Global Estimate of Shark Mortality
Induced by Longline Fisheries

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Biologie B.Sc.

20.06.2012

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Acknowledgements

First and foremost I would like to thank Dr. Boris Worm for trusting me with this project and giving me the chance and support to do this work. My deep gratitude also belongs to Aurelie Cosandey-Godin, to whom I owe this opportunity. She helped with the visual representation of my data and supported me continuously throughout my work. I wish to thank Brendal Davis and Christine Ward-Paige for all their help and advice. I am indebted to Stacey Henderson for her edits and friendship. Finally, I would like to express my gratefulness for the support that the German Academic Exchange Service has granted me for my time in Canada.

Abstract

It has been long known that Chondrichthyes species, owing to their slow life history characteristics, show little resilience to high fishing pressure. Among these are pelagic sharks, which roam the open ocean and migrate over large distances. Often they are accidentally caught as bycatch in high seas fisheries. More recently a trend towards targeting these large predators for their meat and highly priced fins has evolved, while simultaneously they are also receiving increased attention as a species group of conservation concern. However, limited information is available on the extent of global shark fisheries and the total associated mortality. Pelagic longline gear is thought to account for the majority of shark catch on the high seas (80%). My study compiles available data on shark catch rates of this gear type, global pelagic longline effort, reported landings and estimated IUU catch. I estimate the global catch of pelagic sharks by longline fisheries in the year 2000 to be 22,701,324 individuals, 7.6 times the reported landings. 19,531,567 of these sharks potentially contribute to the global shark fin trade and 20,474,681 were discarded. 80% of discards were finned (16,379,745 ind.), while 15% of animals released alive suffered from post-release mortality (614,240 ind.). In total 20,145,808 sharks were killed, which clearly shows a need for improved reporting of shark catch and discards. It also underlines the importance of effective finning bans to increase survival of sharks caught as bycatch and strict management of directed and incidental shark fisheries.

Zusammenfassung

Die Haie des offenen Ozeans sind ausgeprägte K-Strategen und können aufgrund dieser Anpassungen nur geringem Fischereidruck standhalten. Diese Raubfische zeigen eine weitläufige Verbreitung und legen lange Strecken zurück. Häufig werden sie dabei als Beifang Opfer industrieller Hochseefischer, deren Ziel Thunfische und Schwertfische sind. In letzter Zeit wird es jedoch zunehmend üblich Haie als primären Fang anzuvisieren, da Haifleisch und Flossen einen steigenden Preis auf dem Weltmarkt erzielen können und besonders in Asien nachgefragt werden. Gleichzeitig wird dem Schutz der Haie eine zunehmende Bedeutung beigemessen, allerdings ist nur unzureichend bekannt, wie viele Haie jährlich durch die Aktivitäten der Fischereien auf der Hochsee sterben. Der Langleinenfischerei wird aber der Großteil dieser Mortalität zugeschrieben (80%). In dieser Studie wurden verfügbare Informationen über Fangraten der pelagischen Langleinenfischerei, den globalen Aufwand der Fischerei, die gemeldeten Anlandungen und des geschätzten illegalen, unregulierten und nicht berichteten Fangs (IUU) zusammen getragen. Daraus ergibt sich ein weltweiter geschätzter Fang der Langleinenfischerei im Jahre 2000 von 22.701.324 Haien, 7,6 mal mehr als die gemeldeten Anlandungen. 19.531.567 trugen davon potentiell zu dem internationalen Flossenhandel bei und 20.474.681 wurden zurück über Bord geworfen. Achtzig Prozent der Rückwürfe wurden davor die Flossen abgeschnitten ("finning", 16.379.745 Haie), während fünfzehn Prozent der Haie, die lebend zurück geworfen wurden an den Folgen der Prozedur starben (614.240 Haie). Insgesamt wurden 20.145.808 Haie durch die Langleinenfischerei getötet, ein klares Zeichen für die Notwendigkeit besserer Berichterstattung der Fischereien über den gesamten Fang und Rückwürfe. Zusätzlich unterstreichen diese Ergebnisse die Bedeutung von effektiven Reglementierungen des "finning", um die Überlebensrate von Beifang zu erhöhen, und die verbesserter Verwaltung von allen Fischereien deren Fang Haie einschließt.

1 Introduction

For millions of years sharks have roamed every ocean on this planet (Ferretti et al. 2010). They are exceptionally well adapted, migrate over vast distances and are often top predators in marine ecosystems. Historically, humans depicted them as vicious beasts and most people still perceive them as a threat. With an increasing concern for the state of the world's oceans, such as the depletion of fish populations, sharks, like other pelagic predators are now seen as a subject of concern, and as key components to healthy oceans (Baum et al., 2003; Myers & Worm, 2005; Ferretti et al. 2010).

For sharks, an emerging interest is mostly centered around the practice of shark finning, where the fins of the shark are removed and the body is discarded at sea. The inherently high rate of waste renders this a societal issue, but there is also a debate about shark finning as an animal welfare problem. Finning is driven by increased wealth in Asia, where shark fins are considered a traditional delicacy and achieve a high market value (Clarke, 2004). Shark populations are highly affected by the expansion of fisheries in the 20^{th} century as they are being 'accidentally caught' alongside targeted fish species and are then finned, fully discarded, retained or released alive (Bonfil, 1994; Dulvy et al., 2008). The discarding of unwanted catch, or 'bycatch', is a major fisheries management problem as many bycatch species are mismanaged and unmonitored (Alverson et al., 1994; Kelleher, 2005). Total bycatch is made up of both 'discards', which can be defined as the part of total catch that is disposed at sea, and 'incidental catch', which is the proportion of retained catch that is landed but was not intended for use (FAO, 2010).

