4/1/6457).

3.3.2 Study area

Palau supports a dive industry consisting of approximately 20 tourism businesses that use mainly small speed boats to provide day trips for tourists to visit reef sites for two to three dives per day. In 2010, it was estimated that approximately 41,000 tourists visited Palau to engage in dive activities, of which approximately 8,600 visited the country specifically to dive with sharks (Vianna et al. 2012). Most of the popular dive sites are on the southwest (leeward) area of the barrier reef that surrounds Babeldaob, the main island of Palau (7°N, 134°W). This area encompasses dive sites that vary in topography from relatively sheltered sand flats and coral gardens to steep walls and promontories that project into oceanic waters on the outer reef slope (Colin 2009). Diving occurs in a variety of habitats including sandy channels and caverns, however the main drawcard for divers visiting Palau are the “drop-off” dives on the steep reef slope exposed to the open ocean, where there are usually moderate to strong tidal currents. These dives sites are characterised by high visibility (> 30 m) and a rich diversity of marine life with high abundances of large pelagic species. Many of these dive sites host aggregations of reef sharks, which are composed mainly of resident grey reef (*Carcharhinus amblyrhynchos*) and whitetip reef sharks (*Triaenodon obesus*) (Vianna et al. 2013; Vianna et al. 2012). Dives at these sites are typically conducted during periods of relatively high tidal currents when sharks swim just off the edge of the slope. Divers enter the water up-current and, on arrival at the aggregation sites, attach themselves by a hook and line to the reef crest so that they can remain stationary to view sharks and large fish passing along the drop-off (Vianna et al. 2012). Once safety time limits at these depths (typically between 12-25 m) are attained, the divers release hooks and lines and drift along the reef crest making a slow ascent to the surface. For reasons of safety, the routes and durations of these dives are similar through time (G.M.S.V. and M.G.M. pers. obs.).

3.3.4 Data collection

Our dataset consisted of counts of sharks sighted during dives by dive guides who worked as employees of a dive tourism business. Standard questionnaires were completed after the day trips by dive guides from October 2007 to November 2012. A total of 62 dive guides recorded information for 2,360 dives at 52 dive sites in Palau. Each questionnaire contained information on the dive site visited, date, species and counts of individual sharks sighted by the guide. Dive guides estimated the depth of the divers during the sightings, current strength (0- no current; 1- weak; 2- moderate; 3- strong current), visibility (in meters), and recorded dive time and number of tourist divers in the group. Each completed questionnaire provided observations from a single dive guide.

Most of the dive guides engaged in collecting data for the study were local residents familiar with identification of the species of reef sharks in Palau. Guides were instructed to report the total number of individual sharks of each species observed during the entire dive. We also instructed the dive guides to be conservative with counts, observing features that could permit individual identification (e.g., pigment patterns, marks and scars), reducing the potential for repeated counts. An office staff member was responsible for administration and management of the survey, encouraging dive guides to return questionnaires regularly. This staff member was also trained to enter data and maintain the dataset. To promote engagement and consistency in data collection, we also established an annual event to provide feedback to the participants, where the dive guides who collected data regularly would receive small rewards. During these events, the researchers involved in the project would also provide lectures to the dive community, where updates on relevant issues and results obtained from the dataset were presented.

We used passive acoustic telemetry to monitor the attendance of resident grey reef sharks at four key dive sites (Blue Corner, Siaes Corner, Ulong Channel and New Drop-off), known to host predictable aggregations of sharks (Figure 3.1). An array of four Vemco VR2w acoustic receivers monitored sharks tagged with acoustic transmitters from November 2008 to December 2012, a period that overlapped the dive guide records of shark counts. The receivers were deployed at depths between 25 and 40 m on the barrier reef drop-off or slope and recorded the presence of tagged sharks within a range of 200 m of the receiver location (Vianna et al. 2013). We internally tagged 39 grey reef sharks (38 females, 1 male) with Vemco V16 coded tags with battery life ranging between three and a half and ten years. Ten of these tags were also fitted with pressure sensors, which provided a record of depth of the tagged sharks (for full description see Vianna et al. 2013). Temperature loggers were deployed near the dive sites at 15 m depth and provided records of daily temperature from January 2009 to March 2012. We used the number of sharks detected by the receivers as an index of the relative abundance of the tagged sharks at the monitored sites.

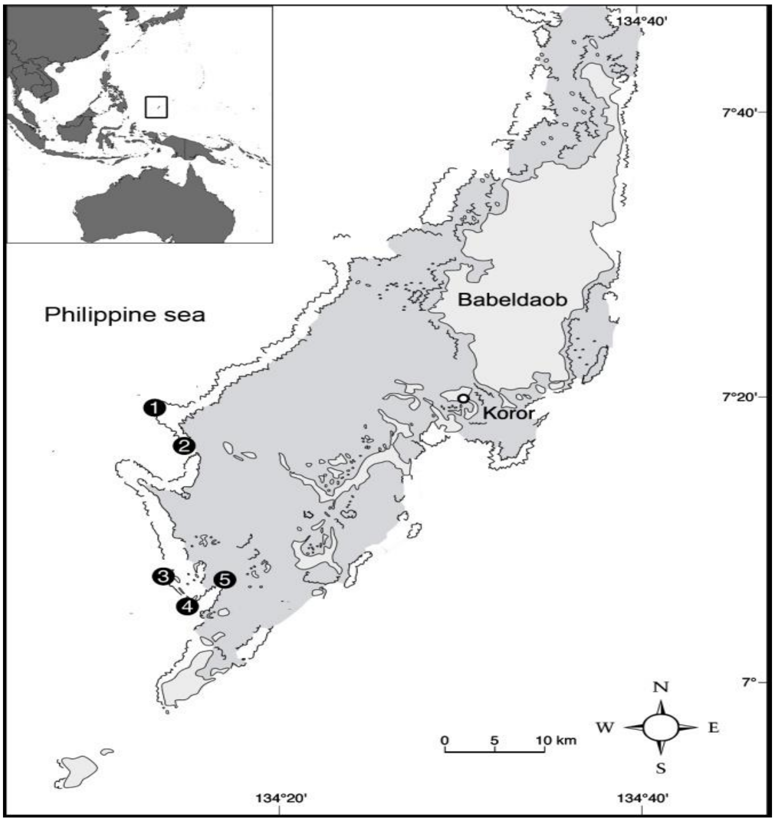

Figure 3.1: Study area in Palau. Numbers indicate location of dive sites monitored: 1) Siaes Corner, 2) Ulong Channel, 3) Blue Corner, 4) New Drop-off and 5) German Channel. Grey shade represents lagoonal area, light grey indicates islands. Numbers one to four also indicate the location of acoustic receivers

3.3.5 Data analysis

We limited our analysis to data from experienced dive guides, defined as guides who participated for at least three of the five years during which the study was undertaken, who had returned a minimum of 100 questionnaires. In order to obtain a reasonable representation of questionnaires for each calendar month, our analysis focused on the dive sites that also yielded a minimum of 100 questionnaires. We estimated the daily relative abundance (no. day^{-1}) of sharks observed by dive guides as the mean value of all dives in a given day at the same site. Given daily variation in diving activities, we also calculated a mean daily abundance for each calendar week.

We calculated the frequency of occurrence of each species as the proportion of days reported when a given species was sighted by dive guides. Our statistical analyses focused on grey reef and whitetip reef sharks, the two most abundant species recorded by dive guides at our study sites. We first used linear regression to compare the daily relative abundance of grey reef sharks observed by dive guides and the number of individually tagged sharks recorded by receivers at the same site on the same day. This analysis allowed us to determine whether there were correlations between diver counts and the number of sharks tagged attending the array as a relative measure of abundance. Our dataset only included days when sharks were detected by receivers on a minimum of two occasions.

We also used linear regression to investigate the effects of the presence of divers on the behaviour of sharks at the study sites. For this analysis, we regressed the number of tagged grey reef sharks present at a given site and day against the number of tourist divers reported to be in the water during the corresponding day. Multiple dives reported on the same day at a given site were treated as separate samples unless occurring simultaneously (in the same hour), in which case we summed the number of tourist divers reported by each guide as a measure of the total potential influence on the sharks. We also used linear regression to analyse the relationship between the mean depth of the tagged sharks and 1) the number of tourist divers reported to be in the water during a dive and 2) the mean depth of these divers.

We used circular regression (deBruyn & Meeuwig 2001) to relate monthly patterns in mean daily relative abundance of grey reef sharks observed by dive guides with telemetry records. We used a *t*-test for slopes to compare the regressions of monthly observations by dive guides with the mean number of grey reef sharks detected using telemetry. Monthly estimates of relative abundance observed by dive guides and number of sharks detected by telemetry were calculated by averaging the daily values across a given month. For the regression, we included only telemetry values that had two or more corresponding observations by dive guides. The explanatory variable "month" was sine-transformed to account for cyclical variation in abundance of sharks. We also fitted circular regressions to investigate patterns of seasonality in the mean monthly relative abundance of sharks observed by dive guides at the selected study sites. This analysis was performed for all sharks combined but also separately for grey reef and whitetip reef sharks.

We used multiple linear regression to examine the influence of environmental factors on the relative abundance of sharks observed by dive guides. Our response variable was the log-transformed daily abundance of sharks (i.e., all sharks combined, grey reef, and whitetip reef sharks) averaged per week. Explanatory variables included in the models were: year, current strength, temperature, visibility, number of tourist divers and moon phase. We applied the Akaike's Information Criterion (AIC) test statistics including AIC, $_{\Delta}$AIC (difference between AIC of a given model and best fitted model) and $_{w}$AIC (weighted AIC) to select the models with best fit (Zuur et al. 2007). Since the order of inclusion of variables influences the AIC model selection process, we analysed the correlation coefficients of explanatory and response variables and used the function Regsubsets of the "leaps" R-package (Lumley 2013) to determine the order of inclusion of the variables in building the models. We validated our models by inspecting the residuals for patterns indicating likely violation of assumptions and fitted correlograms to visually inspect our dataset for auto-correlation. This analysis was performed for the data collected at Blue Corner, the site that yielded the largest number of weekly records (n=148) from the dive guides.

All analyses used R statistical software (R Development Core Team 2010) and all summary metrics were reported as mean values and standard errors (±SE).

3.4 Results

3.4.1 Dive guide datasets

Our final dataset, filtered to only include records of the most frequently visited dive sites and observations of selected guides (those returning more than 100 questionnaires), consisted of data for 1,252 dives (53%) that were collected by 24 dive guides (39%) at five dive sites (10%) (Blue Corner, Siaes Corner, New Drop-off, Ulong Channel and German Channel) over a period of five years. These dive sites are known to be aggregations or hotspots of charismatic megafauna, including reef sharks. The total number of dives at each site varied from 118 at Siaes Corner to 388 at Blue

Corner, with an overall mean dive time of 57±0.22 min and a mean dive depth of 16±0.18 m (Table 3.1).

Dive guides reported seeing sharks during all dives at the selected sites. Grey reef and whitetip reef sharks were the species most commonly observed, with a frequency of occurrence of 86% and 83% and mean relative abundance per dive of 10.1±0.3 and 5.3±0.1 respectively (Table 3.2). Blacktip reef sharks (*Carcharhinus melanopterus*) were also sighted frequently (14% of dives) but with relative abundance of 0.3±0.1 sharks per dive. The other species of observed sharks were recorded very infrequently (2% of dives) and in low numbers (0.02 sharks per dive) (Table 3.2). Shark relative abundances at Blue Corner and Ulong Channel were higher than at other sites with mean values of 20.3±0.6 and 19.0±0.7 per dive respectively, while lower relative abundance was recorded at German Channel with mean value of 11.1±0.4 sharks per dive (Table 3.2).

3.4.2 Integration of dive guide and telemetry data

Paired sets of abundance estimates provided from dive guides and acoustic detections were available for 406 dives (Table 3.1). For the dives when telemetry data were available, the number of sharks detected by acoustic receivers at a given site varied from one to 19 with a mean of six grey reef sharks detected per day (±0.02).

The regression analysis indicated a significant and strong relationship (R^2=0.74, p<0.001) between the mean daily relative abundance of grey reef sharks observed by dive guides and the number of tagged individuals detected by telemetry (Figure 3.2). Lowest relative abundance (10 sharks per dive) was observed on days when the number of sharks detected by telemetry was also low (1-3 sharks per day). An increase in the number of sightings by dive guides corresponded to increased numbers of tagged sharks detected acoustically. The highest relative abundance of 19 grey reef sharks was observed by guides when a maximum of 12 tagged sharks were detected on acoustic receivers.

Table 3.1 Descriptive metrics of dive guide observations and telemetry data at the monitored sites in Palau. SD: standard deviation, *n*: sample size

	Blue Corner					Ulong Channel					Siaes Corner					New Drop-off					German Channel					Total				
Metrics	Mean	Min	Max	SD	*n*	Mean	Min	Max	SD	*n*	Mean	Min	Max	SD	*n*	Mean	Min	Max	SD	*n*	Mean	Min	Max	SD	n	Mean	Min	Max	SD	*n*
Number of dives	388	-	-	-	-	223	-	-	-	-	118	-	-	-	-	138	-	-	-	-	385	-	-	-	-	250.4	118	388	130.4	5
Estimated area of dive site (m^2)	17000	-	-	-	-	27000	-	-	-	-	19000	-	-	-	-	22000	-	-	-	-	10000	-	-	-	-	19000	10000	27000	6285	6
Dives per month	7.9	1	31	5.3	48	4.8	1	18	3.4	45	2.8	1	7	1.6	41	3.3	1	13	2.5	40	7.9	1	37	6.0	47	5.7	1	48	4.6	48
Dive time (min)	56	30	70	6.4	354	60	25	88	7.6	206	57	20	68	6.3	108	57	45	85	6.5	123	57	30	80	6.8	336	57.4	20	88	6.9	1127
Divers depth	16.3	5	35	5.1	258	15.4	5	45	4.7	158	18	10	25	5.4	86	15.4	5	30	5.3	87	15.7	5	30	5.1	281	16.2	5	45	5.1	870
Divers per dive	17.5	10	40	7.5	354	16	10	40	6.7	204	15.5	10	30	6.6	110	13.9	10	30	5.2	123	19.4	10	40	8.3	334	17.2	10	40	7.5	1125
Days with telemetry data	185	-	-	-	-	122	-	-	-	-	67	-	-	-	-	32	-	-	-	-	-	-	-	-	-	101.5	32	185	66.9	4
Sharks detected daily (telemetry)	7.2	2	19	2.9	185	6.9	3	13	2.6	122	2.7	1	8	1.3	67	3.2	2	7	1.0	32	-	-	-	-	-	6.0	1	19	3.1	406

Table 3.2 Frequency of occurrence (FO) and mean daily relative abundance of sharks observed by dive guides (Abund) and SE of most common species of sharks at the monitored sites in Palau.

	Blue Corner		Ulong Channel		Siaes Corner		New Drop-off		German Channel		Overall	
Species	FO (%)	Abund	FO (%)	Abund	FO (%)	Abund	FO (%)	Abund	FO (%)	Abund	FO (%)	Abund
All sharks	100	20.3 (0.6)	100	19.0 (0.7)	100	13.8 (0.9)	100	11.5 (0.6)	100	11.1 (0.4)	100	15.6 (0.3)
Grey reef shark	86	12.4 (0.5)	89	13.4 (0.6)	94	10.9 (0.9)	87	6.9 (0.6)	83	6.8 (0.3)	86	10.1 (0.3)
Whitetip reef shark	86	7.7 (0.3)	86	5.5 (0.3)	76	2.7 (0.3)	88	4.3 (0.3)	81	4 (0.2)	83	5.3 (0.1)
Blacktip reef shark	13	0.3 (0.1)	9	0.2 (0.2)	8	0.2 (0.1)	22	0.4 (0.2)	17	0.25 (0.1)	14	0.3 (0.1)
Others[a]	1	0.01 (0.0)	1	0.01 (0.1)	0	0	1	0.01 (0.0)	4	0.04 (0.1)	2	0.02 (0.0)

[a]Other species include hammerhead, zebra, bull, nurse, and lemon sharks.

Data generated by dive guides showed monthly variation in the number of grey reef sharks (Figures 3.3 and 3.4), with peaks of relative abundance occurring from February to June and lower values from August to November. This pattern was generally similar to that observed in the telemetry data (Figure 3.3). While there was no significant difference between the slopes of the regressions of the mean relative abundance observed by guides and telemetry detections as a function of month (*t*-test for slopes, t=-0.76, p=0.47), there was some divergence between the two data sets during March and April (Figure 3.3A), when detections appeared proportionally lower than numbers observed by dive guides.

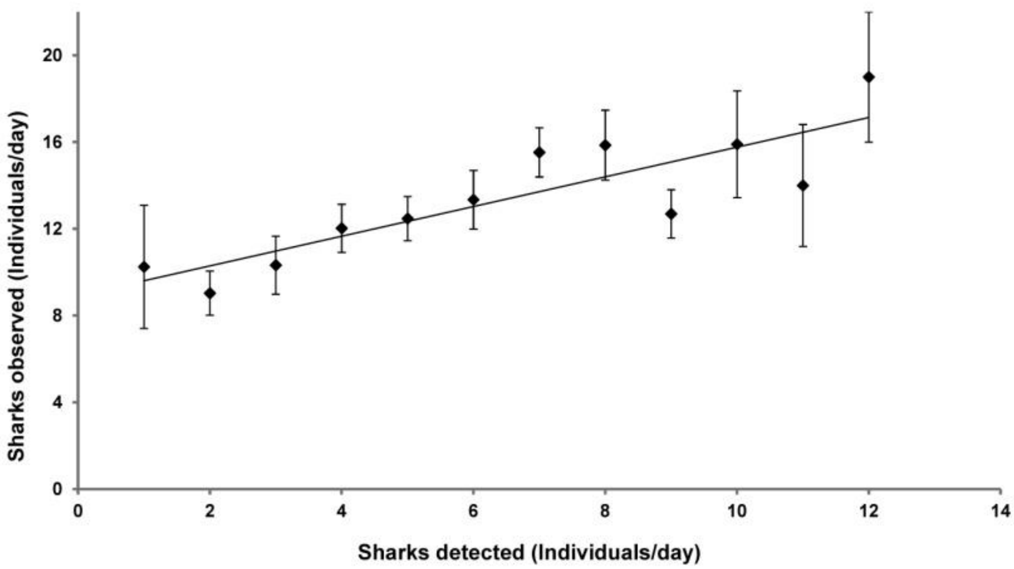

Figure 3.2 Relationship between daily underwater observations and acoustic telemetry of grey reef sharks in Palau. Mean daily relative abundance of grey reef sharks observed by dive guides as a function of daily number of sharks detected by telemetry. Error bars indicate SE. y=0.68x+8.92, R^2=0.74.

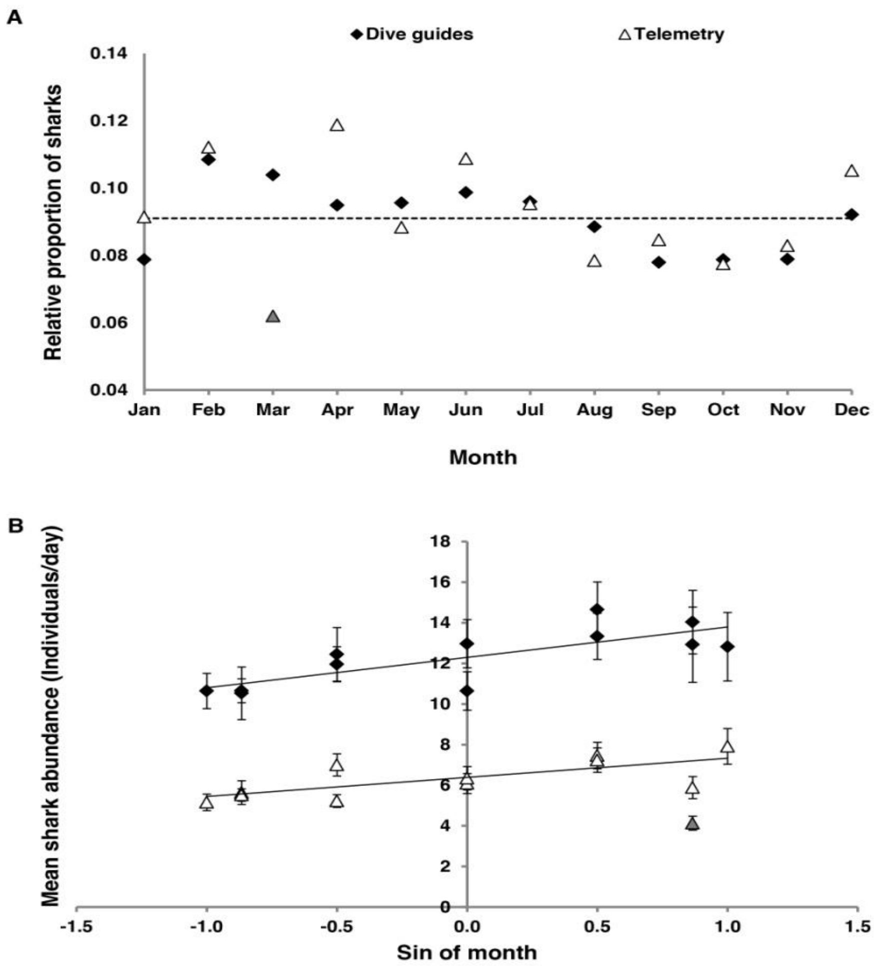

Figure 3.3 Grey reef shark abundance at monitored sites in Palau. A) Proportion of sharks observed by dive guides and detected by telemetry monthly (mean number of sharks observed daily in each month divided by the sum of mean values of all the months). Dashed line indicates the expected relative proportion in absence of seasonal variation. B) Mean monthly relative abundance of sharks as function of sin-transformed month. Error bars= SE. Dive guides: $y=1.49x+12.23$, $R^2=0.60$. Telemetry: $y=0.94x+6.39$, $R^2=0.51$. *Grey triangle indicates detection during low receiver performance and was not included in the analysis (see discussion).

The linear regressions showed no significant relationship between the number of grey reef sharks detected by telemetry and the number of tourist divers present during the dives (p=0.48). Mean values varied from 6.7±0.3 sharks detected when up ten tourist divers were present to 7.2±1.1 when 40 or more tourist divers were present. Similarly, there were no significant relationships between the mean depth of tagged grey reef sharks and the number of tourist divers present during the dive (p=0.31) or the mean depth of the tourist divers (p=0.44).

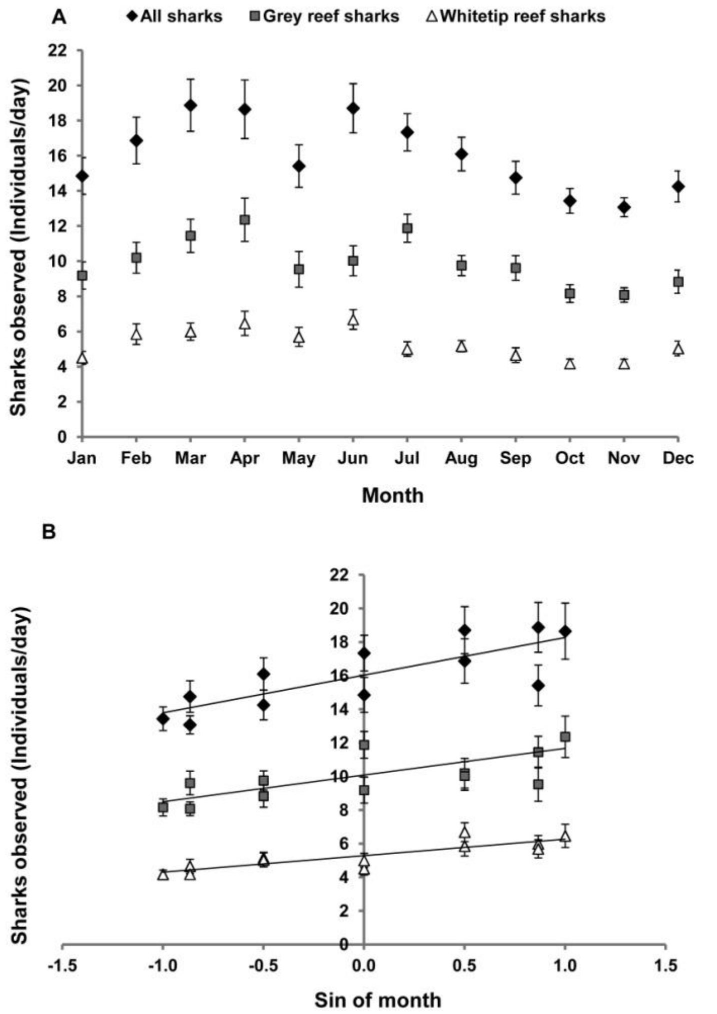

Figure 3.4 Monthly patterns of abundance of reef sharks observed by dive guides in Palau. A) Relative abundance of common species of reef sharks observed by divers at monitored sites. B) Relative abundance of common species of reef sharks observed by dive guides as a function of sin-transformed months. Error bars indicate SE. All sharks: $y=2.70x+16.30$, $R^2=0.81$, Grey reef: $y= 1.59x+10.08$, $R^2=0.64$, Whitetip: $y=0.99x+5.27$, $R^2=0.73$. *May values of abundance of "All sharks" and "Grey reef sharks" not included in regressions.

3.4.3 Relative abundance of sharks observed by dive guides in relation to environmental drivers

Grey reef and whitetip reef sharks were present at the monitored sites through the year however, there was seasonal variation in the number of individuals of both species. Lower values of monthly relative abundance occurred in October and November, with means of 8.1±0.4 for grey reef sharks and 4.2±0.2 for whitetip reef sharks. Between March and April, the relative abundance of sharks was higher with monthly means of 12.4±1.2 and 6.5±0.7 for grey reef and whitetip reef sharks respectively (Figure 3.4). There was a sharp decline in relative abundance of grey reef sharks in May and June to a mean of 9.4±1.2. A similar, but less pronounced pattern was also observed for whitetip reef sharks with relative abundance of 5.7±1.0 in May. The circular regressions indicated that the overall seasonal patterns were statistically significant with sine (month) explaining 81% of the variation in relative abundance of all sharks (p<0.001), 64% of the variation in relative abundance for grey reef (p=0.003) and 73% for whitetip reef sharks (p<0.001).

Multiple regression indicated that current and temperature were the key environmental factors influencing the numbers of sharks recorded by dive guides (R^2=0.18, p<0.001; Table 3.3). There was a positive linear relationship between current and the relative abundance of all sharks (R^2=0.14, p<0.001), grey reef (R^2=0.13, p<0.001) and whitetip (R^2=0.07, p=0.002) reef sharks, while temperature displayed a negative linear relationship with relative abundance of all sharks (R^2=-0.04, p=0.02) and grey reef sharks (R^2=0.05, p=0.03) (Table 3.3, Figure 3.5). Year, visibility, moon phase and number of tourist divers in the water had little influence on the number of sharks sighted during the dives (Table 3.3).

Table 3.3 Multiple regression ranking results of the mean relative abundance of sharks observed by divers (Abund, response variable) as a function of the following explanatory variables: current strength (Cur), temperature (Temp), visibility (Vis), year, moon phase (Moon) and number of tourist divers in the water (Divers), *n*=148 weeks. Model with best fit for each analysis highlighted (bold).

Species	Model	df	AIC	ΔAIC	wAIC	p-value	F-value
All sharks	Ab_{DG}~Null	2	-32.10	22.78	0.00	0.48	0.71
	Ab_{DG}~Cur	3	-50.25	4.64	0.05	<0.001	4.58
	Ab_{DG}~Temp	3	-36.03	18.86	0.00	0.02	-2.42
	Ab_{DG}~Vis	3	-30.43	24.46	0.00	0.48	0.72
	Ab_{DG}~Year	3	-30.22	24.67	0.00	0.54	-0.61
	Ab_{DG}~Moon	5	-30.22	24.67	0.00	0.28	1.28
	Ab_{DG}~Divers	3	-30.23	24.66	0.00	0.98	0.03
	Ab_{DG}~Cur+temp	**4**	**-54.89**	**0.00**	**0.49**	**<0.001**	**14.6**
	Ab_{DG}~Cur+temp+vis	5	-53.73	1.15	0.28	<0.001	9.9
	Ab_{DG}~Cur+temp+vis+moon	8	-51.98	2.91	0.11	<0.001	5.72
	Ab_{DG}~Cur+temp+vis+moon+year	9	-50.39	4.50	0.05	<0.001	4.93
	Ab_{DG}~Cur+temp+vis+moon+divers	10	-49.98	4.90	0.04	<0.001	4.28
Grey reef sharks	Ab_{DG}~Null	2	9.80	22.37	0.00	0.54	0.06
	Ab_{DG}~Cur	3	-6.24	6.33	0.01	<0.001	4.68
	Ab_{DG}~Temp	3	4.30	16.87	0.00	0.03	-2.26
	Ab_{DG}~Vis	3	11.04	23.61	0.00	0.39	0.86
	Ab_{DG}~Year	3	11.79	24.37	0.00	0.59	-0.54
	Ab_{DG}~Moon	5	11.90	24.48	0.00	0.29	1.28
	Ab_{DG}~Divers	3	9.36	21.94	0.00	0.21	1.26
	Ab_{DG}~Cur+temp	**4**	**-12.58**	**0.00**	**0.32**	**<0.001**	**14.35**
	Ab_{DG}~Cur+temp+moon	7	-12.14	0.43	0.26	<0.001	6.94
	Ab_{DG}~Cur+temp+moon+divers	8	-11.91	0.66	0.23	<0.001	6.10
	Ab_{DG}~Cur+temp+moon+divers+vis	9	-10.53	2.05	0.12	<0.001	5.29
	Ab_{DG}~Cur+temp+moon+divers+vis+year	10	-8.84	3.74	0.05	<0.001	4.63
Whitetip reef sharks	Ab_{DG}~Null	2	41.28	7.63	0.01	0.50	0.68
	Ab_{DG}~Cur	**3**	**33.65**	**0.00**	**0.28**	**0.002**	**2.66**
	Ab_{DG}~Temp	3	41.33	7.67	0.01	0.06	-1.89
	Ab_{DG}~Vis	3	43.01	9.36	0.00	0.85	-0.19
	Ab_{DG}~Year	3	42.66	9.01	0.00	0.54	-0.61
	Ab_{DG}~Moon	5	42.15	8.50	0.00	0.17	1.69
	Ab_{DG}~Divers	3	41.86	8.21	0.00	0.19	-1.33
	Ab_{DG}~Cur+temp	4	33.67	0.02	0.28	0.003	5.94
	Ab_{DG}~Cur+temp+moon	7	35.34	1.68	0.12	0.009	3.24
	Ab_{DG}~Cur+temp+moon+divers	8	34.94	1.29	0.15	0.007	3.11
	Ab_{DG}~Cur+temp+moon+divers+year	9	36.46	2.80	0.07	0.01	2.72
	Ab_{DG}~Cur+temp+moon+divers+year+vis	9	36.46	2.80	0.07	0.02	2.36

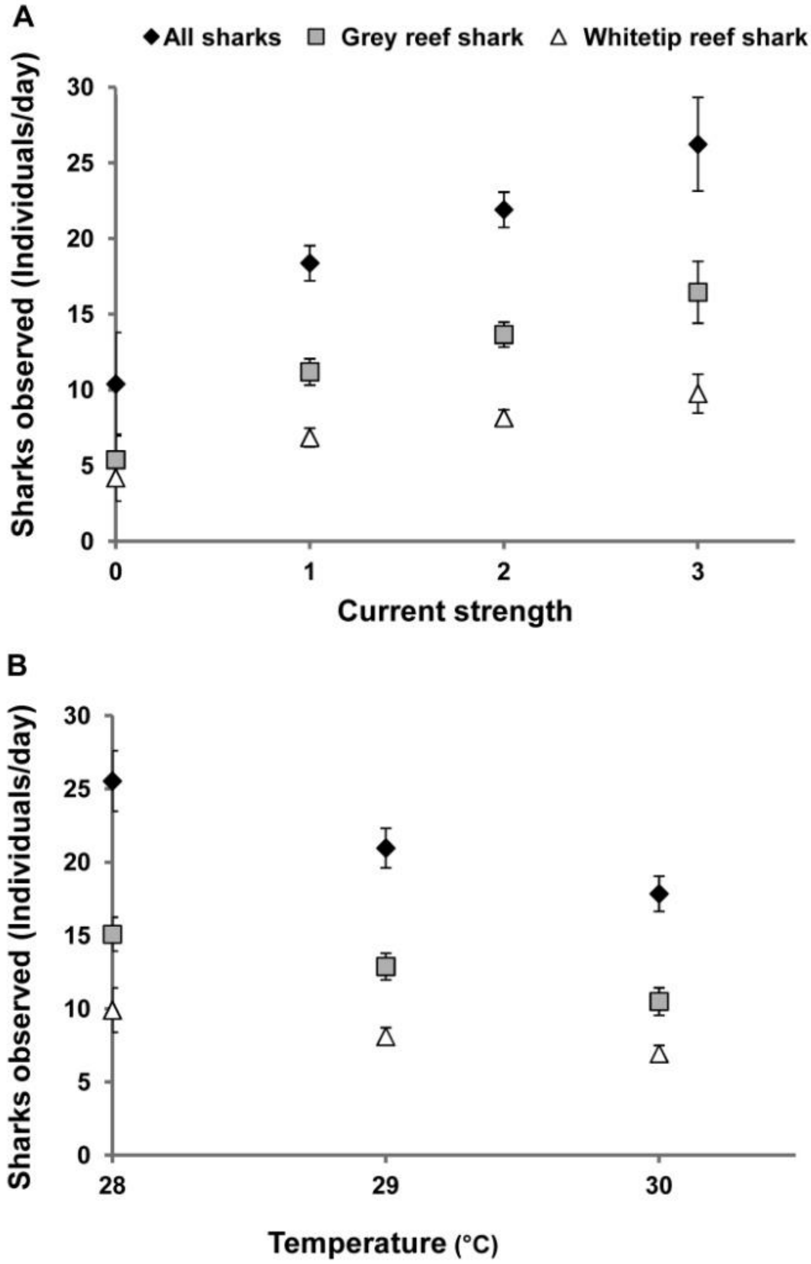

Figure 3.5 Environmental drivers of relative abundance of sharks at monitored sites in Palau. Relationship of mean daily relative abundance of sharks observed by dive guides and A) Current strength (*n*=143 dives), and B) Temperature. (*n*=123 dives). Error bars indicate SE.

3.5 Discussion

3.5.1 Citizen science as a means to monitor reef sharks

Our analysis of data generated by dive guides suggests that citizen science initiatives can provide estimates of the relative abundance of reef sharks that are consistent with the estimates from long-term telemetry. Patterns in relative abundance of grey reef sharks as reported by dive guides and numbers detected by telemetry at the monitored sites followed very similar trends at both daily and monthly scales. The high R^2 value indicated a strong positive relationship between the two metrics, with increases of daily relative abundance of grey reef sharks observed by dive guides matched by a corresponding linear increase in numbers of grey reef sharks detected by telemetry. While data generated by professional dive guides have great potential for providing estimates of relative abundance (Hussey et al. 2013; Huveneers et al. 2009), changes in population size over small and large scales (Friedlander et al. 2012; Ward-Paige & Lotze 2011; Ward-Paige et al. 2010b) and insights into the ecology and population trends of marine predators in reef and coastal habitats (Brunnschweiler & Baensch 2011; Hussey et al. 2013), the biases and limitations of such datasets remain poorly understood. One earlier study found that experience levels of observers made little difference in their abilities to detect sharks (Ward-Paige & Lotze 2011) however, another study suggested that observations by dive guides might underestimate site fidelity (Brunnschweiler & Barnett 2013). Our study is the first to examine the ability of experienced observers to monitor patterns at a variety of temporal scales. For the most part, we found that dive guides produced datasets of shark relative abundance that tightly mirrored patterns generated by acoustic telemetry. Indeed, in some circumstances counts by dive guides may have been more accurate than those obtained by telemetry techniques. For example, one of the few discrepancies between dive guide observation and telemetry datasets occurred between March and April, when the relative proportion of sharks detected by telemetry was lower than those recorded by dive guides. This result might be a consequence of the presence of transient sharks during these months or higher attendance of individuals not tagged but that frequently visited the monitoring sites during this period. However, lower values of telemetry more likely reflected a decrease in receiver efficiency (Simpfendorfer et al. 2008), since the timing coincided with field work in Palau when new tags were deployed on sharks. Indeed, an analysis of receiver metrics showed lower performance of the array caused by signal collisions due to the large number of tags in the vicinity of some receivers at this time (see Vianna et al. 2013 for more detail).

Although there was a close correlation between dive guide counts and telemetry results, to some extent this may have been a function of the particular circumstances of our study. We used experienced dive guides to gather data and the addition of tourist divers and less experienced guides might have reduced the strength of the relationship. While there is some evidence that diving experience may not necessarily be positively correlated with count accuracy (Ward-Paige & Lotze 2011), this is likely to depend on the circumstances surrounding the dive and may only be the case under relatively benign conditions of low current, simple topography and with relatively few sharks. During the study, experienced guides leading groups of tourist divers tended to follow predetermined routines, visiting specific landmarks over a time bounded by limits for safe recreational diving. Given the perpetually clear waters on the outer reefs of Palau (visibility typically > 30 m), this meant that the sampling area covered by guides was likely to remain relatively constant among dives at a given dive site. The opportunity to view sharks is a focal point of the diving tourist experience in Palau (Vianna et al. 2012), so that dive guides are likely to actively locate sharks during a dive. Additionally, dive guides are familiar with the local fauna at each dive site, which is also likely to reduce misidentifications and search effort. Finally, the sharks in many of the popular dive sites appear to be uninterested in and relatively unwary of divers. Indeed, we found no significant correlation between the numbers or depth of sharks recorded by telemetry and the numbers of tourist divers present in the dives. The rapid habituation of sharks to the presence of divers was first noted in some of the early behavioural studies in reef systems (Nelson 1977) and at our study sites this behaviour meant that sharks were likely to remain in the local area despite the presence of tourist divers, making it relatively easy to obtain reliable counts of numbers. Together, these characteristics of the diving experience in Palau mean that it is ideally suited for a citizen science approach to shark monitoring in partnership with the recreational diving community. While the degree to which such features exist at other recreational diving localities in the wider Indo-Pacific region is unclear, the broad distribution of the species monitored in our study (grey reef and whitetip reef sharks) and the generally favourable diving conditions on coral reefs suggest that similar monitoring programs could be implemented in many locations across the region.

To be successful, monitoring programs need to have well defined objectives and standardised protocols that are effective in collecting accurate data of the target species. In our study, this was possible through data collection by recreational dive guides. However, alternative strategies might be necessary for species of sharks where diving conditions do not allow for underwater visual surveys by recreational divers, such as turbid coastal waters or waters below the limits of recreational diving depths. For such areas, programs designed to collect information from recreational catch and release fishers (Lowry et al. 2007) and visual census conducted from vantage points (Speed et al. 2011) could provide useful citizen science data for the monitoring of shark populations.

Our study suggests that programs that use dive guides to monitor shark relative abundance in coral reefs could be a cost-effective alternative to traditional science-based surveys. However, this is not to imply that the set up and maintenance of such monitoring programs do not involve considerable logistics. We found that the success of our long-term program relied in part on sufficient resources for personnel, training and management of datasets to ensure data quality. On-ground leadership, encouragement and feedback was required to ensure that participants remained engaged in the program and maintained regular sampling throughout the study, as has been highlighted in other studies (Huveneers et al. 2009). In part, this was done through incentive schemes by the dive tourism operator that involved small rewards (donated by local industry) to those guides that provided the most regular returns of questionnaires on an annual basis.

3.5.2 Environmental influences on the abundance patterns of sharks

Dive guide data revealed a seasonal cycle in relative abundance of sharks, with peaks from March to June and the lowest values recorded in October and November. Dive guides also recorded relatively low numbers of both grey and whitetip reef sharks in May, a pattern that was more pronounced for the former species. This decrease in relative abundance coincided with an increase in water temperatures from around 25°C in previous months to a peak of 29°C in May (Vianna et al. 2012). Reproduction in reef sharks is known to be closely tied to temperature variation (Speed et al. 2012) and it may be that this sudden decline in the numbers of sharks may result from reproductive events occurring elsewhere on the reef that coincided with the peak in water temperatures. Some support for this hypothesis is found in dive guide observations of numerous females with fresh mating scars at this time.

