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Shark pelagic longline fishery in the Gulf of Gabes: Inter-decadal inspection reveals management needs

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Abstract

This study explores the status of exploited shark populations in the Gulf of Gabes in relation to fishing pressure, based on data pertaining to shark longline fishery, collected during two periods. Catch data from 48 and 96 pelagic longline sets collected, respectively, during 2007/2008 and 2016/2017, were used to compare species composition and catch rates between periods. Four species were recorded during 2007/2008, while 11 additional species of pelagic and demersal elasmobranchs along with teleosts were fished during 2016/2017. Elasmobranch species dominated the catches with 94% and 99.3% in terms of specimens number, respectively, during 2016/2017 and 2007/2008. The sandbar shark, *Carcharhinus plumbeus*, was the predominant species in catch (>84% of all fishes) during both periods. Two other species of sharks, *Carcharhinus brevipinna* and *Isurus oxyrinchus*, were relatively common, while the other species were a minor component. Despite the increase in terms of diversity pertaining to species captured during 2016/2017, the nominal catch rates of elasmobranch and *C. plumbeus* decreased by 39.17% and 42.21%, respectively, suggesting populations' declines. In addition, size distribution analyses revealed that this fishery may opportunistically operate on breeding and nursery areas, which affect main species over most of their life stages. The mortality and hooking location proportions were species-specific, with some species having significant percentages of live specimens at the time of haulback, providing an opportunity to release the sensitive life stages. Given the described state of shark exploitations in the Gulf of Gabes, urgent and efficient fishery regulation measures and conservation strategies, together with further investigations, are required to allow changing the unregulated shark longline fishery to a sustainable one.

Keywords: Pelagic longline; sharks; Gulf of Gabes; overfishing; bycatch.

Introduction

Elasmobranchs have historically been considered as a considerable food resource in southern Tunisia. Their exploitation dates back to the beginning of the last century; sharks caught in Djerba were cut into strips, dried and shipped elsewhere to be exchanged with dates or other commodities (De Fages & Ponzevera, 1903). Currently, Tunisia is one of the main leaders in terms of elasmobranch production in the Mediterranean Sea. The annual catch of elasmobranchs is about 2000 tons, over 70% of which are from the Gulf of Gabes (DGPA, 2016), where 27 different species of sharks and 21 of batoids were recorded in previous studies (Bradai *et al*., 2006). In this area, elasmobranchs are exploited either as the target of specific fisheries or, more often, as by-catch of fisheries targeting other commercial species (Bradai *et al*., 2006; Echwikhi *et al*., 2013, 2014; Saidi *et al*., 2016) and sold in local markets. Elasmobranch specific fisheries began in the early-1980s, using gill-nets, targeting smooth-hounds, *Mustelus* spp. In the late 1980s, specific gillnets, with different stretched mesh sizes, were used to target sandbar shark, *Carcharhinus plumbeus*, and guitarfish, *Rhinobathos* spp. (Echwikhi *et al*., 2013). These fisheries are seasonal and operate during spring–summer, i.e. when species move to shallow waters for reproduction. In recent years, pelagic longlines, for swordfish, have also been used to directly target sharks, mainly *C. plumbeus* (Echwikhi *et al*., 2014).

Elasmobranchs are vulnerable to fishing mortality, due to their life histories characteristics, as well as behaviors such as mating aggregations (Stevens *et al*., 2000;

Gallucci *et al*., 2006; Dulvy *et al*., 2014). They have low resistance and resilience to fishing pressure levels compatible with sustainable exploitation of teleosts and invertebrate stocks (Simpfendorfer, 2000). While data on elasmobranch landings and stock status are usually poor or non-existent (Worm *et al*., 2013), the emerging picture illustrates a dramatic decline of several elasmobranch populations in the Mediterranean Sea (Ferretti *et al*., 2008, 2013; Maynou *et al*., 2011; Colloca *et al*., 2017; Bradai *et al*., 2018). At least 53% of sharks and batoids in the Mediterranean Sea are at risk of extinction, thus urgent measures to conserve their populations and habitats are required (Dulvy *et al*., 2016). Furthermore, the available information related to the Gulf of Gabes indicates that landings of elasmobranch have been declining since the late 2000s, suggesting that data on fishery characteristics, species composition, fishing effort, and management are needed. Nevertheless, fishery impacts on elasmobranch species have received little attention in Tunisia (Saidi *et al*., 2016).

A preliminary analysis of shark longline fishery was conducted in 2007-2008 (Echwikhi *et al*., 2014). Results showed that captures were mainly composed of sandbar shark, accounting for 93.5% of the total catch in terms of number. Given the conservation issues for Mediterranean sharks and the absence of a catch monitoring program, basic information pertaining to this specific artisanal shark longline fishery is clearly required for the conservation and the management of exploited species. Therefore, such fishery was inspected during two consecutive fishery seasons, i.e. 2016 and 2017.

The present study aimed to investigate the status of exploited shark populations in the Gulf of Gabes in relation to fishing pressure, based on fishery data collected during 2016-2017 in comparison with those of Echwihki *et al*. (2014), recorded during 2007-2008. This goal was achieved by: (1) investigating temporal variability of the catch composition, (2) examining the trend in catch rates and (3) providing recent biological information (size composition and sex ratios) for the main species in capture. Besides, information on animal condition “at-haulback” and hook location, to evaluate the possibility of releasing live specimens, are also provided.

Materials and Methods

The study was conducted in the Gulf of Gabes, recognized as an elasmobranch biodiversity “hotspot” in the Mediterranean Sea and one of the main fishing areas of artisanal vessels targeting elasmobranchs (Bradai *et al*., 2006; Echwikhi *et al*., 2013, 2014).

Fishery description

The shark longline fleet consists of small wooden vessels, ranging in length from 8 to 15 m, powered by 45-320 HP diesel engines and incorporating 5 to 6 crew members. This fleet belongs to the harbors of Zarzis and Djerba and operates in the southern part of the Gulf of Gabes (Fig. 1). The artisanal fleet changes its gear and target species over time, depending on market demands and species occurrences. Sharks were targeted yearly from mid June to October, however, principally in July-August. Five vessels were involved in this fishery in June-October, while about 15 other vessels engaged in this fishery during July and August.

Pelagic longline consists of 10 to 50 km nylon monofilament mainline (1.6 mm diameter), sustaining a series of double nylon monofilament branchlines at about 34-40 m intervals. Each branchline is 6-6.5 m long and 1.4 mm in diameter, terminating with a single baited J hook. The hooks were *Mustad* pattern, size 2/0 stainless steel with a 10° offset, usually baited with mackerel (*Scomber scombrus*).