This study focuses on pelagic species of the true sharks or Selachii in the order Elasmobranchii of the Chondrichthyes or cartilaginous fishes. Pelagic sharks are highly mobile predators found in all oceans, both within the neritic (coastal) zone and beyond the continental margin, with their distribution overlapping intense high seas fisheries (Camhi et al., 2008; Dulvy et al., 2008). Because of their slow life history characteristics (e.g. low fecundity, slow growth, long lifespan, late maturity) sharks have a low intrinsic rate of population growth, which makes them more vulnerable to fishing pressure than traditional target species (Camhi et al., 2008; Dulvy et al., 2008; Snelson Jr et al., 2008). This suggests that they likely cannot tolerate current fishing pressure (Hoenig & Gruber, 1990; Myers & Worm, 2005) and since our ability to monitor inaccessible oceanic ecosystems is limited, there is a lack of knowledge on the population status of many pelagic species (Dulvy et al., 2008). Additionally, there is substantial evidence for cascading ecosystem effects as a consequence of shark removal from the oceans (Ferretti et al., 2010; Myers et al., 2007; Stevens, 2000). While sharks have been traditionally considered bycatch in high seas fisheries, they provide an important source of food and income to some developing coastal nations (Rose, 1996; Vannuccini, 1999).

Sharks are often caught incidentally worldwide by various gear types such as longlines, trawls, purse seines and gillnets in fisheries that largely operate in international waters, but also on the continental shelves in various Exclusive Economic Zones (EEZ, a zone extending up to 200 nautical miles from the coast of a given country) (Camhi et al., 2008). Some fisheries also target sharks directly, for example the silky shark (*Carcharhinus falciformis*) fishery in the Gulf of Mexico (Vannuccini, 1999). Of all gear types catching sharks, the pelagic longline industry is thought to account for the largest proportion of total pelagic shark catch, mainly due to high effort and because their distribution overlaps the pelagic sharks' habitat (Bonfil, 1994; Camhi et al., 1998). A longline set can extend for up to 100 kilometres. Attached to a mainline, which is suspended with floats, are thousands of shorter branchlines, each connected to a hook (Gilman et al., 2007). After a certain time (10 hours on average), the line is hauled onto the boat by the crew (Ward et al., 2004). Sometimes captured sharks are released, and whether they survive varies with factors like hook robustness and location, as well as handle and release practices of fishers (Gilman et al., 2007). Haulback mortality, or how many sharks are already dead when brought alongside the boat, depends largely on gear configuration, soak time (the time a hook remains in the water) and species (Bromhead et al., 2012; Gilman et al., 2007; Morgan et al., 2010). The growing demand for shark fins and meat now provides an incentive for some fisheries to actively target sharks (Gilman et al., 2007). Due to increased value and the dwindling of traditional target species, the distinction between target and non-target catch (incidental as well as bycatch) is becoming blurred (Aires-da-Silva et al., 2008; Camhi et al., 1998; Rose, 1996). Many fishers fin as many sharks as possible, because revenue from shark products, especially fins, comprises a significant amount of their income (Gilman et al., 2007). Sharks often constitute a substantial proportion of the total catch, particularly in pelagic longline fisheries targeting tuna or swordfish (Dulvy et al., 2008; Gilman et al., 2007).

According to the Food and Agriculture Organization of the United Nations (FAO) reported chondrichthyes catches reached a peak in 2003 (FAO, 2012). However, due to the long-established classification as non-target catch and relatively low monetary value, most shark fisheries have little to no management or regulations and remain chronically data deficient (Clarke et al., 2006; Lack & Sant, 2009; Rose, 1996; Camhi, 1998). The FAO is the only international body to report global fisheries landings, but their database does not provide a comprehensive overview of shark catches, since discards are not reported and a large proportion of the total shark catch is thought to be either illegal, unreported or unregulated (IUU: illegal, unreported and unregulated catch) (Clarke et al., 2006; Lack & Sant, 2008; Watson & Pauly, 2001; Camhi et al., 1998). This severely impedes conservation efforts, since there is an urgent need for data to assess stock statuses and determine appropriate fishing levels for sustainable use (Lack & Sant, 2009).

Growing public and scientific concern about the conservation status of sharks has resulted in the implementation of several international and regional efforts to protect them from overexploitation. Four species of sharks are listed in the appendices of the Convention on International Trade in Endangered Species of Fauna and Flora (CITES), limiting trade of these species (Table 1). A further seven are listed in appendices of the Convention on Migratory Species (CMS), a treaty that aims to improve international cooperation in the conservation of migrating species. Similarly, in 1999, the FAO developed the International Plan of Action for the Conservation and Management of Sharks (IPOA-Sharks), whose implementation is voluntary for participating countries (FAO, 1999). Unfortunately, the overall effectiveness of these measures has been found insufficient, largely due to poor follow-through by participating countries (Lack & Sant, 2011). However, regional finning bans or regulations, implemented since the year 2000, have likely increased shark survival in some parts of the ocean (USA, Australia, South Africa, Europe) (Gilman et al., 2007).

