Comparative abundance of reef sharks in the Western Indian Ocean

Chris Clarke[1,2], James Lea[1,3] and Rupert Ormond[4,5]

[1]Danah Divers, Marine Research Facility, PO Box 10646, Jeddah, 21443, Saudi Arabia.
[2]University Marine Biological Station, Millport, Isle of Cumbrae, Ayrshire, Scotland KA28 0EG, UK
[3]University of Plymouth, Drake Circus, Plymouth, Devon, PL4 8AA, UK
[4]Marine Conservation International, South Queensferry, Edinburgh, Scotland, EH30 9WN, UK
[5]Centre for Marine Biodiversity & Biotechnology, Heriot-Watt University, Edinburgh, EH14 4AS, UK
Corresponding author: rupert.ormond.mci@gmail.com

Abstract. Surveys were conducted over a four year period to assess the abundance of sharks at various remote coral reefs in the Western Indian Ocean, including the Jeddah region of the Red Sea; the isolated islands of Bassas da India, Europa and Aldabra; and the southern three atolls of the Maldives. Two methods were used: direct observation (UVS) by SCUBA divers following chumming, and Baited Remote Underwater Video-cameras (BRUVs). Combined these recorded some 795 sharks of 11 different species. Three findings were notable: i) in some locations, especially those receiving more effective protection, medium-sized sharks such as blacktip reef shark, *Carcharhinus melanopterus*, and grey reef shark, *Carcharhinus amblyrhynchos*, were relatively abundant, with the main species observed probably depending on habitat factors, such as the presence of extensive lagoons and channels; but ii) shark community composition varied considerably between areas, with for example blacktip reef shark being most abundant at Aldabra, and Galapagos shark, *Carcharhinus galapagensis*, most abundant at Bassas da India; nevertheless iii) in all locations the largest predatory sharks such as tiger shark, *Galeocerdo cuvier*, appeared either scarce or absent, potentially a consequence of their wide-ranging movements combined with shark fishing activities in adjacent areas.

Key words: BRUV, coral reef, Maldives, Seychelles, Mozambique Channel

Introduction

In recent decades, due to increasing demand for their fins, an estimated 26-73 million sharks have been caught globally per annum (Clarke *et al.* 2006). In consequence some populations have been reduced to an estimated <10% of pre-exploitation levels (Baum & Myers, 2004; Ferretti *et al.* 2008); however the exact extent of decline remains uncertain due to a lack of baseline data, underreporting of catch and widespread illegal fishing (Clarke *et al.* 2006; Lack & Sant, 2006). These declines are of particular concern, not only due to the threat to shark biodiversity, but because predator loss may permanently alter community structure and disrupt ecosystem services (Ferretti et al. 2010).

Whilst some of the most severe declines have been recorded in the Atlantic (Baum & Myers, 2004; Ferretti et al. 2008), there is increasing concern for Indian Ocean shark populations. Data suggest a similar trajectory of biomass decline, but delayed by the later industrialisation of fisheries (Tremblay-Boyer, 2011).

In the Seychelles there have been several periods of intense exploitation (Nevill *et al.* 2007), and in the Maldives mechanisation of the fishing fleet combined with demand for fins saw shark landings increase from 460 tonnes/yr pre-1977 to 1,340 tonnes/yr post-1977 (Anderson & Ahmed 1993). By 2006, despite the high economic value of shark tourism ($7.4 million in 2002), Maldives shark populations were considered overexploited (Martin & Hakeem, 2006), in consequence of which in March 2010 all shark fishing and product export was banned (MRC, 2009). Even in the Chagos Archipelago, 500km south of the Maldives, high levels of poaching combined with shark bycatch in the licensed tuna long-line fishery has caused the number of sharks seen per dive to decline by >90% (Graham et al. 2010; Sheppard et al. 2012).