Each fishing boat uses from 400 to 1200 hooks, contained in 3-4 boxes. Longliners operate their lines manually and longline is generally set at sunset and allowed to soak overnight, before hauling back in the morning after about 10-12 hours. The fishing trips are often of short duration, generally of about 4 days. The fishing depth is usually between 40 and 100 m. Currently, there is no management on hook usage, size or species capture for pelagic longlines targeting sharks.

Data source

We relied on data collected onboard of vessels, using pelagic longline during two periods (2007/2008 and 2016/2017), in the south part of the Gulf of Gabes (Djerba-Zarzis). The first dataset collected by Echwikhi *et al*. (2014) consisted of 48 longline sets (35950 hooks), whilst in 2016–2017 observers monitored 35 pelagic longline trips, consisting of 96 sets and 116500 hooks deployed.

Data were collected by observers placed on fishing vessels, recognized as part of the artisanal pelagic longline fleet, targeting sharks during two consecutive fishery seasons (July-September). The boats were chosen randomly among vessels of the port of Zarzis and Djerba

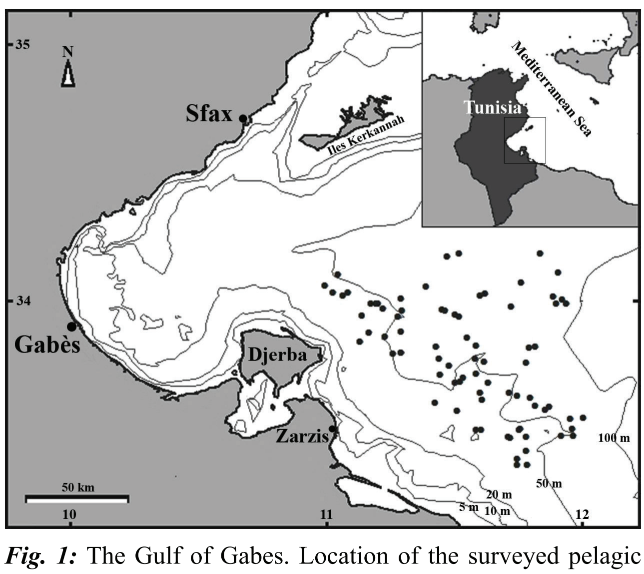

Fig. 1: The Gulf of Gabes. Location of the surveyed pelagic longline sets during 2016/2017.

(Gulf of Gabes), where the majority of longliners targeting sharks are based. To obtain accurate information, observers were trained to collect information on gear characteristics as well as to identify and record species, sex and size of all animals captured on pelagic longline fishing sets. Observers had no influence on the choice of fishing location and the organization of the fisheries operations.

Observers collected information for each longline set, including the setting position, time of gear deployment and retrieval, length of the main and branchlines, type of bait, number and type of hooks, number of floats and length of float lines. Catch composition was recorded, including the number of individuals by species retained or discarded.

For each set, all fish caught were identified to the lowest possible taxon, enumerated, sexed and measured to the nearest mm. Standard measurements were disc width (DW) for batoids and total length (TL) for sharks and other species. For each species, observers recorded whether the specimens were dead or alive at the time of hauling and if they were landed, released alive or discarded dead. Species-specific percentages of live and dead specimens were calculated based on sex and life stages for common species. Hooking location was also recorded for the main shark species caught and then classified as critical (oesophagus, gills or eye) or non-critical (jaw, hinge, roof of mouth), using criteria developed by Meka (2004) and Arlinghaus *et al.* (2008).

Data analysis

Based on the total number of hooks deployed, and number of individuals caught of each species, the catch per unit effort (CPUE) was calculated as the number of individuals caught per 1000 hooks (Ind/1000H), and data are presented as mean ± 95% confidence interval (C.I). In order to investigate the impact of pelagic longline of each life stage, specimens were classified as neonate, juvenile or adult based on the available reproductive information from the area (Capapé *et al.*, 2003; Saidi *et al.*, 2005, 2008; Enajjar *et al.*, 2012).

The hypothesis of parity in the sex-ratio was tested with chi-square statistics ($\chi 2$) at a 95% confidence level. Sex specific size composition data were evaluated for normality (Shapiro Wilk's test) and compared using Mann-Whitney and 2-sample Kolmogorov-Smirnov (K-S) tests. The differences in hooking location and alive/dead at-haulback proportions were compared between sexes and life stages, using $\chi 2$ contingency tables. Statistical significance was declared at $P < 0.05$.

Results

Species composition and catch rate evolution

Taking into account both periods, a total of 15 different taxa pertaining to elasmobranchs and teleosts were caught (Table 1). Four species were captured during both

Table 1. Species composition, Number caught, Percentage of the total catch and Nominal CPUE (± C.I) by species for shark pelagic longline fishery off the Gulf of Gabes during 2016/2017 and 2007/2008.

	2016/2017			**2007/2008**			**Statut IUCN**
Species	No. caught	All fishes (%)	Ind /1000H	No. caught	All fishes (%)	Ind /1000H	
Xiphias gladius	40	3.28	0.34 ± 0.21	4	0.68	0.11 ± 0.10	
Euthynnus alletteratus	5	0.41	0.04 ± 0.02				
Coryphaena hippurus	7	0.57	0.06 ± 0.05				
Carcharhinus plumbeus	1024	84	8.79 ± 2.60	547	93.5	15.22 ± 3.59	**EN**
Carcharhinus brevipinna	23	1.90	0.20 ± 0.16	22	3.76	0.61 ± 0.34	NA
Isurus oxyrinchus	56	4.60	0.48 ±0.25				**CR**
Mustelus mustelus	13	1.07	0.11 ± 0.12				**VU**
Pteroplatytrygon violacea	11	0.90	0.09 ±0.06	12	2.05	0.33 ± 0.16	LC
Glaucostegus cemiculus	3	0.25	0.03 ±0.05				**EN**
Pteromylaeus bovinus	2	0.16	0.02 ±0.03				**CR**
Taeniurops grabatus	10	0.82	0.09 ±0.07				DD
Raja clavata	3	0.25	0.03 ±0.04				NT
Epinephelus aeneus	6	0.50	0.05 ±0.06				
Epinephelus costae	11	0.90	0.09 ±0.10				
Epinephelus marginatus	5	0.41	0.04 ±0.01				

IUCN category (NA= Not Applicable; LC = Least Concern, NT = Near Threatened, VU = Vulnerable, EN = Endangered, CR = Critically Endangered) is provided for those species with adequate data (Dulvy *et al.*, 2016).

periods, while 11 demersal and pelagic species appeared only in the 2016/2017 examination. Five of the captured elasmobranch species are considered as threatened (Vulnerable, Endangered, and Critically Endangered), two of which are Critically Endangered in the Mediterranean according to the IUCN Red List of Threatened Species (Table 1).