There has been a dramatic decline in the abundance of several species, with an estimated decrease of 75% for scalloped hammerhead (*Sphyrna lewini*), thresher (*Alopias vulpinus, Alopias superciliosus*) and white shark (*Carcharodon carcharias*) over the last 15 years (Baum et al., 2003). Moreover, the severe depletion of many other shark stocks has been widely acknowledged, with 18 species of pelagic sharks now listed as threatened (two endangered, 16 vulnerable) and another 12 as near threatened by the International Union for Conservation of Nature (IUCN, Table 1). Historical collapses following over-exploitation, such as the Norwegian porbeagle shark (*Lamna nasus*) fishery in the 1960's (Anderson, 1990), are sometimes discussed and underline the urgent need for conservation measures (Ferretti et al., 2010; Stevens, 2000). A recent ecological risk assessment for several species caught in Atlantic pelagic longline operations identified the silky (*Carcharhinus falciformis),* shortfin mako (*Isurus oxyrinchus)* and bigeye thresher shark (*Alopias superciliosus)* as being at high risk, and oceanic whitetip (*Carcharhinus longimanus*) and longfin mako shark (*Isurus paucus*) as highly vulnerable to longline fisheries, indicating possible conservation priorities (Cortés et al., 2009).

Table 1 Species listed in Cites, CMS appendices and species assessed as Endangered or Threatened by the IUCN

Institution	Common name	Species
CITES		
	Whale shark	*Rhincodon typus*
	Great white shark	*Carcharodon carcharias*
	Basking shark	*Cetorhinus maximus*
CMS		
	Whale shark	*Rhincodon typus*
	Great white shark	*Carcharodon carcharias*
	Basking shark	*Cetorhinus maximus*
	Longfin mako	*Isurus paucus*
	Shortfin mako	*Isurus oxyrinchus*
	Porbeagle	*Lamna nasus*
	Spiny dogfish (northern hemisphere)	*Squalus acanthias*
IUCN		
Endangered		
	Scalloped hammerhead	*Sphyma lewini*
	Great hammerhead	*Sphyma mokarran*
Vulnerable		
	Whale shark	*Rhincodon typus*
	Smalltooth sand tiger	*Odontaspis ferox*
	Pelagic thresher	*Alopias pelagicus*
	Bigeye thresher	*Alopias superciliosus*
	Thresher shark	*Alopias vulpinus*
	Basking shark	*Cetorhinus maximus*
	Great white	*Carchardon carcharias*
	Shortfin mako	*Isurus oxyrinchus*
	Longfin mako	*Isurus paucus*
	Porbeagle shark	*Lamna nasus*
	Tope shark	*Galeorhinus galeus*
	Oceanic whitetip shark	*Carcharhinus longimanus*
	Dusky shark	*Carcharhinus obscurus*
	Sandbar shark	*Carcharhinus plumbeus*
	Night shark	*Carcharhinus signatus*
	Smooth hammerhead	*Sphyrna zygaena*
Near Threatened		
	Frilled shark	*Chlamydoselachus anguineus*
	Bluntnose sixgill shark	*Hexanchus griseus*
	Crocodile shark	*Pseudocarcharias kamoharai*
	Silvertip shark	*Carcharhinus albimarginatus*
	Bronze whaler	*Carcharhinus brachyurus*
	Spinner shark	*Carcharhinus brevipinna*
	Silky shark	*Carcharhinus falciformis*
	Galapagos shark	*Carcharhinus galapagensis*
	Bull shark	*Carcharhinus leucas*
	Blacktip shark	*Carcharhinus limbatus*
	Tiger shark	*Galeocerdo cuvier*
	Blue shark	*Prionace glauca*

Despite the alarming evidence for the number of sharks traded annually in international fin trade (26-73 million, median 38 million) (Clarke et al., 2006) and their demonstrated vulnerability to overfishing (Baum et al., 2003; Bonfil, 1994; Cortés et al., 2009), stakeholders of the shark trade have voiced concerns about the "misconception of shark fishing industry", claiming that "sharks are not endangered" (Mahtani, 2012). Such statements have fuelled a debate, which calls for strong scientific evidence to predict the degree and impact of fishing mortality on shark populations and determine the true extent of this problem (Camhi et al., 2008). Their vulnerability to overfishing, mismanagement, and limited protection, warrants a clear need for more accurate information on total pelagic shark catches. I attempt to incorporate recent estimates for IUU and longline fishing effort in order to provide a realistic global estimate of total shark mortality resulting from pelagic longlining, a major contributor to total shark catches. This study aims to create a baseline estimate useful in assessing global shark exploitation and will hopefully contribute to filling the existing knowledge gap on shark fisheries.

2 Material and Methods

For this work I aimed to amalgamate available information from published papers and reports to estimate worldwide shark catch from pelagic longline fisheries. I used independent estimates of global longline effort and IUU catches and compiled available shark catch rates and finning rate estimates from various fisheries across oceans, as well as published post-release mortality estimates. All information was then combined to provide an estimate of total shark catch, total mortality and discards (finned vs. alive). Since information on global longline effort was only available for the year 2000 (Lewison et al., 2004) and the IUU catch estimate study was also based on the period 2000-2003 (Agnew et al., 2009), I used the year 2000 as a baseline year in this study. However, some countries implemented regulations to reduce shark finning around this time, making it more complex to estimate the actual proportion of finned sharks for more recent years, due to variations in the nature, compliance and enforcement of those rules.