There are however various relatively isolated islands and atolls, such as Îles Éparses in the Mozambique Channel and Aldabra Atoll in the Seychelles, which have historically been subject to limited human influence, with past literature suggesting their fish stocks were comparatively unimpacted (Stevens, 1984; van der Elst & Chater, 2001; Quod & Garnier, 2004). Such locations could provide refuges for scarce or overexploited species. Consequently comparative surveys were undertaken to assess relative shark abundance and diversity in five Western Indian Ocean locations where sharks might remain relatively unexploited.

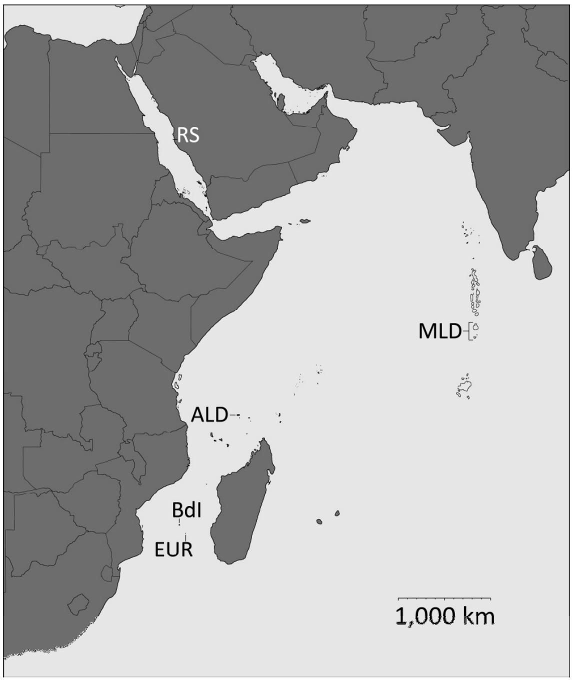

Figure 1: The Western Indian Ocean region, indicating the location of each study region: the southern Maldives (MLD), Saudi Red Sea (RS), Aldabra Atoll (ALD), Bassas da India (BdI) and Europa (EUR).

Methods

Study Area

Fieldwork was conducted between 2008 and 2011 within five, primarily remote, coral reef areas of the Western Indian Ocean (Fig. 1). Work in the Red Sea (March - June 2009) took place 10-30 km offshore of Jeddah, Saudi Arabia, central Red Sea. Three coral reef areas were surveyed: a small seamount near the Eliza Shoals (<2 km^2, N21°41', E038°45') and two outer reefs, one of which has been a baited shark observation site (see Clarke *et al.* 2011) since 1995 (Silky Point: N21°16', E039°00') whilst the other represents a bait-free control (Mismari: N21°19', E39°01'). Aldabra Atoll (S09°24', E46°20') was surveyed between March and April 2008. Aldabra is a World Heritage Site located 1,100 km southwest of the main Seychelles group. It is a very large (370 km^2) raised coralline atoll, with an expansive (208 km^2) but shallow central lagoon

Surveys in the Maldives (February - March 2011) focused on the three most southern atolls: Huvadhoo, Fuvamullah and Addu Atoll. Huvadhoo Atoll (N0°31', E73°18') is substantial in size (3,152 km^2) with an extensive lagoon containing numerous islands and patch reefs. Fuvamullah (S0°17', E73°25') is a small island (5.4 km^2) without any lagoon or channel systems. Addu Atoll (S0°39', E73°09) is relatively small (150 km^2) yet has a large lagoon.

Bassas da India and Europa were surveyed in July 2010. The islands lie within the Mozambique Channel and are part of the 'Îles Éparses'. Bassas da India (S21°27', E39°42') is an uninhabited atoll, ~10 km in diameter enclosing a large lagoon (90km^2) up to 10 m deep (van der Elst & Chater, 2001), while Europa (S22°21', E40°21') is a small (~30 km^2) coralline island, surrounded by a fringing reef, but also possessing a small mangrove-fringed lagoon. A French military attachment and team of meteorologists are based on Europa.