Elasmobranch species dominated the catch with 94% and 99.3% in terms of number, during 2016/2017 and 2008/2008, respectively. However, the contribution of shark in catch greatly exceeded those of batoids during both periods (Table 1). Sandbar shark, *C. plumbeus*, was the main species observed, accounting for 84% and 93.5% of the total catch, respectively, during 2016/2017 and 2007/2008. During 2016/2017, this species was followed by shortfin mako, *Isurus oxyrinchus*, (4.6%) and spinner shark, *C. bervipinna*, (1.9%), whereas other elasmobranch species constitute a minor component (<1%) (Table 1). Among batoids, pelagic stingray *Pteroplatytrygon violacea* was the most important, accounting for 0.9% in terms of number (Table 1). Swordfish averaged 3.3%, during 2016/2017, while other teleost species were of secondary importance. All the specimens of *P. violacea* were discarded, *Taeniurops grabatus* and *Raja clavata* were generally used for bait and all other species were landed.

The pooled CPUE for elasmobranch in 2007/2008 was 16.16 fish/1000 hooks, and sandbar shark represented 94.1% of the pooled value (Fig. 2). In 2016/2017, the elasmobranch CPUE decreased to 9.82 fish/1000 hooks, while the sandbar shark contributed by 89.51% to the total catch number. Despite the increase in the number of species caught during 2016/2017, the pooled elasmobranch CPUE decreased by 39.17%, between the two periods (Fig. 2). In addition, the mean nominal CPUE of *C. plumbeus* decreased by 42.21% between the two periods. The same trend was noted for spinner shark and pelagic stingray (Fig. 2). On the contrary, the mean nominal CPUE values of swordfish increased between the two periods. Although the shortfin mako was not observed in 2007/2008 catch, it was considered as the second most significant shark species captured during 2016/2017.

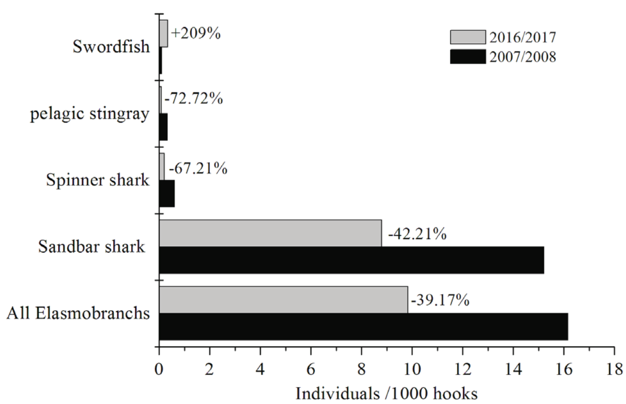

Fig. 2: Catch per unit effort (CPUE; number of individual/1000 hooks) plotted for all elasmobranch and species caught in each period. The percentages represent the changes in CPUE between the two periods.

Size composition

The size distribution of the main species revealed that with respect to sharks, captures comprise mainly juveniles, while adult specimens dominate in batoid species. Overall, there were no significant differences from expected 1:1 sex ratio for almost all species. Furthermore, except *C. plumbeus*, all the species caught did not show significant sex-specific differences in terms of size distribution (Table 2).

All life stages of *C. plumbeus* were captured with dominance of juveniles during both periods (Table 2; Fig. 3A). However, the proportion of adult specimens in catches increased during 2016/2017 (Table 2). On the other hand, the capture of life stages was monthly related for both sexes ($\chi 2$; $p<0.05$). Adult specimens were mostly common during June to August period (Fig. 4).

The specimens examined, pertaining to *C. brevipinna*, were almost all juveniles during both periods (Fig. 3B). In addition, there was no significant difference in terms of size distribution and mean size between male and female (Table 2). The captured size range of *I. oxyrinchus* included mainly juveniles (Fig. 3C). The size composition of females and males did not differ significantly (Table 2).

Mortality at haulback and hooking location

Mortality rate at haulback varied significantly among captured species ($\chi 2$, $p<0.05$) (Table 3). Among the most commonly caught species with at-vessel mortality, the sandbar (56.64%) and spinner (43.47%) sharks had the highest overall mortality rates and the shortfin mako (33.3%) had the lowest ones. Conversely, batoids species have low mortality rates at the point of hauling. The mortality at haulback rates did not vary, based on sex, for all species ($\chi 2$, $p>0.05$). However, mortality rates were related to life stages for *C. plumbeus,* with adults being more affected ($\chi 2$, $p<0.05$) (Fig. 5).

Hook locations were considered only for the common three shark species. The proportion of sharks with critical hooking differed significantly across species, with shortfin mako being more hooked as critical (Table 3; $\chi 2$; $p < 0.05$). For sandbar shark, the majority of hooking locations was considered non-critical (81.44%), including jaws and the corner of the jaw. Five percent of specimens were entangled, while 13.47% of the hooking was critical (Oesophagus, gills). For *C. brevipinna*, 91.30% of the hooking were non critical, while 8.70% were considered critical. Conversely, shortfin mako sharks were hooked more frequently in critical location (73.21%). On the other hand, results from contingency table analysis indicated that hooking on critical location was significantly different among life stages of *C. plumbeus*, with adult specimens experiencing the highest proportion ($\chi 2$; $p<0.05$) (Fig. 5).

Table 2. Numbers by sex, Sizes (range and mean), Sex ratios and percentage of each life-history stage of elasmobranch species captured in pelagic longline fishery in the Gulf of Gabes during 2007/2008 and 2016/2017.

Species	Period	Sex	N	Mean length; range (cm)	Mann–Whitney U-tests Kolmogorov-Smirnov	Sex ratio	Life stages in catch (%)		
							Newborns	**Juveniles**	**Adults**
Carcharhinus plumbeus	2007/08	F	361	102.39; 53-172	K-S, D=0.120; $p>0.05$	χ^2=55.98; $p < 0.05$	12.30	85.50	2.30
		M	186	107.17; 59-172			9.68	86.56	3.76
	2016/17	F	488	131.95; 60-210	K-S, D=0.00; $p<0.05$	χ^2=3.75; $p <0.05$	7.50	65.94	26.56
		M	523	117.93; 60-182			6.26	80.85	12.89
Carcharhinus brevipinna	2007/08	F	16	100.70; 60-135	U=38.50; $p>0.05$	χ^2=4.54; $p <0.05$	12.50	87.50	
		M	6	105.50; 75-130				100	
	2016/17	F	14	116.36; 70-218	U=33.5; $p>0.05$	χ^2=1.087; $p >0.05$	14.29	71.43	14.29
		M	9	123.67; 104-160				100	
Isurus oxyrinchus	2016/17	F	29	103.41; 74-180	U=311; $p>0.05$	χ^2=0.071; $p >0.05$		100	
		M	27	91.63; 60-130			7.40	92.60	
Pteroplatytrygon violacea	2007/08	F	7	50-65	U=15.50; $p>0.05$	χ^2=0.033; $p >0.05$			100
		M	5	45-70					100
	2016/17	F	11	52.2;45-60		χ^2=11; $p <0.05$			100
		M	-	-					-
Mustelus mustelus	2016/17	F	8	109.25; 67-164	U=9.00; $p>0.05$	χ^2=0.692; $p >0.05$		80	20
		M	5	75.75; 57-106				87.75	12.5
Taeniurops grabatus	2016/17	F	8	96.37;71-140	U=4.50; $p>0.05$	χ^2=3.60; $p <0.05$			100
		M	2	81;75-87					100
Raja clavata	2016/17	F	2	46;30-62				50	50
		M	1	48				100	
Pteromylaeus bovinus	2016/17	F	1	93					100
		M	1	38				100	-
Glaucostegus cemiculus	2016/17	F	3	130-150					100
		M	-	-					