2.1 Catch rates

Catch per unit effort (CPUE, number of sharks per 1000 hooks) and finning proportion data were compiled from peer-reviewed literature and technical reports (Table 3). Reports are made publicly available online by the FAO and regional management bodies like ICCAT (The International Commission for the Conservation of Atlantic Tunas), NOAA (National Oceanic and Atmospheric Administration of the United States of America), IATTC (Inter American Tropical Tuna Commission), IOTC (Indian Ocean Tuna Commission), NAFO (Northwest Atlantic Fisheries Organization), SEAFDEC (Southeast Asian Fisheries Development Center) and others. The reports are based on either the analysis of data from implemented fishery observer programs or the results of scientific experiments. Some of these characterize local fishing methods and their effectiveness or variation with area, depth or season, while others compare catch composition when using different hook types (J-hooks or circle hooks) or bait types.

I only included data derived from on-board observer programs or scientific experiments, where scientifically trained on-board observers record the characteristics of the fishing operation (effort, depth, soak time, region) and every individual that is caught. Often, information on discards, bait, and hook type etc. is recorded, depending on the scope of the program. Logbook data and other forms of reporting, as well as port-observer information, were considered unreliable in the context of this work, because fishers usually do not report discards and if so, the reported numbers are likely underestimates, and landings at port do not represent the total catch since they also cannot account for discards.

Data was considered relevant to this study when it represented effort after 1990 and before 2011 to gain information for a time frame of about 10 years prior and post 2000. Where CPUE data was not directly reported, but the number of observed hooks and the number of observed specimen was available, this information was used to calculate multi-species shark CPUE (sharks per 1000 hooks= (number of specimen*1000)/number of observed hooks). Every entry represents one study in the database, except when the target species differed and in once case where two different vessels were using stainless steel wire leaders and nylon monofilament leaders and catch rates differed largely as a consequence (Yokota et al., 2006). After the data was compiled, an average CPUE for each ocean basin was calculated.

2.2 Total catch, landings and discards

The average CPUE estimate was then multiplied with an effort estimate for the year 2000, which is available for each ocean basin and includes pelagic longline effort for all countries, excluding artisanal and IUU fishing effort (Lewison et al., 2004). This way an estimate for total catch in the Pacific, Atlantic and Indian Oceans was obtained and then summed to obtain estimated global total catch in 2000.

Total landings were calculated by using reported landings from the online FAO database and a published estimate of IUU (Agnew et al., 2009). The percentage of pelagic and large coastal sharks in the total reported landings averages 0.12% since 1990 (FAO, 2012). Since the proportion of sharks is unknown for IUU catch, I assumed that the same proportions as in reported landings apply (0.12% of the total estimated catch). The sum of FAO reported landings and IUU estimated landings approximately constitute total pelagic and large coastal shark landings in weight. I assume that about 80% of this was caught by longline gear, as estimated by Bonfil (1994).

The weight of sharks is highly variable across species and oceans, but the average weight for a pelagic shark is approximately 36kg (Worm et al. in preparation). Using this factor, total landings in tonnes were converted to an approximate number of landed individuals. Assuming that the IUU estimate and FAO database can account for all landed sharks, every shark that is caught and not landed must have consequently been discarded. Thus the difference between total estimated catch and landed sharks should give the number of discarded sharks (total catch minus total landings equals discard).

2.3 Finning and post-release mortality

My literature review indicated that in 2000 approximately 80% of sharks were finned (Table 2) and thus are deemed dead discards. The remaining 20% of discards can potentially survive the process of being discarded. Research indicates that about 15% of blue sharks that are released alive suffer from post-release mortality (Campana et al., 2009 (a); Campana et al., 2009 (b); Moyes et al., 2006; Musyl et al., 2011). Due to a lack of published data on other species and since blue sharks constitute the large majority of shark catch by longlines (Bonfil, 1994; Gilman et al., 2007), I assume that this can be applied to the overall catch, which leads to a conservative estimate for post release mortality. Those dead sharks added to finned and landed sharks equals the total number of dead sharks. Most finned and many landed sharks contribute to the international shark fin trade.

Table 2 Proportion of sharks finned

Fishery	Flag	% Finned	Comments	Reference
Swordfish	USA (Hawaii)	65	pre-regulations (2002)	Gilman et al. 2007
Swordfish	Italy	0.0	no market	Gilman et al. 2007
Tuna and Swordfish	South Africa	100	pre-regulations (1998)	Gilman et al. 2007
Tuna	USA (Hawaii)	76	pre-regulations (2002)	Gilman et al. 2007
Tuna	Fiji	84.0		Gilman et al. 2007
Tuna	New Zealand	83.8		Francis et al. 2001
Tuna	China, Federal States of Micronesia	96.8		Bromhead et al. 2012
Tuna	NA	67.8		Williams et al. 1997
Median		79.9		

3 Results

A total of at least 72,439,314 hooks were observed in 47 studies, three studies did not report the number of hooks that were observed. Coverage of FAO major fishing areas is shown in Figure 1, for some areas there were less studies available (Southwest Pacific, Southeast Pacific, Mediterranean), while others have good coverage (Eastern Central Pacific, Southeast Atlantic, Northwest Atlantic).