Survey methods

Underwater Visual Surveys: The primary survey method involved baited underwater visual surveys (UVS), where the same team of trained observers on SCUBA deployed a bait-filled perforated drum. The number and species of elasmobranchs seen were recorded, along with arrival times, duration of stay, estimated size, and where possible, sex, distinguishing marks, and notable behaviour. Most UVSs were of one-hour's duration, but on occasion had to be cut short. Additionally, all opportunistic encounters were recorded in as much detail as conditions allowed.

Baited Camera Traps: Some of the more recent survey work (Maldives 2011 and Red Sea 2009) also employed multiple sets of baited, remote, underwater video-cameras (BRUVs). A standard set comprised four cameras (GoPro HD Hero) set 0.5-1 km apart, each baited with mackerel (three whole plus three minced to facilitate odour dispersal) contained within a rigid plastic mesh bag and suspended in the field of vision of the camera on a PVC arm. Each set was left to soak for two hours, following which the footage was observed and any elasmobranchs recorded, as for UVS.

Data Analysis: Catch per unit effort (CPUE) was calculated as number of individuals of each species recorded per hour. Where during UVS or BRUV work it was suspected that the same individual had returned it was not recounted. Species abundance was compared using a General Linear Model (GLM) and three predictive factors : Region (Maldives, Red Sea, Aldabra, Bassas da India, Europa), Habitat (Lagoon, Patch Reef, Channel, Outer Reef, Seamount) and Survey Method (UVS, BRUV).

Results

Over 254 hours of UVS and BRUV survey were conducted across the five different study areas: Aldabra (28.3 hrs), southern Maldives (179.3 hrs), Bassas da India (11.5 hrs), Europa (15.3 hrs) and the Saudi Red Sea (19.7 hrs). Some 795 sharks of 11 different species were sighted, which were, in order of decreasing abundance: grey reef (*Carcharhinus* *amblyrhynchos*), blacktip reef (*C. melanopterus*), whitetip reef (*Triaenodon obesus*), scalloped hammerhead (*Sphyrna lewini*), Galapagos (*C. galapagensis*), sicklefin lemon (*Negaprion acutidens*), silvertip (*C. albimarginatus*), tawny nurse (*Nebrius ferrugineus*), silky (*C. falciformis*), tiger (*Galeocerdo cuvier*) and zebra shark (*Stegostoma fasciatum*). A further three species were recorded during opportunistic encounters: whale (*Rhincodon typus*), thresher (*Alopias spp.*), and great hammerhead shark (*Sphyrna mokarran*).

	Region	MLD^{U}	MLD^{B}	RS^{B}	ALD^{U}	BdI^{U}	EUR^{U}
	Hours	35.33	144.00	19.72	28.25	11.47	15.28
WT	Σ	95	30	1	1	-	-
	Mean	**2.69**	**0.21**	**0.05**	**0.04**	**-**	**-**
	SD	*4.92*	*0.32*	*0.22*	*0.20*	-	-
BT	Σ	1	17	-	115	-	5
	Mean	**0.03**	**0.12**	**-**	**4.07**	**-**	**0.33**
	SD	*0.14*	*0.26*	-	*4.48*	-	*0.58*
GR	Σ	223	35	5	21	-	-
	Mean	**6.31**	**0.24**	**0.25**	**0.74**	**-**	**-**
	SD	*23.76*	*0.79*	*0.37*	*1.38*	-	-
TN	Σ	15	1	-	5	-	-
	Mean	**0.42**	**0.01**	**-**	**0.18**	**-**	**-**
	SD	*2.38*	*0.06*	-	*0.55*	-	-
LM	Σ	-	-	-	47	-	-
	Mean	**-**	**-**	**-**	**1.66**	**-**	**-**
	SD	-	-	-	*2.13*	-	-
TG	Σ	-	3	-	-	-	-
	Mean	**-**	**0.02**	**-**	**-**	**-**	**-**
	SD	-	*0.10*	-	-	-	-
ZB	Σ	-	1	-	-	-	-
	Mean	**-**	**0.01**	**-**	**-**	**-**	**-**
	SD	-	*0.06*	-	-	-	-
GP	Σ	-	-	-	-	34	17
	Mean	**-**	**-**	**-**	**-**	**2.97**	**1.11**
	SD	-	-	-	-	*5.50*	*2.78*
ST	Σ	5	-	7	-	21	14
	Mean	**0.14**	**-**	**0.36**	**-**	**1.83**	**0.92**
	SD	*0.76*	-	*0.57*	-	*2.23*	*2.74*
HH	Σ	1	-	3	1	-	55
	Mean	**0.03**	**-**	**0.15**	**0.04**	**-**	**3.60**
	SD	*0.15*	-	*0.23*	*0.59*	-	*9.16*
SK	Σ	-	-	14	-	2	-
	Mean	**-**	**-**	**0.71**	**-**	**0.17**	**-**
	SD	-	-	*0.79*	-	*0.41*	-
All	Σ	340	87	30	190	57	91
	Mean	**9.62**	**0.60**	**1.52**	**6.73**	**4.97**	**5.95**
	SD	*22.46*	*0.88*	*1.61*	*5.28*	*5.19*	*10.94*