Discussion

The Gulf of Gabes is recognized as an elasmobranch biodiversity "hotspot" within the Mediterranean Sea, as well as an area where several species found favorable habitats for reproduction (Bradai *et al*., 2005; Enajjar *et al*., 2015). Accordingly, an unregulated shark longline fishery subsists and it is restricted to a few months of activity on the basis of the seasonal occurrence of species, mainly sandbar sharks. While sharks have been traditionally targeted using drift longline (De la Serna *et al*., 2002), actually this is the only active shark pelagic longline fishery in the Mediterranean Sea.

Investigation conducted during 2016/2017 showed that 15 taxa were recorded, among them only four species were registered during 2007/2008. However, numerous species recorded during this study were founded in pelagic longline landings during 2007/2008, such as *I. oxyrinchus* (Echwikhi *et al*., 2014). During 2007/2008, four pelagic species were recorded, while during 2016/2017 captures included pelagic and demersal species. Although some sporadic catches of demersal species were reported (Megalofonou *et al*., 2005), usually pelagic longline captures in the Mediterranean Sea are typically pelagic or coastal-pelagic species (De la Serna *et al*., 2002; Megalofonou *et al*., 2005; Ceyhan & Akyol, 2014). These captures could be related to the fact that some deep-water species ascend close to the surface at night, where they might be taken by pelagic longlines (Castro *et al*., 1999). Nevertheless, the capture of demersal species such as *Epinephelus* spp. in pelagic

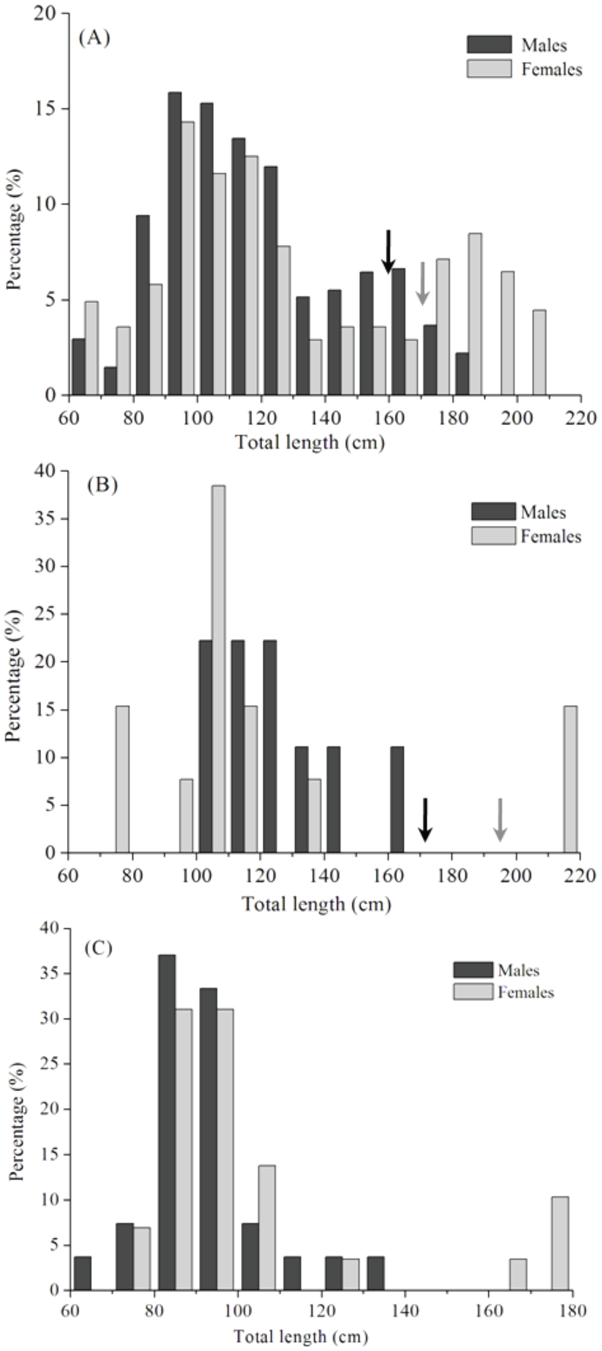

Fig. 3: Length–frequencies distribution of *Carcharhinus plumbeus* (A), *Carcharhinus brevipinna* (B) and *Isurus oxyrinchus* caught with pelagic longline in the Gulf of Gabes during 2016/2017.

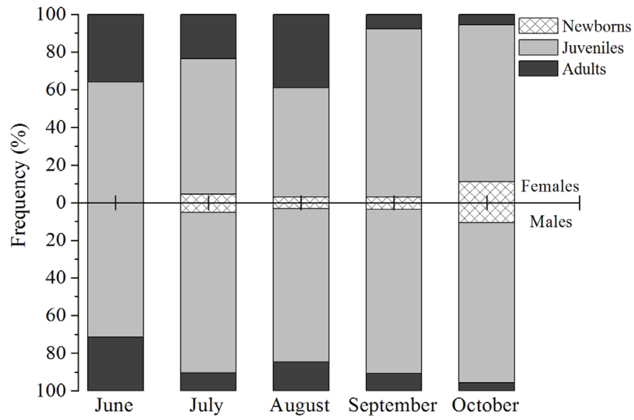

Fig. 4: Monthly capture of life-history stages of *Carcharhinus plumbeus* with pelagic longline in the Gulf of Gabes during 2016/2017.