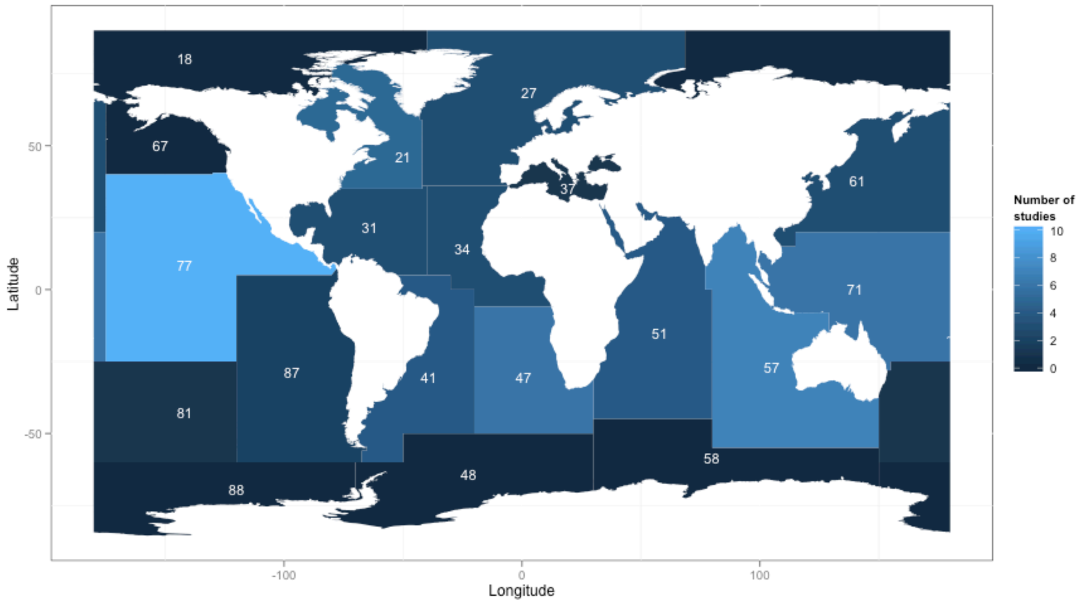

Figure 1. Number of studies representing each FAO major fishing area.

18 Arctic Sea	34 Atlantic, Eastern Central	48 Atlantic, Antarctic	61 Pacific, Northwest	81 Pacific, Southwest
21 Atlantic, Northwest	37 Mediterranean	51 Indian, Western	67 Pacific, Northeast	87 Pacific, Southeast
27 Atlantic, Northeast	41 Atlantic, Southwest	57 Indian, Eastern	71 Pacific, Western Central	88 Pacific, Antarctic
31 Atlantic, Western Central	47 Atlantic, Southeast	58 Indian Ocean, Antarctic and Southern	77 Pacific, Eastern Central	

For the year 2000, longline effort was 728,000,000 hooks (Pacific), 518,000,000 hooks (Atlantic) and 154,000,000 hooks (Indian) as estimated by Lewison et al. (2004) and catch per unit effort was estimated to be 16.46, 19.40 and 4.33 sharks per 1000 hooks on average for the Pacific, Atlantic and Indian Oceans, respectively (Table 3).

Table 3 Average CPUE (sharks per 1000 hooks) from literature review

Fishery	Ocean	Region	Year	CPUE	Hooks	Reference
Swordfish	Pacific	Southeast	2001-2006	6.90	155,060	Vega et al. 2009
Swordfish	Pacific	Eastern Central	1994-2006	16.70	NA	Gilman et al. 2007
Swordfish and tuna	Pacific	Southeast	2004	3.57	72,090	Vega and Licandeo 2009
Swordfish and sharks	Pacific	Northwest	2005	38.69	19,800	Yokota et al. 2006
Swordfish and sharks	Pacific	Northwest	2005	91.08	28,800	Yokota et al. 2006
Swordfish and sharks	Pacific	Northwest	2002-2003	47.78	36,480	Yokota et al. 2009
Tuna	Pacific	Eastern Central	2006	2.60	180,000	Beverly et al. 2009
Tuna	Pacific	Western Central	2005-2006	2.32	75,101	Ward et al. 2008
Tuna	Pacific	Southwest	1990-1998	7.45	12,725,046	Francis et al. 2001
Tuna	Pacific	Western Central	2005-2009	3.55	NA	Bromhead et al. 2012
Tuna	Pacific	Western Central	2005-2008	1.23	95,150	Ward et al. 2009
Tuna	Pacific	Eastern Central	1994-2006	2.20	NA	Gilman et al. 2007
Tuna	Pacific	Eastern Central	2005-2006	3.54	2,773,427	Curran et al.2011
Tuna and billfish	Pacific	Western Central	2005	3.33	44,100	Kim et al. 2006
Tuna and billfish	Pacific	Central	1990-1999	7.82	10,944,000	Worm et al. 2005
Sharks	Pacific	Eastern Central	2004	25.20	15,200	Galeana-Villaseñor et al. 2008
Sharks	Pacific	Eastern Central	2005-2006	60.00	18,800	Galeana-Villaseñor et al. 2009
Mahimahi, tuna, billfish and sharks	Pacific	Eastern Central	2004-2006	10.59	43,424	Swimmer et al. 2010a
Mahi-mahi, tuna and sailfish	Pacific	Eastern Central	1999-2008	4.56	1,974,700	Whoriskey et al. 2011
Dolphinfish and Mahimahi	Pacific	Eastern Central	2004-2006	2.42	33,876	Swimmer et al. 2010b
Dolphinfish and Mahimahi	Pacific	Western Central	2005-2006	4.39	62,464	Kim et al. 2007
Average Pacific				16.47		
Swordfish	Atlantic	Southwest	2003-2004	7.16	16,624	Kerstetter et al. 2007
Swordfish	Atlantic	Northwest	2002	31.33	427,312	Watson et al.2005
Swordfish	Atlantic	Southeast	2000-2005	23.30	447,000	Basson et al.2007
Swordfish	Atlantic	Western Central	1992-2000	11.14	413,873	Beerkircher et al. 2002
Swordfish	Atlantic	Southeast	1998-2005	2.94	880,000	Petersen et al. 2009
Swordfish and tuna	Atlantic	Northwest	2001-2006	18.33	624,854	Carruthers et al. 2009
Swordfish and tuna	Atlantic	Western Central	2003-2004	5.65	30,600	Kerstetter and Graves 2006
Swordfish and tuna	Atlantic	Western Central	1992-2003	10.77	NA	Brooks et al. 2005
Swordfish and tuna	Atlantic	Mediterranean	1998-1999	0.53	1,582,000	Megalofonou et al. 2005
Swordfish and sharks	Atlantic	Northeast	2000-2003	32.47	267,109	Bolten et al. 2005
Swordfish and sharks	Atlantic	Northeast	2000	14.39	139,500	Ferreira et al. 2010
Swordfish, tuna and sharks	Atlantic	Southwest	2004-2008	26.67	145,828	Sales et al. 2010
Swordfish, tuna and sharks	Atlantic	Southeast	2000-2005	85.30	8,829,000	Basson et al.2007
Tuna	Atlantic	Southwest	2006-2007	17.18	7,800	Afonso et al. 2011
Tuna	Atlantic	Southeast	2000-2005	12.40	71,800	Basson et al.2007
Tuna	Atlantic	Southeast	1998-2005	15.28	3,520,000	Petersen et al. 2009
Tuna	Atlantic	Atlantic	1995-2003	3.38	4,318,119	Senba and Nakano 2005
Tuna	Atlantic	Eastern Central	2007-2008	2.79	226,848	Dai et al. 2009
Tuna and billfish	Atlantic	Northwest	1990-1999	30.60	1,116,000	Worm et al. 2005
Tuna and billfish	Atlantic	Southwest	2006-2007	2.47	50,170	Pacheco et al. 2011
Sharks	Atlantic	Northwest	1991-1992	23.62	17,526	Branstetter and Musick 1993
Black scabbardfish	Atlantic	Eastern Central	2009	88.09	4,700	Pajuelo et al. 2010
Average Atlantic				21.17		
Swordfish and tuna	Indian	Eastern	NA	3.85	6,226	Promjinda et al. 2008
Swordfish and tuna	Indian	Western	2004-2006	3.60	29,449	Gamblin et al. 2007
Swordfish and tuna	Indian	Western	2009-2010	11.76	14,112	Kiszka et al. 2010
Swordfish, tuna and sharks	Indian	Eastern	2004	4.91	3,871	Prajakjit 2006
Tuna	Indian	Indian	2004-2008	0.55	14,121,000	Huang and Liu 2010
Tuna	Indian	Eastern	2003-2011	2.28	522,992	Kar et al. 2011
Tuna	Indian	Eastern	2005-2011	5.92	38,333	Promjinda and Chanrachkij 2011
Tuna	Indian	Eastern	2011	1.19	8,375	Chaidee and Darumas 2011
Tuna	Indian	East-West	2000-2006	4.93	2,476,148	John and Varghese 2009
Average Indian				4.33		