Table 1: The total (Σ) and mean number of sharks per hour recorded for each region, with standard deviation (SD). Shark species abbreviated as follows: whitetip reef (WT), blacktip reef (BT), grey reef (GR), tawny nurse (TN), sicklefin lemon (LM), tiger (TG), zebra ZB), galapagos (GP), silvertip (ST), hammerhead spp. (HH), silky (SK). Region abbreviations as per Fig. 1, with superscripts 'U' and 'B' indicating method (UVS and BRUV respectively).

Table 1 shows the method-specific CPUEs for each species in each region. It should be noted that due to logistical constraints effort could not be evenly distributed between the regions and habitats as originally intended. For UVS, the southern Maldives showed the highest total CPUE (mean 9.62 sharks per hour). However the BRUVs CPUE for the Maldives was 0.60 sharks per hour, compared to 1.52 for the Saudi Red Sea. Figure 2 shows the proportional contribution of each species to the total number of individuals sighted. It shows considerable differences in relative abundance between areas with, for example, blacktip reef sharks being the most abundant species on Aldabra, but Galapagos sharks at Bassas da India.

Table 2 shows the results of the GLM analysis, confirming highly significant effects on CPUE of both region and habitat for most species, save of both region and habitat for nurse, tiger or zebra shark and of habitat for scalloped hammerhead, though this lack of effect most likely reflects inadequate sightings.

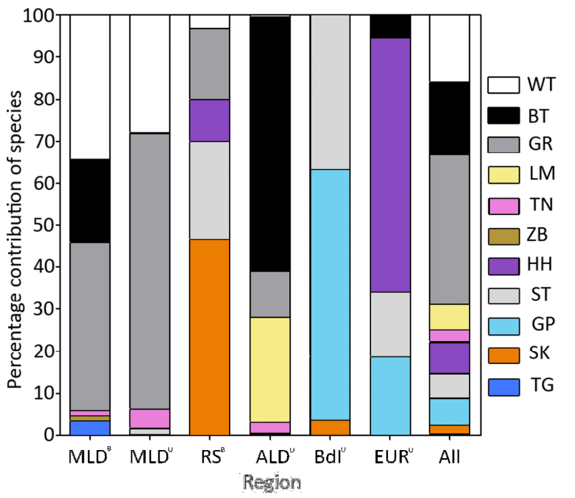

Figure 2. The proportional representation of shark species from each region. Abbreviations as per Fig. 1 and Table 1.

Discussion

UVS means varied by a factor of nearly 2 to 1, with the southern Maldives recording the highest number of sharks per hour (9.62) and Bassas da India the lowest (4.97). However CPUE and associated standard deviation was strongly influenced by aggregations of some species: e.g. groups of up to 50 grey reef sharks in the channels of Huvadhoo in the Maldives, of up to 19 blacktip reef sharks in the lagoon at Aldabra, of up to 30 scalloped hammerhead sharks off Europa, and up to 20 Galapagos sharks in the lagoon of Bassas da India.