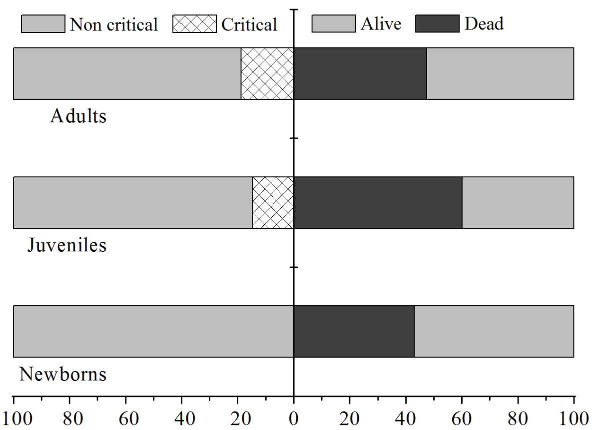

Fig. 5: Percentage (%) of hooking location (critical vs. non critical) and mortality at-haulback in the different life-history stages of *Carcharhinus plumbeus*.

gear could be related to gear modification in response to the decrease in catch. Additional investigations are needed to elucidate the basis of occurrence pertaining to unusual species in pelagic longline.

During both periods, the catch rate of swordfish in the Gulf of Gabes is quite low compared to other Mediterranean areas, mainly Italy, Greece, and Turkey where CPUE vary from 3 to 10 Ind/1000 hooks (Damalas *et al*., 2007; Báez *et al*., 2009; Cambiè *et al*., 2013; Ceyhan & Akyol, 2014). The spatial and environmental variables, such as sea surface temperature, play a key role regarding swordfish distribution in the Mediterranean Sea (Tserpes *et al*., 2008). The scarcity of swordfish in the Gulf of Gabes has led to the exploitation of sharks by the vessels using pelagic longline (Echwikhi *et al*., 2014).

The sandbar shark *C. plumbeus* dominated catches with more than 80% in terms of number, during both periods. The predominance of the sandbar sharks was consistent with the general accounts of its distribution and abundance in the Mediterranean Sea (Bradai *et al*., 2005; Saidi *et al*., 2005). On the other hand, this dominance could be ascribed to the selectivity of the gear. Although, *I. oxyrinchus* was not observed during 2007/2008, it became, numerically, the second more abundant species during 2016/2017. Catch rates of this species are generally low throughout the Mediterranean Sea (Megalofounou *et al*., 2005; Báez *et al*., 2009; Ceyhan & Akyol, 2014). This could be assigned to the population declines of the species in the Mediterranean due to regional depletion from historical fishing (Ferretti *et al*., 2008). Besides, the configuration of fishing gear and hook depth could be another reason. In fact, a number of studies confirmed the effect of fishing depth on catch rates (Shiode *et al*., 2000).

Results showed that nominal CPUE for total elasmo-

Table 3. Hooking location and mortality at-haulback of elasmobranch species captured in pelagic longline fishery in the Gulf of Gabes during 2016/2017.

Species	No. caught	Hook location		Mortality (%)
		Critical	**Non critical**	
Carcharhinus plumbeus	1024	138 (13.47%)	834 (81.44%)	580 (56.64%)
Carcharhinus brevipinna	23	2 (8.70%)	21 (91.30%)	10 (43.47%)
Isurus oxyrinchus	56	41 (73.21%)	15 (26.79)	18 (32.14%)
Mustelus mustelus	13	-	-	0
Pteroplatytrygon violacea	11	-	-	0
Glaucostegus cemiculus	3	-	-	1 (33.33%)
Pteromylaeus bovinus	2	-	-	0
Taeniurops grabatus	10	-	-	0
Raja clavata	3	-	-	0

branch and main species exhibited significant decreases between 2007/2008 and 2016/2017. Indeed, the most plausible explanation for such CPUE might be attributed to populations decline. The negative temporal trend for elasmobranch species in the Gulf of Gabes is in line with the general decrease of Mediterranean sharks population observed during the last 50 years (Aldebert, 1997; Ferretti *et al*., 2008, 2013; Colloca *et al*., 2017), also perceived by the fishers (Maynou *et al*., 2011) and clearly correlated with the increasing trend regarding fishing effort (Dell'Apa *et al*., 2012; Barausse *et al*., 2014). On the other hand, the results represent an indicator of a broader decline in terms of abundance pertaining to the species in the area.

A check of the size distribution for most species showed that with respect to sharks, captures comprise mainly juveniles, while mature specimens dominate in batoid species. Furthermore, the size distribution of the sandbar sharks is quite similar between both periods, with the dominance of juveniles. However, results reveal that all life stages of sandbar and spinner sharks were available in the continental shelf, where longliners operate. The extremely wide continental shelf of the Gulf of Gabes provides a large habitat that constitutes nursery areas for some species (Bradai *et al*., 2005; Enajjar *et al*., 2015).

The pelagic longline fishery overlaps with the parturition period of *C. plumbeus* in the area (Saidi *et al*., 2005), including then a sizeable capture of all life-history stages. The capture of all life stages suggests that the fishery may opportunistically operate in breeding or nursery areas. On the other hand, the increase of proportion pertaining to adult females in catch suggests a shift towards larger specimens which could potentially cause population decline. Because of the overlap of this fishery with the high use areas in coastal waters, it may be among the greatest current threats to the *C. plumbeus* in the Mediterranean Sea and thus should be monitored to avoid future stock depletion of such vital resource. Sandbar shark possesses one of the lowest intrinsic population growth rates yet estimated for any shark species and it is therefore highly susceptible to overexploitation, as well as being very slow to recover from stock depletion (Sminkey & Musick, 1996; Cortés, 1998; McAuley *et al*., 2007). The low reproductive capacity of *C. plumbeus* coupled with the moderate fishing pressure make them susceptible to overfishing in the Gulf of Gabes. Therefore, this fishery requires careful management to avoid stock depletion.

Catches of shortfin mako sharks were composed of juveniles. Inspection of shark bycatch in longline fisheries confirm an absolute dominance of juveniles in the Mediterranean catches, whose size ranges between 60 and 160 TL cm (Buencuerpo *et al.,*1998; De la Serna *et al*., 2002; Megalofonou *et al*., 2005). However, some records reported mature specimens (Soldo & Jardas, 2002; Celona *et al*., 2004; Kabasakal, 2015). According to these results, the Mediterranean is inhabited by juvenile and large individuals. However, the absence of adults' specimens in longline fisheries could be related to the gear selectivity and hook depth. On the other hand, the decline of the population in the area could be another explanation (Ferretti *et al*., 2008).

At vessel mortality percentages of elasmobranchs caught in pelagic longline fisheries are species-specific (Gilman *et al*., 2008; Ellis *et al*., 2017). Generally, batoids, including the pelagic stingray and eagle rays tend to have very low percentages of dead specimens at-haulback (Ellis *et al*., 2017). The hooking mortality for shortfin mako, reported in this study, was in the range of 5-56% as reported for the species in several studies (Megalofonou *et al.*, 2005; Epperly *et al.*, 2012; Gallagher *et al.*, 2014; Gilman *et al.*, 2016; Campana *et al.*, 2016), while studies comprising greater sample sizes have generally reported a mortality of 35–56% (Beerkircher *et al.*, 2004; Coelho *et al.*, 2012; Bromhead *et al.*, 2012). There are far fewer reported estimates for sandbar and spinner sharks; however, the reported respective mortalities in the present study were in the range of mortality rates estimated for most species of genus *Carcharhinus* (Beerkircher *et al*., 2004; Morgan & Burgess, 2007; Coelho *et al*., 2012; Ellis *et al*., 2017). On the other hand, the mortality rates for *C. plumbeus* (41%) and *C. brevipinna* (0%) reported by Echwikhi *et al*. (2014), in the same area, were lower than those estimated in this study.