These figures translate to an estimated total shark catch by pelagic longline gear of 11,991,734 individuals (Pacific), 10,967,330 individuals (Atlantic) and 667,439 individuals (Indian) summing to a total of 22,701,324 sharks globally (Table 4). About 119,632 tonnes landed pelagic and large coastal sharks were reported to the FAO for the year 2000 (FAO, 2012), of which 80% (95,705.6 tonnes) are assumed to come from pelagic longline catch (Bonfil, 1994) or 2,658,489 individuals when converted with a factor of 36 kg per individual (average weight of a pelagic shark) (Worm et al., in preparation). Estimated IUU catch was between 11 and 26 million tonnes with an average of 18.5 million tonnes (Agnew et al., 2009). This translates to 493,333 individual pelagic and large coastal sharks from pelagic longlines, converted with an average weight of 36kg per shark, assuming these species constitute the same proportion to total IUU catch as calculated for pelagic and large coastal sharks to total FAO reported landings (0.12%) and assuming that 80% of these sharks come from pelagic longline catch. Total landings thus were approximately 3,151,822 sharks. Consequently, 20,474,681 sharks would have been discarded and fins of 19,531,567 sharks caught by pelagic longline gear potentially contributed to the fin trade. Under the conservative assumption that 15% of released sharks suffer from post-release mortality, a total of 20,145,808 sharks were killed by pelagic longline gear in 2000, 16,379,745 of which were only partially utilized (fins) and at least 614,240 died after being released alive and thus were not utilized at all (Table 4).

Table 4 Summary statistics for mortality by longline gear

Measure	Estimate	Unit	Comments	Source
Catch				
Pacific	11,991,734	individuals		
Atlantic	10,967,330	individuals		
Indian	667,439	individuals		
Total	23,626,503	individuals	Based on longline effort estimates and average CPUE	Lewison et al. 2004 and this study (Table 3)
Reported				
Landings	2,658,489	individuals	Pelagic and large coastal sharks from longlines	FAO (2012)
Unreported				
IUU	493,333	individuals	Pelagic and large coastal sharks from longlines	Agnew et al. 2009
Results				
Landings	3,151,822	individuals	IUU and reported	
Discards	20,474,681	individuals	Difference estimated catch- landings	
Finned sharks	16,379,745	individuals	80% of total catch	This study (see Table 2)
Post release mortality	614,240	individuals	15% of alive discards	Musyl et al. 2011
Total sharks killed	20,145,808	individuals		
Fin trade	19,531,567	individuals		

4. Discussion

I estimated that pelagic longline catch potentially contributes 19,531,567 individuals to the global shark fin trade. When assuming that catch from longlines accounts for about 80% of total pelagic and large coastal shark catch, the resulting figure (23,437,881 individuals) is comparable to the upper limit of an estimate , which suggests that about 7-24 million sharks in the fin trade are pelagic sharks (Clarke as cited in Camhi et al., 2008). Pelagic species contribute a major part to the total trade of the estimated 38,000,000 (26,000,000-73,000,000) sharks (Clarke et al., 2006).