Short-term (daily, weekly) changes in relative abundance of sharks at the monitored sites were correlated with current strength and temperature. Current strength appeared to be the more important driver of variations in relative abundance of whitetip reef sharks, with mean relative abundance steadily increasing with the current flow. For grey reef sharks, our models identified a combination of both current strength and temperature as the principal drivers of relative abundance. These sharks were three times more abundant during dives when currents were strong than when they were weak and relative abundance was also higher when water temperatures decreased from 30°C to 28°C. Earlier studies have noted the association of reef sharks with areas of strong current flow, typically around reef promontories, channels and passes (Nelson & Johnson 1980) although why this occurs remains unclear. Our previous analyses of telemetry data at the same sites in Palau (Vianna et al. 2013) also shows that water temperature strongly influences the vertical movements of reef sharks, so that the mean depths occupied by sharks are greater when the layer of warm water near the surface (< 40 m depth) expands to deeper waters (> 60 m depth) (Vianna et al. 2013). Therefore, the reduction in number of sharks observed by dive guides during times of higher water temperatures could be associated with sharks occupying a greater vertical range of habitat, much of which is inaccessible to most recreational divers (i.e., > 40 m depth) during these periods.

3.5 Conclusions

Some scepticism surrounds the use of citizen science due to potential problems with the quality of data generated by untrained observers (Goffredo et al. 2010). While mindful of the caveats mentioned above, we showed that counts by dive guides in Palau provided an effective method to monitor shark relative abundance. Our approach is relevant to many other citizen science initiatives because the technique of acoustic telemetry that we used to validate data collection by dive guides is one of the most rapidly-growing means of monitoring animals in marine environments. For example, collaborative initiatives such as the Ocean Tracking Network have now deployed acoustic arrays for tracking whales, seals, sharks, penguins, fish and a huge range other species in marine environments worldwide (see: http://oceantrackingnetwork.org/about/ocean). The development of arrays of listening stations by programs such as these offers the opportunity to validate citizen science initiatives, since both often target the charismatic megafauna that inhabit coastal systems. Such comparative studies will be necessary to ensure that the data citizen science initiatives provide to management and conservation strategies in marine systems is credible, precise and reliable.

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Chapter 4- Socio-economic and community benefits from shark-diving tourism in Palau: A sustainable use of reef shark populations

Foreword

A well-established diving industry can assist conservation strategies by functioning as a platform to collect data for long-term monitoring of shark populations. Besides the potential for data collection, the social and economic benefits that may arise from diving tourism can also assist conservation by creating a strong association between the improvement of the livelihoods of local communities and conservation of charismatic megafauna, such as reef sharks. While this relationship seems evident in Palau, the magnitude of the socio-economic benefits resulting from shark-diving tourism is still unknown.

4.1 Abstract

Arguments for conservation of sharks based on their role in the maintenance of healthy marine ecosystems have failed to halt the worldwide decline in populations. Instead, the value of sharks as a fishery commodity has severely reduced the abundance of these animals. Conservation may be assisted by the development of an alternative approach that emphasizes the economic value of sharks as a non-harvested resource. Our study quantifies the value of a tourism industry based on shark diving.

Using data collected from surveys, as well as government statistics, we show that shark diving is a major contributor to the economy of Palau: generating US$18 million per year and accounting for approximately 8% of the gross domestic product of the country. Annually, shark diving was responsible for the disbursement of US$1.2 million in salaries to the local community, and generated US$1.5 million in taxes to the government. If the population of approximately 100 sharks that interact with tourists at popular dive sites was harvested by fishers, their economic value would be at most US$10,800, a fraction of the worth these animals as a non-consumptive resource. Fishers earn more selling fish for consumption by shark divers than they would gain by catching the sharks. Shark diving provides an attractive economic alternative to shark fishing, with distribution of revenues benefiting several sectors of the economy, stimulating the development and generating high revenues to the government, while ensuring the ecological sustainability of shark populations.

4.2 Introduction

Over the last 20 years, ecotourism based on viewing and interacting with marine megafauna has become increasingly popular (Higham and Lück 2008). Examples of this type of tourism include turtle and whale watching, snorkelling with seals, diving and snorkeling with manta rays and sharks (Anderson et al. 2011; Anderson and Ahmed 1993; Dearden et al. 2008; Dicken and Hosking 2009; Jacobson and Robles 1992; Kirkwood et al. 2003; Orams 2002). The occurrence of aggregations of megafauna in areas remote from population centres means that such tourism also provides significant benefits to local economies, where few alternative sources of income may exist (Garrod and Wilson 2004; Milne 1990). Importantly, the development of a well-managed ecotourism industry based on megafauna provides the opportunity for local people to utilize natural resources in a sustainable manner over the long-term (Mau 2008).

The economic value of tourism based on marine megafauna is large. In 2008, a study of whale watching estimated that this form of tourism was available in 119 countries, and involved approximately 13 million participants annually, generating an income to operators and supporting businesses (hotels, restaurants and souvenirs) of over US$2.1 billion (O'Connor et al. 2009). This industry is estimated to have the potential to generate annual revenues of over US$2.5 billion (Cisneros-Montemayor et al. 2010). The development of whale watching has been paralleled by growth in tourism based on other types of marine mega-fauna. In particular, tourism to observe sharks and rays has become increasingly common. At the forefront of this relatively new market are industries that focus on whale sharks (*Rhincodon typus*), with estimates calculated in 2004 suggesting that these generated more than US$47.5 million worldwide, providing important revenues to developing countries such as Ecuador, Thailand and Mozambique (Graham 2004).

Diving with other species of sharks has followed a similar trend of growing popularity. In 2005, it was estimated that approximately 500,000 divers were engaged in shark-diving activities worldwide (Topelko and Dearden 2005). An increasing range of opportunities for this type of tourism are available, including cage diving, shark feeding and drift diving with reef and oceanic sharks. Shark-diving tourism can be found in more than 40 countries (Carwardine and Watterson 2002), with new destinations and target species being established rapidly, due to the increasing recognition of the economic potential of this activity (De la Cruz Modino et al. 2010; Dicken and Hosking 2009).

The presence of coral reefs and warm coastal waters that naturally attract divers means shark tourism can form an important and valuable element of tourism in many developing countries throughout the tropical Indo-Pacific and Caribbean. However, the growing demand for shark products, principally for shark fin soup, threatens the future of these valuable industries. Due to their conservative life-history traits of slow growth, low rates of reproduction and late ages at maturity, shark populations cannot withstand high rates of exploitation and when depleted often take many years to recover (Field et al. 2009). For this reason, fishing for sharks both as a target species and as by-catch has severely reduced shark populations in many parts of the world's oceans (Baum et al. 2003; Field et al. 2009; Myers 2003; Myers et al. 2007), including tropical reef systems (Robbins 2006; Ward-Paige et al. 2010). This decline is likely to continue unless governments and local people can be convinced of the economic benefits of the non-destructive use of shark resources.

In the small island developing states of the Indo-Pacific, the major obstacles to altering the perceptions of sharks are both historical and cultural. Fishing has provided the economic basis of island societies for millennia and is still a central part of cultural and economic life in many regions (Johannes 1981). Fishing rights and grounds are often managed through complex traditional systems by social units such as clans or villages (Brunnschweiler 2009; Johannes 1981) and in many cases small-scale shark fishing is an important part of local culture. This stands in marked contrast to the industrial-scale fisheries that supply the demand for shark fin (Clarke et al. 2007).

However, this cultural heritage may predispose local people and governments towards the primary view of sharks as a fishery resource.

Palau is unusual among Indo-Pacific nations in its recognition of the importance of sharks as a tourism resource for the nation's economy. The coral reefs of Palau still host large populations of top-order predators and this factor distinguishes the Palauan diving experience from that available in many other places throughout the tropics where sharks have been severely reduced in numbers or eradicated by fishing (Baum et al. 2003; Myers 2003; Myers et al. 2007). Diving with reef sharks and manta rays are among the main attractions for tourists to the country (Anon. 2001). To protect this resource, the national government recently declared the waters around Palau as a shark sanctuary. This initiative prohibits the capture, sale or possession of shark and shark fishing gear by all foreign vessels within Palauan waters.

The recognition of the contribution of reef sharks to the economy represents an important achievement by the government and people of Palau as well as being of international significance. However, the scale of this contribution is still unknown, since there has never been a quantitative assessment of the value of sharks as a tourism resource to the Palauan economy. The aims of the study are to estimate the contribution of shark diving in Palau to (a) business revenues from sectors related to the tourism industry, (b) the income of fishers, (c) wages and salaries received by Palauan residents employed in the dive industry, and (d) government tax revenue, with items (b) and (c) subsets of (a). Business revenues from shark diving and fishers' income attributable to shark diving will be compared with estimated income from shark fishing for the same shark resources. Data were collected using a series of standard questionnaires distributed widely among divers and tourist operators. These were followed by interviews and other questionnaires with a wider range of stakeholders, including fishers and local people. The information was integrated into an economic model for the analysis.

4.3 Methods

4.3.1 Study area

The Republic of Palau is a complex of approximately 300 islands, spread over an Economic Exclusive Zone (EEZ) that covers 629,000 km^2 of the north Pacific (7°N Lat and 134°E Long). Palau has a population of approximately 20,000 with roughly two-thirds of the inhabitants living on the island of Koror (Figure 4.1). In 2008, the Gross Domestic Product (GDP) of Palau was estimated as US$218.4 million (Anon. 2010). Although subsistence agriculture and fishing are important economic activities, the local economy of Palau relies primarily on tourism, which attracts approximately 80,000 overseas visitors per year, generates more than US$1.5 million in taxes from hotels and restaurants annually, and is one of the main sectors of employment in the country (Anon. 2009; PVA 2010).

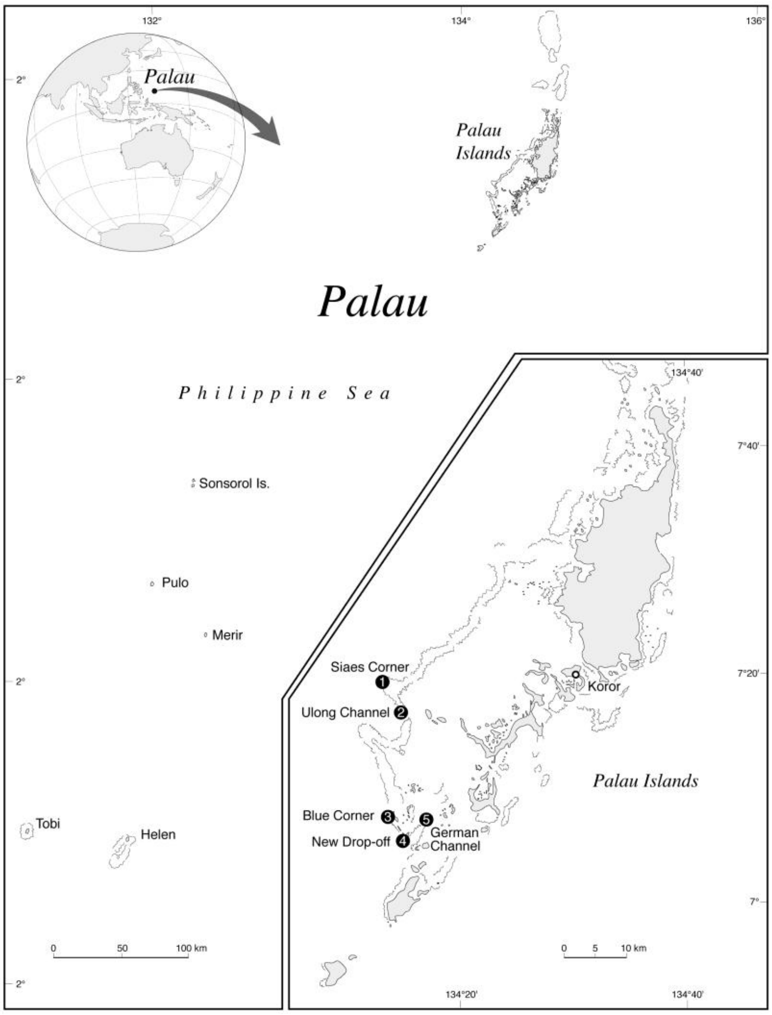

Figure 4.1 Republic of Palau. Numbers indicate the most popular shark-diving sites: 1) Siaes Corner; 2) Ulong Channel; 3) Blue Corner; 4) New Drop-off; 5) German Channel.

The marine environment is the main draw-card for tourists to Palau, particularly for diving and snorkelling (Anon. 2004). Palau is recognized as a world-class diving location and the abundance of large pelagic fish, most notably sharks, has established the country as a popular shark-diving destination (Carwardine and Watterson 2002).

Shark diving in Palau relies on dive sites that host aggregations of sharks that are predictable both in their numbers and timing of appearance. Such sites tend to be on the outer reef slope near drop-offs and are usually associated with strong tidal currents**.** Aggregations can be found at a number of dive sites, mainly on the slope of the barrier reef, on the southwest side of the lagoon (Figure 4.1). Typically, shark diving occurs during incoming tides, when the sharks are swimming off the slope of the reef and divers can position themselves at the edge of the drop-off using hook and line attachments of the diver to the reef. According to the dive guides, the number of sharks sighted by divers is related to the dive site and tidal movements. The length of time of the experience varies and is usually terminated by the divers due to no-decompression time limits. Although several species of sharks can be found in Palau, the shark-dive industry relies mainly on interactions with two species, the whitetip (*Triaenodon obesus*), and the grey reef shark (*Carcharhinus amblyrhynchos*), with the latter drawing most of the attention of the divers due to its size, abundance and behaviour. In 2010, there were 18 licensed dive tour operators who offered dive trips to popular shark-diving sites in Palau.

4.3.2 Survey

The socio-economic survey was based on four different questionnaires that collected information from people directly interested in, or affected by, the shark-diving industry in Palau. These stakeholders included tourists, dive operators, dive guides and local fishers (Table 4.1). This onsite survey was conducted in March (pilot) and May/June 2010 and provided a total of 297 completed questionnaires. Of this total, 246 respondents were divers (shark and non-shark divers), ten were dive operators, 20 were dive guides working within the industry and 21 were local fishers (Table 4.1).

A pilot study trailed the survey questionnaire for divers as well as providing a general profile of the tourists engaged in diving activities, including both shark and non-shark divers. This pilot was structured as a face-to-face interview conducted by a single interviewer with a target sample size of 30 dive tourists. Divers visiting Palau typically spend several days engaged in dive activities and interviews were done after at least a few days of diving so that tourists had sufficient experience and knowledge of the location and their expenditures. The pilot study provided the basis for the design of a self-administered questionnaire, structured to obtain information about the demographic characteristics of the divers visiting Palau, their motivations, satisfaction and expenditures. The self-administered questionnaire included questions about expenditure on accommodation, other activities (e.g., land tours) and living costs while in Palau. It also assessed the diver's knowledge of the shark sanctuary and its influence on their decision to visit Palau (Supplementary Table S4.1). Self-administered questionnaires and a printed explanation of the purpose of the research were available in both English and Japanese and were handed to the divers either at the end of the dive trips at the dive shops or at the airport prior to departure from Palau. For this reason, it was possible to sample divers (both shark and non-shark divers) engaged in dive activities with the main dive operators of Palau. The self-administered questionnaire was answered by 216 dive tourists in May and June 2010. Since this questionnaire required minimal changes from the questionnaire used during the pilot study, the information collected by both the pilot and the main questionnaire were pooled, yielding a sample size of 246 tourists.

Table 4.1 Structure, content and sample size of the questionnaires and interviews conducted for data collection of the economic value of sharks in Palau in 2010.

Respondent	***n***	**Date**	**Structure**	**Information collected**
Tourist (Pilot)	30	March 2010	Face-to-face questionnaire	Demographic characteristics; motivations to visit Palau; satisfaction and expenditures on: diving, shark diving, accommodation, other activities and living costs while in Palau; knowledge of the shark sanctuary and influence on decision to visit Palau.
Tourist (Main)	216	May/June 2010	Self-administrated questionnaire	Demographic characteristics; motivations to visit Palau; satisfaction and expenditures on: diving, shark diving, accommodation, other activities and living costs while in Palau; knowledge of the shark sanctuary and influence on decision to visit Palau.
Dive operator	10	May/June 2010	Face-to-face questionnaire	Number of tourists taking dive trips, tourist preferences, main dive attractions and activities, expenditures, expectations regarding the industry and effects of the creation of the shark sanctuary
Dive guide	20	May/June 2010	Face-to-face questionnaire	Popular dive sites for shark diving, number of divers visiting sites, average number of sharks per dive in each site, most common species of shark sighted during dives.
Fisher	21	May/June 2010	Face-to-face questionnaire	Fishing frequency, fishing techniques, income from fishing, level of interaction with sharks, perception of shark and conservation
Fish Market	1	July 2010	Interview	Number of fishers supplying fish, fishing frequency, profile of buyers, market volume and market prices

The dive operator questionnaire obtained information about the characteristics of the operator's business, including the number of tourists taking dive trips and their preferences, main dive attractions and activities, expenditures and expectations regarding the dive industry and effects of the creation of the shark sanctuary. This questionnaire was answered by 10 dive operators during face-to-face interviews. However, one incomplete form was discarded from the analysis. Operators interviewed by our study included those responsible for most of the dive tourism in Palau.

Twenty dive guides of eight nationalities working for nine dive operators were also interviewed. The dive-guide questionnaire was presented in a face-to-face interview that focused on obtaining information about the most popular dive sites for shark diving in Palau. It also aimed to provide an estimate of the number of divers visiting these sites throughout the year, average number of sharks in each site per dive and most common species of shark sighted during dives.

Since conservation regulations were likely to affect fishing activities, fishers were also surveyed in face-to-face interviews using a standard questionnaire. This provided information about their fishing activities, techniques, level of interaction with sharks, perception of shark conservation and income from fishing. The interviews were conducted in the main fish market in Koror. The owner of the fish market was also interviewed regarding the fishers' activities, market and market prices.

All interviews were conducted in accordance with the requirements of the National Statement on Ethical Conduct in Human Research (Australia) and the policies and procedures of The University of Western Australia. The survey was also supported by the Ministry of Natural Resources, Environment and Tourism of Palau.

4.3.3 Estimating business revenue

The study is based on the estimation of financial revenue within the shark-diving industry, and the magnitudes of key components of that revenue. We recognize that revenue does not equate to net economic benefits from the industry. For that we would need to estimate both the supply curve and the demand curve for shark-diving services, in order to calculate producer surplus and consumer surplus (Just et al., 2004). This is not attempted due to lack of market data that would be needed for statistical analysis of supply or demand. Nevertheless, revenue provides a useful indicator of the economic importance of the industry, and is consistent with common economic metrics such as Gross Domestic Product. The approach taken allows us to focus on economic benefits that are retained within Palau, whereas much of the producer and consumer surplus generated by the industry would be captured by foreign businesses and consumers. To further reduce the influence of leakage in between sectors of the economy, the analysis of the direct, indirect and induced benefits from shark diving was restricted to quantifying the revenues obtained by businesses directly benefiting from the presence of shark divers (i.e., dive and tour operators, hotels, restaurants and souvenir shops). The calculation of the economic benefits from shark diving to the local community were restricted to wages provided by the dive operators to their employees and the revenues obtained by the fishers from selling their catches to shark divers.

We took a conservative approach to all calculations. For example, a comprehensive estimate of the economic benefits from shark-diving would include the salaries generated by businesses such as hotels and restaurants that are attributable to the presence of shark divers. However, our analysis was conservative in that it included only the salaries directly generated by the shark-diving industry, i.e. dive operators.

This approach was adopted to avoid the risk of including benefits that are not actually attributable to shark diving. The focus was on economic activity within Palau and data were drawn from the survey and from official statistics from the government of Palau (available online). The proportion of all the divers surveyed that visited Palau mainly or specifically to engage in shark-diving activities (shark divers) was used to quantify the percentage of total revenues from all divers that was attributable to the presence of shark divers (shark-diving parameter or SDP). A detailed list of variables, parameters, formulas and data sources are presented in Tables 4.2 and 4.3.

Annual business revenue from sharks (*BRS*) in the shark-diving industry and associated businesses was estimated as

$$BRS = DET \times D \times SDP \tag{1}$$

where *DET* is average expenditure per dive tourist per trip (assumed to be the same for shark divers and other divers), *D* is the number of dive tourists per year (from official statistics) and *SDP* is the proportion of all divers who are shark divers (estimated from the surveys). *DET* consists of accommodation expenses, diving expenses and other expenditure such as souvenirs and land-based tours (from surveys), over the duration of the visit to Palau (Supplementary Table S4.2). Airfares to and from Palau were not included in the calculation of *BRS* since there is little or no in-flow from these expenditures to the local economy in Palau.

To put the shark-diving tourism industry in context, the annual total number of tourists visiting Palau was estimated based on the average number of tourist arrivals from 2007 to 2009 (PVA 2010) (Supplementary Table S4.3). This was used to estimate the annual business revenue from tourism as a whole (Table 4.3).

Table 4.2 Description of variables and constants used to calculate parameters and estimates of economic benefits related to the tourism and shark-diving industry in Palau.

Abbreviation	Constants and estimates	Description	Values	Units	Source	Comments
D	Number of divers per year	Sum of number of divers of each nationality	40 976	No./Year	PVA (2010); Anon. (2004), Anon. (2001)	Based on the percentage of tourist, of each nationally, who are visiting Palau to dive
FI	Fisher income	Average income from fishing x days fishing	23 800	USD/Year	Fisher questionnaire	Based on four days of fishing per week for a 50 weeks
ND	Number of non-diving tourists per year	T - D	38 798	No./Year	PVA (2010); Anon. (2004), Anon. (2001)	
NSDP	National shark diving parameter	(SDP x D)/T	0.11	-	Pilot and Tourist questionnaires; PVA (2010)	
SDP	Shark-diving parameter	Shark divers/D	0.21	-	Pilot and Tourist questionnaires	Shark diver is defined as a diver who visits Palau mainly or specifically to dive with sharks
T	Annual number of tourists	Average number of tourists visiting Palau from 2007 to 2009	79 774	No./Year	PVA (2010)	Based on mandatory visitors questionnaires when entering the country, PVA (2010)
TAX	Tourist taxes	Rock Islands Use permit + Green Tax + Departure Tax	60	USD/Trip		Rock Island permit: $25.00, Green tax: $15.00 and Departure tax: $20.00
TFP	Tourism fish market parameter	Percentage of fish sold to tourists x TP	0.44	-	Fish market representative interview	Based on sellings to hotels and restaurants
TP	Tourism parameter	T/(Local Population + T)	0.8	-	PVA (2010); Anon. (2010)	Indicates the percentage of sales that can be attributed to tourists instead of local consumers
W	Wages parameter	Percentage of revenues of dive industry addressed to pay wages	0.18	-	Operator questionnaire	
BT	Business revenue tax	Four percent of business revenues	0.04	-		
AT	Accommodation tax	BT + (Room tax/2)	0.09	-		Since 80% of the tourists interviewed during the survey reported to share the accommodation room with another person we divided the 10% "Room tax" by two to calculate the tax paid by each tourist
C	Diving costs parameter	Percentage of revenues of the dive industry used to pay costs of diving operation	0.54	-	Operator questionnaire	Represents the percentage of total revenues spent by dive operators on: fuel, maintenance, licenses, wages and extra costs of dive operation

Table 4.3 Description of formulas and sources of data used to calculate parameters and estimates of economic benefits related to the tourism and shark-diving industry in Palau in 2010

Abbreviation	Variables	Formula	Units	Source	Comments
Business revenues from tourism					
BRD	Business revenues from divers	D x DET	USD/Year		
BRND	Business revenues from non-divers	ND x NDE	USD/Year		
BRS	Business revenues from sharks	BRD x SDP	USD/Year		
BRT	Business revenues from tourism industry	BRD + BRND	USD/Year		
Economic benefits from shark diving					
DCIDI	Direct community income from dive industry	D x DED x W	USD/Year	Operators questionnaire	Represents the expenditure of dive industry on wages
DCISD	Direct community income from shark-diving	DCIDI x SDP	USD/Year	Operators questionnaire	Expenditure of the shark-diving industry on salaries
FISD	Indirect value of shark diving to fisher	FI x TFP x NSDP	USD/Year	Fisher questionnaire; Fish market interview	
CSDO	Cost of shark-diving operation	Diving expenses x D x C x SDP	USD/Year	Operators questionnaire	Represents the expenditure of shark-diving operations on: fuel, maintenance, licenses, wages and extra costs of dive operation
Tax revenues from shark diving					
DTSD	Direct taxes from shark divers	SDP x D x TAX	USD/Year		
BRTSD	Business revenue tax from shark diving	SDP x D x BT x Diving expenses + NSDP x T x AT x Accommodation expenses + NSDP x T x BT x Other expenses	USD/Year		BRTSD is the sum of revenue taxes from shark divers from diving, accommodation and other expenses
TTRSD	Total tax revenues from shark diving	DTSD + BRTSD	USD/Year		

Table 4.3 Cont.

Total revenues					
TRD	Total revenues from divers	D x TDET	USD/Year		
TRND	Total revenues from non-divers	ND x TNDE	USD/Year		
TRS	Total revenues from sharks	TRD x SDP	USD/Year		
TRT	Total revenues from tourism industry	TRD + TRND	USD/Year		
Expenditures					
DDE	Daily diver expenditure	DET/length of stay	USD/Day	Pilot and Tourist questionnaires	
DED	Diver expenditure on dives	Sum of diving expenses/ respondents	USD/Trip	Pilot and Tourist questionnaires	Average expenditure of a diver on dives per trip
DNDE	Daily non-diver expenditure	NDE/length of stay	USD/Day	Pilot and Tourist questionnaires	Average expenditure of a non-diver on dives per trip
NDE	Non-diver expenditure per trip	Accommodation expenses + Extra expenses + Tours	USD/Trip	Estimated based on Pilot and Tourist questionnaires	Assumes that expenditures on accommodation and extras by a non-diver tourist are similar to a diver's expenditure on these items. Tours refers to the sum of one land-based (US$100.00) and one marine day trip (US$100.00)
TNDE	Total non-diver expenditure per trip	NDE + TAX	USD/Trip		
DET	Diver expenditure per trip	Accommodation expenses + Diving expenses + Extra expenses	USD/Trip	Pilot and Tourist questionnaires	Average of the total expenditures in the specified categories by divers. "Extra" includes extras expenses during the trip not specified in the other categories (i.e. souvenirs, land-based tours, etc)
TDET	Total diver expenditure per trip	DET + TAX	USD/Trip		

4.3.4 Estimating fishers' income

A component of the business revenue from shark diving is received by fishers. Fishers make profits by selling their catch to the shark divers via a chain of commerce (i.e., fish market, hotels and restaurants). This represents a source of income that would not be available if the shark divers were not visiting Palau. Of interest is a comparison of this revenue and the revenue that fishers would generate by catching and selling the sharks that form the basis of the Palau shark-diving industry.

Fisher's income from shark diving (*FISD*) was calculated as follows:

$$FISD = FI \times TFP \times D \times SDP/T \qquad (2)$$

where *FI* is average annual fisher income in total (from fisher questionnaire), *TFP* is the tourism fish-market parameter (the proportion of fish sold to tourists, based on an interview with a fish-market representative to determine fish sales to hotels and restaurants, multiplied by *TP*, the proportion of hotels and restaurants revenue attributable to tourists), and *T* is the annual number of tourists visiting Palau (from official statistics, PVA, 2010), (Tables 4.2 and 4.3).

4.3.5 Estimating wages and salaries

Another component of business revenue from shark-diving is dispersed through the Palauan economy by payment of wages and salaries to employees of dive businesses. Direct community income from shark diving (*DCISD*) is calculated as follows:

$$DCISD = D \times SDP \times DED \times W \qquad (3)$$

where *DED* is diver expenditure on dives (from questionnaires) and *W* is the proportion of dive industry income that is allocated to paying wages and salaries (from operator questionnaire), (Tables 4.2 and 4.3).

4.3.6 Estimating tax revenue

All tourists in Palau (divers and non-divers) pay taxes, including at least a departure tax and a green tax. Popular tourist destinations, including Jellyfish Lake and most of the popular sites for shark diving, are situated within the Rock Islands Conservation Area. To visit these, tourists are also required to pay a Rock Islands use permit. For the purposes of our study these taxes were summed and treated as a single value (*TAX*) in calculations (Table 4.2). It is important to note that our calculations include the recently implemented green tax (US$15), mandatory for all the tourists departing from Palau since November 2009. *TAX* is not included within the business revenue (*BRS*) calculated above. Additionally, the Palauan government imposes a revenue tax of 4% on most of the expenditures made by shark divers (and all the tourists), including accommodation, restaurants and others (such as land tours and souvenirs). This component of tax revenue is included within BRS. Tax revenue from the shark-diving industry (*TTRSD*) is calculated as follows:

$$TTRSD = TAX \times D \times SDP + SDP \times D \times BT \times Diving\ expenses + NSDP \times T \times AT \times Accommodation\ expenses + NSDP \times T \times BT \times Other\ expenses \quad (4)$$

where *BT* is the business revenue tax (4%, see Table 4.2) , *NSDP* is the national shark-diving parameter (the proportion of shark divers out of all tourists) and *AT* is the accommodation tax (9%, see Table 4.2).

4.3.7 Estimating the operational cost of shark diving

A complete analysis of the costs involved in shark-diving tourism would need to include all sectors of the economy of Palau that provided services to shark divers. Such an analysis was beyond the scope of the present study. However, data from the interviews of the dive operators provided an estimate of general costs of fuel, equipment maintenance, governmental licenses, wages and extra costs involved in the dive operation in Palau. The operational cost of shark diving (CSDO) was then calculated as follows:

$$CSDO = \text{Diving expenses} \times D \times C \times SDP \quad (5)$$

where C was the percentage of the total revenues collected by the dive operators to cover the costs of fuel, maintenance, licenses, wages and extra costs (Table 4.2).

4.4 Results

4.4.1 Demographics and profile of respondents

Respondents to our survey originated from four principal regions. Europeans constituted the largest group and accounted for 36% of the total. Of this group, 9% of all tourists were from Germany and 6% from Britain. Slightly fewer divers of East Asian origin were interviewed (33% of respondents) with 23% of respondents originating from Japan. Divers from the Americas accounted for 21% of respondents, nearly all of whom (20%) originated from the USA. Australian divers accounted for 7% of respondents, and were the only country represented from Oceania. On average, respondents spent 5.6 days (95% confidence interval (CI) = 5.5-5.7) diving during their trip to Palau, with an average total trip duration of 8.1 days (95% CI = 7.9-8.3) (Supplementary Table S4.4).

Seventy-five percent of the divers said they were "interested" or "very interested" in shark ecotourism. Shark diving was indicated as the main or specific reason to visit Palau and was a principal attraction that determined the choice of holiday destination for 21% of the respondents. Approximately 71% of divers were unaware of the creation of the shark sanctuary prior to their trip. Of the 29% of divers who were aware of the sanctuary prior to their arrival, 42% reported that this was an important factor in their decision to choose Palau as a holiday destination.

4.4.2 Business revenue of tourism and shark diving

Of the 80,000 tourists who visit Palau every year, approximately 51% are divers (Anon. 2004). The business revenue generated by these divers (BRD) for Palau is US$82.8 million per year (95% CI= US$76.4-89.3 million), representing about 59% of the total revenue from tourism (Table 4.4). We estimate that the business revenue from non-diver tourists (BRND) is US$57.2 million (95% CI=US$52.4-62.0 million) (Table 4.4), which means the total business revenue of the tourism industry to Palau (BRT) was estimated to be US$140.0 million (95% CI=US$129.0-151.0 million) annually (Table 4.4).

Approximately 8,600 shark divers visit Palau each year. Based on these numbers, the total business revenue generated by shark diving (BRS) for the Palauan economy was estimated to be US$17.4 million per year (95% CI= US$16.0-18.7 million) (Table 4.4).

Fishers benefitted modestly from the shark-diving industry by supplying tourists with their catches via restaurants and hotels. This was estimated to provide an individual annual income (FISD) of approximately US$1,180 per fisher (95% CI= US$915-1,440) (Table 4.4), or approximately 5% of a fisher's total annual income (Tables 4.2, 4.3).

Table 4.4 Revenues from shark-diving industry and related sectors in Palau in 2010. CI (95%): 95% confidence interval.

Code	Variable	Mean (US$)	CI (95%) (US$)
Annual business revenues			
BRD	All divers	82.8 million	76.4-89.3 million
BRS	Shark divers	17.4 million	16.0-18.7 million
BRND	Non-divers	57.2 million	52.4-62.0 million
BRT	Tourism industry	140.0 million	129.0-151.0 million
DCISD	Direct community income	1.2 million	1.1-1.3 million
FISD	Individual fisher income	1 180	915-1 440
CSDO	Costs of shark diving	3.5 million	3.2-3.8 million
Annual tax revenues from shark diving			
DTSD	Direct taxes (TAX)	517 600	-
BRTSD	Business revenue taxes	962 000	887 000-1.0 million
TTRSD	Total	1.5 million	1.4-1.6 million
Total revenues			
TRD	All divers	85.3 million	78.8-94.7 million
TRS	Shark divers	18 million	16.6-19.3 million
TRND	Non-divers	59.5 million	54.7-64.3 million
TRT	Tourism industry	144.8 million	133.8-154.5 million

The payment of wages and salaries to people employed in the shark-diving industry (DCISD) was estimated to be US$1.2 million annually (95% CI=US$1.1-1.3 million) (Tables 4.3 and 4.4), while the total expenses of the dive operators for logistics, consumables and maintenance for shark-diving operations (CSDO) was estimated to be approximately US$3.5 million annually (95% CI = US$3.2-3.8 million) (Table 4.4).

The annual direct tax revenue from shark divers (*DTSD)* was estimated to be US$517,600 (Table 4.4). In combination with the business tax revenues generated by the shark-diving industry and sectors that support infrastructure and services to shark divers (such as hotels, restaurants and souvenir shops) the total tax revenues from shark diving (TTRSD) collected by the government was estimated as US$ 1.5 million per year (95% CI=US$1.4-1.6 million) (Tables 4.3 and 4.4). The combination of business revenue plus tax revenue not already counted within business revenue amounts to US$18 million per year for the industry as a whole (TRS).

4.5. Discussion

4.5.1 The economic value of shark-diving tourism

The small island developing states of the Indo-Pacific are characterized by a limited range of economic opportunities. However, their tropical locations, scenic beauty and diversity of marine life often make these places highly attractive holiday destinations for tourists. For this reason, tourism is a major source of revenue and increasingly occupies a central position in the economy of these countries (Anderson et al. 1999; Anon. 2003; McElroy 2003; Milne 1992). In the fiscal year of 2009/2010, the annual GDP of Palau was estimated to be US$218.4 million (Anon. 2010), with tourism representing the main source of income and accounting for US$124 million or 56% of the GDP (Anon. 2001, 2010). Our estimate of the total revenues of the tourism industry (US$144 million) (TRT, Table 4.4) was broadly in accordance with this figure, which provides a degree of confidence in our results. Our conservative estimate of revenue generated by the diving industry was US$85 million (TRD, Table 4.4), so that this sector accounted for a minimum of 39% of the GDP of Palau. Given that the opportunity to view sharks is the principal reason for visiting Palau for 21% of divers, the shark-diving industry accounts for at least 8% of the GDP of the country.

This result clearly shows the importance of shark diving to the economy of Palau. The implications of our work are not limited to Palau, as our estimates of the economic contribution of shark diving are comparable to those of studies from a range of other localities. In the Canary Islands, the shark and ray-diving industry was estimated to be worth US$22.8 million annually (cf. US$18 million for Palau). Palau hosts approximately half of the number of divers that visit the Canary Islands annually (De la Cruz Modino et al. 2010), implying that the total expenditure of divers in Palau is roughly twice that of visitors to the Canary Islands. Additionally, in 2009/2010 shark diving contributed significantly more to the GDP of Palau (8%) than the Canary Islands (0.11%) (De la Cruz Modino et al. 2010). These differences in relative importance reflect both a broader and more developed resource base in the economy of the Canary Islands than Palau and also the more sporadic nature of shark and ray encounters in the Canary Islands. This unpredictability limits the ability of operators to market their product and the prices that can be charged for their services (De la Cruz Modino et al. 2010). Divers with an advanced level of experience are often willing to pay more and go to specific destinations if they can be assured that the product they seek will be delivered (Dearden et al. 2006; Jones et al. 2009) and this may influence their choice of diving destination. Shark aggregations in Palau are highly predictable, so the dive operators can market and sell a product at a greater price with the expectation of reliable delivery to clients.

In the Maldives, a shark-diving industry based on interactions with grey reef sharks (*C. amblyrhynchos*) was estimated to complete 77,000 dives and yield approximately US$2.3 million annually in revenues in 1993 (Anderson and Ahmed 1993). The value of this industry was considerably lower than our estimate for Palau (Anderson and Ahmed 1993) and to some extent, this dissimilarity can probably be explained by the 17-year time lag between studies and substantial differences in methods. In the Maldives, estimates were based solely on the direct revenues from diving. Accommodation, restaurants and local businesses that also benefit from expenditures by divers were not considered. Even though earnings were likely underestimated, the shark-diving industry in the Maldives yielded twice as much as the export earnings of the three major shark fishing industries in the country for the same period (Anderson and Ahmed 1993).

The economic benefits of shark diving are not restricted to well-established tourist markets such as the Canary Islands and the Maldives. In 2009, a developing tiger shark-diving industry at Aliwal Shoal, South Africa, was estimated to have an annual value of approximately US$1.8 million. This industry delivers a specialized experience with reasonable predictability and a high rate of satisfaction (Dicken and Hosking 2009). In comparison to Palau, the total revenues were an order of magnitude less, which largely reflected the difference in the scale of shark-diving industries between the two locations; Palau hosted 8,600 divers and the Aliwal Shoals only 1,000 divers in 2009. However, when all shark-diving industries in South Africa are considered together, economic values are more comparable to Palau. Overall, South Africa hosts 12,500 tourists in activities that include cage diving with great white sharks (*Carcharodon carcharias*), snorkelling with whale sharks and diving with other sharks. These combined activities yielded a minimum of US$6.8 million yearly to the South African economy (Dicken and Hosking 2009; Gallagher and Hammerschlag 2011; Hara et al. 2003). Similarly, a shark diving industry in Moorea, French Polynesia, hosting 15,200 divers per year, was estimated to generated approximately US$5.4 million per year (Clua et al. 2011)

Over the past 20 years, a number of studies have assessed the economic value of sharks and rays as a tourism asset in many localities across the Indian Ocean (Anderson and Ahmed 1993; Catlin et al. 2010; Dicken and Hosking 2009; Hara et al. 2003; Rowat and Engelhardt 2007; WWF-Philippines 2006). As discussed previously, the age of these studies and the variety of economic models used to calculate values imply that caution is required when comparisons are made among studies. However, the outcomes of this work suggest that shark diving (including whale sharks) could be generating global revenues of more than US$40 million dollars annually. In reality this value is likely to be much greater, since the economic value of many industries such as Fiji, French Polynesia and Solomon Islands are yet been quantified (Brunnschweiler 2009; Clua et al. 2010; Gallagher and Hammerschlag 2011).

4.5.2 Comparison with value of shark fishing

From information provided by acoustic tracking studies, surveys of dive guides and community monitoring programs (>1,500 logs of shark sightings returned to researchers; Meekan et al., unpublished data) approximately 100 sharks were estimated to be interacting with the industry in the five most popular sites for shark diving. The consistency in the average numbers of sharks reported by dive guides for each dive site suggested that these estimates were reasonably accurate. An average estimate of 20 sharks per dive site (thus100 sharks in five dive sites) is also consistent with the abundance of reef sharks in aggregations in other localities such as the Maldives, Johnston Atoll and the Marshall Islands (Anderson and Ahmed 1993; Economakis and Lobel 1998; McKibben and Nelson 1986). Furthermore, reef sharks can display high levels of site fidelity (Garla et al. 2006; Papastamatiou et al. 2009; Speed et al. 2011). In Palau, our comprehensive and ongoing acoustic telemetry studies show that tagged sharks have been detected on a daily basis at the same site at which they were tagged for over 2 years (>1.5 million tag detections of 30 tagged sharks). Sharks transit between nearby sites 92-3 km) on occasion, but these movements are temporary and individuals tend to return to sites where they were originally tagged, where they spend up to 99% of their time. Thus, there is strong evidence that the average number of reef sharks at popular dive sites remains relatively constant through time.