Soak time and respiratory mode are primary factors that affect immediate mortality (Dapp *et al*., 2016; Ellis *et al*., 2017). Since *C. plumbeus* and *C. brevipinna* are considered obligate ram ventilators, they have significantly immediate mortality percentages (Carlson *et al*., 2004; Dowd *et al.,* 2006). However, the higher mortality of *C. plumbeus* associated with this fishery may be related mainly to the soak time, which was longer than 10h. Increased soak time generally increases hooking mortality, although the magnitude of the effect differs among species (Ward *et al*., 2004). Demersal species with buccal pump ventilation may survive capture and handling on deck better than faster swimming taxa that are obligate ram ventilators (Revill *et al*., 2005; Rodríguez-Cabello *et al*., 2005). Size proved to be another factor affecting at-vessel mortality in various species (Davis, 2002). Our data revealed that at-vessel mortality rates increase as size increases for sandbar sharks. The adult specimens, mainly pregnant females, may be more susceptible to fishery-induced mortality compared to other life-history stages. The significant proportions of alive specimens at-haulback provide an opportunity to release the susceptible life stages.

The anatomical hooking location represents an indicator of the degree of injury and probability of haulback and post-release survival (Gilmen *et al*., 2016). The rate of hooking on critical location, observed in our study, varied between species and was the highest for *I. oxyrinchus* with 73.21%, while *C. plumbeus* and *C. brevipinna* were more often hooked externally. On the other hand, for sandbar sharks, the critical hook location increased according to size. Several factors such as hook size and type, as well as fish size may affect anatomical hooking location (Epperly *et al*., 2012). However, the mechanism of prey captures and mouth size could also affect hook location, but require further study.

Elasmobranch landing statistics lack information on species composition, even for the most important species in the capture, thus only catch trends can be assessed. In Zarzis harbor, where elasmobranch fisheries were the most developed, annual landings increased from 1995, with fluctuation between years, and peaked in 2002 and 2003, respectively, for batoids and sharks (Fig. 6). Expressed as percentages, the landings of sharks and batoids decreased, respectively, by 33% and 50% during the period 2002/2003 and 2015 (Fig. 6). The sharp increase in the trend could be ascribed to a noticeable shift towards a direct elasmobranch fishery and/or to an enhancement in fishing effort. Although the decline of elasmobranch in the Mediterranean was acknowledged by several observations (Ferretti *et al*., 2008; 2013; Colloca *et al.*, 2017), and confirmed by fishers as well (Maynou *et al*., 2011), the rate of reduction in the different sectors of the Mediterranean is unclear. This decrease may be attributed to overharvesting as the case in several area of the Mediterranean Sea (Aldebert, 1997; Ferretti *et al*., 2008; Colloca *et al*., 2017).

A decade of unregulated longline fishing has led to a number of changes in catch composition and, particularly, to changes in the abundance of dominant species, *C. plumbeus*, affected by longlining activities over most of their life stages. Given the high biological vulnerability of elasmobranch species to exploitation, the declines observed in other Mediterranean areas and the continuous unregulated fishing pressure in the Gulf of Gabes, it is strongly suspected that this stock is declining. Thus, investigation on stocks' assessments and elasmobranch fisheries surveys in the area are promptly needed.

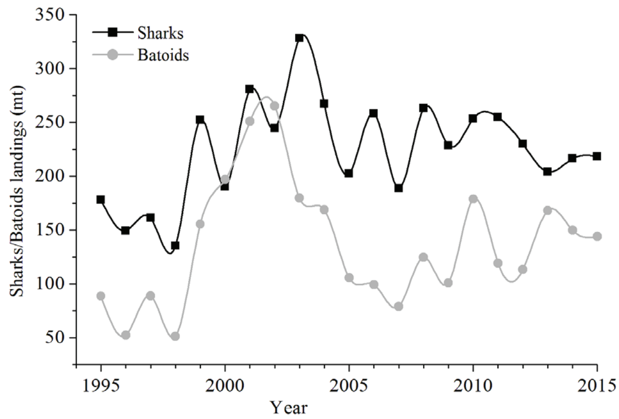

Fig. 6: Annual sharks and batoids landings in the Zarzis harbor between 1995 and 2015.

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References

Aldebert, Y., 1997. Demersal resources of the Gulf of Lions (NW Mediterranean) impact of exploitation on fish diversity. *Vie et Milieu*, 47 (4), 275-284.

Arlinghaus, R., Klefoth, T., Kobler, A., Cooke, S.J., 2008. Size selectivity, injury, handling time, and determinants of initial hooking mortality in recreational angling for Northern pike: the influence of type and size of bait. *North American Journal of Fisheries Management,* 28 (1), 123-134.

Báez, J.C., Real, R., Caminas, J.A., Torreblanca, D., Garcia-Soto, C., 2009. Analysis of swordfish catches and by-catches in artisanal longline fisheries in the Alboran Sea (western Mediterranean Sea) during the summer season. *Marine Biodiversity Records*, 157 (2), 1-4.

Barausse, A., Correale, V., Curkovic, A., Finotto, L., Riginella,

E. *et al*., 2014. The role of fisheries and the environment in driving the decline of elasmobranchs in the northern Adriatic Sea. *ICES Journal of Marine Science*, 71 (7), 1593-1603.

Beerkircher, L.R., Cortés, E., Shivji, M., 2004. Characteristics of shark by-catch observed on pelagic longlines off the southeastern United States, 1992-2000. *Marine Fisheries Review,* 64 (4), 40-49.

Bradai, M.N., Saidi, B., Bouaïn, A., Guélorget, O., Capapé, C., 2005. The Gulf of Gabès (Central Mediterranean): Nursery area for the sandbar shark, *Carcharhinus plumbeus* (Nardo, 1827) (Chondrichthyes: Cacharhinidae). *Annales. Series Historia Naturalis*, 15 (2), 187-194.

Bradai, M.N., Saidi, B., Enajjar, S., 2018. Overview on Mediterranean Shark's Fisheries: Impact on the Biodiversity. p. 211-230. In: *Marine Ecology - Biotic and Abiotic Interactions*. Muhammet Turkoglu (Ed.). IntechOpen.