Total mortality estimated here is 7.6 times higher than reported landings, which underlines the urgent need for improved reporting to the FAO and indicates that reported catches should not solely be relied upon for management decisions. Notably, the figure reported here is at best conservative, as it does not include artisanal catches and other pelagic and demersal gear types.

4.1 Assumptions, problems with methods and data

Average catch rates form the basis of this study. They vary strongly (in this study 0.53 – 91.08; mean 16.36; SE 3.05) which can be attributed to variance in abundance, bait used, hook type, soak time of gear, the depth at which gear is set, the season and other factors. Most of these characteristics change considerably with different regions, regulations and, most importantly, target species and many studies compare rates between different gear configurations. An average CPUE for each study was taken. However, if the target species changed, a separate record was entered into the database since fishing strategies are typically adapted to target species. Fisheries targeting sharks and those that take them as incidental or bycatch were included and often cannot be strictly differentiated (Dulvy et al., 2008). In Europe for example, most fisheries now also target sharks (Hareide et al., 2007). This method assumes that the tested gear configurations represent real fishing operations and that the compiled studies will be representative for the composition of fishing methods in each ocean. This can be a realistic assumption considering that studies on gear changes are based on typical gear and can lead to the implementation of transformations in a fleet. However, more information on global fisheries needs to be compiled and analyzed to verify this assunption, unfortunately the scope of this study did not allow this. Generally CPUE in this study accounts for shark catch of all species. However, to represent the Northeast Pacific in this dataset, two cases (Bolten & Bjorndal, 2005; Ferreira et al., 2010) only considering blue shark catch were included. The CPUE from these studies can only be considered a minimum estimate, although blue sharks comprise the majority of shark catch in most fisheries (Dulvy et al., 2008; Bonfil et al., 1994). Furthermore, data derived from observer programs is not always entirely objective. Being observed on board during fishing might lead to changes in fishers' behaviour and strategy, nevertheless, it is the most reliable fishery dependent data source (Allard & Benoît, 2009).

Due to a lack of published data, post release mortality included in this study only applies to blue sharks released alive and unfortunately does not account for hooking mortality, which is another major contributor to shark mortality. However, this information is omitted, as it is not possible to determine whether dead sharks would be preferably finned in contrast to sharks still alive at haulback. Therefore the percentage of sharks surviving the discarding process is overestimated here, i.e. total mortality is likely greater.

Furthermore, the post-release mortality rate used here is based only on blue shark estimates. Although blue sharks constitute up to 92% of shark catch from longlines (Gilman et al., 2007), other species might be less resilient and have higher mortality rates. Consequently, applying this rate to total catch can be representative only to some degree and in fisheries capturing fewer blue sharks this will be an underestimate.

To estimate how much pelagic longline gear contributes to total shark catch, a study by Bonfil (1994) was consulted. I referred to a recent study on the development of global fishing effort to determine whether Bonfil's estimate is still suitable. Anticamara et al. (2011) report that global effort for relevant gear types (trawlers, seiners, other gear/not known) increased at similar average rates (between 0.4-1% annually) since 1950. On the other hand, drift gillnets contributed second most to total high sea shark catch in Bonfil's study and the use of this gear type has largely been phased out (Bonfil 1994). Regardless, it is unlikely that the proportions estimated by Bonfil have changed immensely unless the category unknown/other (as reported to the FAO), which now exerts the second highest effort globally (Anticamara et al., 2008), includes new gear types with markedly higher shark bycatch.

I also based my estimate on the percentage of sharks in IUU catch on reported landings. Due to the high market price of fins and known large scale misreporting of shark catches, sharks are likely more prevalent in IUU catch than in reported landings.

Therefore, the IUU estimate calculated here is conservative. Since FAO reports cannot account for total elasmobranch catch and are largely incomplete, the reported tonnage of shark landings is also conservative. Consequently, the discards reported here are overestimated, because not all landings can be accounted for.

4.2 Spatial resolution and data coverage

The low spatial resolution of this study is partly due to a lack of reporting and accessible information on effort, landings, and species specific data. Although higher spatial resolution might produce a more accurate estimate, the highly migratory nature of many shark species requires a worldwide perspective on their exploitation. Additionally, international fleets on the high seas usually fish in various regions and thus it might not be effective to take a region specific approach. The broad scope of this study reflects available data on worldwide shark catches. Global coverage as shown in Figure 1 might to some degree represent the availability of scientific works for certain areas. It indicates that observer coverage for the southern Pacific, central Atlantic and the Mediterranean might be low compared to other regions such as the northwest and eastern central Atlantic. Due to the scope of this study, this review is not an exhaustive compilation of all data but rather a representative overview. Nevertheless, this research assessed longline effort for all major ocean regions, to determine total number of sharks caught in the year 2000 (Figure 1, compare Lewison et al., 2004).

4.3 Future research needs and knowledge gaps

More data is needed to estimate artisanal shark catches and effort and how these figures compare with global shark catches estimated here. This might be a large factor that tends to be excluded from studies due to limited information. Small scale fisheries tend to operate closer to shore and might consequently have a big impact on some pelagic species which use coastal waters as nursery grounds and for other critical activities.