Our data from community monitoring (Meekan et al., unpublished data), dive guide interviews (this study), tracking work (Vianna et al., unpublished data) and diving surveys of sharks throughout Palau (Meekan et al., unpublished data) show that the shark community in popular dive sites is dominated by grey reef sharks (approximately 80% of sightings by divers), with white tip sharks comprising most of the remainder of sightings. This pattern is consistent in both space and time. Using the estimate of annual business revenues of US$18 million, the present value of approximately 100 sharks interacting with the tourism industry in the five major Palauan dive sites over 16 years (a conservative estimate of life span of both grey and white tips; Smith et al., 1998) was approximately US$200 million (assuming real discount rate of 5%).

The significance of reef sharks in Palau and other tropical localities as a non-consumptive resource contrasts strongly with their value as a fishery. The price of a set of shark fins (first dorsal, both pectorals and lower caudal) varies according to the species and market fluctuations, and ranges from US$20 to US$90 (Clarke et al. 2008). While fins are valuable, the shark meat is considered to be of poor quality, with an average price per kilo ranging from US$2 to US$4.6 (Chen and Phipps 2002). A large grey reef shark, which is the biggest of the sharks regularly interacting with divers in Palau, weighs approximately 40kg (Wetherbee et al. 1997). Considering that the sharks interacting with the tourism industry tended to be adults (Meekan *et al*. unpublished data), the maximum total revenues that could be obtained from the targeting of these 100 animals by a fishery for the international market was approximately US$10,800. This represents 0.006% of the life time value of the same sharks used as a non-consumptive resource in Palau.

4.5.3 Socio-economic benefits from shark diving

The shark diving industry spent approximately US$1.2 million on wages and salaries to employees resident in Palau. These are a key benefit of the industry. The industry is labour-intensive, with relatively low guide-to-diver ratios and also requires employment of staff for maintenance, boat operation, catering and office work. Therefore, the shark-diving industry results in dispersion of revenues and makes a contribution to the economy by generating jobs and income to the community and taxes to the government (De la Cruz Modino et al. 2010; Milne 1992). A proportion of salaries paid to staff is used to purchase additional goods and services, which in turn have a multiplier effect, generating more jobs and further dispersing the revenues from shark diving (Lejárraga and Walkenhorst 2010; Milne 1992). Shark divers in Palau are also responsible for generating jobs in different sectors of the tourism industry such as hotels, restaurants and souvenir shops. Wages and salaries for these workers were not quantified by our study and thus it is likely we have underestimated the economic benefit to Palau of the shark-diving industry.

Taxes paid by shark divers in Palau generated an income of approximately US$1.5 million to the government. This accounts for approximately 14% of the tax revenue collected from the main industries by the Palauan Government in 2008 (Anon. 2009). Compared to other industries, the taxes paid by shark divers alone were the third highest contributor to the gross tax revenue in Palau and were roughly 24 times higher than the taxes collected from the fishing industry in 2008.

We estimated that the provision of fish to restaurants for consumption by shark divers gave an additional annual income of approximately US$1,200 per fisher. According to the management of the fish market, 55 fishers regularly sold their catches to supply both the tourism industry and the local population through the market. If these fishers were engaged in shark-fishing activities, the maximum revenues that they could obtain for the once-off capture and sale of the sharks interacting with the tourism industry would be around US$196, or only 16% of the annual income each one would have earned by keeping these sharks alive.

The economic benefit from shark diving to the economy of Palau can be divided into various components: direct (the amount spent by visitors on shark-diving activities), indirect (the amount spent by shark tourists on additional services and products), induced (the amount spent by shark-dive operators on inputs such as wages and fuel) and tax receipts. The magnitudes of indirect and induced benefits are dependent on the links between different sectors of the Palauan economy and the leakage of revenue offshore to foreign economies (Anon. 1996; Lejárraga and Walkenhorst 2010; Milne 1992). While our study quantified the major direct benefits generated by the presence of shark divers, estimates of indirect and induced benefits were restricted to the expenditures of the shark-diving operators on wages for the employees and the revenues obtained by fishers from the selling of fish to shark-diving tourists via the local fish market. These two groups were considered the most relevant Palauan stakeholders liable to benefit from the shark-diving industry. A full analysis of indirect and induced effects of the shark-diving industry was beyond the scope of this study, since it would have required quantification of benefits and wages generated through third parties not directly involved with shark diving (Lejárraga and Walkenhorst 2010; Milne 1992). Furthermore, secondary links are affected by leakage of capital to overseas markets (Lejárraga and Walkenhorst 2010; Meyer 2007), which are typically high in small island developing states due to the import of manufactured goods (Anon. 1996; Lejárraga and Walkenhorst 2010; Meyer 2007).

It is possible that the future establishment of shark sanctuaries in other countries would increase the supply of shark-diving opportunities, with negative effects on Palau. However, this impact is likely to be more than offset by increases in demand. There has been rapid growth in shark-diving (and other megafauna) tourism world-wide (Gallagher and Hammerschlag 2011) spurred on, in part, by increasing populations and material wealth throughout East and South East Asia. Furthermore, loss and damage to coral reef ecosystems is increasing (Bellwood et al. 2004) and is paralleled by a rapid decline in reef shark populations worldwide (Robbins et al. 2006; Ward-Paige et al. 2010). These declines in shark numbers are occurring even in coral reef systems that are intensively managed, such as the Great Barrier Reef (Robbins et al. 2006). Considering these trends and the results reported here, it is unlikely that shark fishing could be more profitable than shark diving under any realistic future scenario. Our study shows that fishers would make greater returns by supporting the shark-diving industry (e.g. by supplying fish to restaurants) than by competing for the same resource.

4.5.4 Possible negative impacts of shark diving

The effects of the presence of large numbers of tourists on the relatively small island nations may not always be positive (Anon. 1996; Ghina 2003; Scheyvens and Momsen 2008). Among the main problems, the infrastructure needed to support the tourism industry can impose increased pressures on limited natural resources (Anon. 1996). When poorly regulated, tourism based on the observation of marine megafauna can also cause disturbances to the animals, which can lead to negative behavioral and ecological consequences (Lusseau 2004; Williams et al. 2006). SCUBA diving can also have damaging effects on reef communities (Davis and Tisdell 1995; Hawkins et al. 1999; Poonian et al. 2010; Tratalos and Austin 2001).

Long-term interactions between sharks and divers have been suggested to interfere with the behavior and ecology of shark populations. A number of studies have suggested that shark provisioning has the potential to alter feeding habits, metabolic rates, relative abundance, residency and reproductive patterns of sharks (Brunnschweiler and Baensch 2011; Clua et al. 2010; Fitzpatrick et al. 2011). However, as yet there is little unequivocal evidence of such effects. The presence of divers in the absence of food stimulus has also been associated with short-term changes in the behavior of some sharks (Cubero-Pardo et al. 2011; Smith et al. 2010). The large numbers of sharks observed at dive sites and the high level of site fidelity demonstrated by our tracking data (Vianna et al., unpublished data) suggests that sharks are likely to be habituated to the presence of divers at popular dive sites in Palau. However, the possible impacts of diving on the behavior of reef sharks at these aggregation sites is still unclear and needs to be addressed.

Socio-cultural disturbances to resident populations due to tourism are often caused by local people lacking the necessary qualifications to supply the services required by the tourism industry. This can cause the local communities to receive limited access to the economic benefits of tourism (Anon. 1996; Valentine 1992). Palauans have an extensive knowledge of the marine environment and a tradition as seafarers and fishers as a central part of their culture that has developed over millennia (Johannes 1981). Thus, they provide a highly-skilled work force for the dive industry. Additionally, they provide part of the shore staff of the dive operators and related businesses, so that a significant part of the revenues gained from shark diving reaches local communities through the payment of wages and salaries. This in turn flows through to other parts of the Palauan economy.

4.5.5 Effects of shark fishing ban on the shark-diving industry

In 2009, Palau created a nation-wide shark sanctuary in the waters of their Exclusive Economic Zone. We found that only 29% of divers had knowledge about the creation of the sanctuary prior to their arrival in Palau (Supplementary Table S4.1), probably reflecting the recent nature of sanctuary legislation. However, it is important to note that a high percentage of divers (78%) stated that the sanctuary would have a reasonable degree of importance on a decision to re-visit Palau, suggesting that the creation of the sanctuary could play an important role in the selection of a destination by shark divers in the future.

4.5.6. Potential sources of error

Two potential sources of error in our estimates of economic values are identified: firstly, the degree to which our sample was representative, and secondly the accuracy of our estimates of the economic value derived from non-diving activities. The length of stay of tourists in Palau was correlated with nationality (Anon. 2001). Considerable effort was made in our study to obtain samples that included tourists of most nationalities involved with the shark-diving industry. However, the final sample included relatively low numbers of Taiwanese and Koreans, who tend to have shorter-than-average stays. This could have resulted in an over-estimation of the average length of stay, and thus an over-estimate of the economic value of tourists. However, this is unlikely to have had a large effect on our results, given that Government surveys showed that the total tourist expenditure per trip was similar irrespective of nationality (Anon. 2004).

In the case of Taiwanese divers, travel was organized by Taipei-based companies, so that a smaller proportion of revenues may remain in Palau, thus leading to an over-estimate of their value to the Palauan economy. Nevertheless, Taiwanese companies typically have a Palauan workforce as part of their staff, which reduces our potential for error.

Another possible cause of sample bias is that divers were surveyed only in March and May/June 2010. Any seasonal variations in the proportion of divers from different nationalities were not captured by our results.

The second possible area of error was the estimation of expenditures of non-diver tourists, to inform our estimate of the value of the tourism industry as a whole. Unlike the diver-related values, this was not based on a purpose-conducted survey, but rather on collation of secondary data from a range of sources, including expenditures on accommodation, food, souvenirs and non-diving tourist activities. Nevertheless, as noted earlier, an International Monetary Fund estimate of tourism incomes for Palau for 2009/2010 was US$124 million (Anon. 2010), broadly in accordance with our estimate (US$144 million).

4.6 Conclusion

Palau's success in harnessing sharks as a profitable, renewable and non-consumptive resource presents a model applicable to other diving destinations throughout the tropics. Shark diving provides an attractive economic alternative to shark fishing, with distribution of revenues benefiting different sectors of the economy including the tourism industry, government and the local community. A well-managed shark-diving industry promotes the ecologically and economically sustainable use of these animals and provides a robust and compelling argument for the conservation of shark populations.

4.7 References

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4.8 Supplementary Tables

Table S4.1 Total numbers of tourists and divers arriving in Palau by nationality from 2007 to 2009. Modified from www.visit-palau.com/publication/index.cfm.

Questions	***n***	**%**
Main reason to visit Palau (*n=228*)		
General Diving activities	134	59%
Mainly to dive with sharks	35	15%
Specifically to dive with sharks	13	6%
Dive activities and sight-seeing	30	13%
Snorkelling	8	4%
Other	8	4%
Knowledge about the sanctuary before the trip (*n= 244*)		
Yes	70	29%
No	160	66%
Unsure	14	6%
Influence of Sanctuary in decision to go to Palau (*n= 70*)		
Did not influence	28	40%
Influenced a bit	13	19%
50% of the reason	9	13%
Major influence	14	20%
Primary reason	6	9%
Importance of sanctuary on intention to return to Palau (*n= 210*)		
Not important	15	7%
Minor importance	31	15%
Quiet important	40	19%
Important	57	27%
Very important	67	32%
Interest in shark-diving (*n= 230*)		
Negative towards	0	0%
Not interested in	7	3%
A little interested	33	14%
Interested	80	35%
Very interested	93	40%
Do not know/not sure	17	7%

Table S4.2 Summary of responses to questionnaire about knowledge and relevance of the shark sanctuary in the decision to visit Palau by divers in 2010.

Code	Average tourist expenditure per trip	Mean (US$)	CI (95%) (US$)
-	Accommodation	588	529-647
DED	Diving	749	680-818
-	Extra	684	589-780
-	Tours (1 Land-based + Marine day trip)	200	-
DDE	Daily diver	285	263-307
DNDE	Daily non-diver	210	188-232
TDET	Total diver	2 081	1 924-2 239
TNDE	Total non-diver	1 534	1 410-1 657

Table S4.3 Breakdown of expenditures of divers while on holiday in Palau in 2010. CI (95%): 95% confidence interval.

Country	2007	2008	2009	Average Tourists	Estimate divers
Aust/NZ	733	711	700	714	714
Germany	476	621	629	575	575
Guam	1 848	2 258	3 374	2 493	1 246
Hong Kong	465	344	334	381	285
Italy	328	344	327	333	333
Japan	29 198	30 018	26 688	28 634	26 057
Korea	14 342	14 186	13 009	13 845	692
Micronesia	964	1 041	1 055	1 020	0
Philippines	1 719	949	998	1 222	0
China	464	439	534	479	0
Taiwan	29 005	19 981	16 278	21 754	4 786
Russia	302	637	295	411	411
Switzerland	140	187	225	184	184
UK	389	335	373	365	365
USA Mainland	5 956	5 235	5 193	5 461	3 822
Other Europe	882	1 027	1 074	994	994
Others	964	946	801	903	506
Total	**88 175**	**79 259**	**71 887**	**79 773**	**40 975**

Note: Modified from PVA (2010). Number of divers is based on estimate percentage of divers from each nationality. Source: Anon. (2004), PVA personal communication

Table S4.4 Comparison of results of four questionnaire-based studies of length of stay, number of days, diving and average expenditures per trip of tourists in Palau.

	Our study (2010)	**Comprehensive exit survey analysis report, (Anon. 2001)**	**Dive tourism in Palau: Resources use, value and management, (Anon. 2001)**	**Palau tourism economic valuation survey, (Anon. 2004)**
Tourist profile	Divers	General tourist	Divers	General tourist
Year	2010	2001	2001	2004
Average length of stay	8.1	7.1	6.9	5.1
Average tourist expenditure per trip (US$)	2 081	1 025	-	1 784*
Average days diving	5.6	-	5.1	-

* Average price of package tours including airfare

Chapter 5- The status of reef shark populations in the world's first shark sanctuary

Foreword

In recent years, the potential value of shark-diving tourism for conservation has become evident. However, this activity is often restricted to a few dive sites in areas of easy access, usually in the vicinities of centres of human activity. As a consequence, local conservation strategies that aim to protect shark-diving sites may provide localised protection, restricted to only part of the home range of individuals. Therefore, the assessment of shark populations in marine protected areas where shark-diving tourism occurs, such as the Palau Shark Sanctuary, need to take into account the spatial variation of anthropogenic pressure, and distribution of shark populations.

5.1 Abstract

Shark sanctuaries are promoted as a management tool to assist conservation following global declines of shark populations. However, a lack of baseline abundance data prevents the evaluation of the effectiveness of shark sanctuaries as a conservation strategy. Our study assessed the status of populations of reef sharks four years after the declaration of the world's first shark sanctuary in Palau. We used underwater surveys and stereo-photogrammetry to assess abundance and size structure of shark populations on the reefs over approximately 6 degrees of latitude. We documented very large differences in abundances of sharks across the sanctuary.

Highest densities of 10.9±4.7 SE sharks/ha occurred on reefs adjacent to islands where most of the human population of Palau resides. In contrast, a lower density of 1.6±0.8 SE sharks/ha was recorded on the mostly uninhabited reefs and atolls. There was a strong negative relationship between the density of sharks and derelict fishing gear entangled on the reefs. Our results also suggested that fishing was a major factor structuring both species composition and size of individuals, with significant reductions of mean total length associated with lower abundance. Our observations of recently derelict fishing gear indicate that the low densities of sharks may be a consequence of recent, and possibly ongoing, fishing. This implies that there is an urgent need for better regulation, enforcement and surveillance that targets both illegal and licensed commercial fisheries to provide effective protection for shark communities within the Palau Shark Sanctuary.

5.2 Introduction

The current exploitation rates of elasmobranchs by fishing exceed the rebound capacity of many populations (Worm et al. 2013), causing declines and ultimately increasing the extinction risk of a large number of species (Dulvy et al. 2014). For sharks, this pressure is driven by both targeted and by-catch fisheries often to supply demand for the shark-fin trade (Clarke et al. 2006). This industry has been the major factor responsible for the depletion of shark populations in virtually all marine environments of the world and poses a major threat to sharks living in continental shelf waters (Dulvy et al. 2014).

Shark populations inhabiting ecosystems of easy access are particularly vulnerable to exploitation (Dulvy et al. 2014). On corals reefs, a few studies have demonstrated that remoteness from centres of high human population density, can provide some degree of protection for reef sharks (Nadon et al. 2012; Richards et al. 2012; Ward-Paige et al. 2010b). However, long-distance commercial fleets can now reach virtually everywhere in the world (Swartz et al. 2010). In remote areas where protection and/or enforcement are deficient the high market value of some target species may provide an attractive economic justification for exploitation (Dulvy et al. 2003). Indeed, the documented declines in shark populations in many remote locations due to commercial fishing and poaching suggest that remoteness alone may not be sufficient to prevent exploitation, which highlights the need for active and effective conservation strategies (Friedlander et al. 2012; Luiz & Edwards 2011).

The growing recognition of the urgent need to conserve shark populations has led some nations to declare large areas of their Exclusive Economic Zones (EEZ) as "Shark Sanctuaries" (Chapman et al. 2013; Davidson 2012). Generally, these consist of large marine protected areas (MPAs) that assist conservation by prohibiting commercial fisheries from targeting or retaining sharks within large parts or even over the entire range of some populations. Shark sanctuaries can now be found in more than ten countries and territories, covering an area of more than 12 million square kilometres of ocean (PEW Charitable Trusts 2013). At the forefront of the implementation of sanctuaries are a number of small island nations in the Indo-Pacific region and more recently in the Caribbean. These nations are characterized by large EEZs relative to their land mass and economies that rely principally on the coastal and marine environment (Techera 2012). Traditionally, commercial and subsistence fisheries have been among the most important financial and cultural assets for these nations (Johannes 1981; Techera 2012), but within the last few decades, tourism has become an increasingly large contributor to their economies. In particular, tourism based on shark-diving is now a major industry throughout the Indo-Pacific and Caribbean regions (Clua et al. 2011; Gallagher & Hammerschlag 2011; Vianna et al. 2011; Vianna et al. 2012). Recognition of the economic value of sharks as a renewable resource (i.e., as a resource for tourism rather than a fishery) has coincided with growing scientific evidence of their role in maintaining ecological resilience and community structures of coral reef ecosystems (Ruppert et al. 2013; Baum & Worm 2009).

Typically, shark sanctuaries ban shark fishing, trade and exports of shark parts and products within the territory and EEZ. However, there is considerable variation in practices that are permitted within sanctuaries among countries (Davidson 2012; Techera 2012). In general, prohibitions target commercial fishing, with exceptions that allow for traditional practices of artisanal fishing. Moreover, shark sanctuaries laws tend not to regulate fisheries targeting other species of commercial importance such as tunas and reef fish. However, these fisheries may still impact populations through incidental catches and reduction of prey availability (Bromhead et al. 2012; Clarke 2013). This suggests that proximity of human populations may still have a direct effect on shark populations within sanctuaries, and shows the need for a better understanding of the impact of these fisheries.

The large scale of sanctuaries (thousands to millions of km^2) and the remoteness of islands and reefs within these areas can also present a major challenge for surveillance and enforcement and require a level of infrastructure (vessels, planes, etc.) that is often beyond the capacity of many of the small island nations where they have been established (Bergin 1988; Techera 2012). In areas where enforcement is deficient, remoteness from human populations may provide some degree of protection for sharks (Nadon et al. 2012; Ward-Paige et al. 2010b). However, modern fishing fleets can reach virtually any area of the ocean and illegal, unreported and unregulated fishing (IUU) is likely to be most intense in remote areas that lack the capacity to enforce protection (Agnew et al. 2009; Field et al. 2009).

These uncertainties have generated some debate regarding the effectiveness of large sanctuaries as a means to protect sharks (Chapman et al. 2013; Davidson 2012; Dulvy 2013; Rife et al. 2013). However, there is an almost complete lack of empirical data that might be used to evaluate the validity of such arguments. Sanctuaries have typically been created without any baseline surveys of shark populations, fish assemblages, or benthos. We thus lack the ability to directly assess recovery of populations that have been fished historically, or any concomitant changes in the resilience or structure of reef communities. Such data are essential to identify population and ecosystem responses, assess the scale of threats and design cost-effective surveillance and enforcement strategies.

In 2009, Palau declared the first national shark sanctuary, prohibiting commercial shark fishing within an area of 629 000 km^2. The sanctuary is situated in a region of intense commercial fishing, where tuna and sharks have been targeted by regional and international fleets (Bromhead et al. 2012). Further, Palau borders some of the leading shark fishing nations in the world, where shark populations have been severely depleted and IUU fishing is a major problem (Agnew et al. 2009; Green et al. 2003; Varkey et al. 2010). These factors suggest shark populations within the sanctuary in Palau may experience some level of illegal fishing pressure, particularly on isolated reefs where enforcement is costly and logistically challenging. Here, we used underwater video surveys to assess the status of the populations of reef sharks in Palau four years following the establishment of the shark sanctuary. Our main objectives were to 1) quantify differences in identity, density and total length of reef sharks in remote and populated areas across the sanctuary and; 2) identify environmental and anthropogenic variables that could potentially explain distribution patterns. This study provides the first broad-scale assessment of the status of reef shark populations following the establishment of a shark sanctuary.

5.3 Methods

5.3.1 Study area

Palau is an archipelago consisting of the Main Island Group, situated in the north, and the Southwest Islands, a collection of relatively isolated oceanic islands and atolls in the southern part of the country (Figure 5.1). The former is comprised of a complex of volcanic and limestone islands and a large shallow lagoon (~40 m deep) that is surrounded by a barrier reef extending for approximately 260 km (Colin 2009). The Southwest Islands are situated between 300 and 500 km from the Main Island Group and are composed of a true atoll (Helen's Reef) and five low coral islands (Merir, Pulo Anna, Tobi, Sonsorol and Fanna) that are surrounded by coral reefs with relatively narrow reef flats and steep slopes. Helen's Reef is the southernmost and most remote reef of Palau, situated approximately 500 km from the Main Island Group and 250 km northwest of Indonesia. Palau has a population of approximately 20 000 inhabitants, almost all of whom reside on the Main Island Group. Historic reports describe high human populations in the Southwest Islands in the early 1900s (Johannes 1981), however, the current population in this region is restricted to approximately 25 inhabitants, mainly situated at Tobi (SEDAC 2013) and five Palauan rangers who are permanently based on Helen's Reef.

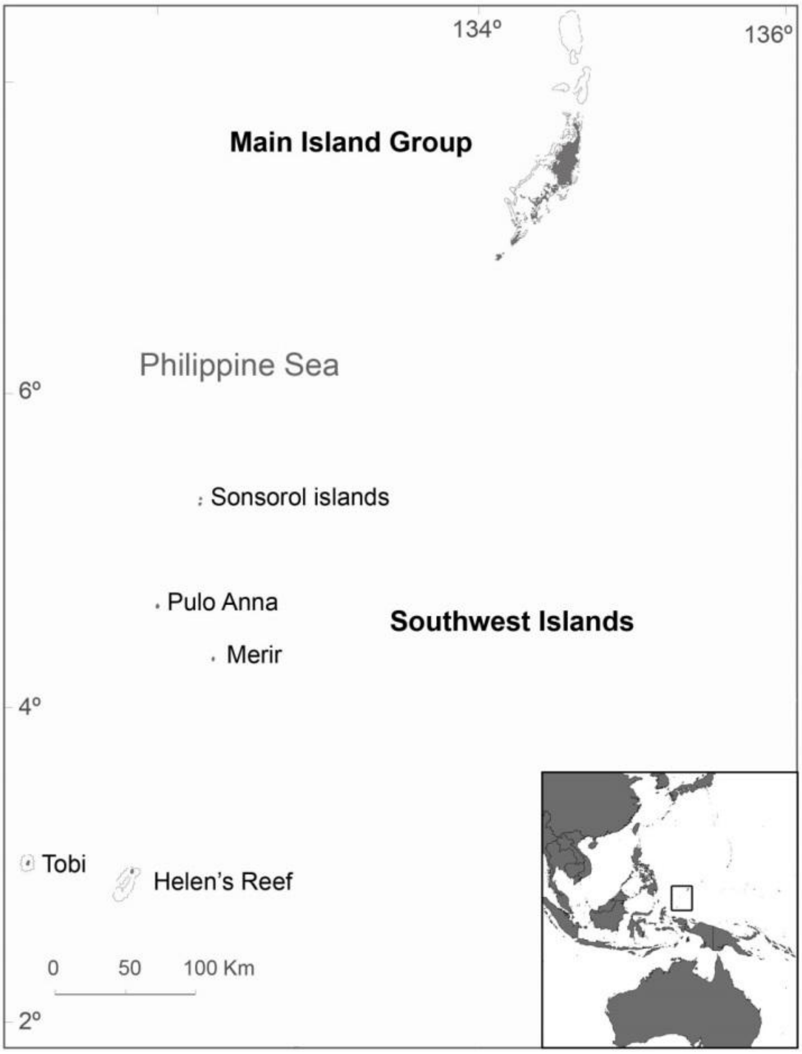

Figure 5.1 Reefs and islands of the Main Island Group and Southwest Islands in the Palau Shark Sanctuary.

5.3.2 Sampling methodology

We sampled 34 belt-transect (McCauley et al. 2012) dives on the coral reefs of islands and atolls located at the Main Island Group (n=16 dives) and Southwest Islands in June and October 2012. Sampling sites on the Main Island Group were distributed to cover the latitudinal range of the entire barrier reef. On the Southwest Islands, we conducted a total of 18 belt-transect dives on Helen's Reef, Tobi, Merir, Pulo Anna. All belt-transects were conducted on the fore reef at depths between nine and 15 meters. For each dive, the principle observer swam at a constant speed along the transect counting and filming sharks. A supporting team (2-3 divers) followed laying measuring tapes and informing the observer at the end of the transect (300 m). The support team also used the measuring tapes to make estimates of underwater horizontal visibility. Where strong currents prohibited the use of tapes (n=11 dives), we conducted 15 min timed-swim transects, which was the approximate time required to sample a belt-transect. The length of the timed-swim transect was then calculated from GPS points of marker buoys deployed at the beginning and end of each transect. We then estimated the area covered in each transect as the distance sampled multiplied by the horizontal visibility to each side of the transect. Density estimates of sharks were calculated as the abundance of each shark species divided by the area covered by each transect. Sampling was conducted by experienced observers who were familiar with the species present in the region.

We also used dive-operated video cameras to collect stereo-footage of sharks sighted during the belt-transects. We used this footage to extract measurements of fork length of individual sharks using the software EventMeasure (http://www.seagis.com.au). Consistent with other studies, fork lengths were then converted to total length using standardised FL:TL conversions (Froese & Pauly 2010). These estimates were used to calculate a mean total length of sharks for each reef. Because these size measurements were accurate (Harvey & Shortis 1995), we also used individual measurements to differentiate among multiple sharks sighted on the same transects and therefore reduce any bias associated with double counting.

We also conducted 212 manta-tow transects to quantify the amount of derelict fishing gear entangled on the reefs where belt transects were completed. These involved towing a snorkeler behind a small boat at constant speed (5 km/h) for five minutes. On each transect, the observer recorded the number of distinct items of fishing gear entangled on the reef at depths between five and 15 m. To avoid potential bias in the shark counts that could be related to the presence of the manta-tow boat, the tows and dives were conducted at different times at each site. We estimated the density of derelict fishing gear as the number of items recorded in each transect divided by the area covered.

5.3.3 Anthropogenic and environmental variables

To investigate potential anthropogenic stressors on populations of reef sharks, we calculated the total number of people living within a radius of 50 and 300 nautical miles (nm) of each sampling site. Calculations were based on estimates of number of persons per 2.5 arc-minute grid cells in 2000, extracted from the Gridded Population of the World Version 3 (SEDAC 2010).

We used remote sensing to generate data on indicators of primary productivity and sea surface temperature (SST). For each sampling site, we used the mean concentration of Chlorophyll-a within 4 km resolution cells and at a temporal resolution of 8 days from Aqua MODIS (NASA 2013). We also extracted SST values for each sampling site (0.011° cells), with resolution of 1 km sourced from Multi-Scale Seas Surface Temperature Maps (NOAA 2013) for the day of each dive.

Finally, to assess the potential influence of habitat on the density of sharks, we recorded percentage benthic cover within each transect in the categories of hard coral, soft coral, macroalgae, encrusting algae or bare reef and percentage of coral cover in one square metre quadrats at three equidistant points along each belt-transect, using still frames from the stereo-footage.

5.3.4 Data Analysis

We used permuted *t*-tests (*n*=9 999) to investigate differences in density of reef sharks in the Main Island Group and the Southwest Islands. We also used a permuted *t*-test to investigate differences in size structure (i.e., total length). Here, we only analysed data of grey reef sharks as the frequency of sightings of other species was too low to allow size comparisons. A permuted multivariate ANOVA (PERMANOVA) was used to test for differences in assemblage structure of sharks between the two regions, based on an Euclidean resemblance matrix with the Hellinger transformation (Legendre & Gallagher 2001).

We then used linear regression to model shark density as a function of the effects of environmental parameters and anthropogenic stressors among reefs. Reef sharks have home ranges on the order of tens of square kilometres (Speed et al. 2010), meaning that for many of the reefs sampled in our study, the range of individuals might cover the entire reef (Table S5.1). For this reason, the regressions were conducted at the level of reef rather than transect. This was also appropriate as variables such as human population were also estimated at the level of reef rather than transect. To this end, density estimates for each belt-transect on a given reef were treated as replicates to calculate a mean value of the density of sharks for each reef. As a result our sample size for the regression analysis constituted of five reefs, which restricted our models to the analysis of a single environmental or anthropogenic variable at a time. Shark densities were log-transformed to meet the assumptions of linear regression (Zar 1999).

Analyses used R statistical software (R Development Core Team 2010) and Primer 6; all summary metrics are reported as mean values and standard errors (±SE).

5.4 Results

Overall, we observed a mean density (±SE) of 6.0±2.4 sharks/ha (from 0.0 to 66.7 sharks/ha) across all sampled sites. However, there was a major difference in shark densities between the reefs of the Main Island Group and the Southwest Islands (p=0.02, F_{34}=2.46), with mean values of 10.9±4.7 and 1.6±0.8 sharks/ha observed in each region, respectively (Figure 5.2a). In the Southwest Islands, the reefs around Tobi had the highest density of reef sharks (mean 7.1±5.0 sharks/ha, Figure 5.2b), while no sharks were sighted on the reefs of Pulo Anna (Table S5.1).

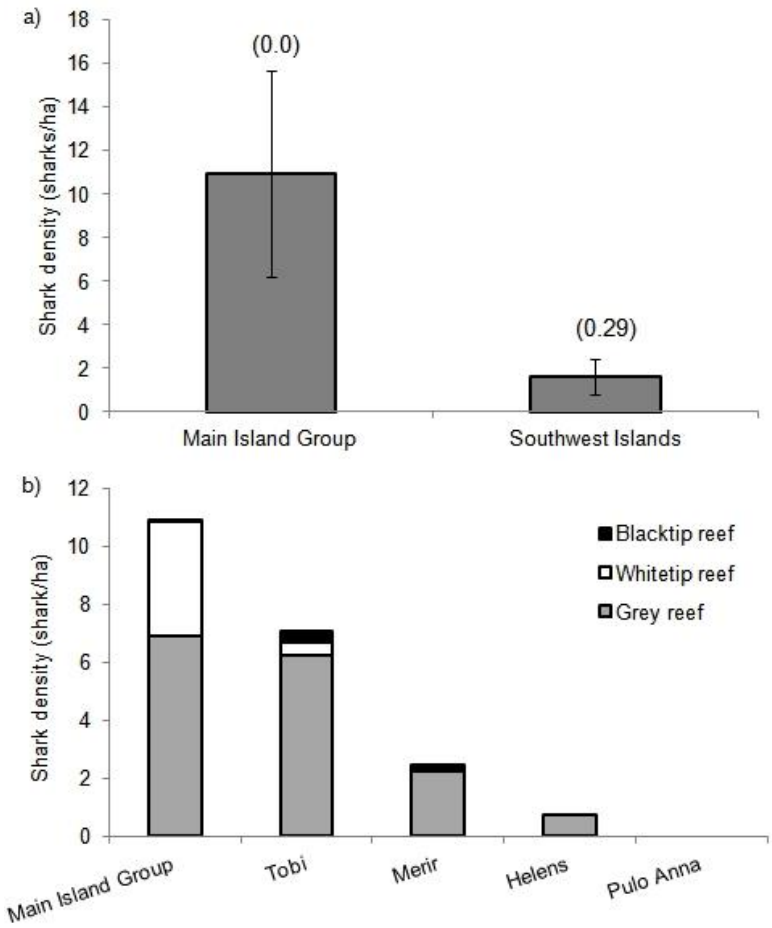

Figure 5.2 Density of reef sharks in Palau. a) Density of reef shark species combined by area; b) Density of each species of reef shark by reef. Values in brackets represent the mean density of derelict fishing gear sighted on each reef (items/ha). Error bars represent SE.

Shark assemblages differed significantly between regions (p=0.01, t_{34}=4.96). The grey reef shark (*Carcharhinus amblyrhynchos*) was the most common species recorded, representing 69% of overall sightings, and 63% and 92% of the sightings at the reefs of the Main Island Group and Southwest Islands, respectively (Figure 5.2b). Whitetip reef sharks (*Triaenodon obesus*) were also common, comprising 30% of overall sightings. This species occurred predominantly in the Main Island Group, with a single individual recorded in the Southwest Islands (Tobi). Blacktip reef sharks (*Carcharhinus melanopterus*) were also recorded, but represented only 2% of the individuals sighted.

We estimated the total lengths of 70 individual sharks using stereo-video measurements. Mean total length of all grey reef sharks (*n*=47) was 121±46 cm, however, individuals were significantly smaller (p=0.003, t_{47}=4.09) in the Southwest Islands (85±11 cm) when compared to sharks in the Main Island Group (124±5 cm, Figure 5.3). Size measurements of whitetip reef sharks (*n*=23) were obtained only from the Main Island Group, where mean total length of these sharks was 119±24 cm.

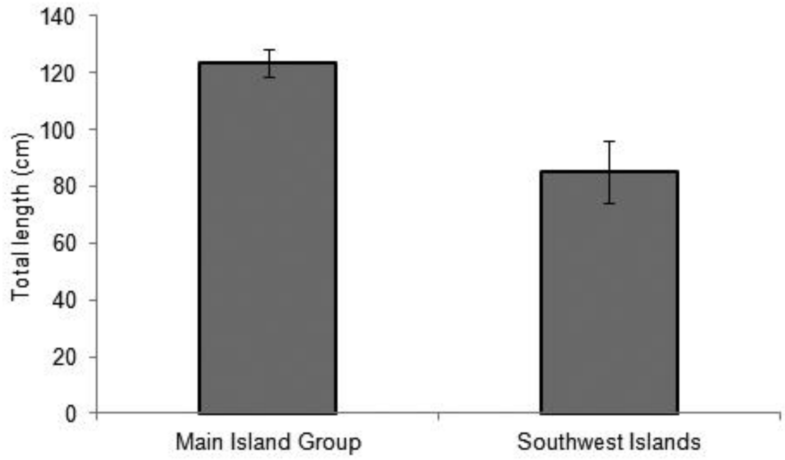

Figure 5.3 Total length of grey reef sharks measured through stereo-video photogrammetry during belt-transect dives at the Main Island Group (n=39) and Southwest Islands (n=8) of the Palau Shark Sanctuary. Error bars represent SE.

Linear regression revealed a strong and negative relationship between the density of reef sharks and sightings of derelict fishing gear on the reefs (p=0.01, R^2=0.96; Figure 5.4). Derelict fishing gear mainly consisted of fishing lines commonly used in commercial longlines (75% of sightings), but also included large multi-filament seine nets (15%), typically used by foreign fishing vessels in the Pacific (Donohue et al. 2001). Derelict gear was only observed in the Southwest Islands, with an overall mean of 0.3±0.06 items/ha and values of 1.0±0.5 and 0.3±0.1 items/ha on reefs at Pulo Anna and Helen's Reef, respectively (Table S5.1). These values were paralleled by low densities of sharks (Figures 5.2b and 5.4). No strong relationships were identified between shark densities and the remaining anthropogenic and environmental variables (Table S5.2).

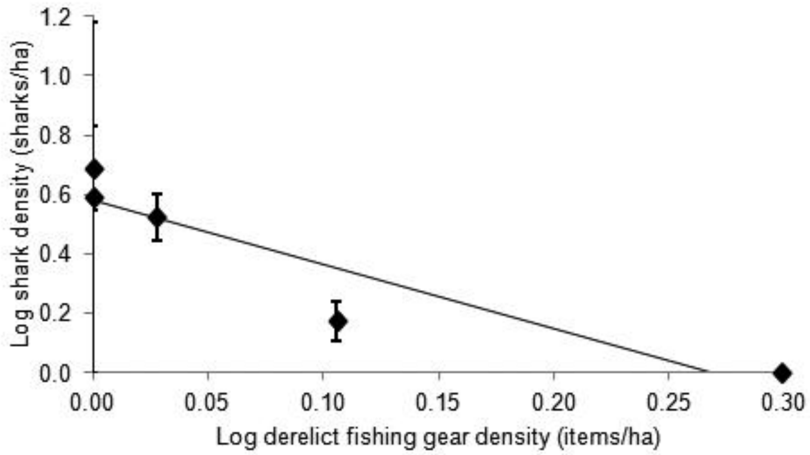

Figure 5.4 Linear regression showing the relationship between the log-transformed mean density of reef sharks (species combined) sighted during belt-transects and mean density of derelict fishing gear entangled on reefs (R^2=0.96; *p*=0.01). Error bars represent SE.

5.5 Discussion

Our surveys revealed a difference of an order of magnitude between the densities of sharks recorded on the reefs of the remote Southwest Islands and the Main Island Group of Palau. Individuals of the most abundant species in Palau, the grey reef shark, were also significantly smaller in the Southwest Islands. The lower numbers and smaller sizes of sharks on reefs in the Southwest Islands were associated with many sightings of derelict commercial fishing gear entangled on the reefs. As reductions in mean size and population density are acknowledged indicators of overfishing of sharks (Stevens et al. 2000), our results suggest that fishing has been and may continue to be a major factor shaping patterns in abundance, species composition and size structure of the populations of sharks across the Palau Shark Sanctuary.

Shark densities appeared to be unrelated to other environmental, anthropogenic or physical variables, including reef morphology (Table S5.2). Differences in habitat complexity are known to influence the abundance of sharks (Richards et al. 2012), however, on offshore isolated coral reefs, where variability of environmental factors is often lower than in other habitats, biological factors may better explain patterns of use of habitat (Heupel & Simpfendorfer 2014). However, in many places across the Pacific, anthropogenic pressures, such as fishing, represent the main factors shaping shark populations and largely override the effect of environmental and physical factors (DeMartini et al. 2008; Nadon et al. 2012; Richards et al. 2012). Moreover, although factors such as shark behaviour and survey biases may influence on the density estimates derived from belt-transect, the use of standardised methods produces comparable results to examine the relative spatial differences in density of reef sharks (Ward-Paige et al. 2010a).

We observed greater densities of sharks on reefs of the Main Island Group, adjacent to relatively large human populations. This finding contrasts with surveys in the Central and Western Pacific and Caribbean, where there are usually negative correlations between the density of reef sharks and the presence of humans (Nadon et al. 2012; Richards et al. 2012; Ward-Paige et al. 2010b). This may reflect differences in human behaviour, with large human populations in these regions engaged in shark fishing (Nadon et al. 2012). In Palau, fishing by the local population does not generally target sharks and the proximity of populated areas and presence of local boats and vessel traffic may in fact deter foreign vessels from the risk of fishing illegally. This might also explain the relatively high density of sharks observed at Tobi, the only one of the Southwest Islands that hosts a significant resident population of people.