The higher values are similar to those recorded at Sha'ab Rumi in the Sudanese Red Sea (5.9 per hour) by Hussey *et al.* (2011), and in the Chagos Archipelago (~500km south of the Maldives) in the

1970s (4.2 per hour; Graham *et al.* 2010). However the high CPUE for the Saudi Red Sea reefs included an area that has been baited on a semi-regular basis since 1995, while the site in Sudan (Hussey *et al.* 2011) had only been baited by tour boats on an occasional basis.

Test	R^2(adj.)	Factor	d.f.	*F*	*P*
WT	50.5	Region	4	22.18	**<0.001**
		Habitat	7	2.39	**0.023**
		Method	1	107.97	**<0.001**
GR	38.28	Region	4	6.81	**<0.001**
		Habitat	7	11.26	**<0.001**
		Method	1	26.59	**<0.001**
BT	77.7	Region	4	108.85	**<0.001**
		Habitat	7	22.65	**<0.001**
		Method	1	1.70	0.194
LM	63.68	Region	4	54.55	**<0.001**
		Habitat	7	10.27	**<0.001**
		Method	1	0.00	1.000
TN	2.52	Region	4	1.13	0.344
		Habitat	7	0.89	0.518
		Method	1	5.48	**0.020**
GP	36.28	Region	4	16.6	**<0.001**
		Habitat	7	6.18	**<0.001**
		Method	1	0.00	1.000
SK	58.86	Region	4	50.45	**<0.001**
		Habitat	7	20.32	**<0.001**
		Method	1	0.00	1.000
TG	0.00	Region	4	0.31	0.869
		Habitat	7	0.55	0.793
		Method	1	3.99	**0.047**
ZB	0.00	Region	4	0.15	0.961
		Habitat	7	0.72	0.657
		Method	1	2.12	0.147
HH	16.11	Region	4	9.89	**<0.001**
		Habitat	7	0.39	0.910
		Method	1	0.04	0.834
ST	42.75	Region	4	14.75	**<0.001**
		Habitat	7	10.01	**<0.001**
		Method	1	1.36	0.245

Table 2. GLM results from the model of $\log_{10}$(CPUE+1) = Region + Habitat (Region) + Method. Significant outputs in bold. Despite transformation the data only approached, but still differed from, normal. Abbreviations as per Table 1.

CPUE on Chagos has since decreased markedly, to 0.4 in 2006 (Graham *et al.* 2010). These data suggest that Chagos may now be more impacted than the Maldives or Aldabra, which is unexpected given its more remote location and new status as the largest marine reserve (Sheppard *et al.* 2012). However, the surveys at Chagos were un-baited surveys which may confound comparison between the two sites. Furthermore, the lack of residents who would report illegal activities may have made the area more vulnerable to poaching. Additionally whereas Chagos has been fished for tuna by longlining (Sheppard *et al.* 2012), only pole and line is employed in Maldives, a method avoiding shark by-catch (Adam, 2006).

The BRUV CPUEs are lower than those obtained using UVS, but this is not unexpected since the cameras monitor a more limited field of view than does the human observer. On the other hand, the presence of divers may inhibit the approach of some species, notably tiger sharks (Dale *et al.* 2011), which are thus more readily detected by BRUVS. This disparity between methods is reflected in the GLM results for several species (Table 2). Nevertheless BRUV CPUEs were higher than those recorded in BRUV surveys at other reefs around the world where sharks are considered common. For example, at Eleuthera, Bahamas, Brooks *et al.* (2011) recorded 112 sharks over 418.5 hours (0.26 sharks per hour overall), with tiger sharks showing a CPUE of just 0.013 (Brooks *et al.* 2011).

The finding for the Maldives is also of interest in relation to previous studies that reported a considerable decline in reef sharks there prior to protection (Martin & Hakeem, 2006). However, those studies primarily concerned the central and northern atolls of the Maldives, which historically experienced higher fishing pressure (Anderson & Ahmed, 1993).