Bradai, M.N., Saidi, B., Enajjar, S., Bouain, A., 2006. The Gulf of Gabès: a spot for the Mediterranean elasmobranches. p. 107-117. In: *The Proceedings of the Workshop on Mediterranean Cartilaginous Fish with Emphasis on Southern and Eastern Mediterranean.* Başusta, N., Keskin, C., Serena, F., Seret, B. (Eds). Turkish Marine Research Foundation, Turkey.

Bromhead, D., Clarke, S., Hoyle, S., Muller, B., Sharples, P. *et al*., 2012. Identification of factors influencing shark catch and mortality in the Marshall Islands tuna longline fishery and management implications. *Journal of Fish Biology*, 80 (5), 1870-1894.

Buencuerpo, V., Rios, S., Moron, J., 1998. Pelagic sharks associated with the swordfish, *Xiphias gladius*, fishery in the eastern North Atlantic Ocean and the Strait of Gibraltar. *Fishery Bulletin*, 96 (4), 667-685.

Cambiè, G., Muino, R., Mingozzi, T., Freire, J., 2013. From surface to mid-water: Is the swordfish longline fishery "hitting rock bottom"? A case study in Southern Italy. *Fisheries Research*, 140, 114-122.

Campana, S.E., Joyce, W., Fowler, M., Showell, M., 2016. Discards, hooking and post-release mortality of porbeagle (*Lamna nasus*), shortfin mako (*Isurus oxyrinchus*) and blue shark (*Prionace glauca*) in the Canadian pelagic longline fishery. *ICES Journal of Marine Science*, 73, 520-528.

Capapé, C., Hemida, F., Seck A.A., Diatta, Y., Guélorget, O. *et al*., 2003. Distribution and reproductive biology of the spinner shark, *Carcharhinus brevipinna* (Müller and Henle, 1841) (Chondrichthyes: Carcharhinidae). *Israel Journal of Zoology*, 49 (4), 269-286.

Carlson, J.K., Goldman, K.J., Lowe, C.G., 2004. Metabolism, energetic demand, and endothermy. p. 203–224. In: *Biology of Sharks and Their Relatives*. Carrier, J.C., Musick, J.A., Heithaus, M.R. (Eds). CRC Press, Boca Raton, FL.

Castro, J.I., Woodley, C.M., Brudek, R.L., 1999. *A preliminary evaluation of the status of shark species*. Food and Agriculture Organization (FAO), FAO Fisheries Technical Paper No 380, 72 pp.

Celona, A., Piscitell, L., De Maddalena, A., 2004. Two large shortfin makos, *Isurus oxyrinchus*, Rafinesque 1809, caught off Sicily, western Ionian Sea. *Annales*. *Series Historia Naturalis*, 14 (1), 35-42.

Ceyhan, T., Akyol. O., 2014. On the Turkish surface longline fishery targeting swordfish in the eastern Mediterranean Sea. *Turkish Journal of Fisheries and Aquatic Sciences*, 14, 825-830.

Coelho, R., Santos, M.N., Amorim, S., 2012. Effects of hook and bait on targeted and bycatch fishes in an equatorial Atlantic pelagic longline fishery. *Bulletin of Marine Science*, 88 (3), 449-467.

Colloca, F., Enea, M., Ragonese, S., Di Lorenzo, M., 2017. A century of fishery data documenting the collapse of smoothhounds (*Mustelus* spp.) in the Mediterranean Sea. *Aquatic Conservation: Marine and Freshwater Ecosystems*, 27 (6), 1145-1155.

Cortés, E., 1998. Demographic analysis as an aid in shark stock assessment and management. *Fisheries Research*, 39, 199-208.

Damalas, D., Megalafonou, P., Apostolopoulou, M., 2007. Environmental, spatial, temporal and operational effects on swordfish (*Xiphias gladius*) catch rates of eastern Mediterranean Sea longline fisheries. *Fisheries Research*, 84 (2), 233-246.

Dapp, D.R., Walker, T.I., Huveneers, C., Reina, R.D., 2016. Respiratory mode and gear type are important determinants of elasmobranch immediate and post-release mortality. *Fish and Fisheries,* 17, 507-524.

Davis, M.W., 2002. Key principles for understanding fish bycatch discard mortality. *Canadian Journal of Fisheries and Aquatic Sciences,* 59, 1834-1843.

Dowd, W.W., Brill, R.W., Bushnell, P.G., Musick, J.A., 2006. Standard and routine metabolic rates of juvenile sandbar sharks (*Carcharhinus plumbeus*) including the effects of body mass and acute temperature change. *Fisheries Bulletin*, 104, 323-331.

De Fages, E., Ponzevera, C., 1903. *Les pêches maritimes de la Tunisie*. Bouslama Publisher, Tunisie, 181 pp.

De la Serna, J.M., Valeiras, J., Ortiz, J.M., Macías, D., 2002. Large pelagic Sharks as By–catch in the Mediterranean Swordfish Longline Fishery: Some Biological Aspects. Scientific Council Meeting, Sept. 2002, Atlantic Fisheries Organization, NAFO SCR, NW, 1-8.

Dell'Apa, A., Kimmel, D.G., Clò S., 2012. Trends of fish and elasmobranch landings in Italy: associated management implications. *ICES Journal of Marine Science*, 69 (6), 1045-1052.

D.G.P.A. (Direction Générale de la Pêche et de l'Aquaculture). 2016. Annuaire des statistiques des pêches en Tunisie. 122 p.

Dulvy, N.K., Allen, D.J., Ralph, G.M. Walls, R.H.L., 2016. The conservation status of Sharks, Rays and Chimaeras in the Mediterranean Sea [Brochure]. IUCN, Malaga, Spain.

Dulvy, N.K., Fowler, S.L., Musick, J.A., Cavanagh, R.D., Kyne, P.M. *et al*., 2014. Extinction risk and conservation of the world's sharks and rays. eLife, 3, e00590,1-34.

Echwikhi, K., Saidi, B., Bradai M.N., 2014. Elasmobranchs longline fisheries in the Gulf of Gabès (southern Tunisia). *Journal of the Marine Biological Association of the United Kingdom*, 94 (1), 203-210.

Echwikhi, K., Saidi, B., Bradai, M.N., Bouain, A., 2013. Preliminary data on elasmobranch gillnet fishery in the Gulf of Gabès, Tunisia. *Journal of Applied Ichthyology*, 29 (5), 1080-1085.

Ellis, J.R., McCully Phillips, S.R., Poisson, F., 2017. A review of capture and post-release mortality of elasmobranchs. *Journal of Fish Biology*, 90, 653-722.

Enajjar, S., Bradai, M.N., Bouain, A., 2012. Age, growth and sexual maturity of the Blackchin guitarfish *Rhinobatos cemiculus* in the Gulf of Gabes (southern Tunisia, central Mediterranean). *Cahiers de Biologie Marine*, 53 (1), 17-23.