As our work was the first baseline survey of shark abundance in the Palauan sanctuary, it was not possible to determine if our results are a function of a legacy of fishing that occurred before implementation of the sanctuary, or are part of an ongoing issue. Time since implementation (age) is a major determinant of the effectiveness of MPAs (Edgar et al. 2014). Given that many shark species have conservative life history traits (Dulvy et al. 2014), it is likely that the short period of time since implementation of the sanctuary (four years) may be insufficient to allow the recovery of shark populations and thus that the low densities in the remote areas do represent a legacy effect to some extent.

In our study we could not definitively quantify either the length of time the derelict fishing gear had been present on the reef or the effectiveness of these gear to catch sharks. However, sightings of derelict fishing gear mostly included items relatively free of encrustation and fouling organisms, suggesting that these gear losses were relatively recent, on the order of weeks to months (Matsuoka et al. 2005; Saldanha et al. 2003). Further, parts of longlines also represented a high proportion (approximately 75%) of the derelict gear sighted in our survey. Longline fishing is the main source of shark mortality in the Central and Western Pacific (Bromhead et al. 2012; Clarke 2013) and derelict longlines may also impact on reef shark populations. Derelict fishing gear can also continue “ghost fishing” on reefs where it has been discarded or lost, leading to prolonged impacts on the marine community (Matsuoka et al. 2005). Indeed, ghost fishing by derelict gear was confirmed by our observations of fish (including a juvenile grey reef shark) entangled in a discarded net on the reef at Pulo Anna (Figure S5.1).

Low densities of sharks may also reflect IUU fishing and the reefs of the Southwest Islands are a known target of this activity. IUU vessels targeting reef fishes and sharks are sighted frequently by local Palauan rangers based on Helen's Reef and it is likely that this type of fishing makes a significant contribution to low densities of sharks in the region. Palau relies on a single patrol vessel for enforcement of fishery regulations and apprehension of IUU fishers across an EEZ that covers 629 000 km^2. This very limited infrastructure places obvious restrictions on the ability of the nation to enforce regulations and apprehend illegal fishers. Collaboration with Regional Fisheries Management Organizations (RFMO; e.g., Western Central Pacific Fisheries Commission) may provide some assistance by aiding states to strengthen legal and administrative measurements that deter nationals from IUU fishing (Erceg 2006). However, such efforts are likely to have little effect on the fishing activities of foreign fleets not part of the local RFMO.

In Palau, the legal commercial tuna fishery is largely dominated by foreign longline vessels that are licensed under access agreements (Sisior 2006) and forbidden from targeting (through gear restrictions, such as a ban on wire leaders) and retaining sharks within the Palauan EEZ. Although these measures are likely to reduce shark catches to some extent (Ward et al. 2008), relatively high rates of fishing mortality (i.e., >20%; Bromhead et al. 2012) for sharks taken as by-catch are still likely to occur. Catches by commercial longlines do tend to be predominantly composed of oceanic species, but can also include reef sharks (Bromhead et al. 2012) as their movements are not restricted to reef-based activities (Heupel et al. 2010; McCauley et al. 2012; Mourier & Planes 2012). Thus, longlining in the commercial tuna fishery could also potentially explain some of the patterns in abundance of reef sharks we recorded, although this is difficult to verify because of the very low numbers of observers employed to monitor the commercial fishery in the region (<5%) (Clarke 2013).

Shark sanctuaries such as the one established by Palau typically include large areas of open ocean and thus might also be expected to protect oceanic sharks. We did not assess the status of these species since this was beyond the scope and capabilities of our study. However, since oceanic sharks represent a large component of the offshore commercial and IUU fisheries in the region (Bromhead et al. 2012; Clarke 2013), it seems probable that populations of oceanic species will show similar patterns of low abundance in the region of the Southwest Islands. More information on the population status, movement and impact of fishing mortality on oceanic sharks is necessary to evaluate the conservation outcomes of shark sanctuaries for this group.

Assuming that IUU fishing pressure has been removed from a sanctuary, the recovery of reef shark populations in isolated areas, such as the Southwest Islands in Palau, is likely to be slow (i.e., decades) as a consequence of the slow rebounding capacity of sharks (Smith et al. 1998). High residency levels are common to at least some segments of the reef shark populations (Espinoza et al. 2014). In Palau, residency combined with the relatively large distance between reefs of the Main Island Group and the Southwest Islands may represent physical constrains to re-colonization of depleted reefs. However, there is growing evidence that reef sharks may engage in large-scale movements crossing large extends of open ocean (tens to hundreds of km) between isolated reefs (Chapman et al. 2005; Heupel et al. 2010; Mourier & Planes 2012). These movements are likely to be a major dispersal mechanism and may assist re-colonization of isolated reefs and recovery of reef shark populations in very large MPAs.

In summary, our study provides an assessment of the distribution and abundance of reef sharks across Palauan waters four years after the establishment of the shark sanctuary. Contrasting with previous studies in the Pacific and Caribbean, the abundance of sharks in the remote, nearly uninhabited areas of Palau was significantly lower than in localities close to the main centers of human population. As no baseline data of abundance are available, we cannot determine unequivocally if these patterns were a legacy of earlier fishing pressure that has now ceased since the implementation of the sanctuary, or an ongoing phenomenon associated with by-catch mortality and illegal fishing. However, our observations of recently derelict fishing gear suggests that the latter is in fact the case, implying an urgent need for better enforcement and surveillance that targets both IUU and commercial fisheries in order for the sanctuary to have the desired conservation outcome for shark communities over the entire spatial extent of the MPA. The patterns we recorded in Palau are likely to be representative of other small island states that have declared shark sanctuaries in the Indo-Pacific. Indeed, issues involving IUU fishing, the enforcement of fishery regulations and the loss of shark resources may be even greater, given that Palau is relatively prosperous compared to many of its neighbours and it has a vibrant marine-tourism industry where shark diving returns large amounts of revenue to the nation (Vianna et al. 2012). This means that Palau has at least some capacity to patrol its waters and has a large vested interest in preserving shark populations as a non-consumptive resource. This is not necessarily the case in other island states, irrespective of the political intentions of the declaration of sanctuaries. Baseline surveys must be an essential part of the establishment of sanctuaries because without them, we lack any means to judge the effectiveness of sanctuaries as a management tool or to identify problems that could be hampering strategic goals. This point is relevant not just to shark sanctuaries, but to the ongoing investments in the establishment of large MPAs across the world's oceans.

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5.7 Supplementary Material

Table S5.1 Summary of reef metrics, environmental and anthropogenic features of reefs sampled in Palau. Standard errors are given in brackets

	Sampling				Reef Metrics		Environmental Factors					Anthropogenic Factors		
Reef	**No. dives**	**Total area sampled-belt transect (ha)**	**Total area sampled-manta tow (ha)**	**Shark density (sharks/ha)**	**Total area (ha)**	**Reef perimeter (km)**	**Reef morphology**	**SST mean±SE (°C)**	**Chl-a mean±SE (mg/m^3)**	**Predominant benthos**	**Coral cover mean±SE**	**Ghost fishing gear density (items/ha)**	**Human population within 50 nm**	**Human population within 200 nm**
Main Island Group	16	15.6	72.7	10.9±4.7	231,299	328	Barrier reef	28.9±0.18	0.15±0.03	Hard Coral	61±12.8	0	18,851	19,144
Helens	11	15.9	198.4	0.7±0.3	16,154	59	Barrier reef	29.6±0.02	0.33±0.09	Hard Coral	97±2.3	0.3±0.12	23	25,845
Merir	3	3.9	31.2	2.4±0.6	155	7.4	Fringing reef/slope	29.5±0.03	0.2±0.0	Algae	49±23.3	0.22±0.06	-	704
Pulo Anna	2	2.7	19.2	0.0±0.0	519	8.9	Fringing reef/slope	29.1±0.0	0.2±0.0	Hard Coral	98±2.5	0.99±0.51	-	783
Tobi	2	2.7	38.4	7.1±7.1	219	6	Fringing reef/slope	29.4±0.0	0.2±0.0	Hard Coral	95±5.0	0.05±0.05	23	72,041

Table S5.2 Summary output of linear regressions of log-transformed mean shark density at each reef as a function of anthropogenic and environmental variables

Variable	n	p-value	R2	SEE	Intercept	Se int	Slope	SE slope
Derelict fishing gear	5	0.01	0.96	2.3	1.88	0.1	-2.02	0.2
Human pop within 50 nm	5	0.35	0.13	0.2	1.38	0.1	0.10	0.1
Human pop within 300 nm	5	0.46	0.29	0.1	2.49	2.3	-0.29	0.3
SST	5	0.68	0.01	0.0	-11.95	26.6	0.42	0.9
Coral Cover	5	0.43	0.32	0.2	1.06	0.6	-0.01	0.0
Chlorophyll-a	5	0.48	0.26	0.3	1.25	0.9	-4.40	1.9
Reef area	5	0.42	0.14	0.3	1.25	0.3	-0.16	0.1

SEE= standard error of estimate for model (linear regression), SE int= standard error of the intercept, SE slope= standard error of the slope

Figure S5.1 Dead grey reef shark entangled in a derelict fishing net at Pulo Anna, evidencing the ghost fishing pressure on shark populations at the Palau Shark Sanctuary.

Chapter 6- General Discussion

In this thesis I used a multi-disciplinary approach, combining ecological and socio-economic data with citizen science, to present the first assessment of shark populations in Palau. My thesis described the distribution, spatial ecology and conservation of reef sharks in the context of the main anthropogenic drivers shaping the shark populations within the Palau Shark Sanctuary.

In Palau the interactions between the shark-diving industry and reef shark populations represent a major driver for conservation near centres of human population. These interactions are important socio-economically, as the high revenues generated by the industry have flow-on effects into the national economy and local community (Chapter 4). This industry also provides an operational platform for the collection of data to be used for monitoring trends in shark populations at relatively low cost and with little impact on the abundance or behaviour of shark populations (Chapters 2 and 3).

Contrastingly, evidence of fishing pressure at the remote and uninhabited reefs of Palau show that illegal unreported and unregulated (IUU) fishing continues to impact shark populations within the shark sanctuary. My results suggest that IUU fishing has contributed to major reductions of an order of magnitude in density of reef sharks within these remote areas when compared to reefs near centres of human population (Chapter 5). The depletion of reef sharks can reduce the resilience of coral reefs (Ruppert et al. 2013), jeopardizing regional biodiversity. Due to its illegal nature, IUU fishing also deprives the country of a non-consumptive economic resource that is potentially valuable but not currently explored (i.e., shark diving tourism at the Southwest Islands), with no economic return or compensation for the country.

The evidence of IUU fishing within the shark sanctuary highlights the need for a strategy of enforcement and surveillance that is effective in reducing fishing pressure to allow recovery of shark populations in Palau. Such a strategy needs to take into account the economic limitations of the country and should be based on cost-effective methods that target critical areas of the shark sanctuary.

6.1 Reef shark aggregations and spatial ecology

The analysis of the ecological datasets I collected in Palau suggests that regular and predictable aggregations of reef sharks in Palau occur mainly in the southwest barrier reef of the Main Island Group (Chapters 2, 3, 4 and 5). In this area, female grey reef sharks displayed high levels of residency at the monitored sites over multiple years (Chapter 2). Aggregative behaviour and high levels of residency are likely to increase the vulnerability of shark populations to fishing pressure. This could partially explain the absence of shark aggregations at the Southwest Islands, where indicators of intense fishing pressure were observed (Chapter 5).

Aggregative behaviour and high levels of residency have been demonstrated for many other species of reef sharks in coastal and oceanic environments (Barnett et al. 2012; Bond et al. 2012; Hussey et al. 2013; Speed et al. 2011). The drivers for such behaviour are not entirely known, however physical, environmental and oceanographic characteristics of sites are thought to influence physiological processes such as reproduction (Economakis and Lobel 1998; Speed et al. 2012). In Palau, the positive relationship between shark abundance and current strength (Chapters 2 and 3) suggests that use of aggregation sites may be associated with energetic budgets, where individuals would attend specific sites of strong current as a strategy to minimize the energetic demand of active swimming. This hypothesis requires further testing, but may provide a mechanism to explain the regular association of some species of sharks with areas of high water flow (Nelson and Johnson 1980) and therefore, explain the predominant occurrence of aggregations at the mouth of reef channels and promontories in the southwest area of the barrier reef.

The more than 100 studies that have described the patterns of attendance and horizontal movements of sharks over the last 50 years (Speed et al. 2010) contrast with an almost complete lack of information on vertical movements and vertical use of habitat by many common species, including reef sharks. In Palau, grey reef sharks displayed seasonal patterns of vertical use of the water column, which were correlated with monthly trends in water temperature (Chapter 2). On a shorter time scale, the vertical movements were correlated with the lunar cycle, most likely a consequence of cyclical variations of ambient light on the reef. Knowledge of the vertical movement of reef sharks is useful for the shark-diving industry as it may influence when animals would be more likely to be available for viewing by divers (Chapter 3). Vertical movements are also likely to affect the vulnerability of sharks to fishing pressure. In this context, my study may assist the design of fisheries regulations to aid the reduction of by-catch of reef sharks in Palau.

6.2 Shark-diving tourism: a role in conservation

Traditionally, arguments for shark conservation have largely been based on the ecological role of these animals as high or top-order predators, where they maintain the resilience of ecosystems, control the abundance of fast-growing species at lower trophic levels and influence the behaviour of prey (Heithaus et al. 2008; Ruppert et al. 2013). However, such arguments have failed to prevent overfishing of sharks (Dulvy et al. 2014; Worm et al. 2013). In recent years, there has been a growing recognition of the economic value of the shark-diving industry as another compelling argument for shark conservation (Chapter 4). In addition, the industry can also provide data for management and conservation strategies (Chapter 3).

The increasing interest of tourists in shark diving has resulted in the rapid growth of the industry into a multi-million dollar business worldwide (Cisneros-Montemayor et al. 2013; Gallagher and Hammerschlag 2011). Shark diving has been portrayed as a profitable and sustainable alternative to fishing (Cisneros-Montemayor et al. 2013) and in Palau, the industry constitutes a significant component of the economy, generating approximately US$18 million annually. These revenues permeate through the national economy, generating jobs and accounting for more than 8% of the GDP of the country (Chapter 4). Similarly, valuation assessments of shark diving in other tourism destinations (i.e., Fiji and Borneo; Appendixes II and III) show that the socio-economic benefits from the shark-diving industry observed in Palau are comparable to other localities, and are likely to be similar throughout the Indo-Pacific. The economic value of the industry across a broad scale (e.g., the Western Pacific) provides a compelling argument for shark conservation in countries that rely on marine tourism (diving tourism in particular), and is being used increasingly as a major tool in the portfolio of strategies of conservation agencies to lobby for the establishment of large-scale shark sanctuaries covering entire exclusive economic zones (EEZ) of countries around the world (Dulvy 2013; PEW Charitable Trusts 2013).

In many locations, the shark-diving industry has provided relatively qualified and experienced divers to collect data that can assist in the assessment and long-term monitoring of shark populations (Huveneers et al. 2009; Meekan et al. 2006; Ward-Paige et al. 2010). In the shark sanctuaries of the Indo-Pacific and Caribbean, where limited financial resources may be available, citizen science may be used in combination with traditional methods, reducing costs of monitoring programs, while collecting longitudinal datasets that may assist identification of trends in abundance of reef sharks (Chapter 3). This information may also be used to evaluate the effectiveness of management strategies and to assess the impacts of fisheries and tourism on shark populations.

The ecological impacts of shark-diving operations on shark populations are still poorly understood. Negative effects of tourism on wildlife may include animal habituation and behavioural changes, physical damage to the reef and modification of habitat (Corcoran et al. 2013; Davis and Tisdell 1995; Green and Giese 2004). Additionally, sociological impacts associated with tourism activities such as exclusion of local communities due to increases in prices (Valentine 1992) and revenue leakage from the tourism destination (Lejárraga and Walkenhorst 2010) have also been reported. The impacts associated with the shark-diving industry are likely to vary among locations and need to be investigated so that the cost and benefits of the industry can be assessed and appropriate mechanisms for prevention and mitigation can be incorporated in management strategies.

6.3 Effectiveness of the shark sanctuary

Palau is considered a prime location for shark diving within the international diving community (Carwardine and Watterson 2002). This reputation is largely a consequence of the high density of sharks at aggregation sites, the most popular dive sites in the country (Chapters 3, 4 and 5). Since 2009, Palau has also been promoted globally as an icon of shark conservation, mainly because of the implementation by the Palauan Government of the world's first shark sanctuary. My analysis of the status of the reef shark populations (Chapter 5) combined with the analysis of patterns of attendance of sharks at dive sites (Chapters 2 and 3), indicates a large variation of shark density across the country. This variation appears to be partially a consequence of a gradient of anthropogenic pressure (Chapter 5). High densities of sharks were restricted to some sites near relatively populated areas, while low densities of sharks were observed at the remote, uninhabited reefs, with the overall pattern strongly correlated with indicators of fishing (Chapters 3, 4 and 5).

While it was not possible to verify the legal status of the fishing activities occurring at the Southwest Islands, my analysis indicates that they were most likely to be illegal and were probably occurring due to the limited enforcement capacity of the Palauan Government in these remote areas, a task that is further complicated by the large size of the sanctuary (Pala 2013; PEW Charitable Trusts 2013; Rife et al. 2013). It is also possible that the fishing pressure on shark populations was partially a result of by-catch in legal commercial fisheries (e.g., tuna longline fishery). Sharks can be a large component of the catches of some commercial fisheries (Bromhead et al. 2012; Clarke et al. 2013) and fishing mortality associated with by-catch is a major cause of the depletion of shark populations (Dulvy et al. 2014; Mandelman et al. 2008; Stevens et al. 2000). This suggests that while the legislation in Palau sets the legal framework for conservation, it provides limited protection as illegal fishing and/or post-release mortality from legal fisheries are likely to be shaping the demographics of shark populations in areas away from those used by the diving industry.

A possible caveat of this conclusion is the temporal scale of my study. Age is an important factor in determining the success of MPAs (Edgar et al. 2014). My analysis of the status of shark populations occurred approximately four years after the implementation of the Palauan MPA. This period may have been insufficient for reef shark populations to recover from earlier fishing pressure (Smith et al. 1998) and is only approximately half of the time thought to be necessary for MPAs to achieve high conservation outcomes (Edgar et al. 2014). However, the strong and negative relationship between the densities of reef sharks and derelict fishing gear across the reefs and the anecdotal evidences of ongoing IUU fishing suggest that the harvest of sharks still remains a major factor limiting the effectiveness of the sanctuary.

Overfishing has caused severe depletions of sharks globally and there is an urgent need for management and conservation strategies that are effective in promoting recovery of and protection for remaining populations (Dulvy et al. 2014; Worm et al. 2013). Previous studies have shown that no-take MPAs may provide effective protection for sharks (Bond et al. 2012; Da Silva et al. 2013; Heupel et al. 2009; Knip et al. 2012; Robbins et al. 2006). However, the effectiveness of MPAs in protecting shark populations is largely dependent on a combination of features including the degree of fishing, level of enforcement, isolation of habitats, age, and size of reserve (Edgar et al. 2014). For this reason, only a very limited number of MPAs around the world may combine the necessary features that can maximise conservation of shark populations. My research shows that the spatial variation in conservation effectiveness of the shark sanctuary is most likely a consequence of deficient enforcement and legal loopholes, allowing uncontrolled catches of sharks despite the fact that the other physical requirements necessary for optimal efficiency of reserves (i.e., isolation of habitats and area larger than 100 km^2, Edgar et al. 2014) are intrinsic features of the sanctuary in Palau. But in order to become more effective, the sanctuary requires the implementation of efficient enforcement strategies and measures to prevent fishing mortality.

6.4 Future research

The rapid growth of the shark diving globally indicates that there is an increase of the socio-economic importance of this industry. This phenomenon may lead to market shifts, potentially influencing many economic sectors related tourism (e.g., assessor services) and therefore permeating in the national economy. Further analysis of longitudinal socio-economic data is necessary to assess the long-term effects of this industry on national economies and potential shifts of the socio-economic importance of shark-diving over time.

Baseline information and longitudinal datasets are essential for the assessment of sanctuary effectiveness over time. Long-term (years) and broad-scale (numerous island groups, 100s-1000s km) monitoring programs designed to assess the status of shark populations prior to and following protection should be an integral part of the management of shark sanctuaries.

Reef sharks are an important component of the fauna of elasmobranchs in tropical waters, but constitute only a fraction of the shark assemblage inhabiting the territorial waters of Palau. Future research is necessary to assess the distribution, abundance and status of the populations of other guilds of sharks, including large coastal and oceanic species. This research is particularly important as these species undergo large migrations (100-1000s of km) and may cross the jurisdictional borders of the sanctuaries (Block et al. 2011; Howey-Jordan et al. 2013; Werry et al. 2014). In particular, oceanic sharks are vulnerable as by-catch in the international fishing fleet operating longlines in the region (Bromhead et al. 2012; Clarke 2013), and may in fact be the guild of sharks that experiences the most severe impact from commercial fishing in Palau. Conservation of large sharks presents major challenges (Dulvy et al. 2014; Heupel et al. 2014) that could be partially addressed by large-scale shark sanctuaries. As such, special attention should be taken to assess fishing mortality and the status of populations of oceanic sharks within the sanctuary. While the sampling methods used in this thesis were effective in assessing populations of reef sharks, the assessment of large, wide-ranging species presents some major logistic challenges (Pala 2013). A combination of a fishery observer program (Clarke 2013) and fishery-independent surveys (Letessier et al. 2013) may constitute a suitable strategy to assess the status of these populations. Consideration must also be given to closing pelagic fisheries with high rates of by-catch.

The removal of sharks from coral reefs ecosystems may result in ecological impacts and flow-on effects that are complex and poorly understood (Ruppert et al. 2013). The gradient of anthropogenic impact on shark populations on the reefs in Palau offers an opportunity to investigate the resilience and recovery rates of coral reef systems and reef community following the removal of high order predators under different scenarios of disturbance.

An increasing body of research indicates that site fidelity and residency are common features among reef sharks (Barnett et al. 2012; Papastamatiou et al. 2009; Speed et al. 2011). Empirical evidence shows that these sharks may also perform large-scale directional movements crossing tens to hundreds of kilometres of open water (Heupel et al. 2010; Mourier and Planes 2012), however, the frequency of movements between distant reefs and the implications of these for the recolonization and recovery of shark populations in remote areas is unknown. Large-scale movements may represent a fundamental mechanism in the recovery of reef shark populations affected by shark fishing (Chin et al. 2013a). Investigating the genetic connectivity between populations of reef sharks of the Main Island Group and the remote Southwest Islands may provide clues of the frequency of such movements, which could assist the understanding of the recovery capacity of reef shark populations in remote reefs.

My surveys of sharks were limited to those species found on shallow coral reefs. Sexual and ontogenetic segregation is common in shark populations (Speed et al. 2010) including reef sharks (Barnett et al. 2012; Chin et al. 2013b; Speed et al. 2011). Segregation of parts of populations of reef sharks might be related to several factors including reduction of predation risk (Speed et al. 2011), reproductive strategies (Economakis and Lobel 1998; Speed et al. 2012) and differing physiological tolerances (Morrissey and Gruber 1993). The sexual segregation of grey reef sharks in Palau resulted in only females (and one juvenile male) being tagged in my study. Future research is needed to describe the distribution and abundance of other segments (i.e., males) and life history stages (i.e., juveniles) of reef shark populations in Palau across depths and habitats. Also identification of potentially critical habitats for populations, such as nurseries, is also essential to ensure that all life history stages are adequately protected.

The large scale of shark sanctuaries combined with the limited capacity of small island nations to enforce and manage these MPAs demonstrates the need for further research to evaluate the total costs involved with implementation, management and enforcement of sanctuaries. My research may assist determination of the most effective and economically viable models of management of shark sanctuaries under different scenarios of surveillance and enforcement, providing realistic expectations of the potential conservation and economic outcomes from the creation of these MPAs.

6.6 References- General Introduction and Discussion

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Appendices

I-Vianna G.M.S., Meekan M.G., Pannell D.J., Marsh S, Meeuwig J.J. (2010). WANTED DEAD OR ALIVE? The relative value of reef sharks as a fishery and an ecotourism asset in Palau, Australian Institute of Marine Science and University of Western Australia, Perth, pp 34.

II-Vianna G.M.S., Meeuwig J.J., Pannell D.J. , Sykes H, Meekan M.G. (2011). The socio-economic value of the shark-diving industry in Fiji. Perth, Australian Institute of Marine Science. University of Western Australia, Perth, pp 26.

III-Vianna G.M.S., Meekan M.G. (2012). The economics of shark diving in the Semporna region, Malaysia. Perth, Australian Institute of Marine Science. University of Western Australia, Perth, pp 12.

IV-Questionnaire designed to collect socio-economic data from tourist divers for valuation of shark diving industry in Palau.

WANTED DEAD OR ALIVE?
The relative value of reef sharks as a fishery and an ecotourism asset in Palau

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Photo cover: The grey reef shark (*Carcharhinus amblyrhynchos*) is the most abundant species sighted during shark dives in Palau. Photo by: Carlos Villoch contributed by Micronesian Shark Foundation.

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Executive Summary

- Arguments for conservation of sharks based on their role in the maintenance of healthy marine ecosystems have failed to halt a worldwide decline in populations of these top-order predators.

- This decline is driven by the economic value of sharks as a fishery and the growing market for shark fin products.

- An alternative approach for conservation stresses the economic value of sharks as a focus of dive tourism. In this context, sharks may have a greater value as a non-harvested resource than as a fishery.

- Our study quantified the economic benefits of the shark-diving industry to the community and Government of Palau.

- A series of questionnaires were used to survey the demographics, income and expenditure of divers visiting Palau, the markets, income and expenditures of dive tour operators and the income and interactions with shark fishers.

- The results of these questionnaires and recent statistics of tourism and revenues published by the Government of Palau were used to calculate the contribution of shark diving.

- The shark-diving industry attracts 8,600 divers each year or approximately 21% of the divers visiting Palau.

- The value of sharks to the Palauan economy was estimated to be US$18 million per year, accounting for approximately 8% of the gross domestic product of Palau.

- An individual reef shark in Palau was estimated to have an annual value of US$179,000 and a life-time value of US$1.9 million to the tourism industry.

- The annual income in salaries paid by the shark-diving industry to the local community was estimated to be US$1.2 million.

- The annual tax income to the Government of Palau generated by shark diving was estimated to be US$1.5 million or 14% of the business tax revenue.

- A fishery targeting the same 100 sharks that are interacting with the tourism industry in Palau would obtain a maximum of US$10,800, or 0.00006% of the life-time value of these animals as a non-consumptive resource.

- The tax revenues collected from shark diving were roughly 24 times higher than those from the fishing industry.
- The creation of the shark sanctuary could play an important role on the selection of Palau as a diving destination by tourists.

Background

Over the last 20 years, ecotourism to view and interact with marine megafauna has become increasingly popular (Higham and Lück 2008). Examples of this type of tourism include turtle and whale watching, snorkelling with seals and shark diving (Jacobson and Robles 1992; Anderson and Ahmed 1993; Orams 2002; Kirkwood *et al.* 2003; Dearden *et al.* 2008; Dicken and Hosking 2009). The occurrence of many aggregations of megafauna along the coasts of regional areas remote from centres of population means that such tourism also provides significant flow-on effects and diversification to local economies where few alternative sources of income exist (Milne 1990; Garrod and Wilson 2004). Importantly, the development of a well-managed ecotourism industry based on megafauna provides the opportunity for local people to utilise natural resources in a sustainable manner over the long-term (Mau 2008).

The economic value of tourism based on marine megafauna is enormous. In 2008, a study of whale watching estimated that this form of tourism was available in 119 countries, involved approximately 13 million participants and generated an income to operators and supporting businesses (hotels, restaurants and souvenirs) of over US$2.1 billion (O'Connor *et al.* 2009). This industry is estimated to have the potential to generate annual revenues of over US$2.5 billion (Cisneros-Montemayor *et al.* 2010). The development of whale watching has been paralleled by growth in tourism based on other types of marine megafauna. In particular, tourism to observe sharks and rays has become increasingly common. At the forefront of this relatively new market are industries that focus on whale sharks (*Rhincodon typus*) with estimates calculated in 2004 suggesting that these generated more than US$47.5 million worldwide, providing important revenues to developing countries such as Ecuador, Thailand and Mozambique (Graham 2004).

Diving with other species of sharks has followed a similar trend of growing popularity. In 2005, it was estimated that approximately 500,000 divers were engaged in shark-diving activities worldwide (Topelko and Dearden 2005). An increasing range of opportunities for this type of tourism are available, including cage diving, shark feeding and drift diving with reef and oceanic sharks. Shark-diving tourism can be found in more than 40 countries (Carwardine and Watterson 2002), with new destinations and target species being established rapidly, due to the increasing recognition of the economic potential of this activity (Dicken and Hosking 2009; De la Cruz Modino *et al.* 2010).

While there are no estimates of the total revenue of the shark-diving industry worldwide, this form of tourism has been shown to be of great economic value in many locations. In the province of Gansbaai, South Africa, cage diving with great white sharks (*Carcharodon carcharias*) generated US$4.1 million and hosted almost 30,000 divers in 2003 (Hara *et al.* 2003). On the east coast of South Africa, diving with tiger sharks (*Galeocerdo cuvier*) was estimated to generate US$1.8 million in 2007 , an important contribution to the economic viability of the local communities around

Umkomass (Dicken and Hosking 2009). In the Canary Islands, the revenues generated by shark and ray-diving activities were estimated to be responsible for the creation of 429 jobs, providing an in-flow to the local economy of US$22.8 million annually (De la Cruz Modino *et al.* 2010). The value of individual grey reef sharks (*Carcharhinus amblyrhynchos*) viewed by the dive industry in the Maldives was estimated to be up to US$35,000 annually in 1993, a figure approximately 100 times greater than the profits that could be obtained if the same shark was caught and sold for consumption (Anderson and Ahmed 1993).

Due to the presence of coral reefs and warm coastal waters that naturally attract divers, shark tourism forms an important and valuable element of tourism in many developing countries throughout the tropical Indo-Pacific and Caribbean. However, the growing demand for shark products, principally for shark fin soup, threatens the future of these valuable industries. Due to their conservative life-history traits of slow growth, low rates of reproduction and late ages at maturity, shark populations cannot withstand high rates of harvest and when depleted often take many years to recover (Field *et al.* 2009). For this reason, fishing for sharks both as a target species and as by-catch has severely reduced shark populations in many parts of the world's oceans (Baum *et al.* 2003; Myers 2003; Myers *et al.* 2007; Field *et al.* 2009), including tropical reef systems (Robbins *et al.* 2006; Ward-Paige *et al.* 2010). This phenomenon is likely to continue unless governments and local people can be convinced that ecotourism provides an attractive alternative for the use of shark resources.

In the islands of the Indo-Pacific, the major obstacles to altering the perception of sharks are both historical and cultural. Fishing has provided the economic basis of island societies for millennia and is still a central part of cultural and economic life in many regions. Fishing rights and grounds are often managed through complex traditional systems by social units such as clans or villages (Johannes 1981; Brunnschweiler 2009) and in many cases small-scale shark fishing is an important part of local culture. This stands in marked contrast to the industrial-scale fisheries that supply the demand for shark fin. However, this cultural heritage may predispose local people and governments towards the primary view of sharks as a fishery resource.

Palau is exceptional among Indo-Pacific nations in its recognition of the importance of sharks as a resource for tourism for the nation's economy. The coral reefs of Palau still host large populations of top-order predators and this factor distinguishes the Palauan diving experience from that available in many other places throughout the tropics where sharks have been severely reduced in numbers or eradicated by fishing (Baum *et al.* 2003; Myers 2003; Myers *et al.* 2007). Diving with reef sharks and manta rays are among the main attractions for tourists to the country (Anon. 2001b). To protect this resource, the national government declared the waters around Palau a shark sanctuary in 2009, where shark fishing is prohibited. This initiative places Palau among a small group of nations that have a nationwide ban on commercial shark fishing.

The recognition of the contribution of reef sharks to the economy represents an important achievement by the government and people of Palau. However, the scale of this contribution is still unknown, since there has never been a quantitative assessment of the value of sharks to tourism and the local and national economy. This project addresses this issue with our principal objective being to quantify the economic value of sharks as a tourism resource to the economy of Palau. This was done using a series of standard questionnaires distributed widely among divers and tourist operators in Palau. These were followed by interviews and other questionnaires with a wider range of stakeholders, including fishers and local people.

Study Area

The Republic of Palau is a complex of approximately 300 islands, spread over an Economic Exclusive Zone (EEZ) that covers 629,000 km^2 of the north Pacific (7°N Lat and 134°E Long). Palau has a population of approximately 20,000 with roughly two-thirds of the inhabitants living on the island of Koror (Figure 1). In 2008, the Gross Domestic Product (GDP) of Palau was estimated as US$218.4 million (Anon. 2010). Subsistence agriculture and fishing are important economic activities however, the local economy of Palau relies primarily on tourism, which attracts approximately 80,000 overseas visitors per year (Anon. 2001b) (Table 1), generates more than US$1.5 million in taxes from hotels and restaurants annually and is one of the main sectors of employment in the country (www.palaugov.net/stats).

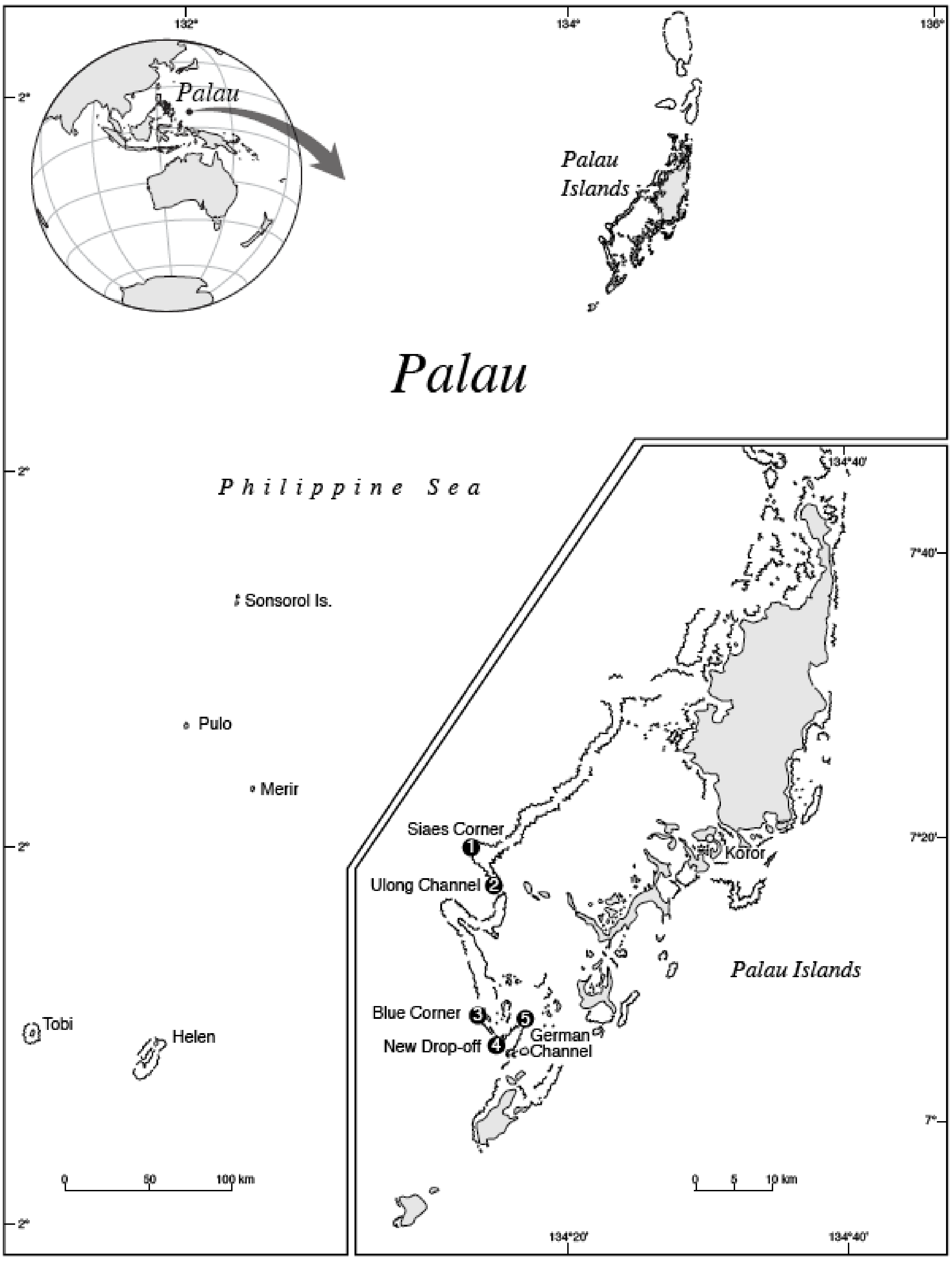


Figure 1: Map of Palau. Insert shows main archipelago with most popular shark-diving sites: 1) Siaes Corner; 2) Ulong Channel; 3) Blue Corner; 4) New Drop-off; 5) German Channel.

Table 1: Numbers of tourists and divers arriving in Palau by nationality from 2007 to 2009. Modified from www.visit-palau.com/publication/index.cfm.

Country of Origin	2007	2008	2009	Average	Divers
Aust/NZ	733	711	700	715	715
Germany	476	621	629	575	575
Guam	1,848	2,258	3,374	2,493	1,247
Hong Kong	465	344	334	381	286
Italy	328	344	327	333	333
Japan	29,198	30,018	26,688	28,635	26,058
Korea	14,342	14,186	13,009	13,846	692
Micronesia	964	1,041	1,055	1,020	0
Philippines	1,719	949	998	1,222	0
China	464	439	534	479	0
Taiwan	29,005	19,981	16,278	21,755	4,786
Russia	302	637	295	411	411
Switzerland	140	187	225	184	184
UK	389	335	373	366	366
USA Mainland	5,956	5,235	5,193	5,461	3,823
Other Europe	882	1,027	1,074	994	994
Others	964	946	801	904	506
TOTAL	88,175	79,259	71,887	79,774	40,976

Source: Extracted from Palau Visitor Authority statistics (www.visit-palau.com/publication/index.cfm), Anon. (2004) and Palau Visitor Authority, personal communication.

The marine environment is the main draw-card for tourists to Palau, particularly for diving and snorkelling (Anon. 2004). Palau is recognized as a world-class diving location and the abundance of large pelagic fish, most notably sharks, has established the country as a popular shark-diving destination. Most of the popular dive sites are located within the state waters of Koror or Peleliu. Each state requires tourists to purchase a diving permit costing US$25.00 and US$20.00 respectively. While Peleliu diving permits grant access to the dive sites for a period of 14 days, the Rock Islands use permit, issued by Koror State, grants tourists general access to some areas of the Rock Islands including beaches, kayaking and snorkelling sites. This permit also grants access to the dive sites and is valid for a period of ten days. Alternatively, tourists may purchase a Jellyfish Lake permit (US$35.00), that grants access to the same sites as the Rock Islands use permit and also includes access to Jellyfish Lake, arguably the most popular non-diving destination in Palau (only snorkelling is permitted).

Secondary Data

The country of origin and numbers of tourists arriving in Palau were obtained from surveys by the Palau Visitors Authority (PVA) and were based on mandatory visitor questionnaires completed on entry to the country. These statistics were available online (www.visit-palau.com/publication/index.cfm) and a summary is presented in Table 1. The percentage of divers among the tourists of each nationality was provided by the PVA (personal communication) and other sources (Anon. 2004) (see Table 1). Estimates of the gross tax revenue of hotels, restaurants and fishing industry were provided by the Office of Planning and Statistics (www.palaugov.net/stats). Other sources of data used by our study are shown in Tables 2 and 3.

Definitions

Shark diving: a SCUBA-diving activity during which observation of sharks is the major objective.

Shark diver: a diver who visits Palau principally to dive with sharks.

Shark-diving industry: the services provided by the dive industry focussed on fulfilling the demands of shark divers.

Economic value: Total revenues (business revenues + tax revenues) generated by an industry.

Direct socio-economic benefit: Community and government income earned directly from jobs or taxes generated by the shark-diving industry.

Indirect socio-economic benefit: Community and government income earned directly from jobs or taxes generated by services supporting the shark-diving industry (e.g. hotels and restaurants).

Table 2: Description of formulas, values and sources of data used to calculate parameters and estimates of economic benefits related to the tourism and shark-diving industry in Palau.