Shark abundance would also be expected to be greater on Aldabra than through the rest of the Seychelles, since no fishing is allowed within 1km of its shore (SIF, 2002), while elsewhere sharks have been specifically targeted, with significant declines in large sharks being reported for the Mahe plateau (Nevill *et al.* 2007). It is also possible that the lower CPUE for Bassas da India compared to Europa reflects poaching, which on the latter is deterred by the French military presence.

The relative abundance of different species varied considerably between areas in a manner which had not been anticipated. The southern atolls of Maldives most closely matched the typical Indian Ocean pattern and were characterised by channel-associated aggregations of grey reef sharks, along with frequent whitetip reef shark sightings. By contrast Bassas da India lacked grey, blacktip and whitetip reef sharks, but was characterised by aggregations of juvenile Galapagos sharks in the lagoon, while Aldabra was distinguished by numerous blacktip reef and sicklefin lemon sharks associated respectively with the very shallow lagoon and the atoll channels.

In general however large species of shark were notably scarce or completely absent; very few tiger sharks were recorded, and there was only one sighting of a great hammerhead. It might be that these species are naturally present in only small numbers, since at Aldabra, for example, Stevens (1984) caught only a single specimen over the course of a whole year. Alternatively they may be present only intermittently, since tiger sharks often exhibit absences from particular sites for several months (Dale *et al.* 2011).

In addition however it seems possible that despite the isolation or putative protected status of the study areas, their populations of large sharks have nevertheless been depleted by fishing, as individuals can range over large ocean areas (Sims, 2010), thus exposing themselves to risk of capture away from protected areas. In the Seychelles shark fishing and finning remains legal (Nevill *et al.* 2007), and anecdotal accounts suggest that sightings of large sharks there were rare even by the end of the 1960s (Smith & Smith, 1969), while the small size of the fisheries exclusion zone around Aldabra means that large species must spend much of their time beyond it.

The apparently low abundance of tiger sharks should however be treated with caution since UVS may significantly underestimate the abundance of some large species. A 2005 survey of Seychelles fishermen, asking which three shark species they caught most frequently, resulted in a list that still included tiger, oceanic whitetip and hammerhead sharks, even though a comparable survey of recreational divers failed to document any of these species (Nevill, 2005). Similarly in the Northwest Hawaiian Islands, whilst only one tiger shark was recorded during three years of UVS, the species constitutes up to 20% of longline catches (Dale *et al.* 2011). In addition due to logistical constraints the study is temporally limited, and therefore unable to account for any potential seasonal or long term variation both within and between regions.

Acknowledgement

The authors thank the Founder and Board of the Save Our Seas Foundation for funding and facilities. We also thank the divers, ships' crews and engineers of Danah Divers and MY Save Our Seas, and also the Maldivian, Seychellois and French governments for their support for the present study.

References

Adam MS (2006) Country Review: Maldives. In: Review of the state of world marine capture fisheries management: Indian Ocean. FAO Fisheries Technical Paper. No. 488. pp. 383-391

Anderson RC, Ahmed H (1993) The shark fisheries of the Maldives. FAO Technical Report, Ministry of Fisheries and Agriculture, Male, Republic of Maldives. 77pp.

Baum JK, Myers RA (2004) Shifting baselines and the decline of and the decline of pelagic sharks in the Gulf of Mexico. Ecol Lett. 7: 135-145

Brooks EJ, Sloman KA, Sims DW, Danylchuk AJ (2011) Validating the use of baited remote underwater video surveys for assessing the diversity, distribution and abundance of sharks in the Bahamas. Endang Species Res. 13:231-243

Clarke C, Lea JSE, Ormond RFG (2011) Reef-use and residency patterns of a baited population of silky sharks, *Carcharhinus falciformis*, in the Red Sea. Mar Freshwater Res. 62:668-675

Clarke SC, McAllister MK, Milner-Gulland EJ, Kirkwood GP, Michielsens CGJ, Agnew DJ *et al.* (2006) Global estimates of shark catches using trade records from commercial markets. Ecol Lett, 9:1115–1126

Dale JA, Meyer CG, Clarke CE (2011) The ecology of coral reef top predators in the Papahanaumokuakea Marine National Monument. J Mar Biol. doi:10.1155/2011/725602.