Enajjar, S., Saidi, B., Bradai, M.N., 2015. The Gulf of Gabès (Central Mediterranean Sea): a nursery area for sharks and batoids (Chondrichthyes: Elasmobranchii). *Cahiers de Biologie Marine*, 56 (2), 143-150.

Epperly, S.P., Watson, J.W., Foster, D.G., Shah, A.K., 2012. Anatomical hooking location and condition of animals captured with pelagic longlines: the grand banks experiments 2002-2003. *Bulletin of Marine Science*, 88, 513-527.

Ferretti, F., Myers, R.A., Serena, F., Lotze, H.K., 2008. Loss of large predatory sharks from the Mediterranean Sea. *Conservation Biology,* 22 (4), 952-964.

Ferretti, F., Osio, G.C., Jenkins, C.J., Rosenberg, A.A., Lotze, H.K., 2013. Long-term change in a meso-predator community in response to prolonged and heterogeneous human impact. *Scientific Reports*, 3, 1057.

Gallagher, A.J., Orbesen, E.S., Hammerschlag, N., Serafy, J.E., 2014. Vulnerability of oceanic sharks as pelagic longline by-catch. *Global Ecology and Conservation,* 1, 50-59.

Gallucci, V.F., Taylor, I.G., Erzini, K., 2006. Conservation and management of exploited shark populations based in reproductive value. *Canadian Journal of Fisheries and Aquatic Sciences*, 63 (4), 931-942.

Gilman, E., Clarke, S., Brothers, N., Alfaro-Shigueto, J., Mandelman, J. *et al*., 2008. Shark interactions in pelagic longline fisheries. *Marine Policy,* 32, 1-18.

Gilman, E., Chaloupka, M., Merrifield, M., Malsol, N., Cook, C., 2016. Standardized catch and survival rates, and effect of a ban on shark retention, Palau pelagic longline fishery. *Aquatic Conservation: Marine and Freshwater Ecosystems,* 26, 1031-1062.

Kabasakal, H., 2015. Occurrence of shortfin mako shark, *Isurus oxyrinchus* Rafinesque, 1810, off Turkey's coast. *Marine Biodiversity Records*, 8, e134.

Maynou, F., Sbrana, M., Sartor, P., Maravelias, C., Kavadas, S. *et al*., 2011. Estimating trends of population decline in long-lived marine species in the Mediterranean Sea based on fishers' perceptions. PLoSONE, 6 (7), e21818, 1-10.

McAuley, R.B., Simpfendorfer, C.A., Hall, N.G., 2007. A method for evaluating the impacts of fishing mortality and stochastic influences on the demography of two long-lived shark stocks. *ICES Journal of Marine Science*, 64, 1710-1722.

Megalofonou, P., Yannopoulos, C., Damalas, D., De Metrio, G., Deflorio, M. *et al*., 2005. Incidental catch and estimated discards of pelagic sharks from the swordfish and tuna fisheries in the Mediterranean Sea. *Fishery Bulletin*, 103 (4), 620-634.

Meka, J.M., 2004. The influence of hook type, angler experience, and fish size on injury rates and the duration of capture in an Alaskan catch-and-release rainbow trout fishery. *North American Journal of Fisheries Management,* 24 (4), 1309-1321.

Morgan, A., Burgess, G., 2007. At-vessel fishing mortality for six species of sharks caught in the Northwest Atlantic and Gulf of Mexico. *Gulf and Caribbean Research,* 19 (2): 123–130.

Revill, A.S., Dulvy, N.K., Holst, R., 2005. The survival of discarded lesser-spotted dogfish (*Scyliorhinus canicula*) in the western English Channel beam trawl fishery. *Fisheries Research*, 71, 121-124.

Rodríguez-Cabello, C., Fernández, A., Olaso, I., Sánchez, F., 2005. Survival of small-spotted catshark (*Scyliorhinus canicula*) discarded by trawlers in the Cantabrian Sea. *Journal of the Marine Biological Association of the United Kingdom,* 85, 1145-1150.

Saidi, B., Bradai, M.N., Bouain, A., 2008. Reproductive biology of the smooth-hound shark *Mustelus mustelus* in the Gulf of Gabès (south central Mediterranean Sea). *Journal of Fish Biology,* 72, 1343-1354.

Saidi, B., Bradai, M.N., Bouain, A., Guéorget, O., Capapè, C., 2005. Reproductive biology of the sandbar shark, *Carcharhinus plumbeus* (Chondrichthyes: Carcharhinidae) from the Gulf of Gabès (southern Tunisia, Central Mediterranean). *Acta Adriatica*, 46, 47-62.

Saidi, B., Enajjar, S., Bradai, M.N., 2016. Elasmobranch captures in shrimps trammel net fishery off the Gulf of Gabès (Southern Tunisia, Mediterranean Sea). *Journal of Applied Ichthyology,* 32, 421-426.

Shiode, D., Hu, F., Shiga, M., Yokota, K., Tokai, T., 2005. Midwater float system for standardizing hook depths on tuna longlines to reduce sea turtle by-catch. *Fisheries Science,* 72, 1182-1184.

Simpfendorfer, C.A., 2000. Predicting population recovery rates for endangered western Atlantic sawfishes using demographic analysis. *Environmental Biology of Fishes*, 58, 371-377.

Sminkey, T., Musick, J., 1996. Demographic analysis of the sandbar shark, *Carcharhinus plumbeus*, in the western North Atlantic. *Fishery Bulletin*, 94, 341-347.

Soldo, A., Jardas, I., 2002. Large sharks in the Eastern Adriatic. p.141-155. In: *Proceedings of the 4th meeting of the European Elasmobranch Association,* Livorno, Italy 2000. Vacchi, M., La Mesa, G., Serena, F. Séret, B. (Eds). ICRAM, ARPAT & SFI. Livorno, Italy.

Stevens, J.D., Bonfil, R., Dulvy, N.K., Walker, P.A., 2000. The effects of fishing on sharks, rays, and chimaeras (chondrichthyans), and the implications for marine ecosystems. *ICES Journal of Marine Science*, 57, 476-494.

Tserpes, G., Peristeraki, P., Valavanis, V.D., 2008. Distribution of swordfish in the eastern Mediterranean, in relation to environmental factors and the species biology. *Hydrobiologia,* 612 (1), 241-250.

Ward, P., Myers, R.A., Blanchard, W., 2004. Fish lost at sea: The effect of soak time on pelagic longlines. *Fishery Bulletin,* 102, 179-195.

Worm, B., Davis, B., Kettemer, L., Ward-Paige, C.A., Chapman, D. *et al*., 2013. Global catches, exploitation rates, and rebuilding options for sharks. *Marine Policy*, 40, 194-204.