Abbrev.	Parameters and estimates	Description	Values	Units	Source	Comments
D	Number of divers per year	Sum of number of divers of each nationality	40,976	No./Year	Table 1; Anon. (2004), Anon. (2001a), Anon. (2001b)	Based on the percentage of tourists of each nationality visiting Palau to dive
FI	Fisher Income	Average income from fishing x days fishing	23,800	USD/Year	Fisher questionnaire	Based on four days of fishing per week for 50 weeks
ND	Number of non-diving tourists per year	T - D	38,798	No./Year	Table 1; Anon. (2004), Anon. (2001a), Anon. (2001b)	
NSDP	National shark diving parameter	(SDP x D)/T	0.11	-	Pilot and tourist questionnaires; Table 1	
S	Number of sharks	Sum of average number of sharks sighted on each of the five most popular sites for shark diving	100	No.	Dive guide questionnaire	Calculated from the following sites: Blue Corner, German Channel, Siaes Corner, Ulong Channel and New Drop-Off
SDP	Shark diving parameter	Shark divers /D	0.21	-	Pilot and tourist questionnaires	A shark diver is defined as a diver who visits Palau principally to dive with sharks
T	Annual number of tourists	Average number of tourists visiting Palau from 2007 to 2009	79,774	No./Year	Table 1	
TAX	Tourist taxes	Rock Islands use permit + green tax + departure tax	60	USD/Trip	Table 1	Rock Island permit: $25.00, green tax: $15.00 and departure tax: $20.00
TFP	Tourist fish market parameter	Percentage of fish sold to tourists x TP	0.44	-	Market representative interview	Based on sales to hotels and restaurants
TP	Tourism parameter	T/(Local Population + T)	0.8	-	Table 1 and Anon. (2010)	Percentage of sales that can be attributed to tourists rather than local consumers
W	Wages parameter	Percentage of revenues of dive industry used to pay wages	0.18	-	Operator questionnaire	
BT	Business revenue tax	Four percent of business revenue	0.04	-		
AT	Accommodation tax	BT + (Room tax/2)	0.09	-		Since 80% of tourists interviewed during the survey shared accommodation with another person, we divided the 10% "Room tax" by two to calculate the tax paid by each tourist

Table 3: Description of formulas and sources of data used to calculate parameters and estimates of economic benefits related to the tourism and shark-diving industry in Palau in 2010.

Abbrev.	Variables	Formula	Units	Source	Comments
Economic value					
EVD	Economic value of divers	D x TDET	USD/Year		
EVIS	Economic value of individual shark	EVS/S	USD/Year		
EVND	Economic value of non-divers	ND x TNDE	USD/Year		
EVS	Economic value of sharks	EVD x SDP	USD/Year		
EVT	Economic value of tourism industry	EVD + EVND	USD/Year		
Business revenues					
BRD	Business revenues from divers	D x DETUSD/Year			
BRIS	Business revenues from individual sharks	BRS/S	USD/Year		
BRND	Business revenues from non-divers	ND x NDE	USD/Year		
BRS	Business revenues from sharks	BRD x SDP	USD/Year		
BRT	Business revenues from tourism industry	BRD + BRND	USD/Year		
Economic benefits from shark diving					
DCIDI	Direct community income from dive industry	D x DED x W	USD/Year		Expenditure of dive industry on salaries
DCISD	Direct community income from shark diving	DCIDI x SDP	USD/Year		Expenditure of the shark-diving industry on salaries
FISD	Indirect value of shark diving to fisher	FI x TFP x NSDP	USD/Year	Fisher questionnaire; Fish market interview	
Tax revenues from shark diving					
DTSD	Direct taxes from shark divers	SDP x D x TAX	USD/Year		
BRTSD	Business revenue tax from shark diving	SDP x D x BT x Diving + NSDP x T x AT x Accom + NSDP x T x BT x Other	USD/Year		The sum of tax revenue from shark divers from diving, accommodation and other expenses
TTRSD	Total tax revenues from shark diving	DTSD + BRTSD	USD/Year		
Expenditures					
DDE	Daily diver expenditure	DET/length of stay	USD/Day	Pilot and tourist questionnaires	
DED	Diver expenditure on dives	Sum of diving expenses/ respondents	USD/Trip	Pilot and tourist questionnaires	Average expenditure of a diver on dives per trip
DNDE	Daily non-diver expenditure	NDE/length of stay	USD/Day	Pilot and tourist questionnaires	Average expenditure of a non-diver
NDE	Non-diver expenditure per trip	Accommodation + other expenses + tours	USD/Trip	Estimated based on pilot and tourist questionnaires + TAX	Assumes that expenditures on accommodation and extras by a non-diver tourist are similar to a diver's expenditure on these items. Tours refers to the sum of one land-based ($100.00) and one marine day trip ($100.00)
TNDE	Total non-diver expenditure per trip	NDE + TAX			
DET	Diver expenditure per trip	Accommodation + diving + other expenses	USD/Trip	Pilot and tourist questionnaires + TAX	Average of the total expenditures in each item. "Other" expenses include souvenirs, land-based tours etc.
TDET	Total diver expenditure per trip	DET + TAX	USD/Trip		

Shark Diving

Shark diving in Palau relies on dive sites that host aggregations of sharks that are predictable both in their numbers and timing of appearance. Such sites tend to be on the outer reef slope near drop-offs and are usually associated with strong tidal currents**.** Aggregations can be found at a number of dive sites, mainly on the slope of the barrier reef, on the southwest side of the lagoon (Figure 1). Typically, shark diving occurs during incoming tides, when the sharks are swimming off the slope of the reef and divers can position themselves at the edge of the drop-off using hook and line attachments of the diver to the reef (Photo 1). This technique, known locally as hook diving, is used to keep the divers in place against the current flow with minimal effort and contact to the reef and to make divers' behaviour predictable to the sharks. The technique optimizes the shark-diving experience since it allows close encounters with sharks for extended periods of time.

Photo 1: Shark divers use hooks attached to the reef to stay in place against the current and view sharks at the dive site. Photo: Richard Brooks, contributed by Micronesian Shark Foundation.

According to the dive guides, the number of sharks sighted by divers is related to the dive site and tidal movements. The length of time of the experience varies and is usually terminated by the divers due to no-decompression time limits. Although several species of sharks can be found in Palau, the shark-dive industry relies mainly on interactions with two species, the whitetip (*Triaenodon obesus*), and the grey reef shark (*Carcharhinus amblyrhynchos*), with the latter drawing most of the attention of the divers due to its size, abundance and behaviour.

Diving Industry

In 2010, there were 18 licensed dive tour operators who offered dive trips to popular shark-diving sites in Palau. Typically, dives involved day trips aboard small speed boats that had an average carrying capacity of 12 people. The average flat-rate charge for the dive trip during our study was US$125.00 for two SCUBA tanks (i.e. two dives), with an optional extra dive costing on average US$50.00. Live-aboard boats were also available but consisted of only four boats with total capacity of 64 divers, thus represented a small portion of the market (approximately 8%).

The tourism industry in Palau principally caters to Asian, American and European tourists (Table 1) and for this reason, dive operators often employ overseas workers to suit the needs of their particular clientele base. Operators also benefit from local knowledge and the work force includes many locals. Consequently, the staff of dive tourism operations typically consists of a mix of overseas and Palauan workers.

Methods

Survey

The socio-economic survey was based on five different questionnaires that collected information from people directly interested in, or affected by, the shark-diving industry in Palau. These stakeholders included tourists, dive operators, dive guides and local fishers (Table 4). This onsite survey was conducted in March (pilot) and May/June 2010 and provided a total of 297 completed questionnaires. Of this total, 246 respondents were divers (shark and non-shark divers), ten were dive operators, 20 were dive guides working within the industry and 21 were local fishers.

A pilot study trialled the survey questionnaire and its delivery to the divers as well as providing a general profile of the tourists engaged in diving activities, including both shark and non-shark divers. This pilot was structured as a face-to-face interview conducted by a single interviewer with a target sample size of 30 dive tourists. Divers visiting Palau typically spend several days engaged in dive activities and interviews were done after at least a few days of diving so that tourists had sufficient experience and knowledge of the location and their expenditures (Table 4).

Table 4: Structure, content and sample size of the five questionnaires and interviews conducted for data collection of the economic value of sharks in Palau in 2010.

Respondent	η	Date	Structure	Information collected
Tourist (pilot)	30	March 2010	Face-to-face questionnaire	Demographic characteristics, motivations to visit Palau, satisfaction and expenditures on diving, shark diving, accommodation, other activities and living costs while in Palau, knowledge of the shark sanctuary and influence on decision to visit Palau
Tourist (main)	216	May /June 2010	Self-administered questionnaire	Demographic characteristics, motivations to visit Palau, satisfaction and expenditures on diving, shark diving, accommodation, other activities and living costs while in Palau, knowledge of the shark sanctuary and influence on decision to visit Palau
Dive operator	10	May / June 2010	Face-to-face questionnaire	Number of tourists taking dive trips, tourist preferences, main dive attractions and activities, expenditures, expectations regarding the industry and effects of the creation of the shark sanctuary.
Dive guide	20	May / June 2010	Face-to-face questionnaire	Popular sites for shark diving, number of divers visiting these sites, average number of sharks per dive in each site, most common species of shark sighted during dives.
Fisher	21	May / June 2010	Face-to-face questionnaire	Fishing frequency, fishing techniques, income from fishing, level of interaction with sharks, perception of sharks and conservation
Fish Market	1	July 2010	Interview	Number of suppliers, fishing frequency, buyers, market volume and market prices

The pilot study provided the basis for the design of a self-administered questionnaire, structured to obtain information about the demographic characteristics of the divers visiting Palau, their motivations, satisfaction and expenditures. The self-administered questionnaire included questions about expenditure on accommodation, other activities (e.g. land tours) and living costs while in Palau. It also assessed the diver's knowledge of the shark sanctuary and its influence on their decision to visit Palau (Table 4). Self-administered questionnaires and a printed explanation of the purpose of the research were available in both English and Japanese. Many of these questionnaires were supplied to divers at the airport just prior to their departure from Palau. The self-administered questionnaire was answered by 216 dive tourists in May and June 2010. Since this questionnaire required minimal changes from the questionnaire used during the pilot study, the information collected by both the pilot and the main questionnaire were pooled, yielding a sample size of 246 tourists (Table 4).

The dive operator questionnaire obtained information about the characteristics of the operator's business, including number of tourists taking dive trips and their preferences, main dive attractions and activities, expenditures and expectations regarding the dive industry and effects of the creation of the shark sanctuary (Table 4). This questionnaire was answered by ten dive operators during face-to-face interviews, however, one incomplete form was discarded from the analysis.

Twenty dive guides of eight nationalities working for nine dive operators were also interviewed. The dive guide questionnaire was presented to subjects during a face-to-face interview that focused on obtaining information about the most popular dive sites for shark diving in Palau. It also aimed to provide an estimate of the number of divers visiting these sites throughout the year, average number of sharks in each site per dive and most common species of shark sighted during dives (Table 4).

Since conservation regulations are likely to affect fishing activities, fishers were also surveyed in face-to-face interviews using a standard questionnaire. This provided information about their fishing activities, techniques, level of interaction with sharks, perception of shark conservation and income from fishing. The interviews were conducted in the main fish market in Koror. The owner of the fish market was also interviewed regarding the fishers' activities, market and market prices (Table 4).

Economic variables and data analysis

Based on the survey data, a range of variables were estimated to quantify the value of sharks as a tourist resource to the economy of Palau, and the benefits from the shark-diving industry to the local community. A detailed list of variables, formulas and parameters used in these calculations and the data sources are presented in Tables 2 and 3.

Parameters

The average total number of tourists visiting Palau on an annual basis was calculated as the average number of tourist arrivals from 2007 to 2009 (Table 1). Two parameters were used to quantify the revenues of different sectors of the economy generated by the presence of shark divers (Table 2). The shark diving parameter and national shark diving parameter were the percentage of shark divers among the total number of divers surveyed (from the tourist questionnaire) and the proportion of shark divers among the total number of tourists that visited Palau (from government statistics) respectively (Tables 1 and 2). The number of sharks used in the calculations of the economic value of an individual shark was an estimate of the total number of sharks (grey and whitetip reef sharks) regularly seen by dive guides at the five most popular shark diving sites in Palau (Blue Corner, Ulong Channel, Siaes Corner, New Drop-off and German Channel), (Figure 1, Table 2). The number of sharks was calculated by summing the average number of sharks regularly sighted in each one of these dive sites (data from the dive guide questionnaire), and assumed that sharks sighted at different dive sites were different individuals. Although this assumption was necessary for the calculations, it is likely that individuals can transit between dive sites. Thus, the economic value of an individual shark was an estimation of the average value of a shark (not a marginal value), based on reported numbers (Table 2).

Using the data from the operator questionnaires, we estimated the percentage of revenues of the dive industry used to pay wages in Palau. We then estimated the percentage of the expenditures on shark diving by tourists that could be attributed to the payment of these wages. The resulting parameter was assumed to represent the economic contribution of shark diving to the local community in Palau (Table 2).

All tourists in Palau (divers and non-divers) visiting sites in the Rock Islands are required to pay at least three taxes, including a Rock Islands use permit, departure and green taxes (see below). For the purposes of our study these values were summed and treated as a single value (tourist taxes) in calculations (Table 2). It is important to note that the green tax (US$15.00) was implemented in November 2009. Consequently, our estimate of tourist taxes from shark divers is based only on a one year period.

Business revenue and economic value

We took a conservative approach to all calculations. For example, although it is common practice by divers to purchase a Rock Islands use permit and a Peleliu dive permit, the latter tax was not included in our calculations due to the lack of information on the number of divers purchasing both permits. Similarly, airfares to and from Palau were not included in the calculations since there is little or no in-flow from these expenditures to the local economy in Palau.

Our study estimated the financial revenue of the shark-diving industry and the magnitude of key components of that revenue. We recognise that revenue does not equate to net economic benefits from the industry. For the latter, estimates of both the supply curve and the demand curve for shark-diving services would be required in order to calculate producer and consumer surpluses (Just et al., 2004). This was not attempted due to a lack of market data required for any statistical analysis of supply or demand. Nevertheless, revenue provides a useful indicator of the economic importance of the industry and is consistent with common economic metrics such as Gross Domestic Product. The approach we take allows us to focus on economic benefits that are retained within Palau, whereas much of the producer and consumer surplus generated by the industry would be captured by foreign businesses and consumers.

Annual business revenue from sharks (*BRS*) in the shark-diving industry and associated businesses was estimated as

$$BRS = DET \times D \times SDP \quad (1)$$

where *DET* was average expenditure per dive tourist per trip without tourist taxes (assumed to be the same for shark divers and other divers), *D* was the number of dive tourists per year (from official statistics) and *SDP* was the proportion of all divers who were shark divers (estimated from the surveys). We also estimated the annual business revenue from tourism as a whole (Table 3). Business revenue was calculated both for the industry and on a per shark basis.

We calculated estimates of the economic contribution of divers and on a broader scale, the entire tourism industry to Palau in order to place the economic value of sharks within the context of the economy of the country. The value of sharks as a non-consumptive resource was calculated as the expenditure of divers multiplied by the shark diving parameter (the percentage of shark divers of the total number of divers surveyed) (Table 3).

For the calculation of the economic value of the typical non-diving tourist, we included the following expenses: accommodation, living (food and drink), other costs (souvenirs, etc) a land-based tour (estimated as US$100.00) and one marine-based day trip (estimated as US$100.00) during their holiday (Table 3). Considering the variety of tourist activities in Palau and assuming that tourists would be expected to visit more than two popular destinations during their time in the country, it is likely that this approach provides a relatively conservative estimate of the economic value of non-diver tourists.

Socio-economic benefits from shark diving

The annual economic contribution of the shark-diving industry to the economy of Palau has two main components: community income and taxes collected by the government. Direct community income is a component of the business revenue from shark diving (BRS) and is dispersed through the Palauan economy by payment of wages and salaries to employees of dive business. Direct community income from shark diving (*DCISD*) was calculated as follows:

$$DCISD = D \times SDP \times DED \times W \quad (2)$$

where *DED* was diver expenditure on dives (from questionnaires) and *W* was the proportion of dive industry income that was allocated to paying wages and salaries (from operator questionnaire) (Tables 2 and 3).

The taxes collected by the government that were gained from shark-diving tourism were estimated in two ways. Firstly, the direct tax income from shark diving was calculated as the combination of tourist taxes paid by shark divers (Rock Islands use permit, green tax etc, see above) (Table 3). Additionally, the Palauan government imposes a revenue tax of 4 per cent on most of the expenditures made by shark divers (and all other tourists), including accommodation, restaurants, land tours and souvenirs etc. This component of tax revenue was included within BRS. Tax revenue from the shark-diving industry (*TTRSD*) was calculated as follows:

$$TTRSD = TAX \times D \times SDP + SDP \times D \times BT \times Diving\ expenses + NSDP \times T \times AT \times Accommodation\ expenses + NSDP \times T \times BT \times Other\ expenses \quad (3)$$

where *BT* was the business revenue tax (4%, see Table 2) , *NSDP* was the national shark-diving parameter (the proportion of shark divers out of all tourists) and *AT* was the accommodation tax (9%, see Table 2).

The combination of these two sources of income gave an estimate of the tax revenue provided to the government by shark divers (Table 3).

A third and smaller economic contribution of the shark-diving industry was also calculated. This was the indirect economic value of the shark-diving industry to fishers, which was estimated as the profits a fisher obtained from selling his fish to the shark divers via a chain of commerce (i.e. fish market, hotels and restaurants). This represented a source of income that would not be available if the shark divers were not visiting Palau and therefore, represented a source of income directly related to the preservation of sharks interacting with the diving industry and was calculated as follows:

$$FISD = FI \times TFP \times D \times SDP/T \quad (4)$$

where FI was average annual fisher income (from fisher questionnaire), TFP was the tourism fish-market parameter (the proportion of fish sold to tourists, based on an interview with a fish-market representative to determine fish sales to hotels and restaurants, multiplied by TP, the proportion of hotels and restaurants revenue attributable to tourists), and T was the annual number of tourists visiting Palau (from official statistics, PVA 2010), (Tables 2 and 3). This calculation assumed that Palauan locals could represent up to 20% of the market of hotels and restaurants (Table 3).

Results

Demographics and profile of respondents

Respondents to our survey originated from four principal regions (Figure 2). Europeans constituted the largest group and accounted for 36% of the total. Of this group, 9% of all tourists were from Germany and 6% from Britain. Slightly fewer divers of East Asian origin were interviewed (33% of respondents). Of these 23% originated from Japan. Divers from Hong Kong comprised 6% of the total respondents, while divers from the Americas accounted for 21% of respondents, nearly all of whom (20%) originated from the USA. Australian divers accounted for 7% of respondents, and were the only country represented from Oceania (Figure 2).

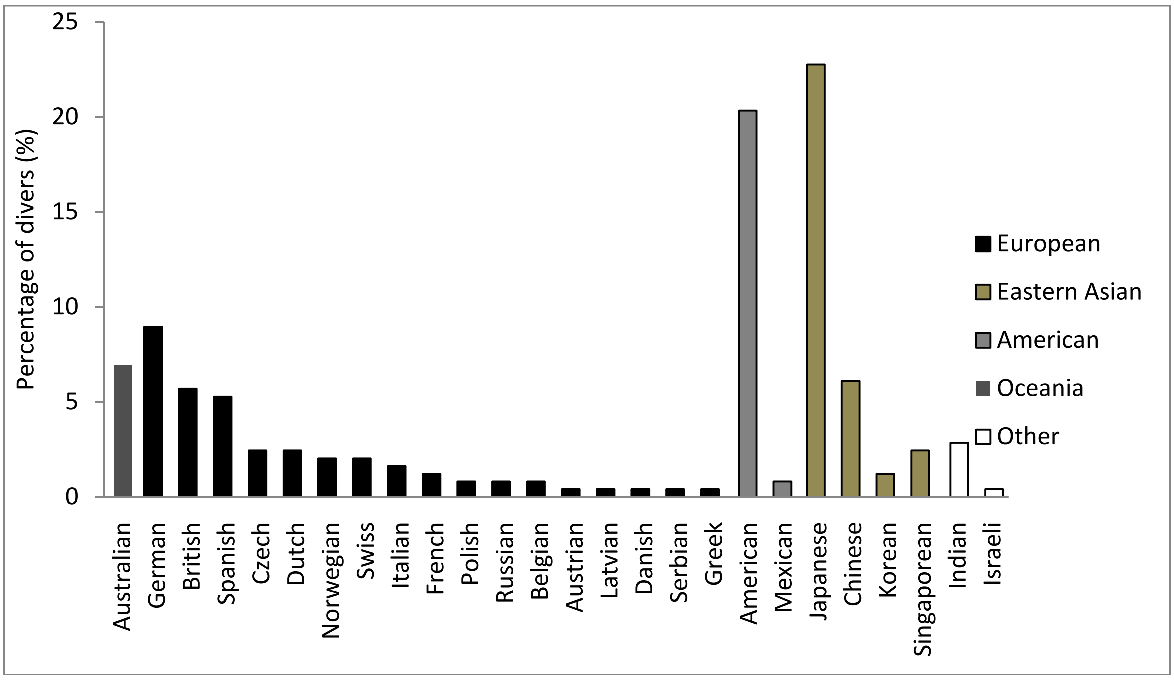


Figure 2: Frequency distribution of divers by nationality in the sample of tourists (n=246) surveyed in Palau in 2010.

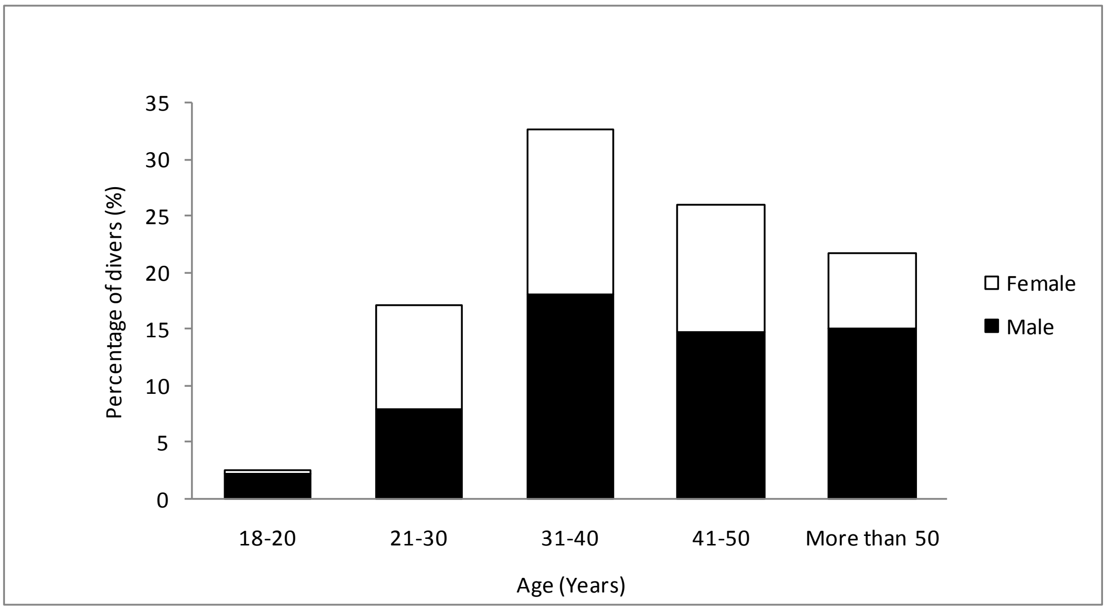


Figure 3: Frequency distribution of divers by gender and age classes in the sample of tourists (n=240) surveyed in Palau in 2010.

Over half (58%) of the survey respondents were male. Most divers (59%) were between 31 and 50 years of age, with 22% older than 50 years (Figure 3). Generally, divers had a reasonable level of experience (more than 50 dives) and 57% had more than 100 logged dives. Inexperienced divers (< 50 dives) accounted for 26% of respondents.

Over two-thirds of divers (69%) had annual incomes in excess to US$50,000. In this group, divers with annual incomes between US$50,000 and US$79,999 represented 31% of the total sample (Figure 4). On average, respondents spent 5.6 days (95% CI= 5.5-5.7) diving during their trip to Palau, with an average total trip duration of 8.1 days (95% CI=7.9-8.3) (Table 5), although trip duration varied with nationality (Figures 5 and 6).

Seventy-five percent of the divers said they were "interested" or "very interested" in shark ecotourism (Table 6). Shark diving was indicated as the main or specific reason to visit Palau and was a principal attraction that determined the choice of holiday destination for 21% of the respondents.

Approximately 72% of divers were unaware of creation of the shark sanctuary prior to their trip (Table 6). Of the 29% of divers that were aware of the sanctuary prior to their arrival, 42% reported that this was an important factor on their decision to choose Palau as a holiday destination (Table 6).

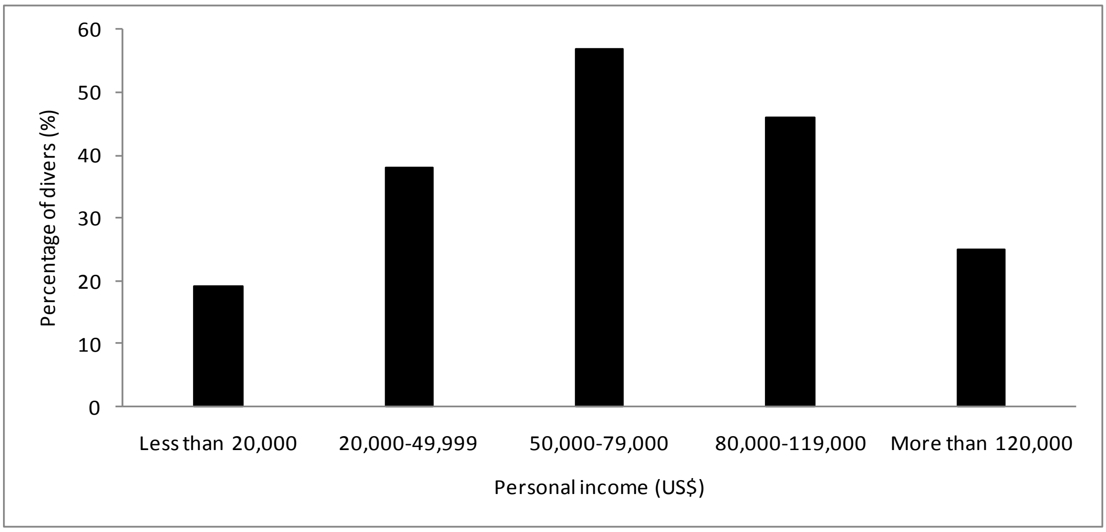


Figure 4: Frequency distribution of divers by annual income (US dollars) in the sample of tourists (n=185) surveyed in Palau in 2010.

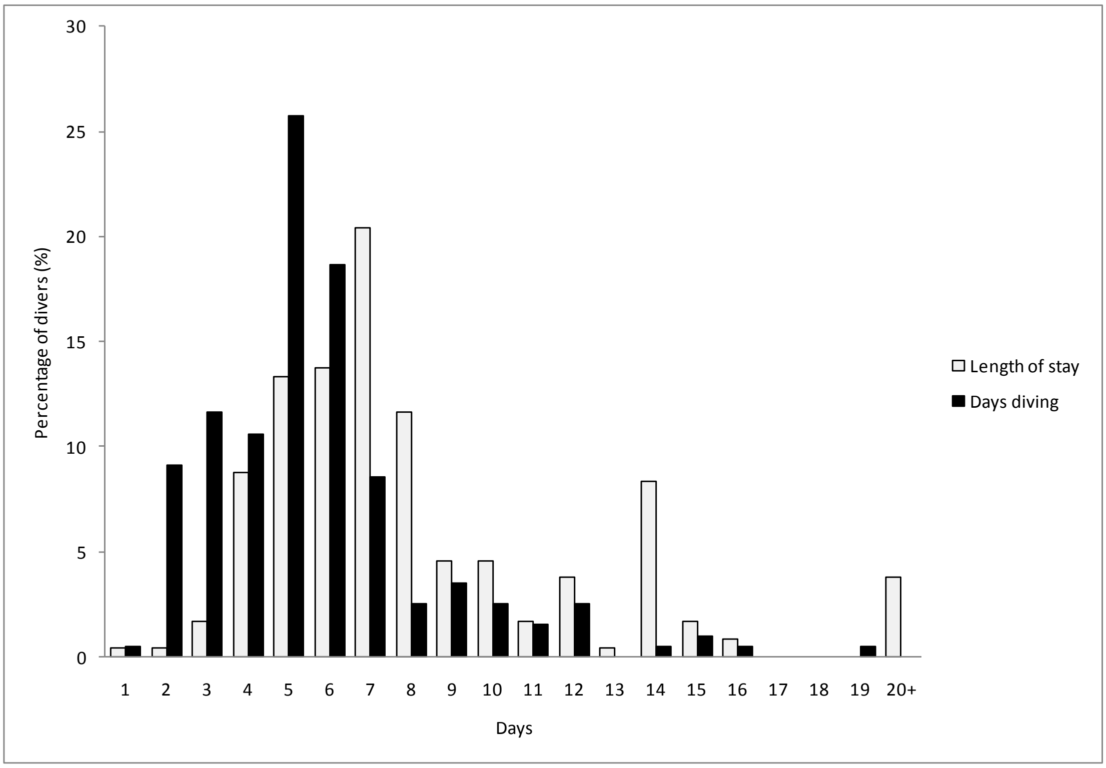


Figure 5: Frequency distribution of average length of stay (n=240) and average number of days diving in the sample of tourists (n=198) surveyed in Palau in 2010.

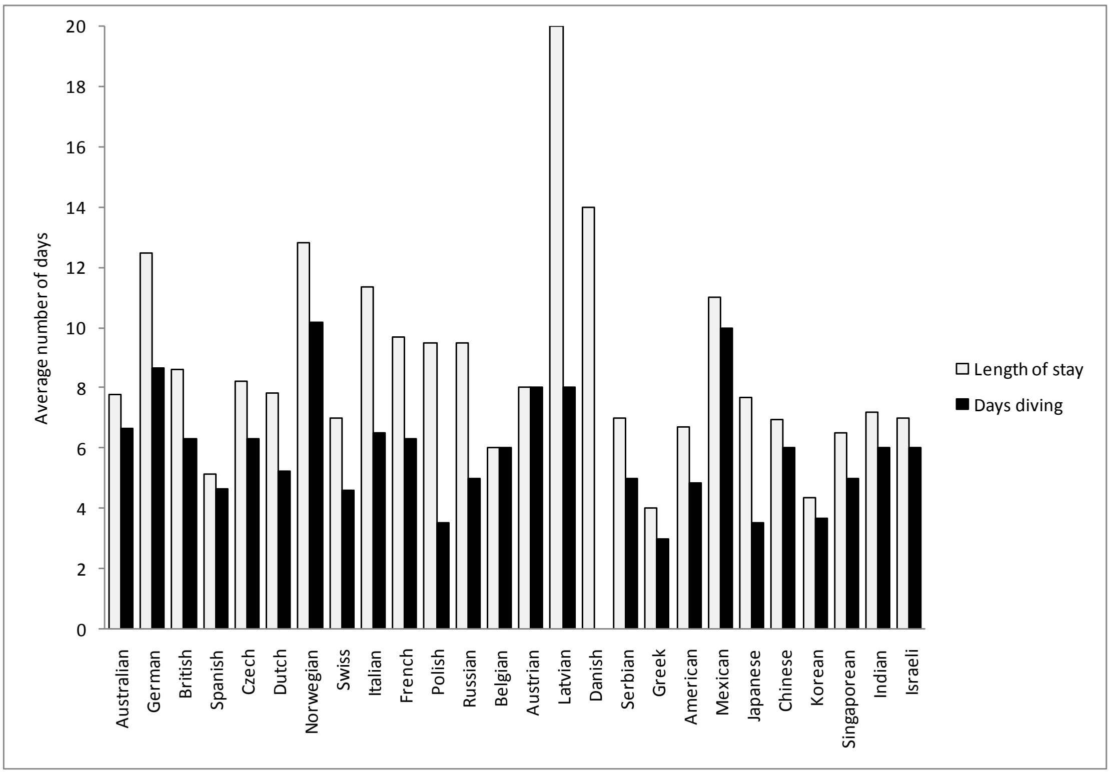


Figure 6: Frequency distribution of average length of stay (n=240) and average number of days diving by divers of different nationalities in the sample of tourists (n=198) surveyed in Palau in 2010.

Table 5: Comparison of results of four questionnaire-based studies of length of stay, number of days, diving and average expenditures per trip of tourists in Palau.

	Our Study (2010)	Comprehensive exit survey analysis report (Anon. 2001)	Dive tourism in Palau: Resource use, value and management (Anon. 2001)	Palau tourism economic valuation survey (Anon. 2004)
Tourist profile	Divers	General tourist	Divers	General tourist
Year	2010	2001	2001	2004
Average length of stay	8.1	7.1	6.9	5.1
Average tourist expenditure per trip (US$)	2,081	1,025	-	1,784*
Average days diving	5.6	-	5.1	-

* Average price of package tours including airfare

Table 6: Summary of responses to questionnaire about knowledge and relevance of the shark sanctuary in the decision to visit Palau by divers in 2010.

	N	%
Main reason to visit Palau (*n=228*)		
General diving	134	59%
Mainly to dive with sharks	35	15%
Specifically to dive with sharks	13	6%
Dive activities and sight-seeing	30	13%
Snorkelling	8	4%
Other	8	4%
Knowledge about the sanctuary before the trip (*n=244*)		
Yes	70	29%
No	160	66%
Unsure	14	6%
Influence of sanctuary in decision to go to Palau (*n=70*)		
Did not influence	28	40%
Influenced a bit	13	19%
Moderate influence	9	13%
Major influence	14	20%
Primary reason	6	9%
Importance of sanctuary on intention to return to Palau (*n=210*)		
Not important	15	7%
Minor importance	31	15%
Moderate importance	40	19%
Important	57	27%
Very important	67	32%
Interest in shark diving (*n=230*)		
Negative	0	0%
Not interested	7	3%
A little interested	33	14%
Interested	80	35%
Very interested	93	40%
Do not know/ not sure	17	7%

Economic value of tourism

Of the 80,000 tourists who visit Palau every year, approximately 51% are divers (Table 1), (Anon. 2004). The economic value of these divers to Palau is US$85.3 million per year (95% confidence interval (CI) US$78.8-94.7 million), which represents about 59% of the total value of tourism (Table 5). Based on these figures and our estimate of the economic value of the non-diver tourists of US$59.5 million (95% CI=US$54.7-64.3 million) (Table 7), the economic value of the tourism industry to Palau was estimated to be US$144.8 million (95% CI=US$133.8-154.5 million) annually (Tables 7 and 8).

The business revenue generated by these divers (BRD) for Palau was US$82.8 million per year (95% CI= US$76.4-89.3 million), representing about 59% of the total revenue from tourism

(Table 4). We estimated that the business revenue from non-diver tourists (BRND) was US$57.2 million (95% CI=US$52.4-62.0 million) (Table 4), so that the total business revenue of the tourism industry to Palau (BRT) was estimated to be US$140.0 million (95% CI=US$129.0-151.0 million) annually (Table 4).

Table 7: Expenditure of divers (US dollars) in Palau in 2010. CI (95%): 95% confidence interval.

Code	Average tourist expenditure per trip	Mean (US$)	CI(95%) (US$)
-	Accommodation	588	529-647
-	Diving	749	680-818
-	Other	684	589-780
-	Tours (1 land-based + 1 marine day trip)	200	-
DDE	Daily diver	285	263-307
DNDE	Daily non-diver	210	188-232
TDET	Total diver	2,081	1,924-2,239
TNDE	Total non-diver	1,534	1,410-1,657

Note: Estimated from 167 questionnaires.

Table 8: Socio-economic value (US dollars) of shark-diving industry and related sectors in Palau in 2010. CI (95%): 95% confidence interval.

Code	Variables	Mean (US$)	CI(95%) (US$)
Annual economic value			
EVD	All divers	85.3 million	78.8-94.7 million
EVS	Shark divers	18 million	16.6-19.3 million
EVND	Non-divers	59.5 million	54.7-64.3 million
EVT	Tourism industry	144.8 million	133.8-154.5 million
EVIS	Individual shark	179,000	165,445-192,515
Annual business revenues			
BRD	All divers	82.8 million	76.4-89.3 million
BRS	Shark divers	17.4 million	16.0-18.7 million
BRND	Non-divers	57.2 million	52.4-62.0 million
BRT	Tourism industry	140.0 million	129.0-151.0 million
BRIS	Individual shark	174,000	160,000-187,000
Economic benefits to the community from shark diving			
DCISD	Direct community income	1.2 million	1.1-1.3 million
FISD	Individual fisher income	1,180	915-1,440
Annual tax revenue from shark diving			
DTSD	Direct (TAX)	517,600	
BRTSD	Business revenue taxes	962,000	887,000-1.0 million
TTRSD	Total	1.5 million	1.4-1.6 million

Economic value of sharks

Approximately 8,600 shark divers visit Palau each year and observations by dive guides suggest that around 100 sharks interact with these divers in the five most popular shark diving sites. On this basis, the total value of sharks to the Palauan economy was estimated to be US$18 million per year (95% CI= US$16.6-19.3 million) (Table 8). The value of an individual shark to the economy at these dive sites was estimated to be US$179,000 per year (95% CI= US$165,000-US$192,000) (Table 8).

The total business revenue generated by shark diving (BRS) for the Palauan economy was estimated to be US$17.4 million per year (95% CI= US$16.0-18.7 million) (Table 4). The average contribution of each of the sharks (BRIS) was estimated to be US$174 000 per year (95% CI= US$160 000-US$187 000) (Table 4).

Socio-economic benefits of shark diving

The annual income generated by tourist taxes on shark divers was estimated to be US$517,600 (Table 8). In combination with the business tax revenues generated by the shark-diving industry and sectors that support infrastructure and services to shark divers (such as hotels, restaurants and souvenir shops) the total tax revenues from shark diving (TTRSD) collected by the government was estimated as US$1.5 million per year (95% CI=US$1.4-1.6 million)(Tables 3 and 8). The direct community income from shark diving was estimated to be slightly smaller than this value at US$1.2 million annually (95% CI=US$1.1-1.3 million) (Tables 3, 7 and 8). Fishers also benefitted marginally from the shark diving by supplying tourists with their catches via restaurants. This was estimated to provide an individual income of approximately US$1,180 annually (95% CI= US$915-1,440) (Table 8), or approximately 5% of a fisher's total annual income (Tables 2 and 3).

Discussion

The economic value of shark-diving tourism

The small island nations of the Indo-Pacific are characterized by a limited range of economic opportunities. However, their tropical locations, scenic beauty and diversity of marine life often make these places highly attractive holiday destinations for tourists. For this reason, tourism is a major source of revenue and increasingly occupies a central position in the economy of these countries (Milne 1992; Anderson *et al.* 1999; Anon. 2003; McElroy 2003). In the fiscal year of 2009/2010, the annual GDP of Palau was estimated to be US$218.4 million (Anon. 2010), with tourism representing the main source of income and accounting for 56% of this total (Anon. 2001b; Anon. 2010) . Our conservative estimate of the annual economic value of the diving industry was US$85 million, so that this sector accounted for a minimum of 39% of the GDP of

Palau. Given that the opportunity to view sharks is the principal reason for visiting Palau for 21% of divers, the shark-diving industry accounts for approximately 8% of the GDP of the country.

Economic value of individual sharks

A Palauan reef shark residing at one of the five most popular dive sites was estimated to have an average annual value of US$179,000 to the tourism industry and government. Grey and whitetip reef sharks are the main species interacting with divers in Palau. Assuming that there is limited variation in the number of sharks interacting with the tourism industry during a single generation and using a very conservative estimate of life span of 16 years for both species (Smith *et al.* 1998; Compango 1984), the lifetime economic value of each individual shark will be approximately US$1.9 million (present value at birth, assuming real discount rate of 5 percent). Given that approximately 100 sharks were interacting with the tourism industry at five major dive sites, the total present value of a generation of sharks interacting with the diving industry in Palauan waters is approximately US$200 million. These estimates of the annual value of an individual shark to the tourism industry in Palau are consistent with those made in other locations. In 1994, the annual value of each Caribbean reef shark (*Carcharhinus perezi*) interacting with the shark-diving industry of the Bahamas was estimated to be US$250,000 (Hall 1994), while in the Maldives, a single grey reef shark was estimated to generate annual revenues in 1993 of US$33,500 (Anderson and Ahmed 1993).