Ferretti F, Myers RA, Serena F, Lotze H (2008) Loss of Large Predatory Sharks from the Mediterranean Sea. Conserv Biol. 22:952-964

Ferretti F, Worm B, Britten GL, Heithaus MR, Lotze HK (2010) Patterns and ecosystem consequences of shark declines in the ocean. Ecol Lett. 13:1055-1071

Fourmanior P (1952) Observations sur la faune marine et la pêche l'ile Europa. Mémoires de l'Institut Scientifique de Madagascar, Série A. 7:167-188

Graham NAJ, Spalding MD, Sheppard CRC (2010) Reef shark declines in remote atolls highlight the need for multi-faceted conservation action. Aquat Conserv. 20:543-548

Hussey NE, Stroth N, Klaus R, Checkchak T, Kessel ST (2011) SCUBA diver observations and placard tags to monitor grey reef sharks, *Carcharhinus amblyrhynchos*, at Sha'ab Rumi, The Sudan: assessment and future directions. J Mar Biol Assoc UK. doi:10.1017/S0025315411001160

Lack M, Sant G (2006) Confronting shark conservation head on. TRAFFIC International: Cambridge.

Martin RA, Hakeem AAA (2006) Development of a sustainable shark diving ecotourism industry in the Maldives: challenges and opportunities. Maldives Mar Res Bull. 8:56pp

Meyer CG, Clark TB, Papastamatiou YP, Whitney NM, Holland KN (2009) Long-term movement patters of tiger sharks *Galeocerdo cuvier* in Hawaii. Mar Ecol Prog Ser. 381: 223-235

MRC (2009) Maldives, the first country in the region to ban shark fishing. Marine Research Centre: http://www.mrc.gov.mv/index.php/news_events/maldives_bans_shark_fishing

Nevill J, Robinson J, Giroux F, Isidore M (2007) Seychelles National Plan of Action for the Conservation and Management of Sharks. Seychelles Fishing Authority, Victoria, Seychelles. 59pp

Nevill JEG (2005) Establishing a baseline for shark fishery management in the Seychelles. MSc University of Newcastle upon Tyne

Quod J-P, Garnier R. 2004. A preliminary assessment of the coral reefs of Europa (Mozambqiue Channel). Reef Encounter. 32:23-25

Seychelles Island Foundation (2002) Aldabra Atoll, Seychelles: Report of initial management effectiveness evaluation. Initial Assessment, UNESCO. 118pp

Sheppard CRC, Ateweberhan M, Bowen BW, Carr P, Chen CA, Clubbe C *et al.* (2012) Reefs and islands of the Chagos Archipelago, Indian Ocean: why it is the world's largest no-take marine protected area. Aquat Conserv. doi: 10.1002/aqc.1248

Sims DW (2010) Swimming behaviour and energetics of free-ranging sharks: New directions in movement analysis. *In* Domenici P, Kapoor BG, Eds.; Fish Locomotion: An Eco-ethological Perspective; Science Publishers, USA; pp 407-435

Smith JLB, Smith MM (1969) The fishes of Seychelles. The JLB Smith Institute of Icthyology. Rhodes University, Grahamstown, South Africa. 223pp

Stevens JD (1984) Life-history and ecology of sharks at Aldabra Atoll, Indian Ocean. P R Soc B. 222:79-106

Tremblay-Boyer L, Gascuel D, Watson R, Christensen V, Pauly D (2011) Modelling the effects of fishing on the biomass of the world's oceans from 1950 to 2006. Mar Ecol Prog Ser. 442:169-185

van der Elst R, Chater S (2001) The ichthyofauna of Bassas da India atoll in the Mozambique Channel. In: Proceedings of the 6th Fish Indo-Pacific Conference, Durban.