Furthermore, data on other gear types is very limited and more information is needed on exerted effort as well as shark bycatch rates. Information on bycatch rates could come from higher on-board observer coverage or directed research studies in these fisheries.

Improvements need to be made in the rate of reporting to the FAO. Species specific reporting is critical to assess the impact of total catches at a species specific level, which can take into account the inherent vulnerability to exploitation and life history.

Although blue sharks are the most prevalent catch, post-release mortality estimates for other species are crucial to further improve conservation measures and identify options to increase survival of more vulnerable species.

To update the total mortality estimate to a more recent time frame, one would need to incorporate information on various regulations and quantify compliance worldwide. In the case of a real reduction in finning, measures of post-release mortality rates must be refined and hooking mortality needs to be taken into account where sharks are released as bycatch.

4.4 Conclusion

Sharks comprise a large proportion of total catch in pelagic longline fisheries. They make up over 25% of total catch in many fisheries (eg. Australia tuna and billfish, Fiji tuna, Hawaii swordfish), 50% of the catch in the Hawaiian swordfish fishery (Gilman et al., 2007) and New Zealand tuna fishery (Francis et al., 2001) and account for 26 – 152% (mean 34%) in the North Atlantic (Campana et al., 2006). In some regions this provides an important part of fishers' income, through fins or utilization of the whole shark and in poor coastal communities shark meat is a valuable source of protein (Rose, 1996). Industrial high seas fishing in all oceans imposes high fishing pressure on shark populations and is largely unregulated (Dulvy et al., 2008). Life history traits such as slow growth, low fecundity, late maturity and a long lifespan make sharks particularly vulnerable to overfishing, endangering not only shark species but also the ecosystems in which they often play an important role as top predators. Although the mechanisms are poorly understood, depletion of sharks can have cascading effects, such as changes in community structure (Stevens, 2000; Ferretti et al., 2010). These are expected to be less pronounced in pelagic than in coastal systems (Kitchell et al., 2002; Ferretti et al., 2010), but might nonetheless lead to decreased stability (Worm & Duffy, 2003), making marine ecosystems that are already in peril due to climate change effects and other anthropogenic impacts (Verity et al., 2002) more vulnerable (Lotze et al., 2010).

The results presented here estimate global shark mortality from pelagic longline gear and outline how this catch is utilized. This can be used as an indicator in evaluating to what extent the FAO data represents actual fishing mortality for sharks and provide a baseline estimate for how many sharks were removed from the ocean in 2000. The large number of pelagic sharks caught by longlines warrants stricter and enforceable regulations on the high seas.

Finning regulations, if they are enforced, should drastically reduce fishing mortality for sharks and, due to limited storage space on board (Gilman et al., 2007; Petersen et al., 2009), provide incentives to avoid shark bycatch. Since this study is conducted in reference to the year 2000, in which most countries did not have management in place to regulate the finning of sharks, it is important to note than some fisheries have implemented effective finning restrictions, for example the Hawaii tuna and swordfish fishery, the Australian tuna and billfish fishery (Gilman et al., 2007), and the Canadian fisheries (DFO, 2007). Note that the results by Gilman rely on interviews conducted with fishers and thus might be limited in detecting illegal activities, which fishers might not wish to report. Additionally several regional management bodies (e.g. ICCAT, IATTC, NAFO, IOTC) have banned finning, but loopholes exist and enforcement is poor (Camhi et al., 2009). Despite these management measures, the reported trade volume in shark fins shows no sign of decline, suggesting that supply is not decreasing. The power of anti-finning measures depends heavily on successful enforcement and these results could mean that regulations are not effective. However this could also mean that more sharks are now landed whole and their fins sold or that the fins come from another source, i.e. non-regulated fisheries (Worm et al., in preparation), likely these scenarios all contribute to some degree. Dulvy et al. (2008) pointed out that finning bans are an essential tool but costly to enforce and that the situation had not substantially improved until 2008 (see also Lack & Sant, 2011). Wide-ranging anti-finning laws are needed to control mortality of pelagic sharks, since finning is the largest source of mortality and where implemented they need to be strictly enforced and loopholes need to be closed (Lack & Sant, 2011).

Additionally, gear changes to reduce haulback mortality and facilitate the safe release of sharks, while improving crew safety and promoting handling methods less deleterious to sharks, are a primary management issue, as post-release mortality and haulback mortality are major factors where sharks are taken as bycatch. However, if fishers consider sharks a valuable catch species, they will likely try to increase, rather than decrease the catch rate for these species. Bycatch can be a serious threat to shark populations, but as they increasingly compete with traditional target species, directed fisheries are becoming more common. Consequently these species should be responsibly managed, as their populations are being actively exploited.

Even though there is large uncertainty in the global mortality and catch estimate presented here, these numbers provide an important insight into the magnitude of longline shark catches and how mortality could change with bycatch prevention, handling and regulations. The goal must be to increase post-release survival of sharks caught in all gear types, and where appropriate, implement management and conservation measures that protect these vulnerable species and the ecosystems and communities depending on them.

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Erklärung

Hiermit versichere ich, dass ich vorliegende Arbeit selbstständig verfasst, keine anderen als die angegebenen Quellen und Hilfsmittel benutzt und die Arbeit bisher oder gleichzeitig keiner anderen Prüfungsbehörde unter Erlangung eines akademischen Grades vorgelegt habe.

Unterschrift Lisa Kettner

Ort, Datum Lumby, BC 20.06.2012