The significance of reef sharks in Palau and other tropical localities as a non-consumptive resource contrasts with their value as a fishery. The price of a set of shark fins (first dorsal, both pectorals and lower caudal) varies according to the species and market fluctuations and ranges from US$20 to US$90 (Clarke *et al.* 2007). While fins are valuable, the shark meat is considered to be of poor quality, with an average price per kilo ranging from US$2.00 to US$4.60 (Chen and Phipps 2002). A large grey reef shark, which is the biggest of the sharks regularly interacting with divers in Palau, weighs approximately 40kg (Wetherbee *et al.* 1997). Considering that the sharks interacting with the tourism industry tended to be adults (Meekan *et al*. unpublished data), the maximum total revenues that could be obtained from the targeting of these 100 animals by a fishery for the international market was approximately US$10,800. This represents 0.00006% of the life time value of the same sharks used as a non-consumptive resource in Palau (US$190 million).

Socio-economic benefits from shark diving

We estimated that approximately US$1.2 million was spent per year by the shark-diving industry on salaries to employees resident in Palau. These are a key benefit of the industry and because of the labour-intensive nature of diving, with relatively low guide-to-diver ratios (and therefore, more guides) and the need for roles involving maintenance, boat operation, catering and office work, the shark-diving industry maximizes dispersion of revenues and makes a major contribution to the economy by generating jobs and income to the community and taxes to the government (Milne 1992; De la Cruz Modino *et al.* 2010).

Beyond the direct return of salaries to the community, the shark-diving industry indirectly provides benefits by increasing the buying power of the population. A proportion of salaries will be used to purchase additional goods and services, which in turn have a multiplier effect, generating more jobs and further dispersing the revenues from shark diving (Milne 1992). The great numbers of shark divers in Palau are also responsible for jobs and revenues generated in different sectors of the tourism industry such as hotels, restaurants and souvenir shops. These contributions were not quantified by our study and thus it is likely we have underestimated the economic benefit to Palau of the shark-diving industry.

Tourist taxes paid by shark divers in Palau generated an income of approximately US$1.5 million to the government. This accounts for approximately 14% of the tax revenue collected from all industries by the Palauan Government in 2008 (www.palaugov.net/stats). Compared to other industries, the taxes paid by shark divers were the third highest contributor to the gross tax revenue in Palau and were roughly 24 times higher than the taxes collected from the fishing industry in 2008.

We estimated that the provision of fish to restaurants for consumption by shark divers gave an additional annual income of approximately US$1,200 per fisher. The manager of the fish market reported that 55 fishers regularly sold their catches to supply both the tourism industry and the local population. If these fishers were engaged in shark-fishing activities, the maximum revenues that they could obtain for the capture and sale of the sharks interacting with the tourism industry would be around US$196, or only 16% of the annual income each one would have earned by keeping these sharks alive.

Wider context of results

This study clearly shows the vital importance of shark diving to the economy of Palau. The implications of our work are not limited to Palau, as our estimates of the economic contribution of shark diving are comparable to those of studies from a range of other localities. In the Canary Islands, the shark and ray-diving industry was estimated to be worth US$22.8 million annually. Palau hosts approximately half of the number of divers that visit the Canary Islands annually (De la Cruz Modino *et al.* 2010), implying that the total expenditure of divers in Palau is roughly twice that of visitors to the Canary Islands. Additionally, in 2009/2010 shark diving contributed significantly more to the GDP of Palau (8%) than the Canary Islands (0.11%) (De la Cruz Modino *et al.* 2010). These differences in relative importance reflect both a broader and more developed resource base in the economy of the Canary Islands than Palau and also the more sporadic nature of shark and ray encounters in the Canary Islands. This unpredictability limits the ability of operators to market their product and the prices that can be charged for their services (De la

Cruz Modino *et al.* 2010). Divers with an advanced level of experience are often willing to pay more and go to specific destinations if they can be assured that the product they seek will be delivered (Dearden *et al.* 2006; Jones *et al.* 2009) and this may influence their choice of diving destination. Shark aggregations in Palau are highly predictable, which implies that the dive operators can market and sell a product at a greater price with the expectation of reliable delivery to clients.

In the Maldives, a shark-diving industry based on interactions with grey reef sharks was estimated to complete 77,000 dives and yield approximately US$2.3 million annually in revenues in 1993 (Anderson and Ahmed 1993). The value of this industry was considerably lower than our estimate for Palau (Anderson and Ahmed 1993) and to some extent, this dissimilarity can probably be explained by the 17-year time lag between studies and substantial differences in methods. In the Maldives, estimates were based solely on the direct revenues from diving. Accommodation, restaurants and local businesses that also benefit from expenditures by divers were not considered. Even though earnings were likely to be underestimated, the shark-diving industry in the Maldives yielded twice as much as the export earnings of the three major shark-fishing industries in the country for the same period (Anderson and Ahmed 1993).

The economic benefits of shark diving are not restricted to well-established tourist markets such as the Canary Islands and the Maldives. In 2009, a developing tiger shark-diving industry at Aliwal Shoal, South Africa was estimated to have an annual value of approximately US$1.8 million. This industry delivered a specialized experience with reasonable predictability and a high rate of satisfaction (Dicken and Hosking 2009). In comparison to Palau, the total revenues were an order of magnitude less, which largely reflected the difference in the scale of shark-diving industries between the two locations, with Palau hosting 8,600 divers and the Aliwal Shoals only 1,000 divers in 2009. However, when all shark-diving industries in South Africa are considered together, economic values are more comparable to Palau. Overall, South Africa hosts 10,700 tourists in activities that include cage diving with great white sharks, snorkelling with whale sharks and diving with other sharks. These combined activities yielded a minimum of US$6.5 million yearly to the South African economy (Hara *et al.* 2003; Dicken and Hosking 2009).

Across the entire Indo-Pacific, shark diving (including whale sharks) generates at least US$40 million dollars annually (Anderson and Ahmed 1993; Hara *et al.* 2003; WWF-Philippines 2006; Rowat and Engelhardt 2007; Dicken and Hosking 2009; Catlin *et al.* 2010). In reality this value is likely to be much greater, since the economic value of many recent and developing industries has not yet been quantified (e.g. Fiji and French Polynesia; Brunnschweiler 2009; Clua *et al.* 2010).

Shark sanctuary

In 2009, Palau created a nation-wide shark sanctuary in the waters of their Exclusive Economic Zone (EEZ). Since this time, the Maldives and Honduras have followed suit, also banning shark fishing within their EEZs. Most divers (66%) had no knowledge about the creation of the sanctuary prior to their arrival in Palau, probably reflecting the recent nature of sanctuary legislation. However, it is important to note that a high percentage of divers (78%) stated that the sanctuary had a reasonable degree of importance on their decision to re-visit Palau, suggesting that the creation of the sanctuary could play an important role on the selection of a destination by shark divers in the future.

Demography and profiles of dive tourists

Tourists that visit Palau generally come from four main regions, with a predominance of Asians (Japanese, Taiwanese, Korean and Chinese), followed by Americans (USA and Guam), Europeans (Germans, Italians, Russians, Swiss, British and others) and people from Oceania (Australians, New Zealanders and Micronesians) (Table 1). Virtually all tourists visiting Palau are in some way engaged in marine recreation, although there are differences in preferences and motivations among nationalities (Anon. 2001b). Respondents to our surveys did not entirely replicate the pattern of origin of all tourists, being dominated by Europeans, followed by Asians (mostly Japanese) and Americans. After the Japanese, Taiwanese and Koreans are the two most numerous nationalities of tourists in Palau (Table 1). Koreans accounted for a small percentage of respondents to our survey and most of these tourists do not dive. While few Taiwanese visitors dive, they form a large percentage of the tourist market thus are important in terms of absolute numbers of divers. These divers were not represented in our respondents and we assumed that their motivations and expenditures were equivalent to those of Japanese divers.

We estimated that most tourists spent an average of 5.6 days of their stay engaged in diving activities. This value is consistent with an estimate of 5.1 days calculated in 2001 (Anon. 2001b) and suggests that there has been little change in this variable over the last decade. The average length of stay of the dive tourist in our survey was 8.1 days, a value higher than the 7.1 days obtained by a survey of all tourists visiting Palau (Anon. 2001a) and of 6.9 days obtained by a survey of divers and snorkelers in 2001 (Anon. 2001b). In these 2001 surveys, the length of stay varied among nationalities with European and Americans staying from 7.5 to 11 days, while Korean and Taiwanese tourists stayed for 4 and 4.5 days, respectively. The longer length of stay found in our survey could thus be related to the relatively low frequency of Korean and Taiwanese divers in our sample. Ultimately, the variation of the length of stay of tourists from different nationalities appears to be related to flight schedules, particularly for tourists of Asian origin (Anon. 1999; Anon. 2001b; Anon. 2001a; Anon. 2004).

Of the divers surveyed by our study, 81% were in their 30s or older and 70% had annual income exceeding US$50,000. Although the age profile was similar to the profile of tourists surveyed in 2004 (78% of divers older than 29 years of age), the proportion of tourists earning more than US$50,000 was higher in our survey (60% in 2004) (Anon. 2004). This difference between surveys could be due to a general increase in income of tourists over time. Most of our sample (57%) was composed of divers who had completed more than 100 dives, indicating that divers who choose Palau as a tourism destination are, in general, reasonably experienced and are therefore likely to cause less damage to the reefs than are novice divers (Davis and Tisdell 1995).

Potential Sources of Error

Considerable effort was made in our study to obtain samples that were representative of most nationalities involved with the shark-diving industry in Palau. However, the length of stay of tourists in Palau is related to nationality (Anon. 2001b; Anon. 2001a) and for this reason, the low numbers or absence of Taiwanese and Koreans in our sample could have resulted in an overestimation of the average length of stay by our study, which in turn could affect our calculations of the economic value of tourists in Palau. Government surveys showed that the total tourist expenditure per trip was similar irrespective of nationality (Anon. 2004), suggesting that the length of stay and differences in nationality would not affect our estimates of economic value. However, it is also important to note that divers were surveyed only in March and May/June 2010 and seasonal variations in the proportion of divers from different nationalities were not captured by our results.

Taiwan provides the second largest group of tourists visiting Palau. Between 2007 and 2009, the Taiwanese nationals accounted for 27% of the total number of tourists and 12% of the divers (Table 1). As mentioned above, Taiwanese divers were not represented in our respondents and we assumed that their motivations and expenditures were equivalent to those of Japanese divers. The nature of the Taiwanese tourism industry, which is controlled by Taipei-based companies, implies that a share of the revenues generated by this sector might not reach Palau. However, Taiwanese companies typically have a Palauan workforce as part of their staff and services such as transportation are often provided by Palauan businesses (Anon. 1999). This indicates a degree of interaction between the local economy and the Taiwanese sector, which reduces the potential for overestimates of the value of this part of the tourism industry.

From information provided by dive guides and from community monitoring programs (Meekan *et al.* unpublished data) it was estimated that approximately 100 sharks were interacting with the industry over five of the most popular sites for shark diving. During shark dives it is often possible to view most of the animals present at a site at the same time and for extended periods (up to an hour). This provides an opportunity to estimate numbers with a reduced likelihood of double counting. The consistency in the average numbers of sharks estimated by each dive guide and for each dive site suggested that these estimates were reasonably accurate. An average estimate of 20 sharks per dive site (100 sharks in 5 dive sites) is also consistent with the abundance of reef sharks in aggregations at the Maldives, Johnston Atoll and the Marshall Islands (McKibben and Nelson 1986; Anderson and Ahmed 1993; Economakis and Lobel 1998). It is however, important to consider that the movement patterns of reef sharks in Palau remains unknown. Migration of individuals between dive sites could result in an overestimation of the total number of sharks interacting with the industry and consequently, an underestimation of the value of each animal to the dive industry. Alternately, the estimate of 100 sharks does not necessarily mean that these are the same animals at all times, which implies that the total number of individuals could be higher than that estimated by the guides. This would imply an overestimation of the value of each shark. Neither of these two scenarios would affect the estimate of the total economic value of reef sharks to the Palauan economy.

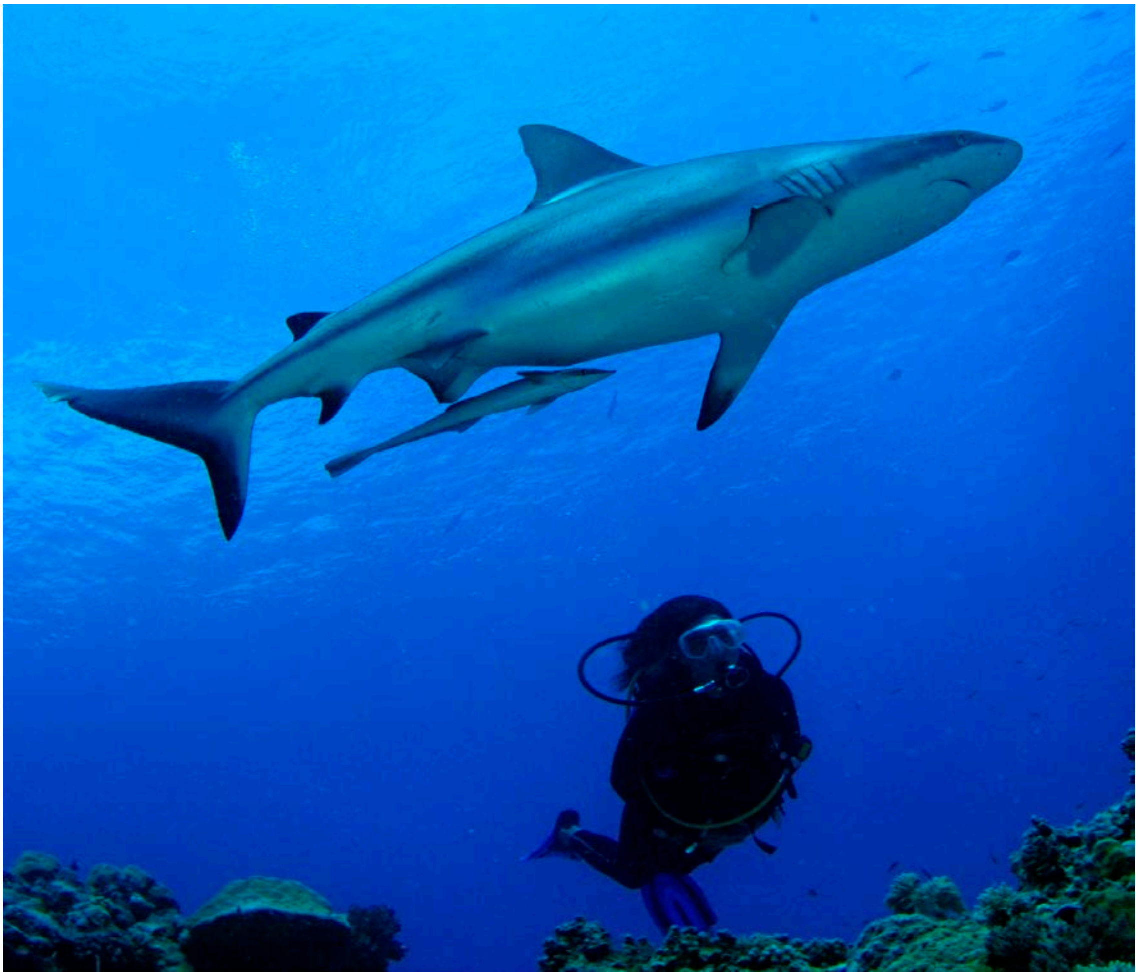
Our study quantified salary flow, indirect benefits to fishers and the taxes paid by shark divers as the principal returns of the shark-diving industry to the Palauan economy. A range of indirect benefits, such as revenues from suppliers of dive operators, tax revenues from landing fees at the airport and the induced benefits of suppliers of other sectors of the tourism industry (such as hotels, restaurants and souvenir shops) were not included. As these indirect links depend on the degree of interaction among business (Milne 1992), they lay beyond the scope of our study and for this reason, the total value of sharks to the Palauan economy is almost certainly underestimated by our work.

The estimate of the value of the tourism industry included the expenditure of non-diver tourists, which was based on costs for accommodation, food, drinks and souvenirs and an estimated cost for non-diving tourist activities. A survey in 2004 that included non-divers showed high rates of participation in activities such as repeated day trips to the Rock Islands, land tours, snorkelling trips and kayaking, with the average expenditure for the latter two activities estimated as US$448 and US$164, respectively (Anon. 2004). Consequently, our assumption that a non-diver tourist would be engaged in one land-based and one marine-based tour spending a total of US$200 is a very conservative estimate of their expenditures. For this reason, it is unlikely that we have overestimated the economic value of the tourism industry in Palau. Furthermore, according to the International Monetary Fund, the estimated tourism incomes for Palau for the financial year of 2008/2009 and projected to 2009/2010 were US$113 and US$124 million, respectively (Anon. 2010). Our estimate of the economic value of the tourism industry (US$144 million) was broadly in accordance with these projections and for this reason we believe that our study provides a reasonable evaluation of the economic value of the shark-diving industry to Palau.

Conclusion

Our report demonstrates the economic benefits of a well-organised shark-diving industry and the value of sharks as a non-consumptive resource. Each year, the number of tourists visiting Palau is four times greater than the population of permanent inhabitants and due to the demand this places on resources, the Palauan Government aims to target tourists that have high expenditure and low environmental impact. Shark divers fit this profile and represent a major source of revenue that accounts for approximately 8% of the GDP. Shark diving in Palau was responsible for the generation of the annual tax revenue of US$1.5 million to the government and US$1.2 million per year in salaries to the local community. The economic benefit of shark diving outweighed the profits available from these animals as a harvested resource by a factor of 10^4 on an individual, lifetime basis. In other terms, for a shark fishing industry to replace the economic revenues available from shark diving in Palau, it would require the harvest of over 100,000 sharks per year. Such an industry would be unsustainable and would swiftly cause the collapse of stocks. In contrast, the shark diving industry is a sustainable use of these resources that provides not only a renewable, permanent source of income, but also retains the ecosystem services of these key-stone predators within the reefs of Palau.

Palau's success in exploiting sharks as a profitable, renewable and non-consumptive resource is a model that could be applicable to other diving destinations throughout the tropics. Although the shark-diving industry is an important driver for the conservation of the sharks, over the long term very large numbers of divers might also have the potential for negative impacts on shark populations. The identification of critical habitats and studies of movement patterns and behaviour of the main species interacting with the shark-diving industry are necessary to ensure shark diving remains compatible with shark conservation in Palau.



Diver observing a grey reef shark (*Carcharhinus amblyrhynchos*) swimming near drop-off of the barrier reef in Palau.
Photo: Carlos Villoch: contributed by Micronesian Shark Foundation.

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The socio-economic value of the shark-diving industry in Fiji

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DISCLAIMER

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1. Executive Summary

We quantified the economic revenues generated by shark diving and the distribution of these revenues to the principal local stakeholders involved with the industry, including businesses, government and local community.

Shark-diving contributed US $42.2 million to the economy of Fiji, a sum composed of revenues generated by the industry combined with the taxes paid by shark-divers to the government.

This estimate was based on self-administered questionnaires designed to collect information on the costs and benefit of the shark-diving industry. We conducted the study in August/September 2011 and distributed questionnaires on the islands of Viti Levu (including the islands of Nananu-i-Ra and Beqa), Vanua Levu, Taveuni and Kadavu, the Yasawa and Mamanuca groups. Questionnaires were answered by 289 divers, 18 dive operators, six resort managers (surveyed at Pacific Harbour and Coral Coast only), 14 dive guides and nine local subsistence fishers from villages that regularly received payment from shark-diving operators for the use of the reef of which they are the traditional owners.

We took a conservative approach to all calculations in order to reduce the risk of over-estimating the value of shark-diving to the Fijian economy

We calculated the economic revenue of shark-diving to Fiji based on three key pieces of information:

(1) Total number of divers visiting the country and the proportion of tourists engaged in dive activities from the Fiji International Visitor Survey 2009
(2) All expenditures of the divers visiting Fiji primarily to engage in shark-diving activities ("dedicated shark-divers") as revealed by our surveys;
(3) The expenditures of divers who visited Fiji for reasons other than diving with sharks, but chose to engage in shark-diving while in the country ("casual shark-divers") as revealed by our surveys. Expenditures of these divers were allocated as the proportion of their trip spent shark diving, rather than for their entire visit.

In 2010 we estimated that approximately 49,000 divers were engaged in shark-diving activities in Fiji accounting for 78% of the 63,000 divers visiting the country. Dedicated and casual shark-divers accounted for 24% and 54% of all divers we interviewed respectively.

The shark-diving industry contributed US $17.5 million in taxes to the government, a sum composed of corporate taxes from shark-diving (US $11.6 million) and the direct taxes from shark-divers (US $5.9 million)

A minimum of US $4 million was generated annually by shark-diving for local communities. This revenue consisted of salaries paid by the industry to employees (US $3.9 million annually) and community levies paid by dive operators to traditional owners in villages for access to reefs (US $124,200 annually). Employees of the dive industry were predominantly Fijian (13 of 14 dive guides who responded to surveys).

Community levies from shark-diving have played a significant role in promoting the conservation of reefs through systems of traditional ownership.

Viti Levu hosted the largest number of dedicated and casual shark-divers (17,000) with Pacific Harbour accounting for around 50% of the shark-divers, or approximately 8,600 tourists. The Mamanuca/Yasawa group also hosted a large number of shark-divers (11,000) while Vanua Levu/Taveuni hosted approximately 3,600. Kadavu had only 17% of divers identified as casual shark-divers and no dedicated shark-divers interviewed during our survey.

Shark-diving generated approximately US $10.2 million on Viti Levu (63% of business revenues from diving) and US $3.2 million (40% of the business revenues) in the Mamanuca/Yasawa groups.

2. Background

An increasing global market for shark fins has driven a shift in exploitation of sharks from one of largely by-catch to a target fishery around the world. Typically, such fisheries are poorly managed and regulated and fail to consider the consequences of shark life-history traits of slow growth, late maturity and low fecundity (Field et al., 2009; Stevens et al., 2000). This has led to the rapid collapse of fisheries (Ferretti et al., 2008; Myers and Worm, 2003) so that today, there are many examples of severe overfishing of populations of coastal and pelagic sharks from both developed and developing countries, as well as in international waters (Baum et al., 2003; Dulvy et al., 2008; Ferretti et al., 2008; Luiz and Edwards, 2011; Myers and Worm, 2003; Stevens et al., 2000; Ward-Paige et al., 2010).

This global over-exploitation of sharks highlights the need for convincing economic arguments that can halt or reduce declines and assist the implementation of more effective conservation strategies (Vianna et al. 2010, Clua et al. 2011). Worldwide concern over the ecological and economic impacts of the loss of sharks as apex predators in marine ecosystems has led a number of small island nations to grant greater protection to shark populations. Since the Republic of Palau created a nationwide shark sanctuary in 2009, other Pacific island states such as the Republic of the Marshall Islands and the territories of Tokelau, Guam and the Northern Marianas have followed suit by banning commercial shark fishing and the trade of shark parts, including fins, within their waters. These bans are not restricted to the Pacific Ocean: the Republic of the Maldives recently implemented the first nationwide shark sanctuary in the Indian Ocean and the Honduras and the Bahamas have also created sanctuaries extending bans on commercial shark fishing to Atlantic waters. Protection measures have also been adopted by the American states of Hawaii, Oregon, Washington and the more recently California, which effectively ban commercial shark fishing and the shark fin trade off the west coast of the United States. In 2011, the Canadian cities of Toronto, Oakville and Mississauga also adopted shark conservation measures and passed bans on the sale of shark fins, thus targeting the marketing of shark products.

The trend towards conservation by tropical island states has been assisted by the increasing recognition of the value of sharks as a non-consumptive resource for a shark-diving tourism industry that is growing very rapidly (Gallagher and Hammerschlag, 2011). As of 2011, established shark-diving operations are found in at least 83 locations in 29 countries, including tropical and temperate waters around the world (Gallagher and Hammerschlag, 2011). Destinations with well-established shark-diving include countries such as South Africa, the United States and Australia. However, in 2010, island nations of Oceania and the Greater Caribbean together were responsible for approximately 38% of the locations offering dedicated shark encounters for divers (Gallagher and Hammerschlag, 2011).

The analysis of the economic revenues generated by the shark-diving industries across the Indo-Pacific has highlighted the high economic value of sharks as a non-consumptive resource for nations where tourism represents a major part of the economy. In French Polynesia, the dive industry based on interactions with lemon sharks in the lagoon of Moorea Island was estimated to generate approximately US $5.4 million annually (Clua et al. 2011). Similarly, the shark-diving industry in Palau, Micronesia, was estimated to generate US $18 million per year, accounting for approximately 8% of the gross domestic product (GDP) of the country (Vianna et. al. 2010). These studies demonstrate substantial benefits to several sectors of the local economy and the high economic value associated with the conservation of sharks.

The Republic of Fiji is one of the most developed island nations in the Indo-Pacific, with tourism occupying a central role in the economy of the country (Central Inteligence Agency, 2011). Similar to other destinations across the region, nature tourism represents one of the main products of the tourism industry in Fiji (Anon., 2009). The diving industry in Fiji is well-established, with dive centres spread across all the main tourist destinations as well as relatively remote areas. Shark-diving activities have been identified in at least three destinations where they rely on the observation of different species ranging from reef to large coastal sharks (Gallagher and Hammerschlag, 2011). The shark-diving industry in Fiji has been described as having an important socio-economic role, generating jobs and revenues to local community (Brunnschweiler, 2009), but the amount of this contribution to the economy as a whole in Fiji remains unknown. Here, we address this issue using socio-economic surveys of the main tourism operators of the shark-diving industry and diving tourists visiting Fiji. We quantify the economic value of the shark-diving industry in the country, including the economic revenues generated by divers and the distribution of these revenues to the principal local stakeholders involved with the industry including businesses, government and local community.

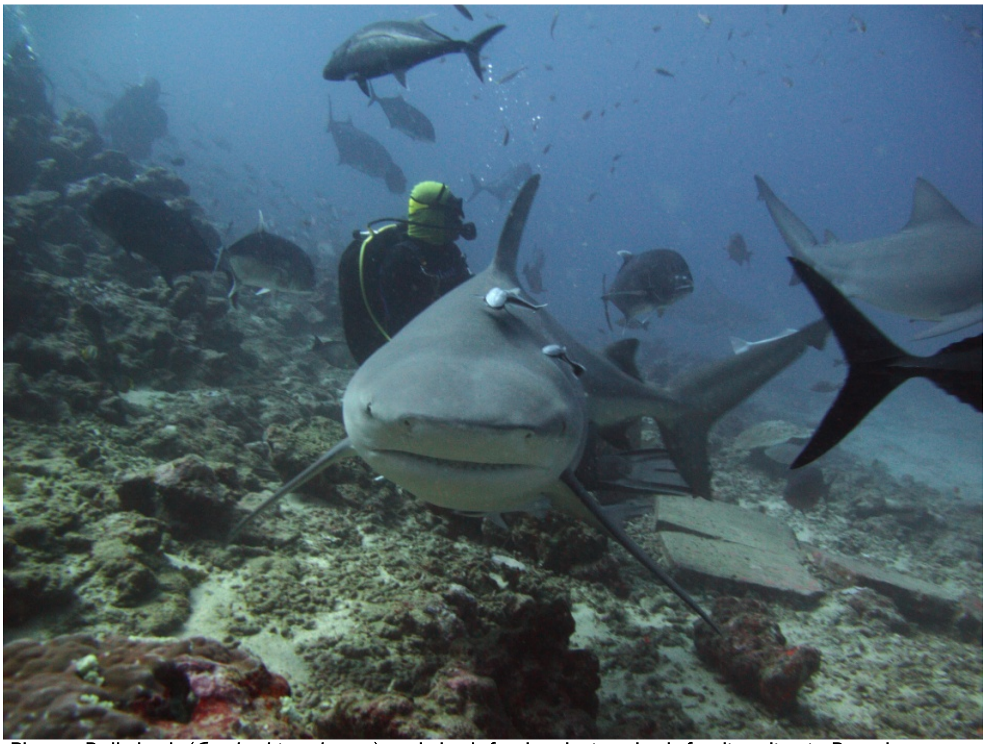

Photo: Bull shark (*Carcharhinus leucas*) and shark feeder during shark-feeding dive in Beqa lagoon. Photo by Gabriel Vianna

3. Methods

3.1 Shark-diving in Fiji

Fiji has a well-established diving industry with resorts and independent businesses offering diving operations on the main islands and island groups across the country. Many dive operations in Fiji advertise in-water interactions with sharks. While many of these activities rely on opportunistic sightings, dedicated shark-diving operations exist in specific areas (Table 1). For the purpose of this study, we defined "shark-diving" as a SCUBA dive in which a planned underwater interaction with sharks was the primary attraction of the dive.

3.1.1 Viti Levu

Pacific Harbour and the Coral Coast

Pacific Harbour is the most famous shark-diving destination in Fiji as it offers the opportunity of reliable sightings of a number of species of large sharks. Bull (*Carcharhinus leucas*) and tiger sharks (*Galeocerdo curvier*) represent the main attraction for tourists diving in the area, with 120 and 5 individuals of these species identified at one of the principal dive sites respectively (Neumann pers. comm.). Besides these large coastal sharks, six smaller species are typically sighted, including grey reef (*Carcharhinus amblyrhynchos*), whitetip reef (*Triaenodon obesus*), blacktip reef (*C. melanopterus*), silvertip (*C. albimarginatus*), sicklefin lemon (*Negaprion acutidens*) and tawny nurse (*Nebrius ferrugineus*) sharks.

Two operators specialise in shark-feeding dives, offering dive trips four to five days per week at two dive sites next to Pacific Harbour in Beqa Lagoon (Figure 1). Five resorts and one liveaboard boat operation based in areas nearby have established agreements with one of the shark-diving operators and also bring their divers to observe the shark-feeding operation.

Pacific Harbour in Beqa Lagoon has gained increasing attention of the international diving community as a world-class destination for shark-diving, due to the size, diversity and abundance of sharks and the reliability with which they can be observed. This place is the main attraction for shark-divers visiting Fiji and is located on the southern coast of the main island of Viti Levu close to international airports (Figure 1). This ease of access makes Pacific Harbour a popular destination for both divers that travel to Fiji specifically to see sharks (hereafter termed "dedicated shark-divers") and divers that choose shark-focused dives as just part of a wider experience of diving in Fiji (hereafter termed "casual shark-divers").

In addition to Pacific Harbour, a smaller shark-feeding dive is also operated three times a week from a resort situated at the Coral Coast (southern coast of Viti Levu). This operation relies on attracting divers to engage with approximately 15 whitetip and blacktip reef sharks.

Bligh waters

Dive operators based on the northern coast of Viti Levu (Rakiraki area and Nananu-I-Ra island) (Figure 1) and liveaboard vessels based on Viti Levu offer dive trips to the area of Bligh Waters. This area is advertised mainly as a destination to see soft coral. However, the opportunity to view sharks is the focus of at least one dive (Table 1). Shark-diving operations rely on opportunistic sightings of grey and whitetip reef sharks that occur at a site during specific current conditions, with approximately 10 sharks typically sighted per dive at such times.

3.1.2 Vanua Levu and Taveuni

The area of Vanua Levu and Taveuni includes dive sites at the Koro Sea and Somosomo Strait. Abundant soft corals constitute the main draw card for divers to the area. However operators also advertise shark-diving based on opportunistic sightings at two dive sites (Table 1). On Vanua Levu, a dedicated shark dive focuses on scalloped hammerhead sharks (*Sphyrna lewini*) is offered by at least three dive operators. This dive consists of opportunistic sighting at locations where hammerhead sharks are known to regularly occur. The occurrence of hammerhead sharks is believed to be tide-dependent. Therefore, the dive operators coordinate the trips to optimise the chances of shark sightings that can vary from single individuals to schools of tens of hammerhead sharks.

3.1.3 Mamanuca and Yasawa Islands

At least 16 resorts at the Mamanuca and Yasawa Islands conduct dive operations in the northwest part of Fiji. However, two areas offer shark-diving (Figure 1). Close to Mana Island in the Mamanuca group (Table 1), a site where sharks were formerly fed by dive guides known as The Supermarket, is now visited for opportunistic sightings of reef sharks. Although shark-feeding is no longer a regular activity, relatively high abundances of grey, whitetip and blacktip reef sharks are reputed to remain in the area.

A dedicated shark-feeding dive is offered in the central part of the Yasawa Islands group. Three dive operators from the islands of Tavewa, Nauya-Lailai and Nacula participate in the shark-diving at this site (Figure 1, Table 1), with dives offered twice a week with boats from the three operators bringing divers to the site simultaneously. This operation relies on the presence of grey, whitetip and blacktip reef sharks and occasionally lemon sharks.

3.1.4 Kadavu

The main attraction for divers visiting Kadavu (Figure 1) is the abundance and quality of hard corals of the Great Astrolabe Reef. Shark-diving in this area relies on opportunistic sightings of reef sharks including grey, whitetip and blacktip reef sharks in at least one dive site (Table 1). Besides the opportunistic sightings of sharks, an important draw card for divers visiting Kadavu is the regular and predictable sightings of manta rays (*Manta birostris*).

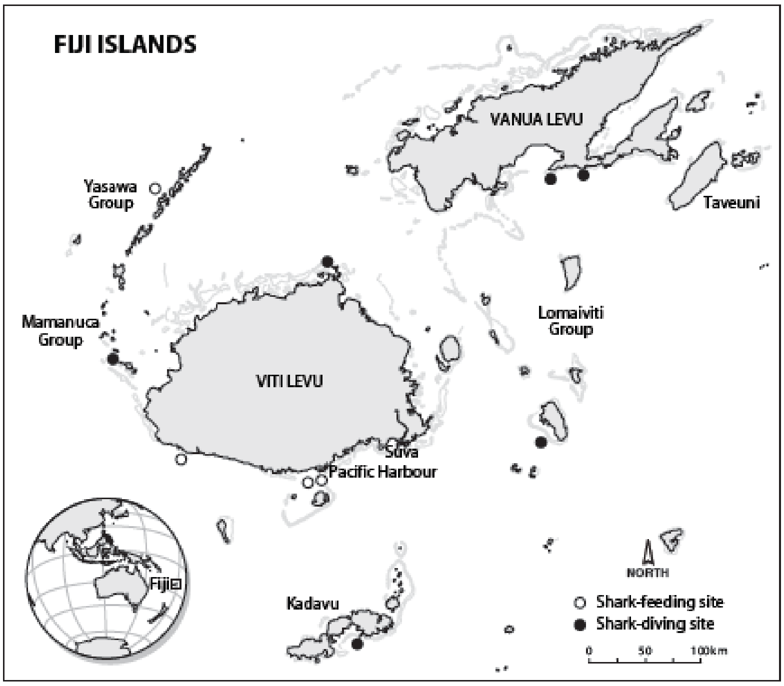

Figure 1. Main shark-diving sites of Fiji identified during survey in 2011.

Table 1. Main shark-diving sites and location in Fiji in 2011.

Dive site	Area	Type of dive	Number of operators	Frequency (days/week)	Most common species
Shark Reef Marine Reserve	Pacific Harbour-Viti Levu	Feeding	1	5	Bull, Tiger, Grey reef, whitetip and blacktip reef sharks
The Bistro	Pacific Harbour-Viti Levu	Feeding	1 (6)*	4	Bull, Tiger, lemon, tawny nurse and silvertip sharks
Breath Taker	Rakiraki-Viti Levu	Opportunistic	4	2	Grey reef, whitetip and blacktip reef sharks
Sand Patch	Coral Coast- Viti Levu	Feeding	1	3	Whitetip and blacktip reef sharks
Dream House	Savusavu-Vanua Levu	Opportunistic	4	1	Hammerhead sharks
Grand Central Station	Savusavu-Vanua Levu	Opportunistic	2	-	Grey reef, tawny nurse, whitetip and blacktip reef sharks
The Cathedral	Yasawa group	Feeding	3	2	Grey reef, lemon, whitetip, blacktip reef sharks
The Supermarket	Mamanuca group	Opportunistic **	-	-	Grey reef, tawny nurse, whitetip and blacktip reef sharks
Eagle Rock	Kadavu	Opportunistic	2	2	Grey reef and whitetip reef sharks
Nigali Pass	Gau Island-Lomai Viti	Opportunistic***	2	2	Grey reef and whitetip reef sharks

* The shark-feeding is operated by a single operator however six other operators are permitted to attend the feeding operation.
**Former shark-feeding site
*** Occasionally used for shark-feeding

3.2 Tourism in Fiji

Similarly to other Pacific Island nations, the Fijian economy relies mainly on primary production and on a tourism industry focused on the natural environment. In 2010, Fiji hosted 631,868 visitors mainly from Australia and New Zealand (66%), Asia (16%), Europe (9%) and North America (10%), who on average stayed in the country for 9.5 days (http://www.statsfiji.gov.fj). In the same year, tourism generated approximately US $558 million in revenues (Anon., 2011) and was responsible for approximately 18% of the gross domestic product (GDP) of the country (US $3,100 million) (International Monetary Fund, 2010). The per capita GDP in Fiji was estimated as US $3,524 per year in 2010.

3.2.1 Survey techniques

The socio-economic survey targeted the main stakeholders involved in the shark-diving industry in Fiji, including tourist divers, dive operators, resort managers, dive guides and members of local communities that retain traditional ownership of the reefs utilized as shark-diving sites (qoliqoli). The survey was based on self-administered questionnaires designed to target each of these groups and collect information regarding the costs and benefit of the shark-diving industry, and builds on the survey used in a similar study in Palau (Vianna et al., 2010). We conducted the onsite survey in August/September 2011, collecting a total of 336 answered questionnaires, primarily focused on divers (Table 2). We distributed questionnaires on the islands of Viti Levu (including the islands of Nananu-i-Ra and Beqa), Vanua Levu, Taveuni and Kadavu, the Yasawa and Mamanuca group.

Questionnaires were answered by 289 divers, 18 dive operators, six resort managers (surveyed at Pacific Harbour and Coral Coast only), 14 dive guides and nine local subsistence fishers (Table 2). This last group consisted of members of a local village that regularly receives payment from shark-diving operators for the usage of the reef of which they are the traditional owners. The tourist questionnaire was structured to obtain information about the demographic characteristics of the divers, their motivations in visiting Fiji, satisfaction with diving experience, and expenditures while in the country. Expenditures were divided among the categories of accommodation, living costs, diving (and shark-diving, when applicable), domestic transfers and other activities while in Fiji (e.g. land tours). Self-administered questionnaires and a printed explanation of the purpose of the research were handed to the divers at the end of the dive trips at dive operators or resorts.

The questionnaire for dive operators obtained information about the characteristics of the business, including number of tourists taking dive trips and their preferences, main dive attractions and activities, information about employees and operators' expectations regarding the dive industry. We also collected detailed information regarding the expenditures related to the diving operation, most notably the expenditures related to the cost of running a shark-diving operation and the expenditures on salaries and contributions to the local communities for usage of traditionally-owned reef. This questionnaire was answered by the main operators engaged in dedicated shark-diving in Fiji, including all the shark-diving operators at Pacific Harbour, the principal destination for shark-diving in the country.

We interviewed 13 Fijian and one English dive guide working for eight different dive operators distributed across the country (Table 2). This sample reflects the high proportion of Fijian citizens employed by the diving industry in the country. The dive-guide questionnaire provided information about the salaries paid by the diving industry, popular shark-diving sites and their characteristics and number of tourists visiting these sites annually.

Since conservation regulations were likely to affect fishing activities, fishers were also surveyed using a standard questionnaire. This provided information about their fishing activities, techniques, level of interaction with sharks, perception of shark conservation and income from fishing. The interviews were conducted at Galoa, which is one of the main villages benefiting from the community levy paid by the shark-diving operators at Pacific Harbour.

All interviews were conducted in accordance with the requirements of the National Statement on Ethical Conduct in Human Research (Australia) and the policies and procedures of The University of Western Australia.

Table 2. Number of questionnaires collected during the survey in Fiji in August/September 2011.

Area	Questionnaires					Estimated no. of dive operators in the area
	Divers	Dive guides	Fishers	Resorts	Dive operators	
Fiji	289	14	9	6	18	-
Viti Levu	196	6	8	6	10	14
Pacific Harbour*	180	4	8	6	2	2 (6)**
Mamanuca/Yasawa group	34	0	1	0	4	16
Vanua Levu/ Taveuni	34	6	0	0	4	10
Kadavu	25	2	0	0	0	5

*Data from Pacific Harbour are a sub-sample of data from Viti Levu.
** These six dive operators are based either at resorts along the Coral Coast or on islands in the area. These operators also attend shark-feeding dives operated from the Pacific Harbour.

3.2.2 Economic variables and data analysis

We took a conservative approach to all calculations in order to reduce the risk of over-estimating the value of shark-diving to the Fijian economy. Our calculations were based on the parameters and estimates calculated from our surveys, combined with official estimates of the number of visitors from the Fiji Bureau of Statistics: (http://www.statsfiji.gov.fj/Tourism/Visitor_Arrivals.htm).

Our key calculations were as follows:

(1) Total number of divers visiting the country (D) was based on the proportion of tourists engaged in dive activities from the Fiji International Visitor Survey 2009 Report, published by the Ministry of Public Enterprises, Communications, Civil Aviation & Tourism (Anon. 2009).
(2) Total revenues from dedicated shark-divers (SD) were calculated as all expenditures of the proportion of surveyed divers visiting Fiji primarily to engage in shark-diving activities. The contribution of this group to the shark-diving industry was termed the shark-diving parameter (SDP).
(3) Total revenues derived from casual shark-divers (CSD) were calculated as a proportion of the expenditures of divers who visited Fiji for reasons other than diving with sharks, but chose to engage in shark-diving while in the country; for this reason expenditures for casual shark divers were allocated as the proportion of their trip spent shark diving, rather than for their entire visit. The contribution of this group to the shark-diving industry was termed the casual shark-diving parameter (CSDP).

A detailed list of variables, parameters, formulas and data sources is presented in Table 3.

Table 3. Description of constants and parameters used to estimate revenues generated by the shark-diving industry in Fiji.

Abbreviation	Constants and estimates	Description	Values	Units	Source	Comments
Fiji						
T	Visitors in Fiji in 2010	Average number of visitors in the area	631,868	No./Year	Bureau of statistics, 2011	
D	Number of divers in 2010	T x 0.1	63,187	No./Year	Anon., 2009	Based on the estimate that 10% of tourists engage on diving activities while in Fiji.
TSD	Total number of shark-divers	SD + CSD	49,286	No./Year	Based on interviews with shark-diving operator managers	Estimate based on the number of shark-divers hosted by each shark-diving operator
SD	Number of dedicated shark-divers	SDP x D	15,165	No./Year		Dedicated shark-diver is defined as a diver who visits Fiji primarily to dive with sharks
CSD	Number of casual shark-divers	CSDP x D	34,121	No./Year	Operators questionnaire	Casual shark-diver is defined as a tourist who visited Fiji for a reason other than shark-diving but was engaged in shark-diving actives while in the country.
SDP	Shark-diving parameter	Proportion of shark-divers	0.24	-	Tourist questionnaire	Calculated as the proportion of divers who answered the questionnaire who were dedicated shark-divers
CSDP	Casual shark-diving parameter	Proportion of casual shark-divers	0.54	-	Tourist questionnaire	Calculated as the proportion of divers who answered the questionnaire who were casual shark-divers
Pacific Harbour						
T harb	Tourists visiting the area in 2010	T Coral Coast/ No of accom. at Coral Coast x no. of accom. at P. Harbour	24,879	No./Year	Estimated based on Anon., 2009, Bureau of statistics, 2010 and 2011	Estimates based on the percentage of tourist spending most of the time in Fiji in this area (Anon., 2009)
D harb	Number of divers per year	Sum of number of divers hosted by each operator	9,205	No./Year	Based on the interviews with dive-operator managers	
TSD harb	Total number of shark-divers	SD + CSD	8,616	No./Year	Based on interviews with shark-diving operator managers	
SD harb	Number of dedicated shark-divers	SDP harb x TD harb	2,836	No./Year		
CSD harb	Number of casual shark-divers	CSDP harb x TD harb	5,780	No./Year		
SDP harb	Shark-diving parameter	Proportion dedicated of shark-divers harb	0.31	-	Tourist questionnaire	
CSDP harb	Casual shark-diving parameter	Proportion of casual shark-divers hard	0.63	-	Tourist questionnaire	

Viti Levu						
T viti	Tourists visiting the area per year	T x 0.62	384,439	No./Year	Based on Anon., 2009, Bureau of statistics, 2011	Calculated based on estimates of the percentage of tourist spending most of the time at this area (Anon., 2009)
D viti	Number of divers per year	Ave. no. divers per operator x no. of operators	19,033	No./Year	Operators questionnaire	
TSD	Total number of shark-divers	SD + CSD	17,320	No./Year	Based on interviews with shark-diving operator managers	
SD viti	Number of shark-divers	D viti x SDP viti	5,329	No./Year	Operators questionnaire	
CSD viti	Number of casual shark-divers	CSDP viti x D viti	11,991	No./Year	Operators questionnaire	
SDP viti	Shark-diving parameter	Proportion of dedicated shark-divers viti	0.28	-	Tourist questionnaire	
CSDP viti	Casual shark-diving parameter	Proportion of casual shark-divers viti	0.63	-	Tourist questionnaire	
Vanua Levu/Taveuni						
T vanu	Tourists visiting the area per year	T x 0.02	12,637	No./Year	Based on Anon., 2009, Bureau of statistics, 2011	
D vanu	Number of divers per year	Ave. no. divers per operator x no. of operators	6,170	No./Year	Operators questionnaire	
TSD	Total number of shark-divers	SD + CSD	3,582	No./Year	Based on interviews with shark-diving operator managers	
SD vanu	Number of shark-divers	D vanu x SDP vanu	796	No./Year	Operators questionnaire	
CSD vanu	Number of casual shark-divers	CSDP vanu x D vanu	2,786	No./Year	Operators questionnaire	
SDP vanu	Shark-diving parameter	Proportion of dedicated shark-divers vanu	0.13	-	Tourist questionnaire	
CSDP vanu	Casual shark-diving parameter	Proportion of casual shark-divers vanu	0.45	-	Tourist questionnaire	
Mamanuca/Yasawa Group						
T maya	Tourists visiting the area per year	T x 0.21	132,692	No./Year	Based on Anon., 2009, Bureau of statistics, 2011	
D maya	Number of divers per year	Ave. no. divers per operator x no. of operators	20,544	No./Year	Operators questionnaire	
TSD	Total number of shark-divers	SD + CSD	10,876	No./Year	Based on interviews with shark-diving operator managers	
SD maya	Number of shark-divers	D maya x SDP maya	2,417	No./Year	Operators questionnaire	
CSD maya	Number of casual shark-divers	CSDP maya x D maya	8,459	No./Year	Operators questionnaire	
SDP maya	Shark-diving parameter	Proportion of dedicated shark-divers maya	0.12	-	Tourist questionnaire	
CSDP maya	Casual shark-diving parameter	Proportion of casual shark-divers maya	0.41	-	Tourist questionnaire	

Our study estimated the total economic revenue generated by the shark-diving industry and the magnitude of the key components of that revenue. We recognize that economic revenue does not equate to net economic benefits from the industry; calculation of this would have required estimates of both the supply and demand curves for shark-diving services, in order to calculate producer and consumer surpluses (Just et al., 2005). This calculation was beyond the scope of this study, given the lack of market data available for statistical analysis of supply or demand. However, revenue provides a useful indicator of the economic importance of the industry, and is consistent with common economic metrics such as GDP. This approach also allows us to focus on economic benefits that are retained within Fiji, whereas much of the producer and consumer surpluses generated by the industry may be captured by foreign businesses and consumers. To further reduce the influence of leakage between sectors of the economy, the analysis of the direct, indirect and induced benefits from shark-diving was restricted to quantifying the revenues obtained by businesses that benefited directly by the presence of shark-divers (i.e. dive operators, hotels, resorts, restaurants and souvenir shops). The calculation of the flow of economic revenues from shark-diving to the local community was restricted to wages provided by the dive operators to their employees and the community levy paid by the dive operators to the villages to use shark-diving sites located at their traditional fishing grounds.

Photo: Bull sharks (*Carcharhinus leucas*) photographed during shark dive at Beqa Lagoon (Pacific Harbour). Photo by: Gabriel Vianna

Table 4. Description of formulas used to estimate economic revenues generated by the shark-diving industry in Fiji.

Abbreviation	Variables	Formula	Units	Source	Comments
Expenditures					
DET	Diver expenditure per trip	Living costs + Diving expenses + Extra expenses + Transfer expenses	US$/Trip	Tourist questionnaires	Average of the total expenditures in the specified categories by divers. "Extra" includes extras expenses during the trip not specified in the other categories (i.e. souvenirs, land-based tours, etc). Transfer expenses includes domestic transfers only.
DDE	Daily diver expenditure	DET/Length of stay	US$/Day	Tourist questionnaires	
DED	Diver expenditure on dives	Average diving expenses	US$/Trip	Tourist questionnaires	Average expenditure of a diver on dives per trip
DESD	Diver expenditure on shark-diving	Average expense on shark-diving trips	US$/Trip	Tourist questionnaires	
CSDEST	Casual shark-diver expenditure on shark-diving trips	DED x Percentage spent on shark-diving	US$/Trip	Tourist questionnaires	1 day of living costs covers the costs of meals and transfers while in the area.
TDET	Total diver expenditure per trip	DET + DT	US$/Trip		
Business revenues from tourism					
BRSD	Business revenues from dedicated shark-divers	SD x DET	US$/Year		
BRCSD	Business revenues from casual shark-divers	CSD x CSDEST	US$/Year		For this calculation CSD was divided into the sub-classes of divers who visit Fiji primarily for diving and divers who visit Fiji for other activities but were engaged in diving activities while in the country.
BRS	Business revenues from shark-diving	BRSD + BRCSD	US$/Year		
Economic benefits from shark-diving to community					
SSDI	Salaries from shark-diving industry	W x (SD x DED + CSD x DESD)	US$/Year	Operators questionnaire	Expenditure of the shark-diving industry on salaries
CLSD	Community levy from shark-diving	L x TSD	US$/Year		The estimate of CLSD Fiji takes into account solely L harb,L maya and L coral
Tax revenues from shark-diving					
DTSD	Direct taxes from shark-divers	SD x (DET x VAT + DT + HTT/2) + (BRCSD x VAT)	US$/Year		
CTSD	Corporate tax from shark-diving	CT x BRS	US$/Year		CTSD is the sum of revenue taxes from shark-divers from diving, accommodation and other expenses
Costs of shark-diving					
CSDO	Cost of shark-diving operation	C x TSD x DESD	US$/Year	Operators questionnaire	Represents the expenditure of shark-diving operations on: fuel, maintenance, licenses, wages and extra costs of dive operation
Total revenues					
TRS	Total economic revenues from shark-diving	BRCSD + (SD x TDET)	US$/Year		
TTRSD	Total tax revenues from shark-diving	DTSD + CTSD	US$/Year		
DCISD	Direct community income from shark-diving	SSDI + CLSD	US$/Year		

3.2.3 Business revenues from shark-diving

The economic importance of shark-diving varies among areas in Fiji. For this reason, in addition to national estimates of economic revenues of the shark-diving industry we present the local economic revenues from shark-diving for popular diving areas in Fiji (i.e. Viti Levu, Vanua Levu/Taveuni and Mamanuca/Yasawa groups). The economic value of shark-diving in Pacific Harbour is presented both separately and as part of Viti Levu. The lack of official statistics and data from the dive industry prevented calculation of the economic value of shark-diving on Kadavu. However, we present the parameters estimated for the area based on other data collected during the survey.

The annual business revenue from sharks (BRS) in the shark-diving industry and associated businesses was estimated as

$$BRS = BRSD + BRCSD \qquad (1)$$

BRSD was the business revenue generated by dedicated shark-divers:

$$BRSD = SD \times DET \qquad (1.1)$$

where DET was the average expenditure per dive tourist, per trip (Table 5), and SD was the number of dedicated shark-divers visiting Fiji in a year. BRCSD represented the business revenues from casual shark-divers for the portion of their trip spent shark-diving calculated as

$$BRCSD = CSD \times CSDEST \qquad (1.2)$$

where CSD was the number of casual shark-divers (from official statistics and survey data combined – see Table 4) and CSDEST was the expenditure of casual shark-divers on shark-diving trips (Table 4). DET consisted of diving expenses, living costs, (food and accommodation), domestic transfers and other expenditure such as souvenirs (data from surveys), over the duration of the visit to Fiji.

Table 5. Estimates of individual expenditures of divers and shark-divers. All figures are US$.

Area	Diver expenditure on dives (DED)	Diver expenditure on shark-diving (DESD)	Diver expenditure Per trip (DET)	Daily diver expenditure (DDE)	Casual shark-diver expenditure on shark-diving trip (CSDEST)	Total diver expenditure Per trip (TDET)	Living cost	Extra	Transfer
Fiji	555	269	2,300	212	196	2,343	1,168	577	12[illegible]
Viti Levu	396	254	1,383	329	240	1,426	707	171	11[illegible]
Pacific Harbour*	406	253	1,368	334	242	1,411	699	158	10[illegible]
Vanua Levu/Taveuni	554	427	2,899	659	420	2,942	1,386	657	30[illegible]
Mamanuca/ Yasawa	294	101	789	263	150	832	247	68	18[illegible]

* Pacific Harbour is a subgroup of Viti Levu.

The total number of divers visiting Fiji annually was estimated as 10% of the number of visitors to Fiji in 2010 (Bureau of Statistics 2011, Anon. 2009). This value was used to estimate the numbers of shark-divers, casual shark-divers and divers not participating in shark diving visiting Fiji annually and thus the annual business revenue from diving tourism as a whole.

3.2.3 Economic benefits to the community

A component of business revenue from shark-diving is dispersed through the Fijian economy by payment of salaries to employees of dive businesses and by regular payments of the community levy by the dive operators. The latter is the fee paid by dive operators to the traditional owners for use of the reef. Together, these two components constituted the direct community income from shark-diving (DCISD), calculated as follows:

$$DCISD = SSDI + CLSD \qquad (2)$$

where SSDI represented the salaries paid by the shark-diving industry and defined as

$$SSDI = W\,(SD \times DED + CSD \times DESD) \qquad (2.1)$$

and W was the proportion of dive industry income that was allocated to paying wages and salaries (estimated from the operator questionnaire), DED was diver expenditure on dives, and DESD was the diver expenditure on shark-diving (estimated from tourist questionnaires), (Tables 4 & 6).
The community levy from shark-diving paid to the community annually (CLSD) was calculated as

$$CLSD = L \times TSD \qquad (2.2)$$

where L represented the levy paid by each shark-diver to the communities who were the traditional owners of the shark-diving site, and TSD was the total number of shark-divers visiting the site (Tables 4 and 6).

Table 6. Description of tax constants and community levy used to estimate contribution generated by the shark-diving industry in Fiji.

Abbreviation	Constants and parameters	Description	Values	Units	Source	Comments
CT	Corporate income tax		0.28	-		
DT	Departure tax		43	US$/Trip		The airport departure tax is usually prepaid with the air ticket. This tax was increased to US$ 57 in 2011
VAT	Value added tax	Tax on spendings paid by final consumer in all goods and services	0.125	-		Value added tax was increased to 15% in Jan 2011
HTT	Hotel turnover tax	Accommodation cost x 0.05	0.05	-		
W	Wages parameter	Percentage of revenues of dive industry addressed to pay wages	0.22	-	Operators questionnaire	
C	Diving costs parameter	Percentage of revenues of the dive industry used to pay costs of diving operation	0.64	-	Operators questionnaire	Represents the percentage of total revenues spent by dive operators on: fuel, maintenance, licenses, wages and extra costs of dive operation
L harb	Pacific Harbour community levy	Levy to the community paid by divers when engaged in shark-diving	8	US$/Diver	-	This levy is paid directly to the community that retains the traditional ownership of the reef where the shark-diving is operated
L maya	Yasawa community levy		5	US$/Diver	-	
L coral	Coral coast community levy		1.1	US$/Diver	-	

3.2.4 Tax revenue

The tax revenue from the shark-diving industry was composed of two elements. Firstly, the corporate tax from shark-diving (CTSD) included the taxes paid by dive operators and accessory services that could be attributed to the economic revenues generated by shark-divers. This tax was defined as:

$$CTSD = CT \times BRS \quad (3)$$

where CT represented the corporate tax parameter (Table 5).

The second component was the direct tax from shark-divers (DTSD). This included the contributions charged directly to shark-divers (dedicated and casual shark-divers) in all goods and services related to shark-diving while in Fiji and includes the departure taxes paid by shark-divers who visited Fiji primarily to engage in shark-diving activities. This contribution was defined as:

$$DTSD = SD \times (DET \times VAT \times DT + HTT/2) + (BRCSD \times VAT) \quad (4)$$

where VAT represented the Values Added Tax paid by the final consumer for all goods and services in Fiji (Table 5). The departure tax (DT) is usually charged during the purchasing of air ticket and remitted directly to the Fiji Revenue and Customs Authority. The hotel turnover tax (HTT) is the tax contribution on the cost of accommodation, and was divided by two to account for the fact that the majority of tourists visiting Fiji share accommodation between two people (Anon. 2009). The calculation of direct taxes from shark-divers only considered the departure taxes and the hotel turnover taxes paid by dedicated shark-divers as diving with sharks was the primary reason for this group to visit Fiji.

3.2.5 Operational costs of shark-diving

A complete analysis of the operational costs involved in shark-diving tourism would need to include all sectors of the economy of Fiji that provide services to shark-divers. Such an analysis was beyond the scope of the present study. However, we suggest that an analysis of the direct economic cost of shark-diving to diving operators is indicative of the linkages between the shark-diving industry and the general economy of Fiji. Data from the questionnaires supplied to the dive operators provided an estimate of general costs of fuel, equipment maintenance, governmental licenses, wages and extra costs involved in the dive operation in Fiji. The operational cost of shark-diving (CSDO) was then calculated as follows:

$$CSDO = C \times TSD \times DESD \quad (5)$$

where C was the percentage of the business revenues of the dive operators used to cover costs of operation on fuel, maintenance, licenses, wages and extra costs (Table 5).

3.2.6 Total economic revenues from shark-diving

The total economic revenue (TRS) generated by shark-diving in Fiji was defined as business revenue and the departure tax contribution of shark-divers:

$$TRS = BRCSD + (SD \times TDET) \quad (6)$$

where TDET was the diver expenditure per trip combined with departure tax (Tables 4 and 5).

4. Results

4.1 Demographics and profile of respondents

Dedicated shark-divers, those who visited Fiji primarily to dive with sharks, accounted for 24% of all divers we interviewed, with casual shark-divers representing 54% of the divers interviewed. Assuming that these figures are representative, we estimate that in 2010 approximately 49,000 divers were engaged in shark-diving activities in Fiji. This group consisted of both dedicated and casual shark-divers who represented 78% of the 63,000 divers visiting the country (Table 3).

Respondents to our questionnaire were almost exclusively composed of adult divers (98%), with 59% of our sample males and 41% females. These divers originated primarily from Europe (31%), North America (23%) and Australia (23%) (Figures 2 and 3).

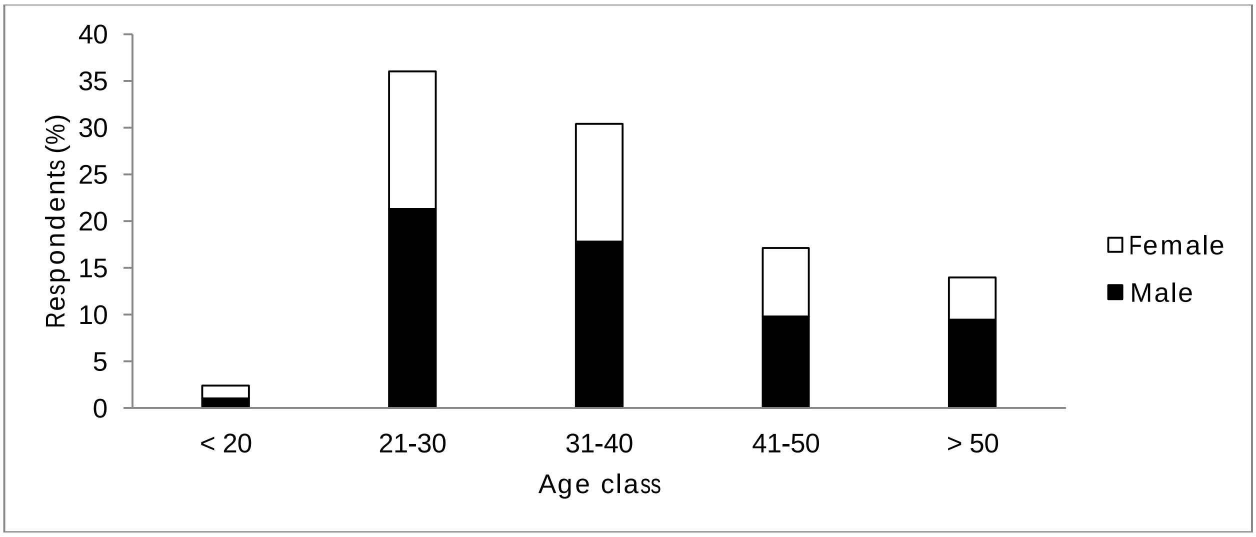

Figure 2. Distribution of divers by age and gender in sample collected during survey in Fiji in August/September 2011.

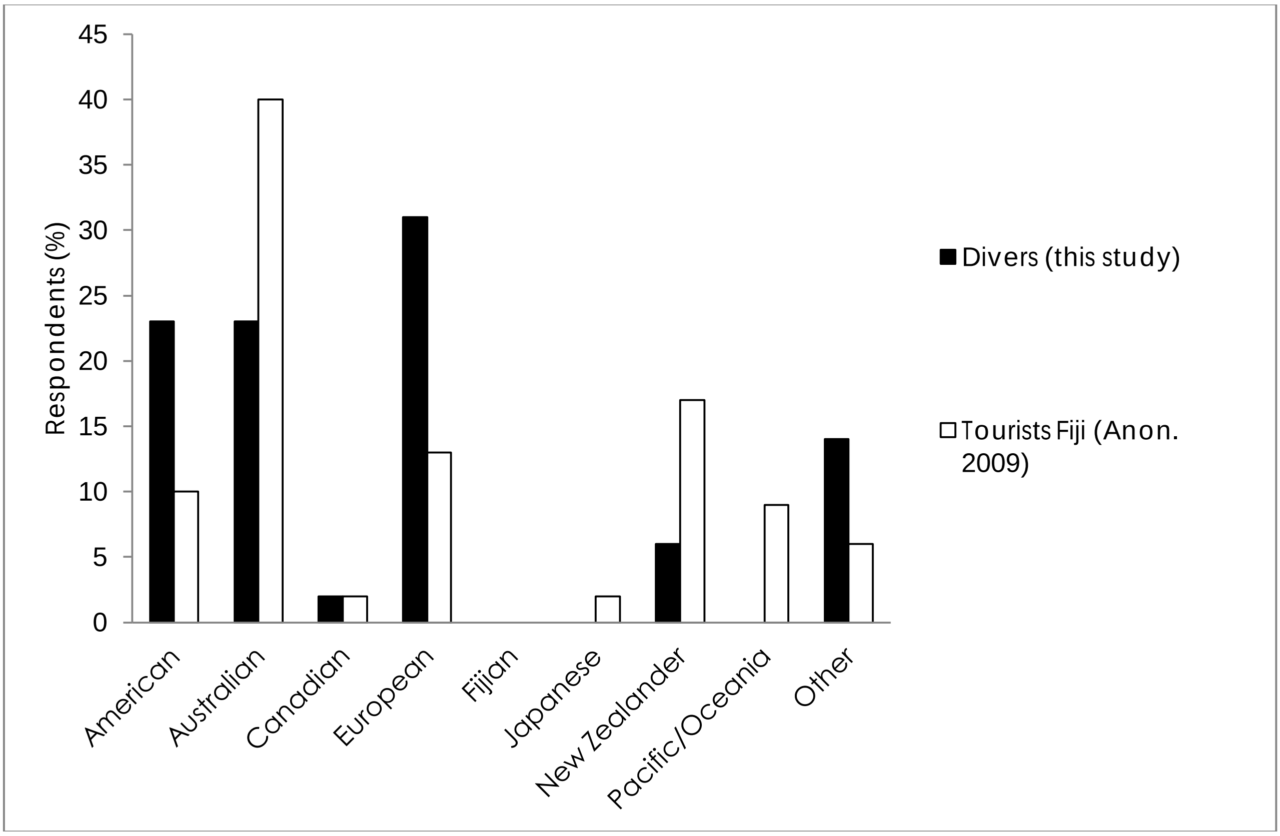

Figure 3. Distribution of divers by area of origin in sample collected during survey in Fiji in August/September 2011, compared with distribution of all tourists (Anon. 2009).

The general level of experience of divers was low, with approximately 30% of divers having completed more than 100 dives. However, dedicated shark-divers tended to be more experienced, with 64% of this group having logged more than 100 dives (Figure 4). Approximately 40% of divers reported an annual income higher than US $80,000 (Figure 5).

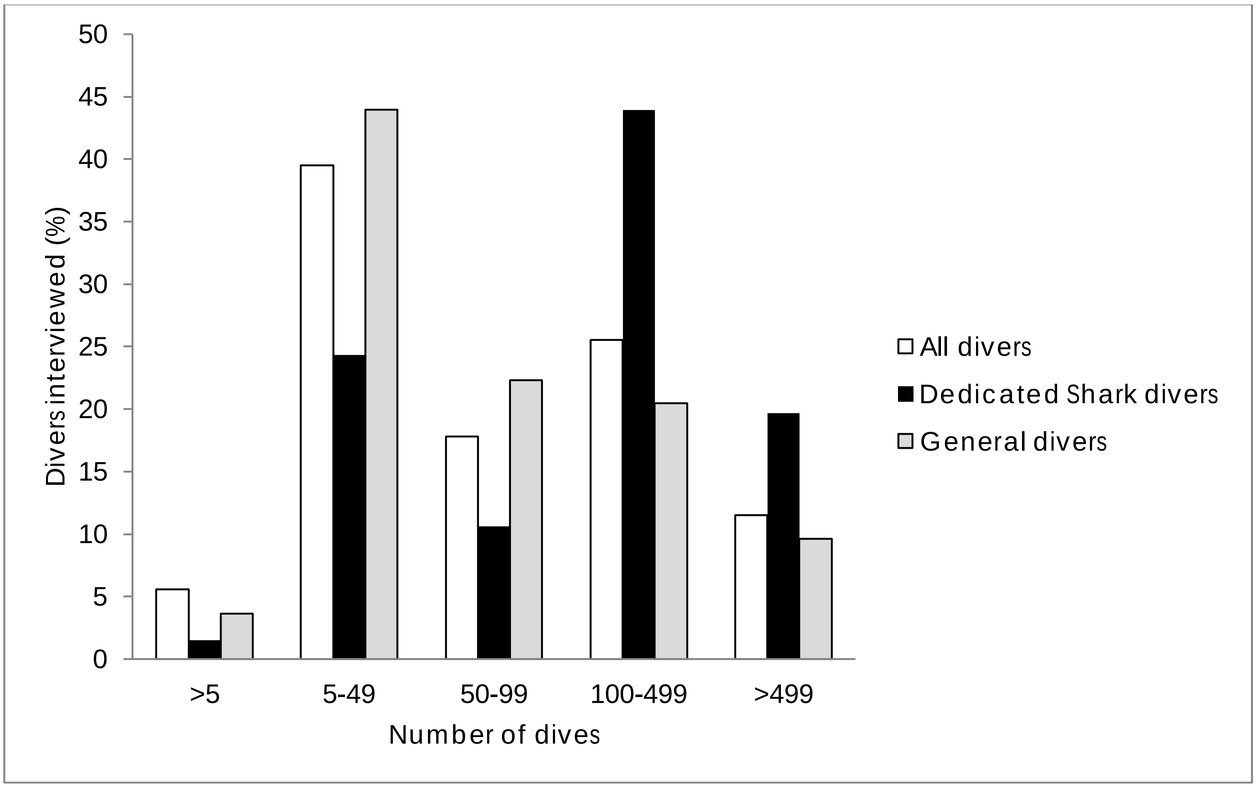

Figure 4. Distribution of divers by diving experience in sample collected during survey in Fiji in August/September 2011.

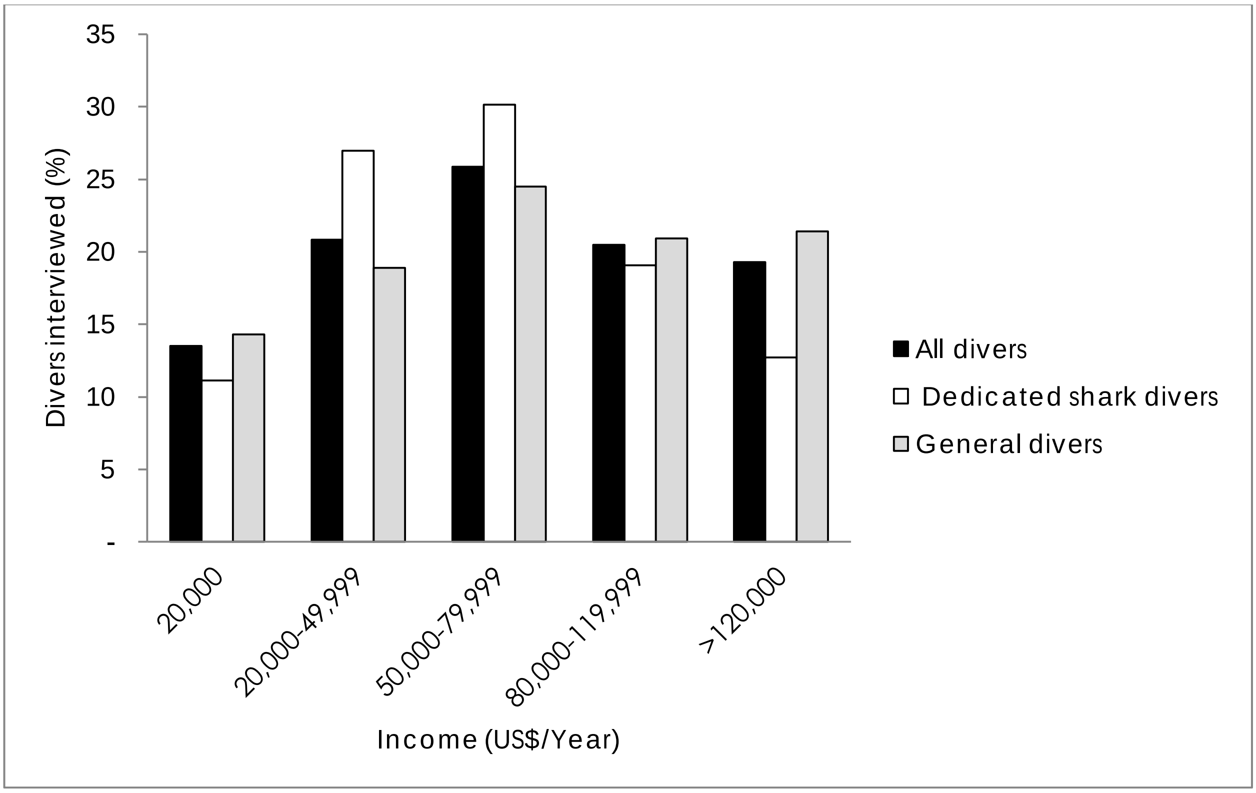

Figure 5. Distribution of divers by income in sample collected during survey in Fiji in August/September 2011.

4.1.1 Shark-diving regions

Viti Levu hosted the largest number (approximately 17,000) of dedicated and casual shark-divers. In this area, Pacific Harbour hosted around 50% of the shark-divers, or approximately 8,600 tourists (Table 3). Of all the divers interviewed in other areas of Fiji, 42% reported they visited Pacific Harbour to dive with sharks while in the country.

The Mamanuca/Yasawa group also hosted a large number of shark-divers, with approximately 11,000 divers engaged in shark-diving activities (Table 3). The area of Vanua Levu/Taveuni hosted approximately 3,600 shark-divers, which represented 58% of the divers visiting the area. Kadavu had the lowest proportion of shark-divers of all regions, with 17% of divers identified as casual shark-divers and no dedicated shark-divers interviewed during our survey.

4.2.2 Business revenues of shark-diving

Based on our estimates of expenditures by divers (Tables 4 and 5) and on the numbers of divers visiting the country provided by official statistics (Bureau of Statistics 2011, Anon. 2009), the diving industry in Fiji generates approximately US $79.5 million in business revenues per year. Shark-diving represents an important sector of this industry accounting for 52% of the business revenues, or approximately US $41.6 million.

Regionally, the shark-diving industry was responsible for generation of US $10.2 million on Viti Levu, accounting for 63% of the business revenues from diving in this area (Table 7). The Mamanuca/Yasawa group hosted the second largest number of shark-divers in Fiji, and generated approximately US $3.2 million in business revenues. The shark-diving industry was less important in the Mamanuca/Yasawa group than in other areas of Fiji, however it was still responsible for 40% of the business revenues from the diving industry in the region.

Table 7. Business revenues from the shark-diving industry in Fiji in 2010. All figures are millions of US$.

Area	Shark-divers (BRSD)	Casual shark-divers (BRCSD)	Total shark-diving (BRS)	Total diving	Relative importance of shark-diving (%)
Viti Levu	7.3	2.9	10.2	16.1	63
Pacific Harbour*	3.9	1.4	5.3	7.9	67
Mamanuca/Yasawa	1.9	1.3	3.2	7.8	40
Vanua Levu/Taveuni	2.3	1.2	3.5	8.1	43

*Data of Pacific Harbour is a sub-sample of data from Viti Levu

4.2.3 Economic benefits to the community from shark-diving

The shark-diving industry in Fiji generated a minimum of US $4 million to local communities annually. These economic benefits could be divided into two components: the first and largest consisted of the salaries paid by the industry to employees and was estimated as US $3.9 million (Table 8). The second was a community levy paid by dive operators (and ultimately by shark-divers) to the villages for the usage of the reef (Table 6) and was estimated to be US $124,200 annually. The distribution of these revenues was restricted to five villages located close to the Pacific Harbour (US $69,900) and at the Mamanuca/Yasawa group (US $54,300). In these two areas, the shark-diving industry payments of salaries in the same period were estimated to be US $575,000 and US $344,000 respectively (Table 8).

Table 8. Salaries generated by the shark-diving industry in Fiji in 2010. All figures are US$.

Area	Salaries from shark-diving industry			Salaries from the diving industry	Relative importance of shark-diving (%)
	Total shark-diving industry (SSDI)	Dedicated shark-divers	Casual shark-divers		
Fiji	3,871,000	1,852,000	2,019,000	7,444,000	52
Viti Levu	1,134,000	464,000	670,000	1,800,000	63
Pacific Harbour*	575,000	253,000	322,000	858,000	67
Mamanuca/Yasawa	344,000	156,000	188,000	861,000	40
Vanua Levu/Taveuni	359,000	97,000	262,000	834,000	43

*Data of Pacific Harbour is a sub-sample of data from Viti Levu

4.2.4 Tax revenues from shark-diving

The total tax contribution of the shark-diving industry in Fiji was estimated as US $17.5 million. This contribution can be divided in two components: the corporate taxes from shark-diving, estimated to be US $11.6 million and the direct taxes from shark-divers estimated as US $5.9 million (Table 9).

Table 9. Tax contribution generated by the shark-diving industry in Fiji in 2010. All figures are millions of US $.

Area	Direct taxes from diving industry				Corporate taxes from diving industry				Total tax revenues from shark-diving (TTRSD)
	Shark-diving total (DTSD)	Dedicated shark-divers	Casual shark-divers	Diving total	Shark-diving total (CTSD)	Dedicated shark-divers	Casual shark-divers	Diving total	
Fiji	5.9	5.0	0.8	11.3	11.6	9.8	1.9	22.4	17.5
Viti Levu	1.5	1.1	0.4	2.4	2.9	2.0	0.8	4.5	4.4
Pacific Harbour	0.8	0.6	0.2	1.2	1.5	1.1	0.4	2.2	2.3
Mamanuca/Yasawa	0.5	0.3	0.2	1.3	0.9	0.5	0.4	2.2	1.4
Vanua Levu/Taveuni	0.5	0.3	0.1	1.1	1.0	0.6	0.3	2.3	1.5

4.2.5 Total revenues from shark-diving

The total contribution of shark-diving to the economy of Fiji was estimated to be US $42.2 million ($35.5 million and $6.7 million from dedicated and casual shark-divers respectively) and was composed of the revenues generated by the industry combined with the departure taxes paid by shark-divers to the government.

5. Discussion

We estimated that the shark-diving industry contributed US $42 million to the Fijian economy in 2010. This revenue came from 49,000 divers or 78% of the total of 63,000 tourists who visited Fiji to dive in that year. These large inputs to the economy highlight the growing awareness among international divers of Fiji as a locality for shark tourism and are consistent with the attitudes of divers towards these animals. Surveys by Brown and Sykes (2011) found that 96% of divers rated sharks as one of the three principal animals they wanted to see on a dive in Fiji and 42% considered sharks as the most important diving attraction.

Our estimates of the total economic value of shark-diving in Fiji were based on the assumption that 10% of the visitors to Fiji were engaged in diving activities (Anon., 2009), the proportion of this group that included dedicated shark-divers (24%) and casual shark-divers (54%) as estimated from our surveys, and from our estimates of expenditures of these two groups on diving (Tables 4 and 5). It was more difficult to assess the value of shark-diving on a regional basis, due to the lack of reliable information about the distribution, numbers and turnover of divers across areas and the location and numbers of dive operators in the country. To estimate the number of divers (and therefore the number of shark-divers) visiting each area, we calculated the average number of divers that used the services of each operator in the area from our questionnaires and multiplied these totals by an estimate of the number of operators in the area. Although there was uncertainty associated with these estimates, our calculation of approximately 46,000 divers visiting three of the four main diving areas in Fiji (Viti Levu, Vanua Levu/Taveuni, Mamanuca/Yasawa group) was in general accordance with the government statistics of 63,000 divers visiting the whole of Fiji (Anon., 2009). These problems with estimating the number of divers on a regional basis (which also did not include the clients of liveaboard operators, seasonal changes in diver numbers and the many small dive businesses in other areas of the country) meant that the total number of divers and the revenues they generated, when summed on a regional basis, were less than the total numbers and revenues calculated from government statistics for Fiji as a whole.

On a regional basis, the most robust estimates for economic value of shark-diving were obtained from Pacific Harbour. Shark-diving at this location focuses on very limited numbers of dive sites and is offered by relatively few operators. The cooperation of these businesses with the survey team allowed a very comprehensive picture of the economic flows from this activity to be constructed. Tourism operations at Pacific Harbour are one of the principal draw cards for shark-diving tourism in Fiji. Shark-diving here has received considerable media attention and promotion (see for example, http://www.fijisharkdive.com/shark-media) and Pacific Harbour is conveniently situated near to the international airports, the major entry and exit points for tourists to the country. Thus, the shark-diving at Pacific Harbour can be easily accessed even if it is not a primary objective of a diving holiday. Indeed, many of the casual shark-divers we interviewed considered a dive with sharks at Pacific Harbour as an important part of their holiday that was pursued while in transit to other diving and resort destinations in Fiji.

Overall, the dive operations at Pacific Harbour were a major contributor to the revenues from shark-diving to Fiji. A total of 8,600 visitors were involved in shark-diving at this locality in 2010 providing approximately US $5.3 million in revenue. This economic contribution is likely to increase in the future given the rapid increase in tourism to this locality and the growing international reputation of the experience among divers. The increasing popularity is shown by a time series of diver participation statistics from a single operator who in 2004 attracted 700 divers. Participation doubled to 1,400 divers only two years later (Brunnschweiler 2009) and more than doubled again in 2010 to 3,000 divers (data from our study). Our interviews of the divers from these operations revealed that the opportunity to dive (safely) in close proximity with bull and tiger sharks that have a reputation as potentially very dangerous was the principal factor that drew divers to participate in this form of tourism. The diversity (up to eight species), abundance (more than 120 individual bull sharks identified at one site with typically more than 10 sighted in a single dive), and size of the animals (many individuals over 2 metres in length) were also important factors on the decision of divers to engage in this shark-feeding dive . Most of the divers were aware of the shark dives at Pacific Harbour in their home countries prior to making the trip to Fiji and for 31% of the divers visiting the area, diving at this location was a principal reason for visiting the country, even if they then continued on to other islands in Fiji.

Shark-diving at Pacific Harbour generated revenues similar to those of Moorea Island in French Polynesia where provisioning of lemon sharks is also a feature of the experience offered to diving tourists. Clua et al. (2011) estimated that a total of 12,623 shark-divers visited Moorea per year, of which 7017 were dedicated shark-divers (i.e. tourists and locals whose main purpose of their visit was to dive with sharks, as defined by our study). Of the total number of shark-divers, 3968 were international tourists and of these, 27% visited Moorea primarily to go shark-diving, a proportion very similar the number of tourists visiting Fiji for the same purpose. Additionally, the estimate of annual revenue generated by Clua et al. (2011) for shark-diving in Moorea (US $5.4 m) was very close to our calculation for Pacific Harbour (US $5.3 m). Clua et al. (2011) suggested that revenues provided by international visitors were by far the largest portion (at US $5.2 m) of the total from shark-diving, although these data must be treated with caution since their estimates were based on assumed expenditure on food, flights and accommodation rather than information provided by divers.

Aliwal Shoal in South Africa also offers a shark-diving experience comparable to Pacific Harbour. At this shoal, operators use food provisioning to attract mainly large tiger sharks for viewing by divers. Dicken and Hosking (2009) estimated that in 2007, this industry was worth US $1.8 million per year in revenue to the region. The lower income at this locality relative to Moorea and Fiji reflects the smaller number of participants (only 1,065 divers). However if shark-diving tourism has been growing at a similar rate in South Africa as the Pacific, then the calculations by Dicken and Hosking (2009) are now almost certainly underestimates. Overall, differences in revenue from shark-diving in Fiji, French Polynesia and South Africa are likely due to the much larger market for diving tourism in Fiji compared to the other localities.

The provisioning of food for sharks is a feature common to businesses at Pacific Harbour, Moorea and Aliwal Shoal. Operators argue that this allows the experience offered to tourists to be of a high quality in terms of predictability, abundance and size of sharks. In turn, this means that they are able to promote these dives very widely with confidence that tourist expectations will generally be satisfied (e.g. Dicken and Hosking 2009). This is very important given the high running costs in terms of logistics (boats, fuel etc) and staff. However, shark-diving in other areas of Fiji generated revenue that was almost eight times that of Pacific Harbour and relatively few of these operators offered provisioning as part of the diving experience. This shows that opportunities for shark interactions for divers that do not involve provisioning are just as important (if not more so) than those where food is supplied to sharks. Evidence that provisioning is not necessarily a prerequisite for development of a shark-diving industry is shown in Palau, where none of the dive operators provide food for sharks. In 2010, approximately 8,600 tourists (21% of total tourist numbers) were categorised by Vianna et al. (2010) as shark-divers. These tourists generated revenues of US $18 million (or 8% of the GDP of Palau), including tax income for the Palauan Government of US $1.5 million and salaries to locals employed by the industry of US $1.2 million (Vianna et al. 2010). Similarly, our study shows that revenues of US $3.5 million per year for shark-diving can be generated by an industry based on opportunistic sightings of hammerhead sharks in Vanua Levu in Fiji.

In contrast to Pacific Harbour, shark-diving at other localities in Fiji was not necessarily seen as the principal goal of the diving trip. Rather, these dives were seen as an important addition to a holiday that had objectives other than just diving with sharks (e.g. viewing a variety of colourful marine life, fish and corals). However, it is interesting to note that most dive operators promoted some form of shark-diving experience irrespective of their location. In part, this may have been due to a perceived need to compete for tourism with the opportunities available at Pacific Harbour, but few operations in other areas of Fiji offered provisioning of sharks as a part of the shark-diving experience.

Our study sampled most of the principal areas in Fiji that host shark-divers and is thus likely to be representative of the tourists visiting the country for this pastime. However, in outlying regions, lower numbers of diving tourists reduced sample sizes and this increased uncertainty in estimates. Our estimate of the number of diving tourists visiting Fiji each year (10% of the total) was provided by government sources (Anon., 2009). Although we made an effort to cover a large range of dive operations, unequal distribution of divers across the areas, variations in the size of operations and restricted access to operator's information are probable sources of uncertainty in our estimates of numbers of divers on a regional basis. Furthermore, we conducted the survey during the months of August and September and could not examine seasonal changes in visitor numbers. Thus, our calculations are based on annual figures for numbers of divers using the services of dive operators. The estimates of salaries provided by the shark-diving industry to the local community were based solely on the salaries generated by operators (Table 4). This approach was likely to underestimate the total contribution, since the input of businesses providing services to shark-divers was not included. We adopted this conservative approach due to the lack of an appropriate wage parameter (Tables 4 and 6).

In addition to economic benefits, recognition of the importance of sharks as a draw card for tourists has had some important conservation outcomes in Fiji. The economic value of the shark-diving industry was responsible for the creation of the Shark Reef Marine Reserve in Beqa Lagoon that elevated the status of the shark-feeding site and the surroundings to no-take marine protected areas (MPAs) supported by the local communities. A levy charged on divers is distributed to the villages of traditional owners of the reef in compensation for the loss of income due to the cessation of fishing and MPA boundaries are patrolled to ensure compliance (Brunnschweiler, 2009). Similarly, unofficial and official bans on shark fishing have been imposed on a number of other dive sites throughout the region such as in parts of the Yasawa group, Vanua Levu and Taveuni. Conservation is also aided by awareness-raising by operators of long-term (monthly, yearly) trends in shark numbers. When businesses have a vested interest in healthy populations of sharks, monitoring trends in numbers over time (formally or informally) can become a part of dive operations. In some cases, this information has been made available to researchers for detailed analysis, which provides useful scientific insights into the status and the ecology of these animals (Brunnschweiler and Baensch, 2011).

In summary, we have shown that shark-diving provides very significant economic revenue to Fiji that is likely to grow in the future if current trends in diving tourism continue and shark populations remain in place. Diving at Beqa Lagoon provides the centrepiece of this industry, but is by no means the major revenue earner; shark-diving occurs throughout Fiji and is a feature of the diving experience offered in all localities we visited during this study. The revenues from shark-diving flow through to local Fijians through the provision of salaries and service to the industry and have played a significant role in the conservation of reefs through systems of traditional ownership. For these reasons, shark-diving provides a model for the non-extractive use of reef resources for the benefit of both local people and the reef ecosystem itself.

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THE ECONOMICS OF SHARK DIVING IN THE SEMPORNA REGION, MALAYSIA.

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Contents

Executive Summary

- We were tasked with estimating the economic value of shark diving ecotourism in the Semporna region of Sabah, Malaysia
- During September and October 2012, we surveyed dive tourists, businesses, operators and guides using self-administrated questionnaires
- We obtained a total of 356 completed questionnaires, of which 307 were answered by dive tourists and 33 by dive guides, sampled across 12 dive operators in the area. We also collected information from 16 of the 22 dive operators identified in the region, sampling the town of Semporna and islands of Mabul, Pom Pom and Mataking.
- Questionnaires included expectations of divers and "willingness-to-pay" for daily fees intended to:1) provide funds for enforcement of the proposed Semporna Shark Sanctuary (SSS) and 2) to generate jobs for the local shark fishers, who might lose income with the establishment of the proposed sanctuary.
- We interviewed managers of dive businesses to estimate the average annual salaries of the employees and the annual salary revenues generated by shark tourism that returned to the local community.
- From businesses, we gathered data on the number of tourists taking dive trips and their preferences, main dive attractions and activities, information about employees and operators' expectations regarding the dive industry and expenditures related to the diving operation (particularly salaries).
- Europe was the main source of diving tourists (49%), followed by divers from domestic localities (17%). Interviews with divers showed that the principal motivation to visit the area was to engage in general diving activities (37%), but 25% of divers came to the Semporna region specifically to dive Sipadan and 6% of the total came to the region principally to dive with sharks.
- Although not the sole motivation for diving in Semporna, 73% of divers stated that they were interested or very interested in diving with sharks.
- Business revenues from shark diving in the region in 2011 were $7.8 million USD.
- Tax revenue to the government from shark diving totalled $1.5 million USD.
- Estimated community income from shark diving was $1.4 million USD.
- Based on a willingness-to-pay survey, the estimated annual revenues that could be collected through a park fee to be used to enforce the proposed sanctuary would be between $943,000 and $1.5 million USD.
- Estimated annual revenues that could be collected through park fees and used to generate jobs for local fishers who might lose income with the creation of the proposed sanctuary would be between $781,000 and $1.2 million USD.
- The protection of sharks in the Semporna region would result in loss of approximately $122,000 USD from shark fishing on an annual basis, a small fraction (2%) of the annual revenues generated by shark-diving tourism.

Introduction

In 2011, established shark-diving operations could be found in at least 83 locations in 29 countries, including tropical and temperate waters around the world (Gallagher and Hammerschlag 2011). The economic revenues generated by these industries are potentially very large. In French Polynesia, shark diving generates approximately US$5.4 m annually (Clua et al. 2011), while in Palau, Micronesia, the industry generates US$18 m per year, accounting for approximately 8% of the Gross Domestic Product of the country (Vianna et al. 2012). These studies not only demonstrate a high economic value associated with shark diving tourism but also show that these benefits are distributed across several sectors of the local economy.

Worldwide, shark-diving tourism is threatened by the collapse of shark populations due to overfishing (Anderson and Ahmed 1993; Anderson et al. 1999). This phenomenon not only has major implications for local economies involved in shark diving, but also for the integrity of the ecology of marine systems, where sharks, as apex predators, have an important role in the top-down regulation of energy flows and system functions. The Semporna region of Sabah, Malaysia, is a good example of this problem. In 2011, the region received more than 68% of the divers visiting Sabah (Sabah Tourism Board, personal communication). Islands of the Semporna region such as Mabul, Pom Pom, Kampalai and Tun Sakaran Marine Park are popular for diving although the dive sites around the island of Sipadan are a principal draw card for divers visiting the region. According to the local diving industry, the popularity of Sipadan for diving is largely associated with the opportunity to dive with large predatory fishes, most notably sharks. Unfortunately, sharks are also the target of fisheries in the region, leading to an ongoing loss of abundance that potentially threatens this ecotourism industry.

Options for the protection of sharks, including the creation of a shark sanctuary, lack hard data as to the value of the shark diving industry. Our report addresses this information gap. We conducted surveys of the diving industry to determine the importance of sharks as an attraction for divers and to estimate the economic value that this form of dive tourism provides for the local community. We contrast the value of this industry with the potential revenue that targeted fishing of sharks provides to the economy. As the region has been proposed as a shark sanctuary, we also surveyed divers to determine the extent to which they were willing to provide revenue to support the imposition and enforcement of a sanctuary and to aid fishermen whose activities might be displaced by the banning of shark fishing in the sanctuary.

Methods

Survey

Our study was conducted during the months September and October 2012 in the Semporna region of Sabah, Malaysia. Research principally involved a combination of three, self-administrated questionnaires that targeted dive tourists, operators and guides. These questionnaires followed a similar model that our research team has employed in valuations of the shark-diving industry in Palau and Fiji (Vianna et al. 2011; Vianna et al. 2012).

We obtained a total of 356 completed questionnaires, of which 307 were answered by dive tourists and 33 by dive guides, sampled across 12 dive operators in the area. We also collected information from 16 of the 22 dive operators identified in the region, sampling the town of Semporna and islands of Mabul, Pom Pom and Mataking.

The tourist questionnaire was structured to obtain information about the demographic characteristics of the divers, their motivations to visit the Semporna region, satisfaction with diving experience and expenditures while in the region. Expenditures were divided among the categories of accommodation, living costs, diving (and shark diving, when applicable), domestic transfers and other activities while in region (e.g. land tours). Self-administered questionnaires and a printed explanation of the purpose of the research were handed to the divers at the end of the dive trips at dive operators or resorts.

Questionnaires included an assessment of the expectations of divers regarding the major diving destinations in the Semporna region notably Sipadan, Mabul, Kapalai and Tun Sakaran Marine Park. We also included an assessment of the divers "willingness-to-pay" for daily fees intended to: 1) provide funds for enforcement of the proposed Semporna Shark Sanctuary (SSS) and 2) to generate jobs for the local shark fishers, who might lose income with the establishment of the proposed sanctuary.

We interviewed managers of dive businesses based in Semporna town, Mabul, Pom Pom and Mataking. Our survey included companies that currently held licences to dive on Sipadan and also dive companies that operated exclusively in other sites of the Semporna region. We used these data to estimate the average annual salaries of the employees of the diving industry and the annual salary revenues generated by shark tourism to the local community.

The questionnaire for dive operators obtained information about the characteristics of the business, including number of tourists taking dive trips and their preferences, main dive attractions and activities, information about employees and operators' expectations regarding the dive industry. We also collected detailed information regarding the expenditures related to the diving operation, most notably the expenditures on salaries. These data were cross-checked with information collected from questionnaires completed by dive guides, with the former also provided information regarding the profile of the employees of the diving industry in the region.

All interviews were conducted in accordance with the requirements of the National Statement on Ethical Conduct in Human Research (Australia) and the policies and procedures of The University of Western Australia.

Economic variables and data analysis

We defined the shark dive parameter (SDP) as the percentage of divers visiting the area because of the possibility of diving with sharks (defined hereafter as "shark divers") (Table 1). This was calculated as the proportion of the divers that we interviewed who stated that their visit to the area was conditional on the possibility of sharks being sighted during their dives.

We estimated the revenues brought to the region by shark diving from a combination of data collected by our survey (the average expenditures of divers and SDP) and records of the total number of divers visiting the Semporna Region in 2011 (Table 1). The latter data was provided by Sabah Tourism Board and constituted of a subset of a broader tourist survey conducted by the Board (*personal communication*). The number of divers visiting the area annually was a key component of our estimates. For this reason, we also generated an independent estimate based on the number of divers visiting the area as reported by the dive operators during interviews. Our estimates (28,206 divers) were close to those provided by Sabah Tourism Board (34,959 divers).

Our estimate of business revenues brought to the region by the non-consumptive use of sharks by the diving industry (BRS) was based on an expenditure approach and quantified the direct economic benefits from shark-diving tourism related to diving, accommodation, living costs and local transport. As it was not within the timeframe or scope of our study to estimate multiplier effects of the industry, we contend that the data we present here are conservative estimates of the economic value of sharks as a tourism resource for the region.

We applied the SDP to our estimates of business revenue taxes from diving (BRTD, Table 2) to estimate the direct tax contribution of sharks as a tourism resource (i.e. for shark diving) in the Semporna region (BRTSD, Table 2). We estimated the direct tax contribution of shark diving based on the lower threshold of the Business Tax contribution (20%) (Table 1). This conservative estimate was adopted to account for the differences in the size and scale and of various businesses and thus likely variations in tax contributions.

From our willingness-to-pay survey we also estimated the revenues that could be potentially generated from daily entry fees for diving in the proposed Semporna Shark Sanctuary. We estimated the potential revenues for enforcement of the proposed sanctuary (PRES) by weighting the total number of divers visiting the Semporna region in 2011 by the percentage of divers that were interviewed who were willing to pay a fee price range. This value was then multiplied by the average number of days tourists spent diving in the region (Tables 1, 2). For this calculation we used the lower and upper limit of each proposed fee price range to estimate the minimum and maximum revenues divers would be willing to pay. We used the same method to estimate the potential revenues generated from a fee to be used to provide jobs for the local fishermen who might lose income with the creation of the SSS (PRJS) (Table 2).

Table 1: Description of constants and parameters used to estimate revenues generated by the shark-diving in the Semporna region.

Abbreviation	Constants and estimates	Description	Values	Units	Source	Comments
D	Number of divers per year	Sum of number of divers visiting the Semporna region in 2011	34,959	No./Year	Sabah Tourism	Personal communication
SDP	Shark-diving parameter	Shark divers/D	0.23	-	Tourist questionnaires	Shark diver is defined as a diver who would not visit the Semporna region if there were no sharks to be sighted during dives.
W	Wages	Average salary of employees of diving industry in the Semporna region	3,137	USD	Operator questionnaire	
BT	Business revenue tax contribution	Minimum tax rate contribution	0.20			
E	Number of employees	Estimated number of employees in the dive industry in the Semporna region	2,000	Employees	Ministry of tourism, personal communication	
V_i	Fee value of item *i*	Proposed fee value of each item *i* of the questions of wiliness-to-pay	Variable	USD	Tourist questionnaires	
S_i	Number of divers answering item *i*	Number of divers answering item *i* of each question of wiliness-to-pay study	Variable	Divers	Tourist questionnaires	
S_T	Total number of divers answering question	Total number of divers answering each question of wiliness-to-pay study	Variable	Divers	Tourist questionnaires	
A	Average days of diving	Average number of days diving in the Semporna region	4	Days	Tourist questionnaires	

Table 2: Formulas employed for the calculations of economic value of shark-diving industry and distribution of revenues from shark diving in the Semporna region.

Abbreviation	Variables	Formula	Units	Source	Comments
Business revenues from tourism					
BRD	Business revenues from divers	D x DET	USD/Year		
BRS	Business revenues from sharks	BRD x SDP	USD/Year		
Community benefits from shark diving					
DCISD	Direct community income from shark diving	W x SDP x E	USD/Year	Operators questionnaire	Based on the estimate of 2,000 employees in the diving industry in the Semporna region.
Tax revenues from shark diving					
BRTD	Business revenues tax from diving	BRD x BT	USD/Year		
BRTSD	Business revenue tax from shark diving	BRS x BT	USD/Year		
Expenditures					
DET	Diver expenditure per trip	Accommodation expenses + Living expenses + Diving expenses + Extra expenses	USD/Trip	Pilot and Tourist questionnaires	Average of the total expenditures in the specified categories by divers. "Extra" includes extras expenses during the trip not specified in the other categories (i.e. souvenirs, land-based tours, etc).
Potential revenues from Semporna Shark Sanctuary					
PRES	Potential revenues for enforcement	$\sum(S_i/S_T \times V_i) \times D \times A$	USD/Year	Tourist questionnaire	Entry fee designated for enforcement.
PRJS	Potential revenues for jobs	$\sum(S_i/S_T \times V_i) \times D \times A$	USD/Year	Tourist questionnaire	Entry fee designated to aid job generation for fishers.

Our key calculations were as follows:

(1) Total number of divers visiting the Semporna region mainly to dive with sharks in 2011 (SD)
(2) Direct business revenues generated by shark diving activities (BRS)
(3) Direct community income generated by the shark-diving industry (DCISD)
(4) Business revenue tax generated by the shark-diving industry (BRTSD)
(5) Potential revenues generated by fees, paid by divers, to visit the proposed Semporna Shark Sanctuary (PRES and PRJS)

All estimates refer to the year of 2011 and a detailed list of variables, parameters and data sources is presented in Table 1.

Our study estimated the total economic revenue generated by the shark-diving industry and the magnitude of the key components of that revenue. We recognize that economic revenue does not equate to net economic benefits from the industry; calculation of this would have required estimates of both the supply and demand curves for shark diving services, in order to calculate producer and consumer surpluses (Just et al. 2005). This task was beyond the scope of this study, given the lack of market data available for statistical analysis of supply or demand. However, revenue provides a useful indicator of the economic importance of the industry, and is consistent with common economic metrics such as GDP. This approach also allows us to focus on economic benefits that are retained within the region, whereas much of the producer and consumer surpluses generated by the industry may be captured by foreign businesses and consumers. To further reduce the influence of leakage between sectors of the economy, the analysis of the direct, indirect and induced benefits from shark diving was restricted to quantifying the revenues obtained by businesses that benefitted directly by the presence of shark divers (i.e. dive operators, hotels, resorts, restaurants and souvenir shops). The calculation of the flow of economic revenues from shark diving to the local community was restricted to wages provided by the dive operators to their employees. We also calculated the business tax revenues from the dive operators and accessory services that provide services for the shark divers.

Business revenues from shark diving

We estimated the economic value of shark diving in the Semporna region as the annual business revenues generated by the diving industry that could be attributed to shark-diving activities.

The annual business revenue from shark diving (BRS) was estimated as

$$BRS = BRD \times SDP \quad (1)$$

where BRD was the business revenue generated by diving in general:

$$BRD = D \times DET \quad (1.1)$$

where DET was the average expenditure per dive tourist, per trip (Table 2), and D was the number divers visiting the Semporna region per year (Table 1). DET consisted of accommodation, diving expenses, living costs and other expenditure such as souvenirs and transfers (data from surveys), over the duration of the visit to the Semporna region.

Economic benefits to the community

A component of business revenue from shark diving is dispersed through the economy of the region by payment of salaries to employees of dive businesses. This contribution represents the direct community income from shark diving (DCISD), and was calculated as follows:

$$DCISD = W \times SDP \times E \quad (2)$$

where W was the average annual salary paid to the employees of the diving industry (estimated from the operator questionnaire) and E was the number of employees estimated to work for the dive industry in the area (Tables 1 and 2).

Tax revenue

The tax revenue from the shark-diving industry constituted of the business revenue taxes paid by the dive operators and accessory services that could be attributed to the economic revenues generated by shark divers (BRTSD). This tax was defined as:

$$BRTSD = BRS \times BT \quad (3)$$

where BT represented the business revenue tax parameter (Table 1).

Potential economic contribution of Semporna Shark Sanctuary

We estimated the potential revenues to be collected through marine protected area (MPA) fees paid by the divers visiting the proposed SSS designated for enforcement (PRES) and for generation of jobs (PRJS). These estimates were calculated by applying the frequency distribution of willingness-to-pay for a range of proposed fees to be paid by divers. Given S_i as the number of divers interviewed willing to pay the fee value V_i and S_T as the total number of divers answering the question regarding willingness-to-pay, potential revenues were estimated as:

$$PRES = \sum(S_i/S_T \times V_i) \times D \times A \quad (4)$$

Similarly,

$$PRJS = \sum(S_i/S_T \times V_i) \times D \times A \quad (5)$$

where A was the average number of days of diving for our sample.

Results

Revenues

We estimated that 23% of divers visited the Semporna region with the aim of seeing a shark. As a result, the business revenues from shark diving (BRS) in the region in 2011 were $7,834,482 USD (Table 3). Business revenue tax to the government from sharks as a non-consumptive tourism resource (BRTSD) totalled $ 1,566,896 USD (Table 3). Benefits also flowed through the provision of salaries to employees of the diving industry. The average annual salary of employees was $3,137 USD and estimated community income from shark diving was $1,442,843 USD (Table 3).

Table 3: Estimated revenues and income generated by the diving industry in the Semporna region in 2011.

Code	Description	Value (USD)
Annual business revenues		
BRD	All divers	34,062,965
BRS	Shark divers	7,834,482
Annual community income		
ASD	Average annual salary of diving industry employee	3,137
DCIS	Direct community income from diving	6,273,231
DCISD	Direct community income from shark diving	1,442,843
Annual tax revenues		
BRTD	Business revenue tax from diving	6,812,593
BRTSD	Business revenue taxes from shark diving	1,566,896
Estimated revenues from the proposed Sanctuary		
PRES	Potential revenues from fees for enforcement	943,000 to 1.5 million
PRJS	Potential revenues from fees for job generation	781,000 to 1.2 million

Tourist profile

Europe was the main source of diving tourists (49%), followed by divers from domestic localities (17%) (Fig. 1). Interviews with divers showed that the principal motivation to visit the area was to engage in general diving activities (37%), but 25% of divers came to the Semporna region specifically to dive Sipadan and 6% of the total came to the region principally to dive with sharks (Table 4). Although not the sole motivation for diving in Semporna, 73% of divers stated that they were interested or very interested in diving with sharks (Table 5).

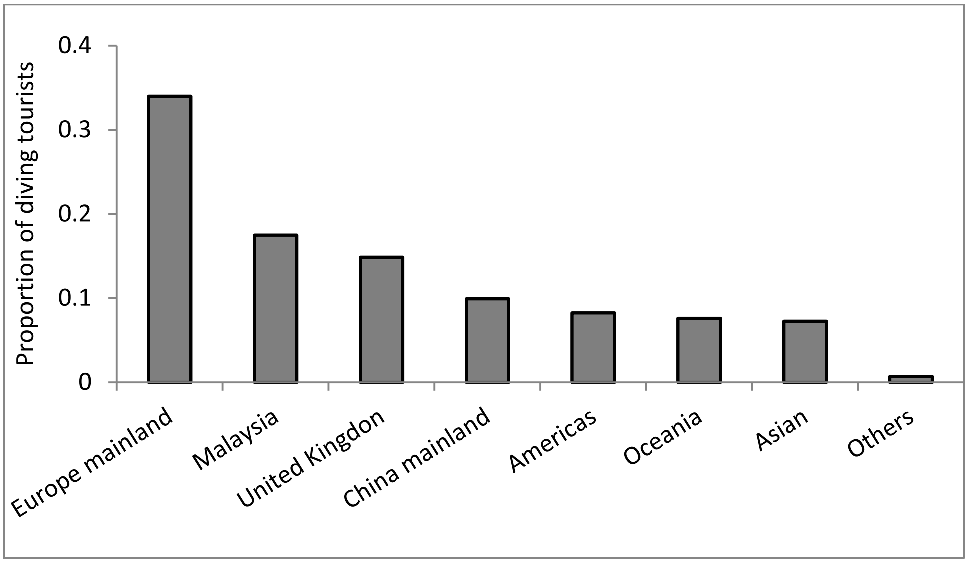

Figure 1. Source of diving tourists visiting the Semporna region in 2012

Table 4. Motivations of divers visiting Semporna region. Data source tourist questionnaires (n=298)

Main motivation (*n=298*)	**Percentage of divers (%)**
General diving	37
Sipadan	25
Sipadan, Mabul and Kapalai	16
Sipadan and Mabul	8
Diving with sharks	6
Diving and sight-seeing	5
Mabul	1
Others	2

Table 5. Diver interest in shark diving. Data source tourist questionnaires (n=282)

Interest in shark diving (*n=282*)	**Percentage of divers (%)**
Negative towards	0
Not interested	6
A little interested	18
Interested	39
Very interested	34
Don't know/not sure	3

Diving fees and projected economic contribution from the proposed Sanctuary (SSS)

Approximately 60% of divers were willing to pay a daily fee of 16 RM or more to be used to enforce the proposed SSS (Table 6), while 53% of divers stated they were willing to pay a daily fee of 16 RM or more to be used to generate jobs for fishers who might lose income with the creation of the SSS (Table 6).

Given these figures, the estimated annual revenues that could be collected through a park fee to be used to enforce the proposed sanctuary (PRES) would be between $943,000 and $1.5 million USD. Similarly, the estimated annual revenues that could be collected through park fees and used to generate jobs for local fishers (PRJS) who might lose income with the creation of the proposed sanctuary would be between $781,000 and $1.2 million USD.

Table 6. Results of willingness-to-pay survey of diving tourists visiting Semporna region for the creation of the Semporna Shark Sanctuary

Proposed daily fee (RM)	Percentage of divers willing to pay a daily fee to be used to enforce the proposed Semporna Shark Sanctuary. (*n=286*)	Percentage of divers willing to pay a daily fee to be used to generate jobs for local fishers who might lose income with the creation of the Semporna Shark Sanctuary. (*n=285*)
None	10%	15%
Up to 15	30%	32%
16 to 30	30%	33%
31 to 60	20%	13%
More than 60	10%	7%

Discussion

The economic value of shark diving in the Semporna region is very substantial. As a whole, diving contributed $34 million USD in business revenue to the region, of which 26% or $7.8 million USD was directly attributable to shark diving. According to the Ministry of Tourism (unpublished data provided by Dr James Ali), the diving industry in the Semporna region is responsible for the generation of approximately 2000 jobs. Assuming that the number of jobs generated in this industry is directly proportional to the number of tourist divers visiting the area, sharks as a non-consumptive tourism resource in the area are responsible for the maintenance of approximately 460 jobs that generate a direct annual income to the local community of $1.4 million USD. Similarly, 22% ($1.56 million) of annual government revenues from business taxes of the diving industry are directly attributable to shark diving.

In 2008, reported landings of sharks caught by commercial and traditional fishing gear totalled 176 tonnes, with an average marked value of RM2.1/kg (provided by Dr James Ali. Source: Annual statistic- Department of Fisheries, Sabah, Malaysia). Assuming that shark catches have remained constant through time, the protection of sharks in the Semporna region would result in loss of approximately $122,000 USD from shark fishing on an annual basis. This value represents only 1.6% of the annual revenues generated by shark-diving tourism and less than 9% of the annual income from jobs currently maintained by the shark-diving industry. These figures make strong arguments for the need to carefully manage shark stocks in the region. The shark-diving industry relies on the regular and predictable sightings of sharks at dive sites and therefore is dependent on healthy shark populations (Vianna et al. 2012, Vianna et al. 2011). If even moderate pressure from fishing that targets sharks reduces populations to levels where encounters with sharks by divers can no longer be guaranteed, it is likely that this kind of tourism will cease. This has been the case in other areas such as the Maldives where fishing has reduced shark stocks (Anderson and Ahmed 1993; Anderson et al. 1999). Given the high economic value and community benefits from shark diving in the Semporna region, loss of sharks could result in significant loss of revenues to the economy and local community.

It is important to note, however, that subsistence fishing is an essential part of livelihoods in most coastal regions of Malaysia. In Sabah, it has been estimated that approximately 22,000 people rely on this activity (http://www.fishdept.sabah.gov.my/capture.asp). Catches are multi-specific, with landings including mainly reef-associated species but also some oceanic fishes notably carangids and scombrids. Captures of sharks are frequent, but represent only a small fraction of total landings. Our willingness to pay survey shows that alternative sources of income could be generated from tourists to replace the loss of sharks as a source of income to subsistence fishermen.

Enforcement is a major issue that strongly determines the effectiveness of MPAs for managing stocks of marine resources. Poor enforcement can invalidate MPA strategies and in many cases, is an issue caused by limited economic resources. Our study shows that there is a willingness by diving tourists to contribute to both the enforcement of a sanctuary and to finance the provision of alternative livelihoods for fishermen displaced from traditional fishing grounds by imposition of a sanctuary. Overall, we found that tourists would be willing to contribute between $943,000 and $1.5 million USD for enforcement and between $781,000 and $1.2 million USD, annually, to generate jobs for the fishermen that might be displaced by the creation of the sanctuary. This financial input would likely flow-on into the local economy, benefitting local businesses that might not be directly involved with the shark-diving industry, and further strengthening the economy of the region. Creation of the sanctuary might also benefit local fishermen in the region through “spill-over effects” on the abundance and size of fishes in areas adjacent to the sanctuary and through the creation of jobs in maintenance and enforcement for members of the local community.

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Information for DAY TRIP DIVERS in the survey of dive tourism in Palau

Palau has recently prohibited all shark fishing activities in its national waters, creating the first shark sanctuary in the world. This closure has important implications for several sectors of the local economy. By answering this questionnaire you will be helping to quantify the economic value of the shark diving experience and the implications of the shark fishing closure for the tourism industry in Palau.

The survey should take approximately 10 minutes to complete. Please feel free to ask the interviewer any questions about the survey either before or during the interview. You can withdraw from participation at any stage in the survey if you wish to do so.

All the information provided by you will be treated as confidential and personal identification is not required. All data will be used in an aggregated way and no individual response will be able to be identified in any reports or papers resulting from the research. Original surveys will be kept safely in accordance with University of Western Australia guidelines.

If you have any questions or complaints about the conduct of the survey you can speak to the interviewer, or contact Professor Jessica Meeuwig, my supervisor, whose business card will be provided to you.

If you are willing to participate, can you please read this summary and sign the release form.

I (the participant) have read the information provided and any questions I have asked have been answered to my satisfaction. I agree to participate in this activity, realising that I may withdraw at any time without reason and without prejudice.

I understand that all information provided is treated as strictly confidential and will not be released by the investigator. The only exception to this principle of confidentiality is if documents are required by law. I have been advised as to what data is being collected, what the purpose is, and what will be done with the data upon completion of the research.

I agree that research data gathered for the study may be published provided my name or other identifying information is not used.

____________________________ ____________________

Participant Signature Date

(Please note that as this document is not a contract between parties, it is not necessary that the researcher sign it. Nor is it necessary to have a witness.)

For survey administration use only	
Survey Number	
Boat ID/Operator	
Date	
Time	
Interviewer	

Survey of tourists taking dive trips in Palau

Section A. Reason for coming to Palau

A.1 Is this your first trip to Palau? Yes ☐ No ☐

If Yes skip to Question A.3, if No please answer Question A.2 and then A.3.

A.2 How many times have you come to Palau previously? ________ (number)

A.3 For what main activity did you come on this trip to Palau? (please tick one box only)

For general dive activities	☐
Mainly to dive with sharks	☐
Specifically to dive with sharks	☐
Dive activities and sight-seeing	☐
Sight-seeing (general tourism)	☐
Other (please specify)	☐

…………………………………….

A.4 Before you came on this trip to Palau, were you aware that Palauan waters have been closed to shark fishing, creating a Shark Sanctuary? Yes ☐ No ☐ Unsure ☐

If Yes:
A.4.1 To what extent did knowing that Palau was closed to shark fishing influence your choice of Palau as a destination? (Please tick one box only)

Didn't influence my decision at all	☐
Influenced my decision a bit	☐
Was about 50% of the reason for my decision	☐
Was a major influence on my decision	☐
Was the primary reason I chose to come to Palau	☐

Section B. General dive trip information

B.1 We are interested in your expectations <u>before you came on this trip to Palau</u>. What were you interested in seeing on dive trips on Palau? (Tick the number that best fits what you wanted from the dive trips: 1 = not interested in this at all, 2 = a little bit interested in this, 3 = quite interested in this, 4 = interested in this, 5 = very interested in this, DK = don't know/not sure)

Possible sights and activities	**1**	**2**	**3**	**4**	**5**	**DK**
Activities:						
a. Coral garden dives						
b. Wreck diving						
c. Channel dives						
d. Drop off dives						
e. Shark watching as a major component of the dive						
f. Jellyfish lake						
g. Other (please specify)……………………						
Sights:						
h. See macro life (little animals among the corals)						
i. See big pelagic animals – e.g. turtles/rays/fish						
j. Swim in close proximity to sharks						
k. See a large number of sharks						
l. Other (please specify) ……………………						

B.2 How have the dive trips you have taken so far on this trip to Palau met with your expectations? Can you indicate how satisfied you were with the activities and sights you have experienced on the dives? <u>Only score for those activities/sights that were scored 3 or higher in question B.1.</u> (1 = not satisfied at all; 2 = barely satisfied, 3 = quite satisfied, 4 = satisfied, 5 = very satisfied, DK = don't know/not sure)

Possible sights and activities	**1**	**2**	**3**	**4**	**5**	**DK**
Activities:						
a. Coral garden dives						
b. Wreck diving						
c. Channel dives						
d. Drop off dives						
e. Shark watching as a major component of the dive						
f. Jellyfish lake						
g. Other (please specify) ………………………						
Sights:						
h. See macro life (little animals among the corals)						
i. See big pelagic animals - e.g. turtles/rays/fish						
j. Swim in close proximity to sharks						
k. See a large number of sharks						
l. Other (please specify) ……………………						

Section C. Questions about your expenditure while in Palau

To estimate the benefit to the economy from shark tourism (and diving tourism more generally) we need to have an estimate of your expenditure while in Palau.

C.1 How long have you been in Palau so far on this visit ____________days

C.2 What will be the total duration of your stay in Palau on this visit?
________days Not decided ☐

C.2.1 **If not decided:** please estimate your likely total stay duration ________ days

C.3 Did you purchase a dive trip package for this trip to Palau? Yes ☐ No ☐

If No: Skip to Question **C.6**
If Yes: Please answer Question **C.4** and **C.5**

C.4 Can you estimate the total cost of the package?

Yes ☐ US$ _____________ No ☐

C.4.1 What was included in the package? (please tick all options included in the package and add details if option is included in the package)

a. Airflights - From ………………… To ……………….. ….. return	☐
b. Accommodation - Where? …………………………… Number of nights? ………………. Type of occupancy? Double ☐ Single ☐ Other ☐	☐
c. Dive trips – How many days? ……… How many dives per day? ………..	☐
d. Food and beverages other than when on dive trips	☐
e. Other (please specify) ……………………………………………………………………….	☐

C.5 Could you please estimate how much more money in total, additional to the cost of the package, you have spent (or will spend) on this visit to Palau (e.g. on accommodation, food, beverages, entertainment, tourism activities, souvenirs).

US$ _____________ in total **Now go to Section D.**

Please answer the following questions (C.6 to C.9) if you did not purchase a package trip to Palau. Otherwise go to Section D.

C.6 What are you paying on average for accommodation while in Palau?

_____________US$ per day **or**

_____________ US$ total

C.7 What are you paying on average for food, beverages and other living costs (not including accommodation) while in Palau?

_____________US$ per day **or**

____ ________ US$ total

C.8 Please estimate what you will pay in total for dive boat trips while in Palau

- for all dive boat trips ___________US$ total

C.8.1 If possible, could you indicate the percentage of this total amount paid for:

- for general dive /snorkeling trips ______ %
- for dive trips with shark watching as a major expectation of the dive ______%

C.9 Please estimate what you will pay in total for other tourist-related activities while you are in Palau (e.g. souvenirs, non-dive activities, entertainment. Do not include accommodation).

______________US$ total

Section D. Overall opinion about the shark diving experience in Palau

D.1 Aside from this trip, how many other dive boat trips have you taken so far on this visit to Palau? ______________ (number)

D.2 Please rate how you feel overall about your diving experience in Palau, with specific regard to the shark watching criteria below.
(1 = poor, 2 = below average, 3 = average, 4 = good, 5 = excellent, DK = don't know/not sure, NA = not applicable to me)

Criteria:	**1**	**2**	**3**	**4**	**5**	**DK**	**NA**
a. Numbers of sharks seen							
b. Number of shark species seen							
c. Quality of the interaction with sharks (e.g. time watching sharks, proximity to sharks)							
d. Overall satisfaction with the shark dive experience							

D.3 Have you visited any other shark eco-tourism areas? Yes ☐ No ☐ Unsure ☐

If yes:

D.3.1 Where? …………………………………………………………………………

D.3.2 How did the shark eco-tourism experience in Palau compare with your visits to other sites? (Please tick the option that applies generally to your other experiences.)

Dives in Palau were a better shark watching experience ☐
Dives in Palau were about the same shark watching experience ☐
Dives in Palau were a worse shark watching experience ☐

D.4 Overall, how would you describe your interest in shark eco-tourism? Please tick one box only.

Negative towards shark eco-tourism ☐
Not interested in shark eco-tourism ☐
A little interested in shark eco-tourism ☐
Interested in shark eco-tourism ☐
Very interested in shark eco-tourism ☐
Don't know/not sure ☐

D.5 How likely are you to make another visit to Palau? Please tick one box only.

I won't make another visit	☐
I'm unlikely to make another visit	☐
I may make another visit	☐
I'm likely to make another visit	☐
I'm definitely planning to make another visit	☐

If you "may make", "are likely to make" or "are definitely planning to make" another visit to Palau, please answer Question D.6 and then go to Section E. Otherwise skip to Section E.

D.6 How important is knowing that Palau has created a shark sanctuary and closed waters to shark fishing to your intention to return again to Palau? Please tick one box only.

Not important at all	☐
Of minor importance	☐
Quite important	☐
Important	☐
Very important	☐

Section E Demographic information

E.1 Please indicate your gender. Male ☐ Female ☐

E.2 What is your age?

Less than 20 years old ☐
Between 21 and 30 years old ☐
Between 31 and 40 years old ☐
Between 41 and 50 years old ☐
More than 50 years old ☐

E.3 What is your nationality? ___________________________

E.4 What is your diving experience? Please tick one box only.

Less than 5 dives ☐
Between 5 and 49 dives ☐
Between 50 and 99 dives ☐
Between 100 and 499 dives ☐
500 dives or more ☐

E.5 Could you please give us an estimate of your annual income? Please tick one box only.

Less than US$20,000/year ☐
Between US$20,000 and US$49,999/year ☐
Between US$50,000 and US$79,999/year ☐
Between US$80,000 and US$119,999/year ☐
US$120,000/year or more ☐

Thank you for your time and the information you have provided.